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BIOLOGICAL PHOSPHATE REMOVAL FROM WASTEWATERS

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PHOSTRIP® PROCESS — A VIABLE ANSWER TO EUTROPHICATION OF LAKES AND COASTAL SEA WATERS IN ITALY

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ABSTRACT

The role of wastewater nutrients in eutrophication was recognized in the 1940's. Until the mid-1970's, the only means for removing wastewater phosphate, the nutrient generally thought to offer the best control measure, was chemical precipitation. The successful, full-scale demonstration at Seneca Falls, NY, introduced the cost-effective alternative of biological phosphorus removal. The method, called the PhoStrip process, causes the microorganisms in activated sludge to bioaccumulate and secrete phosphate. Biological phosphorus removal has since evolved into two types: "sidestream" (PhoStrip), and "fullstream" processes. PhoStrip systems have fully demonstrated their capability for sustained production of effluents averaging 1.0 mg/L, or less, total P, the effluent standard generally enforced. In addition to this unique achievement, PhoStrip systems provide overall plant operations advantages including compatability with any mode of activated sludge treatment, equal effectiveness over a wide range of F/M and P/BOD, sludge volume reduction, and protection against hydraulic surcharge and toxic shock. Tabularized official data from municipal PhoStrip II process, which reduces tankage volume, is described. Actual cost data from PhoStrip installations show major savings. Cost data are projected for the new PhoStrip II process. Thirteen references are cited.

KEYWORDS

Phosphorus, phosphates removal; PhoStrip; Municipal Sewage Treatment; operational results.

INTRODUCTION

The protection of lakes and coastal waters from the abnormal growth of monocellular algae is of increasing concern in areas where seasonal tourism, wildlife and human populations have been affected by eutrophication. Ever since the 1940's identified (Governor's Report, 1944) nutrient enrichment from wastewater discharge as the cause of the severe pollution problems in the Wisconsin Lakes, much scientific discussion has been devoted to selecting the most feasible method for controlling eutrophication. Removal of the nutrients, carbon, nitrogen, and phosphorus , singly and in combination, from wastewater have all been considered. Because carbon is readily assimilated from the atmosphere, its limitation as an effluent control measure for preventing eutrophication has not been pursued. In some areas, only seasonal control of nutrients has been advocated. However, nutrients not removed from wastewater plant effluents will, to some degree, through biological or chemical action, settle to the stream, lake, or estuary bed. A portion of these settled nutrients becomes available again through upwellings of nutrients, particularly during spring and fall turnovers in water bodies.

For some years now, the scientific literature as, for example, cited by Sincero (1984) has indicated phosphorus removal as the preferred way of controlling algal blooms and the growth of other undesirable aquatic vegetation. No living organism can reproduce without phosphorus, a central component of the nucleic acids. All energy consumption and energy production by living organisms require phosphorus.

Obviously, other elements are also essential. However, phosphorus is the least available from the environment in proportion to the amount required. Phosphorous is not replenished from the atmosphere (except, perhaps, polluted rains). The same is not true of nitrogen. Blue-green algae, generally the first algae to bloom seasonally, have the ability to fix nitrogen from the atmosphere.These organisms liberate the nitrogen in forms readily available to support subsequent blooms of non-nitrogen fixing algae.

Nutrients are also disseminated into water bodies from agricultural drainage and run-off from cleared lands. A surprising result of recent work (Vitousek, 1984 and Wood, 1984) is that even forested areas are sources of large quantities of nitrogen through runoff. Phosphorus, on the other hand is conserved in the forested areas. Nitrogen runoff from forested areas exceeds phosphorus runoff by a factor ranging from 40 to 400 fold. Furthermore, even when forested lands are cleared, runoff losses of dissolved inorganic phosphorus do not increase. Phosphorus is tightly bound by biological uptake and by geochemical processes operating in soils. However, massive increases in streamwater exports of nitrate occur after clear-cutting of forests. The evidence, therefore, selects phosphorus control as the most practicable means for preventing undesirable aquatic growths. Control of non-point sources of phoshorus would best be accomplished by institution of agricultural practices which would prevent over-application of phosphate fertilizer and would utilize contour plowing, or similar means, to prevent direct runoff.

With respect to point sources, for many years the only means available for phosphate removal from municipal wastewater was the addition of chemicals to the entire wastewater stream. The dissolved phosphate was precipitated separately or combined with waste biological sludge. All such methods require application of prodigious amounts of chemicals which are expensive and which also produce large quantities of additional sludge requiring costly removal. Furthermore, such processes share one undesirable aspect: they all produce subtitute pollution in which the anion of the salt used to remove the phosphate is liberated to the stream in an ionic amount exactly equaling that of the ions precipitated by the process. In some chemical methods, using mineral acids, or lime, as the precipitating agent, neutralization is required before the wastewater can be discharged, thereby adding increasing costs and complexity.

An effort to develop a more cost-effective, reliable method of wastewater phosphorus removal was begun in 1960 by the senior author. Activated sludge organisms were induced to bioaccumulate the phosphorus for ultimate removal. This work (Levin, 1963) was continued and, through a series of patented processes and improvements, evolved into the PhoStrip process technology. The first full-scale demonstration of one of the early PhoStrip systems took place at Seneca Falls, New York, in 1973.

The Seneca Falls PhoStrip demonstration (Levin et al, 1975) consistently produced an effluent containing well below 1.0 mg/L total P (an average of 0.55) with no filtration and did so while reducing costs of chemicals by 90 percent compared to the classic removal methods. Also, phosphorus sludge production was reduced by about 50 percent over chemical methods. The process proved simple, reliable and improved overall peformance of the activated sludge treatment plant. Effluent dissolved phosphate of about 0.2 mg/L PO_4-P demonstrated that, with the addition of filtration, the PhoStrip process can produce a final effluent total phosphorus at about that level.

DESCRIPTION OF THE PROCESS

The PhoStrip process harnesses wastewater activated sludge microorganisms to take up phosphate from aerating mixed liquor and to release the phosphate in more concentrated form when the settled sludge is subjected to anaerobic conditions. Because only the microbial sludge, the agent responsible for taking up and then releasing phosphate, is subjected to anaerobiosis, the PhoStrip process is a "sidestream" process.

A general flow diagram for the Phostrip process is presented in Figure 1. Primary clarifier effluent enroute to the aeration basin is joined with return activated sludge as in the case of normal activated sludge treatment. However, a portion of the return activated sludge is routed through the Stripper Tank where it undergoes anaerobic detention. During the anaerobic detention, the sludge releases dissolved phosphate which is mechanically distributed throughout the liquid volume. About half of the released phosphate is carried away in the supernatant from the Stripper Tank. Typically, the supernatant is dosed with lime, subjected to a brief mixing period and pumped back to the primary clarifier where the precipitating phosphate settles. The subnatant sludge from the Stripper Tank is conveyed to meet the direct return activated sludge and both join the primary clarifier effluent in discharging into the aeration basin. After a period of conditioning in the anaerobic/aerobic cycling administered by the PhoStrip process, sludge microorganisms induce enzymic activity which enables them to absorb essentially all of the dissolved phosphate in the mixed liquor during the aeration period. The mixed liquor flows to the secondary clarifier where the sludge settles leaving a low phosphate supernatant for discharge as final effluent or further treatment as the case may be. Activated sludge normally wasted from the subnatant stream of the secondary clarifier is now rich in intracellular phosphate.

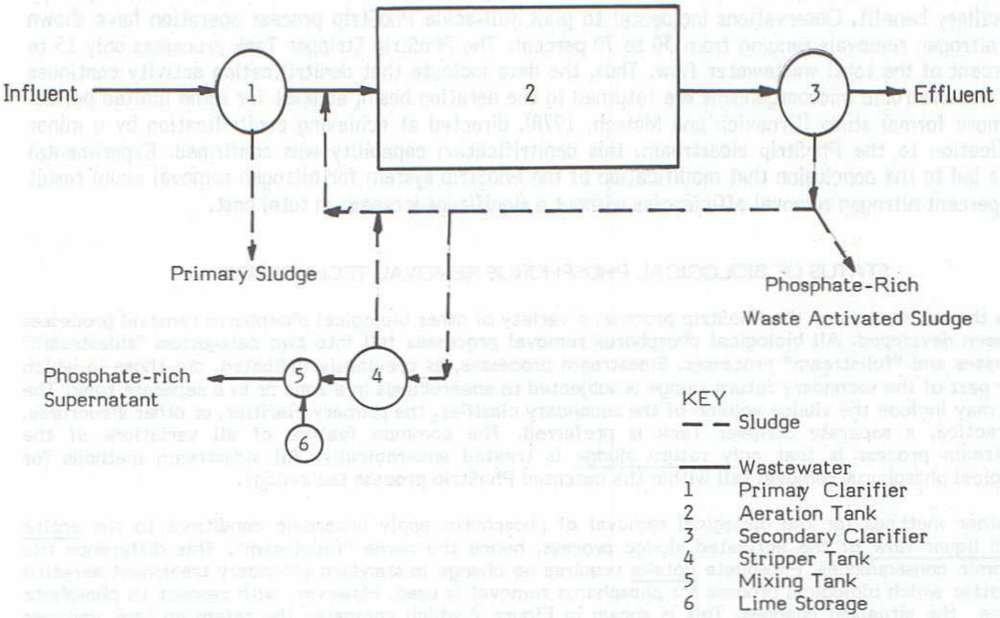


Fig. 1. Standard PhoStrip flow process design

Thus, the PhoStrip process provides two sinks for phosphorus removal: 1. the precipitation of phosphate from the Stripper Tank supernatant, and 2. the wasting of phosphorus-rich activated sludge from the secondary clarifier. Approximately two-thirds of the phosphorus removed from wastewater is precipitated from the Stripper Tank supernatant in normal operation. Lime is the precipitant of choice because of its very high efficiency under the supernatant conditions of high phosphate concentration and small flow volume. The remaining third of the phosphorus is removed with the waste biological sludge. Control of PhoStrip operating conditions permits the proportions of phosphorus removed through these two sinks to be varied considerably in accordance with the objectives of particular plants.

In the PhoStrip process, process streams from thickeners, digesters and other unit operations are returned to the head of the wastewater treatment plant. Capacity of the microorganisms to take up wastewater phosphate is sufficient to remove the influent wastewater phosphate plus the phosphate present in these process streams.

The PhoStrip process may be designed as part of a new wastewater treatment plant without impacting other plant objectives. It is completely compatible with any mode of activated sludge including conventional, plug or mixed flow; tapered feed; step feed; contact; air or high purity oxygen. Alternatively, the PhoStrip process can be retrofit to existing plants. Frequently, a spare clarifier, or other tank, can be converted to the Stripper Tank and the addition of pumps, piping and controls can complete the installation.

The PhoStrip process has been operated with mixed liquor suspended solids ranging from 1 to 10 hours. Successful operating experience includes, but is not limited to: influent BOD values ranging from 70 mg/L to 300 mg/L; influent phosphorus concentrations ranging from 3 mg/L to 20 mg/L; wastewater temperatures ranging from 7 °C to 30 °C; and secondary clarifier NO_2/NO_3-N concentrations ranging from 1 mg/L to 30 mg/L. Any F/M ratio or P/BOD ratio suitable for the activated sludge process will also permit fully efficient operation of the PhoStrip process. Under each set of the above conditions, the process has produced an effluent containing 1.0 mg/L, or less, total P.

For eutrophication situations in which denitrification might be desired, the PhoStrip process may offer an ancillary benefit. Observations incidental to pilot full-scale PhoStrip process operation have shown total nitrogen removals ranging from 30 to 70 percent. The PhoStrip Stripper Tank processes only 15 to 35 percent of the total wastewater flow. Thus, the data indicate that denitrification activity continues after the anaerobic microorganisms are returned to the aeration basin, at least for some limited period. In a more formal study (Drnevich and Matsch, 1978), directed at achieving denitrification by a minor modification to the PhoStrip sidestream, this denitrification capability was confirmed. Experimental results led to the conclusion that modification of the PhoStrip system for nitrogen removal could result in 90 percent nitrogen removal efficiencies without a significant increase in total cost.

STATUS OF BIOLOGICAL PHOSPHORUS REMOVAL TECHNOLOGY

Since the appearance of the PhoStrip process, a variety of other biological phosphorus removal processes has been developed. All biological phosphorus removal processes fall into two categories: "sidestream" processes and "fullstream" processes. Sidestream processes, as previously indicated, are those in which all or part of the secondary return sludge is subjected to anaerobiosis in a zone or in a separate tank. The zone may include the sludge volume of the secondary clarifier, the primary clarifier, or other structures. In practice, a separate Stripper Tank is preferred. The common feature of all variations of the sidestream process is that only return sludge is treated anaerobically. All sidestream methods for biological phosphorus removal fall within the patented PhoStrip process technology.

All other methods for the biological removal of phosphorus apply anaerobic conditions to the entire mixed liquor flow of the activated sludge process, hence the name "fullstream". This difference has economic consequences. Phosphate uptake requires no change in standard secondary treatment aeration no matter which biological process for phosphorus removal is used. However, with respect to phosphate release the situation changes. This is shown in Figure 2 which compares the retention tank volumes required to provide equal release (anaerobic) treatment to organisms in mixed liquor (fullstream methods) compared to the tankage required for equal anaerobic retention of the same mass of organisms in sludge (sidestream method). For example, to provide eight hours of anaerobic retention time for a fullstream method with 50 percent return activated sludge requires tankage equal to 50 percent of the volume of the daily wastewater influent. In the sidestream method, this same amount of anaerobiosis is provided by less than 10 percent of the volume of the daily influent, representing a five-fold reduction in the tankage required for phosphorus removal.

In contrast to the sidestream process, fullstream biological phosphorus removal processes as illustrated in Figure 3, effect phosphorus removal only through sludge wasting which is in turn controlled by the organic load (sludge age) at which the activated sludge system is operated. Therefore, these processes do not offer the possibility of indipendent control of phosphorus and BOD removal mechanisms.

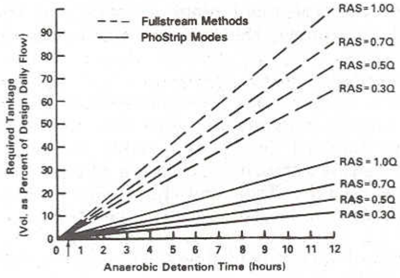
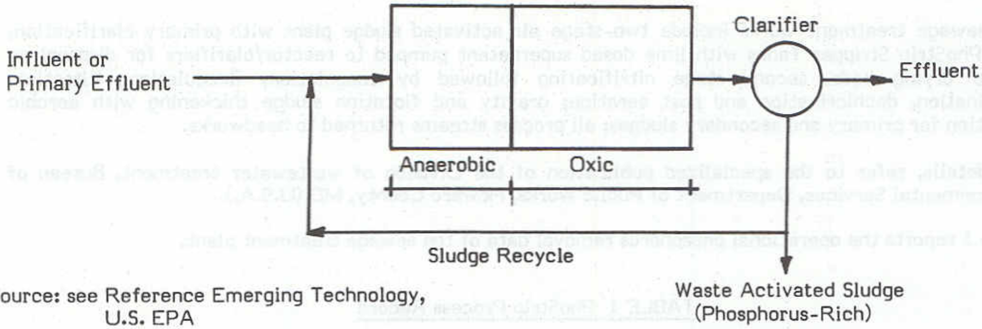


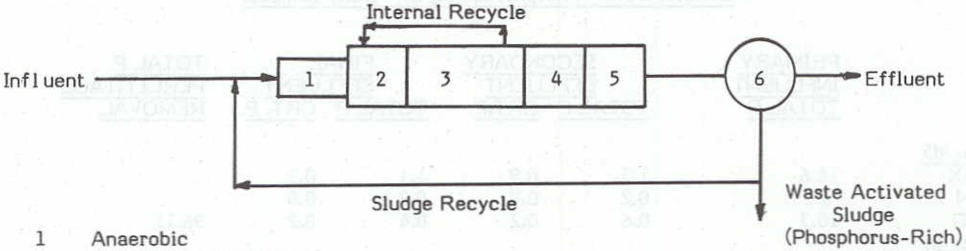
Fig. 2. Comparison of tankage required for equal anaerobic detention of sludge by fullstream and PhoStrip process



Source: see Reference Emerging Technology,
U.S. EPA

Fig. 3. Fullstream biological phoshorus removal
Process flow diagram

Fullstream biological phosphorus removal processes may combine phosphorus and nitrogen removal. Additional tankage is then provided, as seen in Figure 4, to accomodate denitrification.



1	Anaerobic
2	Anoxic (Denitrification)
3	Aeration (Nitrification)
4	Anoxic
5	Re - aeration
6	Clarifier

Source: see Reference Emerging Technology,
U.S. EPA

Fig. 4. Fullstream biological phosphorus removal with nitrification -
- denitrification process flow diagram

In a study (Weston, Inc., 1983) on biological phosphorus removal sponsored by the USEPA, PhoStrip alone was credited with consistently achieving total phosphorus effluent concentrations of 1.0 mg/L or less. For wastewater treatment plants with average flows above 5 MGD and with influent TP concentrations of 5.0 mg/L or greater, PhoStrip was the favored choice among biological and chemical methods. The report cites that the high-phosphate biological sludge produced by the fullstream biological phosphorus removal processes is unstable, leaks phosphate, and must be chemically conditioned prior to disposal to prevent solubilized phosphorus from being reintroduced into the plant. If cost of this chemical treatment is included as recommended by the USEPA, the comparison of methods shows the sidestream process to beeven more favorable.

OPERATING DATA

Fifteen municipal PhoStrip process plants have now been constructed or are under contract. In addition, more than fifteen pilot plants have been operated. The sites include all regions of the U.S. and installations in central Europe. The plants encompass a wide range of activated sludge modes and climates. In no instance has an operating fullscale or pilot plant failed to demonstrate sustained capability to produce an effluent containing 1.0, or less, mg/L total phosphorus. This has been achieved despite the large ranges of operating conditions and wastewater qualities described earlier in this report. For the purposes of this paper, recent operating data were solicited from diverse municipal PhoStrip process plants, as shown in the following sections.

Howard County, MD (Little Patuxent)

The sewage treatment works include two-stage air activated sludge plant with primary clarification, twin PhoStrip Stripper Tanks with lime dosed supernatant pumped to reactor/clarifiers for disposal on sludge drying beds, second stage nitrification followed by coagulation, flocculation, filtration, chlorination, dechlorination and post aeration; gravity and flotation sludge thickening with aerobic digestion for primary and secondary sludges; all process streams returned to headworks.

For details, refer to the specialized publication of the Division of wastewater treatment, Bureau of Environmental Services, Department of Public Works, Howard County, MD (U.S.A.).

Table 1 reports the operational phosphorus removal data of the sewage treatment plant.

TABLE 1 PhoStrip Process Record

Little Patuxent Wastewater Treatment Plant - Savage, Maryland
Howard County, Department of Public Works

Q=15 MGD

Official Data - Phosphorus (mg/L) - Daily Samples

	PRIMARY INFLUENT	SECONDARY EFFLUENT		FINAL EFFLUENT		TOTAL P PERCENTAGE REMOVAL
	TOTAL P	TOTAL P	ORT.P	TOTAL P	ORT. P	
Jan. '85						
MAX	14.6	1.3	0.9	1.1	0.9	
MIN	6.8	0.2	0.0	0.2	0.0	
AVG	10.3	0.6	0.2	0.4	0.2	96.11
Feb. '85						
MAX	16.4	3.6	1.3	2.2	1.8	
MIN	3.7	0.3	0.2	0.2	0.0	
AVG	9.4	1.3	0.5	0.8	0.5	91.48
Mar. '85						
MAX	15.4	2.3	1.5	1.2	0.9	
MIN.	7.1	0.5	0.1	0.2	0.0	
AVG.	9.6	1.0	0.4	0.5	0.2	94.79
Apr. '85						
MAX	11.9	0.7	0.2	0.5	0.2	
MIN	7.4	0.3	0.0	0.0	0.0	
AVG	9.0	0.5	0.1	0.3	0.1	96.66
May '85						
MAX	13.7	1.0	0.5	0.5	0.2	
MIN	7.4	0.4	0.1	0.2	0.0	
AVG	9.4	0.6	0.2	0.3	0.0	96.80
June '85						
MAX	9.8	0.8	0.6	0.4	0.3	
MIN	6.2	0.2	0.1	0.0	0.0	
AVG	8.0	0.4	0.2	0.2	0.1	97.50
July '85						
MAX	9.6	1.6	0.9	0.7	0.7	
MIN	5.9	0.4	0.1	0.2	0.2	
AVG	8.0	0.8	0.5	0.4	0.4	95
Aug. '85						
MAX	10.0	1.7	1.4	1.1	0.7	
MIN	5.9	0.3	0.1	0.2	0.2	
AVG	7.9	0.8	0.4	0.4	0.4	92.40
Sept. '85						
MAX	16.6	2.8	2.0	1.3	1.0	
MIN	6.6	0.4	0.1	0.2	0.1	
AVG	9.4	1.1	0.6	0.5	0.3	94.68

TABLE 1 PhoStrip Process Record (cont'd)

Oct. '85						
MAX	14.2	2.3	1.5	1.0	0.9	
MIN	6.7	0.3	0.1	0.3	0.1	
AVG	8.9	1.0	0.4	0.5	0.3	94.38
Nov. '85						
MAX	12.4	1.8	0.6	0.8	0.8	
MIN	5.7	0.5	0.0	0.2	0.2	
AVG	7/9	1.0	0.2	0.4	0.3	94.93
Dec. '85						
MAX	8.5	2.1	1.6	1.2	0.8	
MIN	4.9	0.5	0.1	0.2	0.1	
AVG	5.8	1.0	0.4	0.5	0.3	91.38
Jan. '86						
MAX	11.1	1.6	1.3	1.5	1.4	
MIN	5.3	0.7	0.2	0.3	0.3	
AVG	6.8	1.1	0.6	0.7	0.6	89.70
Feb. '86						
MAX	9.9	1.9	0.9	1.5	0.9	
MIN	6.3	0.5	0.2	0.4	0.0	
AVG	7.8	1.1	0.5	0.8	0.5	89.74
Mar. '86						
MAX	13.3	2.0	1.5	1.8	1.6	
MIN	5.0	0.7	0.1	0.4	0.3	
AVG	7.7	1.2	0.5	0.7	0.6	90.90
Apr. '86						
MAX	13.4	1.9	1.2	1.5	1.4	
MIN	6.0	0.7	0.2	0.3	0.2	
AVG	8.5	1.1	0.5	0.7	0.5	91.76
May '86						
MAX	14.2	1.9	1.6	1.7	1.6	
MIN	5.6	0.4	0.2	0.3	0.2	
AVG	7.1	0.9	0.6	0.6	0.6	91.55
July '86						
MAX	9.0	2.1	0.8	0.8	1.6	
MIN	4.6	0.3	0.1	0.2	0.2	
AVG	5.9	0.7	0.4	0.4	0.5	93.22

Tahoe-Truckee Sanitation Agency, (T.T.S.A.), CA.

The sewage treatment works are based on an advanced wastewater treatment process scheme, including single stage high-purity oxygen activated sludge plant preceded by influent disinfection and primary clarification, twin Phostrip Stripper Tanks with lime dosed supernatant pumped to reactor/clarifiers, effluent chemically treated, clarified, recarbonatad, filtered and chlorinated, anaerobic digestion supernatant and all process streams returned to headworks. Influent temperatures are as low as 3÷4°C. For details, refer to the publication of the T.T.S.A. (R. Svetich, et.al.).
Table 2 reports the operational phosphorus removal data of the sewage treatment plant.

TABLE 2 PhoStrip Process Record

Tahoe-Truckee Wastewater Treatment Plant - Truckee, Calif.
Tahoe-Truckee Sanitation Agency

Q = 5 MGD

Official Data - Phosphorus (mg/L) - Daily Samples

	PRIMARY INFLUENT	SECONDARY EFFLUENT		FINAL EFFLUENT		TOTAL P PERCENTAGE
	TOTAL P	TOTAL P	ORT.P	TOTAL P	ORT. P	REMOVAL
Jan. '86						
MAX	8.6	1.20	0.89	0.74	0.51	
MIN	5.2	0.28	0.02	0.20	0.08	
AVG	6.3	0.48	0.19	0.33	0.16	94.76

TABLE 2 PhoStrip Process Record (cont'd)

Feb. '86						
MAX	9.10	0.78	0.46	0.58	0.29	
MIN	1.9	0.29	0.02	0.20	0.11	
MAX	6.1	2.50	2.10	0.89	0.78	
MIN	3.2	0.21	0.02	0.14	0.05	
AVG	4.4	0.75	0.53	0.43	0.33	90.22
Apr. '86						
MAX	10.4	3.20	2.70	1.00	0.95	
MIN	4.2	0.20	0.03	0.10	0.09	
AVG	5.4	0.63	0.46	0.40	0.32	92.59
May '86						
MAX	8.4	2.90	2.70	0.78	0.60	
MIN	3.7	0.23	0.04	0.17	0.10	
AVG	5.5	0.70	0.48	0.37	0.29	93.27
June '86						
MAX	8.0	0.45	0.14	0.28	0.18	
MIN	5.4	0.17	0.02	0.12	0.05	
AVG	6.5	0.27	0.07	0.19	0.11	97.07
July '86						
MAX	9.7	1.70	0.95	1.01	0.84	
MIN	5.5	0.34	0.05	0.20	0.11	
AVG	7.8	0.70	0.25	0.43	0.28	94.48
Aug. '86						
MAX	9.9	2.50	2.80	0.70	0.50	
MIN	6.2	0.33	0.05	0.18	0.10	
AVG	8.3	0.74	0.27	0.38	0.23	95.42

Reno-Sparks, NV

The sewage treatment works include primary clarification followed by two-stage air activated sludge, Phostrip process applied to first stage, six Phostrip Stripper Tanks in parallel, lime precipitation of Stripper supernatant in reactor/clarifiers with sludge pumped to anaerobic digester Digester and sludge dewatering process streams returned to headworks. Second stage consist of nitrification followed by chlorination prior to discharge (L.E. Peirano, 1977).
Table 3 reports the operational phosphorus removal data of the sewage treatment plant.

TABLE 3 PhoStrip Process Record

Reno-Sparks Wastewater Treatment Plant - Reno, Nevada

Q = 26 MGD

Official Data - Phosphorus (mg/L) - Daily Samples

	PRIMARY INFLUENT TOTAL P	FINAL EFFLUENT TOTAL P	FINAL EFFLUENT ORT. P	TOTAL P PERCENTAGE REMOVAL
July '86				
MAX	11.99	0.66	0.47	
MIN	8.71	0.20	0.09	
AVG	9.71	0.31	0.16	96.80
Aug. '86				
MAX	10.97	0.49	0.18	
MIN	8.07	0.21	0.10	
AVG	9.16	0.28	0.14	96.94
Sept. '86				
MAX	10.81	0.65	0.40	
MIN	8.31	0.26	0.14	
AVG	9.63	0.36	0.18	96.26

TABLE 3 PhoStrip Process Record (cont'd)

Oct. '86					
MAX	10.45		1.43	1.16	
MIN	7.24		0.27	0.12	
AVG	8.77		0.39	0.20	95.55
Nov. '86					
MAX	10.87		1.77	1.17	
MIN	7.35		0.26	0.12	
AVG	8.73		0.47	0.31	94.61
Dec. '86					
MAX	10.09		0.90	0.47	
MIN	7.61		0.24	0.11	
AVG	8.84		0.38	0.17	95.70
Jan. '87					
MAX	12.46		0.61	0.44	
MIN	7.28		0.26	0.09	
AVG	9.13		0.37	0.16	95.94
Feb. '87					
MAX	12.87		1.64	1.18	
MIN	7.06		0.20	0.08	
AVG	9.36		0.51	0.33	94.55

PHOSTRIP II

Experiments performed at Biospherics and independent studies (Siebritz, et al., 1982, and Ekama, et al., 1982) found that the introduction of BOD-containing primary effluent into the anaerobic sludge induces quicker phosphorus release in the Stripper Tank. Based on these data, the PhoStrip II process, Figure 5, an "enhanced release" mode of the PhoStrip process, has been conceived with the dual advantages: 1) increasing the overall phosphorus removal capability, and 2) allowing significant reduction in the size of the Stripper Tank with concomitant savings in capital costs. A small Pre-Stripper Tank is used to mix BOD-containing wastewater (primary effluent, for example) with the return activated sludge enroute to the Stripper Tank. The sludge quickly absorbs the BOD and begins to release phosphate at a higher rate. Accordingly, reductions in Stripper Tank sizing of up to 50% may be achieved.

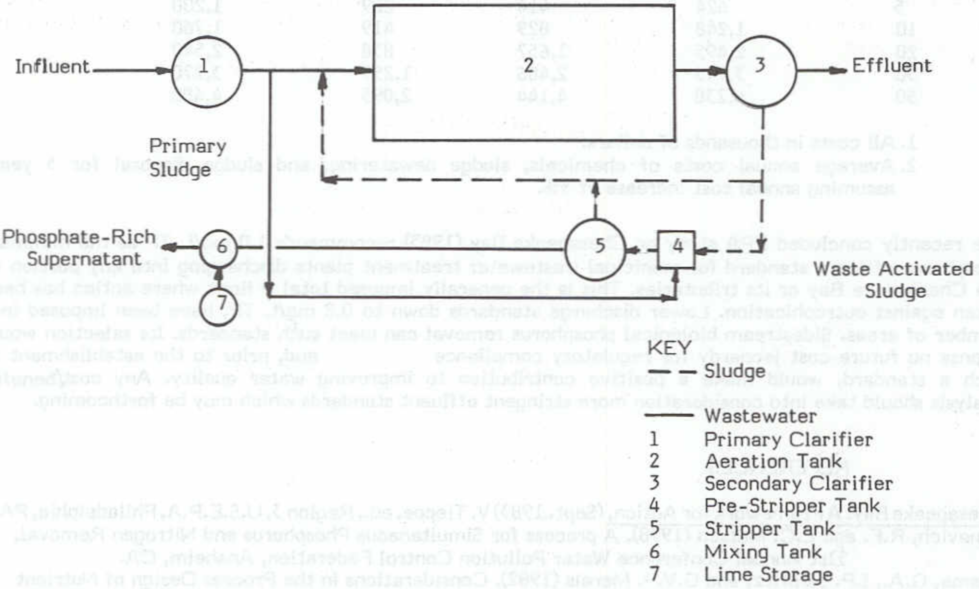


Fig. 5. PhoStrip II process flow diagram

PROTECTION AGAINST WASHOUT ANT TOXIC SHOCK

The Stripper Tank provides a reservoir of activated sludge which is isolated from mainstream events. Thus, hydraulic overloads or toxic shocks, which frequently cause loss of sludge, are readily offset. Upon evidence of a hydraulic or toxic overload, the stripper inlet and outlet valves can be closed preventing any adverse effect of the incident on the sludge in the Stripper Tank. After the hydraulic or shock load has passed through the plant, frequently wiping out the secondary sludge in the mixed liquor and secondary clarifier, the Stripper Tank valves can be reopened. The sludge inventory reintroduced into the mixed liquor is sufficient such that BOD removal and phosphorus removal return to normal efficiency in a matter of hours. This was demonstrated at Seneca Falls (Levin, et al., 1975) when a flood occured. In contrast, days, or weeks, are required for fullstream plants with or without phosphorus removal to restablish sufficient activated sludge for recovery of normal operations.

COST DATA

PhoStrip offers dramatic savings over chemical addition methods. In its PhoStrip operation and Management Report (August 1986), the Tahoe-Truckee Sanitation Agency reported that its 4.33 MGD plant achieved total annual savings of $224,785 per year after PhoStrip was introduced. Similarly, in the paper by L.E. Peirano (1983), it was estimated that PhoStrip achieved $500,000 per year in total annual cost savings and $700,000 per year in operation and maintenance cost savings at 40 MGD plant capacity. The equivalent savings at Reno Sparks would be approximately double these values in current dollars.

The report by the Lenawee County Drain Commissioner (1977), compared mainstream chemical addition with PhoStrip and showed a savings of $17.05 per million gallons of treated wastewater resulting in an annual costs benefit of one-third while maintaining effluent phosphorus at 1 mg/L.PhoStrip II represents an increase in efficiency over PhoStrip which can lower capital costs and increase savings. Table 4 illustrates PhoStrip II savings over costs.

TABLE 4 PhoStrip II Savings and Costs[1]

Plant Flow (MGD)	Annual Operating Costs[2] Chemical Addition	PhoStrip II	Savings	PhoStrip II Installation Costs
5	624	414	209	1,200
10	1,248	829	419	1,760
20	2,495	1,657	838	2,540
30	3,743	2,486	1,257	3,270
50	6,238	4,144	2,095	4,680

1. All costs in thousands of dollars.
2. Average annual costs of chemicals, sludge dewatering, and sludge disposal for 5 years assuming annual cost increase of 5%.

The recently concluded EPA study on Chesapeake Bay (1983) recommends 1.0 mg/L TP as the minimum phosphorus effluent standard for municipal wastewater treatment plants discharging into any portion of the Chesapeake Bay or its tributaries. This is the generally imposed total P limit where action has been taken against eutrophication. Lower discharge standards down to 0.2 mg/L TP, have been imposed in a number of areas. Sidestream biological phosphorus removal can meet such standards. Its selection would impose no future cost jeopardy for regulatory compliance and, prior to the establishment of such a standard, would make a positive contribution to improving water quality. Any cost/benefit analysis should take into consideration more stringent effluent standards which may be forthcoming.

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