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THE IMPACT OF GREATER PEORIA SANITARY DISTRICT AMMONIA DISCHARGES ON ILLINOIS RIVER WATER QUALITY:

PART 2

by

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INTRODUCTION

The Illinois Pollution Control Board (IPCB) and the Illinois Environmental Protection Agency (IEPA) are concerned about ammonia-nitrogen (ammonia-N) in surface water because it can be toxic to fish under certain conditions and because its bio-oxidation can depress dissolved oxygen (DO) concentrations. The IPCB and IEPA have formulated and published rules and regulations to control ammonia-N concentrations in wastewater effluents and surface waters of the state. Generally, these rules and regulations are designed to directly safeguard the water quality of receiving streams. However, one special rule somewhat arbitrarily limits ammonia-N concentrations in effluents from treatment plants handling 50,000 or more raw population equivalents (PE) discharging to the Illinois Waterway to 2.5 mg/l during April through October, and to 4 mg/l at other times.

The Greater Peoria Sanitary District (GPSD) treats a raw PE considerably in excess of 50,000. Consequently, the GPSD approach to ammonia-N removal is predicated on and dictated by this restriction. However, GPSD officials question whether adherence to this rule is essential for achieving or maintaining stream water quality standards below the plant outfall. A study (Butts et al., 1985) was conducted by the Water Quality Section (WQS) of the Illinois State Water Survey (ISWS) during the summer and fall of 1984 to study the relationship between GPSD ammonia-N discharges and possible violations of IPCB standards outside an allowable mixing zone defined through use of a fluorescent tracer dye. This study showed that the effluent standard of 2.5 mg/l, as applied to the GPSD effluent during warm summer periods, is unjustified and severely restrictive. Effluent concentrations of 10 mg/l of ammonia-N could be routinely discharged during periods when the water temperatures are above 15°C, the lowest temperature encountered during the 1984 study. However, nothing was known about mixing and dispersion of the effluent with the river at water temperatures below 15°C.

Consequently, a cold weather study was conducted by the WQS of the ISWS between November 1985 and April 1986 to gather data for developing criteria for defining a cold weather mixing zone and for assessing the impact of GPSD effluent ammonia discharges outside the prescribed mixing area. This report describes the findings and conclusions of the cold weather study and supplements and expands on the detailed information presented in the warm weather report.

General Information

The Greater Peoria Sanitary District sewage treatment plant is located south of Peoria with the effluent discharging to the Illinois Waterway at river mile 160.1 (see figure 1). It is a high-rate activated sludge plant that uses the Kraus process of returning digested sludge to the aeration system. Special treatment is provided for ammonia-N removal: the secondary effluent is passed through 84 rotating biological contactors which support a large population of nitrifying bacteria. Deep tertiary sewage ponds are used to remove suspended solids (SS) and some biochemical oxygen demand (BOD). The effluent is chlorinated.

The plant is designed to handle an average hydraulic load of 37 million gallons per day (mgd). The preliminary and primary treatment facilities can handle a maximum flow of 154 mgd, of which 60 mgd can be routed through the secondary treatment phase. The average annual dry weather flow is about 25 mgd. The average design waste loading is approximately 120,000 pounds per day of 5-day BOD (approximately 706,000 PE) and 132,000 pounds per day of suspended solids.

In the past, the plant received heavy industrial waste loads from three major industries: Pabst Brewing Company, Hiram Walker Distillery, and Bemis Bag Company. These wastes were highly organic and were composed mostly of carbonaceous material. Presently only Bemis is operating. Pabst Brewing has shut down, and the Hiram Walker Distillery has been taken over by Archer Daniels Midland (ADM) for the production of commercial grade alcohol.

Regulatory Implications

IEPA rules and regulations pertaining to effluent discharge and stream water quality standards are contained in State of Illinois Rules and Regulations. Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter 1: Pollution Control Board, dated February 1, 1986. Five sections within these rules and regulations are pertinent to ammonia-N relative to general water use. These are:

Section number	Subject
302.210	Substances Toxic to Aquatic Life
302.212	Ammonia Nitrogen and Un-ionized Ammonia
304.105	Violation of Water Quality Standards
304.122	Nitrogen
304.301	Exceptions for Ammonia Nitrogen Water Quality Violations

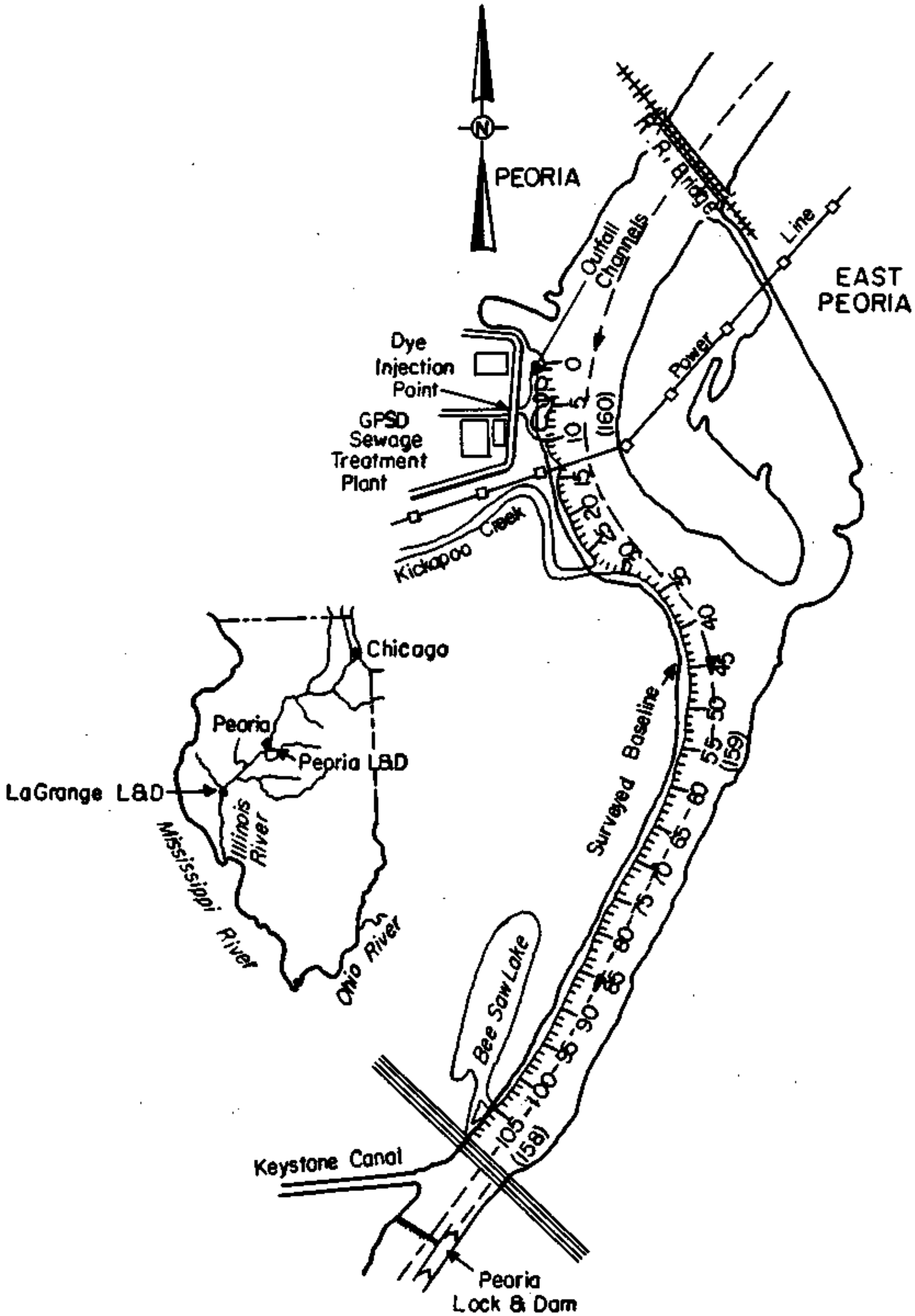


Figure 1. Study area and vicinity map

Four of the five sections are related to stream water quality standards; the exception is rule 304.122, which arbitrarily limits ammonia discharge concentrations irrespective of receiving stream water quality conditions. The four general rules are designed to limit effluent ammonia discharges only to the degree needed to meet stream standards. In contrast, paragraph a) of Section 304.122 stipulates:

> No effluent from any source which discharges to the Illinois River, the Des Plaines River downstream of its confluence with the Chicago River System or the Calumet River System, and whose untreated waste load is 50,000 or more population equivalents shall contain more than 2.5 mg/l of ammonia-nitrogen as N during the months of April through October, or 4 mg/l at other times.

Only three governmental agencies operating sewerage works fall under this rule. They are the Metropolitan Sanitary District of Greater Chicago (MSD), the City of Joliet, and the Greater Peoria Sanitary District. These three agencies must comply with the above regulation even in the absence of evidence that stream water standards are being violated.

Some justification exists for limiting ammonia-N concentrations in the effluents from the various MSD plants and Joliet. Butts et al. (1975) showed that ammonia-N loads originating above river mile 273, near the junction of the Des Plaines and Kankakee Rivers, must be reduced significantly if dissolved oxygen levels are to be improved down to Chillicothe (mile 179). Oxygen suppression also occurs in the LaGrange pool below Peoria, but two recent studies (Butts et al. [1981] and Butts et al. [1983]) indicate somewhat indirectly that present GPSD ammonia-N discharges probably have minimal effect on the DO resources of the LaGrange pool. Butts et al. (1981) showed that during dry, warm 7-day, 10-year low flows the oxygen demand was 57 percent carbonaceous, 13 percent nitrogenous (ammonia-N oxidation), and 30 percent sediment oxygen demand. A BOD-DO model study conducted by Butts et al. (1983) reveals that, for 7-day, 10-year low flows, the time of travel between Chicago and Peoria is so great that most of the carbonaceous and nitrogenous demand would be exerted before it reaches the Peoria area. Consequently, the residual Chicago area loads combined with the GPSD inputs are so small that they have very little impact on LaGrange pool DO resources.

The question that needs to be resolved, based on the facts presented above, is whether the restrictive limitations imposed upon the GPSD treatment plant as set forth in paragraph a) of Section 304.122 are essential in preventing water quality standard violations in the Illinois River below Peoria during the months of November through March. This study was designed and implemented to answer this question. The 1984 warm weather study (Butts et al., 1985) answered this question for the months of April through October.

Scope and Purpose of Study

The primary purpose of this study was to determine the maximum ammonia concentrations which would be permissible in the GPSD-treated effluent for the months November through March to ensure that:

1. Illinois River water ammonia-N levels are not raised to levels which are toxic to native fish as specified in Section 302.210.

2. Illinois River ammonia-N water quality standards are not violated as specified in Section 302.212.

To achieve these two goals, mixing zones had to be defined as dictated by the IPCB's Rules and Regulations (1986). During the warm weather study, fluorescent dye was used to trace the mixing and dispersion characteristics of the effluent with the river. The use of the dye was precluded during this study because of potential freezing conditions. The dye injection pump and dye storage tank would probably freeze during winter operations. Consequently, two alternative methods were selected for use in characterizing mixing. One was to take advantage of the significant differences between the effluent and river temperatures during cold weather. An examination of historical data showed that temperature differentials during the coldest parts of January and February often exceed 13°C. The occurrence of temperature differentials in the area of the outfall would therefore appear to be useful in defining mixing zones.

Temperature, however, can change in an open environment by means other than mixing and dispersion, for example through heat transfer and convection. A conservative substance was needed to back up and substantiate the temperature data. An additional examination of historical data showed that a significant difference usually exists between river and effluent chloride concentrations. During the winter these differences usually range between 200 and 600 mg/l. Therefore, conservative chlorides were measured and compared with field-measured river water temperatures. If the temperature data appeared inadequate or misleading, the chloride information would be used to define or characterize effluent mixing during the winter.

The ultimate goal was to integrate the cold and warm weather data into one complete data base for developing mixing zone prediction equations which would be applicable over a wide range of physical conditions.

Acknowledgments

This study was sponsored and partially funded by the Greater Peoria Sanitary District. The work was performed under the general supervision of the acting Chief of the Illinois State

Water Survey, Richard Schicht. Sampling was conducted under very adverse physical conditions. Field crews had to contend with freezing and windy weather, ice floes, and hazardous barge traffic. Those who deserve extra special mention for doing this are: Harvey Adkins, Dave Green, Dave Beuscher, Jud Williams, and John Mathis.

Jim Kelton did the art and graphics work. Linda Johnson typed the original manuscript, Gail Taylor edited the report, and Dave Hullinger supervised and/or performed laboratory analyses.

Special thanks are extended to the staff of the GPSD who coordinated GPSD and ISWS activities and obligations needed to make the study a success.

METHODS AND PROCEDURES

Water quality and mixing zone sampling runs were scheduled to take place simultaneously during the cold weather period extending from November 1, 1985 through March 31, 1986. However, because favorable river flows and temperatures continued past March 31, the sampling period was extended to April 22, 1986. Using temperature and/or chlorides as a tracer in place of the fluorescent dye reduced laboratory work significantly and permitted the ammonia samples to be collected during mixing zone sampling. In contrast, during the warm weather study water quality sampling had to be delayed until a day or two after the mixing zone data were collected.

Runs were contemplated for GPSD effluent discharge rates of 20, 25, 30, 35, 40, 45, 50, and 55 mgd. All sampling was to take place during periods when the river temperatures were 13°C or less; the goal was to concentrate on grouping the runs into an 8°C to 13°C range and a 0°C to 5°C range. The maximum desirable river flow was 10,000 cfs.

Field Sampling

Sampling locations were determined and water samples were collected by using the procedures developed and employed during the warm weather dye tracer study. Since the warm weather results clearly showed that the mixing zone extension was limited by the IPCB's requirement that no mixing zone shall contain more than 25 percent of the stream cross-sectional area or flow volume, sampling was limited to points approximately 1000 feet downstream of the outfall area. As it turned out, ice floes and adverse weather conditions would have prevented longitudinal sampling much farther downstream than this even if it would have been needed.

Figure 1 shows the study location and the extent of the warm weather study. This figure is a slight modification of figure 1 presented in the report on the warm weather results (Butts et al., 1985); the new revised figure shows the outfall configuration and discharge locations more accurately. Figure 2 shows the immediate cold weather sampling area in more detail; this figure supersedes figure 14 presented in the warm weather report. The original figure showed an incorrect positioning of the second and third outlet channels: they were shown approximately 150 feet too far downstream. This error did not affect the reported results because all the data collections and results were referenced to the bank stationing, which was correct. Shore and offset stakes were reestablished downstream to station 10+50. Periodically, many of the shore stakes were destroyed by ice and had to be replaced.

The sampling routine consisted of: (1) collecting samples and making temperature measurements in the three main effluent channels, (2) collecting river ammonia and chloride background samples and making temperature measurements upstream of the outfall, and (3) making measurements and collecting samples in the mixing zone area. Temperature measurements were taken again midway through and at the end of the run in the three effluent channels and at the end of the run at the background stations. Chloride and ammonia samples were also taken at the end of the runs in the effluent channels and background stations after the initial two runs were completed in November. Unlike in the dye tracer study, predetermined mixing zone sampling locations were not used. The warm effluent provided an easily detectable mixing pattern which could be followed and used to efficiently establish appropriate sampling and measuring points.

Figure 3 shows the boat, equipment, and crew prepared to start a run. The boat was secured in the outfall channel between most runs since boat launching was impossible at the local boat ramps during the cold weather. Some damage occurred to the boat and equipment over the course of the study as a result of vandalism and ice floes. A winch was placed on a boat on the bank near location 4 (figure 2) for use in pulling the boat upstream against very strong effluent currents.

Figure 4 shows sampling in progress at station 0+50. Water samples were collected by using the downrigger-pumping system developed for use during the dye tracer study. For this study, the intake line was shortened so that flushing time was reduced to about 10 seconds; 20 to 30 seconds were allowed to elapse before a sample was taken. Samples were collected in 250-ml plastic bottles. Collection points were selected on the basis of temperature readings. Approximately 178 chloride and 25 to 28 ammonia-N samples could be handled and analyzed in the laboratory per run. Initially only about 60 chloride samples could be handled, but after the first run this number appeared insufficient, and laboratory facilities were streamlined and laboratory help added so the output could be tripled.

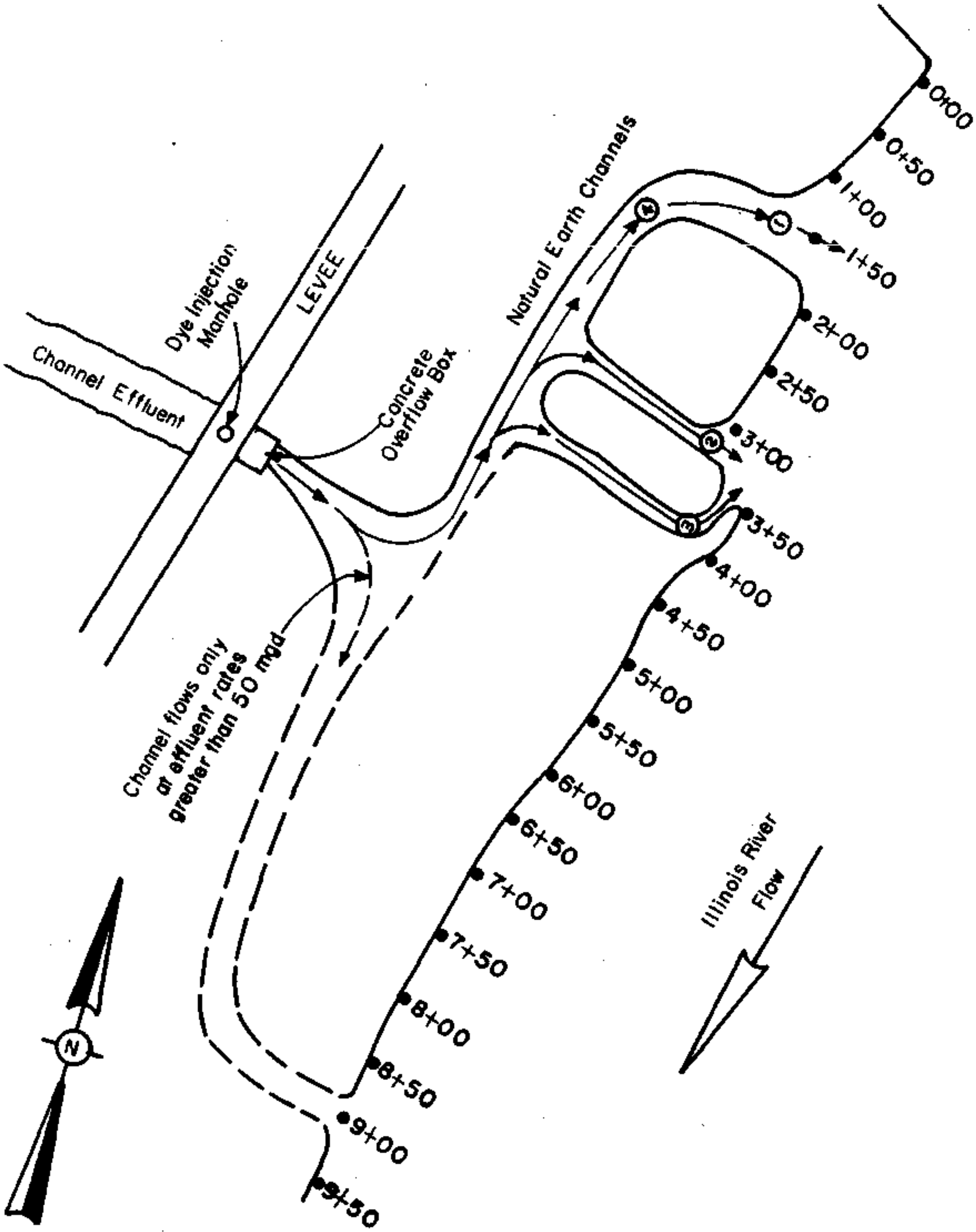


Figure 2. Schematic of GPSD outfall delta showing sampling points

Figure 3. Sampling crew preparing to make run

Figure 4. Winter sampling in river

Temperature measurements were made by using a YSI model 5739 temperature-oxygen probe attached to a YSI model 58 temperature-DO meter. The accuracy of the temperature probe was checked in the laboratory over a range of 5°C to 20°C against a Bureau of Standards-quality mercury thermometer and found to be within 0.1°C over this temperature range.

Ice floes and, at times, barge traffic greatly interfered with sampling. Note that the scene depicted in figure 4 exhibits little ice on the river in the study area. However, massive ice jams could build up in a matter of 10 to 15 minutes. Figures 5 and 6 show massive ice floes which showed up almost instantly as sampling was being completed at station 10+00. Figures 4, 5, and 6 are photographs taken on the same day.

The United States Geological Survey (USGS) flow gage at Kingston Mines (river mile 145.5) was read early each morning before a run was made. The readings in feet were converted to flow with a flow rating table supplied by the USGS. Official flow data will not be available from the USGS until November or December 1986; consequently, in some instances the flow rates used in this report will differ slightly from those which will eventually be published.

When runs required effluent flows in excess of 30 mgd, the GPSD had to store sufficient effluent in their retention lagoons so that a prescribed flow rate could be maintained from 8:00 a.m. to 3:00 p.m. Sampling usually started around 10:00 a.m. and ended between 2:00 and 3:00 p.m. Sampling schedules were coordinated with storage arrangements so that storage time would be minimal to prevent significant cooling of the effluent during very cold conditions. An effort was made to provide as great a temperature differential as practical between the effluent and the river.

Laboratory Analyses

After arrival at the laboratory, the 250-ml water samples were iced overnight and analyzed immediately the next morning for ammonia-N and chlorides. Chloride determinations were made by using the argentometric method (Standard Methods) whereby potassium chromate is added to the samples and titrated with 0.0141-normal silver nitrate.

The determination of permissible ammonia-N levels in the river requires a knowledge of both ambient temperatures and pH. Because of freezing conditions, field determination of pH was impractical and was not attempted. To fulfill the needs of this study, pH readings taken on river samples collected twice a week by ISWS personnel at river mile 161.6 were used.

Samples for ammonia-N determination were distilled with sodium hydroxide by using a Buchi model 320 steam generator with

Figure 5. Sampling boat at station 10+00 hemmed in by ice

Figure 6. Two winter sampling hazards - ice floes and barge traffic

the distillate collected in a boric acid solution. A portion of the distillate was retained for colorimetrie analyses using the Harwood and Kuhn phenol-hypochlorate method.

Data Preparation and Reduction

Presenting the results of a mixing zone and dispersion study in a concise and meaningful way is difficult because so many variables exist that modify basic natural mixing phenomena in a large river system. Theoretical models do not appear to be any more applicable to the data generated during the cold weather study than they did for the data generated during the warm weather study.

The primary method of data display used in this report is the use of areal iso-plots (contours) that show effluent temperature residuals (in terms of percentages) in the sampling area, and the use of ammonia-N and chloride residual percentages in statistical regression analyses. The "contouring" procedure is the same as the one developed for depicting mixing zones using the fluorescent dye tracer. Contour plots were developed for surface, 1-, 3-, and 8-foot depths down to station 10+50 for all completed sampling dates. To enable the development of contours at any depth based on the observed temperature measurements, straight-line extrapolation was used to estimate the temperatures at 1-foot depth increments between measured values. However, very few interpolated data were required for completing the cold weather plots since temperature readings were taken at 1- to 2-foot depth intervals throughout most of the study area.

The plots are all in terms of percentages computed on the basis of the relationship of ambient temperatures measured within the mixing zone to those measured in the effluent channels. The change in effluent and background temperature and chemical values over the period of time required to complete a run was compensated for by using straight line interpolation. This was done on a computer by using the following algorithm:

$$P_t = \frac{T_t - (T_{bi} + T_b^{1})}{T_{ei} + T_e^{1}} \; . \; (1)$$

where P_t = the fraction observed in the mixing zone at the time t
T_t = the temperature, ammonia, or chlorine (parameter) value observed in the mixing zone at time t
T_{bi} = the initial background parameter value observed at time t_{bi}
T_b^1 = the incremental change in the background parameter values =

$$\frac{(t_{bi} - t)\,(T_{bi} - T_{be})}{t_{bi} - t_{be}}$$

where T_{be} = the end background parameter value observed at time t_{be}

T_{ei} = the initial weighted average effluent parameter values =

$$\frac{f_1 T_{e1i} + f_2 T_{e2i} + f_3 T_{e3i}}{f_1 + f_2 + f_3}$$

where f_1 , f_2, f_3 = flow weighting factors given in table 1 for effluent channels 1, 2, and 3 (figure 2)

T_{e1i}, T_{e2i}, T_{e3i} = the initial effluent parameter values observed at time t_{ei}

T_e^1 = the incremental change in the effluent parameter values =

$$\frac{(t_{ei} - t)\,(T_{ei} - T_{ee})}{t_{ei} - t_{ee}}$$

where T_{ee} = the end weighted average effluent parameter values =

$$\frac{f_1 T_{e1e} + f_2 T_{e2e} + f_3 T_{e3e}}{f_1 + f_2 + f_3}$$

where T_{e1e}, T_{e2e}, T_{e3e} = the end effluent parameter values observed at time t_{ee}

The weighting factors f_1, f_2, and f_3 used are listed in table 1. They are rough estimates based on channel width and depths and surface velocities measured for 20-, 35-, and 50-mgd flows. These weighting factors, albeit somewhat crudely devised, are sufficiently accurate for use in this study since the temperature, ammonia-N, and chloride values varied little between the channels on most dates.

RESULTS

Ten successful runs were completed between early November 1985 and mid-April 1986. An additional run was attempted on January 20, 1986, but with about one-third of the sampling completed, the crew was forced off the river by an ice jam. The physical conditions under which the ten successful runs were made are summarized in table 2. The warm weather conditions are included in the table for comparative purposes. Note that the river flows were considerably lower during the warm weather study. The warm weather average and median flow values were 7,771 cfs and 7,834 cfs, respectively, whereas the cold weather values were 12,625 cfs and 10,745 cfs, respectively. During the

Table 1. Effluent Channel Flow Weighting Factors

Effluent Flow Rate (mgd)	Channel 1 (f_1)	Channel 2 (f_2)	Channel 3 (f_3)
20	15	1	5
25	14	1	5
30	14	1	4
35	12	1	4
40	10	1	3
45	8	1	3
50	6	1	2
55	4	1	2

Table 2. Mixing Zone and Dispersion Run Dates and Physical Conditions on Those Dates

	Discharge		Pool	Peoria Dam Operation		
Date	GPSD (mod)	River (cfs)	Stage (msl)	Wickets Down	Valves Open	Needles In
Warm Weather Data (From Table 14 [Butts et al., 1985])						
7/12/84	37	10,156	440.48	0	6	0
7/19	30	8,661	440.22	0	6	0
7/31	25	7,820	440.12	0	6	0
8/07	20	7,106	439.98	0	0	0
8/14	40	8,394	440.38	0	6	0
8/21	35	7,848	439.68	0	6	0
8/28	45	6,088	439.47	0	0	51
9/11	55	7,572	440.81	0	0	0
9/18	50	5,224	440.56	0	0	63
10/23	30	8,837	440.43	6	6	40
Cold Weather Data (new)						
11/05/85	40	17,540	439.98	134	0	0
11/13	35	21,060	441.11	134	0	0
1/09/86	25	10,920	440.38	0	6	0
1/13	20	10,570	440.29	0	6	0
1/16	45	9,446	440.35	0	6	0
1/21	55	11,320	440.73	0	6	0
1/23	30	18,430	439.81	117	6	0
2/18	50	10,020	440.55	0	6	0
4/16	35	8,535	440.56	0	6	0
4/22	40	8,411	440.49	0	6	0

Note: Maximum number of wickets is 134

cold weather study all 134 Peoria dam wickets were down on two dates and 117 were down on another. No winter flows were low enough to warrant needle placement between raised wickets. Although the overall winter flow conditions were not ideal, the winter results were satisfactorily melded with the warm weather data by using only the winter data that were collected within the summer data flow range. This selective process will be addressed in detail later.

Over 4100 temperature readings were taken. Along with these readings, 1402 chloride and 277 ammonia-N samples were collected and analyzed in the laboratory. The daily reading and collection totals are presented in table 3 and are summarized as to location.

The mixing zone ammonia-N results in terms of concentration and residual percentages are given in Appendix A. The river background and effluent results are detailed in table 4. A good range and satisfactory blend of river water temperatures were achieved. Good to excellent effluent-river temperature differentials occurred during eight of the ten sampling dates. The differentials during the two April runs were only fair, but they were adequate to satisfactorily define the mixing zone. The minimum, average, and maximum differences were 3.22°C, 9.36°C, and 13.20°C, respectively. The greatest differences were observed during January.

River ammonia-N background levels increased significantly as water temperatures decreased (table 4). On November 5, 1985, the level was only 0.18 mg/l at a river water temperature of 9.6°C, while on January 13, 1986 the river ammonia-N background level increased to 1.47 mg/l when the water temperature dropped to about 0.2°C. The river background chloride levels also increased seasonally but only moderately. The effluent ammonia-N levels also increased significantly during the height of the cold weather. The effluent chloride levels remained fairly uniform throughout with the exception of those observed on February 18, 1986. The chloride value ballooned to 712 mg/l after having consistently been in the mid-200 mg/l range. This value reflected increased street runoff due to the use of salt for snow removal the previous day.

The contour percent plots based on residual temperature values computed by using equation 1 are presented in Appendix B. Plots are presented for surface, 1-, 3-, and 8-foot depths for each of the ten runs, resulting in a total of 40 figures. The plots are grouped by date.

These plots are very effective in showing the effects of high river flows on mixing. On both November 5, 1985, and April 22, 1986, the effluent discharges were 40 mgd; however, the November run was made at a time when the wickets were down (table 2) and the flow was over twice as great as the flow during the April run when the wickets were up. The high November river flow

Table 3. Number of Samples Collected and Number of In-situ Readings Taken

	Temperature Readings			Chloride Samples			Ammonia-N Samples		
Date	B.G.	Eff.	Mix.	B.G.	Eff.	Mix.	B.G.	Eff.	Mix.
11/05/86	16	6	300	11	3	74	2	3	20
11/13	16	6	350	4	3	81	2	3	20
1/09/86	30	6	350	4	6	139	2	6	16
1/13	6	6	350	4	6	148	2	6	19
1/16	8	9	400	5	6	139	1	6	18
1/20*	3	6	100	3	3	50	1	1	12
1/21	8	9	350	6	6	112	2	6	19
1/23	8	9	400	6	6	138	2	6	19
2/18	8	9	350	3	6	94	1	6	21
4/16	16	9	450	16	6	150	3	6	18
4/22	16	9	500	16	6	142	4	6	18
Totals	135	84	3900	78	57	1267	22	55	200

* Partial Run - Forced off river due to ice floe

B.G. = River background
Eff. = Effluent
Mix. = River mixing zone area

Table 4. River and Effluent Conditions
Observed during Cold Weather Sampling

Parameter	Sampling Dates									
	11/5/85	11/13	1/9/86	1/13	1/16	1/21	1/23	2/18	4/16	4/22
					River Conditions					
Flow, Q (cfs)	17,540	21,060	10,920	10,570	9,446	11,320	18,430	10,020	8,535	8,411
Temp, T (°C) Begin	9.60	8.97	0.25	0.20	0.20	0.20	1.10	0.10	10.04	11.40
End	9.66	9.10	0.40	0.68	0.50	0.48	1.40	0.40	9.85	11.69
Chlorides (mg/l) Begin	49.0	48.0	70.0	79.0	77.3	86.0	76.3	73.3	71.1	74.9
End	50.3	48.0	70.5	81.0	78.0	87.0	75.3	73.3	73.9	74.6
Ammonia-N (mg/l) Begin	0.18	0.37	1.12	1.47	1.11	1.05	0.83	1.27	0.17	0.21
End	0.18	0.37	0.94	0.83	1.11	1.32	1.29	1.27	0.37	0.29
					Effluent Conditions					
Flow (mgd) Channel 1	29	25	18	14	30	31	22	33	25	29
Channel 2	2	2	1	1	4	8	2	6	2	2
Channel 3	9	8	6	5	11	16	6	11	8	9
Total, q	40	35	25	20	45	55	30	50	35	40
Temp, t (°C) Ch. 1 Begin	16.3	16.7	10.3	11.1	13.1	13.2	12.2	12.5	13.5	14.1
Mid	-	-	-	-	14.2	14.6	14.2	14.5	14.0	16.5
End	18.4	17.0	11.3	12.4	13.9	13.8	12.8	13.0	13.8	15.4
Ch. 2 Begin	16.2	16.7	9.5	9.9	13.1	13.2	11.8	12.5	13.3	13.9
Mid	-	-	-	-	14.2	14.5	14.0	14.5	13.9	16.7
End	18.3	16.9	9.9	10.0	14.2	13.8	12.7	13.0	13.8	15.6
Ch. 3 Begin	16.4	16.8	10.1	11.1	13.1	13.1	12.1	12.5	13.4	14.0
Mid	-	-	-	-	14.2	14.5	14.2	14.5	13.9	16.7
End	18.4	17.0	9.3	12.2	14.2	13.8	12.8	13.0	13.9	15.6
Chlorides (mg/l) Ch. 1 Begin	184	184	265	266	283	264	249	712	249	272
End	-	-	267	225	275	250	249	668	253	230
Ch. 2 Begin	184	181	259	260	283	263	248	714	254	269
End	-	-	273	258	271	256	251	670	239	236
Ch. 3 Begin	184	180	264	264	283	260	248	708	249	269
End	-	-	260	260	270	257	249	674	249	240
Ammonia-N (mg/l) Ch. 1 Begin	5.47	7.27	11.44	12.85	14.59	11.33	10.18	7.95	8.76	2.51
End	-	-	11.26	13.35	16.57	10.26	12.93	6.78	9.29	2.46
Ch. 2 Begin	5.69	7.28	11.64	12.75	14.46	11.36	9.77	8.36	8.96	2.10
End	-	-	11.49	13.39	15.77	10.81	13.26	6.72	9.26	2.60
Ch. 3 Begin	5.36	7.32	11.89	12.69	14.34	11.21	8.03	8.21	9.04	2.34
End	-	-	11.38	14.00	15.60	10.64	12.59	7.12	9.55	2.68
Time (Military) Begin	950	919	1030	1052	1014	1036	1000	941	816	807
End	1410	1349	1600	1549	1542	1510	1445	1413	1345	1322

appears to have sheared the effluent's transverse movement, preventing significant mixing in the study area (see 0-foot plots for both dates). The November figure shows essentially parallel contour lines which hug and follow the shoreline, while the April 22 lines project much farther outward in a bubble-like fashion. The 20 percent contour line extended past station 9+50 on November 5, but this same percent contour extended only to station 3+50 on April 22.

The figures given in Appendix B were used to determine the maximum transverse extent of the 1, 2, 3, 5, 7, 10, 15, and 20 percent contours within the study area. The distances derived from the contour plots for both the warm and cold weather studies are tabulated in table 5. These distances represent the maximums observed, independent of depth. Most occurred at the surface, but some occurred at each of the other three depths represented by the plots. The river temperatures listed in table 5 represent the average of the beginning and ending values, and those for the effluent are averages of the flow-weighted beginning and ending values. The information in table 5 was used to statisically generate the regression (prediction) equations used in evaluating and defining the transverse extent of the mixing zone.

The results of the cold weather regression analyses are given in table 6. For contour percentages 1 through 5, only the effluent (q) and river (Q) flows were significantly correlated to the maximum transverse distances listed in table 5. However, the multiple correlation coefficients were only moderately high. The formulation is theoretically correct in that the distances are directly related to the effluent discharge rate and inversely related to the river flow rate. The equations listed in table 21 of the warm weather report (table 7 of this report) show that river temperature and river flow are the two most significant independent variables for contour percentages 1 through 5 for river temperatures above 15°C.

For the 7, 10, 15, and 20 percent contours, the maximum transverse distances are shown to be directly related to effluent discharge rates and indirectly to river temperature (T). This is the same general relationship found to represent the warm weather conditions for these same percentages (see table 21a of the warm weather report, table 7a of this report). The correlations for the 7 through 20 percent contours are high, as shown by the values given in table 6. Note, from table 5, that the extreme observed values can be closely predicted by using the equations representing contour percents 7 through 20. However, the use of these prediction equations is limited by the extreme conditions under which they were developed, as was the case for the warm weather equations.

To achieve more flexible and encompassing expressions all the cold and warm water data presented in table 5 were combined to form prediction equations applicable for river temperatures from 0°C to 31°C. Combining all these data, however, produced

Table 5. Transverse Distances (D) of Contour Percentages from Shore Stakes,and Effluent and River Flows and Temperatures, for Warm and Cold Weather Sampling Dates

	Transverse Distances, D (ft) for Contour Percentages of								Average Conditions during Sampling			
									River		Effluent	
Date	1	2	3	5	7	10	15	20	Temp T(°C)	Flow Q(cfs)	Temp t(°C)	Flow q(mgd)
7/12/84	160	145	140	130	125	120	115	80	29.5	10,156	24.00	37
7/19	145	140	130	70	60	50	35	20	29.5	8,661	24.00	30
7/31	360	240	112	105	87	80	55	20	30.5	7,820	25.00	25
8/07	240	210	190	160	90	70	47	10	31.0	7,106	28.00	20
8/14	380	340	325	295	120	220	165	150	29.5	8,391	25.50	40
8/21	380	365	335	325	295	260	225	215	26.0	7,848	25.00	35
8/28	395	380	365	335	260	235	205	160	25.8	6,088	26.10	45
9/11	315	313	307	297	287	280	260	245	24.5	7,572	24.00	55
9/18	460	455	450	430	410	390	330	260	21.0	5,224	22.56	50
10/23	440	425	410	370	335	280	195	180	15.0	8,837	21.00	30
11/05/85	225	200	175	155	150	125	85	75	9.63	17,540	17.35	40
11/3	200	195	190	150	140	90	80	75	9.03	21,060	16.86	35
1/09/86	180	170	160	150	145	135	125	120	0.33	10,920	10.47	25
1/13	220	195	190	170	160	155	135	120	0.44	10,570	11.67	20
1/16	350	325	300	275	250	200	150	105	0.35	9,446	13.55	45
1/21	272	260	215	200	185	175	150	135	0.34	11,320	13.49	55
1/23	265	260	230	205	200	155	135	125	1.25	18,430	12.48	30
2/18	525	510	495	320	250	225	200	120	0.25	10,020	12.75	50
4/16	345	315	310	270	130	115	105	95	9.95	8,535	13.64	35
4/22	450	375	340	300	210	120	110	85	11.54	8,411	14.76	40

Table 6. Summary of Cold Weather Mixing Zone Equations

Contour Percent	Prediction Equations. D=	Corr. Coeff. R	Extreme D-values (ft) Computed Max.	Computed Min.	Observed Max.	Observed Min.
1	262 + 5.0q - 0.012Q	0.724	436	109	525	180
2	208 + 5.0q - 0.009Q	0.711	407	118	510	170
3	221 + 4.2q - 0.009Q	0.659	376	115	495	160
5	229 + 2.5q - 0.0080	0.754	299	111	320	150
7	130 + 1.8q - 5.7T	0.860	228	100	250	130
10	110 + 1.8q - 6.3T	0.892	207	73	225	90
15	105 + 1.2q - 5.4T	0.858	170	67	200	80
20	120 + 0.1q - 3.9T	0.883	124	77	135	75
		q =	55	20		
		Q =	8411	21060		
		T =	0.25	11.54		

D = Contour projection distance from shore stake (ft)
q = GPSD effluent flow rate (mgd)
Q = River flow rate (cfs)
T = River temperature (°C)

Table 7. Summary of Warm Weather Mixing Zone Prediction Equations (Table 21 of warm weather report [Butts et al., 1985])

Contour Percentage	Prediction Equation	Max. D or L T=15, q=55 or Q=5,000	Min. D or L T=31, q=20 or Q=11,000	Observed D or L Max.	Observed D or L Min.
	a. Transverse Channel Direction				
1	$D = 930 - 12.1T - 0.035Q$	574	170	460	145
2	$D = 970 - 15.0T - 0.036Q$	565	109	455	140
3	$D = 990 - 17.3T - 0.035Q$	556	69	450	112
5	$D = 970 - 17.0T - 0.036Q$	535	58	430	70
7	$D = 368 - 14.3T + 6.1q$	489	47	410	60
10	$D = 330 - 13.0T + 5.5q$	441	37	390	50
15	$D = 170 - 8.7T + 6.0q$	370	20	330	35
20	$D = 165 - 8.8T + 5.9q$	358	10	260	10
	b. Longitudinal Channel Direction				
1	$L = 5485 - 163T + 198q$	13,930	4,392	13,000	3,600
2	$L = 620 - 120T + 190q$	9,270	700	8,200	650
3	$L = 1770 - 108T + 109q$	6,145	602	5,550	600
5	$L = 2380 - 104T + 61q$	4,175	376	3,500	370
7	$L = 1910 - 96T + 59q$	3,715	114	2,850	105
10	$L = 1345 - 73T + 47q$	2,835	22	2,300	20
15	$L = 1615 - 67T + 24q$	1,930	18	1,450	15
20	$L = 1245 - 54T + 22q$	1,645	11	1,250	10

D = transverse distance (ft) from shore stake
L = longitudinal distance (ft) from station 1+50
T = river temperature (°C)
Q = river flow (cfs)
q = GPSD effluent flow (mgd)

poor quality prediction equations. Correlation coefficients relating D to q, t, Q and T were very low, ranging from about 0.4 to 0.6. A close examination of the cold weather data revealed the reason for this: four of the ten cold weather river flows were significantly higher than the maximum summer flow, and two of the remaining six were slightly greater. Consequently, the unabridged winter data, when included with the summer data, produced distorted and misleading results when subjected to statistical analyses.

To achieve meaningful results, only the five sets of winter data which included river flows which fell below or slightly above the summer extreme high value were included in the analyses. The January 13, 1986, flow of 10,570 cfs was included but the January 9, 1986, flow of 10,920 cfs was not so as to avoid weighting the overall data too heavily at the higher end of the flow spectrum. The February 18, 1986, flow of 10,020 cfs was only slightly less than the maximum warm weather value of 10,156 cfs, and was included. The other data sets selected were those for January 16, April 16, and April 22, 1986. Since low flows are most critical, i.e., low flows permit greater transverse mixing, preventing distortions at low flows is critical to this analysis.

The prediction equations developed by combining the five winter data sets containing the lowest river flows with all ten summer data sets are summarized in table 8. The results indicate that all four independent variables are significant under extreme temperature conditions. Good correlations were produced overall, and maximum and minimum observed conditions could be satisfactorily simulated. In fact, the extreme observed values for the three most important percents (10, 15, and 20) were matched extremely well by using the equations. Of equal importance is the fact that the equations appear to provide reasonable estimates for 7-day, 10-year low flow conditions (2,964 cfs), although this flow value is significantly lower than the minimum observed value of 5,224 cfs.

DISCUSSION

The equations listed in tables 7b and 8 play a critical role in arriving at solutions for use in meeting the two principal objectives of this study. The results of combining the warm and cold weather data can be used to establish transverse limits of a mixing zone based upon certain constraints. Once those limits have been ascertained, maximum effluent ammonia-N concentrations can be determined which will not cause standard violations outside the mixing zone as limited by the 25 percent flow/area requirement, and which will not be toxic to fish. The following section discusses transverse distance limitations. Additional discussion on longitudinal distances and areal limitations of mixing zones is then presented. This discussion is based on criteria developed from data collected during the warm weather study.

Table 8. Summary of Mixing Zone Equations Derived by Using Ten Warm Weather Data Sets and Five Cold Weather Data Sets

Contour Percent	Prediction Equation, D =	Corr. Coeff. R	Extreme D-Values (feet)					
			Computed		Observed		7-day, 10-year Q	
			Max.	Min.	Max.	Min.	Max.	WW Max*
1	$2.9q+6.7t-0.035Q-8.3T+547$	0.710	606	145	525	145	704	546
2	$4.0q+14.4t-0.030Q-11.7T+339$	0.804	602	99	510	140	669	539
3	$4.9q+16.9t-0.026Q-13.1T+229$	0.833	597	69	495	112	655	522
5	$3.9q+14.9t-0.034Q-11.2T+297$	0.833	540	41	430	70	616	511
7	$3.6q+23.4t-0.026Q-14.6T+104$	0.833	490	34	410	60	549	474
10	$4.2q+24.2t-0.015Q-12.9T-99$	0.820	389	32	390	50	423	414
15	$4.3q+15.9t-0.013Q-8.7T-56$	0.827	349	21	330	35	362	349
20	$3.7q+13.3t-0.010Q-7.0T-74$	0.724	262	10	260	10	280	281
		q =	55	20			55	55
		t =	14	25			14	30
		Q =	5224	10570			2964	2964
		T =	0.25	31			0.25	31

D = Contour projection distance from shore stake (ft)
q = GPSD effluent flow rate (mgd)
t = GPSD effluent temperature (°C)
Q = River flow rate (cfs)
T = River temperature (°C)

* WW designates warm weather

Transverse Distance Limitations

The equations listed in table 8 represent linear relationships between river temperature, effluent temperature, effluent flow, and river flow and the maximum transverse projection of a certain residual effluent percent. These types of statistically derived equations are generally limited to use within the parametric value range in which they were derived. However, in this case, an additional constraint appears -- the relationship between river and effluent temperature has to be considered. Average effluent temperatures during sampling ranged from 10.47°C to 28.0°C, and average river temperatures ranged from 0.33°C to 31.0°C (table 5). While mathematically correct, the solutions to equations using an effluent temperature of 10.47°C in combination with a river temperature of 31°C are not rational. Therefore, to provide rational input combinations of effluent-river temperatures, a regression equation was developed relating effluent temperature to river temperature, based on the 20 data sets generated during both the warm and cold weather studies. The expression is:

$$t = 0.464T + 12.02 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where t = effluent temperature in °C
T = river temperature in °C

The correlation coefficient for the 20 data sets is 0.97; therefore the equations will give good logical matchups of temperatures. Note that when the river temperature is 0°C the effluent temperature will probably be around 12°C.

Transverse projection distances were computed on the basis of seven temperature data sets: (t=30, T=31), (t=24, T=25), (t=21, T=20). (t=20, T=15), (t=17, T=10), (t=14. T=5), and (t=12. T=0); four river flows (Q): 2964 (7-day, 10-year low flow), 5000, 7500, and 10,000 cfs; and eight effluent flows: 20, 25, 30, 35, 40, 45, 50, and 55 mgd. The temperature set values were derived by using equation 2, with the exception of the (30,31) combination and the (20, 15) combination. An examination of the GPSD treatment plant operating records from 1978 through 1985 revealed that the maximum effluent temperature was 30°C and that this peak value occurred only once, on July 28, 1983. The maximum river temperature recorded during the ISWS twice-weekly sampling over many years is 31°C. Consequently, to examine the extreme condition the (30,31) combination was included in the analyses. The (20,15) combination resulted from a slight computational error using equation 2; t should equal 19 when using a T of 15 in equation 2. However, the (20,15) combination is realistic and representative since its probability of occurrence is high. The results are presented in tables 9, 10, 11, and 12 for the four river flow conditions. The computations were terminated when the computed D-values greatly exceeded the 250-foot distance which has been established as the point in the river cross section, at the effluent location, which represents 25 percent of the river flow.

The information presented in tables 9 through 12 provides a good basis around which a flexible management scheme can be devised and implemented. For instance, the most critical or limiting situation occurs when an effluent with a temperature of 30 C discharges to the river during a 7-day, 10-year low flow situation (table 9). To prevent possible standard violations outside the mixing zone, effluent discharge rates of 45 mgd or less would have to be adhered to if the 20 percent contour is accepted as the outermost mixing zone boundary. If the 15 percent contour is accepted as the outer limit, the GPSO would be limited to a discharge rate in the range of 30 to 35 mgd. Generally, during extremely low flows, such as the 7-day, 10-year value, the effluent-river temperature combinations have only a moderate effect on the variability of "D."

During higher river flows, the effluent limitation can be liberalized greatly Ctable 12). Effluent flow rates of 55 mgd could be tolerated at the (30,31) combination if a 15 or 20 percent mixing limitation is accepted. By limiting the effluent flow rate to 35 mgd and assuming a 1.5 mg/l standard [paragraphs d) and e) of Section 302.212 of the IPCB's Rules and Regulations], the mixing zone could be expanded to the 3 percent contour, which would allow an effluent ammonia-N concentration of 50 mg/l. At an effluent flow rate of 55 mgd, the effluent ammonia-N concentration would be limited to approximately 10 mg/l.

Tables 9 through 12 can be viewed as a type of quality control chart, and management of the ammonia-N effluent quantity can be dictated by their use as such. For example, suppose on a given day the GPSD is discharging 17 mg/l of ammonia-N at a rate of 40 mgd and at a temperature of 24°C. The probable river temperature is 25°C according to equation 2 (a direct river measurement would be better). The flow at Peoria, estimated from the Kingston Mines rating curve, is 8000 cfs. Reference to the (24,25), 40 mgd row in table 11 indicates that an effluent concentration of 21.4 mg/l ammonia-N could be tolerated without violating the 1.5 mg/l standard [paragraphs d) and e) of Section 302.212 of the IPCB's Rules and Regulations]. Since only 17 mg/l are being discharged the system could be considered under control.

Table 13 contains information on observed effluent ammonia-N conditions and their relationship to stream standards for conditions specific to both warm and cold weather study dates. High to extremely high effluent levels could have been tolerated during the cold weather periods without violating stream standards. On January 16, 1986, a relatively high concentration of 15.06 mg/l of ammonia-N was being discharged, but considering all factors it was not even close to the theoretical tolerable level of 250.39 mg/l.

Table 9. Computed Effluent Transverse Projections Using Equations Presented in Table 7

Q = 2964 cfs

Temp. (°C)		Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	Q	1	2	3	5	7	10	15	20
30	31	55							349	283
		50							327	264
		45							305	246
		40						351	284	227
		35						330	263	209
		30						309	241	190
		25						288	220	172
		20					348	267	198	153
24	25	55							306	245
		50							284	226
		45							263	208
		40						283	241	189
		35						262	220	171
		30					332	241	198	152
		25					314	220	177	134
		20					296	199	155	115
21	20	55							301	240
		50							280	221
		45							258	203
		40						275	237	184
		35						254	215	166
		30					334	233	194	147
		25					316	212	172	129
		20					298	191	151	110
20	15	55							329	262
		50							307	243
		45							286	225
		40						316	265	206
		35						295	243	188
		30					384	274	222	169
		25					366	253	200	151
		20					348	232	179	132

Table 9. (Concluded)

Temp. (°C)		Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
17	10	55							325	257
		50							303	238
		45							282	220
		40						307	260	201
		35						286	239	183
		30					387	265	217	164
		25					369	244	196	146
		20					349	223	174	127
14	5	55							321	252
		50							299	233
		45							278	215
		40						299	256	196
		35						278	235	178
		30					390	257	213	159
		25					273	236	192	141
		20					354	215	170	122
12	0	55							332	260
		50							311	242
		45							289	223
		40						315	268	205
		35						294	246	186
		30					416	273'	225	168
		25					398	252	203	149
		20					380	231	182	131

t = GPSD effluent temperature (°C)
T = River temperature (°C)

Table 10. Computed Effluent Transverse Projections Using Equations Presented in Table 7

Q = 5000 cfs

Temp (°C)		Effluent Flow(mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
30	31	55							323	262
		50							301	243
		45						341	280	225
		40						320	258	206
		35						299	237	188
		30					331	278	215	169
		25					313	257	194	151
		20					295	236	172	132
24	25	55							280	224
		50							258	205
		45						273	237	187
		40						252	215	168
		35					297	231	194	150
		30					279	210	172	131
		25					261	189	151	113
		20				282	243	168	129	94
21	20	55							275	219
		50							254	200
		45						265	232	182
		40					317	244	211	163
		35					299	223	189	145
		30					281	202	167	126
		25					263	181	146	108
		20				294	245	160	125	89
20	15	55							303	241
		50							282	222
		45						306	260	204
		40						285	239	185
		35					349	264	217	167
		30					331	243	196	148
		25					313	222	174	130
		20					295	201	153	111

Table 10. (Concluded)

Temp (°C)		Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
17	10	55							299	236
		50							277	217
		45						297	256	199
		40						276	234	180
		35					352	255	213	162
		30					334	234	191	143
		25					216	213	170	125
		20					298	192	148	106
14	5	55							295	231
		50							273	212
		45						289	252	194
		40						268	230	175
		35					355	247	209	157
		30					337	226	187	138
		25					319	205	166	120
		20					301	184	144	101
12	0	55							306	239
		50							285	221
		45						305	263	202
		40						284	242	184
		35					381	263	220	165
		30					363	242	199	147
		25					345	221	177	128
		20					327	200	156	110

t = GPSD effluent temperature (°C)
T = River temperature (°C)

Table 11. Computed Effluent Transverse Projections Using Equations Presented in Table 7

Q = 7500 cfs

Temp (°C)		Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
30	31	55							290	237
		50						325	269	218
		45					320	304	247	200
		40				298	302	283	226	181
		35				278	294	262	204	163
		30			282	259	266	241	183	144
		25		283	257	239	248	220	161	126
		20	286	263	233	220	230	199	140	107
24	25	55						278	247	199
		50						257	226	180
		45					268	236	204	162
		40				276	250	215	183	143
		35				256	232	194	161	125
		30			259	237	214	173	140	106
		25		267	235	217	196	152	118	88
		20	296	247	210	198	178	131	97	69
21	20	55						270	243	194
		50						249	221	175
		45					270	248	200	157
		40				287	252	207	178	138
		35				267	234	186	157	120
		30			274	248	216	165	135	101
		25		282	249	228	198	144	114	83
		20	317	262	225	209	180	123	92	64
20	15	55						310	271	216
		50						289	249	197
		45					320	268	228	179
		40					302	268	228	179
		35					284	226	185	142
		30				289	266	205	163	123
		25			298	270	248	184	142	105
		20			274	250	230	163	120	86

Table 11. (Concluded)

Temp (°C)		Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
17	10	55						302	266	210
		50						281	245	192
		45					323	260	223	174
		40					305	239	202	155
		35					287	218	180	137
		30				300	269	197	159	118
		25				281	251	176	137	100
		20			288	261	232	155	116	81
14	5	55						294	262	206
		50						274	240	187
		45					326	252	219	169
		40					308	231	198	150
		35					290	210	176	132
		30				312	272	189	155	113
		25				292	254	168	133	95
		20			303	273	236	147	112	76
12	0	55						310	274	214
		50						289	252	196
		45					352	268	231	177
		40					334	247	209	159
		35					316	226	188	140
		30					298	205	166	122
		25				318	280	184	145	103
		20				299	262	163	123	85

t = GPSO effluent temperature (°C)
T = River temperature (°C)

Table 12. Computed Effluent Transverse Projections Using Equations Presented in Table 7

Q = 10,000 cfs

Temp.	(°C)	Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
an	31	55						308	258	212
		50					273	287	236	193
		45					255	266	215	175
		40			265	213	237	245	193	156
		35		348	241	193	219	224	172	138
		30		328	217	193	219	224	172	138
		25		308	192	154	183	182	129	101
		20		288	168	134	165	161	107	82
24	25	55			317	249	239	240	215	174
		50			292	230	221	219	193	155
		45			268	210	203	198	172	137
		40		352	243	191	185	177	150	118
		35		332	219	171	167	156	129	100
		30		312	194	152	149	135	107	81
		25		292	170	132	131	114	86	63
		20		272	145	113	112	93	64	44
21	20	55			331	260	241	232	210	169
		50			307	241	223	211	189	140
		45			282	221	205	190	167	132
		40		367	258	202	187	169	146	113
		35		347	233	182	169	148	124	95
		30		327	209	163	151	127	103	76
		25		307	184	143	133	106	81	58
		20		287	160	124	115	85	60	39
20	15	55					291	273	238	191
		50				282	273	252	217	172
		45			331	263	255	231	195	154
		40			306	243	237	210	174	135
		35			282	224	219	189	152	117
		30		372	258	204	201	168	131	98
		25		352	233	185	183	147	109	80
		20		332	209	165	164	126	88	61

Table 12. (Concluded)

Temp. (°C)		Effluent Flow (mgd)	Distance, D, in Feet to Contour Percentages of							
t	T	q	1	2	3	5	7	10	15	20
17	10	55					294	264	234	186
		50					276	243	212	167
		45				274	258	222	191	149
		40			321	254	240	201	169	130
		35			297	235	222	180	148	112
		30			272	215	204	159	126	93
		25		367	248	196	186	138	105	75
		20		347	223	176	168	117	83	56
14	5	55					297	256	230	181
		50				305	279	235	208	162
		45				285	261	214	187	144
		40			336	266	243	193	165	125
		35			312	246	225	172	144	107
		30			287	227	207	151	122	88
		25		382	263	207	189	130	101	70
		20		362	238	188	171	109	79	51
12	0	55					323	272	241	189
		50					305	251	220	171
		45				311	287	230	198	152
		40				292	269	209	177	134
		35			343	272	251	188	155	115
		30			219	253	233	167	134	97
		25			294	233	215	146	112	78
		20		392	270	214	197	125	91	60

t = GPSD effluent temperature (°C)
T = River temperature (°C)

Table 13. Relationship between Mixing Zone Limits And Ammonia-N Standards during Mixing Zone Sampling Dates

Date	River Temp (°C)	River pH	IEPA (or IPCB) Ammonia-N Standards (mg/l)	Contour Percent at 250'	Back-ground NH_3-N (mg/l)	Effluent NH_3-N Conc. (mg/l) Theoretical Limit	Observed	Margins: Theor. minus Obs (mg/l)
7/12/84	29.50	8.37	1.50	1	0.17	149.83	0.80	149.03
7/19	29.50	8.47	1.50	1	0.08	149.92	1.10	148.82
7/31	30.50	8.48	1.50	2	0.06	74.94	0.30	74.64
8/07	31.00	8.20	1.50	1	0.21	149.79	0.30	149.49
8/14	29.50	8.15	1.50	6	0.29	24.71	0.70	24.01
8/21	26.00	8.05	1.50	12	0.17	12.33	0.80	11.53
8/28	25.80	8.00	1.50	8	0.27	18.48	0.50	17.98
9/11	24.50	8.09	1.50	18	0.40	7.93	1.20	6.73
9/18	21.00	8.05	1.50	20	0.36	7.14	0.20	6.94
10/23	15.00	8.04	1.50	12	0.29	12.21	3.40	8.81
		Cold Weather Data (New)						
11/05/85	9.63	8.17	1.50	6	0.18	24.82	5.51	19.31
11/13	9.03	8.06	1.95	5	0.37	38.63	7.29	31.34
11/09	0.33	7.93	5.28	7	1.03	74.40	11.52	62.88
1/13	0.44	7.95	5.00	2	1.15	248.85	13.17	235.68
1/16	0.35	7.95	5.03	2	1.11	250.39	15.06	235.33
1/21	0.34	7.89	5.78	7	1.19	81.38	10.94	70.44
1/23	1.25	7.89	5.36	1	1.06	534.94	11.13	523.81
2/18	0.25	7.75	8.02	1	1.27	800.73	7.52	793.21
4/16	9.95	8.55	1.50	1	0.27	149.73	10.50	139.23
4/22	11.54	8.43	1.50	1	0.25	149.25	2.45	146.80

Note: Theoretical limit = [(100) (Standard Concentration/contour %] minus the background concentration.

Warm weather observed NH_3-N concentrations are GPSD data; cold weather observed NH_3-N concentrations are SWS data.

The standards were not closely tested during either the warm or cold weather dates. However, table 13 indicates that single digit margins did occur on the warm weather dates of September 11, September 18, and October 23, 1984, whereas double- and triple-digit margins occurred for the remaining 17 dates. The smallest margins of 6.73 mg/l and 6.94 mg/l, which occurred on September 11 and September 18, 1984, respectively, are substantial but nevertheless are dwarfed by the respective maximum warm and cold weather margins of 149.49 mg/l and 793.21 mg/l. The effluent discharge rates were 55 and 50 mgd on the two respective September dates Ctable 5). Cutting the September 11 rate back to 40 mgd would have permitted an effluent ammonia-N concentration of over 21 mg/l to be discharged. A similar case could be made for the September 18 situation; i.e., effecting a reduction in the effluent flow rate would increase the tolerable effluent ammonia-N level.

The implementation of one of several management strategies could provide assurances that stream ammonia-N standards are not violated if GPSD effluent standards are relaxed significantly.

The simplest and most easily administered management strategy would be an across-the-board adoption of the 20 percent contour as the mixing zone limitation for all situations and conditions. Such an adoption would limit summer effluent ammonia-N concentrations to approximately 7.5 mg/l; winter limitations would range from about 7.5 mg/l to 40 mg/l. This would essentially provide a 99.99 percent probability that water quality standards would not be violated under any circumstances (see the 20 percent columns in tables 9 through 12). This plan could allow increased discharge rates to be effected during wet weather conditions.

Another relatively simple and easily administered scheme would be to limit the effluent discharge rate to a maximum value and to store volumes generated by excessive flows. For example, the stipulation could be made that the maximum discharge rate would be 40 mgd. An examination of tables 9 through 12 reveals that the 15 percent contour would assure compliances under most conditions when associated with an effluent discharge rate of 40 mgd. This would permit a summer effluent concentration of about 10 mg/l and a winter range of about 10 to 53 mg/l.

The most comprehensive plan, but the one most difficult to administer, would be to adopt a flexible quality control program whereby daily discharge rates could be adjusted to match the t, T, q, and Q values to prevent standard violations for effluent ammonia-N concentration. For example, on a given date, assume that the following conditions prevail: t = 24°C, T = 25°C, q = 40 mgd, Q = 3000 cfs, and effluent ammonia-N = 14 mg/l. From the IPCB's <u>Rules and Regulations</u> the river standard is shown to be 1.5 mg/l. From table 9, row (24,25)-40 and the 15 percent residual column, the permissible effluent concentration is determined to be 10 mg/l (1.5/0.15 = 10 mg/l). Since the ambient level is 14, the stream standards would clearly be violated. By immediately reducing the discharge rate to 30 mgd the permissible effluent concentration could be increased to 15 mg/l (1.5/0.10 = 15 mg/l) as referenced to row (24,25)-30 and the 10 percent residual column of table 9.

For this scheme to be manageable, daily river flow and temperature information would have to be readily available. Routine field determinations of river temperatures could be circumvented by developing a prediction equation similar to equation 2 from long-term records. This could be done by matching the 20 years of twice-weekly river readings taken by the ISWS with those recorded on the GPSD operating reports over the same period. River flow information would have to be obtained from the USGS or the Corps of Engineers. Control charts, similar to those presented as tables 9 through 12, would have to be prepared for 1000-cfs river flow increments from 3000 to 10,000 cfs, and for 1°C effluent temperature changes.

At this point, a discussion is needed of the ambiguities that appear when the D-equations presented in table 8 are used under certain conditions. Certain extreme combinations of data cause some overlapping of the results. As an example, in table 12 in the (30,31) rows for q-values equal to or greater than 40 mgd, inconsistencies occur in the continuity of distances for the respective contour percents. This fact should not be considered a serious flaw in the use of these equations, in that the point has already been made that some anomalies may occur when making predictions based on peripheral data used in the development of regression equations, or when using data outside the development boundaries. In any event, the inconsistencies generally appear for conditions which would not normally be included in any of the general management schemes presented.

Some discussion should be given on the use of temperature differences as a means of defining the mixing zone during the winter. Table 14 has been prepared to aid in this discussion. Correlation and regression coefficients have been generated for each date. Good to excellent correlations exist between the temperature and chloride percentages, indicating that each of these parameters can be used reliably to predict the other. However, the regression coefficients indicate that the temperature percentages are always lower than the chloride ones. This is not unexpected since chlorides are conservative substances while temperature is dissipated in the open environment in ways other than by mixing. However, the fact that a great many temperature points were available for developing the percentage contour plots appeared to be an advantage when compared to using the more accurate but much less numerous chloride data. Over three times as many temperature readings as chloride analyses were available (table 3). This required less data extrapolation and plotting interpretation in generating the contour plots presented in Appendix B.

Table 14. Regression Relationships between Chlorides (CI), Ammonia-N (NH_3), and Temperature (T) (Residual Percentages)

	Cl = A + B(T)				NH_3 = A + B(T)				NH_3 = A + B(Cl)			
	n	r	A	B	n	r	A	B	n	r	A	B
11/05/85	55	0.935	0.974	0.503	20	0.979	-0.758	2.204	20	0.995	-0.700	1.265
11/13	77	0.954	0.457	0.718	20	0.957	0.716	1.768	20	0.965	-3.149	1.617
1/09/86	139	0.928	3.124	1.303	16	0.975	-3.902	1.004	16	0.998	0.684	1.313
1/13	148	0.784	3.630	1.084	19	0.674	9.250	0.774	19	0.790	5.997	1.198
1/16	139	0.924	3.469	1.228	18	0.969	-0.566	0.909	18	0.994	0.384	1.325
1/21	112	0.975	2.436	1.423	19	0.902	1.867	0.892	19	0.981	0.343	1.405
1/23	138	0.943	5.212	1.117	19	0.902	-2.045	0.776	19	0.958	1.516	1.011
2/18	93	0.873	5.387	0.963	21	0.840	-3.555	0.786	21	0.872	-0.779	0.823
4/16	150	0.888	9.007	1.226	18	0.883	-6.749	0.843	18	0.864	2.620	1.202
4/22	142	0.874	2.618	0.336	18	0.942	-7.491	4.609	18	0.987	1.050	1.624
								Total*	188	0.922	1.117	1.278

r = the linear corrlation coefficient
A = the Y-intercept
B = slope of the line

* An overall regression equation (Total) was developed only for the paired ammonia-N and chloride data

Table 14 also contains regression relationships developed between ammonia-N and temperature, and ammonia-N and chlorides. The correlations between the ammonia and temperature percentages are high, and those between ammonia and chlorides are even higher. The expression developed from all 188 ammonia-N and chloride data sets can be used with great reliability to predict ammonia-N concentrations by running quick, inexpensive, and reliable chloride tests on river water. Any monitoring program associated with a relaxation of the ammonia-N effluent standards should consider this fact.

Longitudinal Distance and Areal Limitations

Since the collection of data for use in defining the longitudinal extent of mixing was not feasible during cold weather, the longitudinal and areal criteria developed for warm weather periods will be reviewed, and their relevance and applicability to cold weather conditions will be discussed. The equations pertinent to this discussion are presented in table 7b (table 21b of the warm weather report). Two typographical errors which occurred in table 21 of the warm weather report have been corrected in table 7 of this report: the maximum D for the 2 percent contour has been changed from 545 to 565, and the equal sign between 1345 and 73T in the 10 percent contour equation for L has been changed to a minus sign.

Both the transverse (D-value) and the longitudinal CL-value) distance prediction equations, derived from the statistical analyses of the warm weather data, are presented in table 7. Included are the maximum and minimum predicted distances and the maximum and minimum observed distances. Good agreement occurs between the values. The maximum predicted distances for both transverse and longitudinal directions are consistently greater than the observed ones because the observed low temperature did not occur in association with either the low river flow or high effluent flow. The results merely demonstrate what is likely to happen if this temperature-flow combination should occur. The minimum predicted and observed values show good agreement since the observed minimum values were recorded during conditions close to those for which the minimum predicted values were calculated. The approximate limits of their usage are: $T = 15$ to 31°C, $Q = 5000$ to 11,000 cfs, and $q = 20$ to 55 mgd.

As evidenced by the array of equations developed and the variable output produced, the mixing zone cannot be considered a singular entity. It is a constantly changing phenomenon, with the degree of change governed by fluctuations in the independent variables within the prescribed limits.

The areal extent of the mixing zone must fall within the prescribed area of an equivalent 600-foot-radius circle. The mixing zone configuration can take various arbitrary geometric forms to include this area. An ultraconservative example would be to define the zone as a rectangle with the short side being the transverse projections and the long side the longitudinal projections for given contour percentages as derived by using the equations presented in table 7. The rectangular concept would reduce the longitudinal extent of the zone, but it would extend the transverse projection uniformly along the longitudinal axis.

A second, somewhat liberal concept would be to figure the area in terms of a triangle similar to that proposed by Butts et al. (1984). The triangular area concept probably fits the theoretical configuration more closely than any other geometric design for the higher percentage contours. The warm weather contour plots revealed that contours 5 percent or greater fit a triangular model best. The contour lines for these percentages generally tended to tail off downstream, eventually terminating directly at the shoreline. The contours for percentages below 5 appear to fit a rectangular model better as they tend to fan out downstream because of dispersion and dilution.

A compromise between the two extreme areal concepts explained above would be to consider the zone as a trapezoid having an average end height equal to 75 percent of the transverse projections derived by using the equations presented in table 7a. The 75 percent figure is derived on the basis that the downstream transverse projection is 50 percent of the transverse projection at the outfall calculated by using the table 7a equations.

Note, as evidenced by the contours presented in Appendix B, that the upstream mixing zone terminus is well defined. A large water intake conduit projects several feet above the normal pool water level at station 0+00 and acts as a barrier to excess mixing movement in an upstream direction. Consequently, a mixing zone incorporating a downstream triangular or trapezoidal dispersion pattern should include a small rectangular areal section in the immediate area of the outfall. The longitudinal base should run between stations 0+00 and 5+00. The triangular or trapezoidal area should be computed on the basis of a right triangle with the base starting at station 5+00 and terminating at points dictated by the equations provided in table 7b. Although this fact was presented in the warm weather report, the actual mixing zone areas presented in table 22 of that report did not include this consideration. The mixing zone areas presented in this report do take this fact into consideration.

Recognition was given to the fact that the shoreline immediately below the outfall is not straight but forms a large-radius, convex arc. Essentially then the straight line longitudinal bases assigned to either the rectangular, triangular, or trapezoidal concepts act as cords across this arc. This introduces some error in the total mixing zone area -- the total is slightly understated since the area between the cord and arc is not included. However, because the arc is so large this area is relatively small and encompasses a very shallow near-shore volume. For the sake of simplicity and applicability, a straight-sided geometric configuration should be used to define the mixing zone since it does not significantly exaggerate the acceptable zone in this specific situation.

The maximum areas encompassed by the various contour percentage elements for the three suggested geometric shapes are presented in table 15. In reviewing the tabulated results. the fact that a 600-foot-radius circle has an area equal to 1,130,973 ft should be kept in mind; the values under the dashed lines in the table indicate areas less than this value. A triangular model fits the areal specifications for percentages of slightly above 5 or greater; a trapezoidal model fits for values starting somewhere between 8 and 10 percent; and a rectangular model fits for values starting slightly above 10 percent.

The geometric areas below station 5+00 are computed on the basis of a longitudinal distance equal to L = 350' since L is referenced to station 1+50. To each geometric area below 5+00 the rectangular area equal to D x 500' is added.

The maximum areas resulting from adherence to the 25 percent stream flow or stream cross-sectional area requirement for the 7 to 20 percent contours have also been revised and presented in table 15. These values were obtained by setting the appropriate D-equations in table 7a equal to 250 feet for a temperature, T, of 31°C and solving for the effluent flow, q. These q-values, along with T = 31°C, were used to solve for the appropriate L-value by using the equations in table 7b. The computed q-values for the 7, 10, 15, and 20 percent contours were, respectively, 53, 59, 58, and 62 mgd. The effluent flow rate is a manageable variable whereas river flow, Q, is not, nor does it appear in the L-equations in table 7b. Therefore, the determination of L-values and subsequent maximum areas for D = 250' is not practical for contour iso-percents of 1 through 5.

Table 16 has been prepared to provide an idea of the magnitude of the mixing zone areas being dealt with during cold weather conditions when river flows are compatible with the warm weather river flows. For three of the five compatible dates, the downstream or longitudinal distance, L, could be determined from the appropriate plot in Appendix B for all eight contour designations. Even the 1 percent limitation for these dates fell well within the 1,130,973 ft^2 limitation of the 600-foot radius circle. The critical 10, 15, and 20 percent limitations for all five dates included only a small fraction of the permissible area. The maximum area of 196,000 ft^2, which occurred on January 16, 1986 for the 10 percent contour, included only about 17 percent of the permissible mixing zone area. Consequently, the conclusion can be reached from these facts that the cold weather mixing zone is constrained almost entirely by the 25 percent area/flow limitation as set forth in paragraph c) of Section 302.102 of the IPCB Rules and Regulations.

Table 15. Areal Extent of Mixing Zones for Various Warm-weather Iso-dye Percentage Contours

Contour Percentages	Maximum Area(ft^2) Encompassed			Maximum Area (ft^2) Resulting from Adherence to the 25% Stream Flow/Area Requirement		
	Rectangle	Trapezoid	Triangle	Rectangle	Trapezoid	Triangle
1	8,086,512	6,136,634	4,186,756	*	*	*
2	5,322,300	4,062,350	2,802,400	*	*	*
3	3,500,020	2,694,515	1,889,010	*	*	*
5	2,313,875	1,802,281	1,290,688	*	*	*
7	1,889,985	1,478,614	1,067,243	552,750	445,613	338,875
10	1,316,385	1,042,414	768,443	501,250	407,188	313,125
15	769,600	623,450	477,300	270,000	233,750	197,500
20	642,610	526,708	410,805	271,250	234,688	198,125

* Values cannot be directly calculated by using the D-equations in conjunction with the L-equations presented in table 7

Table 16. Observed Mixing Zone Dimensions for the Five Cold Weather Dates That Have Flows Compatible with Warm Weather Flows

	Date														
	1/13/86			1/16/86			2/18/86			4/16/86			4/22/86		
Contour Percent-ages	Observed Maximum Dist (ft) D	L	Max. Mixing Area (ft^2)	Observed Maximum Dist (ft) D	L	Max. Mixing Area (ft^2)	Observed Maximum Dist (ft) D	L	Max. Mixing Area (ft^2)	Observed Maximum Dist (ft) D	L	Max. Mixing Area (ft^2)	Observed Maximum Dist (ft) D	L	Max. Mixing Area (ft^2)
1	220	1000	253,000	350	940	381,500	525	900	551,250	345	*	*	450	*	*
2	195	970	218,400	325	900	341,250	510	820	494,700	315	*	*	375	*	*
3	190	960	210,900	300	880	309,000	495	800	470,250	310	*	*	340	*	*
5	170	930	183,600	275	870	280,500	320	550	224,000	270	*	*	300	*	*
7	160	900	168,000	250	860	252,500	225	400	123,750	130	*	*	110	*	*
10	155	830	151,900	200	830	196,000	215	350	107,500	115	900	120,750	120	1050	144,000
15	135	750	121,500	150	820	145,500	200	300	90,000	105	230	39,900	110	260	45,100
20	120	260	49,200	105	800	99,750	120	200	4,200	95	210	34,200	85	200	29,750

* Indeterminate from data

Note: The maximum mixing area has been computed on the basis of a rectangular area

CONCLUSIONS

The results of the cold weather study and of the combined cold and warm weather studies lead to the following conclusions:

1. Temperature can be used as a reliable mixing zone tracer when the effluent and river water temperature differential is at least 3°C. A slight error in accuracy results from the use of temperature due to the dissipation of heat by means other than mixing. However, the loss in accuracy is more than made up for by an increase in precision. More precise locations of iso-temperature percent contours are made possible because many more temperature measurements can be recorded than analyses made for other tracers such as chlorides and fluorescent dyes.

2. The maximum transverse distance (D) of the mixing zone in the vicinity of the Greater Peoria Sanitary District (GPSD) outfall is dependent upon four factors: the effluent temperature (t) and effluent flow rate (q) and the river temperature (T) and river flow rate (Q). Prediction equations were developed equating these four factors to the 1, 2, 3, 5, 7, 10, 15, and 20 percent effluent residual percent distances on the basis of five of the ten cold weather data sets and all ten warm weather data sets. Five of the cold weather data sets were not used because the data were obtained during excessive river flows.

3. The prediction equations form a reliable basis for assessing transverse mixing distances. Mixing in the vicinity of the GPSD outfall is limited by the 25 percent cross-sectional area or flow volume requirement contained in the mixing zone definition outlined in the Illinois Pollution Control Board's (IPCB) Rules and Regulations. Limits under which the prediction equations were developed are: t = 10.47°-28°C, T = 0.33°-31°C, q = 20-55 mgd, and Q = 5,224-10,570 cfs.

4. The prediction equations appear to produce reasonable results for 7-day. 10-year low flow river conditions (2964 cfs) in conjunction with critically high river and effluent temperatures of 31°C and 30°C. respectively, although these values fall outside the limits under which the equations were statistically derived. For this extreme condition, effluent ammonia-N concentrations of 10 mg/l could be tolerated if the effluent discharge flow rate was limited to 35 mgd or less.

5. At no time during the warm or cold weather study were the IPCB's river water quality standards violated outside the mixing zone Cas defined by this study) even though effluent ammonia-N levels as high as 15.06 mg/l were observed. Under the study conditions, summer discharge concentrations ranging from 7.14 mg/l to 149.92 mg/l could have been

tolerated without violating standards; during winter conditions, discharge concentrations ranging from 24.82 mg/l to 800.73 mg/l could have been tolerated. The 7.14 mg/l minimum summer level occurred during a 50-mgd discharge rate. If this discharge rate were reduced to 40 mgd, a 15.0-mg/l effluent ammonia-N concentration could be tolerated without violating stream standards. A 21.5 mg/l effluent concentration would havs bee acceptable at q = 20 mgd.

6. The effluent ammonia-N standards can be liberalized significantly without violating stream ammonia-N standards during either the summer or winter months. Three management schemes are proposed which would ensure that stream standards are met at all times. One is a rigid across-the-board plan which specifies that the mixing zone be limited by the 20 percent contour and that would set summer discharges at 7.5 mg/l and would allow winter discharge to range from 7.5 to 40 mg/l. The second scheme would limit the GPSO effluent discharge rate to 40 mgd, thereby setting the summer effluent limit at 10 mg/l and allowing winter limits to range from 10 to 53 mg/l. The third scheme is a flexible plan using daily river and effluent conditions to dictate specific acceptable ammonia-N level at a given time. It would involve the development of extensive quality control charts. If properly administered it would allow up to 15 mg/l of ammonia-N to be discharged during warm weather periods.

7. The cold weather mixing zone areas appear to be limited by the 25 percent stream cross-sectional area-flow volume requirement presented in the IPCB's Rules and Regulations. Sufficient information was contained on the cold weather percentage contour plots to determine longitudinal distances for developing mixing areas. The maximum area for the 10 percent contour constituted only about 17 percent of the permissible mixing zone area.

REFERENCES

Butts, T.A., R.L. Evans, and S.D. Lin. 1975. Water Quality Features of the Upper Illinois Waterway. Illinois State Water Survey Report of Investigation 79, 60 p.

Butts, T.A., R.L. Evans, D.B. Shackleford, and D.H. Schnepper. 1984. The Procedures. Observations, and Results of a Mixing Zone Study for Combined Sewer Overflows at Peoria. Illinois. Illinois State Water Survey Contract Report 349,119 p.

Butts, T., D. Roseboom, T. Hill, S. Lin, D. Beuscher, R. Twait, and R. Evans. 1981. Water Quality Assessment and Waste Assimilative Analysis of the LaGrange Pool. Illinois River. Illinois State Water Survey Contract Report 260, 116 p.

Butts, T.A., D.H. Schnepper, and K.P. Singh. 1983. The Effects of Lake Michigan Discretionary Diversion Strategies on Illinois Waterway Dissolved Oxygen Resources. Illinois State Water Survey Contract Report 324, 53 p.

Butts, T.A., D.B. Shackleford, T.E. Hill, and R.L. Evans. 1985. The Impact of Greater Peoria Sanitary District Ammonia Discharges on Illinois River Water Quality. Illinois State Water Survey Contract Report 373, 199 p.

Illinois Pollution Control Board. 1986. State of Illinois Rules and Regultions. Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter 1: Pollution Control Board, February 1, 1986, 44 p.

Standard Methods for the Examination of Water and Wastewater. 1985. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 16th edition, 1268 p.

Appendix A. Ammonia-N (NH_3-N) Concentrations and Residual Percentages Observed in the Illinois River between November 1, 1985 and April 30, 1986 in the Mixing Zone Area of the Greater Peoria Sanitary District's Treatment Plant Outfall

November 5, 1985

Sta (ft)	Dist (ft)	Depth (ft)	Temp (°C)	Observed NH_3-N (mg/l)	(%)
0+00	50	0	13.4	2.63	44.9
0+50	0	0	11.0	3.60	62.6
1+50	50	0	16.6	1.30	20.5
	100	0	10.8	0.75	10.4
	150	0	10.1	0.03	0
2+50	0	0	16.2	4.69	82.6
	30	0	10.5	0.56	6.9
	100	0	9.9	1.05	15.9
3+50	30	0	15.7	4.88	86.1
	50	0	16.4	4.41	77.4
	100	0	10.0	0.10	0
5+00	0	0	14.0	3.10	53.5
	50	0	14.9	4.11	71.9
	100	0	11.8	1.90	31.5
6+50	30	0	12.5	1.91	31.7
	75	0	11.6	1.27	19.9
8+50	100	0	11.8	1.33	21.1
	150	0	9.9	0.12	0
9+50	30	0	13.4	2.69	45.9
	125	1.5	11.0	0.74	10.3

November 13, 1985

Sta (ft)	Dist (ft)	Depth (ft)	Temp (°C)	Observed NH_3-N (mg/l)	(%)
1+00	50	0	9.2	0.15	0
1+50	50	0	9.4	0.10	0
	0	0	15.5	6.56	85.0
2+50	50	0	9.3	0.47	1.37
	30	0	16.1	4.20	52.6
3+50	75	0	11.5	0.63	3.6
	50	1	15.8	5.68	72.9
	0	0	11.5	2.47	28.8
4+50	75	0	9.3	0.42	0.7
	50	0	12.0	2.41	27.0
	30	0	11.8	2.91	34.9
5+00	75	0	9.3	0.30	0
	0	0	11.6	2.71	32.1
6+00	100	0	9.6	0.52	2.1
	46	0	11.0	2.16	24.6
8+00	50	0	10.9	1.99	22.3
8+50	150	0	9.2	0.49	1.7
	0	0	10.9	1.99	22.3
9+00	30	0	11.0	2.12	24.0
10+00	30	0	11.0	2.12	24.0

January 9, 1986

0+00	50	0	0.4	1.15	0.4
0+50	75	0	1.0	1.14	5.7
	25	0	2.0	2.96	16.3
1+00	0	0	1.2	2.07	8.6
	115	0	6.1	5.02	34.4
1+50	20	0	7.2	8.29	63.1
2+00	25	0	10.6	12.14	96.7
2+50	60	0	5.0	5.25	36.9
	0	0	10.9	12.93	100.0
3+00	0	0	8.6	11.53	92.0
	50	0	3.4	3.49	21.7
3+50	100	11	3.8	2.47	12.9
	100	0	0.5	0.67	0
4+50	50	0	0.5	1.19	1.9
5+50	50	0	0.6	1.00	0.2
8+00	25	0	1.1	1.52	5.0

January 13, 1986

0+00	25	0	4.4	4.92	27.0
0+50	75	0	2.6	4.08	20.7
1+00	50	0	8.0	9.95	66.2
	125	0	1.8	3.26	14.6
1+50	25	1	4.7	7.50	47.6
	25	0	2.8	1.33	0.2
2+00	45	0	11.3	11.74	80.2
2+50	75	4	2.5	4.66	26.2
	75	0	0.9	15.88	100.
	25	0	2.7	7.53	48.1
3+00	0	0	1.5	13.63	94.8
	50	0	2.5	4.54	25.4
	125	10	2.9	1.40	1.7
	125	0	0.7	0.51	0
4+00	50	0	2.6	2.41	9.9
5+00	60	3	1.5	1.40	2.8
6+50	65	0	1.1	0.50	0
9+00	25	0	2.2	1.66	5.6
10+50	100	0	1.5	1.71	6.1

January 16, 1986

Sta	Dist	Depth	Temp	Observed NH_3-N	
(ft)	(ft)	(ft)	(°C)	(mg/l)	(%)
1+00	25	0	5.3	6.92	39.0
1+50	25	0	8.6	9.15	53.8
	50	0	0.9	1.56	3.01
2+00	50	0	13.7	14.66	89.5
2+50	75	7	4.0	2.74	10.69
	75	0	7.8	7.24	40.1
3+00	50	0	12.5	14.86	88.7
3+50	72	9	6.8	8.74	48.9
	72	0	4.1	4.87	24.0
	128	12	2.5	3.63	16.1
	128	0	0.7	1.25	0.9
4+50	115	11	5.6	5.24	25.7
	115	0	0.7	1.28	1.1
5+50	100	6	5.6	5.50	27.0
	100	0	1.0	2.16	6.5
6+50	220	13	3.8	4.71	21.9
9+50	200	11	1.9	2.08	3.8
	200	0	0.5	0.75	2.2

January 21, 1986

Sta	Dist	Depth	Temp	Observed NH_3-N	
(ft)	(ft)	(ft)	(°C)	(mg/l)	(%)
1+00	25	0	0.7	1.38	2.8
1+50	0	0	0.8	1.13	0.4
2+00	50	2.5	1.6	2.89	16.7
	50	0	0.9	1.13	0.3
2+50	65	4	5.5	4.22	29.2
	65	0	0.7	1.24	1.2
3+00	42	2	10.5	8.39	69.8
	42	0	4.1	3.58	23.5
	90	0	8.8	7.01	53.9
3+50	110	11	3.7	3.65	24.5
	110	0	0.9	4.08	28.8
4+00	100	0	5.7	4.15	30.0
5+00	115	0	3.0	2.30	11.2
6+00	180	11	2.4	2.37	11.9
	180	0	0.3	1.38	1.4
7+50	0	0	3.8	2.94	18.2
8+00	120	8	1.8	1.98	7.7
	0	0	0.8	1.24	0
9+00	0	0	5.2	6.25	55.1

January 23, 1986

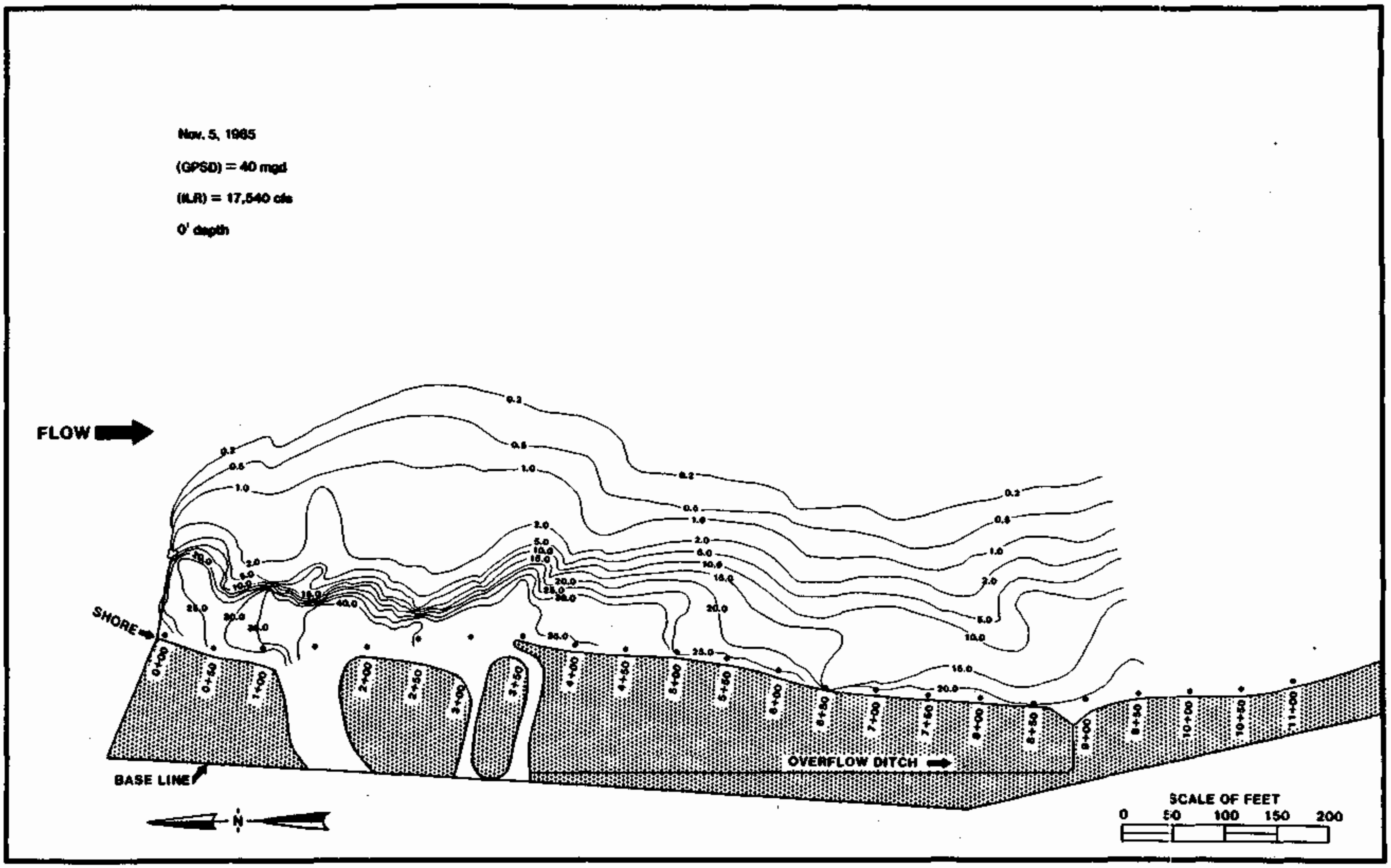
0+00	25	0	5.8	4.45	34.6
1+00	125	0	1.6	1.48	5.2
1+50	125	0	1.5	2.56	14.5
	95	0	3.6	2.13	10.7
2+00	75	0	2.4	1.46	4.4
3+00	85	8	1.7	1.16	1.2
	85	0	5.0	1.77	5.7
3+50	56	3	7.9	6.25	37.9
	56	0	11.3	10.28	66.8
4+50	100	8	4.1	3.08	18.15
	100	0	2.1	1.32	1.6
5+50	110	7	3.5	2.61	9.9
	110	0	1.8	1.54	2.7
6+00	90	0	4.0	3.07	12.3
8+00	75	0	4.7	4.02	17.7
9+00	120	0	4.1	3.72	15.2
	25	0	4.3	3.21	11.9
10+00	25	0	5.9	2.92	10.2
10+50	50	0	4.9	3.00	10.6

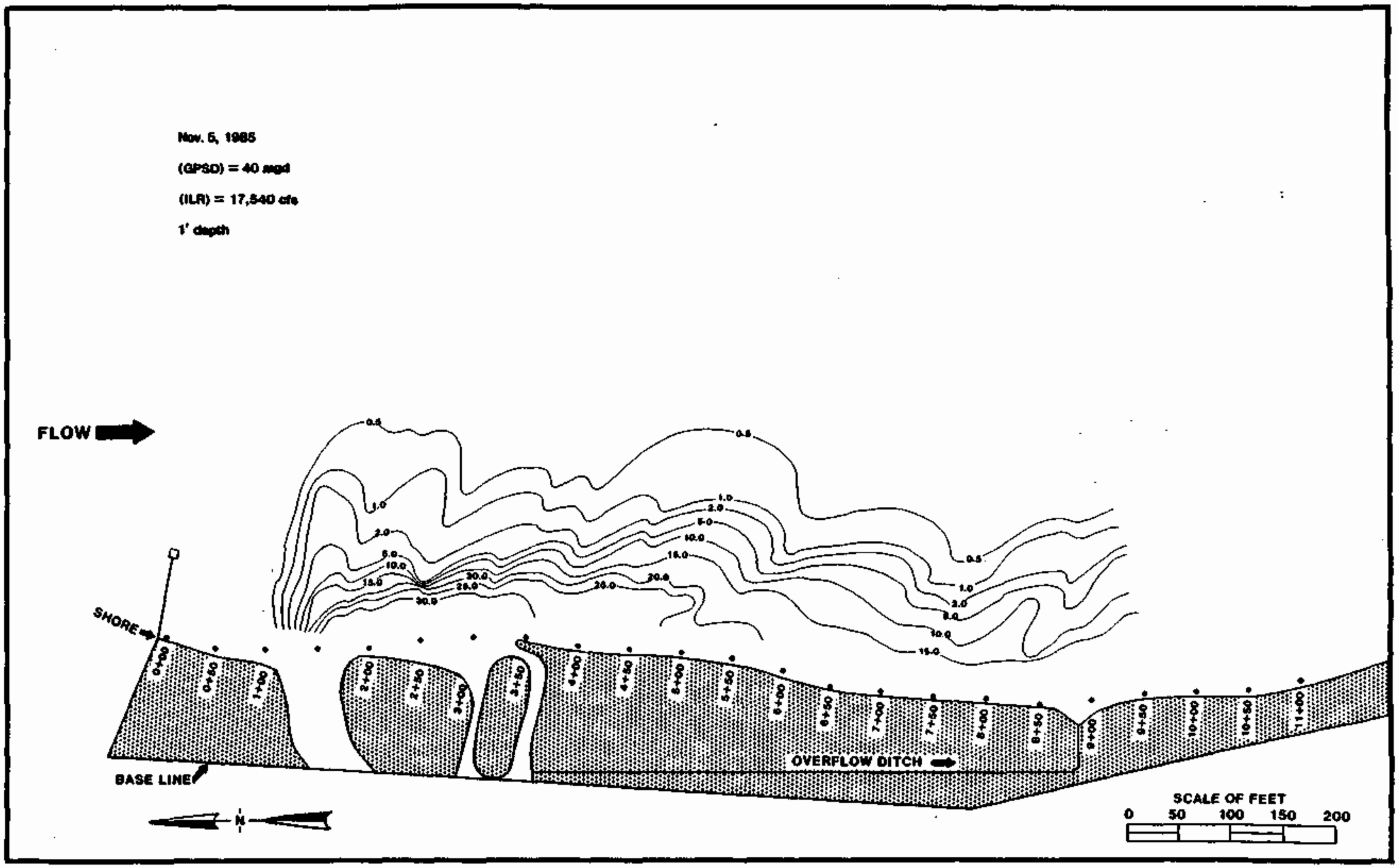
February 18, 1986

0+50	50	0	2.0	1.29	0.3
1+00	100	0	1.0	0.99	0
1+50	0	0	7.0	2.00	9.6
	160	0	0.7	1.27	0
2+00	90	5	1.1	1.45	2.4
	90	0	0.7	1.27	0
2+50	0	0	11.8	7.39	84.8
	115	9	5.2	4.68	47.8
		0	0.8	0.93	0
3+00	117	9	2.8	1.41	2.0
		5	5.0	1.40	1.9
		0	0.6	1.06	0
3+50	74	6	6.4	3.53	38.5
		0	0.9	2.19	15.7
4+50	180	10	2.4	2.01	12.9
		0	0.5	0.92	0
7+00	350	12	0.6	1.33	1.1
		0	0.9	1.04	0
8+00	50	0	0.9	1.06	0
9+00	300	0	0.5	1.20	0

April 16, 1986						April 22, 1986					
0+00	100	0	10.3	0.11	0	0+00	50	0	12.2	0.05	0
0+50	25	0	9.3	0.19	0.1	1+00	85	0	11.9	0.23	0.4
	200	0	10.5	0.21	0.3	1+50	55	0	14.5	2.95	100
1+00	170	0	10.5	0.13	0		110	0	11.9	0.29	2.7
	50	0	10.3	0.11	0	2+00	60	0	14.0	1.53	52.5
1+50	0	0	12.4	2.40	24.4		25	0	14.6	2.09	100
	125	0	10.5	0.08	0	2+50	100	0	14.0	2.14	76.5
2+00	50	2	12.8	6.33	66.9	3+00	100	0	12.8	1.54	52.0
	50	0	11.1	2.23	21.9		25	0	15.3	2.79	100
2+50	95	0	13.4	5.76	60.0	3+50	95	0	13.9	1.80	61.7
3+00	85	8	13.3	6.39	66.3	4+00	110	11	12.0	0.78	21.1
	85	0	11.6	3.24	32.2		110	0	13.9	1.66	58.9
3+50	115	0	11.9	7.61	78.9	4+50	150	0	13.0	1.29	40.8
4+00	56	0	11.7	4.13	41.0	5+50	70	0	12.7	0.98	28.2
6+00	25	0	11.0	1.78	15.6	6+50	50	0	12.4	0.87	23.8
8+00	115	0	11.1	2.41	21.7	8+50	110	0	12.6	0.84	21.9
10+50	125	0	10.5	1.04	7.2	10+50	25	0	13.3	0.74	17.9
	45	0	11.2	2.32	20.4	10+50	170	0	12.4	0.49	8.2

Appendix B. Contour Plots of Residual Effluent Temperature Percents for Surface, 1-, 3-, and 8-Foot Depths for the Ten Cold Weather Sampling Dates


Nov. 5, 1985
(GPSD) = 40 mgd
(ILR) = 17,540 cfs
0' depth
FLOW
SHORE
BASE LINE
OVERFLOW DITCH
0.2
0.5
1.0
2.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
N
SCALE OF FEET
0
50
100
150
200

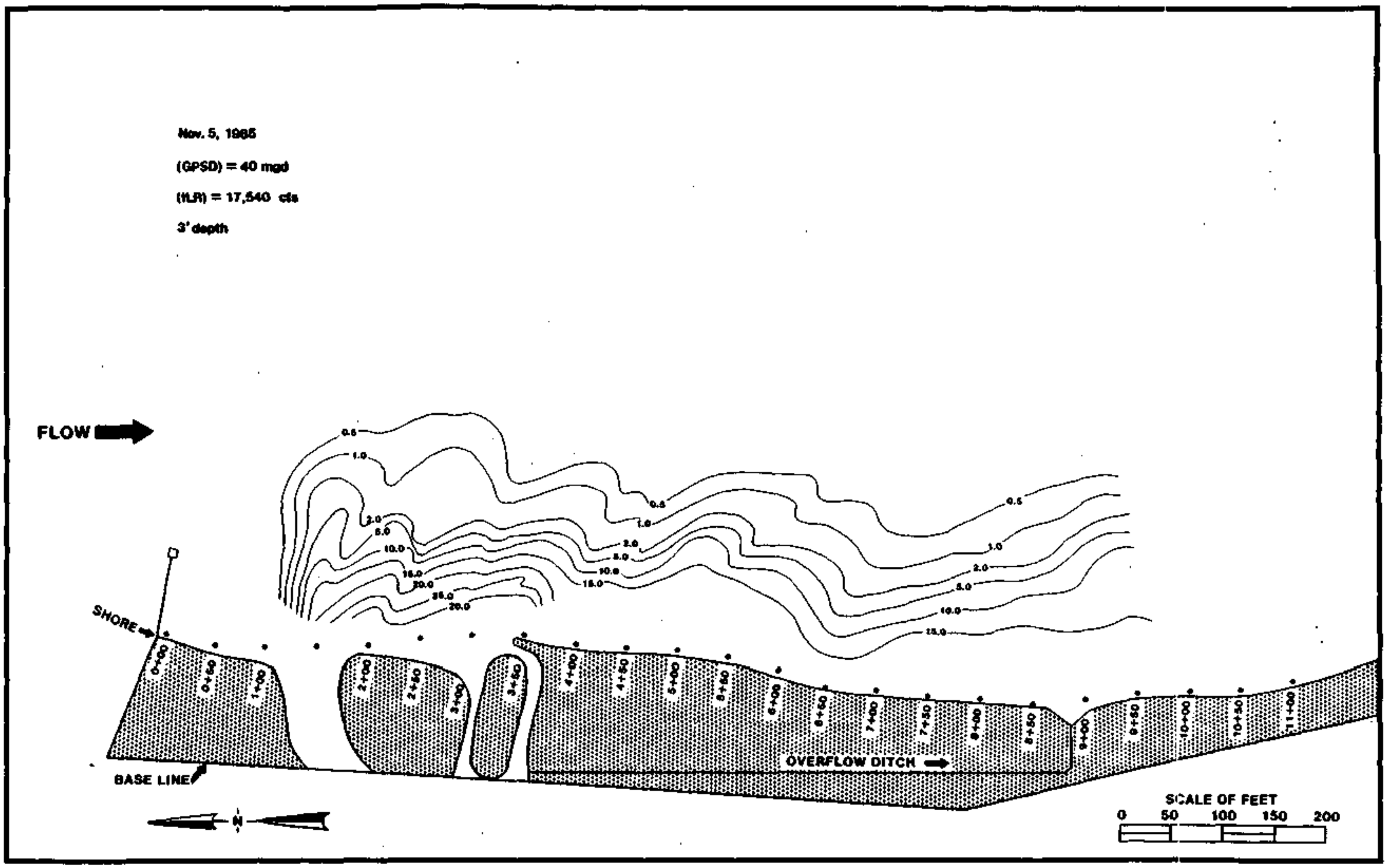


Nov. 5, 1985

(GPSD) = 40 mgd

(ILR) = 17,540 cfs

1' depth

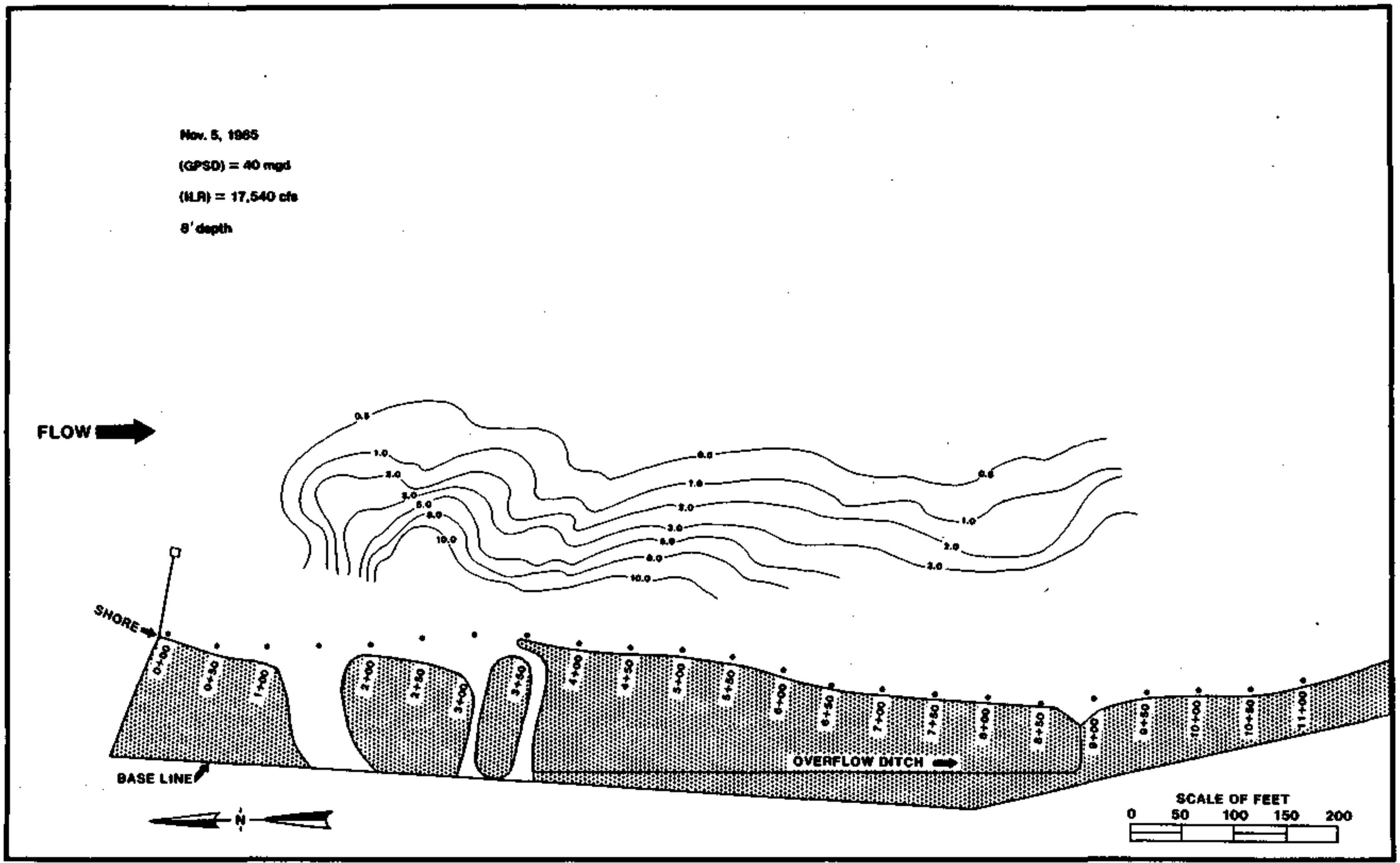


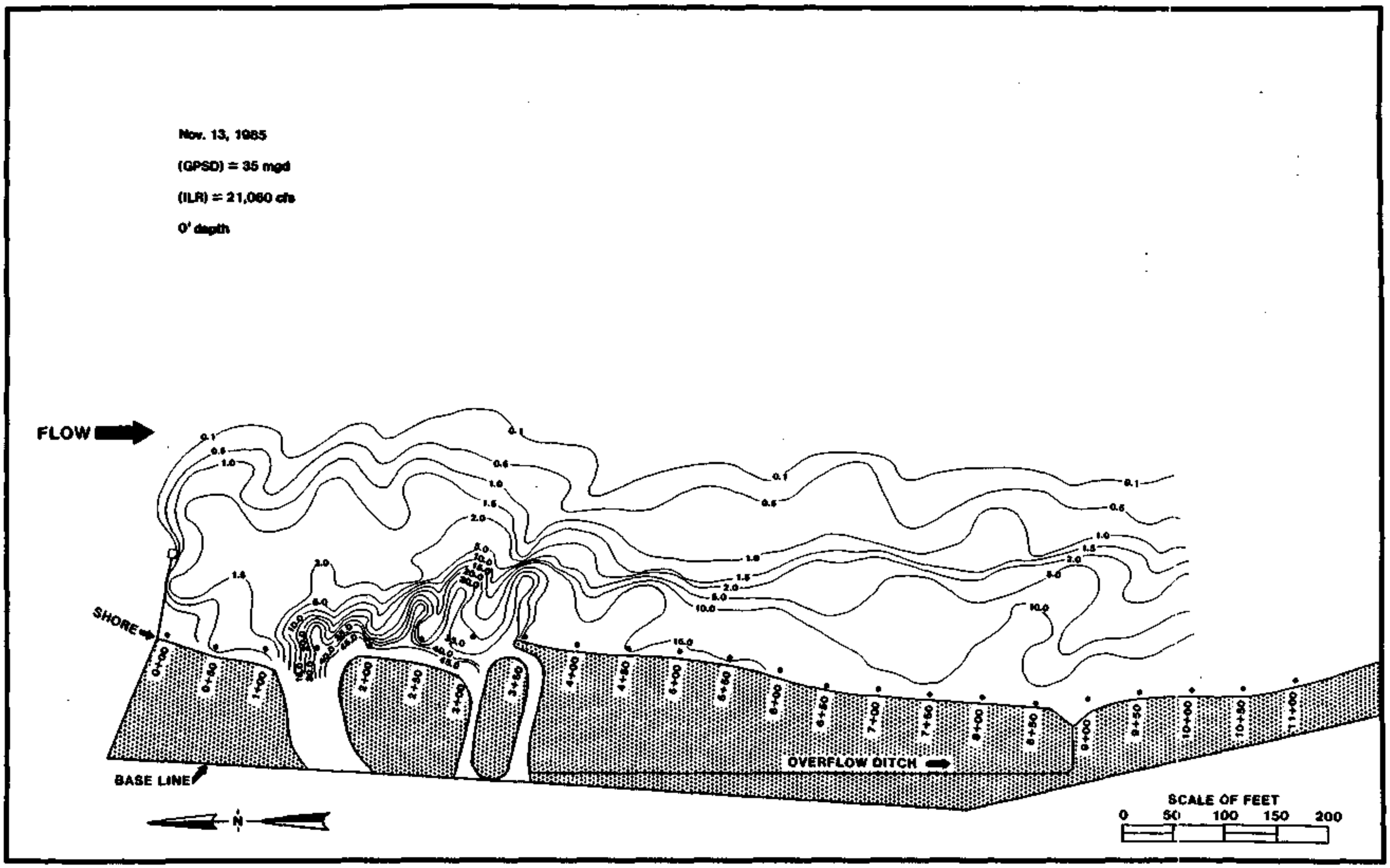
Nov. 5, 1985

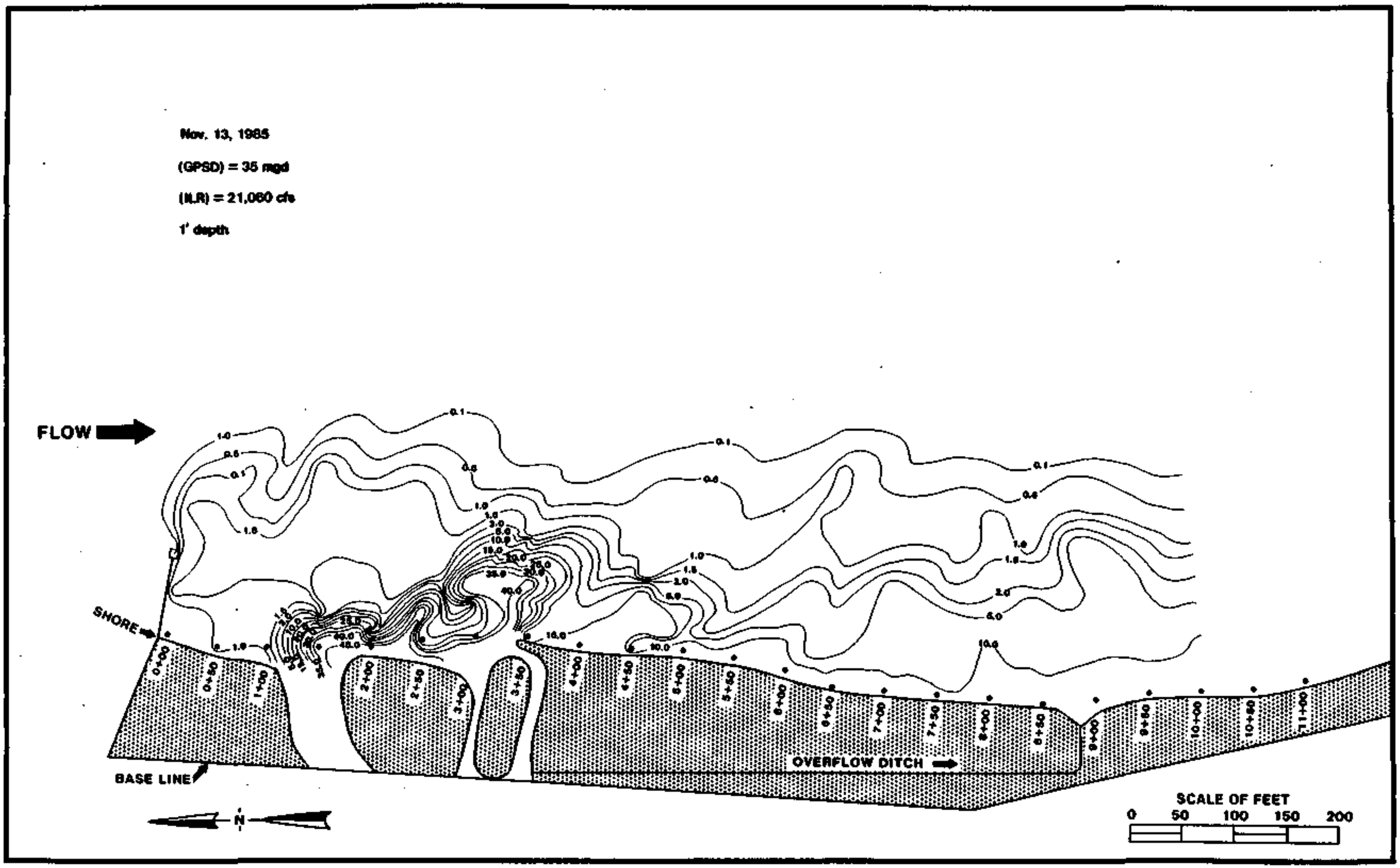
(GPSD) = 40 mgd

(ILR) = 17,540 cfs

3' depth


Nov. 5, 1965
(GPSD) = 40 mgd
(ILR) = 17,540 cfs
8' depth
FLOW
0.5
1.0
2.0
3.0
5.0
8.0
10.0
SHORE
BASE LINE
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200


Nov. 13, 1985
(GPSD) = 35 mgd
(ILR) = 21,060 cfs
0' depth
FLOW
SHORE
BASE LINE
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
0.1
0.5
1.0
1.5
2.0
5.0
10.0
15.0
20.0
30.0
40.0
45.0

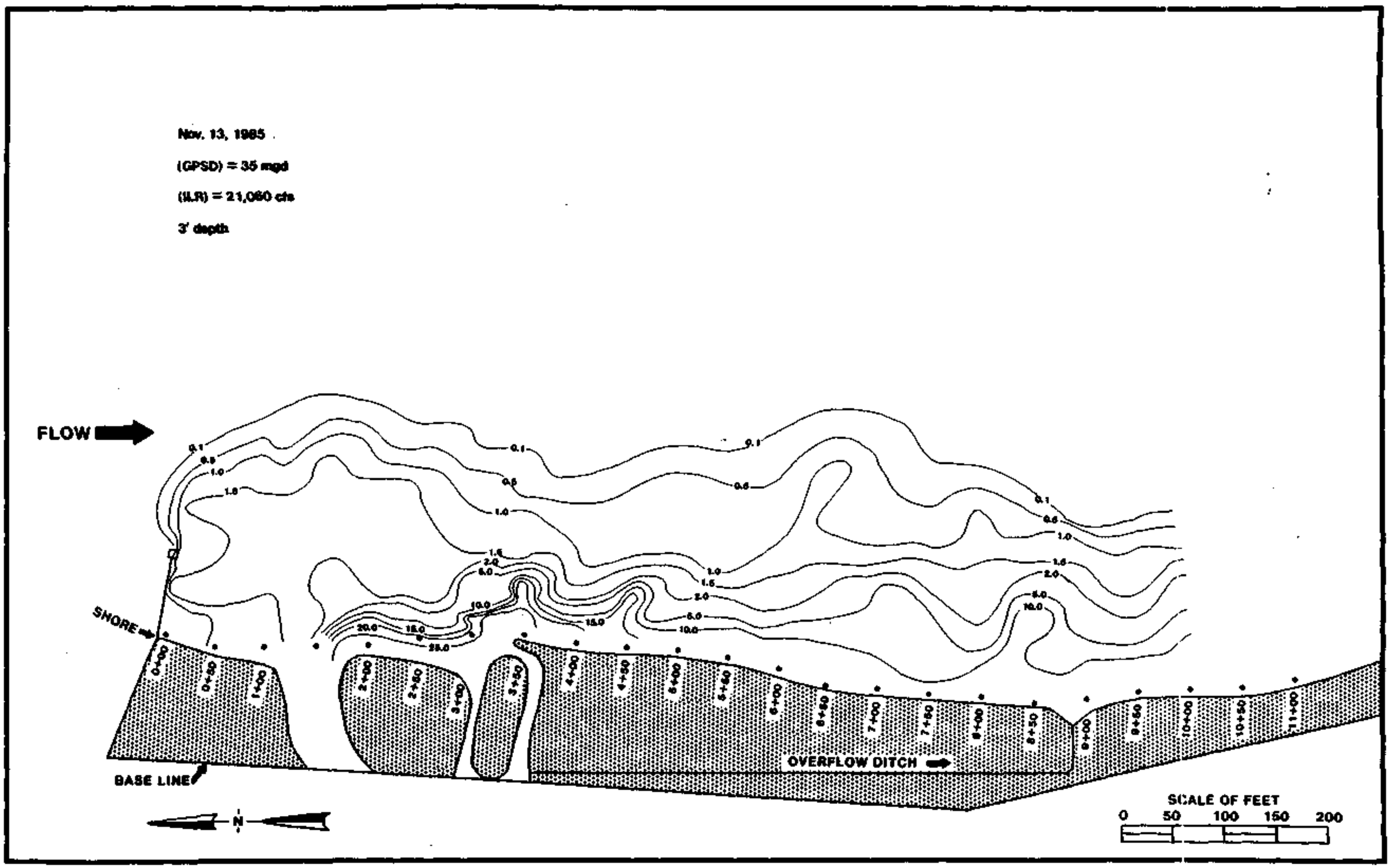


Nov. 13, 1985

(GPSD) = 35 mgd

(ILR) = 21,060 cfs

1' depth

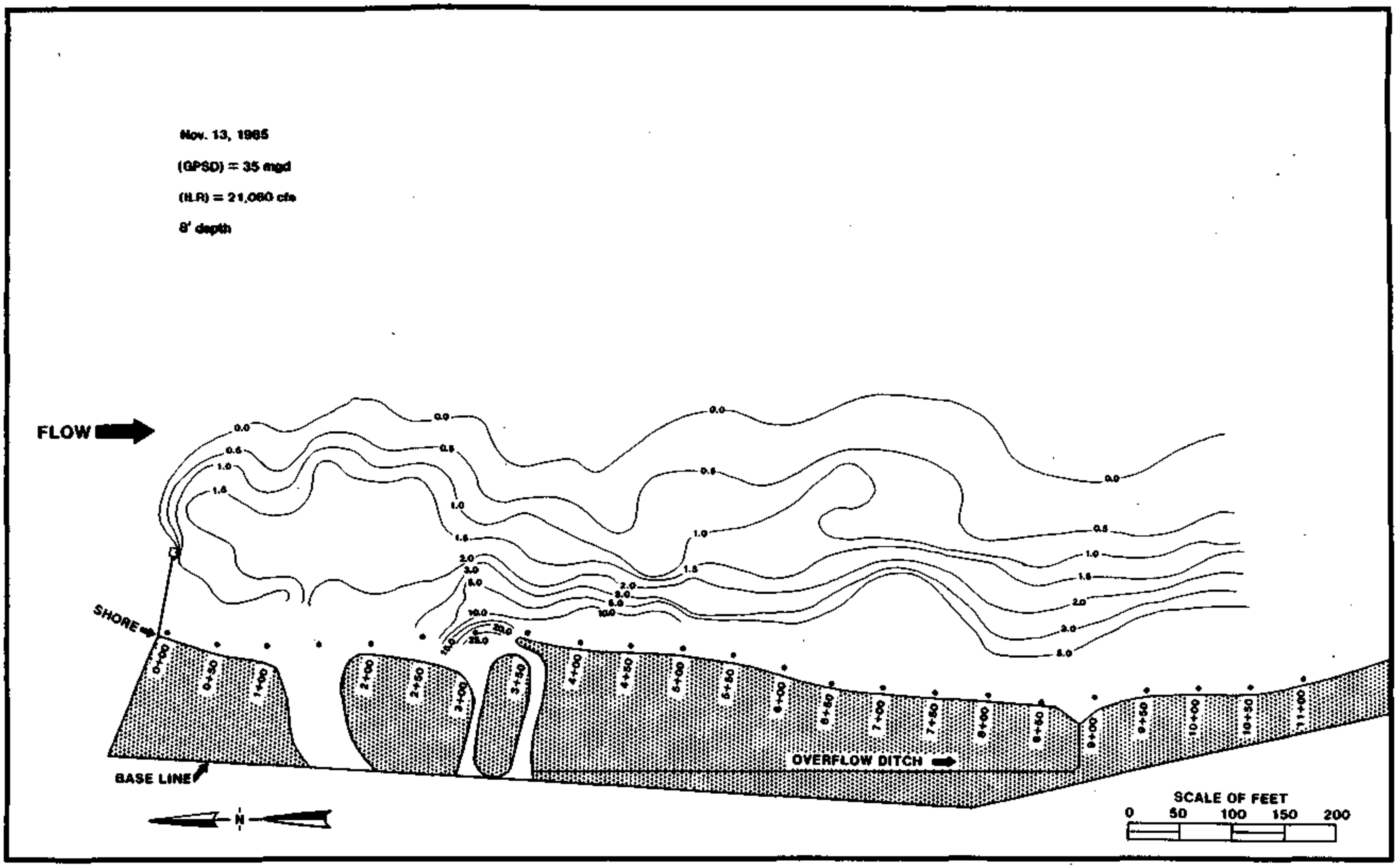


Nov. 13, 1985

(GPSD) = 35 mgd

(ILR) = 21,060 cfs

3' depth

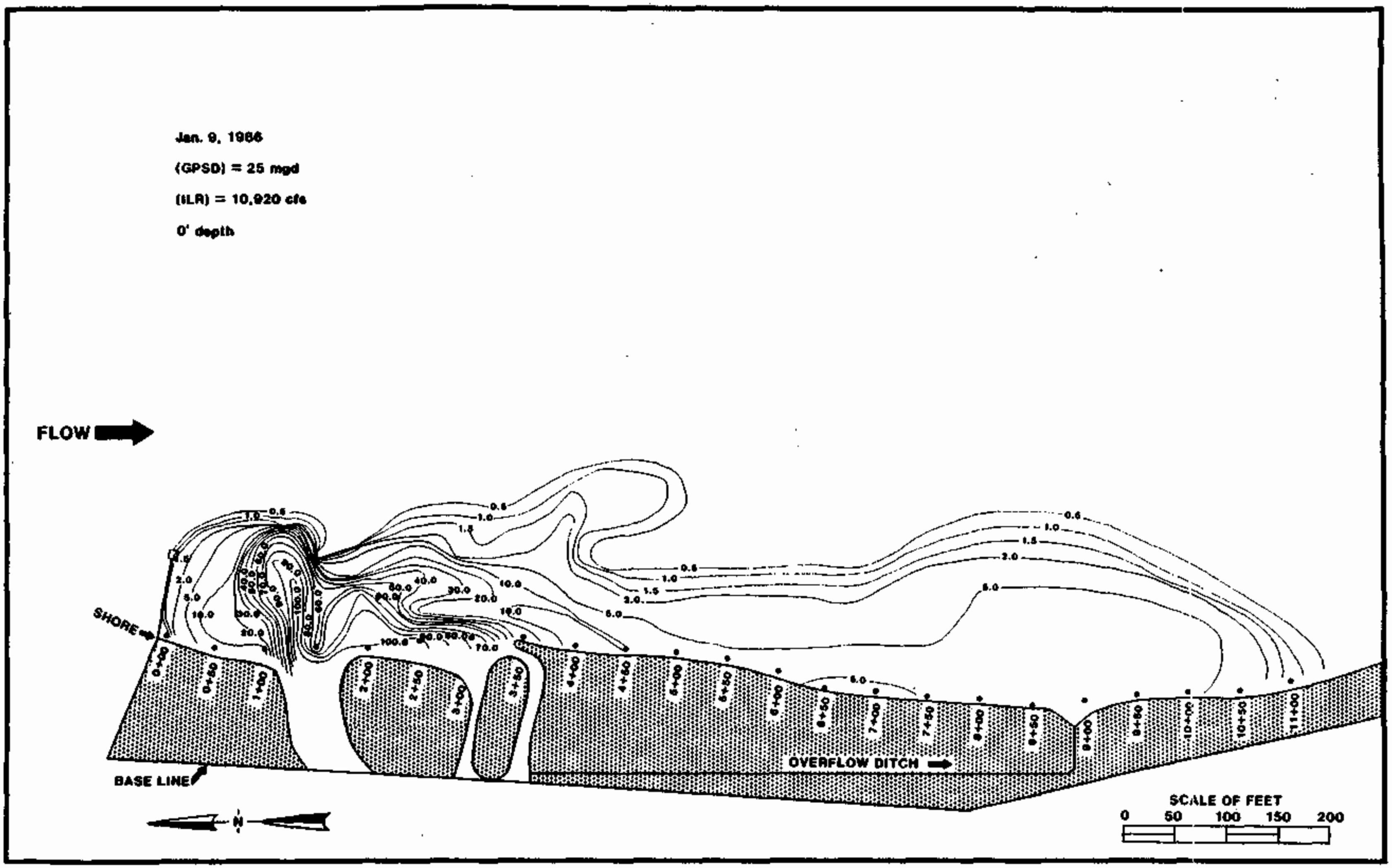


Nov. 13, 1985

(GPSD) = 35 mgd

(ILR) = 21,060 cfs

8' depth

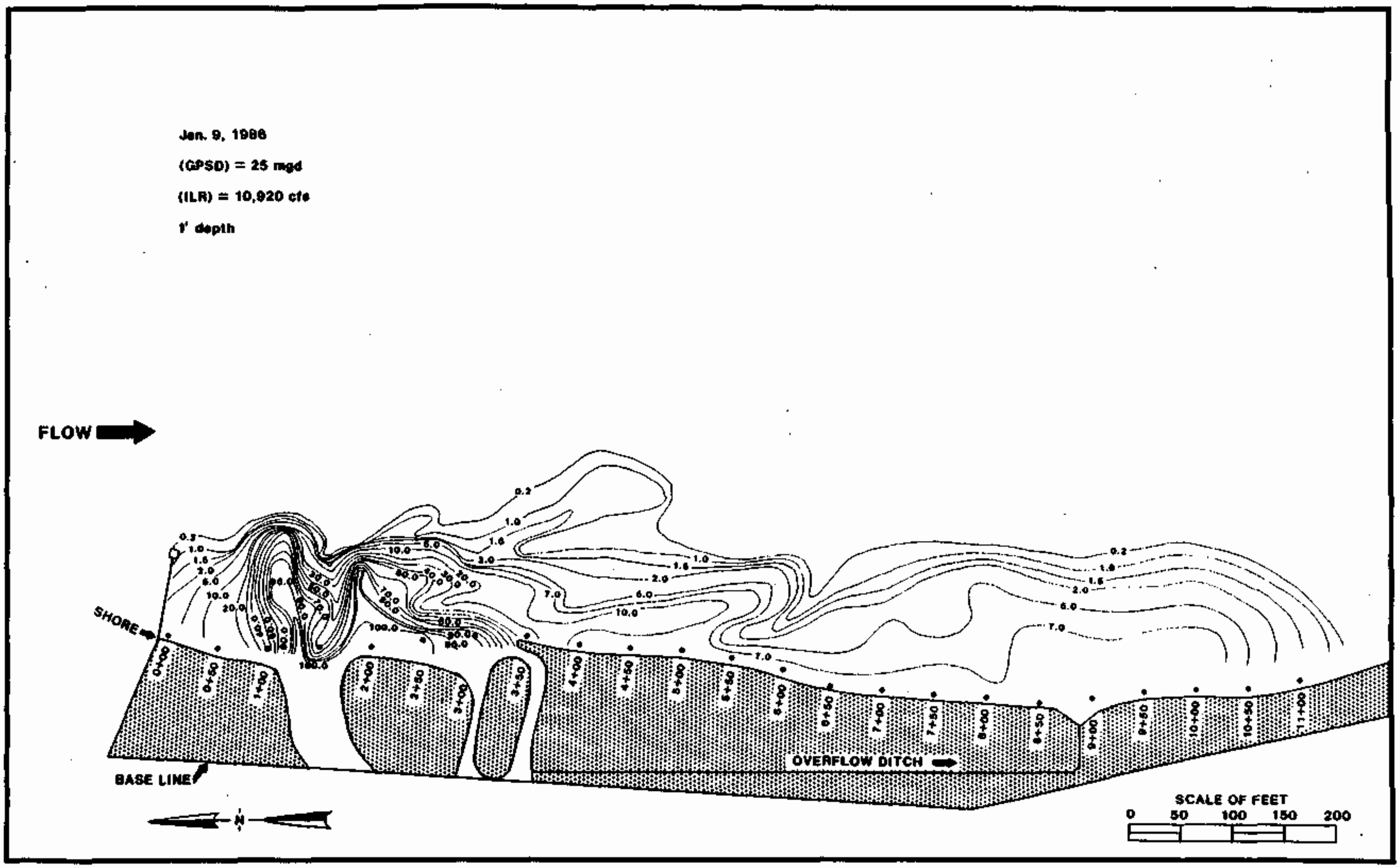


Jan. 9, 1986

(GPSD) = 25 mgd

(ILR) = 10,920 cfs

0' depth



Jan. 9, 1986

(GPSD) = 25 mgd

(ILR) = 10,920 cfs

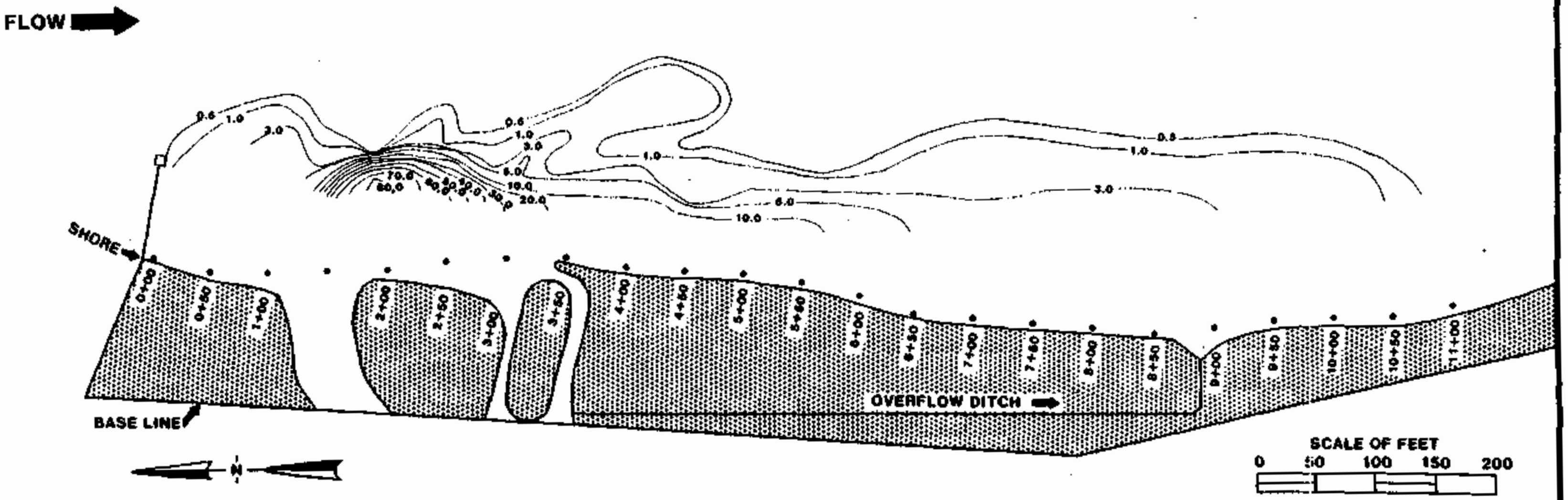
1' depth

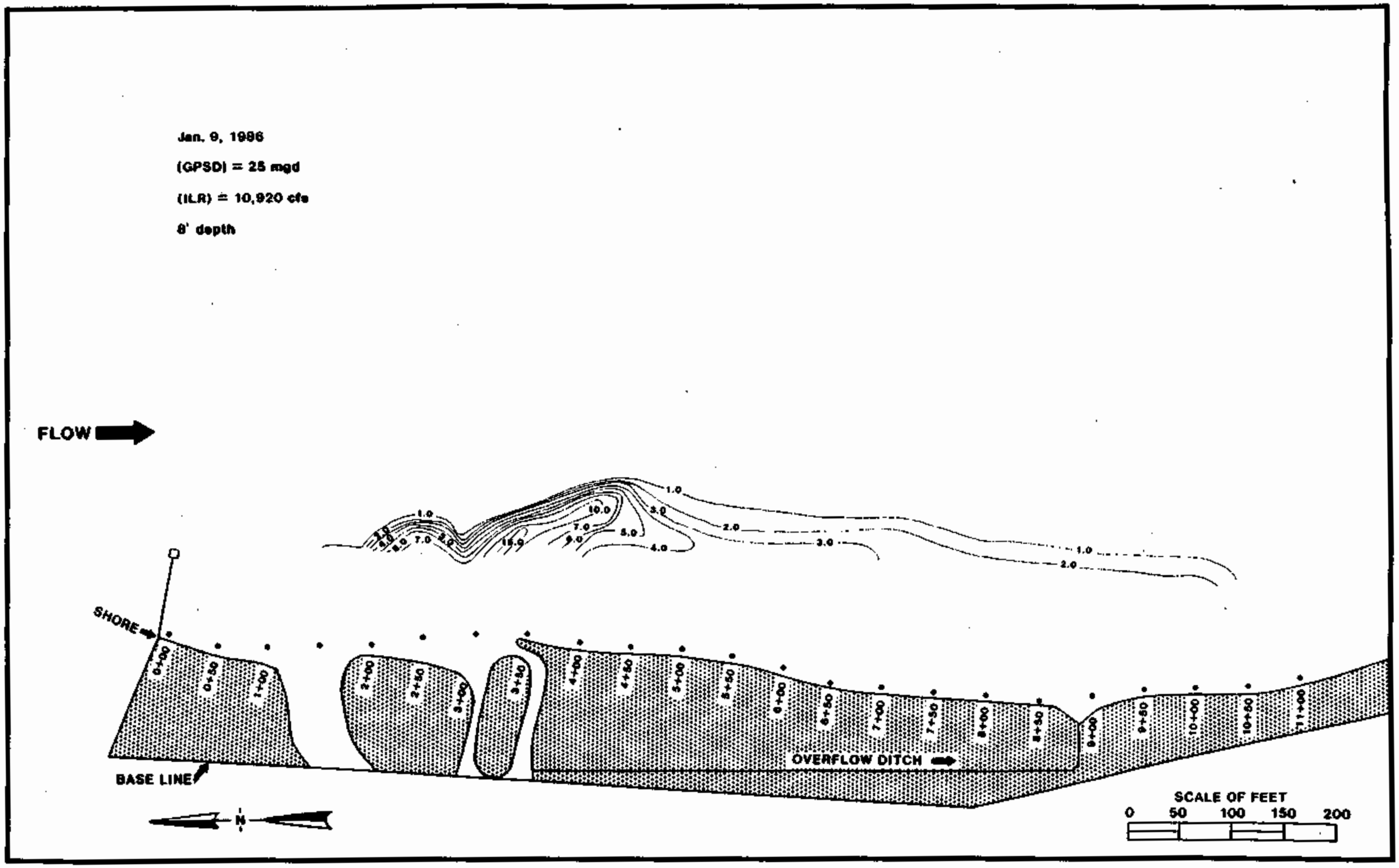
Jan. 9, 1986

(GPSD) = 25 mgd

(ILR) = 10,920 cfs

3' depth



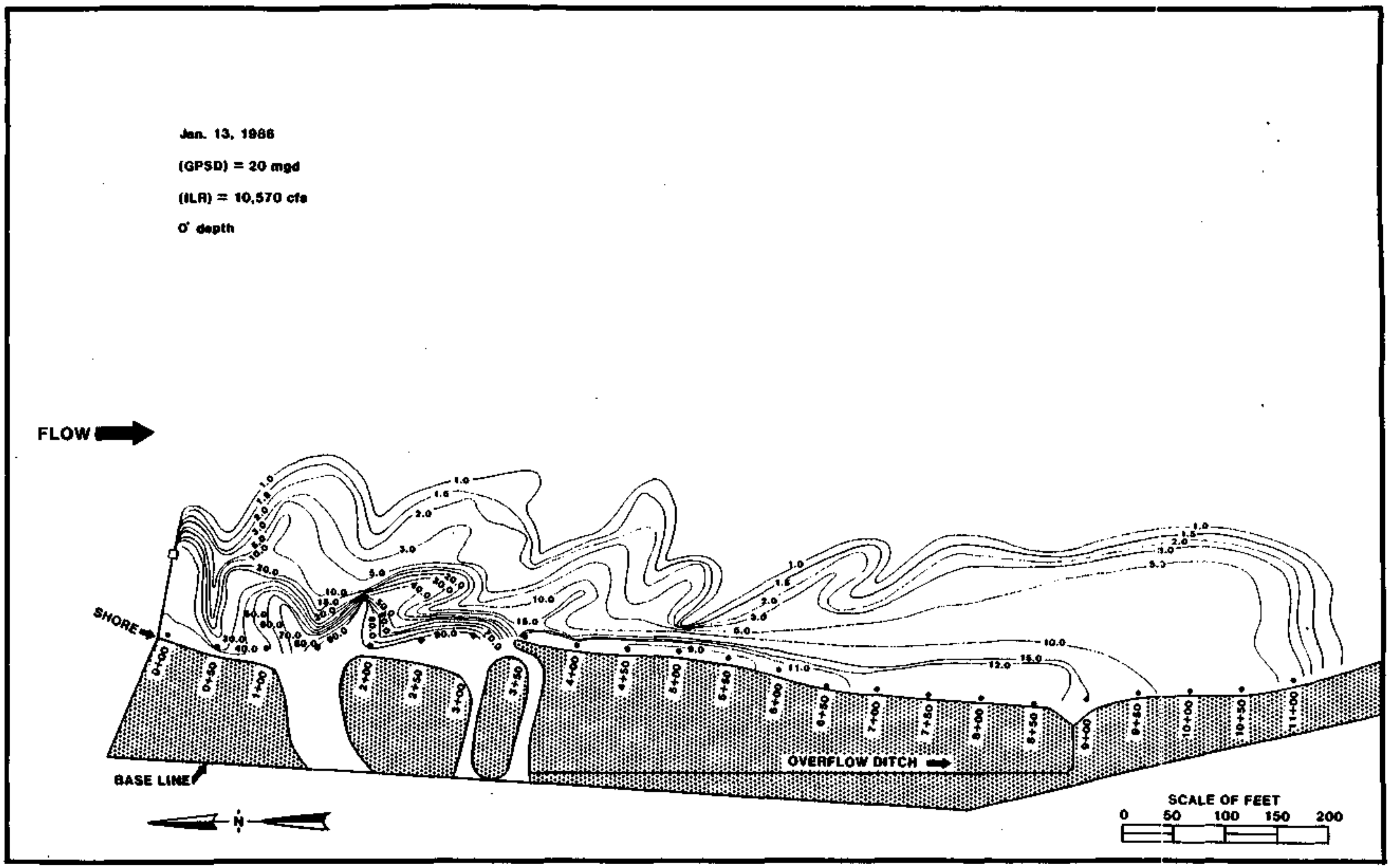


Jan. 9, 1986

(GPSD) = 25 mgd

(ILR) = 10,920 cfs

8' depth

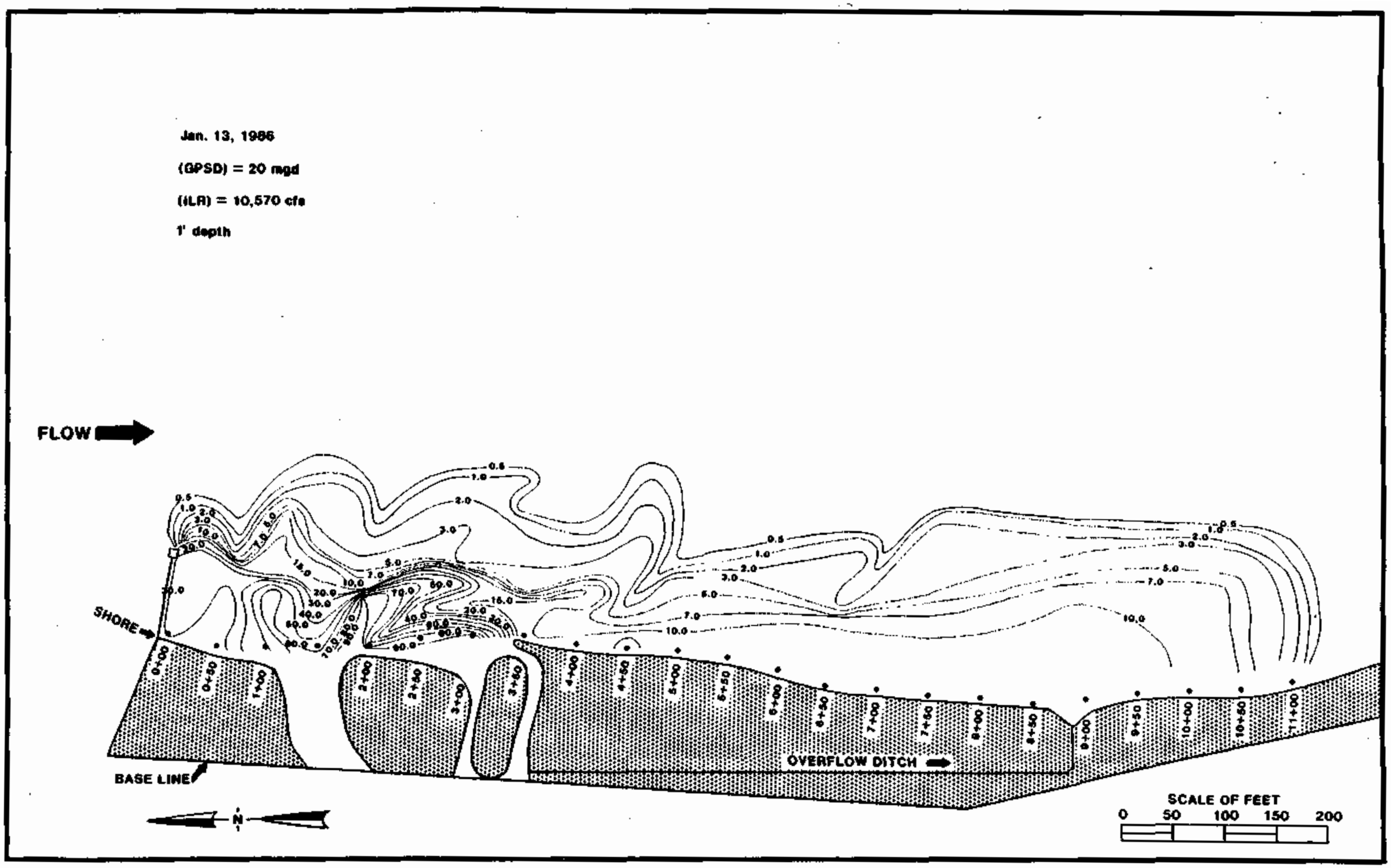


Jan. 13, 1986

(GPSD) = 20 mgd

(ILR) = 10,570 cfs

0' depth


Jan. 13, 1986

(GPSD) = 20 mgd

(ILR) = 10,570 cfs

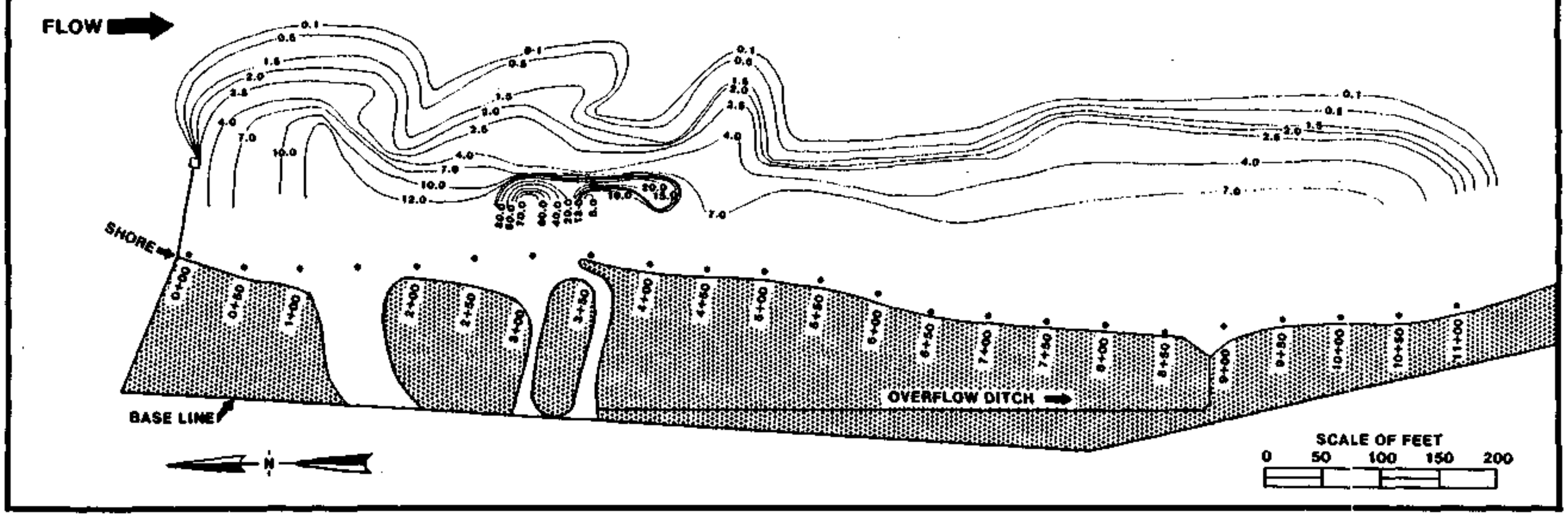
1' depth

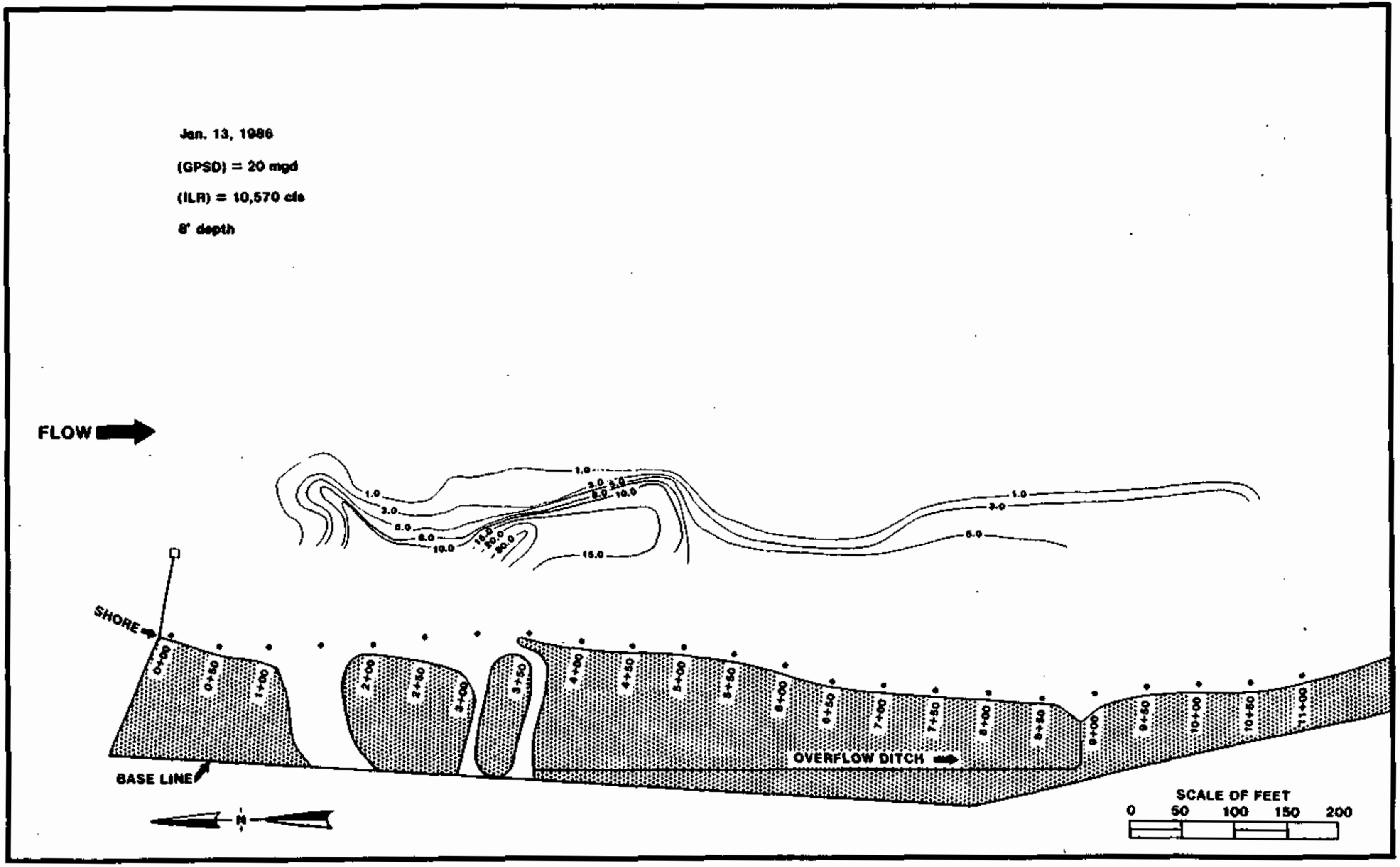
Jan. 13, 1986

(GPSD) = 20 mgd

(ILR) =10,570 cfs

3' depth



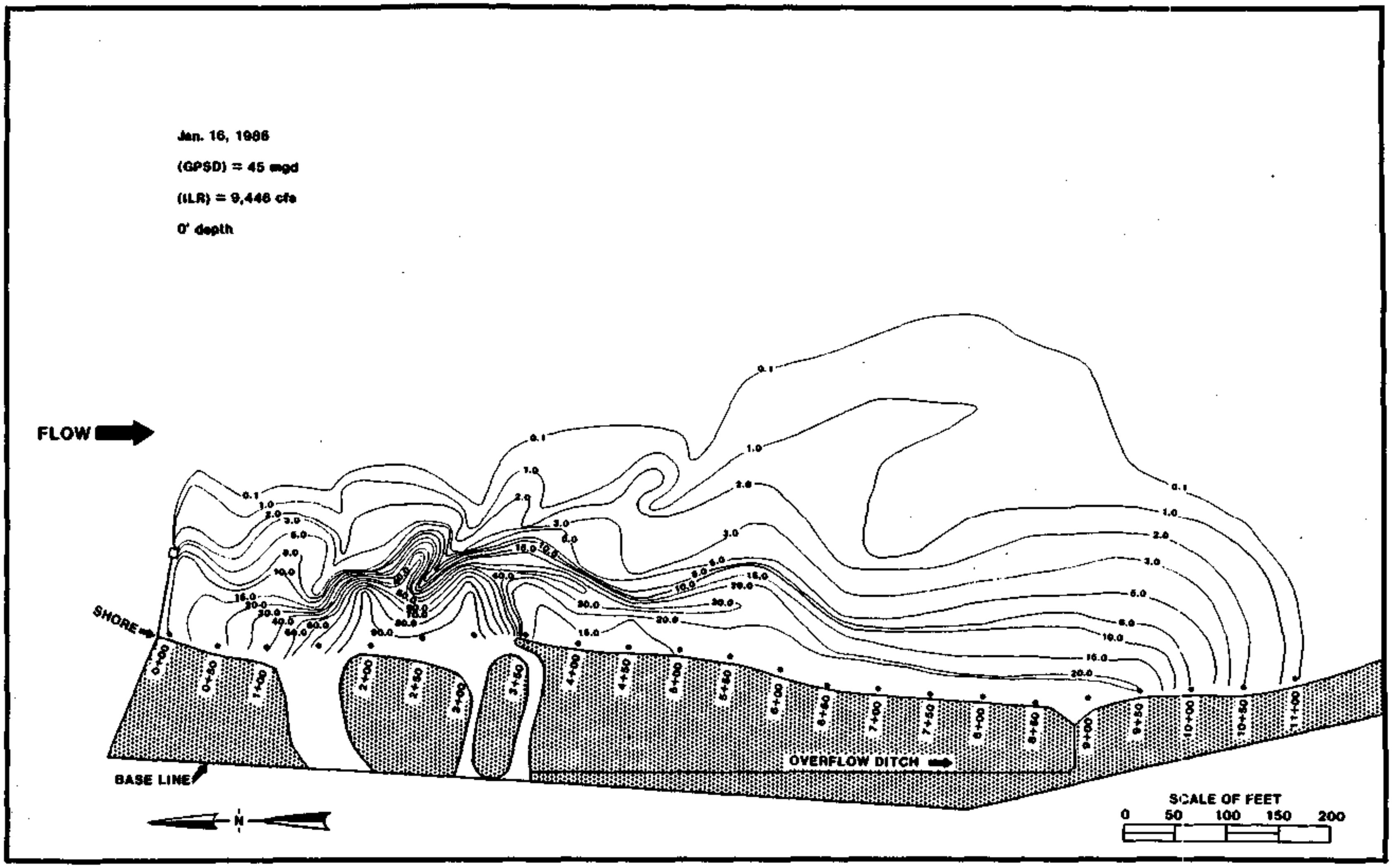


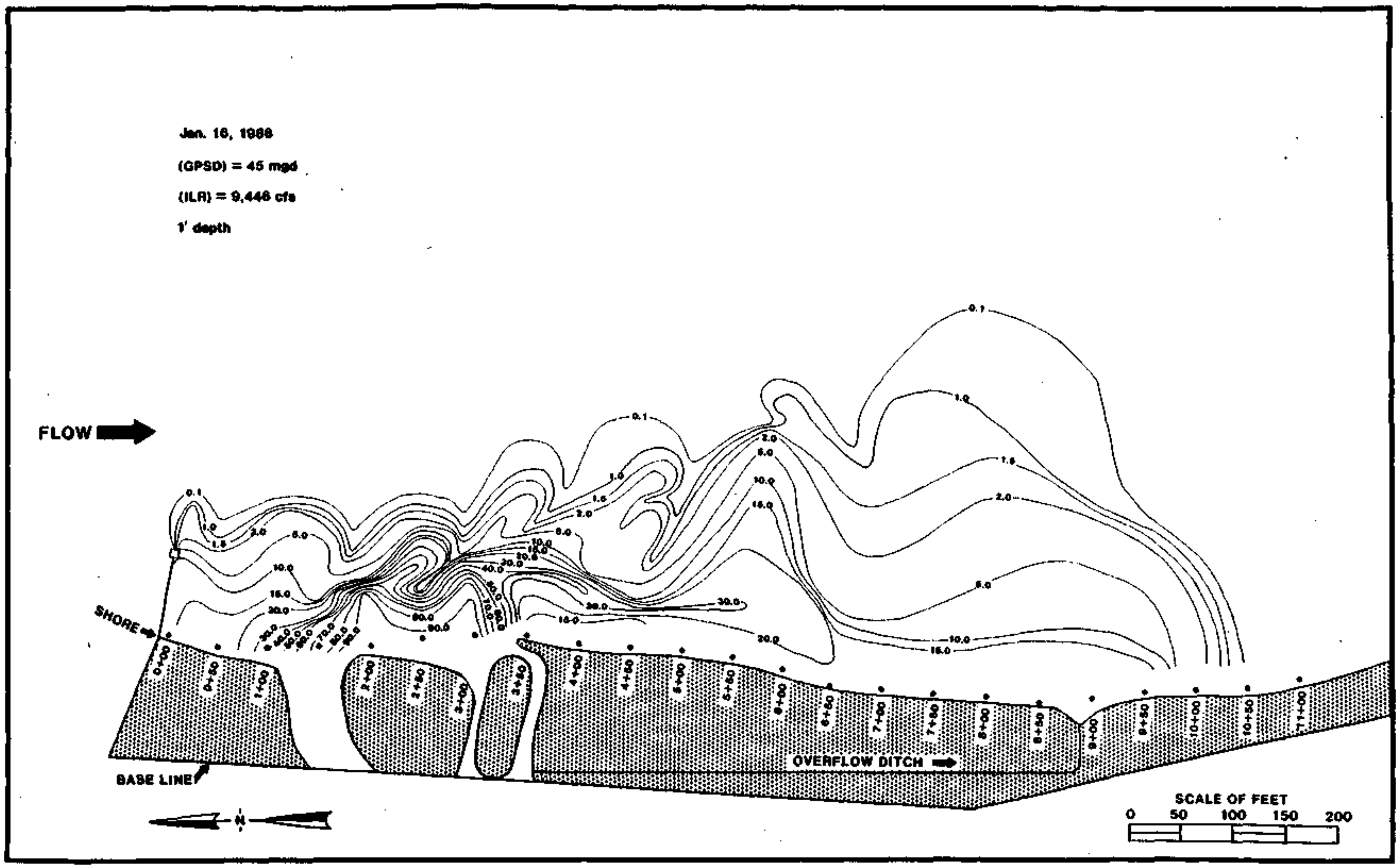
Jan. 13, 1986

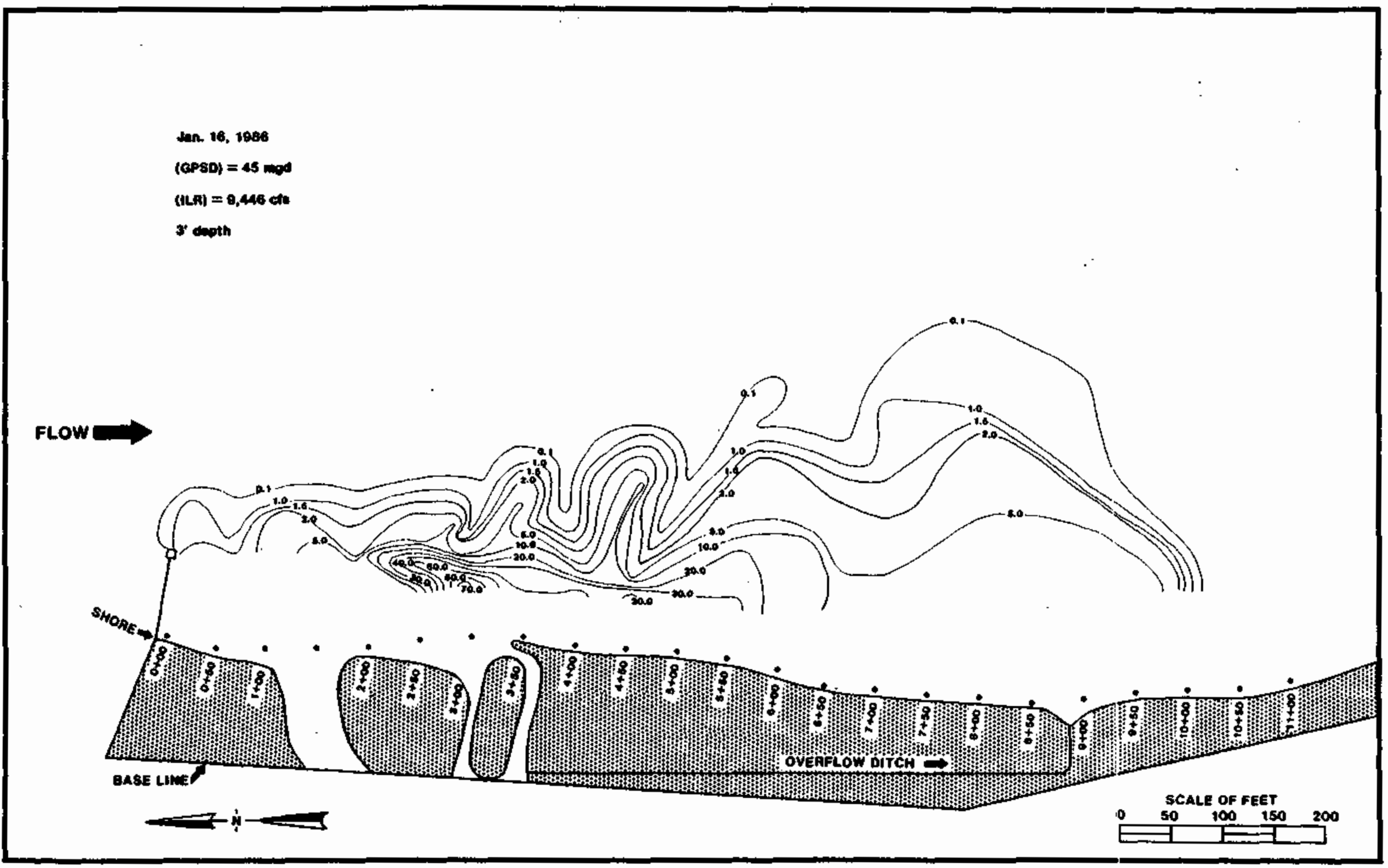
(GPSD) = 20 mgd

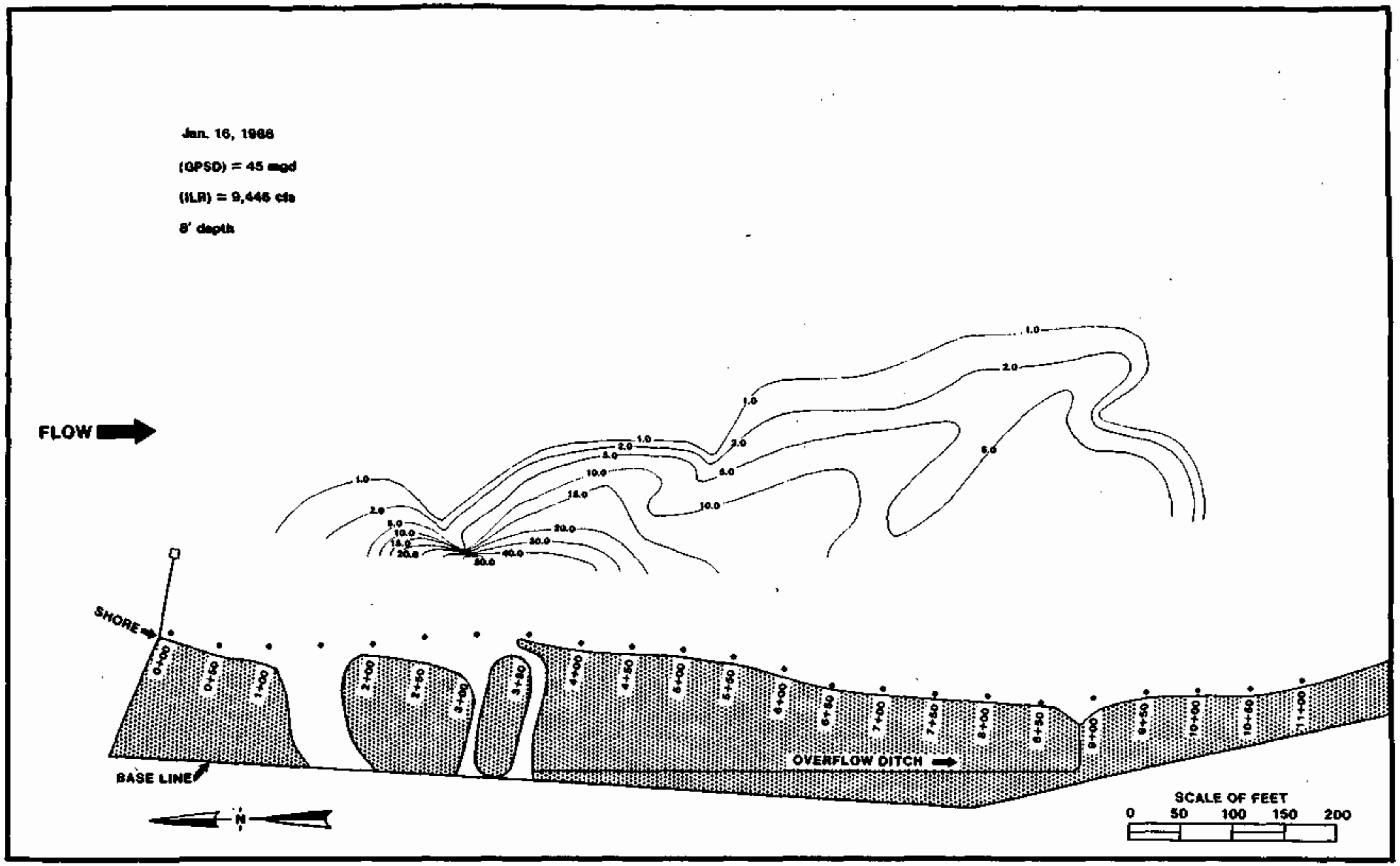
(ILR) = 10,570 cfs

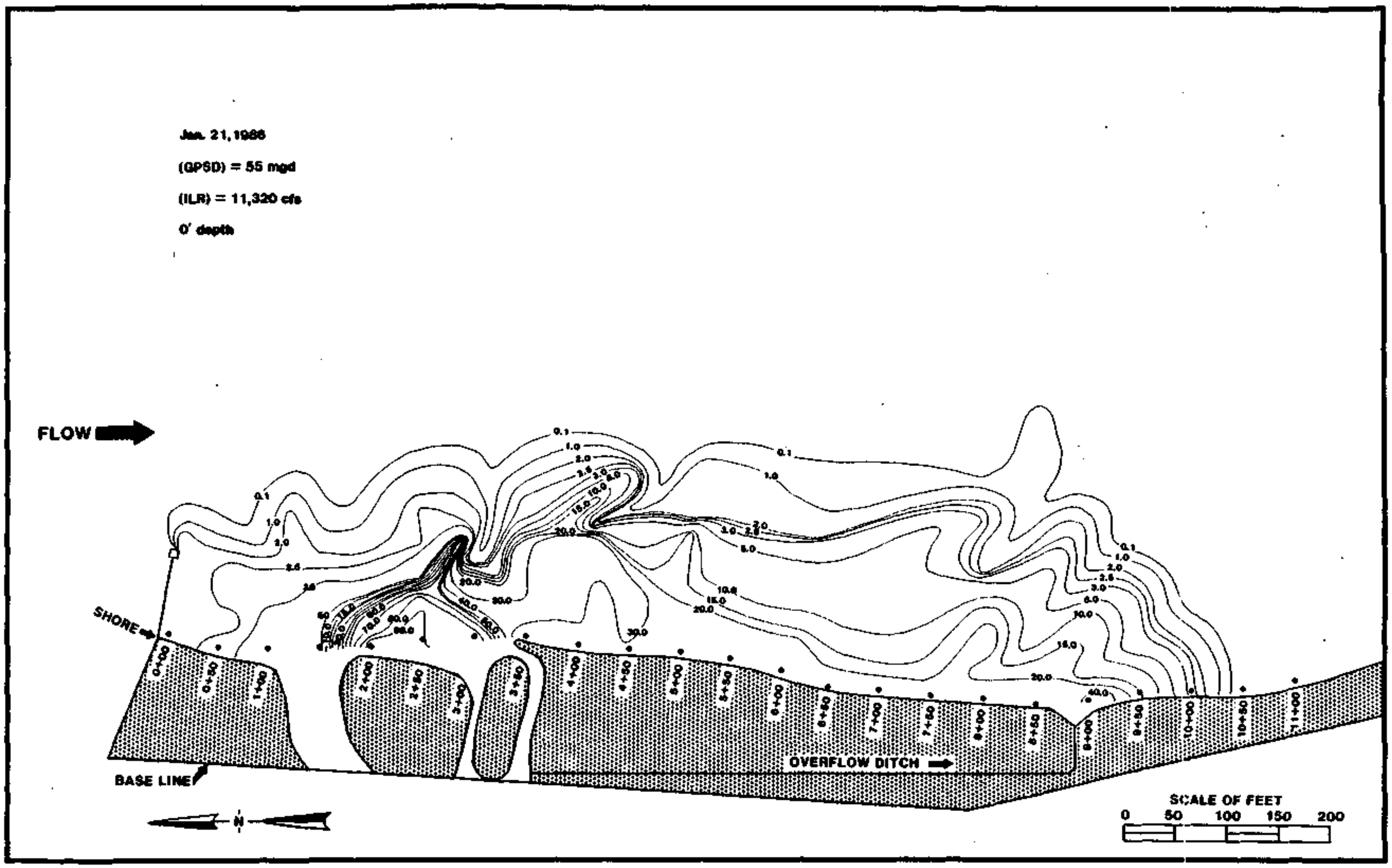
8' depth

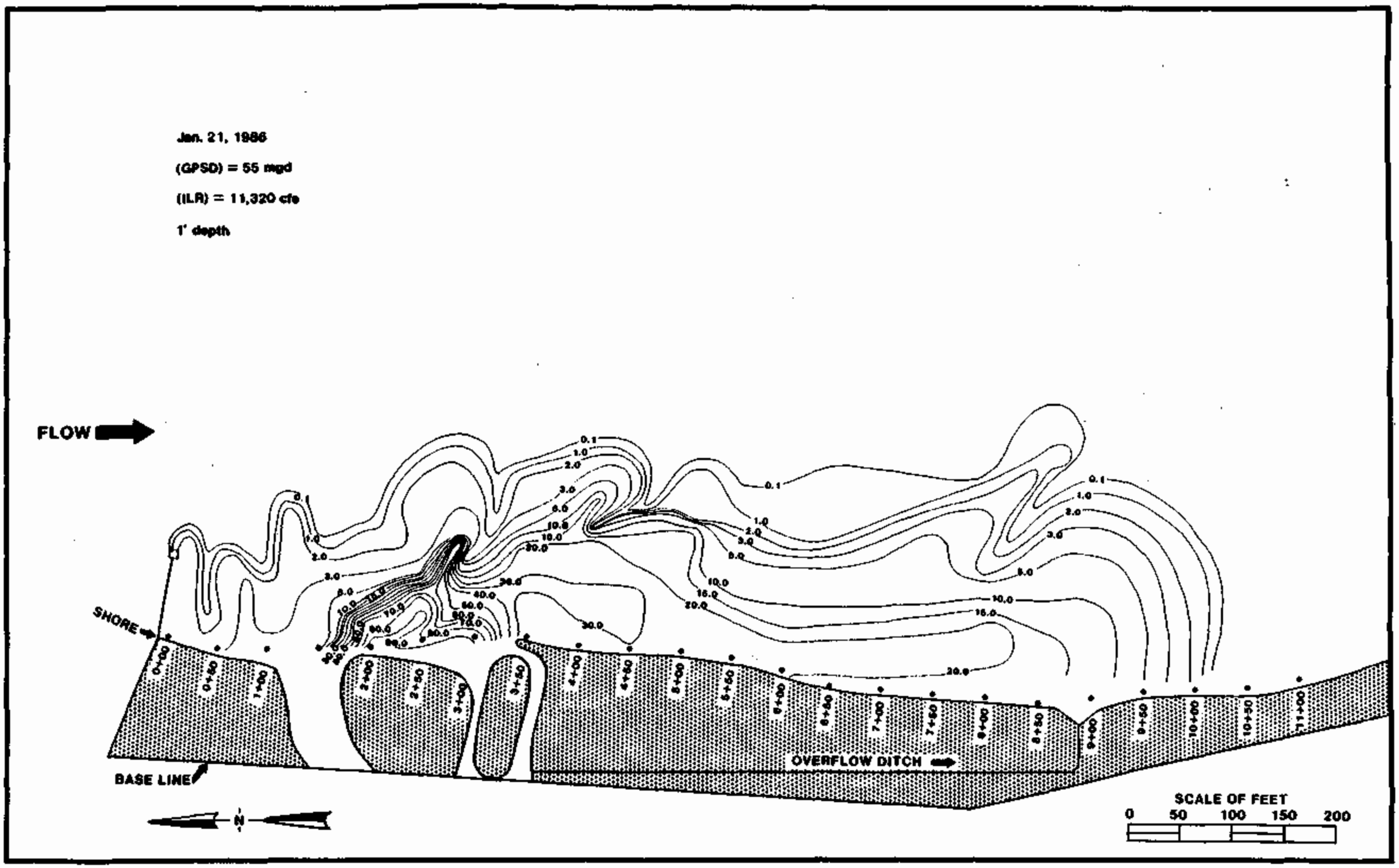

Jan. 16, 1986
(GPSD) = 45 mgd
(ILR) = 9,446 cfs
0' depth
FLOW
SHORE
BASE LINE
N
OVERFLOW DITCH
SCALE OF FEET
0
50
100
150
200
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
0.1
1.0
2.0
3.0
5.0
8.0
10.0
15.0
20.0
30.0
40.0
50.0
60.0
90.0


Jan. 16, 1988
(GPSD) = 45 mgd
(ILR) = 9,446 cfs
1' depth
FLOW
SHORE
BASE LINE
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
0.1
1.0
1.5
2.0
5.0
10.0
15.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0


Jan. 16, 1986
(GPSD) = 45 mgd
(ILR) = 9,446 cfs
3' depth
FLOW
0.1
1.0
1.5
2.0
5.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
SHORE
BASE LINE
OVERFLOW DITCH
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
N
SCALE OF FEET
0
50
100
150
200


Jan. 16, 1986
(GPSD) = 45 mgd
(ILR) = 9,446 cfs
8' depth
FLOW
1.0
2.0
5.0
10.0
15.0
20.0
30.0
40.0
50.0
SHORE
BASE LINE
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200


Jan. 21, 1986
(GPSD) = 55 mgd
(ILR) = 11,320 cfs
0' depth
FLOW
SHORE
BASE LINE
N
OVERFLOW DITCH
SCALE OF FEET
0
50
100
150
200
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
0.1
1.0
2.0
2.5
3.0
5.0
10.0
15.0
20.0
30.0
40.0
50
60.0
70.0
80.0

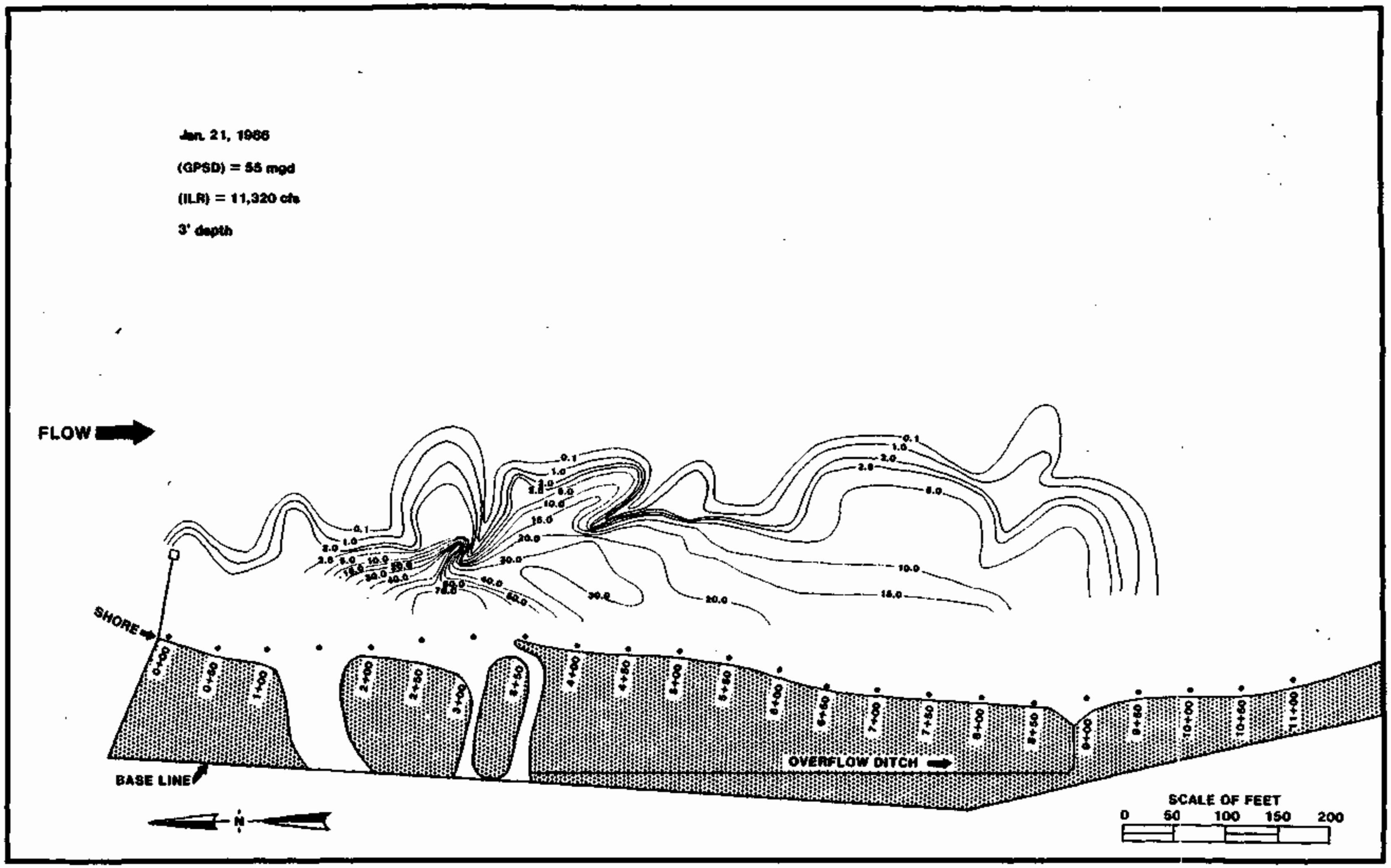


Jan. 21, 1986

(GPSD) = 55 mgd

(ILR) = 11,320 cfs

1' depth

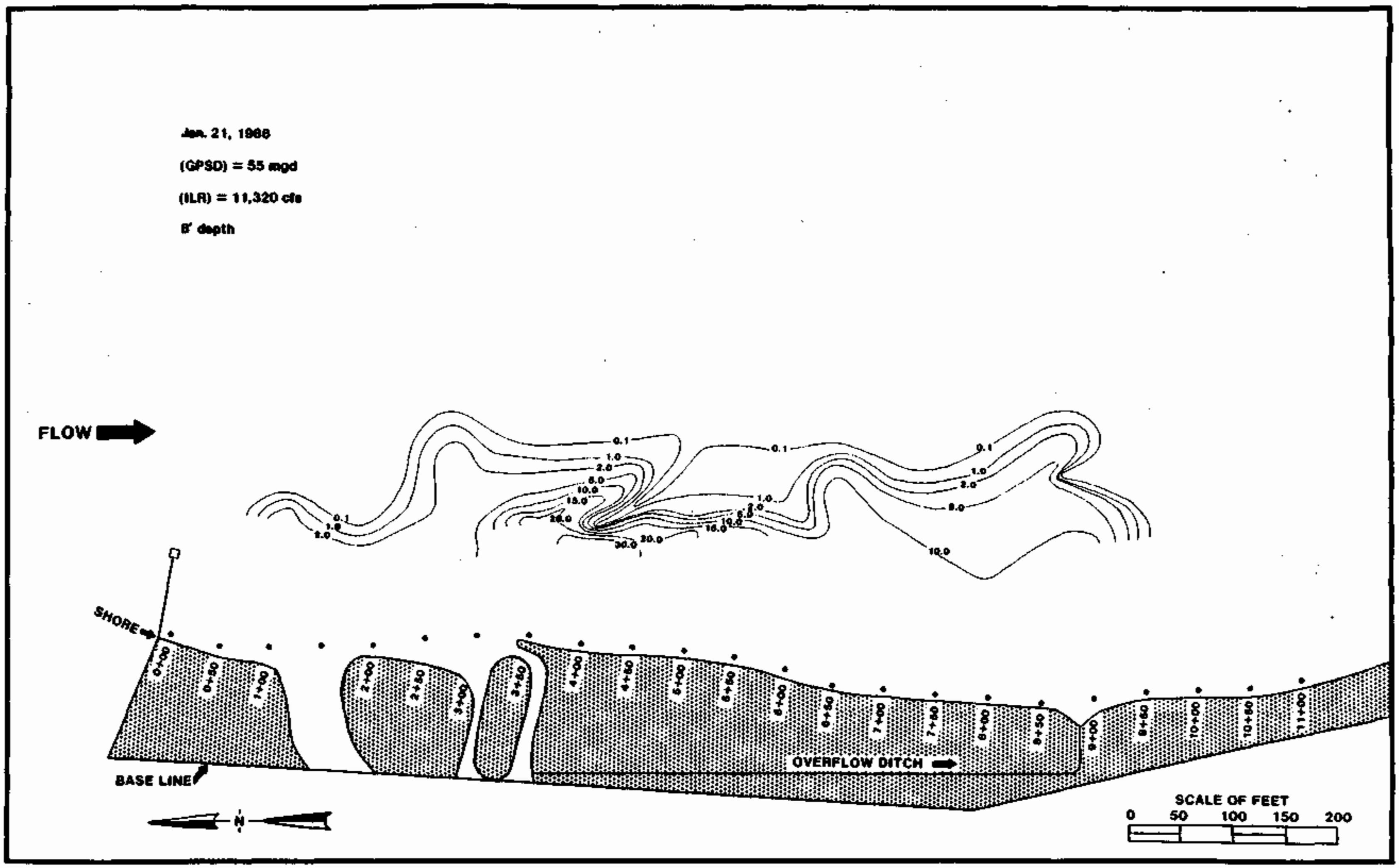


Jan. 21, 1986

(GPSD) = 55 mgd

(ILR) = 11,320 cfs

3' depth

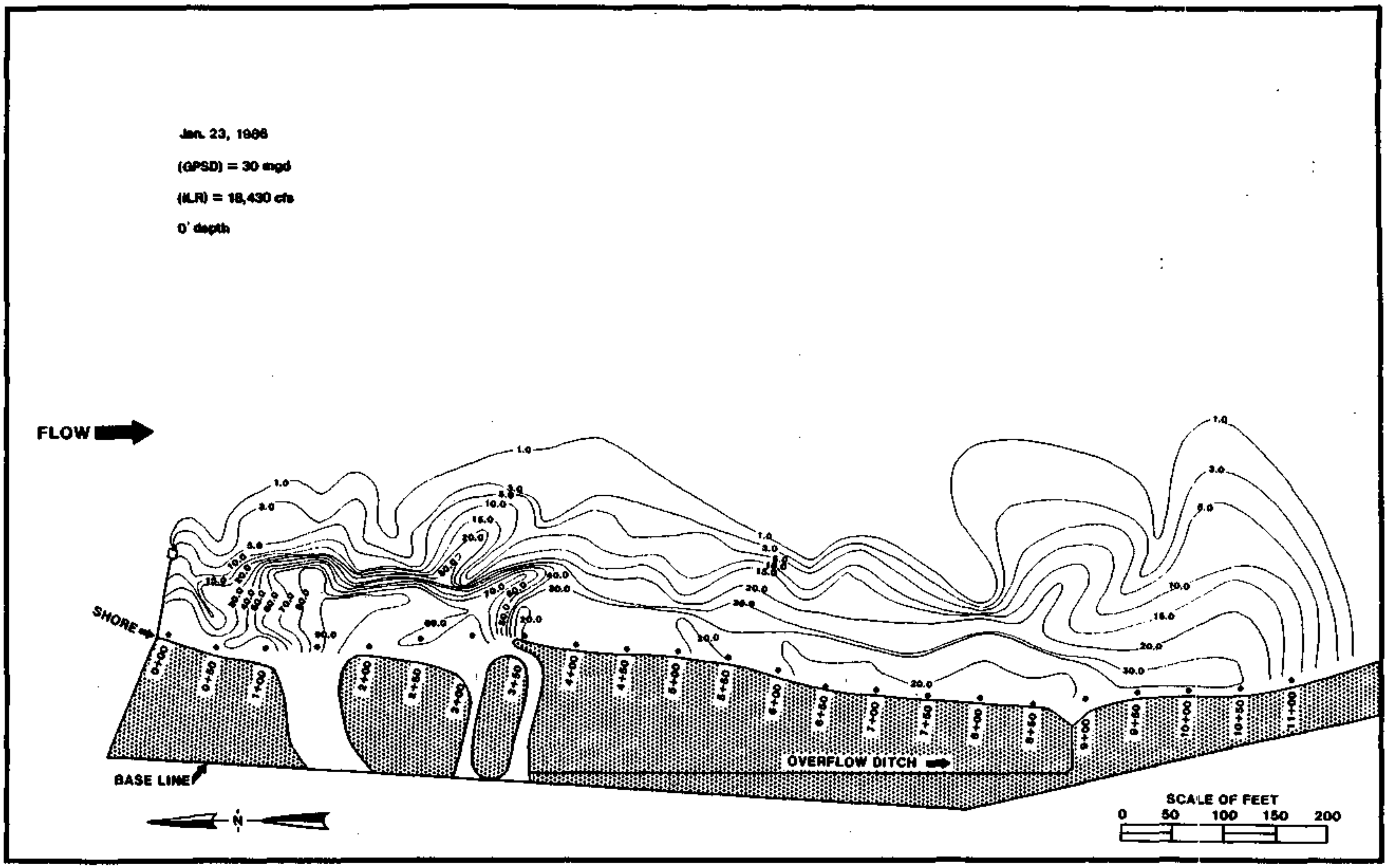


Jan. 21, 1988

(GPSD) = 55 mgd

(ILR) = 11,320 cfs

8' depth

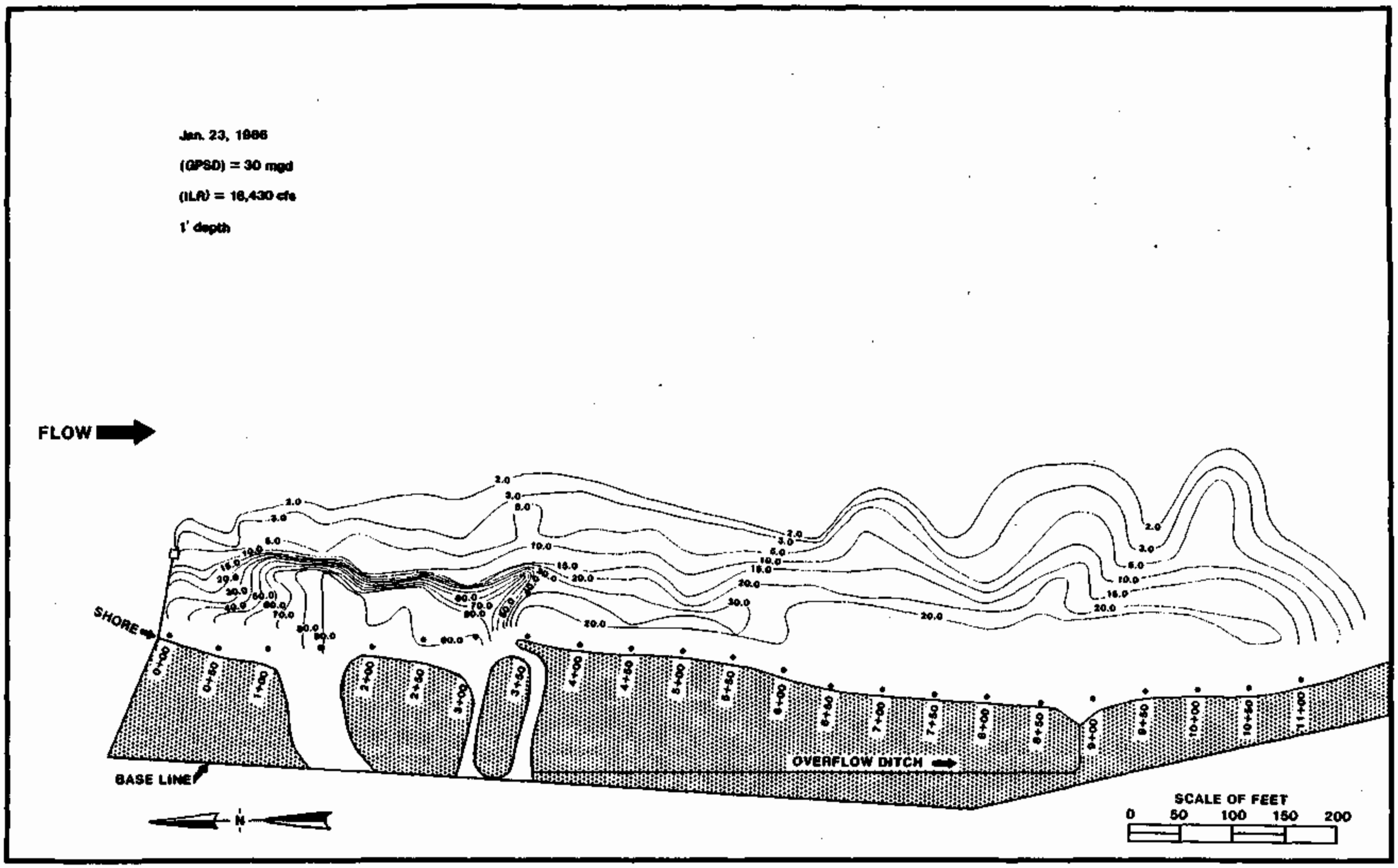


Jan. 23, 1986

(GPSD) = 30 mgd

(ILR) = 18,430 cfs

0' depth

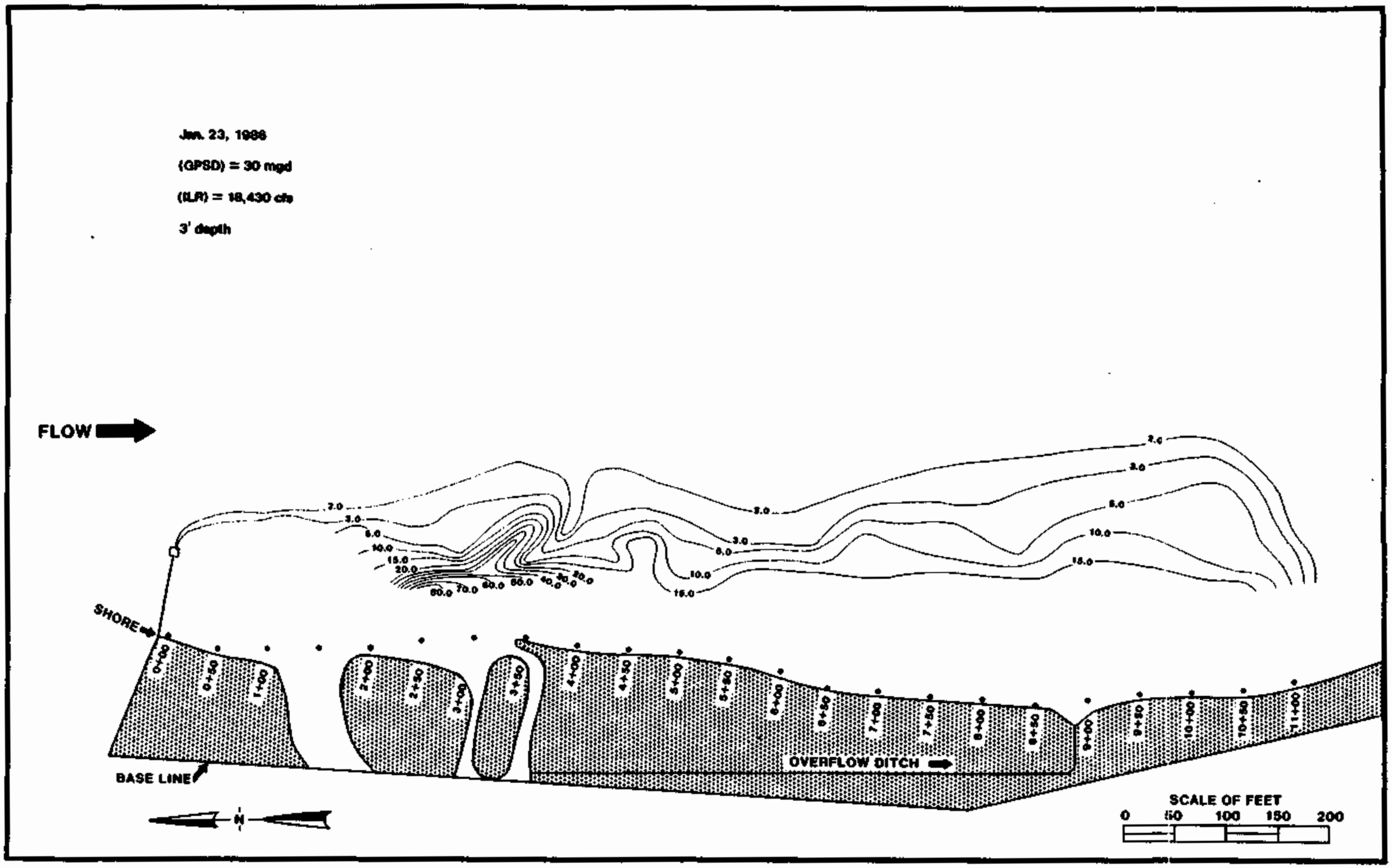


Jan. 23, 1986

(GPSD) = 30 mgd

(ILA) = 16,430 cfs

1' depth

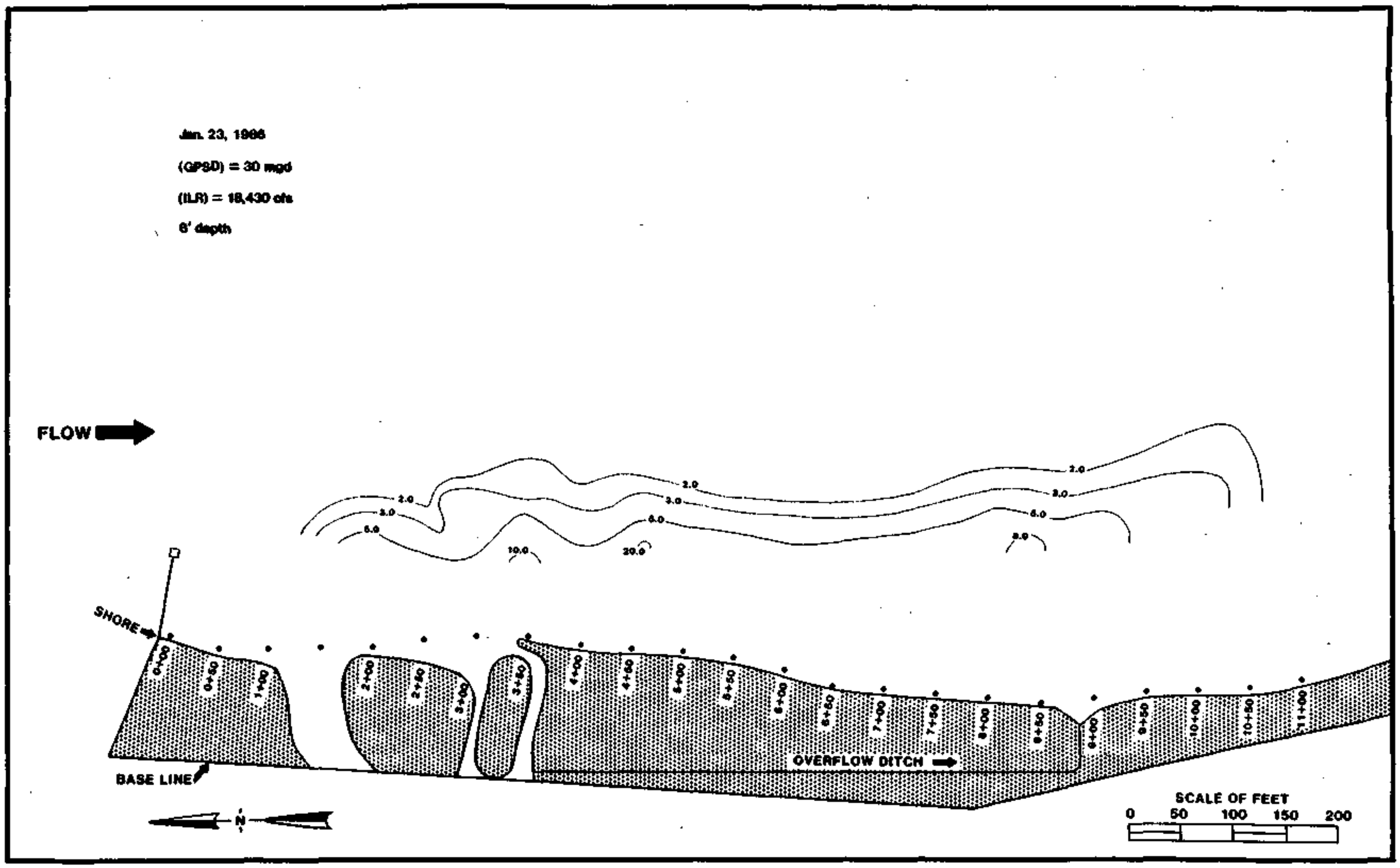


Jan. 23, 1986

(GPSD) = 30 mgd

(ILR) = 18,430 cfs

3' depth

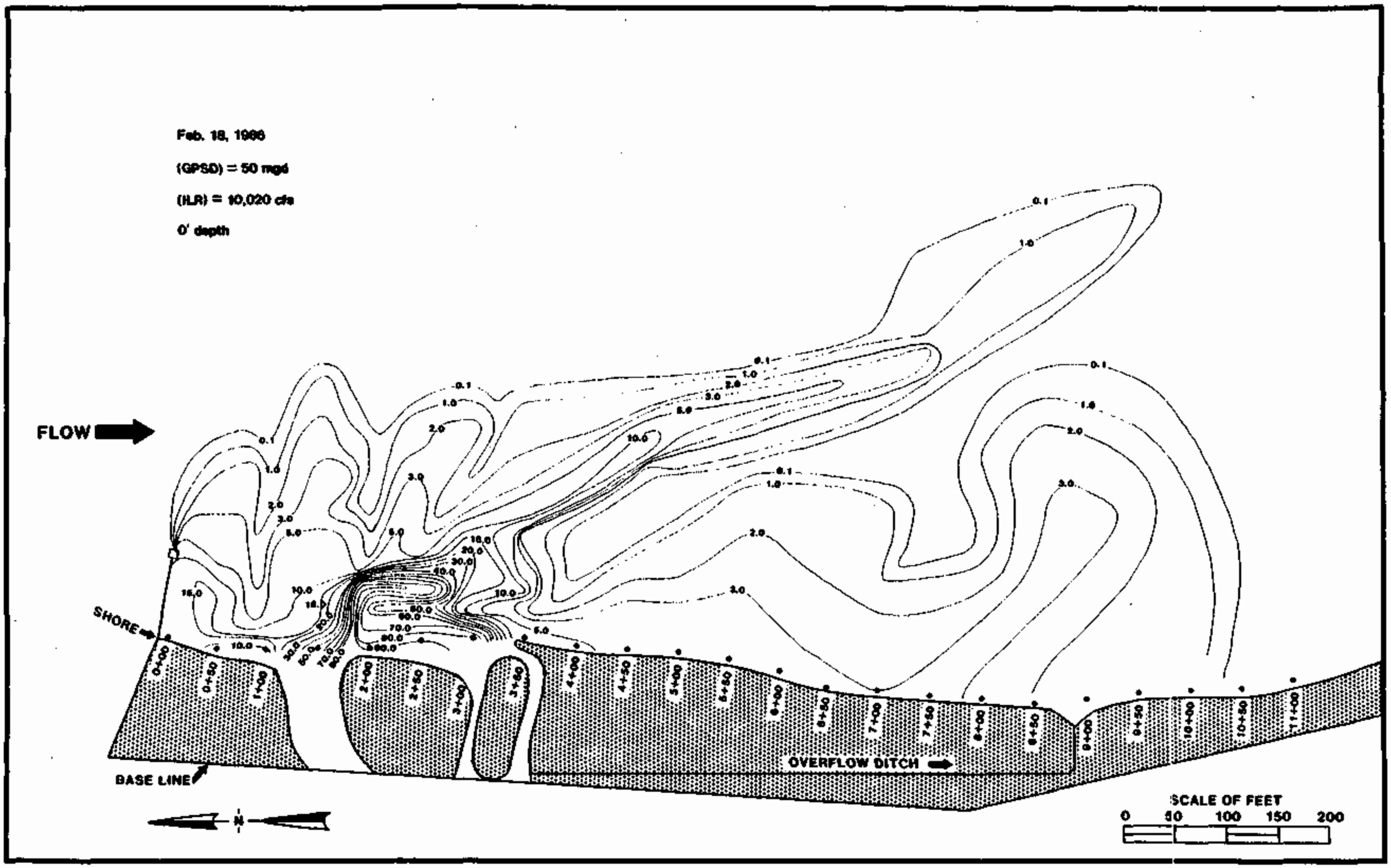


Jan. 23, 1986

(GPSD) = 30 mgd

(ILR) = 18,430 cfs

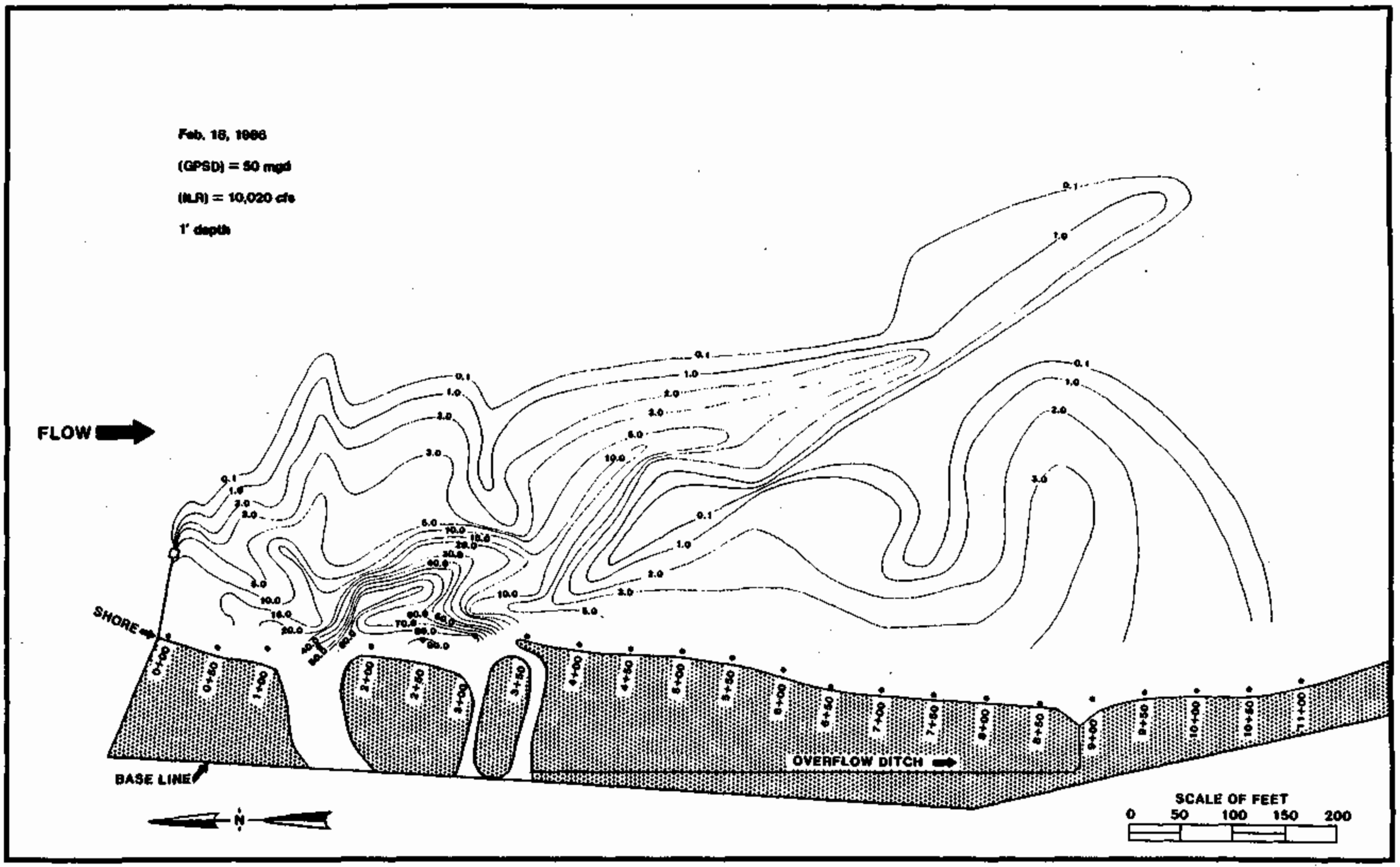
6' depth

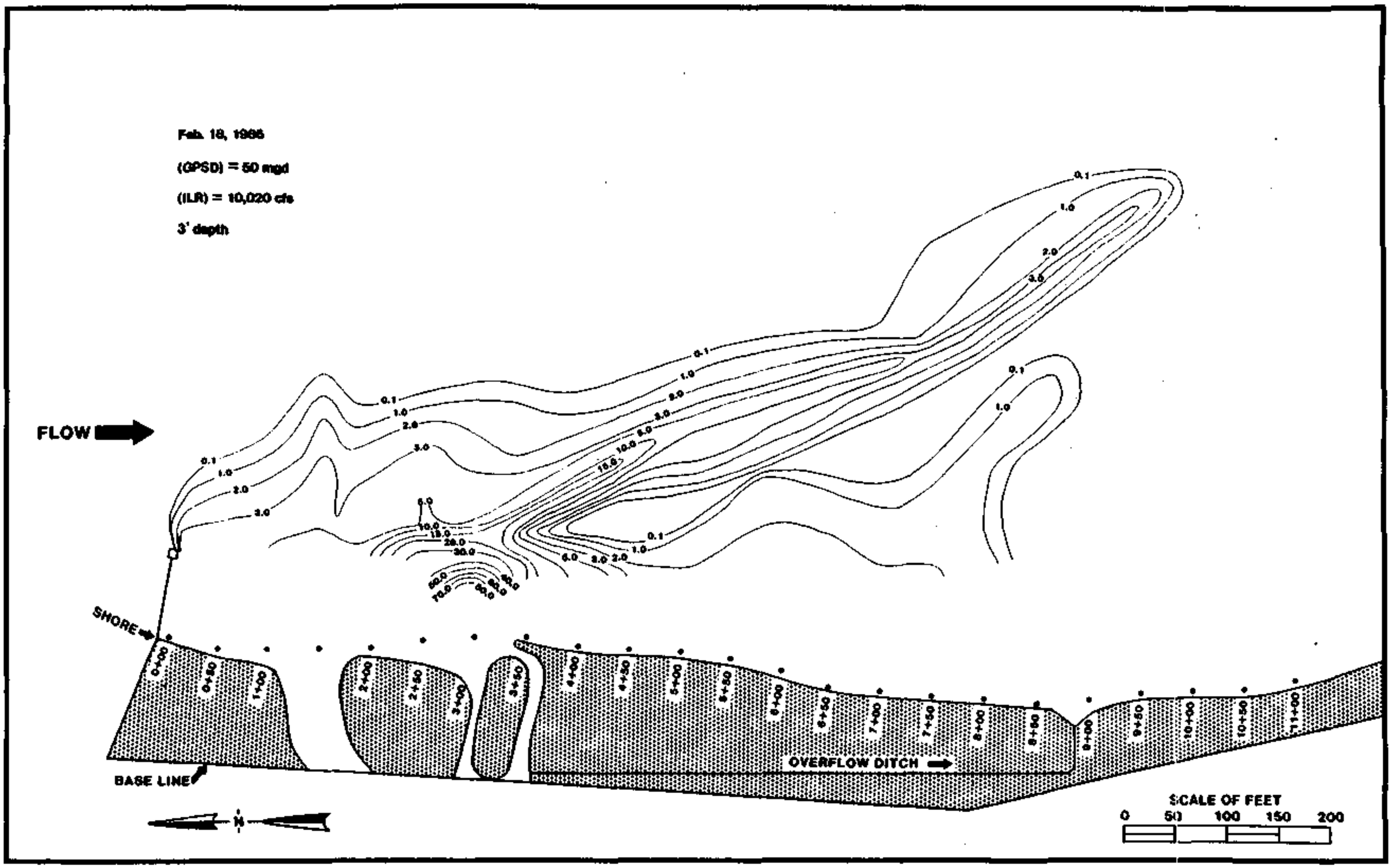

Feb. 18, 1966

(GPSD) = 50 mgd

(ILR) = 10,020 cfs

0' depth


Feb. 18, 1986
(GPSD) = 50 mgd
(MLR) = 10,020 cfs
1' depth
FLOW
SHORE
BASE LINE
OVERFLOW DITCH
N
SCALE OF FEET
0 50 100 150 200
0.1
1.0
2.0
3.0
5.0
10.0
15.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00

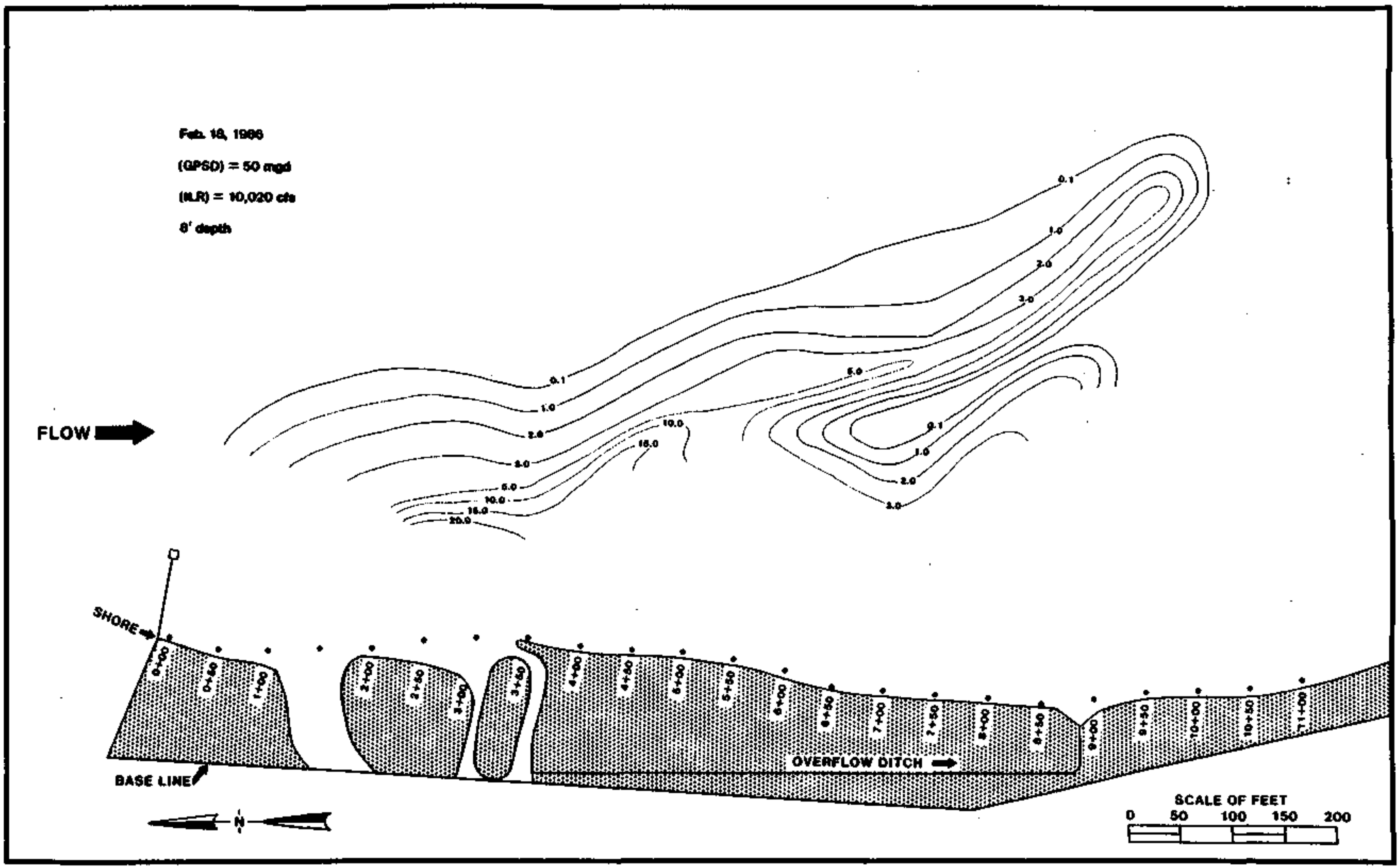


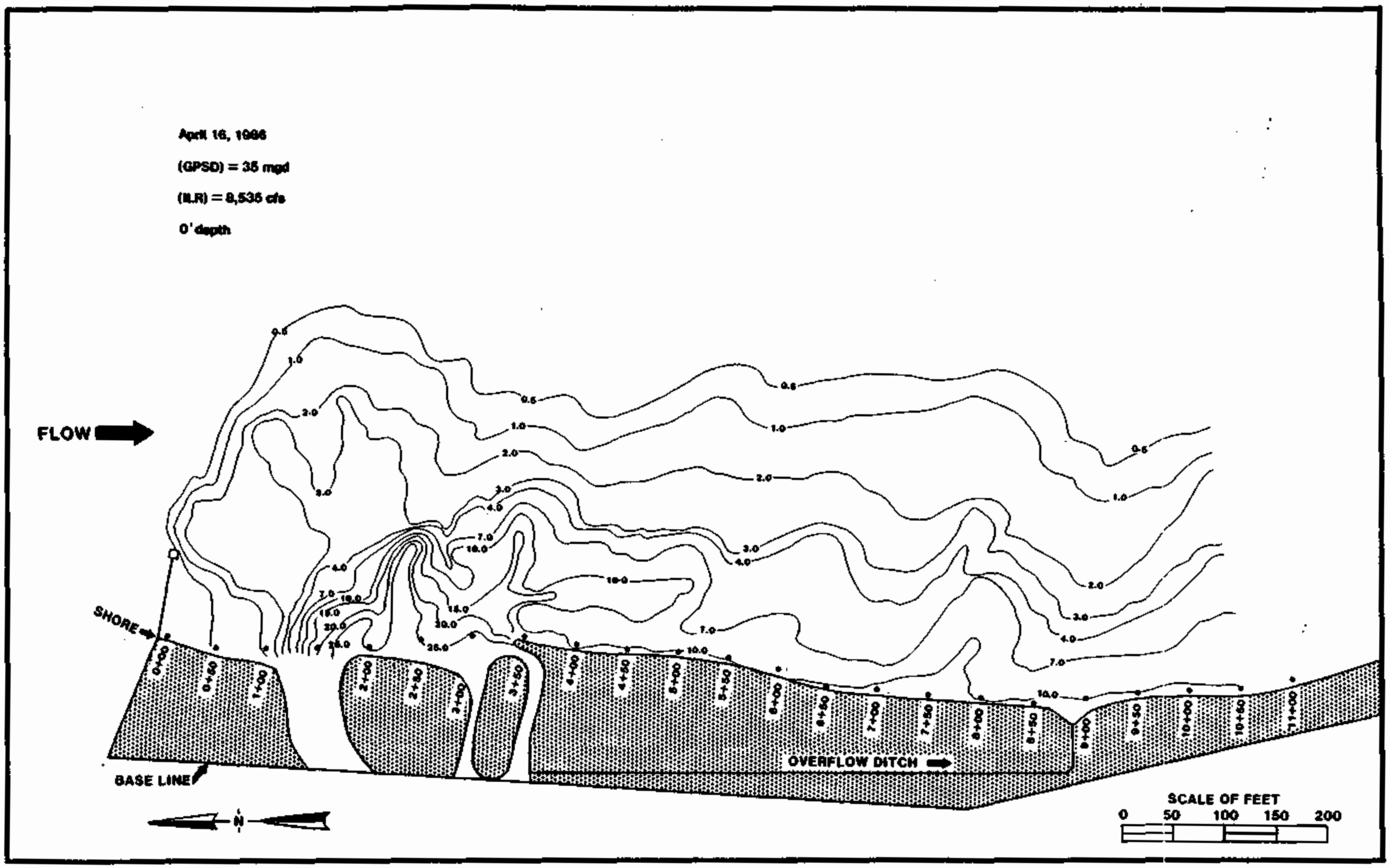
Feb. 18, 1986

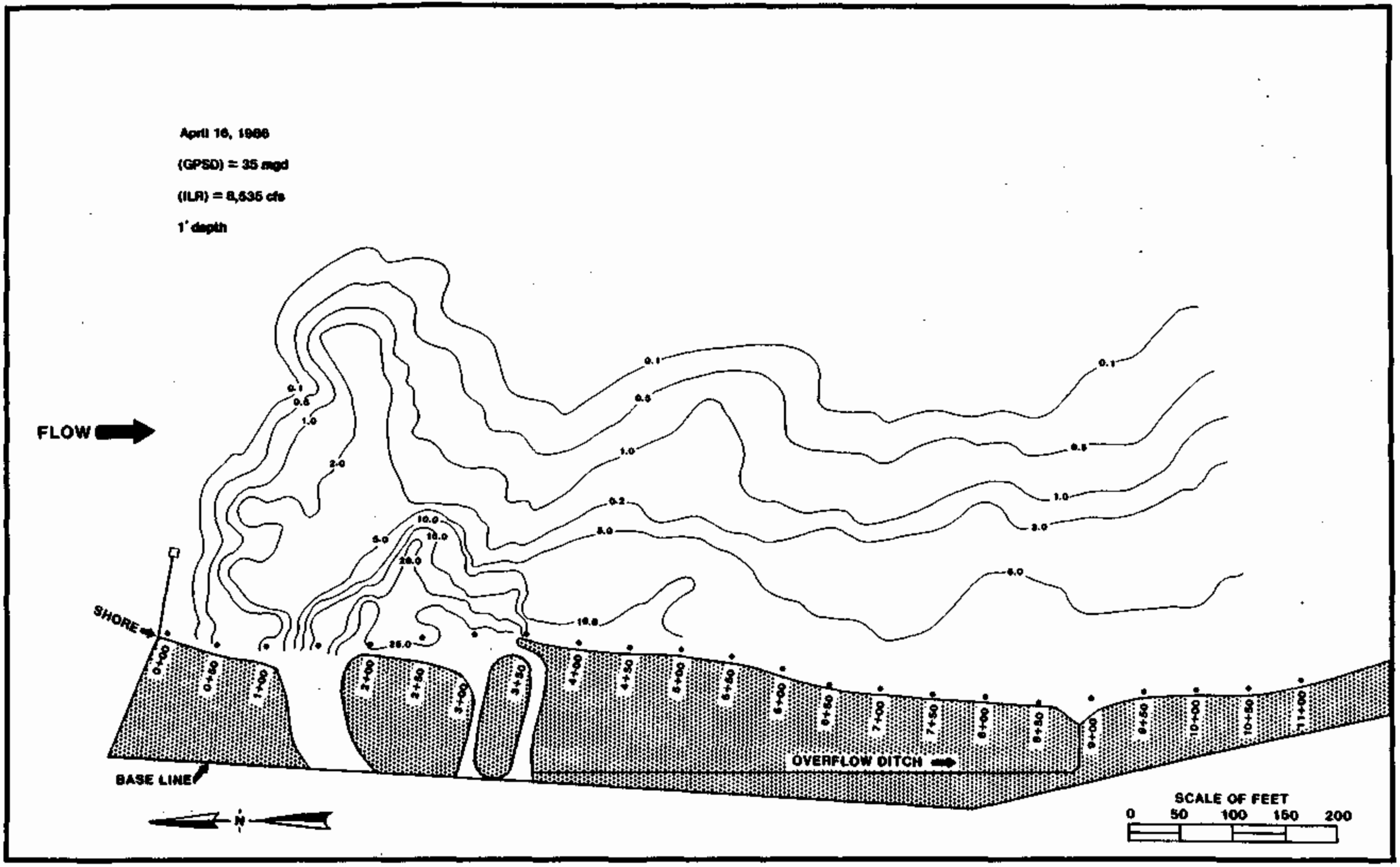
(GPSD) = 50 mgd

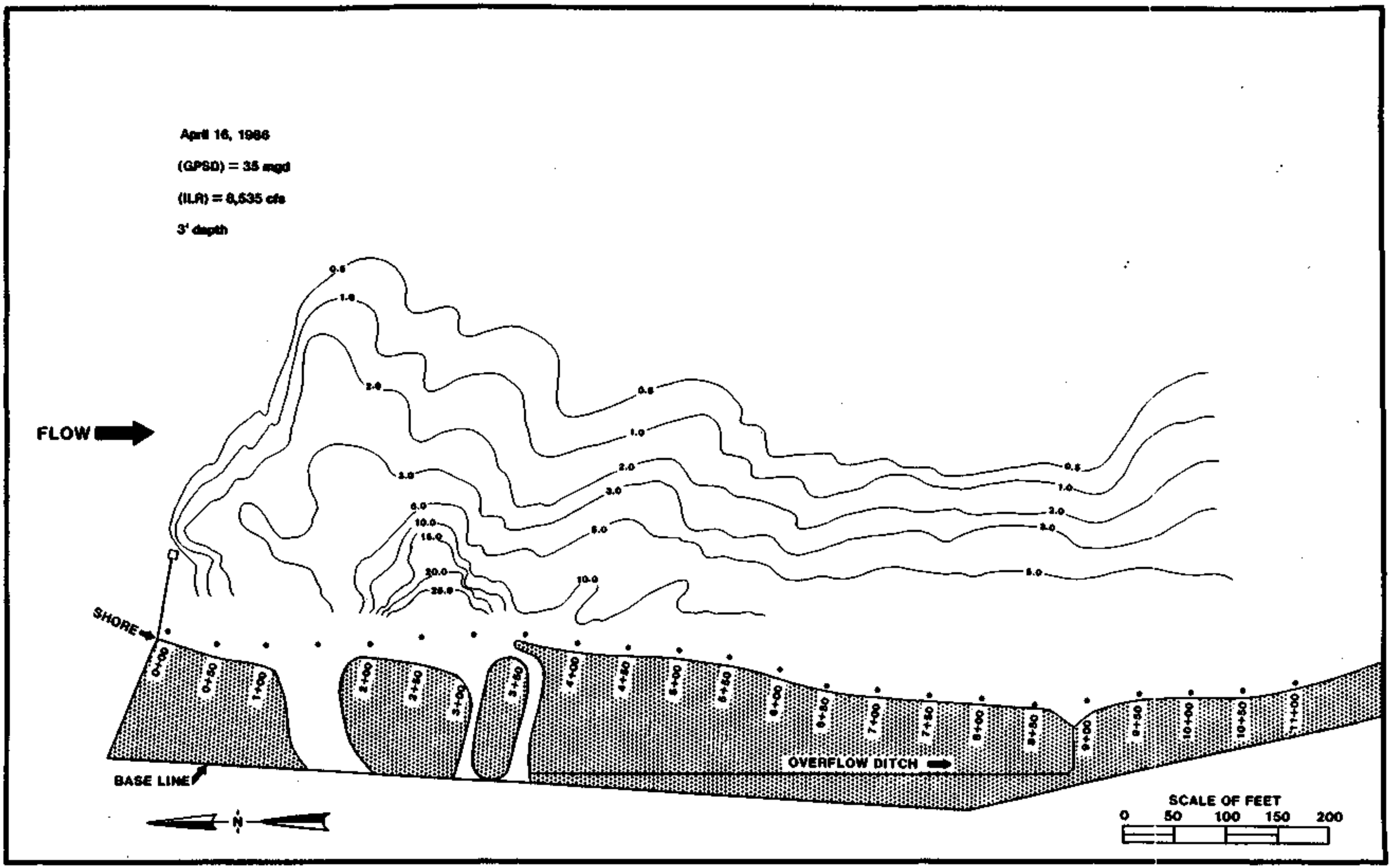
(ILR) = 10,020 cfs

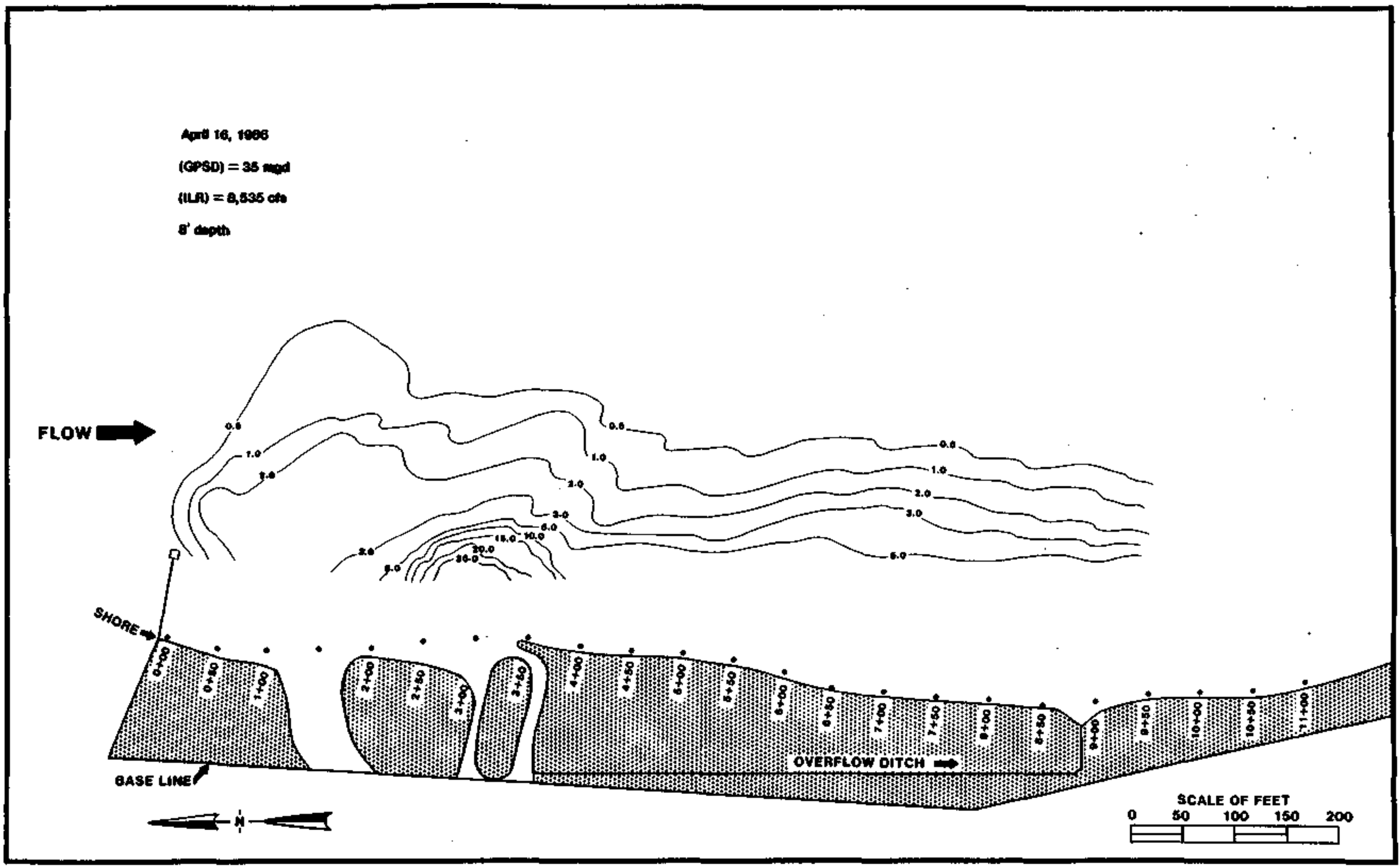
3' depth


Feb. 18, 1986
(GPSD) = 50 mgd
(ILR) = 10,020 cfs
8' depth
FLOW
0.1
1.0
2.0
3.0
5.0
10.0
15.0
20.0
10.0
15.0
5.0
0.1
1.0
2.0
3.0
0.1
1.0
2.0
3.0
SHORE
BASE LINE
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200


April 16, 1986
(GPSD) = 35 mgd
(ILR) = 8,535 cfs
0' depth
FLOW
SHORE
BASE LINE
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
0.5
1.0
2.0
3.0
4.0
7.0
10.0
15.0
20.0
25.0


April 16, 1986
(GPSD) = 35 mgd
(ILR) = 8,535 cfs
1' depth
FLOW
0.1
0.5
1.0
2.0
0.1
0.5
1.0
0.2
5.0
10.0
15.0
20.0
5.0
10.0
25.0
0.1
0.5
1.0
2.0
5.0
SHORE
BASE LINE
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200


April 16, 1986
(GPSD) = 35 mgd
(ILR) = 8,535 cfs
3' depth
FLOW
0.5
1.0
2.0
3.0
5.0
10.0
15.0
20.0
25.0
SHORE
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
OVERFLOW DITCH
BASE LINE
N
SCALE OF FEET
0
50
100
150
200

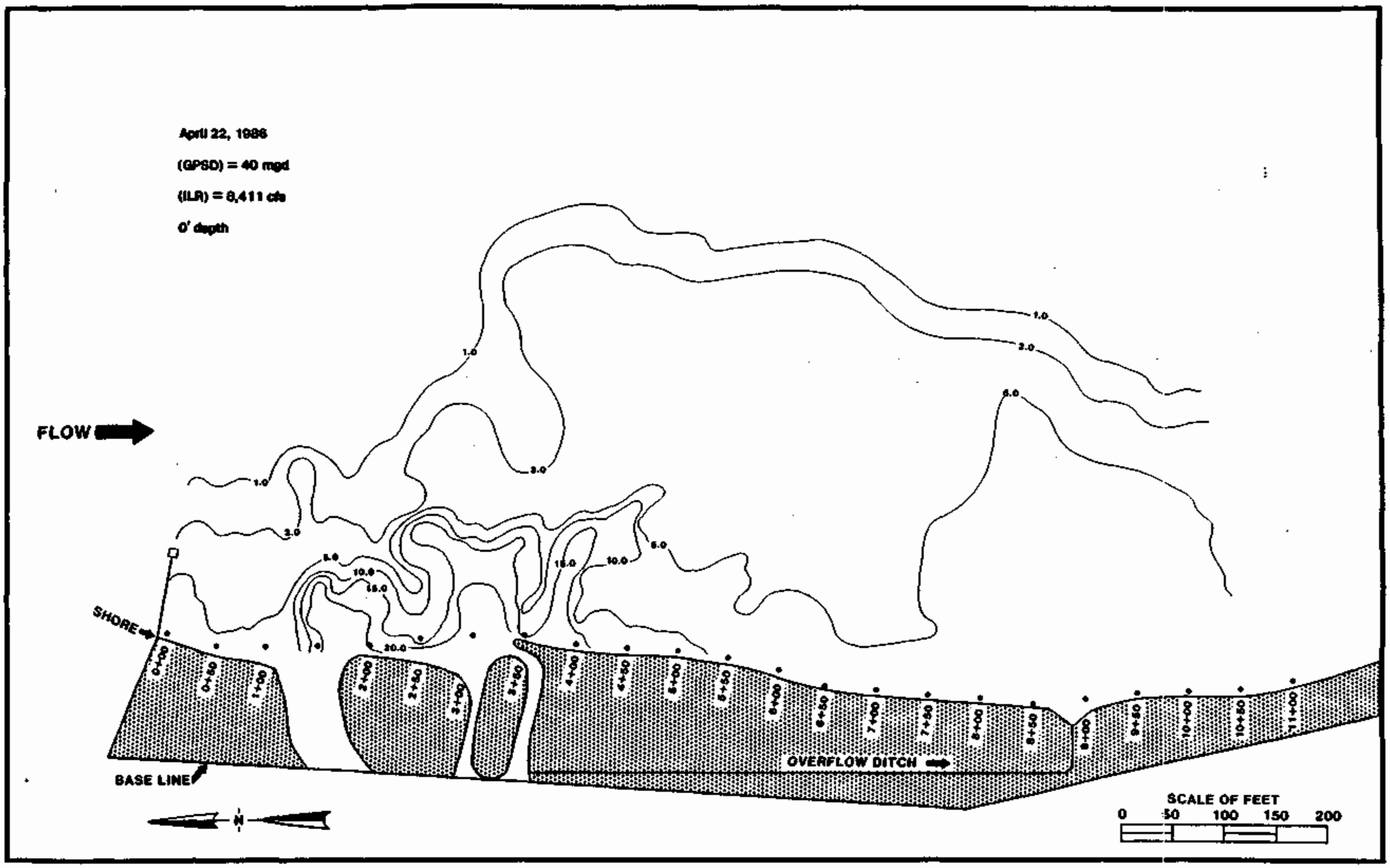


April 16, 1986

(GPSD) = 35 mgd

(ILR) = 8,535 cfs

8' depth

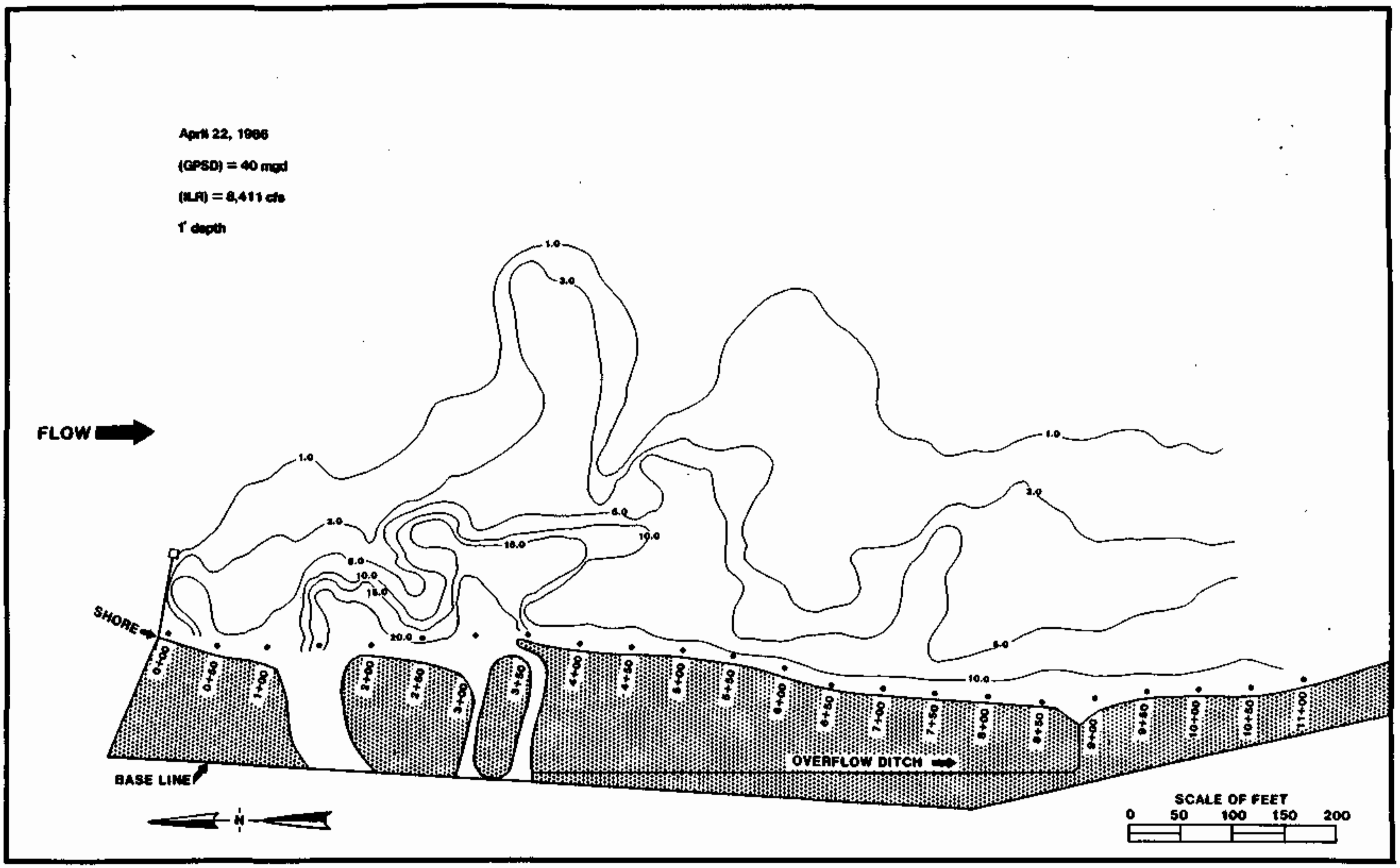


April 22, 1986

(GPSD) = 40 mgd

(ILR) = 8,411 cfs

0' depth

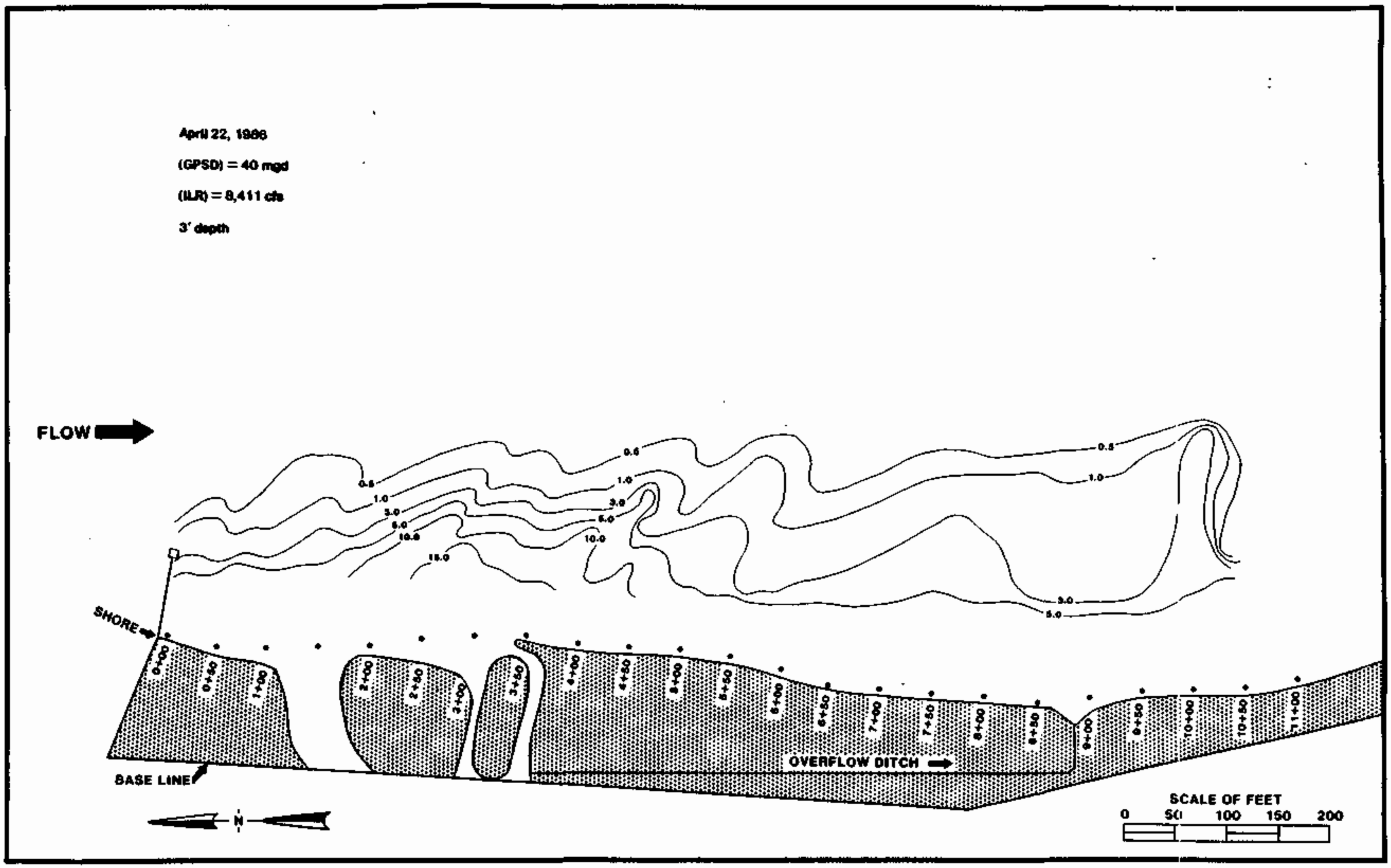


April 22, 1986

(GPSD) = 40 mgd

(ILR) = 8,411 cfs

1' depth

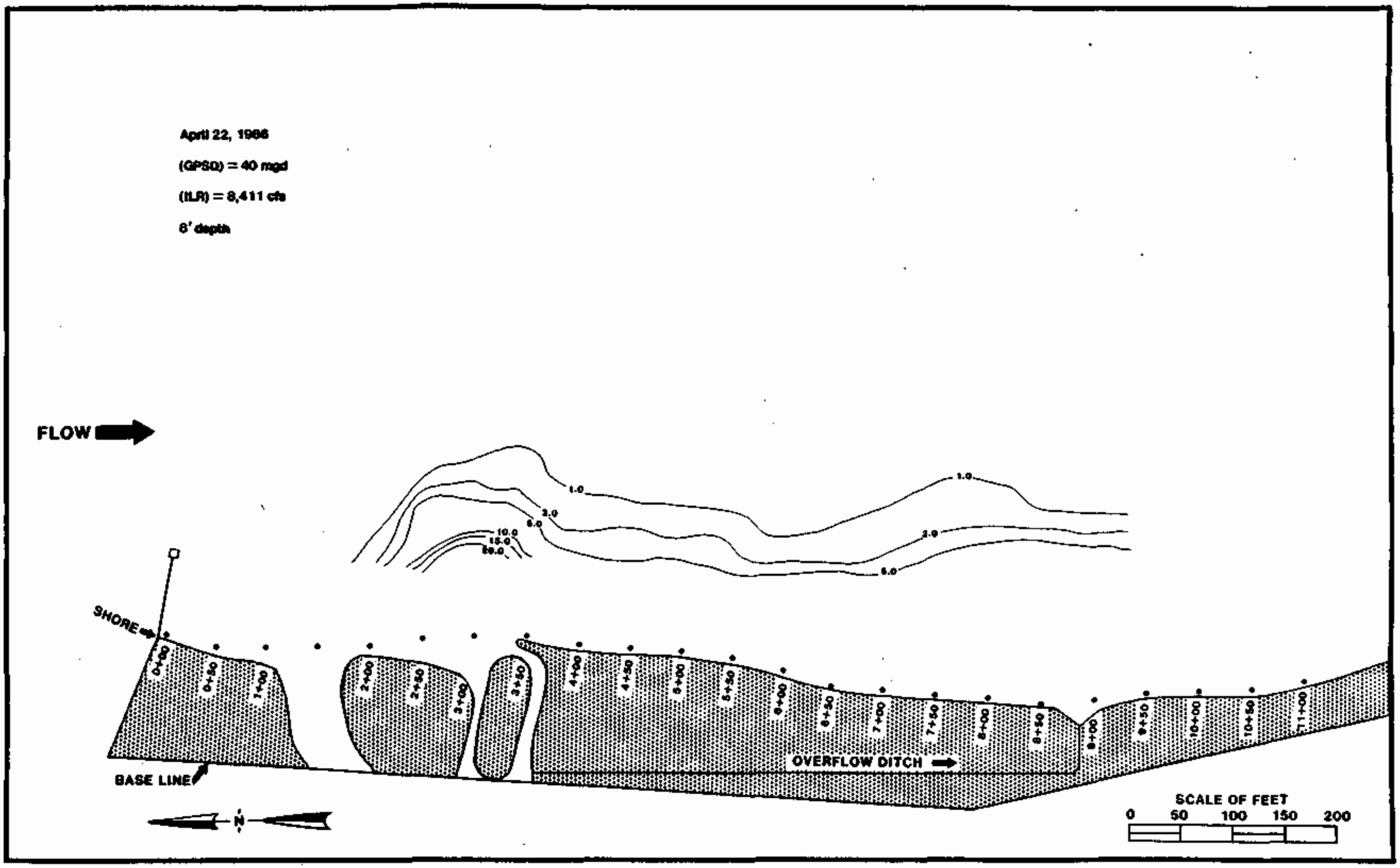


April 22, 1986

(GPSD) = 40 mgd

(ILR) = 8,411 cfs

3' depth


April 22, 1986
(GPSD) = 40 mgd
(ILR) = 8,411 cfs
8' depth
FLOW
1.0
2.0
5.0
10.0
15.0
20.0
SHORE
BASE LINE
0+00
0+50
1+00
2+00
2+50
3+00
3+50
4+00
4+50
5+00
5+50
6+00
6+50
7+00
7+50
8+00
8+50
9+00
9+50
10+00
10+50
11+00
OVERFLOW DITCH
N
SCALE OF FEET
0
50
100
150
200