Proceedings of the Iowa Academy of Science

Volume 83 | Number

Article 6

1976

A Study of Two Facultative Lagoons for Municipal Wastewater Treatment in Iowa

Kevin N. Nelson
Iowa State University

Lavene K. Payne
Iowa State University

Ruth B. Wildman
Iowa State University

A Study of Two Facultative Lagoons for Municipal Wastewater Treatment in Iowa

KEVIN N. NELSON, LAVENE K. PAYNE, and RUTH B. WILDMAN[1]

NELSON, KEVIN N., LAVENE K. PAYNE, AND RUTH B. WILDMAN (Department of Botany and Plant Pathology, Iowa State University, Ames, Iowa 50011). A study of two facultative lagoons for municipal wastewater treatment in Iowa. Proc. Iowa Acad. Sci. 83(4):133-142. 1976.

Two 2-celled facultative lagoons, comparable in design and serving small communities in rural Iowa, were studied for seven consecutive summer weeks. Chemical and physical parameters of water quality were monitored in samples taken from influent and effluent structures and at two depths and three to six locations in each cell. The composition and density of the phytoplankton was monitored, and total and fecal coliform counts were made. A diurnal study showed wide fluctuations in the chemical composition of influent wastewater. The quality of effluent water was comparable for the two lagoons although one was loaded to design capacity and the other to half capacity. During the study period, both lagoons met the Iowa standards and approached the EPA standards.

INDEX DESCRIPTORS: Wastewater treatment, facultative lagoons, oxidation ponds.

Over the past 25 years, facultative lagoons (also called oxidation or stabilization ponds) have been widely used and increasingly adopted as the means of treating wastewater for small communities in the United States. This method has been generally regarded as successful in the Great Plains states for producing effluent quality equivalent to secondary treatment, but there is evidence (Barsom, 1973) that existing lagoons cannot meet the Federal requirements established for secondary treatment by all publicly owned wastewater treatment facilities by July 1, 1977. The greatest assets of lagoons as they are currently designed appear to be low cost of installation and maintenance and ease of operation. Two international symposia (U.S. Dept. H.E.W., 1961; McKinney, 1970) have been held to discuss lagoon design, problems, and performance, but there is little evidence that suggestions and evaluations have been put into general practice.

In his report for an EPA contract study of lagoon performance and the state of lagoon technology, Barsom (1973) was highly critical of inadequate state requirements and insufficient enforcement of the few criteria that are required. He noted that operating data for municipal lagoons have been noticeably lacking in the literature, and the available data seem to be minimal and of questionable quality. Inadequate sampling, "dry lab" analyses, and lack of data on influent to compare with effluent quality were cited. Without valid operating data, it is difficult to objectively assess lagoon effectiveness in producing effluent that will not cause deterioration of water quality in receiving streams. Without adequate testing and reporting, it is impossible to know whether actual performance matches design performance, although in practice the latter often has been accepted as sufficient qualification for a lagoon system. Treatment frequently has been considered adequate without monitoring unless there are complaints. It is uncertain how many, if any, existing lagoons will be able to meet the rigorous EPA standards which became effective August 17, 1973 (Federal Register, 1973).

In order to expand the meager fund of basic data and to assess operating effectiveness, a study of facultative lagoons in small Iowa communities was carried out during the summer of 1974. This paper reports and compares the chemical and physical data on water quality, coliform counts, and identification and enumeration of phytoplankters for two 2-celled lagoons.

MATERIALS AND METHODS

Scope. Fifteen students working with four group leaders collected and analyzed data for seven consecutive weeks on two 2-celled facultative lagoons of comparable size and design. One lagoon had been in operation for 13 years and was loaded to design capacity; the other had been in use for four years and was loaded at half design capacity. Influent, in-cell, and effluent quality were monitored. Groups were assigned measurements of biological, chemical, and hydrological parameters, and an effort was made to determine carbon and nutrient budgets. This paper reports data on water quality, coliform counts, and phytoplankton.

Sites. Two-celled, facultative lagoons for the towns of Jewell (Hamilton County) and Zearing (Story County), Iowa were selected for detailed study. Table 1 summarizes physical and operational information for these sites, using a modification of the data summary sheet employed in an EPA contract survey of lagoon performance (Barsom, 1973). Each lagoon had a single operator who was certified by the Iowa Department of Environmental Quality. Water quality parameters tested by the operator included dissolved oxygen (Hach OX-2-P), pH (Hach 17), temperature (Fisher-Hatfield 14-95), and relative stability (Fisher-Hatfield 17-532). The cells at both lagoons were operated in parallel during the winter and in series during the summer.

Sampling Procedures and Analyses

Chemical parameters. Influent and effluent samples were collected directly from the respective structures. In-cell samples were collected from 3-6 locations in each cell and at 2 depths. At each in-cell location, a surface (15 cm) grab sample ("T") was taken. A Van Dorn sampler was used to collect samples from a depth of 3.5-4 ft (107-122 cm) ("B") at the same locations. Measurements of pH (Leeds and Northrup pH meter calibrated at the site), dissolved oxygen (Yellow Springs Instrument Co., Model 54, calibrated at the site or Hach (1973) azide modification of the Winkler method with fixation at the site), and water temperature (Whitney underwater thermometer) were made at the same locations.

From each water sample, (1) a 10-ml aliquot was combined with 10 ml of chilled 20% trichloroacetic acid (TCA) for analysis of inorganic phosphate (Ames, 1966), (2) a 118-ml aliquot was acidified to pH ≤ 2 with 18 N H_2SO_4 for analysis of total nitrogen, total phosphorus, and selected checks of other chemical parameters, and (3) the remaining sample was treated with $HgCl_2$ to a final concentration of 40 mg/l. All samples were stored on ice until they could be returned to the laboratory for analysis. Hach Chemical Company modifications (Hach, 1973) of "Standard Methods" (APHA, 1971) were used for determinations of alkalinity, chloride, total hardness, iron, ammonium and nitrate nitrogen, and turbidity. A Hach DR/2 meter (Hach Chemical Co., Ames, Iowa) was used for spectrophotometric measurements. Spot

[1] Department of Botany and Plant Pathology, Iowa State University, Ames, IA 50011.

Table 1. *Summary of physical and operational data for facultative 2-celled lagoons at Jewell and Zearing, Iowa.*

	Jewell Lagoon	Zearing Lagoon
Lagoon designer	Jon E. McClure, McClure & Culver, Engr.; Jefferson, Iowa	Oakes Engineering Co.; Des Moines, Iowa
Location from municipality	¼ mile (0.40 km) SE	¼ mile (0.40 km) SE
Receiving stream	Mud Lake drainage ditch to Skunk River	Middle Minerva Creek to Iowa River
Area	5.14 + 5.19 = 10.33 acres (4.18 ha)	3.3 + 4.42 = 7.72 acres (3.12 ha)
Volume	14,894,696 gal (56,419,303 l)	13,637,190 gal (51,656,022 l)
Depth	5 ft (1.52 m)	6 ft (1.83 m)
Flow		
Design	100,000 gal/day (378,788 l/day)	100,000 gal/day (378,788 l/day)
Actual (1974)	87,800 gal/day (332,575 l/day)	58,000 gal/day (219,697 l/day)
Organic loading		
Design	18.8 lb BOD/day/acre (21.0 kg/day/ha)	19.9 lb BOD/day/acre (22.3 kg/day/ha)
Actual (1974)	18.5 lb BOD/day/acre (20.7 kg/day/ha)	10.4 lb BOD/day/acre (11.6 kg/day/ha)
Years in operation	13	4
Population served	1152 (1970)	528 (1970)
Pre-treatment	Raw	Raw
Post-treatment	None	None

checks for confirmation were carried out at the Engineering Research Institute Analytical Laboratory (ERI Anal. Lab.), Iowa State University. Filtration of water samples through 1.2 or 0.8μm pore size membrane filters was required to remove turbidity (primarily due to algal cells) for measurement of ammonium nitrogen. Nitrite nitrogen was determined at the ERI Anal. Lab. on a small number of samples (20) using "Standard Methods" (APHA, 1971). Inorganic phosphorus was determined by an ascorbic acid reduction method (Ames, 1966) with volumes increased 8 times to permit use of a Bausch and Lomb Spectronic 20 spectrophotometer. Total nitrogen and total phosphorus were determined at the ERI Anal. Lab. using a Technicon Autoanalyzer II.

Biochemical oxygen demand. Collections and BOD_5 analyses were carried out by a separate group working on the lagoon study. Samples were collected in standard 300-ml BOD bottles from within the influent, cross-over (Zearing only), and effluent structures and at three locations in the receiving stream: upstream, 0.6 - 3.0 m downstream from the outlet pipe (where some visible mixing occurred), and 7.6 - 15.2 m downstream from the outlet pipe. Collection times coincided with sampling for water chemistry. Samples were chilled in the field and analyzed promptly on return to the laboratory using "Standard Methods" (APHA, 1971).

A diurnal study was made August 16-17 on samples taken from the influent, primary and secondary cells (composite of samples from two depths at three locations within each cell), and effluent structures of the Zearing lagoon.

Coliform bacteria. Each week for five weeks, grab samples were collected from the influent and effluent structures at each lagoon and stored on ice until they could be returned to the laboratory. Fecal and total coliform densities were determined using the membrane filter technique outlined in "Standard Methods" (APHA, 1971).

Phytoplankton. Plankton samples were collected weekly from two locations per cell at each site and from the effluent drain at Zearing. The sequence of stations (see Figure 1) follows a hypothetical path of organic load from inflow to outflow (i.e., Station #1 is the backwater station in the primary cell, #2 is near the cross-over pipe in the primary cell, #3 is near the cross-over entrance in the secondary cell, and #4 is the backwater station in the secondary cell). Surface water samples were collected, treated with Lugol's iodine solution, and allowed to settle for 24 hours. The liquid was decanted to a volume with sufficient concentration of algal cells to permit counting in a Palmer cell under 100 or 400X magnification.

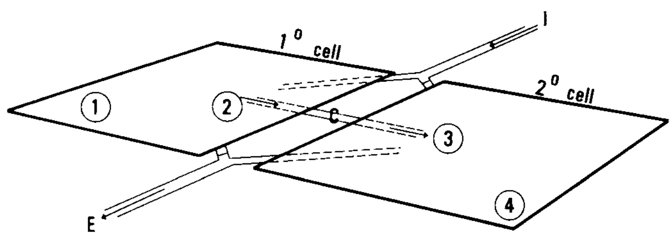


Figure 1. Diagrammatic path of load during lagoon use of cells in series. I, influent; C, cross-over; E, effluent; (1)-(4), sampling stations for phytoplankton.

RESULTS

Chemical and physical parameters. Parameters for the two lagoons are compared in Table 2 and Figures 2-9. Figures 10 and 11 show fluctuations of ammonium nitrogen and total phosphorus during the diurnal study.

Concentrations of ammonium, nitrate, and total nitrogen (Figures 2-4) decreased from high influent levels to relatively stable, moderate to low levels in the cells and effluent of both lagoons. During the period of the study, percentage reductions in ammonium, nitrate, and total nitrogen, based on mean values for influent and effluent, were 98, 52, and 78%, respectively, at Jewell, and 87, 47, and 88% at Zearing. Concentrations of inorganic and total phosphorus (Figures 5, 6) showed roughly the same pattern of decrease from influent to cell levels and stability throughout in-cell and effluent sampling. During the period of

Table 2. *Selected chemical and physical data for water from influent, bottom and top of primary and secondary cells, and effluent; Jewell and Zearing lagoons, summer 1974.*

		Jewell					Zearing				
Parameter	Station[a]	N[b]	Mean	Standard Deviation	Minimum	Maximum	N[b]	Mean	Standard Deviation	Minimum	Maximum
pH	I	5	8.4	0.76	7.7	9.4	6	8.2	0.44	7.5	8.8
	1°B	24	9.0	0.36	8.4	9.6	29	8.6	0.46	7.4	9.4
	1°T	31	9.3	0.19	9.0	9.7	33	8.6	0.50	7.4	9.6
	2°B	23	9.2	0.24	8.6	9.5	28	8.9	0.51	8.0	9.9
	2°T	22	9.4	0.11	9.2	9.6	33	8.9	0.53	7.8	10.0
	E	5	9.5	0.19	9.2	9.7	5	8.9	0.45	8.4	9.6
Alkalinity (mg/l $CaCO_3$)	I	2	373	102.53	300	445	3	530	65.57	460	590
	1°B	5	246	22.75	220	270	12	340	43.72	270	420
	1°T	8	246	15.22	235	270	16	336	34.25	280	400
	2°B	7	208	5.67	200	215	12	309	54.53	220	400
	2°T	8	210	5.98	200	220	16	318	48.58	230	415
	E	1	205	—	—	—	3	287	49.33	230	320
Total Hardness (mg/l $CaCO_3$)	I	3	267	55.08	230	330	4	296	46.44	250	355
	1°B	6	258	49.57	220	350	14	326	36.91	270	400
	1°T	10	265	48.82	230	370	19	339	22.81	280	390
	2°B	8	189	41.56	160	280	14	309	20.63	270	330
	2°T	10	213	64.13	160	320	19	309	14.65	280	340
	E	2	200	42.43	170	230	4	311	21.75	280	330
Iron (mg/l)	I	2	0.22	0.021	0.20	0.23	4	1.10	1.117	0.15	2.50
	1°B	6	0.33	0.606	0.0	1.50	14	0.40	0.322	0.01	1.00
	1°T	8	0.14	0.226	0.0	0.50	19	0.35	0.246	0.02	0.70
	2°B	8	0.20	0.417	0.0	1.2	14	0.25	0.305	0.0	0.90
	2°T	9	0.19	0.274	0.0	0.75	19	0.23	0.256	0.03	0.75
	E	1	0.0	—	—	—	4	0.44	0.449	0.05	0.90
Turbidity (FTU)	I	—	—	—	—	—	3	49.33	20.03	30	70
	1°B	—	—	—	—	—	12	60.25	27.20	10	95
	1°T	—	—	—	—	—	16	46.38	32.70	0	99
	2°B	—	—	—	—	—	12	9.17	8.53	0	22
	2°T	—	—	—	—	—	16	8.63	7.68	0	20
	E	—	—	—	—	—	3	9.33	12.10	0	23

[a] I, influent; 1°B, primary cell (107-122 cm); 1°T, primary cell (15 cm); 2°B, secondary cell (107-122 cm); 2°T, secondary cell (15 cm); E, effluent.
[b] Number of samples.

the study, the percentage reductions in inorganic and total phosphorus, based on mean values for influent and effluent, were 96 and 91%, respectively, for Jewell, and 92 and 77% for Zearing. The mean value of influent total phosphorus was considerably higher at Jewell than at Zearing, although in-cell and effluent levels were comparable in the two systems.

Figure 7 shows the wide ranges in dissolved oxygen levels. Predictably, dissolved oxygen levels were higher at the top than at the bottom sampling stations of each cell in both lagoons, due to surface photosynthetic activity of algae and greater bacterial demand for oxygen in bottom sediments. Water temperature rose from influent levels and remained relatively stable throughout the cells and effluent.

The greatest difference between the two lagoons in the parameters tested was in chloride concentration (Figure 8). Mean values for top and bottom locations in both cells and in effluent exceeded 300 mg/l at Zearing throughout the summer, although the mean of influent samples was only 72 mg/l. At Jewell, mean values for in-cell stations and effluent were consistently $\leq$ 50 mg/l. The increase in conductivity (Figure 9) from influent levels to higher values in both cells and effluent at Zearing undoubtedly reflects the elevated chloride concentration.

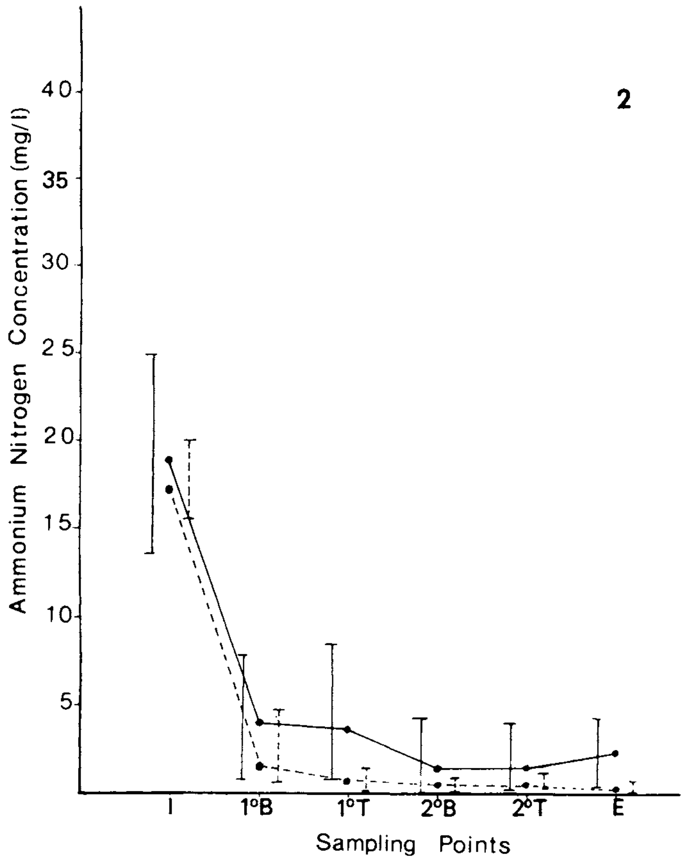
The diurnal study at Zearing showed a general pattern of widely fluctuating influent levels and relatively stable in-cell and effluent levels of chemical parameters. Figures 10 and 11 are representative. Dissolved oxygen concentrations followed the expected pattern of high afternoon levels during peak photosynthetic activity and low night levels. Carbon dioxide concentrations dropped from late morning until late evening before stabilizing, again reflecting algal demand for CO_2 for daytime photosynthesis. Peak influent levels of ammonium nitrogen and inorganic and total phosphorus occurred around 8:00 AM. In addition to the normal input from the municipal sewer system, ground water seepage and storm sewer or other run-off appears to contribute to the influent of the Zearing lagoon under certain conditions. During the diurnal study, a heavy rainstorm occurred around 9:00 AM and had stopped by 10:00 AM. Dramatic increases in influent turbidity were observed within the hour.

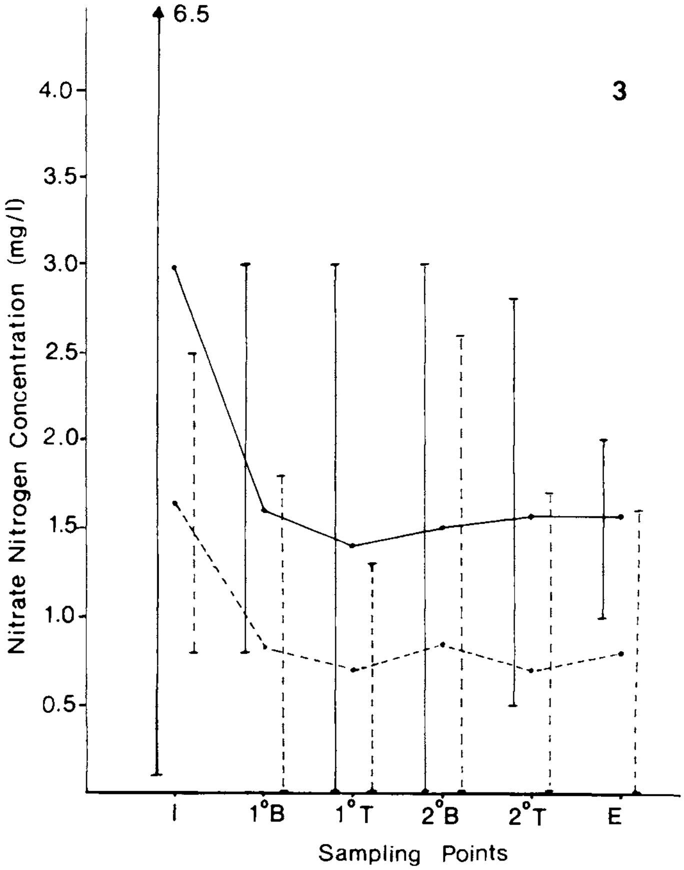
Biochemical oxygen demand. Table 3 shows the mean values of BOD_5 for lagoon and receiving stream stations during the study. The Zearing lagoon showed average values of 87% reduction before secondary cell treatment and 89% reduction in effluent, thus meeting the EPA requirement of 85% reduction in BOD_5. This is the newer of the two lagoons and had been in operation four years, with a 1974 figure of actual organic loading at roughly half the design capacity (Table 1). The Jewell lagoon had been in operation 13 years and was operating at capacity organic loading in 1974, according to the design and actual figures (Table 1). The average summer BOD_5 reduction from influent to effluent at Jewell was 82%.

Table 3. *Mean summer values of BOD$_5$ for lagoon and receiving stream locations, July 8 - August 17, 1974.*

	Jewell			Zearing		
Location	No. of Samples	Average BOD$_5$ (mg/l)	Standard Deviation	No. of Samples	Average BOD$_5$ (mg/l)	Standard Deviation
Influent	8	162	65	7	149	40
Cross-over		—	—	7	20	5
Effluent	8	30	8.8	6	16	7
Upstream	7	4	1.1	7	3	0.9
Outlet[a]	6	8	4.7	3	6	5
Downstream[b]	7	5	2.6	4	5	2

[a] 0.6 - 3.0 m downstream from outlet pipe; mixing visible.
[b] 7.6 - 15.2 m downstream from outlet pipe.





Figures 2-9. Comparison of chemical and physical parameters in Jewell and Zearing lagoons. I, influent; 1°, primary cell; 2°, secondary cell; E, effluent; B, 3.5 - 4 ft (107 - 122 cm); T, surface (15 cm). ________, Zearing lagoon; - - - - - - - - - -, Jewell lagoon. Points represent mean values for the study period; range at each location is shown.

Coliform bacteria. Percentage reductions of total and fecal coliform bacteria exceeded 99.9% in both lagoons throughout the test period. The ranges for influent coliform counts per 100 ml at Jewell were: total, 42 x 10^8 - 96 x 10^8; fecal, 34 x 10^7 - 25 x 10^8. Jewell effluent ranges were: total, 30 x 10^2 - 69 x 10^2; fecal, 710 - 25 x 10^2. At Zearing, influent ranges were: total, 23 x 10^8 - 96 x 10^8; fecal, 86 x 10^6 - 70 x 10^8; effluent ranges were: total, 35 x 10^2 - 74 x 10^3; fecal, 210 - 43 x 10^2. The geometric means of fecal coliform bacteria on data collected throughout the study period were 1730/100 ml for Jewell and 1330/100 ml for Zearing. The geometric means of total coliform bacteria were 3870/100 ml for Jewell and 5130/100 ml for Zearing.

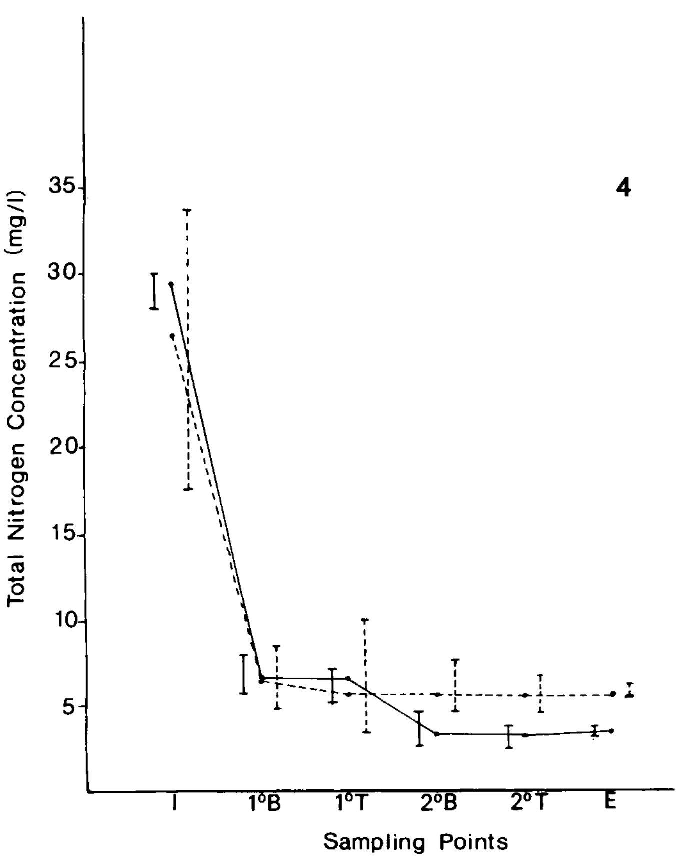
Phytoplankton. Table 4 lists the phytoplankters identified in the two lagoons, the stations (see Figure 1) where they were found in surface grab samples, and the maximum number per sample during the study period (26 June - 8 August, 1974) with date and location.

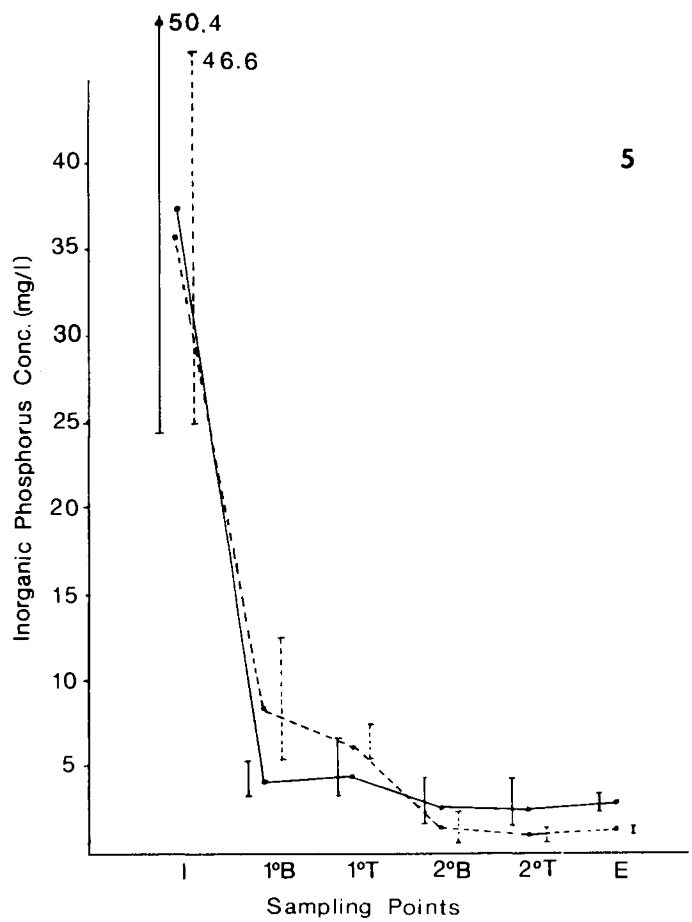
During the summer, dominant algae at Jewell were *Chlamydomonas, Microcystis, Oscillatoria,* and *Scenedesmus.* In late June, *Chlamydomonas, Micractinium, Oscillatoria,* and *Scenedesmus* were the dominants, but *Micractinium* was replaced by minor blooms of *Actinastrum, Ankistrodesmus,* and *Spirulina* early in July. The diatom *Nitzschia* began to appear in plankton samples and reached bloom proportions by 10 July, although it failed to grow on diatometer

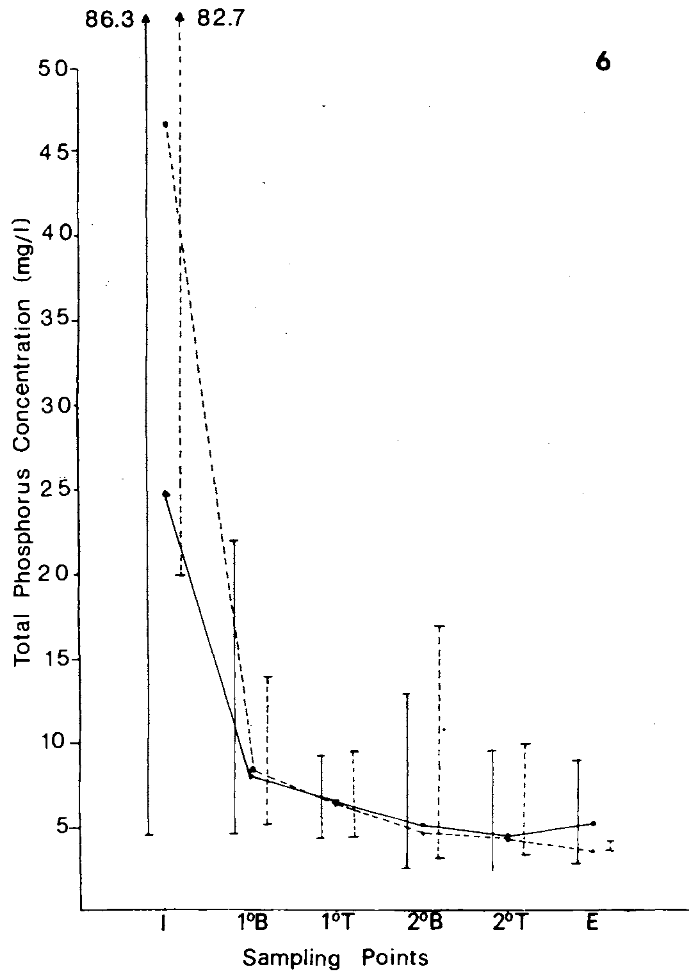
Table 4. *Phytoplankton in surface samples, Jewell and Zearing lagoons, June 26-August 8, 1974.*[a]

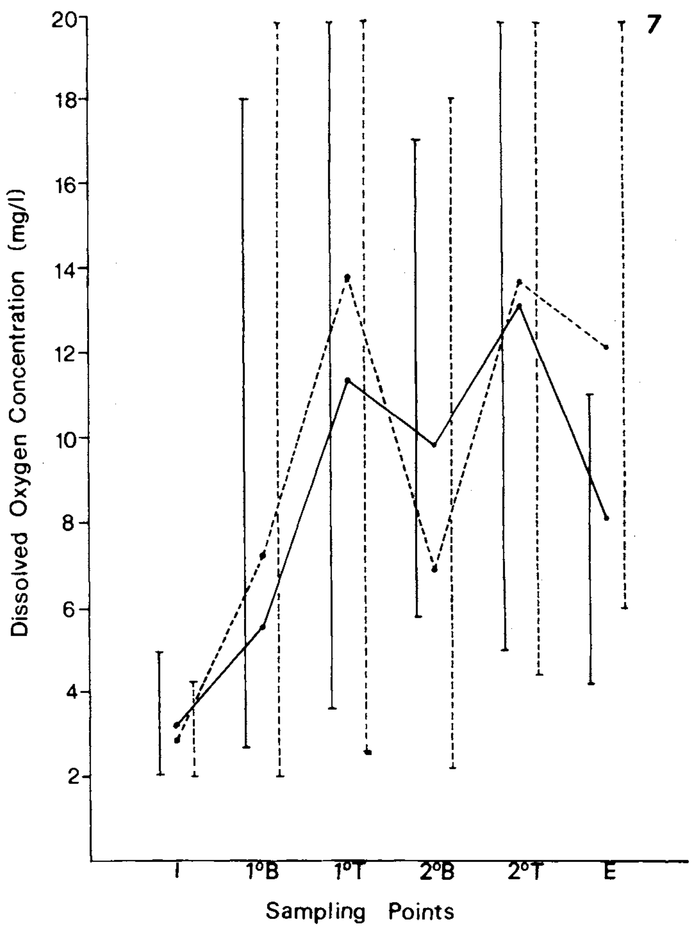
Taxa	Stations[b]	Maximum Density Number/ml	Maximum Density Date	Maximum Density Location[b]	Maximum number/ml in Zearing effluent
Actinastrum gracilimum G. M. Smith	J 1-4	12,606	7/3	J 3	—
Anabaena spiroides v. *crassa* Lemm.	J 1-4	1,060	7/17	J 2	—
Ankistrodesmus falcatus (Corda) Ralfs	J 1-4; Z 1-4,E	14,182	7/3	J 3	273
Chlamydomonas sp.	J 1-4; Z 1-4,E	215,833	7/17	J 3	5,000
Coelastrum microporum Nägeli	J 3,4; Z 1	3,031	7/17	J 4	—
Cyclotella meneghiniana Kütz.	J 1,2,4; Z 3,4,E	15,910	8/8	Z E	15,910
Gomphonema parvulum v. *micropus* (Kütz.) Cl	Z 2	273	7/3	Z 2	—
Melosira italica (Ehr.) Kütz.	J 1,2,4	38,018	7/17	J 1	—
Merismopedia punctata Meyen	J 1,3,4	1,970	7/10	J 3	—
M. tenuissima Lemm.	J 1-4; Z-2	90,258	7/17	J 3	—
Micractinium pusillum Fresenius	J 1-4	2,545	6/25	J 4	—
Microcystis aeruginosa Kütz. (colonies)	J 1-4; Z 1-4,E	12,500	7/24	J 1	970
M. aeruginosa Kütz. (cells)	J 1-4; Z 1-4,E	2.25×10^6	7/24	Z 2	58,182
M. incerta Lemm. (cells)	J 1-4; Z 1-4,E	113,803	7/17	J 3	17,455
Nitzschia sp.	J 1-4; Z 1-4,E	158,030	7/10	J 1	10,606
Oocystis natans v. *major* G. M. Smith	Z 1,2	7,960	7/3	Z 1	—
Oscillatoria tenuis C. A. Agardh	J 1-4; Z 1-4	71,015	8/8	J 4	—
Pediastrum duplex v. *cohaerens* Bohlin	Z 3,4,E	745	7/10	Z 4	530
Phacus sp.	J 1,2,4; Z 4	7,818	7/24	J 2	—
Scenedesmus acuminatus (Lag.) Chodat	J 1-4; Z 2	39,394	7/3	J 3	—
S. quadricauda (Turp.) de Breb.	J 1-4; Z 1,3,4,E	13,258	7/3	Z 1	1,590
Schroederia judayi G. M. Smith	J 2-4; Z 1-4,E	11,182	7/3	Z 2	1,590
Spirulina laxissima G. S. West	J 1-4	22,061	7/3	J 3	—
Sphaerocystis schroeteri Chodat	J 1-4; Z 1,2,4	98,100	7/24	Z 1	—

[a]Identifications and enumerations were performed by Michael L. Edwards.
[b]J, Jewell; Z, Zearing. Station numbers refer to stations in Figure 1; E, effluent.









substrates. A succession of populations of *Merismopedia, Coelastrum, Melosira, Sphaerocystis,* and *Phacus* occurred during July, but all had declined or disappeared by 8 August. *Microcystis* increased rapidly in numbers throughout July to form a dense bloom that persisted at the time of the last sampling (8 August).

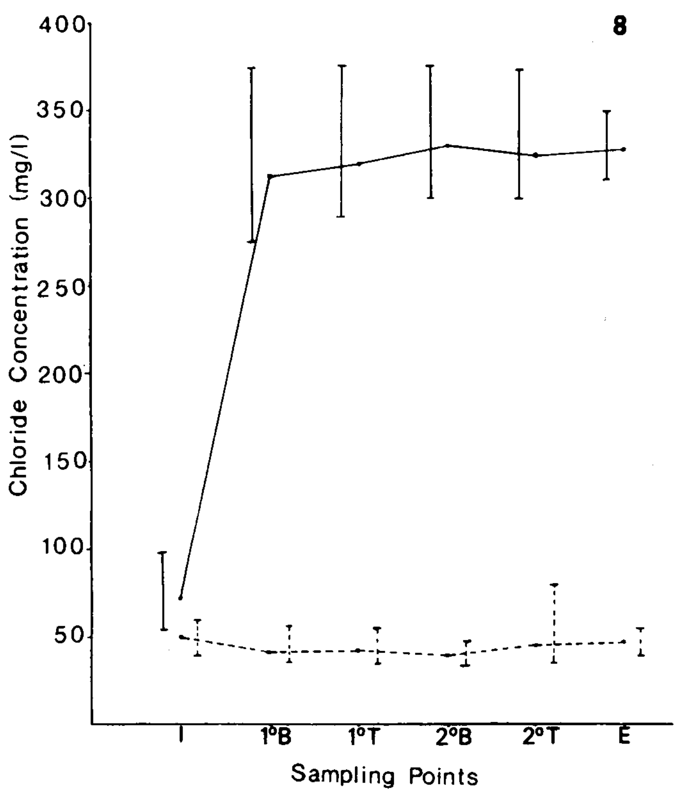
The Zearing lagoon had smaller populations of phytoplankters and less diversity in June than did Jewell. *Chlamydomonas* was dominant. Lack of diversity characterized the Zearing lagoon throughout the summer. *Nitzschia* and *Sphaerocystis* made appearances late in July, and the *Chlamydomonas* population declined. A dense *Microcystis* bloom had developed by late July and remained dominant at the time of the last sampling on 8 August. At that time, *Cyclotella* was second in population density. Twelve of the 23 taxa appeared in maximum density in the secondary cell. When a species appeared in the Zearing effluent, the density is shown in Table 4 for comparison with maximum in-cell density. Only one species, *Cyclotella meneghiniana*, appeared in higher density in effluent than in-cell samples at Zearing. By August, dense blooms of *Microcystis* produced surface scums of dead and decaying cells which were wind-swept to leeward corners of each lagoon. These unsightly gray-blue mats caused unpleasant odors on still days and served as substrates for aquatic fungi.

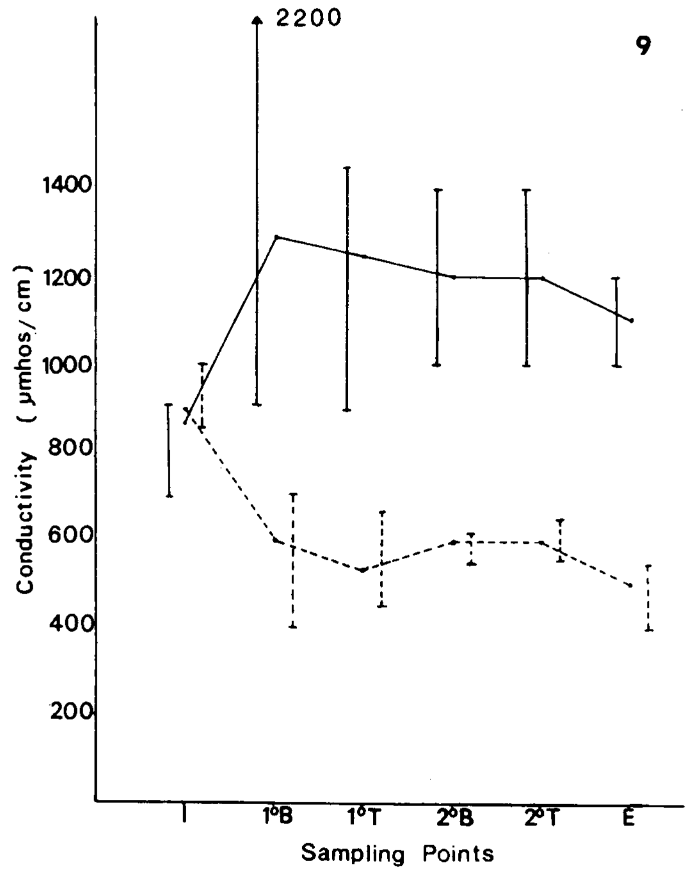
During the diurnal study at Zearing on 16 August, *Microcystis, Nitzschia,* and *Cyclotella* were the dominant phytoplankters. *Microcystis* showed vertical movement over the 24-hour period with greatest density (2.6 x 10^4 cells/ml) in surface samples at 11:00 AM and lowest density (2.4 x 10^3 cells/ml) at 3:00 AM. One of the difficulties in obtaining a valid population count of *Microcystis* during a bloom results from dying colonies rising to the surface, breaking up, and moving horizontally in the path of the prevailing wind. *Cyclotella* showed a similar though less clear-cut trend with maximum density (9.2 x 10^4 cells/ml) at the surface at 5:00 PM and minimum density (3.9 x 10^4 cells/ml) at 3:00 AM. The density of the *Nitzschia* population at the surface fluctuated throughout the 24-hour period.

DISCUSSION

In our study, emphasis was placed on a comparison of influent, in-cell, and effluent water quality in order to get a more complete picture of the lagoon system. Many states, including Iowa, have evaluated lagoons as equivalent to secondary treatment in quality of effluent despite lack of a definitive standard for "secondary treatment" until 1973. The most commonly used criterion for acceptable processing of wastewater was 85% reduction of BOD_5, but without analysis of influent samples to compare with effluent, criteria based on percentage reduction are meaningless. Monitoring of influent parameters was required by only three states (BOD in Colorado, Minnesota, and Missouri; coliform bacteria and suspended solids in Colorado); only 28 states required monitoring and reporting of effluent data (Barsom, 1973). Iowa required monthly reports on effluent dissolved oxygen and a "relative stability" test and reports twice annually on effluent BOD.

Even when specified percentage reductions are met, deterioration in receiving stream quality may occur if the effluent has residual high levels of BOD and coliform bacteria. The rigorous new EPA





requirements recognize this. In defining standards for secondary treatment, fixed minima for BOD5, suspended solids, and fecal coliform bacteria are specified rather than percent reduction only.

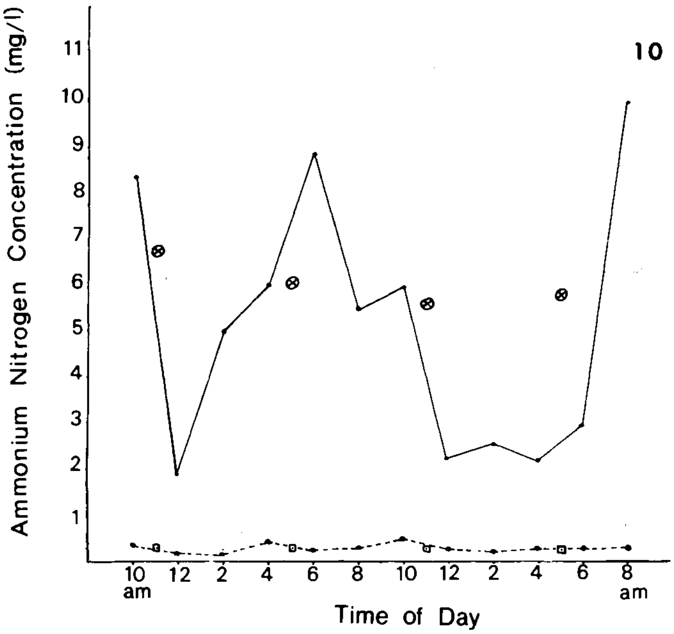
Physical and chemical parameters. Although the EPA standards for secondary wastewater treatment do not specify minimum acceptable levels of inorganic ions, heavy discharges of nitrogen and phosphorus can seriously affect the quality of receiving waters. Published data on removal of these nutrient elements in lagoons indicate a wide range in efficiency, undoubtedly reflecting the levels of uptake by lagoon biota, adsorption on floc and bottom sediments, and precipitation as insoluble compounds at a high pH.

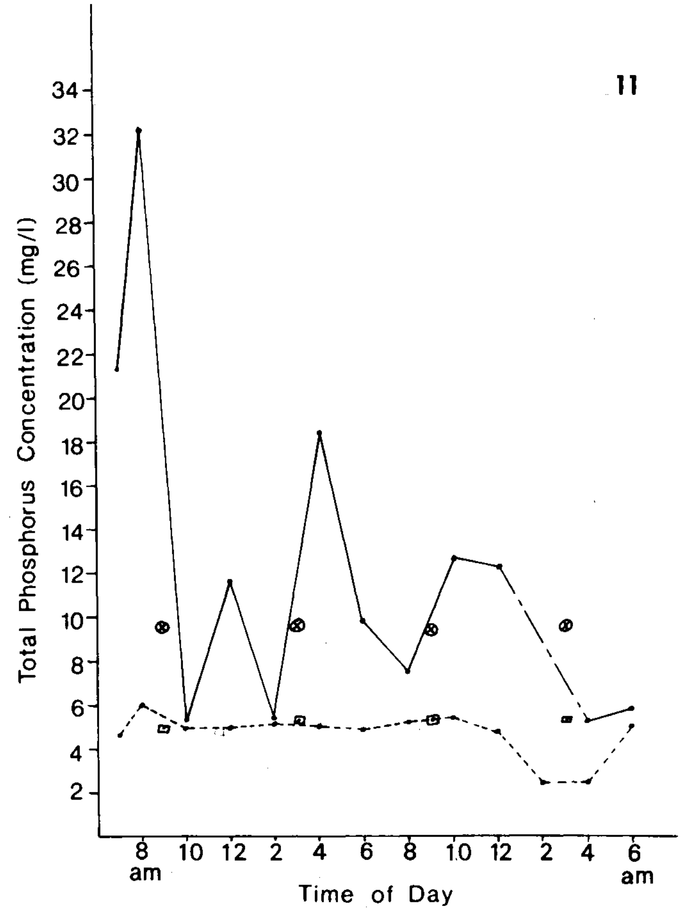
In our study, the substantially lower concentrations of ammonium, nitrate, and total nitrogen and of inorganic and total phosphorus in the primary cell compared with influent levels probably reflect the dilution factor of a small volume entering the large volume of the cell where the natural lagoon processes are successfully at work. Concentrations of nitrogen and phosphorus in the secondary cell remained relatively stable and sufficiently high, however, to support large algal populations. Nutrient elements (e.g., nitrogen and phosphorus) are used by algae while the sewage-degrading bacteria supply carbon dioxide for algal photosynthesis. Additionally, the normally high pH of facultative lagoons causes formation and precipitation of insoluble phosphates (Bogan *et al.*, 1960; Fitzgerald and Rohlich, 1958; Toms *et al.*, 1975).

Based on mean influent and effluent values, the Jewell and Zearing lagoons reduced ammonium nitrogen 98 and 87%, respectively, which compares very favorably with values found in other field studies. Fitzgerald and Rohlich (1958), Lyman *et al.* (1970), and Cooley and Jennings (1961) reported 75-90% removal of ammonium nitrogen with proper loading, maintenance, and adequate detention time.

Removal of inorganic and total phosphorus was high at our study lagoons with average reductions of 96 and 91%, respectively, for Jewell and 92 and 77% for Zearing. The greatest removal of phosphorus in a Kansas study (Lyman *et al.*, 1970) was in ponds with the highest pH and the heaviest algal growth. Zoltek (1974) concluded that approximately 90% of the phosphorus in effluent from a secondary wastewater treatment plant is in the form of orthophosphate. Humenik and Hanna (1970) reported good removal of organic nitrogen but no appreciable uptake of phosphorus in a symbiotic algal-bacterial system. Richmond (1970) noted that lagoons do not dependably remove substantial amounts of soluble orthophosphate or total phosphorus and recommended complete detention except for two weeks in late fall and again in early spring when receiving waters are best able to assimilate effluent. In a study of 30 tertiary oxidation ponds in Illinois, Barsom and Ryckman (1970) found that in 22 the effluent phosphorus concentration actually exceeded the equivalent form of phosphorus (ortho, poly, or total) in the influent. The same study revealed much lower removal of ammonia nitrogen (47%) and total nitrogen (17%) than in Lyman's study (1970) or ours. Variations in nutrient removal would be expected to be closely associated with the density of organisms. One factor in the high levels of reduction in the Jewell and Zearing lagoons may be the characteristic blue-green algal uptake and storage of more phosphate than is needed for current growth (luxury consumption). The blue-green alga *Microcystis* was the predominant bloom organism in both lagoons.

The unusually high concentration of chloride in the Zearing cells and effluent remains unexplained on the basis of current operation. Both towns soften their water, and Zearing back-flushes with sodium chloride nightly. Although the diurnal study did not detect influent chloride concentrations comparable to in-cell levels, we believe the back-flushing at Zearing was the source of the chloride ions.





Figures 10 and 11. Diurnal fluctuations in ammonium nitrogen and total phosphorus in the Zearing lagoon. ———, influent; - - - - - - - - - -, effluent; ⊗, primary cell; ⊡, secondary cell.

The EPA requirements recognize the importance of pH by specifying that effluent values remain within the pH range of 6.0 to 9.0. The Zearing effluent met this criterion during the period of the study, but the minimum pH of the Jewell effluent was 9.2. An alkaline pH range, coupled with abundant inorganic nutrients, is conducive to dense blue-green algal blooms. Although algae are essential to the natural processes of waste stabilization in a facultative lagoon, excessive algal growth is one of the major problems associated with lagoons.

Biochemical oxygen demand. Both lagoons appeared to meet the EPA (1973) standards, although the older, more heavily loaded Jewell lagoon was borderline, with an average BOD_5 reduction of 82% from influent to effluent. Although neither lagoon met the EPA criterion for suspended solids, both lagoons achieved the EPA minimum BOD_5 level of 30 mg/l for a 30-day period. The BOD_5 levels for points in the receiving streams below the outlets did not seem to be seriously raised by entrance of the effluent. However, further measurements of stream flow rate and BOD_{26} should be carried out to determine the actual impact of discharging algae-laden effluent on the quality of the receiving stream (King *et al.*, 1970).

Coliform bacteria. Both lagoons effectively reduced total and fecal coliform counts from influent levels of 10^7-10^9 cells/100 ml to 10^3-10^4 cells/100 ml, surpassing 99.9% reduction throughout the test period. Under Iowa law, the maximum allowable fecal coliform content for a Class B fishing stream is 2,000 organisms/100 ml. The effluent quality of the Jewell and Zearing lagoons approaches this standard, although the receiving streams are subject only to the less rigorous "General Water Quality Criteria" (Code of Iowa, 1974). Since discharge is continuous but in small volume (and actually had stopped by August in the Zearing lagoon), the dilution factor provided by the volume of the receiving stream would be sufficient to achieve the coliform standard for general recreational waters. The EPA standard to be met by 1977 states that the geometric mean of the values for effluent samples collected in a period of 30 consecutive days shall not exceed 200 fecal coliform bacteria/100 ml and the geometric mean of the values for seven consecutive days shall not exceed 400/100 ml. The geometric means of fecal coliform bacteria/100 ml calculated for the Jewell and Zearing lagoons during the study period were 1730 and 1330, respectively. Increased detention seems to be called for since bacterial die-off depends primarily on detention time (Missouri Basin Engineering Health Council, 1971).

Phytoplankton. Diverse algae were found in the Jewell and Zearing lagoons during our study, but many species occurred only in small numbers or in successions of minor blooms. The dominant phytoplankters over longer periods were the blue-green algae *Microcystis* and *Oscillatoria*, as well as *Chlamydomonas* and *Scenedesmus*, green algae commonly reported for lagoons. Considerable numbers of diatoms were found in the plankton, but growth on artificial substrates was extremely sparse. In a summary of studies on phytoplankton associated with sewage lagoons, Fitzgerald and Rohlich (1958) noted seasonal variations as well as the possibility of different populations at different locations in the same cell. Species of *Chlamydomonas, Scenedesmus,* and *Euglena* were cited in two reviews (Fitzgerald and Rohlich, 1958; Missouri Basin Engineering Health Council, 1971) as generally most numerous, with *Chlorogonium, Micractinium, Ankistrodesmus, Chlorella, Oscillatoria, Anabaena, Carteria, Phormidium, Navicula, Closterium,* and *Anacystis* also common in large growths.

Algal populations are key factors in lagoon performance and effluent quality. They enhance aerobic conditions in the upper layers of the lagoon (Vennes, 1970), but the ultimate BOD in effluent may be detrimental to receiving waters when algae are discharged (Barsom, 1973; Bartsch, 1961; King *et al.*, 1970). Hendricks and Pote (1974) calculated that the conventional lagoon design, which attempts to match inflow BOD with algal synthesis in order to meet the oxygen requirements of the sewage, results in vast overproduction of algae. Many more new algal cells than bacterial cells are produced, and the scale of degradative and photosynthetic activity becomes far greater than is actually needed.

CONCLUSIONS

1. The facultative lagoons in operation at Jewell and Zearing, Iowa, achieved the following reductions, respectively, based on mean values of influent and effluent during the period of our summer study: ammonium nitrogen, 98 and 87%; nitrate nitrogen, 52 and 47%; total nitrogen, 78 and 88%; inorganic phosphorus, 96 and 92%; total phosphorus, 91 and 77%. Reduction was attributed to uptake of these nutrient elements by algae and precipitation of phosphorus at high pH levels. Levels of nitrogen and phosphorus remained high enough to support algal blooms. Influent levels of nitrogen, phosphorus, and other chemical parameters fluctuated widely over a 24-hour period, but effluent levels remained stable.

2. With effluent BOD_5 levels of 30 mg/l and 16 mg/l (Jewell and Zearing, respectively), both lagoons appeared to meet the EPA standard (< 30 mg/l for 30 consecutive days) over a six-week summer period. The Jewell lagoon achieved an average of 82% BOD_5 reduction for the period while the reduction at Zearing was 89% (EPA standard, 85%).

3. The mean pH values for Jewell and Zearing were 9.5 and 8.9, respectively (EPA standard, 6.0-9.0).

4. Reductions in total and fecal coliform bacteria exceeded 99.9% in both lagoons, but the geometric means for effluent fecal coliform bacteria were 1730/100 ml for Jewell and 1330/100 ml for Zearing (EPA standard, 200/100 ml).

5. Phytoplankters present in largest numbers were *Chlamydomonas, Scenedesmus, Microcystis, Oscillatoria, Cyclotella,* and *Nitzschia*. The blue-green alga *Microcystis* was the predominant bloom organism in both lagoons.

6. The only noticeable odor was associated with mats of decaying blue-green algae which were wind-swept to corners of each cell.

7. These two facultative lagoons, comparable in design, produced effluent of comparable quality, with the Jewell lagoon showing a slightly better record in reduction of inorganic ions. The Jewell lagoon has been in operation nine years longer than the Zearing lagoon and was operating at design capacity of organic loading compared to Zearing's loading of half design capacity. However, the flow rate at Zearing was 66% of that at Jewell. Zearing showed better performance than Jewell in BOD_5 reduction and in fecal coliform reduction.

8. During the summer of 1974, both lagoons approached but did not fully meet the EPA 1977 standards. Longer detention time and reduced algal densities should permit these lagoons to achieve the EPA standards.

ACKNOWLEDGMENTS

This investigation was supported by National Science Foundation Grant No. GY11187. We acknowledge with appreciation the contributions of Michael Edwards, Thomas Blewett, and Robert Rousseau; the cooperation of other student members of the study team; and the assistance and advice of Dr. J. J. O'Toole (project director and group leader), Dr. Arnold van der Valk (group leader), and Dr. Craig Davis (Coordinator, Environmental Studies), all of whom are faculty members at Iowa State University.

LITERATURE CITED

AMERICAN PUBLIC HEALTH ASSOCIATION. 1971. Standard methods for the examination of water and wastewater, 13th ed. American Public Health Association, New York.

AMES, B. N. 1966. Assay of inorganic phosphate, total phosphate, and phosphatases. Pages 115-118 *in* E. F. Neufeld and V. Ginsburg, eds. Methods in Enzymology, Vol. 8. Academic Press, New York.

BARSOM, G. M. 1973. Lagoon performance and the state of lagoon technology. EPA Tech. Ser. Rept. R2-73-144. U. S. Environmental Protection Agency, Washington, D.C.

——— and D. W. RYCKMAN. 1970. Evaluation of lagoon performance in light of 1965 Water Quality Act. Pages 63-80 *in* R. E. McKinney, ed. 2nd International Symposium for Waste Treatment Lagoons, Kansas City, Missouri, 1970.

BARTSCH, A. F. 1961. Algae as a source of oxygen in waste treatment. J. Water Pollut. Control Fed. 33:239-249.

BOGAN, R. H., O. E. ALBERTSON, and J. C. PLUNTZE. 1960. Use of algae in removing phosphorus from sewage. J. Sanit. Eng. Div., Proc. Am. Soc. Civ. Eng. 86 (SA5): 1-20.

CODE OF IOWA. 1974. Department of Environmental Quality, Water Quality Commission. Chapter 16, Water quality standards. February 12, 1974.

COOLEY, C. E., and R. R. JENNINGS. 1961. Study of the performance of a sewage stabilization pond at Farmville, Virginia. Pages 41-51 *in* Waste stabilization lagoons. Proc. Symp. on Waste Stabilization Lagoons, Kansas City, Missouri, 1960. Public Health Service Publ. No. 872, U. S. Department Health, Education, and Welfare, Washington, D.C.

FEDERAL REGISTER. 1973. Environmental Protection Agency. Water programs. Secondary treatment information. Federal Register 38(159):22297-22299.

FITZGERALD, G. P. and G. A. ROHLICH. 1958. An evaluation of stabilization pond literature. Sew. & Ind. Wastes 30:1213-1224.

HACH CHEMICAL COMPANY. 1973. Water analysis handbook. Ames, Iowa.

HENDRICKS, D. W., and W. D. POTE. 1974. Thermodynamic analysis of a primary oxidation pond. J. Water Pollut. Control Fed. 46:333-351.

HUMENIK, F. J., and G. P. HANNA, JR. 1970. A symbiotic system for advanced treatment of wastewater. Water & Sew. Works 117:198-202.

KING, D. L., A. J. TOLMSOFF, and M. J. ATHERTON. 1970. Effect of lagoon effluent on a receiving stream. Pages 159-167 *in* R. E. McKinney, ed. 2nd International Symposium for Waste Treatment Lagoons, Kansas City, Missouri, 1970.

LYMAN, E. D., M. W. GRAY, and J. H. BAILEY. 1970. A field study of the performance of waste stabilization ponds serving small towns. Pages 387-404 *in* R. E. McKinney, ed. 2nd International Symposium for Waste Treatment Lagoons, Kansas City, Missouri, 1970.

MCKINNEY, R. E., ed. 1970. 2nd International Symposium for Waste Treatment Lagoons. June 23-25, Kansas City, Missouri.

MISSOURI BASIN ENGINEERING HEALTH COUNCIL. 1971. Waste treatment lagoons — state of the art. EPA 17090 EHX.

RICHMOND, M. S. 1970. Quality performance of waste stabilization lagoons in Michigan. Pages 54-63 *in* R. E. McKinney, ed. 2nd International Symposium for Waste Treatment Lagoons, Kansas City, Missouri, 1970.

TOMS, I. P., M. OWENS, J. A. HALL, and M. J. MINDENHALL. 1975. Observations on the performance of polishing lagoons at a large regional works. Water Pollut. Control (G.B.) 74:383-399.

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. 1961. Waste stabilization lagoons. Proc. Symp. on Waste Stabilization Lagoons, Kansas City, Missouri, 1960. Public Health Service Publ. No. 872. U. S. Government Printing Office, Washington, D. C.

VENNES, J. W. 1970. State of the art — oxidation ponds. Pages 366-376 *in* R. E. McKinney, ed. 2nd International Symposium for Waste Treatment Lagoons, Kansas City, Missouri, 1970.

ZOLTEK, J., JR. 1974. Phosphorus removal by orthophosphate nucleation. J. Water Pollut. Control Fed. 46:2498-2520.