DIFFUSE SOURCE LOADINGS FROM FLAT COASTAL WATERSHEDS:

Water Movement and Nutrient Budgets

FINAL REPORT

PREPARED BY
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by

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EXECUTIVE SUMMARY

A study of dissolved nutrient loadings from predominantly agricultural and forested watersheds on the Eastern Shore of Chesapeake Bay reveals that approximately 10 kg nitrogen (N) $ha^{-1}yr^{-1}$ runs off from mixed cropland areas while only 0.2 kg N $ha^{-1}yr^{-1}$ runs off from non-fertilized forest areas. Dissolved phosphorus (P) runoff is about 0.9 kg P $ha^{-1}yr^{-1}$ from cropland and 0.2 kg P $ha^{-1}yr^{-1}$ from forested areas. These rates indicate that agricultural loadings significantly increase the ratio of nitrogen to phosphorus concentration in receiving tributaries (mostly due to high nitrates). Because particulate concentrations of N & P were not measured, the above watershed loading rates are conservative (i.e., underestimates). Subsurface groundwater inputs are quite variable and difficult to quantify, but generally appear to be insignificant compared to surface runoff from ditches. However, large concentrations of nitrate (2-12 ppm) were found in the groundwater near the Bay and may be transported during periods of extended precipitation to the estuary.

In the Choptank River, the largest tributary east of the Bay, calculations show that diffuse sources account for at least 78% of the total N loading (1500 metric tons) and at least 62% of the total P loading (275 metric tons). The implication of this is that in tributaries such as the Choptank, more efforts must be made to understand and control non-point sources. Although advanced treatment of effluent from sewage treatment plants (STP) in large municipalities (Easton and Cambridge) would probably make an impact

on the water quality of downstream segments, the upper segments of the Choptank are dominated by agricultural runoff. Thus advanced treatment in STP at small upstream towns would be inconsequential in terms of nutrient load reductions in the upper Choptank subestuary. Therefore, in order to improve water quality of non-urbanized Eastern Shore subestuaries, we must focus increasingly on agricultural practices which minimize nutrient runoff e.g., no-till cultivation, grass buffer strips along fields adjoining the Bay, and winter cover crops.

INTRODUCTION

The water quality of the Chesapeake Bay is a prime factor in the maintenance of the present Chesapeake Region economic system and its supporting ecosystem. Declining water quality impacts directly not only on recreational and commercial activities but also detracts from the image of the Bay as a healthy productive ecosystem. Several agencies of state and federal government have been charged with monitoring and maintaining standards of water quality for the Bay and its tributaries. These agencies have in the past been effectively concentrating their efforts on regulating inputs to the various tributaries of the Bay from point sources (i.e., industrial, commercial and municipal outfalls) in order to manage water quality. However, there are suggestions that nutrient loadings from non-point or diffuse sources (such as agricultural wastes, storm runoff, and seepage from poorly operating septic field systems) may be as much as a magnitude greater in rural areas than loadings from point sources such as sewage treatment plants (STP) (Wallace et al. 1972).

Previous estimates of the proportion of Chesapeake Bay pollution attributable to non-point sources were highly speculative due to the lack of runoff data from the eastern shore coastal plain region of Chesapeake Bay, the richest agricultural area in Maryland. Unfortunately marked differences in slope, land use patterns and agricultural practices between the rolling topography of Chesapeake Bay's western shore and the flat terrain of the eastern shore, make extrapolation of runoff loading rates to the entire Bay from one site a tenuous proposition. Therefore, to estimate non-point inputs to the eastern shore tributaries of Chesapeake Bay, an extensive data set is necessary (including both water movement and water quality) from typical eastern shore watersheds.

The critical issue we have addressed concerns the relative magnitudes of diffuse source pollutants from various land use patterns in the Chesapeake Bay region. Hopefully, the results of these studies will be instrumental in determining the extent that efforts should be made by government agencies to limit point source pollution sources in rural basin areas around Chesapeake Bay. If non-point source loadings greatly exceed that from point sources, it makes little sense to spend millions of dollars to install expensive nutrient removal technology at the numerous STP. Instead, more attention should be directed to understanding and minimizing diffuse sources of pollution. On the other hand relatively small diffuse source loadings would indicate that upgrading of STP with phosphorus and/or nitrogen removal might be cost effective in terms of improving water quality.

In order to quantify the magnitude of diffuse source pollution inputs into particular sub-watersheds of Chesapeake Bay, data is required from areas representing major topographic, hydrologic and land use units. We have been studying several watersheds within the Choptank River basin, an area which is characteristic of much of the eastern shore of the Chesapeake Bay.

CHOPTANK RIVER BASIN CHARACTERISTICS

A comparison of the physical characteristics of major river systems in Maryland (Table 1) shows that the Choptank is the largest river of the eastern shore in terms of volume and navigable reach.

TABLE 1. Physical characteristics of selected river systems in Maryland

	Total basin area[a] (includ water) sq km	Navigable length[b] km	Land Drainage[a] area sq km	Total estuarine area 10^6 m^2	Total MLW volume 10^6 m^3	Intertidal estuarine volume 10^6 m^3	Diffuse sources loading: dilution ratio m^2/m^3
Chester R.	1,036	61	834	202	835	81.7	1.0
Eastern R.	518	14	292	226	1045	74.4	.3
Choptank R.	2,246	93	1,880	366	1441	156.3	1.3
Nanticoke R.	2,111	54	2,036	75	190	52.9	10.7
Wicomico R.	619	16	572	47	107	134.3	5.3
Pocomoke R.	2,300	51	1,913	387	1073	252.0	1.8
Sassafrass	290	24	253	37	158	--	1.6
Patuxent R.	2,409	86	2,272	137	659	58.6	3.4
Potomac R.	8,664	158	7,413	1,251	7288	241.7	1.0

[a]Maryland Department of Natural Resources Water Resources Administration Basin Plans

[b]Cronin and Pritchard 1975.

The main stem of the Choptank extends 107.8 km from its mouth (delineated by Blackwalnut and Cooks Points) to the Delaware State line. The river basin has a total area (including water surfaces) of 2,246 sq km (867 square miles).

In terms of potential influence of diffuse sources, the Choptank River is in the median range with a diffuse source ratio of 1.3 (m^2m^{-3}). This ratio is an index of dilution potential balanced against potential diffuse source inputs and is obtained by dividing surrounding land drainage (1,880 km^2) by the mean low water volume (1441 x 10^6m^3) of the river. Although this value does not take into account different land use patterns or the relative flushing characteristics of each of the subestuaries, it is useful as a first approximation of the relative influence of diffuse source inputs from the land per unit volume (dilution potential) of each river system. The influence in terms of land forcing functions is much greater in areas having a large ratio. Since the Choptank ratio of 1.3 is in the median range of watersheds it is a particularly representative basin for the investigation of diffuse source loadings on the eastern shore.

The water quality of the Choptank River is also quite typical of the major eastern shore rivers (Table 2). Levels of chlorophyll a, coliform bacteria, nitrogen and phosphorus are rather modest considering the relatively high discharge (approx. 10 MGD) from municipal sources. However, the Choptank's large volume (Table 1) produces much greater dilution potential than smaller rivers such as the Wicomico River which receives lower inputs, but has very poor water quality (Table 2). Therefore, because of its large size and

TABLE 2. Comparative water quality of selected river systems in Maryland in 1970's.

	Aver.[a] chl a mg l^{-1}	Median[a] Fecal Coliform MPN	Aver. Total[a] Phosphorus μg l^{-1}	Inorganic[a] Nitrogen μg l^{-1}	Approximate Point Discharge MGD
Sassafrass R.	70	90	81[b]	579[d]	
Chester R.	50	-	31	949[c]	.57
Eastern B.	37	-	149	439[d]	.04
Choptank R.	74	800	229	526[d]	10.04
Nanticoke R.	54	160	81	935	1.19
Wicomico R.	111	1500	399	3164	4.00
Pocomoke R. & S.	46	730	480	916	.73
Patuxent R.[e]	147	2100	4100	--	24.54

[a]Values are not average for the entire river but means of segment having highest concentrations. All data from Maryland Resources Administration "Maryland Water Quality 1975", Department of Natural Resources

[b]Total phosphate

[c]$NO_2 + NO_3$

[d]Nitrate

[e]Patuxent data from EPA Tech Report 58 (1973)

typical loading patterns, the Choptank River watershed is an ideal area for the study diffuse source and point source loadings on a highly agricultural flat coastal plain.

The soil series in the upper Choptank (Fincher 1976) consists of the following: Pocomoke 38%, Fallsington 25%, Sassafras 18%, Woodstown 6%, Rumsford 5%, Evesboro 4%, minor soils 4%. A detailed listing of types in the lower basin, more representative of our study area, is presented in Table 3. Drainage problems are associated with the Pocomoke, Fallsington and Woodstown soil series (see Table 4). Because of poor overall topographic relief, these soils are prone to be problematic for agriculture unless drainage ditches are utilized. However, corn yields can be comparable to that of the midwestern U.S. corn belt (160 bush/acre) on the Sassafras and other rich upland soils where drainage problems are negligible. In the higher elevation areas of the Choptank watershed in Queen Anne and Talbot Counties the highest corn yields in the state of Maryland are often reported.

Poor drainage in low lying fields can result in protracted periods of waterlogging producing anaerobic soils. In addition to stresses induced to crop-plants from oxygen depletion, dentrification may occur when soil carbon levels are high (Denmead et al. 1979, Firestone et al. 1979, Terry and Tate 1980). High dentrification rates can result in a substantial loss of nitrate in field soils causing reduced fertility. This was apparently the case in the wet spring of 1979 when there was considerable rainfall just after planting. Therefore, variable amounts of nitrogen in the fertilizers are lost into the atmosphere immediately after application. Thus,

TABLE 3. Aerial coverage (hectares) of soil types in the two lower counties of the Choptank River Basin.

Soil Type	Dorchester[a] County	Talbot[b] County	Total	% Total
AGRICULTURAL SOILS				
Barclay		3,995	3,395	2.16
Bayboro	2,212		2,212	1.19
Bibb	79		79	.04
Downer		1,089	1,089	.59
Elkton		10,202	10,202	5.51
Fallsington	9,146	3,824	12,970	7.00
Galestown	5,483	285	5,768	3.11
Johnston	390		390	.21
Keyport	2,782	5,455	8,237	4.45
Klej	2,258	130	2,388	1.29
Lakeland	765		765	.41
Matapeake	3,826	5,177	9,003	4.86
Mattapex	5,317	7,298	12,615	6.81
Othello	15,622	719	16,341	8.82
Plummer	269	40	309	0.17
Pocomoke	2,634	170	2,804	1.51
Portsmouth	664	145	809	.44
Sassafras	20,460	15,838	36,298	19.60
Woodstown	6,471	5,574	12,045	6.50
BORROW PITTS		157	157	.08
COASTAL BEACHES	86	47	133	.07
MADE LAND	34	282	316	.17
MIXED ALLUVIAL	816	1,980	2,796	1.51
STEEP LAND		904	904	.49
SWAMP	7,047		7,047	3.80
TIDAL MARSH	33,060	2,478	35,538	19.19
	119,421	65,789	184,610	100%

[a]Mathews, 1963

[b]Reybold, 1970

TABLE 4. Soils of uplands and terraces of the Choptank River Basin on Maryland's Eastern Shore[a]

Parent Material	Somewhat Excessively Drained	Well Drained	Moderately Well Drained	Poorly Drained	Very Poorly Drained
Sand and loamy sand	Galestown Lakeland	-	Klej	Plummer	Rutlege
Sand, silt and clay	-	Sassafras	Woodstown	Fallsington	Pocomoke
Mantle of silt over sand	-	Matapeake	Mattapex	Othello	Portsmouth
Clay or silty clay	-	-	Keyport	Elkton	Bayboro
SOILS OF FLOOD PLAINS OR BOTTOM LANDS					
Sand, silt and clay	-	-	-	Bibb	Johnston

[a]Mathews, 1963

there are questions concerning the fate of nitrogen in fertilizers in any particular year. Denitrification rates of from 5 to 50 percent have been reported for a wide range of agricultural practices (see Nielson and MacDonald 1978). It is of utmost significance whether the nitrogen from fertilizers used in farming activities on the eastern shore ends up in Chesapeake Bay, in the atmosphere, or is lost to groundwater.

The land use statistics for the upper and lower Choptank Basin are shown in Table 5. The most extensive use is agriculture (66%) with forested land being the second most important category (29%). Urban areas with commercial and residential development presently comprise a relatively small fraction (4%) of the land use, while the marsh interface which buffers the Chesapeake Bay is less than 1% of the land area. Therefore, analysis of the land use pattern reveals that approximately 95% of the surface area (above mean high water) can be accounted for with projected data from forested and crop land in the Choptank watershed.

BACKGROUND OF HORN POINT WATERSHEDS

Three watersheds draining into LeCompte Bay, Dupont Cove and Lakes Cove were chosen for the study of diffuse source inputs to the Choptank River watershed (Figure 1). All of these watersheds are situated on the 850 acre (3.44 sq km) campus of the Horn Point Environmental Laboratories, a branch of the University of Maryland Center for Environmental and Estuarine Studies.

This area was originally patented in 1659 and was undoubtedly cleared for the planting of tobacco soon after. The remains of a

TABLE 5. Land use in four segments of Choptank River Basin (hectares)[c]

Land Use	Lower[a] Choptank	Upper[b] Choptank	Tuckahoe[c] Creek	Delaware Segment	Total
Agriculture	32,916	42,390	28,978	11,631	115,915
Forested	11,591	18,353	10,848	9,591	50,383
Development	3,344	1,746	111	1,864	7,065
Marshes	483	929	0	0	1,412
	48,334	63,418	39,937	23,086	174,775

[a]downstream town of Choptank (includes Hunting Creek Watershed)

[b]upstream from town of Choptank to the Delaware line

[c]compiled from Solyst and Davidov 1979 (Md) and Fincher 1975 (Del)

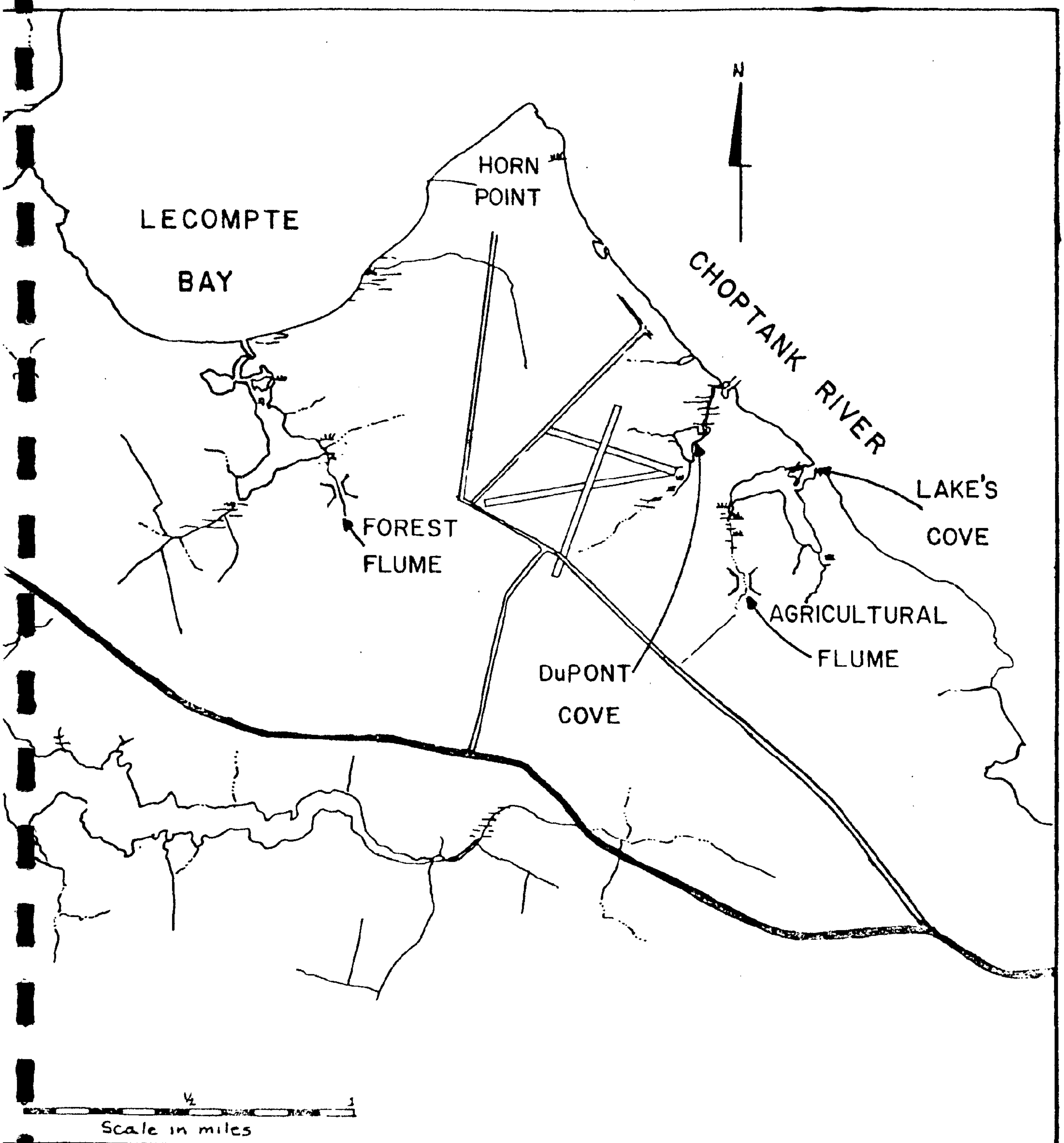

Figure 1. Map of study area showing sites of agricultural and forest flumes.

brick house dating from the late 1600's adjacent to Dupont Cove (Figure 1) indicate a rather impressive plantation in this area over 300 years ago. In the 1700's vacillating tobacco prices and increasing impoverishment of organic matter in soils caused farmers to shift to less nutrient demanding crop species. Wheat and corn became the principal crops in the area by the late 1700's and continued to be extensively planted in the 1800's.

In the early twentieth century many farmers began using inorganic fertilizers and diversified their farming operations to include vegetables which were canned in the nearby town of Cambridge. A resident of the area remembers when the watershed which is now entirely a pine forest supported a tomato farm, a common cash crop in the early 1900's. When T. Coleman Dupont purchased Horn Point in the 1920's, he restored a major portion of the property to forest and loblolly pines were planted over most of the watershed. Thus, the forested area of our study has not been fertilized in any way for over 50 years. The pines have been systematically cut in various portions of the watershed since then. The USGS map of 1942 shows that the central portion of about one-quarter of the watershed was not forested at that time. Also, an aerial photograph from a conservation plan reveals that the southeastern portion of the watershed was thinned in the 1960's. In addition to selective cutting, Rhus radicans vines have taken over much of the canopy. This makes it known to those who have had to spend extensive amounts of time sampling in it as a "pine-poison ivy" subclimax forest. A few hardwood species are in the shrub layer, but seldom has succession progressed far enough to have these transgressive species in the canopy. The 1 m deep ditches in the watershed were undoubtedly dug when the area was still under cultivation to help relieve the high water table conditions.

The crops now regularly planted in the agricultural watershed consist of three species: corn, small grains (wheat or barley) and soybeans. These are planted in a 2-year rotation described in detail in the methods section. This is presently the typical sequence of cropping on the Delmarva Peninsula. Thus the Horn Point runoff data should have wide applicability to many sites on the eastern shore of Chesapeake Bay.

METHODS

The first factor in estimations of watershed loading rates is the quantification of the runoff component within the overall water budget of the study area. The second includes the periodic measurement of concentrations of materials of interest (nitrogen and phosphorus in this case) contained in the runoff. Our approach to measuring each of the above factors is detailed below under respective sub-divisions followed by a description of agricultural practices carried out at Horn Point during this study.

WATER BUDGET

Waterborne materials move from the land to the estuary either through surface or groundwater flows. These two flows are part of the larger hydrologic cycle of the low flat coastal areas around Chesapeake Bay which needs to be quantified for an accurate assessment of diffuse-source pollution. Precipitation is either intercepted by vegetation such as crop or forest canopies or bare ground. After the rain hits the land it may move across the ground surface or soak into the soil depending on the previous field moisture levels. Most of the precipitation is returned to the atmosphere via evaporation or transpiration. Some of the soil moisture moves to deep aquifers, but most of it moves laterally through the soil to eventually reach ditches, streams or the estuary. Main pathways are depicted in Figure 2 from Daniels, et al. (1976) where the line width approximates the relative annual volume of water in that direction.

Components of the water budget which require field measurements

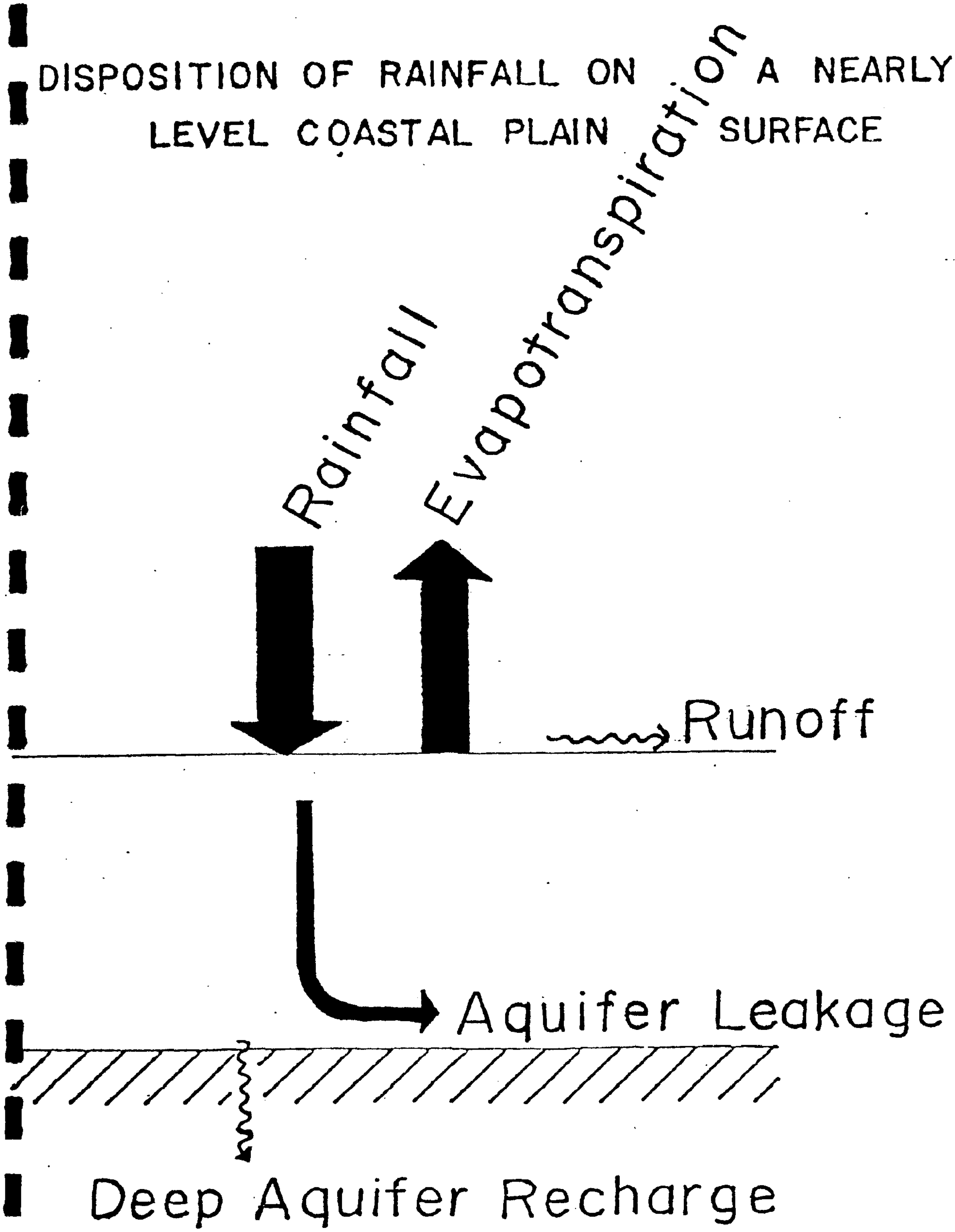

Figure 2. Graphical description of water movement.

are precipitation, interception, surface flow, groundwater levels, and moisture. These measurements in combination with calculations for evapotranspiration and groundwater flow will roughly describe the water budget. Measurements of precipitation, surface flow, and groundwater levels are reported below with additional details using $O^{16}:O^{18}$ methods available in Christy 1980.

Determination of Surface Flows

The surface flows were measured at the mouths of the watersheds by Parshall flumes installed in existing drainage ditches. Selection of Parshall flumes as the measuring devices was based on their ability to remain accurate with a relatively high percentage submergence, a problem in low flat coastal plain areas (Lomax et al. 1980). For example, Parshall flumes will remain accurate to 70% submergence and only need a 5% correction in head for 80% submergence. Also they remain clear of debris which often catches in V-notch weirs giving erroneously high water flow estimates.

Flow meter/water sampling instrumentation was calibrated by the manufacturer (Leopold & Stevens) for standard prefabricated three-foot Parshall flumes (Fisher & Porter Co., Towson, Md.). At 15-minute intervals, a punch tape recorded the head in feet (Stevens Model 1001), providing a digital record of the height of water on the inlet side (ha) of the flume. Also on the inlet side, a Stevens totalizing flow meter with stripchart recorder (Stevens Model 61R), triggered the sampling pump. (See Figure 3.)

To correct the head and flow meter records for submerged conditions, the outlet or downstream head (hb) was recorded with a Type level

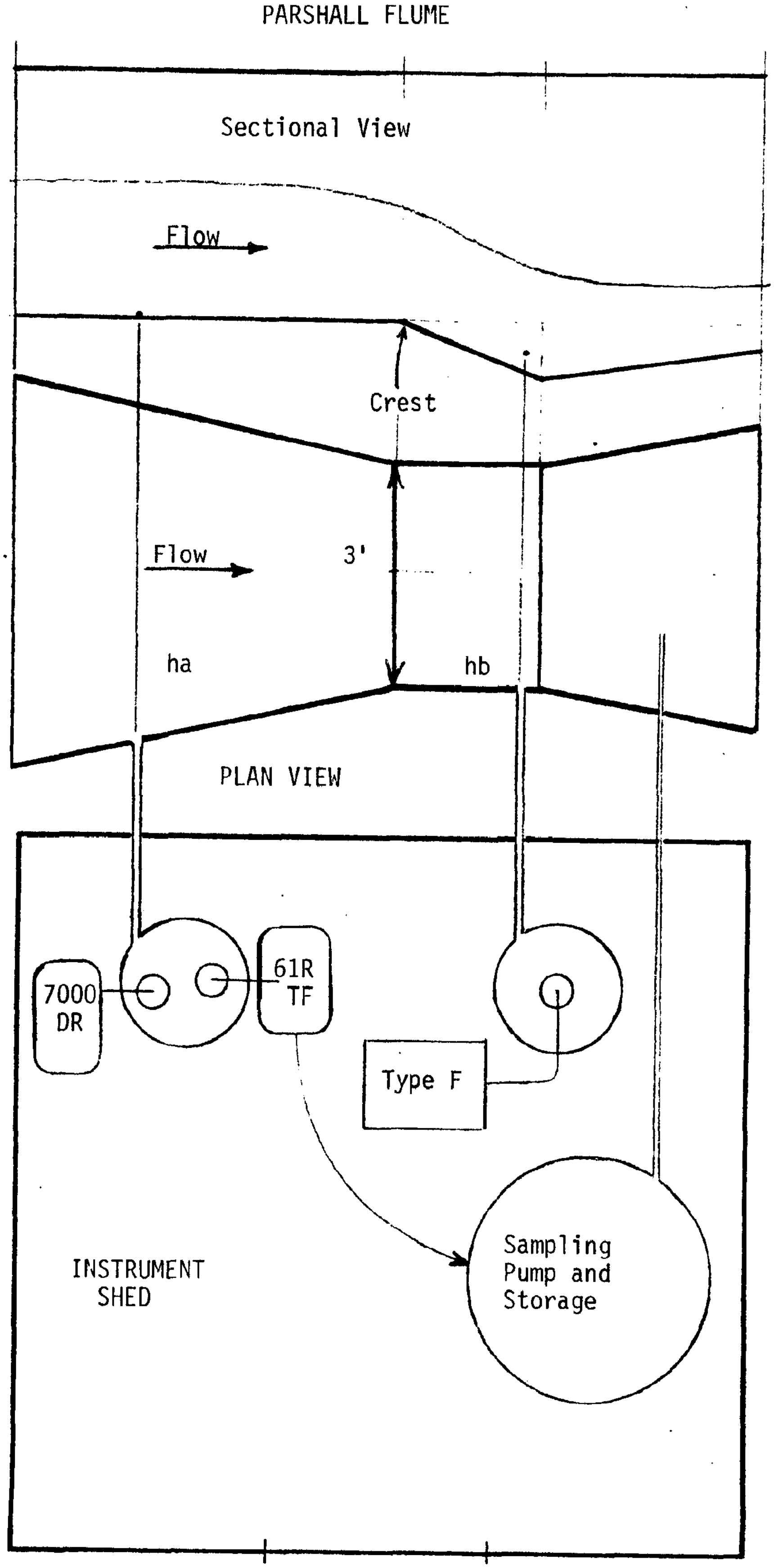

Figure 3: Diagramatic representation of flow measuring and sampling apparatus at the Parshall flumes installed in the HPEL Agricultural and forest watersheds. 7000 DR= Stevens 7000 digital recorder; 61R TF=Stevens 61R totalizing flowmeter; Type F=Type F Stage level recorder.

F-recorder (Leopold & Stevens). If the outlet head was less than 70% of the inlet head, no submergence adjustments of the upstream hydrograph were necessary for determination of flows. For submergence values between 70% and 100%, standard corrections for Parshall flumes were used to obtain the equivalent inlet head without submergence.

The surface water flow records were more complete for the agricultural watershed than for the woods watershed because of instrument failures. Despite the instrument problems encountered during flume flow measurements, sufficient reliable data were obtained to calculate a yearly budget. Base flow rates were often less than critical for this flume size, requiring an estimation calibration of the flow when the head was lower than 3 cm. (There was insufficient variation in base flow to have much effect on the accumulated runoff).

Determination of Groundwater Flows

Groundwater movement was calculated from water table measurements and a detailed sediment mapping from the grid of 290 shallow wells at HPEL. Ten cm (4 in), thin-walled P.V.C. pipes were installed in 10 cm (4 in) hand-augered bore holes. Upon completion of the bore hole, the sediments usually maintained enough integrity for pipe insertion and were sealed with clay around the upper portion of the casing. When encountering saturated sands, the hole walls tended to cave in and normal augering became impossible. In this instance, the P.V.C. casing was pushed down into the sands as far as possible. An 8.3-cm (3¼-in) sand auger was then inserted down the inside of the casing to bail out the sands. In some cases, wells were sunk as deep as 2.9 m (9½ ft) using this method until encountering an underlying tight sedimentary layer. In order to prevent temporarily ponded water from flooding the well, at least 10 cm (4 in) of the P.V.C. pipe was left above the ground surface. In areas of known ponded water extensions were added so that the pipes were above the average ground level by 30 cm (1 ft) or more. Each well top was capped with P.V.C. plugs to exclude precipitation.

The sediment map (Figure 4) was developed for the 1-3 m deep sedimentary horizon from the drilling logs recorded for each groundwater well. Each location was classified into one of the four categories. Shallow sand indicated that a sandy stratum at least 0.3 m (1 ft) thick was found within 1.5 m (5 ft) of the ground surface. When a profile lacked a sandy stratum, but contained layers of sand and silt intermixed, then the location was designated Sand/Silt. The Deep Sand category indicated a sandy stratum starting below 1.5 m (5 ft) and continuing at some places below 3.0 m (10 ft). Grain size was generally larger for deep sands than for shallow sands. When a profile showed uniform silt with no extensive sand it was categorized as Silt.

NUTRIENT CONCENTRATIONS

Triggered by the flow meter instrumentation in the flumes, samples of the flowing water were taken at intervals equivalent to 150,000 liters of discharge. The volume-integrated samples were collected weekly and subsampled for laboratory analysis. Additionally, grab samples of surface water were analyzed for nutrients. Ground water samples were taken from selected wells on a biweekly schedule and analyzed immediately in the laboratory.

The laboratory procedures for nutrient concentration were

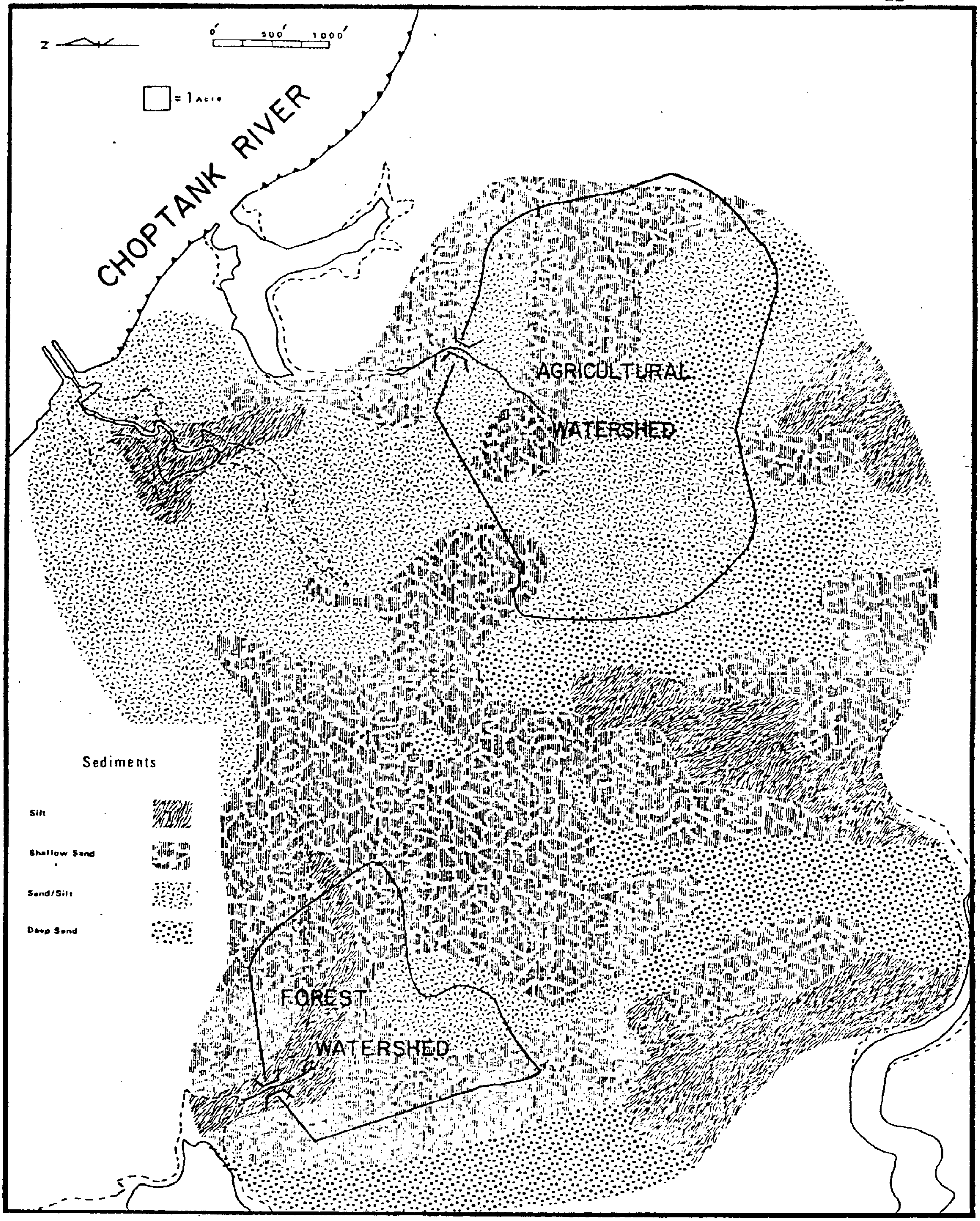

Figure 4. Classification of sediment types below the top horizon at the Horn Point study site.

carried-out as follows. Nitrate and nitrite nitrogen were determined by cadmium reduction of a filtered sample followed by colorimetric measurement of nitrite (APHA, 1975). Nitrite nitrogen was measured on a filtered (pore size = 0.45 micron) sample prior to reduction of the nitrate to nitrite. Ammonia nitrogen was determined colorimetrically by a modified phenol-hypochlorite technique (Strickland and Parsons, 1972). Orthophosphate was determined on a filtered sample by the ascorbic acid method (APHA, 1975). The total phosphate concentration was measured after persulfate digestion of a whole sample by the orthophosphate procedure. Chloride ion concentration was determined by the argentometric method (APHA, 1975).

AGRICULTURAL PRACTICES

During the initial phase of diffuse source pollution research at Horn Point, tenant farming continued without alteration of cultivation practices common to this region. The majority of farmers on the Eastern Shore of the Chesapeake Bay rotate their crops over a two year period. Corn is planted the first spring and harvested in early fall so that small grains (i.e., wheat, barley or millet) can be planted that fall. When the small grains are harvested in early summer, soybeans are planted in the stubble without plowing using a contact herbicide to control weed populations. After soybeans are harvested in late fall, the land is not usually cultivated again until the following spring when corn is again planted. Fertilizers are applied at various times of the year depending on which crops are being planted.

Figure 5 shows that of the 86 total hectares in the agricultural watershed, 54 hectares are cropland with predominant coverage in soybeans

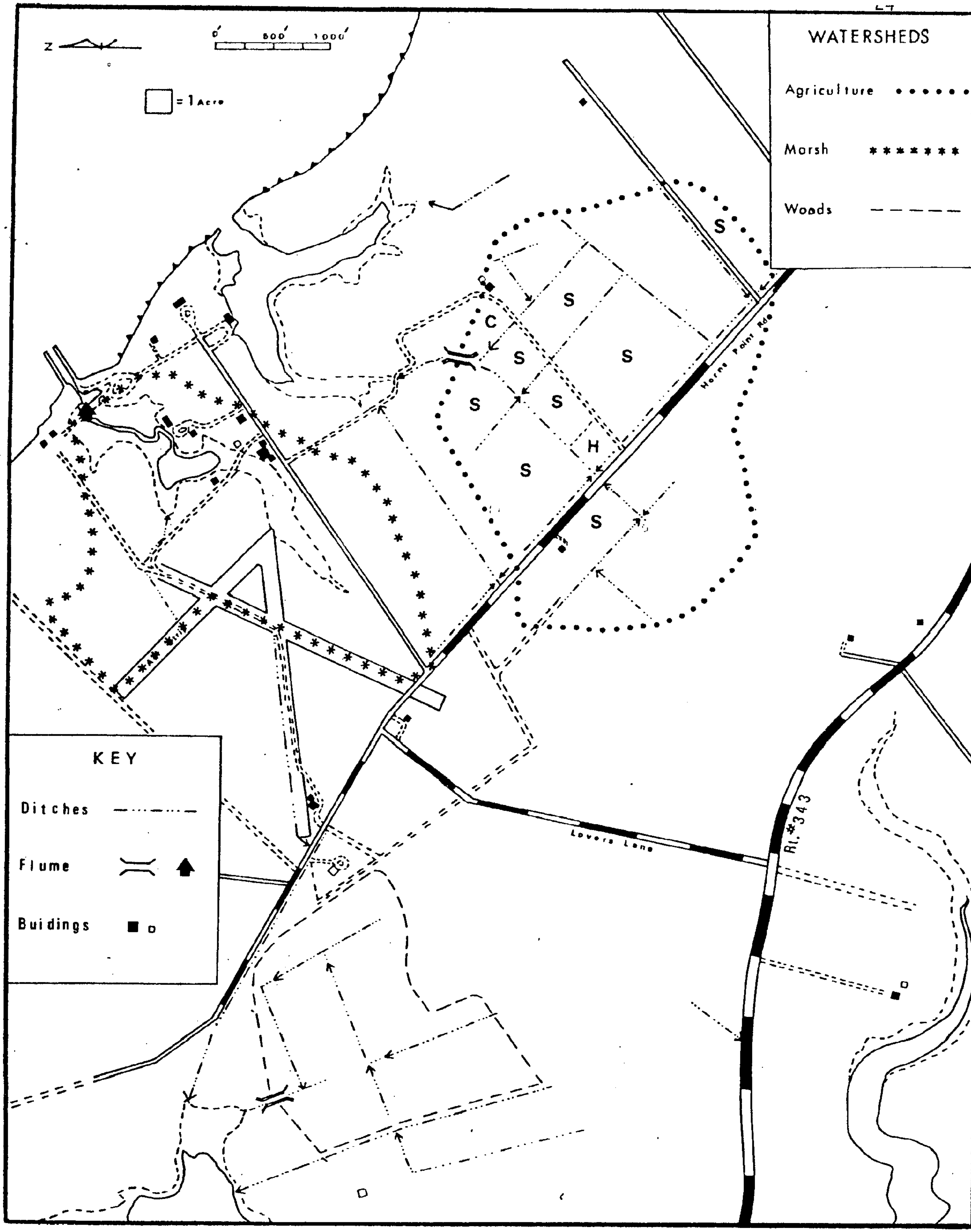

Figure 5. Map of HPEL study site showing man made features and crop locations in agricultural watershed. Crop symbols 1979: C = corn, S = soybeans, H = hay.

during 1979. Soybeans were planted in 37 ha, corn in 7 ha, and hay in 10 ha. In general, the farming operations at HPEL are standard agricultural practices recommended by the Cooperative Extension Service for heavy soils in low lying areas on the Eastern Shore.

The corn was fertilized at planting using 357 kg/ha (400 lbs/acre) of 5-20-30 (N:P:K). This rate is equivalent to 18 kg N/ha nitrogen (20 lbs/acre) and 71 kg P/ha phosphorus (80 lbs/acre). At about eight weeks, the corn was booster-fertilized with anhydrous ammonia at 135 kg N/ha (120 lbs/acre). The soybeans received much less nitrogen of 268 kg/ha (300 lbs/acre) of 5-20-30 at planting. The portion of watershed planted in soybeans had an equivalent of 13 kg N/ha nitrogen (15 lbs/acre) and 54 kg P/ha phosphorus (60 lbs/acre). The red clover hay crop was fertilized with an application of 268 kg/ha (300 lbs/acre) of 10-20-20 at planting. Of the remaining 32 ha, in the agricultural watershed, approximately 25 ha were forested with the remaining 7 in miscellaneous categories such as grass and roads.

RESULTS

Precipitation records (Table 6) indicate that the non-point source studies at Horn Point were begun in the relatively dry year of 1976 and continued until the relatively wet year of 1979. When precipitation is corrected for evaporative losses from the soil surface to obtain an indication of soil moisture charge and discharge patterns, both 1976 and 1977 are obviously years in which no net recharge occurred (Table 7). The resulting low water tables were monitored using the well system in the latter part of 1976. Recharge occurred in 1978 (29 cm) and 1979 (71 cm) because of increased precipitation which also produced ample runoff events.

High intensity, high volume precipitation events provide overland flow or quick flow. Those storms which exceeded 1.8 cm (.70 inches) during 1979 are listed in Table 8. This storm size was selected to show the temporal variation in rainfall events which would most likely provide overland flow. Some of these storms provided so little quickflow that the gradual rise and fall of the hydrograph did not show any overland flow period. The soil moisture indication on Table 8 was obtained in relative terms from the water table depth and the time since the previous rain.

Surface water discharge on a monthly basis was calculated from flume head measurements. Both the upstream and downstream heads were used to calculate the flow rate of water leaving the watershed for each storm. A sample analysis and hydrograph is shown in Appendix A. During all of calendar year of 1979, there was surface discharge continuously from the agricultural watershed. Taking into account

TABLE 6. Monthly precipitation at Horn Point Environmental Laboratory (HPEL) in centimeters

DATE				YEAR			
MONTH	1973	1974	1975	1976	1977	1978	1979
January	-	7.3	13.4	11.8	5.9	19.3	15.6
February	-	4.3	6.1	2.9	2.3	3.1	18.2
March	-	13.0	12.1	6.4	4.7	18.7	8.5
April	-	3.6	9.9	0.7	5.6	8.9	8.4
May	-	15.9	10.4	7.7	10.5	14.5	9.9
June	-	10.0	17.7	1.5	9.1	7.9	8.4
July	-	2.4	17.5	9.1	4.6	16.6	19.4
August	-	17.9	9.6	3.9	10.1	13.2	23.4
September	-	7.3	19.9	8.4	9.3	1.3	17.4
October	-	1.9	8.4	16.1	9.5	2.9	11.7
November	4.7	3.1	7.4	3.5	10.4	7.2	10.2
December	10.5	12.5	10.2	6.9	15.5	9.8	4.8
Yearly Totals	-	99.0	142.44	79.0	97.6	123.5	155.9

Table 7. Pan-evaporation data at Horn Point Environmental Laboratory (HPEL) cm per month.

MONTH	1975	1976	1977	1978	1979
March		∿0	6.2	1.3	3.6
April		12.3	11.2	10.5	8.4
May	13.7	12.5	12.9	10.5	12.6
June	14.8	15.9	14.2	15.2	13.2
July	12.3	15.9	16.5	14.9	13.4
August	15.7	14.9	15.1	14.4	13.3
September	7.7	10.2	10.9	10.5	8.9
October	6.4	6.3	7.0	8.8	7.2
November	5.3	4.5	4.6	6.3	4.3
December	1.6	∿0	∿0	2.2	∿0
Yearly Totals	77.6	92.5	98.8	94.5	84.9
net charge[a] discharge	+23.0	-13.5	- 1.2	+29.0	+71

[a]Total Precipitation (Table 6) minus pan-evaporation.

Plus (+) indicates net charge and minus (-) indicates net discharge.

TABLE 8. Storm event data at Horn Point Environmental Laboratory from August 1978 through August 1979

DATE	Precipitation (cm)	Total Duration (Hours)	Prestorm Soil Condition
8/2/78	2.1	2.5	Wet
8/3	1.8	2	Wet
8/5-6	1.9	18	Wet
8/31	4.9	10	Dry
11/26-27	2.4	15	Dry
12/4-5	2.7	9	Wet
12/9	1.9	12	Wet
1/1-3/79	4.4	-	Dry
1/20-22	5.1	-	Frozen
1/24	2.8	-	Wet
2/18-19	4.6	10	Frozen
2/24-26	10.7	32	Wet
3/5-6	3.5	36	Wet
3/11	1.8	9	Wet
3/24	2.3	6	Dry
4/3-4	2.6	48	Dry
4/26-27	3.2	-	Dry
5/25	4.5	-	Wet
6/4	2.5	-	Wet
6/11	4.6	-	Wet
7/1-2	5.8	-	Wet
7/21	2.6	-	Dry
7/24	2.7	-	Wet
7/29-30	6.9	-	Saturated
8/3	4.5	-	Saturated
8/12	4.6	-	Wet
8/21	2.9	-	Wet
8/28	2.9	-	Saturated
8/29	4.6	-	Saturated

the area of the watershed, the surface discharge is presented in Table 9 with units of centimeters allowing for direct comparison with precipitation data.

One of the largest runoff events in the last 30 to 40 years occurred in February 1979 when a relatively large snowfall, equivalent to 4.5 cm precipitation, was followed closely by heavy rain on frozen ground. This event caused sufficient surface water flow to cause the depth of water at the agricultural flume to exceed the height of the flume (1 meter). That storm sequence was of such a magnitude that it destroyed many small bridges, dams and other structures on small creeks on the eastern shore. From the flume discharge measurements, it was calculated that most of the snow and rain were discharged in the relatively short time of three days. As a result of the soil conditions and the rapid rate of rainfall, the runoff for the month of February is approximately two-thirds of the total precipitation. This event produced the largest percentage of runoff any month on record at Horn Point. The remaining one-third of February's precipitation which was not measured as surface water runoff was lost to the atmosphere (evaporation or sublimation) or lost to the soil and sediment for storage or deep recharge.

The twelve months shown in Table 9 are not from the same year but are from three calendar years. To achieve accurate nitrogen and phosphorus discharge values, the months having reliable nutrient concentration data were combined into an idealized model year. Although the idealized model year is composed of non-sequential months, the total precipitation is very close to the expected precipitation for calendar year 1979. The alternative to this

Table 9. Monthly surface water discharge of nitrogen and phosphorous from agricultural watershed, HPEL.

Month	Precip. cm	Runoff cm	Nitrate & Nitrite Nitrogen mgN/ℓ	Nitrate & Nitrite Nitrogen Kg/ha	Total Phosphate μgP/ℓ	Total Phosphate g /ha
Jan. 79	15.6	10.3	2.0	2.0	240	250
Feb. 79	18.2	12.2	1.0	1.2	130	160
Mar. 79	8.5	3.2	1.1	0.4	100	32
Apr. 79	8.4	3.8	1.2	0.4	150	57
May 79	9.6	3.1	5.0	1.5	50	15
Jun. 79	8.4	2.5	0.7	0.2	160	40
Jul. 79	19.4	7.7	0.7	0.5	60	46
Aug. 79	23.4	7.8	0.6	0.5	100	78
Sep. 76	8.4	1.4	0.2	0.0	200	28
Oct. 76	16.1	4.9	0.3	0.1	60	29
Nov. 77	10.4	3.6	0.3	0.1	170	61
Dec. 77	15.5	5.8	0.3	0.2	260	150
TOTAL	161.9	66.3		7.1		946
				7.1 Kg N/ha/yr		1 Kg P/ha/yr

approach would be to have only nutrient concentrations without runoff or vice versa.

The hydrology of the woods watershed is markedly different from that of the agricultural watershed. Presentation of surface water runoff in length units, that is centimeters, allows for direct comparison of the watershed hydrology, even though the area of the woods watershed is much smaller than that of the agricultural watershed. As shown in Table 10, runoff in February 1979 at the woods flume was almost the same as that from the agricultural flume. Throughout the winter months the runoff from the two watersheds is similar, but the annual total is quite different. The woods watershed would be expected to have a lower percentage of precipitation appear as runoff because of the increased evapotranspiration rates associated with the forest canopy which would increase water loss compared to the agricultural watershed.

The movement of nutrients from the forested and agricultural watersheds to the estuary are presented in Tables 9 and 10. Using these concentrations of N and P presented in Tables 11 and 12 and the runoff measurements, the flux of nitrogen and phosphorus were calculated. Nitrogen discharge from the agricultural watershed in May 1979 appears to reflect the application of fertilizer. The January 1979 discharge is not as easily explained, but probably reflects both reduced winter assimilation of nitrate by vegetation and denitrification as well. Marbury and Stevenson (1980) suggest that ice reduces denitrification substantially during the winter at Horn Point Marsh. Therefore, more nitrate is available for runoff during cold winter months than in warmer months.

Table 10. Monthly surface water discharge of nitrogen and phosphorous from woods watershed, HPEL.

Month	Precip. cm	Runoff cm	Nitrate & Nitrite Nitrogen µg N/ℓ	Nitrate & Nitrite Nitrogen g/ha	Total Phosphate µg P/ℓ	Total Phosphate g/ha
Jan. 79	15.6	9.1	50	45	70	64
Feb. 79	18.2	11.8	50	59	20	24
Mar. 79	8.5	3.1	60	19	90	28
Apr. 79	8.4	1.9	0	0	80	15
May 77	10.5	0.2	100	2	40	1
Jun. 79	8.4	0.5	20	1	100	5
Jul. 79	19.4	2.1	40	8	80	17
Aug. 79	23.4	1.9	10	2	150	28
Sep. 79	8.4	0.4	20	1	100	4
Oct. 76	16.1	2.3	0	0	140	32
Nov. 78	7.2	1.8	90	16	30	5
Dec. 77	15.5	4.8	10	5	40	19
TOTAL	159.2	39.9		158		242
				.16 Kg N/ha/yr		.24 Kg P/ha/yr

Table 11. Concentration values for agricultural watershed, HPEL.

Date	Nitrate N µg/ℓ	Nitrite N µg/ℓ	Ammonia N µg/ℓ	Ortho Phosphate P µg/ℓ	Total Phosphate P µg/ℓ	Chloride mg/ℓ	Total Particulate Matter µg/ℓ	BOD mg/ℓ	Total Dissolved Solids mg/ℓ
04-10-78	136	0		5	25	18			
05-16-78							130		1062
07-08-78	136			260	360		38		
07-31-78				60	120		16		
08-07-78	132			265	400		5		
08-14-78				30	50		12		
09-01-78							38		
11-27-78		1		280	334	4,700			
11-27-78	91	1	460	65	80	4,000			
12-04-78 (11 am)		13		0	12	117			
12-04-78 (2 pm)		8		8	30	94			
12-05-78 (10 am)		2	>1,000	165	260	13			
01-02-79	2,000	19	3,000	175	210	6	246		124
01-08-79		21	3,000	115	200	11	177	8	230
01-21-79		46	1,640	232	295	8	200		165
01-22-79	2,050	28	>2,000	165	265	13	190	5	257
02-25-79	912	3		106	163	1			
02-26-79	1,000	5	360	135	54	1	61	4	49
02-27-79	800	10	710	145	200	4	212	5	392
03-06-79	1,100	20	1,540	185	90	8	235	8	183
Peak Flow 04-04-79	700	6		102	42	10	90		166
End Flow 04-05-79	1,200	16		100	200	17	30		178
05-14-79	5,766	3		0	43	50			
05-23-79 Baseline	7,808	1		0	51	41			
05-31-79	587	5		18	56	12			
06-01-79	570	7	140	47	140	14	26		207
06-04-79	510	7		62	134	10	161	2	203
06-11-79	1,145	6	186	16	203	6	1,090	6	134
07-30-79	685	6		29	62	12	68		174
08-13-79	656	3		30	100	9	27	2	195

Table 12. Concentration of selected components for woods watershed, HPEL.

Date	Nitrate N µg/ℓ	Nitrite N µg/ℓ	Ammonia N µg/ℓ	Ortho Phosphate P µg/ℓ	Total Phosphate P µg/ℓ	Chloride mg/ℓ	Total Particulate Matter µg/ℓ	BOD mg/ℓ	Total Dissolved Solids mg/ℓ
04-10-78	16	3	-	10	40	3			
05-16-78							130		
07-08-78	4			20	80		22		
07-31-78				20	90		16		
08-07-78	32			20	90		12		
08-14-78	20			45	160		49		
09-01-78							44		
11-27-78		2		50	94				
11-27-78*	90	1	690	30	18	4,750			
12-04-78 (11 am)	56	9		80	94	3,500			
12-04-78 (2 pm)		1		57	64	3,000			
12-05-78	7	4		45	68	91			
01-02-79		6	2,780	40	70	16	0		214
01-08-79	55	3	3,780	10	35	9	17	5	125
01-22-79	40	16	72,000	5	75	2		2	89
02-27-79	48	4	1,280	10	22	2	63	5	0
03-06-79	58		3,080	9	90	4	9	4	90
04-05-79	6	0		25	84	4	10		130
06-01-79	24	6	28	Interference	12	2	2		139
06-04-79	17	5		Interference	120	2	11	1	145
06-11-79	1	0	245	67	89	2	21	5	41
07-30-79	38	7		30	78	8	0		108
08-13-79	10	4		51	150	0	32	1	166

*Composite

According to calculations and measurements for the agricultural watershed, the runoff at the flume accounted for approximately 42 percent of the precipitation for one year. This percentage value is higher than might have been expected and can possibly be explained by subsurface water movement to the drainage ditch. Characteristics of groundwater movement have been approached in three ways. First, through the use of two transects of groundwater wells; secondly, from data collected on a closely spaced grid of wells; and third, from the entire network of groundwater wells on the HPEL site.

Two transects on the study site were selected for more intense observation and sampling. These two transects both originate near the estuary and cross the higher ground toward the next potential groundwater outlet with the intention that the transect will cross the groundwater divide. Variations in water table elevation in the two transects have not been useful in describing groundwater divide or peak from which the water would move one way or the other. The variation in water table along the transect indicates that the water table divide moves without simple explanation. If this variation could be accounted for, it would require a three dimensional analysis (see Christy, 1980). The elevations have, however, shown that during parts of the year the groundwater is moving in one direction, toward and under the woods, and in the other part of the year it is moving toward the estuary.

Groundwater elevations for the entire study site have not been analyzed sufficiently to include a picture of these data. Some significant findings, however, can be mentioned. The groundwater regime is not at all uniform on the study site. There are more valleys and ridges than might be expected for the relatively flat landscape. It has also been observed that the groundwater does not necessarily follow the surface watershed in extent and direction (Christy, 1980). However, Figure 6 shows two transects which give a reasonably accurate representation of the spatial patterns in groundwater quality.

The most interesting data collected from the transects are presented in Table 13. These mean values for all available data indicate that throughout the year there is a difference between various parts of the landscape. Perhaps the most striking constituent is the nitrate nitrogen. Figure 7 shows the variation in nitrate nitrogen with time at the two wells close to the estuary. Figures 8 and 9 show the nitrogen concentrations as a function of the transect distance. It is rather obvious from these figures that the nitrate nitrogen is higher close to the estuary. This observed phenomenon has several possible explanations (elaborated in the discussion). Other constituents such as chloride do not have an obvious relationship to physical location. Neither lateral distance, depth, nor their interaction, correlate with the chloride concentrations. One untested hypothesis is that chloride concentration relates to sediment "cracks", which would provide increased hydraulic conductivity.

The intense groundwater elevation experiment during the spring and summer of 1979 shows how the groundwater moves toward the wooded area at a rate seemingly related to evapotransporation. As shown in Figures 10 and 11 the slope on the groundwater is flatter in March than it is in July. In July the groundwater slope approaches one

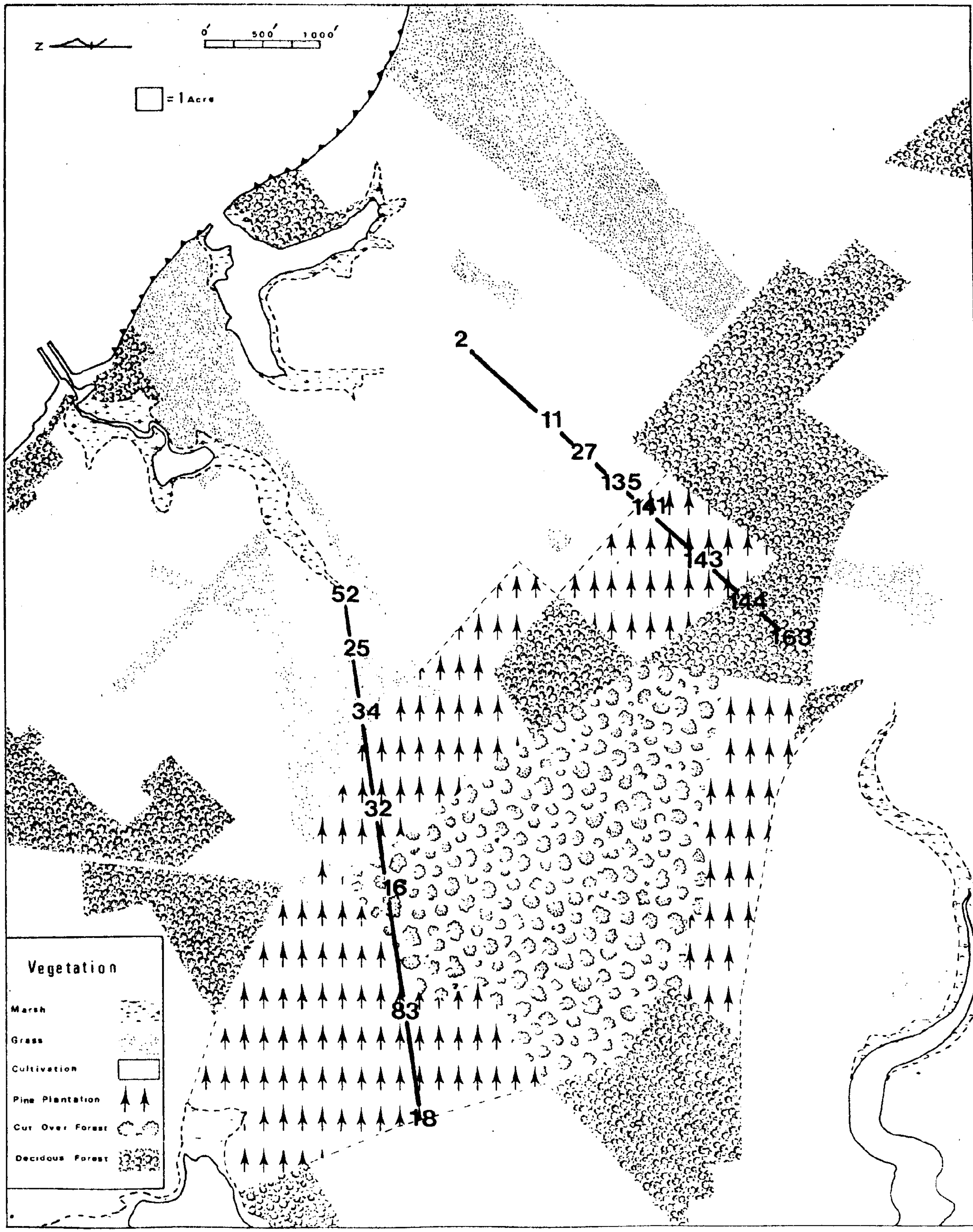

Figure 6. Location of well transects used for groundwater nutrient study. Wells A-2 through W-163 are the east transect. Wells M-52 through W-18 are the west transect.

Table 13. Summary of nutrient concentrations in two well transects at HPEL, 1978-1979. (Values are means for all available data.)

	Nitrate +Nitrite µgN/ℓ	Nitrite µgN/ℓ	Ammonia µgN/ℓ	Ortho Phosphate µgP/ℓ	Total Phosphate µgP/ℓ	Chloride mgcl/ℓ	Depth m
A-2	4,000	4	130	7	33	50	3.04
A-11	700	5	1140	27	51	45	2.43
A-27	55	6	690	3	30	100	1.77
M-25	800	4	150	20	57	15	3.04
M-34	75	3	800	8	44	20	2.90
M-52	1,600	2	180	17	38	25	1.22
W-16	120	7	1010	11	20	140	3.04
W-18	205	7	320	39	125	535	4.27
W-32	120	4	210	27	63	350	3.04
W-83	340	9	640	62	142	50	1.52
W-84	270	-	-	-	30	90	2.90
W-135	120	4	970	2	22	15	2.90
W-141	35	1	1470	4	27	35	2.90
W-143	90	3	740	4	24	30	2.90
W-144	40	3	310	6	33	50	2.90
W-163	20	10	480	7	32		2.90

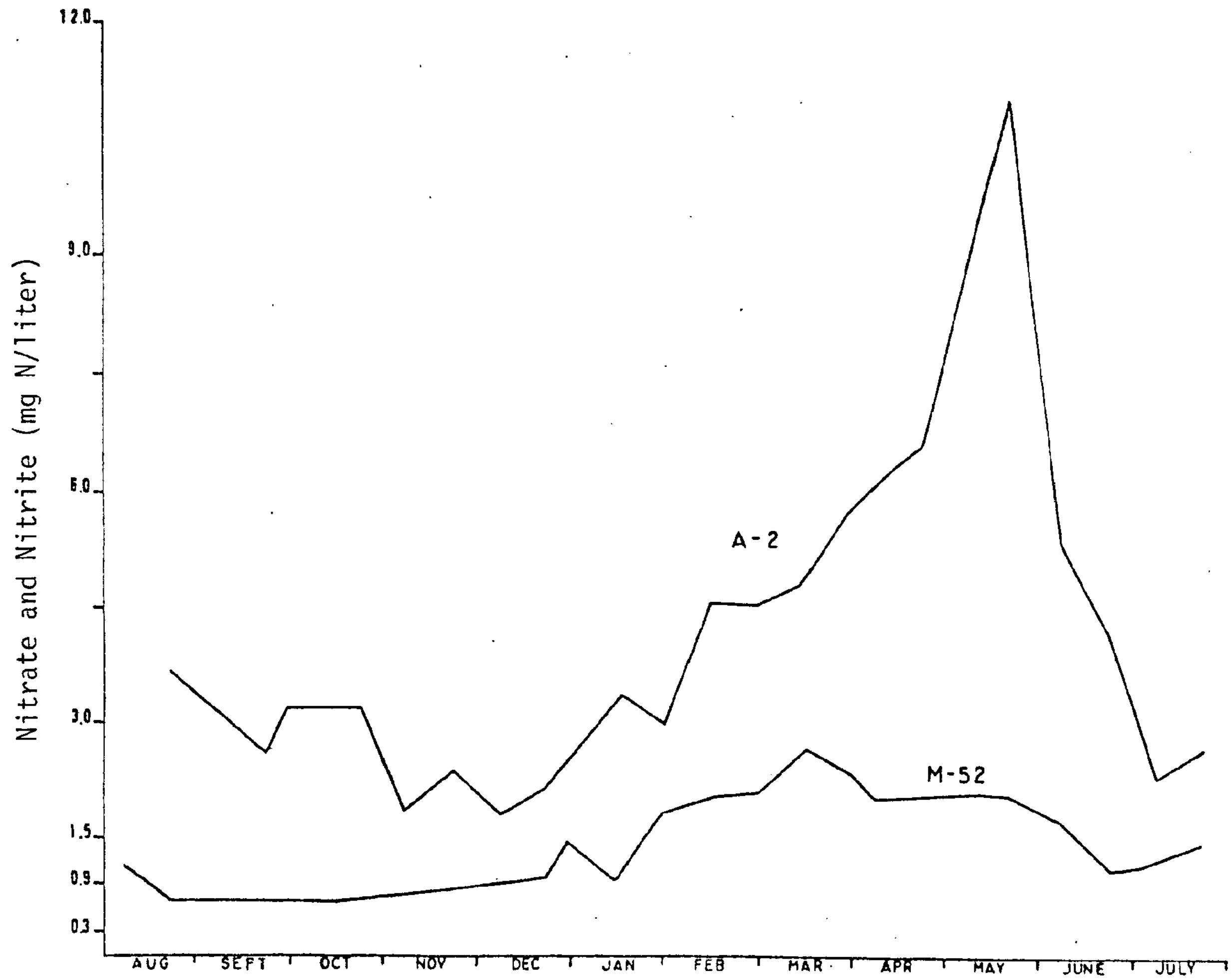

Figure 7. Time variation in nitrogen concentration at the two wells nearest the estuary at the end of each transect, HPEL, 1978-1979.

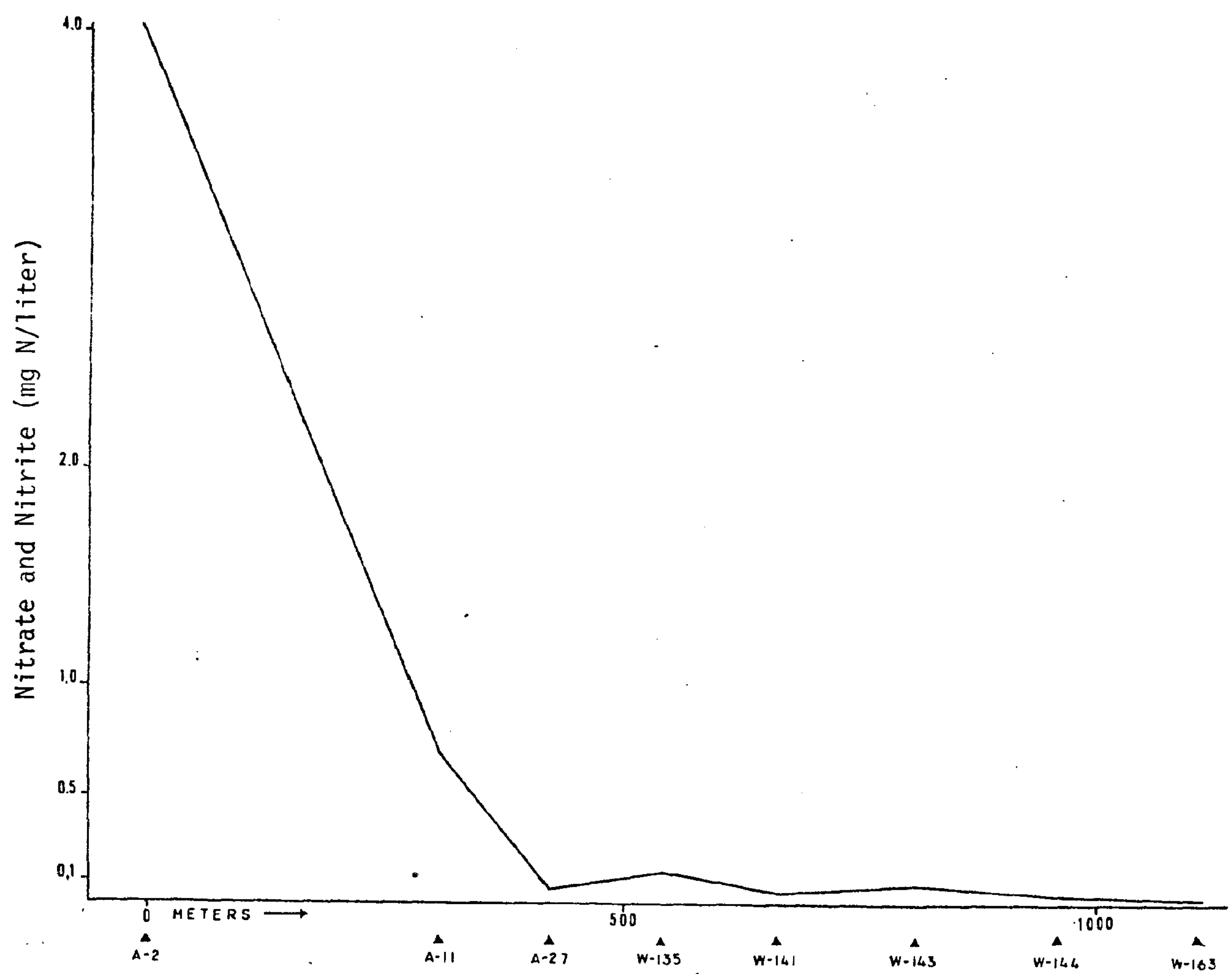

Figure 8. Nitrogen concentrations in groundwater along east transect, HPEL, mean values for 1978-1979.

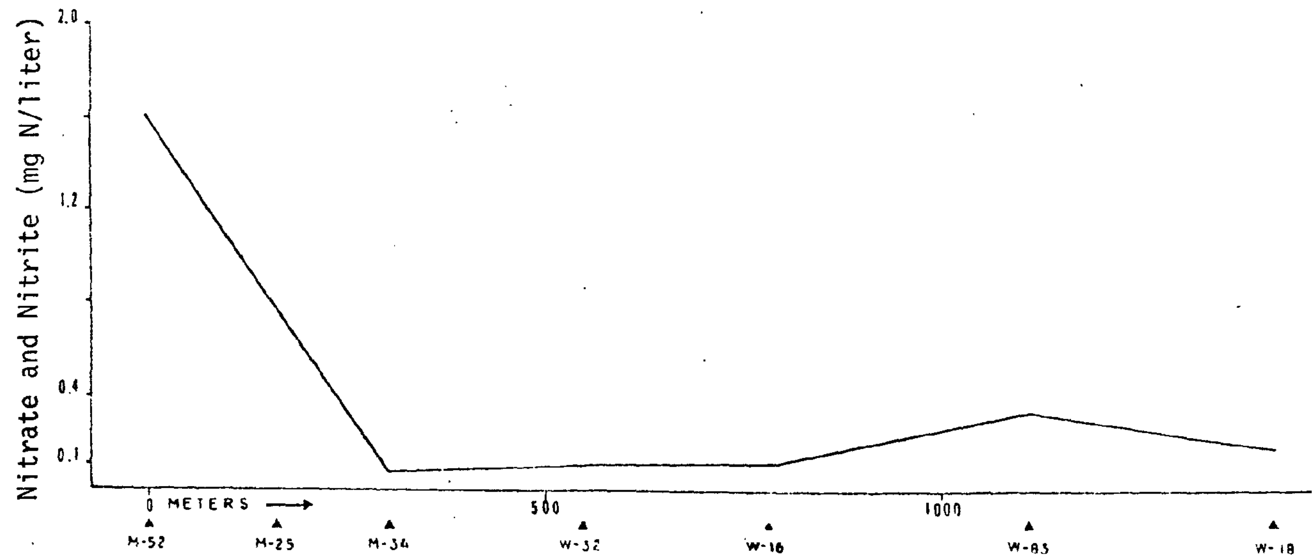

Figure 9. Nitrogen concentrations in groundwater along west transect, HPEL, mean values for 1978-1979.

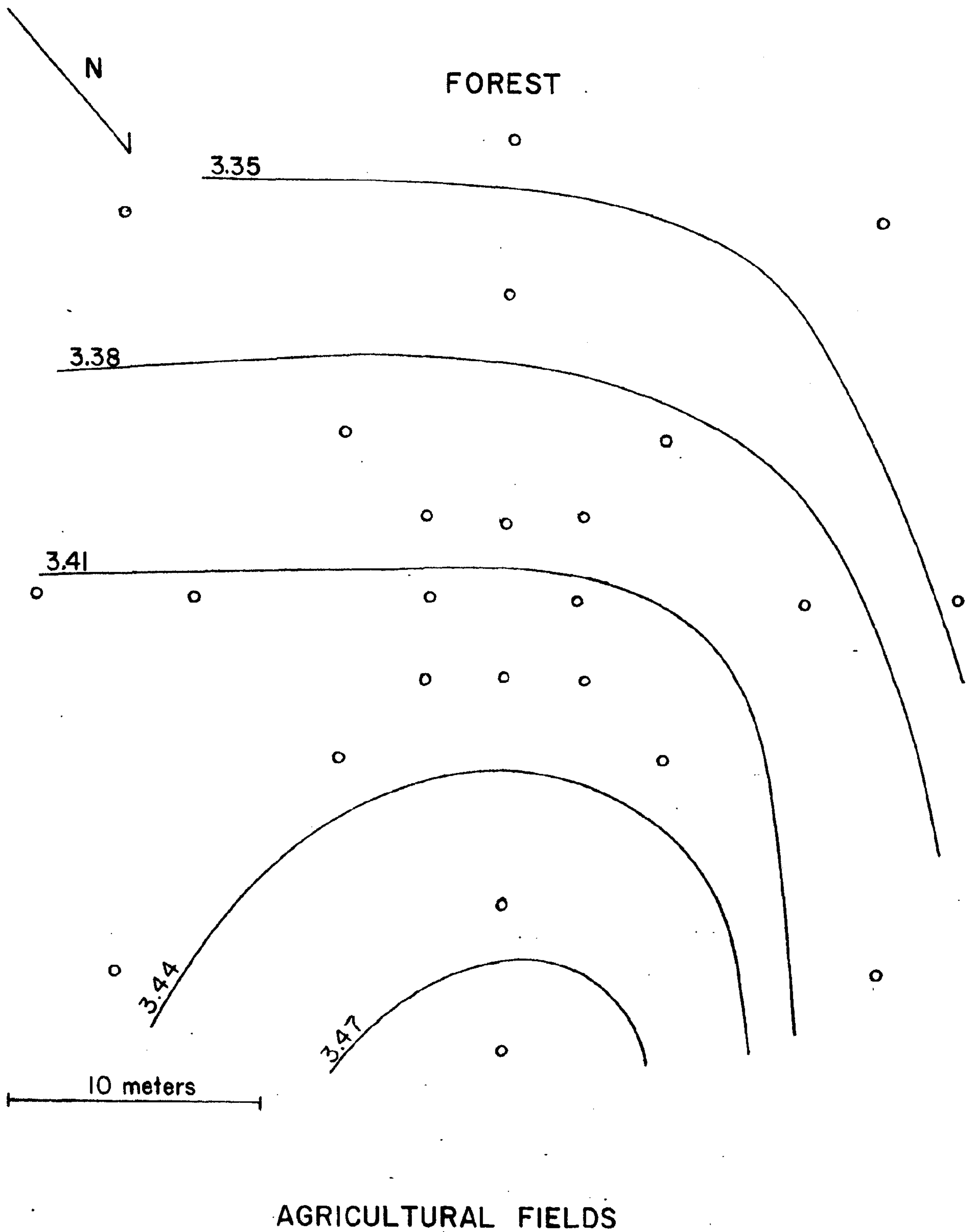

Figure 10. Water table contour lines showing slope of groundwater towards the woods. Circles represent well locations. HPEL, March 6, 1979 (meters above sea level).

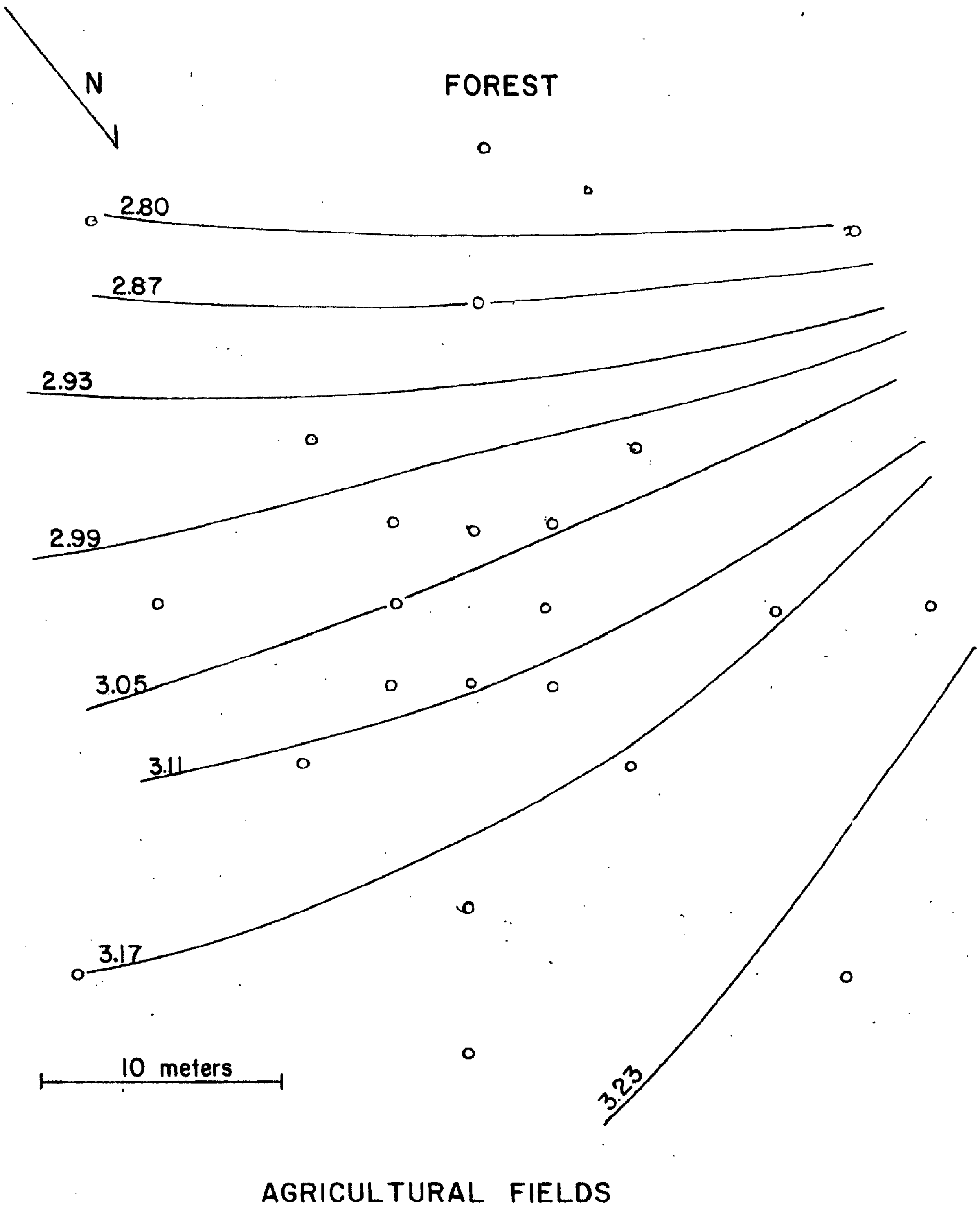

Figure 11. Water table contour lines showing slope of groundwater towards the woods. Circles represent well locations. HPEL, July 25, 1979 (meters above sea level).

percent which is significantly different from zero and significantly different from the flat ground surface at the point where these wells were installed. This intense groundwater elevation study substantiates the hypothesis that the groundwater flows away from the estuary even during part of a wet year!

Using the intense grid groundwater slope and the surface watershed runoff totals, there is an indication that groundwater is not moving to the estuary at a significant flow rate. From a crude water budget, the precipitation of 162 cm is accounted for by 66 cm of runoff in the agriculture watershed and approximately 90 cm of pan evaporation. The sum of runoff (66) and evaporation (90) is 156 cm, which is only 6 cm less than the total precipation. It had been expected that the subsurface lateral movement of water would be a larger percentage of the water budget than the 6 cm implied in this calculation. The small lateral movement is somewhat substantiated by the intense grid values of water table slope. Using the July, 1979 contour lines (Figure 11), it can be calculated from slope, conductivity, permeable depth and area, that the lateral flow in July accounts for about one centimeter of precipitation. It is hypothesized that some groundwater is reaching the drainage ditches and appearing at the flume to be measured as surface water. From this hypothesis it is suggested that subsurface groundwater movement as a pathway for pollutants to reach the estuary may not be as important as previously anticipated. The relatively deep drainage ditches appear to be the main mode of transport for nitrogen and phosphorus to the Bay ecosystem in this low flat coastal plain area.

DISCUSSION

Surface Export

A substantial number of diffuse source studies have now been completed on various land use types which can be used for comparison with the Horn Point watersheds. Table 14 reviews several studies where a variety of basins have been investigated along with contrasting types of development (e.g., suburban, shopping centers, urban). Kauppi (1979) found very high correlations of percent cultivation in a series of small basins with the amount of phosphorus and nitrogen export in each. In totally forested basins he calculated .04 kg $ha^{-1}yr^{-1}$ P and 1.3 kg $ha^{-1}yr^{-1}$ N export. In contrast, in basins under 70% cultivation, P was 0.34 kg $ha^{-1}yr^{-1}$ and N was 7.4 kg $ha^{-1}yr^{-1}$. Kauppi also concluded that drainage density and distance of fields from streams in the basin determined their relative influence on export. The greater the distance of fields from feeder streams, the less culitvation seemed to affect water quality.

At Horn Point, our agricultural areas are immediately adjacent to the drainage ditches where flux measurements are made. This lack of buffering around the drainage ditches is one of the major reasons why the agricultural watershed at Horn Point has a higher value of P (1 kg $ha^{-1}yr^{-1}$) and N export (7.1 kg NO_3+NO_2 $ha^{-1}yr^{-1}$) than the average for the eleven watersheds at Rhode River studied by Correll et al. (1977).

We estimate that unmeasured nitrogen fractions (NH_4, dissolved organic nitrogen) are approximately 50% of the NO_3+NO_2 export at the

TABLE 14. Dissolved export rates (kg $ha^{-1}yr^{-1}$) from basins with varying degrees of development

LAND USE	AREA	TOTAL PHOSPHORUS	TOTAL NITROGEN	N:P RATIO	REFERENCE
70% cultiv.	Loytaneenoja Basin, Finland	.34	7.4	22	Kauppi, 1979
13% cultiv.	Kuokkalanoja Basin, Finland	.15	4.6	30	Kauppi, 1979
0% cultiv.	Vaha-Askanjoki Basin, Finland	.04	1.3	33	Kauppi, 1979
10c,38f,18o,17p,6r*	N.Br. Muddy Cr. Rhode R., Md.	1.4	4.0	3	Correll et al., 1977
17c,31f,49o,2p,11r	N.Br. Sellman Cr. Rhode R., Md.	.6	2.4	4	Correll et al., 1977
28c,45f,5o,21p,1r	S.Br. Sellman Cr. Rhode R., Md.	1.9	8.6	5	Correll et al., 1977
16c,46f,12o,10p,11r	Mean Rhode R. Watersleds, Md.	.9	3.8	4	Correll et al., 1977
Single Fam. Suburb.	Florida	0.2	1.5	8	Mattraw and Sherwood, 1977
Shopping Center		2.1	30.2	14	Hartigan et al., 1978
General Urban	Gt. Lakes	0.3-2.1	6.2-10.0	5-20	PLUARG 1978
Developing Urban	Gt. Lakes	23.0	63.0	3	PLUARG 1978
Presettlement forest	Lake George, New York	.04	1.2	30	Watson et al., 1979
Post settlement (96% forest)	Lake George, New York	.08	1.6	20	Watson et al., 1979
Presettlement forest	Lake Wingra, Wisconsin	.35	10.5	30	Watson et al., 1979
Post settlement (75% urban)	Lake Wingra, Wisconsin	.61	10.6	17	Watson et al., 1979

*c=% crops; f=% forest; O=% old fields; p=% pasture; r% residential

Horn Point agricultural watershed. Thus the total dissolved N export would be on the order of 10 kg $ha^{-1}yr^{-1}$. This is also higher than any of the watersheds on the western shore studied by Correll et al. (1977) at Rhode River (see Table 14). This figure is in close agreement with the nitrogen exports reported on Lake Wingra and Lake George by Watson et al. (1979), but is lower than figures for most developed urban and suburban areas reported from similar flat terrain around the Great Lakes and Florida (Table 14). The differences between loadings reported at Rhode River and Horn Point watersheds can be partially attributed to the increased amount of land under cultivation in our agricultural watershed than reported by Correll et al. (1977).

A detailed analysis of the inputs and outputs from the agricultural watershed is presented in Table 15. Since soybeans comprised the largest crop cover, the input of nitrogen fertilizer was only 1.5 metric tons (M.T.), a small amount compared with what it would have been if corn was planted in a percentage more reflective of the equal mix of soybeans and corn normally planted in the Choptank basin. Although nitrogen fixation associated especially with the legumes (soybeans and clover) was in the range 3.5 - 7.8 M.T., most of this fixed nitrogen goes directly into organic matter and is not immediately available in the runoff. Therefore the nitrogen flux (0.9 M.T.) we report is lower than expected in years when corn is planted in the watershed. Present studies where corn is the only crop appear to confirm that the flumes had higher nitrogen concentrations (Fisher pers. com.).

Another factor which may have diminished the potential export of nitrate is the relatively wet spring of 1979. Alternating wet and dry conditions increase denitrification rates in agricultural fields (Nielsen and Macdonald 1978). In many areas of the eastern shore, obvious nitrogen deficiencies were apparent on corn grown in the wetter fields in 1979. Therefore, because the high proportion of soybeans in the watershed in this year plus atmospheric losses, we suspect 10 kg $ha^{-1}yr^{-1}$ N export to be a somewhat conservaive estimate for agricultural lands of the Choptank Basin. For comparison in Delaware, Ritter et al. (1979) found that Blackwater Cr. watershed (57% cropland) exported 20.6 kg N $ha^{-1}yr^{-1}$, while Stockley Branch (45% cropland) exported 18.2 kg N $ha^{-1}yr^{-1}$, in 1976 and 1977. Also they report higher areas phosphorus (.58 kg $ha^{-1}yr^{-1}$) from their watersheds during the same time period.

Table 15 shows that twice as much phosphorus (3.0 M.T.) than nitrogen was applied to the agricultural watershed in 1979. However only a tenth of that moves in the soluble phosphorus fractions that we measured. We assume that a substantial amount of phosphorus moves with the particulate fraction. Table 16 shows that the forested watershed has a hundred times less phosphorus inputs -- all as precipitation and only a fourth of input is exported in the dissolved fraction of the runoff. The net difference may be taken up by the forest or exported in the particulate fraction.

The nitrogen budget for the forested watershed (Table 16) is very unbalanced with a very small fraction of the nitrogen being exported. Our runoff rate is not quite as low as Bedient et al. (1978) reported (Table 17) but is much lower than Borman et al. (1977) found at Hubbard Brook (4.0 kg N $ha^{-1}yr^{-1}$). The latter

TABLE 15. Mass balance calculation of inputs and outputs of nitrogen and phosphorus in the Horn Point agricultural watershed during 1979.

ha.	Parameter	kgN/ha	kgP/ha	kgN	kgP
	INPUTS				
	Fertilizers:				
37	Soybeans (268 kg/ha 5-20-30)	13.4	53.6	496	1983
7	Corn (357 kg/ha 5-20-30)+	17.9	71.4	125	500
	(107 kg/ha Anhydrous Ammonia-82%N)	87.7	—	614	—
10	Red Clover (268 kg/ha 10-20-20)	26.8	53.6	268	536
				1503	3019
	N-Fixation:				
37	Soybeans[a]	55-140		2035-5180	
39	Corn and Other[b]	.4-3.		16-117	
10	Red Clover[c]	140-250		1400-2500	
				3451-7797	
86	Precipitation[d]	10.5	0.9	903	77
	Estim. Inputs =			6000-10000	3000
	OUTPUTS				
	Harvested Crops:				
37	629 bu Soybeans (1.6 kgN & .16 kgP bu)	27.2	2.72	1006	101
7	504 bu Corn (.41 kgN & .073 kgP bu)	29.5	5.26	207	37
10	30 T Clover (17.1 kgN & 1.4 kgP T)	153.9	4.2	1539	42
				2752	180
54	Denitrification (15% of applied N)[e]			225	—
86	Flume Export	10.0	0.9	860	81
	Estim. Surface Outputs =			4000	300
	Net Difference =			2000-6000	2700
	Net Diff. per ha =			23-70	31

[a]Hardy and Holsten 1976
[b]Tjepkema and Van Berkum 1977
[c]Stewart 1965
[d]Miklas et al. 1977
[e]Allison 1955

TABLE 16. Mass balance calculation of inputs and outputs of nitrogen and phosphorus in the forested watershed at Horn Point during 1979.

ha.		kgN/ha	kgP/ha	kgN	kgP
	INPUTS				
35	N-Fixation[a]	1-17	--	35-595	--
35	Precipitation[b]	10.5	0.9	368	32
	Estim. inputs =			403-963	32
	OUTPUTS				
35	Denitrification[c]	?	--	0	
35	Flume Export	.16	.24	5.6	8.4
	Estim. surface outputs =			5.6	8.4
	Net difference =			397-957	23.6
	Net diff. per ha =			11.3-27.3	.67

[a]Borman et al. 1977

[b]Miklas et al. 1977

[c]Viets 1978

TABLE 17. Nutrient export rates (kg $ha^{-1} yr^{-1}$) assoicated with various crops and forested watersheds

LAND	Ortho P	TSP	TP	NO_2+NO_3	NH_3	TKN	TN	REFERENCE
Contour Corn		0.16	1.65	1.62	0.84		59.3	Alberts et al., (1978)
Terrace Corn		0.08	0.23	0.90	0.21		6.35	Alberts et al., (1978)
Pine Forest		0.06-0.11	0.22-0.37					Duffy et al., (1978)
Cultivated Muckland	0.06-30.7			39.2-87.5	1.0-1.9			Duxbury and Peverly (1978)
Fallow	0.1-1.2		0.4-2.9	0.2-0.3		0.4-4.1		Nicholaichuk and Read (1978)
Prairie	0.02	0.03	0.11	0.12	0.14	0.71		Timmons and Holt (1978)
Forest			0.21	0.06				Bedient et al., (1978)
Cotton		1.11	6.7				11.6	Menzel et al., (1978)
Wheat		0.3	2.2				7.2	
Rangeland		0.04-0.06	0.54-1.86				1.7-6.3	
Agric		1.0		7.1				This study
Pine		.24		.16				This study

investigators concluded that the 55 yr old Beech-Maple Forest at Hubbard Brook is very conservative in terms of nitrogen retention. Therefore the pine forest at Horn Point and that studied by Bedient et al. (1978) have extremely "tight" nitrogen budgets. The reason that pine forests might have comparatively tight nitrogen cycling is that successional systems tend to be more efficient in trapping nutrients than systems nearer climax, where steady state (input=output) is approximated (Vitousek and Reiners 1975).

Ground Water Concentrations

The most remarkable aspect of the groundwater concentrations is the enormous increase in nitrate in wells adjacent to the marsh. These concentrations (1.54 - 4.0 mg l^{-1}) are higher than the maximum reported by Stevenson et al. (1977) for the marsh embayment (1.1 mg l^{-1}) at Horn Point. It is not yet clear why this concentration occurs in this zone. Since there is no concurrent increase in chloride concentrations, there is little reason to suspect that this increased concentration is associated with brackish water groundwater intrusions from the estuary. Another possibility which seemed initially plausible was high nitrogen fixation rates in this area. However, a recent study of nitrogen fixation by Lipschultz (1978) in adjacent marsh areas where the high concentrations are present showed relatively insignificant N-fixation potential.

A third hypothesis appears reasonable involving the loess cap which is deepest in zones surrounding the marsh. Boyce et al. (1976) have found up to 50-60 mg l^{-1} nitrate in loess soils in Nebraska. The highest concentrations were found in low rainfall areas where the nitrate remains unleached in the parent material. As rainfall increases the nitrate decreases to concentrations from 1.0 - 5.0 mg l^{-1} -- which are in the range we found. Boyce et al. (1976) speculate that the origin of the nitrate in the parent loess material might be due to nitrification of organic matter associated either with grassland during deposition or from the palesol. Biggs (pers. com.) doubts that this soil is really wind deposited since few radiocarbon dates are available. Further study of the nitrogen cycle of Mattapex soils is needed to promote our understanding of a soil type which has wide distribution around Chesapeake Bay.

Perhaps the simplest explanation for the high nitrate concentrations is that they are the result of the attempt at cultivation of essentially marsh muck. The highest NO_2+NO_3 value in Table 17 is associated with cultivated muckland in New York. Duxbury and Peverly (1978) concluded that most of the nitrate associated with muck histosols is the result of mineralization of organic material and not directly from additions of fertilizers. Thus there is reason to believe that high nitrate concentrations found at Horn Point are also only indirectly related to cultivation and not directly to fertilization.

Diffuse Source Loadings in the Choptank Basin

In order to determine whether the N & P loadings measured at Horn Point watersheds reflected those that occur in other areas of the Choptank Basin, we compared our data to that simultaneously collected by the U.S. Geological Survey at Greensboro, Md. Since the Greensboro gaged station drains 293 square km of the upper basin it can be used for testing whether the comparatively small scale watersheds at Horn Point reflect larger basin segments which have more complex land use patterns with more potential sources and sinks.

Table 18 shows that the nitrogen export of the Upper Choptank River is in excellent agreement with our adjusted value for the agricultural watershed (10 kg N $ha^{-1}yr^{-1}$). Furthermore the phosphorus export at Greensboro is only slightly higher than our agricultural watershed. Therefore it appears that the land use mix in the predominantly agricultural watershed at Horn Point produces a very close approximation to the output of the larger upper basin.

The results at Horn Point were then used to obtain the diffuse source loading of the Choptank River in Table 19. Of the four land use categories given in Table 1, marshes were omitted because of the continuing controversy whether they serve as net nutrient sources or sinks to the estuary (see Stevenson et al. 1977) and comprise less than 1% of the watershed. Although we did not study any developed land use categories, a range of values were chosen from studies of urban and suburban areas enumerated in Table 14. Since developed land comprises such a small proportion of the watershed (4%), only a small amount of error is expected with this approach. Total non-point loading was then estimated at 1.16 to 1.23 thousand metric tons (M.T.) of nitrogen and 160 to 180 M.T. of phosphorus. These values were then compared with those projected from most recent available data of point source inputs to major segments of the Choptank Basin (Table 20).

Table 21 presents the final percentage diffuse source contribution of N and P in each part of the Choptank River. For both

TABLE 18. Total nitrogen and phosphorus flux of upper Choptank north of USGS Greensboro Gage (drainage area = 293 km^2) for water year 1979[a]

MONTH	DISCHARGE MEAN CFS	DISS. CONC N mg/l	DISS. CONC P mg/l	DISSOLVED TOTAL N $kg\ km^{-2}d^{-1}$	DISSOLVED TOTAL P $kg\ km^{-2}d^{-1}$
Oct	21	1.6	.07	0.32	.012
Nov	28	-	-	0.32	.016
Dec	96	1.9	.11	1.5	.088
Jan	417	1.6	.10	5.6	.348
Feb	646	-	-	8.6	.917
Mar	371	1.4	1.2	4.3	.185
Apr	183	1.2	.04	1.8	.061
May	135	1.9	.09	2.1	.101
Jun	241	1.7	.12	3.4	.241
July	85	1.5	.18	1.1	.123
Aug	77	1.1	.08	0.7	.052
Sep	83	1.2	.08	0.8	.055
				---	----
				2.75	0.183
Total export ($kg\ N\ ha^{-1}yr^{-1}$) =				10.04	0.67

[a]U.S. Geological Survey (1979)

TABLE 19. Estimated nitrogen and phosphorus non-point (10^3 kg/yr)[d] loadings from various land use types in Choptank Basin

Segment	Cropland[a]	Forest[b]	Developed[c]	TOTAL NON-POINT LOADING Low Est.		TOTAL NON-POINT LOADING High Est.
NITROGEN:						
Lower Choptank	325.9	1.9	5.0 - 33.4	332.8	-	361.2
Upper Choptank	419.7	2.9	2.6 - 17.5	425.2	-	440.1
Tuckahoe Cr.	286.9	1.7	0.2 - 1.1	288.8	-	289.7
Delaware Segment	115.1	1.5	2.8 - 18.6	119.4	-	135.2
Basin Total	1147.6	8.0	10.6 - 70.6	1166.2	-	1226.2
PHOSPHORUS:						
Lower Choptank	42.8	2.8	.7 - 7.0	46.3	-	52.6
Upper Choptank	55.1	4.4	.3 - 3.7	59.8	-	63.2
Tuckahoe Cr.	37.7	2.6	.0 - .2	40.3	-	40.5
Delaware Segment	15.1	2.3	.4 - 3.9	17.8	-	21.3
Basin Total	150.7	12.1	1.4 - 14.8	164.2	-	177.6

[a] Assuming a loading of 9.9 kg N/ha and 1.3 kg P/ha

[b] Assuming a loading of 0.16 kg N/ha and 0.24 kg P/ha

[c] Assuming loadings of from 1.5 to 10.0 kg N/ha and from 0.2 - 21. kg P/ha (see Table 14)

[d] 1×10^3 kg = 1 metric ton = 2,205 lbs.

TABLE 20. Estimated municipal discharge of nitrogen and phosphorus in the Choptank Basin in late 1970's[a]

Segment	Design MGD	Aver. flow MGD	N[b] M.T./yr	P[c] M.T./yr
Lower Choptank R (downstream from town of Choptank)	10.582	7.026	291.3	97.0
Upper Choptank R (from town of Choptank to Delaware line)	.734	.673	27.9	9.3
Tuckahoe Creek	0	0	0	0
	11.316	7.699	319.2	106.3

*Source: [a] Solyst J and R Davidov. 1979. The "208" Water Quality Management Plan for the Choptank Basin. Maryland Department of Natural Resources, Annapolis, MD.

[b] Assumes a N loading = .03 g/liter wastewater
Source: U.S. EPA Process Design Manual for Nitrogen Control

[c] Assumes a P loading = .01 g/liter wastewater
Source: U.S. EPA Process Design Manual for Phosphorus Removal (EPA 625/1-76-001a)

TABLE 21. Comparative nitrogen and phosphorus loadings associated with major Choptank River segments.

Segment	MLW Volume[a] 10^6 m^3	Diffuse Source Loading[b] Metric Tons	Estimated Total Loading Metric Tons	Percent Attributable to Diffuse Sources	Calculated Concentration[d] mg/L
NITROGEN:					
Lower Choptank	1497	347.0	638.3	54%	.42
Upper Choptank	68	432.6	460.5	94%	6.77
Tuckahoe Creek	8	289.3	289.3	100%	36.16
Delaware segment	2[e]	127.3	127.3+	100%	63.65
Total Basin	1575	1196.2	1515.4	78%	.95
PHOSPHORUS:					
Lower Choptank	1497	49.4	146.4	49%	.10
Upper Choptank	68	61.5	70.8	87%	1.04
Tuckahoe Creek	8	40.4	40.4	100%	5.05
Delaware segment	2[e]	19.6	19.6+	100%	9.80
Total Basin	1575	170.9	277.2	62%	0.18

[a]Cronin and Pritchard 1975.

[b]Average non-point loading estimate from Table (19).

[c]From Tables (19) and (20).

[d]Assumes no losses due to: biological uptake, sedimentation or denitrification in the river or adjoining wetlands.

[e]Assuming that drainage density is 1% of total land area of the segment (230 km^2) and with an average depth of 1 meter.

nitrogen and phosphorus, non-point sources account for from approximately 50% in the lower portion of the Choptank River to essentially 100% in the upper fresh water portions. The overall diffuse source loading percentage is 78% for N and 62% for P.

One conclusion of our study is that diffuse source nutrient loadings are significant in the rural eastern shore tributaries of Chesapeake Bay with land use mixes and soil types similar to the Choptank River. Furthermore, our calculations suggest that nitrogen and phosphorus of point source inputs upstream in the Choptank are minimal compared with diffuse sources. To improve water quality in the fresher portions of the Choptank River, efforts should be directed toward reducing outputs of N and P associated with present agricultural practices. However, significant reductions in algal blooms in the lower portions of the Choptank River could be obtained by improved treatment of sewage. Nitrogen removal appears much more critical than phosphorus, since it appears to be the limiting nutrient in late spring and summer in this area (Stevenson et al. 1977) when algal blooms are most prolific.

Because advanced sewage treatment systems are presently very expensive, it might be more cost-effective to apply wastewater to forested land. Our study shows that the pine forest at Horn Point is very effective at retaining nitrogen inputs, and systems like this may be good prospects for spray irrigation. A study of spray irrigation has indicated that this disposal technique works well on a coastal plain site on the western shore at St. Charles, Maryland with only minor problems when the forest is oversprayed with sewage (Athanas et al. 1981). Species could be planted which have high tolerance to waterlogging such as loblolly pine, white cedar or bald cypress. These species all have high commercial value and could be harvested periodically to help offset treatment costs.

Finally Table 21 shows projected concentrations of N and P in the major segments of Choptank River. However, actual measured concentrations reported by Water Resources Administration (see Solyst and Davidov 1979) in the Choptank, during the late 1970's are about a magnitude lower, with the same trend of increasing N and P in an upstream direction. This indicates that the river itself is assimilating N and P into organic material and "sinks out" a large proportion of the input loading. Also processes such as denitrification may be operating in it surrounding wetlands to liberate nitrate in gaseous forms.

FUTURE RESEARCH

One problem which emerges from past research at Horn Point is the lack of accounting for the initial input of nitrogen and phosphorus in the mass balance calculation. It is obvious in Figures 12 and 13 that particulates could be a major term in the budgets of these watersheds. Although particulate N and P were not measured in this study, a subsequent year's data on sediment outputs is now being analyzed (Fisher pers. com.). If particulate export of N and P do not turn out to be significant, the possibility of nutrient accumulation in the soils should be investigated.

Phosphorus is more likely than nitrogen to accumulate in the agricultural watershed. Both N and P are assimilated by the forest in proportion to its net productivity which needs to be quantified for an understanding of its importance in the forested watershed. Also, effort should be made to determine the magnitude of organic and inorganic phosphorus and nitrogen pools in both watersheds.

More research is also needed to ascertain the relative loss of nitrogen attributable to denitrification and nitrogen fixation in both forested and agricultural watersheds. Rapid denitrification might occur when water tables are oscillating, accounting for a large percentage of the nitrogen imbalance seen in Fig. 12.

In addition, the possibility that nitrates move into the estuary below the inter-flow zone intercepted by the ditches during periods of high rainfall, needs to be examined. This hypothesis could be tested by determining groundwater seepage into the bottom of Chesapeake Bay using techniques similar to those used by Lee

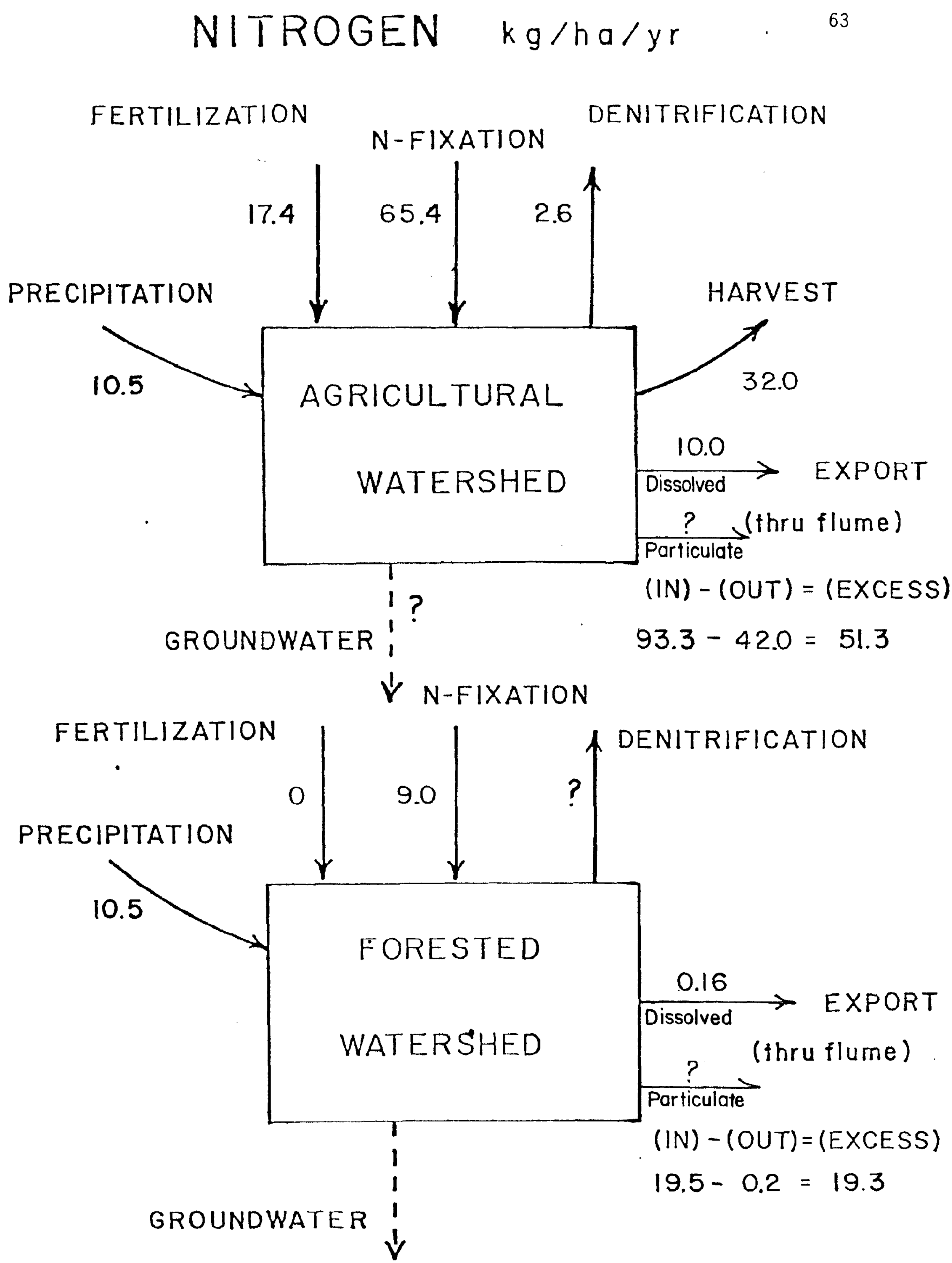

Figure 12. Yearly nitrogen budget for agricultural and forest watersheds at Horn Point

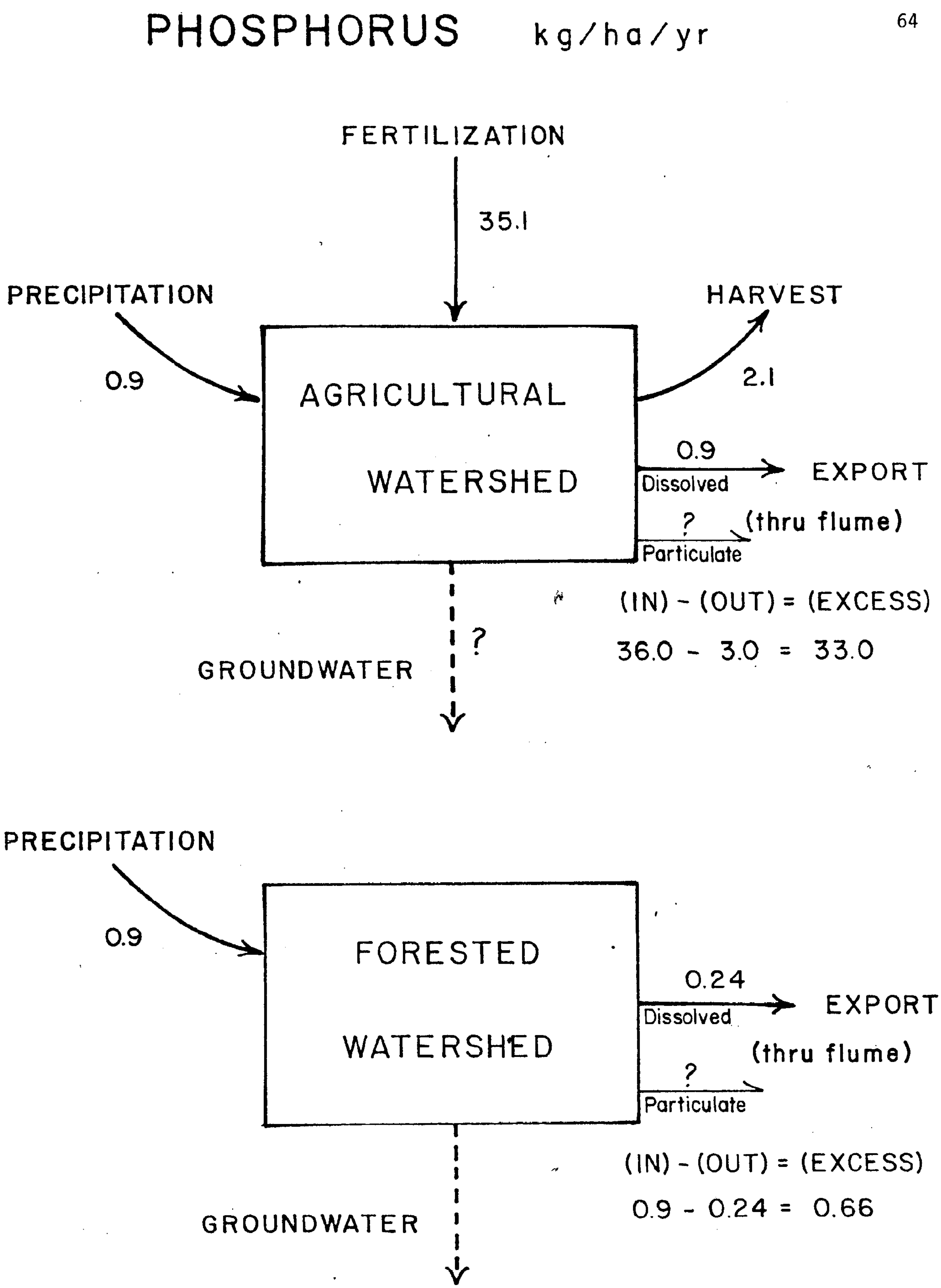

Figure 13. Yearly phosphorus budget for agricultural and forest watersheds at Horn Point

(1977) or Fellows and Brezonik (1979). The latter were able to measure subsurface hydraulic inputs into Lake Conway, Florida by using lysimeters along the shoreline in the shallows and measured nutrient loadings simultaneously.

Finally efforts should be made to evaluate the effects of alternative BMP's (e.g., buffer strips, using winter cover crops, grassed waterways, instituting "no-till" practices, and etc.) at reducing non-point loadings. Walter et al. (1979) have cautioned that BMP's derived from previously developed soil and conservation practices have little direct effect on non-adsorbed or soluble pollutants (e.g., nitrate). More research is necessary to evaluate options to encourage removal of nitrates from runoff. A system of experimental watersheds equipped with flumes is needed to study effects of manipulating agricultural practices on reducing nitrate concentrations. In addition, it would serve as a more convincing longer term experiment to the local farm community, which now is skeptical of short term studies which are sometimes extrapolated beyond their limitations because of time necessities. A series of well designed long-term watershed studies would provide coastal resources managers with a unique and valuable data base for guiding land use decisions in future years.

MANAGEMENT OPTIONS

Previously the 208 plans mandated in Public Law 92-500, attempted to catalog and control pollution loadings when there was little understanding of the actual extent of the non-point source problems in various portions of Chesapeake Bay. For example, runoff from feedlots was thought to be a major diffuse source problem. However, overall budgets show these activities occur in such small proportions in this region that they are trivial compared with cropland loadings. Only after considerable amount of data is available, on surface and subsurface loadings and mass balance calculations made for each major watershed, can realistic control measures be formulated (Schmidt, 1979). Coastal Zone Management could make a major impact in this area if it would promote the implementation of a groundwater/surface water quality monitoring system for major tributary segments of the Bay. This management option would have maximum impact by providing non-point source information essential for effectively carrying out provisions of the Clean Water Act. The State of Maryland Department of Health and Mental Hygiene monitors core stations in Chesapeake Bay to determine concentrations over long time periods. To date, however, no scientific evaluation of what information is needed for time-series statistics for trend analysis has been attempted. Other states, such as Illinois have already analyzed their monitoring network and found they could reduce by two-thirds the number of stations necessary for detecting trends (Wallin and Schaeffer 1979). The basic statistics for developing an evaluation of sampling frequencies monitoring networks has been recently reviewed by Ward, et al. (1979).

One management necessity that emerges from our study is the control of soils with very high nitrate concentrations. This area is adjacent to the marsh areas and tends to be in the Mattapex series. Many Eastern Shore farmers cultivate very close to the marshes and Bay shorelines often disturbing the muck soil so that surface losses become probable. Efforts could be made to encourage or mandate wider buffer strips alongside the Bay and its marshes which would prevent this soil from moving into the estuary. We suggest that strong incentives such as easements are necessary to promote these green areas. Sharp and Bromley (1979) point out that one of the obstacles in reducing agricultural pollution is that although technology is currently available, cordination between governmental agencies is the limiting factor in the implementation of a financial incentive program for enhancement of rural water quality.

More research needs to be done to determine what type of vegetation should be encouraged in the buffer strips. A high nitrogen requiring non-leguminous crop which could be grown with no-till cultivation would be ideal. One possibility might be Reed Canary grass (Phalaris arundinacea), a leafy perennial of wide agricultural importance as a wetland grass. It can take up an average of 300 kg N $ha^{-1}yr^{-1}$ (Kardos and Sopper 1973). Precaution should be taken to exclude species which have any nitrogen fixation associated with them, since that would only compound the high nitrogen concentrations in this zone.

In summary, the far reaching implication of our study which deserves further attention is the overall conclusion that diffuse source loadings, in terms of nitrogen and phosphorus, are the most significant inputs into the Choptank estuary. Although not a magnitude greater than point sources as suggested previously (Wallace et al. 1972), they are three times greater in the case of N loadings and almost twice that for P loadings. This suggests more effort must be expended to develop and encourage "best management practices" (BMP's) for Eastern Shore agriculture, the most important source of non-point inputs into this region of Chesapeake Bay.

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APPENDIX A

One Day Record of Storm Hydrograph for Parshall Flume at Agricultural Watershed, HPEL February 25, 1979

STORM OF 2 25 1979
TIME OF 1ST READING: 0:00

TIME	UPSTRM HEAD HA (FT)	DWNSTR HEAD HB (FT)	SUBMRG RATIO HA/HB	CORRCN FACTOR QC/QF	FREFLO DISCH QF (CFS)	ACTUAL DISCH QC (CFS)	DT (MIN)	DQ (CU.FT)	QT (IN)
0	3.44	3.38	.983	.511	83.08	42.47	30.0	76440.2	.0000
30	3.34	3.29	.985	.503	79.33	39.87	30.0	71760.3	.0989
60	3.28	3.23	.985	.504	77.11	38.82	30.0	69884.1	.1917
90	3.25	3.18	.978	.525	76.00	39.94	30.0	71883.4	.2821
120	3.17	3.11	.981	.516	73.10	37.74	30.0	67935.8	.3750
150	3.09	3.03	.981	.518	70.23	36.38	30.0	65485.6	.4629
180	3.00	2.95	.983	.508	67.05	34.09	30.0	61367.5	.5476
210	2.91	2.86	.983	.510	63.93	32.62	30.0	58715.4	.6270
240	2.83	2.79	.986	.500	61.20	30.58	30.0	55038.5	.7029
270	2.76	2.72	.986	.501	58.84	29.47	30.0	53053.6	.7741
300	2.70	2.66	.985	.502	56.85	28.54	30.0	51373.2	.8427
330	2.66	2.62	.985	.503	55.54	27.92	30.0	50263.8	.9091
360	2.60	2.57	.988	.491	53.59	26.29	30.0	47324.6	.9741
390	2.55	2.53	.992	.478	51.98	24.84	30.0	44703.5	1.0354
420	2.50	2.48	.992	.478	50.40	24.10	30.0	43387.9	1.0932
450	2.45	2.44	.996	.465	48.83	22.69	30.0	40837.8	1.1493
480	2.41	2.41	1.000	.450	47.58	21.43	30.0	38591.5	1.2021
510	2.39	2.38	.996	.465	46.97	21.84	30.0	39312.6	1.2520
540	2.36	2.35	.996	.465	46.05	21.42	30.0	38557.9	1.3028
570	2.34	2.32	.991	.480	45.44	21.82	30.0	39274.4	1.3527
600	2.31	2.30	.996	.466	44.53	20.73	30.0	37311.8	1.4035
630	2.26	2.24	.991	.481	43.03	20.71	30.0	37273.6	1.4518
660	2.22	2.21	.995	.466	41.84	19.50	30.0	35106.4	1.5000
690	2.18	2.18	1.000	.450	40.67	18.32	30.0	32973.0	1.5454
720	2.16	2.14	.991	.483	40.08	19.35	30.0	34826.1	1.5880
750	2.16	2.15	.995	.467	40.08	18.70	30.0	33663.3	1.6331
780	2.19	2.17	.991	.482	40.96	19.75	30.0	35554.0	1.6766
810	2.22	2.23	1.005	.000	41.84	.00	30.0	.0	1.7226
840	2.29	2.28	.996	.466	43.93	20.45	30.0	36817.5	1.7226
870	2.17	2.15	.991	.483	40.37	19.48	30.0	35068.1	1.7702
900	2.18	2.16	.991	.482	40.67	19.62	30.0	35310.8	1.8156
930	2.19	2.16	.986	.498	40.96	20.40	30.0	36725.9	1.8612
960	2.20	2.17	.986	.498	41.25	20.54	30.0	36972.8	1.9087
990	2.20	2.16	.982	.514	41.25	21.19	30.0	38147.8	1.9566
1020	2.19	2.15	.982	.514	40.96	21.05	30.0	37897.9	2.0059
1050	2.25	2.26	1.004	.000	42.73	.00	30.0	.0	2.0549
1080	2.43	2.33	.959	.594	48.20	28.62	30.0	51513.8	2.0549
1110	2.53	2.41	.953	.616	51.35	31.61	30.0	56892.2	2.1215
1140	2.54	2.48	.976	.533	51.66	27.52	30.0	49537.3	2.1951
1170	2.52	2.45	.972	.547	51.03	27.92	30.0	50256.5	2.2592
1200	2.49	2.44	.980	.520	50.08	26.06	30.0	46907.2	2.3242
1230	2.46	2.40	.976	.535	49.14	26.31	30.0	47352.2	2.3848
1260	2.41	2.34	.971	.552	47.58	26.25	30.0	47241.7	2.4461
1290	2.40	2.33	.971	.552	47.27	26.09	30.0	46970.9	2.5072
1320	2.39	2.31	.967	.567	46.97	26.63	30.0	47932.0	2.5679
1350	2.39	2.31	.967	.567	46.97	26.63	30.0	47932.0	2.6299
1380	2.35	2.27	.966	.569	45.74	26.02	30.0	46844.9	2.6919
1410	2.45	2.35	.959	.593	48.83	28.93			2.7525

TO CONVERT INCHES TO CU.FT. MULTIPLY BY .7732+06

One Day Record of Storm Hydrograph for Parshall Flume at Agricultural Watershed, HPEL February 26, 1979

STORM OF 2 26 1979

TIME OF 1ST READING: 0:00

TIME	UPSTRM HEAD HA (FT)	DWNSTR HEAD HB (FT)	SUBMRG RATIO HA/HB	CORRCN FACTOR QC/QF	FREFLO DISCH QF (CFS)	ACTUAL DISCH QC (CFS)	DT (MIN)	DQ (CU.FT)	QT (IN)
0	2.43	2.33	.959	.594	48.20	28.62			.0000
							30.0	51513.8	
30	2.41	2.30	.954	.609	47.58	28.99			.0666
							30.0	52190.3	
60	2.71	2.51	.926	.705	57.18	40.28			.1341
							30.0	72512.9	
90	2.75	2.56	.921	.721	59.51	42.88			.2279
							30.0	77181.3	
120	2.76	2.56	.928	.700	58.84	41.21			.3277
							30.0	74181.2	
150	2.65	2.46	.928	.698	55.21	38.54			.4237
							30.0	69366.0	
180	2.56	2.36	.922	.718	52.30	37.53			.5134
							30.0	67552.7	
210	2.48	2.29	.923	.713	49.77	35.49			.6008
							30.0	63873.4	
240	2.39	2.23	.933	.683	46.97	32.07			.6834
							30.0	57721.1	
270	2.30	2.17	.943	.647	44.23	28.62			.7580
							30.0	51522.9	
300	2.23	2.10	.942	.653	42.14	27.53			.8247
							30.0	49556.8	
330	2.16	2.01	.931	.691	40.08	27.69			.8887
							30.0	49845.5	
360	2.19	2.18	.995	.466	40.96	19.10			.9532
							30.0	34382.1	
390	2.16	2.05	.949	.628	40.08	25.16			.9977
							30.0	45291.2	
420	2.04	1.96	.961	.587	36.65	21.51			1.0563
							30.0	38723.8	
450	1.99	1.92	.965	.573	35.25	20.20			1.1063
							30.0	36355.3	
480	1.94	1.88	.969	.558	33.88	18.91			1.1534
							30.0	34033.2	
510	1.90	1.84	.968	.560	32.79	18.37			1.1974
							30.0	33074.5	
540	1.86	1.80	.968	.563	31.72	17.85			1.2402
							30.0	32125.5	
570	1.83	1.75	.956	.603	30.92	18.63			1.2817
							30.0	33537.4	
600	1.83	1.79	.978	.527	30.92	16.28			1.3251
							30.0	29302.9	
630	1.79	1.73	.966	.567	29.87	16.94			1.3630
							30.0	30488.4	
660	1.81	1.70	.939	.662	30.39	20.12			1.4024
							30.0	36212.8	
690	2.09	1.68	.804	.912	38.07	34.73			1.4492
							30.0	62519.7	
720	1.92	1.93	1.005	.000	33.33	.00			1.5301
							30.0	.0	
750	1.78	1.73	.972	.548	29.60	16.23			1.5301
							30.0	29214.8	
780	1.73	1.67	.965	.571	28.31	16.17			1.5679
							30.0	29109.4	
810	1.70	1.65	.971	.553	27.55	15.23			1.6055
							30.0	27413.0	
840	1.69	1.63	.964	.574	27.29	15.67			1.6410
							30.0	28202.6	
870	1.70	1.65	.971	.553	27.55	15.23			1.6775
							30.0	27413.0	
900	1.73	1.68	.971	.551	28.31	15.60			1.7129
							30.0	28083.9	
930	1.76	1.71	.972	.549	29.09	15.98			1.7492
							30.0	28760.6	
960	1.76	1.73	.983	.510	29.09	14.83			1.7864
							30.0	26689.6	
990	1.73	1.71	.988	.491	28.31	13.89			1.8210
							30.0	25007.5	
1020	1.66	1.68	1.012	.000	26.54	.00			1.8533
							30.0	.0	
1050	1.59	1.61	1.013	.000	24.81	.00			1.8533
							30.0	.0	
1080	1.50	1.52	1.013	.000	22.64	.00			1.8533
							30.0	.0	
1110	1.44	1.45	1.007	.000	21.24	.00			1.8533
							30.0	.0	
1140	1.37	1.38	1.007	.000	19.65	.00			1.8533
							30.0	.0	
1170	1.30	1.30	1.000	.450	18.10	8.15			1.8533
							30.0	14674.0	
1200	1.24	1.25	1.008	.000	16.81	.00			1.8723
							30.0	.0	
1230	1.18	1.20	1.017	.000	15.55	.00			1.8723
							30.0	.0	
1260	1.12	1.23	1.098	.000	14.33	.00			1.8723
							30.0	.0	
1290	1.06	1.06	1.000	.450	13.15	5.92			1.8723
							30.0	10659.4	
1320	1.01	1.02	1.010	.000	12.19	.00			1.8861
							30.0	.0	
1350	.97	.95	.979	.522	11.44	5.97			1.8861
							30.0	10754.6	
1380	.93	.91	.976	.525	10.71	5.63			1.9000
							30.0	10127.8	
1410	.89	.87	.975	.529	10.00	5.29			1.9131

TO CONVERT INCHES TO CU.FT. MULTIPLY BY .7732+06

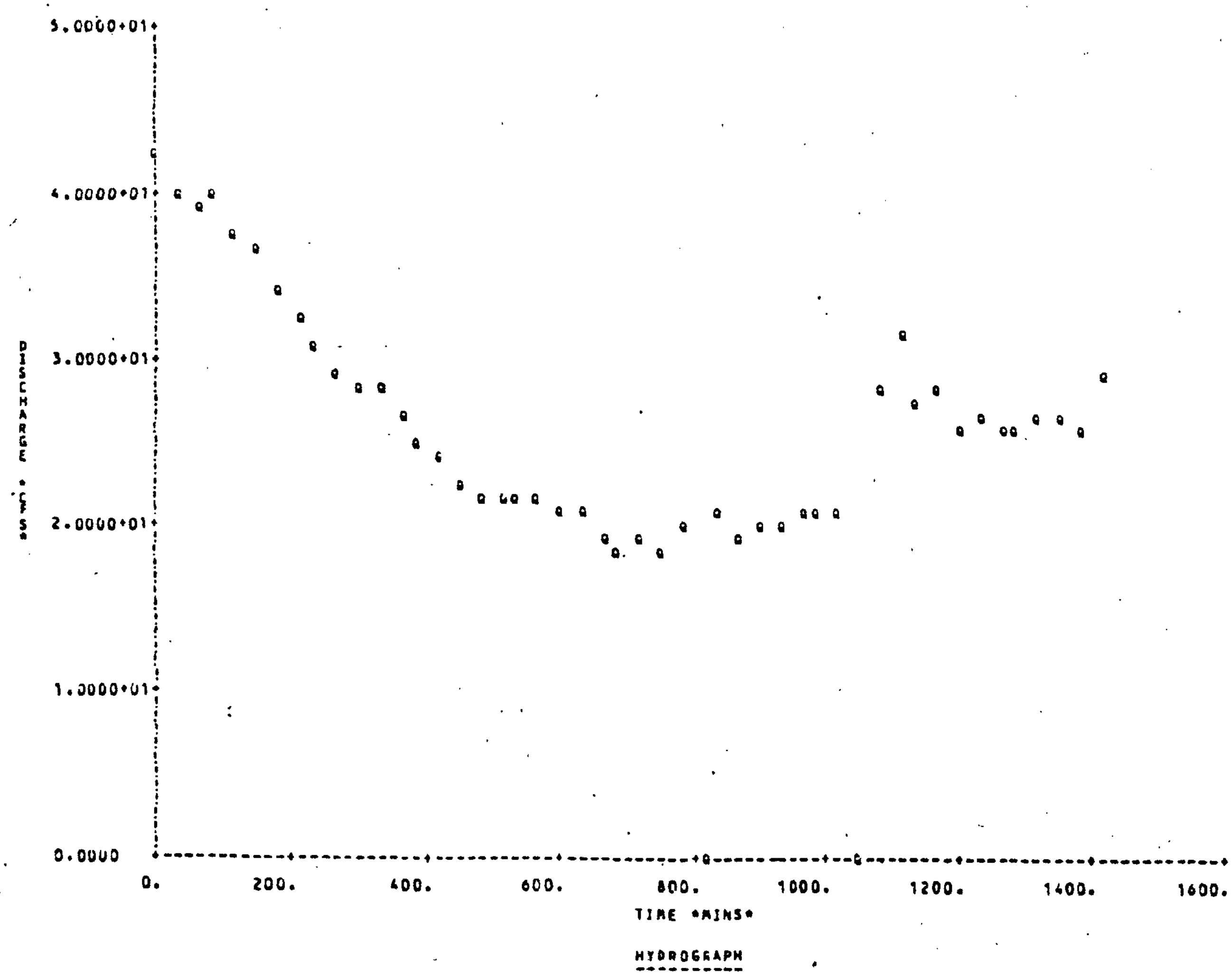


Figure Aa Calculated hydrograph for agricultural watershed at HPEL, February 25, 1979.

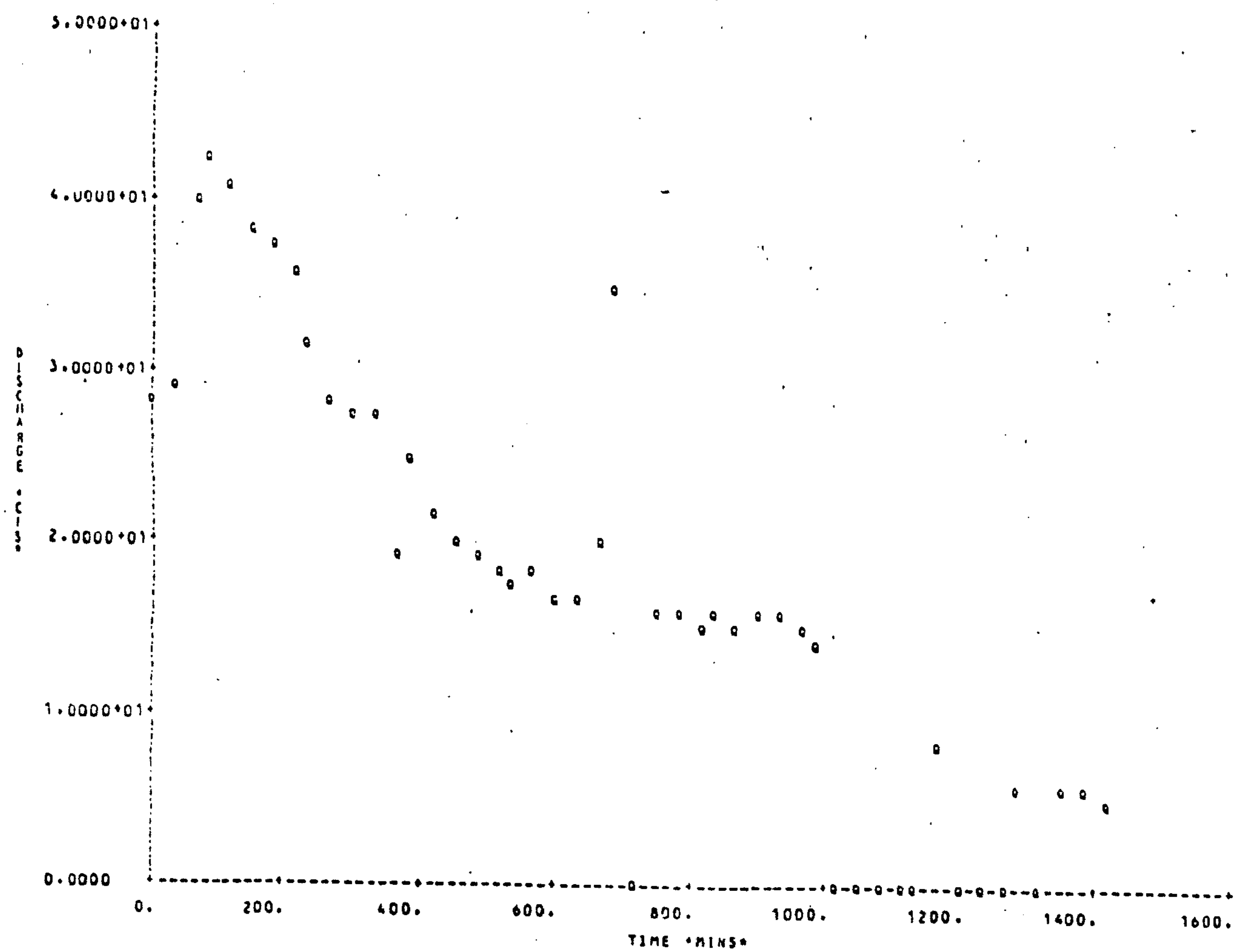


Figure Ab Calculated hydrograph for agricultural watershed at HPEL, February 26, 1979.

APPENDIX B

TABLE

WELL NO. A- 2

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		1		15	20	
08-23-78		2		9	18	
08-31-78				5	50	
09-07-78				5	18	
09-14-78				5	-	
09-21-78	2,600	4		0,5	30	46
09-27-78	3,200	0		5	30	49
10-12-78	3,200	5		0	15,5	44
10-26-78	3,200	5		10	9	39
11-09-78	1,900	0		9	10	48
11-23-78	2,300	1	-	0	0	40
12-07-78	1,800	1		0	20	47
12-21-78	2,200	1		5	14	36
01-04-79	-	0		0	50	45
01-18-79	3,400	1	20	0	90	47
02-01-79	3,000	2	80	5	40	42
02-15-79	4,600	2	320	0	24	48
03-01-79	4,600	1	130	0	20	48
03-15-79	5,200	3	-	0	34	58
03-29-79	5,800	5	30	0	32	50
04-11-79	6.400	2	26	9	26	49
04-26-79	6.600	2	270	0	50	49
05-10-79	6.200	3	38	7	40	48
05-24-79	11,000	2	83	8	24	49
06-07-79	5,580	8	142	17	94	204
06-21-79	4,292	6	--	16	30	44
07-06-79	2,364	7	63	20	22	38
07-19-79	2,740	7	36	7	28	36
08-09-79	3,109	15	470	36	86	39
08-23-79	3,770	8	87	8	68	38

TABLE

WELL NO. A-11

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78				40	20	
08-23-78				100	110	
08-31-78				15	18	
09-07-78				9,9	10,10	
09-21-78		8		0	30	64
09-27-78		3		0	5	66
10-12-78	340			0	5	
12-07-78	760	2		0	18	54
12-21-78	470	1		9	24	
01-04-79		1		0	30	51
01-18-79	240	9	1,380	0	90	56
02-01-79	240	2	600	5	12	50
02-15-79	220	3	1,300	3	22	52
03-01-79	380	4	640	0	12	50
03-15-79	880	3	-	0	0	47
03-29-79	660	3	80	51,50	20,0	2
04-11-79	580	5	166	32	68	6
04-26-79	440	5	581	190	274	6
05-10-79	60	1	2,198	165	246	20
05-24-79	72	4	> 2450	--	140	34
06-07-79	253	58	1414	6	58	50
06-21-79	638	12		7	24	49
07-06-79	842	11	1587	4	17	54
07-19-79	270	4	1717	out	28	out
08-09-79	2,201	21	1,090	0	8	82
08-23-79	3,232	50	790	1	49	80

TABLE

WELL NO. A- 27

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		4		30	80	
08-23-78		3		9	100	
08-31-78	18			5	18	
09-07-78	58			5	10	
09-14-78	20			0	-	
09-21-78	60,66,82	4		0,0	30	81
09-27-78	34	8		5	9	90
10-12-78	10	0		0	0	100
10-26-78	14	1		-	9	82
11-09-78	12	5		5	8	90
11-23-78	20	2		0	0	84
12-07-78	30	1		0	20	100
12-21-78	22	5		0	0	90
01-04-79	115	5		0	40	100
01-18-79	-	-	900	0	64	97
02-01-79	16	10	640	0	12	45
02-15-79	28	10	1620	1	28	98
03-01-79	28	16	590	0	14	98
03-15-79	46	8	-	0	0	89
03-29-79	53	10	350	0	60	100
04-11-79	100	11	322	0	40	97
04-26-79	84	10	>350	12	26	107
05-10-79	92	10	252	0	22	78
05-24-79	110	9	455	11	40	98
06-07-79	137	9	403	6	9	240
06-21-79	148	1		6	24	91
07-06-79	61	4	352	0	0	88
07-19-79	27	6	1,290	0	48	108
08-09-79	42	8	1,349	2	38	92
08-23-79	18,22	4	752	1	123	95

TABLE

WELL NO. M- 25

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		0		30	130	
08-23-78		2		185	300	
08-31-78	20			55	70	
09-07-78	10			35	70	
09-14-78	12			9	20	
09-21-78	520	21		0	30	28
10-12-78	-	1		5	15	
12-07-78	920	0		0	150	13
12-21-78	800	0		11	16	11
01-04-79	680	6		15	60	14
01-18-79	610	3	420	0	20	15
02-01-79	800	0	300	5	64	12
02-15-79	1,040	1	470	4	24	14
03-01-79	1,000	1	110	5	22	14
03-15-79	1,020	1		0	0	12
03-29-79	1,000	1	50	9	6	18
04-11-79	1,250	3	178	9	44	22
04-26-79	1,150	1	58	45	80	36
05-11-79	1,080	0	20	15	50	10
05-24-79	960	4	42	17	42	26
06-07-79	960	8	96	13	64	47
06-21-79	876	20		21	36	8
07-06-79	585	1	17	0	0	10
07-19-79	806	1	17	contam.	28	11
08-09-79	1,081	4	192	6	48	11
08/23/79	920	3	61	6	103	10

TABLE

WELL NO. M- 34

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		0		45	120	
08-23-78	74	1		15	0	
08-31-78	210			12	0	
09-07-78	152			12	18	
09-14-78	110			0	-	
09-21-78	112,126	5		0	0	24
10-12-78	46	0		5	35	3
12-07-78	70	0		7	18	24
12-21-78	23	2		5	14	20
01-04-79	60	3		0	30	23
01-18-79	20	10	1300	5	90	24
02-01-79	20	2	680	5	76	21
02-15-79	50	4	765	5	22	22
03-01-79	34	6	660	2	34	23
03-15-79	44	3		0	0	20
03-29-79	67	4	305	0	52	22
04-11-79	58	2	298	5	32	22
04-26-79	/	2				
05-04-79	69	4		13	52	20
05-10-79	74	3	360	6	32	20
05-24-79	82	4	770	17	48	24
06-07-79	106	2	662	11	70	31
06-21-79	108	0		12	39	20
07-06-79	86	4	1306	0	30	18
07-19-79	77	3	1400	1	33	19
08/09/79	85	6	1098	14	94	22
08/23/79	50	3	838	11	168	20

TABLE

WELL NO. W- 16

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78	84	1		9	30	
08-23-78	56	3		0	24	
09-21-78	31			60		
10-12-78	92			9	0	
01-18-79	240		T.T.	24	T.T.	T.T.
02-01-79	120	5,6	-	20	60	48
02-15-79	280	3	>10,000	30	70	86
03-01-79	160	4	3,500	0	6	125
03-15-79	44	2		0	0	188
03-29-79	48	7	165	0	0	220
05-11-79	72	22	938	8	14	245
05-24-79	60	3	980	7	10	255
06-07-79	130	14	1,539	5	10	175
06-21-79	---	1		T. Turbid	25	
07-06-79	250	6	655	0	11	82
07-19-79	37	2	695	out	11	out
08-08-79	194	8	348	6	29	78
08-23-79	146	19	286	2	17	56

TABLE

WELL NO. M- 52

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78				60	90	
08-23-78				50	60	
08-31-78				30	50	
09-07-78				25	10	
09-14-78				40	-	
09-21-78		6		20	30	28
10-12-78	700	0		0	15	18
12-07-78	900	0		12	40	27
12-21-78	1,000	0		25	22	24
01-04-79	1,400	6		5	30	27
01-18-79	1,000	0	140	7	90	25
02-01-79	1,900	0	1200	6	20	22
02-15-79	2,000	2	350	15	28	24
03-01-79	2,100	0	120	7	22	23
03-15-79	2,700	0		0	0	22
03-29-79	2,300	1	12	8	32	24
04-11-79	2.300	3	42	9	44	22
04-26-79	2,000	1	104	6	44	21
05-10-79	2.100	1	18	22	90	20
05-24-79	2.050	3	48	12	32	22
06-07-79	1,750	2	15	8	60	32
06-21-79	1,125	0		16	24	38
07-06-79	1,358	2	21	0	0	20
07-19-79	1,400	3	275	8	16	18
08-09-79	1,146	7	122	34	65	20
08/23/79	741	1	20	16	66	20

TABLE

WELL NO. W-18

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		5		35	210	
08-23-78		1		65	90	
08-31-78	168			75	120	
09-07-78	224			85	80	
09-14-78	192			0		
09-21-78	132,116,100				70	
10-12-78	600	47,44		12	40	450
12-07-78	127	5	-	300	400	350
01-04-79		13				
03-01-79	152	4	1420	0	-	475
03-15-79	58	5		0	interf.	490
03-29-79	38	13	330	5	104	490
05-04-79	43	1		0	INTER.PRECIP.	450
05-10-79	450	2	131	0	INTER PRECIP.	480 505
05-24-79	78	5	160	12	Interf.	535
06-07-79	106	3	119 Green	11	Interf.	1895
06-21-79	44	3		11	Interf.	442
07-06-79	221	3	161 Green	2	Interf.	392
07-19-79	149	2	132	2	51	455
08-09-79	326 368	3	136	20	86	335
08-23-79	408	5	276	21	129	316

TABLE

WELL NO. W- 32

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		1		70	130	
08-23-78		1		85	120	
08-31-78				110	160	
09-07-78				40	80	
09-21-78		9		20	60	26
10-12-78	340	2		9	20	25
12-07-78	480	32		65	96	335
01-04-79	184	7		10	50	135
01-18-79	133	1	270	30	86	255
02-01-79	20	0	560	25	64	360
02-15-79	58	1	640	8	30	390
03-01-79	67	1	590	5	26	405
03-15-79	60	1		0	0	390
03-29-79	52	1	50	8	42	165
05-11-79	64	0	66	13	50	465
05-24-79	72	5	53	12	24	400
06-07-79	91	6	55	17	88	1150
06-21-79	100	1	-	11	29	340
07-06-79	75	1	53	0	39	350
07-19-79	76	1	54	12	25	360
08-09-79	68	2	110	25	70	360
08-23-79	94	5	49	13	95	360

TABLE

WELL NO. W- 83

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		2		60	80	
01-04-79		13		185	340	14
01-18-79	480	21	1790	-	420	29
02-01-79	360	0	680	25	40	34
03-01-79	440	4	500	13	50	42
03-15-79	280	0		20	52	47
03-29-79	310	11	190	25	60	56
05-11-79	460	43	>360	145	220	58
05-24-79	400	3	805	84	132	80
06-07-79	610	13	826	117	204	55
06-21-79		2		45	50	59
07-06-79	103	2	250	0	37	66
07-19-79	out	W.E.S	585	--	--	57
08-09-79	123	3	957	0	yellow	55
08-23-79	154	3	113	92	157	43

TABLE

WELL NO. W- 135

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78	56	10		0	60	
08-23-78	100	5		0	10	
08-31-78	96			0	24	
09-07-78	64			0	0	
09-14-78	70			12	20	
09-21-78	61,62	5		0	0	84
09-27-78	80,58	0		5	15	82
10-12-78	10	0		0	0	98
10-26-78	51	0		0	5	100
11-09-78	46	0		5	0	102
11-23-78	80	1		0	0	100
12-07-78	85	8		5	10	118
12-21-78	70,75	5		5	6	110
01-04-79	-	4		6	44	59
01-18-79	300	10	1700	--	70	51
02-01-79	200	2	620	0	20	42
02-15-79	340	3	4700	4	24	42
03-01-79	340	7	1500	0	18	50
03-15-79	290	1		0	0	52
03-29-79	273	4	72	8	32	56
04-11-79	247	2	173	0	20	57
04-26-79	253	3	102	0	30	56
05-10-79	18	4	300	0	16	185
05-24-79	19	6	386	8	6	185
06-07-79	39	0	320	0	6	120
06-21-79	25	11	---	7	15	104
07-06-79	18	1	524	0	0	102
07-19-79	18	1	568	0	19	90
08-09-79	43	4	957	0	100	102
08-23-79	111	8	680	4	100	73

TABLE

WELL NO. W- 141

SAMPLE DATE	μg N/ℓ NITRATES	μg N/ℓ NITRITES	μg N/ℓ AMMONIA	μg P/ℓ ORTHO PHOSPHATE	μg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78					0	
08-23-78					0	
08-31-78	136			9	18	
09-07-78	30			5	70	
09-14-78	50			5	0	
09-21-78	50,44,84			0	0	17
09-27-78	T.T.			25	12	18
10-12-78	38	2		0	9	32
10-26-78	60			0	9	16
11-09-78	10	0		5	10	19
11-23-78	11	2		0	8	15
12-07-78	19	0		0	14	18
12-21-78	14	1		5	0	16
01-04-79	28	0		0	46	19
01-18-79	12	2	280	0	70	19
02-01-79	8	0	280	0	20	15
02-15-79	28	1	640	3	16	16
03-15-79	10	2		0	0	16
03-29-79	55	1	145	9	44	17
04-11-79	40	3	352	8	26	16
04-26-79	32	2	7350	7	32	15
05-11-79	36	2	7350	6	30	14
05-24-79	35	4	441	17	60	16
06-07-79	42	0	565	0	44	14
06-21-79	37	0	-	5	24	15
07-06-79	28	1	396	4	15	15
07-19-79	29	1	367	3	28	14
08-09-79	44	1	393	0	97	14
08-23-79	39	2	570	5	85	16

TABLE

WELL NO. W- 143

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78		1		12	30	
08-23-78		2		5	10	
08-31-78	100			5	18	
09-07-78	56			5	0	
09-14-78	20			5	-	
09-21-78	74,106,93			0	0	32
09-27-78	92	4		5	15	34
10-12-78	100	0		0	0	
10-26-78	64,71	0		0	9	30
11-09-78	58	0		15	0	36
11-23-78	42	0		0	0	32
12-07-78	52	0		0	16	32
12-21-78	80	1		0	0	34
01-04-79	51,68	0		0	32	38
01-18-79	-----	-----	140	-----	-----	37
02-01-79	52	0	95	0	12	36
02-15-79	92	2	240	5	16	36
03-01-79	84	2	240	0	12	36
03-15-79	60	0		0	0	36
03-29-79	90	8	207	0	24	36
04-11-79	82	7	3	6	42	35
04-26-79	80	4	126	0	34	34
05-10-79	44	2	7350	13	54	16
05-24-79	50	10	315	17	44	36
06-07-79	101	0	171	10	66	36
06-21-79	126	14		11	35	34
07-06-79	151	7	low	0	14	33
07-19-79	188	0	low			32
08-09-79	164	1	26	1	62	34
08-23-79	233	5	22	4	107	34

TABLE

WELL NO. W- 144

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78	72	1		9	20	
08-31-78	108			9	24	
09-07-78	70			12	24	
09-14-78	18			9	0	
09-21-78	64,50			0,0	40	30
09-27-78	52,66	1		9	5	42
10-12-78	23	3		0	0	14
10-26-78	44,36	0		0	5	28
11-09-78	84	1		0	0	32
11-23-78	17	2		0	0	26
12-07-78	15	1		0	14	28
12-21-78	12	1		5	0	29
01-04-79	1	9		36	90	30
01-18-79	19	3	280	5	70	31
02-01-79	4	0	500	0	76	36
02-15-79	30	2	350	3	18	28
03-01-79	34	1	640	2	20	28
03-15-79	30	27	-	0	0	28
03-29-79	40	2	212	0	32	28
05-11-79	34	2	236	10	32	25
05-24-79	34	7	207	16	22	28
06-07-79	43	0	251	0	50	36
06-21-79	45	0		10	30	27
07-06-79	38	1	318	5	13	27
07-19-79	36	0	282	5	31	26
08-09-79	40	2	213	3	114	26
08-23-79	42	4	235	10	167	22

TABLE

WELL NO. W- 163

SAMPLE DATE	µg N/ℓ NITRATES	µg N/ℓ NITRITES	µg N/ℓ AMMONIA	µg P/ℓ ORTHO PHOSPHATE	µg P/ℓ TOTAL PHOSPHATE	mg Cl/ℓ CHLORIDES
08-17-78	48	0		40	40	
08-23-78	52	6		20	30	
08-31-78	24			9	24	
09-07-78	8			9	0	
09-14-78	24			20		
09-21-78	32,18	4		16	30,50	
09-27-78	20	1				
12-07-78						10
12-21-78	9	3		0	0	12
01-04-79	16	13		5	32	30
01-18-79	20	43	1390	0	50	60
02-01-79	18	0	860	3	20	59
02-15-79	36	21	900	4	22	58
03-01-79	20	20	900	0	10	60
03-15-79	14	6		0	0	58
03-29-79	25	16	180	0	20	58
04-11-79	16	18	206	0	48	60
04-26-79	21	12	92	0	28	60
05-10-79 D	21	21	212	0	50	60
05-24-79	24	16	235	22	36	62
06-07-79	27	0	213	0	88	28
06-21-79	27	9		10	24	53
07-06-79	8	3	832	0	0	57
07-19-79	9	4	261	1	25	52
08-09-79	32	6	105	6	67	55
08-23-79	21	7	286	3	91	56

APPENDIX C

Othello Silt Loam
Profile Description

Horizon

A1 0 to 2 inches, dark grayish brown (2.5Y 4/2) silt loam, very weak medium granular structure, friable, slightly sticky, very strongly acid, abrupt smooth boundary.

A2g 2 to 16 inches, light gray (2.5Y 7/2) silt loam with common medium distinct yellowish brown (10YR 5/8) mottles, weak medium granular structure friable, slightly sticky, very strongly acid, clear smooth boundary.

B2g 16 to 28 inches, grayish brown (2.5Y 5/2) silty clay loam with common coarse distinct yellowish brown (10YR 5/6) and a few medium distinct mottles of strong brown (7.5 YR 5.6), moderate medium subangular blocky structure, friable, sticky, continuous clay films, very strongly acid, clear wavy boundary.

B 28 to 34 inches, light gray (5Y 7/2) silt loam with many medium distinct yellowish brown (10YR 5/8) mottles, weak medium subangular blocky structure, friable and slightly sticky, some dark gray coats in large cracks, very strongly acid, clear wavy boundary.

II 34 to 40 inches, grayish brown (10 YR 5/2) and dark gray (10YR 4/1) loam with about 15 percent small rounded gravel, common medium distinct yellowish brown (10 YR 5/6) mottles, massive to very weak medium subangular blocky structure, friable, slightly sticky, very strongly acid, clear to abrupt smooth boundary.

IIcg 40 to 55 inches, light brownish gray (2.5 Y 6/2) loamy sand with about 20 percent rounded gravel, coarse blotches of yellowish brown (10 YR 5.6) single grained, loose to very friable, very strongly acid.

Site Characteristics

Location: Dorchester County: Center for Environmental and Estuarine Studies, 3 miles west of Cambridge, Maryland, woods on east side of road between Horn Point Road and Route #343, 3/8 mile north of intersection with Route #343
Vegetation: Loblolly pine, sweet gum, black gum, and red maple
Parent Material: Coastal Plain sediments, silty materials over sands
Physiography: Coastal Plain
Slope: less than 1 percent
Elevation: 12 feet
Drainage: Poorly drained
Permeability: Moderate
Root distribution: Few small roots down to IIc.
Moiture: Ground Water 45 inches
Date: December 15, 1976
Description by: Richard L. Hall

Mattapex Silt Loam
Profile Description

Horizon

Ap 0-10 inches, very dark grayish brown (10YR 3/2) silt loam, weak medium granular structure, very friable, mildly alkaline, abrupt smooth boundary.

B1 10-15 inches, yellowish brown (10YR 5/4) silt loam, weak medium subangular blocky structure, friable, very dark grayish brown filled worm holes, mildly alkaline, clear smooth boundary.

B21 15-24 inches, light yellowish brown (10YR 6/4) silt loam, moderate medium subangular blocky structure, friable, grayish brown thin coats and filled old root channels, mildly alkaline, clear smooth boundary.

B22 24-30 inches, pole brown (10YR 6/3) silt loam, common medium distinct light gray (5Y 6/1) and a few medium distinct strong brown (7.5 YR 5/8) mottles, moderate medium subangular blocky structure, friable, discontinuous clay films, mildly alkaline, abrupt wavy boundary.

IIB23g 30-34 inches, grayish brown (2.5YR 5/2) loam, common medium distinct light gray (2.5YR 7/2) and brownish yellow (10YR 6/6) mottles and few pockets of dark gray (N 4/0), weak coarse angular structure parting to moderate medium subangular blocky, firm, continuous clay films and compressed roots in large cracks, moderately alkaline, clear wavy boundary.

IIAg 34-54 inches, dark grayish brown (10YR 4/2) sandy loam, common medium faint pole brown (10YR 6/3) and a few coarse distinct strong brown (75YR 5/8) mottles, massive in place parting to weak medium subangular blocky structure when disturbed, firm in place, pockets of light brownish gray (10YR 6/2) friable loamy sand, about 15 percent rounded gravel coated with thin clay films, mildly alkaline, clear wavy boundary.

IIIB2g 54 to 69 inches, light gray (2.5Y 7/2) silty clay loam, many medium distinct strong brown (7.5 YR 5/8) and olive gray (5Y 5/2) mottles, weak coarse subangular blocky structure parting to moderate fine subangular blocky, friable, discontinuous clay films and dark grayish brown (2.5Y 4/2) filled old root channels, mildly alkaline.

Site Characteristics

Location: Dorchester County, Center for Environmental and Estuarine Studies 3 miles west of Cambridge, Maryland, 2000 feet north of Horn Point Road and 50 feet east of enterance road.
Vegetation: Corn stubble
Parent Material: Coastal Plain Sediments, silts over medium textured materials
Physiography: Coastal Plain
Slope: less than 1 percent
Elevation: 13 feet
Drainage: Moderately well drained
Permeability: Moderate

Richard L. Hall
Soil Scientist

Bertie Silt Loam
Profile Description

Horizon

Ap 0-8 inches dark grayish brown (10YR 4/2) silt loam, moderate fine granular structure; friable; medium acie; abrupt smooth boundary.

B21 8-15 inches light yellowish brown (2.5Y 6/4) heavy silt loam; faint brown (10 YR 5/2) and light brownish gray (10YR 6/2) mottles; weak medium subangular blocky structure; friable; grayish brown clay skins; slightly acid; clear smooth boundary.

B22 15-25 inches light yellowish brown (2.5Y 6/4) heavy silt loam; common medium brownish yellow (10YR 6/6) and light brownish gray (10YR 6/2) mottles; weak medium subangular blocky structure; friable; light olive brown clay skins slightly acid, gradual boundary.

B3g 25-32 inches light gray (5Y 6/1) silt loam; common fine distinct strong brown (7.5 YR 5/6) and a few coarse faint gray (5Y 5/1) mottles; weak medium subangular blocky structure; firm; medium acid; clear smooth boundary.

IIA-B 32-45 inches; dark gray (10YR 4/1) heavy gravelly loam common meidum distinct strong brown (7.5YR 5/6) and brown (7.5YR 5/4) mottles, weak medium subangular blocky structure; friable; very strongly acid; clear smooth boundary.

IIA-B 45-52 inches; very dark grayish brown (10YR 3/2) gravelly loam; common coarse distinct grayish brown (10YR 5/2) mottles; weak coarse subangular blocky structure; friable; very strongly acid; clear smooth boundary.

IIICg 52-60 inches; light gray (2.5Y 7/2) silty clay loam; common medium prominent strong brown (7.5YR 5/8) and common coarse distinct brown (7.5YR 5/2) mottles; structureless, massive; friable; extremely acid.

Site Characteristics

Location: Dorchester County, Center for Environmental and Estuarine Studies 3 miles west of Cambridge, Maryland, 100 feet north of Horn Point Road and 100 feet east of main entrance road.
Vegetation: Corn stubble.
Parent material: Coastal Plain sediments; silts over medium textured materials.
Physiography: Coastal Plain
Slope: less than 1 percent
Elevation: 12 feet
Drainage: Somewhat poorly drained
Permeability: Moderate
Root distribution: few below 15 inches
Moisture: Moist
Described by: R.L. Hall
Date: November 11, 1976

Map Legend for Soils maps

Symbol	Soil Type
BoA	Bertie silt loam, 0 to 2 percent slopes
BeB	Bertie silt loam, 2 to 5 percent slopes
BeC	Bertie silt loam, 5 to 15 percent slopes
Bx	Bibb silt loam
MsA	Mattapex silt loam, 0 to 2 percent slopes
MsB	Mattapex silt loam, 2 to 5 percent slopes
MsC	Mattapex silt loam, 5 to 15 percent slopes
OhA	Othello silt loam, 0 to 2 percent slopes
OhB	Othello silt loam, 2 to 5 percent slopes
OhC	Othello silt loam, 5 to 15 percent slopes
Ot	Othello silt loam, possibility of ponded water
SU	Sulfihemist
WoA	Woodstown loam, 0 to 2 percent slopes
WoB	Woodstown loam, 2 to 5 percent slopes
WoC	Woodstown loam, 5 to 10 percent slopes

Special Symbols

Pond – Pond

Fill – Fill

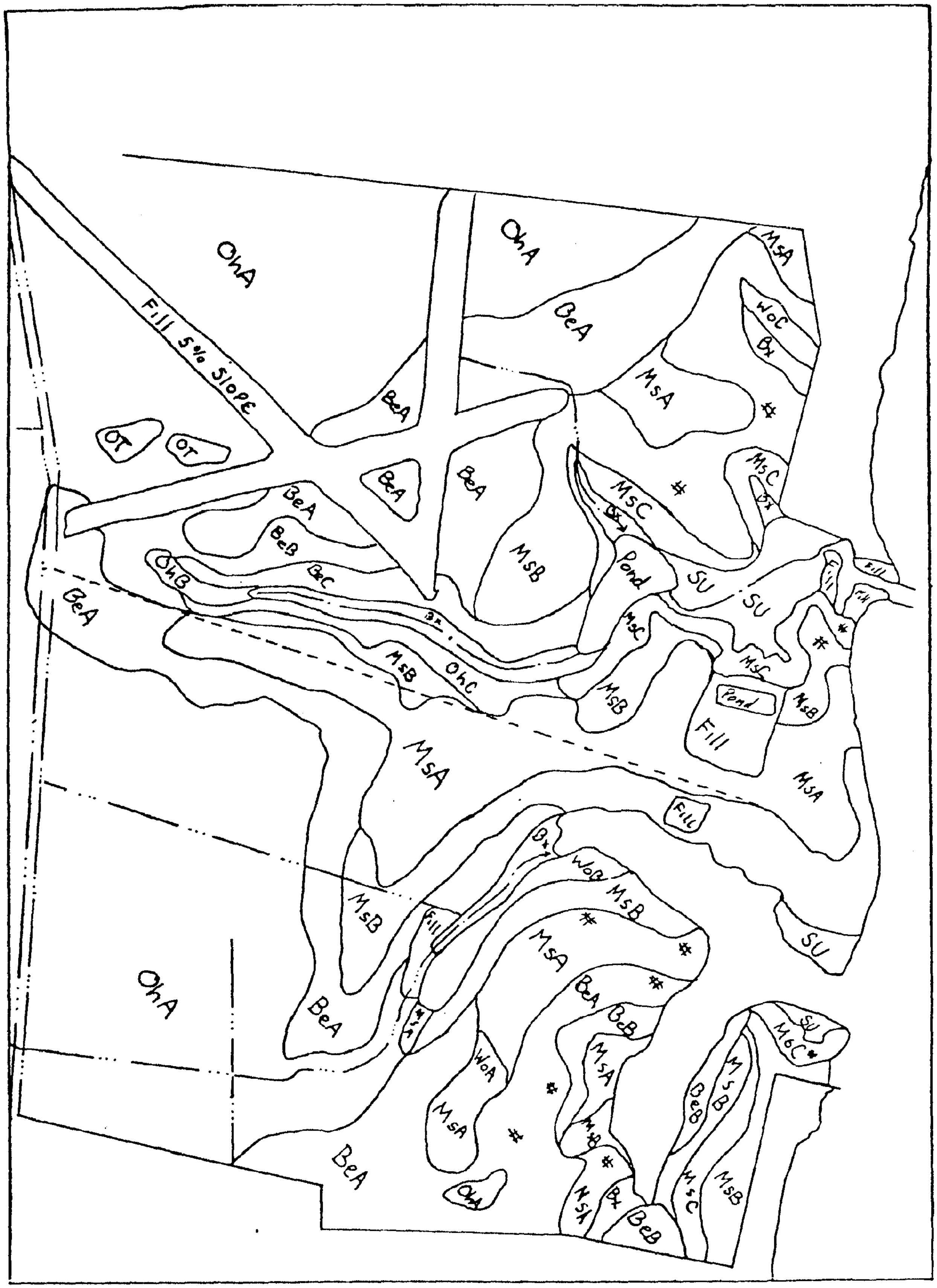
– Kitchen midden

– Wet spot

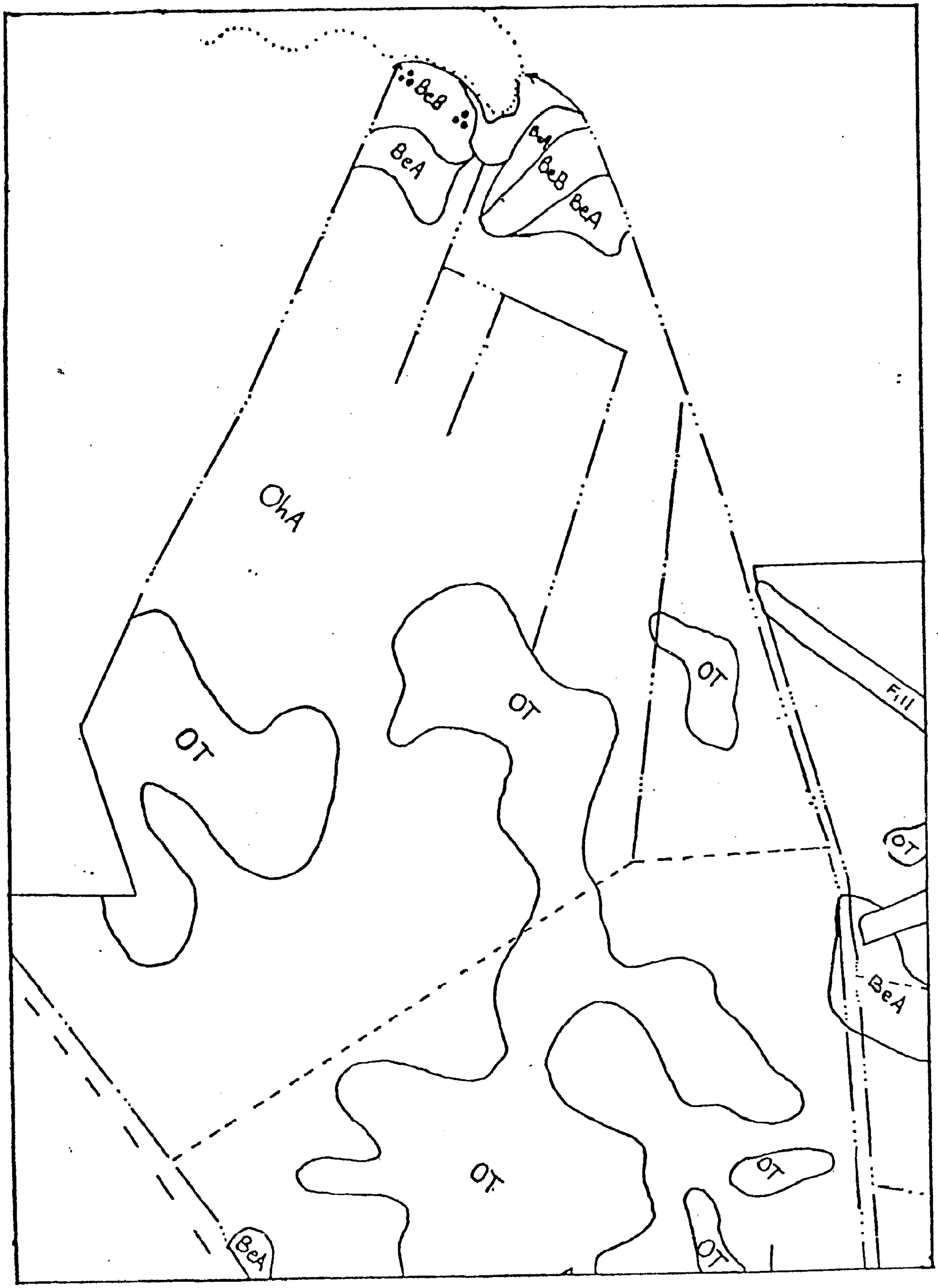
– Peremial stream

Drainage ditch, not crossable with farm machinery

– Gravel



Soils map of agricultural areas, HPEL.

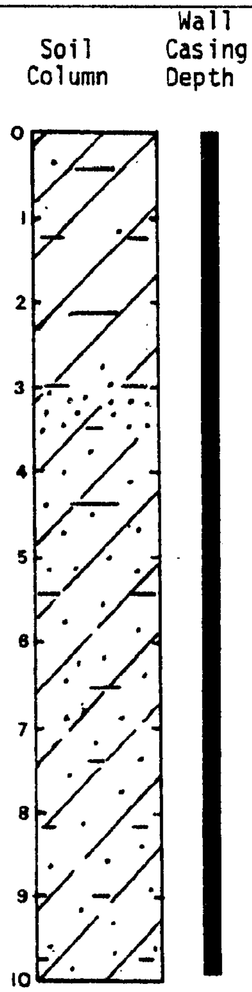


Soils map of wooded land, HPEL.

DRILLING LOG

Hole # A-17	Geologist: Christy	Date: 4-12-77	Max. Depth Augered 10'

Location: Approximately 82' South-west of Md. State Wildlife building, at the side of the road



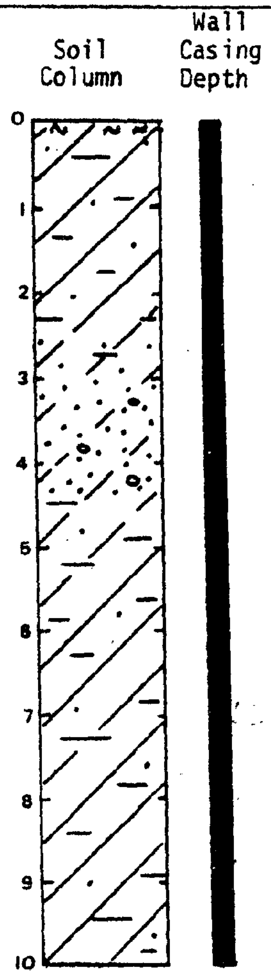
SOIL DESCRIPTION

0 to 3'	Gray-brown SILT, with some Clay and a trace of fine Sand
3' to 3½'	Light brown SAND, with some Silt and a trace of Clay
3½ to 6½'	Light, cream-brown SILT, with some fine Sand and some Clay. Ratio of silt and fine sand variable in any one zone NOTE: water filling hole at about 5'.
6½ to 10'	Light, gray-brown SILT with fine Sand and a trace of Clay.

DRILLING LOG

Hole # W-25	Geologist: Christy	Date: 3-23-77	Max. Depth Augered 10'

Location: Approximately 1250 ft. West of the turn in Lover's lane



SOIL DESCRIPTION

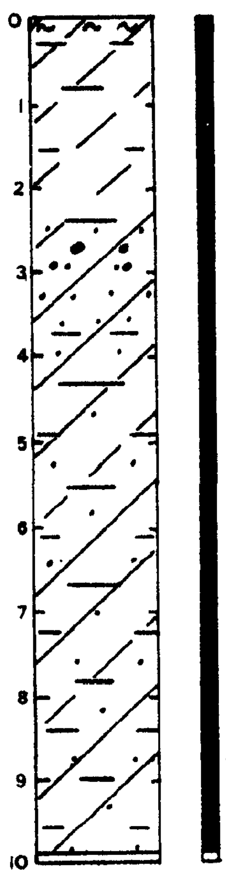
0 to 2½'	Gray-brown, mottled SILT, with some Clay and a trace of fine Sand NOTE: water seepage filled hole at about 2½'
2½ to 3'	Gray-brown, mottled SILT, with Sand and a trace of Clay NOTE: this is a transitional zone
3 to 4'	Yellowish-brown, mottled SAND, with a trace of Silt NOTE: some gravel, but less than 4%
4 to 4½'	Yellowish-brown mottled SAND↔SILT transition
4½ to 10'	Gray-brown mottled SILT, with some Clay and a trace of fine Sand. Very tight and difficult augering.

DRILLING LOG

Hole #	Geologist:	Date:	Max. Depth Augered
W-42	Christy and Jones	5-1-77	9.8'

Location: Approximately 650' east of Lover's Lane on Rt. 343
34' north from edge of woods

Soil Column / Wall Casing Depth



SOIL DESCRIPTION

0-2½' Gray brown SILT, mottled, some Clay and trace of fine Sand

2½'-3' Gray brown SILT with some Sand, some Clay and a trace of Gravel

2'-3¾' Very light brown SILT with some Sand, trace of Gravel

3¾ -9¾' Gray brown SILT with some Clay trace of Sand

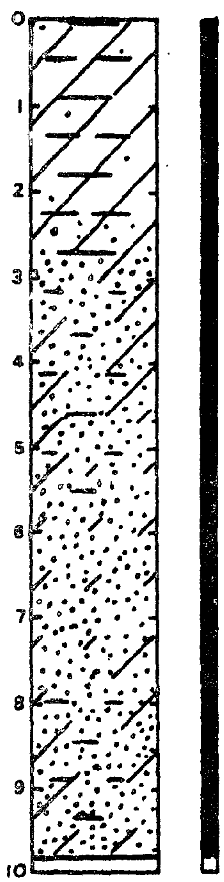
NOTE: somewhat moist at 7'
color change at 8¾' - light chocolate brown
brightly mottled with some gray

DRILLING LOG

Hole #	Geologist:	Date:	Max. Depth Augered
W-149	Christy	9-15-77	9 3/4'

Location: Approximately 84' South-west of Horn Point Road. Along woods Lane opposite the Golf Course Road. and 24' east of lane

Soil Column | Wall Casing Depth



Soil Description

0 to 2½'	Gray-brown mottled SILT, with some Clay and a trace of fine Sand
2½ to 2¾'	Light brown, lightly mottled SILT, with some Clay and some Sand (Transitional layer)
2¾ to 5½'	Lightbrown SAND, with some Silt and a trace of Clay NOTE: this deposit has alternating layers, the more sand rich are light brown and the more silt rich are brightly mottled. Each layer is about 6"thick
5½ to 7'	Light brown to gray blue SAND, with a trace of SILT
7 to 8'	Uniform dark blue gray SAND, with a trace of Silt NOTE: Seepage at about 7'
8 to 9'	Uniform dark blue-gray SAND with some silt and a trace of Clay NOTE: silt in several lenses at a higher percent than Sand