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# Nutrients in Wastewater from a Phosphate Fertilizer Manufacturing Plant Stored for Irrigation

J. H. Smith[1], J. A. Bondurant[1], W. A. Wolleson[2], and J. F. Cochrane[2]

[1] Snake River Conservation Research Center, USDA-ARS, Kimberly, ID
[2] J. R. Simplot Co., Minerals and Chemical Division, Pocatello, ID

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**Summary.** Wastewater from a fertilizer manufacturing plant in southern Idaho was pumped into a storage impoundment during the winter months and stored for irrigating and fertilizing agricultural crops the next summer. Analyses of water samples from the impoundment taken monthly showed the following mean annual nutrient concentrations: Total Kjeldahl Nitrogen (TKN) 94, $NH_4^+$–N 61, $NO_3^-$–N 8, total P 17, ortho P 15, and K 17 mg/L. The impoundment surface area averaged 10.5 ha with a maximum pond volume during the year of 362,000 $m^3$. Accumulated nutrients in the impounded wastewater available for irrigating and fertilizing agricultural crops at the beginning of the growing season was TKN 30.2, $NH_4^+$–N 23.2, $NO_3$–N 4.3, total P 9.7, and K 6.2 metric tons. Nitrification in the pond was minimal. Redox potentials were between 480 and 500 mv at all depths and locations measured in the pond in the summer and denitrification was minimal. The redox potential indicated that the water was near oxygen saturation.

With the increased use of wastewater in the United States, storage facilities have been constructed for impounding wastewater for crop land irrigation in the summer. A computer search of all available data bases did not find any published literature citations relating to nutrients contained in impounded waters for irrigating and fertilizing agricultural crops. Several published articles were found on the subject of nutrients in wastewater impoundments and eutrophic lakes where the objective was to evaluate the influence of the nutrients and provide for their removal or reduction.

Pipes (1980) suggested that the subjects of disinfection (particularly virus inactivation), nitrification and denitrification, and potential health hazards from land disposal of effluents, seem to be of interest to a number of investigators. Ashton (1979) reported on algal fixation of N in a eutrophic lake receiving municipal and industrial effluents in South Africa. He estimated N fixation to be 1.13 metric tons in the lake with an area of 492 $km^2$ during a two month period in 1975. Others researchers have reported on nitrification in wastewater impoundments [Prakasam et al. (1979); Reinhard (1979); Reddy (1983); Reddy and Graetz (1981); and Shade (1979)]. Their emphasis has been mostly on nitrification in wastewater impoundments where N is unwanted and is being removed. Argaman and Miller (1979) modeled recycling systems that were designed to provide nitrification and denitrification in systems where N was being removed in wastewater treatment. Stratton (1969) developed a mathematical relationship showing that $NH_3$ volatilization from wastewater impoundments obeyed a first order reaction proportional to the $NH_3$–N concentration in solution. He reported that warm eutrophic impoundments are potentially able to liberate significant quantities of gaseous $NH_3$–N to the atmosphere by natural degasification.

The objectives of this research were to measure concentrations of fertilizer nutrients in wastewater impounded from a fertilizer manufacturing plant, to determine changes in concentrations of nutrients with storage, to measure inflow into storage and outflow for irrigation, and to calculate seepage and nutrient losses, with a goal of determining how much water and nutrient would be available for use in irrigating and fertilizing agricultural crops.

## Materials and Methods

A wastewater impoundment was constructed in a hillside east of Pocatello, Idaho, 1,414 m above mean sea level. The impoundment was designed to contain approximately $10^6$ $m^3$ of wastewater, and its impoundment dike, bottom, and side slopes were specified to be compacted to no less than 95% of maximum soil density as determined by ASTM D698 standard Proctor Method A. The impoundment liner, 10 cm thick after compaction, was installed on the bottom and side slopes. The bentonite-polymer mixture in the liner was specified to be no less than 3.4% of the dry soil blended mixture to give a design seepage rate of less than 6 mm/day. The walls of the impoundment were covered with rip rap of crushed stone to the elevation of the spillway. A concrete inlet structure almost 11 m high with its top at the same level as the dam was built to allow pumping water into and out of the impoundment with the filling point at about the 1,414 m elevation.

Water samples were taken from the surface of the water at the four corners of the impoundment at monthly intervals from Nov. 20, 1981 to Oct. 27, 1982. Water pH and temperature measurements were made on site. The water samples were taken to the laboratory and analyzed immediately for Chemical Oxygen Demand (COD), $NH_4^+$–N, $NO_3^-$–N, and total Kjeldahl N (TKN). The water was then subsampled and frozen for later analyses for total and ortho P and for K. COD, $NH_4^+$, and TKN analyses were according to American Public Health Assn. Inc. (1971), $NO_3$ was determined with a specific ion electrode, P by persulfate oxidation (USEPA 1974), and K by flame photometry.

Redox measurements to determine oxygen saturation in the water were made in the reservoir on May 27 and June 29, 1982, using a portable millivolt meter and probe from a small row boat with reservoir profiles from the surface to the bottom of the water taken continuously across the reservoir. Because of the almost continuous windy conditions on the reservoir, water mixing was thorough as indicated by the similar redox measurements from the surface to the bottom of the impoundment. Average monthly wind and air temperature measurements recorded by a meteorological station located on the inlet structure are reported in Table 1.

Water volume pumped into the impoundment, water level, and evaporation from an evaporation pan were measured regularly. Water volume pumped from the impoundment was measured part of the time and because of problems with the water meter in the pipeline leading from the impoundment and another water source used for irrigation mixed with the impounded wastewater calculation of a water balance were not possible. Seepage losses from

**Table 1.** Wind speed and air temperature at a wastewater reservoir near Pocatello, Idaho from September 1981 to October 1982

| | Average wind speed, km/h | Days of record | Air temperature, °C Monthly average | | |
|---|---|---|---|---|---|
| | | | Maximum | Minimum | Mean |
| Sept. 1981 | 10.8 | 16 | 24.3 | 12.8 | 18.6 |
| Oct. | 14.1 | 23 | 12.6 | 4.7 | 8.7 |
| Nov. | 14.5 | 28 | 7.1 | 1.9 | 4.5 |
| Dec. | 18.4 | 16 | 3.7 | − 0.8 | 1.5 |
| Jan. 1982[a] | – | 0 | −1.9 | −11.2 | −6.6 |
| Feb. | 20.8 | 15 | 1.2 | − 4.8 | −1.8 |
| Mar. | 20.0 | 29 | 3.6 | − 0.7 | 1.5 |
| April | 18.5 | 28 | 8.4 | − 0.5 | 4.0 |
| May | 14.0 | 31 | 15.5 | 5.0 | 10.3 |
| June | 12.0 | 30 | 21.1 | 9.8 | 15.5 |
| July | 11.5 | 31 | 24.4 | 14.2 | 19.3 |
| Aug. | 11.9 | 19 | 27.6 | 15.8 | 21.7 |
| Sept. | 12.0 | 27 | 21.1 | 11.3 | 16.2 |
| Oct. | 13.8 | 29 | 10.7 | 3.3 | 7.0 |

[a] January data obtained from Pocatello airport

**Table 2.** Constituents of impounded phosphate fertilizer manufacturing wastewater at Pocatello, Idaho

| Sampling date | TKN | $NH_4^+$–N | $NO_3$–N | COD | P Total | P Ortho | K | pH | Temp °C | Redox potential mv |
|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | | | | | | | | | |
| 11-20-81 | 82 | 56 | 8 | 146 | 11.0 | 9.6 | 17 | 7.9 | 3.0 | |
| 12-19-81 | 88 | 62 | 8 | 80 | 24.9 | 20.8 | 18 | 8.5 | 1.0 | |
| 1-29-82 | 101 | 70 | 10 | 58 | 25.8 | 25.2 | 19 | – | 0.5 | |
| 2-26-82 | 56 | 49 | 8 | 39 | 14.7 | 14.3 | 10 | – | 3.5 | |
| 3-30-82 | 100 | 64 | 12 | 108 | 26.7 | 20.5 | 17 | 7.5 | 6.0 | |
| 4-29-82 | 94 | 66 | 12 | 78 | 23.9 | 22.4 | 18 | 8.4 | 10.5 | |
| 5-27-82 | 82 | 57 | 11 | 50 | 24.2 | 19.2 | 18 | 8.1 | 15.5 | 500–480 |
| 6-29-82 | 107 | 89 | 6 | 95 | 13.5 | 11.8 | 19 | 7.7 | 22.0 | 500–480 |
| 7-29-82 | 78 | 52 | 4 | 90 | 6.8 | 6.6 | 16 | 7.2 | 25.0 | |
| 8-26-82 | 102 | 50 | 3 | 126 | 6.6 | 6.4 | 19 | 8.1 | 20.2 | |
| 9-29-82 | 116 | 55 | 4 | 104 | 14.1 | 12.5 | 18 | 7.9 | 11.0 | |
| 10-27-82 | 116 | 57 | 6 | 102 | 11.1 | 10.2 | 16 | 8.1 | 7.0 | |
| Mean | 94 | 61 | 8 | 90 | 16.9 | 15.1 | 17 | | | |

the reservoir were calculated from measurements of pond level made at intervals of at least one month when water was not being pumped into or out of the reservoir. Evaporation and rainfall were accounted for in calculating seepage loss.

## Results and Discussion

Concentrations of plant nutrients and COD as well as pH, temperature of water, and redox potentials are presented in Table 2. During February rapid thawing of a heavy snowpack occurred and the ensuing runoff exceeded the runoff diversion canal capacity and ran into the reservoir on the uphill side, diluting the normal concentrations of nutrients. Therefore the average of the January and March nutrient concentrations were used in calculating the water and nutrients contained in the impoundment and the seepage losses of nutrients for February, rather than the measured February data.

### *Nutrients in Wastewater*

The majority of N in the impoundment was ammonia, with an average concentration of 61 mg N/l for the twelve months with relatively little variation from the mean. Nitrate concentrations averaged 8 mg N/l during the year with no indication of appreciable nitrification occurring in the reservoir. It was expected that nitrification would occur in the impoundment, however, it did not, possibly because of the toxicity of $NH_3$ in the system to both the ammonification and nitrification processes (Smith and Burns 1962). While $NH_3$ is much more toxic to Nitrobacter in conversion of $NO_2^-$ to $NO_3^-$ where 0.5 mg $l^{-1}$ may decrease the reaction by 50% than to Nitrosomanas, there may have been enough $NH_3$ also to limit the oxidation of $NH_4^+$. Calculated levels of $NH_3$ in the reservoir ranged from 1 to 33 mg $l^{-1}$ during the months when water temperature was above 6 °C.

Total P in the impoundment averaged 16.9 and ranged from 6.6 to 25.8 mg/l during the year. Ortho P represented 89% of the phosphorus in the wastewater (Table 2). Potassium in the wastewater was relatively constant with an average of 17 mg/l. The water pH was always above neutrality and reflected treatment additives from the pretreatment system at the fertilizer manufacturing plant. Water temperature varied with season of the year and ranged from 0.5 to 25 °C. The reservoir was covered with up to 25 cm of ice from mid-December 1981 to late February 1982.

### *Oxidation-Reduction Potential*

Redox measurement profiles across the reservoir from the surface to the bottom showed 500 mv at the surface and 480 mv at the bottom. During the summer when the temperature was high enough for denitrification to occur, the wind speed, which averaged 11 km/h from June to September (Table 1) was sufficient to keep the reservoir mixed and aerated reducing the probability for denitrification. The 480 to 500 mv redox potential measurements correspond to oxygen concentrations in the water near oxygen saturation. The three factors required for denitrification to occur are nitrate, an energy source, and anaerobic conditions. Redox potential values decreasing toward 225 mv are required for denitrification and usually if sufficient energy is present, all of the nitrate in the system will be denitrified when a redox potential of 225 mv is reached (Smith et al. 1976).

### *Chemical Oxygen Demand*

The average COD in the reservoir was 90 mg/l for the year. There were some variations from this figure as shown in Table 2 but the values were not high enough to provide the necessary energy to support a significant microorganism population.

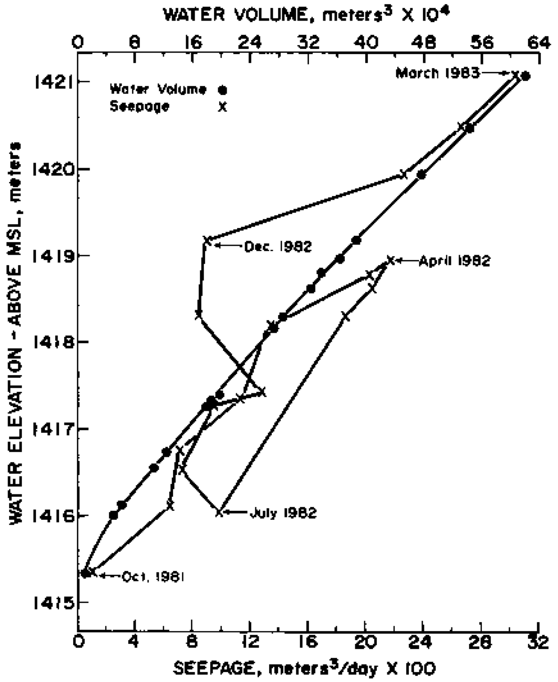


**Fig. 1.** Volume of stored wastewater and seepage losses related to depth in a reservoir near Pocatello, Idaho, from October 1981 through March 1983

Most of the COD was attributed to an algal population in the reservoir. The 90 mg/l of COD in the reservoir was made up mostly by living organisms.

*Seepage Losses*

The volume of water in the wastewater reservoir was almost linear in relation to depth from the 1,415.3 m to 1,421 m elevation above mean sea level (Fig. 1). The water volume ranged from 138,000 to 618,000 m³ for the water depths reported above. During the first two seasons of operating the wastewater impoundment, as the reservoir was filled and the depth increased, the seepage rate increased from 150 to about 2,160 m³/day. The maximum seepage occurred when the water averaged 4 m deep. The irrigation season then started and the water level was lowered by pumping for fertilizing and irrigating agricultural crops. As the reservoir level decreased, seepage also decreased to about 1,000 m³/day. As filling started again, and while the reservoir was low, additional bentonite and polymer were applied to the reservoir bottom with big-gun sprinklers and the sealing was improved. After this treatment, seepage remained relatively constant at under 1,000 m³/day until the water level reached about 4 m deep at which time seepage again increased with additional filling to the maximum depth at elevation 1,421 m above MSL and a seepage rate of 3,000 m³/day. The time represented in Fig. 1 was October 1981 to March 1983. The points on the seepage curve in Fig. 1 have been joined to show the sequence of reservoir filling, emptying, and filling a second time.

During the year of observations, the water stored in the reservoir increased from 125,000 m³ to 362,000 m³, then decreased to 62,000 m³ and was again filled to

**Table 3.** Water and nutrients lost from wastewater reservoir by seepage during the months of November 1981 through October 1982

| Month | Water Elev. m* | Seepage $m^3$ $month^{-1}$ | TKN | $NH_4^+$–N | $NO_3$–N | P Total | P Ortho | K |
|---|---|---|---|---|---|---|---|---|
| | | | metric tons $month^{-1}$ | | | | | |
| 11/81 | 1,416.7 | 22,059 | 1.81 | 1.24 | 0.18 | 0.24 | 0.21 | 0.38 |
| 12/81 | 1,417.3 | 35,670 | 3.14 | 2.21 | 0.28 | 0.89 | 0.74 | 0.62 |
| 1/82 | 1,418.1 | 41,185 | 4.16 | 2.88 | 0.41 | 1.06 | 1.04 | 0.78 |
| 2/82 | 1,418.7 | 57,017 | 5.70 | 3.82 | 0.63 | 1.50 | 1.30 | 1.03 |
| 3/82 | 1,419.0 | 66,881 | 6.69 | 4.28 | 0.80 | 1.79 | 1.37 | 1.14 |
| 4/82 | 1,418.6 | 60,749 | 5.71 | 4.01 | 0.73 | 1.45 | 1.51 | 1.09 |
| 5/82 | 1,418.3 | 57,611 | 4.72 | 3.28 | 0.63 | 1.39 | 1.11 | 1.04 |
| 6/82 | 1,416.0 | 30,742 | 3.29 | 2.74 | 0.18 | 0.41 | 0.35 | 0.58 |
| 7/82 | 1,416.6 | 22,294 | 1.74 | 1.16 | 0.09 | 0.15 | 0.15 | 0.36 |
| 8/82 | 1,417.3 | 29,451 | 3.00 | 1.47 | 0.09 | 0.19 | 0.19 | 0.56 |
| 9/82 | 1,417.4 | 38,493 | 4.46 | 2.12 | 0.15 | 0.54 | 0.48 | 0.69 |
| 10/82 | 1,418.3 | 24,758 | 2.87 | 1.41 | 0.15 | 0.28 | 0.25 | 0.40 |
| | Total | 486,910 | 47.29 | 30.62 | 4.32 | 9.89 | 8.70 | 8.67 |

* meters above mean sea level

**Table 4.** Water and nutrients contained in reservoir on sampling dates at monthly intervals for one year

| Date | Pond | | TKN | $NH_4^+$–N | $NO_3^-$–N | P Total | P Ortho | K |
|---|---|---|---|---|---|---|---|---|
| | Area ha | Volume $m^3$ | metric tons | | | | | |
| 12-01-81 | 9.63 | 125,019 | 10.25 | 7.00 | 1.00 | 1.38 | 1.20 | 2.12 |
| 01-04-82 | 10.35 | 185,011 | 16.28 | 11.47 | 1.48 | 4.61 | 3.85 | 3.33 |
| 02-01-82 | 10.90 | 272,179 | 27.49 | 19.05 | 2.72 | 7.02 | 6.86 | 5.17 |
| 03-01-82 | 11.30 | 337,833 | 33.78 | 19.26 | 3.92 | 8.85 | 7.70 | 6.08 |
| 04-01-82 | 11.44 | 362,073 | 30.21 | 23.17 | 4.34 | 9.67 | 7.42 | 6.16 |
| 05-01-82 | 11.22 | 326,494 | 30.69 | 21.55 | 3.92 | 7.80 | 7.31 | 5.88 |
| 06-01-82 | 11.00 | 287,509 | 23.58 | 16.39 | 3.16 | 6.96 | 5.52 | 5.18 |
| 07-01-82 | 8.83 | 62,642 | 6.70 | 5.58 | 0.38 | 0.85 | 0.72 | 1.19 |
| 08-01-82 | 9.74 | 107,759 | 8.40 | 5.60 | 0.43 | 0.73 | 0.71 | 1.72 |
| 09-01-82 | 10.31 | 178,122 | 18.17 | 8.91 | 0.53 | 1.18 | 1.14 | 3.38 |
| 10-01-82 | 10.40 | 192,354 | 22.31 | 10.58 | 0.77 | 2.71 | 2.40 | 3.46 |
| 11-01-82 | 11.00 | 287,849 | 33.39 | 16.41 | 1.73 | 3.20 | 2.94 | 4.61 |
| Mean | 10.51 | 227,154 | 21.77 | 13.75 | 2.02 | 4.58 | 3.98 | 4.02 |

288,000 $m^3$ when water sampling was terminated. The surface area of the pond varied from 8.8 to 11.4 ha (Table 4). During this period the total N was initially 10.25 then increased to 33.78, decreased to 6.70 and increased again to 33.39 metric tons in storage. Ammonia, $NO_3$–N, total and ortho P, and K followed similar trends as shown in Table 4.

Seepage loss was 487,000 $m^3$ for the year of the investigation (Table 3). Water and nutrient losses increased as the reservoir was filled and decreased as it was drained. Total N loss for the year totaled 47 metric tons with monthly losses ranging from 1.8 to 6.7 metric tons. Ammonia in the wastewater made up 65% of the total N and seepage loss of $NH_3$–N amounted to 30.6 metric tons for the year with monthly losses of 1.2 to 4.3 metric tons. Nitrate-N losses were 4.3 metric tons for the year with monthly losses ranging from 0.1 to 0.7 metric tons. Total P losses were 9.9 metric tons for the year and monthly losses ranged from 0.15 to 1.79 metric tons. Ortho P made up about 88% of the total P and losses were 8.7 metric tons for the year. Potassium losses from the system were slightly less than P with 8.7 metric tons lost for the year and monthly losses of 0.36 to 1.14 metric tons.

Nutrient losses from the reservoir were calculated by multiplying the nutrient concentration by the calculated water loss for the month. While the water and nutrients were lost from the reservoir and not available for irrigation and fertilizing crops, no evaluation is made of nutrient movement under the reservoir. The anions will move freely with the water but the cations will only move with the water after the soil cation exchange capacity is saturated with $NH_4^+$, $PO_4^{+3}$, $K^+$, etc.

## Conclusions

From November 1981 to April 1982 about 525,000 $m^3$ of wastewater were pumped into the reservoir. Calculations of seepage loss for this six month winter and spring period amounted to 283,560 $m^3$. During the months of March and April 1982, daytime temperatures were above freezing and irrigations could be made for fertilizing agricultural land. This was also the time when the maximum volume of water was in storage and when it would be desirable to lower the water level to decrease seepage losses. At the time of maximum storage volume the water in storage contained TKN 33.8, $NH_3$–N 19.3, $NO_3^-$–N 3.9, total P 8.8, and K 6.1 metric tons of the respective nutrients. All of the water and nutrients could be distributed onto the land for fertilizing growing or prospective crops. Pumping this water onto the land could supply the basic fertilization for about 300 hectares of land and additional area could be fertilized and irrigated with less enriched water from the Pocatello city sewage treatment system mixed with the fertilizer plant effluent during the crop growing season.

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