AD-A068 534 VERMONT WATER RESOURCES RESEARCH CENTER BURLINGTON F/G 13/2
SPRAY APPLICATION OF WASTEWATER EFFLUENT IN WEST DOVER, VERMONT--ETC(U)
APR 79 E A CASSELL, D W MEALS, J R BOUZOUN DACA89-77-1360
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Special Report 79-6

April 1979

SPRAY APPLICATION OF WASTEWATER EFFLUENT IN WEST DOVER, VERMONT

AN INITIAL ASSESSMENT

E.A. Cassell, D.W. Meals and J.R. Bouzoun

Prepared for
DIRECTORATE OF CIVIL WORKS
OFFICE, CHIEF OF ENGINEERS
By
UNITED STATES ARMY
CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

Unclassified (18) CRREL (19) SR-79-6

SR-79-6

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Special Report 79-6

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) SPRAY APPLICATION OF WASTEWATER EFFLUENT IN WEST DOVER, VERMONT: AN INITIAL ASSESSMENT.

5. TYPE OF REPORT & PERIOD COVERED
(9) Special rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) E.A. Cassell, D.W. Meals and J.R. Bouzoun

8. CONTRACT OR GRANT NUMBER(s)
(15) P.O. No. DACA 89-77-1360 pre masters

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Vermont Water Resources Research Center, New
601 Main Street
Burlington, Vermont 05401
411 170

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
DA Project 0403;
Project CWIS 31280

11. CONTROLLING OFFICE NAME AND ADDRESS
Directorate of Civil Works
Office, Chief of Engineers
Washington, D.C. 02314

12. REPORT DATE
(11) April 1979 (12) 42p.

13. NUMBER OF PAGES
42

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

DDC
RECEIVED
MAY 15 1979
C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
This study was performed by the Vermont Water Resources Research Center under contract to CRREL.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Effluents
Hydrology
Land application
Spray application
Surveillance
Wastewater
Water quality

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Runoff from spray application of secondary wastewater effluent on a forested hillside in West Dover, Vermont, was monitored for a six-week summer period (11 July-19 August 1977). Both quantity and quality of applied effluent and site drainage were monitored. On-site groundwater and two adjacent streams were sampled for water quality. Drainage flows were relatively constant during the study period in spite of highly variable inputs to the site. There is evidence that substantial quantities of water may be leaving the spray site by moving through the subsurface fragipan layer. On a mass basis, 95% of the total nitrogen, 96% of the ammonia nitrogen, 92% of the nitrate-nitrogen, 98% of the organic nitrogen, 99% of the total phosphorus, and 79% of the BOD_5 were removed →

20. Abstract (cont'd)

Cont

by spray application. Heavy precipitation was observed to flush most nutrient forms, especially nitrate-nitrogen, from the spray site. Groundwater on the spray field contained lower concentrations of nutrients than did the applied effluent, but higher concentrations than those found in site drainage. No hazardous nitrate levels were detected in groundwater. No elevations of nutrient concentrations in the Deerfield River or Ellis Brook were detected during the study period. However, there was some evidence of increased chloride concentrations in Ellis Brook.

PREFACE

This report was prepared by Dr. E.A. Cassell, and D.W. Meals, Director and Research Specialist, respectively, of the Vermont Water Resources Research Center; and by John R. Bouzoun, Environmental Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was funded under DA Project 0403, *Wastewater Management*; Task, *Land treatment*; Project CWIS 31280, *Evaluation of Existing Facilities for Wastewater Land Treatment*. This study was performed by the Vermont Water Resources Research Center, under contract to the U.S. Army Corps of Engineers, CRREL, Purchase Order No. DACA 89-77-1360.

Technical reviewers of the manuscript were C.J. Martel and C.J. Merry of CRREL.

The authors express their appreciation to the Prudential Committee of the North Branch Fire District No. 1, West Dover, Vermont, for their cooperation in carrying out this study. Particular thanks are due to Wallace Bronson, plant operator, Marc Simon, assistant operator, and other members of the treatment plant staff for their cooperation and invaluable assistance throughout the study. Christopher Allen, of the University of Vermont, collected some of the samples, and transported them to CRREL. Paul Folkman, also of the University of Vermont, assisted in equipment installation. Thomas Jenkins, Patricia Schumacher, and Helen Hare of CRREL performed the analyses and coordinated the sample delivery schedule.

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These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
gallon	0.003785412	$meter^3$
million gallons/day	0.04381264	$meter^3/s$
$foot^3/s$	0.02831685	$meter^3/s$
acre	0.4046873	hectare
pound	0.4535924	kilogram
degrees Fahrenheit	$t_{°C} = (t_{°F} - 32)/1.8$	degrees Celsius

*Exact

SPRAY APPLICATION OF WASTEWATER EFFLUENT IN WEST DOVER, VERMONT: AN INITIAL ASSESSMENT

E.A. Cassell, D.W. Meals and J.R. Bouzoun

INTRODUCTION

In recent years, land application has become increasingly recognized as an effective method of providing advanced treatment to municipal wastewater. Highly efficient renovation rates (nutrient removal) have been reported in a variety of land treatment systems. The North Branch Fire District (NBFD) No. 1 land treatment system in West Dover, Vermont, is, in some respects, typical of land treatment practice; however, it is one of only a few facilities known to employ land treatment of effluent during the winter in a cold region. Previously no data existed concerning the performance of this system.

This study consisted of a six-week monitoring program designed to determine the amounts of nitrogen, phosphorus, and other constituents applied to the eastern slope of the effluent spray field, and the amounts of these constitutents in drainage from the spray field. Site performance was assessed in terms of mass balance of various nutrient forms across the eastern slope. In addition, data on site groundwater and adjacent streams were collected and examined to provide an initial estimate of the impact of effluent application.

The results of this study serve as an initial approximation of the performance of the NBFD No. 1 land treatment system. The results reported may serve as a foundation for further, more extensive, investigation, particularly in winter months.

SITE DESCRIPTION

Location

The general locations of the West Dover, Vermont, North Branch Fire District No. 1, the wastewater treatment facility and the spray site are shown in Figure 1. The treatment facility and the spray site are located just southeast of West Dover, Vermont, about 14 miles north of the Massachusetts-Vermont state line.

Climate

Because of West Dover's approximately 1700-ft elevation and its location just east of the peaks of the Green Mountains, the area experiences a climate similar to that of extremely northern Vermont. Cooling air masses that rise across the Green Mountains cause high precipitation, averaging about 55 in./yr. Snowfall averages over 100 in. annually; 170 in. of snow fell in 1972.

Mean annual temperatures for the West Dover areas are 40-45°F. Frost-free periods average 60-90 days annually with the first fall freeze generally occurring in late September. On the average, the area has about 120 days of snow cover per year.

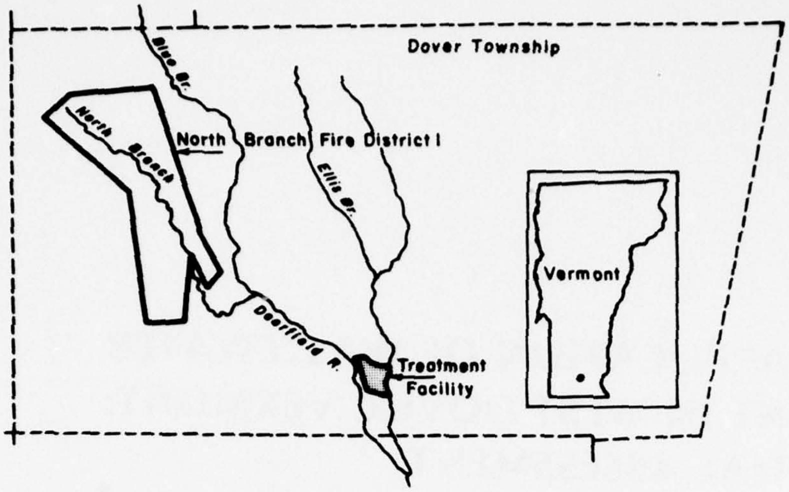


Figure 1. General location map.

Table I. Design loadings summary.*

Design loadings	*Initial (1974)*	*Design (1992)*
Population equivalent		
Winter maximum day	7,250	10,250
Flows (MGD)		
Winter season (121 days)		
Average daily flow	0.35	0.55
Maximum daily flow	0.58	0.82
Peak flow, maximum hour	2.04	2.84
Spring season (61 days)		
Average daily flow	0.07	0.11
Maximum daily flow	0.21	0.48
Peak flow, maximum hour	0.38	0.85
Summer-fall season (183 days)		
Average daily flow	0.17	0.30
Maximum daily flow	0.32	0.78
Peak flow, maximum hour	0.59	1.38
Suspended solids		
Primary influent (mg/l)	300	300
lb/day, average day		
Winter season	880	1,380
Spring season	175	425
Summer-fall season	275	750
lb/day, winter maximum day	1,460	2,050
Biochemical oxygen demand		
Primary influent (mg/l)	255	255
BOD_5 loading, lb/day, average day		
Winter season	740	1,170
Spring season	150	360
Summer-fall season	235	635
BOD_5 loading, lb/day		
Winter maximum day	1,205	1,745

*Source: Cassell (1977).

Plant loading

North Branch Fire District No. 1 serves an area that is dominated by two major ski areas and their associated lodging, eating, and service establishments. There are numerous recreational and permanent residences as well. The estimated wastewater flow for the Fire District, population equivalents, and BOD_5 loadings that served as a basis for the original design of the plant (Cassell 1977) are:

Year	Wastewater flow (gal./day)	Population equivalent	BOD_5 (lb/day)
1972	578,000	7,250	1,230
1992 ±	820,000	10,250	1,745

The wastewater is essentially municipal and its flow varies seasonally. Its greatest flows occur during the winter season. Table I presents a summary of design loadings and indicates the anticipated magnitudes of these seasonal variations.

Plant process

The North Branch Fire District No. 1 wastewater treatment facility provides secondary treatment and disposes of chlorinated effluent by spraying onto forested land. The process flow diagram for the treatment facility is shown in Figure 2. The plant and spray field layout are presented in Figure 3. The treatment facility can be described as an extended aeration (by oxidation ditch) activated sludge process with effluent chlorination. Since the treatment process has been described in detail in earlier reports (Cassell 1977), this report will concentrate on the land treatment components of the operation.

The chlorinated secondary effluent is stored in a 2.2-million-gallon clay-lined polishing pond until it can be sprayed. A 16-million-gallon holding pond stores the overflow from the polishing pond during periods when spraying is limited or not advisable.

Spray system

The spray system includes three spray pumps, various controls, and a network of spray lines and nozzles distributed across the spray field. A 12-in. cast iron suction line connects the polishing pond with the spray pumps, which are located in the basement of the control building. A chlorine solution line is tapped into this suction line just upstream of the pumps to permit the spray effluent to be chlorinated directly.

Each spray pump consists of a $^1/_{16}$-in. opening strainer, a 350-gal./min centrifugal pump, an air-activated Camflex spray valve, a bypass line, and a transmitting flow meter for flow monitoring. The pumps discharge into a manifold system, which in turn feeds the 12 spray lines on the spray site.

The spray pumps and the 12 camflex spray valves are manually or automatically controlled from the operation panel in the control building. A cam/timer system is used to program the desired timing and selection of spray laterals. Under normal operation, the spray system is divided into three sections, each consisting of one spray pump and four headers. At any given time, each pump is pumping to one header in its section. The desired flow to each lateral is determined by the number of nozzles on the lateral, the desired application rate, and the spray schedule. The pump flow meter indicates flow rate, which in turn can be selected by adjustment of the Camflex valve. The cam/timer is then set to alternate between each line in the section. In the summer season, automatic operation typically involves two spray pumps and lines 5 through 12. Each spray pump sprays one of its four lines for approximately 15 minutes each hour until the desired volume has been sprayed. Because of nozzle freezing problems, winter spraying is done manually with no alternation between lines. Each time spraying terminates in a given line an automatic drain valve opens, and the manifold is drained back into the polishing pond.

The 12 polyvinyl chloride (PVC) header lines run underground from the control building up the center access trail of the spray site. A north-south spray lateral runs off each of these headers. The lines are parallel to each other, are 75 ft apart, follow the contours of the spray site, and are suspended 5 to 15 ft above the ground. Vegetation is cleared 5 to 10 ft from either side of the line. Nozzles that spray downward are located at low points in each line, and drain each line after spraying to prevent freezing in winter. These downward nozzles are closed in summer. Nozzles that spray upward are installed at 25 to 50-ft intervals on the tops of the lines.

Natural features

The spray of the lines covers approximately 34 acres (13.75 hectares) of land. A 200-ft buffer zone separates the sprayed area from the fenced perimeter of the spray site, bringing the total area of the spray site to 50± acres (20.2 hectares). The spray site, which rises about 100 ft above the plant site, is located on a knoll west of the control building. The eastern side of this knoll drains toward the plant and Ellis Brook at slopes between 8 and 15%. The western side drains towards the Deerfield River at slopes in excess of 25% (see Fig. 3).

This study was limited to the 20.5-acre eastern slope of the spray field. This eastern slope drains into the interceptor ditch (see Fig. 3). The predominant soil type on the eastern slope is Peru, a moderately well-drained soil having a compact glacial till layer (fragipan) that ranges from 15 to 30 in. below the surface. Depth to bedrock is 4 to 10 ft or more (USDA Soil Conservation Service 1973).

The precise nature of the fragipan underlying Peru soils is unknown. However, general characteristics of fragipan suggest high bulk density (1.80±), a firm and brittle texture, and low permeability (less than 0.2 to 0.6 in./hr. (USDA Soil Conservation Service 1973). The distribution and thickness of the fragipan layer on the spray field itself are also unknown; however, some generalizations can be made. True fragipans are not common on slopes greater than 25%. Thus,

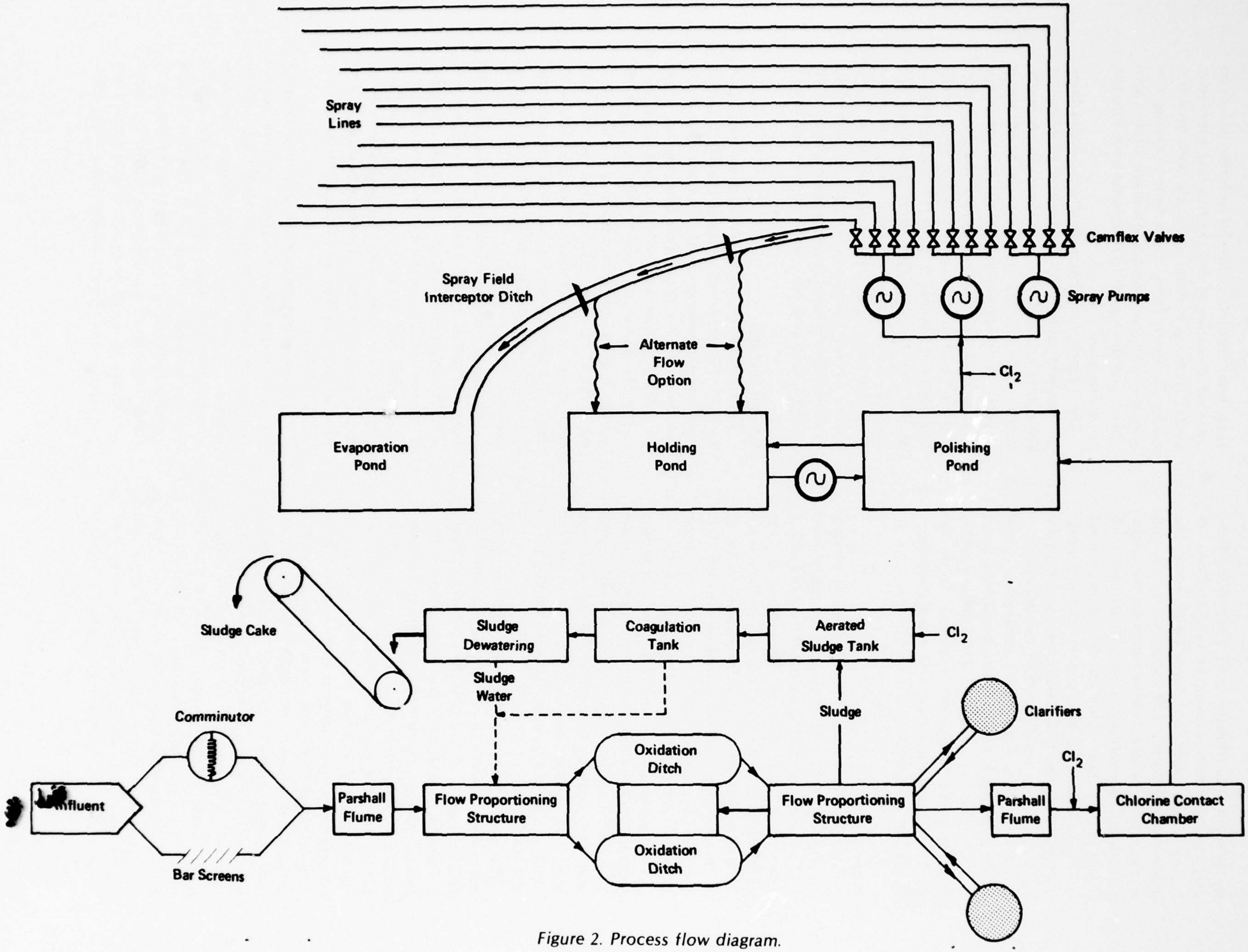


Figure 2. Process flow diagram.

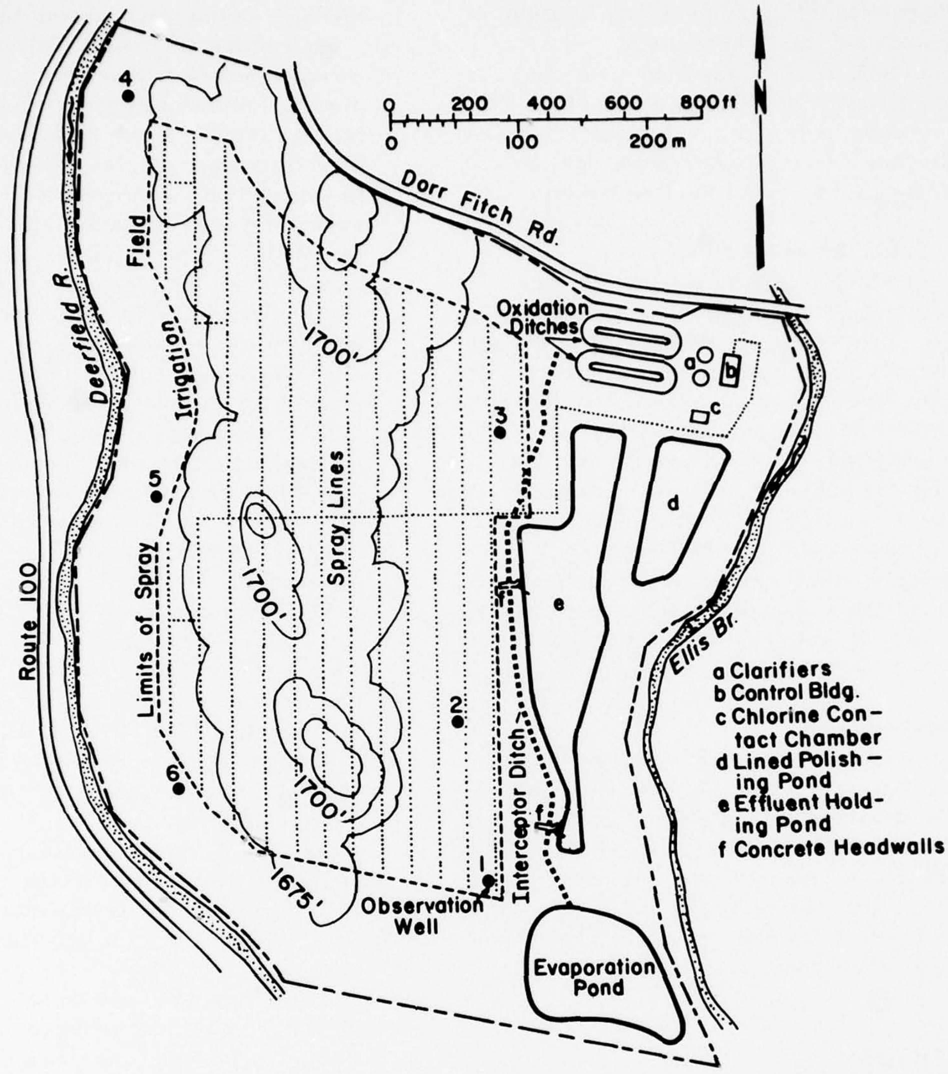


Figure 3. Plant and spray field layout—NBFD no. 1.

it may be that the eastern slope of the spray field has a relatively well defined fragipan layer while the western slope draining toward the Deerfield River may lack this impermeable layer.

Permeability is moderate above the fragipan and low within it. Depth to the seasonal high water table is 1.5 to 2 ft and a saturated condition is common above the fragipan during wet seasons.

Available information also indicates that the treatment facility is located in an area of significant groundwater activity. The spray field is underlain by bedrock formations that tend to be extensively fractured and thus of high groundwater formation potential. On-site observations support indications of significant groundwater activity. Subsurface water was frequently encountered during construction of the facility. Several natural springs have been observed on the eastern slope of the spray field, and plant personnel observed water flowing in the spray field interceptor trench even before spraying was begun. High groundwater conditions exist in the spray field during the period of snow melt, but it is suggested that this condition is of short duration (3 to 4 weeks) (USDA Soil Conservation Service 1973).

Six 4-in. PVC observation wells are located in or adjacent to the spray field. The locations of these wells are shown in Figure 3.

About 90% of the spray field is forested. Approximately 40% of the spray area, primarily the eastern slope, is forested with maples, beeches and birches. Conifers, white pines, spruces and firs dominate the rest of the forested area.

Spray field interceptor ditch

The interceptor ditch, which is cut down to the underlying fragipan, runs southerly along the eastern perimeter of the spray field and discharges into the evaporation pond (see Fig. 3). Its northern end is approximately 1 ft deep and its southern end is approximately 15 ft deep. This ditch prevents spray field runoff from directly entering the holding pond, which under certain weather conditions could cause repeated pumping and spraying of the same water.

Both groundwater and surface runoff are collected in the interceptor ditch. Two concrete headwalls are installed in the ditch and can be used to divert flow to the holding pond.

Evaporation pond

The evaporation pond is located in the southeastern corner of the site. It is approximately 300 ft square, an average of 3.5 to 5 ft deep, and yields a capacity of about 3.4 million gallons. Flow from the interceptor ditch is collected in the evaporation pond and a large amount percolates into the ground. Over most of the year, evaporation is minimal.

METHODS

The quantity and quality of wastewater effluent applied to the spray field and flow in the interceptor ditch were monitored over the six-week period of 11 July through 19 August 1977. In addition, the water quality in the observation wells and in the two adjacent streams was monitored.

The daily volume of effluent spray was derived from plant operational records that were corrected for the back-drainage of the pipelines that followed each line shutdown. Only the amounts sprayed through lines 5-9 were included. Grab samples of spray effluent were taken directly from a spray line in operation two times per week. Forty-eight hour composite samples were taken weekly from the interceptor ditch flow. Flow in the ditch was measured continuously during each 48-hour sampling period.

Each observation well that contained water was sampled every two weeks. Both Ellis Brook (flowing south along the eastern boundary of the facility) and the North Branch of the Deerfield River (flowing south along the western margin of the spray field) were sampled once every two weeks at points upstream and downstream of the facility property. Figure 3 shows the locations of these sampling points.

In early July 1977, equipment for automatic measurement and sampling in the interceptor ditch was installed and initially calibrated. A diagram of this installation is presented in Figure 4. A 90° V-notch weir was attached to the southern headwall as the primary flow measuring device. The weir was fabricated from ⅛-in. aluminum plate with a head capacity of 6 in. An ISCO Model 1530 float-type totalizing flow meter was mounted on the top of the headwall. The 4-in. steel float dropped into a 6-in.-diam PVC stilling well that was bolted to the headwall. A standard steel staff gage was mounted next to the weir on the upstream side and aligned with the apex of the V-notch. The flow meter was initially calibrated against the weir using standard hydraulic curves and this calibration was rechecked weekly.

During flow monitoring, output from the flow meter was recorded hourly on an ISCO Model 1710 digital printer. This printer recorded date, time, incremental flow and total flow at each print.

Water sampling was accomplished with an ISCO Model 1680 automatic sequential sampler. During each 48-hour sampling period, a sample was drawn every 45 minutes from the interceptor ditch, just upstream of the weir. Each sampling initiated a print cycle in the digital printer. Samples were maintained in an ice bath in the insulated sampler base during the sampling cycle. At the end of each 48-hour sampling cycle, a single flow-proportionate composite sample was made up using flow data recordings to determine proportions.

Immediately upon collection, both grab and composite samples were analyzed in the treatment facility laboratory for total coliform bacteria, temperature, pH, and conductivity. Samples were then transported on ice, and in sterile containers, to the CRREL water quality laboratory where they were analyzed for BOD_5, total N, NH_4-N, NO_3-N, total phosphorus and

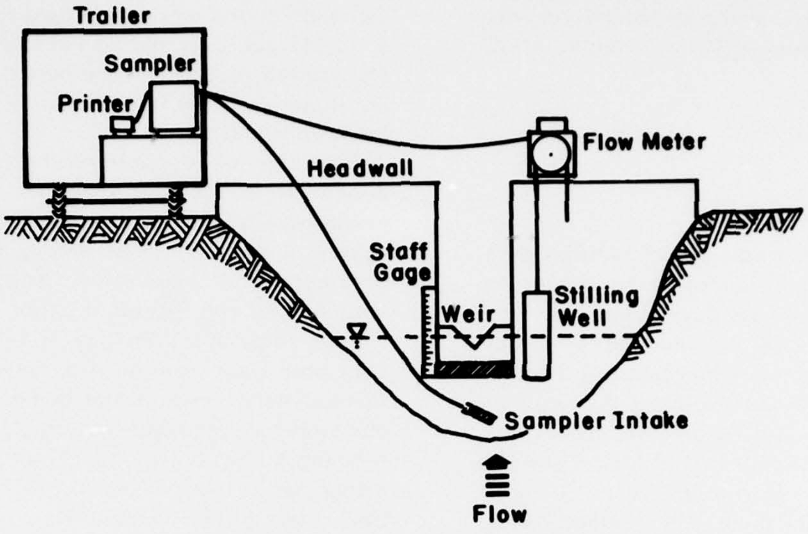
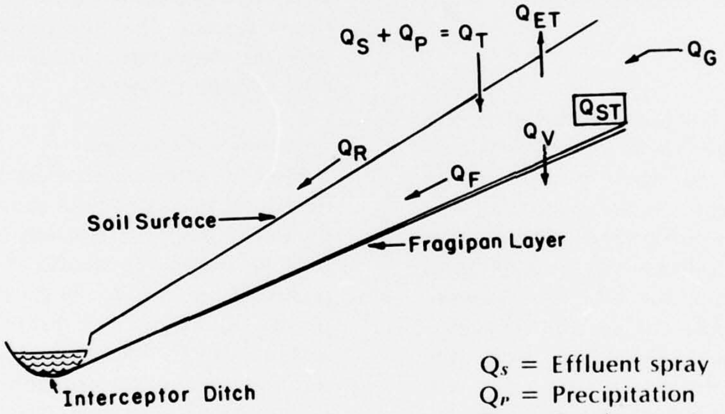


Figure 4. Diagram of interceptor ditch monitoring installation.



Q_S = Effluent spray
Q_P = Precipitation
Q_T = Total water input on site
Q_{ET} = Evapotranspiration
Q_V = Percolation through fragipan
Q_{ST} = Soil water storage
Q_F = Subsurface flow
Q_R = Surface runoff
Q_G = Groundwater input
Q_D = Interceptor ditch flow
Q_U = Unaccounted for water

$$Q_D = Q_F + Q_R$$
$$Q_F = Q_T - Q_{ET} - Q_V - \Delta Q_{ST} - Q_R + Q_G$$
$$Q_D = Q_T - Q_{ET} - Q_V - \Delta Q_{ST} - Q_R + Q_R + Q_G$$
$$Q_D = Q_T - Q_{ET} - Q_V - \Delta Q_{ST} + Q_G$$
$$Q_U = Q_V \pm \Delta Q_{ST} - Q_G$$
($\Delta Q_{ST} = 0$ at equilibrium)

Figure 5. Schematic hydrologic model of West Dover spray site.

chloride. Analyses were performed in conformance with standard analytic procedures described in CRREL Report 76-19 (Iskandar, et al. 1976).

RESULTS

Statistical analysis

During the 40-day study period, samples were collected on 18 days. In order to determine whether these sampling days could be considered representative of the entire 40-day period, the daily mean temperature, precipitation and spray application volumes the sampling and nonsampling days were compared statistically. Using the *z*-Score Test of Means and the χ^2 Inference of Variance Test (Robbins and Ryzin 1975, Snedecor and Cochran 1967), the 18 days of sampling were shown to be representative of the entire 40-day study period within a 99% confidence limit (see App. A). Thus, throughout this study a number of inferences have been made regarding the average weekly and overall site behavior based on the 18 days of sample data.

Hydrology

For the purposes of this study, the spray site was assumed to behave under equilibrium conditions according to the model shown schematically in Figure 5. In evaluating the water balance across the eastern slope of the site, effluent spray volumes Q_S, precipitation amounts Q_P, and interceptor ditch flow Q_D were measured directly, while the amount of evapotranspiration Q_{ET} was estimated from the literature. Groundwater input flow Q_G was assumed to be zero.

Flow input to the eastern slope (Q_T)

Records of spray schedule, spray effluent volume applied, and precipitation and temperature obtained at the site are presented in Appendix B. Total spray volumes as recorded on plant flow meters were corrected for the pipe drain-back which follows shutdown of each line. These corrected spray volumes were adjusted to determine the amount applied to the eastern slope (i.e., spray lines 5-9). These adjusted daily volumes of effluent Q_S applied to the eastern slope are listed in Table II. The volume of effluent sprayed on the eastern slope over the 40-day study period totaled 4, 294, 473 gal. and averaged 715,744 gal./wk. Total rainfall Q_P over the study period was determined to be 6.8 in. or 3,779,981 gal. over the 20.5-acre eastern slope. The rainfall records for the period of the study are shown in Table III.

Evapotranspiration

Estimates of evapotranspiration Q_{ET} were drawn from several sources. Lull (1968) estimated Q_{ET} for northeastern forests at 0.12 in./day. A nomograph predicting Q_{ET} from the parameters of elevation, solar radiation, temperature and saturated vapor pressure provided a value of 0.13 in./day (Follett et al. 1973). Long-term data from an experimental evaporation pan in a forested watershed in northern Vermont gave average daily potential Q_{ET} values for July and August between 0.117 and 0.138 in./day respectively (Anderson et al. 1977). The mean of this range (0.127 in./day) was selected as a representative value for *Potential* Q_{ET}. In this study *Potential* Q_{ET} was assumed to be representative of the site, since actual Q_{ET} from the vegetation plus evaporation of finely sprayed effluent were expected to approach the potential value as compared with Q_{ET} in an undisturbed forest system. Thus, evapotranspiration for the site was estimated at 0.127 in./day (71,070 gal./-day, 497,486 gal./week).

Interceptor ditch flow

Flow in the interceptor ditch was continuously measured over a 48-hour period each week during the study period (usually from noon Tuesday through noon Thursday). Flow volume was recorded at hourly intervals by the digital printer. An example of this printout is presented in Appendix C. For the days when flow was not recorded, estimates of ditch flow were derived from the precipitation data, applied effluent volumes, and ditch flows measured preceding and following the effluent applications. These daily values of ditch flow are presented in Table IV. About 183,525 ft^3 (1,372,950 gal.) of water flowed through the ditch over the study period. Ditch flow averaged approximately 0.05 ft^3/s (4,600 ft^3/day; 34,390 gal./day).

Water balance

The summations of measured and estimated flow components for each day for which full records of ditch flow exist are presented in Table IV. As illustrated in Figure 5, the expression of water balance across the eastern slope may be written as:

Table II. Spray effluent volumes.

Date	Recorded spray volume (gal.)	Lines in operation	Mode*	Drain loss (gal.)	Corrected spray volume (gal.)	Approximate % applied to eastern slope	Adjusted effluent volume applied to eastern slope (gal.)
11 July	238,000	5,6,8,9	M	4,372	233,628	100	233,628
12 July†							
13 July†							
14 July†							
15 July	310,000	5,6,8,9	M	4,372	305,628	100	305,628
16 July							
17 July							
18 July	345,000	5,6,8,9		4,372	340,628	100	340,628
19 July†	410,000	5,6,8,9	M	4,372	405,628	100	405,628
20 July†	448,000	5,6,8	M	3,181	444,819	100	444,819
21 July†	396,000	7,8,9,10	M	4,666	391,334	72	280,586
22 July	400,000	7,8,9,10	M	4,666	395,334	72	284,640
23 July	102,000	7,8,9,10	M	4,666	97,334	72	70,080
24 July	104,000	7,8,9,10	M	4,666	99,339	72	71,520
25 July							
26 July†	391,000	7,8,9,10,11	M	5,955	385,045	61	233,337
27 July†	403,000	7,8,9,10,11	M	5,955	397,045	51	240,609
28 July†	17,000	7,8,9,10	M	4,666	12,334	72	8,880
29 July	147,000	9,10,11	A	26,040	120,960	19	22,982
30 July							
31 July							
1 August							
2 August	53,000	9,10,11	A	22,320	30,680	19	5,829
3 August†	404,000	5-12	A	87,992	316,008	63	199,085
4 August†	163,000	5-8	A	34,192	128,808	100	128,808
5 August	199,000	5-12	A	65,994	133,006	56	74,483
6 August	58,000	5-12	A	21,998	36,002	56	20,161
7 August	47,000	5-12	A	21,998	25,002	56	14,000
8 August	319,000	5,8,9,12	A	71,852	247,148	67	165,589
9 August†	262,000	5-12	A	87,992	174,008	56	97,270
10 August†	244,000	5-12	A	76,993	167,007	56	93,524
11 August†	130,000	5-12	A	65,994	64,006	56	35,843
12 August	101,000	5-12	A	87,992	13,008	56	7,284
13 August	55,000	5-12	A	21,998	33,002	56	18,481
14 August	61,000	5-12	A	21,998	39,002	56	21,841
15 August	299,000	5-12	A	65,994	233,006	56	130,483
16 August†	400,000	5-12	M	10,999	389,001	56	217,452
17 August†	18,000	9	M	1,191	16,809	100	16,809
18 August†	164,000	5-12	A	87,992	76,008	56	42,488
19 August	179,000	5-12	A	76,993	102,007	56	57,124
						Total =	4,289,519

*A = automatic, M = manual

†Days samples were taken

Table III. Rainfall records.

Date (1977)	Rainfall (in.)	Calculated volume on eastern slope (ft^3)
11 July	0.27	20,092
12 July*	0.11	8,186
13 July*	0.99	73,670
16 July	0.2	14,883
17 July	0.4	29,766
21 July*	0.2	14,883
25 July	0.8	59,532
2 August*	2.0	148,830
5 August	0.6	44,649
6 August	Trace	
8 August	0.05	3,721
10 August*	0.6	44,649
12 August	0.25	18,604
16 August*	0.2	14,883
17 August*	0.12	8,930

*Days samples were taken.

$$Q_D = Q_T - Q_{ET} - Q_V - \Delta Q_{ST} + Q_G$$

or

$$Q_T - Q_{ET} - Q_D = Q_V + \Delta Q_{ST} - Q_G = Q_L$$

where Q_L is flow unaccounted for.

The results in Table V show considerable volumes of water are unaccounted for in each case.

In similar fashion, using the estimated average weekly ditch flows, a water balance for each week was calculated; these values are summarized in Table VI. Over the six-week study period the total water balance (in cubic feet) was calculated to be:

$$\begin{array}{ccccccc} Q_T & - & Q_{ET} & - & Q_D & = & Q_L \\ 1{,}078{,}809 & & 380{,}000 & & 183{,}525 & & 515{,}284 \end{array}$$

Interceptor ditch hydrographs

The flow records permitted the construction of a hydrograph of ditch flow for each of the 48-hour monitoring periods. These hydrographs are presented in Figures 6, 7, and 8. Each hydrograph clearly reflects the response of trench flow to one or more unique hydrologic events including both precipitation and/or effluent spray application. The ditch hydrograph

Table IV. Measured and estimated interceptor ditch flow.

Week	Date	Daily flow (ft^3/s)	Weekly total (ft^3/s)	Weekly mean
	11 July	7,500		
	12 July	7,000*		
1	13 July	9,900†	38,050	7,610
	14 July	6,850*		
	15 July	6,800		
	16 July	6,800		
	17 July	5,500		
	18 July	5,500		
2	19 July	5,400*	37,250	5,321
	20 July	5,200†		
	21 July	4,350*		
	22 July	4,500		
	23 July	4,500		
	24 July	4,000		
	25 July	5,000		
3	26 July	4,200*	28,725	4,104
	27 July	3,975†		
	28 July	3,050*		
	29 July	4,000		
	30 July	3,000		
	31 July	3,000		
	1 August	4,000		
4	2 August	4,200*	24,825	3,546
	3 August	3,325†		
	4 August	3,000*		
	5 August	4,300		
	6 August	4,000		
	7 August	3,500		
	8 August	3,100		
5	9 August	1,300*	25,525	3,646
	10 August	3,425†	25,525	3,646
	11 August	5,200*		
	12 August	5,000		
	13 August	4,500		
	14 August	4,000		
	15 August	4,000		
6	16 August	4,000*	29,150	4,164
	17 August	5,150†		
	18 August	3,500*		
	19 August	4,000		

*Partial day flow records.
†Full day flow records.
All other figures are estimates.

Table V. Daily water balance.

$$Q_S + Q_P - Q_{ET} - Q_D = Q_L$$

Date	Q_S Spray vol. (ft^3)	Q_P Precip (ft^3)	Q_{ET} Evapotrans (ft^3)	Q_D Ditch flow (ft^3)	Q_L Flow unaccounted for (ft^3)
13 July	0	73,670	9,500	9,900	+ 54,270
20 July	59,468	0	9,500	5,200	+ 44,768
27 July	32,167	0	9,500	3,975	+ 18,692
3 August	26,616	0	9,500	3,325	+ 13,791
10 August	12,503	44,649	9,500	3,425	+ 44,227
17 August	2,247	8,930	9,500	5,150	− 3,473

Table VI. Weekly water balance.

Week	Q_S Spray vol. (ft^3)	Q_P Precip (ft^3)	Q_{ET} Evapotrans (ft^3)	Q_D Interceptor ditch flow (ft^3)	Q_L Flow unaccounted for (ft^3)
11-15 July	72,093	101,812	47,500	38,050	+ 88,355
16-22 July	234,799	59,452	66,500	37,250	+ 190,501
23-29 July	86,552	59,452	66,500	28,725	+ 50,779
30 July-5 August	54,573	193,221	66,500	24,825	+ 156,469
6-12 August	57,977	67,627	66,500	25,525	+ 33,579
13-19 August	67,470	23,781	66,500	29,150	− 4,399
Totals	573,464	505,345	380,000	183,525	515,284

Mean weekly water balance:

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ (95{,}578 & + & 84{,}224) & - & 63{,}333 & - & 30{,}588 & = & 85{,}881 \end{array}$$

Table VII. Hydrograph lag times (t_l) for interceptor ditch flow.

Date	Q_S (ft^3)	Q_P (ft^3)	Q_T (ft^3)	Lines in operation	Mode	Antecedent conditions	t_l (hr)
20 July	59,468	0	59,468	5,6,8	M	No rain/high spray	5
27 July	32,167	0	32,167	7,8,9,10	M	No rain/high spray	4.75
3 August	26,616	0	26,616	5-12	A	Rain/low spray	7.5
10 August	12,503	44,649	57,152	5-12	A	Rain/moderate spray	7
17 August	2,247	8,930	11,177	5-12	M	Rain/high spray	3.5

Table VIII. Concentration times (t_c) for interceptor ditch flow.

Date	Lines in operation	Application	Mode	t_c (hr)
13 July		Rain		2
20 July	5,6,8	Effluent	M	4
27 July	7,8,9,10	Effluent	M	4
10 August	5-12	Effluent	A*	3
17 August	5-12	Effluent	M	4

*Antecedent condition, rain.

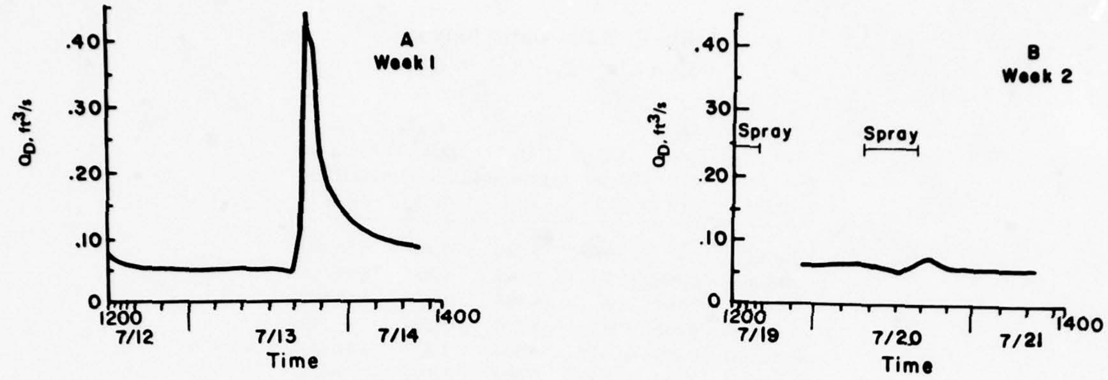


Figure 6. Interceptor ditch flow hydrographs, weeks 1 and 2.

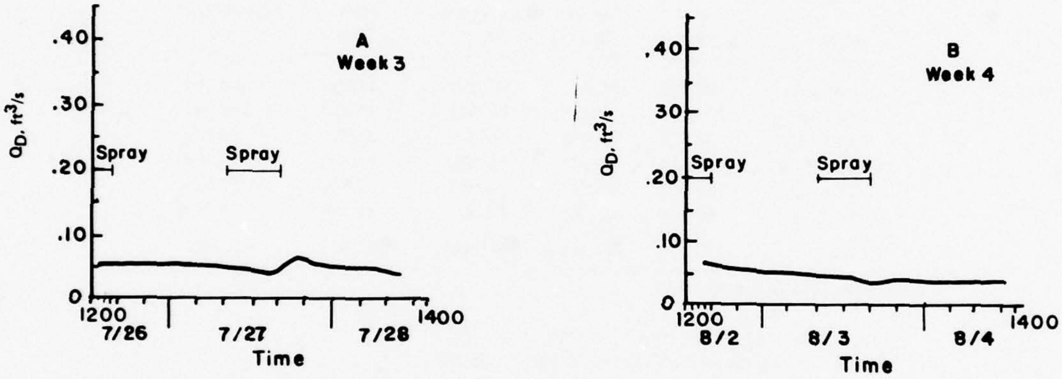


Figure 7. Interceptor ditch flow hydrographs, weeks 3 and 4.

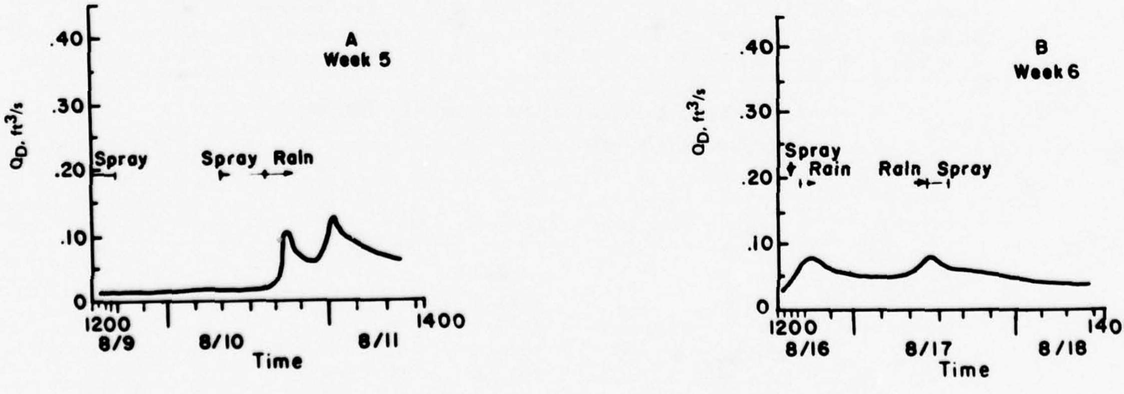


Figure 8. Interceptor ditch flow hydrographs, weeks 5 and 6.

for the period 12-14 July (Fig. 6a) shows the ditch response to an intense rainfall event. In this case, a peak flow rate of 0.44 ft^3/s was measured in response to more than 1 in. of rain. The hydrographs of 19-21 July (Fig. 6b), 26-28 July (Fig. 7a) and 2-4 August (Fig. 7b) demonstrate the response to effluent spray application only. The other hydrographs (Fig. 8) are more complex, reflecting the influence of both precipitation and effluent application.

Hydrograph lag times t_l (the elapsed time from event initiation to the beginning of the rising limb of the hydrograph) for several effluent application events are shown in Table VII. The lag times are consistently shorter under conditions when the spray field is under the manual operation mode than when the spray system is operated on automatic cycle. Lag times also become shorter as more spray lines are operated.

Concentration times t_c (the time from start of rising limb to the hydrograph peak) are presented in Table VIII. The shortest t_c results from rainfall alone. The concentration times associated solely with effluent application are substantially longer.

Water quality

The complete results of water quality analysis are presented in Appendix D. Summaries of these data are presented below.

Applied wastewater

Table IX summarizes the mean, maximum and minimum values of water quality parameters for the wastewater applied to the eastern slope during the study period. In most respects, these values are consistent with those expected for normal effluent from an efficient secondary treatment plant. The NBFD No. 1 effluent is, however, of somewhat higher quality than the wastewater applied to test cells at CRREL (Iskandar et al. 1976). Total coliform counts were 0 on four occasions due to chlorination of the effluent immediately before spraying.

The predominant form of nitrogen applied to the eastern slopes was nitrate nitrogen.

The nitrate concentrations in the effluent (mean of 3.5 mg/l) were considerably higher than the ammonia nitrogen (NH_4-N) concentration (mean 1.4 mg/l) in five of the six weeks studied. This is due to nitrification in the polishing and holding ponds before effluent spraying, as well as the fact that the secondary portion of the plant is operating substantially below design capacity.

Increases in the concentrations of both the total nitrogen and the total phosphorus study (23 July-15 August) (see App. D) can be attributed to a change in plant operation. During this time, the north oxidation canal was being drained to waste the mixed liquor solids. This operation resulted in accelerated effluent handling through the polishing pond and thus reduced the effluent retention time in the pond before spraying.

During the period 23 July-5 August, there was a significant increase in the organic nitrogen (Kjeldahl-ammonium) component of total nitrogen (see App. D). This increase coincided with a pronounced algae bloom in the polishing pond.

Ditch flow

Table X summarizes water quality values for the interceptor ditch during the study period. Concentrations of all measured parameters except total coliform bacteria were significantly reduced from effluent concentrations. Mean total coliform counts (and all individual measurements) were higher in the ditch flow than in the sprayed effluent.

Concentrations of nitrogen and phosphorus in the ditch flow over the study period were substantially lower than in the wastewater applied. They were remarkably constant in comparison with the variation in application concentrations. Figure 9 shows the weekly variation of total nitrogen and total phosphorus in both effluent and ditch flow. Total nitrogen did not exceed 1.3 mg/l, total phosphorus was below measurable levels and ortho-phosphorus did not exceed 0.06 mg/l. As in the effluent, the dominant form of nitrogen was nitrate (mean concentration 0.8 mg/l). Ammonia nitrogen concentrations averaged less than 0.2 mg/l. The nutrient concentrations in the ditch flow did not reflect the oxidation canal drainage or the algae bloom noted above.

Groundwater

Table XI summarizes the water quality monitoring results of observation wells on the spray field. Over the entire study period, only wells 2, 3, and 6 contained water; wells 1, 4 and 5 were consistently dry. Concentrations of all parameters were significantly lower in the groundwater than in the sprayed effluent.

Table IX. Applied wastewater quality.*

Parameter†	Mean	Max	Min
pH (pH units)	8.2	8.7	7.1
Conductivity (µmhos)	320	460	322
Total coliform (colonies/100 ml)	1775	8000	0
BOD_5	6.5	10.4	0.6
Total nitrogen	7.8	12.3	5.3
Kjeldahl-N	4.2	5.6	1.5
Nitrate-N	3.5	7.6	0.7
Ammonia-N	1.4	3.0	0.2
Total phosphorus	4.7	6.5	2.8
Chloride	56.2	68.4	45.4

*12 Determinations of each parameter were made from grab samples.

†All values are in milligrams per liter except as noted.

Table X. Quality of interceptor ditch flows.*

Parameter†	Mean	Max	Min
pH (pH units)	7.6	8.0	6.5
Conductivity (µmhos)	166	170	160
Total coliform (colonies/100 ml)	3167	**	1400
BOD_5	5.0	9.2	0.6
Total nitrogen	1.1	1.5	0.9
Kjeldahl-N	0.3	0.5	0.2
Nitrate-N	0.8	1.2	0.7
Ammonia-N	<0.2	0.3	<0.1
Total phosphorus††	0.04	0.06	0
Chloride	37.0	38.6	35.6

*Six determinations of each parameter were made for 48-hour flow proportionate samples.

†All values are in milligrams per liter except as noted.

**Three determinations yielded colonies too numerous to count.

††Values for total phosphorus were <1.0; therefore, the ortho-P value is given.

Table XI. Average groundwater quality in observation wells.*

	Well 2			Well 3			Well 6		
Parameter†	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
pH (pH units)	6.5	6.7	6.2	6.2	6.4	6.1	6.4	6.5	6.3
Conductivity (µmhos)	180	210	160	213	240	199	198	255	165
Total coliform (colonies/100 ml)	83	100	70	>110	**	110	0	0	0
BOD_5	1.3	2.3	0.6	0.7	1.0	0.2	1.1	1.7	0.7
Total nitrogen	<1.8	2.2	<1.4	<3.5	3.9	2.9	<1.1	1.6	<0.8
Kjeldahl-N	0.3	0.6	<0.1	<0.2	0.3	<0.1	<0.2	0.2	<0.1
Nitrate-N	1.5	1.6	1.3	3.3	3.7	2.6	1.0	1.5	0.6
Ammonia-N	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.2	<0.1
Total phosphorus††	0.1	0.12	0.06	0.09	0.12	0.05	0.6	0.8	0.05
Chloride	38.4	41.9	36.3	37.6	39.9	36.3	41.5	44.1	38.6

*Three determinations were made of each parameter.

†All values are in milligrams per liter except as noted.

**Too numerous to count.

††Ortho-phosphorus was reported.

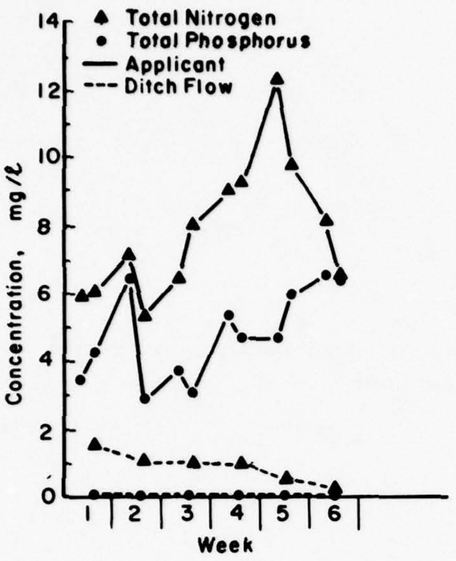


Figure 9. Nitrogen and phosphorus concentrations in sprayed effluent and interceptor ditch flow.

However, with the exception of total coliform bacteria and BOD$_5$, groundwater generally showed slightly higher values for nutrient forms than did ditch flow, particularly for total nitrogen, nitrate-nitrogen and total phosphorus. Chloride values for groundwater were not significantly different from those of the ditch flow.

As in the sprayed effluent and in the ditch flow, nitrate-nitrogen was the predominant form of nitrogen found in the groundwater, accounting for 73%-95% of the total nitrogen. Ammonia-nitrogen concentrations were consistently low in all well water samples. Well 3, near in the northeastern corner of the eastern slope, exhibited the highest nitrate-nitrogen and total nitrogen concentrations (averaging <3.3 mg/l and <3.5 mg/l respectively).

Surface water

Table XII summarizes water quality data for the North Branch of the Deerfield River and for Ellis Brook. The quality of the Deerfield River water appeared not to change as it passed along the western boundary of the spray field. There were no substantial differences between water quality above and below the spray field. Total coliform counts exceeding the Vermont Class B stream standards (500 colonies/100 ml) and phosphorus levels slightly higher than those in the ditch flow occurred at both river sampling points. These data suggest that the Deerfield River may be receiving some organic loading from other sources upstream from the spray site. Values for other parameters were well within the range expected for surface waters of the region.

Samples from Ellis Brook showed average values for the measured parameters similar to or lower than those for samples from the Deerfield River. In several cases, coliform values exceeded Class B standards but nutrient concentrations were consistently low. In most cases there was little difference between the water quality of Ellis Brook upstream and downstream of the plant. Slight increases in conductivity, BOD$_5$ and total phosphorus were noted in the downstream samples. The largest upstream/downstream difference was evident in chloride values; the average downstream concentration (2.5 mg/l) appears to be substantially greater than the average upstream concentration (0.8 mg/l).

DISCUSSION

The weekly mean values of sprayed effluent volumes Q_S, precipitation Q_P and ditch flow Q_D for the six-week study period are plotted in Figure 10. It is evident from this graph that, while weekly inputs Q_T to the eastern slope varied considerably over the study period, ditch flow was remarkably constant. Weekly Q_T ranged from less than 100,000 ft^3 to nearly 300,000 ft^3, while Q_D varied only between about 25,000 and 40,000 ft^3/wk; thus, the eastern slope of the spray field appeared to moderate highly variable water inputs considerably, and damped out large fluctuations in total hydraulic loading to the spray site.

Water balance

The water balance over the eastern slope shows that measured and estimated flow components failed to account for the total volume of water applied to the spray field. Over the six-week study period, more than 500,000 ft^3 remained unaccounted for, an average of over 85,000 ft^3/wk. This unaccounted for water cannot be entirely the result of measurement error but rather indicates significant leakage from the system (i.e., Q_V and/or Q_{ST}).

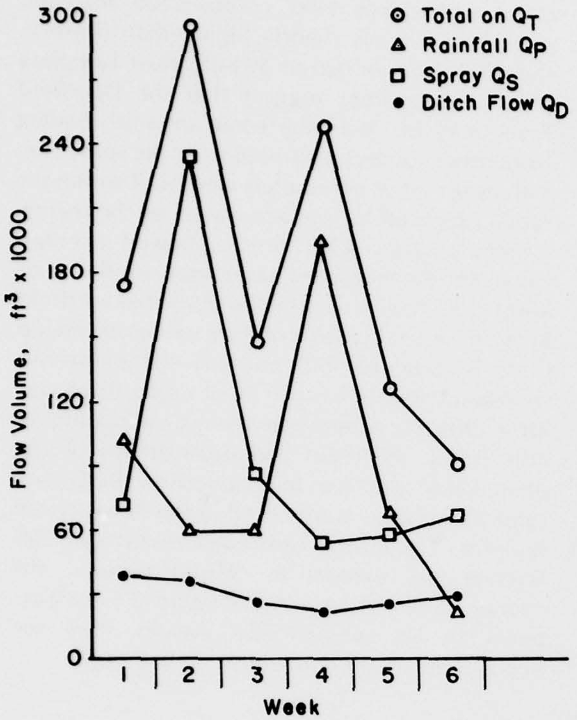


Figure 10. Mean weekly flow volumes across eastern slope.

Table XII. Average surface water quality.*

Parameter†	Upstream Mean	Upstream Max	Upstream Min	Downstream Mean	Downstream Max	Downstream Min
North branch of Deerfield River						
pH (pH units)	6.9	7.0	6.8	6.9	7.0	6.6
Conductivity (μmhos)	103	120	88	105	120	90
Total coliform (colonies/100 ml)	>410	††	300	>525	††	400
BOD_5	0.7	0.9	0.6	0.5	0.7	0.4
Total nitrogen	0.5	0.7	0.4	<0.4	0.7	<0.2
Kjeldahl-N	0.3	0.6	0.2	<0.3	0.6	<0.1
Nitrate-N	0.2	0.2	0.1	0.1	0.2	0.1
Ammonia-N	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Total phosphorus**	0.07	0.11	0.4	0.08	0.16	0.04
Chloride	18.4	21.6	16.2	19.3	22.8	16.8
Ellis Brook						
pH (pH units)	7.5	7.7	7.2	7.2	7.2	7.1
Conductivity (μmhos)	39	37	42	49	55	43
Total coliform (colonies/100 ml)	>750	††	300	>450	††	100
BOD_5	0.2	0.6	0.0	0.4	0.6	0.0
Total nitrogen	<0.3	0.4	<0.3	<0.3	0.4	<0.03
Kjeldahl-N	<0.1	0.2	<0.1	0.2	0.2	0.1
Nitrate-N	0.2	0.2	0.2	<0.2	0.2	<0.1
Ammonia-N	<0.1	0.1	<0.1	<0.1	0.1	<0.1
Total phosphorus**	0.04	0.06	0.02	0.07	0.10	0.04
Chloride	0.8	1.0	0.6	2.5	3.5	1.6

*Three determinations were made of each parameter on grab samples.

†All values are in milligrams per liter except as noted.

**Ortho-phosphorus values reported.

††Too numerous to count.

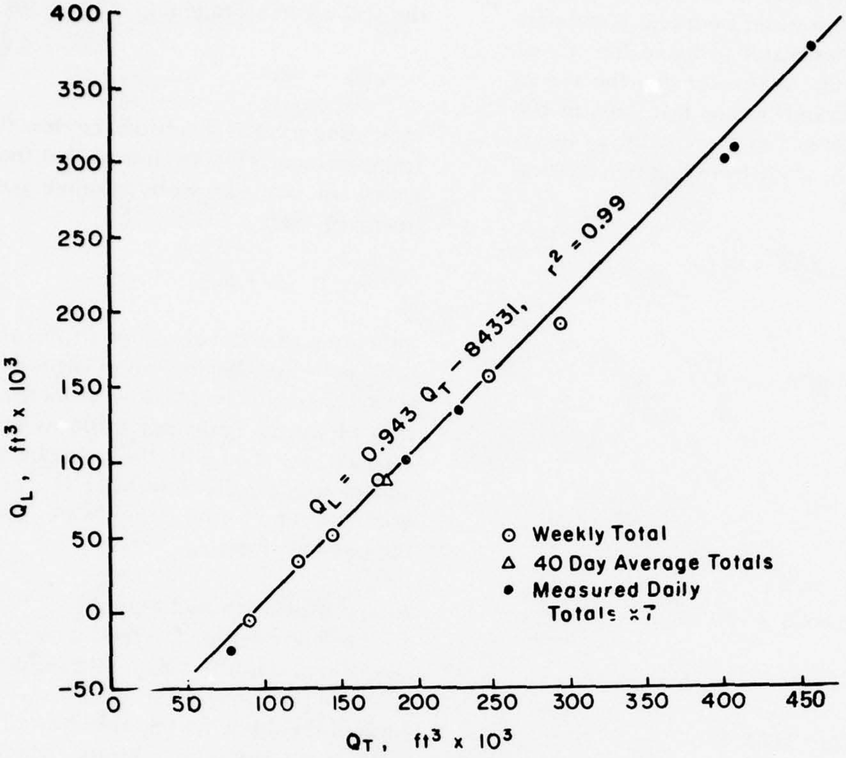


Figure 11. Unaccounted for water vs total applied water.

In order to account for this missing water through measurement error alone, measurements of applied spray volume and rainfall would have to be in error by 30-60% or measurements of ditch flow by 130-630%. But it is not likely that the treatment plant instruments overestimate spray application volumes by such amounts; nor are the rainfall records likely to be in error to that degree. Weekly recalibrations of the ditch flow meter showed differences between meter flow values and flow values based on measured head over the weir to be consistently less than 5%. Measurements of the actual volume of water passing through the weir in a given time period showed agreement within 10% of the flow meter.

Figure 11 plots the relationship between the total volume of water applied to the site Q_T and the volume of unaccounted for water Q_L. The points indicated by the open circles are derived from the weekly totals as shown in Table VI. The closed circles are the measured daily totals from Table V multiplied by 7, and the open triangle is the weekly average totals also from Table VI. The linear relationship

$$Q_L = 0.943Q_T - 84.331$$

where Q_L and Q_T are in cubic feet per week, shown in Figure 11, is a strong one, having a correlation coefficient r^2 of 0.99. An interpretation of the meaning of this relationship appears to be important to the understanding of the behavior of the spray site.

The eastern slope consists of Peru soil, a moderately permeable, compact glacial till and is believed to be underlain by a fragipan layer 15 to 30 in. below the surface; no site specific data exist. This fragipan, although thought to be typically impermeable, does have a finite permeability. Depth to bedrock is 4 to 10 ft and the bedrock is thought to be characterized by considerable fracturing. Small bedrock outcrops exist on the eastern slope. Thus, since the fragipan layer has a finite permeability and the fragipan overlays fractured bedrock, it appears that it is possible for water to leave the site as groundwater flow Q_V. Water leaving the site in this fashion, or through major fractures in the fragipan, would appear in the model as unaccounted for flow Q_L, since from Figure 5 (assuming $Q_G = 0$):

$$Q_T = Q_D + Q_{ET} + Q_V \pm \Delta Q_{ST}$$

or

$$Q_D + Q_{ET} + (Q_V \pm \Delta Q_{ST}) - Q_T = 0$$

and, since

$$Q_V \pm \Delta Q_{ST} = Q_L$$

then

$$Q_D + Q_{ET} + Q_L - Q_T = 0.$$

Then

$$Q_L = Q_T - (Q_D + Q_{ET})$$

which, in Figure 11, has been approximated by the relationship:

$$Q_L = 0.943Q_T - 84{,}331$$

where Q_L and Q_T are in cubic feet per week.

At applied water volumes Q_T less than 89,428 ft^3/week, Q_L is negative, indicating that the amount of water leaving the site $Q_D + Q_{ET}$ exceeds the amount applied Q_T. For example, during the week of 13-19 August more water flowed through the ditch Q_D than was applied Q_T to the eastern slope. This indicates a depletion of the soil water storage by lateral subsurface flow along the top of the fragipan layer.

At applied water volumes Q_T greater than 89,428 ft^3/wk, Q_L is positive; this indicates that the amount of water leaving the site $Q_D + Q_{ET}$ is less than the amount applied Q_T. At these higher water applications, lateral subsurface flow undoubtedly continues along the top of the fragipan into the ditch, although the soil water storage is probably not being depleted. The model for the eastern slope states that:

$$Q_L = Q_V \pm \Delta Q_{ST}$$

When it is assumed that there is no change in the soil water storage (i.e., $\Delta Q_{ST} = 0$), then:

$$Q_L = Q_V$$

indicating a vertical subsurface flow through the fragipan layer. If it is assumed that there is an increase in the soil water storage (i.e., ΔQ_{ST} is positive), then:

$$Q_L = Q_V + \Delta Q_{ST}$$

indicating that the elevation of the groundwater table will rise. The amount of vertical subsurface flow Q_V would increase with increasing elevation of the groundwater table as described by Darcy's Law. To verify the water balance model and to specifically determine Q_V require a program for monitoring groundwater elevations on the eastern slope.

Interceptor ditch hydrographs

The relationship observed between the mode of effluent application and the lag time between spray initiation and the beginning of the rising limb of the ditch hydrograph showed that the lag time is shorter (3.5-5 hours) when the spray system is operated manually and longer (7-7.5 hours) when the system is cycled automatically. Such a pattern is not surprising because in the manual operation mode the same spray lines are operated for the duration of the daily spray period. Under this condition, the infiltration capacity of the soil surface may be exceeded, resulting in increased surface runoff. Thus, some of the applied effluent reaches the ditch more quickly as surface runoff, yielding a relatively rapid response in ditch flow. On automatic cycle, short intervals of spraying are alternated among the spray lines throughout the day. This mode of effluent application is less likely to exceed the soil's infiltration capacity; most of the effluent enters the ditch as subsurface flow and this results in a slower response in ditch flow rate.

Water quality — Eastern slope characteristics

As discussed in the previous paragraph, some of the wastewater applied to the eastern slope in West Dover infiltrates into the soil and travels through the soil as subsurface flow into the interceptor ditch; under certain circumstances, some of the wastewater also moves downslope as surface runoff to the ditch. Numerous surface flow discharges were noted entering the ditch from the eastern slope; these ranged from areas of obviously wet soil to flowing rivulets. Several small areas of standing water were observed on the eastern slope. Vegetation characteristics of wet areas (sphagnum and jewelweed, *Impatiens capensis*) were noted in several areas; this indicated relatively consistent water flow. Thus, it appears that not all of the wastewater applied to the eastern slope is subject to the renovation processes characteristic of infiltration type land treatment systems.

A strong relationship was observed between the concentration of nitrate nitrogen in the ditch flow and the magnitude of ditch flow (Fig. 12). Its concentration increased linearly with increasing ditch flow. The relationship was found to be statistically weaker for total phosphorus (r^2 = 0.13) and total nitrogen (r^2 = 0.50); phosphorus concentrations in the ditch flow appear to be independent of Q_D. Chloride concentration also appears to be independent of Q_D. However, the slightly negative slope may indicate dilution by rainfall at the higher ditch flow Q_D.

Mass balances

Mass balances between the applicant and the flow in the interceptor ditch were calculated using mean weekly concentrations of the applicant and concentrations measured in the 48-hour composite ditch sample. For the purpose of this study, rainfall was assumed to be free of nitrogen, phosphorus, BOD_5 and chloride.

Total nitrogen

An input/output analysis of total nitrogen for the complete daily and weekly flow in the study period are summarized in Table XIII and plotted in Figure 13. Over the entire six weeks of the study period, 116.8 kg of total nitrogen were applied to the eastern slope and 5.9 kg were carried off in the interceptor ditch flow. Thus, an average difference of 95% was experienced between the sprayed effluent and the ditch flow. Daily differences ranged from 68 to 99%. On the average, 18.6 kg of nitrogen were not accounted for across the eastern slope each week; a total of 110.9 kg was not accounted for over the six-week period.

These differences for total nitrogen encountered in West Dover are somewhat higher than values reported in other studies. Pound and Crites (1973) and Crites (1976) reported nitrogen removal rates ranging from 30 to 80% for various land application systems across the country. Nitrogen removal rates of 75 to 80% have been reported in systems similar to the West Dover system (Lance 1975). Iskandar et al. (1976) found 38 to 73% nitrogen removed in test cells receiving secondary effluent of higher nutrient concentrations than that of West Dover. However, most of these studies reported annual average removal rates, and since the present study was conducted in mid-summer, higher removal rates might be expected.

No investigations were conducted on the fate of the nitrogen retained on the eastern slope, but several possible mechanisms are suggested by the literature. Nitrogen may be stored in the soil through incorporation by microorganisms, adsorption by organic matter, and adsorption by soil cation exchange capacity (Lance 1975).

Nitrogen also may be incorporated into growing plants. In one irrigation system, *crop uptake* was cited as the primary means of nitrogen removal (Clapp et al. 1977). In the West Dover system, *plant growth* may be an important means of nitrogen removal. Nitrogen uptake rates for trees have been observed in the range of 40-200 kg/ha/yr (Gessel 1962). This would amount to 332-1660 kg N/yr for the eastern slope. Weinstein (1976) documented a nitrogen uptake rate of 8.1 g/m^2/yr in a forested spray irrigation site at Sunapee, N.H. At this rate, the eastern slope could take up 672.3 kg N/yr. Uptake by trees in this reported range could account for the removal observed at West Dover in this study. In addition, prolific growth of understory vegetation would take up some quantity of nitrogen.

Denitrification has been cited as a particularly important mechanism of nitrogen removal in land treatment (Iskandar et al. 1976, Crites 1976). Three conditions are required for denitrification: 1) aerobic conditions for oxidation to nitrate-nitrogen; 2) exposure to anaerobic conditions; and 3) sufficient organic carbon as a bacterial energy source (Lance 1975). In West Dover, much of the total nitrogen applied to the eastern slope is already in the nitrate form due to nitrification in the plant and polishing ponds. Frequent effluent application promotes saturated conditions which facilitate denitrification (Iskandar et al. 1976). However, some research has found little evidence of denitrification in forested land treatment systems (Hook and Kardos 1977). Furthermore, nitrification in

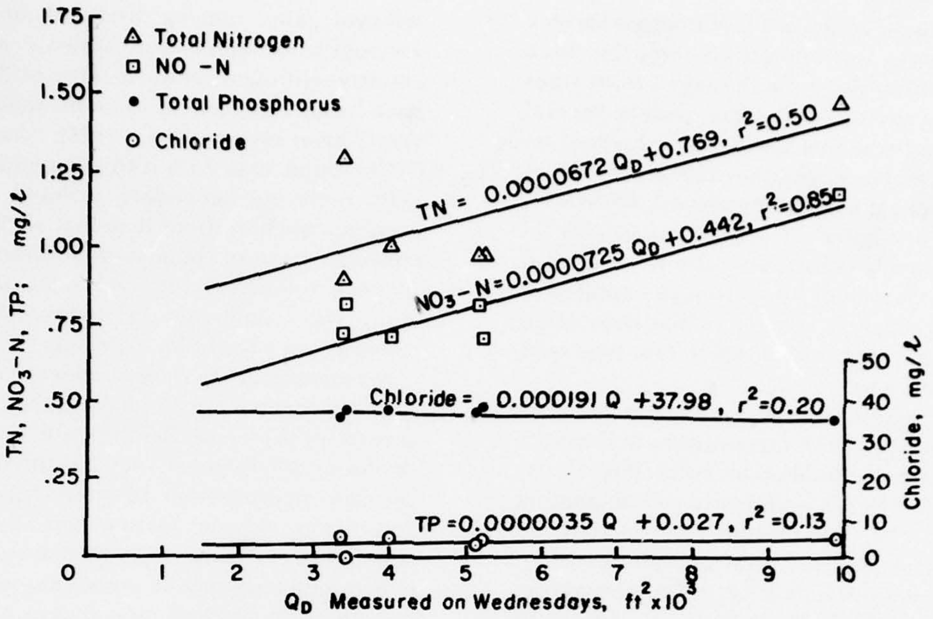


Figure 12. Water quality vs ditch flow rates.

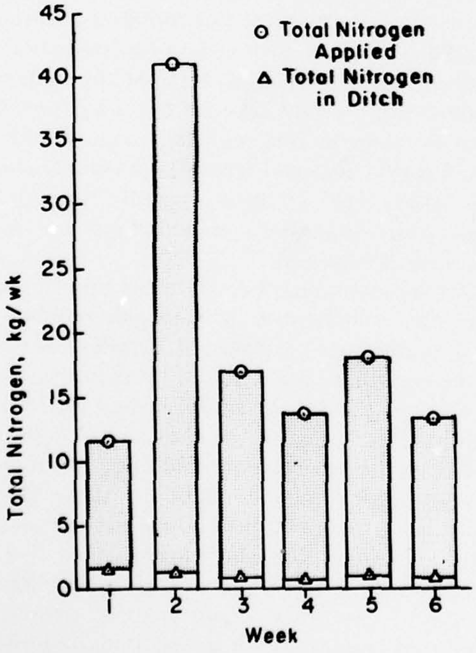


Figure 13. Input/output diagram for total nitrogen.

Table XIII. Input/output analysis for total nitrogen.

Date	Applied (kg)	In ditch (kg)	Difference (%)
Daily			
13 July	0	0.42	
20 July	10.44	0.15	98.6
27 July	6.56	0.11	98.3
3 August	6.86	0.08	98.8
10 August	3.89	0.13	96.6
17 August	0.46	0.146	68.3
Weekly			
11-15 July	12.0	1.6	87
16-22 July	41.2	1.1	97
23-29 July	17.6	0.8	95
30 July-5 August	14.1	0.6	96
6-12 August	18.1	0.9	95
13-19 August	13.8	0.8	94
Weekly avg	19.5	0.9	95
6-week			
	116.8	5.9	95

some land treatment systems has been shown to be limited by the supply of organic matter as an energy source (Crites 1976). The applied effluent in West Dover tends to be very low in organic matter. Thus, the importance of denitrification on the eastern slope is difficult to assess at this time.

Finally, nitrogen may be "removed" from the system by leakage through the fragipan. While this means would not represent true renovation by land treatment, it would appear as a net retention in the mass balance.

It should be noted that on 13 July a net export of nitrogen occurred from the eastern slope. On this day, rain was the only input to the site. This nitrogen loss from the spray site appears to have been due to a flushing effect and was observed similarly for all other parameters measured. Eighty percent of the nitrogen in this flush on 13 July was in the nitrate form.

Ammonia nitrogen

Table XIV and Figure 14 show an input/output analysis for ammonia nitrogen. Over the entire study period, 17.4 kg of ammonia nitrogen was applied to the eastern slope and 0.74 kg was measured in the interceptor ditch; this represented a difference of 96%. Daily differences ranged from 78 to 98%. On the average, 2.78 kg of ammonia nitrogen was not accounted for across the eastern slope each week and a total of 16.66 kg was not accounted for over the six-week study period.

While mass balances for ammonia nitrogen are rarely reported for land treatment systems, the reported concentrations in percolated water have been extremely low, as were concentrations detected in the ditch at West Dover (Iskandar et al. 1976, Norum 1976). Ammonia nitrogen concentrations in effluent at West Dover are very low and what does reach the eastern slope appears likely to be rapidly oxidized to nitrate. Furthermore, ammonia nitrogen is known to be strongly sorbed on soil colloids (Lance 1975, Iskandar et al. 1976). Thus, little ammonia nitrogen is expected to drain from the eastern slope.

Nitrate nitrogen

Table XV and Figure 15 show an input/output analysis of nitrate nitrogen. Over the study period, 52.3 kg of nitrate nitrogen was applied to the eastern slope and 4.4 kg left the slope in ditch flow. This represents a difference of 92%. Daily differences ranged from 62 to 98%. On the average, 8 kg of nitrate nitrogen was not accounted for across the eastern slope each week and a total of 47.9 kg over the six-week period.

Removal rates for nitrate nitrogen in West Dover are higher than those reported for other land treatment systems. Nitrate nitrogen removal rates of 0-46% were found in a spray irrigation system in Sunapee, New Hampshire (Frost et al. 1973). High nitrate nitrogen concentrations (0.6-26.5 mg/l) have been reported in percolates from many land treatment systems (Frost et al. 1973, Norum 1976, Iskandar et al. 1976). The nitrate nitrogen concentrations of 0.7 to 1.2 mg/l in drainage ditch water from the eastern slope were consistently low compared with the reported values.

On 13 July, a significant mass of nitrate nitrogen (as well as other materials) was exported from the eastern slope following a heavy rain. Since nitrate nitrogen is known to be a mobile anion, this is believed to represent a flushing action similar to flushing actions observed in other land treatment systems. Iskandar et al. (1976) reported significant leaching of nitrate nitrogen from test cells. Dugan et al. (1975) reported a noticeable washout of nitrate nitrogen with heavy precipitation.

Organic nitrogen

Table XVI and Figure 16 show mass balances of organic nitrogen (Kjeldahl minus ammonia). Over the study period, 46.8 kg of organic nitrogen was applied to the eastern slope and 0.81 kg was observed in the ditch flow. This represents a difference of 98%. Daily differences ranged from 82 to 100%. On the average, 7.66 kg of organic nitrogen was not accounted for across the eastern slope each week and a total of 45.99 kg was not accounted for during the six-week period.

Total phosphorus

Table XVII and Figure 17 show input/output analysis for total phosphorus. Over the study period, 75 kg of phosphorus was applied to the eastern slope and 0.24 kg of phosphorus was observed in the ditch flow. This represents a difference of more than 99%. Daily differences ranged from 98.5 to 100%. On the average, almost 12.5 kg of phosphorus was not accounted for across the eastern slope each week and more than 74 kg of phosphorus was retained over the six-week period.

Table XIV. Input/output analysis for ammonia nitrogen.

Daily	Applied (kg)	In ditch (kg)	Difference (%)
Daily			
13 July	0	0.03	
20 July	0.67	0.015	97.8
27 July	0.46	0.011	97.6
3 August	0.83	0.019	97.7
10 August	0.88	0.03	96.6
17 August	0.064	0.014	78.1
Weekly			
11-15 July	5.9	0.11	98
16-22 July	2.6	0.11	96
22-29 July	1.2	0.08	93
30 July-5 August	1.7	0.14	92
6-12 August	4.1	0.22	95
13-19 August	1.9	0.08	96
Weekly avg	2.9	0.12	95.9
6-week			
	17.4	0.74	96

Table XV. Input/output analysis for nitrate nitrogen.

Date	Applied (kg)	In ditch (kg)	Difference %)
Daily			
13 July	0	0.34	
20 July	4.72	0.10	97.9
27 July	2.37	0.08	96.6
3 August	2.64	0.07	97.3
10 August	2.27	0.08	64.8
17 August	0.32	0.12	62.5
Weekly			
11-15 July	1.8	1.3	28
16-22 July	18.6	0.7	96
23-29 July	6.4	0.6	91
30 July-5 August	5.4	0.5	91
6-12 August	10.5	0.6	94
13-19 August	9.6	0.7	93
Weekly avg	8.7	0.7	92
6-week			
	52.3	4.4	92

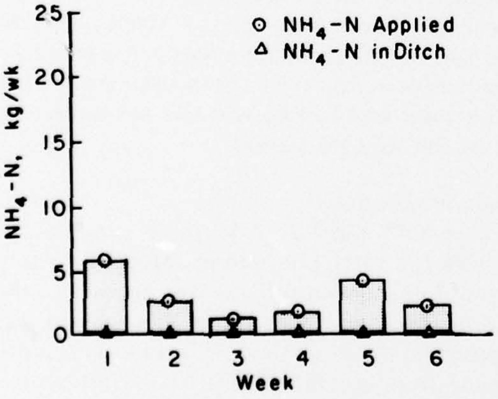


Figure 14. Input/output diagram for ammonia nitrogen.

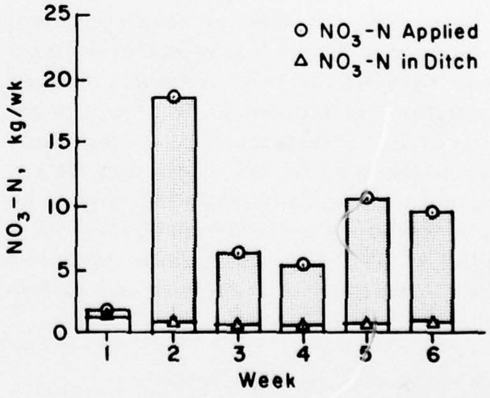


Figure 15. Input/output diagram for nitrate nitrogen.

Table XVI. Input/output analysis for organic nitrogen.

Date	Applied (kg)	In ditch (kg)	Difference (%)
Daily			
13 July	0	0.056	
20 July	5.05	0.03	99.4
27 July	3.73	0.022	99.4
3 August	3.39	0	100.0
10 August	0.74	0.02	97.3
17 August	0.076	0.014	81.6
Weekly			
11-15 July	4.3	0.22	95
16-22 July	19.9	0.21	99
23-29 July	10.0	0.16	98
30 July-5 August	6.9	0	100
6-12 August	3.4	0.14	96
13-19 August	2.3	0.08	96
Weekly avg	7.8	0.14	98
6-week			
	46.8	0.81	98

Table XVII. Input/output analysis for total phosphorus.

Date	Applied (kg)	In ditch (kg)	Difference (%)
Daily			
13 July	0	0.02	
20 July	7.75	0.007	99.9
27 July	3.05	0.007	99.8
3 August	3.73	0.006	99.8
10 August	1.86	0	100.0
17 August	0.41	0.006	98.5
Weekly			
11-15 July	7.8	0.06	99
16-22 July	30.6	0.05	99
23-29 July	8.3	0.05	99
30 July-5 August	7.6	0.04	99
6-12 August	8.5	0	100
13-19 August	12.2	0.03	99
Weekly avg	12.5	0.04	99
6-week			
	75	0.24	99

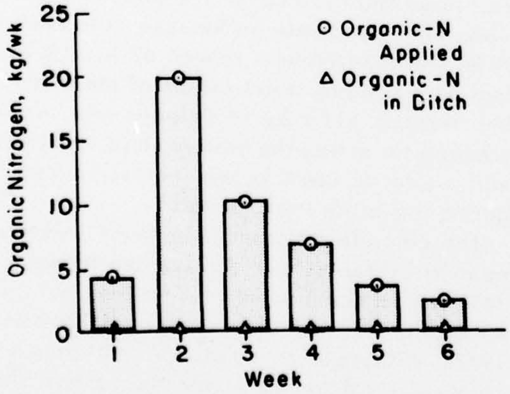


Figure 16. Input/output diagram for organic nitrogen.

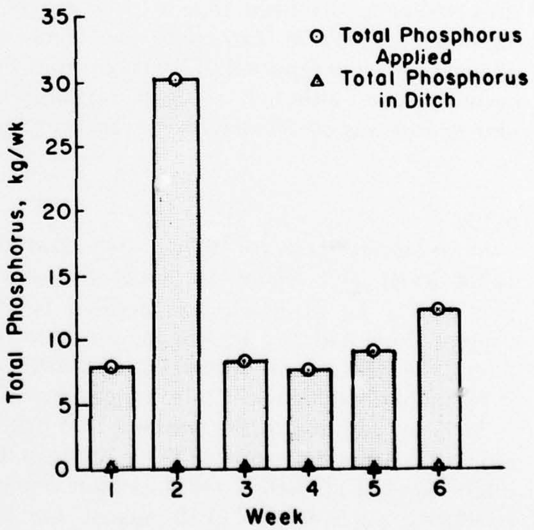


Figure 17. Input/output diagram for total phosphorus.

Similar differences for phosphorus are widely reported in the literature. In a Pennsylvania system, 97 to 99.6% of applied phosphorus was removed in the first 6 in. of soil (Kardos and Sopper 1973). Frost et al. (1973) reported 95 to 98% phosphorus removal in New Hampshire. Iskandar et al. (1976) observed phosphorus removal of 99.8 to 100% in test cells.

Phosphorus removal mechanisms are well documented in the literature. Soil fixation of phosphorus by sorption and mineralization are thought to be the most significant mechanisms of phosphorus removal in land treatment systems (Tofflemire and Chen 1977, Crites 1976). Plant uptake and biological immobilization are other important means of phosphorus retention. Ranges of tree uptake of phosphorus from 1.3-24 kg of P/ha-yr are reported in the literature (Gessel 1962, Kramer and Kozlowski 1960). At these rates, trees on the eastern slope could take up about 10.8-199.2 kg of phosphorus in one year. Weinstein (1976) reports phosphorus uptake of 1.23 g/m^2-yr in a spray irrigated forest in Sunapee, New Hampshire; this would amount to an uptake of about 102.1 kg P/yr on the eastern slope. Thus, on an annual basis, tree growth could account for about 25 to 50% of phosphorus retention on the West Dover site.

Leaching of phosphorus from land treatment sites has generally been shown to be minimal (Baillod et al. 1977). Extremely low levels of phosphorus were reported in drainage from the eastern slope, although a slight washout of phosphorus was observed with the rain on 13 July.

BOD_5

Input/output data for BOD_5 are shown in Table XVIII and Figure 18. Over the study period, 111 kg of BOD_5 was applied to the eastern slope and 23.5 kg was measured in the ditch flow. The overall difference for BOD_5 was 79% and daily differences rates ranged from 73 to 99%. In addition to the washout that occurred on 13 July, a net export of BOD_5 (more in the ditch than was applied to the slope) was observed during the week of 13-19 August. On the average, 14.6 kg BOD_5 was not accounted for across the eastern slope each week and a total of 87.5 kg of BOD_5 was not accounted for during the six-week period.

BOD_5 differences observed in West Dover were generally lower than values reported elsewhere in the literature. BOD_5 removals of 88 to 98% (Pound and Crites 1973) and more than 94% (Iskandar et al. 1976) have been observed in land treatment systems. The export of BOD_5 on 13 July and during the week of 13-19 August is unexplained, although rainfall washout was probably a contributing factor.

Total coliform

The concentration of total coliform bacteria was quite variable over the course of the study. The total coliform levels in the ditch flow often exceeded those in the effluent. Although bacteria removal in other land treatment systems has been observed to be essentially complete (Pound and Crites 1973, Iskandar et al. 1976), coliform organisms have been observed to regrow in the soil (Pound and Crites 1973, Crites 1976).

Animals have been known to contribute to the coliform export in land treatment systems. Percolates from test cells at CRREL have sometimes been contaminated by coliform organisms from animal activity (Schumacher, personal communication). Numerous deer and other animals have been observed on the West Dover spray field; coliform export from the eastern slope may reflect this activity, and in addition rapid overland flow across the site may contribute to this condition.

Chloride

An input/output analysis for chloride is given in Table XIX and Figure 19. Over the six weeks of study, 858.7 kg of chloride was applied to the east slope and 192.3 kg left the slope in the ditch flow. This represents an average difference of 78%. Daily differences ranged 82 to 93% with two days yielding a net export of chloride. On the average, 111.1 kg of chloride was not accounted for across the eastern slope each week and a total of 666.4 kg was not accounted for during the entire study period.

The chloride differences at West Dover appear to be fairly high. An average removal of 34% was reported in New Hampshire, but up to 80% chloride removal was recorded (Frost et al. 1973). Although a significant difference in chloride is calculated across the eastern slope on a mass basis, the mean effluent chloride concentration was 56.2 mg/l, while ditch flow averaged 37 mg/l, only a 34% reduction based on concentration.

Table XVIII. Input/output analysis for BOD_5.

Date	Applied (kg)	In ditch (kg)	Difference (%)
Daily			
13 July	0	0.28	
20 July	15.49	0.09	99.4
27 July	2.73	0.68	75.1
3 August	6.03	0.44	92.7
10 August	3.33	0.89	73.3
17 August	0.04	1.24	
Weekly			
11-15 July	13.5	1.1	92
16-22 July	61.2	0.6	99
23-29 July	7.4	4.9	34
30 July-5 August	12.4	3.3	73
6-12 August	15.4	6.6	57
13-19 August	1.1	7.0	
Weekly avg	18.5	3.9	79
6-week			
	111.0	23.5	79

Table XIX. Input/output analysis for chloride.

Date	Applied (kg)	In ditch (kg)	Difference (%)
Daily			
13 July	0	9.98	
20 July	80.2	5.68	92.9
27 July	53.2	4.22	92.1
3 August	50.1	3.41	93.2
10 August	20.0	3.59	82.0
17 August	3.63	5.4	
Weekly			
11-15 July	94.3	38.4	39
16-22 July	316.5	40.7	87
23-29 July	143.1	30.5	79
30 July-5 August	102.8	25.4	75
6-12 August	92.9	26.7	71
13-19 August	109.1	30.6	72
Weekly avg	143.1	32.0	78
6-week			
	858.7	192.3	78

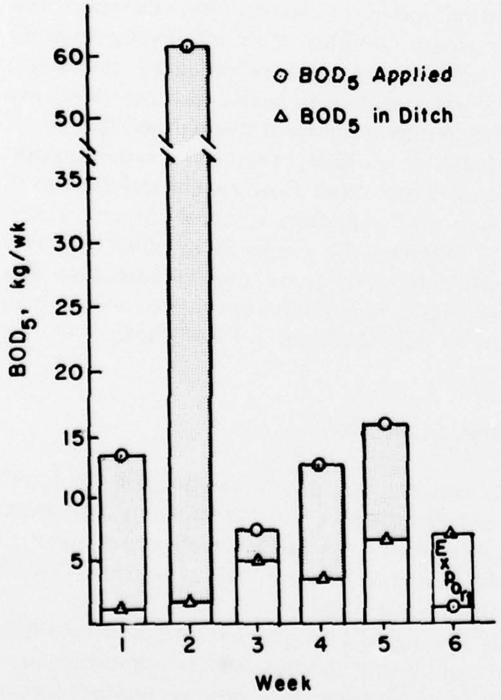


Figure 18. Input/output diagram for BOD_5.

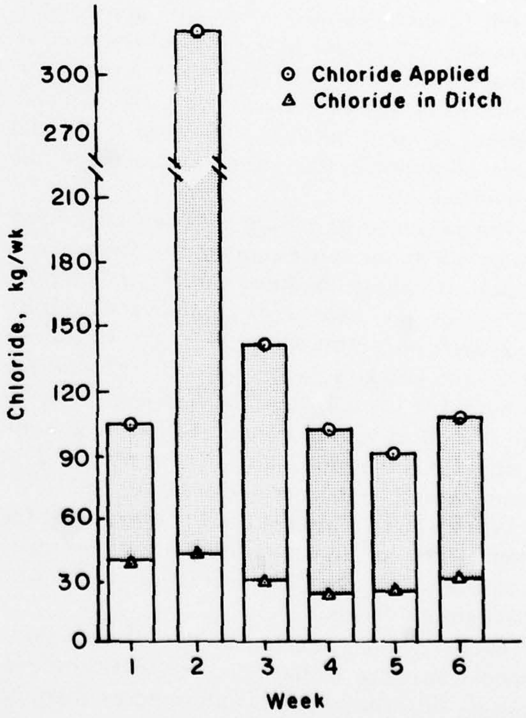


Figure 19. Input/output diagram for chloride.

Table XX. Summary—Input/output analysis.

Constituent	Mass applied (kg)	Mass in ditch flow (kg)	Difference (%)
Total nitrogen	116.8	5.9	95
NH_4-N	17.4	0.74	96
NO_3-N	52.3	4.4	92
Organic nitrogen	46.8	0.81	98
Total phosphorus	75.0	0.24	99
BOD_5	111.0	23.5	79
Chloride	858.7	192.3	78

Groundwater

Groundwater in the West Dover spray field generally contained very low concentrations of the measured constituents. Groundwater contained 15% of the BOD_5 levels of the effluent, 27% of the total nitrogen, less than 10% of the ammonia nitrogen, 55% of the nitrate nitrogen and 2% of the total phosphorus. These concentrations are comparable to levels found in the groundwater of other land treatment sites (Satterwhite and Stewart 1977, Urie 1973). Groundwater chloride concentrations were 70% of effluent concentrations and no appreciable amounts of ammonia nitrogen were detected in the observation wells. Groundwater in the observation wells generally contained higher concentrations of total nitrogen, nitrate nitrogen and total phosphorus than were measured in the ditch flow.

The presence of nitrate nitrogen in groundwater is a major concern in land treatment with regard to public health (Kardos and Sopper 1973). In no case did groundwater nitrate nitrogen concentrations in West Dover exceed the Safe Drinking Water Act of 1974 nitrate standard of 10 mg/l. Thus, there appears to be little hazard of nitrate contamination of groundwater from the study area. There are no data from control wells in the West Dover NBFD No. 1 Wastewater Treatment Facility that permit the comparison of the measured nitrate nitrogen concentrations in the observation wells with background levels.

Wells 2 and 3 located on the eastern slope tended to show higher levels of total nitrogen, nitrate nitrogen and total phosphorus than did well 6 on the western slope. On several occasions, surface runoff was observed in the immediate vicinity of wells 2 and 3; the area around well 2 was consistently wet. It seems possible, therefore, that surface runoff, subject to less treatment than subsurface water, may have directly entered the eastern slope wells. It is also interesting to note that total coliform levels of 70-110 colonies/100 ml were detected in wells 2 and 3, while none were found in well 6. This may also be due to surface water input to wells 2 and 3.

Surface water

Water quality data for the Deerfield River indicate little, if any, effects of the spray field. There were no significant differences in the concentrations of the measured constituents between the upstream and downstream sampling locations.

However, there is some indication that water quality in Ellis Brook is influenced by the treatment operation. Most parameters showed little increase between the upstream and downstream sampling points, but two constituents — conductivity and chlorides — showed definite increases in the downstream samples. Average conductivity was 25% higher in Ellis Brook downstream of the plant than upstream. Average chloride concentration showed a threefold increase between the upstream and downstream samples. It is interesting to note that both parameters are regarded as conservative constituents of water quality, relatively unaffected by movement through soil (Dugan et al. 1975). It is likely that this contamination resulted from ditch flow reaching Ellis Brook through the evaporation pond. Some of the water reaching the evaporation pond is known to infiltrate; it is quite conceivable that this water could reach Ellis Brook. No increase in nutrients was observed in Ellis Brook.

CONCLUSIONS

1. Flows in the interceptor ditch of the North Branch Fire District No. 1 Wastewater Treatment Facility were relatively constant in spite of highly variable effluent and precipitation inputs to the eastern slope.
2. During the study period, approximately 48% of the total spray and precipitation onto the eastern slope was not accounted for as either evapotranspiration or interceptor ditch flow. There the underlying fragipan layer must be highly fractured and/or discontinuous.

3. The total nitrogen and nitrate nitrogen concentrations exhibited strong positive correlations with the quantity of ditch flow, whereas the chloride concentration was inversely correlated to interceptor ditch flow. The total phosphorus concentration in the ditch flow was not correlated to ditch flow quantities.

4. The following are the differences between the mass sprayed onto the eastern slope and the mass in the interceptor ditch during the study period: total nitrogen 95%, ammonia nitrogen 96%, nitrate nitrogen 92%, organic nitrogen 98%, total phosphorus 99%, BOD_5 79%, and chloride 78%. (See Table XX.)

5. Heavy precipitation was observed to flush most nutrient forms, especially nitrate nitrogen, from the eastern slope.

6. Groundwater on the spray field contained nitrogen, phosphorus and BOD_5 concentrations much lower than those of the applied effluent. There was no evidence of hazardous nitrate nitrogen levels in the groundwater. However, possible contamination of observation wells by surface runoff was observed.

7. During the study period, water quality in the North Branch of the Deerfield River was unaffected by effluent application on the spray field.

LITERATURE CITED

Anderson, E.A., H.J. Greenan, R.Z. Whipkey and C.T. Machell (1977) NOAA-ARA Cooperative Snow Research Project — Watershed hydro-climatology and data for water years 1960-1974. U.S. Dept. of Commerce, U.S. Dept. of Agriculture, June.

Baillod, C.R., R.G. Waters, I.K. Iskandar and A. Uiga (1977) Preliminary evaluation of 88 years rapid infiltration of raw municipal sewage at Calumet, Michigan. In *Land as a Waste Management Alternative* (R.C. Loehr, Ed.), Ann Arbor Science, Ann Arbor Michigan.

Bouzoun, J.R. (1977) Land treatment of wastewater at West Dover, Vermont. CRREL Special Report 77-33. AD A035709.

Cassell, E.A. (1977) Existing information collection on the North Branch Fire District No. 1 Wastewater Treatment Facility. Report submitted to CRREL, January.

Clapp, C.E., D.R. Linden, W.E. Larson, G.C. Marten and J.R. Nylund (1977) Nitrogen removal from municipal wastewater effluent by a crop irrigation system. In *Land as a Waste Management Alternative* (R.C. Loehr, Ed.), Ann Arbor Science.

Crites, R.W. (1976) Land treatment of wastewater by infiltration-percolation. In *Land Treatment and Disposal of Municipal and Industrial Wastewater* (R.L. Sanks and T. Asano, Eds.), Ann Arbor Science.

Dugan, G.L., R.H.F. Young, L.S. Lau, P.C. Ekern and P.C.S. Lah (1975) Land disposal of wastewater in Hawaii. *J. Water Poll. Contr. Fed.*, vol. 47, no. 8, p. 2067-2087.

Follett, R.F., G.A. Reichman, E.J. Doering and L.C. Benz (1973) A nomograph for estimating evaportranspiration. *J. Soil and Water Cons.*, vol. 28, no. 2, p. 90-92.

Frost, T.P., R.E. Towne and H.J. Turner (1973) Spray irrigation project, Mt. Sunapee State Park, New Hampshire. In *Recycling Municipal Wastewater and Sludge Through Forest and Cropland* (W.E. Sopper and L.T. Kardos, Eds.), Pennsylvania State University Press, Pennsylvania State University, University Park, Pennsylvania.

Gessel, S.P. (1962) Progress and problems of mineral nutrition of forest trees. In *Tree growth* (T.T. Kazlowski, Ed.), Ronald Press.

Hook, J.E. and L.T. Kardos (1977) Nitrate relationships in the Penn State 'Living Filter' System. In *Land as a Waste Management Alternative* (R.C. Loehr, Ed.), Ann Arbor Science.

Iskandar, I.K., R.S. Sletten, D.C. Leggett and T.F. Jenkins (1976) Wastewater renovation by a prototype slow infiltration land treatment system. CRREL Report 76-19. ADA 029744.

Kardos, L.T. and W.E. Sopper (1973) Percolation of municipal wastewater through land disposal by spray irrigation. In *Recycling Municipal Wastewater and Sludge Through Forest and Cropland* (W.E. Sopper and L.T. Kardos, Eds.), Pennsylvania State University Press.

Kramer, P.J. and T.T. Kozlowski (1960) *Physiology of trees*. New York: McGraw-Hill.

Lance, J.C. (1975) Fate of nitrogen in sewage effluent applied to soil. *J. Irr. and Dr. Div., ASCE*, IR 3, p. 131-144.

Lull, H.W. (1968) A forest atlas of the northeast. Northeastern Forest Experiment Station, U.S. Department of Agriculture, Upper Darby, Pa.

Norum, E.M. (1976) Review of Muskegon County wastewater management system. In *Land Treatment and Disposal of Municipal and Industrial Wastewater* (R.L. Sanks and T. Asano, Eds.), Ann Arbor Science.

Pound, C.E. and R.W. Crites (1973) Wastewater treatment and reuse by land application, Volume II. Environmental Protection Agency, EPA-660/2-73-006B.

Robbins, H. and J.V. Ryzin (1975) *Introduction to statistics*. Science Research Associates, Inc.

Satterwhite, M.B. and G.L. Stewart (1977) Evaluation of an infiltration-percolation system for final treatment of primary sewage effluent in a New England environment. In *Land as a Waste Management Alternative* (R.C. Loehr, Ed.), Ann Arbor Science.

Schumacher, P., CRREL, personal communication.

Snedecor, G.W. and W.G. Cochran (1967) *Statistical methods*. Ames: The Iowa State University Press.

Tofflemire, T.J. and M. Chen (1977) Phosphate removal by sands and soils. In *Land as a Waste Management Alternative* (R.C. Loehr, Ed.), Ann Arbor Science.

U.S. Department of Agriculture (1973) *Soil survey interpretations*. Peru Soil Series, August, U.S. Department of Agriculture.

Weinstein, D.A. (1976) *The effects of spray irrigation on a mixed forest ecosystem*. M.S. Thesis, University of New Hampshire.

Urie, D.H. (1973) Phosphorus and nitrate levels in groundwater as related to irrigation of Jack Pine with sewage effluent. In *Recycling Treated Municipal Wastewater*

APPENDIX A: STATISTICAL ANALYSIS OF SAMPLING DAYS

Symbols

μ_0, σ, σ^2 represent the population mean, standard deviation, and variance respectively.
$\overline{X}, s, s^2$ represent the sample mean, standard deviation, and variance respectively.
n represents the number of observations in the sample.

RAINFALL

	Population	Sample
	15[*]	7[†]
Mean, in./day	0.45	0.60
Standard deviation, in./day	0.51	0.70
Variance (in./day)^2	0.26	0.48

Test of means

Hypothesis: The sample mean is the same as the population mean at the 1% level of significance.

$\alpha = 0.01$

$$z = \frac{\overline{X}-\mu_0}{\sigma/\sqrt{n}} = \frac{0.60-0.45}{0.51/\sqrt{7}} = 0.78$$

1% level of significance: $z < -2.58, z > 2.58$

$0.78 < 2.58.$

Cannot reject the hypothesis that $\overline{X} = \mu_0$.

Test of variance

Hypothesis: The sample variance is the same as the population variance at the 1% level of significance.

$\alpha = 0.01$

$$\frac{(n-1)s^2}{\chi^2_{\alpha/2,n-1}} < \sigma^2 < \frac{(n-1)s^2}{\chi^2_{1-\alpha/2,n-1}} \qquad \chi^2_{0.005,6} = 18.458 \quad \chi^2_{0.995,6} = 0.676$$

$$\frac{(6)(0.48)}{18.458} < \sigma^2 < \frac{(6)(0.48)}{0.676}$$

$$0.16 < \sigma^2 < 4.26 \qquad \sigma^2 = 0.26$$

---

[*] 15 is the number of days it rained during the study period.

[†] 7 is the number of days it rained during the study period when samples were taken.

$$\frac{(n-1)s^2}{\sigma^2} > \chi^2_{\alpha/2,n-1}$$

$$\frac{(6)(0.48)}{0.26} = 11.08, \quad \chi^2_{0.005,6} = 18.548$$

$$11.08 < 18.548$$

Cannot reject hypothesis that $s^2 = \sigma^2$.

Therefore, there was no significant difference between the amount it rained on days samples were taken and the amount it rained on all rainy days during the study period.

TEMPERATURE

	Population	Sample
	40*	18†
Mean, °F	73.2	72.5
Standard deviation, °F	7.0	5.6
Variance, (°F)^2	49.2	30.8

Test of means

Hypothesis: The sample mean is the same as the population mean at the 1% level of significance.

$$\alpha = 0.01$$

$$z = \frac{\overline{X}-\mu_0}{\sigma/\sqrt{n}} = \frac{72.5-73.2}{7.0-\sqrt{18}} = -0.42$$

1% level of significance: $z < -2.58, z > 2.58$

$$-0.42 > -2.58.$$

Cannot reject the hypothesis that $\overline{X} = \mu_0$.

Test of variance

Hypothesis: The sample variance is the same as the population variance at the 1% level of significance.

$$\alpha = 0.01$$

$$\frac{(n-1)s^2}{\chi^2_{\alpha/2,n-1}} < \sigma^2 < \frac{(n-1)s^2}{\chi^2_{1-\alpha/2,n-1}} \qquad \chi^2_{0.005,17} = 35.718$$

$$\chi^2_{0.995,17} = 5.697$$

$$\frac{(17)(30.8)}{35.718} < \sigma^2 < \frac{(17)(30.8)}{5.697}$$

$$14.66 < \sigma^2 < 91.91 \qquad \sigma^2 = 49.2$$

$$\frac{(n-1)s^2}{\sigma^2} > \chi^2_{\alpha/2,n-1}$$

---

* 40 is the total number of days during the study period.

† 18 is the number of days samples were taken.

$$\frac{(17)(30.8)}{49.2} = 10.64, \chi^2_{0.005,17} = 35.718$$

$10.64 < 35.718.$

Cannot reject hypothesis that $s^2 = \sigma^2$.

Therefore, there was no significant difference between the average daily temperature during the entire study period and the average daily temperature on days samples were taken.

SPRAY VOLUME APPLIED TO THE EASTERN SLOPE

	Population	Sample
	31*	18†
Mean, gal x 10^3/day	138.37	136.16
Standard deviation, gal x 10^3/day	128.50	142.44
Variance, (gal x 10^3/day)^2	16,513.4	20,289.6

Test of means

Hypothesis: The sample mean is the same as the population mean at the 1% level of significance.

$\alpha = 0.01$

$$z = \frac{\bar{X}-\mu_0}{\sigma/\sqrt{n}} = \frac{136.16-138.37}{128.50/\sqrt{18}} = -0.07$$

1% level of significance: $z < -2.58, z > 2.58$

$-0.07 > -2.58.$

Cannot reject the hypothesis that $\bar{X} = \mu_0$.

Test of variance

Hypothesis: The sample variance is the same as the population variance at the 1% level of significance.

$\alpha = 0.01$

$$\frac{(n-1)s^2}{\chi^2_{\alpha/2,n-1}} < \sigma^2 < \frac{(n-1)s^2}{\chi^2_{1-\alpha/2,n-1}} \qquad \chi^2_{0.005,17} = 35.718 \quad \chi^2_{0.995,17} = 5.697$$

$$\frac{(17)(20,289.6)}{35.718} < \sigma^2 < \frac{(17)(20,289.6)}{5.697}$$

$$9,657 < \sigma^2 < 60,545 \qquad \sigma^2 = 24,285$$

$$\frac{(n-1)s^2}{\sigma^2} > \chi^2_{\alpha/2,n-1}$$

---

* 31 is the number of days water was applied to the eastern slope during the entire study.

† 18 is the number of days samples were taken.

$$\frac{(17)(20{,}289.6)}{16{,}513.4} = 20.9,\ \chi^2_{0.005,17} = 35.718$$

$20.9 < 35.718.$

Cannot reject hypothesis that $s^2 = \sigma^2$.

Therefore, there was no significant difference between the average daily volume of water applied to the eastern slope during the entire study period and the average daily volume of water applied to the eastern slope on sampling days.

APPENDIX B: PLANT OPERATION DATA, 11 JULY TO 19 AUGUST 1977

Date	Total spray vol. (gal.)	Lines in operation	Times in operation	Mode†	Rainfall (in.)	Temp. (°F)			General weather
						Mean	Max	Min	
11 July	238,000	5,6,8,9	0800-1230	M	0.27	74	96	53	Clear
12 July*	0			–	0.11	68	89	48	Overcast, rain
13 July*	0			–	0.99	74	93	56	Overcast, rain
14 July*	0			–	0	78	97	58	Clear
15 July	310,000	5,6,8,9	0430-1030	M	0	70			Sunny
16 July	0			–	0.2	74			Overcast
17 July	0			–	0.4	76			Overcast
18 July	345,000	5,6,8,9	0415-1000	M	0	78			Sunny
19 July*	410,000	5,6,8,9	0400-0915	M	0	81			Sunny
20 July*	448,000	5,6,8	0400-0820	M	0	71			Sunny
21 July*	396,000	7,8,9,10	0800-1445	M	0.20	70	91	49	Sunny
22 July	400,000	7,8,9,10	0900-1515	M	0	80	104	56	Sunny
23 July	102,000	7,8,9,10	0810-1050	M	0	62			Sunny
24 July	104,000	7,8,9,10	0800-1040	M	0	78			Sunny
25 July	0			–	0.80	91	109	74	Heavy rain
26 July*	391,000	7,8,9,10	0830-1500	M	0	80	104	56	Clear
27 July*	403,000	7,8,9,10	0815-1615	M	0	66	92	40	Sunny
28 July*	17,000	7,8,9,10	0820-0900	M	0	59			Clear
29 July	147,000	9,10,11	0850-1600	A	0	63	90	36	Clear
30 July	0		.	–	0	66	95	36	Overcast
31 July	0			–	0	68	94	43	Sunny
1 August	0				0	78	100	57	Cloudy
2 August*	53,000	9,10,11	1025-1615	A	2.0	71	86	56	Clear
3 August*	404,000	5-12	0820-1600	A	0	75	102	48	Cloudy
4 August*	163,000	5-8	0810-1625	A	0	76	94	57	Cloudy
5 August	199,000	5-12	0845-1645	A	0.60	78	98	57	Clear
6 August	58,000	5-12	0905-1100	A	0.01	74			Overcast
7 August	47,000	5-12	0910-1055	A	0	84			Overcast
8 August	319,000	5-8	0840-1605	A	0.05	80	98	63	Overcast
		9-12	1030-1605						
9 August*	262,000	5-12	0830-1615	A	0	70	92	48	Cloudy
10 August*	244,000	5-12	0745-1445	A	0.60	81	98	64	Cloudy
11 August*	130,000	5-12	1045-1600	A	0	73	86	60	Clear
12 August	101,000	5-12	0710-1755	A	0.25	80	99	62	Overcast
13 August	55,000	5-12	0915-1055	A	0	65	82	48	Clear
14 August	61,000	5-12	0910-1050	A	0	76	88	64	Clear
15 August	299,000	5-12	0900-1110	M	0	69	88	50	Clear
			1110-1615	A					
16 August*	400,000	5-12	0845-1535	M	0.20	72	97	46	Overcast
17 August*	18,000	9	1105-1430	M	0.12	72	82	62	Overcast
18 August*	164,000	5-12	0805-1625	A	0	68	84	52	Clear
19 August	179,000	5-12	0930-1600	A	0	57	78	36	Clear

* Denotes days samples were taken.

† M = manual; A = automatic.

APPENDIX C: EXAMPLE OF DITCH FLOW PRINTOUT

```
 13 00  07 13   T
006312  00195

 14 00  07 13   T
006493  00131

 15 00  07 13   T
006665  00172

 16 00  07 13   T
006826  00161

 17 00  07 13   T
007242  00416

 18 00  07 13   T
008829  01587

 19 00  07 13   T
010264  01435

 20 00  07 13   T
011122  00858

 21 00  07 13   T
011791  00669

 22 00  07 13   T
012369  00578

 23 00  07 13   T
012839  00520

 00 00  07 14   T
013369  00430

 01 00  07 14   T
013817  00448

 02 00  07 14   T
014242  00425

 03 00  07 14   T
014647  00405

 04 00  07 14   T
015037  00390

 05 00  07 14   T
015413  00376

 06 00  07 14   T
015776  00363

 07 00  07 14   T
016127  00351
```

```
 13 00  07 20   T
003477  00011

 13 26  07 20   S
003558  00081

 13 56  07 20   S
003655  00097

 14 00  07 20   T
003667  00012

 14 26  07 20   S
003753  00061

 14 56  07 20   S
003862  00104

 15 00  07 20   T
003875  00013

 15 26  07 20   S
003970  00095

 15 56  07 20   S
004033  00113

 16 00  07 20   T
004097  00014

 16 26  07 20   S
004207  00110

 16 56  07 20   S
004338  00131

 17 00  07 20   T
004354  00016

 17 26  07 20   S
004473  00119

 17 56  07 20   S
004607  00134

 18 00  07 20   T
004622  00015

 18 26  07 20   S
004731  00109

 18 56  07 20   S
004845  00114

 19 00  07 20   T
004859  00014
```

```
 19 00  08 10
002746  00011

 19 42  08 10   S
002910  00164

 20 00  08 10   T
002975  00065

 20 27  08 10   S
003071  00096

 21 00  08 10   T
003184  00113

 21 12  08 10   S
003225  00041

 21 57  08 10   S
003377  00152

 22 00  08 10   T ← Timed print
003386  00009

 22 42  08 10   S
003542  00156
                     Time
 23 00  08 10   T ← Date
003630  00088 ←      Incremental
                       Flow
 23 27  08 10   S    Totalized
003806  00176          Flow

 00 00  08 11   T
004065  00259

 00 12  08 11   S ← Sample print
004165  00100

 00 57  08 11   S
004516  00351

 01 00  08 11   T
004536  00020

 01 42  08 11   S
004819  00283

 02 00  08 11   T
004928  00109

 02 27  08 11   S
005036  00153

 03 00  08 11   T
005266  00130
```

APPENDIX D: WATER QUALITY DATA, 11 JULY TO 19 AUGUST 1977

Table D1. Effluent.*

Date	*Temp (°C)*	*pH*	*Conductivity (μmhos)*	*Total coliform (no./100 ml)*	*BOD$_5$*	*Total nitrogen*	*Kjeldahl-N*	*NH$_4$-N*	*NO$_3$-N*	*Total phosphorus*	*Chloride*
12 July	19	7.3	325	1,000	6.6	5.9	4.7	3.0	1.2	3.4	45.4
14 July	19	7.4	350	2,800	6.6	6.0	5.3	2.8	0.7	4.2	47.1
19 July	26	8.1	367	0	10.0	7.1	4.1	0.7	3.0	6.4	53.0
21 July	21	8.7	370	0	8.4	5.3	2.8	0.2	2.5	2.8	52.2
26 July	22.5	8.6	322	2,000	3.0	6.4	4.6	0.5	1.8	3.7	55.9
28 July	20	8.6	340	0	3.0	8.0	4.7	0.5	3.3	3.0	60.9
2 August	23	7.8	369	4,000	8.0	9.0	5.6	1.0	3.4	5.3	68.4
4 August	21	8.6	420	3,000	–	9.2	5.6	1.2	3.6	4.6	64.6
9 August	24	7.3	410	–	10.4	12.3	4.7	2.4	7.6	4.6	57.0
11 August	23	7.1	460	500	8.4	9.7	4.5	2.6	5.2	5.9	56.2
16 August	23	7.1	410	8,000	–	8.1	2.8	1.3	5.3	6.5	58.3
18 August	21	7.2	435	0	0.6	6.3	1.5	0.7	4.8	6.3	55.9

* All values are in milligrams per liter except as noted.

Table DII. Ditch composite.*

Date	*Temp (°C)*	*pH*	*Conductivity (μmhos)*	*Total coliform (no./100 ml)*	*BOD$_5$*	*Total nitrogen*	*Kjeldahl-N*	*NH$_4$-N*	*NO$_3$-N*	*Total phosphorus*†	*Chloride*
14 July	20	6.8	160	2,700	1.0	1.5	0.3	0.1	1.2	0.06	35.6
21 July	24	8.0	170	5,400	0.6	1.0	0.3	<0.1	0.7	0.05	38.6
28 July	17	7.9	160	1,400	6.0	1.0	0.3	0.1	0.7	0.06	37.5
4 August	19	7.1	170	**	4.7	0.9	0.2	0.2	0.7	0.06	36.2
11 August	19	7.0	170	**	9.2	1.3	0.5	0.3	0.8	0.00	37.0
18 August	18	6.5	165	**	8.5	1.0	0.2	<0.1	0.8	0.04	37.1

* All values are in milligrams per liter except as noted.

† Value of total phosphorus <1.0, Ortho-P value given.

** Too numerous to count.

Table DIII. Groundwater.*

Date	*Temp (°C)*	*pH*	*Conductivity (μmhos)*	*Total coliform (no./100 ml)*	*BOD$_5$*	*Total nitrogen*	*Kjeldahl-N*	*NH$_4$-N*	*NO$_3$-N*	*Total phosphorus*†	*Chloride*
Well 2											
21 July	18	6.4	210	80	2.3	2.2	0.6	<0.1	1.6	0.12	41.9
4 August	17	6.7	170	100	0.9	1.7	0.2	<0.1	1.5	0.11	37.0
18 August	14.5	6.2	160	70	0.6	<1.4	<0.1	<0.1	1.3	0.06	36.3
Well 3											
21 July	18	6.1	240	110	0.2	2.9	0.3	<0.1	2.6	0.12	39.9
4 August	16	6.4	200	**	0.9	3.9	0.2	0.2	3.7	0.09	36.3
18 August	15	6.1	200	110	1.0	<3.7	<0.1	<0.1	3.6	0.05	36.5
Well 6											
21 July	18	6.3	755	0	1.7	0.8	0.2	<0.1	0.6	0.05	44.1
4 August	18	6.5	175	0	0.9	1.0	0.2	0.2	0.8	0.08	41.7
18 August	13	6.3	165	0	0.7	<1.6	<0.1	<0.1	1.5	0.04	38.6

*All values are in milligrams per liter except as noted.

†Ortho-P.

** Too numerous to count.

Table DIV. Deerfield River.*

Date	Temp (°C)	pH	Conductivity (μmhos)	Total coliform (no./100 ml)	BOD_5	Total nitrogen	Kjeldahl-N	NH_4-N	NO_3-N	Total phosphorus†	Chloride
Upstream											
21 July	24	7.0	120	**	0.6	0.7	0.6	<0.1	0.1	0.11	21.6
4 August	22	6.8	100	520	0.6	0.4	0.2	<0.1	0.2	0.05	17.3
18 August	16	6.8	88	300	0.9	0.4	0.2	<0.1	0.2	0.04	16.2
Downstream											
21 July	27	7.0	120	**	0.4	0.7	0.6	<0.1	0.1	0.05	22.8
4 August	22	6.9	105	650	0.3	0.4	0.2	0.2	0.2	0.16	18.3
18 August	16	6.6	90	400	0.7	<0.2	<0.1	<0.1	0.1	0.04	16.8

* All values are in milligrams per liter except as noted.

† Ortho-P.

** Too numerous to count.

Table DV. Ellis Brook.*

Date	Temp (°C)	pH	Conductivity (μmhos)	Total coliform (no./100 ml)	BOD_5	Total nitrogen	Kjeldahl-N	NH_4-N	NO_3-N	Total phosphorus†	Chloride
Upstream											
21 July	27	7.7	39	**	0.0	0.4	0.2	<0.1	0.2	0.06	1.0
4 August	21	7.3	42	1,200	0.6	0.3	0.1	0.1	0.2	0.05	0.9
18 August	15	7.2	37	300	0.1	<0.3	<0.1	<0.1	0.2	0.02	0.6
Downstream											
21 July	28.5	7.2	55	**	0.1	0.4	0.2	<0.1	<0.2	0.06	3.5
4 August	22	7.2	49	800	0.5	<0.3	0.2	<0.1	<0.1	0.10	2.3
18 August	16	7.1	43	100	0.6	0.3	0.1	<0.1	0.2	0.04	1.6

* All values are in milligrams per liter except as noted.

† Ortho-P.

** Too numerous to count.