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A case study of land treatment in a cold climate—West Dover, Vermont

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A case study of land treatment in a cold climate — West Dover, Vermont

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

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A slow rate land treatment system that operates throughout the year in a very cold climate is described in detail. Information on the geology, soils, vegetation, wildlife and the climate at the site is also presented. Winter operational problems such as ice formation on the elevated spray laterals, and freezing and plugging of the spray nozzles are discussed, as are their solutions. The detailed results of a 1-year study to characterize the seasonal performance of the system, to develop N and P budgets for the system, to monitor specific hydrologic events on the spray field, to monitor shallow groundwater quality, to monitor the groundwater quality in off-site wells, and to monitor the water quality of two rivers that border the site are presented. Recommendations for the design and operation of other slow rate land treatment systems to be constructed in cold climates are included.

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PREFACE

This report was prepared by J.R. Bouzoun, Research Environmental Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory; D.W. Meals, Program Coordinator, and Dr. E.A. Cassell, Director, Vermont Water Resources Research Center at the University of Vermont, Burlington. Funding for this project was provided by the Corps of Engineers Civil Works Information Project CWIS 31634, *Develop Data to Update Design Manual for Land Treatment of Wastewater.*

C.J. Martel and G. Abele of CRREL technically reviewed the manuscript of this report.

The authors acknowledge the assistance of the following personnel, whose cooperation was essential to the success of this project: W. Bronson, chief operator of the West Dover Facility; S. Snyder and S. Illenye, field technicians with the Vermont Water Resources Research Center, for their efforts in collecting samples during periods of extreme weather and for their assistance in reducing the data; T.F. Jenkins and P. Schumacher, CRREL, for coordinating the sample delivery schedule and performing the nutrient and Cl analyses.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

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*
acre	4046.873	metre^2
foot	0.3048*	metre
foot^3	0.02831685	metre^3
foot^3/second	0.02831685	metre^3/second
gallon (U.S. liquid)	3.785412	litre
inch	25.4*	millimetre
pound (avoirdupois)	0.45359247*	kilogram
degrees Fahrenheit	$t_{°C} = (t_{°F} - 32)/1.8$	degrees Celsius

* Exact.

A CASE STUDY OF LAND TREATMENT IN A COLD CLIMATE – WEST DOVER, VERMONT

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

1. INTRODUCTION

J.R. Bouzoun

Together with soil infiltration rates, the volume of the storage ponds for slow rate land treatment systems has more impact on the costs of these systems than any other design decision the engineer must make. The result of increasing storage volume is shown in Figure 1. The example shown by the dashed line indicates that for a design flow of 3 mgd (million gallons per day) and a hydraulic loading rate of 1.5 in./week, a nonoperating time of 10 weeks results in a total land requirement of approximately 750 acres without a buffer zone. If the nonoperating time is increased to 20 weeks, the solid line in Figure 1 indicates that the total land area required increases to approximately 900 acres. The result of this increase in field area is a significant increase in both the capital costs and operating and maintenance costs, as shown in the U.S. Environmental Protection Agency (EPA) report on estimating the costs of land treatment systems (Reed et al. 1979). As a result of increasing the amount of storage, the costs of the pumping and distribution system, the storage pond, site clearing and field preparation, recovering the renovated water (if this is necessary or desirable), the monitoring wells, roads and fencing will all increase. All of these increases are directly related to increases in the size of the spray field area, which are related to the storage volume that is designed into the system.

The current design guidance for storage requirements is based on climatic parameters such as temperature, precipitation, and depth of snow cover. The National Oceanographic and Atmospheric Administration (NOAA) and the EPA have developed a set of computer models that predict storage requirements for land treatment systems based on these climatic data (EPA et al. 1981).

An example of this design guidance for storage, taken from the *Process Design Manual for Land Treatment of Municipal Wastewater* (EPA et al. 1981), is shown in Figure 2. Along the southern part of the New Hampshire-Vermont border, Figure 2 indicates that between 120 and 140 days of storage are required for overland flow and slow infiltration land treatment systems.

The North Branch Fire District Number 1 Wastewater Treatment Facility, in West Dover, Vermont, is located in this area. This slow rate land treatment system is atypical in that the wastewater flow during the winter is considerably higher than the summer flow, wastewater is applied to the land throughout most of the winter, and the system was constructed with only 33 days of storage capacity.

Because this system is one of the few slow rate systems operated during the winter in a very cold climate, an extensive research program was conducted to document its operation and its performance.

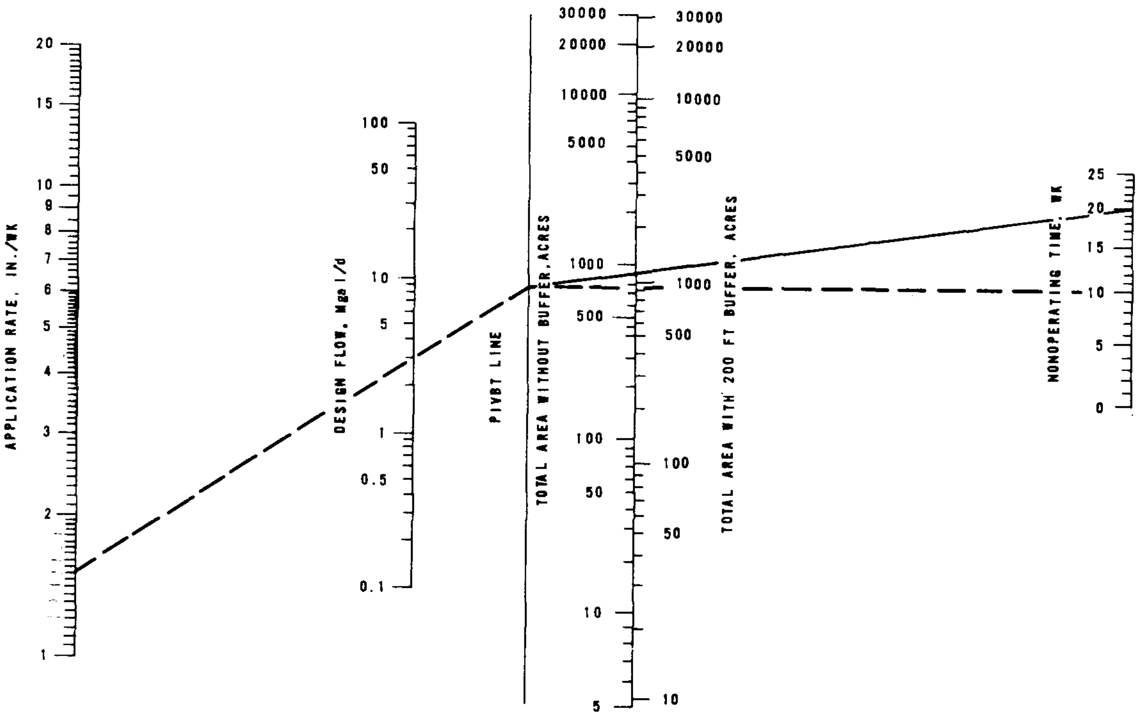


Figure 1. Total land requirement for slow rate land treatment systems—includes land for application, roads, storage and buildings (from EPA et al. 1977).

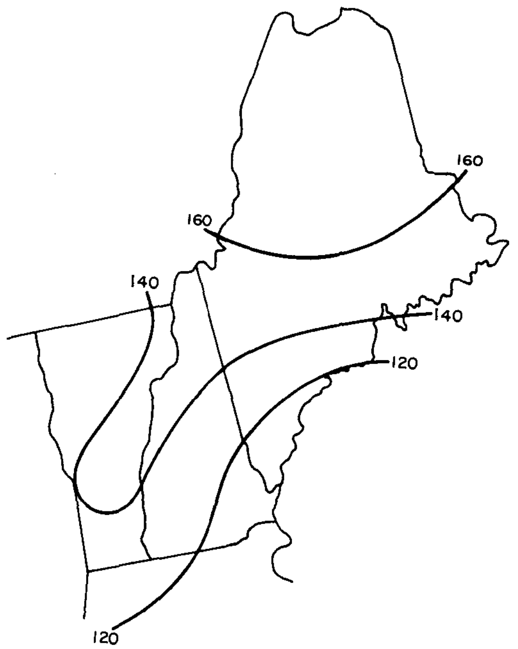


Figure 2. Estimated wastewater storage days, based on climatic factors only (after EPA et al. 1981).

PURPOSE

This document is a final report on the West Dover, Vermont, land treatment system. Specifically, this report will:

1. Provide a detailed description of the West Dover, Vermont, land treatment system and its method of operation.
2. Present information on the freezing problems associated with spray irrigation of wastewater at the site during the winter, and their solutions.
3. Present the results of an intensive 1-year study of the wastewater treatment capabilities of the system, with emphasis on the winter and the spring runoff period.

SCOPE

This report presents a synthesis of two previous reports written on the West Dover system (Bouzoun 1977, Bouzoun 1979) and also presents the results of a 1-year study conducted at the site by the Vermont Water Resources Research Center and sponsored by CRREL (Meals and Cassell 1980). During the Vermont Water Resources Research Center study, the site hydrology in response to spray and precipitation events was studied, organic and nutrient budgets of the site were developed for each season, shallow groundwater quality within the spray area was monitored, and the off-site impacts of the system were studied.

LITERATURE CITED

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

Bouzoun, J.R. (1979) Freezing problems associated with spray irrigation of wastewater during the winter. CRREL Special Report 79-12.

Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Agriculture (1977) Process design manual for land treatment of municipal wastewater. EPA 625/1-77-008 (COE EM 1110-1-501).

Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Interior, U.S. Department of Agriculture (1981) Process design manual for land treatment of municipal wastewater. EPA 625/1-81-013 (COE EM 1110-1-501).

Meals, D.W. and E.A. Cassell (1980) Spray application of wastewater in West Dover, Vermont: A case study of operation in a cold climate. Grant completion report prepared for CRREL (unpublished).

Reed, S.C., R.W. Crites, R.E. Thomas and A.B. Hais (1979) Cost of land treatment Systems. EPA-430/9-75-003.

2. DESCRIPTION OF TREATMENT FACILITY AND PROBLEMS WITH WINTER OPERATIONS

J.R. Bouzoun

WASTEWATER TREATMENT FACILITY

Background

The treatment facility that serves North Branch Fire District Number 1, located in the Township of Dover, Vermont, is about 14 miles north of the Vermont-Massachusetts border, and south-southeast of the village of West Dover (Fig. 3). The treatment facility encompasses about 80 acres and is bounded on the west by the North Branch of the Deerfield River and on the east by Ellis Brook. The maximum elevation at the site is 1717 ft above sea level, and the minimum elevation is approximately 1600 ft (Cassell 1977).

The climate of the region is classified as "cold temperate." The mean annual temperature of the Dover area is about 43°F. Average annual precipitation is approximately 55 in. and snowfall ranges in excess of 100 in. annually. On the average the area has around 120 days with snow cover per year and a frost-free period of about 90 days (Cassell 1977).

When a treatment plant was proposed for West Dover in 1972, high level treatment alternatives needed to be considered because on 27 May 1971 the Vermont Water Resources Board had adopted strict water quality controls. Rule 10 of these *Regulations Governing Water Classification and Control of Quality* (Vermont Water Resources Board 1971) establishes controls on discharges to "upland streams" and "pristine streams." Upland streams are defined as all those stretches upstream of the most upstream discharge of wastes from an existing municipal treatment plant, or upstream of a community sewer discharging wastes requiring treatment in a manner to be approved by the Department of Water Resources. Pristine streams are defined as those stretches of upland streams which flow above the 1500-ft elevation, or have a 7-day low flow (10 year return) of less than 1.5 ft^3/s. Discharges which may degrade, in any respect, the the quality of the receiving water are not permitted to enter pristine streams (Vermont Water Resources Board 1971).

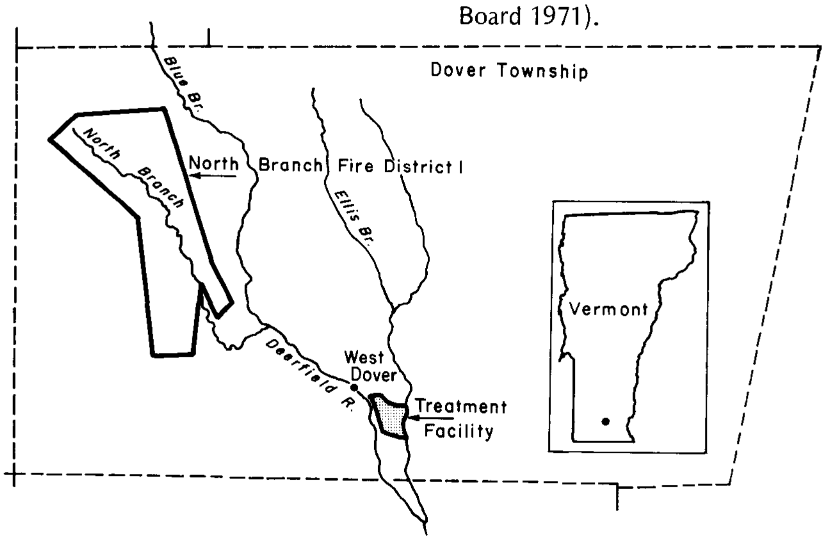


Figure 3. General location map.

The North Branch of the Deerfield River is considered pristine due to elevation at all points above the municipal treatment plant in the Village of Wilmington. Therefore, no discharge is allowed to Ellis Brook or the North Branch of the Deerfield River in the West Dover area, and off-stream disposal is necessary at the West Dover site. An alternative would have been to pipe the wastewater downstream of the existing Wilmington municipal discharge. The engineering firm retained by North Branch Fire District Number 1 studied this alternative, as well as land treatment and groundwater recharge, and concluded that land treatment was most economical (Dufresne-Henry 1972).

Design

The population of the district to be served by the system was very difficult to estimate because of the recreation industry in the area. The West Dover area currently has two major ski areas with related lodging and restaurants. There are also many private recreational residences, which are used primarily during the ski season, and permanent residences in this area. Also there are significant differences between the weekday and weekend-holiday population. Due to the recreational activities in the district, the engineering firm working for the district divided the population into three categories: commercial and transient people, overnight staff and guests, and residents. The design populations for the years 1972 and 1992 are summarized in Table 1.

The design unit flows are 10, 80 and 80 gallons per capita per day for commercial and transient people, overnight staff and guests, and residents respectively.

The computed wastewater flows, the five-day biochemical oxygen demand (BOD_5) and suspended solids loadings are broken down into winter, spring, summer and fall to indicate the anticipated seasonal variations (Table 2).

The wastewater generated throughout the district is pumped from the final collection point on State Route 100 to the treatment facility. This facility provides biological stabilization prior to spray irrigation. Figure 4 is a hydraulic schematic of the entire facility.

Table 1. Design population by category.

Year	*Commercial and transient*	*Overnight staff and guests*	*Residential*
1972	13,050	3230	2360
1992±	13,050	3230	5310*

*Projected 1992± residential population is based on an increase of 125% of present residential population.

Table 2. Design loadings summary.

	Initial (1974)	*Design (1992)*
Population equivalent		
Winter maximum day	7250	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
Primary influent, lb/day, avg. day		
Winter season	880	1380
Spring season	175	425
Summer-fall season	275	750
Primary influent, lb/day, winter maximum day	1460	2050
Biochemical oxygen demand		
Primary influent, mg/L	255	255
BOD loading, lb/day, avg. day		
Winter season	740	1170
Spring season	150	360
Summer-fall season	235	635
BOD loading, lb/day, winter maximum day	1205	1745

The headworks of the facility consist of a comminutor placed in parallel with a bar screen bypass channel, followed by a parshall flume and a flow proportioning structure. The headworks are designed for a flow range of 0.35 to 3.5 mgd. The flow proportioning structure controls the amount of flow going to each of the oxidation canals.

There are two orbital oxidation ditches, each 254 ft long with a 14-ft bottom width, a 28-ft top width and an average water depth of 6 ft. Each oxidation ditch has a 442,000-gal. capacity which provides approximately 24 hours of detention time at the winter average design flow. Based on a food-to-mass ratio of 0.06:1, normal recycle flow is estimated to be about 40% of the incoming flow. There are two 14-ft aerators in each canal. At 90 rpm and standard conditions, each rotor has a minimum oxygenation capacity of 50 lb of oxygen per hour when submerged

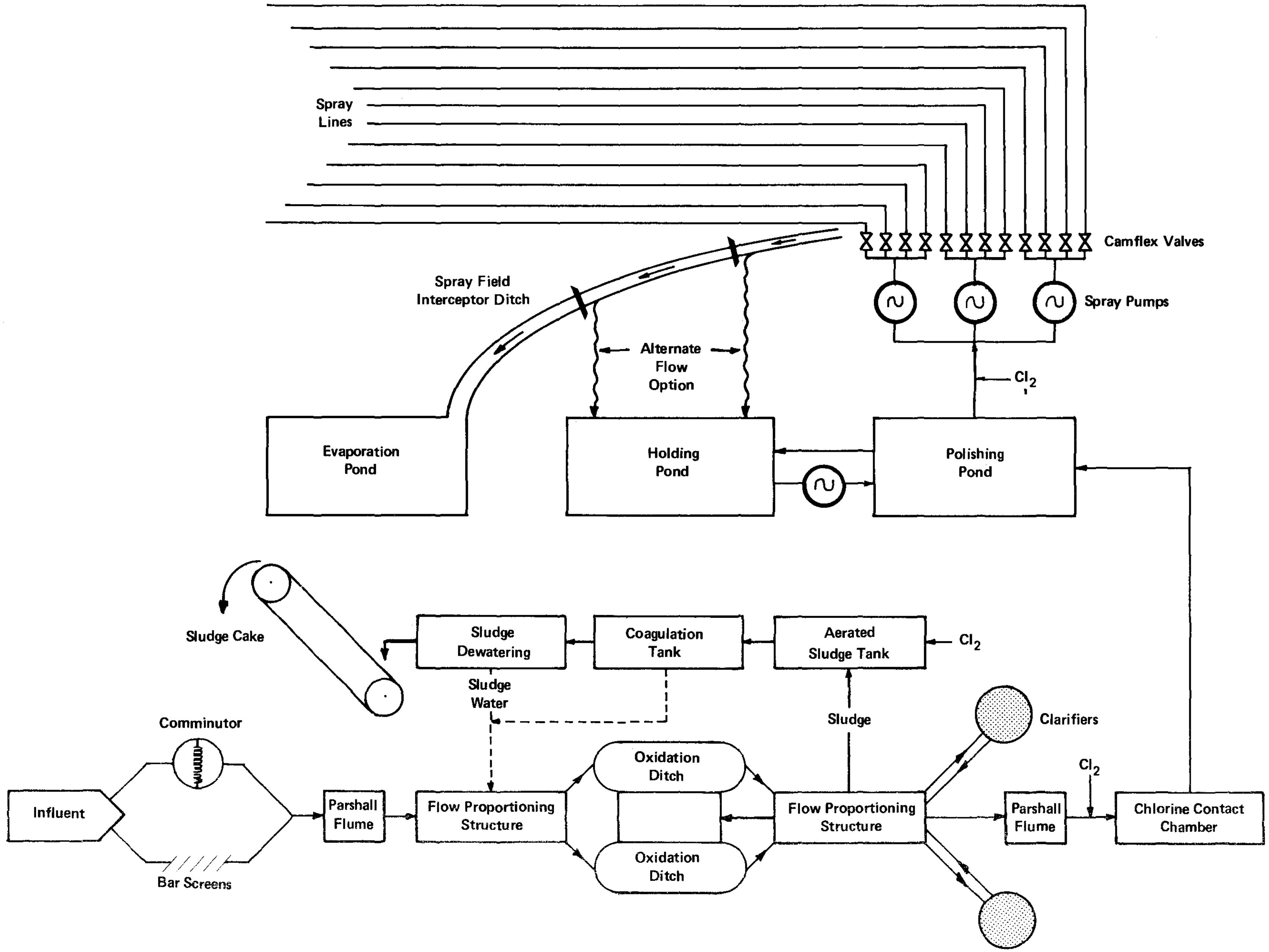


Figure 4. Hydraulic schematic of the West Dover waste treatment facility.

9 in. This is decreased to 17 lb/hr when the rotor is submerged 3 in. The rotors are designed to maintain a minimum velocity of 1 ft/s through the canals.

Each of the two secondary clarifiers is 42 ft in diameter and has a 10-ft side water depth. Each can hold 104,000 gal. and is designed with an overflow rate of 300 gal./day ft^{-2} at the maximum winter daily flow. The clarifiers can be used in tandem or separately, and each can receive flow from either oxidation canal.

The clay-lined polishing pond has a capacity of 2.2 x 10^6 gal., which gives a detention time of 4 days at the design winter average daily flow of 0.55 mgd. It has a maximum depth of 5 ft and surface area of 1.7 acres and stores the chlorinated secondary effluent from the clarifiers until it is sprayed. The overflow from the polishing pond passes by gravity through a pipe to a holding pond. The unlined holding pond was constructed over fragipan and has a capacity of 16 x 10^6 gal., which gives a detention time of 29 days. A pump is used to transfer water from the holding pond back into the polishing pond for application to the spray field. When both ponds are full, there are provisions for automatically starting the spray system to prevent overflowing.

The spray system includes the spray pumps, controls, and a network of spray laterals and nozzles in the spray field. A 12-in. suction line runs from the polishing pond to three pumps located in the basement of the control building. Each spray pump system consists of a 1/16-in. opening strainer, a 350-gal./min pump, an air-activated automatic control valve, a bypass line, and a transmitting flowmeter that monitors flow. Each spray pump discharges into a separate header which feeds four of the spray laterals on the spray field. Each spray header has an adjustable, automatically controlled Camflex spray valve with an accompanying automatically controlled header drain valve. The drain manifold is piped back into the polishing pond. All header lines run underground from the control building and through the center access trail of the spray site. Four spray laterals extend from each header in a north-south direction. The 12 spray laterals run parallel to each other, 75 ft apart, and follow the undulating contours of the spray site. Figure 5 is a profile view of a typical spray lateral. The spray laterals are suspended 5 to 15 ft above the ground and consist of 2- and 3-in. galvanized steel pipe insulated by a jacket of PVC pipe. Vegetation is cleared 5 to 10 ft from either side of each lateral. There are 66 low points in the system where 3/4-in. spray nozzles have been installed. These nozzles spray downwards and rapidly drain the laterals after each spray cycle. Two types of nozzles that spray upwards have been used at 50- and 25-ft centers on the rest of each spray lateral, depending on the season. Additional information on the spray nozzles and their operating characteristics will be presented later in this report.

The 3 spray pumps and 12 Camflex spray valves can be automatically or manually controlled from the operation panel. A timer system can be 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 laterals. At any given time each pump will distribute water to one lateral in a section. The flow to each lateral is determined by the number of nozzles on the lateral, the desired application rate, and the spray schedule. The pump flowmeter indicates the flow rate, which is controlled by adjustment of the Camflex valve. The timer is used to alternate between each lateral in the section and to control the amount of time each lateral is in use.

The spray site is located on a forested knoll west of the plant. This knoll is 1700 ft above sea level, about 2000 ft long and rises 100 ft above the plant site. The eastern side of this knoll slopes at an average of 8 to 15% toward the plant site. The western side slopes even more steeply (25%) into a Pleistocene valley cut by the North Branch of the Deerfield River. Figure 6 shows the relative positions of the spray site and the other unit processes at the facility.

There are approximately 34 acres of actual spray area covered by the laterals. A 200-ft buffer zone separates the spray area from the perimeter of the

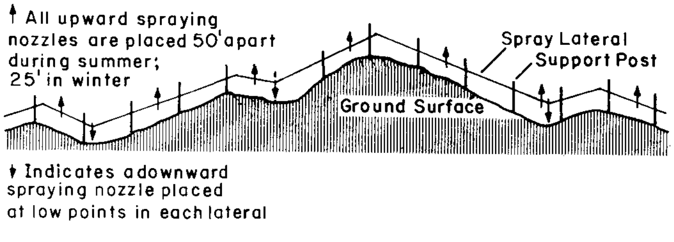


Figure 5. Cross section of a typical spray lateral (not to scale).

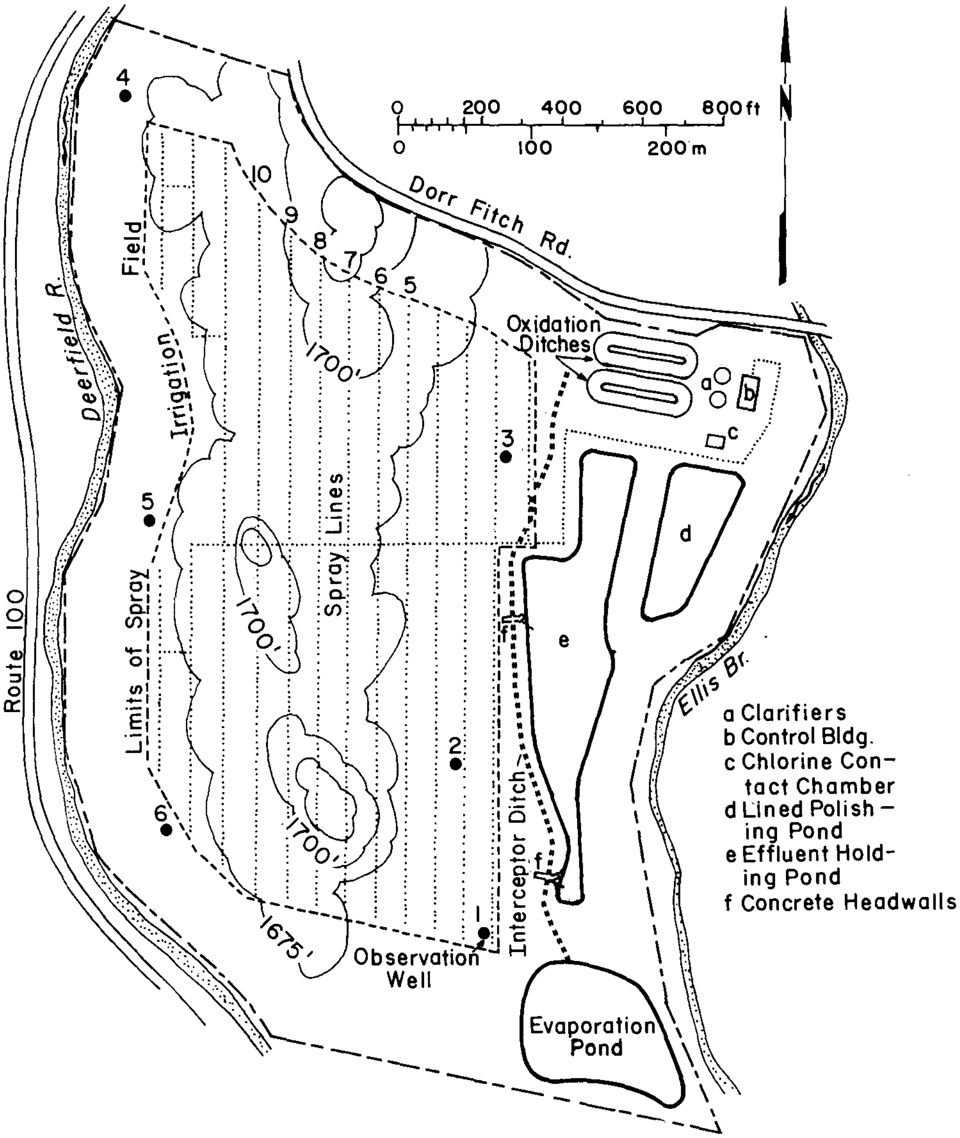


Figure 6. Relative position of various unit processes.

spray site, bringing the total area of the spray site to approximately 50 acres.

An interceptor trench runs southerly along the eastern perimeter of the spray field. The purpose of the interceptor trench is to prevent spray field runoff from entering the holding pond. Groundwater and surface runoff from the easterly sloping portion of the spray field are collected in the interceptor trench and flow by gravity to the evaporation pond. Two concrete headwalls are installed in the trench and can be used to divert flow back into the holding pond. These headwalls are also equipped with weirs so that the flow in the trench can be measured.

The evaporation pond is located on the southern edge of the site. It is approximately 300 ft square and is between 3.3 and 5 ft deep with a design volume of about 3.4×10^6 gal. The flow from the interceptor trench is collected in the evaporation pond where it can percolate into the ground.

Two identical solution-feed gas chlorinators, each with a maximum capacity of 300 lb of chlorine per day, can be used to feed a solution of chlorine and plant water to the headworks, the sludge return lines, the spray pump suction line, the sludge holding tank and the chlorine contact tank. Each chlorinator is a standby for the other. Gas is provided in 150-lb cylinders. The chlorine contact tank, divided into two identical compartments, is 31 ft long by 24 ft wide with a side water depth of 7.5 ft and is designed to provide a 19-minute contact time at the peak winter flow. There is a parshall flume for flow measurement immediately upstream of the chlorine contact chamber.

Chlorine solution feed rates can be manually or automatically set to feed in proportion to flow entering the chlorine contact tank. Automatic switching to mixed minimum feed rates for low flows is also possible. Normally, one chlorinator is used to chlorinate the chlorine contact chamber, and the second is used to chlorinate other points in the system. A total feed rate is set, and Rotameters are used to proportion the chlorine flow to the desired application points.

Geology

The Dover area lies on the eastern flank of the Green Mountain anticlinorium, an arched complex of folds. The Green Mountains were formed at the close of the Ordovician period about 425 million years ago. The anticlinorium consists of a central area of Precambrian metamorphic rocks—gneisses, schists, quartzites, and lime-silicate granulites—mantled by a lower Paleozoic sequence of volcanic rocks.

Only general information is available about the bedrock geology underlying the West Dover facility. The spray site is underlain by two major formations: Wilmington Gneiss and the Hoosac Formation.

Wilmington Gneiss, which underlies the southwestern portion of the spray site, is composed mainly of coarse gray, buff, and pink microclineaugen gneiss, with small quantities of quartzites, schists, and calc-silicate granulite. This formation is probably Precambrian.

The Hoosac Formation underlies the remainder of the spray site and consists mainly of medium to coarse-grained muscovite, chlorite, biotite, garnet, quartz schists, and interbedded amphibolites. Fossil evidence indicates a Lower Cambrian age. The Hoosac Formation ranges in thickness from 700 to 2000 ft.

Unconsolidated surface material deposited during the Pleistocene overlies the bedrock. The Dover area experienced two glaciations, separated and followed by periods of postglacial erosion and deposition. The Bennington Glacial Stade covered all New England and left behind surficial material known as Bennington glacial till. Bennington till is sandy and silty with very little clay. It is often very hard and most fragmented material is derived from the parent bedrock.

The Shelburne Glacial Stade occurred later, and extended southward approximately to Dover, Vermont. This glacial episode deposited material known as Shelburne drift in a thin veneer over the bedrock. Shelburne drift is predominantly an ablation till of loose sandy texture, with a high percentage of angular cobbles and boulders composed of local bedrock.

The surficial material covering the bedrock in the West Dover area is very thin. Based on well drillers' records since 1966, depth to bedrock ranges from 2 to 32 ft in the vicinity of the treatment site. The water well supplying the treatment facility is drilled into the shale which lies 28 ft below the ground surface. Bedrock is closer to the surface in the spray field, and several bedrock outcrops are visible on the upper slopes of the spray field.

Soils

Prior to design and construction of the West Dover facility there was no specific soil survey conducted at the site. However, the county soil survey map (SCS 1974) and the narrative soil report (SCS 1972) did include the spray field site. From these documents it was initially determined that the predominant soil type in the spray field was Peru/18 (Fig. 7). This soil is moderately well drained, and has a compacted glacial till layer (fragipan) that occurs from 15 to 30 in. below the surface. The density and texture of this fragipan layer is variable. Permeability of the soil above the fragipan is high in comparison to the permeability of the fragipan. Depth to the seasonal high water table is 1½ to 2 ft; however, a continuous saturated condition exists above the fragipan during wet seasons. Depth to bedrock is 4 to 10 ft or more. The dominant slope of the spray area on the east side is from 8 to 15%. The west side of the spray area has a slope greater than 25%.

The origin and distribution of the fragipan underlying the Peru soils on the spray site were unknown. A typical profile of the Peru soil is shown in Figure 8. Fragipan type 1 is the most common form in accurately mapped Peru soils. Fragipan type 2 is less common, while type 3 is poorly defined and occurs only in special cases of Peru soils.

Fragipan types 1 and 2 are more common on slopes of less than 25%. On slopes greater than 25%, type 3 (not a true fragipan) is far more common. Thus it was hypothesized that the east slope of the spray field had a well defined fragipan layer, while the west slope, draining toward the North Branch, lacked this impermeable layer.

The soils located in the spray area along the North Branch of the Deerfield River were originally classified as Windsor/14 gravelly subsoil series (Fig. 7). These soils are well drained and have developed from a sand that extends to a depth of about 23 in. Below 23 in. the soil material is coarse sand and gravel. The permeability of the soil is rapid to very rapid. Depth to water table and bedrock is typically 3 to 5 ft or more.

In the flood plain along Ellis Brook, well-drained Podunk/24 soil was mapped (Fig. 7). This soil

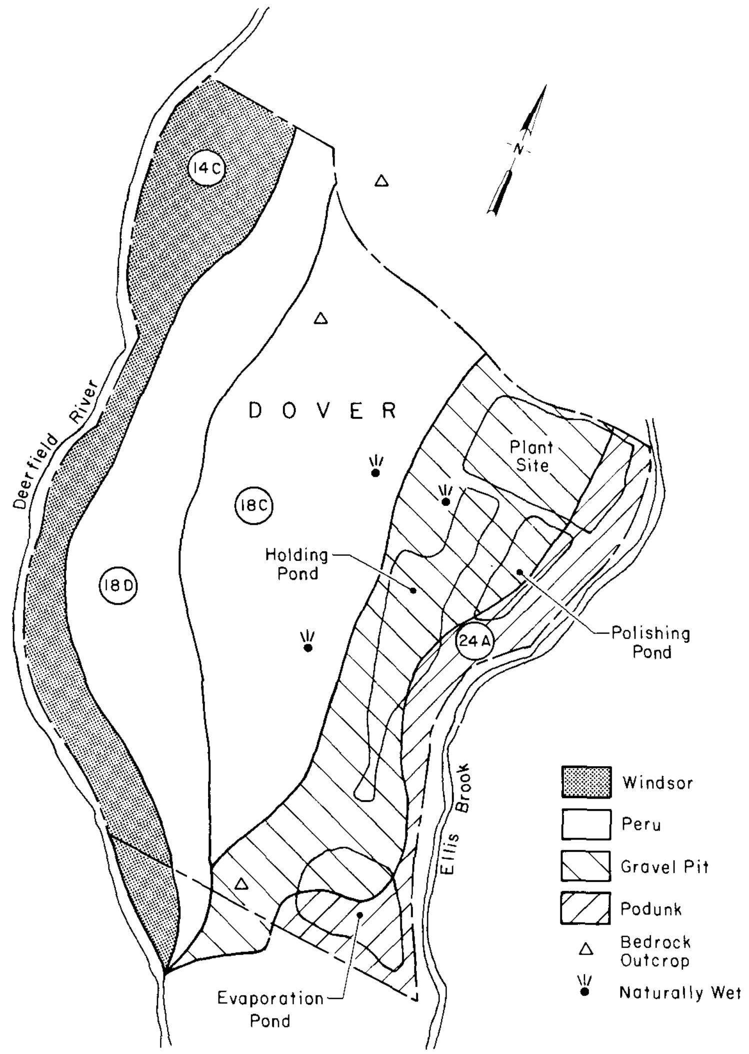


Figure 7. Original soils map of West Dover facility.

consists of a sandy loam material 28 to 36 in. deep. The permeability of this sandy loam is moderately rapid. Depth to seasonal water table is 1½ to 2½ ft, and depth to bedrock is typically greater than 5 ft.

It was hypothesized that the fragipan layer was relatively continuous on the eastern slope of the spray field and, therefore, would minimize the amount of deep percolation of any precipitation or applied wastewater. Instead, the applied wastewater or precipitation would move down through the soil until it reached the fragipan layer. Then, it would move laterally on the top of the fragipan until it flowed into the interceptor ditch that runs in a north-south direction along the eastern base of the spray field.

A water balance for the eastern slope of the spray field is described by the following equation:

$$Q_T - Q_{ET} - Q_D = Q_L$$

where

Q_T = total volume of wastewater and precipitation applied to the eastern slope
Q_{ET} = total volume of evapotranspiration
Q_D = total volume flowing through the ditch
Q_L = total volume of water not accounted for

During a 6 week study in July and August 1977, a water balance for the eastern slope was developed. The results are shown in the following equation (Cassell et al. 1979).

$$\begin{array}{ccccccc} Q_T & - & Q_{ET} & - & Q_D & = & Q_L \\ 1{,}078{,}809\ \text{ft}^3 & - & 380{,}000\ \text{ft}^3 & - & 183{,}525\ \text{ft}^3 & = & 515{,}284\ \text{ft}^3 \end{array}$$

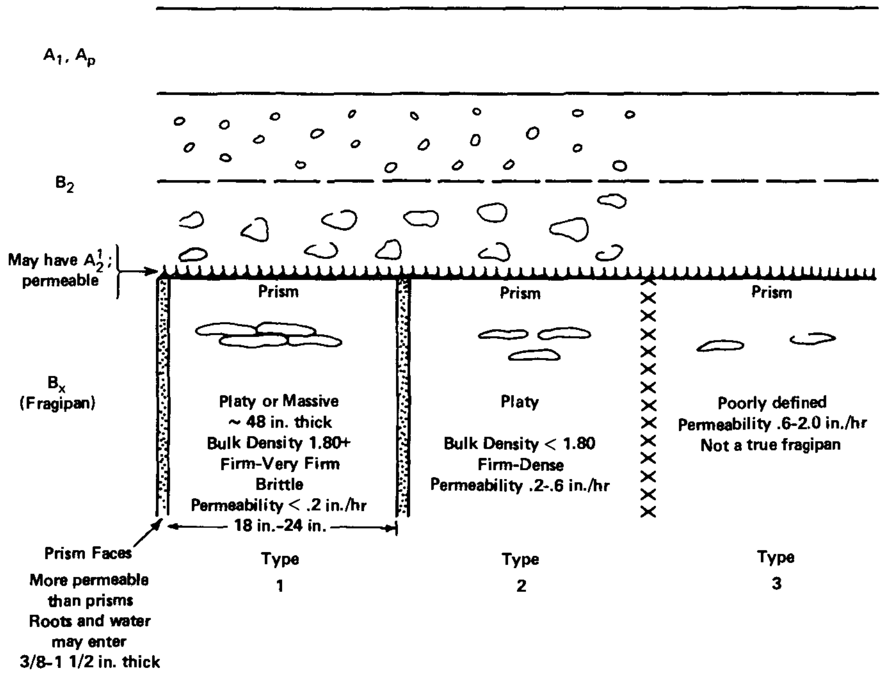


Figure 8. Typical profile of Peru soils with three fragipan types shown.

Figure 9. Detailed soils map of West Dover facility.

This shows that 47.8% of the total volume of wastewater and precipitation applied to the eastern slope of the spray site could not be accounted for. This indicated that the original hypothesis concerning the presence and integrity of the fragipan layer was probably incorrect.

A detailed soil survey of the spray field was conducted in October 1978 to specifically map the soils in the spray field and to determine the extent of the fragipan layer. The results of this detailed soil survey are shown in Figure 9 (Yost 1978).

The predominant soil in the spray field was identified as Berkshire fine sandy loam. The Berkshire soils are described as deep, well-drained soils that formed in glacial till, that have a permeability ranging from 0.6 to 6.0 in./hr throughout their entire profile, and that have no fragipan layer. This absence of a fragipan layer was confirmed by examination of test pits which were dug in conjunction with the soil survey.

Other soils present in the pray field were identified as Podunk and Walpole. The Podunk soils are deep, moderately well drained fine sandy loam soils on floodplains that formed in sandy alluvial sediments. Their permeability ranges from 0.6 to 6.0 in./hr in the surface layers to 2.0 to 20 in./hr in their deeper layers. Walpole soils are deep, somewhat poorly to poorly drained soils on terraces, with fine sandy loam in their surface layers and gravelly loamy sand in their substrata. They formed in glacial outwash and, like the Podunk soils, have a permeability that ranges from 2.0 to 20 in./hr.

The most important result of this soil survey was that it confirmed the lack of a fragipan layer beneath the east slope of the spray field. Therefore, deep percolation of the applied wastewater into the groundwater is not totally restricted.

Groundwater

Although no detailed groundwater investigations have been conducted in or near the spray site, available information indicates that the treatment facility is located in an area of significant groundwater activity. The Wilmington Gneiss underlying part of the spray site tends to be extensively fractured and thus has high groundwater potential. The major gravel deposit along Ellis Brook (Fig. 7) is a potential groundwater container. The North Branch of the Deerfield River and Ellis Brook may contribute to groundwater recharge. The spray site may also contribute to the flow of the North Branch from the west slope of the spray field or to Ellis Brook through the gravel underlying the plant site.

Studies by the U.S. Geological Survey and the Vermont Department of Water Resources suggest that the area near the western boundary of the treatment facility property along the North Branch is an area of moderate groundwater potential (Vermont Department of Water Resources 1968). This area is underlain by relatively thin deposits of coarse-grained stratified glacial drift and stream gravel. It is deemed suitable for shallow wells and infiltration galleries that should yield sufficient quantities of water for domestic, commercial, and light industrial use.

On-site observations support these suggestions of significant groundwater activity. Subsurface water was frequently encountered during construction of the treatment facilities, particularly near the oxidation canals and in the holding pond. Several natural springs have been observed on the east slope of the spray field. Plant personnel observed water flowing in the spray field interceptor trench even before spraying began.

High groundwater conditions exist in the spray field during the period of snow melt, usually for no more than 4 weeks.

According to information from the Vermont Department of Water Resources, 15 domestic water wells have been drilled near the facility since 1966. Depths of the wells range from 100 to 700 ft, with a median depth of 200 ft. Reported water yields range from 0.5 to 50 gpm (gallons per minute), with a median yield of 4 gpm. Wells with particularly high yields seem to be clustered around the facility site. The water well for the plant, drilled in March 1975 to a depth of 155 ft, yields 30 gpm. In the context of regional and local water wells, this is a high yield. Little water quality data exist for the wells. Since 1975, 12 samples from the treatment plant's well have been sent to the Vermont Department of Health for bacteriological analysis. All samples showed no detectable coliform bacteria.

Information is not available to determine the direction of groundwater movement or how streams are recharged in the site area. It is apparent that groundwater is flowing from the knoll where the spray field is located and the soil types along the North Branch and along Ellis Brook seem conducive to groundwater movement.

Vegetation and wildlife

There are no site-specific data on vegetation or wildlife for the treatment facility. About 90% of the spray field is forested. Approximately 40% of the spray area, primarily the eastern slope of the knoll, is forested with species of the northern hardwoods—maples, beeches, and birches. The understory consists of a fairly dense stand of balsam, spruce, and hemlock. Part of the hillside was at one time a sugarbush, as evidenced by light stands of 8 to 16-in. sugar maples. Some areas of the spray field are extensively populated by blackberry bushes, particularly near the base of the eastern slope.

More than half the forested area of the spray field is dominated by conifers—white spruce, spruce and fir—primarily along the crest and western slope of the knoll. These species dominate in the areas of thinnest, most acid soils, which are also subject to the most extreme microclimates. Trees and other vegetation were cleared from an area of 10 to 20 ft wide during placement of the spray lines.

The only information about wildlife is drawn from reports of local residents. Prior to construction, the area was often frequented by deer, although it was not regarded as a deer yard. In past years, a sizable fox population was noted in the area of the spray field. A 5-ft chain-link fence now surrounds the entire spray field and presents a major barrier to animal life in the area. Deer apparently use the area as a sanctuary of sorts from local dogs since, in the spring, deer can jump the fence while dogs can't.

Climate

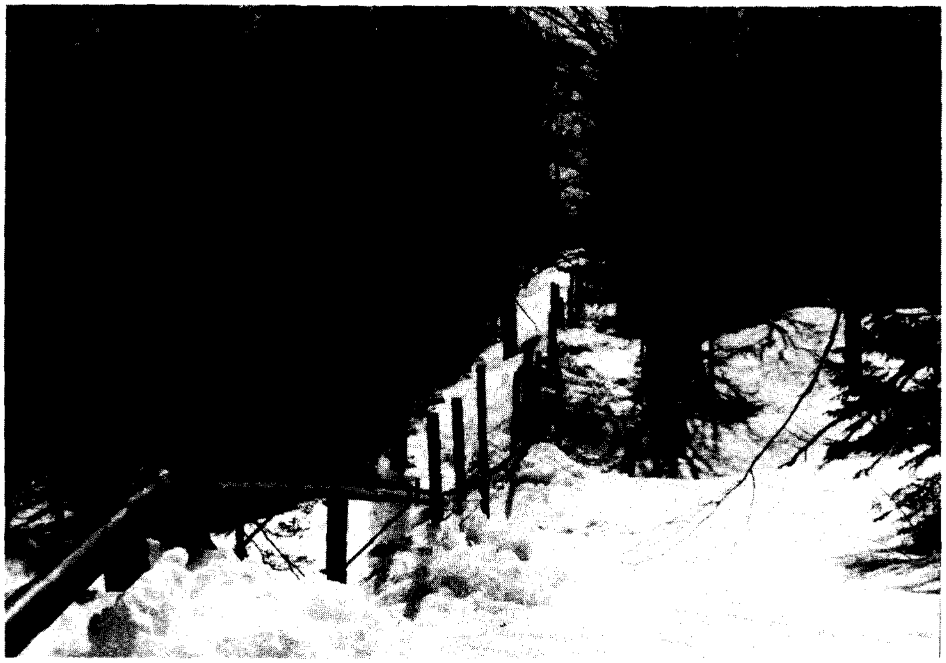
Because of its elevation and location east of the peaks of the Green Mountains, the Dover area experiences a climate similar to that of extreme northern Vermont. Adiabatic cooling of air masses rising across the Green Mountains causes high precipitation, with the annual amount averaging about 55 in. Although snowfall averages over 100 in. annually, 170 in. of snow fell in 1972.

Mean annual temperature for the Dover area is about 40 to 45°F. Frostfree periods average 60 to 90 days. The first fall freeze generally occurs in the last half of September and the last spring frost usually occurs in late May.

There are no compiled data for wind direction and velocity in the area. However, local observations suggest that the prevailing winds are from the northwest in winter and west or southwest in summer. Consequently, in winter exposure is likely to be greatest on west facing slopes and least on east facing slopes.

WINTER OPERATIONAL PROBLEMS AND SOLUTIONS

There are two methods of operating the spray system—automatic or manual. During automatic operation, a timer system is used to program the desired timing and selection of spray laterals. After one spray lateral has operated for a specified length of time, it automatically shuts off and the next one begins. During manual operation, the operator turns on the spray pump and adjusts the Camflex valve of the selected spray lateral. It will spray until the operator shuts it off.

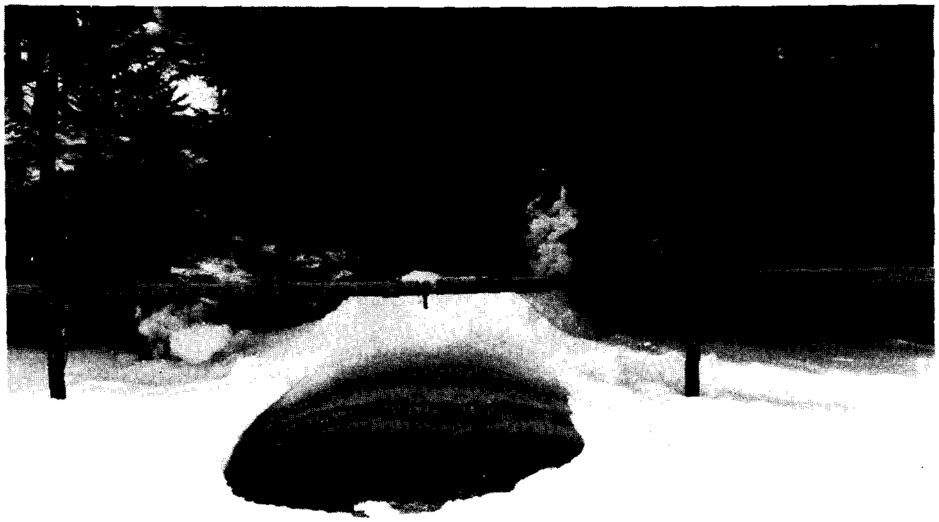


a. Lateral 7.

Figure 10. Typical spray laterals.

b. Lateral 9.

Figure 10 (cont'd).



a. Lateral 2.

Figure 11. Downward spraying nozzle.

b. Lateral 8.

Figure 11 (cont'd). Downward spraying nozzle.

Figure 10 shows two spray laterals during March 1978. Figure 5 is a cross section of a typical lateral. There are 66 low points in the system where, originally, 1/2-in. spray nozzles were installed. These nozzles spray downwards to rapidly drain the laterals after each spray cycle (Fig. 11). Originally, Buckner Turf King rotary sprinklers were installed every 50 ft along the spray laterals, except at the low points. Additional information on these nozzles and their operational characteristics is presented below.

Downward-spraying nozzles

Originally, Parasol 1/2 E40 nozzles, manufactured by the Spraying Systems Co., were installed at the 66 low points along the spray laterals. Their purpose was to drain the low sections of the spray lateral after completion of a spray cycle. During the first winter of operation (1975-76) it was found that Parasol nozzles effectively drained most of the wastewater within 1 hour of the completion of a spray cycle. However, a small quantity of wastewater continued to drip from these nozzles for several hours. This wastewater had a temperature of about 40°F when it was within the lateral, but it froze at ambient air temperatures as high as 27°F when it dripped out. During the next spraying cycle, the nozzles remained frozen and would not spray. The frozen nozzles became a problem at the end of a spray cycle because there was no way for the wastewater to drain from the low points in the laterals. The laterals were then susceptible to damage caused by the progressive freezing of the wastewater left in them.

Because of these problems the engineering firm of Dufresne-Henry of Springfield, Vermont, the system designer, conducted a special study (Dufresne-Henry 1976a). They evaluated several alternatives or partial solutions to the problem. Many alternatives were eliminated after an initial screening indicated they would be too expensive. Others were eliminated after field testing showed they did not alleviate the problem.

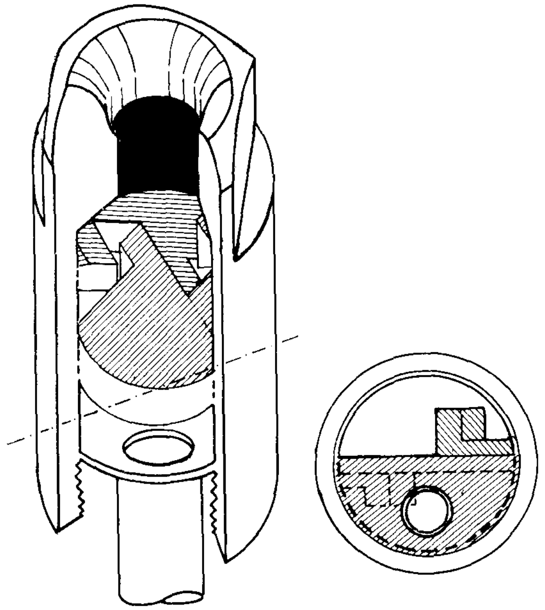
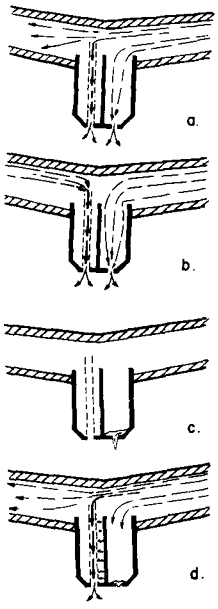


Figure 12. Modified Fulljet 3/4 HH6W nozzle.

After several tests, Dufresne-Henry recommended installation of modified Fulljet 3/4 HH6W nozzles, also manufactured by the Spraying Systems Co. This modified Fulljet nozzle contains two vanes, each of which can be isolated from the other. One of the vanes is fed through the body of the nozzle itself, and the other is fed through a 3/8-in. brass tube that extends upward out of the base of the spray nozzle (Fig. 12).

When the spray lateral is shut off, the wastewater drains by gravity through both vanes until the liquid level in the lateral reaches the top of the brass tube. At this point, liquid stops flowing through the vane fed by the tube. The other vane continues to drain. Because the liquid quickly passes by the entrance to the tube, the weeping action described previously does not occur and the vane remains open. The other vane is subject to weeping and may freeze shut during the final stages of drainage. However, when the lateral is brought back on line, liquid passes through the open vane and heat from the flowing liquid transfers through the brass partition separating the two vanes and quickly thaws the other, restoring the nozzle to normal operation (Fig. 13).

After installation of these modified nozzles, wastewater was sprayed at ambient air temperatures as low as 0°F. Dufresne-Henry also recommended that automatic alternating of spray lines not be practiced during the winter months in order to minimize operational difficulties. Instead, they recommended that the spray lines be used continuously over the course of the spray day (a spray day might be only a few hours).



Spraying.

Draining. Brass tube in left half drains quickly, until liquid level is below its top. Then only right half continues to drain.

Line drained. Small amount of ice has formed to block right half of nozzle. Brass tube is open and ready for next spray cycle.

Next spray cycle. Water initially sprays through the brass tube on the left side. The heat from the liquid melts the ice plug blocking the right half of the nozzle and spraying resumes in the normal manner as shown in a.

Figure 13. Operation of modified Fulljet 3/4 HH6W nozzle.

Upward-spraying nozzles

Originally, about 300 Buckner Turf King rotary sprinklers were installed as the high point nozzles for the system. Again, during the winter of 1975-76, these sprinklers had problems, and Dufresne-Henry conducted a special study to identify and correct them (Dufresne-Henry 1976b). They determined that the Buckner nozzles were unsatisfactory for use during winter operations because: 1) they were susceptible to freezing damage, 2) they plugged due to freezing, and 3) they required excessive maintenance because the nozzle had moving parts and because it had to be kept perfectly level.

They also noted that the spray diameter of the Buckner nozzles (55 to 65 ft) was significantly greater than the width of the corridor cleared along each spray lateral (10 to 20 ft). This resulted in a significant ice buildup on many of the trees along the spray laterals during the winter. In an effort to find a suitable winter replacement for the Buckner nozzles, Dufresne-Henry reviewed the available literature and selected several nozzles for on-site testing. As a result, they recommended that the Buckner nozzles, located every 50 ft along the spray laterals, be replaced with Fulljet 1/4 HH14W nozzles (manufactured by the Spraying Systems Co.) at 25-ft intervals.

The Fulljet nozzles were recommended because their application rate (0.275 in./hr) was very close to the design application rate of 0.25 in./hr. By placing the Fulljet nozzles at 25-ft intervals along each spray lateral, more than 600 of them were needed, as compared with approximately 300 Buckner nozzles. This was more than a 100% increase that offset the lower capacity of the Fulljet nozzles (6.20 gpm for the Buckner versus 2.75 gpm for the Fulljet), so the capacity of the new system with Fulljet nozzles was essentially the same as with the Buckner nozzles. As with the downward-spraying nozzles, there have been very few problems associated with the new nozzles during the winter.

Snow and ice buildup

After the problems with the nozzles had been solved and the system operated throughout the winters of 1976-77 and 1977-78, snow and ice buildup began to cause problems. This section discusses these difficulties and the method used by the operator to alleviate them.

As spraying continued throughout the winter, large amounts of snow and ice formed under the spray laterals, particularly within the spray circle of the nozzles. During the winter of 1977-78, only laterals 5 through 9 were used (see Fig. 6). Typically, the operator would operate two of these laterals all day. On the next day he would use two different laterals while he tried to remove the ice that had built up during the previous day. Although the operator worked hard to remove the ice from the laterals, a large amount did accumulate around the spray nozzles (Fig. 14). As these mounds continued to build, their weight actually caused sags in the spray laterals (Fig. 15). Because there was no way of draining them, these low points were susceptible to freezing and bursting, or plugging.

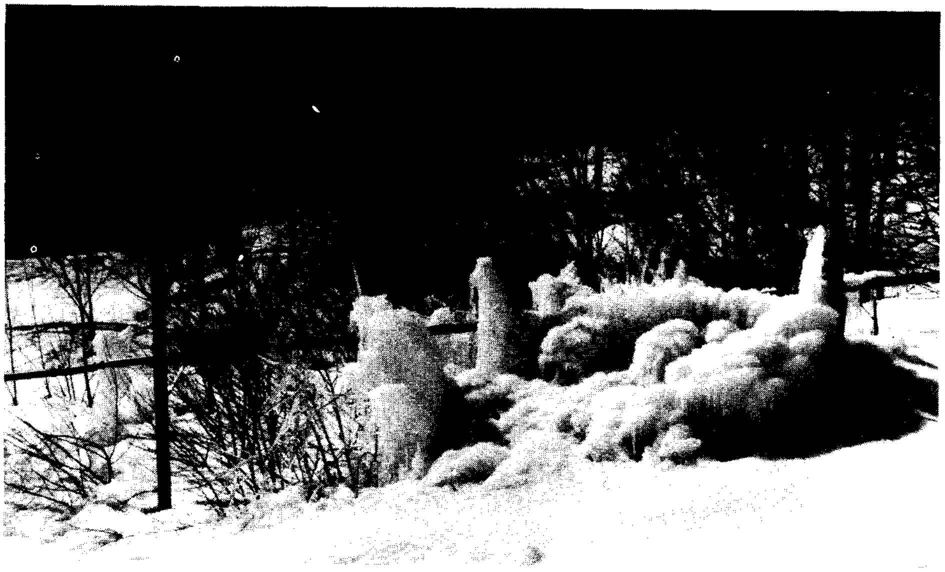


Figure 14. Snow and ice buildup near spray nozzle.

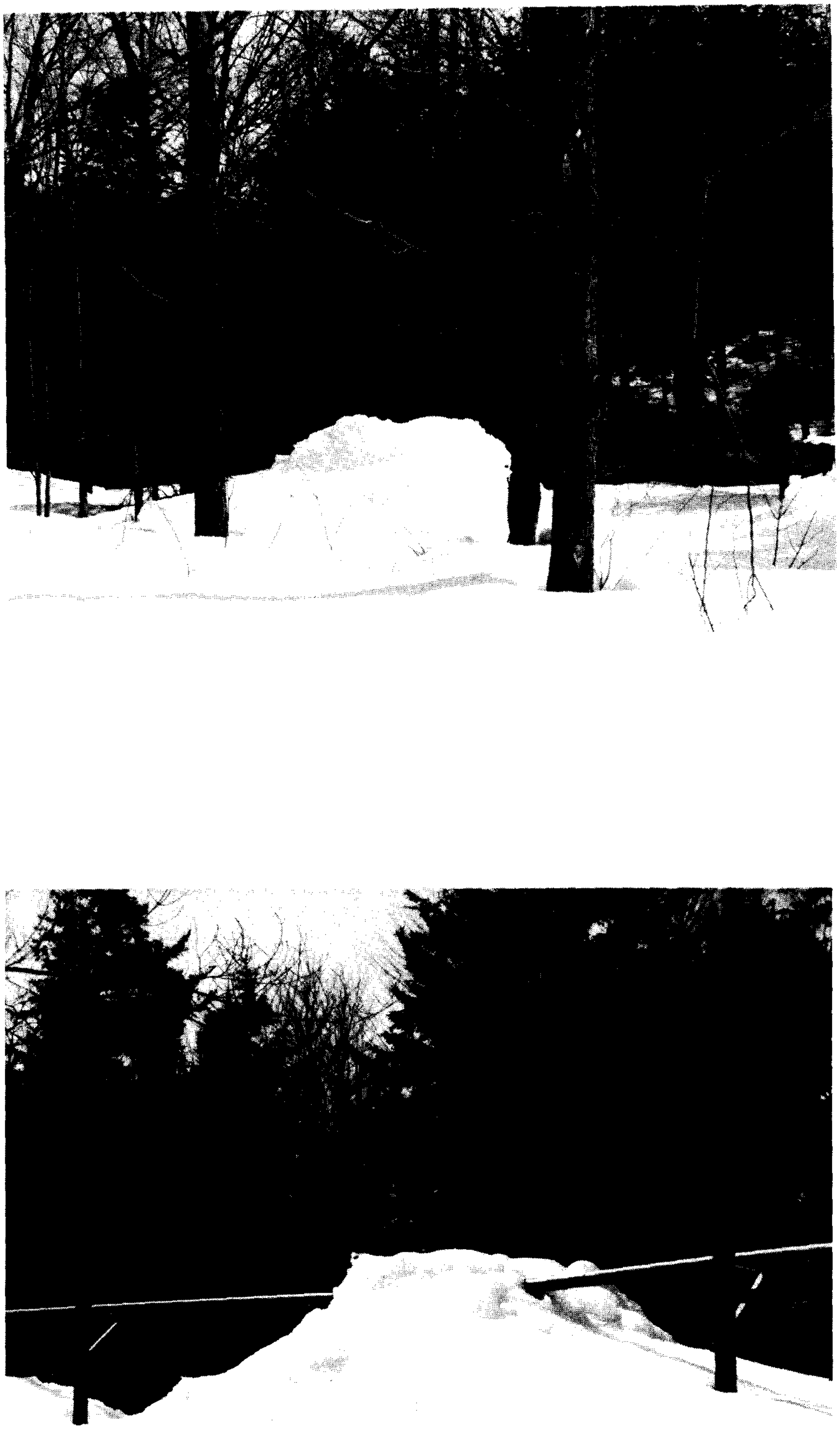


Figure 15. Sags in spray lateral 10.

b. Lateral 7.

Figure 16. Experimental risers on spray laterals.

To minimize the buildup of ice and snow on the laterals, the operator, acting on the recommendations of Dufresne-Henry (Dufresne-Henry 1977), removed the spray nozzle from the lateral and placed it on top of a copper riser, about 30 to 36 in. long. Angling the riser approximately 20 to 30 degrees from the vertical directed the spray away from the lateral. Figure 16 shows two of these experimental risers on spray laterals. The results were excellent, and the operator intends to install these risers along the entire length of several laterals. Also, he plans to have all the risers on one lateral lean towards the west and those on the next lateral lean towards the east. Then he can select laterals where the spray will not be blown back on them by the wind.

Recommendations

As a result of several winters' experience in spraying wastewater at ambient air temperatures as low as 0°F at West Dover, Vermont, it is recommended that the following be considered when designing a wastewater spray irrigation system to be used during the winter in cold climates.

1. Where possible, distribution laterals should be buried deep enough to protect them against freezing, and vertical risers should be insulated.
2. The risers should be high enough above the ground to ensure that they will not be buried by either naturally occurring snow or the snow and ice formed by spraying.
3. The risers should be reinforced to provide stability against the weight of ice and snow that may adhere to them.
4. Provisions should be made to back-drain both the risers and the distribution laterals after a spray cycle to prevent freezing.
5. If it is too expensive to bury the laterals and they are suspended above the ground, as at West Dover, the use of Fulljet nozzles, modified as discussed previously, at the low points in the line should be considered.
6. The use of risers at a sufficient angle to ensure that the spray does not freeze on the laterals should be considered when the laterals are above the ground.
7. The ability to manually start and stop spraying from specific laterals, as compared to spraying and draining many laterals several times per day, should be built into the system.
8. If the spray nozzle diameter is fixed by the wastewater application rate allowed at the site, and if the system is being built in a forested area, corridors cut for the spray laterals should be wide enough so that spray does not freeze to the trees.

LITERATURE CITED

Cassell, E.A. (1977) Existing information collection of the North Branch Fire District No. 1 wastewater treatment facility. Contract Report. CRREL.

Cassell, E.A., D.W. Meals and J.R. Bouzoun (1979) Spray application of wastewater effluent in West Dover, Vermont: An initial assessment. CRREL Special Report 79-6.

Dufresne-Henry Engineering Corp. (1972) Feasibility study on water pollution control facilities for expanded Fire District No. 1, Town of Dover, Vermont. Springfield, Vermont.

Dufresne-Henry Engineering Corp. (1976a) North Branch Fire District No. 1, West Dover, Vermont: Interim report on spray field alterations. Springfield, Vermont.

Dufresne-Henry Engineering Corp. (1976b) North Branch Fire District No. 1, West Dover, Vermont: Second interim report on spray field alterations. Springfield, Vermont.

Dufresne-Henry Engineering Corp. (1977) North Branch Fire District No. 1, West Dover, Vermont: Final report on spray field alterations (draft). Springfield, Vermont.

Soil Conservation Service (1972) Narrative soil report.

Soil Conservation Service (1974) General soil map, Windham County, Vermont.

Soil Conservation Service (1978) Detailed soil survey of West Dover land treatment site. Letter dated 25 October.

Vermont Department of Water Resources (1968) Groundwater favorability map of the West Deerfield River Basin. Montpelier.

Vermont Water Resources Board (1971) Regulations governing water classification and control of quality. Montpelier.

3. YEAR-ROUND STUDY OF TREATMENT FACILITY

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

PURPOSE

The purpose of the following year-round study was to assess the renovative ability of a slow rate land treatment system that operates under severe spring and winter conditions. The experimental program at the West Dover, Vermont, facility was designed to address two main objectives:

1. To determine the seasonal variations in wastewater renovation at the site, particularly during the winter and spring months. This required:
   a. Determining the quantity and quality of the wastewater applied to the east slope of the spray field.
   b. Determining the quantity and quality of the drainage from the east slope of the spray field.
   c. Developing mass balances for nitrogen (N) and phosphorus (P) across the east slope of the spray field.
   d. Monitoring specific hydrologic events on the east slope of the spray field.
   e. Monitoring the shallow groundwater quality in the spray field monitoring wells.
   f. Monitoring precipitation, evaporation and air temperatures at the site.
2. To determine the off-site effects of operating the system. This required:
   a. Monitoring the groundwater quality at several off-site wells.
   b. Monitoring the water quality in both the North Branch of the Deerfield River and Ellis Brook.

A comprehensive program of hydrologic and water quality monitoring on the eastern slope of the spray field was implemented to achieve these objectives.

METHODS AND MATERIALS

Hydrologic measurements

To permit calculation of water balances across the east slope, four major components of water input to and output from the east slope were measured: volume of applied effluent, flow in the interceptor ditch, precipitation, and pan evaporation.

The total daily volume of effluent applied was derived from plant operational records. This volume was adjusted to account for the drain-back of the pipelines that followed each spray lateral shutdown. Only the amount of effluent actually applied to the east slope (that being sprayed through laterals 5, 6, 7, 8, 9 and half of lateral 10) was included in water balance calculations. Only laterals 5 through 10 were used because laterals 11 and 12 are to the west of the crest of the knoll; therefore, any wastewater from these laterals would not be intercepted by the ditch at the eastern toe of the knoll. Laterals 1 through 4 were not used because of their proximity to the interceptor ditch, particularly at the north end of the spray field where lateral 1 crosses the interceptor ditch.

Spray field drainage was measured as flow in the interceptor ditch, which could include surface runoff from the east slope as well as any subsurface flow intercepted by the ditch. Equipment for continuous flow measurements was installed in a heated shelter attached to the southernmost headwall on the interceptor ditch (Fig. 17). Initially, a 90° V-notch weir with a capacity of 0.44 ft^3/s was installed in the headwall as the primary device for flow measurement; however, in January 1979 a compound V-notch-rectangular weir with a 11.3 ft^3/s capacity was installed to accommodate the anticipated high flows of spring

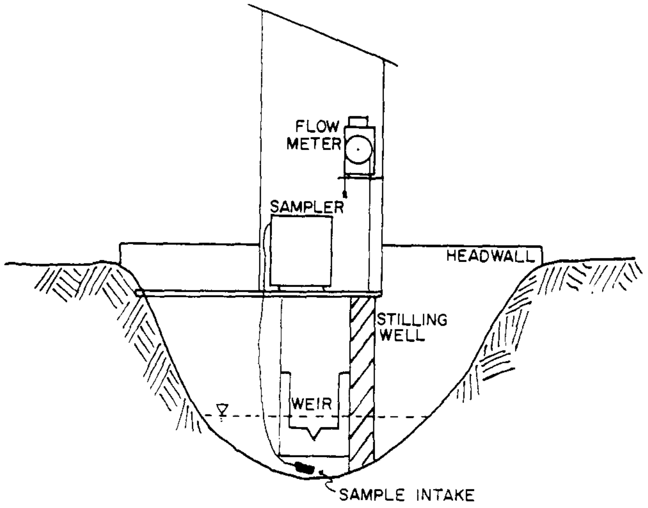


Figure 17. Interceptor ditch monitoring and sampling station.

runoff. The compound weir, designed and fabricated at the University of Vermont (UVM), was precisely calibrated in a flume by CRREL personnel.

An ISCO model 1530 float-type totalizing flowmeter was used to measure flow through the weir. This flowmeter employed a 4-in. steel float in a 12-in. square stilling well situated directly below the instrument shelter in the pool upstream of the weir. A steel staff gauge was fixed to the outside of the stilling well and aligned with the apex of the weir to provide an easily visible reference for calibration of the flowmeter. Flowmeter calibration was checked at least weekly throughout the study.

Output from the flowmeter was recorded continuously using an ISCO model 1710 digital printer. This printer recorded date, time, incremental flow and total flow at each point. The print interval was variable from 5 to 60 minutes.

The instrument shelter was constructed with several special features to permit operation in extreme cold weather. In addition to an electric heater and full insulation, a blower directed warm air down the stilling well to prevent ice formation. The pool below the shelter was enclosed in polyethylene sheeting to protect it from wind and drifting snow. Another blower directed warm air from the shelter into the enclosed area and this, in addition to two heat lamps mounted directly over the weir, kept ice from forming on and near the weir.

Precipitation was measured by a standard weighing bucket rain gauge that automatically recorded the data; it was located near the plant control building. This gauge operated throughout the winter, using ethylene glycol as antifreeze. The gauge was installed by CRREL personnel and was maintained by the treatment plant staff.

Evaporation was measured from June 1979 through October 1979 by a standard class A evaporation pan located near the control building. The pan was read and maintained according to standard procedures by the treatment plant staff.

Water quality monitoring

The water quality monitoring program at West Dover was designed to determine nutrient input to the spray field, nutrient export from the spray field, on-site groundwater quality, and water quality in adjacent surface waters and off-site groundwater. Thus, a monitoring schedule was implemented which included sampling of the sprayed effluent, the interceptor ditch flow, the six spray field observation wells, Ellis Brook and the Deerfield River, as well as several off-site private water supply wells.

Grab-samples of the effluent spray were taken weekly during fall, winter and summer, and once every 5 days during the spring runoff period (14 March-15 May 1979) directly from an operating spray line on the east slope. These samples were analyzed for pH, conductivity, suspended solids, BOD_5, and fecal coliform bacteria at the UVM laboratory. Samples were delivered to CRREL for analysis of total P, ammonia-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), total kjeldahl nitrogen (TKN), and chloride (Cl).

Water was sampled in the interceptor ditch with an ISCO model 1680 automatic sampler. The sampler, housed in the instrument shelter on the headwall (Fig. 17), drew samples from the pool above the weir through 1/4-in Tygon tubing. This intake line was heated in the winter to prevent freezing. The ISCO sampler was capable of automatically collecting up to 28 discrete samples at variable time intervals. Collected samples were maintained in an ice bath in the insulated sampler base.

During the fall, winter and summer, grab samples were taken from the ditch on the average of once a week on randomly selected days. From 14 March through 15 May 1979, the automatic sampler was used to collect hourly samples over a 48-hour sampling cycle each week. Eight composite samples were prepared for analysis, each being a flow-proportional composite of samples from one 6-hour period. Also during this spring runoff period, two grab samples were taken from the ditch every 5 days for bacteriological analysis.

Samples from the interceptor ditch were analyzed for temperature, pH, conductivity, suspended solids, BOD_5, and fecal coliform bacteria at the UVM laboratory, except during the spring runoff period when these analyses were performed in the treatment plant laboratory. Subsamples were delivered to CRREL for total P, ortho-P, NH_4-N, NO_3-N, TKN and Cl analysis.

Grab samples from all spray field observation wells were collected on the average of once each month during fall, winter, spring and summer, but once every 5 days during the spring runoff. Several of the wells were dry during most of the study period. Spray field groundwater samples were analyzed for temperature, pH, conductivity, and fecal coliforms at UVM, and for total P, ortho-P, NH_4-N, NO_3-N, TKN and Cl at CRREL.

Ellis Brook and the Deerfield River were sampled on the average of twice a month at points just above and just below the plant site (see Fig. 6). During the spring runoff, the two streams were sampled twice every 5 days. These surface water samples were analyzed for essentially the same parameters as the effluent spray and ditch flow samples.

Several off-site domestic water wells were sampled occasionally during the study. Additionally, precipitation samples and ground snow samples from the spray field were analyzed. All of these samples were analyzed for the same parameters as listed above.

All analyses conducted by UVM—i.e. temperature, pH, conductivity, suspended solids, BOD_5 and fecal coliform bacteria—were performed in accordance with *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 1976). Analyses for ortho-P, total P, NH_4-N, NO_3-N, TKN and Cl were conducted at CRREL in accordance with *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 1976) or other approved methods.

RESULTS AND DISCUSSION

Hydrology

Water inputs to east slope

Complete records of the treatment plant spray schedule, total volumes of effluent applied, and the actual volumes applied to the east slope are presented by Meals and Cassell (1982). A summary of the total monthly amount of applied effluent is given in Table 3. Over the 11-month period for which complete spray records exist, a total of 6,097,567 ft^3 (about 45.6×10^6 gal.) of effluent was sprayed onto the east slope. Although this averaged 544,324 ft^3 per month, effluent application was not evenly distributed over the year. Monthly spray volumes ranged from a low of 329,862 ft^3 in December 1978 to a high of 1,218,517 ft^3 in March 1979. Table 4 shows that the

Table 3. Total monthly effluent application (ft^3) to the east slope.

Month	*Volume applied*
December 1978	329,862
January 1979	386,421
February	496,495
March	1,218,517
April	674,654
May	505,461
June	518,691
July	354,728
August	742,229
September	538,309
October	332,200
Total	6,097,567

Table 4. Average monthly spray event duration (hr).

Month	*Duration*
October 1978	9.3
December	11.7
January 1979	10.9
February	65.7
March	53.1
April	30.2
May	20.6
June	30.9
July	28.4
August	15.8
September	10.0
October	-

Table 5. Total monthly precipitation.

Month	*Precipitation (in.)*	*Volume on east slope (ft^3)*
December 1978	4.39	326,682
January 1979	9.13	679,409
February	2.13	158,504
March	3.68	373,847
April	2.15	159,992
May	6.18	459,885
June	1.70	89,298
July	2.81	209,106
August	3.38	251,523
September	5.85	435,328
October	4.68	348,262
Total	45.58	3,391,836

length of the average monthly spray event varied considerably during the study.

Total monthly precipitation is shown in Table 5. The full precipitation data for the study period are given by Meals and Cassell (1982). Total precipitation from 1 December 1978 through 31 October 1979 was 45.58 in. or 3,391,836 ft^3 on the 20.5 acres of the east slope. Precipitation during the study was within the normal range, although June and July were somewhat drier than normal. Thirteen individual precipitation events of greater than 1 in. in 24 hours occurred during the study period.

Water export from east slope

There were two major means of water export from the east slope that were measured throughout the study: evaporation (evapotranspiration) and the flow in the interceptor ditch.

Mean monthly evaporation rates are given in Table 6. Full evaporation pan data are given by Meals and Cassell (1982). All water balance calculations assumed that pan evaporation was equivalent to potential evapotranspiration on the West Dover spray field.

Table 6. Mean monthly evaporation rates (in./day).

Month	*Rate*
June 1979	0.30
July	0.20
August	0.20
September	0.14
October	0.12
Average	0.19

All records of flow in the interceptor ditch are presented by Meals and Cassell (1982). Because of equipment failures, there are lapses in the ditch flow records during the study period. In the early weeks of the project, electronic feedback between the sampler and the flowmeter caused spurious flow values to be recorded so that the only reliable flow data recorded were for the period 12–23 October and 31 October–5 November 1978.

After this malfunction was corrected, ditch flow was recorded continuously from 30 November 1978 through 28 May 1979, with the exception of a 7-day period in January when a power loss cut off heat and the stilling well froze.

Beginning on 29 May, the electrical system servicing the monitoring station began to experience frequent high voltage surges of unknown origin that burned out the sensitive integrated circuitry in the flowmeter. During the months of June and July, the flowmeter was damaged three times and returned to the factory for repair on each occasion. None of the protective measures taken were able to keep the problem from happening again. As a result, no flow records were obtained for June and July 1979. The flowmeter functioned well for a short period from 1 August through 22 August, after which another voltage surge again burned it out. The meter was again repaired and placed back in service in early October. However, from 5–23 October, the plant operator pumped water from the holding pond directly into the ditch above the weir, rendering ditch flow data useless for the purposes of this study. No flow data were recorded again until 24 October 1979.

Table 7 presents total monthly volumes of ditch flow for those months where complete flow data exist. Some estimated daily flow values are included in the monthly totals for January, May and August to fill short periods of missing data. Over the 6-month period of continuous flow record (December 1978 through May 1979), a total of 2,827,287 ft^3 of water flowed through the interceptor ditch, an average flow rate of 0.18 ft^3/s (15,552 ft^3/day).

Ditch flow was not constant through this period. The ditch was completely dry during part of October 1978, but flowed continuously thereafter. The lowest monthly ditch flow of 136,325 ft^3 was found in December 1978, the average rate being 0.05 ft^3/s. The highest monthly flow of 1,012,553 ft^3 was found in March, an average flow of 0.38 ft^3/s.

Figure 18 shows the daily pattern of flow rate in the ditch over the study period. During warm weather, both precipitation and effluent application often resulted in distinct peaks in the ditch hydrograph. In the winter, ditch flow also reflected effluent application.

Table 7. Total monthly water inputs and outputs on the east slope (ft^3).

Month	*Spray* *(Q_S)*	*Precipitation* *(Q_P)*	*Evapotranspiration* *(Q_{ET})*	*Ditch flow* *(Q_D)*
December 1978	329,862	326,682	0	136,325
January 1979	386,421	679,409	0	273,289
February	496,495	158,504	0	211,260
March	1,218,517	273,847	0	1,012,553
April	674,654	159,992	0	670,280
May	505,461	459,885	350,643*	523,580
June	518,691	89,298	669,735	-
July	354,728	209,106	461,373	-
August	742,229	251,523	461,373	399,630**
September	538,309	435,378	312,543	-
October	332,200	348,262	276,824	-

*Estimated as in Cassell et al. (1979), ET for May = 0.152 in./day.

**Nine days of missing data estimated.

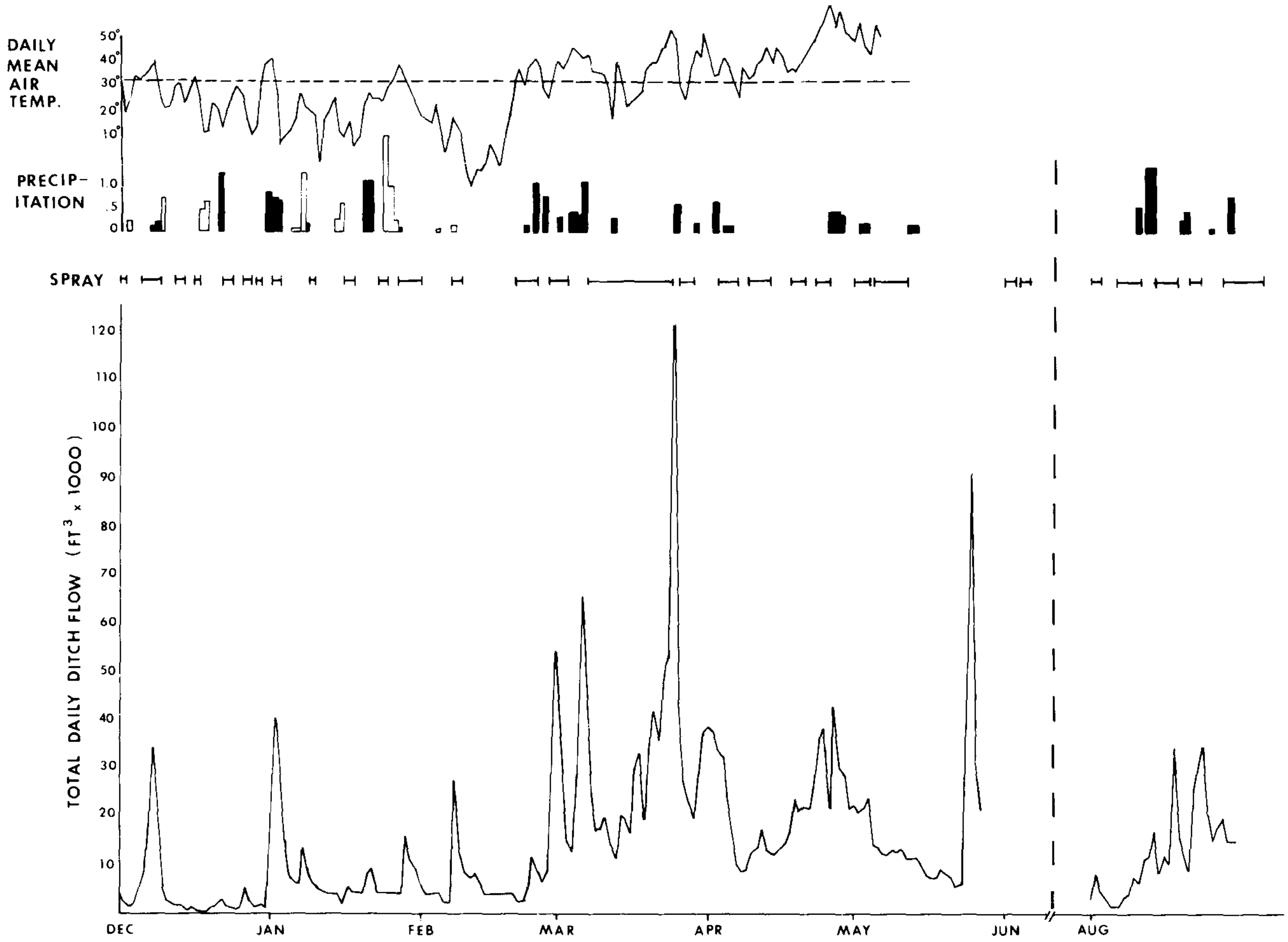


Figure 18. Daily ditch flow, effluent application, precipitation and mean air temperature.

but generally in a subdued manner. In very cold weather effluent application sometimes had almost no effect on ditch flow (e.g. December 10-18 1978). Occasionally, however, a particularly heavy spray application, even in very cold weather, did cause a substantial increase in ditch flow (e.g. February 5-14 1979).

In both winter and spring, ambient air temperature was a major influence on ditch flow. Midwinter thaws, especially when accompanied by rainfall, gave rise to major increases in ditch flow (e.g. 1-2 January 1979). The ditch hydrographs had their highest peaks in the spring with rising temperature, snowmelt, rains, and heavy effluent application (see 24 March 1979 in Figure 18). The highest ditch flow rate of 2.69 ft^3/s was recorded on 25 March following 16 consecutive days of spray application, a moderate rainfall and mean daily air temperature above 50°F.

Water balance across east slope

A summary of the measured hydrologic components, Q_S, Q_P, Q_{ET}, and Q_D, is given in Table 7. As illustrated in Figure 19, the water balance across the east slope may be written as:

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

or

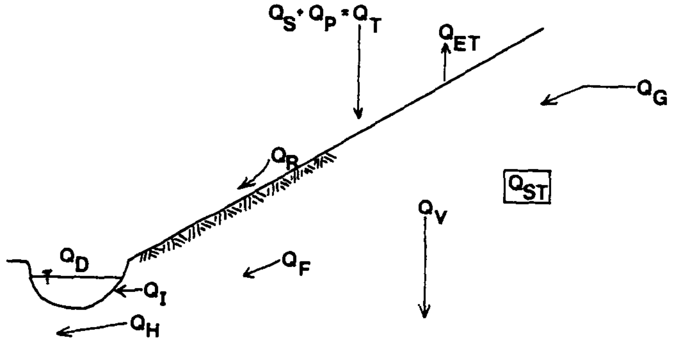
$$Q_T = Q_{ET} + Q_D + Q_V \pm \Delta Q_{ST} + Q_H - Q_G$$

The term Q_L (water unaccounted for) is essentially a summation of the unmeasured parameters of Q_V, Q_H, Q_G, and Q_{ST}, and thus a simplified water balance may be written as:

$$Q_T = Q_{ET} + Q_D + Q_L\,.$$

Since daily or weekly water balances, such as those used in an earlier study (Cassell et al. 1979), were judged to be too short term to adequately reflect the seasonal behavior of the spray field, all water balances in this study have been calculated on a monthly basis. Water balances calculated for those months with sufficient ditch flow data are presented in Table 8.

The results in Table 8 show that over a 6-month period, only about half of the water input to the east slope was actually recovered in the ditch. Consequently, considerable volumes of water were unaccounted for over the period of the study.



Q_S = effluent spray
Q_P = precipitation
Q_T = total water input to spray field
Q_{ET} = evapotranspiration
Q_R = surface runoff
Q_G = groundwater input
Q_{ST} = soil moisture storage
Q_V = deep percolation
Q_F = subsurface flow

Q_I = subsurface flow intercepted by ditch
Q_H = subsurface flow under ditch
Q_D = ditch flow
Q_L = unaccounted for water
$Q_D = Q_I + Q_R$
$Q_F = Q_T - Q_{ET} - Q_R - Q_V - \Delta Q_{ST} + Q_G$
$Q_D = Q_T - Q_{ET} - Q_V \pm \Delta Q_{ST} - Q_H + Q_G$
$Q_L = Q_T - Q_{ET} - Q_D$
$Q_L = Q_V + Q_H \pm \Delta Q_{ST} - Q_G$

Figure 19. Schematic hydrologic model of the West Dover spray site.

Table 8. Monthly water balances (ft^3).

Month	*Effluent and precipitation* *(Q_T)*	*Evapotranspiration* *(Q_{ET})*	*Ditch flow* *(Q_D)*	*Flow unaccounted for* *(Q_L)*
December 1978	656,544	0	136,325	520,219
January 1979	1,065,830	0	273,289	792,541
February	654,999	0	211,260	443,739
March	1,492,364	0	1,012,553	479,811
April	834,646	0	670,280	164,366
May	965,346	350,643*	523,580	91,123
August	993,752	461,373	399,630**	132,749
Total (Dec-May)	5,669,729	350,643	2,827,287	2,491,799

*No on-site evaporation data: estimated at 0.152 in./day as in Cassell et al. (1979).
**Nine days of missing data estimated.

General hydrologic behavior of east slope

For the purposes of this study, it is convenient to interpret the hydrologic behavior of the spray field in terms of the model shown schematically in Figure 19. This model is similar to the one presented in an earlier report (Cassell et al. 1979), but has been modified to reflect changes in understanding of the spray field's soils, particularly the absence of a fragipan layer. The total water input to the system (Q_T) is the sum of sprayed effluent (Q_S), direct precipitation (Q_P) and groundwater inflow (Q_G). Water output from the system is made up of evapotranspiration (Q_{ET}), subsurface flow (Q_F), surface runoff (Q_R), soil water storage (Q_{ST}), deep percolation (Q_V), and ditch flow (Q_D). Since all subsurface water moving down the east slope is not intercepted by the ditch, the term Q_F (subsurface flow) is divided into Q_I (the flow intercepted by the ditch) and Q_H (the flow which moves under and past the ditch). In addition, revised soils information suggests that the soil moisture storage capacity on the east slope (Q_{ST}) is substantially larger than was believed in earlier studies, although this term cannot be quantified.

In evaluating the water balance across the east slope, effluent spray volumes (Q_S), precipitation (Q_P), interceptor ditch flow (Q_D), and evapotranspiration (Q_{ET}) were measured directly. No data were available for the other terms.

Discussion of the hydrologic behavior of the West Dover spray field must include consideration of the differences between plant influent flows and effluent volume applied. During the 11-month period from December 1978 through October 1979, the total volume of effluent applied to the spray field (both east and west slopes) exceeded the plant influent volume by a substantial margin. As shown in Table 9, about 7.6 x 10^6 ft^3 of effluent was applied over the 11-month period, while the plant influent totaled 4.3 x 10^6 ft^3.

Net interception of precipitation by the holding pond, polishing pond and other plant tankage can account for only 0.6 x 10^6 ft^3 of this difference; thus, during this period, the applied effluent volume exceeded the sum of all known inputs by nearly 1.7 x 10^6 ft^3.

As shown in Table 9, the volume of sprayed effluent was significantly less than the plant influent during the fall and winter months; thus, the negative values in the *Unexplained Difference* column of Table 9 can be explained as in-plant storage of water. In the spring and summer, however, the situation was reversed—substantially more water was applied to the spray field than was received as influent or intercepted by the ponds as precipitation. While some of this difference can be accounted for as reduction of in-plant storage, the overall totals shown in Table 9 indicate that over the year more water was sprayed than came into the plant as influent or as intercepted precipitation.

The most plausible explanation for this is evident by consideration of the hydrologic model shown in Figure 19. The soils underlying the east slope can transmit subsurface flow down the east slope and underneath the ditch. The holding pond is located just east of the ditch. The term Q_H included in the model represents the portion of subsurface flow moving under the ditch. This water can enter the holding pond, depending on its depth in the soil. Field observations have shown groundwater emerging through the dike walls and pond bottom on numerous occasions. Any water which enters the holding pond in this fashion can be pumped onto the spray field. The amount of seepage from the pond into the ground is unknown.

Table 9. Plant influent versus effluent applied (ft^3).

Month	*Influent*	*Effluent applied*	*Difference**	*Net precipitation interception***	*Unexplained difference*
December 1978	428,552	430,619	+ 2,067	+156,170	+154,103
January 1979	607,405	569,265	- 38,140	+324,791	-362,931
February	552,466	610,133	+ 57,667	+ 75,773	- 18,066
March	578,666	1,724,724	+1,146,058	+130,912	+1,015,146
April	273,626	886,216	+612,590	+ 76,484	+536,106
May	273,894	541,405	+267,511	+ 65,812	+201,699
June	239,808	578,473	+338,665	-233,010	+571,675
July	315,867	403,420	+ 87,553	-136,960	+224,513
August	358,508	838,531	+480,023	- 7,115	+487,138
September	357,172	666,154	+308,982	+ 87,512	+221,470
October	356,102	398,640	- 42,538	+ 84,667	-127,205
Total	4,342,066	7,647,580	+3,305,514	+625,036	+2,680,478

*Negative value indicates influent greater than effluent volume.

**Negative value indicates evaporation exceeds precipitation.

(Assumption: Total area of precipitation interception and evaporation = polishing pond, holding pond, oxidation canals and clarifiers = 9.8 acres. Note that evaporation component of net precipitation interception is high for months when water surface area of holding pond is less than total area of ponds [typically June through August]).

Table 10. Monthly distribution of water input*.

Month	Q_T *(ft^3)*	Q_{ET} *(% of* Q_T*)*	Q_D *(% of* Q_T*)*	Q_L *(% of* Q_T*)*
December 1978	656,544	0	21	79
January 1979	1,065,830	0	26	74
February	654,999	0	32	68
March	1,492,364	0	68	32
April	834,646	0	80	20
May	965,346	36	54	10
August	993,752	46	40	14

*Inadequate ditch flow data for June, July and September and October 1979.

The hydrologic model points to the importance of deep percolation (Q_V) and changing soil moisture storage (Q_{ST}) in the east slope water budget. In addition, since water can apparently flow under the ditch (Q_H), it is clear that ditch flow does not represent a complete accounting of the "removal" process in terms of either water quality or water quantity. It appears probable that some portion of the nutrient mass which appears to be removed by the east slope (i.e. not present in ditch flow), as well as some fraction of water "unaccounted for," is lost by deep percolation, soil water storage and subsurface flow under the ditch. It can be argued that in the absence of detectable off-site effects this "loss" of wastewater constituents in deep percolation is an acceptable form of treatment; however, this aspect of spray field hydrology must be considered in any evaluation of the land treatment process at West Dover and at other locations.

The monthly water budgets, shown in Table 10, clearly show that the hydrologic behavior of the spray field varied with season. These water budgets show the proportion of Q_T (i.e., total water input) recovered in ditch flow was lowest in the winter months. The magnitude of Q_L (unaccounted for water) during this time is likely the result of storage of both effluent and precipitation on the spray field as ice and snow. In the spring, however, this pattern was reversed, with most of the input water and stored water leaving the east slope in ditch flow. In the summer evapotranspiration became a major component of water output, while Q_L remained fairly low. This pattern plays a critical role in the disposition of wastewater constituents introduced to the east slope in effluent over the seasonal cycle.

It should be noted that, unlike the data reported in an earlier study (Cassell et al. 1979), no significant relationship between total water input and unaccounted for water was observed. For the summer of 1977, a strong positive linear relationship ($r^2 = 0.99$) was noted between the total volume of water applied to the east slope (Q_T) and the quantity of water unaccounted for in the budget (Q_L). Similar calculations over this 11-month project period, however, show no such relationship ($r^2 = 0.015$). It is most likely that winter storage of input water as ice and snow masked this relationship between Q_T and Q_L.

Specific hydrologic event studies

In order to better understand the behavior of the east slope of the spray field, 10 specific hydrologic events such as intense rainstorms, spring snowmelt and heavy spray application were carefully monitored. The characteristics of the 10 monitored individual runoff events are given in Table 11. During such events, the automatic sampler was used to collect a series of discrete samples of ditch flow which were analyzed in order to determine patterns of nutrient export over the course of the event.

A detailed discussion of the results of these specific hydrologic studies is presented in Appendix A.

As a result of these detailed hydrologic studies several conclusions can be reached about the behavior of the east slope of the spray field. First, ambient air temperature affected the timing of ditch flow. Freezing temperatures caused ditch flow to peak later than above freezing temperatures did. Second, temperature also affected the quantity of ditch flow. The highest ditch flow was in the spring during periods of rising temperatures and rainfall. Third, temperature influenced the concentration of wastewater constituents in the interceptor ditch. When the major source of water input was spray or melting snow and ice, the concentrations of ortho-P, NO_3-N and Cl increased with increasing ditch flow. When rainfall was the primary input their concentrations decreased with increasing ditch flow.

Water quality

Quality of applied effluent

Complete results of water quality analyses are presented by Meals and Cassell (1982).

Table 12 summarizes the mean monthly values of the water quality parameters for the wastewater applied to the east slope during the study period. These values are consistent with those expected in the effluent from a secondary treatment plant, except that NO_3-N levels appear to be somewhat high.

Figure 20 shows that effluent quality varied seasonally. Total N concentrations were highest during the winter months and dropped substantially during the summer. Effluent total P levels also appeared to peak in the winter, although seasonal variation was not as pronounced as with N. The higher levels of N and P in the effluent in winter are likely due to a reduction in the rates of in-plant biological activity because of low temperatures.

The predominant form of N applied to the east slopes was NO_3-N (Table 12). NO_3 concentrations in the effluent (mean of 11.8 mg/L) were considerably higher than NH_4-N concentrations (mean of 0.8 mg/L). NO_3-N made up an average of 77% of the total N in the effluent over the study period. This may be due to additional nitrification in the polishing and holding ponds.

Interceptor ditch water quality

Table 13 gives the mean monthly values of the water quality parameters for flow in the interceptor ditch during the study period. Monthly mean

Table 11. Characteristics of the monitored individual runoff events.

Event no.	*Date*	*Event type*	*Sampling interval*	*No. of samples collected*
1	13-16 Oct. 1978	spray/rain	2 hr	26
2	9-10 Dec. 1978	snow/rain	3 hr	9
3	21-25 Feb. 1979	winter rain/melt	6*hr/2 hr	14
4	2-8 March 1979	spring melt	6 hr*	22
5	3-5 April 1979	spray/melt	6 hr*	8
6	19-21 April 1979	spray/melt	6 hr*	8
7	23-25 April 1979	spray/melt	6 hr*	8
8	28-30 April 1979	rain/melt	6 hr*	8
9	3-5 May 1979	spray/rain	6 hr*	8
10	31 July-6 Aug. 1979	spray/dry	2 hr	59

*Six-hour composites of hourly samples.

Table 12. Mean monthly water quality of the effluent.

Month	Temp. (°C)	pH	Conductivity (µmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Total P (mg/L)	Ortho-P (mg/L)	NH_4-N (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Total N (mg/L)	Cl (mg/L)
October 1978	-	7.0	140	105.0	27.2	100	4.6	3.4	0.0	2.4	11.8	14.2	49.9
November*	4.0	7.2	265	40.0	1.4	0	3.8	4.6	0.1	1.5	19.2	20.7	60.9
December	4.0	6.3	310	4.4	8.3	0	4.3	-	0.4	2.6	17.6	20.2	75.0
January 1979	2.2	6.5	433	7.5	7.0	TNTC†	5.1	0.0	2.3	4.1	16.4	20.5	67.6
February	-	-	-	-	-	-	-	-	-	-	-	-	-
March	3.2	6.6	319	5.2	15.2	29	4.4	-	1.5	4.7	15.8	20.5	67.9
April	6.4	6.4	205	4.2	5.5	0	3.3	-	0.5	2.1	10.0	12.1	55.4
May	16.2	7.6	202	19.8	11.8	0	3.8	-	0.05	2.9	4.8	7.7	44.8
June	20.5	7.4	338	18.5	-	156	4.6	-	0.1	3.9	10.2	14.1	60.4
July	20.8	7.8	295	10.2	1.4	0	2.8	-	0.4	3.1	7.7	10.8	58.4
August	22.0	8.1	375	30.6	16.4	6	1.8	-	0.7	5.6	8.1	13.7	46.4
September	17.5	8.0	260	11.1	2.7	0	3.2	-	0.0	2.0	7.6	9.6	45.0
October	-		-		-	-	-	-	-	-	-	-	-

*One sample in November.

†Too numerous to count.

Table 13. Mean monthly water quality in the interceptor ditch.

Month	Temp. (°C)	pH	Conductivity (µmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Total P (mg/L)	Ortho-P (mg/L)	NH_4-N (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Total N (mg/L)	Cl (mg/L)
October 1978	7.5	6.9	200	12.1	0.4	0	0.30	0.19	0.03	0.90	6.4	7.3	46.2
November	2.2	6.6	150	40.0	4.1	28	0.25	0.62	0.10	0.70	8.4	9.1	44.6
December	0.5	6.1	116	2.7	1.7	9	0.10	0.30	0.00	0.61	8.1	8.7	37.1
January 1979	0.4	6.8	55	1.3	5.7	159	-	0.08	0.00	0.50	7.8	8.3	38.1
February	1.0	6.3	166	5.1	1.4	102	-	0.30	0.30	1.10	9.8	10.9	42.8
March	5.5	6.8	177	1.8	1.3	5	0.60	0.27	0.02	1.01	8.1	9.1	37.6
April	12.0	6.6	126	1.4	1.3	8	0.42	0.07	0.01	0.72	4.8	5.5	26.5
May	16.7	6.5	129	1.5	1.3	2	0.30	0.04	0.00	0.40	3.0	3.4	24.8
June	12.6	6.7	110	0.7	0.9	22	0.10	0.04	0.00	0.20	0.8	1.0	26.8
July	14.8	6.0	128	1.2	0.9	54	0.15	0.04	0.10	0.60	0.4	1.0	31.7
August	18.4	6.8	176	0.6	1.4	140	0.08	0.05	0.00	0.50	0.6	1.1	39.4
September	11.8	6.3	152	0.4	0.7	159	0.00	0.05	0.00	0.20	2.0	2.2	41.2
October	7.8	6.5	131	0.4	1.1	16	0.16	0.17	0.04	0.70	2.4	3.1	34.2

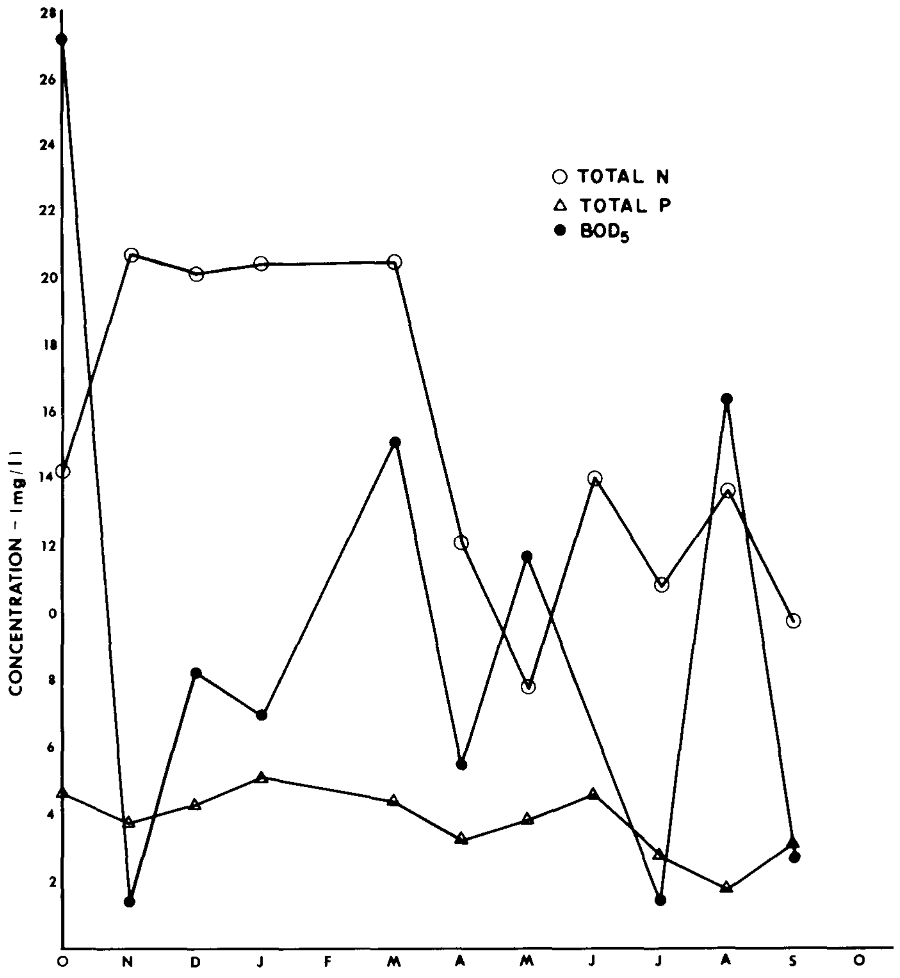


Figure 20. Monthly average concentration of total N, total P and BOD_5 in applied effluent.

concentrations of all measured parameters, except fecal coliform bacteria and conductivity for October 1978, were significantly lower than concentrations in the applied effluent. Fecal coliform counts were sometimes actually higher in the ditch flow than those in the applied effluent.

Figure 21 shows the patterns of mean monthly concentrations of total N, total P, NO_3-N and BOD_5 in the ditch flow. As observed in the applied effluent, nutrient levels were highest in the winter and lowest in the summer. The highest monthly mean concentration of total N in the ditch flow was 10.9 mg/L in February 1979, and the highest single value of total N recorded over the study period was 17.6 mg/L on 8 February 1979. Mean monthly total P concentrations never exceeded 0.6 mg/L (March 1979) and the highest single value of total P was 2.0 mg/L on 7 March 1979.

As with the applied effluent, NO_3 was the dominant form of N found in the ditch flow, averaging 82% of total N. NH_4-N concentrations averaged less than 0.1 mg/L.

As mentioned earlier, the concentrations of most wastewater constituents were substantially lower in the ditch flow than in applied effluent. Figures 22a and b show a comparison of mean monthly effluent and ditch flow concentrations of total P and total N, while Figures 22c and d give a similar comparison for NO_3-N and Cl over the study period. Concentrations of these constituents in ditch flow are related to concentrations in the effluent.

The percent reduction in concentration of several wastewater constituents after the wastewater flowed down the east slope is given in Table 14 and in Figure 23. Reduction of total-P concentration ranged from a low of 87% during spring runoff in April 1979 to a high of 100% in September 1979. The average reduction of total-P concentration was 94% over the study period. The 95 to 96% reduction in total-P concentration recorded in July and August 1979 is

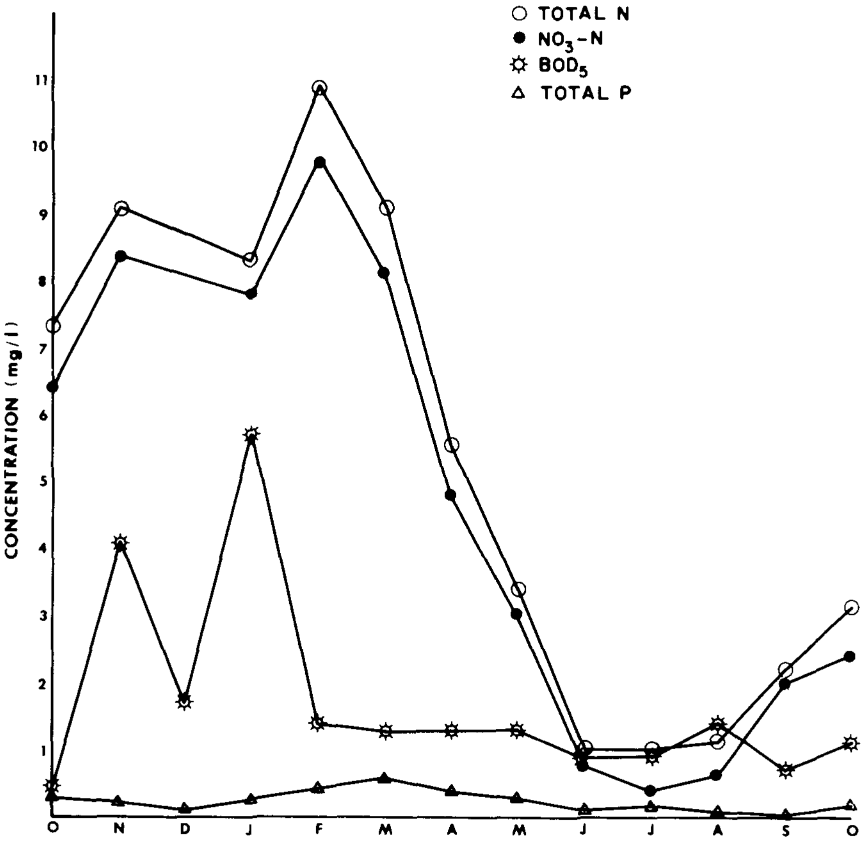
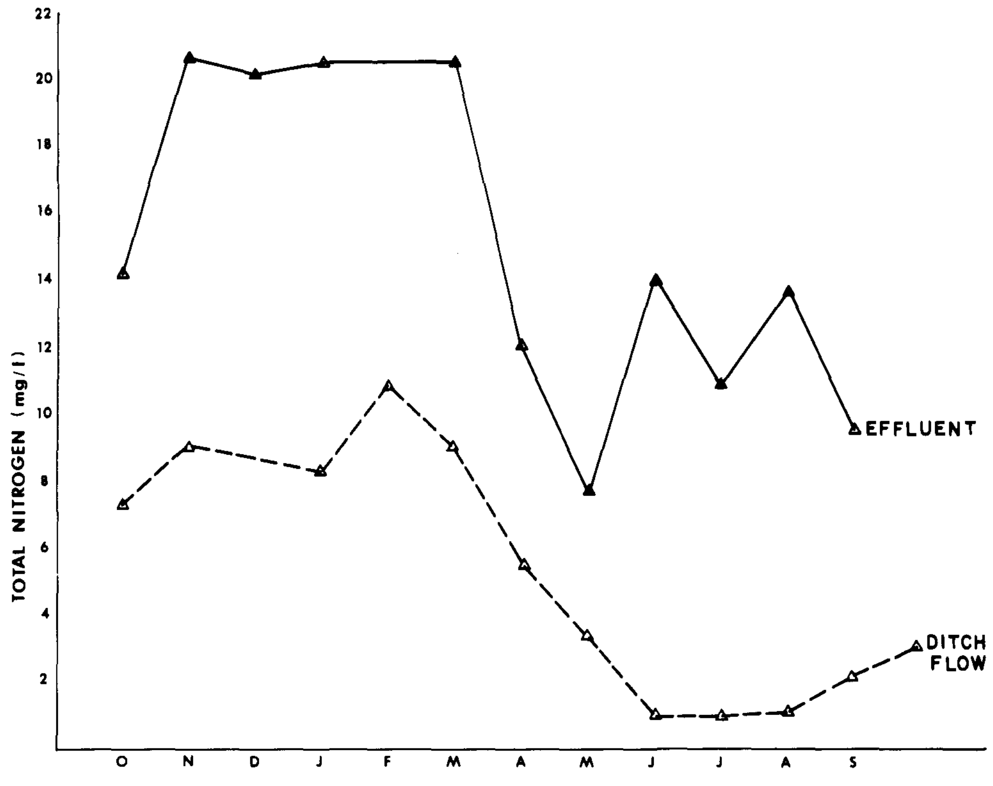


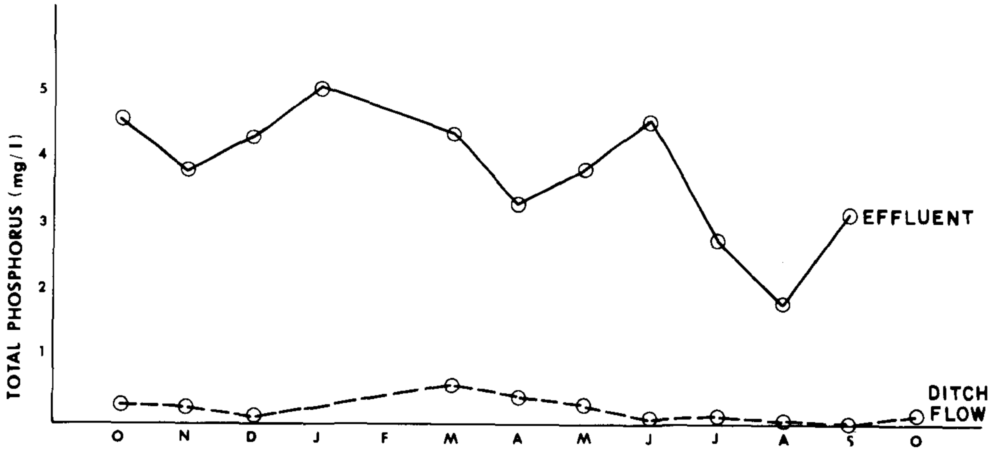
Figure 21. Monthly average concentration of total N, NO_3-N, BOD_5 and total P in interceptor ditch flow.

Table 14. Concentration reduction of wastewater constituents in interceptor ditch (%).

Month	*Total P*	*Ortho-P*	*Total N*	*TKN*	*NO_3-N*	*BOD_5*	*Cl*
October 1978	93	94	48	62	46	98	7
November	93	86	56	53	56	-	27
December	98	-	56	76	54	80	50
January 1979	-	-	60	88	52	18	44
February	-	-	-	-	-	-	-
March	91	-	56	33	49	91	45
April	87	-	54	66	52	76	52
May	92	-	56	86	38	89	45
June	98	-	93	95	92	-	56
July	95	-	91	81	95	36	46
August	96	-	92	91	92	91	15
September	100	-	77	90	74	74	8
Mean	94	90	67	75	64	72	36

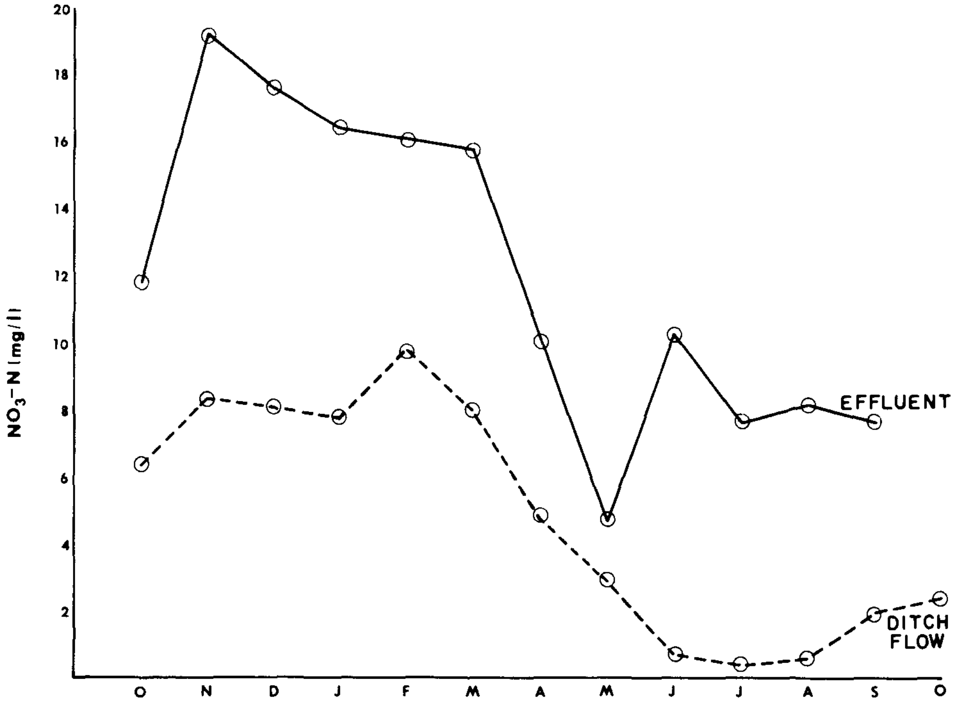


a. Total N.

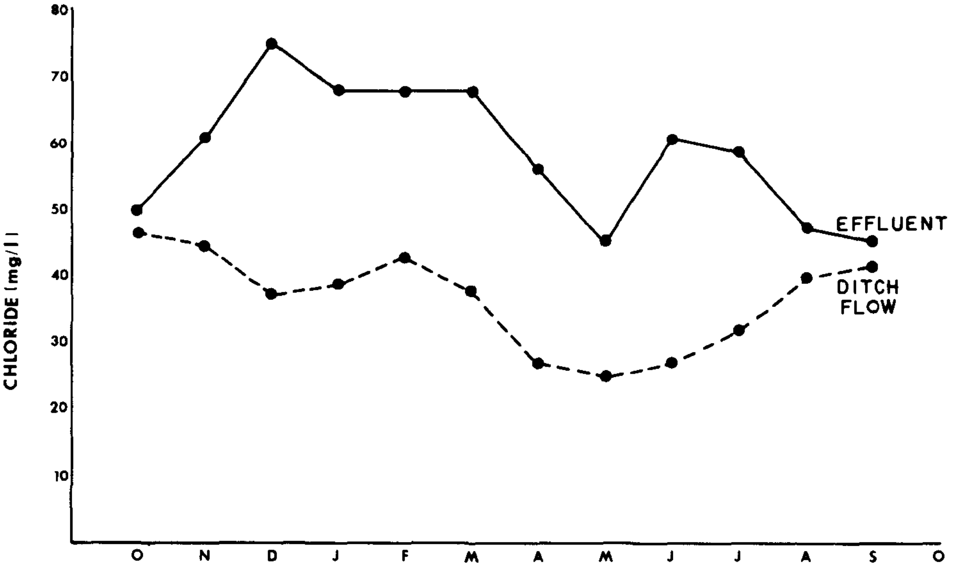


b. Total P.

Figure 22. Comparisons of monthly average concentrations of wastewater constituents in applied effluent and interceptor ditch flow.

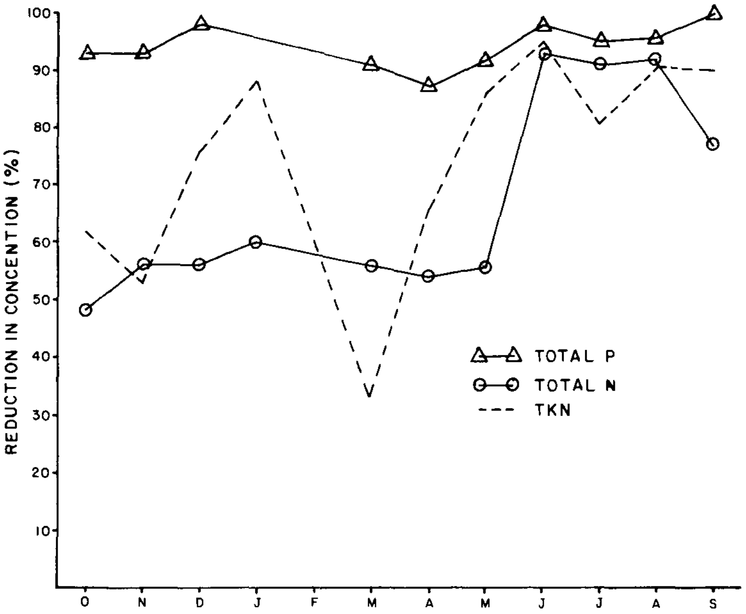


c. NO_3-N.

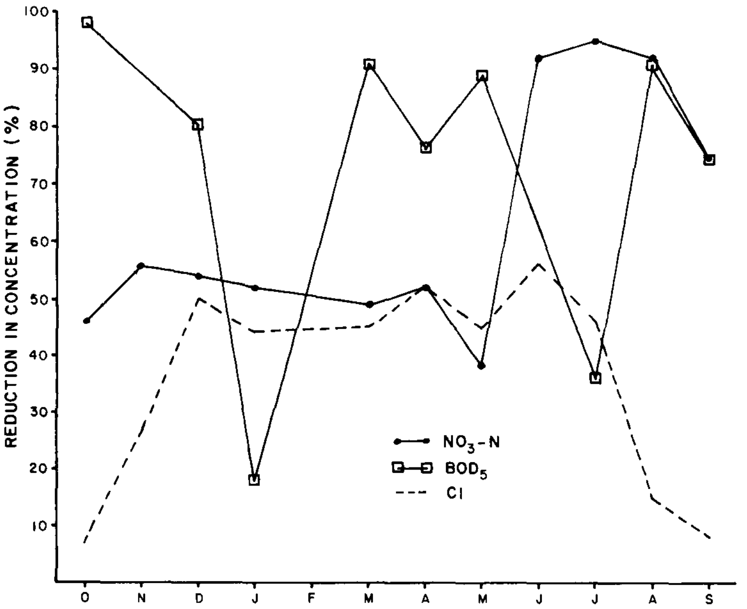


d. Cl.

Figure 22 (cont'd). Comparisons of monthly average concentrations of wastewater constituents in applied effluent and interceptor ditch flow.



a. Total P, total N and TKN.



b. NO_3-N, BOD_5 and Cl.

Figure 23. Monthly reduction in concentrations of wastewater constituents after the wastewater moved down the east slope into the interceptor ditch.

consistent with reductions in P concentrations obtained by other forested land treatment systems (Sopper 1973). Reductions of soil-water ortho-P concentrations on the order of 70 to 95% have been reported for a land treatment system at Lake Sunapee, New Hampshire (NHWSPCC 1978).

The reduction in total-N concentration varied from 48% in October 1978 to 93% in June 1979, averaging 67% over the study period. In the summer of 1979, the total-N reduction was 91 to 92%.

Reduction of NO_3-N concentration ranged from 38% in March 1979 to 95% in July 1979 and averaged 65% through the year (Fig. 23a).

Cl reduction varied from a low of only 7% in October 1978 to a high of 56% in June 1979, averaging 36% overall. Cl concentration reductions in July-August 1979 ranged from 15 to 46%.

BOD_5 concentration reductions were quite variable, ranging from 18% in January to 98% in October, and averaging 72%.

Water quality data from the ditch were analyzed to determine possible correlations with flow rate. In the summer of 1977, positive correlations were observed between flow and total-N concentration ($r^2 = 0.50$) and between flow and NO_3-N ($r^2 = 0.85$) (Cassell et al. 1979). In this study, however, no such correlations were found. The fact that no strong relationships between flow and water quality were observed in this study is probably due to the seasonal variability in the renovative behavior of the east slope (e.g. plant uptake, denitrification) and to the character of the east slope water balance (e.g. freezing of effluent in winter, snow melt and runoff in spring).

On-site groundwater quality

Mean monthly water quality data from the spray field observation wells are shown in Table 15. Two of the wells, well 1 in the southeast corner of the east slope and well 4 near the middle of the base of the west slope, were dry over most of the study period (see Fig. 6 for locations of wells). With the exception of well 6, concentrations of all wastewater constituents were significantly lower in the spray field groundwater than in the sprayed effluent. However, with the exception of fecal coliform counts, most observation well water samples contained higher concentrations of N, P and other parameters than the ditch flow.

Wells 1 and 4 showed lower concentrations of nutrient forms than did the other observation wells. This, coupled with the fact that both of these wells contained water only for brief periods during spring and fall, suggests that wells 1 and 4 are not strongly influenced by effluent application. In contrast, the quality of the water in wells 2, 3, 5 and 6 implies that these wells may directly intercept sprayed effluent that percolates through the soil. Additional field observations suggest that wells 2 and 6 are probably influenced by surface runoff as well.

As with applied effluent and ditch flow, NO_3-N was the predominant form of N found in spray field groundwater, generally accounting for 50 to 95% of the total N. NH_4-N concentrations were consistently low in all well samples, below detectable levels in most cases. Wells 3 and 6 consistently had the highest mean NO_3 and total-N concentrations, averaging 6.7 mg/L NO_3-N and 8.6 mg/L total N, and 10.1 mg/L NO_3-N and 10.1 mg/L total N respectively. Wells 2 and 3 showed the highest mean total-P concentrations, averaging 0.6 mg/L and 0.8 mg/L respectively.

The observation wells on the spray field are only about 2-3 ft deep, intercept only the very upper levels of soil water, and therefore do not represent the true groundwater beneath the spray field. All but two of the wells (wells 2 and 6) are dry most of the year, suggesting that these wells do not routinely intercept the groundwater table. As noted earlier, the data suggest that wells 2 and 6 are probably significantly influenced by surface runoff in addition to subsurface flow. Thus, observation well data do not accurately indicate the effect on true groundwater of effluent application, nor do the well data reflect the final level of wastewater renovation after full passage through the soil profile. Rather, observation well data reflect groundwater quality at some stage between the applied effluent and deep-percolated water.

Generally, the levels of N, P and other water quality parameters observed in the observation wells were comparable to those reported by other workers (Sopper 1976, Sopper and Kerr 1978, Dryden and Chen 1978, Nutter et al. 1978, Cole and Schiess 1978). NO_3-N levels, however, tended to be somewhat higher than those reported elsewhere, possibly due to the high proportion of NO_3-N in the effluent.

It is interesting to note that fecal coliform bacteria were present in significant numbers only in wells 2 and 6, suggesting the possibility of surface runoff entering these wells. These wells often contained bacteria levels higher than those measured in the applied effluent. This is possibly the result of addition of bacteria to the east slope by animals or the regrowth of coliform organisms in the soil (Pound and Crites 1973).

Reductions of P, N and Cl concentrations in three spray field observation wells are shown in Table 16. The reductions varied by season and among

Table 15. Mean monthly water quality in observation wells.

Month	*pH*	*Conductivity (μmhos)*	*Fecal coliforms (no./100 mL)*	*Total P (mg/L)*	*Ortho-P (mg/L)*	*NH_4-N (mg/L)*	*TKN (mg/L)*	*NO_3-N (mg/L)*	*Total N (mg/L)*	*Cl (mg/L)*
				Well 1						
March 1979	6.4	154	0	-	0.8	0.0	-	1.0	-	3.2
April	6.6	61	1	-	0.5	0.0	-	0.8	-	3.8
May	-	74	-	-	-	-	-	-	-	-
October	-	38	-	-	-	-	-	-	-	-
				Well 2						
November 1978	6.4	90	-	-	-	-	-		-	-
December	6.4	90	0	0.4	0.15	0.0	0.8	6.3	7.1	19.1
February 1979	6.4	80	1	-	0.12	0.0	0.6	5.6	6.2	14.8
March	6.3	101	1	-	0.04	0.0	-	5.9	-	16.8
April	6.3	80	0	0.2	0.04	0.0	0.6	4.9	5.5	15.5
May	6.1	99	0	0.2	0.03	0.0	-	4.7	-	17.4
June	6.9	110	4	0.4	-	0.0	2.8	3.1	5.9	20.3
July	-	150	-	-	-	-	-	-	-	-
August	5.3	148	106	0.7	0.02	0.0	2.3	1.2	3.5	31.7
September	6.5	150	0	0.2	0.14	0.0	0.9	1.9	2.8	-
October	6.2	120	14	2.4	0.11	0.0	8.6	3.0	11.6	33.8
November	6.3	175	4	-	0.03	0.0	-	3.4	-	36.8
				Well 3						
November 1978	5.4	120	0	-	-	-	-	-	-	-
February 1979	6.5	145	0	-	0.03	0.0	0.8	12.1	12.9	40.0
March	6.2	113	2	0.0	0.04	0.0	1.1	7.4	8.5	22.8
April	6.3	103	0	1.0	0.04	0.02	0.2	6.3	6.5	20.8
May	6.4	108	3	0.1	0.03	0.0	0.04	4.6	4.6	21.2
June	6.4	127	0	0.1	0.05	0.0	0.8	3.8	4.6	27.9
August	-	295	-	-	-	-	-	-	-	-
September	5.9	210	78	0.0	0.06	0.0	0.5	3.3	3.8	-
October	6.4	150	34	3.6	0.12	0.0	9.0	6.1	15.1	37.0
November	5.7	130	0	0.3	0.02	0.0	1.2	8.1	9.3	39.6
				Well 4						
March 1979	6.6	111	0	-	0.03	0.0	-	0.2	-	6.3
April	6.5	120	0	0.2	0.03	0.0	0.2	0.1	0.3	5.9
May	7.1	160	0	0.2	0.02	0.0	0.4	0.0	0.4	15.2
October	7.2	187	0	0.2	0.05	0.0	1.2	0.0	1.7	16.7
November	6.6	125	0	0.0	0.02	0.0	0.3	0.0	0.3	14.3
				Well 5						
November 1978	6.5	100	0	0.0	0.03	0.0	-	0.03	-	13.4
March 1979	5.9	204	0	-	0.05	0.0	-	10.5	-	48.5
April	6.2	117	0	0.3	0.03	0.0	0.05	6.8	6.8	34.0
May	6.4	113	0	0.0	0.20	0.0	0.3	3.6	3.9	18.8
September	6.5	120	7	0.0	0.02	0.0	0.2	0.0	0.2	-
October	6.3	85	0	0.0	0.02	0.0	0.3	0.3	0.6	20.6
November	6.3	90	0	0.0	0.02	0.0	0.4	0.4	0.8	21.6
				Well 6						
October 1978	6.2	-	0	0.0	0.05	0.0	-	9.2	-	60.0
November	5.5	205	0	0.0	0.03	0.0	-	9.5	-	52.1
December	6.4	180	0	0.3	0.21	0.0	0.3	9.8	10.1	48.1
February 1979	6.3	180	1	1.05	0.04	0.0	-	12.4	-	51.3
March	6.2	234	0	-	0.03	0.2	-	12.9	-	46.1
April	6.5	149	0	0.1	0.02	0.03	0.7	10.0	10.7	39.4
May	5.9	145	0	0.15	0.02	0.0	0.8	9.1	9.9	36.3
June	6.4	195	0	0.0	0.05	0.0	1.4	7.4	8.8	37.9
September	6.1	210	2	0.0	0.02	0.0	0.9	6.1	7.0	-
October	6.5	85	0	0.0	0.02	0.1	1.3	7.7	9.0	36.9
November	6.2	170	0	0.0	0.03	0.0	1.1	8.7	9.8	40.5

Table 16. Percent concentration reduction in observation wells in comparison to applied effluent.

	Total P			*NO_3-N*			*Total N*			*Cl*		
Month	*2*	*3*	*6*	*2*	*3*	*6*	*2*	*3*	*6*	*2*	*3*	*6*
October 1978	-	-	100	-	-	22	-	-	-	-	-	-20
November	-	-	100	-	-	50	-	-	-	-	-	14
December	91	-	93	64	-	44	65	-	50	74	-	36
January 1979	-	-	-	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-	-	-	-
March	-	100	-	63	53	18	-	58	-	75	66	32
April	94	70	97	51	37	0	54	46	12	72	62	29
May	95	97	95	2	4	-90	-	40	-28	61	53	19
June	91	98	100	70	63	4	58	67	38	66	54	37
July	-	-	-	-	-	-	-	-	-	-	-	-
August	61	-	-	85	-	-	74	-	-	32	-	-
September	94	100	100	75	56	20	71	60	27	-	-	-
October	-	-	-	-	-	-	-	-	-	-	-	-
Mean	88	93	98	58	43	8	64	54	20	63	59	21

Table 17. Ratios of NO_3-N:Cl for effluent, ditch flow and observation well samples.

Month	*Effluent*	*Ditch flow*	*Well 2*	*Well 3*	*Well 6*
October 1978	0.24	0.14	-	-	0.15
November	0.32	0.19	-	-	0.18
December	0.23	0.22	0.33	-	0.20
January 1979	0.24	0.20	-	-	-
February	-	0.23	0.38	0.30	0.24
March	0.23	0.22	0.35	0.32	0.28
April	0.18	0.18	0.32	0.30	0.25
May	0.11	0.12	0.27	0.22	0.25
June	0.17	0.03	0.15	0.14	0.19
July	0.13	0.01	-	-	-
August	0.17	0.02	0.04	-	-
September	0.17	0.05	-	-	-

the three wells. Concentration reductions are generally poorest in the spring months; in May, well 6 had substantially higher N concentrations than those found in applied effluent. Well 6 typically contained higher concentrations of effluent constituents than did other wells, with the exception of total P. Well 2 generally exhibited higher concentration reductions than well 3. In general, concentration reductions in observation wells were less than those in ditch flow.

The concentration reductions observed in the spray field observation wells have been due to in-soil renovation or to dilution by on-site groundwater or precipitation. No data are available to definitely distinguish between these possibilities. As a general indication of wastewater renovation in the soil, Leland et al. (1979) compared N:Cl ratios in applied wastewater with those in groundwater to assess N interception by the soil. This approach is based on the premise that of these two highly mobile elements, only N is significantly transformed in the soil, and that any major change in the N:Cl ratio is due to changes in N concentration. Dilution by on-site groundwater or precipitation would cause little change in overall groundwater N:Cl ratios.

The NO_3-N:Cl ratios for the West Dover spray site are given in Table 17. Except during the spring months, NO_3-N:Cl ratios in the ditch flow were lower than those in the applied effluent, indicating a net removal of NO_3, particularly during the growing season. The NO_3-N:Cl ratios in the observation wells, however, were generally higher than those in either the effluent or ditch flow during the winter and spring months. This suggests that NO_3-N is added to, rather than removed from, the spray field soil water. A similar NO_3-N enrichment of spray field soil water was observed in a forested land treatment site in New Hampshire (NHWSPCC 1978) where it was thought that NO_3 enrichment was the result of the N recycled from plant litter on the spray field.

Snow and ice, and precipitation quality

Table 18 gives the results of analyses of ice and snow samples collected from the spray field by CRREL personnel in March 1978.

The snow samples generally had nutrient levels between those of the applied effluent and ditch flow. The snow samples contained relatively high concentrations of N (particularly organic N) and BOD_5, but contained little P.

Table 18 also presents three analyses of ice taken from the spray field (i.e. frozen effluent) in March 1978. These ice samples contained high concentrations of N and P. The concentrations of NO_3-N and total P were lower in the ice than in typical applied effluent; however, NH_4-N and TKN levels were substantially higher. No direct comparisons between ice quality and effluent quality are possible because no samples were taken from the effluent which formed the ice.

Samples of precipitation were taken occasionally for analysis during the study. In January 1979 several samples were taken of falling snow. Sample 1 (Table 19) was taken near White River Junction, Vermont, on I-91 about 60 miles northeast of the plant; sample 2 was taken in Dummerston, Vermont, about 10 miles northeast of the plant; and sample 3 was taken near the instrument shelter at the southeast corner of the spray field. As shown in Table 19, snow from the spray field contained substantially higher concentrations of N and Cl than the other two snow samples. There was little difference in conductivity, pH or ortho-P among snow samples.

Table 19 also includes analytical data for a number of samples of rainfall. Rain gauge 1 was located near the plant control building and rain gauge 2 was located about 1 mile to the east. Not unexpectedly, the precipitation samples tended to be somewhat acidic (mean pH = 5.2). The rain samples contained low levels of NH_4-N, but several fairly high values for TKN were recorded.

Mass balances

Monthly balances of mass applied in effluent and mass exported in ditch flow were calculated for P, N, BOD_5, and Cl for those months where sufficient data existed. Input mass was determined on the basis of mean monthly effluent concentrations and the monthly effluent volume applied to the east slope. Export mass was calculated on the basis of concentrations either from grab sampling and total ditch flow over the period most closely bracketing the sampling time, or actual mass export calculated during monitored events. For the purposes of this project, precipitation was assumed to be free of P, N, BOD_5, and Cl. Monthly figures for input (applied effluent) and output (ditch flow) are shown in Tables 20 and 21, respectively. Table 22 shows monthly average constituent removal in terms of both mass and percent of input. A mass balance for total P, NO_3-N and Cl is shown in Table 23 for the 6 month winter-spring period.

Table 18. Analysis of snow and ice samples—winter 1978.

Date	*Number*	*Depth of core (in.)*	*Density*	*NH_4-N (mg/L)*	*NO_3-N (mg/L)*	*TKN (mg/L)*	*BOD_5 (mg/L)*	*Total P (mg/L)*
				Snow samples				
20 March 1978	S1A	26.0	0.35	0.12	0.26	1.45	3.8	0
	S1B	24.0	0.38	0.12	0.23	2.00	3.0	0
	S1C	30.9	0.51	0.19	0.23	3.64	3.1	0
	S2A	24.0	0.40	0.06	0.13	1.18	2.3	0
24 March 1978	CS1	30.0	0.54	0.04	0.11	21.28	2.3	0.11
	CS2	30.0	0.31	0.09	0.11	11.80	1.7	0
	CS3	30.0	0.35	0.27	0.14	9.66	2.7	0
Mean		27.8	0.40	0.13	0.17	7.3	2.7	0
				Ice samples				
20 March 1978	A	52.0	0.73	3.3	2.7	9.6	5.8	1.5
	B	60.0	0.75	2.2	1.4	5.4	4.8	1.3
	C	84.0	0.51	2.0	3.6	17.0	6.3	2.2
Mean		65.4	0.66	2.5	2.6	10.7	5.6	1.7

Table 19. Precipitation quality.

Date	*Conductivity (µmhos)*	*pH*	*Ortho-P (mg/L)*	*NH_4-N (mg/L)*	*TKN (mg/L)*	*NO_3-N (mg/L)*	*Total N (mg/L)*	*Cl (mg/L)*
Snow sample 1								
26 Jan. 1979	0	5.5	0.05	0.0	0.3	0.0	0.3	1.1
Snow sample 2								
26 Jan. 1979	0	5.3	0.02	0.0	0.5	0.0	0.5	0.2
Snow sample 3								
26 Jan. 1979	0	4.8	0.05	0.1	1.9	0.2	2.1	4.9
Rain gauge 1								
17 July 1979	-	6.1	-	0.2	0.0	0.0	-	0.7
18 July 1979	-	4.9	-	0.4	-	0.0	-	0.1
2 Aug. 1979	-	-	-	0.1	-	0.1	-	0.2
19 Aug. 1979	-	4.7	-	-	-	-	-	1.1
20 Aug. 1979	-	4.5	-	0.1	0.3	0.1	0.4	0.5
28 Aug. 1979	-	4.5	-	0.0	0.0	0.1	0.1	0.1
30 Aug. 1979	-	6.4	-	0.0	0.0	0.0	0.0	-
3 Sept. 1979	-	5.0	-	0.0	0.3	0.0	0.3	-
7 Sept. 1979	-	4.3	-	0.0	0.7	0.0	0.7	-
16 Sept. 1979	-	4.3	-	0.0	-	0.0	-	1.0
22 Sept. 1979	-	-	-	0.0	1.2	0.0	1.2	0.7
23 Sept. 1979	-	-	-	0.0	0.4	0.0	0.4	0.1
2 Oct. 1979	-	4.6	-	0.0	0.6	0.0	0.6	0.4
3 Oct. 1979	-	5.9	-	0.0	0.9	0.0	0.9	0.7
8 Oct. 1979	-	6.5	-	0.3	1.9	0.2	2.1	0.6
12 Oct. 1979	-	-	-	-	-	-	-	0.8
23 Oct. 1979	-	6.0	-	0.0	0.3	0.3	0.6	0.4
29 Oct. 1979	-	-	-	0.3	0.6	0.3	0.9	0.2
3 Nov. 1979	-	4.1	-	0.2	0.2	0.4	0.6	1.4
Rain gauge 2								
10 Aug. 1979	-	5.4	-	-	-	-	-	-
30 Aug. 1979	-	6.9	-	0.0	0.4	0.0	0.4	-
Mean	-	5.2	-	<0.1	0.5	<0.1	0.6	0.6

Table 20. Wastewater constituents applied in effluent (lb).

Month	*Ortho-P*	*Total P*	*NH_4-N*	*Organic N*	*NO_3-N*	*Total N*	*BOD_5*	*Cl*
December 1978	-	88.6	8.2	45.4	362.4	416.0	170.9	1544.6
January 1979	0.4	123.0	55.6	43.4	395.7	494.7	168.9	1631.0
February*	-	148.8	58.9	77.4	499.1	635.4	359.6	2101.7
March	-	334.7	114.2	243.4	1202.0	1559.6	1156.3	5165.7
April	-	138.9	21.2	67.2	421.3	509.7	231.7	2333.6
May	-	119.9	1.5	89.9	151.5	242.9	372.4	1413.8
June	-	149.0	3.3	123.0	330.3	456.6	-	1955.9
July	-	61.9	8.8	59.7	170.6	239.2	31.1	1293.5
August	-	83.3	32.4	227.1	375.4	634.9	759.9	2150.2
September	-	107.6	0.0	67.2	255.5	322.8	90.8	1512.4
Total	-	1355.8	304.0	1043.9	4163.9	5511.8	-	21,102.2
Mean		135.6	30.4	104.5	416.5	551.2	430.1	2110.3

*No effluent analysis in February; mean of January and March concentrations used.

Table 21. Wastewater constituents exported in ditch flow (lb).

Month	Ortho-P	Total P	NH_4-N	Organic N	NO_3-N	Total N	BOD_5	Cl
December 1978	4.6	-	0.9	4.6	89.3	94.8	22.7	375.9
January 1979	1.8	-	1.1	10.6	120.2	131.8	61.3	604.7
February	2.9	-	2.6	8.6	122.4	133.6	14.8	609.1
March	13.2	-	3.1	-	443.8	-	88.0	2154.8
April	2.6	-	0.2	-	258.6	-	48.7	1369.3
May	2.4	-	0.0	-	73.2	-	38.1	776.5
August	2.2	-	0.0	-	166.9	-	15.0	1149.0

Table 22. Mass removal across east slope (lb).

Month	Total P		NH_4-N		Organic N		NO_3-N		Total N		BOD_5		Cl	
December 1978	< 84.0*	<95†	7.3	89	40.8	90	273.2	75	321.2	77	148.2	88	1168.7	76
January 1979	<121.3	<98	54.5	98	32.8	76	275.6	70	362.9	73	107.6	64	1026.3	63
February	<145.9	<98	56.2	96	68.8	89	376.8	75	501.8	79	344.8	96	1492.5	71
March	<321.4	<96	111.1	97	-	-	758.2	63	-	-	1068.4	92	3010.9	58
April	<136.2	<98	20.9	99	-	-	162.7	39	-	-	183.0	79	964.3	41
May	<117.5	<98	1.5	100	-	-	78.3	52	-	-	334.2	90	637.4	45
August	< 81.1	<97	32.4	100	-	-	208.6	56	-	-	744.9	98	1001.1	46
Mean		<97		97		-		62		-		87		57

*Pounds removed.

†Percent of applied effluent.

Table 23. Six-month nutrient budget (lb)—December 1978 through May 1979.

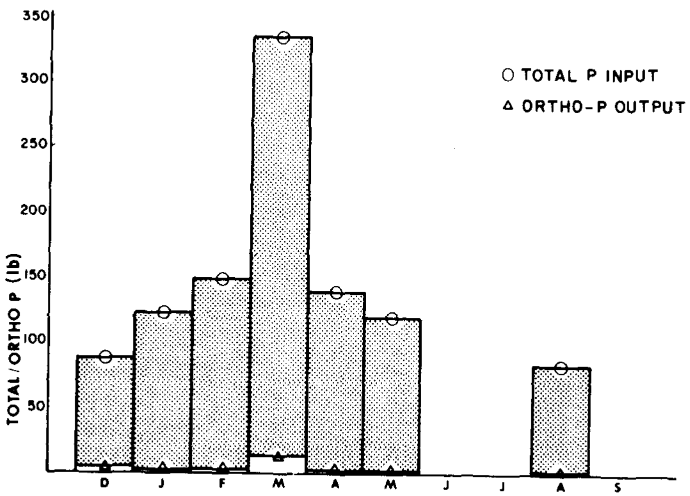
Total P	NH_4-N	NO_3-N	BOD_5	Cl
		Applied		
953.9	259.5	3032.0	2459.7	14,190.4
		Export		
27.6*	7.9	1107.4	273.6	5890.3
		Retained		
<926.3	251.5	1924.6	2186.1	8300.1
97%	97%	63%	89%	58%

*Ortho-P, not total P.

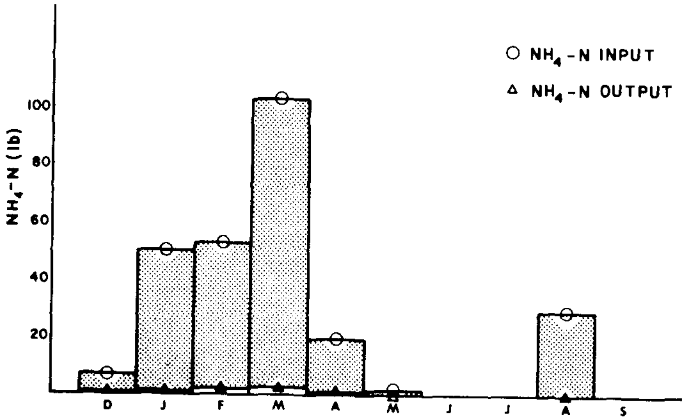
The input and output of P are shown graphically in Figure 24a. Unfortunately, effluent samples were typically analyzed for total P while ditch flow samples were most commonly analyzed for ortho-P. Thus, no direct comparison of input and output is possible for P. Table 22 and Figure 24a do, however, indicate the upper limits for P mass removal (i.e. <97%), based on a comparison between the input of total P and the output of ortho-P. From December 1978 through September 1979, 1355.8 lb of P was applied to the east slope, an average of 135.6 lb/month. During the period December 1978 through May 1979 (the longest continuous period of complete ditch flow record), 27.6 lb of ortho-P was exported in ditch flow, an average of 4.6 lb/month. Compared to the 953.9 lb of total P input during December through May, this represents a difference of 926.3 lb, or 97% of input mass apparently retained on the east slope. Monthly P removal ranged from a low of 95% or more in December 1978 to a high of more than 98% in various months.

Similar P mass removal rates have been observed in a number of other land treatment systems. Forested areas are known to be highly efficient in removing P from applied wastewater (Sopper 1973). Frost et al. (1973) reported 92 to 98% P removal at Lake Sunapee, New Hampshire. Leland et al. (1979) reported 85 to 99% P removal at a spray irrigation facility in Michigan; winter P removal of 77% was reported earlier for the same system (Burton and Hook 1978). Bouwer and Rice (1978) cited greater than 90% P removal after 10 years of land application at Flushing Meadows, Arizona.

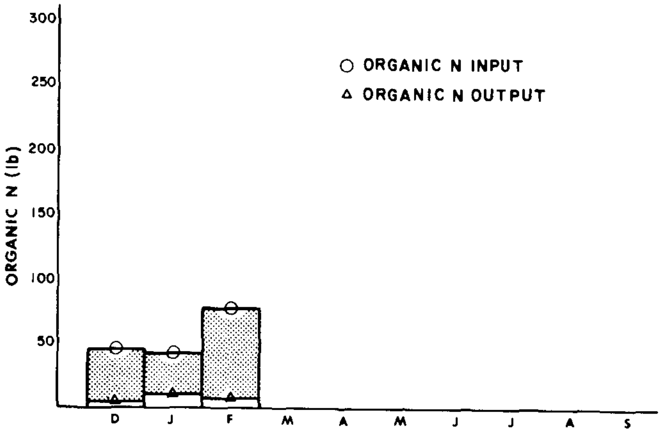
The input-output analysis for NH_4-N is shown in Figure 24b. Because applied effluent was consistently low in NH_4, the mass of NH_4 applied to the east slope



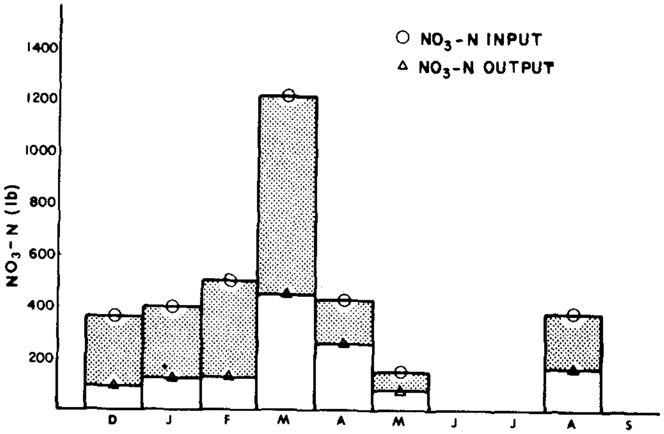
a. Phosphorus.



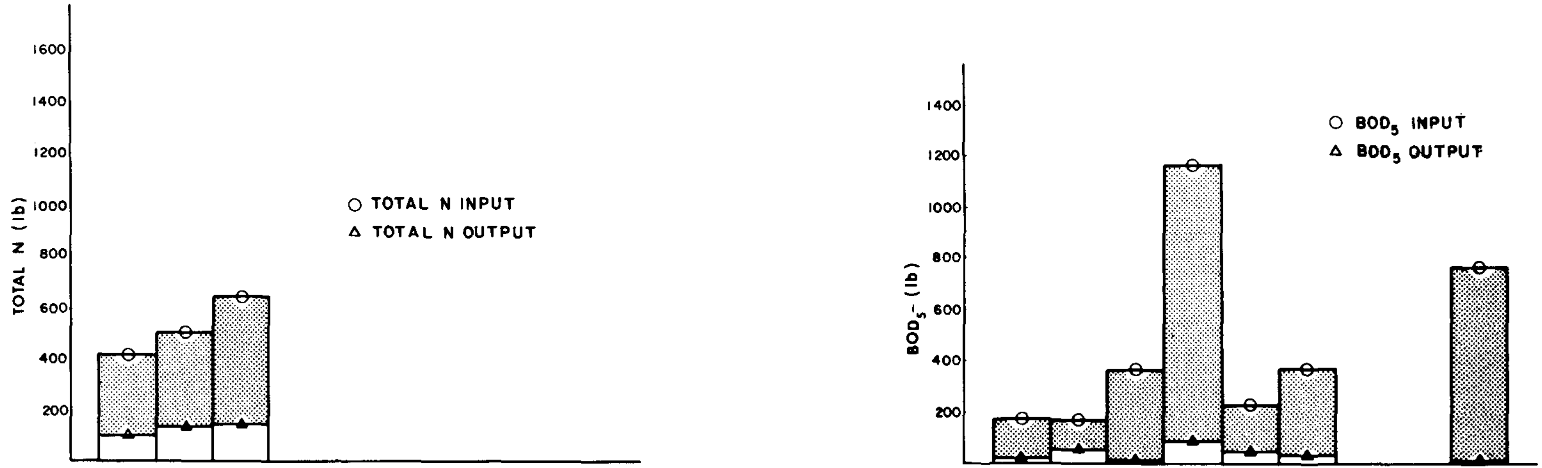
b. Ammonium.



c. Organic N.

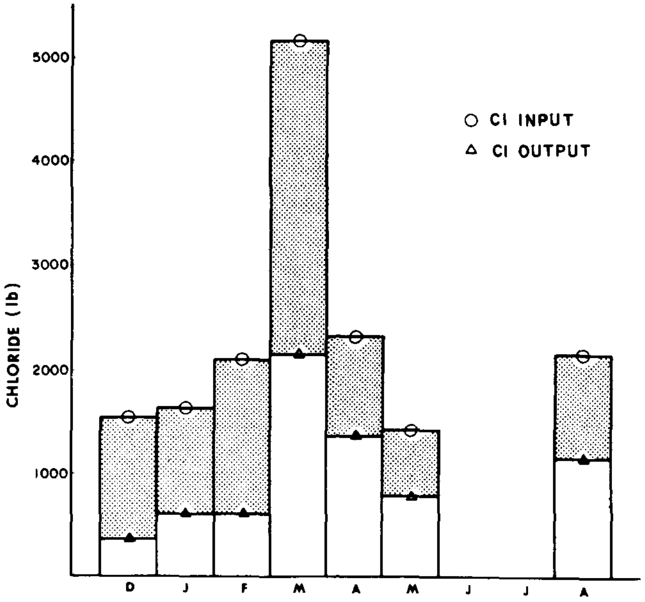


d. Nitrate.



e. Total N.

f. BOD_5



g. Chloride.

Figure 24. Monthly mass input (applied effluent) and output (ditch flow) of wastewater constituents.

was small compared to that of other constituents. From December 1978 through September 1979, 304.0 lb of NH_4-N was applied to the east slope. During the 6-month period of December through May, a total of 7.9 lb of NH_4-N was exported in ditch flow, compared to 259.5 lb applied. This represents a removal rate of 97%. Monthly NH_4-N removal varied from a low of 89% in December to a high of 100% in May and August. These rates are quite similar to the average 96% NH_4 removal observed at West Dover in 1977 (Cassell et al. 1979).

Mass balances for NH_4-N are rarely reported in the literature, but concentrations of NH_4-N in the percolate water from land treatment systems are typically quite low (Iskandar 1976, Nutter et al. 1978). The 60 to 91% NH_4 removal reported by Leland et al. (1979) in Michigan is somewhat lower than the 89 to 100% removal observed in West Dover. This may be due to the extremely low levels of NH_4-N in the effluent applied to the east slope.

Figure 24c shows mass input and output for organic N (TKN minus NH_4-N). Unfortunately, organic N data exist only for December, January and February, since TKN analyses were largely omitted from ditch samples in other months. Over this 3-month period, 166.2 lb of organic N was applied to the east slope; 23.8 lb of organic N was exported in ditch flow. This represents an average 86% reduction in organic N mass. The monthly reductions varied from 76% in January to 90% in December. These levels were somewhat lower than the 82 to 100% organic N removal reported in the summer of 1977 (Cassell et al. 1979).

Figure 24d shows the input and output of NO_3-N. From December 1978 through September 1979, 4163.9 lb of NO_3-N was applied to the east slope in the effluent; 3032.0 lb of this total was applied over the 6-month period, December through May. During this 6-month period, 1107.4 lb of NO_3-N left the spray field in ditch flow. Thus, 1924.6 lb of NO_3-N was retained by the east slope during this time (63% of the input mass). Monthly NO_3 removal ranged from a low of 39% in April to a high of 75%.

NO_3-N is a critical concern in land treatment systems, primarily because of health considerations. Poor removal of NO_3 has been observed at many land treatment sites (Sopper 1976, Burton and Hook 1978, Urie et al. 1978). Frost et al. (1973) reported NO_3-N removal of 0 to 46% in New Hamphsire. There have been, however, several favorable cases cited in the literature which compare reasonably well with patterns observed at West Dover. Leland et al. (1979) reported an average of 85% NO_3-N removal in Michigan; NO_3 removal in winter was 61%, while up to 99% of the applied NO_3 was removed in warm weather.

The input and output of total N is shown in Figure 24e. As with organic N, lack of TKN data prohibits calculation of total N output except for the 3-month period December through February. Over this period, 1546.1 lb of total N was applied to the slope, while 360.2 lb was reported in ditch flow, an overall reduction of 77%. Individual monthly reduction levels varied from 73% in January to 79% in February. These reductions are substantially lower than the average 95% reduction observed in the summer of 1977 (Cassell et al. 1979).

N removal at West Dover compares well with values reported in the literature. Lance (1975) reported 75 to 80% N removal in systems similar to West Dover. Spyridakis and Welch (1976) reported N removals of 56 to 91% in a variety of systems. An average annual N removal of 84% has been observed in a forested land treatment system (Cole and Schiess 1978).

Monthly BOD_5 input-output patterns are shown in Figure 24f. Monthly BOD_5 inputs were quite variable, ranging from 31.1 lb in July to 1156.3 lb in March; the mean BOD_5 input was 430.1 lb/month. In the 6-month period of complete record, 2459.7 lb of BOD_5 was applied to the east slope. BOD_5 in the interceptor ditch ranged from a low of 14.8 lb in February to a high of 88.0 lb in March. Total export from December through May was 273.6 lb. The overall BOD_5 removal was 89% of the applied mass. Monthly removals ranged from 64% in January to 98% in August.

The BOD_5 removals observed at West Dover are generally comparable to those reported elsewhere. BOD_5 removals of 88 to 98% were reported by Pound and Crites (1973); BOD_5 removal rates of 90% and more have been observed in an overland flow test system (Jenkins et al. 1978). Iskandar et al. (1976) reported an annual BOD_5 removal of 94% in test cells at CRREL.

Figure 24g shows the input and output of Cl for the east slope. From December 1978 through September 1979, 21,102.2 lb of Cl was applied to the east slope; of this total, 14,190.4 lb was applied during the 6-month period December through May. Monthly Cl export in ditch flow ranged from 375.9 lb in December to 2154.8 lb in March; a total of 5890.3 lb of Cl was exported in ditch flow from December through May. This represents an overall difference of 58%. Monthly Cl mass removal rates varied from a low of 41% to a high of 76% in December.

Although the 1978-79 Cl removal rates were lower than those found in the earlier work, they still appeared to be somewhat higher than values reported in the literature. An average Cl removal of 34% has been reported in New Hampshire, with values ranging from 0 to 80% (Frost et al. 1973). Leland et al. (1979) reported Cl removals as high as 39% in warm weather, but long term removals in that study were in the 0 to 2% range. It should be noted that the mass balance procedure used in that study made estimates of Cl exported in infiltrated water and did not count that mass as retained or removed. In contrast, Cl lost in the "unaccounted for" water at West Dover was calculated as being removed. Thus, Cl removal on the east slope in this study would be expected to be higher than that reported by Leland et al. (1979).

Off site effects

Surface water quality

Tables 24 and 25 summarize mean monthly water quality data for Ellis Brook and the Deerfield River respectively.

The quality of the Deerfield River appears to be unaffected as it flows along the western boundary of the spray field since no significant differences between upstream and downstream water quality were observed over the course of the study. Levels of fecal coliform bacteria in the Deerfield River exceeded 200 colonies/100 mL (the Vermont class B stream standard) on several occasions. The total P concentrations at both sampling points suggest some organic loading from sources upstream of the spray site.

Concentrations of suspended solids, fecal coliforms, P and Cl were generally lower in Ellis Brook than in the Deerfield River. There was little difference between upstream and downstream water quality in Ellis Brook except that conductivity and Cl concentration were significantly higher at the downstream station. The largest upstream-downstream difference was evident in the Cl values, the average downstream concentration of 2.4 mg/L being substantially higher than the average upstream concentration of 1.0 mg/L.

Ellis Brook seems to be influenced by the operation of the treatment plant because of the substantial increases in conductivity and Cl concentrations that were consistently observed at the downstream location. Downstream conductivity was 30% higher, on the average, than upstream of the spray field. Similarly, Cl concentrations were, on the average, 140% higher just downstream of the plant.

The two likely causes of this impact are:

1. Water infiltrates from the evaporation pond into Ellis Brook. All interceptor ditch flow enters the evaporation pond. The pond is not sealed—the water which enters the evaporation pond infiltrates into the ground. Both Cl and conductivity are relatively unaffected by movement through soil.
2. Groundwater from the east slope flows into Ellis Brook. No increases in nutrient concentration were observed in Ellis Brook.

Off-site groundwater

Table 26 summarizes data from samples of groundwater taken from wells located outside the spray field. Well WS is private and is approximately ¼-mile west of the plant site on the Dorr Fitch Road. Well RCI is located directly across the Deerfield River from the western slope of the spray field. The plant well supplies drinking water for the plant control building and is located near the eastern edge of the plant site about 600 ft from the spray field. Well Z is a private well located about 5000 ft east of the plant on the Dorr Fitch Road. Wells WS, RCI and Z are shallow dug wells, whereas the plant well is a drilled well 155 ft deep.

The data in Table 26 indicate no contamination of the sampled wells by the sprayed effluent. Well Z shows higher levels of NO_3-N and Cl but the siting of this well suggests that this is likely due to contamination from an adjacent septic tank leach field.

In the absence of preoperation background data, it is difficult to evaluate water quality data from off-site wells. With the exception of well Z, none of the wells tested appear to suffer any major contamination. The Cl levels in well RCI and the plant well may be due to their proximity to highways that receive large quantities of salt in the winter. With the limited data available, it can only be said that no case of major contamination was observed in private wells near the spray field.

Wastewater renovation on east slope

Land treatment of treated wastewater at West Dover, Vermont, was shown to be highly effective during all seasons of the year. Concentrations of N and P, as well as other constituents, were reduced dramatically in interceptor ditch flow as compared to concentrations in applied effluent. In terms of mass balance, the east slope performed as well as or better than most land treatment systems reported in the literature, even under severe winter conditions. Few off-site influences were observed. Although this study was not designed to generate definitive data to assess the specific renovative processes on the east slope, it is worthwhile to discuss some of the possible mechanisms of nutrient removal.

The important P retention mechanisms in the soil include chemical sorption and subsequent mineralization. Initially, P is rapidly adsorbed by soil particles, removing it from the soil water solution (Enfield 1977). During sorption P is bound on soil particle surfaces (particularly on clay particles by many processes, including reactions with iron, aluminum, and calcium ions [EPA et al. 1977]). Following

Table 24. Mean monthly values of water quality indicators in Ellis Brook.

Month	pH		Conductivity (µmhos)		Suspended solids (mg/L)		BOD_5 (mg/L)		Fecal coliforms (no./100 mL)		Total P (mg/L)		Ortho-P (mg/L)		NH_4-N (mg/L)		TKN (mg/L)		NO_3-N (mg/L)		Total N (mg/L)		Cl (mg/L)	
October 1978	7.1*	7.8†	23	30	47.0	28.0	0.5	0.8	-	-	0.0	0.0	0.04	0.02	0.0	0.0	0.5	0.4	0.0	0.05	0.5	0.4	1.2	1.4
November	6.8	6.8	20	25	-	-	2.4	1.5	0	0	0.0	0.0	0.02	0.02	0.0	0.0	-	-	0.1	0.1	-	-	0.9	1.9
December	6.7	7.4	15	18	39.5	20.2	0.8	6.0	23	9	-	-	0.04	0.03	0.0	0.0	-	0.1	0.3	0.3	-	0.4	2.8	1.6
January 1979	7.4	7.0	8	8	6.6	6.2	1.4	1.5	6	16	-	-	0.12	0.14	0.0	0.0	0.2	0.5	0.3	0.6	0.5	1.1	0.7	2.8
February	6.7	6.6	106	144	5.6	3.2	0.7	1.4	1	2	-	-	0.06	0.02	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.1	2.4
March	7.0	7.1	21	34	8.0	9.4	1.0	0.7	5	3	0.1	-	0.07	0.14	0.0	0.0	0.1	-	0.2	0.3	0.3	-	1.1	2.0
April	6.9	6.8	21	28	3.2	1.6	0.6	1.0	1	1	0.2	0.1	0.03	0.03	0.01	0.0	0.0	0.2	0.1	0.1	0.1	0.3	1.0	1.4
May	6.8	6.7	30	34	0.5	0.7	0.6	0.7	2	5	0.1	0.2	0.02	0.02	0.0	0.0	0.1	0.1	0.04	0.03	0.1	0.1	0.9	1.6
June	7.3	7.3	32	36	0.4	0.4	0.4	0.05	4	2	0.05	0.0	0.02	0.02	0.0	0.0	0.05	0.0	0.0	0.0	0.05	0.0	0.8	2.4
July	6.9	7.0	32	37	0.5	0.5	0.6	0.4	33	68	0.0	0.0	0.02	0.03	0.05	0.2	0.0	0.0	0.05	0.0	0.05	0.0	0.8	1.8
August	7.2	7.1	45	62	1.9	2.0	0.5	0.6	59	25	0.0	0.0	0.02	0.04	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	1.1	4.5
September	7.1	7.2	36	38	0.4	0.4	0.4	0.7	54	50	0.05	0.0	0.02	0.02	0.0	0.0	0.3	0.0	0.1	0.0	0.4	0.0	1.3	1.9
October	7.2	7.0	27	37	0.2	0.3	0.9	0.9	20	15	0.03	0.03	0.02	0.02	0.0	0.0	0.3	0.3	0.1	0.1	0.4	0.4	1.1	2.0
Average	7.0	7.0	32	42	4.6	4.4	0.7	0.8	18	12	0.07	0.07	0.03	0.02	<0.1	<0.1	0.2	0.2	0.1	0.2	0.3	0.3	1.0	2.4

*Upstream values.

†Downstream values.

Table 25. Mean monthly values of water quality indicators in the North Branch of the Deerfield River.

Month	pH		Conductivity (µmhos)		Suspended solids (mg/L)		BOD_5 (mg/L)		Fecal coliforms (no./100 mL)		Total P (mg/L)		Ortho-P (mg/L)		NH_4-N (mg/L)		TKN (mg/L)		NO_3-N (mg/L)		Total N (mg/L)		Cl (mg/L)	
October 1978	7.2*	7.1†	65	70	42.0	35.7	0.8	1.3	-	-	0.2	0.1	0.04	0.04	0.0	0.05	0.7	0.6	0.05	0.1	0.75	0.7	12.4	13.9
November	6.7	6.5	50	55	-	-	1.1	0.9	0	0	0.0	0.0	0.02	0.02	0.0	0.0	-	-	0.0	0.0	-	-	12.1	13.2
December	6.5	7.4	30	33	9.2	4.5	1.6	1.4	-	45	-	-	0.06	0.06	0.0	0.0	0.1	0.2	0.3	0.3	0.4	0.5	9.8	15.0
January 1979	7.6	7.0	5	2	11.8	1.9	1.6	1.2	230	143	-	-	0.08	0.05	0.0	0.0	0.1	0.4	0.3	0.25	0.4	0.6	9.2	10.2
February	6.8	6.8	76	90	20.7	14.6	1.7	1.4	424	408	-	-	0.21	0.03	0.0	0.0	0.2	0.3	0.8	0.4	1.0	0.7	25.5	25.6
March	7.0	7.0	44	46	16.3	15.0	1.0	0.9	11	8	0.5	-	0.04	0.06	0.0	0.0	0.0	-	0.2	0.3	0.2	-	11.0	11.8
April	6.8	6.8	38	39	3.0	3.0	0.7	0.9	3	3	0.7	0.2	0.04	0.04	0.0	0.0	0.0	0.0	0.2	0.1	0.2	0.1	10.1	10.8
May	6.7	6.7	49	51	1.5	1.6	0.6	0.8	13	16	0.1	0.2	0.02	0.02	0.0	0.0	0.2	0.2	0.06	0.08	0.26	0.28	10.0	10.9
June	6.9	7.2	70	75	0.7	0.6	0.4	-	100	71	0.05	0.1	0.05	0.03	0.0	0.0	0.1	0.1	0.25	0.2	0.35	0.3	15.4	16.1
July	6.8	7.0	80	86	1.5	1.5	0.6	0.5	138	167	0.0	0.0	0.02	0.02	0.1	0.0	0.5	0.4	0.05	0.0	0.55	0.4	16.6	17.1
August	7.2	7.2	107	107	1.1	0.9	0.7	0.5	86	80	0.0	0.0	0.03	0.03	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.2	18.3	21.0
September	7.1	7.1	67	72	1.4	1.1	0.8	0.8	202	203	0.05	0.0	0.02	0.02	0.6	0.6	0.2	0.2	0.0	0.2	0.2	0.4	14.4	16.4
October	7.0	7.2	35	43	2.1	1.6	0.6	0.8	73	56	0.05	0.0	0.02	0.02	0.05	0.0	0.3	0.3	0.2	0.1	0.5	0.4	8.8	8.4
Average	6.9	6.9	50	52	7.7	5.5	0.8	0.9	55	54	0.2	0.1	0.04	0.04	<0.1	<0.2	0.2	0.2	0.1	0.2	0.3	0.4	11.6	12.8

*Upstream values.

†Downstream values.

Table 26. Mean values of water quality indicators in off-site wells.

Well	*Temp. (°C)*	*pH*	*Conductivity (μmhos)*	*Fecal coliforms (no./100 mL)*	*Ortho-P (mg/L)*	*Total P (mg/L)*	*NH_4-N (mg/L)*	*TKN (mg/L)*	*NO_3-N (mg/L)*	*Cl (mg/L)*
WS	10.1	6.6	33	<1	0.07	0.0	0.0	0.1	<0.1	1.0
RCI	11.2	7.0	136	0	0.09	0.0	0.0	0.1	<0.1	10.6
Z*	6.0	6.7	200	0	0.06	-	0.0	0.9	2.8	65.3
Plant	11.0	6.9	144	0	0.04	0.2	0.0	0.2	0.1	13.7

*One sample

initial adsorption it is thought that a slower mineralization, which forms relatively insoluble P compounds, predominantly the phosphate salts of calcium, iron, and aluminum, takes place. Mineralization is thought to remove adsorbed P, thus making adsorption sites available again for additional adsorption (Enfield 1977). P adsorption and mineralization differ quantitatively in different soils. The role of the organic matter in the soil may be important and is not well understood.

The amount of P actually retained in a soil is not only a function of soil characteristics but can also depend on the rate at which effluent is applied to the soil. High effluent infiltration rates have been observed to result in an increase in the concentration of soluble P in soil water (Sommers et al. 1977). The adsorption of P onto soil surfaces is not instantaneous, and thus the kinetics of P adsorption are a factor in renovation efficiency. If the rate of wastewater application exceeds the rate of P sorption in the soil, "leakage" of P through the system can be expected, despite all available adsorption sites not being filled. However, without specific laboratory analyses of east slope soils, the potential for this at West Dover cannot be evaluated.

Plant uptake is another P removal mechanism in land treatment systems and, indeed, the presence of vegetation has been shown to be critical for wastewater renovation in land treatment systems (Cole and Schiess 1978). Based on values for P uptake from the literature, it has been estimated that tree growth on the east slope could account for up to about 440.9 lb P/year (Cassell et al. 1979). The abundance of understory vegetation on the east slope is undoubtedly another important source of P uptake.

The N applied to the east slope is subject to all the complex transformations that N can undergo in soil systems. Nitrification of NH_4-N to NO_3-N by bacteria is known to be important in many land treatment systems (EPA et al. 1977). However, nitrification is probably not critical at West Dover since most of the N in the applied effluent is already in the NO_3 form. Even so, the general absence of NH_4-N from east slope drainage does suggest that what little NH_4-N is applied is almost completely removed, either through nitrification or by direct adsorption in the soil (EPA et al. 1977).

Denitrification, the conversion of NO_3-N to gaseous N_2 by soil micro-organisms, has been cited as a particularly important mechanism of N removal in a spray field (Sopper 1973, Iskandar et al. 1976, Spyridakis and Welch 1976, EPA et al. 1977). Denitrification requires anaerobic conditions, sufficient organic carbon to serve as a bacterial energy source, as well as a relatively high soil temperature (Lance 1975, EPA et al. 1977). These conditions are surely present on the east slope at certain times of the year. Extended periods of effluent application can promote localized anaerobic conditions by saturating the soil. The presence of living plants is also thought to promote denitrification by lowering soil oxygen concentrations from respiration in the root zone and by root excretions of organic matter (EPA et al. 1977). Winter conditions, however, are poor for denitrification, since denitrification at soil temperatures below 50°F is minimal (Lance 1975, EPA et al. 1977).

Research has shown the importance of understory vegetation—shrubs and grasses—to N uptake in land treatment systems (Sopper 1976, Cole and Schiess 1978, Urie et al. 1978). The prolific growth of understory vegetation on the east slope, particularly in the areas originally cleared around the spray lines, suggests that this may be an important method of N removal at West Dover. However, without harvest and removal, the understory must be regarded as a temporary N sink. High rates of NO_3-N leaching have been reported when herbaceous vegetation dies back in the fall (Urie et al. 1978).

Significant N removal has been observed on the east slope over the period of this study. NO_3 concentrations in the ditch flow dropped sharply in late May and early June, the time of increasing soil temperature and plant growth. The export pattern observed in event 10 (see Appendix A) points to a significant NO_3 removal mechanism operating on the east slope.

There are two additional pathways of nutrient "removal" functioning on the east slope. First, in the winter months much of the effluent is retained on the spray field as ice so that many wastewater constituents are withheld from ditch flow until the ice melts. The removal rates reported for the winter in this study reflect, in part, on-site storage rather than true renovation. Second, the unaccounted-for-water term in the water budgets accounts for some portion of the reported nutrient removals across the spray field. Some evidence suggests that unaccounted for water leaves the east slope largely as deep percolation and as subsurface flow too deep to be intercepted by the ditch. This unaccounted for water undoubtedly carried effluent constituents with it. This phenomenon explains observed Cl removals, for example. The quantitative importance of these two "removal" mechanisms on the east slope, however, is not known.

Based on the above and on observed spray field data, it is possible to devise an outline of how the spray field functions at West Dover, Vermont. In warm weather, much of the applied effluent is evaporated and transpired, denitrification is at a maximum, and growing plants take up a substantial quantity of the applied P and N. Treatment effectiveness is thus at a maximum, and only a very small proportion of the input water and nutrients appear in the ditch flow. With the end of the growing season and lower air temperatures, evapotranspiration decreases, and biological processes are slowed. Thus, treatment effectiveness diminishes, and a greater proportion of input water and nutrients tends to be exported in the ditch flow.

During the coldest months, few biological processes are active and higher concentrations of nutrients are observed in ditch flow. Most applied effluent is stored on the spray field as ice or snow. Research has indicated that the buildup of a substantial ice pack in early winter may prevent severe frost penetration into the soil, allowing significant infiltration from ice melt at the ground surface even during cold months (Leland et al. 1979). Storage of frozen effluent on the spray field results in a significant retention of both the total water input and the applied wastewater constituents.

In the spring, water flow and nutrient export in the ditch are high because of heavy effluent application and the melting of stored-effluent ice. However, dilution by rainfall and melting snow tends to moderate the concentration of wastewater constituents in spray field drainage, so that concentrations in the ditch flow remain substantially lower than in the applied effluent.

CONCLUSIONS AND RECOMMENDATIONS

Ability of West Dover facility to renovate wastewater

1. Over the study period there was a considerable seasonal variation in the removal of N and P by the system. Removals were highest in the summer and fall and lowest during the winter and spring.
2. During the spring months of March, April and May, total N removal averaged 55% across the spray site, while NO_3-N and total-P removal averaged 46 and 90%, respectively. During this same time the concentrations of these parameters in the ditch flow averaged 6.0 mg/L of N, 5.3 mg/L of NO_3-N, and 0.44 mg/L of P respectively.
3. During the winter months of December, January and February, total N removal averaged 58% across the spray site. At the same time NO_3-N removal averaged 82%, while 95 to 98% of the total P was removed. During this same period the concentrations of these parameters in the ditch flow averaged 9.3 mg/L of N, 8.6 mg/L of NO_3-N, and 0.1-0.6 mg/L of P respectively.
4. During the summer and fall months, 76% of the total N was removed while NO_3-N and total P removals averaged 76 and 96% respectively. The average ditch flow concentrations of these parameters were 3.5 mg/L of N, 3.0 mg/L of NO_3-N and 0.14 mg/L of P respectively.
5. A considerable volume of effluent, along with its associated contaminants, is stored on the spray site as ice during the cold winter months.
6. At all times of the year a considerable portion of the applied effluent apparently leaves the site as groundwater. In addition, some portion of the nutrients, reported in this study as removed, actually leave the spray site in this groundwater.
7. The largest export of N and P from the spray site is observed during the spring runoff and at other times when individual precipitation or spray events are of such magnitude to cause surface runoff from the spray site.
8. The pattern and extent of export of nutrients from the spray site during an individual runoff event are highly variable and are dependent upon: 1) the intensity of the precipitation or spray event, 2) the temperature, and 3) the antecedent weather conditions.
9. The maximum concentrations in the ditch flow of total P, ortho-P, NO_3-N, and TKN observed over the period of this study were 2.0 mg/L, 2.0 mg/L,

15.8 mg/L, and 17.6 mg/L, respectively. Concentrations greater than 0.6 mg/L of total P, 0.5 mg/L of ortho-P, 13.5 mg/L of NO_3-N, and 15.0 mg/L of TKN were observed only four times throughout the 11-month study period. These higher values were all associated with periods of high ditch flow.

Off-site effects

1. There are no data on the quality of the surface water or groundwater adjacent to the spray site prior to the operation of the West Dover facility. Therefore, no background data are available to compare with the off-site water quality observed in this study.
2. No discernible change in the quality of the Deerfield River was observed as it flowed past the western slope of the spray site.
3. There is a significant increase in the conductivity and Cl levels in Ellis Brook as it flows past the eastern boundary of the plant site. Since no surface discharge from the West Dover Facility ever enters Ellis Brook, this impact must be the result of subsurface flow. Topography and site layout suggest this could be caused by leakage from the polishing, holding or evaporation ponds, or from subsurface flow from the east slope of the spray site.
4. There is no evidence of contamination of nearby off-site wells.

Recommendations

1. Over the study period about 40% more effluent was pumped to the spray site than flowed into the plant as influent. This difference was probably derived from: 1) precipitation intercepted by the various plant ponds (primarily the polishing and holding ponds), 2) the "drain back" volumes associated with spray line shut down, and 3) subsurface flow entering the holding pond. *Plant pumping costs can be reduced by minimizing the volume actually pumped to the spray site.* There are several alternatives that should be considered to address this recommendation.
    a. Subsurface flow into the holding pond could be reduced or eliminated by intercepting it up-slope of the holding pond. Implementation of this recommendation would be capital intensive.
    b. Spray application schedules should be adjusted to minimize use of the holding pond for storage. In winter months, this could be accomplished, in part, by increasing the amount of effluent stored on the hillside as ice. The holding pond should be isolated from plant operations and the spray application field as far as practicable.
    c. Each time a spray line is shut off, the volume of effluent in the line drains back into the polishing pond. Since this plant feature can, in the summer, increase total volumes pumped up to 30%, changes in the system should be made so that effluent isn't drained back when temperatures are above freezing. However, during cold weather this drain back feature is required to prevent freezing of the lines.
2. During the study period, surface runoff (i.e. overland flow) through natural drainage paths was frequently seen entering the interceptor ditch. Usually, at times when surface runoff was evident, ditch flows were high and nutrient export was also at its highest. *Contaminant export from the spray site can be reduced by eliminating or reducing surface runoff from the spray field.* There are several alternative actions that could be taken to reduce surface runoff from the east slope:
    a. During warm weather, spray schedules should ensure that application rates along each spray line do not exceed the infiltration capacity of the soil.
    b. Spray application should make maximum use of the spray lines near the crest of the spray site to maximize the opportunity for wastewater infiltration into the ground. This is particularly important in the winter when the application rates during continuous spraying frequently exceed the infiltration rates of the soil.
    c. The quantity of the overland flow which exits from the spray site could be reduced by selective terracing across natural drainage paths. At the same time this would encourage percolation of the overland flow into the ground.
3. Over the study period the greatest renovative capacity of the spray site was observed during the months of active plant growth. *Spray site renovative capacity can be increased by appropriate management of on-site vegetation.* There are several alternative recommendations to increase the renovative capacity of the spray site:
    a. The old and mature trees on the site should be systematically and selectively cut to promote vigorous young tree growth. This would enhance plant nutrient uptake.
    b. Vegetation along the spray line corridors should be managed to promote maximum understory development. This would enhance nutrient uptake and help protect spray lines from falling ice-laden limbs.
    c. As much as possible, slash and harvested trees should be removed from the spray site.

LITERATURE CITED

American Public Health Association, American Water Works Association, Water Pollution Control Federation (1976) *Standard methods for the examination* *of water and wastewater,* 14th ed. Washington, D.C.: American Public Health Association.

Bouwer, H. and R.C. Rice (1978) The Flushing Meadows Project. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 1. U.S. Army Cold Regions Research and Engineering Laboratory, p. 213-220.

Burton, T.M. and J.E. Hook (1978) Use of natural terrestrial vegetation for renovation of wastewater in Michigan. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 2. CRREL, p. 199-206.

Cassell, E.A., D.W. Meals and J.R. Bouzoun (1979) Spray application of wastewater effluent in West Dover, Vermont: An initial assessment. CRREL Special Report 79-6.

Cole, D.W. and P. Scheiss (1978) Renovation of wastewater and response of forest ecosystems: The Pack Forest study. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 1. CRREL, p. 323-331.

Dryden, F.D. and C. Chen (1978) Groundwater recharge with reclaimed waters from the Pomona, San Jose Creek, and Whittier Narrows plants. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 1. CRREL, p. 241-251.

Enfield, C.G. (1977) Wastewater phosphorus removal using land application. *Civil Engineering—ASCE.* Vol. 47, no. 6, p. 58–60.

Environmental Protection Agency, U.S. Army Corps of Engineers and U.S. Department of Agriculture (1977) Process design manual for land treatment of municipal wastewater. EPA 625/1-77-008.

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

Gilman, D. (1972) Narrative Soil Report, SCS.

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.

Jenkins, T.F., C.J. Martel, D.A. Gaskin, D.J. Fisk and H.L. McKim (1978) Performance of overland flow land treatment in cold climates. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 2. CRREL, p. 61-70.

Lance, J.C. (1975) Fate of nitrogen in sewage effluent applied to soil. *Journal of the Irrigation and Drainage Division, ASCE.* Vol. 101, Internal Report 3, p. 131-144.

Leland, D.E., D.C. Wiggert and T.M. Burton (1979) Winter spray irrigation of secondary municipal effluent. *Journal of Water Pollution Control Federation.* Vol. 51, no. 7, p. 1850-1858.

Meals, D.W. and E.A. Cassell (1982) Operational and meteorological data for the West Dover, Vermont, land treatment system. CRREL Internal Report 780.

New Hampshire Water Supply and Pollution Control Commission (1978) Effects of spray irrigation with stabilization pond effluent on surface and groundwaters. Report Tr-20 (for New England Interstate Water Pollution Control Commission).

Nutter, W.L., R.C. Schultz and G.H. Brister (1978) Land treatment of municipal wastewater on steep forest slopes in the humid southeastern United States. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 1. CRREL, p. 265-274.

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

Sommers, L.E., D.W. Nelson, L.B. Owens and M. Floyd (1977) Phosphorus dynamics in soils irrigated with municipal wastewater. Purdue University, West Lafayette, Indiana: Indiana Water Resources Research Center, Technical Report No. 99.

Sopper, W.E. (1973) A decade of municipal wastewater. In *Proceedings of the Symposium on Land Treatment of Secondary Effluent* (J.E. Flack, Ed.). Colorado State University.

Sopper, W.E. (1976) Use of the soil vegetation biosystem for wastewater recycling. In *Land Treatment and Disposal of Municipal and Industrial Wastewater* (R.L. Sanks and T. Asano, Eds.). Ann Arbor Science.

Sopper, W.E. and S.N. Kerr (1978) Utilization of domestic wastewater in forest ecosystems—The Pennsylvania State University Living Filter Project. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 1. CRREL, p. 333-340.

Spyridakis, D.E. and E.B. Welch (1976) Treatment processes and environmental impacts of waste effluent disposal on land. In *Land Treatment and Disposal of Municipal and Industrial Wastewater* (R.L. Sanks and T. Asano, Eds.). Ann Arbor Science.

Urie, D.H., J.H. Cooley and A.R. Harris (1978) Irrigation of forest plantations with sewage lagoon effluents. In *State of Knowledge in Land Treatment of Wastewater: Proceedings of an International Symposium, August 20–25, Hanover, New Hampshire.* Vol. 2. CRREL, p. 207-213.

APPENDIX A. STUDIES OF SPECIFIC HYDROLOGIC EVENTS

As previously mentioned, 10 specific hydrologic events, such as intense rainfall, spring snowmelt and extended periods of spray application, both separately and in various combinations, were carefully monitored during the study. This was done to determine the effects of spray event duration, precipitation intensity and duration, and ambient air temperature on both the quantity and quality of ditch flow. A detailed discussion of these 10 events and their results is presented in this appendix.

Event 1

This event, which was monitored from 13 to 16 October 1978, was characterized by a relatively small spray event (13,863 ft^3 over 6.5 hours) and two periods of moderate rain (0.73 in. and 0.77 in.). Figure A1 presents the event 1 ditch hydrograph, and the concentrations and mass export from the east slope of ortho-P, NO_3-N, and Cl, respectively. The initial flow in the ditch was virtually zero, but it began to increase at 1900 on 13 October, about 2½ hours after spraying ceased. Ditch flow peaked at 0.21 ft^3/s on 14 October at 1300 during the second day of rain. Following this peak, flow decreased rapidly, then more gradually through 16 October. Because at this time rainfall was measured by a nonrecording gauge, it is impossible to specifically relate ditch flow to rain intensity or time.

A water budget calculated for the event is shown below:

$$Q_S + Q_P - Q^*_{ET} - Q_D = Q_L$$

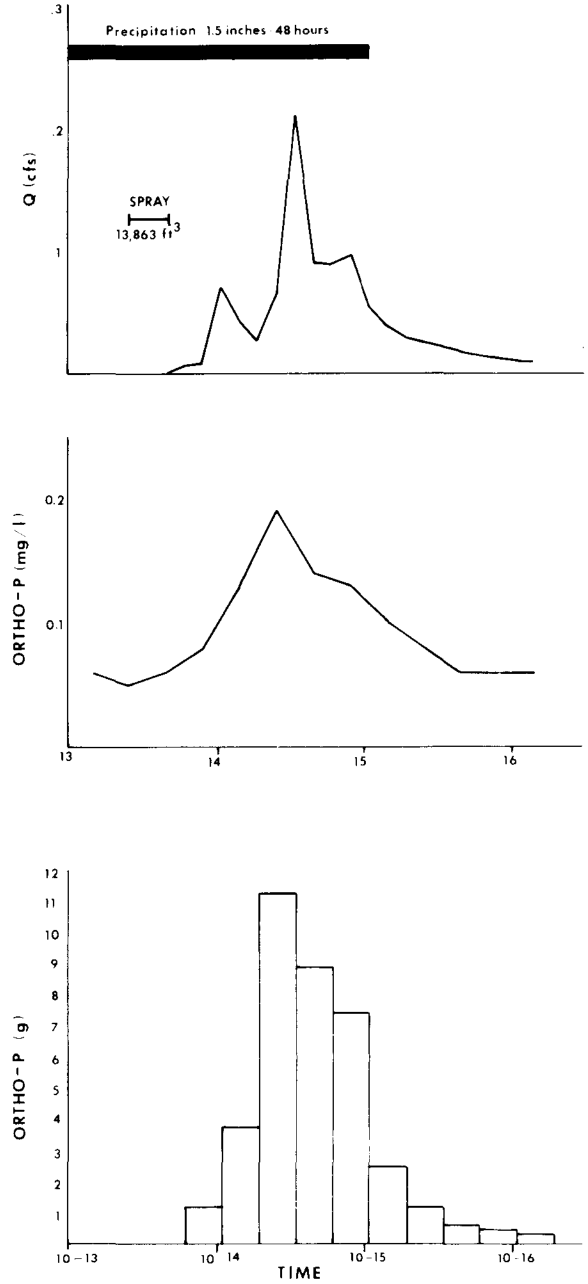
$$13{,}863 + 111{,}622 - 12{,}492 - 10{,}207 = 102{,}786\ (ft^3)$$

$$(10\%) \quad (8\%) \quad (82\%)\ (\%\ \text{of}\ Q_S + Q_P).$$

where

Q_S = effluent spray
Q_P = precipitation
Q_{ET} = evapotranspiration
Q_D = ditch flow
Q_L = unaccounted for water.

This budget shows that very little of the water input to the east slope during this event left as ditch flow, and thus most of the input must have percolated into the ground.



a. Ortho-P.

Figure A1. Concentration and mass export of three wastewater constituents during event 1. Hydrograph of ditch flow is included at the top of each figure group for comparison.

Ortho-P concentrations increased as ditch flow increased, with the peak concentration of 0.19 mg/L occurring shortly before the peak flow (Fig. A1a). However, since no sample was taken at exactly the time of peak flow, the actual peak ortho-P concentration may have been higher and may have occurred later. In contrast, the concentrations of both NO_3-N and Cl clearly decreased with increasing flow (Fig. A1b and c).

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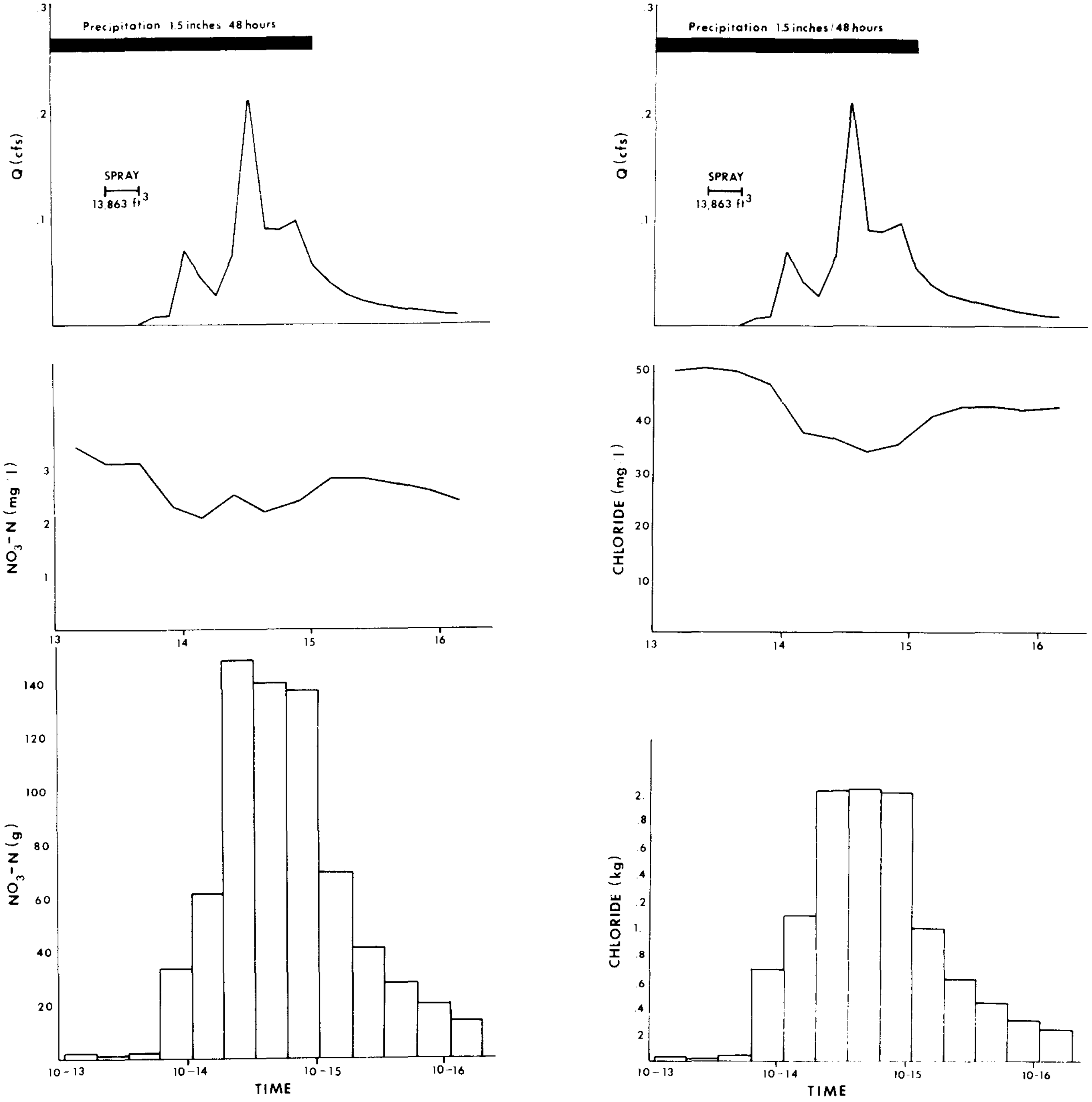
*Estimated at 0.051 in./day.



b. NO_3-N.

c. Chloride.

Figure A1 (cont'd). Concentration and mass export of three wastewater constituents during event 1. Hydrograph of ditch flow is included at the top of each figure group for comparison.

Mass export from the east slope of ortho-P, NO_3-N and Cl is also shown graphically in Figure A1. Although the magnitude of export is different among the three constituents considered, in each case the pattern of mass export is positively related to flow. Nearly all of the ortho-P (97%), most of the NO_3-N (84%), and nearly half of the Cl (43%) were retained by the east slope during this event (see Meals and Cassell 1982).

Table A1 presents all the water quality data collected during event 1. Levels of pH and conductivity decreased with increasing flows, while BOD_5 and suspended solids concentrations appeared to increase with the flow. NH_4-N was below detectable levels during most of the event, making a brief appearance about 7 hours after the hydrograph peaked.

Table A1 shows that both suspended solids and ortho-P increased with increasing flow and fell off

Table A1. Event 1—ditch flow water quality.

Date	Time	pH	Conductivity (µmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Ortho-P (mg/L)	Total P (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
13 Oct 78	0100	6.5	150	-	-	-	-	-	-	-
	0400	-	-	19.1	-	0.06	0.0	0.1	3.4	48.9
	0700	6.2	150	-	-	-	-	-	-	-
	1000	-	-	17.7	-	0.05	0.0	0.0	3.1	49.5
	1300	6.1	145	-	0.9	-	-	-	-	-
	1600	-	-	13.2	-	0.06	0.0	0.0	3.1	48.9
	1900	6.1	150	-	0.7	-	-	-	-	-
	2200	-	-	31.6	-	0.08	0.0	0.0	2.3	46.7
14 Oct 78	0100	6.2	100	-	-	-	-	-	-	-
	0400	-	-	68.6	-	0.13	0.0	0.0	2.1	37.4
	0700	6.1	135	-	2.0	-	0.0	0.0	-	-
	1000	-	-	84.1	-	0.19	0.0	0.1	2.5	36.1
	1300	6.1	105	-	1.6	-	-	-	-	-
	1600	-	-	11.0	-	0.14	0.0	0.0	2.2	33.9
	1900	6.2	120	-	0.9	-	-	-	-	-
	2200	-	-	11.1	-	0.13	0.0	0.0	2.4	35.4
15 Oct 78	0100	6.1	120	-	-	-	-	-	-	-
	0400	-	-	5.7	-	0.10	0.0	0.0	2.8	40.6
	0700	6.1	130	-	-	-	-	-	-	-
	1000	-	-	4.8	-	0.08	0.0	0.0	2.8	42.2
	1300	6.3	130	-	0.9	-	-	-	-	-
	1600	-	-	5.0	-	0.06	0.0	0.0	2.7	42.1
	1900	6.1	130	-	1.4	-	-	-	-	-
	2200	-	-	3.5	-	0.06	0.0	0.0	2.6	41.7
16 Oct 78	0100	6.1	130	-	1.5	-	-	-	-	-
	0400	-	-	4.8	-	0.06	0.0	0.0	2.4	50.4

with decreasing flow. These two parameters appear to be associated, suggesting that runoff carried particulate matter with it. These data, coupled with the fact that both Cl and NO_3-N were diluted at high ditch flows, suggest that the hydrograph for event 1 was caused largely by surface runoff.

Event 2

Event 2 began 9 December 1978 and ended early on 10 December 1978. This event followed an extended period of spray application between 5 and 8 December. Two small rains (0.16 in. and 0.04 in.) fell prior to the monitoring period and 0.71 in. of snow (water equivalent) fell on 9 December. Mean daily air temperature was 42°F on 8 December. Mean daily air temperatures were below freezing on the 9th and 10th, although the high temperature on both days reached 36°F.

At the start of the event, ditch flow was gradually receding following the effluent application from 5-8 December (see hydrograph, Fig. 2). At 0600 on 9 December, after 6 hours of snowfall, the ditch flow began to rise sharply. The flow peaked at 0.44 ft^3/s at 0900 on 9 December, then dropped quickly over the next 3 hours to the previous rate of decreasing flow.

A total of 17,391 ft^3 of water flowed through the ditch during the event monitoring period. The water budget for event 2 is:

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 0 & + & 52{,}835 & - & 0 & - & 17{,}391 & = & 35{,}444\ (ft^3) \\ & & & & & & (33\%) & & (67\%\text{ of }Q_S + Q_P). \end{array}$$

This budget shows that one-third of the amount of water that fell as snow appeared as ditch flow. However, if only the estimated increment of ditch flow above that provided by the earlier spray application is considered, the water budget for this event looks quite different:

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 0 & + & 52{,}835 & - & 0 & - & 3417 & = & 49{,}418\ (ft^3) \\ & & & & & & (6\%) & & (94\%\text{ of }Q_S + Q_P). \end{array}$$

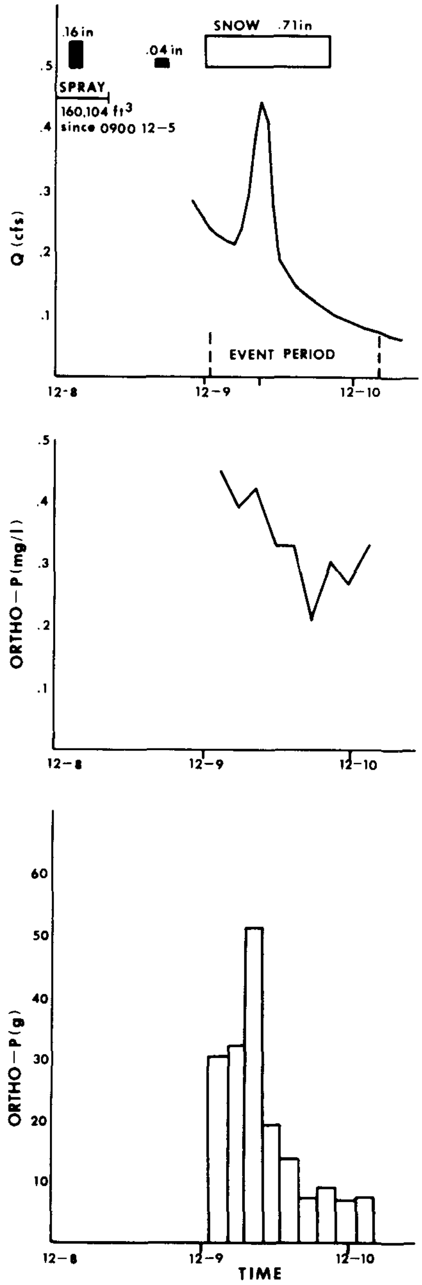
In this case only an estimated 6% of the water input as snow appeared as an added increment of ditch flow. It appears that runoff, resulting from snowfall at or just above the freezing point, caused the ditch flow hydrograph shown in Figure A2.

Figure A2 shows concentration and mass export of ortho-P, NO_3-N, and Cl, respectively, during event 2. Ortho-P, NO_3-N, and Cl concentrations all generally decreased throughout the event, although ortho-P levels began to rise during the last 8 hours of event 2.

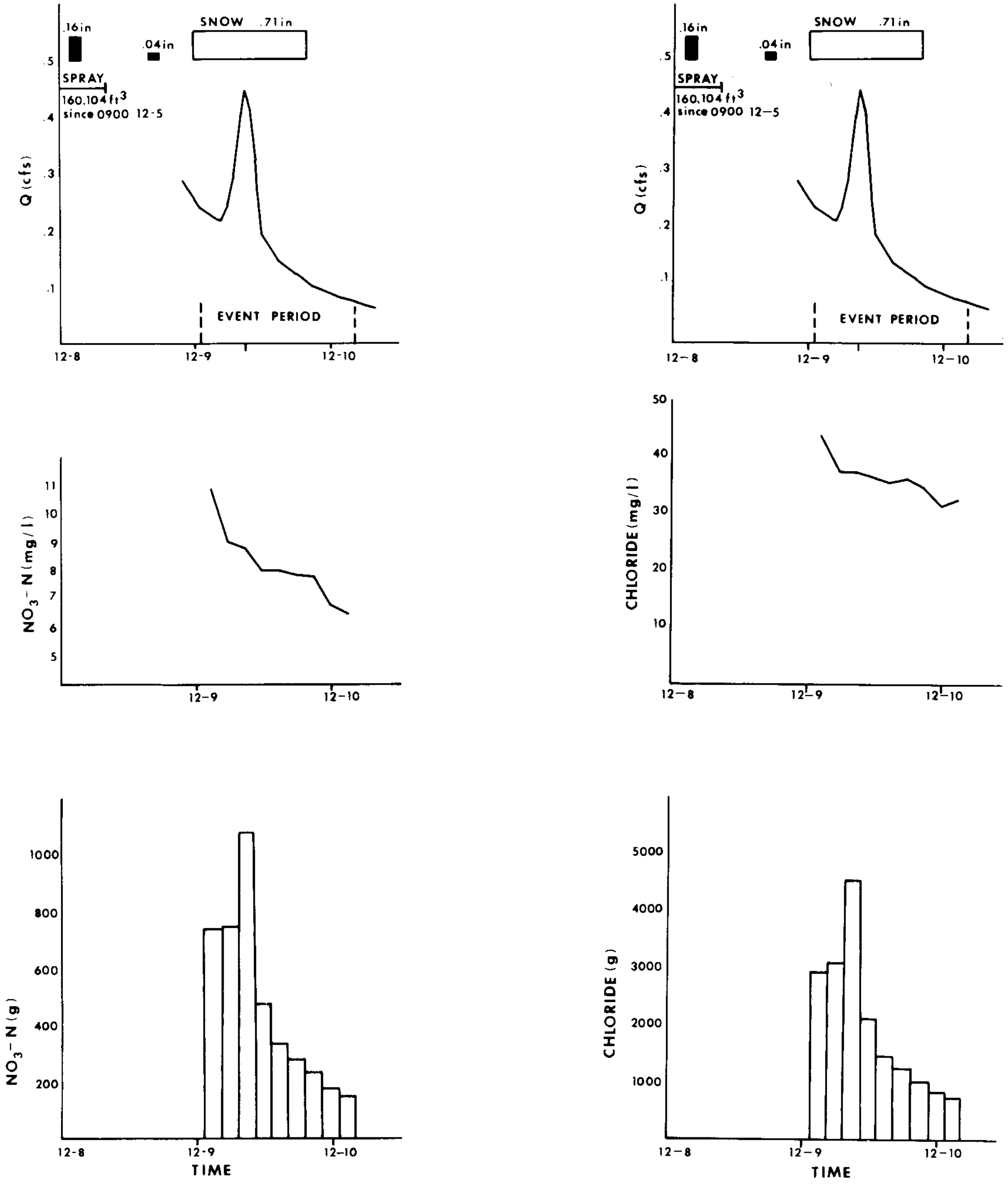
The nutrient mass export patterns of ortho-P, NO_3-N, and Cl shown in Figure A2 followed the pattern of ditch flow. Since only insignificant amounts of P, N, and Cl can be assumed to be in snow, the mass exported in the ditch flow must be flushed off the spray field (see Meals and Cassell 1982).

Table A2 gives all the water quality data collected during event 2. Other wastewater constituents did not follow the same pattern as P, NO_3, and Cl. BOD_5 and TKN were at a maximum during high flows and then decreased steadily over the remainder of the event. Fecal coliform levels declined throughout the event, and NH_4 remained below detectable levels. No significant changes were observed in suspended solids, pH or conductivity.

The event 2 hydrograph can be considered a melt runoff. The ditch flow probably originated as snowmelt or ice-melt during the warm periods of the day. It is likely that the nutrients being exported from the east slope during event 2 also originated from the snowfall or ice-snow pack.



a. Ortho-P.



b. NO_3-N.

c. Chloride.

Figure A2. Concentration and mass export of three wastewater constituents during event 2. Hydrograph of ditch flow is included at the top of each figure group for comparison.

Table A2. Event 2–ditch flow water quality.

Date	*Time*	*pH*	*Conductivity (μmhos)*	*Suspended solids (mg/L)*	*BOD_5 (mg/L)*	*Fecal coliforms (no./100 mL)*	*Ortho-P (mg/L)*	*NH_4-N (mg/L)*	*TKN (mg/L)*	*NO_3-N (mg/L)*	*Cl (mg/L)*
9 Dec 78	0247	5.8	150	0.4	-	22	0.45	0.0	0.9	10.9	43.7
	0547	5.9	80	-	-	-	0.39	0.0	0.7	9.0	37.6
	0847	6.0	120	0.4	1.5	22	0.42	0.0	0.3	8.8	37.2
	1147	6.1	130	0.4	3.5	12	0.33	0.0	1.6	8.0	36.4
	1447	6.1	40	0.2	1.6	10	0.33	0.0	0.6	8.0	35.9
	1747	5.9	150	0.2	1.3	4	0.21	0.0	0.6	7.9	36.1
	2047	6.0	145	0.0	1.3	8	0.30	0.0	0.5	7.8	34.9
	2347	5.8	120	0.1	2.4	6	0.27	0.0	0.2	6.8	31.9
10 Dec 78	0247	5.9	120	0.2	1.0	8	0.33	0.0	0.0	6.5	32.3

Event 3

Event 3 took place between 21 and 25 February 1979 and was characterized by an extended period of spray application that began before the event was monitored, a relatively intense rain, and rising air temperatures. Effluent application began at 1530 on 20 February and continued for 89½ hours until 0900 on 24 February. During this time 193,525 ft^3 of effluent was applied; 154,604 ft^3 was applied during the monitored event (0930 on 21 February to 0110 on 25 February). Rain fell on 22 February (0.16 in. in 4 hours) and again on 24 February (1.02 in. over 18 hours). The mean daily air temperature was above freezing during most of the event, climbing to 42°F on 24 February. There was considerable snow cover on the spray site throughout the event.

The ditch hydrograph for event 3 is shown in Figure A3. Ditch flow was consistently low during the first 60 hours, falling to zero for more than 12 hours on 21 and 22 February. During this period of no flow, a brief spike (0.008 ft^3/s) occurred at 0600 on 22 February, apparently in response to the rain which fell from 0400 to 0800 on that same day. Ditch flow resumed several hours later, gradually climbing to about 0.1 ft^3/s over the next 48 hours. The hydrograph began to rise with the second period of rainfall, which began at 0800 on 24 February, peaking at nearly 0.18 ft^3/s late in the afternoon of the 24th. At 2000, ditch flow began to decrease slowly despite the continuing rainfall.

The water budget calculated for event 3 is:

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 154{,}604 & + & 87{,}810 & - & 0 & - & 24{,}433 & = & 217{,}981\ (ft^3) \\ & & & & & & (10\%) & & (90\%\ \text{of}\ Q_S + Q_P). \end{array}$$

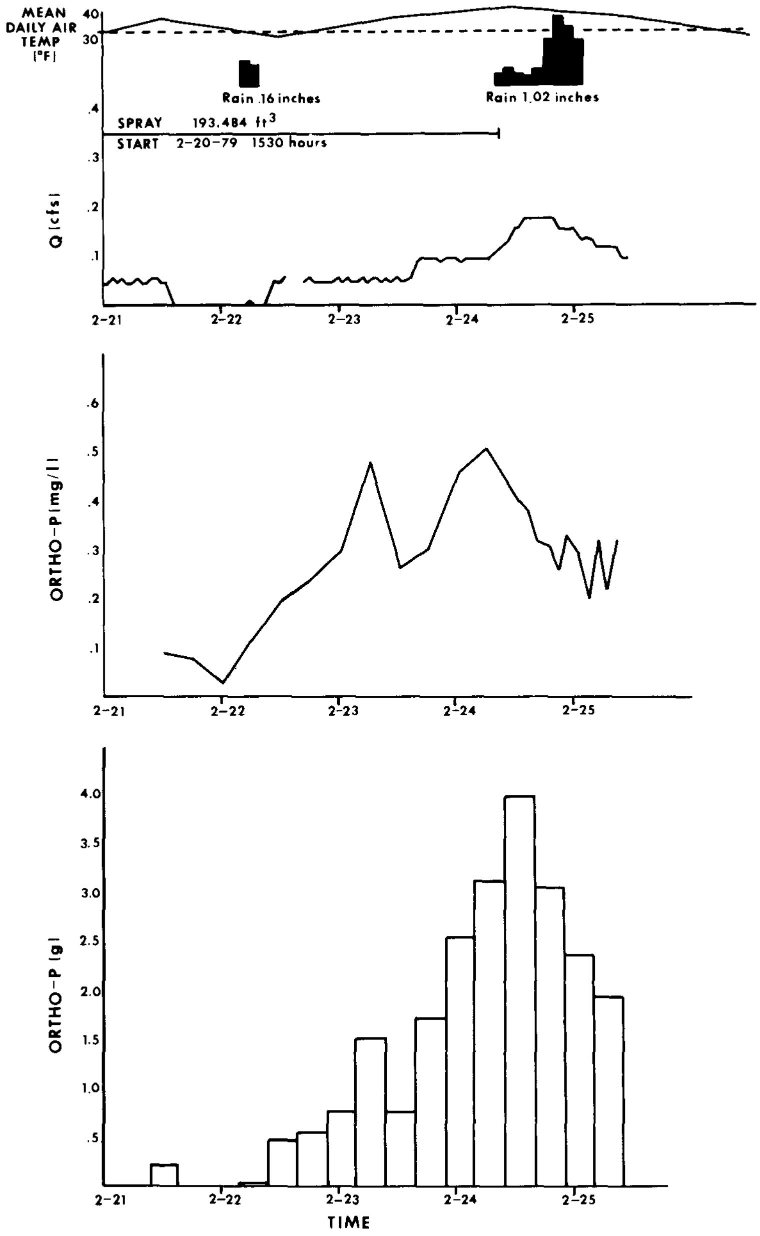
During this event only 10% of the input water left the site as ditch flow and, therefore, must have entered the ground or have been stored on-site as ice.

Figure A3 shows the concentration and mass export patterns for ortho-P, NO_3-N, and Cl, respectively, during the event. Concentrations of all three constituents began to increase with rising flow on 22 February. P and NO_3 reached peak levels at 0700 on 24 February, just before the end of spray and the onset of rain. Cl concentration peaked earlier and remained high for nearly 20 hours. The concentration of each constituent dropped sharply with the rising hydrograph and increasing rainfall.

Figure A3 shows that the mass export patterns of ortho-P, NO_3-N, and Cl generally followed the hydrograph. Over the time of this event, about 90% of the ortho-P, NO_3-N, and Cl applied was retained by the east slope, that is, it did not run off in ditch flow (see Meals and Cassell 1982).

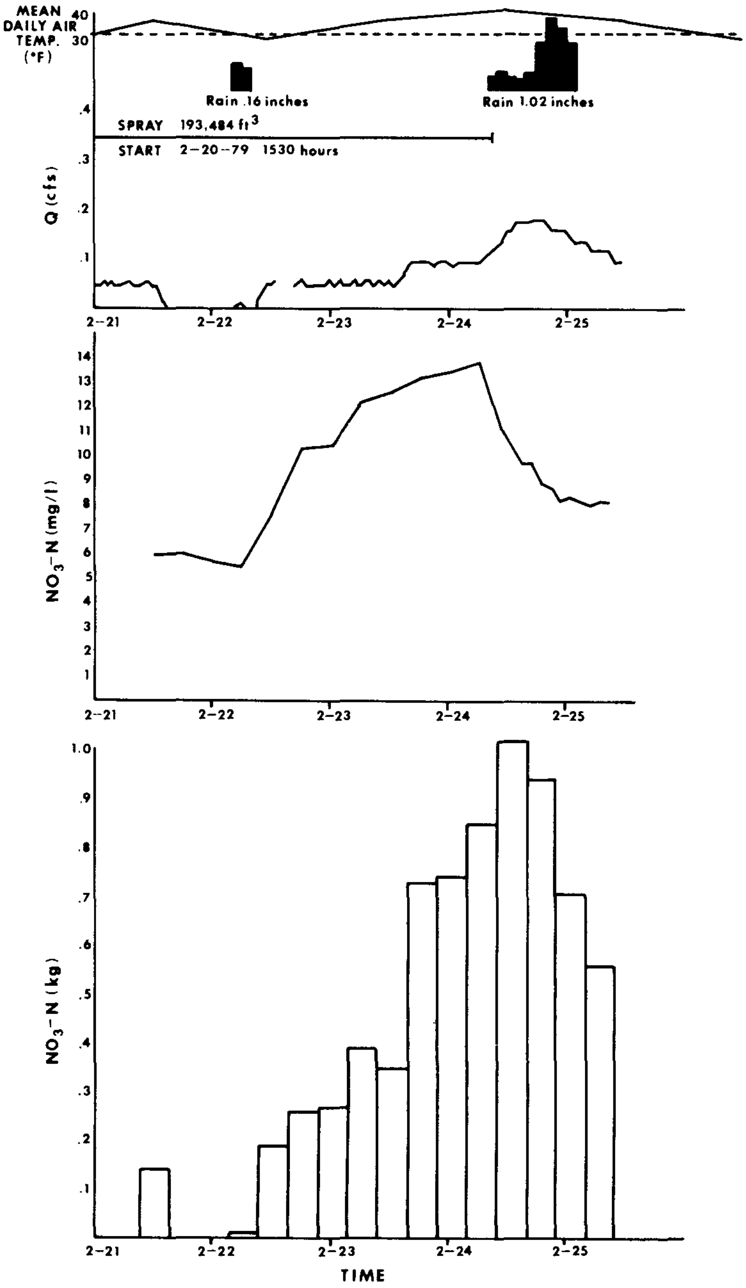
Table A3 summarizes all the data collected during event 3. BOD_5 levels began to increase with increasing flow on 23 February and remained elevated throughout the event. Fecal coliform bacteria concentrations increased moderately with the higher ditch flows that followed the rain on 22 February, then rose dramatically as ditch flow peaked on the 23rd. NH_4-N concentrations increased during the rising limb of the hydrograph, starting on the 24th, then decreased after the hydrograph peak. TKN values increased with increasing ditch flow in the early stages of the event and then remained relatively constant throughout the event.

During the early period of this event, up to about 1100 on 24 February, the pattern of increasing flow, ortho-P, NO_3-N and Cl concentrations, as well as increases in other parameters, indicates that the ditch flow was largely the result of snowmelt or spray runoff. After 1000 on 24 February the continued increase in flow, coupled with decreases in the concentration of ortho-P, NO_3-N, Cl, etc., suggests that the ditch flow was being diluted by rainfall.



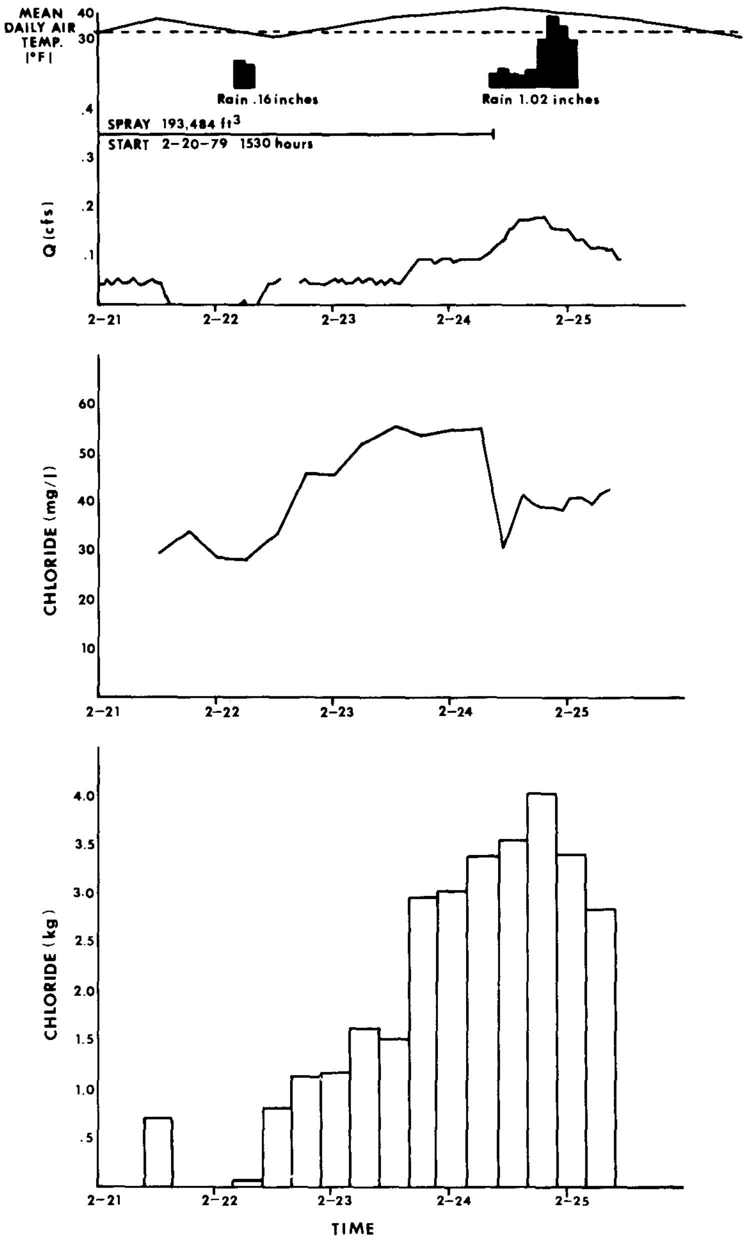
a. Ortho-P.

Figure A3. Concentration and mass export of three wastewater constituents during event 3. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A3 (cont'd). Concentration and mass export of three wastewater constituents during event 3. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. Chloride.

Figure A3 (cont'd).

Table A3. Event 3–ditch flow water quality.

Date	Time	pH	Conductivity (μmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	NH_4-N (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
21 Feb 79	1230	6.5	119	0.2	0.8	0	0.09	0.0	0.3	5.9	29.5
	1830	6.3	121	0.6	0.4	8	0.08	0.4	0.6	6.1	30.4
22 Feb 79	0030	6.4	125	0.6	0.5	2	0.30	0.5	0.4	5.7	28.3
	0630	6.2	120	1.2	0.6	6	0.12	0.0	0.9	5.5	28.1
	1230	6.3	138	0.4	0.8	2	0.20	0.0	0.8	7.6	33.2
	1830	6.3	180	0.6	0.4	26	0.24	0.1	1.3	10.3	45.3
23 Feb 79	0030	6.4	182	0.4	0.8	20	0.30	0.1	1.1	10.4	45.5
	0630	6.8	200	0.5	0.8	28	0.48	0.2	1.7	12.2	51.5
	1230	6.6	210	0.5	0.4	24	0.26	0.5	1.4	12.6	55.3
	1830	6.5	218	0.5	0.9	12	0.31	0.6	1.4	13.2	53.6
24 Feb 79	0030	6.5	220	0.5	1.1	10	0.46	0.6	1.7	13.4	54.4
	0630	6.5	220	0.5	1.3	2	0.51	0.4	2.0	13.8	55.0
	1110	6.4	175	0.7	2.6	10	0.43	0.7	-	11.0	30.4
	1310	6.0	170	0.5	2.9	288	0.40	0.8	1.4	10.4	-
	1510	6.1	165	0.5	2.0	0	0.38	0.1	1.0	9.7	41.3
	1710	6.2	160	0.2	2.0	232	0.32	0.2	1.2	9.7	39.7
	1910	6.0	160	0.4	1.6	276	0.31	0.0	1.0	8.9	38.7
	2110	6.2	152	0.6	1.8	112	0.26	0.3	0.6	8.7	38.7
	2310	6.1	150	0.4	1.8	212	0.33	0.1	1.3	8.2	38.1
25 Feb 79	0110	6.2	150	0.3	1.8	0	0.29	0.1	0.9	8.3	40.2
	0310	6.1	150	0.5	3.1	996	0.20	0.0	1.2	8.2	40.8
	0510	6.2	150	0.7	2.2	244	0.32	0.2	0.6	8.0	39.8
	0710	6.1	152	0.7	1.5	0	0.22	0.5	1.1	8.1	41.8
	0910	6.3	150	0.4	1.6	400	0.32	0.3	0.9	8.1	42.6

Event 4

Event 4 (2–8 March 1979) covered the period of peak spring runoff from the spray field. Between 3 and 6 March, 2.21 in. of rain fell, leaving 167,457 ft^3 of water on the east slope. This rainfall closely followed 4 consecutive days of effluent application that ended at 1530 on 2 March, during which 325,535 ft^3 of effluent was applied to the east slope. Air temperatures during the event climbed well above freezing, yet considerable snow and ice cover remained on the site.

Flow in the ditch (Fig. A4) began to decrease about 3 hours after spraying ended. By 4 March, 27 hours after the rainfall began, ditch flow began to increase. Ditch flow peaked at 1.28 ft^3/s at 2000 on 6 March. During the event monitoring period (1444 on 2 March through 1353 on 8 March) 180,646 ft^3 of water flowed through the ditch.

The water budget calculated for event 4 is:

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

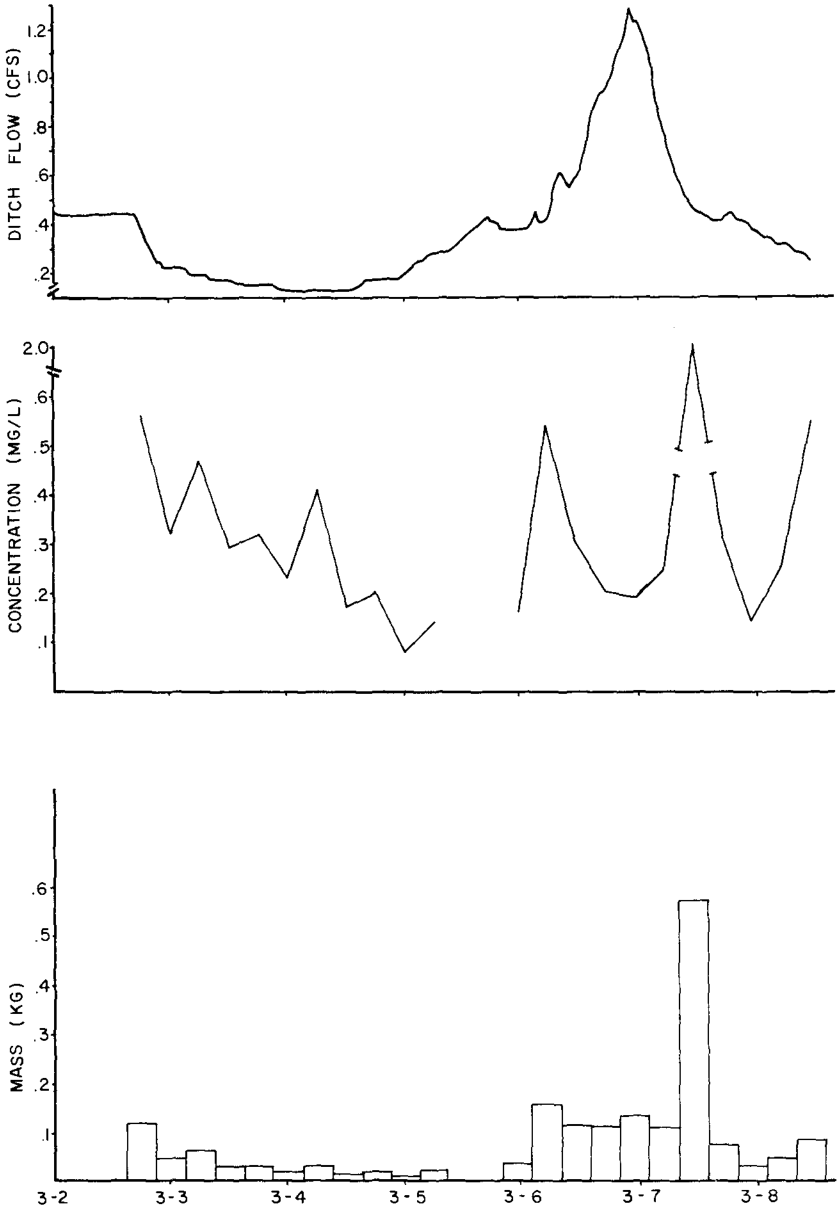
$$0 + 164{,}457 - 0 - 180{,}646 = -16{,}189\ (ft^3).$$

The water budget shows that more water came off the east slope during the event than went on as rainfall, suggesting a considerable portion of the ditch flow resulted from snow and ice melting.

Figure A4 shows concentration and mass export for ortho-P, NO_3-N, and Cl, respectively, during event 4. Levels of ortho-P in the ditch, which had been dropping with decreasing flow, began to increase with the rising limb of the hydrograph (Fig. A4). However, as ditch flow continued to rise, ortho-P levels dropped dramatically, but again increased during the falling limb of the hydrograph. The mean concentration of ortho-P was 2.0 mg/L. NO_3-N and Cl concentrations generally decreased throughout the event, dropping to a minimum during peak ditch flow (Fig. A4b and c). As flow decreased after the peak, NO_3-N concentration began to rise slightly.

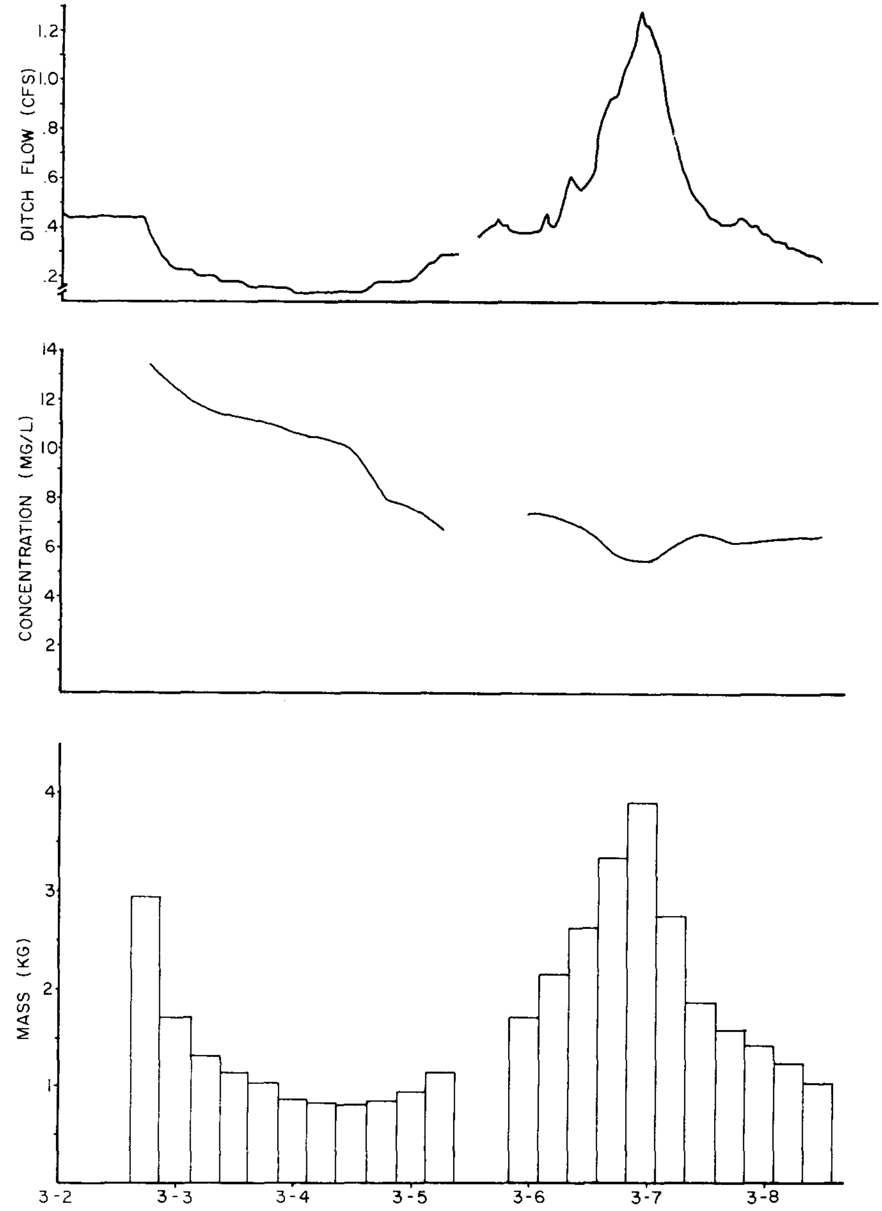
The mass exports of ortho-P, NO_3-N, and Cl are shown in Figure A4. Export of ortho-P did not follow the ditch flow pattern; there were large decreases in ortho-P concentration at high flows. The most ortho-P was exported during the falling limb of the hydrograph. Export of NO_3-N and Cl followed the hydrograph pattern despite their somewhat decreased concentration at peak flow (see Meals and Cassell 1982).

All water quality data collected during event 4 are given in Table A4. Levels of pH, suspended solids, BOD_5, fecal coliform and NH_4 did not show any apparent correlation with ditch flow. Conductivity, however, showed a moderate decrease as ditch flow began to increase, then dropped substantially to its minimum at peak flow.



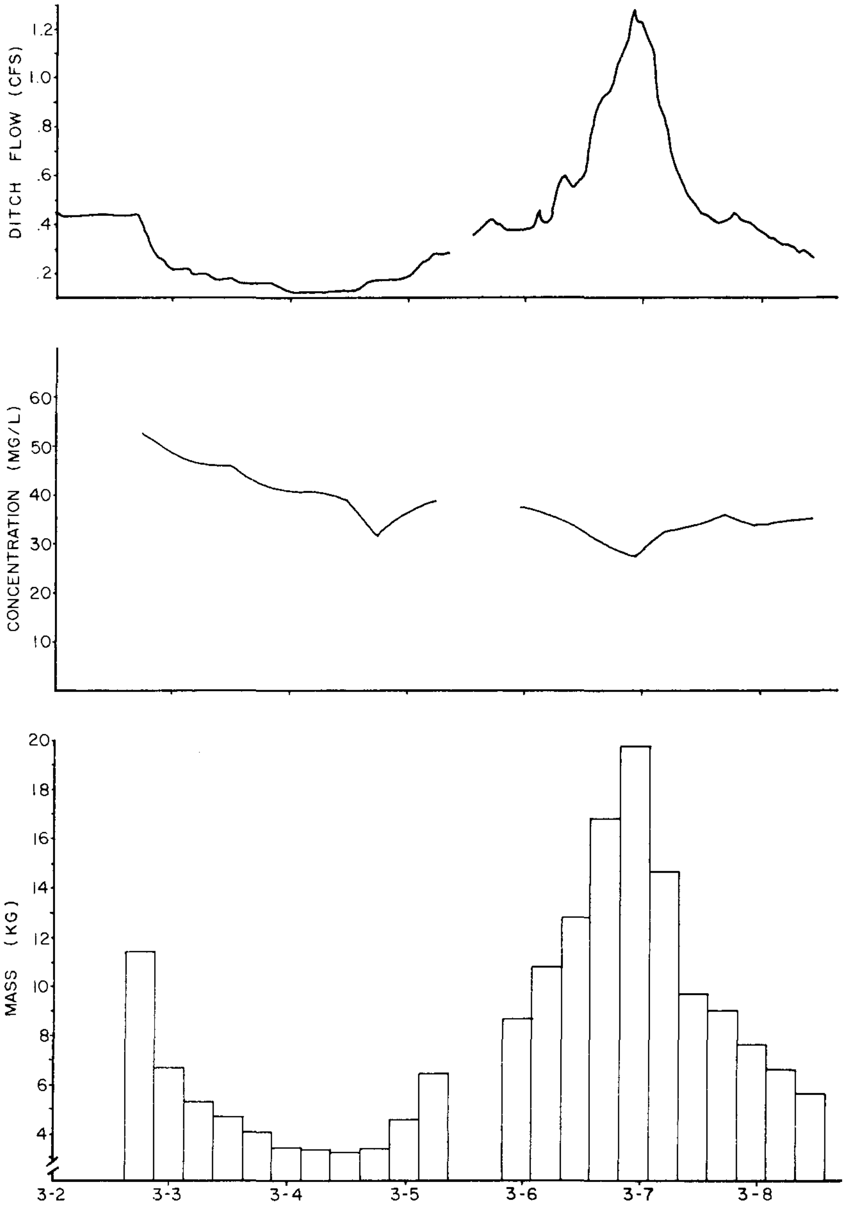
a. Ortho-P.

Figure A4. Concentration and mass export of three wastewater constituents during event 4. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A4 (cont'd). Concentration and mass export of three wastewater constituents during event 4. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. **Chloride.**

Figure A4 (cont'd).

Table A4. Event 4—ditch flow water quality.

Date	Time	pH	Conductivity (μmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	NH_4-N (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
2 March 79	1744	6.8	273	0.02	0.6	0	0.56	0.1	1.2	13.4	52.4
	2344	7.2	242	0.53	-	0	0.32	0.0	1.0	12.4	48.2
3 March 79	0544	7.1	229	0.04	1.4	0	0.47	0.0	1.2	11.5	46.0
	1144	7.1	220	0.18	1.2	0	0.29	0.0	1.1	11.3	46.0
	1744	7.1	210	0.10	1.0	0	0.32	0.0	0.7	11.0	42.6
	2344	7.1	204	0.14	1.6	0	0.23	0.0	0.7	10.6	40.6
4 March 79	0544	7.4	195	0.14	1.2	0	0.41	0.0	1.1	10.4	40.9
	1144	7.0	190	0.10	1.0	0	0.17	0.0	1.6	9.8	38.9
	1744	7.1	150	0.26	1.1	0	0.20	0.0	0.9	8.0	31.3
	2344	7.1	160	0.10	1.9	0	0.08	0.0	1.2	7.6	36.7
5 March 79	0544	7.3	155	-	1.3	0	0.14	0.0	1.0	6.7	38.4
	2253	7.0	160	0.05	1.4	0	0.16	0.0	-	7.4	37.3
6 March 79	0453	7.1	160	0.02	1.2	0	0.54	0.0	-	7.2	36.1
	1053	7.2	150	0.07	1.1	0	0.30	0.0	-	6.8	33.3
	1653	6.9	135	0.21	2.6	0	0.20	0.0	-	5.8	29.4
	2253	7.0	122	0.12	1.2	0	0.19	0.0	-	5.4	27.4
7 March 79	0453	7.1	143	0.09	1.2	0	0.25	0.0	-	6.0	32.3
	1053	7.0	150	0.08	0.7	0	2.0	0.0	-	6.5	33.9
	1653	7.1	160	0.08	1.4	0	0.31	0.0	-	6.2	35.4
	2253	7.2	185	0.07	2.8	0	0.14	0.0	-	6.3	33.3
8 March 79	0453	6.9	195	0.08	0.8	0	0.25	0.0	-	6.4	34.3
	1053	7.0	190	0.05	2.0	0	0.55	0.0	-	6.4	34.4

Because there was no nutrient input to the east slope via effluent application during event 4, the mass of contaminants actually exported represents nutrient flushing from the spray field. Early in the event, during the rising limb of the hydrograph, considerable amounts of snow and ice melted. At the times of highest flow, runoff from rainfall appeared to dominate ditch flow. However, as the rainfall subsided and the temperatures remained high, the ditch flow began to reflect the characteristics of the melting ice and snow.

Event 5

Event 5 took place on 3 through 5 April 1979, during a spray event that followed a moderate rainstorm. Between 0600 and 2200 on 2 April 0.67 in. of rain fell (49,858 ft^3 on the east slope), some 10 hours before the monitored period of the event. From 1230 on 3 April to 1620 on 4 April, 96,694 ft^3 of effluent was applied to the east slope. Mean air temperatures were above freezing during the event and 4 April saw a maximum air temperature of 56°F. Some snow and ice remained on the site.

Ditch flow peaked at 0.57 ft^3/s during the rainfall on 2 April, then declined on 3 April (Fig. A5). The ditch water began to rise again during the early hours of 3 April before effluent application began at 1230. Ditch flow remained variable over the spray period, rising to a maximum of 0.43 ft^3/s shortly before the end of spraying. After effluent application ended, ditch flow slowly declined.

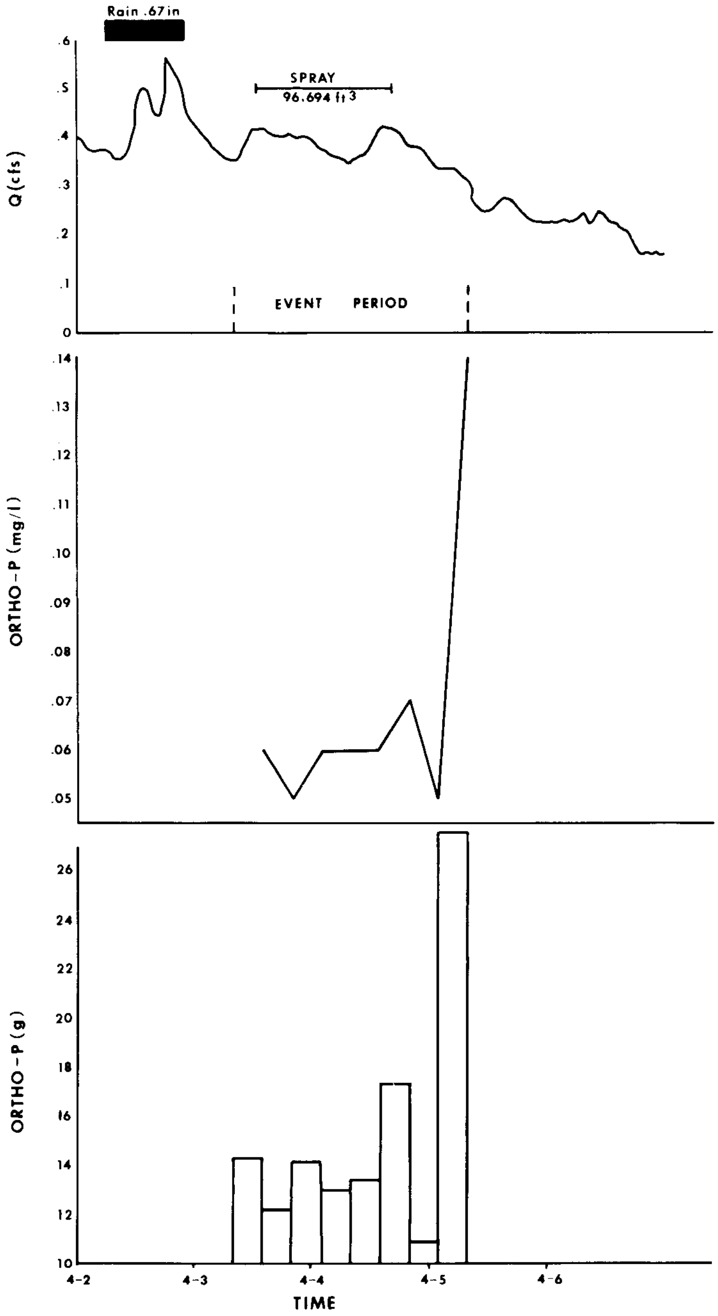
The water budget for event 2 was:

$$\begin{array}{lllllll} Q_S & + Q_P & - Q_{ET} & - Q_D & = & Q_L & \\ 96{,}694 & + 0 & - 0 & - 64{,}700 & = & 31{,}924 & (\text{ft}^3) \\ & & & (67\%) & & (33\% \text{ of } Q_S + Q_P). & \end{array}$$

This water budget shows that ditch flow during the monitored period totaled two-thirds of the water input; however, the cyclical nature of the ditch flow may indicate varying diurnal rates of snow melt.

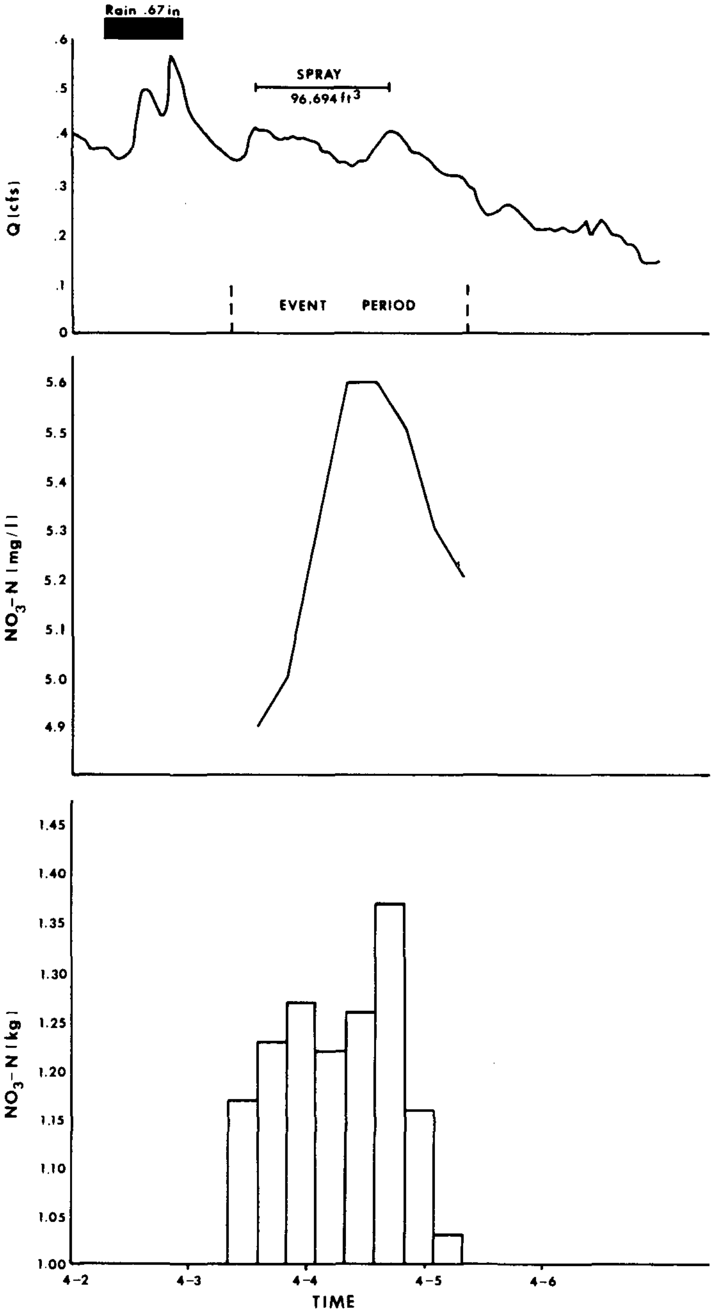
Concentration and mass export values for ortho-P, NO_3-N, and Cl during event 5 are shown in Figure A5. Ortho-P concentrations varied between 0.05 mg/L and 0.07 mg/L during most of the event, then increased to 0.14 mg/L at the end of the monitoring period. NO_3-N and Cl levels, however, increased during the period of spray application and peaked near the end of the application period and at the time of the second peak flow in ditch flow.

The values of all other water quality data collected over event 5 are summarized in Table A5. While BOD_5 and pH decreased through the event, fecal coliform levels showed a general increase. NH_4-N remained



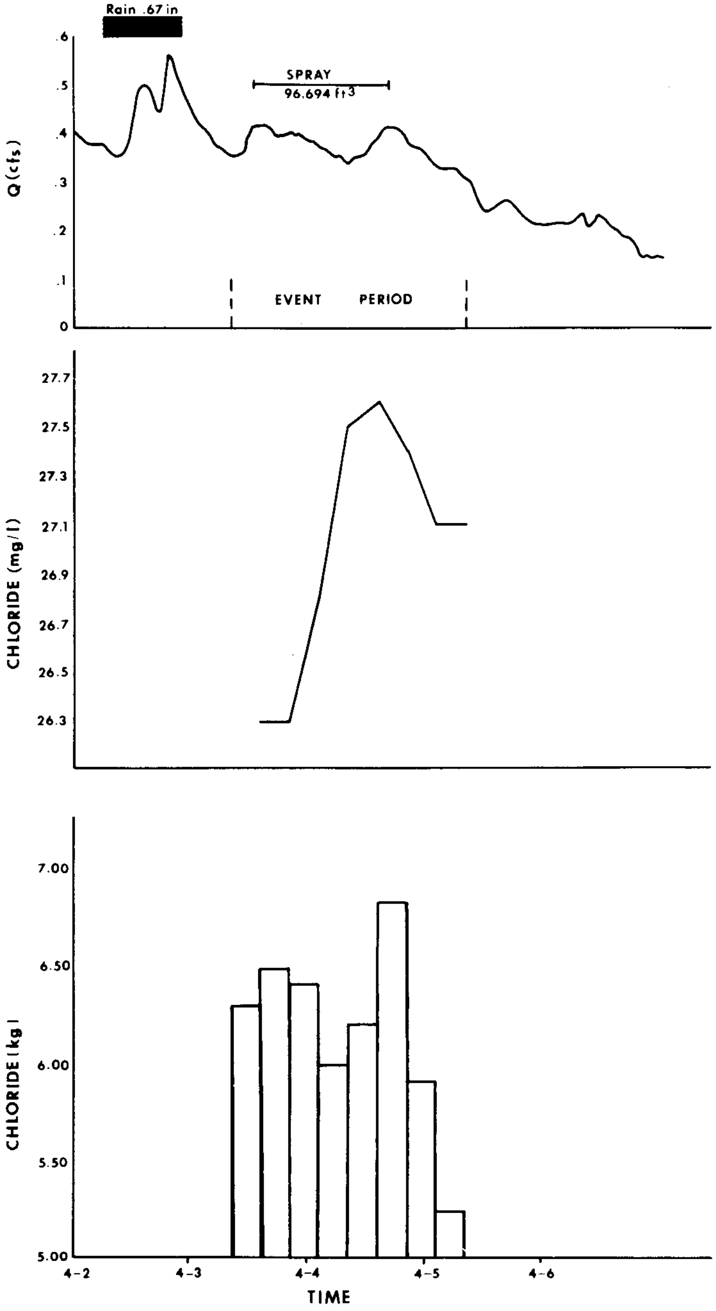
a. Ortho-P.

Figure A5. Concentration and mass export of three wastewater constituents during event 5. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A5 (cont'd). Concentration and mass export of three wastewater constituents during event 5. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. Chloride.

Figure A5 (cont'd).

Table A5. Event 5—ditch flow water quality.

Date	Time	pH	Conductivity (µmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
3 April 79	1400	6.6	122	-	3.2	5	0.06	0.0	4.9	26.3
	2000	6.6	122	-	3.2	3	0.05	0.0	5.0	26.3
4 April 79	0200	6.6	128	0.04	1.8	10	0.06	0.0	5.3	26.8
	0800	6.5	130	-	4.8	6	0.06	0.0	5.6	27.5
	1400	6.2	130	0.06	1.2	6	0.06	0.0	5.6	27.6
	2000	6.2	123	0.02	1.3	14	0.07	0.0	5.5	27.4
5 April 79	0200	6.1	118	-	1.7	12	0.05	0.1	5.3	27.1
	0800	6.1	115	-	1.8	13	0.14	0.0	5.2	27.1

below detectable limits over much of the monitoring period.

Mass export values of ortho-P, NO_3-N, and Cl are also shown in Figure A5. Export of two of the three constituents paralleled ditch flow; the exception was ortho-P, which demonstrated an export pattern paralleling ortho-P concentration patterns. Mass balance calculations show that 70% of the NO_3-N and 69% of the Cl applied over the event period were retained on the spray site during the event (see Meals and Cassell 1982). While lack of effluent ortho-P data prevents the calculation of a mass balance, ortho-P concentrations in ditch flow were much lower than ordinarily found in applied effluent.

The ditch flow reflected runoff from the rainfall during 2 April and some runoff from effluent spraying during 3 and 4 April. Most of the nutrients exported from the spray field during this event appear to be associated with spray runoff. This event shows a behavior that is typical of the spray site when high soil moisture levels may be present.

Event 6

Event 6 fell between 19 and 23 April, during the latter part of a heavy effluent application (101,156 ft^3 applied between 0840 on 14 April and 0940 on 20 April). There had been no precipitation since 5 April, and no rain fell during the event. Mean daily air temperatures were above freezing, but night temperatures fell well below freezing. Some snow and ice remained on the spray site.

The hydrograph bracketing the period of event 6 shows a distinct diurnal cyclic pattern (Fig. A6), with flow peaks each evening. This phenomenon is likely related to the daily temperature cycle, with ditch flow peaking as a result of snow and ice melt during mid- and late-afternoon when temperatures reached their highest (53° to 57°F). Average daily ditch flow began to increase on 18 April shortly after spraying began and is superimposed on the diurnal cycle. Ditch flow peaked at 1600 on 19 April at 0.35 ft^3/s.

The water budget for event 6 is:

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 42{,}741^{*} & + & 0 & - & 0 & - & 44{,}190 & = & -1{,}519\ (\text{ft}^3). \end{array}$$

The water budget shows that more water flowed through the ditch than was applied during the event and may indicate snow and ice melt. This figure may be deceptive because it does not include the effluent applied in the 20 hours before the arbitrary start of the event. If a water budget is calculated from the start of the spray event (18 April, 0840) through the end of event monitoring (21 April, 1308), 34% of water input is unaccounted for, apparently indicating groundwater recharge.

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 101{,}156 & + & 0 & - & 0 & - & 66{,}950 & = & 32{,}206\ (\text{ft}^3) \\ & & & & & & (66\%) & & (34\%\text{ of } Q_S + Q_P). \end{array}$$

Patterns of concentration and mass export for ortho-P, NO_3-N, and Cl are shown in Figure A6. Ortho-P, NO_3-N, and Cl increased during the first 30 hours of monitoring, peaking on 20 April, about 10 to 12 hours after spraying ended.

Patterns of ortho-P, NO_3-N, and Cl mass export are also shown in Figure A6. Mass export during the event followed a bimodal pattern, similar to that of flow. Maximum mass export, however, did not consistently coincide with peak flow. Ortho-P and NO_3-N mass export peaked during the falling limb of the hydrograph on 19, 20 and 21 April. Cl export peaked first during effluent application on 19 April, then increased again during the falling limb of the

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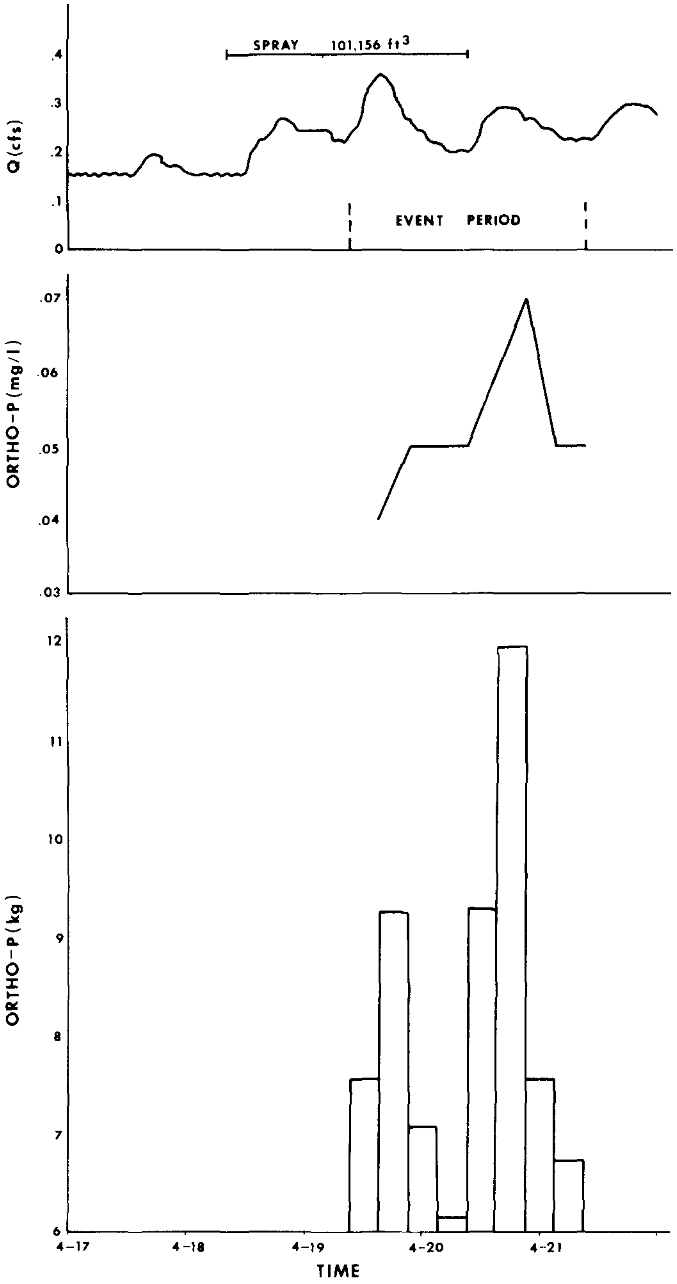
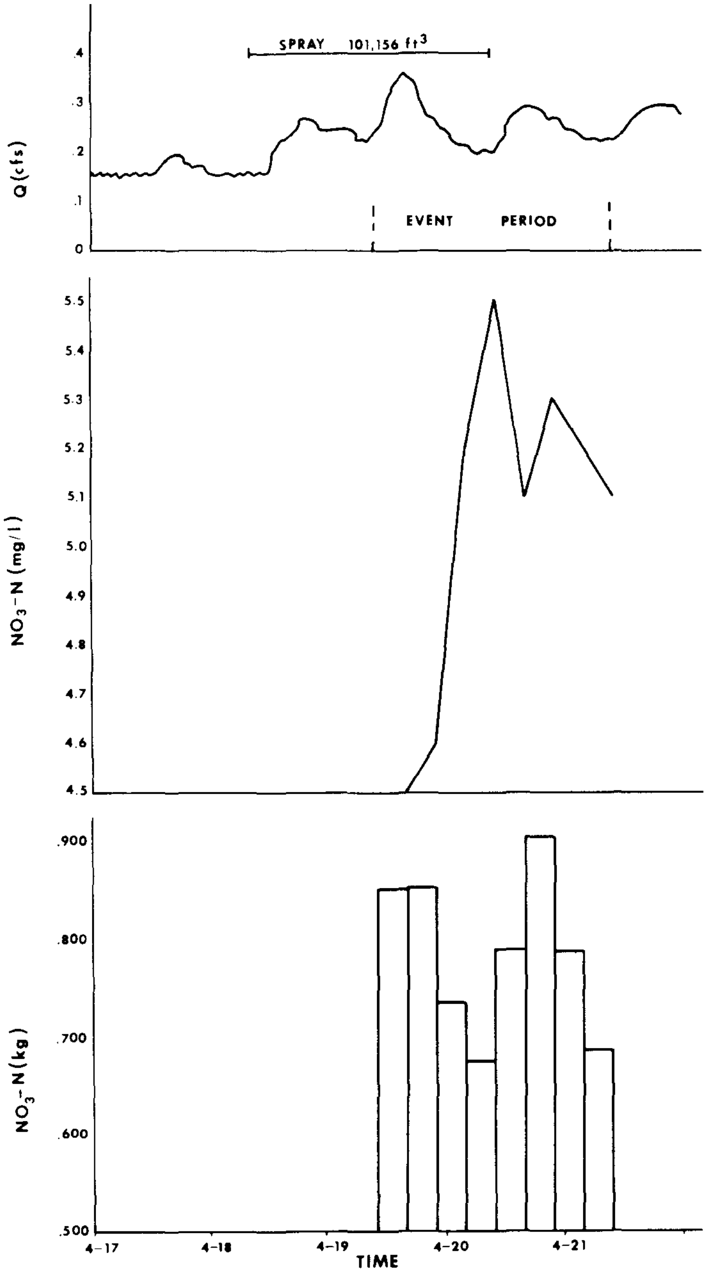
*Only that portion sprayed while event was monitored included.



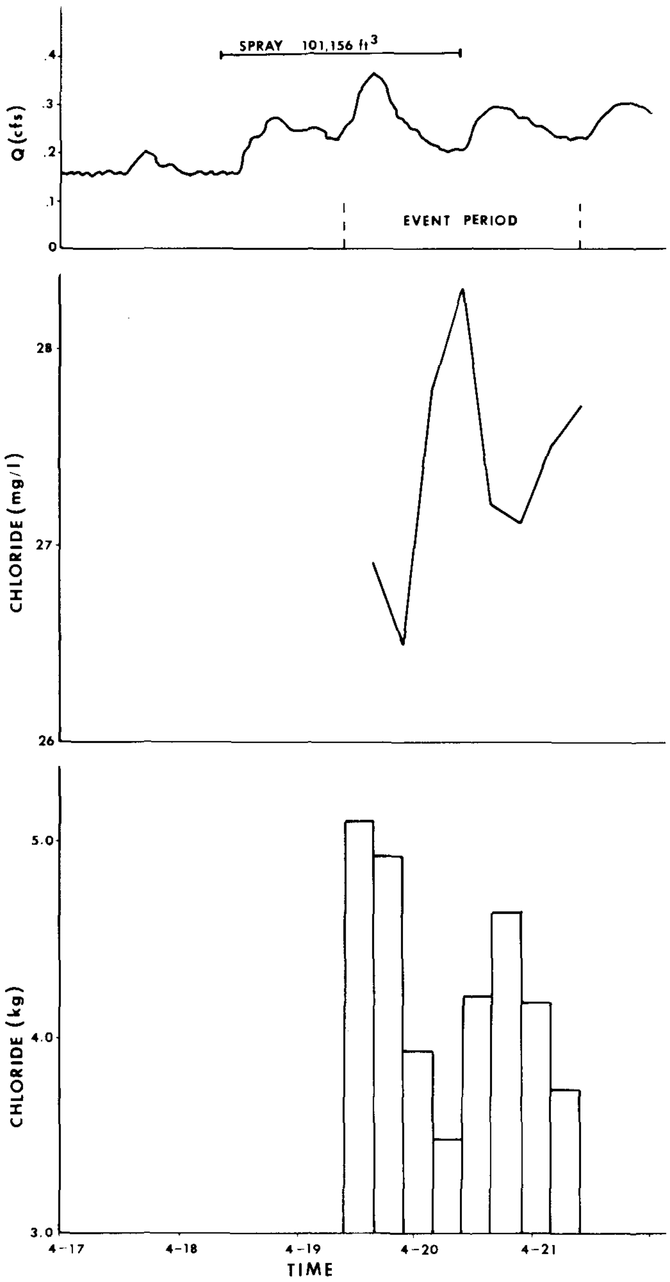
a. Ortho-P.

Figure A6. Concentration and mass export of three wastewater constituents during event 6. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A6 (cont'd). Concentration and mass export of three wastewater constituents during event 6. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. *Chloride.*

Figure A6 (cont'd).

Table A6. Event 6—ditch flow water quality.

Date	Time	pH	Conductivity (µmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	Total P (mg/L)	NH_4-N (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
19 April 79	1608	6.4	123	0.13	1.9	0	0.04	-	0.0	-	4.5	26.9
	2208	6.4	125	0.20	2.6	1	0.05	-	0.0	-	4.6	26.5
20 April 79	0408	6.4	132	0.07	0.4	2	0.05	-	0.0	-	5.2	27.8
	1008	6.4	131	0.04	0.8	3	0.05	-	0.0	-	5.5	28.3
	1608	6.4	130	0.28	0.9	0	0.06	0.6	0.0	0.9	5.1	27.2
	2208	6.4	131	0.15	1.8	1	0.07	0.2	0.0	0.6	5.3	27.1
21 April 79	0408	6.4	132	0.12	0.8	3	0.05	0.2	0.0	0.8	5.2	27.5
	1008	6.4	129	0.15	0.9	0	0.05	0.1	0.0	0.4	5.1	27.7

hydrograph on 20 and 21 April. Mass balance calculations show that 44% of the applied NO_3-N and 42% of the applied Cl were retained on the east slope during event 6. The lack of effluent ortho-P data prevents the calculation of a mass balance for P (see Meals and Cassell 1982).

The values for all water quality data collected during event 6 are shown in Table A6. The water quality of the ditch flow only varied over a very narrow range during this event. Suspended solids increased with increasing flow, while BOD_5 and fecal coliform levels seemed to be inversely related to flow. Levels of pH and conductivity were essentially unchanged during the event.

The ditch flow observed during this event appeared to reflect both spray application and diurnal snow-ice melt, as evidenced by the bimodal mass export patterns and by the cyclical nature of ditch flow. The highest concentrations of NO_3-N and Cl appear to be associated with the spray application event, while maximum ortho-P concentrations appear to be related more closely to snow and ice melt.

Event 7

Event 7 took place between 23 and 25 April 1979, during a period of heavy effluent application (155,241 ft^3 in 48½ hours). There was no precipitation during the event. Mean daily air temperatures were well above freezing, although the minimum temperatures dropped below 32°F on 23 and 24 April. Daily highs were above 70°F during the monitoring period. Some snow remained on the site.

The ditch flow again followed the diurnal pattern observed earlier in event 6, although the peaks on 23 and 24 April were greatly amplified by effluent application (Fig. A7). Ditch flow began to rise about 3 hours after effluent application began and peaked at 1600 on 23 April. Flow then gradually receded on the morning of the 24th. Flow began to increase again at 1200 on the 24th, reaching a peak of 0.66 ft^3/s at 1900. Following this peak, ditch flow declined steadily through the end of the monitoring period.

The water balance for event 7 is:

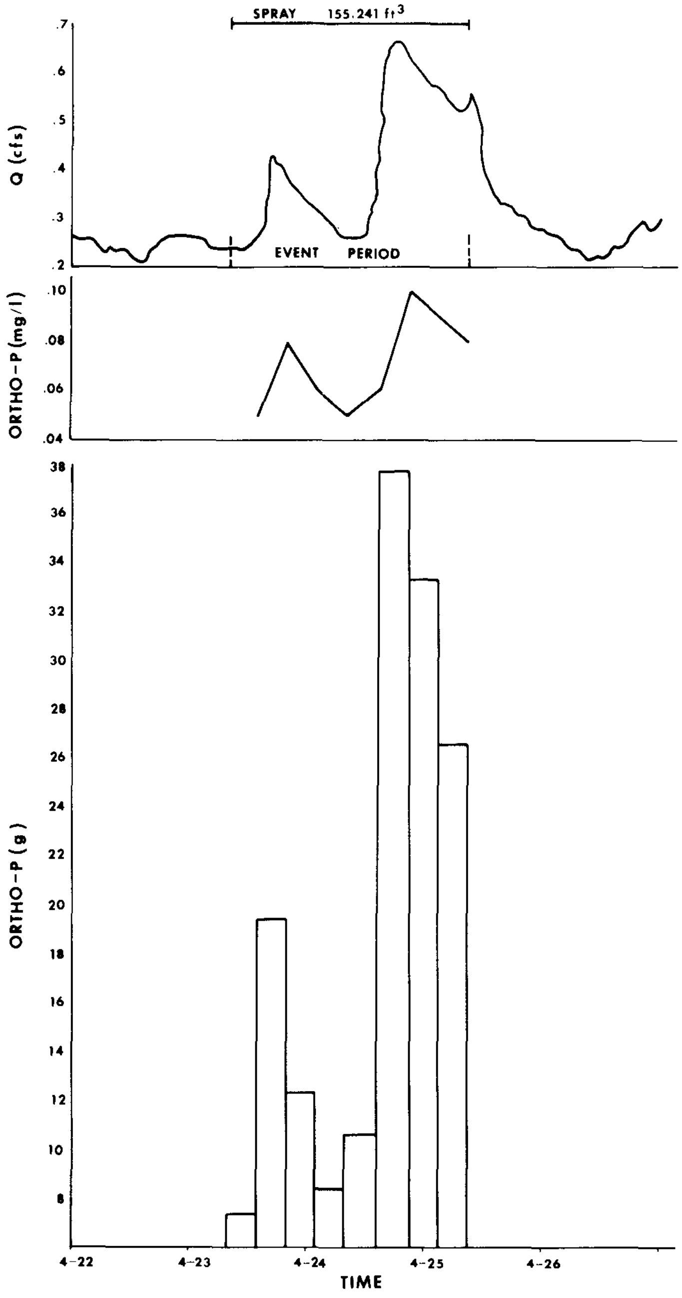
$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 155{,}241 & + & 0 & - & 0 & - & 71{,}900 & = & 83{,}341\ (ft^3) \\ & & & & & & (46\%) & & (54\%\ \text{of}\ Q_S + Q_P). \end{array}$$

The water balance indicates that ditch flow was just less than half of the applied effluent volume and, therefore, considerable amounts of applied effluent entered the ground to be stored as soil moisture or to percolate into the groundwater.

The concentrations of ortho-P, NO_3-N, and Cl during the event monitoring period are shown in Figure A7. Ortho-P concentration paralleled ditch flow, with distinct peaks coinciding with flow peaks on both 23 and 24 April. NO_3 concentrations followed ditch flow; however, they peaked well after the 23 April hydrograph peak and appeared to be increasing during the falling limb of the 24 April hydrograph peak. Cl levels dropped during the 23 April peak in ditch flow, then began to increase throughout the rest of event monitoring period.

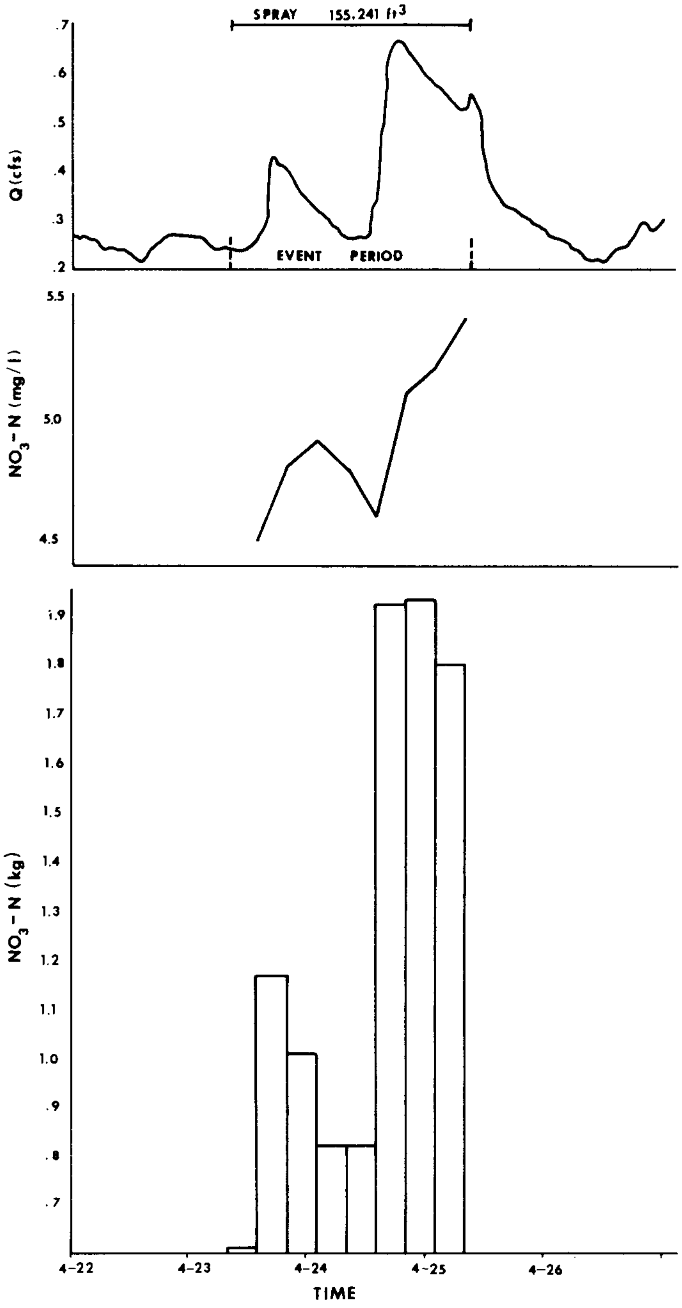
Nutrient exports patterns during event 7 are also shown in Figure A7. Patterns of mass export of ortho-P, NO_3-N, and Cl followed ditch flow, with maximum export at peak flows. Mass balance calculations show that 72% of the applied NO_3 and 77% of the applied Cl were retained on the east slope during event 7. The lack of ortho-P data for the sprayed effluent prevents calculation of a mass balance for P (see Meals and Cassell 1982).

The values for all water quality data collected during event 7 are given in Table A7. Fecal coliform levels appeared to peak with the hydrograph; however, conductivity, pH, suspended solids, and BOD_5 remained essentially constant through the event.



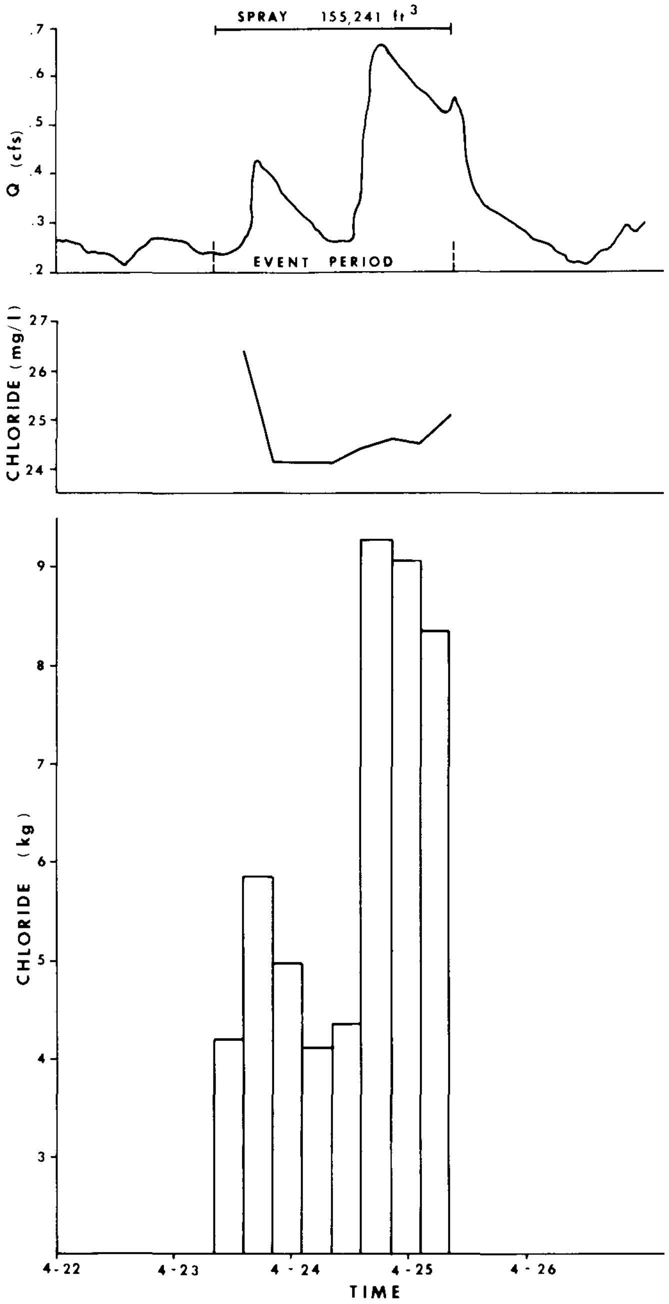
a. Ortho-P.

Figure A 7. Concentration and mass export of three wastewater constituents during event 7. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A7 (cont'd). Concentration and mass export of three wastewater constituents during event 7. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. Chloride.

Figure A 7 (cont'd).

Table A7. Event 7–ditch flow water quality.

Date	Time	pH	Conductivity (μmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
23 April 79	1430	6.4	120	0.12	1.1	1	0.05	0.1	4.5	26.4
	2030	6.6	123	0.09	1.2	99	0.08	0.0	4.8	24.1
24 April 79	0230	6.5	125	0.09	0.9	16	0.06	0.0	4.9	24.1
	0830	6.5	125	0.25	0.9	6	0.05	0.0	4.8	24.1
	1430	6.6	127	0.09	1.0	8	0.06	0.0	4.6	24.4
	2030	6.5	127	0.08	1.0	48	0.10	0.0	5.1	24.6
25 April 79	0230	6.4	125	0.07	1.5	21	0.09	0.0	5.2	24.5
	0830	6.3	127	0.03	0.7	7	0.08	0.0	5.4	25.1

The runoff collected in the interceptor ditch clearly reflected the melt-freeze diurnal cycles so typical of Vermont spring weather, as well the heavy application of spray.

Event 8

Event 8 was monitored from 0910 on 28 April through 0910 on 30 April 1979. Some 0.87 in. of rain had fallen during 26 and 27 April, before the event monitoring period, and an additional 0.37 in. fell during the event, from 1800 to 2400 on 28 April. No effluent was applied during this event. Air temperatures were well above freezing during the entire time and some snow and ice remained on the spray field.

Flow in the ditch during event 8 was clearly responsive to rainfall (Fig. A8). At the start of the event ditch flow was decreasing after the rainfall on 27 April. At 2100 on 28 April, 3 hours after rain began, flow began to rise sharply to a peak of 0.61 ft^3/s at 2300. When the rain ended, ditch flow receded through the remainder of the monitoring period.

The water balance for event 8 is:

$$\begin{array}{ccccccccc} Q_S & + & Q_P & - & Q_{ET} & - & Q_D & = & Q_L \\ 0 & + & 27{,}534 & - & 0 & - & 53{,}960 & = & -26{,}426\ (ft^3)\ . \end{array}$$

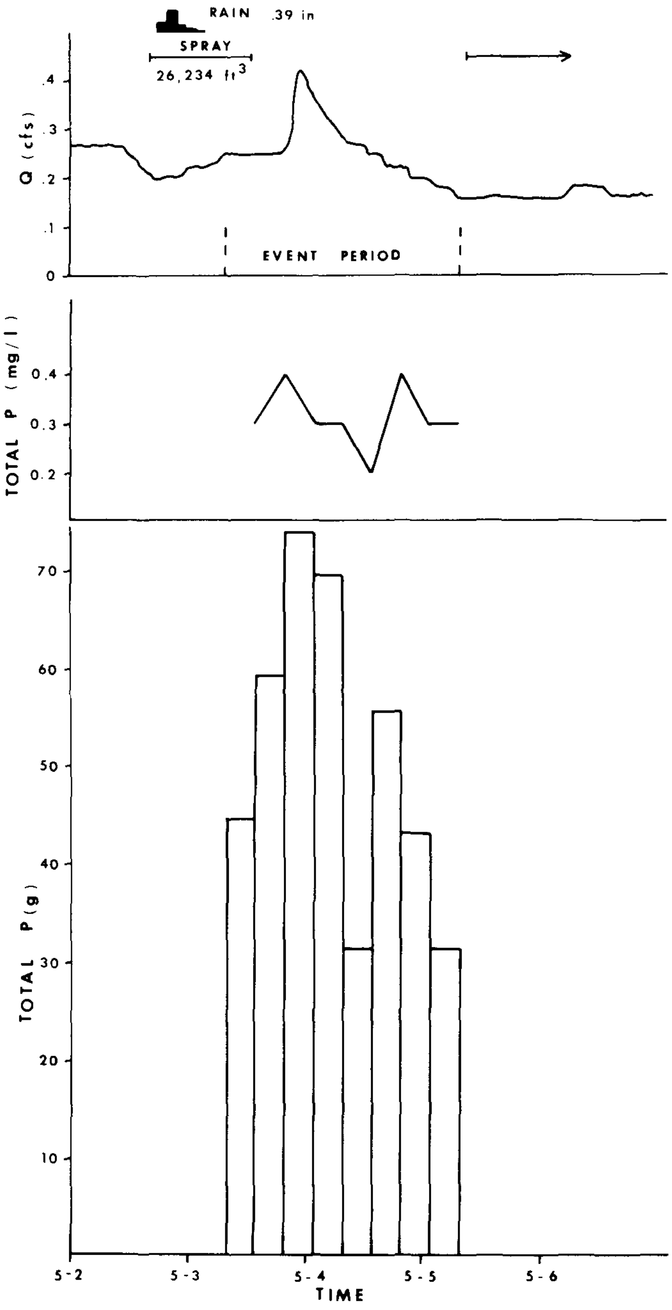
The water balance shows that substantially more water flowed through the ditch than was added as precipitation. The additional water in the ditch may have been the result of either snow melt from the spray field or the gradual release of accumulated spray field groundwater. If, however, the apparent base ditch flow of about 0.25 ft^3/s is subtracted from the event hydrograph, water output in this added ditch flow (10,760 ft^3) is just 40% of precipitation input.

Patterns of concentration of ortho-P, NO_3-N, and Cl during event 8 are shown in Figure A8. The maximum concentration of ortho-P (0.48 mg/L) occurred during decreasing ditch flow on 28 April, at a level substantially above that observed during the remainder of the monitoring period. Ortho-P concentrations then peaked again at 0.06 mg/L, with the hydrograph declining through the rest of the event. NO_3-N and Cl levels dropped during peak flow and increased with decreasing flow, an indication of rainfall runoff.

Mass exports of ortho-P, NO_3-N, and Cl during event 8 are also shown in Figure A8. Ortho-P export peaked during decreasing flow on 28 April, then again during the hydrograph peak, also on 28 April. Mass export of NO_3-N and Cl clearly followed the pattern of ditch flow.

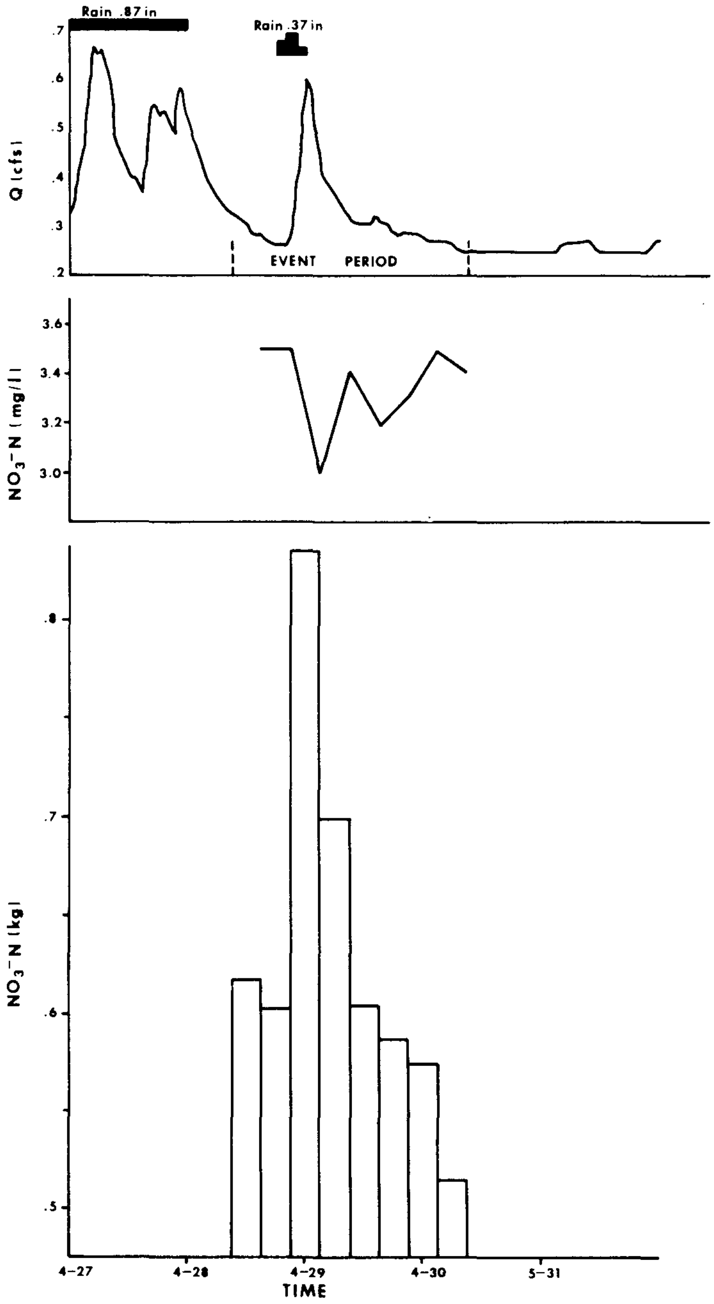
Because no effluent was applied during event 8, all export of ortho-P, NO_3-N, and Cl, as well as other pollutants, must be considered to be quantities flushed from either the surface of the spray site or as a result of subsurface flow (see Meals and Cassell 1982).

Table A8 gives the complete set of water quality data collected over event 8. Concentration of suspended solids peaked during high ditch flow; levels of coliforms and TKN also peaked during high flows, although the magnitude of increase was slight. Total P and ortho-P patterns were similar throughout the event.



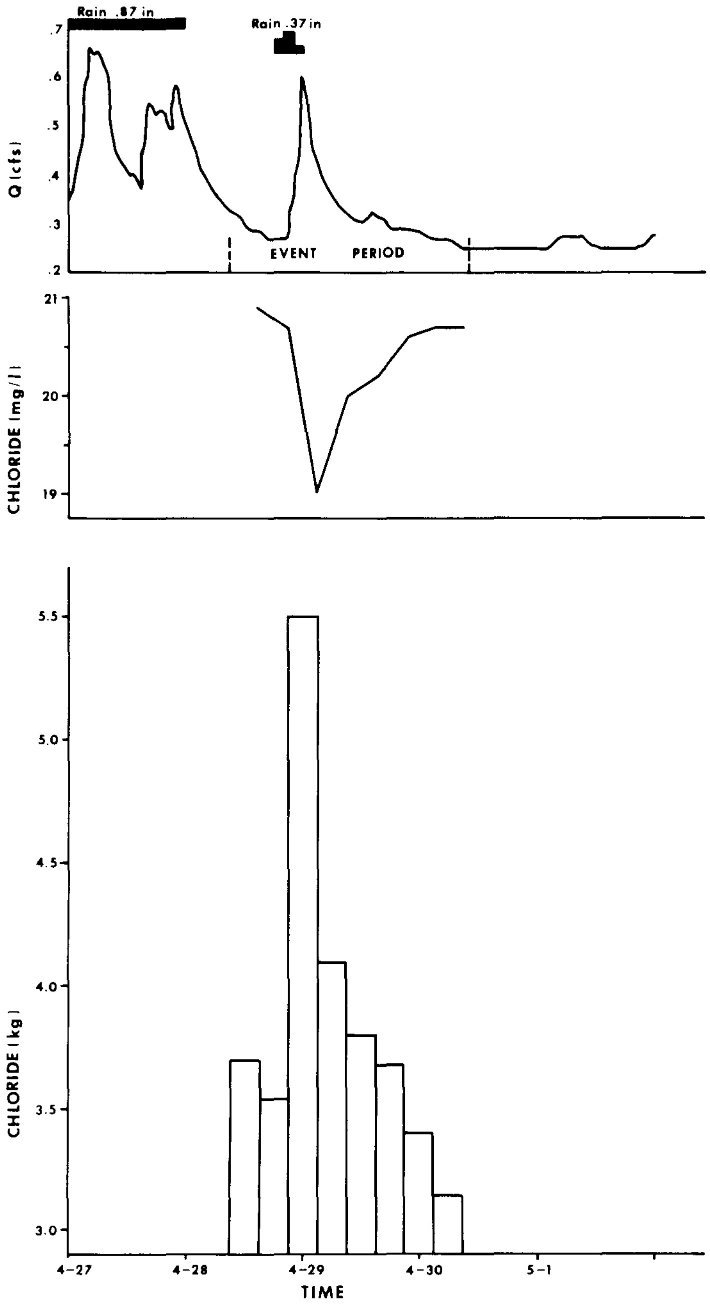
a. Ortho-P.

Figure A8. Concentration and mass export of three wastewater constituents during event 8. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N

Figure A8 (cont'd). Concentration and mass export of three wastewater constituents during event 8. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. Chloride.

Figure A8 (cont'd).

Table A8. Event 8—ditch flow water quality.

Date	Time	pH	Conductivity (μmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	Total P (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
28 April 79	1510	6.8	118	0.44	1.4	2	0.48	1.9	0.8	0.0	3.5	20.9
	2110	6.8	122	0.72	1.2	7	0.05	0.2	0.5	0.0	3.5	20.7
29 April 79	0310	6.8	115	2.4	0.9	3	0.06	0.3	1.1	0.0	3.0	19.0
	0910	6.8	119	0.18	1.0	0	0.05	0.3	0.4	0.0	3.4	20.0
	1510	6.9	120	0.18	0.9	2	0.05	0.4	0.6	0.0	3.2	20.2
	2110	6.9	123	0.14	0.7	1	0.05	0.6	0.9	0.0	3.3	20.6
30 April 79	0310	6.9	120	0.05	0.6	2	0.04	0.2	0.9	0.0	3.5	20.7
	0910	6.9	118	0.03	0.7	2	0.04	0.1	0.8	0.0	3.4	20.7

Event 9

Event 9 occurred between 0830 on 3 May and 0830 on 5 May 1979, immediately following a period of relatively light effluent application (26,234 ft^3) and rain (0.39 inches) on 2 May . Air temperatures were well above freezing. Essentially no snow remained on the east slope. During this event a total of 6871 ft^3 of spray was applied over two periods.

Ditch flow, which had been decreasing after effluent application on 1 May, began to increase at 2300 on 2 May, about 6 hours after spraying started. Flow increased only slightly, then became constant about 12 hours after the spraying began. At 1900 on 3 May, ditch flow increased dramatically to a peak of 0.42 ft^3/s at midnight. Flow then decreased through the rest of the monitoring period (Fig. A9). It is difficult to explain the cause of the hydrograph peak on 3 and 4 May since no rain fell and spraying had stopped a number of hours earlier. One explanation for the 9-hour lag time between the end of spraying and peak flow might be found by examining the groundwater in the east slope. Since the volume of effluent applied was small, surface runoff was minimal, if not completely absent. It may, therefore, be postulated that the increase in ditch flow was caused by subsurface flow emerging in the ditch.

A water budget for event 9, including only the inputs after 0800 on May 3 is:

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

$$6871 + 0 - 22{,}622 - 46{,}590 = -62{,}341\ (ft^3).$$

The water budget shows that substantially more water flowed through the ditch than was applied during the event. Even if all spray and precipitation on 2 and 3 May are included, Q_L is still negative (-13,956 ft^3). This water surplus may be the result of continuing depletion of water stored in east slope soils during the spring.

Figure A9 shows concentrations of total P (*not* ortho-P as in earlier event descriptions), NO_3-N, and Cl during event 9. Total P concentration decreased during the high flows of 4 May, then rose during the falling limb of the hydrograph. NO_3 levels also dropped during high flow, then increased with decreasing flow. Cl concentration showed a general decline through this event period.

The values for all water quality parameters collected during event 9 are summarized in Table A9. Values for most parameters varied only slightly over the monitoring period, showing no discernible pattern. BOD_5 concentrations appeared to be slightly higher in the initial hours of monitoring. The pH increased from 6.6 to 7.2 during the falling limb of the hydrograph.

Nutrient export during event 9 is also shown in Figure A9. Total P export peaked at peak flow, then receded, generally following the same pattern as concentration during the falling limb of the hydrograph. NO_3 and Cl export followed a similar pattern.

The nutrient budget for event 9 shows a pattern quite different from those of the other monitored events. When nutrient input is calculated to include all effluent applied from 1630 on 2 May through 1330 on 3 May, a substantial quantity of total P was retained on the east slope during event 9. This was not the case, however, for NO_3 or Cl. A net export of NO_3 took place during the event, and 97% of the applied Cl was exported in ditch flow (see Meals and Cassell 1982).

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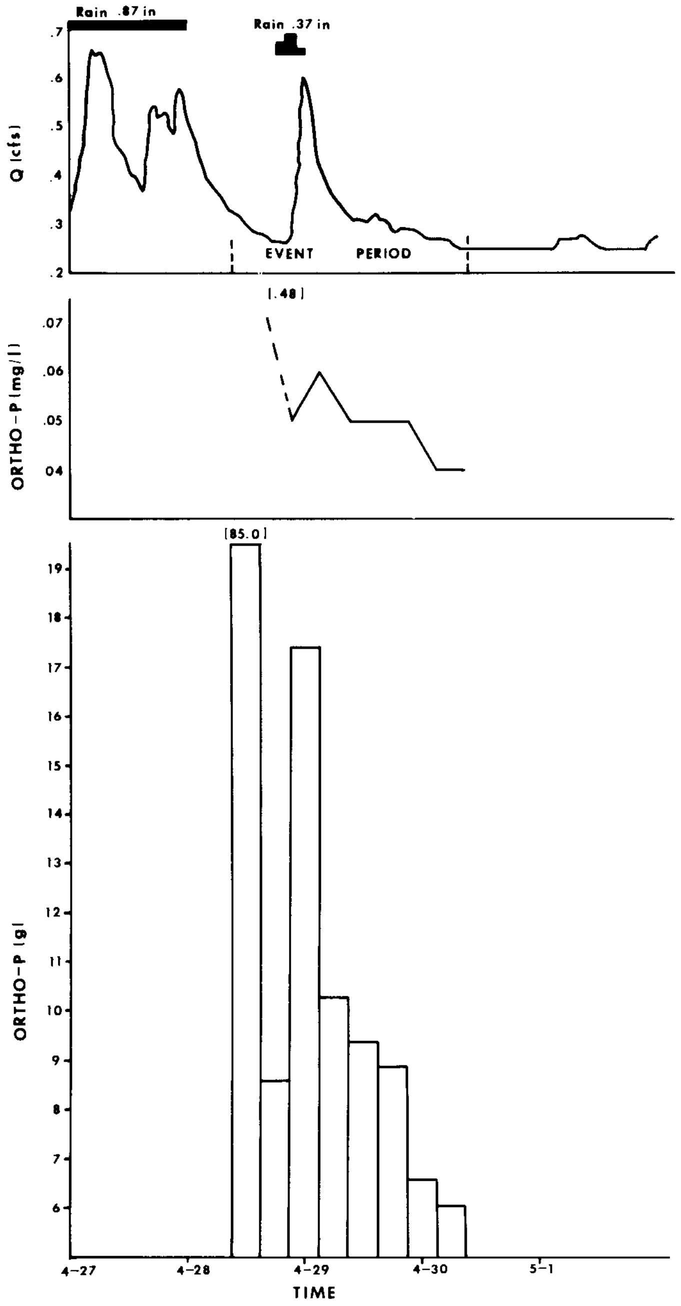
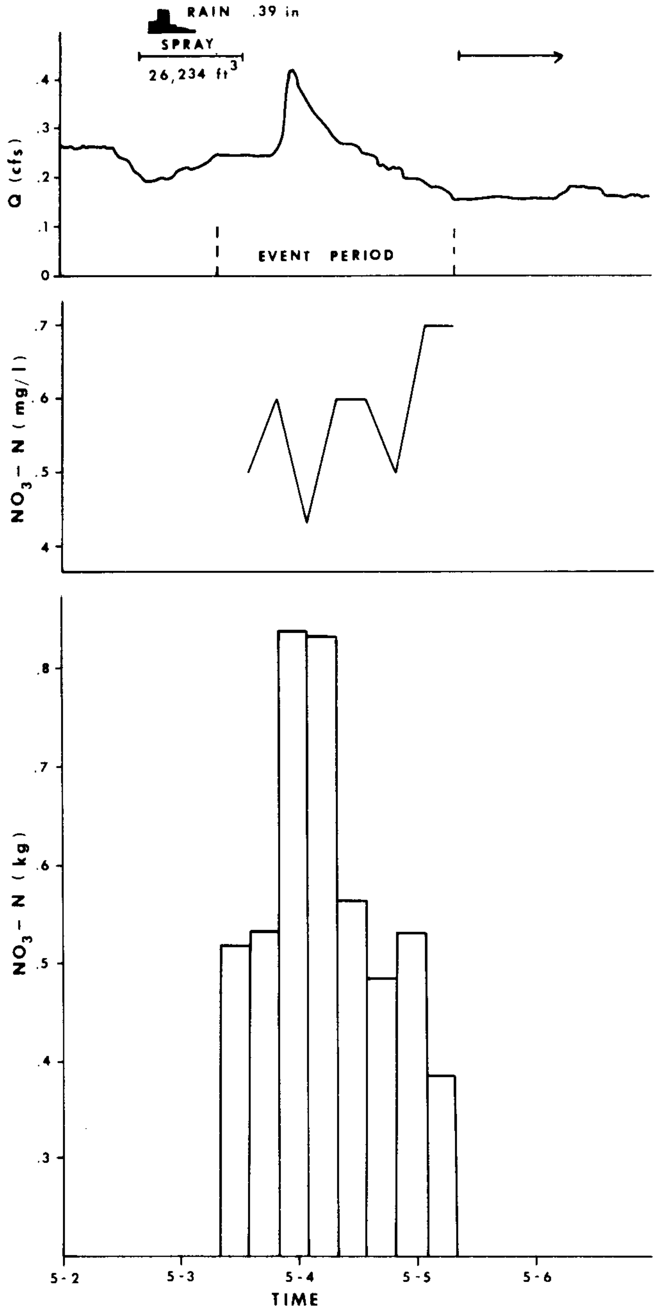
*Estimated at 0.152 in./day as in Cassell et al. (1979).



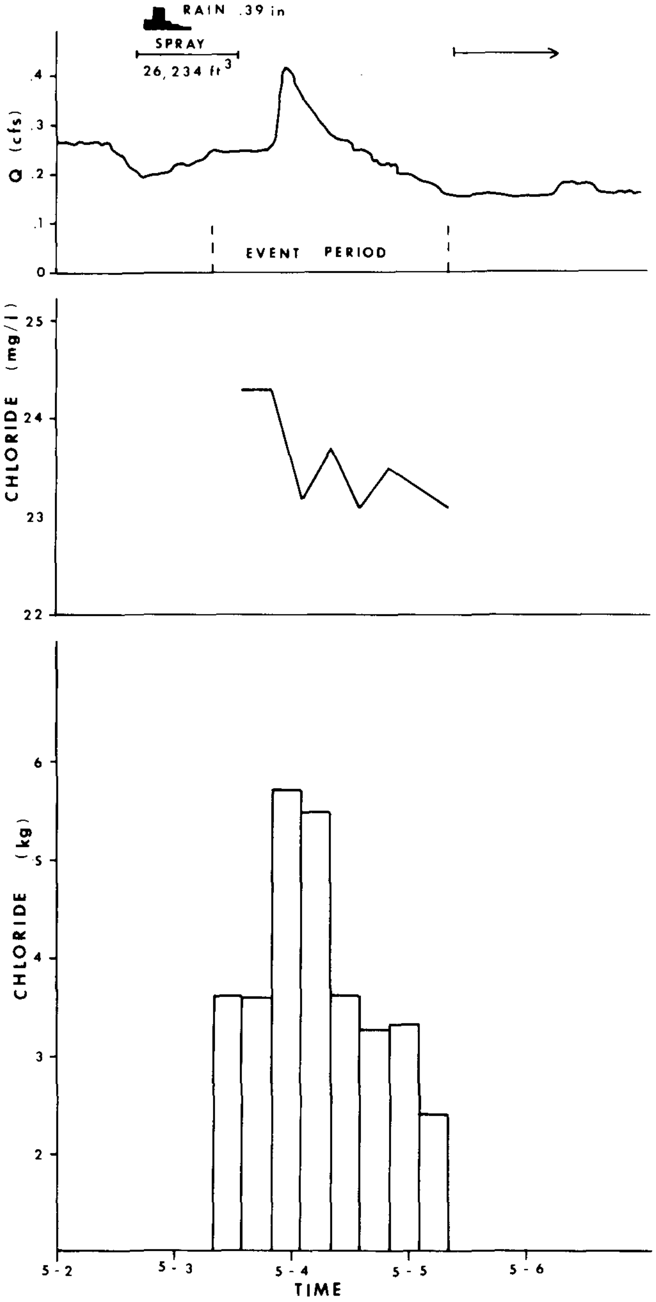
a. Ortho-P.

Figure A9. Concentration and mass export of three wastewater constituents during event 9. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A9 (cont'd). Concentration and mass export of three wastewater constituents during event 9. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. Chloride.

Figure A9 (cont'd).

Table A9. Event 9—ditch flow water quality.

Date	*Time*	*pH*	*Conductivity (μmhos)*	*Suspended solids (mg/L)*	*BOD_5 (mg/L)*	*Fecal coliforms (no./100 mL)*	*Ortho-P (mg/L)*	*Total P (mg/L)*	*TKN (mg/L)*	*NH_4-N (mg/L)*	*NO_3-N (mg/L)*	*Cl (mg/L)*
3 May 79	1430	6.6	135	0.12	2.0	2	0.04	0.3	0.2	0.0	3.5	24.3
	2030	6.6	135	0.07	2.4	0	0.04	0.4	0.0	0.0	3.6	24.3
4 May 79	0230	6.6	130	0.05	1.2	3	0.04	0.3	0.0	0.0	3.4	23.2
	0830	6.5	132	0.07	0.7	3	0.04	0.3	0.0	0.0	3.6	23.7
	1430	7.2	118	0.18	0.6	1	0.03	0.2	0.0	0.0	3.6	23.1
	2030	7.2	118	0.07	1.3	3	0.04	0.4	0.0	0.0	3.5	23.5
5 May 79	0230	7.2	122	0.06	0.8	5	0.03	0.3	0.0	0.0	3.7	23.3
	0830	7.2	123	0.06	1.2	1	0.03	0.3	0.0	0.0	3.7	23.1

Event 10

Event 10 was a special study conducted from 1 August through 4 August 1979 to trace an isolated, dry-weather spray event across the east slope and interceptor ditch. There was no precipitation or effluent application in the 6 days prior to the event. Beginning at 0800 on 1 August, effluent was applied at a constant rate for 24 hours. During this period, the east slope received 99,752 ft^3 of effluent.

The event 10 ditch flow hydrograph is shown in Figure A10. Flow in the ditch began to increase at 2100 on 1 August, 13 hours after spraying began. Ditch flow peaked at 0.15 ft^3/s at 0900 on 2 August, 1 hour after spraying ended. Following the peak, flow decreased rapidly. The low flow levels present before spraying were attained about 58 hours after spraying ended.

Water budgets for event 10 were calculated in two ways. First, all ditch flow during the period was included:

$$Q_S + Q_P - Q_{ET} - Q_D = Q_L$$
$$99{,}752 + 0 - 125{,}761 - 21{,}930 = -47{,}939\ (ft^3).$$

Second, only the added increment of ditch flow above an estimated base flow of 0.02 ft^3/s was included:

$$Q_S + Q_P - Q_{ET} - Q_D = Q_L$$
$$99{,}752 + 0 - 125{,}761 - 11{,}304 = -37{,}313\ (ft^3).$$

Both water budgets clearly show a water output greater than water input during the event. In this case, the negative value of Q_L results not from an excess of ditch flow (as in event 4), but from the high rate of evapotranspiration that could account for more water than was input as spray. In light of this, ditch flow was unexpectedly high. Data from spray field tensiometers (Fig. A11) show a trend toward decreasing soil moisture during the event, indicating a depletion of the water stored in the spray field soils. This depletion may have, in part, contributed to ditch flow.

Water quality monitoring was conducted intensively during event 10. Discrete ditch flow samples were taken at 2-hour intervals from 1500 on 31 July through 0800 on 6 August. In addition, east slope observation wells and adjacent surface waters were sampled twice daily throughout the event period.

Concentration patterns of ortho-P, NO_3-N, and Cl in ditch flow are shown in Figure A12. Ortho-P concentrations began to increase several hours after ditch flow began to increase, peaking at 0.09 mg/L at the time of peak flow. As ditch flow decreased, ortho-P levels receded to the levels before spraying. As flow dropped back to base level, however, ortho-P concentration appeared to increase somewhat.

NO_3-N, which had been below detectable levels in the ditch flow, began to increase in concentration about 3 hours after the ditch flow began to increase. NO_3 reached a maximum of 2.8 mg/L at peak flow, then dropped rapidly with the falling limb of the hydrograph. NO_3 concentration dropped to zero about 6 hours after ditch flow returned to base level.

Cl levels in ditch flow increased dramatically some 5 hours after ditch flow began to rise. The maximum Cl concentration of 47.0 mg/L occurred during the hydrograph peak. The concentration decreased slowly through the falling limb of the hydrograph, but remained elevated during the remainder of the monitoring.

All the water quality data collected during event 10 are shown in Table A10. As shown in Figure A13, both pH and conductivity increased during the event. Conductivity increased sharply a few hours after ditch flow began to rise, peaked with the hydrograph, then declined gradually. Conductivity patterns mirrored changes in Cl concentrations; pH showed a

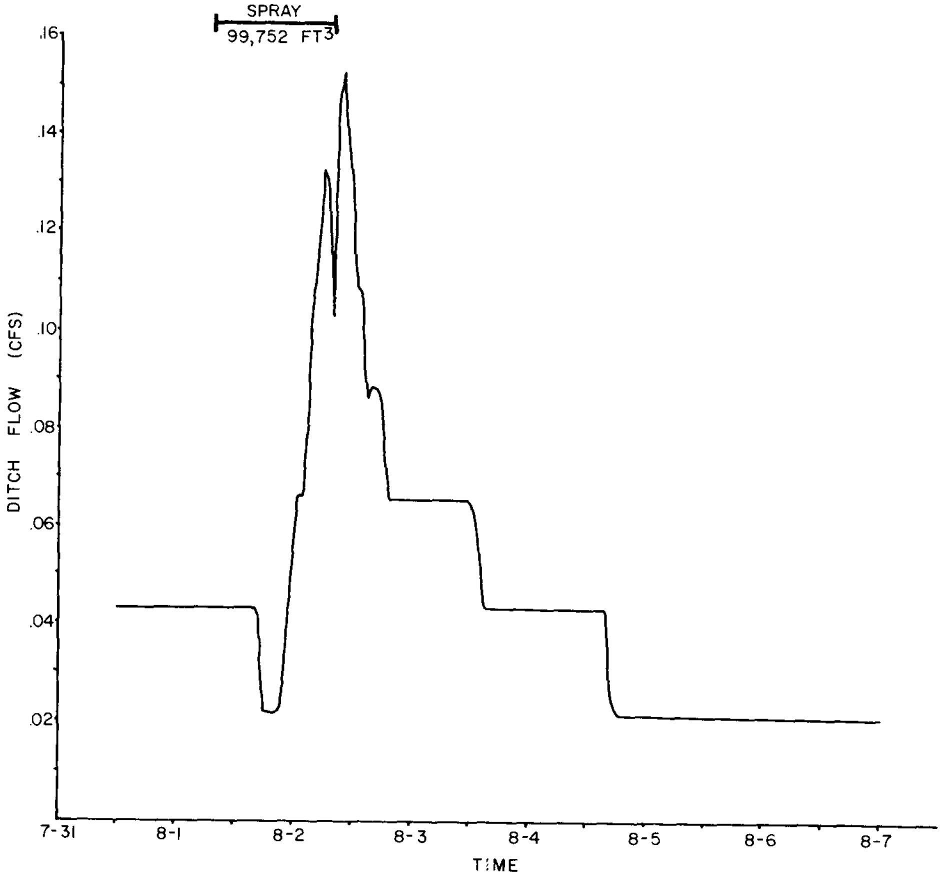


Figure A10. Ditch flow hydrograph for event 10.

general increase over the entire monitoring period. Although only a few analyses were performed, the highest level of fecal coliform bacteria was recorded at the hydrograph peak. Concentrations of BOD_5 and TKN did not appear to vary according to flow. No NH_4-N was detected in ditch flow over the event period.

Mass exports of ortho-P, NO_3-N and Cl during event 10 are also shown in Figure A12. The P mass export pattern followed the ditch hydrograph, with minor peaks occurring with concentration increases. NO_3-N and Cl export clearly paralleled the hydrograph (see Meals and Cassell 1982).

The water quality data for east slope observation wells and Ellis Brook during event 10 are included in the data report (Meals and Cassell 1982). In well 2, the only east slope well with sufficient water for sampling during the event, the water level decreased slowly, while the pH and conductivity levels increased (Fig. A14).

Water quality in Ellis Brook did not show any clear trend during event 10. However, the increases in conductivity and Cl levels at the Ellis Brook downstream sampling site continued to be evident.

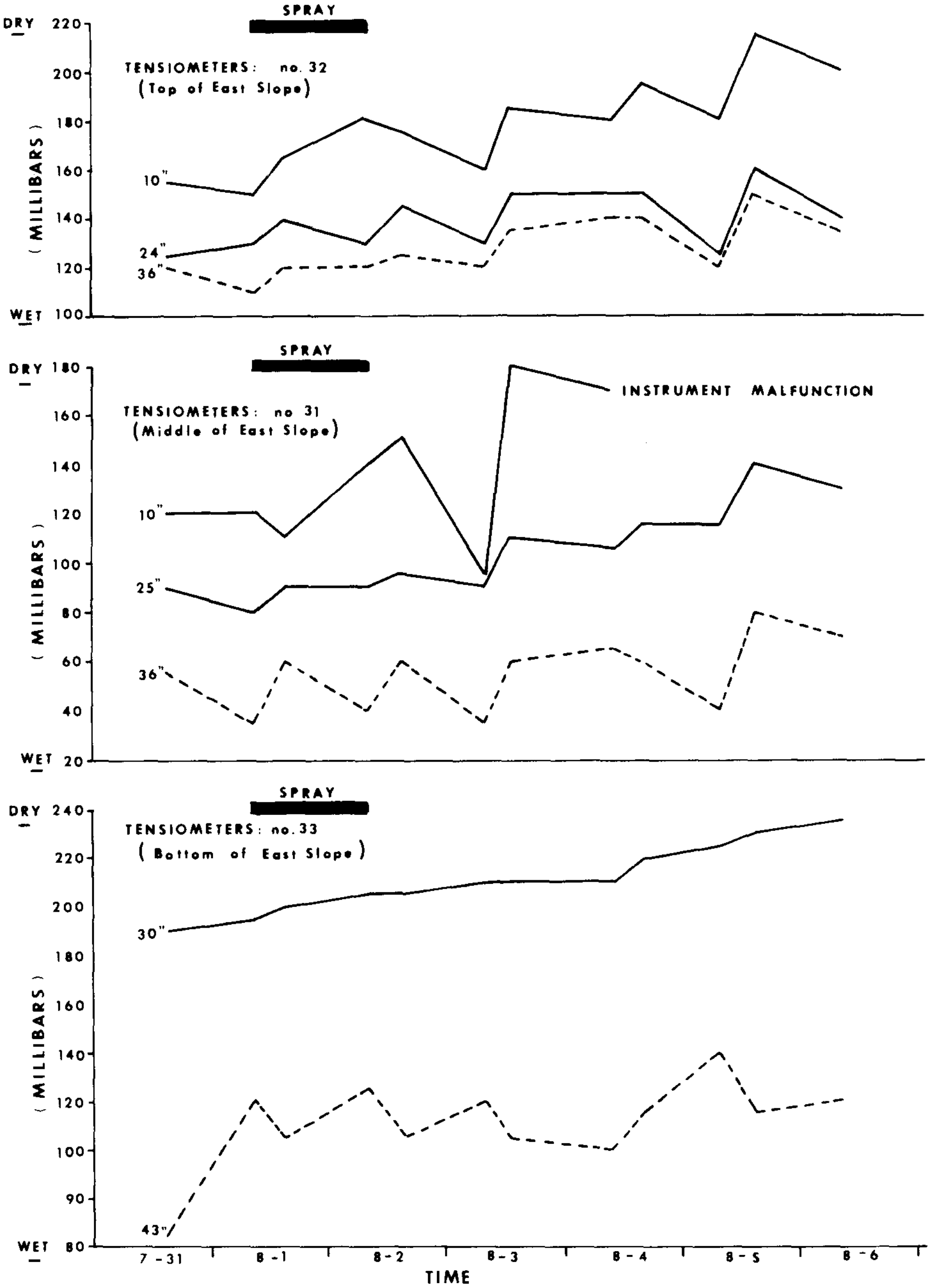
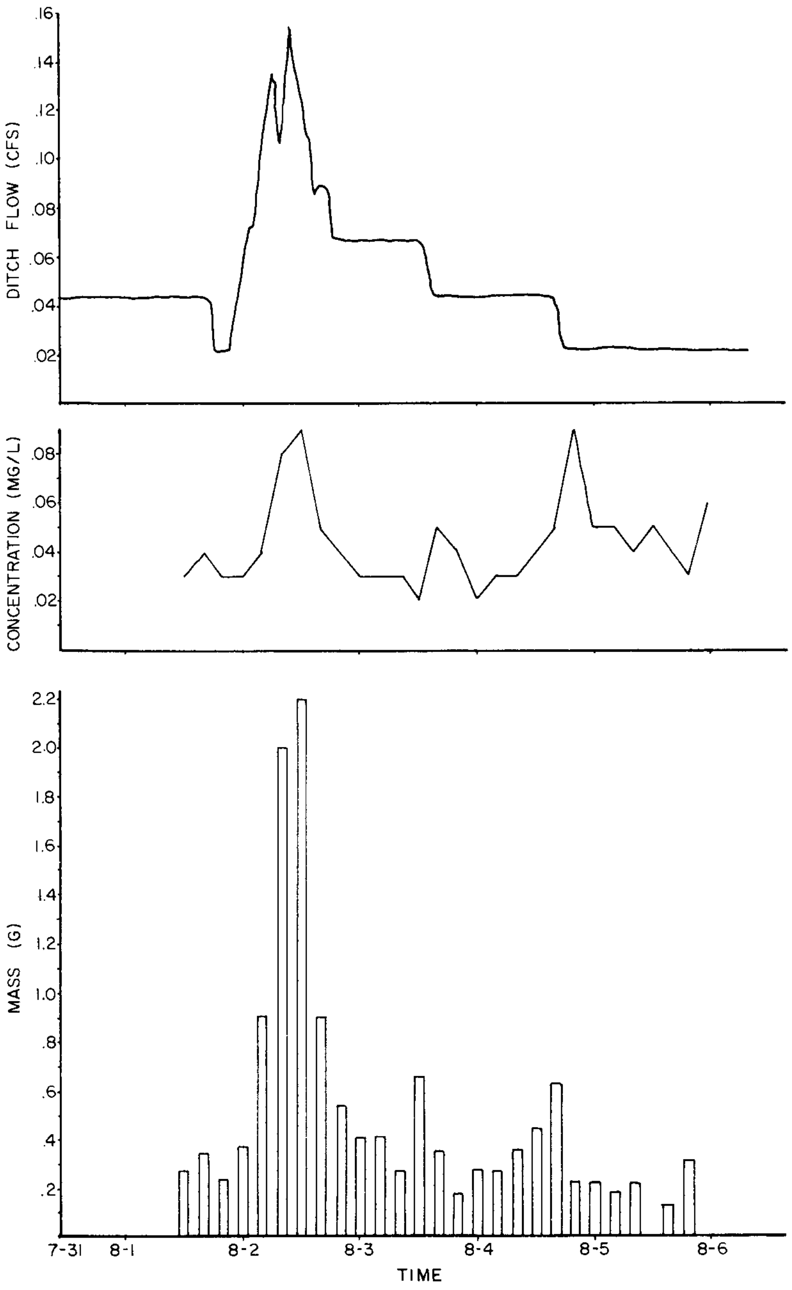
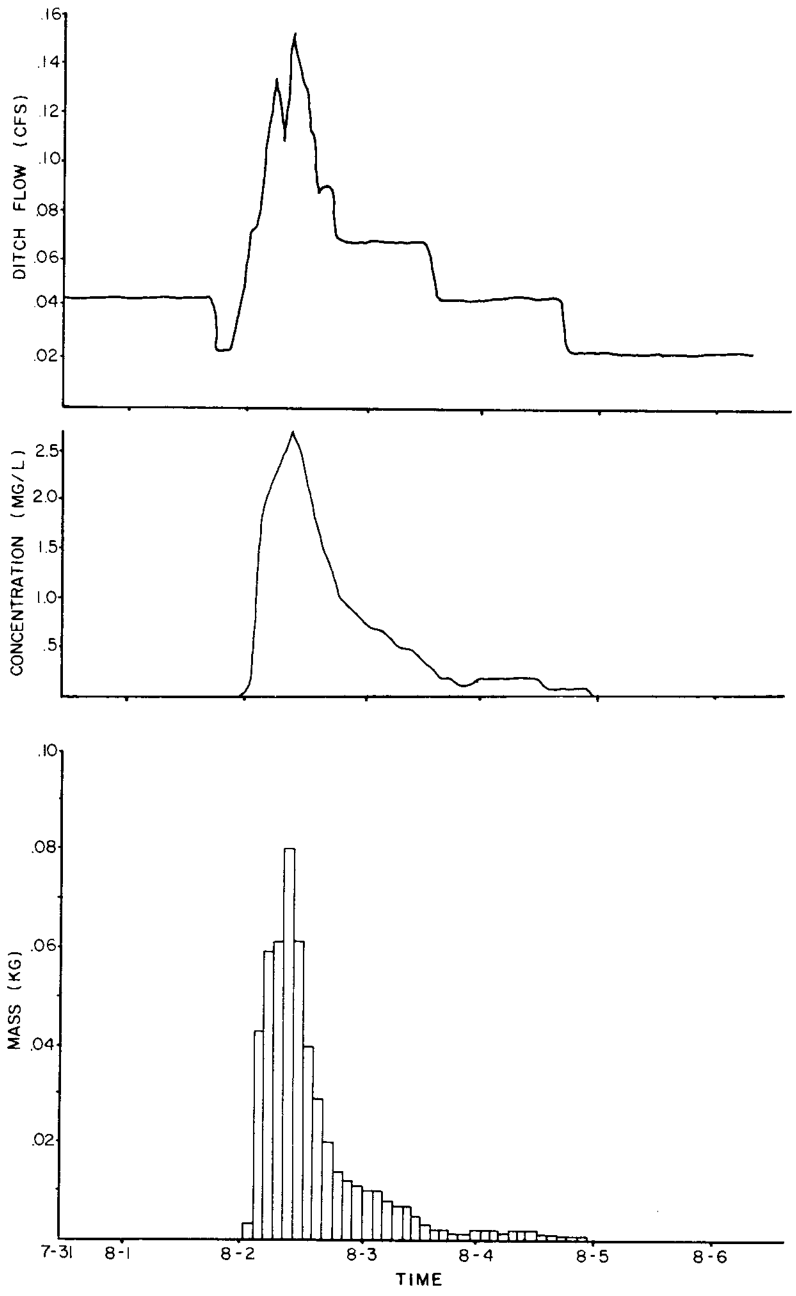


Figure A11. Spray field tensiometer trends for event 10.



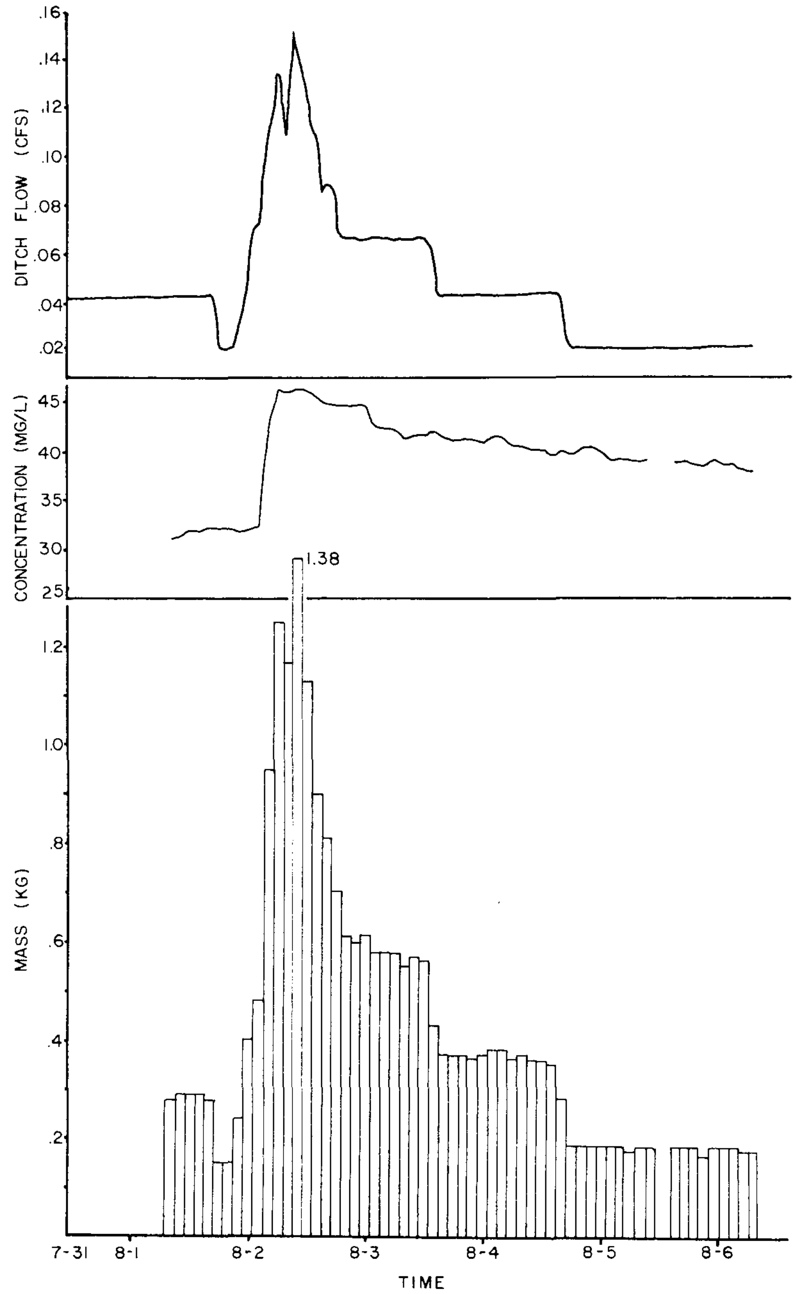
a. Ortho-P.

Figure A12. Concentration and mass export of three wastewater constituents during event 10. Hydrograph of ditch flow is included at the top of each figure group for comparison.



b. NO_3-N.

Figure A12 (cont'd). Concentration and mass export of three wastewater constituents during event 10. Hydrograph of ditch flow is included at the top of each figure group for comparison.



c. Chloride.

Figure A12 (cont'd).

Table A10. Event 10–ditch flow water quality.

Date	Time	pH	Conductivity (μmhos)	Suspended solids (mg/L)	BOD_5 (mg/L)	Fecal coliforms (no./100 mL)	Ortho-P (mg/L)	Total P (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Cl (mg/L)
31 July 79	1800	6.1	148	0.6	1.6	51	-	-	-	0.1	0.0	31.9
1 Aug 79	0000	6.1	148	-	1.8	-	-	-	-	0.0	0.0	31.9
	0600	6.1	152	-	1.5	-	-	-	-	0.0	0.0	31.8
	0900	6.1	154	-	1.8	-	-	-	-	0.0	0.0	31.1
	1100	6.1	152	-	1.8	-	-	-	-	0.0	0.0	31.4
	1300	6.1	154	-	1.9	-	0.03	0.2	1.2	0.0	0.0	31.9
	1500	6.1	155	-	1.2	-	-	-	-	0.0	0.0	31.8
	1700	6.2	155	0.4	1.1	-	0.04	0.1	0.3	0.0	0.0	32.1
	1900	6.1	155	-	1.2	-	-	-	-	0.0	0.0	32.1
	2100	6.1	154	-	1.2	-	0.03	0.1	0.3	0.0	0.0	32.1
	2300	6.1	154	-	1.2	-	-	-	-	0.0	0.0	31.7
2 Aug 79	0100	6.0	158	-	1.4	-	0.03	0.1	0.0	0.0	0.0	31.9
	0300	6.1	160	-	1.5	-	-	-	-	0.0	0.2	32.2
	0500	6.0	205	-	1.4	-	0.04	0.1	0.7	0.0	1.9	42.1
	0700	-	-	-	1.2	-	-	-	-	0.0	2.2	46.3
	0900	6.8	215	-	1.6	-	0.08	0.1	1.1	0.0	2.4	46.0
	1100	6.7	210	0.3	1.6	TNTC*	-	-	-	0.0	2.7	46.4
	1300	6.4	205	-	-	-	0.09	0.2	0.5	0.0	2.5	46.2
	1500	6.7	200	0.03	1.0	266	-	-	-	0.0	2.0	45.4
	1700	6.5	195	-	0.8	-	0.05	0.1	0.5	0.0	1.6	44.9
	1900	6.6	192	-	1.3	-	-	-	-	0.0	1.3	44.7
	2100	6.6	190	-	0.9	-	0.04	0.1	0.5	0.0	1.0	44.5
	2300	6.7	190	-	1.1	-	-	-	-	0.0	0.9	44.7
3 Aug 79	0100	6.7	188	-	0.8	-	0.03	0.1	0.4	0.0	0.8	44.6
	0300	6.6	185	-	0.7	-	-	-	-	0.0	0.7	42.5
	0500	6.4	185	-	0.8	-	0.3	0.1	0.6	0.0	0.7	42.4
	0700	6.5	188	-	2.2	-	-	-	-	0.0	0.6	42.3
	0900	7.4	186	0.6	1.2	0	0.02	0.0	0.3	0.0	0.5	41.3
	1100	7.3	181	-	1.6	-	-	-	-	0.0	0.5	41.7
	1300	7.2	181	-	0.8	-	0.05	0.0	0.2	0.0	0.4	41.7
	1500	7.2	180	-	1.2	-	-	-	-	0.0	0.3	42.0
	1700	7.2	180	0.5	1.4	66	0.04	0.0	0.6	0.0	0.2	41.3
	1900	6.7	181	-	1.4	-	-	-	-	0.0	0.2	41.0
	2100	6.8	180	-	1.6	-	0.02	0.0	0.3	0.0	0.1	41.1
	2300	7.0	178	-	0.5	-	-	-	-	0.0	0.1	41.0
4 Aug 79	0100	7.0	176	-	2.2	-	0.03	0.0	-	0.0	0.2	40.9
	0300	6.9	178	-	2.0	-	-	-	-	0.0	0.2	41.5
	0500	7.0	179	-	1.3	-	0.03	0.1	0.3	0.0	0.2	41.4
	0700	6.8	178	-	1.2	-	-	-	-	0.0	0.2	40.5
	0900	6.7	174	-	1.9	-	0.04	0.0	0.4	0.0	0.2	40.5
	1100	6.8	185	1.4	1.8	28	-	-	-	0.0	0.2	40.1
	1300	6.9	180	-	1.4	-	0.05	0.0	0.4	0.0	0.2	40.2
	1500	6.9	180	-	1.8	-	-	-	-	0.0	0.1	39.5
	1700	6.8	178	0.8	1.6	30	0.09	0.1	0.5	0.0	0.1	39.9
	1900	7.0	175	-	1.7	-	-	-	-	0.0	0.1	39.5
	2100	6.9	176	-	1.5	-	0.05	0.1	0.4	0.0	0.1	40.2
	2300	7.0	177	-	1.2	-	-	-	-	0.0	0.1	40.4
5 Aug 79	0100	7.0	178	-	1.4	-	0.05	0.1	0.5	0.0	0.0	39.9
	0300	7.2	175	-	1.0	-	-	-	-	0.0	0.0	39.0
	0500	7.0	176	-	1.1	-	0.04	0.1	0.5	0.0	0.0	39.3
	0700	6.9	180	-	1.4	-	-	-	-	0.0	0.0	39.0
	0800	7.3	175	0.6	1.9	58	0.05	0.0	0.5	0.0	0.0	38.8
	1100	7.4	170	-	1.6	-	-	-	-	0.0	0.0	39.0
	1600	7.4	168	1.2	1.9	6	0.03	0.0	0.6	0.0	0.0	38.9
	1800	7.2	165	-	1.2	-	-	-	-	0.0	0.0	39.1
	2000	7.5	168	-	1.2	-	0.06	0.1	0.3	0.0	0.0	36.6
	2200	7.5	165	-	1.2	-	-	-	-	0.0	0.0	38.7
6 Aug 79	0000	7.4	165	-	1.2	-	-	-	-	0.0	0.0	39.2
	0200	7.3	169	-	1.4	-	-	-	-	0.0	0.0	38.6
	0400	7.3	168	-	1.2	-	-	-	-	0.0	0.0	38.8
	0600	7.2	164	-	1.4	-	-	-	-	0.0	0.0	37.6
	0800	7.0	168	0.6	1.2	160	-	-	-	0.0	0.0	37.4

*Too numerous to count.

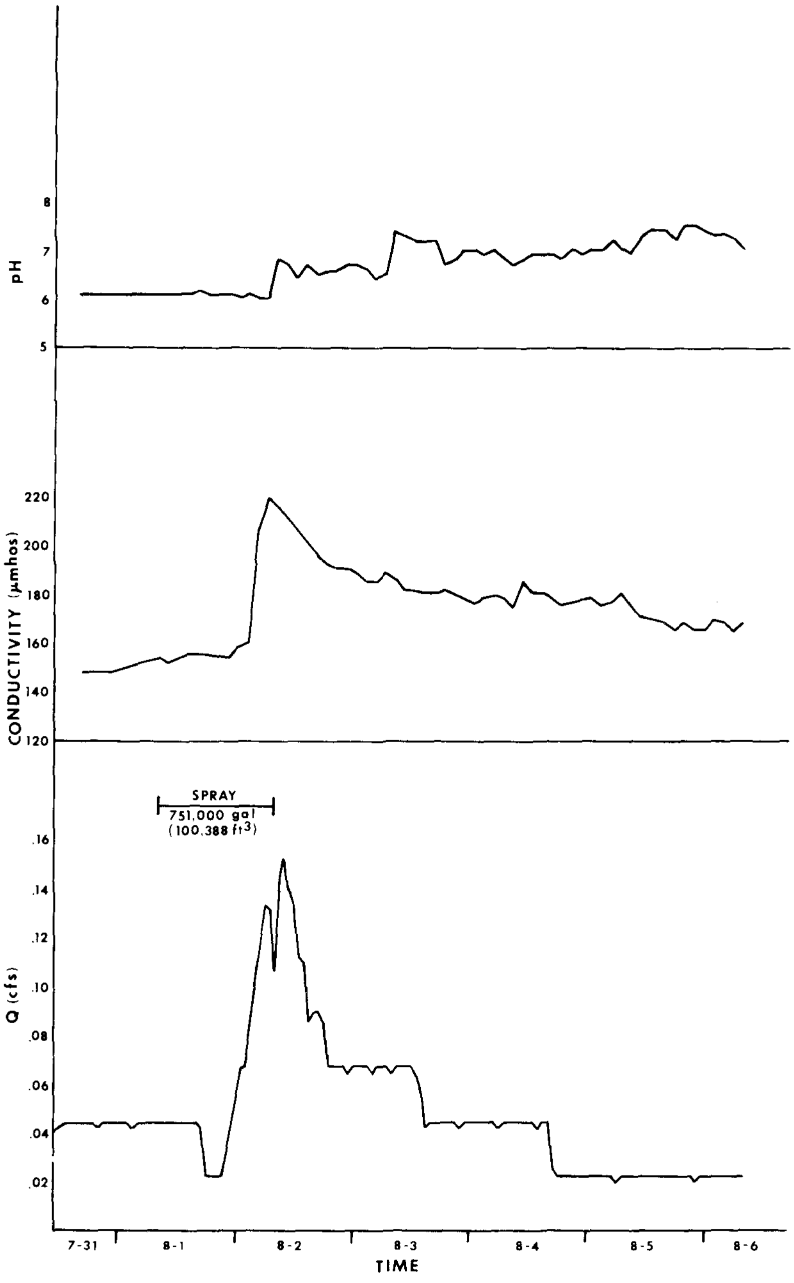


Figure A13. Behavior of pH and conductivity in the ditch flow during event 10.

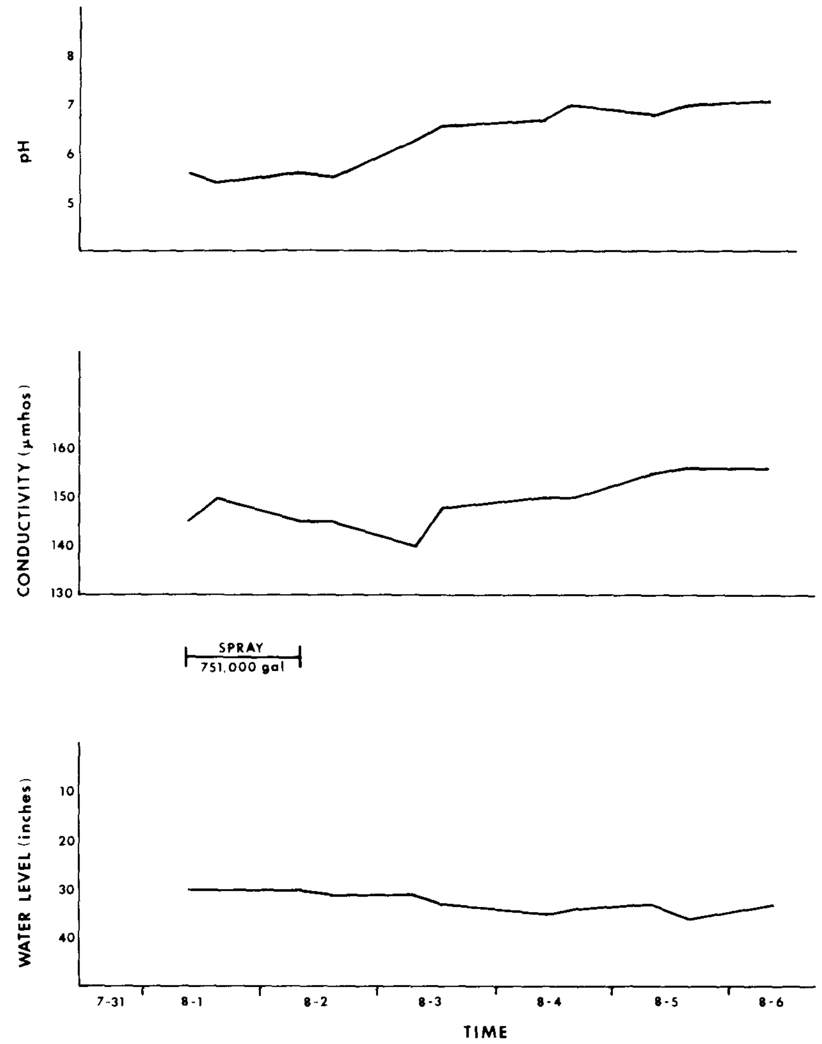


Figure A14. Behavior of pH and conductivity in well 2 during event 10.

Behavior of monitored events

The overall performance of land treatment at West Dover has been described in terms of east slope hydrology, concentration changes between effluent application and interceptor ditch drainage, and mass balances of wastewater constituents. The specific short term behavior of the system may be more clearly seen in the results of the specific events that were intensively monitored during the study. Interpretation of these events suggests several important characteristics of spray field response to effluent application, precipitation, and other environmental parameters (including temperature).

Ditch flow hydrographs during several of the monitored events show the influence of air temperatures on water output from the east slope. In event 2 (9-10 December), for example, the only water input was 0.71 in. (water equivalent) of snow, yet this input generated a distinct spike in ditch flow. Air temperatures varied around 32°F on 9 December. Thus, this hydrograph may be interpreted as a melt phenomenon; the increased ditch flow was a response to melting of snow falling at temperatures near and slightly above freezing.

Event 3, in late February, also demonstrated the effects of temperature on ditch flow. At 2000 on 28 February, ditch flow began to decrease despite continuing rainfall. The explanation for this decrease in flow is that temperatures in the evening hours fell to just below freezing and thus slowed drainage from the east slope.

Two ditch hydrographs in late April (events 6 and 7) show another example of temperature influence on east slope drainage. The hydrographs from both

Table A11. Nutrient export rates—monthly mean versus amount exported during events (g/hr).

Date	Event no.	Ortho-P		NO_3-N		Cl	
		Event	Mean	Event	Mean	Event	Mean
October 1978	1	0.5	-	9	-	139	-
December	2	7	3	157	54	679	229
February 1979	3	5	2	136	82	574	411
March	4	8	8	282	270	1355	1314
April	5	3	2	202	163	1032	863
April	6	1	2	131	163	712	863
April	7	3	2	195	163	1045	863
April	8	3	2	106	163	644	863
May	9	8	1.5	98	45	648	473
August	10	0.3	1	7	102	211	700

events display a consistent cyclic pattern with a period of approximately 24 hours. This cycle follows the daily temperature cycle, with peak flows in late afternoon when air temperatures are the highest. This cycle was evident even in the absence of significant water input; additional water input appears to amplify the daily peaks, but the cycle is maintained. This is particularly evident in the hydrograph of event 7. This pattern of spring ditch flow is the result of the melting of ice and snow on the spray field during the higher temperatures of midday, followed by refreezing at night.

Temperature can not only influence the timing of ditch flow, but also ditch flow quantity. The highest ditch flow during the study was recorded in the spring with the coincidence of rainfall and rising temperatures.

Even in late April, temperature exerts an influence on the east slope water balance. During event 8 substantially more water left the east slope in the ditch than was input as rainfall. This "water surplus" was undoubtedly the result of ice and snow on the spray field melting as a result of both rainfall and temperatures well above freezing.

Finally, temperature appears to influence the concentration of wastewater constituents in the interceptor ditch. During event 4 (2-8 March 1979) the concentrations of P, NO_3, and Cl followed a similar pattern: concentrations of all three constituents increased during the initial rise of the hydrograph, dropped during peak flow, then increased again. This phenomenon may be interpreted as a combination of melt and dilution. The initial phase of rainfall, coupled with warming, began to melt some of the frozen effluent stored in the east slope. The resulting runoff carried high concentrations of P, NO_3, and Cl into the ditch. Then, as precipitation continued and intensified, rainfall became the dominant contributor to the ditch flow, diluting flow in the ditch and causing lower nutrient concentrations. As rainfall ended, runoff from melting ice again dominated ditch flow, and concentrations began to rise.

The concentrations of P, N, and Cl were generally higher during the monitored events than at other times. The highest event-related concentrations of these constituents occurred in later winter and spring, coinciding with the highest ditch flow. Thus, not only did monthly mass export of wastewater constituents reach a maximum during the spring (i.e. March), but nutrient export rates tended to be substantially higher during events than the average rate for the month (Table A11).

The pattern of nutrient concentration in the ditch during monitored events differed with the event type. During events in which the predominant water input was effluent spray or melting ice or snow, concentrations of ortho-P, NO_3-N, and Cl tended to increase with increasing flow in the ditch (e.g. events 5, 7 and 10). In contrast, when rainfall was the primary water input to the east slope, nutrient concentrations tended to decrease with increasing flow (e.g. events 1, 2, 4 and 9). The inverse relationship between flow and concentration observed during precipitation events is a dilution effect. Rainfall which reaches the interceptor ditch (either by runoff or subsurface flow) is "pure" relative to effluent (either sprayed or frozen) and thus dilutes the concentrations of wastewater constituents found in the ditch. However, when water in the interceptor ditch comes from sprayed effluent or melting effluent ice, higher nutrient concentrations accompany rising ditch flows. Both of these phenomena were observed in event 4 when water inputs consisted of both precipitation and melting effluent ice.

It should be noted that the dilution effect of rainfall was observed in events that took place only during the winter and spring months. Other studies of land treatment systems, including an earlier study at West Dover, have shown wastewater constituents to be flushed from the land with major rainfall, particularly mobile forms such as NO_3-N and Cl (Cassell et al. 1979).

Particular attention should be given to event 9 on 3–5 May 1979. The event water balance shows a substantial water surplus that may represent output of water stored in east slope soils. The event mass balance shows a substantial retention of total P (86%), but only a minor Cl removal (3%) and a net export of NO_3-N. The absence of unaccounted for water and the negligible removal of Cl suggest a net pass-through of the effluent applied to the east slope during this event. Thus, event 9 may be useful to examine the performance of the east slope without the complication of Q_L (unaccounted for water) serving as a nutrient removal pathway. Although the conditions of event 9 were not typical of most of the season at West Dover, the observed removal rates for P and Cl are about what might be expected. The observed export of NO_3-N may have been the result of a combination of flushing of the NO_3 accumulated over the winter, the lack of NO_3 uptake by vegetation, or low levels of denitrification in the east slope soils.

The nutrient export patterns for ortho-P, NO_3-N, and Cl associated with event 10, as shown earlier in Figure A12, were quite different from event 9. Ortho-P concentration peaked with flow, then dropped back to base levels. This peak was likely the combined result of surface runoff and subsurface flow entering the ditch. Concentrations of ortho-P were variable during the remainder of the event, but even in the absence of any observed hydrologic input or change, ortho-P concentration rose sharply nearly 3 days after effluent application. This sharp increase might be attributed to sampling or analytical error, or to some other unknown input to the ditch, possibly of animal origin.

NO_3-N concentrations were below detection limits, both before and after the main event 10 flows, and thus the observed NO_3-N output was probably the direct result of effluent application. The initial rise in concentration was likely the result of runoff or subsurface input of applied effluent, but the rapid decrease in concentrations, especially in relation to the very gradual decrease in Cl levels, suggests significant retention of NO_3-N on the east slope. Because the soil conditions were very dry prior to spray application, conditions not conducive to significant denitrification, it seems likely that plant uptake on the east slope was the primary agent for NO_3 removal in this case.

The pattern of Cl concentration in the ditch in event 10 differed from that of either PO_4 or NO_3. Cl levels increased sharply with flow, then declined very gradually, remaining well above base levels throughout the event monitoring period. As with ortho-P and NO_3-N, either effluent runoff or subsurface flow accounts for the initial rise. However, the gradual decline of Cl levels in the ditch suggests that the applied Cl was diluted by east slope groundwater, even though data (Fig. A11) indicate little net depletion of stored soil water over the event.

Another significant aspect of event 10 is the timing of ditch flow and concentrations of exported constituents relative to spray application. While ditch flow began to increase during effluent application, increases in ortho-P, NO_3-N, and Cl concentration did not begin until several hours after ditch flow began to increase. There are two possible interpretations of this phenomenon. In both cases, the initial increase in ditch flow could be the result of newly applied effluent percolating into the soil and hydraulically displacing soil water (either native groundwater or previously applied effluent) from the lower east slope into the ditch. These conditions suggest that "old" soil water, containing low concentrations of nutrients after a relatively long soil contact time and dilution, would reach the ditch first, contributing to increased flow but not to concentrations of ortho-P, NO_3-N, or Cl in the flow. Only when the recently applied effluent arrives in the ditch after a much shorter soil contact time would nutrient concentrations begin to rise.

Alternatively, surface runoff of applied effluent may be responsible for the rising concentrations. Within this framework, the initial rise in concentration could be due to effluent moving downslope as overland flow. Surface runoff from the east slope has been observed in the past, both as sheet runoff and as flow in small rills or channels. Such movement was not, however, actually observed during the monitoring period. The succeeding decline in nutrient concentrations could be interpreted as dilution by the later arrival of renovated water moving as subsurface flow.