A PRELIMINARY INVESTIGATION OF THE FATE OF WATER AND NUTRIENTS ON A SMALL WATERSHED SUBJECTED TO WINTERTIME WASTEWATER SPRAY IRRIGATION

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By

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During the winter of 1975, wastewater from the bottom of the first lake of the Michigan State Water Quality Management Project was sprayed over five acres of a 7.35 acre subwatershed adjacent to Felton Drain. Three spray irrigations of two inches, one irrigation of 1.5 inches, and two of one inch were applied during a two month period to the site which consisted of an open field sloping down to the stream.

Natural precipitation and spray irrigation were measured with rain gages, surface runoff was monitored at the spray site and in Felton Drain by three weirs equipped with a stage recorders, and infiltration was estimated from 47 glass-funnel infiltrometers buried 2.5 feet beneath the surface. Water quality samples were taken to calculate the amounts of phosphorus, nitrate, ammonia, boron, and chloride accompanying the water.

The data collected were used to construct a water balance and individual mass balances for each compound

monitored. The data were often imprecise, and only a rough outline of the processes occurring during the study was discernible. Ammonia gas appears to have been liberated during the spray operation, and an estimated 15 to 20 percent of the spray evaporated before it reached the surface. Large amounts of the spray froze on the surface when the air temperature was subfreezing. Surface runoff occurred but can be controlled in the future to prevent any possible violation of discharge standards. Infiltration was increased by ponding on the site. Boron levels in the wastewater were not high enough to harm the plants. Too much material (especially nitrate) infiltrated with the water to be acceptable, and a preliminary assessment of the potential of winter spray irrigation for a prototype facility indicates that this method probably is not feasible.

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1.1 Background of the MSU Water Quality Project

In recent years, there has been growing concern about the damage to surface waters by nutrient overloading. A major cause of this overloading is the inability of wastewater treatment plants to remove nitrogen and phosphorus. Many tertiary treatment processes have been designed to remove these elements. One system, built by the Institute of Water Research at Michigan State University, consists of four lakes which receive unchlorinated secondary effluent from the East Lansing sewage treatment plant. A major function of these lakes is to remove and recycle the nutrients before they reach natural surface waters or groundwaters (1). While some of the nutrients will be partially removed by plant uptake and by conversions into gases, most of the nutrients will be concentrated by algae in the lakes and recycled by spray irrigation. A 145-acre spray irrigation site has been developed south of the Institute's lakes to accomplish the final stage of recycling. The site consists of forested areas, open fields and a stream (see map, Figure 1).

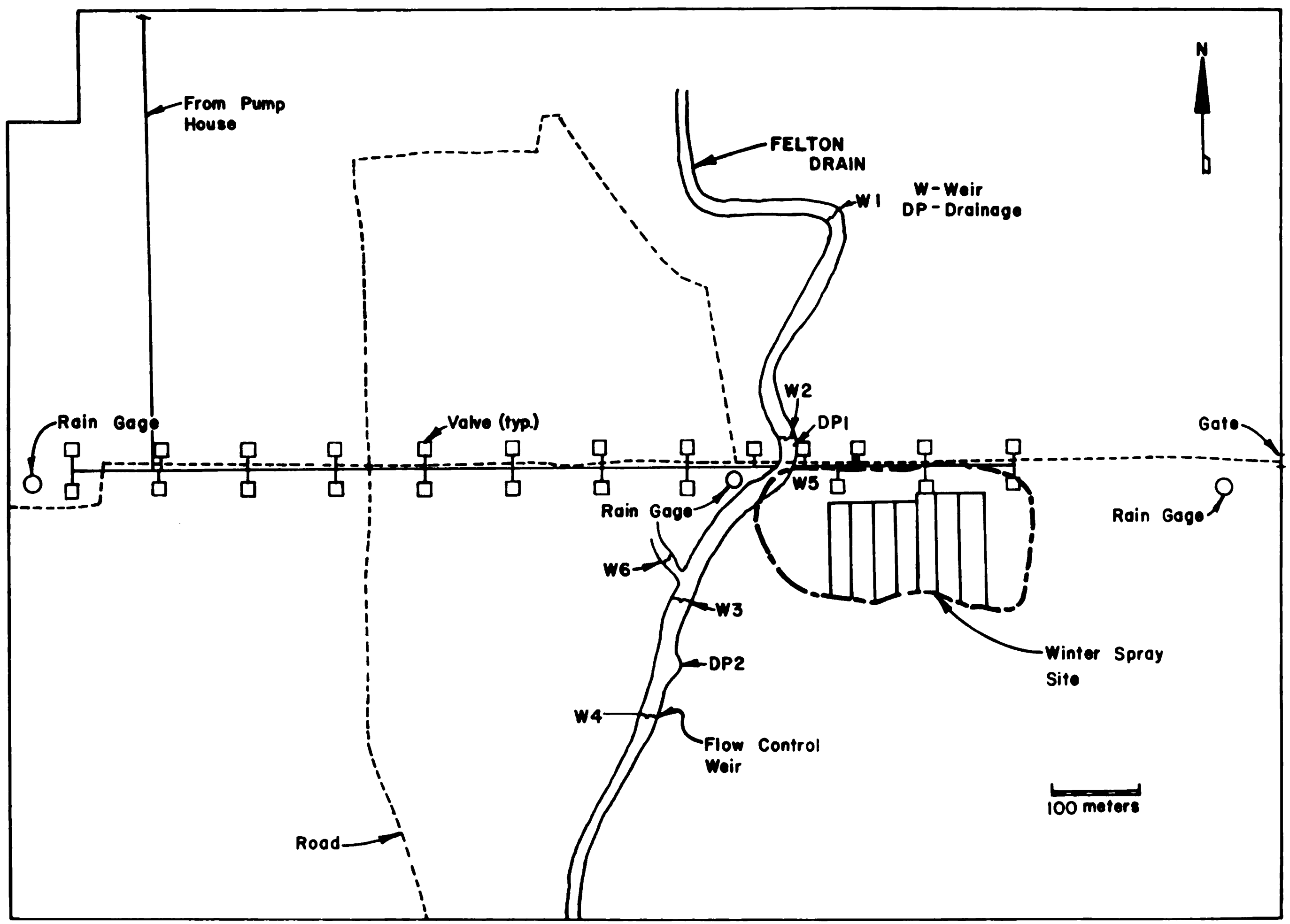


Figure 1.--Map of the MSU Institute of Water Research Spray Site.

During the winter, when biological activity is at a minimum, the discharge from the lakes must still meet pollution standards. To avoid large storage requirements and maintain flexibility, it would be advantageous to spray irrigate throughout the winter. However, problems caused by subfreezing temperatures make winter spray irrigation difficult. Under such conditions, snow and ice accumulate from sprayed water and natural precipitation and melt during thaws, and large amounts of it may run into the stream as surface runoff. The ground will usually be frozen, and infiltration cannot be expected to significantly lessen the overland flow. During the spring thaw, the ground will become saturated with water, and substantial runoff may again occur.

If large amounts of nutrients accompany the run-off, the objective to recycle nutrients will be defeated, and winter spray irrigation may become infeasible. To be an acceptable process, the runoff from the site must meet pollution standards; specifically, the phosphorus must be reduced by 80 percent. Phosphate is readily adsorbed by soil colloids (2), but much of the runoff will occur over frozen soil which will not allow significant interaction. The phosphorus previously attached to the soil is susceptible to erosion, but erosion would probably be insignificant unless the ground cover were torn away (2).

Other nutrients such as ammonia and nitrate are not adsorbed on soil and will present problems if runoff occurs. Ammonia in the wastewater will be converted by bacteria to nitrate. Conversion will proceed more slowly during cold weather, but ammonia should cause few problems in the runoff. Nitrate is normally taken up by the plants, but in the winter most of it will remain in the water. Nitrates easily move through groundwater; and if large levels do infiltrate, winter spray irrigation may again become infeasible.

Boron is present in wastewater in significant amounts from detergents, and concentrations above 2 mg/l are harmful to some plants (3). Levels should be monitored to determine if boron will limit the amount of effluent that can be sprayed.

1.2 Other Projects

1.2.1 Penn State

Only one major study has previously been made on winter wastewater spray irrigation. Researchers at Pennsylvania State University conducted several studies on small watersheds from 1966 to 1969. The studies were concerned with measurement of runoff and water quality during various climatic conditions (4).

The first study was conducted on a 2.4-acre field which sloped down to a channel fitted with a 90° V-notch weir. Runoff was studied as a function of the soil and air temperature. The site was sprayed with two inches of effluent, once a week when possible from December 1966 to July 1967.

Results (Table 1) showed that the lowest runoff occurred during the growing season when evapotranspiration was high. The highest values occurred when the soil was frozen and the air temperature was above freezing. The

Table 1.--Surface Runoff Expressed as Peak Discharge (gpm per acre), Total Discharge (gal./acre), and Percent of the Total Application for the Indicated Dates. [4]

Date	Peak Discharge (gpm/acre)	Total Discharge (gal./arce)	Percent of Total Applied
12/12/66	76	24,120	44
1/3/67	100	28,425	52
1/10/67	111	33,720	62
1/24/67	111	27,832	51
3/24/67	111	54,230	100
3/28/67	81	42,202	78
5/15/67	72	28,506	52
5/22/67	39	6,168	11
5/29/67	56	16,678	31
7/11/67	31	14,031	26

frozen soil prevented much infiltration, and the sprayed effluent could not freeze when air temperatures were above approximately 35°F. When the air temperature was below freezing, much of the effluent would freeze and greatly reduce the amount of runoff. On warm days, ice and snow already on the site would melt and contribute to the flow, and total runoff could conceivably exceed the amount applied. During the warm months, when temperatures were always above freezing, the amount of runoff was influenced by the amount of antecedent rainfall and by the amount of evapotranspiration.

The effect of the effluent on the soil temperature profile varied and seemed dependent on the amount of infiltration although infiltration was not measured. On December 12, 1966, when no soil frost existed and the air temperature was near 32°F, the soil temperature increased near the surface, but decreased deeper down. After irrigation, the frost had melted at some locations, but was still present at others. Little infiltration occurred on December 26, 1966 when soil frost existed, the air temperatures were below freezing all day, and snow and ice were present on the surface; and, as a result, the soil temperature profile remained nearly constant before and after irrigation.

Data which relates the runoff as a percentage of the total applied, the daily maximum and minimum air temperatures, and the frost conditions are shown in Table 2. The nearly constant runoff for all three days indicates that much effluent froze on cold days when soil frost reduced infiltration.

Table 2.--Effects of Air Temperature and Soil Frost Conditions on Surface Runoff for Three Irrigation Applications [4]

		Frost Layer		Air Temp (°F.)	
Date	% Runoff	Before Irrigation	After Irrigation	min	max
12/12/66	44	Absent	Absent	16	27
1/3/67	52	Present	Present	25	40
1/24/67	51	Present	Absent	48	64

Runoff from this small site would sometimes continue for over two days after irrigation was stopped, and the researchers concluded that subsurface flow substantially contributed to the total runoff. Runoff samples were taken at various times after irrigation ceased and were analyzed for phosphorus. The concentration decreased with time and indicated that an increasing amount of subsurface runoff (with its phosphorus adsorbed by the soil) was contributing to the flow.

The net effect of this spray operation was to saturate the site. Irregular clay layers caused a perched water table over much of the site which greatly reduced the temporary storage and transmission capacity. As a result, spray applications of two inches at 0.25 inches per hour would cause considerable runoff.

A second study during 1966-1967 on another 2.5-acre site centered around runoff as a function of antecedent precipitation and the amount of effluent applied.

Three test cycles of six weeks duration were run in October - November 1966 (Cycle I); March - April 1967 (Cycle II); and June - July 1967 (Cycle III). The amount of effluent applied was increased by one inch each week from one inch the first week to six inches the sixth week. The effluent was applied on one day each week at 0.25 inches per hour.

The largest percentage of runoff occurred during Cycle II while the smallest occurred in Cycle III. This result contrasts with the fact that the largest amount of precipitation fell in Cycle III and that the smallest amount fell in Cycle I (see Table 3). During June and July, the growing conditions were such that much more evapotraspiration occurred in Cycle III than in Cycle II

Table 3.--Percentage of Irrigation Amount Appearing as Runoff (R/I) and Inches of Total Precipitation which Occurred During the Week Prior to Irrigation for all Cycles [4]

	Cycle I (Oct-Nov)		Cycle II (Mar-Apr)		Cycle III (June-July)	
Runs and amount Sprayed	Runoff	Antecedent Precip	Runoff	Antecedent Precip	Runoff	Antecedent Precip
inches	percent	inches	percent	inches	percent	inches
1	0.0	0.16	9.0	0.23	0.0	0.41
2	4.1	0.40	26.2	3.44	0.0	0.08
3	11.7	0.00	18.0	0.91	3.5	2.36
4	20.4	0.38	13.4	0.51	8.9	1.58
5	25.0	1.27	14.0	0.35	17.4	1.41
6	19.0	0.00	16.4	0.27	21.6	1.87

and probably caused the lower percentage of runoff. The results also show that a greater runoff percentage tended to occur when antecedent precipitation was high.

Hydrographs for Cycle III were fairly similar and flow sharply decreased after irrigation stopped. While no runoff occurred the first two weeks, the percentage of runoff increased as the irrigation increased from three to six inches. This result indicated that the soil percolation rate controlled the runoff as the soil pores filled with water and saturation conditions were reached.

Hydrographs for Cycle II were not as uniform as those of Cycle III. Runoff peaks sometimes did not occur simulatneously with the end of irrigation, and the flows did not always decrease sharply after the peaks were reached. This phenomenon resulted from the influence of temperature on freezing effluent and thawing ice on the site.

A third study in 1968-1969 was conducted on the first 2.4-acre site to determine the peak runoff rates, total runoff volumes, and chemical quality of the runoff under two different irrigation procedures. One procedure (called the maximum sequence) involved spraying with all four irrigation lines simultaneously. In the other procedure (called the minimum sequence), one line was run at the beginning of the week, two lines were run in the middle of the week, and the fourth line was run at the end of the week. In all cases, each irrigation run was for an eight-hour period and applied two inches of effluent.

Five cycles consisting of a maximum and a minimum sequence were run over different climatic periods. Cycle I (November - December) and Cycle IV (March - April) were typical of late fall and early spring conditions in which greater total runoff percentages and higher peak flow rates occurred during the maximum sequence than the minimum sequence. Cycle II (January) and Cycle III (February-March) were run during the winter when soil frost stopped infiltration and ice coated the surface, and they resulted in more runoff and higher peak flows during the minimum sequence because more effluent was stored as ice during the maximum sequence. This result occurred because the air temperatures were subfreezing during the maximum sequence while the temperatures averaged above freezing during the minimum sequences. Cycle V (May - June) was typical of the growing season, and no runoff occurred due to irrigation. Tables 4 and 5 show the percent runoff and peak runoff rates.

Total phosphorus and total nitrogen levels were measured in the applied effluent and in runoff samples taken at the time runoff started, irrigation stopped, and runoff stopped. Runoff concentrations were lower in sequences with warm weather in which effluent could

Table 4.--Percentage of Effluent Volume Applied Appearing as Runoff during the Minimum and Maximum Sequences for Five Irrigation Cycles [4]

Cycle	Minimum Sequence	Maximum Sequence
I	23	27
II	55	34
III	84	56
IV	11	20
V	0	0

Table 5.--Peak Runoff Rates Relative to Irrigation Application Rates during the Minimum and Maximum Sequences for the Five Irrigation Cycles [4]

Irrigation Sequence	Area Irrigated	Irrigation Cycle I	II	III	IV	V
		%	%	%	%	%
Maximum	Ag 7, 8, 9 & 10	43	52	76	36	0
Minimum	Ag 9	48	108	211	37	0
Minimum	Ag 7 & 10	24	88	85	6	0
Minimum	Ag 8	36	41	83	18	0
Minimum[a]	Ag 7, 8, 9 & 10	36	79	126	20	0

[a]Values given in this row are the peak runoff rates for the entire watershed obtained by averaging the peak runoff rates for the individual runs (Ag 9, Ag 7 & 10 and Ag 8) during the minimum sequences.

infiltrate and percolate through the upper soil layer. During sequences with below freezing temperatures and soil frost that reduced infiltration, the nutrient levels in the runoff were often higher than in the sprayed effluent because pure water would freeze out and concentrate the solids. The minimum sequences generally had a greater percent reduction of nutrients in the runoff than the maximum sequences.

The researchers concluded from this study that the minimum sequence of effluent application was best during periods when infiltration was not decreased by frost. When frost was present, the minimum sequence was not as effective in lowering total runoff as the maximum sequence, but was more effective in lowering the nitrogen and phosphorus content in the runoff.

While the Penn State studies did investigate the surface runoff under different conditions, they failed to determine the fate of the rest of the effluent applied to the site and of the nutrients in the water. Infiltration measurements would have been helpful in order to compute a water balance. Nutrient levels also were not monitored in great detail in the Penn State Study. In order to recycle the nutrients and not pollute the receiving streams and groundwater, the fate of the nutrients added by the spray effluent must be determined.

1.2.2 Muskegon

Very little additional work has been done with winter spray irrigation. Muskegon spray irrigates its municipal and industrial wastewater after aeration in several large basins to remove some of the organics, and the system depends upon plant uptake and soil infiltration to remove the nutrients and remaining organics (5). Because of the size of the project and the relatively poor quality of effluent from the aeration basis, surface runoff cannot be tolerated and usually will not occur because the soil is very sandy and the infiltration rate is high. To avoid saturated soils which will kill the plants and decrease nutrient uptake, tile drains have been constructed to collect the infiltrated water. Soil frost in the winter greatly decreases infiltration and causes surface runoff, and spring thaws add enough water to saturate the soil; therefore, large basins have been constructed to store the aerated wastewater during the five-month period every year when the site cannot be sprayed.

1.3 Purpose and Objective

The general lack of information on winter spray irrigation is a major hindrance in evaluating the usefulness of this procedure as a water quality management alternative. Runoff and infiltration must be extensively investigated under a variety of winter conditions. A water balance needs to be constructed from field data, and a mass balance should be made to determine the fate of the nutrients applied to the system.

For the study described herein, five acres of a small watershed (7.35 acres) were sprayed with treated wastewater during the winter months of 1975 (January - March). A hydrologic survey was performed for the purposes of quantifying the surface runoff and constructing a water balance of the system, and the water quality was monitored in order to construct a chemical mass balance of the system.

Specific questions raised at the beginning of the study were:

(1) Would runoff occur;

(2) If runoff did occur, how much water was involved, what form did the hydrographs take, and what conditions contributed to its occurrence;

(3) How much water infiltrated, and how was it affected by the weather;

(4) What percentage of the infiltrated water reached the groundwater, and how much traveled as subsurface flow to the nearby stream;

(5) What amounts of phosphorus and nitrogen accompanied the infiltrated water and the surface runoff, and how much stayed with the soil.

The ulitmate objective of this research project was to determine the feasibility of wintertime wastewater spray irrigation. The basis for decision was whether or not water leaving the site as surface runoff and infiltrated water met discharge standards and whether or not the process recycled the applied nutrients. This study differs from previous studies in that comprehensive water and mass balances have been attempted to quantify the fate of the materials added by the sprayed wastewater.

II. DATA COLLECTION

To conduct this research project, a small, open-field watershed with easily definable boundaries was sought adjacent to Felton Drain. After studying a contour map of the area and conducting a search in the field, a 7.35-acre subwatershed was finally selected next to the service road that bisects the research site (Figures 1 and 2). Five acres of this site were spray irrigated six times in a two-month period with water from the bottom of Lake One. For the first three spray periods, water was sprayed at a rate of two inches per week in one six-hour application. One week, due to problems with the spray equipment, only 1.5 inches were sprayed. For the last two spray periods, one inch per week was applied in a single three-hour period in order to minimize the runoff that was occurring.

2.1 Hydrology

To measure the surface runoff, four concrete dams with six-foot wide openings were constructed in Felton Drain. The three upstream dams (W1, W2 and W3 in Figure 1) had weir plates fastened across their openings. Each weir plate consisted of two 90° V-notch weirs, nine inches deep. The last dam (W4) had a nine-inch Parshall flume, 15 inches deep, fastened across the dam opening.

The winter spray site slopes down to a depression next to the road and Felton Drain. A ditch was dug from this low spot to Felton Drain, and dikes were built to insure that all runoff went through the channel. The channel was provided with a combination 45° V-notch and rectangular weir (Figure 3) which was attached to a sheet of plywood and placed into the ground (W5, Figure 2).

A natural channel enters Felton Drain above weir 3 and drains a major portion of the area west of Felton Drain. A stop-gate (slotted wooden boards fitting into a concrete base) was constructed at the mouth of this channel (W6, Figure 1).

A drainpipe from a tile drain empties into Felton Drain just upstream of the Parshall flume (DP2, Figure 1). In order to determine the water balance, the water this drainpipe added to the drain had to be either measured or eliminated. Because of the difficulty in measuring the flow out of the pipe, a bypass was constructed which carried the water over the dam.

After spraying, another drainpipe was used to empty the trunk line from the pump house directly into Felton Drain in order to prevent the pipes from freezing

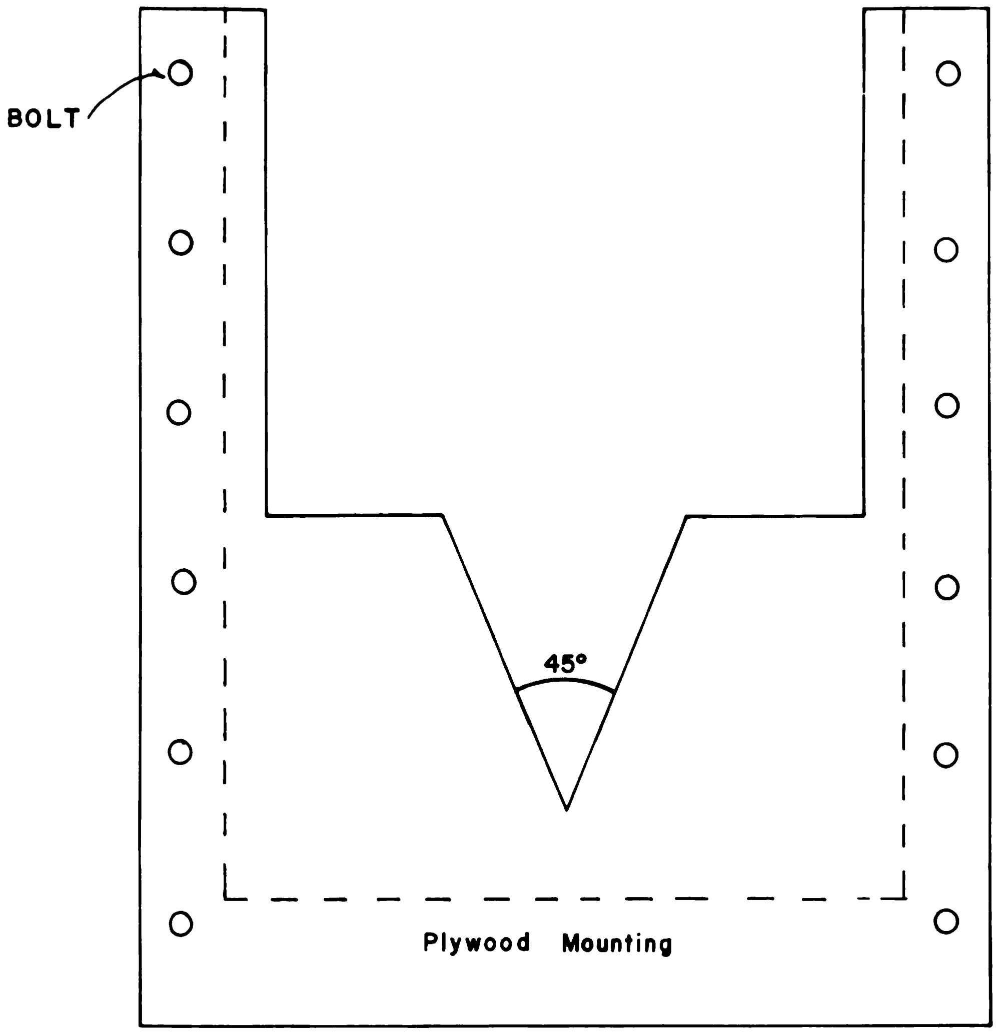


Figure 3.--Weir Plate at the Winter Spray Site.

(DP1, Figure 1). The water from this drainpipe was not measured and had a small impact on the flow in Felton Drain.

Continuous recorders were placed on Weirs 2, 4, and 5 to measure the discharge at the winter spray site, above the site in Felton Drain, and below the site in Felton Drain. A ten-foot deep stilling basin was installed at the Parshall flume (Weir 4), and modified oil drums were buried at the other two sites to act as stilling basins. Stevens type F recorders with floats measured the water heights in the stilling basins and were correlated to the water levels above the weirs and in the flume.

Flow in the Parshall flume was calculated from the flume equation supplied by the manufacturer. A stage-discharge curve for Weir 2 was volumetrically determined in the field. Flow through the spray site weir (Weir 5) was determined from a rating curve created from laboratory measurements. The curve was verified in the field volumetrically.

Natural precipitation was measured by a weighing type rain gage which continuously recorded the amount of water which fell in a bucket. The rain gage was located near the entrance to the spray site at Hagadorn Road (see map, Figure 1). It was close enough to the winter spray project to accurately record the precipitation falling on the site from winter storms.

Infiltration was measured by 47 infiltrometers spaced throughout the winter spray site (see map, Figure 2). Each device consisted of a glass funnel buried about three feet underground which was connected by a piece of plastic tubing to the surface. A number ten "tin" can was placed at each infiltrometer site to measure the amount of water falling from the spray operation. Pan lysimeters were also sprayed next to the site, and others were placed as controls farther outside the site as part of another thesis project (6). A strip recorder at one of the lysimeter sites continuously measured the air temperature, and themistors measured the soil temperature at various depths.

2.2 Water Quality

Water quality samples were taken periodically at the site. Samples were taken at Weirs 2 and 4 an average of once a day when flow existed. Some samples were taken at Weir 3, and Weirs 5 and 6 were sampled daily whenever water flowed through their channels. Samples were taken at Drainpipe 2 until it was bypassed and at Drainpipe 1 when the pipes were drained after spraying. Lake One was sampled six feet below the surface at the outlet structure on days spraying occurred.

Every two weeks, half of the infiltrometers were drained, and if a significant amount of water was obtained (about 100 ml), it was analyzed for its quality. Samples from the lysimeters were obtained whenever the pans were drained and water recovered. Sometimes, several samples were taken from the same pan on a given date because the appearance of the water markedly changed while it was being pumped out.

On days spraying occurred, samples were also taken from the "tin" cans at the infiltrometer sites. The samples were taken immediately after spraying stopped from all the cans containing more than a trace of water. The day before spraying occurred, any snow that had fallen the previous week and/or ice that had frozen from the previous week's spray operation were sampled at a few infiltrometer sites.

When runoff occurred from the winter spray site, samples were taken at the spray site weir (Weir 5) before and during the draining of the field lines. The Parshall flume was also sampled before any runoff and also when the surge from either the winter spray runoff or Drainpipe 1 reached the dam.

The samples were stored at 4°C, and the first month's samples were preserved with 40 mg/l of mercuric chloride. They were analyzed for the total phosphorus, nitrate, ammonia, boron, and chloride concentrations. The Water Quality Laboratory of the Institute of Water Research performed the tests with an auto analyzer

(Technicon Auto Analyzer II), using Industiral Method No. 344-74W (phosphorus), No. 100-70W (nitrate plus nitrite), No. 102-70W (nitrite), No. 98-70W (ammonia), No. 202-72W (boron), and No. 99-70W (chloride) as procedures. Nitrate was computed by subtracting the nitrite determination from the nitrate plus nitrite measurement. Some of the boron levels were also determined by the Curcumin Method in "Standard Methods."

III. DATA ANALYSIS

3.1 Water Balance

3.1.1 Natural Precipitation

The data from the rain gage used in the study was not complete because the clock stopped and the pen malfunctioned on several occasions. These gaps were filled by taking representative values determined by the other two rain gages on the project, the Lansing and East Lansing gages (7), and the 22 gages of the Deer-Sloan Creek micronetwork (8). The daily totals are shown in Table 6 for the period of the study.

3.1.2 Spray Irrigation

The amount of water delivered to the spray site was measured at the pump house next to Lake Four. The amount of water pumped to the pan lysimeters just outside the winter spray site was separated from the amount delivered to the subwatershed by proportioning according to the number of spray heads at each site. Forty-five spray nozzles were located throughout the study in the subwatershed while seven nozzles sprayed the lysimeters during the first two applications and

Table 6.--Natural Precipitation on the Winter Spray Site (1/14/75 to 3/16/75).

Date	Precipitation (inches of water equivalent)
1/18	0.10[a]
1/24	0.04
1/25	0.17
1/29	1.00
2/5	0.09[a]
2/6	0.11[a]
2/15	0.30[a,b]
2/17	0.35[b]
2/18	0.13[a,b]
2/19	0.01[a,b]
2/22	0.27
2/23	0.28
2/24	0.15
2/25	0.13[a]
2/26	0.07[a]
2/28	0.01[a]
3/6	0.02[a,b]
3/7	0.30[a,b]
3/12	0.11
Total	3.64 (726,435 gal. on 7.35 acres)

[a]Snowfall

[b]Estimates

four nozzles were used on the remaining four irrigations. To calculate the amount of water sent to the lysimeters, the present analysis assumes equal flow rates out of each nozzle which is a first-order approximation to the actual flow distribution in the network.

Since the wastewater was sprayed in fine droplets, a significant amount was evaporated before it reached the surface of the ground. The evaporation as a function of wind speed was estimated from a spray irrigation study (9), using averages of the wind speeds measured every three hours at the Lansing airport (10). Since the trees along Felton Drain acted as a windbreak, the wind speeds at the winter spray site may be a little lower than those recorded at the airport, possibly causing the evaporation rates to be too high in this analysis. The amounts of water estimated to have reached the ground surface are shown in Table 7. The total volume (987, 940 gallons) is 74 percent of the total amount pumped from Lake One. The average volume measured in the 37 cans (7.56 inches) was 77 percent of the total amount pumped from Lake One (11) which indicates that the evaporation estimates are close to being correct.

3.1.3 Surface Runoff

The hydrographs caused by natural precipitation, spray irrigation, and snowmelt are shown in Figures 4-8

Table 7.--Wastewater Applied to the Winter Spray Site.

Date	Water pumped from Lake 1 (gal.)	Percent delivered to the subwatershed (%)	Water delivered to the subwatershed (gal.)	Average wind speed during irrigation (mph)	Percent reaching surface (%)	Water applied to the subwatershed (gal.)
1/14/75	296,300	86.5	256,300	14.7	79	202,475
1/21/75	297,600	86.5	257,425	20.7	78	200,790
1/28/75	255,400	91.8	234,455	8.4	85	199,285
2/11/75	185,600	91.8	170,380	4.0	93	158,455
3/4/75	138,600	91.8	127,235	10.9	82	104,330
3/11/75	155,300	91.8	142,565	7.5	86	122,605
Total	1,328,800	89.4	1,188,360	10.0	83.1	987,940

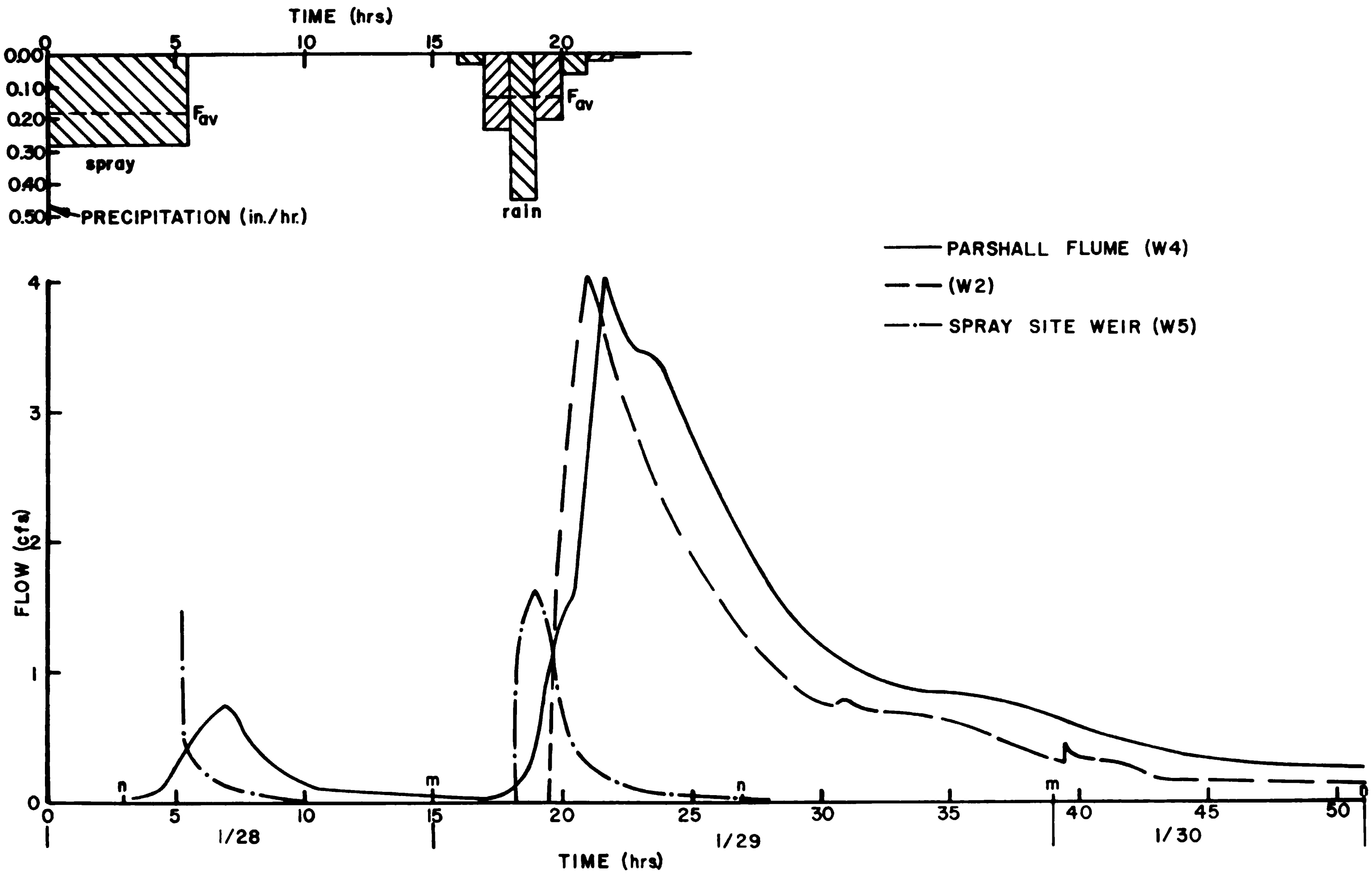


Figure 4.--Spray and Storm of 1/28/75 to 1/30/75.

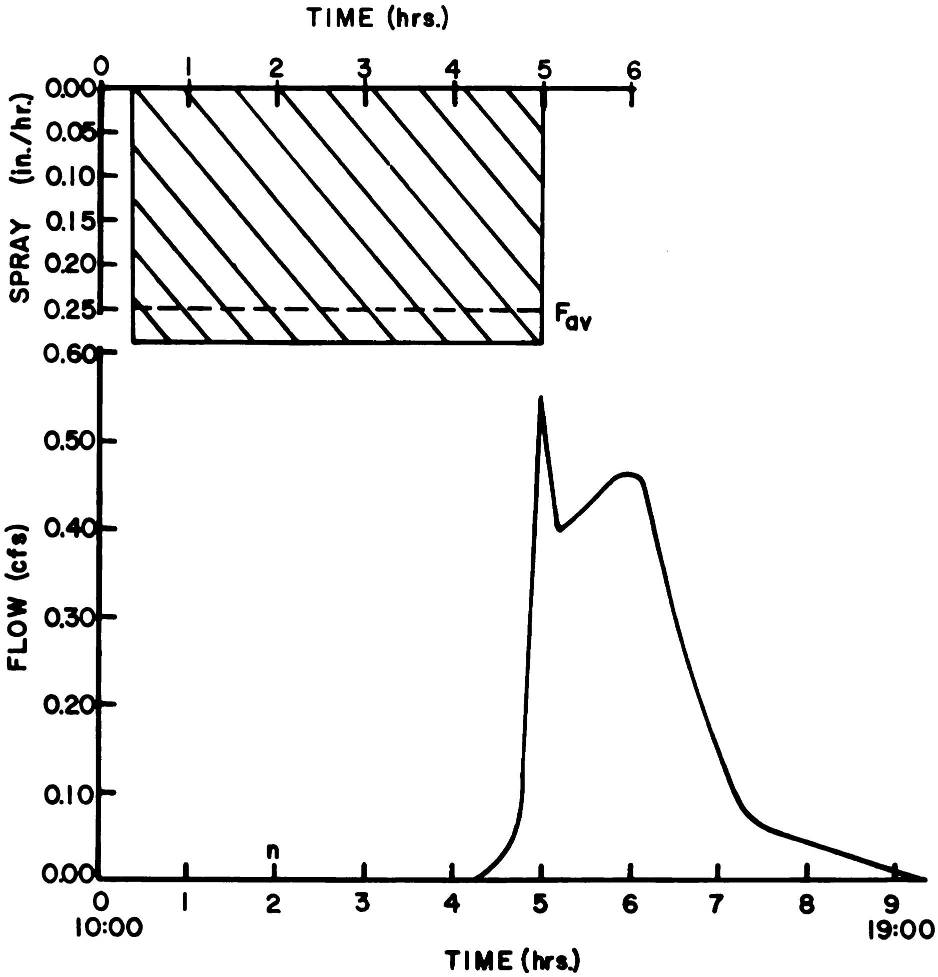


Figure 5.--Spray of 2/11/75 at the Spray Site Weir (W5).

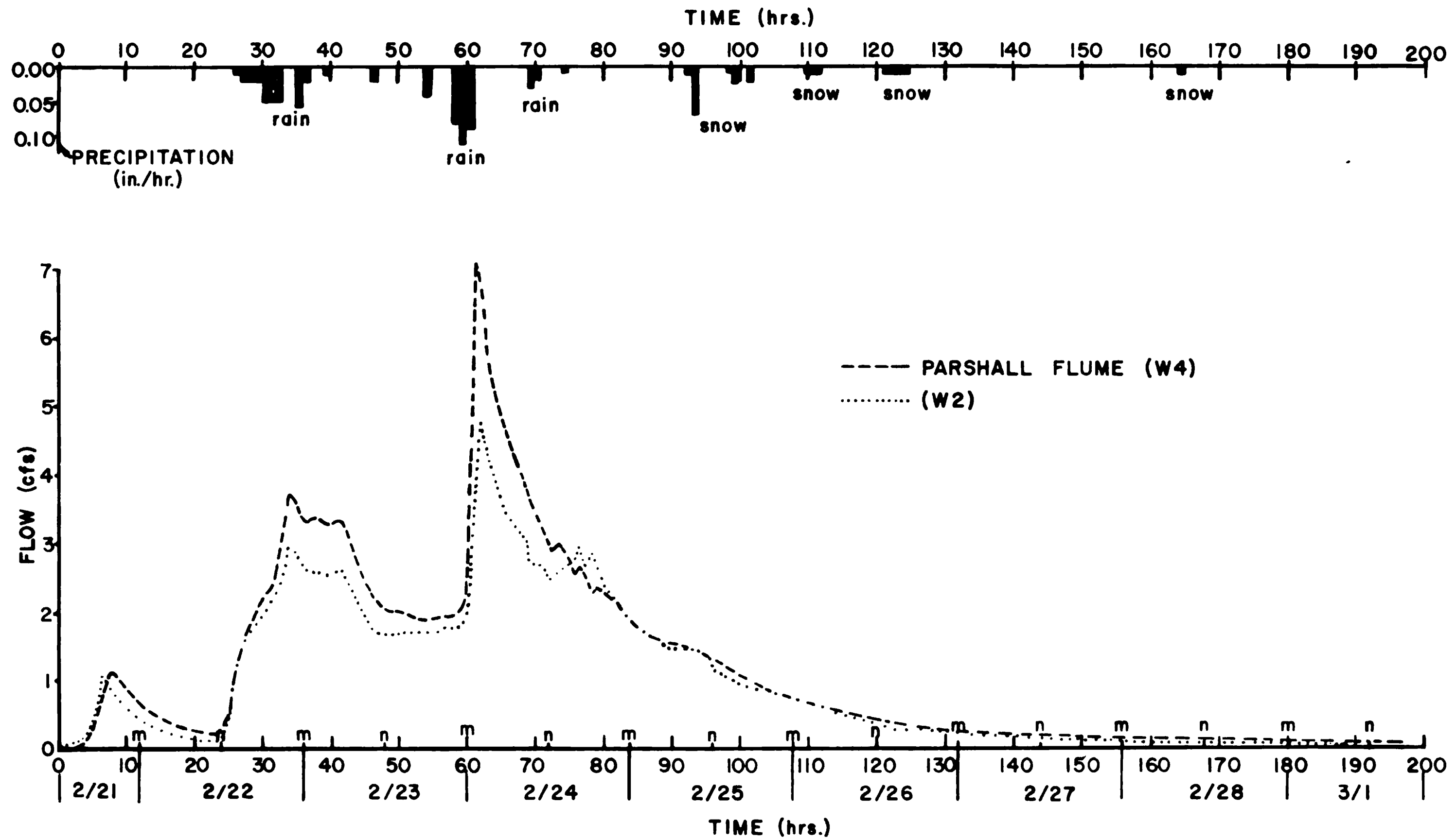


Figure 6a.--Storms and Snowmelt of 2/21/75 to 3/1/75.

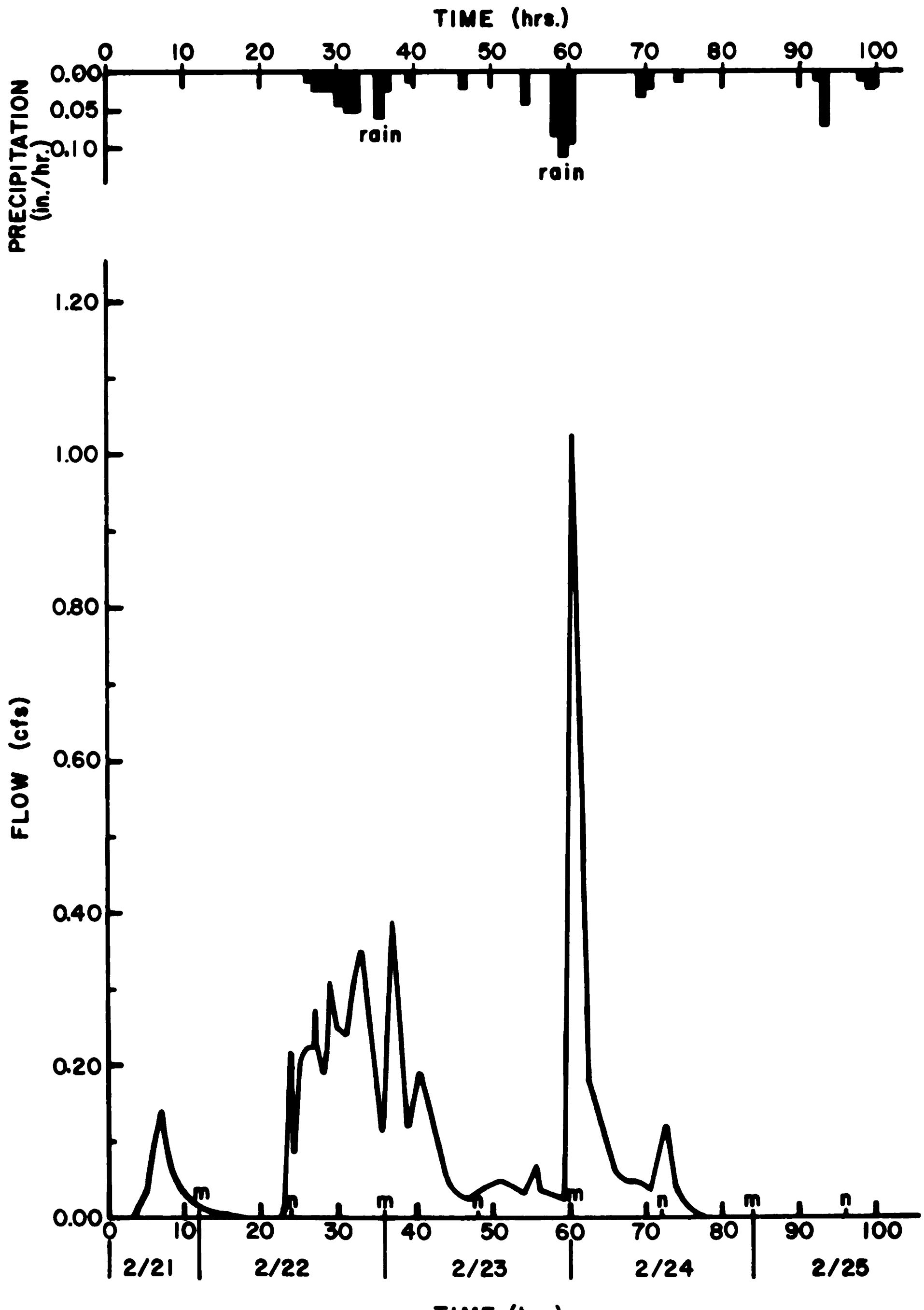


Figure 6b.--Storms and Snowmelt of 2/21/75 to 3/1/75 at the Spray Site Weir.

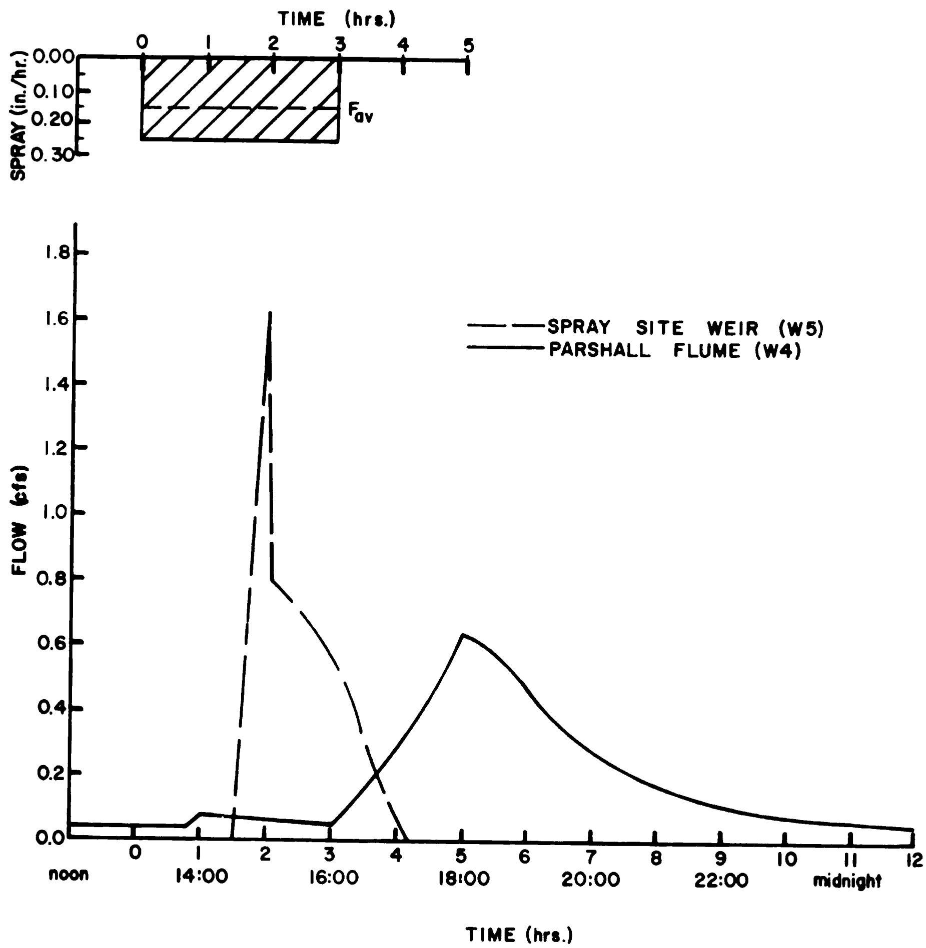


Figure 7.--Spray of 3/4/75.

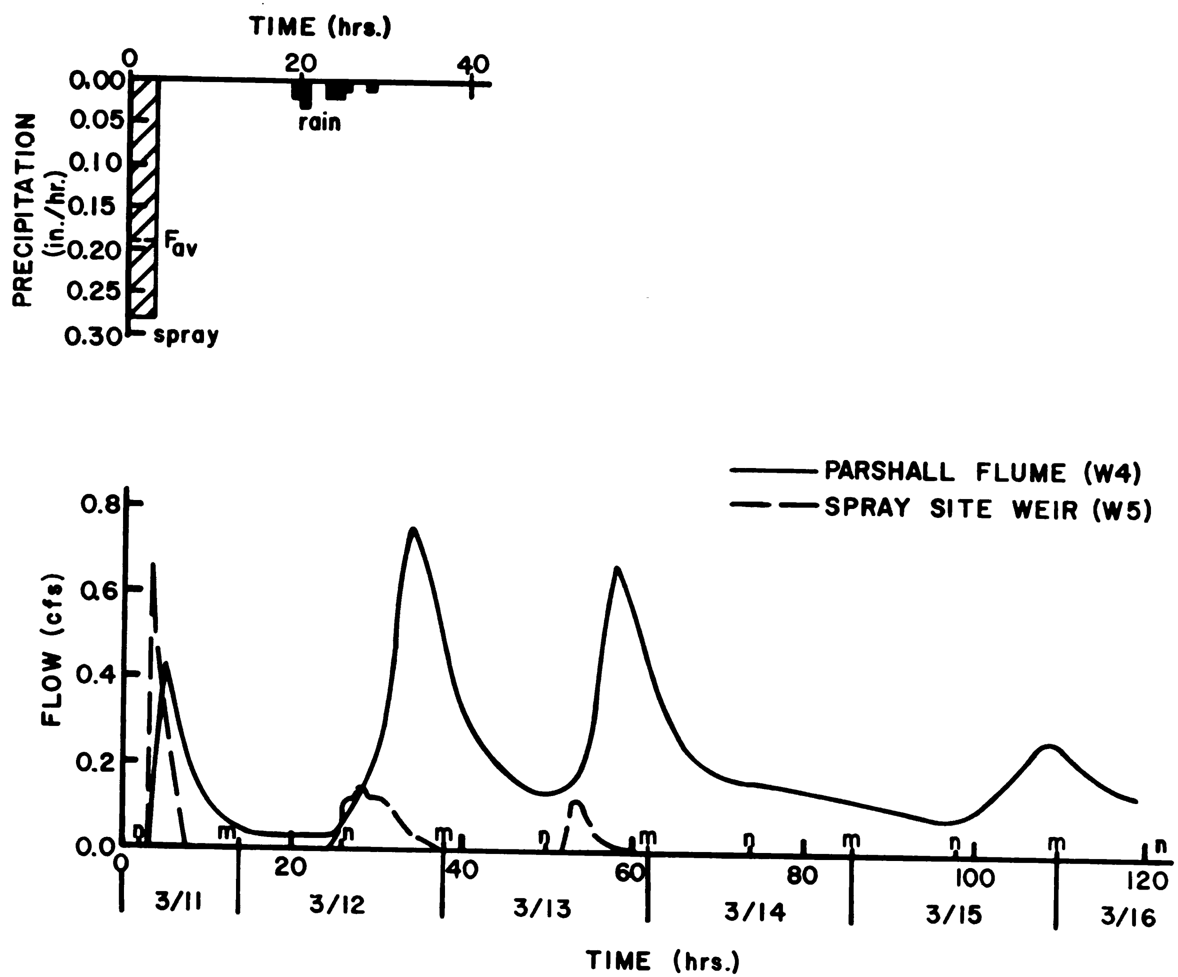


Figure 8.--Spray, Storm, and Snowmelt of 3/11/75 to 3/16/75.

with the accompanying hyetographs marked to show the infiltration indexes (Fav). Data points for the precipitation are shown in Appendix A while data for the hydrographs are listed in Appendix B. The hyetographs for the spray applications are for only five acres of the subwatershed while the natural precipitation hyetographs are for the entire 7.35 acres.

The spray hydrographs are generally short in duration and rise and fall rapidly. The rise times to peak discharge range from one-half to one hour, except for the two hours to the natural peak on February 11, and they cannot be measured too accurately because the time scale on the charts can only be resolved to one-half hour. The durations of these hydrographs ranged from three to seven hours and do not seem to be closely related to the amount of runoff.

The February 11 spray runoff is an anomaly in that its natural peak occurs two hours after the start of runoff. Snowmelt may have caused this result, but a delayed peak discharge did not occur on March 11 when similar conditions existed. Ice catching the float did not cause this peak, and it must have actually occurred.

Runoff totals were calculated by subtracting the base flow from each hydrograph and integrating with the trapezoidal rule. The base flow is defined as the flow that immediately precedes the rise of the hydrograph and remains when the hydrograph diminishes. The base flow occurs only at the Parshall flume (W4) and consists mainly of subsurface flow entering the stream between Weir 3 and the Parshall flume, but sometimes the base flow also contains a small residual amount of runoff from a previous hydrograph.

The infiltration index (Fav) is the average rate at which a watershed is capable of retaining water during a given storm and was calculated by subtracting the amount of surface runoff from the precipitation (12). Figure 9 shows a sample calculation of the total runoff and infiltration index of the March 4, 1975 spray runoff at the Parshall flume.

The total surface runoff during the two-month study is shown in Table 8. The clock in the spray site weir's recorder (W5) stopped on the day of the third spray (January 28), and the first part of the hydrograph was not fully recorded. Since Felton Drain was not flowing except for the spray runoff, the hydrograph from the Parshall flume (W4) was used to calculate the amount of runoff. The value obtained is probably too high as comparisons of the hydrographs from these two locations during the last two spray periods show. This result was partly caused by additional water which entered Felton Drain when the pipeline from the pump house was drained directly into the stream after irrigation stopped

Table 8.--Surface Runoff from the Winter Spray Site.

Date	Spray Site Weir (W5) amount (gal)	Spray Site Weir (W5) percent runoff[b] (%)	Parshall Flume (W4) amount (gal)	Parshall Flume (W4) percent runoff (%)
1/21*	340	0.2		
1/28*	71,200[a]		71,200	35.7
1/29	97,600	48.9		
2/11*	26,300	16.6		
2/21-2/22	12,950	Snowmelt		
2/22-2/24	216,700	155.1		
3/4*	40,475	38.8	45,560	43.7
3/11*	40,300	32.9	45,500	37.1
3/12	26,500	120.7		
3/13	10,000	Snowmelt		
Total	542,365			

*Spray irrigation dates.

[a]Value used is from Parshall flume (W4).

[b]Values represent the runoff as a percentage of the applied water.

Date	Time	Total Flow (cfs)	Total Flow-base Flow(0.052 cfs) (cfs)
3/4/75	16:00	0.052(base)	0
	17:00	0.282	0.230
	18:00	0.643(peak)	0.591(peak)
	19:00	0.487	0.435
	20:00	0.282	0.230
	21:00	0.168	0.116
	22:00	0.105	0.053
	23:00	0.077	0.025
3/5/75	0:00	0.064	0.012
	1:00	0.052(base)	0
		Total =	1.692

Total runoff = $(1.692 \text{ cfs})(1\text{hr})(3600 \frac{\text{sec}}{\text{hr}})(7.48 \frac{\text{gal}}{\text{ft}^3}) =$ 45,560 gallons

Total spray = 104,330 gallons in 3.05 hours

Non-runoff = 104,330 - 45,560 = 58,770 gallons

$(58{,}770 \text{ gallons})(\frac{1 \text{ ft}^3}{7.48 \text{ gal}})(\frac{1 \text{ acre}}{43{,}560 \text{ ft}^2})(\frac{1}{5 \text{ acres}})(\frac{12 \text{ in}}{\text{ft}}) =$ 0.43 inches of non-runoff

Infiltration index $= \frac{0.43 \text{ in}}{3.05 \text{ hr}} = 0.14$ in/hr

Figure 9.--Total Runoff and Infiltration Index (Fav) at the Parshall Flume (W4) on March 4, 1975.

(about 1,500 gallons). Some subsurface flow also occurred at least in the channel beneath the spray site weir, to add to the water in Felton Drain. Runoff totals listed in Table 7 for the Parshall flume were calculated only for the days spraying occurred. The small amount of water from the spray site on January 21 was not enough to register downstream, and the Parshall flume was frozen on February 11; therefore, no values are listed for these two dates.

Table 9 lists the percent runoffs, peak discharges, infiltration indexes, and minimum and maximum air temperatures (6) for the individual hydrographs. No runoff occurred the first week of spraying (January 14), and much of the effluent froze on the site. Because the irrigation lines were drained just above the excavated channel at the lower end of the subwatershed, a small amount of water went over the weir on the second spray period (January 21); but no natural runoff occurred, and much of the effluent again froze on the site. The temperature did not get above freezing until near the end of the spray application. All of the remaining spray applications experienced runoff and had temperatures above freezing for most of the time during spraying, except for the last application (March 11) when the temperature was approximately freezing. No

Table 9.--Surface Runoff, Peak Discharges, Infiltration Indexes, and Air Temperatures for the Winter Spray Site.

Date	Percent runoff (%)	Peak discharge (cfs)	Infiltration index (in/hr)	Air temperature (°F) min.	Air temperature (°F) max.
1/14*	0	0	0	12	23
1/21*	0.2	0.02	0	18	38
1/28*	35.7[a]	1.44	0.18	18	34
1/29	48.9	1.63	0.13	23	38
2/11*	16.6	0.550	0.25	12	37
2/21-2/22	Snowmelt	0.137	---	24[b]	51[b]
2/22-2/24	155.1	1.025	0	32[c]	44[c]
3/4*	38.8	1.625	0.15	16	34
3/11*	32.9	0.660	0.19	9[d]	31
3/12	120.7	0.140	0	24	32
3/13	Snowmelt	0.115	---	13	32

*Spray irrigation dates.

[a]Value used is from Parshall Flume (W4).

[b]Values represent the extremes recorded on 2/21.

[c]Values are extremes recorded during the three day period.

[d]Value taken from East Lansing data [7].

significant amounts of effluent froze on the site on any of the last four spray periods.

Snowmelt is included in some of the runoff totals and explains why there are two occasions when runoff was greater than 100 percent. The spray runoffs of February 11 and March 11 may also contain some snowmelts because there was some snow on the ground when spraying occurred. The snowmelt also affects the infiltration indexes. Even though infiltration is occurring, the infiltration index, as defined, has no meaning when runoff occurs with no precipitation and must be zero when runoff is greater than the precipitation. Values are also lowered by the snowmelt on days with runoff less than the amount applied.

The infiltration indexes of the winter spray site are much higher than those reported for entire watersheds. A study using records from 1931 to 1961 for the Red Cedar River basin (which includes Felton Drain) showed a peak infiltration index in January to March time period of 0.07 inches per hour with average values about one-half that amount (13). A small watershed in Illinois showed values of 0.06 to 0.08 inches per hour over an 18-month study (14). These comparisons are not disturbing because a small subwatershed of a few acres cannot be expected to behave similarly to an entire watershed.

The peak discharges for the spray runoffs are not truly representative of the overland flow because the surge caused by the drainage of the irrigation lines obscured the natural peak. Only on February 11 did a natural peak of 0.465 cfs occur separately from the 0.550 cfs of the spray line drainage. The spray line drainage consists of 2,600 gallons of effluent from the lake and drains out of the pipes in about ten minutes. This volume of water is a significant percentage of the run-off (ten percent on February 11) and is included in the spray totals although it was not separated from the water that was actually sprayed. If the peak discharges are to be accurately measured, this water must be diverted from the spray site weir.

3.1.4 Infiltration

Three of the 47 infiltrometers (numbers 15, 20 and 25) were outside the winter spray site north of the service road and were not used during the study (see map, Figure 2). The first four and the last three infiltrometers were too far from the irrigations lines to receive any sprayed effluent, and the infiltration at these sites came from natural precipitation on the sub-watershed.

A visual inspection of the 44 infiltrometers within the subwatershed in July 1975, revealed that many of the soil plugs above the funnels had settled and/or were cracked around the edges. Both of these phenomena would cause unnatural infiltration rates, and the data from these sites is unreliable. None of the infiltrometers were drained before the study began on January 14, 1975, and infiltration occurring between the time of installation in late November and December 1974 to January 14, 1975, is included in the totals.

The amount of infiltration recorded up to March 16, 1975, is shown in Table 10 for the infiltrometers which appeared to function properly (11). There is no guarantee that these infiltrometers functioned correctly as the excavated soil may have been repacked too tightly to cause settlement or representative infiltration while those that did settle may be truly representative of the surrounding soil. It is interesting to note that the average infiltration of the "good" infiltrometers that were sprayed was exactly the same (1.50 inches) as all of the 37 sprayed infiltrometers averaged together. The average of the seven infiltrometers that were not sprayed was 0.49 inches as opposed to the 0.325 inches averaged from the two that were used (11).

3.1.5 Evaporation

The most significant remaining loss from the water reaching the surface occurred from snow evaporation. Evaporation from snow and ice occurs only when the vapor pressure of the atmosphere is less than the vapor pressure

Table 10.--Total Recorded Infiltration on the Winter Spray Site (12/74 to 3/16/75).

Sprayed area (5 acres)		Non-sprayed area (2.35 acres)	
infiltrometer number	infiltration (inches)	infiltrometer number	infiltration (inches)
5	1.06	1	0.5
6	1.46	4	0.15
7	2.5		
14	0.14	Avg.	0.325
27	0	Std. dev.	0.25
29	0.15	Total Amount	20,740 gallons
36	0.15		
37	0		
38	3.8		
39	0		
40	1.6		
42	7.14		
Avg.	1.50		
Std. Dev.	2.14		
Total Amount	203,640 gallons		

Total infiltrated water = 203,640 + 20,740 = 224,380 gallons of the atmosphere is less than the vapor pressure of the snow (6.11 mb at 0°C). At temperatures above freezing, melting also occurs and is usually very much greater than evaporation (12, pp. 63-64). Snow evaporation is usually so small that attempts to measure it directly or by constructing water balances have been inconclusive due to errors in measurement. Water evaporation formulas and years of studies with evaporation pans have indicated that snow evaporation rarely exceeds one inch of water equivalent per month while a study using turbulent exchange methods showed an average value of less than 0.01 inch of water equivalent per day (14, pp. 310-311).

Because the meteorological tower was not to be installed at the project site until the summer of 1975, accurate weather data was not obtainable for use in any of the empirical snow evaporation equations that have been developed. The best approximation was to make an estimate from the amount of snow cover during the study. Records for East Lansing (7) show that 34 of the 62 days in the study had snow cover. Multiplying this percentage of snow cover (55%) by the maximum evaporation rate of one inch per month for the two-month period gives a value of 1.1 inches of water equivalent. As indicated earlier by the study using turbulent exchange methods, the actual value may only be 0.34 inches or even lower. Lacking any additional information, no refinement of the evaporation rate is possible other than simply rounding off the calculated maximum value to one inch of water equivalent. This value translates to 199,600 gallons of water evaporated from the entire 7.35-acre site.

3.1.6 Totals and Summary

The water balance for the winter spray site is shown in Table 11. The large error probably lies in the output parameters since the precipitation and irrigation were fairly well measured. As discussed earlier, the evaporation total may be 130,000 gallons too high which makes the error even greater, so the discrepancy must occur in the surface runoff and infiltration measurements.

Table 11.--Water Balance for the Winter Spray Site (gallons).

Input		
natural precipitation	726,435	
spray irrigation	987,940	
Total input	1,714,375	(100%)
Output		
surface runoff	542,365	
evaporation	199,600	
infiltration	224,380	
Total output	966,345	(56.4%)
Error (input-output)	748,030	(43.6%)

Subsurface flow might account for four to five percent of the input because the spray hydrographs at the Parshall flume contained this much more of the sprayed wastewater. Extending this percentage to other spray applications of higher amounts and to natural events may be hazardous, but the soil along Felton Drain is very porous and some subsurface flow must have occurred. Some of the extra water at the Parshall flume came from the drainage of the main delivery pipeline directly into the drain, but the amount is small (estimated to be about 1,500 gallons).

Some of the added spray did leave the site because the spray lines went to the edge of the watershed boundary and sprayed some water onto the adjacent subwatershed. Some water was also observed to flow through several of the furrows across the watershed boundary to the next subwatershed. Subsurface flow patterns at the spray site boundary may also have caused some of the water to flow across to adjacent subwatersheds. How much water can be accounted for by these factors is uncertain, but they certainly cannot account for 40 percent of the added water.

The vast majority of the missing water probably infiltrated and was not measured in the infiltrometers. The infiltrometers may have simply failed to measure the water as it passed by, or the water may have thawed certain portions of the soil frost and infiltrated at high rates there. Higher infiltration rates were noted at low areas where ponding occurred, and the effect of this phenomenon may be greater than that indicated by the data. Alternatively, the water may have been frozen in the 2.5 feet above the infiltrometers until the spring thaw. Figure 10 shows the volume that would be available for storage in the five acres sprayed assuming a typical void ratio of 0.70 and a soil moisture content of 50 percent. The calculated value of 835,000 gallons is 87,000 gallons higher than the computed error in the water balance and indicates that it may have been possible for the soil to retain the missing water. Field measurements did indicate a change in infiltration during the spring thaw, but the data were inconclusive. At this time, infiltrometer errors and soil storage are thought to be the prime causes for the large error, but it is impossible to be more certain.

3.2 Mass Balances

3.2.1 Natural Precipitation

The water quality of the natural precipitation was determined from the snow samples taken at the winter spray site. Because the samples cannot be related to any specific amount of precipitation and because most of the concentrations were fairly uniform throughout the

$$e = \text{void ratio} = \frac{\text{volume of the voids}}{\text{volume of the soil particle}}$$

$$n = \text{porosity} = \frac{\text{volume of the voids}}{\text{total volume}} = \frac{e}{1+e}$$

let e = 0.70 (typical value)

$$n = \frac{0.70}{1.70} = 0.41$$

$$\text{total volume} = (2.5\ \text{ft})(5\ \text{acres})(43{,}560\ \frac{\text{ft}^2}{\text{acre}}) = 544{,}500\ \text{ft}^3$$

$$\text{volume of the voids} = (0.41)(544{,}500\ \text{ft}^3)(7.48\ \frac{\text{gal}}{\text{ft}^3}) = 1{,}670{,}000\ \text{gallons}$$

assume soil moisture fills 50% of the void volume

volume available for storage = ½(1,670,000 gal.) = 835,000 gal.

Figure 10.--Storage Volume in the Soil above the Infiltrometers.

study, it was decided that average values for the entire study could be used. Appendix C lists all of the individual sample concentrations and shows that two of the chloride values and one of the phosphorus values are very much higher than the others. Contamination may have caused these values to be in error, and they were discarded and were not used in the analysis. Table 12 shows the averages and the total amounts added which were obtained by multiplying the concentrations by the total amount of precipitation and converting to pounds.

Table 12.--Material Added to the Winter Spray Site by Natural Precipitation (726,435 gal.).

	Total-P	NO_3-N	NH_3-N	B	Cl
Ave. Concen. (mg/l)	0.07	0.81	0.29	0.01	0.42
Total Mass Added (lbs)	0.42	4.91	1.76	0.06	8.60

3.2.2 Spray Irrigation

The material added by the spray operation was determined from the samples taken from the "tin" cans used as rain gages on the subwatershed. Because mercuric chloride was used to preserve the first month's samples, chloride levels were not obtained for all of the spray periods; and a mass balance for chloride was not performed. Table 13 shows the amounts added by irrigation which were

Table 13.--Material Applied to the Winter Spray Site by Spray Irrigation.

Date	Water applied (gal.)	Total-P		NO_3-N		NH_3-N		B	
		conc. (mg/l)	mass applied (lbs)	conc. (mg/l)	mass applied (lbs)	conc. (mg/l)	mass applied (lbs)	conc. (mg/l)	mass applied (lbs)
1/14	202,475	0.71	1.20	12.83	21.67	2.40	4.05	0.39	0.66
1/21	200,790	0.58	0.97	9.06	15.17	2.39	4.00	0.33	0.55
1/28	199,285	0.61	1.01	7.28	12.10	2.21	3.67	0.39	0.65
2/11	158,455	0.57	0.75	6.39	8.44	2.36	3.12	0.30	0.40
3/4	104,330	0.52	0.45	9.10	7.92	1.02	0.89	0.31	0.27
3/11	122,605	0.41	0.42	6.70	6.85	0.06	0.06	0.26	0.27
	987,940[a]	0.58[b]	4.80[a]	8.76[b]	72.15[a]	1.92[b]	15.79[a]	0.34[b]	2.80[a]

[a]Totals of each column.

[b]Average concentration calculated by dividing each total mass by the total water applied during the study.

calculated by multiplying the average of the cans by the volume of water applied and the appropriate conversion factor. Appendix C lists all the data.

A comparison was made between the lake and can samples to check their agreement. The lake concentrations were averaged and adjusted for the evaporation of the spray that occurred, and the mass of material applied was again calculated. Table 14 shows this analysis and compares the total mass applied using the "tin" can concentrations to the mass applied using the lake concentrations. Appendix C lists the original lake data. Nitrate was the best tracer because it remains stable for longer periods of time, and it gave the best results. This success indicates that the spray evaporation percentages are close to being accurate and that the spray totals are accurate. Although there is no ready explanation for the poor boron comparison, the poor ammonia comparison suggests that the gas is lost to the atmosphere during spray irrigation.

3.2.3 Surface Runoff

To calculate the amount of material accompanying the runoff, the spray site hydrographs were divided into segments which corresponded to individual grab samples of the runoff. The hydrographs were integrated over these segments to calculate the total amounts of water

Table 14.--Material Applied to the Winter Spray Site using Lake Samples.

Date	Percent of spray not evaporated (%)	Total-P conc. (mg/l)	Total-P conc./% not evap. (mg/l)	Total-P mass applied (lbs)	NO_3-N conc. (mg/l)	NO_3-N conc./% not evap. (mg/l)	NO_3-N mass applied (lbs)
1/14	79	0.565	0.715	1.21	6.695	8.475	14.31
1/21	78	0.525	0.673	1.13	8.59	11.01	18.44
1/28	85	0.70	0.824	1.37	6.70	7.88	13.10
2/11	93	0.615	0.661	0.87	4.875	5.24	6.93
3/4	82	0.30	0.366	0.32	8.73	10.65	9.26
3/11	86	0.48	0.558	0.57	9.60	11.16	11.41
Total				5.47			73.45

Percent cans/lake:

P: $\frac{4.80}{5.47}(100) = 88\%$

NO_3: $\frac{72.15}{73.45}(100) = 98\%$

Table 14.--Continued

Date	Percent of spray not evaporated (%)	NH_3-N			B		
		conc. (mg/l)	conc. / % not evap. (mg/l)	mass applied (lbs)	conc. (mg/l)	conc. / % not evap. (mg/l)	mass applied (lbs)
1/14	79	2.40	3.04	5.13	0.39	0.49	0.83
1/21	78	2.39	3.06	5.12	0.33	0.42	0.70
1/28	85	2.21	2.60	4.32	0.39	0.46	0.76
2/11	93	2.36	2.54	3.36	0.30	0.32	0.42
3/4	82	1.02	1.24	1.08	0.31	0.38	0.33
3/11	86	0.06	0.07	0.07	0.26	0.30	0.31
Total				19.08			3.35

Percent cans/lake: NH_3: $\frac{15.79}{19.08}(100) = 83\%$ B: $\frac{2.80}{3.35}(100) = 84\%$

which flowed over the weir in these time intervals, and each volume of runoff was then multiplied by the sample concentration to determine the total mass of material which flowed over the weir. Figure 11 shows the time intervals for each hydrograph with the time of sampling also marked, and Table 15 shows the amounts of material accompanying the runoff.

For the hydrographs with more than one sample, the flow was divided at the midpoint between the sampling times. An exception was the February 22-24 hydrograph in which samples taken were only applied to runoff occurring on the day they were taken. The flow for the January 28 spray runoff was also divided at the midpoint between the samples, but the total flows could not both be directly integrated since part of the hydrograph was missing at the spray site weir (W5). The spray site hydrograph was available for the time interval of the second sample, and the total flow was computed. This volume of water was subtracted from the total runoff volume measured at the Parshall flume (W4), and the remaining volume was applied to the first sample.

The two large storms during the study (January 29 and February 22-24) produced large and extended hydrographs at Weir 2 (W2) and the Parshall flume (W4) in Felton Drain. Figures 12 and 13 show the mass flow rates at the various sampling times during these runoff

Table 15.--Material Accompanying Runoff from the Winter Spray Site.

Date	Time of Sample	Amount of runoff (gal.)	Total-P		NO_3-N		NH_3-N		B	
			conc. (mg/l)	runoff amount (lbs)	conc. (mg/l)	runoff amount (lbs)	conc. (mg/l)	runoff amount (lbs)	conc. (mg/l)	runoff amount (lbs)
1/21*	15:30[a]	340								
1/28*	14:50	56,550	0.42	0.198	6.54	3.084	2.57	1.212	0.23	0.108
	15:10	14,650	0.53	0.065	5.72	0.699	2.81	0.343	0.29	0.035
1/29	8:45	95,460	0.09	0.072	2.61	2.078	0.13	0.103	0.14	0.111
	16:10	2,140	0.05	0.001	3.00	0.054	0.13[c]	0.002	0.14[c]	0.002
2/11*	14:35	400	0.49	0.002	7.00	0.023	1.10	0.004	0.06	0.000
	14:50	25,900	1.08	0.233	7.00	1.512	2.85	0.616	0.06[c]	0.013
2/21	15:30	12,950	0.08	0.009	1.36	0.147	0.31	0.033	0.43	0.046
2/22	11:07	79,360	0.06	0.040	2.12	1.403	0.19	0.126	0.20	0.132
2/23	15:00	64,670	0.05	0.027	1.31	0.707	0.11	0.059	0.28	0.151
2/24	9:10	67,800	0.05	0.028	1.01	0.545	0.09	0.049	0.36	0.194
	15:25	4,870	0.17	0.007	1.35	0.055	0.12	0.005	0.30	0.012
3/4*	15:55	30,800	0.10	0.026	7.43	1.909	0.37	0.095	0.25	0.064
	16:10	9,675	0.33	0.027	7.37	0.595	0.37	0.030	0.19	0.015
3/11*	13:30	10,035	0.40	0.033	5.36	0.444	0.04	0.003	0.21	0.018
	14:30	30,265	0.41	0.103	9.60	2.423	0.06	0.015	0.20	0.050
3/12	--[b]	26,500								
3/13	15:45[a]	10,000			0.90	0.075				
Total		542,365	0.19	0.871	3.48	15.753	0.60	2.695	0.21	0.951

*Values represent runoff due to spray irrigation.

[a]Missing values were not reported by the lab.

[b]No sample was taken for this runoff.

[c]Value listed is that of earlier sample that day; actual value was not reported by the lab.

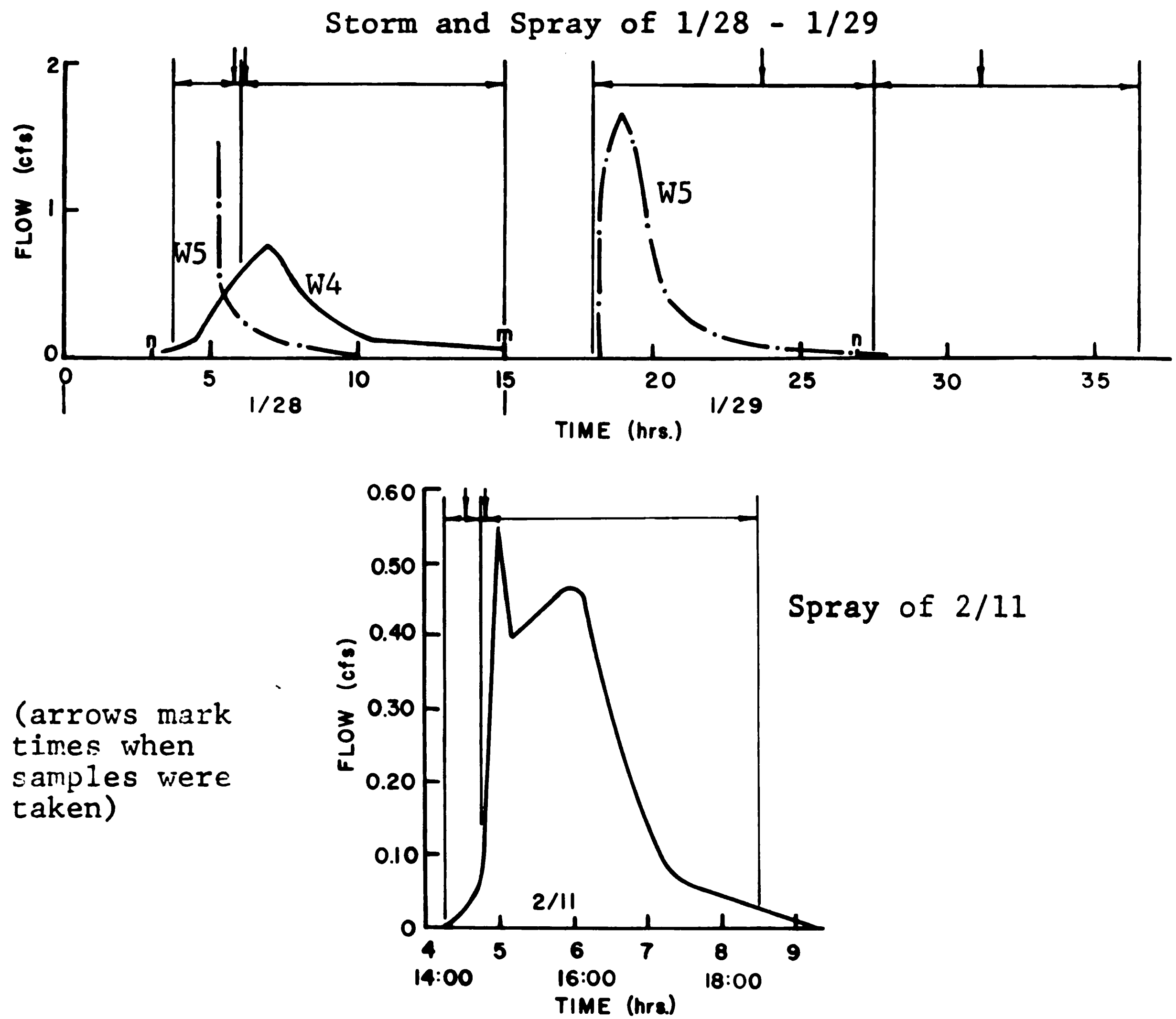


Figure 11.--Sampling Times and Integration Time Intervals at the Spray Site Weir (W5).

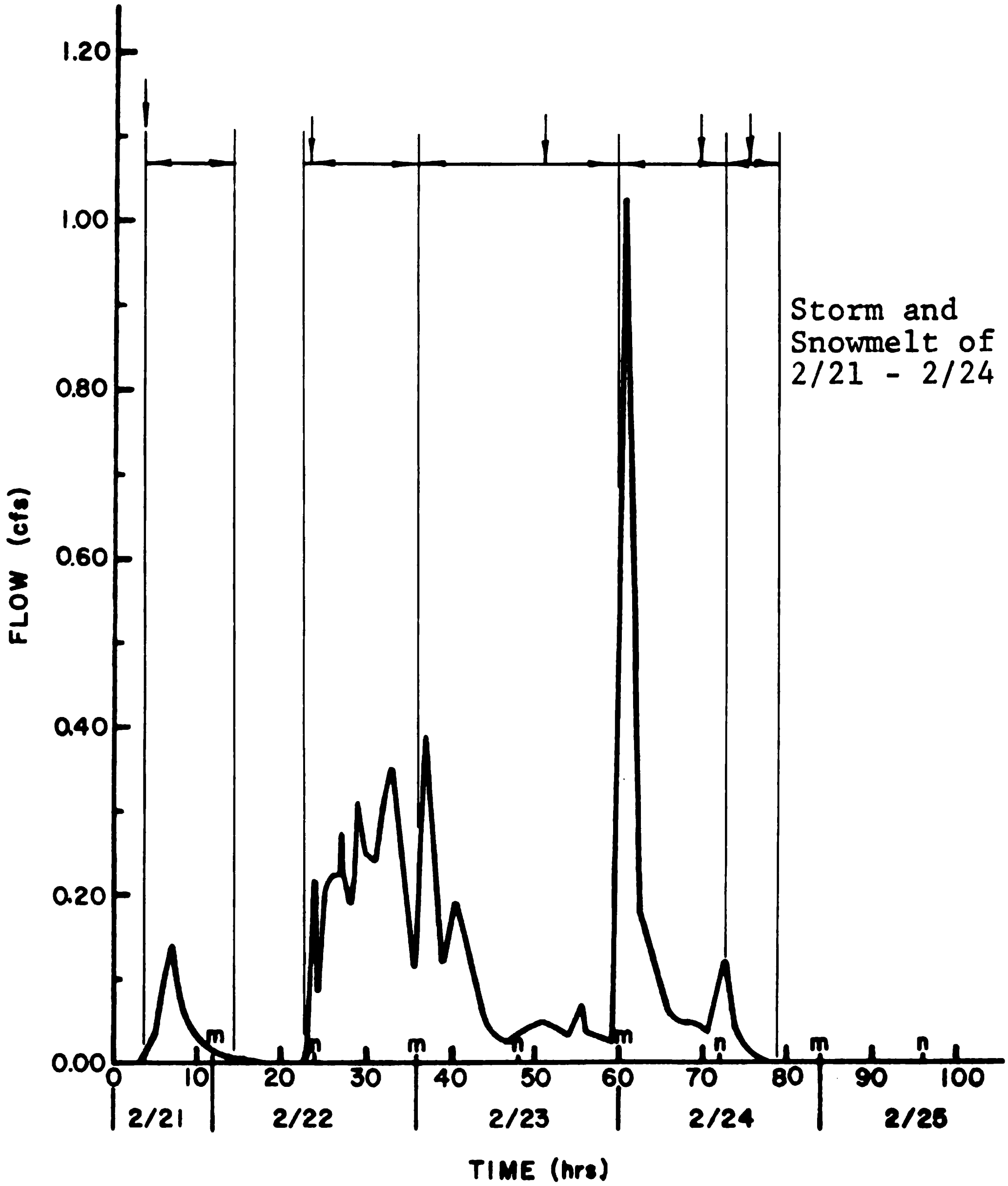
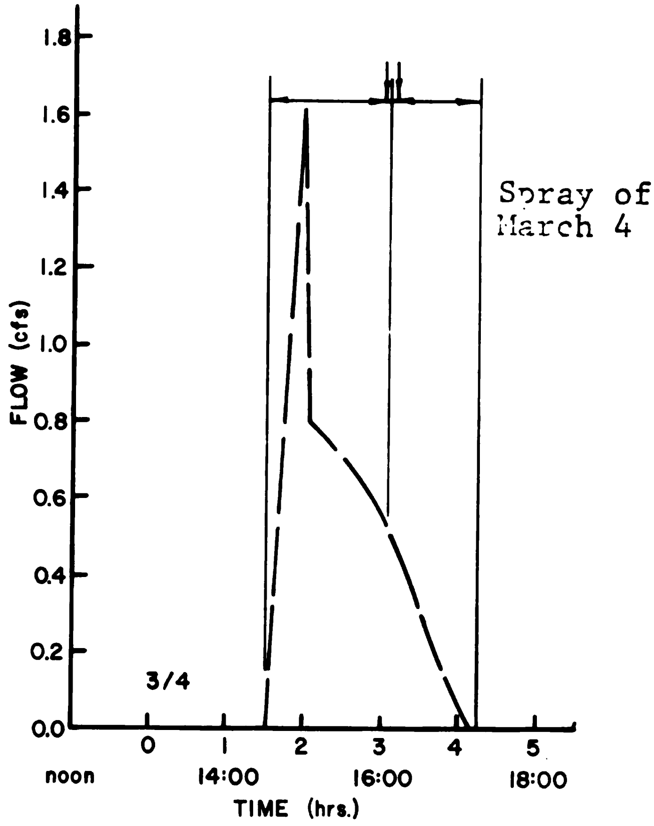


Figure 11.--continued.



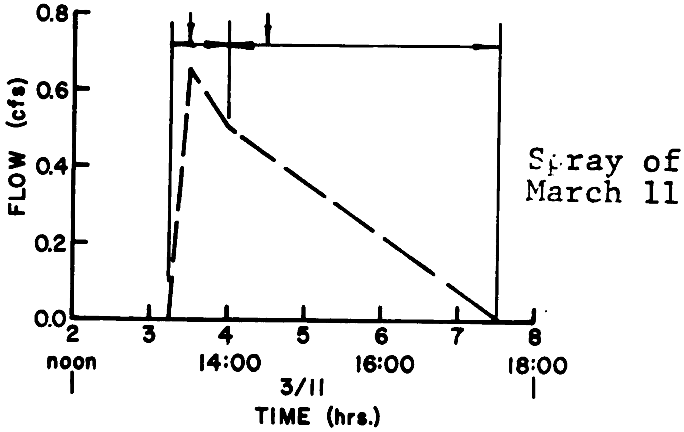
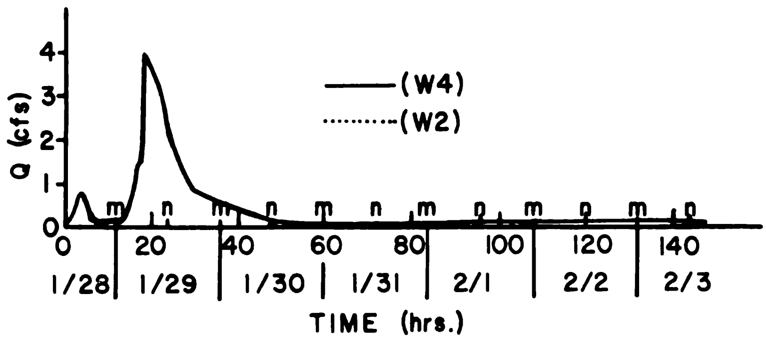


Figure 11.--continued.



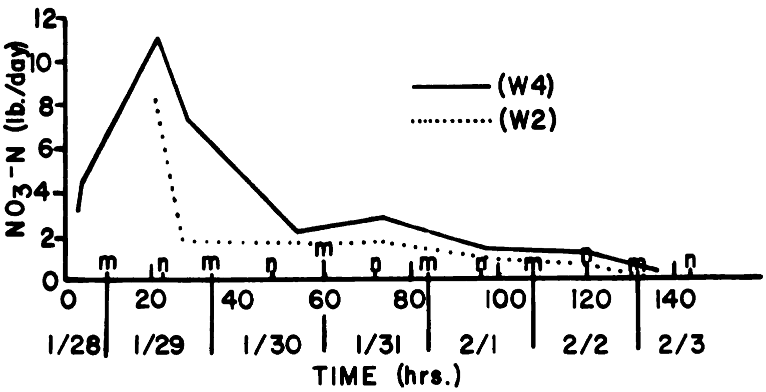


Figure 12.--Mass Flow Rates at the Parshall Flume (W4) and Upstream Weir (W2) for the Spray and Storm of 1/28/75 to 2/3/75.

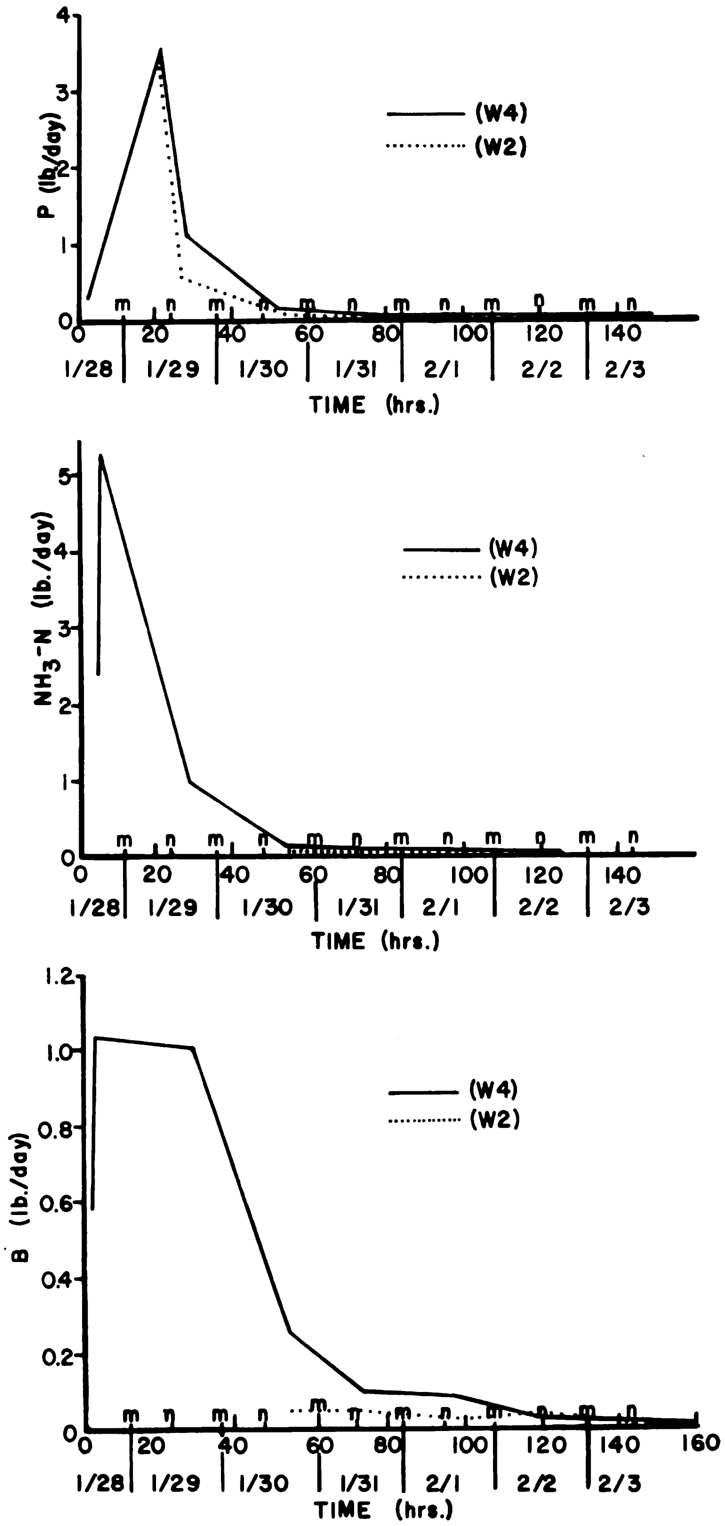


Figure 12.--continued.

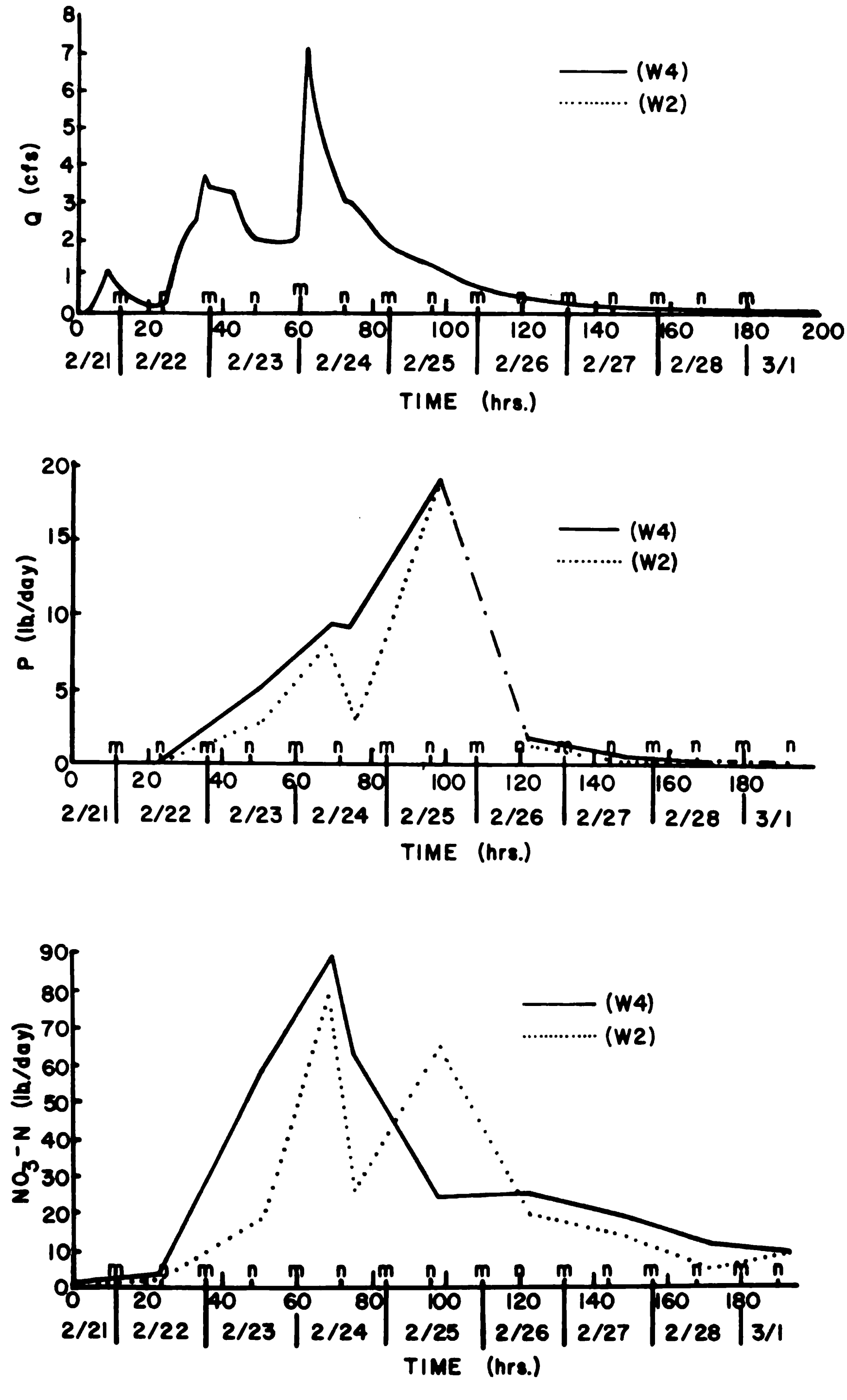


Figure 13.--Mass Flow Rates at the Parshall Flume (W4) and Upstream Weir (W2) for the Spray and Storm of 2/21/75 to 3/4/75.

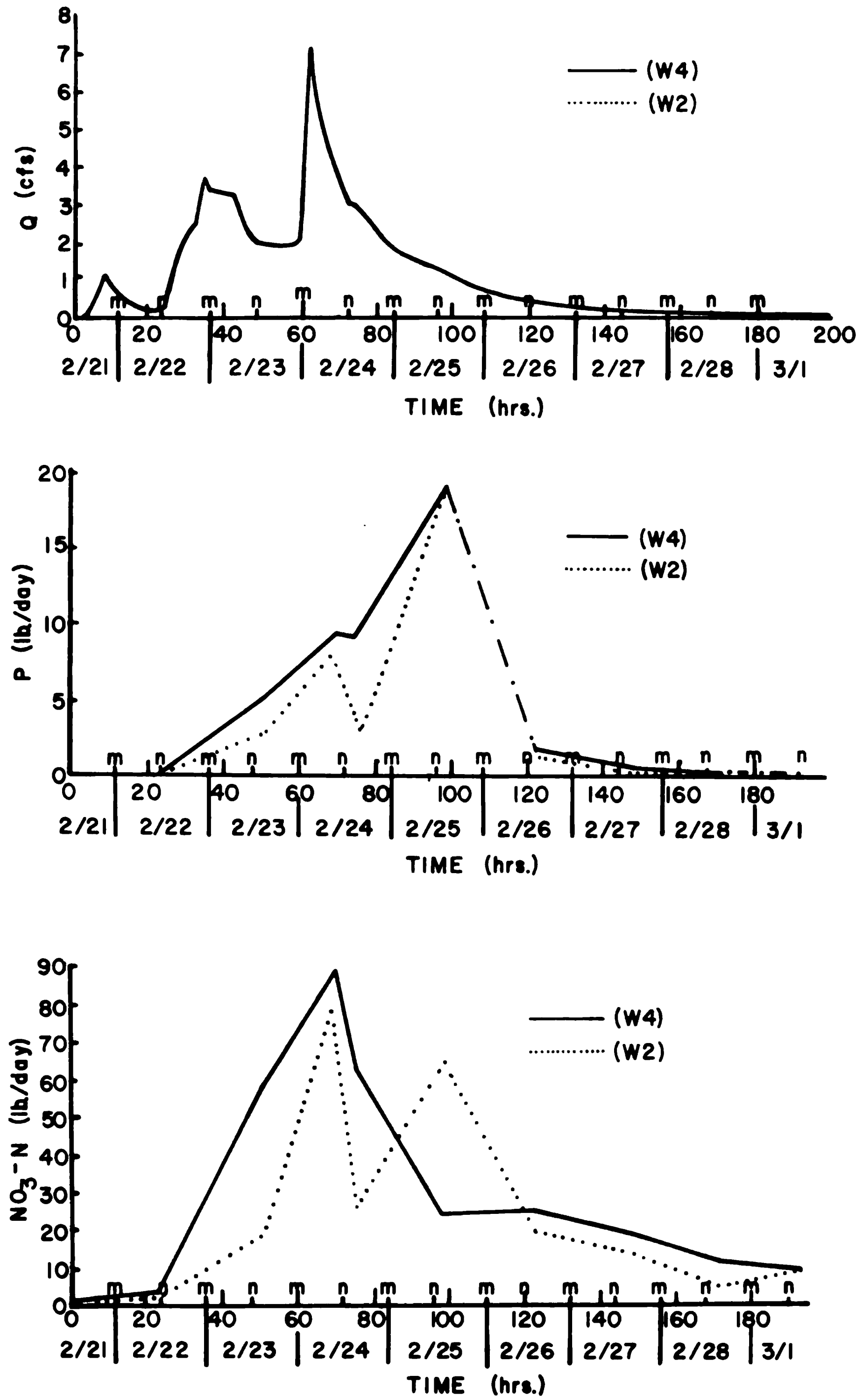


Figure 13.--Mass Flow Rates at the Parshall Flume (W4) and Upstream Weir (W2) for the Spray and Storm of 2/21/75 to 3/4/75.

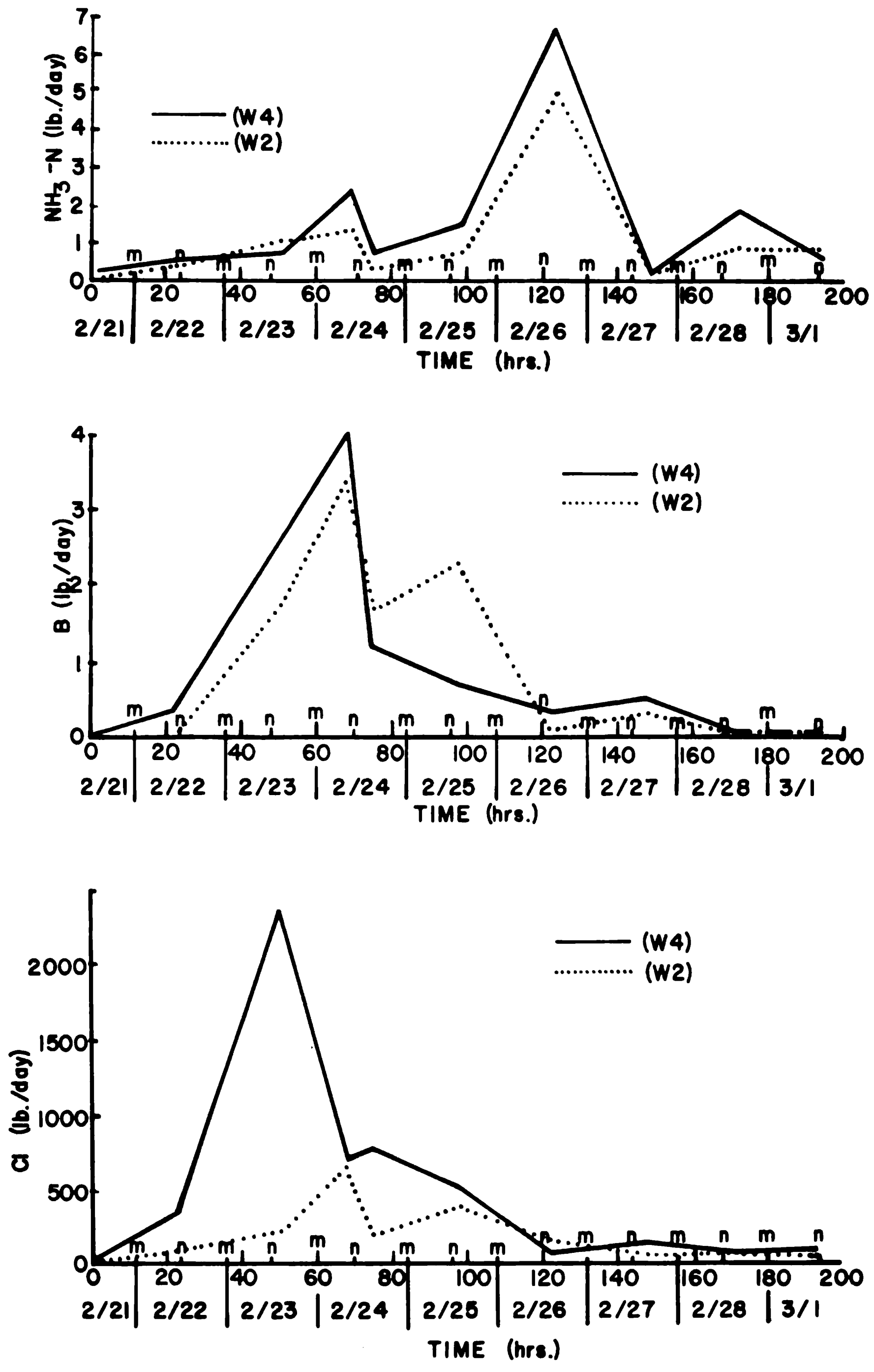


Figure 13.--continued.

periods, and Appendix D tabulates the data points used to make these graphs. The values were calculated by multiplying the flow at the sampling time by the concentration of the material in the sample. The first two points from the January 28 hydrograph at the Parshall flume represent the spray runoff of that day.

The mass flowrates of the two weirs generally parallel each other, and any major differences are more likely the result of erroneous concentrations reported by the lab. These values can only give a general picture of the mass flows because so few samples were taken. More samples, especially during peak flows, would probably produce graphs which generally parallel the hydrographs. The lack of sufficient samples prevented the creation of similar graphs for other hydrographs.

The mass flows for the January 28 and 29 spray and storm parallel the hydrograph fairly closely except for boron and ammonia which, due to the much higher levels found in wastewater, peak during the January 28 spray runoff. The February mass flows peak at different times from runoff caused by snowmelt and large rainstorm. The rain washed material from large piles of chicken manure located upstream of the spray site into Felton Drain, and evidently the different compounds were washed into the drain at different rates.

3.2.4 Infiltration

Water quality samples from the infiltrometers which appeared to be functioning properly were used to calculate the amount of material that infiltrated the soil. Since only a relatively few infiltrometers were judged accurate to use and the data varied over a large range, the useable concentrations were averaged for those infiltrometers sprayed with wastewater and those receiving only natural precipitation. Table 16 lists all of the samples for the "good" infiltrometers, but does not include chloride data since many samples were preserved with mercuric chloride. One of the infiltrometer nitrate values was much higher than the others and was higher than all but a few levels reported for the other samples taken during the study, so it was not used as it is probably in error. To calculate the amount of material which infiltrated, all of the water which was not measured in the water balance was assumed to have infiltrated and was, therefore, added to the measured infiltrated water. The amounts of water measured in the infiltrometers indicated that ten percent of the water infiltrated in the nonsprayed areas and ninety percent infiltrated in the sprayed area, and the new total was divided in these proportions between the two sets of concentrations. The total amounts were again calculated

Table 16.--Material Concentrations in the Infiltrometers at the Winter Spray Site.

Infiltrometer Number	Total-P (mg/1)	NO_3-N (mg/1)	NH_3-N (mg/1)	B (mg/1)
	a. Non-Sprayed Infiltrometers			
1	0.86	2.00	0.33	0.19
4	0.05	0.88	0.37	0.14
Avg.	0.46	1.44	0.35	0.17
Std. dev.	0.57	0.79	0.028	0.035
	b. Sprayed Infiltrometers[a]			
5	1.34	2.90	0.41	0.17
6	0.36,0.05	9.30,5.30	0.44,0.49	0.06,0.11
7	0.12,0.05	5.33,3.00	0.30,0.31	0.01,0.16
38	0.15,0.05	6.20,1.90	0.80,0.04	0.22,0.16
40	0.80,0.07	7.30,5.30	0.61,0.35	0.21,0.18
42	0.15,0.10 0.05,0.12	24.5*,9.60 7.12,6.31	0.33,0.33 0.23,0.11	0.02,0.12 0.11,0.04
Avg.	0.26	5.80	0.37	0.12
Std. dev.	0.38	2.40	0.20	0.07

[a]Each value represents a separate sample.

*Value was not used in computing the average or standard deviation.

by multiplying the amount of water by the concentration and appropriate conversion factor. Table 17 shows the totals.

Table 17.--Material Infiltrated at the Winter Spray Site.

Infiltrated water: 224,380 gal. measured infiltration
748,030 gal. assumed infiltration
972,410 gal total infiltration

	Amount of water (gal.)	total-P (lb)	NO_3-N (lb)	NH_3-N (lb)	B (lb)
Spray	875,170(90%)	1.90	42.33	2.70	0.88
Non-Spray	97,240(10%)	0.21	4.70	0.30	0.10
Total	972,410(100%)	2.11	47.03	3.00	0.98

3.2.5 Totals and Summary

The mass balances for the winter spray site are shown in Table 18. Nitrate is the best tracer shown because it stores well and is not adsorbed by soil. Boron should also balance fairly well, but did not in these calculations. Phosphorus is adsorbed by soil which is reflected in the totals, and ammonia is converted to nitrite and then to nitrate which accounts for its very poor balance.

Table 18.--Mass Balances for the Winter Spray Site.

	Total-P (lbs)	NO_3-N (lbs)	NH_3-N (lbs)	B (lbs)
Input				
natural precipitation	0.42	4.91	1.76	0.06
spray irrigation	4.80	72.15	15.79	2.80
Total	5.22	77.06	17.55	2.86
Output				
surface runoff	0.87	15.75	2.695	0.95
infiltration	2.11	47.03	3.00	0.98
Total	2.98	62.78	5.695	1.93
Output/input (%)	57	81	32	67

The nitrate-nitrogen totals were increased by the ammonia-nitrogen which was converted to nitrate by a maximum of 12 pounds--the difference between the input and output ammonia totals. The true nitrate balance would then be much poorer and would strongly suggest, even more than it does now, that the output totals have been miscalculated on the low side.

The most unreliable data came from the infiltrometers which probably caused most of this error. The missing water that was not measured was assumed to have infiltrated for purposes of calculating the mass balance and minimized this source of error since most of the missing water probably infiltrated. However, if the one inch snow evaporation is reduced to 0.34 inch and the remaining water assumed to have infiltrated, the present output to input ratio for nitrate would rise from 81 percent to 89 percent; and the ratios for the other compounds would also rise, reducing the maximum amount of ammonia that could have converted to nitrate. Any upward adjustment in the output water totals or the output ammonia concentrations would further minimize the influence ammonia conversion has on the nitrate totals.

Concentrating on the nitrate balance, the nitrate's standard deviation from the sprayed infiltrometers was about 40 percent of the average. This large variation, coupled with the high amounts of infiltrated water, is the prime cause of uncertainty in the nitrate balance. Raising the nitrate average to 7.25 for the sprayed infiltrometers (well within the standard deviation) and using a snow evaporation of 0.34 inches, the output to input nitrate ratio will rise to 97 percent. This result occurs if the 24.5 mgl/1 NO_3-N value thought to be in error is used in the averages. Clearly, the numbers can also be adjusted to reach a much lower output total. The standard deviation for the phosphorus infiltration is greater than the average, and the phosphorus totals can be made to balance by choosing a higher infiltrometer concentration well within the standard deviation limits. Of course, the phosphorus totals should not balance because some of the phosphorus is being adsorbed by the soil. The ammonia and boron cannot be made to balance in this way which indicates that ammonia is being converted to nitrate and that the boron is being retained on the site.

3.3 Errors and Data Reliability

The analysis for this study understandably contains simplifications, gaps from missing data, and errors due to unreliable data. Each phase of the analysis has its share of discrepancies which will be discussed in this section.

3.3.1 Water Balance

The natural precipitation data suffers from the fact that the gage was not operating properly on several occasions, but the major shortcoming is the fact that none of the gages at the spray site were sheltered from the wind, but were instead very exposed in open fields. As a result, snowfalls were not recorded accurately, and much of the snowfall values are consistently lower than those values recorded at the Lansing airport gage which was sheltered. A rain gage has been installed in an area sheltered by trees and should give better results in the future.

The amount of wastewater pumped from the lake was accurately measured, but the amount reaching the ground was difficult to determine because of the impreciseness in calculating the water delivered to the lysimeter site and in estimating the amount of spray evaporation. Since the nitrate comparison between the lake samples and the can samples agreed so well and since the amount of water measured in the cans agreed so well with the calculations, the calculations themselves are assumed reasonable. Another small error is the impossibility in determining the amount of water drained from the pipes after spraying which should be subtracted from the totals.

The runoff values are generally accurate when the charts are useable, but equipment failures (such as stopped clocks) and problems with ice freezing the flume, the weirs, and the floats prevented the recording of all the hydrographs. The recorder charts from the Parshall flume absorbed moisture and swelled during the January 29 and February 22-24 storms, and the correct gage heights had to be estimated from the charts by linearly interpolating between the gage readings marked on the charts. Problems in calculating the flow occurred when the water overtopped the weir plates in Felton Drain. These high flow rates were estimated for the dam opening by using the rectangular weir formula with 40 percent losses. During this study, the water never threatened to overtop the dam and overtopped the weir plates on only two occasions.

Two errors exist in the determination of the total surface runoff from the spray site. The use of the flow through the Parshall flume for the January 28 spray runoff probably added too much water to the total. Using the spray runoffs of March 4 and 11 as guides, the total flow may be 8,000 to 10,000 gallons too high if the runoff patterns were identical; however, this error could amount to no more than one percent of the total runoff and is relatively insignificant in the final water balance.

The other error occurred on February 18 when pressure tests were run on the spray system at the watershed. Water was first pumped through the system with the valve next to Felton Drain open and discharging into the drain, and the valve was then closed to raise the pressure. The first time this procedure was tried, a drainage plug was left open on one of the spray pipes near the main delivery valve, and virtually all of the water flowed out over the edge of the winter spray site next to the service road. The drainage plug was closed, the procedure repeated, and a small amount of water was sprayed over much of the spray area. The total amount of water pumped from the lake was 47,100 gallons (32,900 gallons the first time and 14,200 gallons the second time), but approximately 80 percent of it went directly into Felton Drain, according to the hydrographs, with another ten percent flowing over the spray site weir (W5) into the drain. Only a small fraction of the water from the second test was actually applied to the spray site, but the amount is not known; therefore, this water was ignored since no water quality samples were taken. This omission is probably more than offset in the runoff totals by the extra water included in the January 28 spray runoff, but does cause the spray totals to be too small. However, this small amount is easily covered by the margin of error in the precipitation data.

The evaporation figure is very imprecise although an upper limit was set. As indicated in the analysis, the value could reasonably be one-third of this upper limit of one inch, but there is no way to ascertain where the true value lies. This upper limit would most likely occur only under optimum conditions when the vapor pressure gradient is continually favorable for evaporation. Since many of the days with snow cover had temperatures above freezing, the vapor pressure of the atmosphere was greater than the snow surface vapor pressure and evaporation was small. The error associated with this measurement is significant, but is not a major problem within the study.

The infiltrometer measurements were the greatest source of error in this project. It is impossible to gage their accuracy from the field survey or from the data, and one cannot be certain of any of the values. One of the infiltrometers (number 23) which did settle and which was located in an area where a large pond formed from the spray irrigation, contained fairy shrimp after one spray application. This result indicates that a hydraulic connection existed from the surface to the funnel as the fairy shrimp could not have possibly infiltrated through the soil. Unfortunately, this infiltrometer is the only one that can be proven inaccurate.

Studies by other investigators have shown that no device presently exists than can accurately measure infiltration (6, Chapter 3). To accurately measure the infiltration, the collecting device must have confining walls to make sure only vertical flow is measured. Since the infiltrometers in this study did not have confining walls and also had disturbed soil above them, accurate infiltration measurements were impossible to obtain. Representative water quality samples may also be unobtainable, especially in this study where the disturbed soil may react differently with the material in the water. When a soil-air interface is present above the collector, infiltration is again affected because gravity must overcome capillary tension before the water will leave the soil and drop into the collection device. This condition for the infiltrometers in this study may have caused water to pass around the infiltrometers situated in dry soils and to drain into the infiltrometers placed in saturated soils. It is virtually impossible to install infiltration measuring devices without affecting the natural conditions in the soil and, therefore, damaging the accuracy of the measurements.

3.3.2 Mass Balance

The water quality samples had many problems which reduced their accuracy. Because the auto analyzer was not put into operation until the beginning of March 1975, the samples had to be stored for a long period of time. Ammonia does not keep well under any circumstances, and these values are most suspect. The glass sample bottles potentially adsorbed phosphorus and released boron to the water. Except for potential biological action, the nitrate levels should be most accurate. All the samples were refrigerated at 4°C until taken to the laboratory, and biological activity should have been kept to a minimum even after the samples ceased being preserved with mercuric chloride. At the laboratory, however, the samples were stored at room temperature for weeks until analyzed, and those samples that were not preserved may have been altered by the microorganisms in the samples.

The question also exists as to the accuracy of the determinations since many samples of the same event vary greatly in their concentrations. No split samples or samples with known concentrations were sent to the lab, but some determinations were run more than once and reported. A sample from the drainage of the pipeline showed a phosphorus of 0.62 and 0.51. An infiltrometer sample had phosphorus levels of <0.05, 0.12, and 0.21 mg/l P and boron levels of 0.14, 0.06, and 0.12 mg/l B with the <0.05 mg/l P and 0.14 mg/l B designated as the true values. Apparently, some problems did exist, but the lab is probably not responsible for many of the discrepancies. The runoff samples were generally consistent with each other while the "tin" can and infiltrometer samples showed the greatest variability which is probably due to some problem with the cans and infiltrometers themselves.

Errors also occurred in the construction of the mass balances. The material concentrations found from the snow samples were used to calculate the material added by all of the natural precipitation. Snow contains only the material present in the water when the droplets crystallized while rain can capture additional material as the droplets fall through the air, and the computations for the natural precipitation are probably low for this reason. This error is not too significant because the amounts of material involved are small in relation to the total input which is dominated by the sprayed wastewater.

The phosphorus concentrations in the can samples do not vary as much as the other parameters although some phosphorus could have been adsorbed by the plastic liners in the short time the water remained in the can. The plastic liners were not changed during the study and could have been contaminated. Few lake samples were taken, and they do not always agree with the can sample averages. The one exception is the nitrates which balanced in the comparison of lake and can samples, and the sample averages are probably fairly accurate.

Not enough samples were taken to get a truly accurate measurement of the amount of material accompanying the runoff, and the masses calculated are only approximations of the total mass flow. An error in the February 11 spray hydrograph occurred because only two samples were taken. The first sample of the actual overland flow was taken early in the hydrograph, the spray pipes were then drained, and the second sample was taken of the combined flow. This second sample was applied to the rest of the flow, even after the spray pipes finished draining, by the criteria used to proportion the flow. This practice tended to raise the total mass contributed by these runoffs as the concentrations in the spray pipe drainage were higher than the natural runoff for two parameters (phosphorus and ammonia).

The three hydrographs in Table 14 with data missing are not as significant as they might appear. The January 21 runoff is so small that its effect is negligible despite the relatively high concentrations which would have been reported from the wastewater. The March 12 and 13 hydrographs are almost all due to snowmelt and can be expected to have relatively low concentrations similar to those of January 29 and February 21 to 24 which consist of rain and snowmelt. This last statement is reinforced by the nitrate level reported at the spray site weir on March 13 which was the lowest reported during the study. The missing material from these gaps in the table is compensated by the additional water in the January 28 total which was discussed earlier. Since this total runoff may be as much as 8,000 to 10,000 gallons too high and the concentrations are relatively high from the spray runoff, the net error in the mass balance due to this missing data will be reduced. The small amount of material ignored from the February 18 pressure test is also compensated by the January 28 error and by the extra material added in the February 11 spray runoff total discussed in the last paragraph.

Again, the infiltrometers are the primary problem. All of the "missing" water which was not measured was assumed to have infiltrated in the construction of the mass balances, but this assumption was reasonable. The problem with the infiltrometers is the great variability in the reported concentrations. The calculated averages are only rough estimates of the true levels, and the standard deviations show the wide range of values which might be assumed accurate. Since so much water is used in these calculations (57 percent of the water applied), the mass balances are greatly affected by small changes in concentrations; and changes in the averages well within the standard deviations can make the output equal to the input or make the output equal to a small fraction of the input. The reason for this great variability in the data is difficult to explain except by concluding that none of the infiltrometers were useable. Since half of the infiltrometers were sampled in biweekly intervals, no single group of samples from all of the subwatershed could be applied to a single spray event; and since only a few infiltrometers were judged accurate, only a relatively few sets of data were available to use. Yet, even these sets of data varied almost as badly as the data from the "bad" infiltrometers. The failure to get reasonably accurate infiltrometer data is the major source of error in this study.

IV. CONCLUSIONS

From the results of this study, one can draw several tentative conclusions on winter spray irrigation.

1. Fifteen to twenty percent of the sprayed effluent can be expected to evaporate before it reaches the ground over the course of the winter spray period.

2. The spray operation itself will liberate some of the ammonia as gas into the atmosphere.

3. Ponding of the sprayed water increases infiltration rates.

4. Boron levels do not appear to be high enough to affect plant growth at this time, but levels should be monitored to detect any harmful accumulation over a period of time.

5. Nitrate appears to be infiltrating and must be investigated further to determine its effect on the groundwater.

Surface runoff can be controlled if a site is selected or constructed with many depressions and poor runoff characteristics, but nitrate infiltration cannot be reduced because plant activity is at a minimum during the winter. Until more precise research is performed on this last problem, winter wastewater spray irrigation on a prototype scale is not recommended.

V. RECOMMENDATIONS FOR FURTHER WORK

Future work should be devoted to obtaining better data in order to make the water and mass balances more accurate. The stage recorders should be heated to prevent freezing, and gear changes should be made to obtain more detailed hydrographs. An automatic water sampler ought to be installed at one or more weirs, and the sampling frequency at the other weirs should be increased in order to obtain more accurate mass flow rates. A sheltered rain gage to measure snowfall should be installed, and snow cover measurements should be made daily. Samples should also be taken of the rainfall, and other weather parameters (such as windspeed and vapor pressure) must be measured at the site to use in evaporation calculations. Most importantly, better infiltration rates must be measured and representative samples taken of the infiltrated water.

An investigation of the effect of the infiltrated water on the groundwater ought to be made in the future. Subsurface flow must be estimated to determine how much infiltrated water actually reaches the goundwater and how much reappears on the surface. The fate of the nitrate in the infiltrated water should also be investigated because the ability to winter spray irrigate depends on the infiltrated water not polluting the groundwater.

A study to determine the mechanisms which remove the nutrients and other materials could be made in the future to determine how they are reclaimed. Knowledge of these factors and any seasonal differences could be used to promote the optimum recycling of the materials.

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APPENDICES

APPENDIX A - PRECIPITATION

Table 19. Natural Precipitation.

Date	Time	Precipitation (inches)
1/29/75	1:00-2:00	0.03
	2:00-3:00	0.23
	3:00-4:00	0.45
	4:00-5:00	0.20
	5:00-6:00	0.06
	6:00-7:00	0.02
	7:00-8:00	0.01
2/22/75	14:00-15:00	0.01
	15:00-16:00	0.02
	16:00-17:00	0.02
	17:00-18:00	0.02
	18:00-19:00	0.04
	19:00-20:00	0.05
	20:00-21:00	0.05
	23:00-24:00	0.06
2/23/75	0:00-1:00	0.02
	3:00-4:00	0.01
	10:00-11:00	0.02
	18:00-19:00	0.04
	22:00-23:00	0.08
	23:00-24:00	0.11
2/24/75	0:00-1:00	0.09
	9:00-10:00	0.03
	10:00-11:00	0.02
	14:00-15:00	0.01
2/25/75*	8:00-9:00	0.01
	9:00-10:00	0.07
	14:00-15:00	0.01
	15:00-16:00	0.02
	17:00-18:00	0.02

Table 19.--Continued

Date	Time	Precipitation (inches)
2/26/75*	1:00-2:00	0.01
	2:00-3:00	0.01
	3:00-4:00	0.01
	13:00-14:00	0.01
	14:00-15:00	0.01
	15:00-16:00	0.01
	16:00-17:00	0.01
2/28/75*	8:00-9:00	0.01
3/12/75	5:00-6:00	0.02
	6:00-7:00	0.03
	9:00-10:00	0.02
	10:00-11:00	0.02
	11:00-12:00	0.01
	14:00-15:00	0.01

*Values represent snowfall in inches of water equivalent.

Table 20.--Spray Irrigation.

Date	Amount of spray (gal.)	Time of Spray	Intensity of spray (in/hr)
1/28	199,285	9.09-14:30	0.27
2/11	158,455	10:21-15:00	0.25
3/4	104,330	13:00-16:03	0.25
3/11	122,605	10:00-13:13	0.28

APPENDIX B - RUNOFF

Table 21.--Flow through Weir 2 (W2) in Felton Drain (P) denotes the peak discharge.

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
1/29	4:30	0	1/29	21:00	0.555
	5:15	2.78		22:00	0.47
	6:00	4.03(P)		23:00	0.40
	8:00	2.78	1/30	0:30	0.45
	10:00	1.90		1:00	0.36
	12:00	1.34		2:30	0.31
	14:00	0.92		4:30	0.17
	15:30	0.73		12:30	0.14
	16:00	0,80		13:30	0.12
	17:00	0.71		14:30	0.11
	18:00	0.69		16:30	0.10
	19:00	0.67	1/31	14:00	0.06
	20:00	0.63			
2/21	15:30	0	2/22	16:00	1.71
	16:00	0.105		17:00	1.86
	17:00	0.34		18:00	2.02
	18:00	0,80		19:00	2.14
	19:00	1.05(P)		20:00	2.315
	20:00	0.92		22:00	2.99(P)
	21:00	0.755		23:30	2.88
	22:00	0.67	2/23	1:00	2.61
	23:00	0.54		2:00	2.685
2/22	0:00	0.45		4:00	2.54
	1:00	0.39		5:30	2.64
	2:00	0.34		7:00	2.40
	3:00	0.30		9:00	1.98
	4:00	0.26		10:00	1.82
	5:00	0.24		12:00	1.69
	6:00	0.21		16:00	1.75
	7:00	0.20		19:00	1.71
	8:00	0.18		21:00	1.82
	10:00	0.15		23:00	1.71
	11:00	0.20	2/24	0:00	2.06
	12:00	0.22		0:30	2.78
	15:00	1.47		2:00	4.76(P)

Table 21.--Continued

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
2/24	3:00	4.38	2/25	4:00	1.60
	5:30	3.48		5:00	1.57
	9:00	3.01		6:00	1.55
	9:15	2.78		7:00	1.53
	10:00	2.685		8:00	1.52
	11:00	2.73		9:00	1.50
	12:00	2.50		10:00	1.43
	13:00	2.59		11:00	1.34
	15:00	2.73		12:00	1.25
	16:00	2.78		13:00	1.16
	16:30	2.99		14:00	1.10
	17:30	2.73		15:00	1.07
	18:15	2.88		16:00	0.97
	19:00	2.71		23:00	0.73
	20:00	2.36	2/26	15:30	0.29
	21:00	2.23	2/27	17:30	0.15
	22:00	2.14	2/28	16:20	0.09
	23:00	2.04	3/1	13:30	0.09
2/25	0:00	1.90	3/2	11:00	0.03
	2:00	1.71	3/4	17:00	0.02
	3:00	1.66	3/5	11:30	0.005

Table 22.--Flow through Parshall Flume (W4) in Felton Drain.

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
1/28	12:00	0.02	1/29	17:00	0.98
	12:30	0.02		18:00	0.89
	13:00	0.05		19:00	0.86
	13:30	0.13		20:00	0.84
	14:30	0.46		21:00	0.81
	16:00	0.76(P)		22:00	0.77
	17:00	0.46		23:00	0.71
	18:00	0.25	1/30	0:00	0.67
	19:00	0.15		3:00	0.47
	20:00	0.10		4:00	0.41
	21:00	0.07		6:00	0.35
	22:30	0.05		8:00	0.30
	23:30	0.04		9:00	0.28
1/29	1:00	0.03		10:00	0.29
	2:30	0.04		11:30	0.27
	3:00	0.08		13:00	0.25
	4:00	0.46		14:30	0.23
	5:00	1.44		17:00	0.195
	5:30	1.66		19:00	0.18
	6:45	4.03(P)		21:00	0.17
	8:00	3.48		23:30	0.17
	8:30	3.43	1/31	3:00	0.16
	9:00	3.31		6:00	0.15
	9:30	3.05		8:00	0.135
	10:00	2.84		14:00	0.12
	11:00	2.42		17:30	0.105
	12:00	2.04		20:00	0.09
	13:00	1.70	2/1	1:00	0.08
	14:00	1.44		8:00	0.06
	15:00	1.23		10:00	0.05
	16:00	1.10			
2/21	12:00	0.02	2/22	0:00	0.67
	13:00	0.03		1:00	0.59
	14:00	0.04		2:00	0.51
	15:00	0.05		3:00	0.46
	16:00	0.09		4:00	0.41
	17:00	0.20		5:00	0.365
	18:00	0.51		6:00	0.32
	19:00	0.97		7:00	0.30
	20:00	1.10(P)		8:00	0.28
	21:00	1.03		10:00	0.24
	22:00	0.905		11:30	0.26
	23:00	0.785		12:00	0.31

Table 22.--Continued

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
2/22	13:00	0.49	2/24	10:00	3.50
	14:00	0.80		11:00	3.31
	15:00	1.33		12:00	3.05
	16:00	1.72		12:30	2.93
	17:00	1.98		13:30	3.00
	18:00	2.16		14:00	2.95
	19:00	2.29		15:00	2.84
	20:00	2.50		16:00	2.59
	21:00	3.09		16:30	2.66
	21:30	3.48		18:45	2.42
	22:00	3.65		18:45	2.35
	22:30	3.70(P)		19:00	2.39
	23:00	3.60		20:00	2.33
2/23	0:00	3.405		21:00	2.245
	0:45	3.56		22:00	2.16
	2:00	3.405		23:00	2.02
	4:00	3.28	2/25	0:00	1.90
	5:00	3.31		1:00	1.78
	6:00	3.26		2:00	1.70
	7:00	3.05		3:00	1.63
	8:00	2.75		4:00	1.61
	9:00	2.50		5:00	1.55
	9:30	2.37		6:00	1.51
	10:30	2.22		7:00	1.48
	11:30	2.10		8:00	1.44
	12:30	2.02		9:00	1.42
	15:30	2.00		10:00	1.39
	16:00	1.98		11:00	1.35
	17:00	1.94		12:00	1.28
	18:30	1.92		13:00	1.25
	20:00	1.96		14:00	1.16
	21:30	1.96		15:00	1.11
	22:30	1.94		16:00	1.08
	23:30	2.08		17:00	1.03
2/24	0:00	2.46		18:00	1.00
	1:30	7.10(P)		19:00	0.94
	2:30	6.72		20:00	0.87
	3:30	5.59		21:00	0.83
	4:30	5.095		23:00	0.77
	5:30	4.73	2/26	1:00	0.71
	6:30	4.45		3:00	0.66
	7:30	4.21		5:00	0.60
	8:30	3.98		7:00	0.56
	9:00	3.88		9:00	0.50

Table 22.--Continued

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
2/26	11:00	0.46	2/27	14:00	0.22
	12:00	0.44		18:30	0.20
	15:00	0.40	2/28	2:30	0.19
	16:30	0.38		12:00	0.17
	18:30	0.36		17:00	0.15
	20:00	0.335		23:00	0.135
	22:30	0.31	3/1	8:00	0.12
2/27	1:00	0.29		17:00	0.105
	3:30	0.27	3/2	6:00	0.09
	7:00	0.25	3/4	11:00	0.04
	10:00	0.24			
3/4	12:00	0.04	3/4	20:00	0.28
	13:00	0.04		21:00	0.17
	14:00	0.08		22:00	0.105
	15:00	0.06		23:00	0.08
	16:00	0.05	3/5	0:00	0.06
	17:00	0.28		1:00	0.05
	18:00	0.64(P)		2:00	0.05
	19:00	0.49			
3/11	12:00	0.03	3/12	18:00	0.49
	13:00	0.03		19:00	0.67
	14:00	0.17		20:00	0.76(P)
	15:00	0.41(P)		21:00	0.70
	16:00	0.38		22:00	0.64
	17:00	0.28		23:00	0.54
	18:00	0.22	3/13	0:00	0.49
	19:00	0.17		1:00	0.39
	20:00	0.12		2:00	0.35
	21:00	0.09		3:00	0.29
	22:00	0.07		4:00	0.26
	23:00	0.06		5:00	0.22
3/12	0:00	0.05		6:00	0.20
	1:00	0.04		7:00	0.19
	2:00	0.04		8:00	0.17
	11:00	0.04		9:00	0.16
	12:00	0.04		10:00	0.14
	13:00	0.07		11:00	0.135
	14:00	0.12		12:00	0.135
	15:00	0.17		13:00	0.135
	16:00	0.20		14:00	0.14
	17:00	0.28		15:00	0.16

Table 22.--Continued

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
3/13			3/15	0:00	0.12
	16:00	0.20		3:00	0.105
	17:00	0.32		8:00	0.09
	18:00	0.44		10:00	0.08
	19:00	0.59		13:00	0.09
	20:00	0.67(P)		14:00	0.105
	21:00	0.64		15:00	0.12
	22:00	0.58		16:00	0.135
	23:00	0.50		17:00	0.15
3/14	0:00	0.44		18:00	0.17
	1:00	0.37		19:00	0.19
	2:00	0.32		20:00	0.22
	3:00	0.28		21:00	0.24
	4:00	0.26		22:00	0.26
	5:00	0.23		23:00	0.27(P)
	6:00	0.21	3/16	0:00	0.26
	7:00	0.195		1:00	0.24
	8:00	0.19		2:00	0.22
	9:00	0.18		3:00	0.20
	10:00	0.17		4:00	0.19
	11:00	0.17		5:00	0.17
	12:00	0.17		6:00	0.16
	13:00	0.17		7:00	0.14
	14:00	0.16		8:00	0.135
	17:00	0.15		9:00	0.135
	20:00	0.135			

Table 23.--Runoff through Spray Site Weir (W5).

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
1/21	16:00	0	1/21	16:05	0.005
	16:00	0.02(P)		18:00	0
1/28	14:15	1.44(P)	1/29	8:00	0.11
	14:30	0.45		9:00	0.08
	16:00	0.135		10:00	0.05
	17:00	0.065		11:00	0.04
	18:00	0.03		12:00	0.03
	19:00	0.02		13:00	0.025
	20:00	0.015		13:30	0.02
	21:00	0.01		14:00	0.02
	22:00	>0		15:00	0.02
1/29	2:30	>0		16:00	0.01
	3:15	0.815		17:00	0.01
	4:00	1.63(P)		18:00	0.005
	6:00	0.32		22:00	0
2/11	14:15	0	2/11	16:00	0.465
	14:45	0.06		17:30	0.06
	15:00	0.55(P)		18:30	0.03
	15:10	0.40			
2/21	15:30	0	2/21	22:00	0.03
	17:00	0.035		23:00	0.02
	18:00	0.11	2/22	0:00	0.015
	18:45	0.14(P)		1:00	0.01
	20:00	0.08		4:00	0
	21:00	0.05			
2/22	10:30	0	2/22	17:00	0.31(P)
	11:00	0.01		17:05	0.28
	12:00	0.215(P)		18:00	0.25
	12:30	0.09		19:00	0.24
	13:00	0.20		20:00	0.31
	14:00	0.225		21:00	0.35
	14:50	0.225	2/23	0:00	0.115
	15:00	0.275(P)		1:00	0.39(P)
	15:05	0.225		3:00	0.12
	15:15	0.215		4:30	0.19
	16:00	0.19		8:00	0.06
	16:45	0.22		9:00	0.035

Table 23.--Continued

Date	Time	Flow(cfs)	Date	Time	Flow(cfs)
2/23	10:00	0.03	2/24	2:30	0.18
	10:30	0.025		6:00	0.06
	11:30	0.03		7:00	0.05
	12:00	0.035		8:30	0.05
	13:00	0.04		9:30	0.045
	13:30	0.045		10:30	0.04
	15:00	0.05		12:30	0.12
	16:00	0.045		14:00	0.04
	18:00	0.035		15:00	0.025
	19:30	0.07		16:00	0.015
	20:00	0.04		17:00	0.005
	23:30	0.265		18:45	0
2/24	0:30	1.025(P)			
3/4	14:30	0	3/4	16:00	0.575
	15:00	1.625(P)		16:30	0.340
	15:05	0.795			
3/11	13:15	0	3/11	14:00	0.50
	13:30	0.66(P)		15:30	0.29
3/12	10:30	0	3/12	18:00	0.09
	11:00	0.02		20:00	0.04
	12:00	0.09		22:00	0.02
	12:30	0.10		1:00	>0
	12:35	0.11		14:00	0
	13:00	0.12		15:00	0.11
	13:15	0.125		15:30	0.115(P)
	13:20	0.14(P)		16:00	0.10
	15:15	0.12		18:00	0.03
	16:00	0.125		20:00	0.01
	17:00	0.12		21:00	>0

APPENDIX C - WATER QUALITY

Table 24.--Snow Sample Concentrations (mg/l).

Date	Total-P	NO_3-N	NH_3-N	B	Cl
12/20/74	0.04	0.76			2.1
	0.04	0.74			2.3
2/10/75	0.10	0.43	0.25	0.01	2
	0.05	0.40	0.23	0.01	1
	0.05	0.73	0.25	0.02	2
	0.06	0.81	0.33	0.02	2
2/16/75	0.05	0.80	0.31	0.01	1
	0.06	0.52	0.35	0.01	1
	0.05	0.86	0.31	0.01	1
	0.20	0.24	0.32	0.01	1
3/3/75	0.05	1.71	0.82	0.01	8*
3/10/75	0.10	1.00	0.22	0.01	1
	0.10	1.31	0.13	0.01	1
	1.12*	0.89	0.06	0.01	210*
	0.08	0.96	0.16	0.01	1
Avg.	0.07	0.81	0.29	0.01	1.42
Std. Dev.	0.04	0.36	0.18	0.004	0.55

*Values were not used to calculate average and standard deviation.

Table 25.--Spray Sample Concentrations from "Tin"Can Rain Gages (mg/l).

Date	Total-P	NO_3-N	NH_3-N	B
1/14/75	0.73	10.7	3.10	0.43
	0.68	8.70	2.88	0.34
	0.56	18.2	3.78	0.58
	1.30	8.80	1.92	0.29
	0.63	6.98	2.34	0.34
	0.66	32.0	0.03	0.52
	0.67	9.00	1.50	0.28
	0.59	8.90	2.79	0.37
	0.61	12.2	3.27	0.34
Avg.	0.71	12.83	2.40	0.39
Std. Dev.	0.23	7.90	1.13	0.10
1/21/75	0.60	8.10	2.26	0.31
	0.32	7.90	2.26	0.31
	0.68	9.00	2.30	0.35
	0.51	7.30	2.45	0.29
	0.55	10.1	2.37	0.35
	0.60	9.60	2.55	0.37
	0.63	4.56	2.40	0.34
	0.58	9.80	2.48	0.35
	0.72	15.2	2.42	0.32
Avg.	0.58	9.06	2.39	0.33
Std. Dev.	0.12	2.86	0.10	0.03
1/28/75	0.63	7.70	2.28	0.47
	0.50	7.30	2.67	0.23
	0.66	7.90	3.18	0.30
	0.65	6.50	2.94	0.37
	0.55	7.00	0.32	0.56
	0.65	7.80	0.32	0.48
	0.56	7.10	3.06	0.39
	0.71	6.90	2.94	0.31
Avg.	0.61	7.28	2.21	0.39
Std. Dev.	0.07	0.49	1.20	0.11

Table 25.--Continued

Date	Total-P	NO_3-N	NH_3-N	B
2/11/75	0.50	6.30	2.58	0.25
	0.69	6.50	1.57	0.39
	0.64	3.10	2.20	0.50
	0.53	7.60	2.71	0.10
	0.70	6.00	--	0.39
	0.53	7.60	--	0.22
	0.61	7.70	2.50	0.26
	0.51	--	2.62	--
	0.63	7.40	--	0.38
	0.39	5.30	--	0.23
	0.60	--	--	--
Avg.	0.57	6.39	2.36	0.30
Std. Dev.	0.10	1.49	0.43	0.12
3/4/75	0.47	8.94	0.88	0.35
	0.50	9.25	1.05	0.34
	0.48	8.43	1.18	0.30
	0.60	10.32	1.16	0.32
	0.47	9.46	1.03	0.33
	0.54	9.14	1.01	0.28
	0.38	8.83	0.96	0.31
	0.57	8.94	0.92	0.28
	0.63	8.58	1.03	0.27
Avg.	0.52	9.10	1.02	0.31
Std. Dev.	0.08	0.56	0.10	0.03
3/11/75	0.40	6.50	0.03	0.26
	0.46	10.00	0.06	0.18
	0.40	4.30	0.06	0.35
	0.37	6.00	0.08	0.37
	0.34	6.90	0.07	0.35
	0.46	6.00	0.05	--
	0.43	8.60	0.05	0.04
	0.45	5.30	0.07	0.24
Avg.	0.41	6.70	0.06	0.26
Std. Dev.	0.04	1.82	0.016	0.12

Table 26.--Lake Sample Concentrations (mg/l).

Date	Total-P	NO_3-N	NH_3-N	B
1/14	0.62	6.51	2.39	0.29
	0.51	6.86	2.25	0.31
1/21	0.55	6.98	2.30	0.32
	0.50	10.2	2.42	0.29
1/28	0.70	6.70	3.93	0.28
2/11	0.60	3.80	2.80	0.28
	0.63	5.95	1.18	0.28
3/4	0.30	8.73	1.29	0.25
3/11	0.48	9.60	0.06*	0.14

*Value used is from sample taken from pipe drainage after spraying ceased.

APPENDIX D - MASS FLOWS

Table 27.--Mass Flow Rates at Weir 2 (W2) in Felton Drain.

Date	Time	Flow (cfs)	Total-P conc. (mg/l)	Total-P mass flow (lb/day)	*NO_3-N conc. (mg/l)	*NO_3-N mass flow (lb/day)	NH_3-N conc. (mg/l)	NH_3-N mass flow (lb/day)	B conc. (mg/l)	B mass flow (lb/day)	Cl conc. (mg/l)	Cl mass flow (lb/day)
1/29	8:50	2.32	0.26	3.25	0.65	8.13	--	--	--	--		
	16:00	0.80	0.13	0.56	0.41	1.77	--	--	--	--		
1/30	18:00	0.10	0.14	0.08	3.13	1.69	0.16	0.09	0.09	0.05		
1/31	13:50	0.06	0.14	0.05	5.26	1.70	0.13	0.04	0.15	0.05		
2/1	13:25	0.04	0.05	0.01	5.90	1.27	0.14	0.03	0.14	0.03		
2/2	11:50	0.02	0.05	0.005	6.22	0.67	0.12	0.01	0.36	0.04		
2/3	15:25	0.01	0.07	0.004	5.98	0.32	0.09	0.005	0.02	0.001		
2/21	15:35	0	0.07	0	2.18	0	0.28	0	0.01	0	104	0
2/22	11:00	0.20	0.06	0.06	2.06	2.22	0.37	0.40	0.01	0.01	72	78
2/23	15:05	1.73	0.31	2.89	2.00	18.65	0.11	1.03	0.19	1.77	21	196
2/24	9:15	2.78	0.53	7.94	5.17	77.47	0.09	1.35	0.23	3.45	41	614
	15:20	0.75	0.72	2.91	6.45	26.07	0.10	0.40	0.40	1.62	48	194
2/25	15:05	1.07	3.30	19.03	11.10	64.02	0.14	0.81	0.40	2.31	62	358
2/26	15:25	0.29	1.02	1.59	12.90	20.16	3.20	5.00	0.04	0.06	82	128
2/27	17:38	0.15	0.63	0.51	16.86	13.63	0.17	0.14	0.38	0.31	93	75
2/28	16:14	0.09	0.36	0.17	11.17	5.42	2.12	1.03	0.07	0.03	94	46
3/1	13:30	0.09	0.22	0.11	18.70	9.07	1.78	0.86	0.08	0.04	91	44

Table 28.--Mass Flow Rate at the Parshall Flume (W4) in Felton Drain.

			Total-P		NO_3-N		NH_3-N		B		Cl	
Date	Time	Flow (cfs)	conc. (mg/l)	mass flow (lb/day)	conc. (mg/l)	mass flow (lb/day)	conc. (mg/l)	mass flow (lb/day)	conc. (mg/l)	mass flow (lb/day)	conc. (mg/l)	mass flow (lb/day)
1/28	14:50	0.55	0.10	0.30	1.08	3.20	0.80	2.37	0.20	0.59		
	15:50	0.75	0.12	0.49	1.08	4.37	1.30	5.26	0.29	1.17		
1/29	9:00	3.31	0.20	3.57	0.62	11.06	--	--	--	--		
	16:05	1.10	0.17	1.01	1.23	7.29	0.16	0.95	0.18	1.07		
1/30	18:00	0.19	0.12	0.12	2.28	2.33	0.19	0.19	0.27	0.28		
1/31	14:05	0.12	0.10	0.06	4.20	2.72	0.19	0.12	0.16	0.10		
2/1	13:35	0.075	0.06	0.02	3.91	1.58	0.23	0.09	0.23	0.09		
2/2	12:00	0.04	0.05	0.01	5.36	1.16	0.23	0.05	0.14	0.03		
2/3	15:15	0.03	0.05	0.01	2.15	0.35	0.13	0.02	0.11	0.02		
2/21	15:40	0.075	0.05	0.02	2.86	1.16	0.75	0.30	0.18	0.07	122	49
2/22	11:28	0.26	0.05	0.07	2.44	3.42	0.43	0.60	0.23	0.32	247	346
2/23	15:10	2.00	0.50	5.39	5.40	58.21	0.07	0.75	--	--	215	2318
2/24	9:20	3.69	0.47	9.35	4.49	89.30	0.12	2.39	0.20	3.98	35	696
	15:20	2.79	0.63	9.20	4.33	63.25	0.05	0.73	0.08	1.17	53	774
2/25	15:15	1.10	3.2	18.97	4.13	24.49	0.25	1.48	0.11	0.65	83	492
2/26	15:15	0.40	0.91	1.96	11.80	25.44	3.11	6.71	0.14	0.30	32	69
2/27	16:48	0.26	0.49	0.69	13.52	18.95	0.13	0.18	0.35	0.49	88	123
2/28	16:47	0.15	0.12	0.10	14.68	11.87	2.34	1.89	0.07	0.06	82	66
3/1	13:20	0.11	0.09	0.05	15.54	9.21	1.05	0.62	0.13	0.08	139	82