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Effects of Effluent Disposal on a Forest Ecosystem

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COMPLETION REPORT

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LIST OF FIGURES

TABLE OF CONTENTS

ABSTRACT

A forest system in the White Mountains of New Hampshire is evaluated as to its efficiency to renovate waste effluents. There is neither evidence of increased nutrient concentrations in plant components nor evidence of increased growth resulting from applications of nutrient rich waters. Concentrations of phosphorus increased in the litter and soil with a renovation efficiency of 20%. Renovation of other nutrients is considerably less. Recommendations are offered for consideration prior to establishment of other terrestrial waste disposal sites.

MATERIALS AND METHODS

Domestic sewage from the recreational facilities of Mt. Sunapee State Park, Newbury, New Hampshire, is held in septic lagoons for aerobic decomposition. The effluent, injected with chlorine (5 mg/liter), is pumped to the forest and applied at an average rate of 30 liters/m2 each spraying day (Frost et al., 1973). In order to evaluate the capacity of the forest to incorporate nutrients contained in the effluent, six plots (each 0.1 acre, .0405 hectare) were established in the mixed deciduous forest. Four of these plots were bisected by the spray lines and two were located upslope, in an unsprayed portion of the forest, as control plots.

Trees were identified by species and remeasured annually. Forest biomass was estimated from allometric relationships of tree diameter and weight of the components (bole, branch, foliage, root) using the relationships developed by Whittaker et al. (1974) for a similar forest approximately 40 kilometers distant. Supplemental root data were obtained from soil cores and by excavation of pits. Litter standing crop was measured in spring and autumn. Annual fluxes of litter to the forest floor were estimated from twelve 1 m2 litter traps. Fluxes of organic matter and nutrients from litter to soil were estimated from litter bags and tagged branches of assorted size classes on the forest floor.

Litter and plant components were subsampled, oven dried (70°C.), and ground in a Wiley mill at 40 mesh. Soil water solution was collected monthly with ceramic cup sampling tubes at 10 and 30 cm depths as was thrufall and sprayed effluent. Nutrient analyses of these and soil samples were done by the Cooperative Extension Service, Soil Testing and Plant Analysis Laboratory, University of Georgia, Athens, Georgia.

Temperature and precipitation data were obtained from a weather station on Mt. Sunapee. Solar radiation data were available from Durham, New Hampshire. Soil moisture tension on spray and control plots were monitored with tensiometers.

INTRODUCTION

Land disposal systems for waste water renovation utilize the terrestrial ecosystem as a "living filter" by incorporating effluent materials into natural biogeochemical cycles. The efficiency of this renovation system depends upon 1) increased production of the biotic components as greater quantities of nutrients are incorporated into biomass, 2) increased nutrient concentrations in the perennial components, and 3) increased fixed storage in the soil-litter subsystems to prevent nutrient rich waters from contaminating groundwater supplies. Specific objectives of the study reported here were to determine:

i. rates of production in a forest ecosystem which was being utilized for waste water renovation,
ii. quantities of nutrients, particularly nitrogen and phosphorus, in the major components of the ecosystem,
iii. rates of buildup and transfer of nutrients in and between ecosystem components, and
iv. the seasonality of these fluxes relative to seasonal use of the renovation system.

RESULTS AND DISCUSSION

Organization of the following sections relate to the three efficiency criteria given above.

Forest Productivity

Apportionment of nutrients in the forest depends on both biomass and nutrient concentration in ecosystem components. The biomass distribution of spray (2.5E05 kg/ha) and control (2.0E05 kg/ha) plots, both in the upper range of comparable stands (Rodin and Bazilevich, 1967), is summarized in Table 1. Also presented are nutrient pool magnitudes by forest component (Table 2). It should be emphasized that the different standing pools of organic matter and nutrients for spray and control forests do not represent response to effluent application. The important parameter is the rate of accretion. The average biomass increment of the control plots from 1974 to 1976 was 6279 kg/ha/yr, while on the spray plots it was 6032 kg/ha/yr. These slight differences are not significant and we are forced to conclude that the efficiency of this renovation system has failed the first test.

In addition, spraying is affecting species composition of the forest by increasing white pine mortality. Some of this loss is being countered by increased production of other species. Because of the nutrient relations of white pine, discussed below, this problem may not be excessively severe with reference to renovation. Sopper and Kardos (1973) have also reported reduced growth and increased mortality of conifers subjected to spraying.

Nutrient Concentrations in Perennial Components

High nutrient values characteristic of red oak increase its importance to nutrient cycling beyond that which would be indicated by its biomass. White pine, however, was less important than its very high biomass would indicate due to its low nutrient concentrations. Although equal in biomass to red maple (30%), white pine contributed only 10% of N to the annual cycle. Forests dominated by oaks have a greater requirement for

Table 1. Stand summary statistics (1976).

	Spray	Control
Density (stems/ha)	1149	1322
Standing crop biomass (kg/ha)	251877	200900
Biomass increment (kg/ha/yr)	6032	6279
Litterfall (kg/ha/yr)	3888	3729

Table 2. Summary of forest organic matter and nutrient pools for effluent treated and untreated portions of the forest.

Component	Standing Pool (kg/ha)		N		P		K (kg/ha)		Ca		Mg	
	spray	control	s	c	s	c	s	c	s	c	s	c
overstory												
foliage	3304	2926	70	57	63	52	36	33	321	284	5	4
branch	42934	31352	234	166	318	212	232	168	386	229	17	15
bole	140293	110642	259	177	294	189	106	81	8	6	-	-
root[†]	46752	40140	86	64	98	69	35	29	3	2	-	-
			649	464	773	522	409	311	718	521	22	19
understory												
herbaceous	186	71	3	1	.4	.2	3	1	.2	.2	.2	.1
seedlings	1016	1157	6	7	1	1	4	4	3	3	.4	.4
			9	8	1.4	1.2	7	5	3.2	3.2	.6	.5
detritus												
leaf litter	44383	30199	568	459	58	43	186	142	293	230	31	14
branch litter	3326	1697	22	10	4	2	15	8	29	14	2	1
standing dead	34750	25700	70	44	8	3	31	21	1	.8	-	-
down dead	19000	22730	38	39	4	3	17	19	.8	.7	-	-
			698	552	74	51	249	190	324	246	33	15
litterfall												
leaf	3304	2926	24	23	30	30	18	18	360	350	5	4
branch[‡]	584	803	3	4	4	5	3	4	5	6	-	-
			27	27	34	35	21	22	365	356	5	4
soil												
0-50 cm depth			11380	10900	102	71	129	157	423	404	66	71

[†] root nutrient pools calculated from bole nutrient data

[‡] assuming no translocation from branches before branch fall

nutrients, and consequently a greater uptake, than do pine dominated forests (Duvigneaud and Desmet, 1975). With this in mind species composition should be an important criterion in the selection of an effluent disposal site.

The age of the forest should also be considered in site selection. Absence of increased growth accompanying nutrient additions has been reported in mature coniferous stands (Holmes and Cousins, 1960; Leigbundgit and Richard, 1957) while others (Heilman, 1961; Heilman and Gessel, 1963; Mayer-Krapoli, 1956) have observed growth responses to nitrogen applications. While little information is available of hardwood response to fertilization, Sopper and Kardos (1973) reported that applications of high concentrations of elements produced leaf concentration differences of N, P, and Mg with no change in K or Ca. However, high levels of application and subsequent increased leaf concentrations did not greatly increase growth in the mixed oak-red maple forest.

No significant differences of nutrient concentrations in tree components were detected and similar seasonal patterns of nutrient distributions were evident in all components in both spray and control areas. Approximately 1/3 of all nutrients absorbed by trees are released in leaf fall (Table 3). With this magnitude of turnover, even if higher concentrations had occurred in sprayed trees, a significant amount of added nutrient would not be removed and placed in long term storage. With no evidence of increased nutrient concentrations in perennial tree components, we must conclude that the system has failed the second test of efficiency.

Nutrients in Fixed Storage in the Soil-Litter System

With little additional long term storage of nutrients in trees, the burden of nutrient removal falls to the soil-litter systems. Logically, this is the component upon which we must rely when working with crops which are not removed from the site. The litter component contains approximately 50% of the nutrients in this subsystem. Microbial populations within this layer regulate elemental cycling and are affected by effluent additions to the forest floor.

Table 3. Annual nutrient balance.

	N		P		K		Ca		Mg	
					(kg/ha.yr)					
	s	c	s	c	s	c	s	c	s	c
Increment	55	55	72	68	46	49	69	59	1	1
Return	27	27	34	35	21	22	365	356	5	4
Uptake	82	82	106	103	67	71	434	415	6	5

An indirect measurement of microbial activity was obtained from litter bag studies. While no significant differences were detected in annual decay rates of leaf litter or of branch litter between species, litter bags placed on site in mid-summer showed slower rates of decomposition on the spray area, suggesting that effluent application is temporarily inhibiting litter decomposition and nutrient release. Possible causes of this phenomena include reduced microbial activity resulting from abnormally high moisture contents of the litter layer, associated reduced oxygen (Brandt et al., 1964), and lowering of litter temperature (Richards, 1974).

The detritus-soil subsystem is the only component which evidences differences between effluent treated and non-treated portions of the forest (Table 2). Leaf litter on the non-treated area is less than 70% of that on the treated area with proportional differences in all nutrients. This difference is too large to be totally attributable to the slight (non-statistically significant) difference in foliage production and annual leaf litter fall and must also reflect changes in decomposition associated with effluent applications. Irrespective of the mechanism of litter buildup, early concerns that increased water and nutrient availability would stimulate microbial populations and result in rapid removal of litter from the forest floor were unfounded.

Further examination of data presented in Table 2 indicates that, with the exception of P, less than 20% difference exists between soil nutrient pools on two study areas. Nutrient differences resulting from increased retention occur primarily within the detrital component of the system, probably in the F layer (the colloidal sized litter particles) of the litter layer. Only with regard to P do we see evidence of nutrient retention in the soil component. The soil phosphorus pool in the treatment area is nearly 50% greater than the control with the top 20 cm of soil having approximately twice the available P as the control.

A simple flow chart (Figure 1) facilitates examination of P restitution. In Figure 1a we consider the control portion of the forest. Calculated uptake (Table 3) is 103 kg/ha/yr, with 68 kg incorporated in growth increment and 35 kg returned in litterfall. With precipitation input taken as 0 (Likens et al., 1977), a calculation is made as to the minimum weathering rate of parent materials with the additional assumption that no P is leached from the system. The P flux from parent material

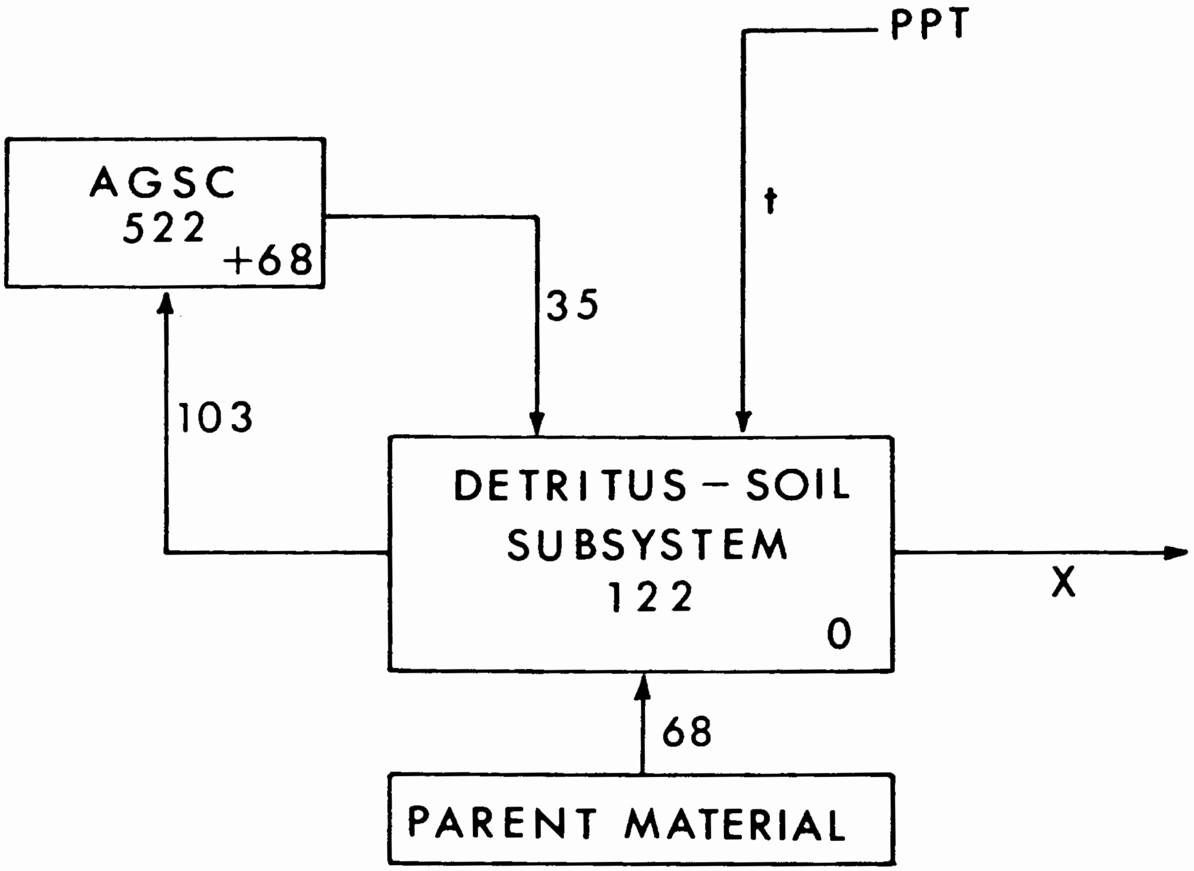

Figure 1a. Phosphorus cycles in untreated stand and estimation of weathering rate assuming no net change in soil P. Units are in kg/ha and kg/ha/yr.

calculated in this manner may also be considered as net influx to the soil block irrespective of the efflux magnitude (X) through leaching and deep drainage. This value, 68 kg/ha/yr, is then used in the examination of P movement in the effluent treated stand, Figure lb. With input of 53 kg/ha/yr (Table 4), assuming no greater loss of P from the stand than normal, there would be an increase in the detritus-soil subsystem equivalent to 49 kg/ha/yr. After five years of effluent additions, the soil system in the treated portion would contain 245 kg/ha more P than the control area. In fact, the difference is only 54 kg/ha, indicating that leaching, drainage, and runoff must equal 38 kg/ha/yr, for a renovation efficiency of 20%.

We have been able to demonstrate a degree of renovation for one element, P. This, plus the elevated nutrient concentrations in the litter, provide partial support for the third criteria of efficiency. Contributing to the low degree of renovation efficiency are the factors of shallow soils and mass flow during periods of effluent application as evidenced by zero tension readings from tensiometers resting on the hardpan layer. Saturated flow is not occurring uniformly throughout the soil block; rather it is probably restricted to root channels and other localized areas of structural non-uniformities.

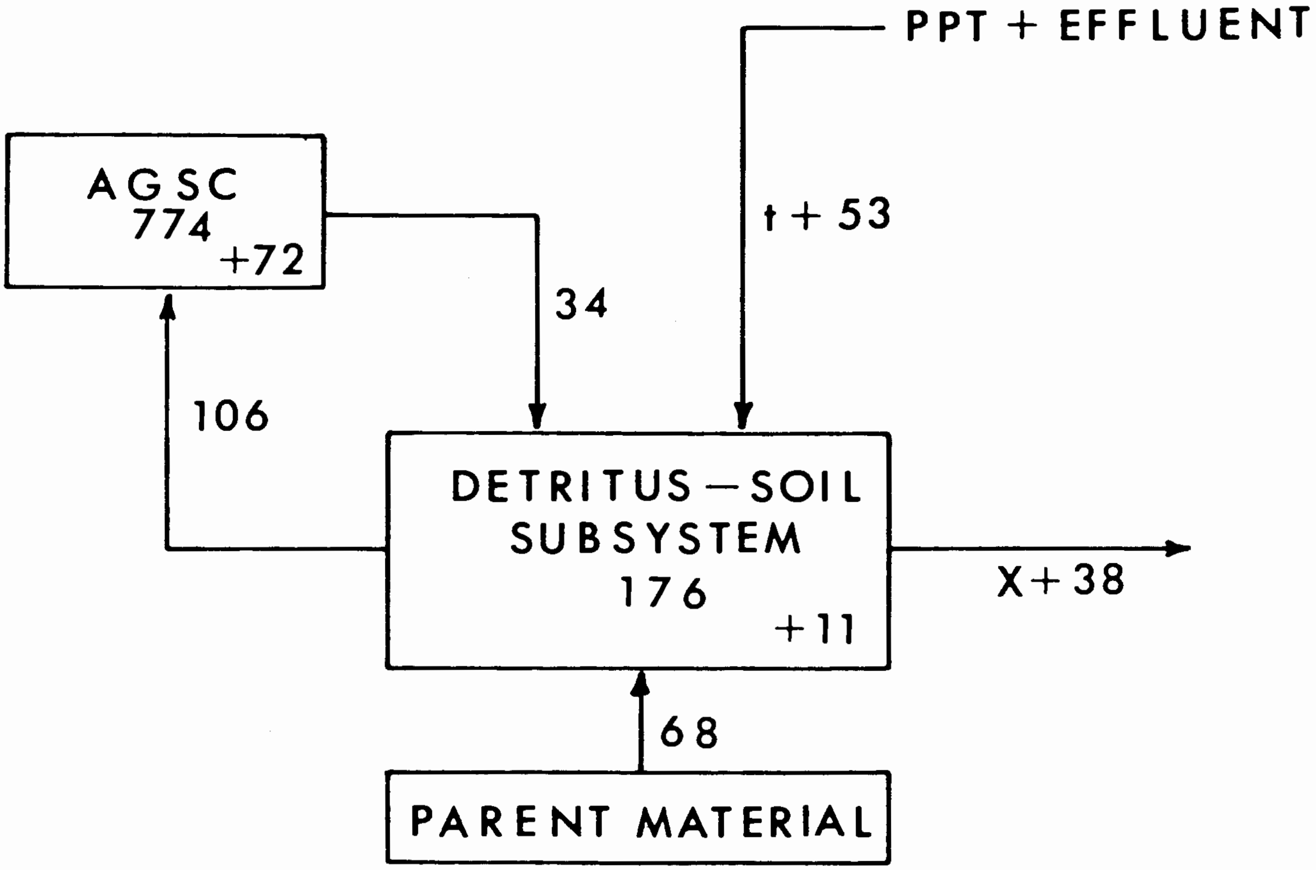

Figure 1b. Phosphorus cycles in effluent treated stand and estimation of P efflux from the system.

Table 4. Nutrient application by waste water.

NO3-N	NH4-N	P	K	Ca	Mg
		(kg/ha/yr)			
152	336	53	131	76	154

SUMMARY AND RECOMMENDATIONS

An examination of the effluent disposal system at Mt. Sunapee State Park, New Hampshire, in light of the efficiency criteria presented earlier, suggests the following:

1) Nutrient and water additions associated with effluent applications did not result in increased plant production.
2) There is no evidence of increased nutrient concentrations in perennial tree components.
3) The effluent treated stand exhibited a greater litter layer with concomitant quantities of nutrients than found in the untreated stand.
4) Calculated renovation efficiency for P, the element showing greatest retention in the soil-letter subsystem, was only 20%.

Specific recommendations can be presented from this study which should be beneficial in the design of other facilities for land applications of wastes.

1) Every effort should be made to locate effluent disposal sites on soils which have good properties for septic leach fields. Selection of the wrong soil type greatly reduces renovation efficiency.
2) If forest systems are to be used for renovation purposes, then we recommend that coniferous stands be avoided because of their susceptibility to altered soil-water status.
3) We also recommend that stands in an early stage of growth (the log-linear phase) be selected to take advantage of the natural period of maximum growth and nutrient incorporation.
4) If the site is to be used for a long period of time, it is imperative that the biological material (trees, grasses, etc.) be periodically removed from the site. If this is not done the natural intrasystem cycles of nutrients (eg. litterfall) will greatly reduce renovation efficiency. Meeting this requirement will also insure satisfying recommendation 3.

5) We strongly urge consideration of forage crop use. Obvious advantages include their greater water and nutrient requirements, and that they are annually removed from the site and are cycled through cattle or other intermediates prior to man's re-ingestion of these nutrients.

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