Septic tank wastewater disposal systems as phosphorus sources for surface waters

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Phosphorus has been identified as the key element controlling growth of algae and aquatic plants in many water bodies. One of the potential sources of phosphorus that must be considered in any evaluation of nutrient loading to a water body is septic tank wastewater disposal systems. While phosphorus ordinarily becomes tightly bound in soils, some sand and gravel areas may allow transport of phosphorus from septic tank wastewater disposal systems to surface waters.

The Voyager Village recreational development located in northwestern Wisconsin (Burnett County) has been criticized because of potential problems of ground and surface water contamination resulting from the possible transport of effluent from septic tanks located within the development. Of primary concern was the potential for aquatic plant nutrient (nitrogen and phosphorus) contamination of surface waters, which could result in excessive growth of algae and other aquatic plants in nearby lakes. To investigate the potential for phosphate and other contaminant transport from septic tank wastewater disposal systems that are being used in the development area, a several-year field study was conducted to provide data necessary to determine the likelihood of significant phosphate transport from the septic tank wastewater disposal system effluent to area surface waters. The results of this study are presented in this paper.

PREVIOUS STUDIES

A review of the literature by Jones and Lee [1, 2] on the transport of phosphorus through soils has shown that, in general, various types of soil particles have strong tendencies for interacting with phosphorus, which would tend to minimize phosphorus transport in ground waters. The potential of a soil to remove phosphate from septic tank wastewater disposal system effluent, however, is controlled by the mineralogy of the area soils rather than by the soil particle size. Clay minerals and iron and aluminum oxides have relatively high capacities for phosphate sorption (immobilization). In calcareous (limestone) soils, phosphate would tend to be immobilized by precipitation reactions, forming hydroxyapatite. It has also been shown that the capacity of a soil to reduce effluent phosphorus concentrations is not necessarily finite.

Previous field studies have demonstrated that most soils, even medium sandy soils, exhibit substantial ability to reduce phosphate concentrations. Reductions found were typically in excess of 95% within a few meters of the tile fields studied. Greatest phosphate transport has been found in aquifer materials consisting of coarse sand or gravel. Even in this type of soil system, substantial phosphorus removal has been observed within short distances of the tile field.

For areas where soils cannot effectively remove phosphate from septic tank effluent, modifications of the septic tank system can be made to remove phosphorus. The efficacy of such a home unit was recently demonstrated by Brandes,[3] whose system removed up to 99.6% of the phosphorus from wastewater introduced into the studied septic tank.

Even though the literature seems to clearly indicate that the likelihood of transport of phosphorus from septic tank effluent to surface waters is small, some pollution control agencies continue to raise questions about the use of septic tanks in recreational lake developments and other areas near water bodies because of the potential for their effluents to cause in-

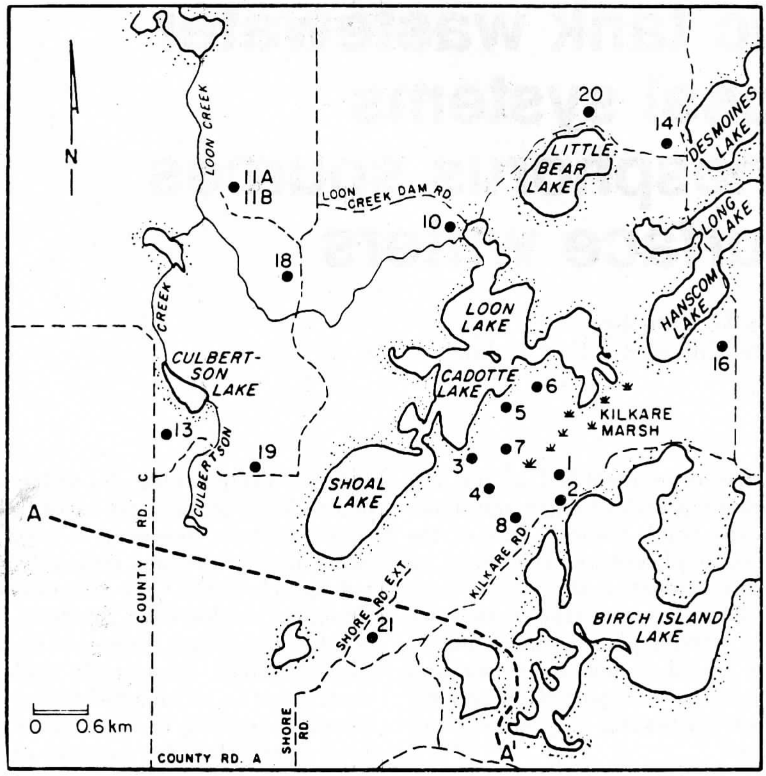

FIGURE 1. Voyager Village development area—location of hydrologic test wells.[4]

creased fertilization of the waterbodies in the region. In several recent instances, inappropriate significance has been given to the phosphorus load contributed by septic tanks to surface waters. It was this type of situation that led to the initiation of this study of the Voyager Village development.

EXPERIMENTAL PROCEDURES

The Voyager Village development area is shown in Figure 1. Using the hydrologic test wells also shown in the figure, the groundwater hydrology of the area was defined by Stephenson [4] as a basis for establishment of the septic tank effluent monitoring study. An existing septic tank system in the vicinity of Wells 3 through 7 was chosen for monitoring. Observation wells were placed in that area as shown in Figure 2. Wells A through J were installed at a depth of 1.5 m (5 ft) below the water table; Wells K, L, and M to 4.6 m (15 ft) below the water table. Later during the study, two additional wells, N and O, were drilled also to a point 1.5 m below the water table. Most of these wells were sampled during the period February 1972 to January 1976.

Although the analysis program was occasionally altered during the course of the study, the following parameters were generally measured: specific conductance, pH, alkalinity, Na^+, Cl^-, K^+, Mg^{2+}, Ca^{2+}, soluble orthophosphate, total phosphorus, NH_4^+, NO_3^-, and organic N. Phosphate analyses were carried out in accordance with the phosphomolybdate method in "Standard Methods" [5-7] or equivalent; analysis for other parameters were also carried out in accord with methods outlined in "Standard Methods" [5-7] or equivalent.

CHARACTERISTICS OF AREA

According to Blackman *et al.*,[8] the climate of Burnett County is continental. Mean temperatures drop below freezing in mid-November; lakes freeze soon after. The average date of the first freeze is September 12; the average last freeze is May 31. The average annual precipitation for Burnett County is about 78 cm; the average runoff is about 24 cm. Maximum precipitation occurs in June; however, highest runoff usually occurs during April in association with the snow melting.

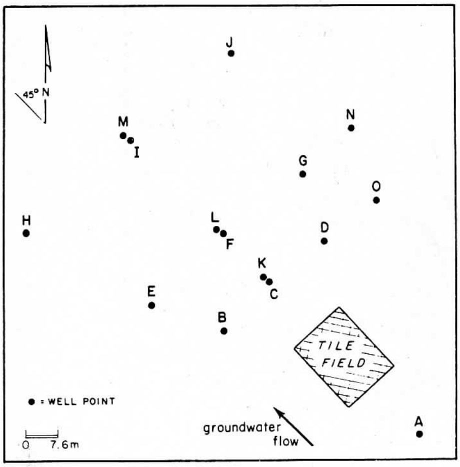

FIGURE 2. Test wells for septic tank monitoring study—Voyager Village development site.[9]

QUALITATIVE DESCRIPTION OF SOILS AND GEOLOGY

N. E. Isaacson & Associates Inc. began an investigation of the hydrologic and hydrogeologic characteristics of the Voyager Village development area in April 1970. These studies were conducted by Stephenson[4] and Huff and Stephenson.[9] They found that stratified sandy soil deposits, mostly glacial drift outwash, characterized the area. The deposits were products of glacial meltwater stream deposition that occurred in recent geologic time. Deposits of the last glacial episode were subsequently covered by younger outwash containing large, melting ice blocks. The hummocky topography of the area was created as the buried ice blocks melted.

The glacial drift deposits are a fine- to medium-grained sand; mean grain size diameter was 0.125 to 0.5 mm. The sand deposits could generally be vertically zoned into two rather distinct and recurring units.

- Sand: dark red brown; fine- to medium-grained; sometimes silty; generally 3 to 9 m thick; permeability ranged from 0.4 to 1.2 $l/cm^2 \cdot d$ overlying
- Sand: light red brown; medium- to coarse-grained; permeability ranged from 1.2 to 4 $l/cm^2 \cdot d$; thickness unknown but estimated at maximum of 46 m.

Stephenson[4] indicated that these layers likely overlaid a crystalline bedrock composed of granite-like Precambrian rocks.

Table I presents representative grain size characteristics for selected and representative samples taken at or near the water table elevation within three wells in the area. The predominant sand grain size at or near the water table was within the medium-grain range, 0.25 to 0.5 mm diameter. The water table occurred in either of the two vertical soil zones described, depending on the location within the development area. According to Huff and Stephenson,[9] the water table was generally within the upper, finer-grained soil east of

TABLE I. Sieve analyses on selected samples—Voyager Village, Burnett County.

Sieve Size	Well No. 2 Weight (g)	Well No. 2 % Total	Well No. 3 Weight (g)	Well No. 3 % Total	Well No. 6 Weight (g)	Well No. 6 % Total
10 mesh (2 mm)[a]	28	1.31	27	1.27	—[b]	—[b]
16 mesh (1.2 mm)	228	10.63	219	10.34	0.5	0.05
40 mesh (0.42 mm)	820	38.29	1 240	58.52	17	1.60
60 mesh (0.25 mm)	788	36.74	379	17.89	375	35.34
80 mesh (0.15 mm)	185	8.62	153	7.22	489	46.09
>80 mesh (0.15 mm)	96	4.48	101	4.77	179	16.87
Totals	2 145	100.07	2 119	100.01	1 061	99.95

[a] Wentworth Scale for sand:

very coarse-grained	1.0 –2.0 mm
coarse-grained	0.5 –1.0 mm
medium-grained	0.25 –0.5 mm
fine-grained	0.125 –0.25 mm
very fine-grained	0.0625–0.125 mm

[b] No contribution made from that fraction. Cited reference.[4]

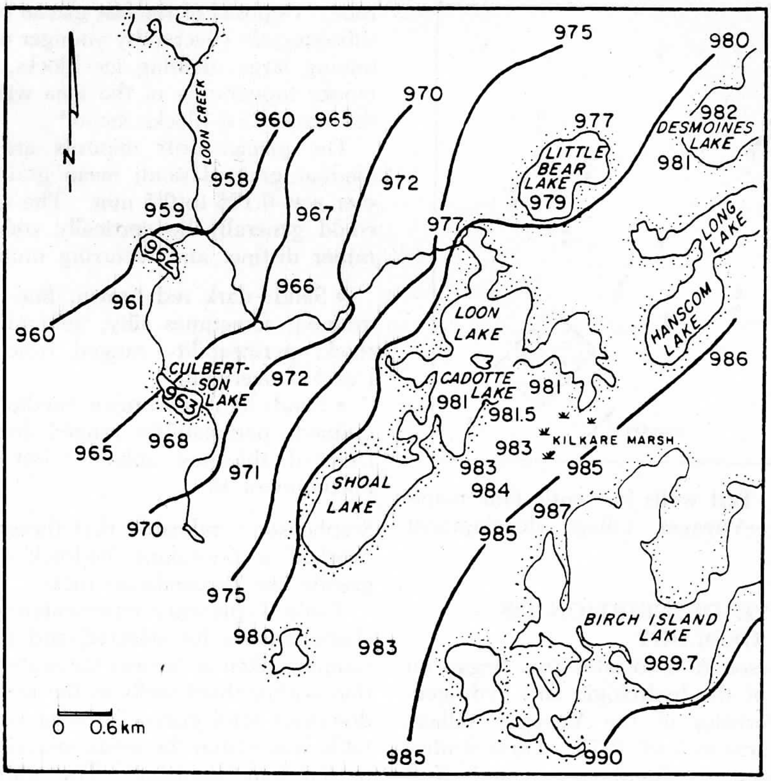

FIGURE 3. Groundwater flow pattern—Voyager Village development site water table elevations on October 17 and 21, 1970. Lake surface elevations on October 3, 1970 (elevations in feet above mean sea level).[4]

Shoal and Cadotte Lakes and within the lower, coarser-grained sands west of that position. They attributed this to the coincidence of the mean water table level in the Shoal and Cadotte Lakes area (299 to 300 m elevation) with the average elevation of the fine/coarse-grained sand boundary (299 ± 1.5 m elevation).

SORPTION TESTS

The results of phosphate sorption tests run on the soils of the study area are presented in Table II. Examination of these data shows that the various samples sorbed from 1 to 5 mg P/100 g soil in 24 hours. This amount of sorption is small when compared with what would be expected in typical clay soils. Various clay mineral soils have been found to sorb, at neutral pH, from 0.03 to 0.07 m*M* phosphorus per gram solid (93 to 217 mg P/100 g solid) at equilibrium.[10] Although the behavior of various types of natural soils from other areas under the particular test conditions used was not generally known, the results of the Voyager Village development area soil tests tended to show low short-term sorption capacity. However, tests of this type do not adequately measure long-term sorption and precipitation such as that associated with hydroxyapatite formation. Comparison of the sorption values with the sorption maxima reported in Tofflemire *et al.*[11] and Ellis and Erickson [12] shows that the amounts of P sorbed by these samples (1 to 5 mg P/100 g) were at the lower end of the range of maximum sorption reported in the literature (2 to 49 mg P/100 g). If higher concentrations had been incorporated in this testing, it is likely that greater sorption capacity would have been found.

HYDROLOGY AND WATER QUALITY

Available water table and surface water elevations for October 1970 as presented by Stephenson [4] are shown in Figure 3 and indicate that the ground water in the Voyager

TABLE II. Phosphate sorption tests on the Voyager Village development area soil (sorption time = 24 hours).

Well number[a]	mg P/100 g solid
6	2.2
6	1.2
9	4.0
9	4.3
17	3.4
17	1.9
18	4.0
18	3.1
24	2.8
24	2.1
38	3.4
38	5.0

Note: Samples provided by Owen Ayres & Associates.
[a] Numbers do not necessarily correspond to monitoring well numbers.

Village development area moved from the southeast to the northwest. According to Stephenson [4] surface water movement was also in this direction, toward the St. Croix River. Estimated permeability values in the sand layers at the wells averaged from 1.2 to 2.4 l/cm²·d.[9] The recharge for the development area ground water appeared to be southeast of Birch Island Lake.

In general, ground water in the development area was found to move in a simple flow pattern. The surface topography of the area apparently had no influence on the direction of groundwater movement. According to Huff and Stephenson,[9] this appeared to be true both for the different seasons and for different conditions. For most, if not all lakes within the Voyager Village development boundaries, ground water entered lakes from the east and southeast perimeters and reentered the groundwater system along the west and northwest perimeters of the lakes.

Groundwater velocity. As discussed by Stephenson,[4] the water table gradient for that portion of the development area between Birch Island and Shoal-Cadotte Lakes is about 1 m/1 000 m. An estimate of groundwater flow volume per metre width of flow path in 46 m of soil was between 242 and 2 019 l/d. The 242 l/d estimate was for the development between Birch Island and Shoal-Cadotte Lakes. Groundwater velocities were calculated to range from 0.15 to 1.2 m/d. In the area of immediate interest where the septic tank study

TABLE III. Chemical analysis of the well point samples from Voyager Village project collected in July 1970 by D. A. Stephenson.

Parameter[a]	Well Point Number 1	2	3	4	5	6	7	8	10	11A[c]	11B	13	14	16	18	19	20	21
pH	7.5	6.6	7.5	6.4	7.0	6.9	7.6	6.9	6.7	—	6.9	6.7	7.0	7.2	7.1	7.1	6.9	6.7
Specific conductance μmhos/cm at 21°C	440	101	251	64	113	265	141	120	91	—	118	97	66	95	220	220	110	97
Turbidity (JTU)	5	0	11	19	0	10	11	0	17	—	—	17	0	15	0	0	8	17
Na^+	12	1.6	4.0	1.5	2.0	5.4	3.3	2.3	1.7	—	3.4	3.7	2.0	3.4	7.2	4.3	2.7	4.3
Mg^{2+}	15.5	2.5	6.5	2.5	6.0	6.5	5.5	5.0	4.0	—	4.1	3.0	2.5	3.0	7.0	15.5	3.5	3.0
Ca^{2+}	50.0	5.5	23.0	3.0	7.0	16.0	12.5	7.0	8.0	—	8.0	5.0	4.0	5.0	19.0	44.0	10.0	5.0
NO_3^--N	0.7	0.15	0.30	0.15	0.08	0.60	0.15	0.07	0.08	1.40	0.17	0.70	1.6	1.0	0.45	0.40	0.15	1.0
NH_4^+-N	0.15	0.45	0.60	0.21	0.11	0.02	0.50	0.01	0.03	0.06	0.09	0.12	0.11	0.10	0.06	0.05	0.12	0.30
Total P	0.4	0.34	0.08	0.06	0.02	0.16	0.13	0.30	0.20	0.12	>4	>4	0.16	0.36	0.77	>4	0.24	0.58
Soluble ortho P[b]	0.007	0.006	0.003	0.001	0.001	0.005	0.005	0.004	0.006	0.08	0.01	0.04	0.005	0.001	0.001	0.013	0.004	0.005
Cl^-	3.0	2.5	12.5	2.5	2.5	13.5	5.0	5.0	2.0	—	5.5	3.0	3.5	4.0	15.5	2.0	4.0	4.5
Fe "soluble"[b]	0.03	0.16	0.01	0.07	0.03	0.03	0.03	0.03	0.11	0.03	0.08	0.4	<0.01	0.03	0.07	0.03	0.13	0.07
Fe total	0.05	0.21	0.23	6.42	2.63	0.47	0.03	0.82	0.98	—	15.1	5.0	1.25	1.40	1.41	0.3	0.23	2.16
Alkalinity as $CaCO_3$	168	38	115	29	59	99	70	45	45	—	62	33	18	33	82	178	52	34

Note: Many of the samples collected contained large amounts of suspended solids that arose from the drilling of the well points. These turbidity, total iron and total phosphate values are expected to be much larger than normally found in ground waters as a result of this contamination.
[a] All values reported as mg/l except pH, specific conductance and turbidity.
[b] Soluble defined as passage through 0.45 μm pore size membrane filter.
[c] Insufficient sample collected for complete analysis.

was conducted, a velocity of about 0.3 m/d appeared to be average.

Groundwater quality. The 21 hydrologic test wells were sampled once in July 1970. The values of the various physical and chemical parameters measured are presented in Table III. Specific conductance values ranged from 64 to 440 μmhos/cm at 21°C; the majority of the well water samples had specific conductance values between 100 and 200 μmhos/cm. The contamination of ground waters by septic tank effluents would be expected to increase the total amounts of salts considerably above the levels found in the wells sampled. The high value of 440 for Well 1 is somewhat surprising since Wells 2, 3, 4, 7, and 8 are located in the same general area and all show values that are more in accord with what is expected. The calcium and alkalinity concentrations were also high in Well 1. It appears that this well was in an area where the ground water had had the opportunity to pick up significant amounts of calcium and carbonate species from the detrital limestone in the region.

Nearly all values for soluble orthophosphate were less than 0.01 mg P/l. The total phosphorus concentrations found in these wells were not generally characteristic of the ground waters since they represented the phosphorus associated with the high turbidity (suspended solids) that resulted from the recent placement of the wells relative to the well sampling. Generally, turbidity values in ground waters are low and frequently zero because of the filtration of the particulate matter by the aquifer material.

The total iron included iron that resulted from the contamination of some of the water by the well point driving operations. The soluble iron represented that iron that would pass through a 0.45-μm pore size filter and was probably, in this case, iron that was in a finely divided particulate form. As indicated by ammonium concentrations in excess of 0.1 mg N/l, the aquifer materials of this area likely have a low sorption capacity for ammonium.

From an overall point of view, the ground waters in the Voyager Village development area were of high quality at the onset of the study. Additional discussion of the characteristics of the study area may be found in Jones and Lee.[1, 2]

RESULTS

Septic tank use. The septic tank-tile field wastewater disposal system monitored for this part of the study went into operation on May 20, 1971, serving a middle-aged couple. This couple resided on the property for 9 months each year during the spring, summer, and fall. They used an automatic washer with a cold water powdered detergent. There was no garbage disposal in use, but a dishwasher was installed in May 1973.[13]

Observation well monitoring. The observation wells (Figure 2) were sampled nine times during the period February 1972 through January 1976. Detailed presentation of the data on the approximately 15 parameters measured in the 13 to 15 wells sampled on each of these occasions has been made by Jones and Lee.[1, 2] Table IV describes the chemical characteristics of the ground water monitored at the onset of the study, after the septic tank system had been used for about 6 months. At this sampling, the specific conductance, sodium, and alkalinity values indicated that septic tank effluent had migrated as far as Well F. The calcium concentration was greater in the deeper wells than in many of the more shallow ones and roughly corresponded to the alkalinity values that were also generally greatest in the deeper wells. Since increases in specific conductance were not noted in the deeper wells, it appears that the septic tank effluent was causing dissolution of calcium carbonate or contained elevated calcium and bicarbonate concentrations at that level.

None of the available forms of aquatic plant nutrients (soluble ortho P, nitrate, ammonium), total P, or organic N showed increased concentrations immediately down groundwater gradient from the septic tank tile field. Organic N values were all slightly lower down groundwater gradient from the tile field than upgradient.

As the study progressed and as the septic tank was used longer, the pattern of septic tank effluent flow, as traced by specific conductance and chloride, became more pronounced. By January 1973, specific conductance values indicated the presence of septic tank effluent in the first tier of wells and at least as far down groundwater gradient as Wells F and L. Higher chloride and nitrate concentrations were also found at Well C, but not beyond that point. There was no detectable movement of soluble orthophosphate or ammonium, however, from the effluent into the ground water at these wells.

Table V presents data from the analyses of selected groundwater samples collected on October 10, 1974. The specific conductance, chloride, calcium, magnesium, nitrate and total

TABLE IV. Voyager Village septic tank monitoring study observation well data (February 16, 1972).

Parameter	Well Point												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Specific conductance μmhos/cm @ 20°C	52	55	63	50	45	73	58	40	56	39	56	73	55
pH	6.2	6.2	6.2	6.0	6.0	6.2	6.1	6.3	6.0	6.1	6.4	6.6	6.3
Cl^-	2.3	2.3	2.3	1.8	1.8	1.2	0.6	1.8	1.8	1.2	2.3	1.8	1.8
Na^+	1.2	2.1	2.4	1.8	1.4	2.2	1.8	1.5	2.3	2.1	1.9	2.0	2.1
K^+	1.1	0.8	0.8	0.2	0.6	1.1	0.8	0.8	0.2	0.4	0.8	0.8	0.9
Ca^{2+}	4.8	6.9	5.9	4.5	4.5	10.1	5.4	3.7	5.2	3.1	5.8	9.2	6.0
Mg^{2+}	2.8	0.7	3.2	2.8	2.4	1.4	1.4	2.2	3.6	2.4	3.2	2.8	2.3
Alkalinity as $CaCO_3$	13.5	18.0	22.5	15.0	13.5	21.0	15.0	13.5	13.5	10.5	28.5	31.5	21.0
SO_4^{2-}	12	10	10	10	9	9	18	7	10	9	9	8	8
Soluble ortho P	0.005	0.004	0.004	0.005	0.004	0.006	0.004	0.004	0.006	0.004	0.004	0.008	0.007
Total P	0.02	0.019	0.019	0.034	0.016	0.064	0.062	0.024	0.079	0.025	0.016	0.012	0.011
NH_4^--N	0.04	0.06	0.05	0.08	—[a]	0.08	0.05	0.04	0.08	0.06	0.04	0.06	0.04
NO_3^--N	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Organic N-N	0.21	0.09	0.16	0.10	0.12	0.20	0.16	0.18	0.09	0.12	0.16	0.16	0.18

Note: All values mg/l unless otherwise stated.
[a] No analysis made.

Kjeldahl nitrogen (TKN) values all indicated that the direction of the effluent movement appeared to be toward Well D as well as down the center (estimated) groundwater flow line. This pattern had been suggested by the data from the previous sampling 14 months earlier. The increased concentrations found at Well D had not yet appeared at wells beyond that point. However, specific conductance, chloride, calcium, and alkalinity values were above background levels all the way down the central groundwater flow line to Well I. The total P and, more significantly, the soluble ortho P concentrations showed that there had been no phosphate transport from the septic tank tile field to the ground water. The higher concentrations of both total and soluble ortho P found at the Wells N and O were possibly caused by sample contamination resulting from the newness of these well points. It is unlikely that they were caused by septic tank effluent contamination since concentrations at Wells D and G were low.

The final set of data collected in this study is presented in Table VI. Specific conductance and chloride data again show septic tank effluent movement along both the estimated down groundwater gradient as well as along a path between Wells D, G, and N. Neither total phosphorus nor soluble orthophosphate concentrations showed evidence of phosphate transport in the groundwater down gradient from this septic tank wastewater disposal system.

DISCUSSION

Examination of data for the 4-year monitoring study shows that septic tank effluent did migrate from the tile field into the ground waters of the region. This conclusion was based on the data for conservative or essentially conservative chemical tracers such as specific conductance and chloride and other parameters that may not be conservative. Data collected during this study showed occasionally elevated nitrate and ammonium concentrations in certain wells, but it did appear that there was appreciable nitrogen removed in this aquifer system. No evidence for phosphate transport from septic tank effluent was found in any of the monitoring wells, even though this was a sand aquifer with a relatively high groundwater velocity. Except for the first sampling, there appeared to be no seasonal effects on chemical constituents at the monitoring wells that could be traced to the 9-month per year occupancy of the household.

To assess the potential for adverse effects on surface water quality resulting from groundwater transport of aquatic plant nutrients from septic tank wastewater disposal system effluent, a number of factors must be considered. The first step in such an assessment is to define the groundwater hydrology of the region of interest. Often, as was found in the Voyager Village development area, there is no relationship between surface topography and direction of ground water flow. Far too often, it is assumed that the hydrology of ground waters surrounding a lake is such that the direction of the flow is toward the lake. For many lakes, the groundwater flow is in on one side and out on the other. Those septic tank wastewater disposal systems that are located on the down groundwater gradient side of the lake generally do not contribute phosphorus or any materials to that particular surface water.

The chemical characteristics both of the unsaturated zone between the tile field and the water table and of the aquifer materials determine to a large extent whether or not aquatic plant nutrients will be transported in the ground water. Closely associated with this factor are the rate of groundwater flow and the distance between a septic tank system and a water body of concern. Soluble phosphate and ammonium can be sorbed by clay minerals. In addition, phosphate can be sorbed by aluminum and iron oxides and other minerals in the soil. Phosphate sorption is usually a rapid process, 80 to 90% complete in 2 to 5 days.[11] The typically slow movement of ground water allows for precipitation of soluble phosphate with calcium. The greater the distance the septic tank disposal system is from a water body, the greater the potential for phosphorus removal by the aquifer materials.

It is the chemical composition of the soils rather than grain size characterisitcs that plays the dominant role in phosphorus removal. Soils in the Voyager Village development area were predominantly fine to medium sands. Even though septic tank effluent was readily measurable in observation wells 60 m (199 ft) downgradient from the septic tank tile field monitored, the sandy aquifer material exhibited complete phosphate removal during the course of the 4-year monitoring study.

It is possible that over a period of time, aquifer material sorption sites will become saturated with phosphorus. However, there is essentially infinite capacity for phosphorus removal through precipitation reactions. Indeed, as discussed by Jones and Lee,[1, 2] some

TABLE V. Voyager Village septic tank monitoring study observation well data (October 10, 1974).

Parameter	A	B	C	D	E	F	G	H	I	J	K	N	O
	Well Point												
Specific conductance μmhos/cm @ 20°C	53	73	88	245	50	82	59	42	70	44	58	52	53
pH	6.4	6.5	6.6	6.4	6.8	6.7	6.8	6.7	6.8	6.8	6.8	6.8	6.6
Cl^-	0.99	1.14	2.48	25.3	0.89	2.48	1.24	0.84	1.74	0.99	0.99	0.99	0.74
Na^+	3.34	3.64	3.87	4.16	4.46	4.24	3.27	3.12	3.19	2.16	2.82	2.71	3.34
K^+	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ca^{2+}	5.10	7.11	9.32	21.5	<5.0	7.61	5.56	<5.0	7.02	<5.0	5.6	5.27	5.23
Mg^{2+}	1.58	2.11	2.86	8.33	1.5	2.23	1.67	1.29	2.23	1.11	1.79	1.67	1.91
Alkalinity as $CaCO_3$	15.4	22.0	30.8	22.8	17.6	26.4	15.4	15.4	22.0	13.2	22.0	15.4	17.6
SO_4^{2-}	10	14	10	15	12	10	12	4	9	10	8	14	20
Soluble ortho P	0.004	0.005	0.005	0.004	0.002	0.003	0.003	0.006	0.004	0.005	0.004	0.014	0.019
Total P	0.008	0.010	0.012	0.006	0.007	0.010	0.008	0.027	0.011	0.016	0.008	0.034	0.032
NO_3^--N	0.22	0.23	<0.20	0.72	<0.20	<0.20	<0.20	0.20	0.20	0.20	<0.20	0.47	0.41
Total Kjeldahl nitrogen	0.03	0.07	0.50	11.6	0.07	0.06	0.01	0.01	0.03	0.01	0.01	0.04	0.03

Notes: All values mg/l unless otherwise stated. Samples were analyzed by WARF Institute, Inc., Madison, Wis.

TABLE VI. Voyager Village septic tank monitoring study observation well data (January 15, 1976).

Parameter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Well Point														
Specific conductance μmhos/cm @ 22°C	65	35.5	73.5	195	39.5	82.5	81	41.2	79.8	45.5	64.5	85	66	58	49
pH	7.7	9.2	7.8	7.8	9.3	7.8	7.6	7.1	7.7	7.5	7.7	7.9	7.7	7.5	7.5
Cl^-	0.8	0.2	1.6	33.0	0.3	2.8	6.2	0.6	3.0	0.5	0.6	0.6	0.7	2.1	0.8
Na^+	2.0	0.8	2.2	3.4	0.9	2.2	2.0	1.4	2.1	1.1	1.7	1.8	1.5	1.4	1.4
Soluble ortho P	0.005	0.008	0.008	0.008	0.006	0.01	0.008	0.008	0.009	0.006	0.01	0.011	0.01	0.009	0.009
Total P	0.32	0.26	0.31	0.25	0.18	0.28	0.14	0.30	0.30	0.36	0.28	0.20	0.32	0.38	0.32

Note: All values mg/l unless otherwise stated.

investigators have indicated that the capacity for phosphorus removal may be independent of prior exposure to phosphorus.

Another condition affecting potential significance of groundwater transport of aquatic plant nutrients is that there must be actual recharging of the water body of interest by the ground water. Especially in glaciated regions, there can exist beneath lakes an impervious clay layer that acts to separate the lake from possible groundwater input. The ground water then flows beneath or around the lake and no contributions of nutrients or other contaminants to the lake can be made by the ground water. Some of these so-called perched lakes were found in the Voyager Village development area.

An important factor that should be considered in making a proper assessment of the significance of septic tank wastewater disposal systems as a source of phosphorus for surface waters is the location of the septic tank system effluent discharge in relation to the water body of concern with respect to excessive fertilization. For many water bodies, any phosphorus transported from septic tank wastewater disposal system effluent would be contributed to a lake or a stream that is a tributary to that water body.

In general, it is likely that available nutrients discharged to tributary lakes or rivers that are considerable distances from the lake of interest will have much less influence on stimulating extensive fertilization problems than would the same nutrients discharged directly to the water body. A large part of the phosphorus present in streams and rivers, especially during periods of high flow, frequently becomes associated with particulate matter where the phosphorus is attached to or becomes incorporated into clay. Further, as available P is used in various biological processes, it becomes less available for stimulation of algal growth because each time it is cycled through a biotic system some part of the phosphorus becomes refractory. This thereby prevents it from stimulating algal growth so that a substantial part of the phosphorus entering streams never reaches the downstream water body in a form that is available to support algal growth. Studies conducted by Cowen and Lee [14] have shown that much of the particulate phosphorus in several rivers is unavailable for algal growth. In addition, for almost any lake, there is on the order of 60 to 90% retention of annual phosphorus load within the lake sediments. This means that for the lake that is ringed by cottages with septic tanks where either the septic tanks have failed or where the subsoil system does not take up the phosphate, while the phosphorus could contribute to the eutrophication problems within the receiving water body, only a small fraction of the phosphorus would actually be transported to downstream water bodies.

An example of this type of situation is the U. S.-Canadian Great Lakes. It would be expected that very little direct phosphate transport because of the use of septic tank wastewater disposal systems would be taking place from residences located on the shores of the Great Lakes. Rather, these inputs are generally made to a tributary lake or stream. Little of the phosphorus from septic tanks located in the Great Lakes Basin would reach the Great Lakes in an available form to thereby contribute to the excessive fertilization of these water bodies.

If aquatic plant nutrients do enter a lake from the ground water, conditions existing in the lake could reduce their impact on the water quality. For example, if groundwater recharge were beneath an existing thermocline, such as may be present during the summer growing season, added nutrients would remain trapped in the hypolimnion. The interactions between the sediments in the lake and the nutrients entering the lake via groundwater flow would tend to convert both nitrogen and phosphorus to forms unavailable for stimulation of algal growth.

Another factor contributing to the overall significance to surface water quality of aquatic plant nutrient transport from septic tank effluent is the growth-limiting element in the down-gradient water body. If nitrogen is the limiting nutrient in the water body of concern during the times of year of concern, as may be the case in some of the Voyager Village development area lakes according to Jones and Lee,[1, 2] it is possible that additions of phosphorus to that water body from the ground water would have no effect on the surface water quality.

In assessing the overall impact on surface water quality of available nutrient contributions from septic tank effluent, consideration must be given to sources and magnitudes of other nutrient inputs to the water body such as urban and agricultural runoff, point source inputs, and atmospheric inputs, in addition to other sources of nutrients in ground water, such as fertilizers or sanitary landfill leachate. It is possible that the contribution of aquatic plant nutrients of septic tank effluent origin to a water body would be insignificant when compared with other nutrient sources that may be readily controllable.

From this and previous studies, it seems that, in general, phosphate will not be transported from septic tank wastewater disposal systems to surface waters and thereby contribute to excessive fertilization problems. However, it is conceivable that there may be a very limited number of water bodies where septic tank disposal systems are located immediately adjacent to a lake and contribute sufficient phosphorus to the lake to stimulate excessive algal or aquatic macrophyte growth. Under these conditions, consideration should be given to either construction of a sewer system to collect all wastewaters and to provide adequate treatment for phosphate removal or modification of the septic tank wastewater disposal system to improve its phosphate retention capacity.

Based on previous unpublished work by the authors, phosphorus removal can be accomplished by the inclusion of limestone or aluminum oxide in the septic tank wastewater disposal system tile field or in a dike that is constructed below the soil surface through which the wastewaters from the septic tank tile field must pass *en route* to the nearby water course. Sikora *et al.*[15] demonstrated the effectiveness of an individual home phosphorus removal system, using a vertical Plainfield sand column followed by a series of columns filled with calcite or dolomite. The most effective of the systems showed 99% P removal during the first months, but removal decreased to 12% in the sixth month of operation. As noted previously, another approach that can be taken is to treat the wastewater with alum in the pipes, prior to introduction into the septic tank. This system has been shown by Brandes [3] to remove up to 99.6% of the phosphorus in the wastewater. Additional field evaluation of these approaches should be made under a variety of conditions to determine the optimum design parameters to maximize phosphate retention. This or similar approaches using aluminum oxide is likely to be a cost-effective way to remove essentially all of the phosphorus present in septic tank wastewater disposal system effluent where there is potential for significant surface water contamination.

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REFERENCES

1. Jones, R. A., and Lee, G. F., "Septic Tank Wastewater Disposal Systems as Phosphorus Sources for Surface Waters." Occasional Paper No. 13, Environmental Engineering, Colorado State University, Fort Collins (July 1977).
2. Jones, R. A., and Lee, G. F., "Septic Tank Wastewater Disposal Systems as Phosphorus Sources for Surface Waters." EPA 600/3-77-129, Robert S. Kerr Env. Research Laboratory, Ada, Okla. (November 1977).
3. Brandes, M., "Effective Phosphorus Removal by Adding Alum to Septic Tank." *Jour. Water Poll. Control Fed.*, 49, 2285 (1977).
4. Stephenson, D. A., "Hydrogeologic Investigations of the Voyager Village Project Site, Burnett County, Wisconsin." Report to N. E. Isaacson and Associates (February 1971).
5. "Standard Methods for the Examination of Water and Wastewater." 12th ed., Amer. Pub. Health Assn., Washington, D. C. (1965).
6. "Standard Methods for the Examination of Water and Wastewater." 13th ed., Amer. Pub. Health Assn., Washington, D. C. (1971).
7. "Standard Methods for the Examination of Water and Wastewater." 14th ed., Amer. Pub. Health Assn., Washington, D. C. (1976).

8. Blackman, R. R., *et al.*, "Surface Water Resources of Burnett County." Wisconsin Conservation Dept., Madison (1966).
9. Huff, D. D., and Stephenson, D. A., "Hydrologic and Hydrogeologic Investigations of the Voyager Village Project Site, Burnett County, Wisconsin." Report to N. E. Isaacson and Associates (Nov. 1971).
10. Grim, R. E., "Clay Minerology." McGraw-Hill, New York (1953).
11. Tofflemire, T. J., *et al.*, "Phosphate Removal by Sands and Soils." Tech. Paper 31, New York State Dept. of Environ. Conservation (1973).
12. Ellis, B. G., and Erickson, A. E., "Movement and Transformation of Various Phosphorus Compounds in Soils." Soil Sci. Dept., Michigan State Univ. and Michigan Water Resources Comm. (1969).
13. Carlson, K. G., N. E. Isaacson & Assoc., Reedsburg, Wis., personal communication, July 5, 1973.
14. Cowen, W. F. ,and Lee, G. F., "Algal Nutrient Availability and Limitation in Lake Ontario During IFYGL, Part I." Report to U. S. EPA Large Lakes Research Station, Grosse Ile, Mich. (1976).
15. Sikora, L. J., *et al.*, "Septic Nitrogen and Phosphorus Removal Test System." *Groundwater,* 14, 309 (Sept.-Oct. 1976).