Task 1.3 Report

Literature Review

For the Project Entitled

Dairy Best Available Technologies in the Okeechobee Basin

SFWMD Contract No. C-11652

Submitted By

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TASK 1.3. LITERATURE REVIEW FOR DAIRY BAT PROJECT

Dairy Waste Management Literature Review

Introduction

A literature review for current and innovative methods of dairy waste management technologies identified and briefly evaluated the technologies currently recognized as the best new opportunities to manage dairy nutrient discharges and organic wastes in a cost-effective manner. The search for these technologies involved three efforts. The first approach was an electronic literature search. This approach allowed a very wide net to be cast, but may not identify very current information (within the last 12 months) and may not identify critical information simply due to the vagaries of the electronic search process, which in this case was based on keyword combinations. The electronic search methods employed are described below.

The second approach used the articles identified in the electronic search as a starting point. The references cited there led to other articles, to a search through recent publications and symposium volumes, for examples of particular technologies and authors. While electronic search means were also used in this step (the search tools available at the University of Florida Marston Science Library), it was to focus the search.

Finally professional libraries of the project team members were searched and the appropriate information in those sources identified.

Electronic Search Methods

An electronic abstract search was conducted by searching the 33 electronic data bases found in Table 1 with combinations of the keywords located in Table.2. Three hundred and seventy eight (378) search-words were created from Table .2 by taking each of the 18 keywords from column 1 and combining it with each of the 21 keywords in column 2. Each data base was searched for each of the 378 search-words. A 10 year period (1990 to the present) was searched.The electronic search was performed by Southern Technology Application Center, a specialty information services firm in Gainesville, FL.

The search returned over 2,500 works pertaining to the “search-words”. The title for each work was used to screen the search results down from 2,532 to 120. Abstracts were obtained for each of the 120 selected works. Review of the abstracts resulted in 50 works to receive detailed review in the next phase of this study.

Literature available from recent conference proceedings not available on electronic databases, “gray literature” sources, and other information received through professional contacts were also included in the final literature review list.

References identified during the broader search are included with the 50 works electronically identified. The initial 2532 article listing and the complete set of 120 abstracts are provided provided separately in electronic format.

TABLE.1
Databases searched electronically for references associated with dairy best available technology and related research

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Agricola,

Apilit,

Aquatic Science & Fish Abstracts,

Biological & Agricultural Index,

Biosis Previews,

Ca search,

CAB Abstracts,

Conference Papers Index,

Dissertation Abstracts Online,

Ei Compendex,

Energy Science and Technology,

Enviroline,

Environmental Bibliography,

Federal Research In Progress,

Fluidex (Fluid Engineering Abstracts),

General Science Abstracts,

GeoArchive, Geobase,

Inside Conferences,

JICST-EPlus – Japanese Science & Technology,

McGraw-Hill Publications,

National Technical Information Service (NTIS),

New Scientist,

Oceanic Abstracts,

PAIS International,

Pascal,

Pollution Abstracts,

Science,

SciSearch,

TULSA,

WasteInfo, and

Wilson Applied Science & Technology Abstracts

TABLE 2.
Basic keywords used to develop keyword search list.

Column 1	Column 2
Animal waste/excrement/manure	Phosphorus treatment ,
Dairy waste/excrement/manure	phosphorus removal,
Chicken waste/excrement/manure	nutrient removal,
Hog waste/excrement/manure	soil amendment for P runoff,
Cow waste/excrement/manure	composting,
Poultry waste/excrement/manure	bio-processing,
	bioprocessing,
	chemical treatment,
	chemical phosphorus treatment,
	biological treatment,
	wetland treatment,
	lagoon treatment,
	algal system,
	duckweed,
	land application,
	agricultural biosolids,
	agricultural biosolids products,
	aquatic farming,
	agricultural biosolids,
	agricultural biosolids products

The initial 2500 articles can be divided into several broad categories (Table 3) that generally reflect the distribution of the literature identified by all search means. Many of the articles referred other agricultural waste streams (eg. Poultry or piggery wastes); some of these articles were appropriate for use However, for this literature search, emphasis has been placed on those articles providing directly applicable information on dairy waste and nutrient management technologies and generally focused less on other waste stream management or more general articles on the subject on animal wastes.

Table 3. Dairy BAT categorization of 120 abstracts identified by electronic search procedures

Category	%
General Treatment	25.6
Chemical Treatment	8.3
Biological Treatment	5.8
Lagoon Treatment	2.5
Manure Management	21.5
Composting	8.3
Duck Weed and Reed Treatment	1.7
Feed Lot Operations/Treatment	4.1
Phosphorus Fate	2.5
P Management on Dairy Farms	9.1
Wetland Treatment	8.3
Gen. Nutrient Protection of Water Quality	2.5

Supplemental Data – FDACS RFP

In 2000, the Florida Department of Agriculture and Consumer Affairs (FDACS) issued a Request For Proposals entitled “RFP - Innovative Technologies for the Treatment of Dairy Solids and Wastewater, and Surface Water Runoff”. These responses do not fall in the category of “Open Literature” or “Gray Literature, but they are informative and useful in the context of this literature search. Several of the RFP responses are cited in this document. Those responses cited are listed separately, under their own category, in the Reference Section. Brief summaries of the proposals are presented in **Appendix A**.

Categorization of Processes and Practices

An attempt has been made to organize this review by management processes, rather than by waste source or process origin. In this way, the processes may be viewed in the context of their applicability to manage dairy process streams that fall into four major categories:

1) Solid manure wastes, including directly collected manure and manure settled from flush water

2) High strength wastewater, including barn flush, HIA runoff, and some pasture runoff

3) Low strength wastewater, including some pasture runoff and effluents from high strength treatment processes

4) Water management and reuse

It is fully recognized that many of the processes discussed in this review do not have the capability to produce effluent meeting stringent phosphorus concentration guidelines, however optimal designs will undoubtedly contain multiple unit processes, each operating within its own optimal range. Solids separation improves the efficiency of high strength treatment processes, removal of carbonaceous material by high strength treatment processes improves the efficiency of low strength treatment processes, and the proper management of feed, effluent, and side streams allows multiple processes to be integrated efficiently.

This categorization corresponds roughly to the environmental engineering unit process definitions of primary systems, which remove suspended solids, secondary systems, which remove Biochemical Oxygen Demand, and advanced (or tertiary) treatment systems, but also allows for some characteristics that are particular to agricultural waste treatment. Advanced treatment systems are a collection of processes that may convert ammonia nitrogen to nitrate by nitrification, remove nitrate by denitrification, remove phosphorus by various physical and chemical mechanisms, polish the effluent to low suspended solids concentrations, and disinfect. Because of the prevalence of long residence time lagoons and ponds as treatment vehicles in the agricultural industry, secondary and advanced treatment, especially nitrification, often are affected in the same basin.

Over the last decade numerous advances have been made in the application of wetland biological processes to water treatment technology. These processes are included in the advanced or tertiary treatment category for processing of low strength wastes even though they may, on occasion, receive and successfully treat high strength wastes.

Solid Waste Collection, Treatment, and Management

Source Reduction and Pasture Management

The primary sources of P in drainage waters from a dairy are manure, fertilizer, and native soil P with manure being by far the largest source. An obvious starting point in phosphorus control is to reduce the amount phosphorus in the manure by reducing imported P in animal feed. Fertilizer reduction is more straight and for the most part have been reduced to nominal levels already. The most extension study done for P reduction in feed for Florida dairies was done by Morris (1989). Results of this study and others are summarized by Harris et al (undated) in an IFAS extension publication. Based on different sources they indicate that recommended level of P for lactating cows is between 0.4 and 0.43% of ration dry matter for optimal performance. They also report that the historically P levels ranged from 0.43 to 0.49% of ration dry matter. Most dairies in Okeechobee have aggressively reduced P levels to the lowest recommended levels (personally communication with dairymen and Jack Van Horn with UF – Dairy Science. Dr. Van Horn et al (2000) have indicated that the recommended P levels might be able to be dropped to 0.38% of ration dry matter, but some additional verification work should be done. Also transitioning lactating cattle from barn rations to pasture grazing can reduce the P intake level (Sollenberger, et al, 2000). In general, it is believed that dairies in the Okeechobee basin are operating close to the minimal recommended level of P in feed so further significant gains in P reduction is not likely until new research is completed. However, every effort should be maintained to keep P ration levels to a minimum.

Perimeter Ditch Collection Systems

During the 1970s and earlier 80s, it became clear that a large source of the P losses from Okeechobee dairies was from the high intensity areas (HIAs) immediately around the milk centers and feed barns. In 1985 a technical committee (Dairy Rule Advisory Committee) was founded by the then Florida Department of Environmental Regulation to develop a dairy waste management design and regulatory language that would address the HIAs and other overloads areas of the Okeechobee dairies. Though no technical publications were produced, the final design for the HIAs included in the Okeechobee Dairy Rule (rule 17-670.500), was for the collection of the runoff from the HIAs using a perimeter ditch. The HIA perimeter ditch design takes advantage of the flat high water table flatwoods soils in the region, in that a shallow ditch around the HIAs near the barn is able to capture both surface and subsurface drainage from the HIA. The collected water from the HIAs is pumped into the waste lagoon for later disposal on a sprayfield. The intend was to encourage the cows to stay within the HIA so that their manure could be contained and collected.

A report completed by Bottcher (1995) assessed some the higher P discharge sites from dairies in the Okeechobee basin. It was found that many of the HIA perimeter ditch systems were too small to adequately maintain the originally designed cow numbers. This has resulted in overloading of outer pastures and poorer herd management in some cases. The general concept appears to be quite good, but improvement is needed to encourage the cows to stay within the perimeter ditch.

Manure Scraping

Manure scraping is the removal of waste from barn floor, concrete pads, and high intensity areas (HIA) with scraping devices that operate in shallow gutters, flushed gutters beneath slotted floors, open floors, and compacted ground. Historically, 25% of animal waste is deposited in milking barns, 50% in high intensity use areas, and 25 % in herd pastures with only a fraction of the total waste stream volume being collected in a waste treatment system (NRCS 1992). Therefore a maximum of 25- 50% of manure removal might be accomplished by scraping (Soil Conservation Service, 1988) unless animal are totaled confined on concrete. Scraping is generally more applicable to concreted surfaces such as, driveways and barn floors. Open ground HIA scraping is also necessary but is less efficient because soil is mixed with the manure. Pasture deposited manure is never removed. Flushing is the typical method of manure removal in milk and feed barns in Florida. Scraping requires more manpower and greater handling of material than flushing, and has therefore typically been used only for management of wastes from areas that cannot be effectively flushed, such as loafing yards, flat barn, and driveways.

Standard methods of scraping are described in NRCS (1992). Scraping can be accomplished using automated mechanical systems or tractor scrapers. A cost analysis of a manure scraping system was performed by Miller (1994). Collection and centralized treatment of dairy barn manure has been proposed by Biomass Processing Technology, Inc (FDACS-BPT, 2000). The barn solids would be collected by a mobile sweeping and collection device, designed to minimize the volume of wash water. The sweeping device would deposit the solids in a holding station where they would be picked up and transported to a central facility and processed to fuel, animal feed, and other products.

Solids Separation

Separation of the solid and liquid streams of untreated manure has distinct advantages. First, removal of solids from the liquid stream significantly reduces the organic load (including organically bound nutrients) from the waste stream and thereby requires smaller treatment units for subsequent liquid stream treatment processes. To this end, high-rate biological processes could be used for treatment of the liquid stream because the fibrous and deleterious (e.g., bedding) material would be removed. High rate biological processes require that this type of material be removed prior before treatment can be effective. Secondly, the separated solid stream could be composted, or stabilized in some other fashion, and sold for off-farm use. This would remove nutrients from the farm. Conversely, the raw solid stream could be land applied at the farm. Thirdly, removal of large quantities of organic material would reduce odors from treatment processes e.g., lagoons (Hunt and Vanotti, 1999).

Solids separation of untreated flushed manure is typically achieved by one of three means: mechanical-physical, sedimentation, and sedimentation augmented with chemical addition. Recent innovations in solids separation of flushed manure include combinations of fine mechanical screening (1mm openings) and various chemical treatments coupled with sedimentation. Fulhage and Hoehne (1998) and Converse, Koegel and Straub (2000) each evaluated two types of fine mechanical screens that effectively screened flushed diary manure. Worley and Das (2000) evaluated the effects of a field scale chemical addition (alum) and sedimentation process on removing solids from flushed swine manure. Their study showed that alum increased solids removal efficiency from 60 percent without alum to 70 percent with alum. Phosphorus removal was increased from 38 percent without alum to 75 percent with alum. Hunt and Vanotti (1999) investigated the use of polymers (polyacrylamide) coupled with sedimentation and followed by fine mechanical screening to remove solids from flushed swine manure. The studies showed that mechanical screening efficiency improved from 5 - 14 percent without polymer to 90 – 94 percent with polymer. Brown and Jones (2000) evaluated a wide range of processes in the laboratory to provide solids-liquid separation of flushed dairy manure which included sedimentation, alum treatment with and without acid pretreatment, polymer treatment (polyacrylamide), and polymer treatment with alum. Each treatment process was evaluated by Brown and Jones (2000) utilized varying ranges of total solids which were produced from combinations of sedimentation and fine mechanical screening of flushed dairy manure. The combined polymer and alum treatment reduced phosphorus to below 1 mg/l P. Sievers, Jenner and Hanna (1992) conducted an extensive laboratory scale evaluation on different types of synthetic polymers and their effectiveness on dilute manure waste streams. These studies revealed that synthetic polymers were the most cost effective chemical coagulant for the waste stream tested.

The liquid stream produced from these processes are generally amenable for further biological treatment (i.e., nitrification-denitrification) and/or further chemical treatment for phosphorus removal to meet nutrient requirements. However, in instances where alum treatment is used, the resulting phosphorus concentration in the liquid stream could be less then 1 mg/l P which could require external phosphorus addition if subsequent biological treatment such as nitrification-denitrification is desired. Alum treatment also consumes alkalinity and reduces the waste stream pH. These parameters are important if subsequent biological treatment is desired (i.e., nitrification-denitrification). An added benefit from alum treatment arises from the fact that the phosphorus "bound" in the sludge will have less tendency to contaminate field runoff with phosphorus (see "Direct Land Application of Collected Solids").

Recent innovations have also evolved in separating bedding sand from manure prior to manure handling. It is well known that sand bedding promotes optimal environmental conditions for the cow; however, operational problems (e.g., rapid deterioration of mechanical equipment due to the abrasive nature of sand) have prevented this practice from being readily implementable. Bickert and Wedel (1998) investigated the use of a sand manure separator to facilitate the use of bedding sand. The commercially available sand manure separator had a separation efficiency between 80 and 90 percent depending on the origin of sand.

Composting

Composting is a biological process that converts organic matter to a stable, humus-like product under controlled conditions. During the composting process, microorganisms utilize decomposable substrates present in organic waste both as an energy source and for conversion to microbial substances. Both manure (separated dairy waste) or manure and liquid wastes (non-separated dairy waste) can be composted. The resultant solid product is reduced in volume, easier to transport and store, and available for land application or off-farm marketing. Composting by-products include carbon dioxide and water under aerobic conditions, and a combustible mixture of carbon dioxide and methane under anaerobic conditions. The physio-chemical properties of manure before, during, and after composting are provided by Eneji et al (1998) and Yossi et al (1993). A variety of systems can be used to compost dairy wastes. The main classifications of composting systems include 1) windrows (non-aerated and aerated), aerated static piles, and 3) aerated bins or vessels. There are also hybrids or variations of these base technologies. Composting technologies vary widely in their level of complexity and cost with windrow systems typically having the lowest complexity and cost and enclosed composting systems the highest complexity and cost. Standard methods of composting are described by Rynk (1994) and Golueke (1997).

Composting does not provide any direct advantages from a phosphorus reduction perspective. There is some ammonia nitrogen loss during the composting process, but other mineral elements such as phosphorus, potassium, other metals are conserved during the process. In the first year of a 5 to 10 year study, Ferguson and Nienaber (1995) found that forage yield, forage nitrogen, and phosphorus uptake, and soil accumulation of N and P were not substantially different between plots where beef feedlot manure and composted feedlot manure had been applied to silage corn. Forage and dry matter yields from manure and compost treatments were equivalent to commercial fertilizer treatments during the first two growing seasons, while P concentrations in the surface soils for manure and compost treatments were higher than those receiving commercial fertilizer only. However, some new technologies maximize the retention of phosphorus available for composting through the addition of chemical amendments to collected manure prior to composting. These amendments facilitate solids settling by acting as a flocculent. Phosphorus chemically binds to the particles that settle out of the water column, potentially increasing the phosphorus removed from the farm, while yielding a more balanced fertilizer after lagoon treatment. Aluminum Sulfate (Alum), a chemical amendment, enhanced settling of solids from swine waste by 10% and consequently, increased phosphorus removal by 37% as demonstrated by Worley and Das (2000) in a field scale test.

Due to the cost of labor and equipment, composting has seen limited application in managing dairy wastes. However, more economical compost system designs are also being developed. Refinement of composting system design was undertaken by Keener et al (1997) for full-scale separated dairy waste composting operations using pilot scale data. In addition, Keener et al (2000) provided a theoretical curve for moisture loss versus compost parameters, as well as the mathematics of predicting acceptable mixing ratios for non-separated dairy waste composting operations. Composting technologies would seem to have the most application to situations where a dairy or private entity wants to produce a product that can be marketed and sold to outside parties. By doing this, P could be exported out off of the farm and potentially out of the basin. An example of this is the proposal by Bion Environmental Technologies (FDACS-BETHAS, 2000) where proprietary solids collection and composting cells would be installed at the dairy location and the company would collect potting soil from these cells.

Anaerobic Digestion and Methane Generation

Methane is a by-product of anaerobic digestion and may be used for energy consuming processes that are currently served by electricity or natural gas. Golueke, (1997) provides standard volume of gas production (5.3 to 70.6 ft^3. per day) per ton of manure based on temperature and duration of anaerobic composting.

Conventional anaerobic digesters are continuously fed and mixed reactors whose solid retention time (SRT) and hydraulic retention time (HRT) are equal. New anaerobic digesters increase SRT for a given HRT, though they differ on the method by which it is achieved. Some of the recently developed digesters include the anaerobic sequence batch reactor (ASBR), upflow anaerobic fixed-bed (UAFB), anaerobic fluidized bed reactor (AFBR), upflow anaerobic sludge blanket (UASB), expanded granular sludge bed (EGSB), downflow anaerobic filter (DFAF), and packed anaerobic bed reactor (PABR). UASB and ESGB rely on formation of sludge granules, while UAFB and AFBR utilize inert solid material. ESGB and AFBR suspend particles with high upflow velocities, while DFAF circulate downward. ASBR digesters operate in four distinct phases.

Volatile solid removal and biogas production for various volatile solid loading rates and hydraulic retention times for a small scale, swine waste, ASBR reactor are provided by Zhang and Dague (1995). Hawkins et al (2000) provides additional data for ASBR and DFAF reactors volatile fatty acid removal at various loading rates. Iranpour et al (2000) compares design features and results from experiments under different conditions for UAFB, AFBR, UASB, and ESGB reactors. Effects of piggery wastewater total suspended solids influent concentration (TSS) on UASB reactor performance is given by Foresti and Oliveira (1995). BOD and TSS removal from a long term full-scale dairy processing facility averaged 80-85% and 70-75% respectively using the hybrid anaerobic process, PABR, as documented by Ross and Valentine (1995). Solids discharged from digesters may be used as fertilizer, as suggested in the proposal by J.A. Jones Environmental Services (FDACS-JAJES, 2000)

Land Application of Collected Solids

Direct Land Application

Land application of collected manure is a popular disposal method practiced on dairy farms. Nutrient rich manure is applied to adjacent agricultural fields to supplement fertilizer requirements. This practice is economically beneficial because manure, a continuously generated waste product, is disposed of rather inexpensively in this fashion while it simultaneously provides vital nutrients required to grow crops on adjacent farm land. The only problem with this practice is when inadequate land is available to handle the nutrient within the manure. If application areas are overloaded with nutrients then excessive quantities of nutrients (particularly phosphorus) from the agricultural fields into waterways causing subsequent problems in the water body (i.e., eutrophication). Phosphorus is widely regarded as the limiting nutrient responsible for eutrophication in South Florida aquatic ecosystems. Nutrient runoff is greatly exacerbated by repeated applications of manure on nutrient saturated soils (Moore and Miller, 1994). Stone et. al. (1998) have shown that with increased farm animal numbers and limited land for waste application, even large wooded riparian zones and soils with high organic matter, features that have typically mitigated high nutrient applications, can become overloaded and their effectiveness negated.

It is important for proper nutrient balances be maintained for land application systems. This requires both effluent / solids testing for P content and establishment of appropriate agronomic rates for the crop.

Land application involves the spreading of dairy waste by permanent irrigation systems or broadcasting by vehicles. Improvements in land application techniques better match manure nutrient load more precisely with crop requirements and prevent the movement of phosphorus from high concentration soils. It is generally considered that land application is the most economical disposal option for animal manure; therefore, treatment or process improvements necessary to enable the practice of land application to continue while meeting the new nutrient requirements may be an economic necessity. However, P levels in sprayfields drainage have been reported (SFWMD monitoring data) in excess of 1.0 mg-P/l for sprayfields that appear in nutrient balance. These means that though land application is likely to be an important part of a waste management system, it is unlikely to achieve the target concentrations for this project.

Accumulation, distribution, and mobility of phosphorus of land applied manure is given by Smith (1998) and Gale (2000). A new program, Manure Application Rate Calculator (MARC) 2000, was developed by Bilton (2000) for use by farmers.

Land Application with Chemical Amendment

The addition of chemical amendments enhances chemical bonding of phosphorus to soil particles, and prevents movement of phosphorus Daniels and Haustein (1998) documented a decrease in dissolved phosphorus levels (15% to 70%) in runoff associated with land applied with alum or HiClay Alumina (HCA).

Research and field investigations by Daniel and Haustein (1998) have shown that phosphorus runoff from nutrient saturated fields can be reduced when water treatment plant residuals (alum sludge) are applied to the fields. Moore, Daniel and Edwards (2000) have shown in full-scale demonstrations that applying aluminum sulfate to poultry litter significantly reduces phosphorus runoff from manure applied fields. Moore and Miller (2000) have also had success in reducing phosphorus runoff from land applied with poultry litter by using alum, quick lime, slaked lime, ferrous chloride, ferric chloride, ferrous sulfate, and ferric sulfate on the manure prior to land application. These technologies/processes may be transferable to the diary industry for the treatment of manure and/or sludge prior to land application.

Even when treated in this manner, phosphorus concentrations in field runoff may exceed the 50 ppb limit with regular application. However, treatment in this fashion may reduce the phosphorus level enough to enable the use of other treatment technologies that are cost-effective for the management of field runoff sufficient to meet the 50 ppb limit.

Chastain and Derby (2000) determined a thickening process that increases phosphorus concentration in sludge by nearly 50%, reducing the volume that must be transported to the fields. Alternative application methods are also being developed. Bittman et al (2000) and Koelsch (2001) discussed deep injection of dairy waste as an elimination method that results in 100% elimination of pollutants from the land surface.

Treatment of High Strength Wastewater

Anaerobic Systems - Lagoons and Reactors

Anaerobic lagoons remove biochemical oxygen demand (BOD) from the waste stream through sedimentation and metabolism of organic matter. Anaerobic lagoon treatment has historically been used for treating barn manure because it is more cost efficient in treating high strength BOD wastes than aerobic treatment and does so essentially without utilizing any mechanical equipment (Metcalf and Eddy, 1991).). An updated design standard for anaerobic lagoons is provided in ASAE standard practice EP403.3, revised December 1998. This revised standard includes the addition of normal runoff and normal precipitation on the lagoon surface between drawdown events when calculating the total runoff volume. Inclusion of these additional inputs reduces the frequency of overflow events, which directly reduces the quantity of nutrients that potentially would be discharged during extreme rainfall events. Nutrients used for biosyntheses are removed from the waste stream only in relatively small quantities. Typical effluent from an anaerobic lagoon receiving dairy manure is 350 mg/l BOD, 200 mg/l total nitrogen, 120 mg/l ammonia N, and 60 mg/l P (Agricultural Waste Management Field Hand Book, 1992). Therefore, anaerobic lagoon treatment of dairy manure alone cannot achieve significant nutrient reduction, particularly for P. Separate treatment of the waste stream for nitrogen and phosphorus removal would be required to achieve a desired level of nutrient (nitrogen and phosphorus) reduction. However, recent research and full scale demonstration projects have proven that anaerobic treatment can be substantially improved and in turn may play a role in the treatment scheme to obtain the desired level of nutrient reduction from dairy waste.

Nitrogen digestion in high strength wastes occurs through anaerobic bacterial digestion of complex nitrogenous compounds to ammonia, other simple nitrogenous compounds, and solids (Haug, 1993). Nitrogen removal in high strength waste systems is typically performed biologically in two steps: nitrification and denitrification. Nitrification is in broad terms the biological conversion of organic and inorganic nitrogenous compounds, from a reduced state to a more oxidized state and most specifically the conversion of ammonia nitrogen to nitrate nitrogen (Wetzel, 1983). This conversion can proceed only under aerobic conditions and is increasingly inhibited when the dissolved oxygen (DO) concentration is below 2 mg/l (Metcalf and Eddy, 1991). Denitrification is the reduction of nitrate to gaseous nitrogen, N_2 and proceeds most efficiently in the absence of oxygen (i.e., under anoxic conditions). Denitrification occurs in the presence of oxygen, but is increasingly inhibited as the DO concentration approaches 1 mg/l (Metcalf and Eddy, 1991). Although these two processes are performed by different microorganisms they are not mutually exclusive. Denitrification relies on the products of nitrification; and therefore, can only be performed after nitrification has been or is being completed. In addition, nitrate is rapidly assimilated and reduced by green plants and in this way is a desirable end product.

Recent improvements in anaerobic treatment include utilizing multiple lagoons in series to enable nitrification (Sukias et al., 2000) and to promote enhanced nutrient uptake (Ribeiro et al. 2000) in the last (aerobic) lagoon. Other improvements include replacing or supplementing anaerobic lagoons with high-rate anaerobic reactors, which require a foot print 5 to 10 times smaller than traditional anaerobic digesters (Ross and Valentine, 1995; Wilkie, 1999;Williams, 1998). All of these high-rate anaerobic processes require fine mechanical screening of the manure for the removal of solids prior to the waste stream entering the digester. Fine screening produces a waste stream with less than 1 percent total suspended solids. Ross and Valentine (1995) investigated the use of a mesophilic upflow packed bed anaerobic reactor (both pilot and full scale) with a hydraulic retention time (HRT) of 3 days that utilized both suspended and attached growth microorganisms. Wilkie (1999) investigated the use of a pilot-scale mesophilic fixed film anaerobic reactor, an attached growth system, with an HRT of 3 days. Williams (1998) investigated a bench-scale thermophilic anaerobic digester, a suspended growth system, with an HRT of 4 days. These high rate anaerobic processes significantly out performed conventional anaerobic lagoons with respect to BOD removal.

Other benefits from high-rate anaerobic processes include odor and pathogen reduction, reduced sludge production and energy recovery (Moser and Mattocks, 2000). Effluent from these processes are readily amenable for subsequent nutrient removal treatment e.g., nitrification-denitrification and/or chemical phosphorus removal.

Aerobic Systems - Lagoons and Reactors

Aerobic processes have not been the treatment of choice for dairy wastes because anaerobic treatment provides more efficient treatment for high strength BOD waste streams (Metcalf and Eddy, 1991). Moreover, anaerobic processes require less mechanical equipment and produce less sludge than aerobic processes.

Aerobic processes are well suited to providing additional treatment to anaerobic lagoon effluent i.e., further BOD removal and nitrification. Sukias et al. (2000) demonstrated in a full-scale project that effluent from multiple stage anaerobic lagoon treatment could support significant nitrification. Sukias et al. (2000) studied the impacts of continuous aeration, night time only aeration, and no aeration. Sukias et al. (2000) also investigated the use of a combined suspended and attached growth system for providing enhanced nitrification. In theory, a combined suspend and attached growth system could support higher biomass of nitrifiers enabling more efficient nitrification. Sukias et al. (2000) found the following: continuous aeration of the suspended growth system provided for 99 percent ammonia removal; night only aeration for the suspended growth system achieved 84 to 90 percent ammonia removal; night only aeration with the combined suspended and attached growth system achieved 93 percent ammonia removal; and, no aeration of the suspended growth system achieved only 60 percent ammonia removal.

Ribeiro et al. (2000) demonstrated in full-scale that effluent from multiple stage anaerobic lagoon treatment could be used in a facultative lagoon to support enhanced nutrient uptake by phototropic microorganisms.

Nitrified effluent from an aerobic or facultative lagoon is readily amenable for denitrification and chemical phosphorus removal. As previously stated, nitrification is only the first step of a two step process that biologically removes total nitrogen from a waste stream. A facultative lagoon receives a low BOD load and physically consists of an aerobic top layer and a anaerobic bottom layer. Natural diffusion of oxygen and the day time production of oxygen from phototrophic bacteria provide sufficient quantities of oxygen to keep the top layer aerobic in a facultative lagoon.

Treatment of Low Strength Wastewater – Advanced Processes

Intensive Biological and Chemical Waste Treatment Technologies

Advanced waste treatment of municipal and industrial wastes has generally been characterized by the use of high rate biological and intensive chemical processes, treating point sources to achieve stringent permit requirements. Traditionally, these processes have not been used by the agricultural industry because advanced treatment was not necessary to comply with governing regulations and due to the inherently higher construction and operation and maintenance costs relative to regulatory accepted management practices.

Advanced treatment processes have been and are currently being investigated to provide advanced treatment to reduce non-point source nutrient (nitrogen and phosphorus) pollution from farms. Advanced treatment typically separates waste treatment into numerous highly efficient treatment processes (i.e., unit processes). By separating the treatment process, each process can be controlled specifically to optimize each process i.e., sequence of preceding or subsequent treatment processes, chemical doses, aeration intensity, mixing intensity, sludge withdrawal, and the control of batch treatment. Advanced treatment process by their nature require the removal of bedding (inert) material prior to treatment. Also, advanced treatment typically requires higher levels of operation and maintenance in order to sustain high levels of treatment.

Biological Processes

From a process standpoint, total nitrogen removal is generally performed biologically through nitrification-denitrification. Nitrification is generally considered the critical and most delicate of the two processes. Phosphorus removal is generally done through chemical treatment and through microbial uptake for biosynthesis.

Conventional secondary biological treatment systems take up phosphorous from solution for biomass synthesis during biochemical oxygen demand (BOD) oxidation. Phosphorous, required in intracellular energy transfer, becomes an essential cell component. For this reason, phosphorous is taken up in an amount related to the stoichiometric requirement for biosynthesis. A typical phosphorous content of microbial solids is 1.5 to 2% on a dry weight basis. (Sedlak, 1991)

A sequence of an anaerobic zone followed by aerobic zone results in the selection of a population rich in organisms capable of taking up phosphorous at levels beyond stoichiometric requirements for growth. With this environment, the biomass accumulates phosphorous levels of 4 to 12% of microbial solids. Wastage of these solids results in approximately 2.5 to 4 times more phosphorous removal from the system than that from conventional treatment. The organism most often associated with enhanced biological phosphorous removal belongs to the genus *Acinetobacter*. Bardenpho ^{TM}, A/O ^{TM}, A^2/O ^{TM}, and PhoStrip ^{TM} are some examples of integrated biological processes for nutrient removal. (Converti, et al, 1995). The Water Environment Federation (WEF, 1998) discussed the expected capabilities of generic and proprietary nutrient removal processes for municipal wastewater. A summary is presented in **Appendix B**, where it may be seen that the lower limit of phosphorus removal for these systems, without chemical assistance, is about 1.0 mg/l.

Sequencing batch reactors (SBR), using a suspended growth activated sludge process, have long been used for treating domestic wastewater. SBR have become increasingly popular in the past few years because the they provides efficient high rate treatment and are relatively simple to control and operate. This seemingly paradoxical statement is qualified by the fact that recent improvements in programmed logic controllers (PLC) has enabled simple and trouble free SBR automation for municipal and industrial waste treatment systems. Zhanh and Dague (1995) and Messe, Creseau, and Danesh (2000) both have investigated the use of anaerobic SBRs to treat swine wastes. This research should be transferable in part to the treatment of dairy wastes. Zhang, Li, Collar and Fry (2000) investigated using aerobic SBRs for treating dairy waste. In their research, Zhang, Li and Collar (2000) also compared one SBR operating alone to two SBRs in series with the two SBR system having half of the total volume of the single SBR system. The two SBR system completely nitrified while the single SBR system did not. Svoboda, Sym and Clark (2000) also investigated aerobic SBR treatment (which included nitrification) of dairy wash water. Svoboda, Sym and Clark (2000) evaluated SBR performance by varying dairy wastewater constituents in each of 6 separate experiments.

Vanotti et al. (2000) investigated high rate nitrification on swine wastewater by using polymer immobilized nitrifying bacteria technology (PINBT). The encapsulated nitrifying bacteria enable a larger than normal nitrifier population to exist which leads to extremely high nitrification rates and thus enables a larger quantity of nitrogen to be denitrified i.e., removed. The PINBT process in this pilot study enabled a 1,000 fold increase in the nitrifier population over conventional systems. Nitrification efficiency ranged from 97 to 99 percent on influent ammonia concentrations ranging from 344 to 2,608 mg/l N. Chemicals were added to maintain a desired pH and alkalinity. Prior to entering the biological system the raw swine manure went through a solids-liquid separation process consisting of fine mechanical screening and chemical treatment with a polymer.

Building upon their above cited work Vanotti et al. (2000) are currently investigating the use of a 4 stage suspended growth biological reactor system to remove total nitrogen from swine manure. This system almost identically resembles a four-stage Bardenpho process used in municipal wastewater treatment to achieve extremely low effluent total nitrogen levels (Metcalf and Eddy, 1991). The four reactors alternate between anoxic (non-aerated) and oxic (aerated) conditions with the first reactor being anoxic and the last being oxic. Nitrification in the overall second reactor (first oxic reactor) is enhanced by PINBT. Chemicals were added to maintain a desired pH and alkalinity and methanol was added to the 2nd anoxic reactor to enhance "polishing" denitrification. The results of these experiments have not been reported.

Montgomery (1998) investigated the use of a dolomitic lime bio-reactor (DLBR, patented by Biochem Technologies) to remove nitrogen and phosphorus from dairy anaerobic lagoon effluent. The DLBR is an upflow reactor which utilizes fixed film biological treatment to remove nitrogen and dolomitic limestone to precipitate phosphorus. This process is novel in that it combines biological total nitrogen removal and chemical phosphorus removal into one overall process. In this experiment, the DLBR failed to reduce phosphorus.

Direct Chemical Addition - Salts of Iron and Aluminum

Chemical addition or precipitation is effective at removing phosphorus and total suspended solids from wastewater and stormwater and involves the addition of metal salts, including aluminum (Al) and iron (Fe). The following discussion of chemical treatment of wastewater and stormwater is a summary of a more exhaustive completed as part of the review process, but is presented as a separate document labeled Addendum A - Chemical Treatment Technologies to keep the main text of this review more consistent.

Nitrogen is not directly removed through most chemical addition, though nitrogen associated with suspended solids will be removed with the chemical floc. Phosphorus concentrations as low as 0.1 mg/l can be achieved with addition of metal salts (USEPA, 1987). Phosphorus removal is limited by the solubility product of the metal (Al and/or Fe) and phosphate in solution.

The two aluminum compounds used for nutrient removal are aluminum sulfate (alum) and sodium aluminate. Phosphorus is removed from aluminum treated water by three primary mechanisms: (1) forming insoluble $AlPO_4$, (2) by adsorption on the surface of $Al(OH)_3$ floc and (3) by entrapment of phosphorus containing particulate matter. Nitrogen associated with particulate matter is also removed with the $Al(OH)_3$ floc. In general, aluminum salts produce more sludge (precipitate) than do iron salts. (Water Environment Federation, 1998)

The two iron compounds most commonly used for nutrient removal are ferric chloride and ferrous sulfate. Phosphorus is removed from iron treated water by three primary mechanisms: (1) forming insoluble $FePO_4$ or $Fe_3(PO_4)_2$, (2) by adsorption on the surface of $Fe(OH)_3$ floc and (3) by entrapment of phosphorus containing particulate matter. Nitrogen associated with particulate matter is also removed with the $Fe(OH)_3$ floc. Iron salts are most effective for phosphorus precipitation within a certain pH range. For ferric (Fe^{+3}) iron, the optimum pH for phosphate removal is 4.5 to 5 standard units. However, good results can be obtained at pH 7. Above a pH of 7, an increase of ferric chloride would be required due to the increased solubility of ferric phosphate at high pH values. For ferrous (Fe^{+2}) iron, the optimum pH is approximately 8. (Water Environment Federation, 1998)

A database (USEPA, 1987) of the results of coagulation used with municipal wastewater treatment in the U.S. is presented in **Appendix C,** where it may be seen that effluent total phosphorus as low as 0.2 mg/l has been consistently achieved at some facilities, using both aluminum and iron salts. An international database (Yeoman, et al, 1988) of municipal wastewater treatment plants using chemical addition for phosphorus reduction is presented in **Appendix D.** Effluent phosphorus values in the

International table appear to be higher than in the U.S. table, but this is partly due to the fact that many entries represent country averages.

Organic polymers cannot replace aluminum or iron salts in removing phosphorus. However, a polymer (or polyelectrolyte) can help a mineral salt coagulant by causing the precipitate to settle faster, reducing effluent fines, and reducing coagulant (aluminum or iron salt) requirement. During periods of intermittent flows, polymers may be used to control additional solids loads and maintain effluent quality. It can also become necessary to use polymer to produce a clear supernatant by removing dispersed metallic floc in the settling prior to discharge to a sand filter. A typical polymer dose when used as a coagulant aid is 0.1 to 0.25 mg/l (USEPA, 1987).

Livingston et. al (1994) reviewed the performance of alum addition to hypereutrophic lakes in Florida, and found that alum treatment of runoff into the lakes using doses of 10-20 mg/l (as Al_2O_3) could reduce the total phosphorus content of the lakes to less than 0.03 mg/l.

Alternative Chemical Processes

Donnert and Salecker (1999) investigated the use of two separate processes to remove phosphorus from municipal and industrial wastewaters in Germany. The first process uses direct precipitation of calcium phosphate induced by Calcite™ to reduce the phosphorus concentration below 1 mg/l P. The second process removes phosphorus through adsorption to activated alumina to remove phosphorus to 1 ppb. This process may be transferable in part to treating dairy wastewater due to its phased approach to treating wastewater with high phosphorus concentrations.

The work of Wigginton and Lenhart (1999) which demonstrated phosphorus removal from storm water using a filter filled with iron-infused media (STORMFILTER™) is probably not transferable for even polishing treatment of dairy wastewater. In the study, the filter received phosphorus concentrations of 0.5 mg/l P and typically removed only 20 percent, with a maximum removal rate of 78 percent.

Nelson, Mikkelsen and Hesierberg (1999) investigated the use of precipitating struvite (magnesium ammonium phosphate hexahydrate) from anaerobic swine lagoon effluent to remove phosphorus. This process may be amenable to treating anaerobic dairy lagoon effluent. Optimum phosphorus removal occurred in this study when the pH was adjusted to 9. This may be a significant draw back to this technology especially if nitrification (a reaction that reduces large quantities alkalinity) occurs prior to this treatment. Struvite is very popular as a fertilizer because it releases nutrients slowly.

Sherman, Van Horn and Nordstedt (2000) demonstrated that alum and ferric chloride could effectively remove phosphorus from dairy manure. In these full scale experiments dairy manure was settled, screened and then treated with chemicals for phosphorus removal. The resulting sludge settling in a subsequent sedimentation basin. Phosphorus was removed from approximately 50 mg/l P to 1 - 5 mg/l P. In light of the nutrient (nitrogen and phosphorus) removal goals, further studies should be performed to quantify the level of phosphorus removal that is achievable on dairy waste water that has been nitrified and denitrified. Typically in wastewater treatment chemical phosphorus removal is the last process before filtration. In this study, the dairy waste had only minimal treatment and thus had high levels of both soluble and particulate materials which may have hindered the level of phosphorus removal that could have been achieved.

Huang and Chiswell (2000) successfully demonstrated that dried water treatment plant alum sludge could be used effectively to remove phosphorus from wastewater. Phosphorus was removed from 15 mg/l P to 2 – 5 mg/l P. However, alum sludge from different sources may have different P adsorption capacity, and sludges with much higher P adsorption capacity have been identified (SJRWMD, unpublished data).

Wetlands and Aquatic Plant Treatment Systems.

Treatment wetlands and floating aquatic plant systems can be effective management tools for dairy waste stream phosphorus (P) when used in combination with pretreatment processing of the waste stream. Phosphorus removal from a wide variety and range of dairy and other animal waste streams have been studied, as well as management of diffuse non-point source P pollution. If sufficient pretreatment is performed (if influent concentrations are low enough) or sufficient land area is available, very high P removal rates can be achieved. Typical removal rates of between about 40 and 70% for constructed systems are the likely result of economically determined available area and current regulatory targets for effluent phosphorus concentrations. Interestingly, natural systems in the south central Florida area appear to be able to provide similar treatment efficiencies to constructed systems. Achievable concentrations are ultimately determined by the background concentration of the biological system that is or does develop in the treatment area.

Wetlands constructed for or used (intentionally or unintentionally) for the purpose of phosphorus removal have been well studied in the past quarter century. Phosphorus removal by wetlands has been well quantified and modeled (e.g. Dunne et al. 1998, Godfry et al. 1985; Kadlec, 1997; Kadlec and Knight, 1993; Moshiri, 1993, NRCS, 1992). Performance data for a large number of treatment wetlands (both constructed and natural) through approximately 1992 is available electronically (NADB 1993) and wetland design sources can now be found in government and academically sponsored internet sites (e.g. www. EPA.gov; www.ag.ohi-state.edu). The average phosphorus removal rate of surface flow wetlands representing a wide range of influent sources and concentrations, wetland designs, area loading rates and climates presented in Kadlec and Knight (1996) was about 58%, with a wide range of removal performance independent of inflow concentration. The basic process governing wetland removal of phosphorus is the settling rate, and the lowest final effluent concentration for any wetland system is the background concentration of the particular wetland, often below 50 parts per billion (ppb) (Kadlec and Knight 1993). Reddy et al. (1996) estimated mass P removal by wetlands and streams in the Lower Kissimmee River and Taylor Creek / Nubbin Slough watersheds of the Lake Okeechobee Basin at 45% with a 3% standard error. Unit area storage of TP in those basins can be estimated from that report as 1.80 – 2.75 g/m2/yr respectively.

Runoff from Lower Kissimmee River (LKR) and Taylor Creek Nubbin Slough (TCNS) dairies to the surrounding landscape were described by Havens et al. (1996). Since implementation of dairy best management practices in the late 1980s runoff has generally decreased to less than 5 mg/l from the LKR dairies and less than 2 mg/l from the TCNS dairies. Seasonal concentration spikes at sampling locations in both areas greatly exceeded these values however. Phosphorus concentration limits for all non-dairy land uses was established in 1989 at 1.2 mg P/L for intensive use areas, and 0.35 mg P/L for improved pastures (Aumen et al 1996).

Gale and Reddy (1995) recommended the establishment of wetlands (as small riparian systems) between fields and streams for the management of diffuse agricultural (including dairy farm) field runoff if the capacity of these wetlands was taken into account. Hunt et al (1995) and Cronk et al (1996) developed general reviews of constructed wetlands for animal wastewater treatment. Hunt et al. found that constructed wetlands may provide more flexibility in pollutant loading combined with less capital and project life cost in the 26 states where they found animal wastes being so treated. In summarizing phosphorus removal mechanisms they identified the oxalate iron fraction associated with P adsorption as a possible reason for long-term declines in phosphorus removal efficiency seen in some treatment wetlands. They characterized average phosphorus concentration of dairy wastewaters compiled from "varying sources" and included the results of operations reductions of dairy wastewaters from three case study farms. Percent removal performance was the only performance result provided. Cronk et al (1996) reviewed the performance of constructed wetlands to treat wastewater from high intensity use areas of ten dairy operations, including design type, costs, and performance for removal of total phosphorus. She concluded that “preliminary results are promising when wetlands are a component of a farm-wide waste management plan, but they are ineffective without pretreatment [such as solids separation and anaerobic lagoon or other organic digestion methods]of the wastewater”. TP removal for five farms located from England to California found percent reductions ranging from 54% to 93% and removal rates from 0.03 to 2.1 g/m2/day. Payne Engineering and CH2M HILL (1997) reported on performance, design and case studies of constructed wetlands for treating animal wastes. They recommended pretreatment (solids separation and stabilization lagoon or similar process) and careful design. They concluded that wetlands should be carefully considered, as they were not universally applicable. The reported treatment levels for total phosphorus were similar to those reported for other studies, and expected effluent TP concentrations were in the range of 10- 50 mg/l. Wetland sizing criteria for the treatment of strong ($[TP]_{in}$ = 10 – 50 mg/l) effluent streams were developed in the report. They also briefly discussed the used of subsurface (SSF) wetlands, noting that potential problems with clogging of SSF systems with particulate matter and the five-times higher installation costs made these systems unlikely for use in agricultural settings.

TP removal from an Oregon dairy waste stream that included solids separation and anaerobic lagoon pretreatment averaged 56.7% (s.d.=17.5) (Geary and Moore 1999). Dairy flush water from the same farm was used to test TP removal by different vegetation mixtures (Moore et al. 1995). Average removal ranged from 53% to 65%, with TP mass treatment of 0.35 to 0.45 g/m2/day for several different plant and depth combinations.

Treatment of runoff from a dairy cattle yard and manure stack area in Ontario Canada included anaerobic, aerobic, and stabilization ponds, two wetland cells in series and finally overland flow (Weil et al, 1998). TP concentrations were reduced by more than 99.7% with an outflow concentration of 0.07 mg/l. The high performance of the system may be linked to the very long retention times in the facultative and aerobic ponds (more than 100 days each).

A combined system for dairy wastewater treatment that included grass filter strips followed by wetland treatment and finally a detention pond showed TP removal over two years that ranged between 73 and 100% (Higgins et al 1993). The total removal was reached only under no flow conditions in a spring season. Outflow concentrations averaged 0.047 mg/l with weighted mean inflows to the system of 0.172 mg/l. only 4% of the inflow was dissolved P, while 50% of the outflow was in soluble form. Yang and Lorimor (2000).

Chen et al (1995) designed a waste treatment system for a 150 cow herd that incorporated both surface and subsurface flow wetlands in addition to facultative and anaerobic lagoon treatment and a final fish pond P removal characteristics of the system were not described. Karpiscak et al (1999) developed and operated a dairy wastewater treatment demonstration system that included solids separation, anaerobic/facultative and aerobic ponds, wetland treatment and recycling. However. TP removal was not reported.

Floating aquatic plant (FAP) systems have also been tested for many years as a method of phosphorus removal (e.g. Reddy and Smith, 1987; and see articles in Gopal, 1987 and Moshiri, 1993). Debusk et al. (1990) tested hyacinth, duckweed, pennywort, water lettuce and frog-bit to optimize uptake of P removal from dairy wastewaster, achieving P effluent levels between 0.24 and 0.87 mg P/L with a seven day retention time. Continuous flow systems did not perform as effectively. Tehir research indicated that the uptake rates compared favorably with removal rates of 18-23 mg P/m2/day they found “for conventional crops (e.g. bermudagrass) irrigated with secondary dairy lagoon effluent.”

Recent results reported in the literature have not shown significantly different methods or results for P removal using this approach. Water Hyacinth was tested for use as a final treatment of piggery wastes in both pilot and full scale operations (Costa et al 1999). Under full-scale operation they measured an average removal rate of 46% for a waste stream with a 48 mg TP/L influent, a 20 day hydraulic retention time of anaerobic lagoon effluent. Information necessary to calculate area removal rates were not provided. The hyacinths produced in the process were recommended as an animal feed supplement. Fallowfield et al. (1999) obtained P removal rates of 54% (average) using small (13.1 m^2) ponds to test the performance of batch fed high rate algal ponds loaded at an average of 0.45 mg TP/m2/dayfor animal waste treatment. He reported that the rates he measured were of the same magnitude as those of others working with this type of treatment systems in the past few decades, citing Goldman et al .1974; Chan et al. 1979; Fallowfield and Garrett, 1985; Aziz and Ng, 1992; Cromar et al .1996. Duckweed has also been tested extensively for its nutrient removal properties, and for both agricultural and stormwater waste streams (Perniel et al 1998; Bergman et al 2000,) Bergaman et al were able to demonstrate through selection of particular geographic genotype isolates (the geographic locations not provided) that plant uptake performance could be considerably improved.

Other wetland treatment applications including submersed macrophyte beds and fixed bed algal P removal have also been tested. Burgoon et al (1991) described TP removal rates of up to .43 g/m2/day in submersed bed microcosms. A P loading range of 0.14 – 0.92 g/m2/day was tested, and removal rates were found to increase in proportion to P loading over that range. Dierberg et al (In Review) describe TP removal of 51% to 78% of influent concentrations of 107 mg TP/L in mesocosm studies. Removal rates at a large scale submersed macrophyte system being tested for P removal of low TP concentration agricultural runoff by the South Florida Water Management District in the Everglades Nutrient Removal Project (Cell 4, ENR) averaged about 46%, with an inflow value of 39 ppb. Dierberg, (Personal Communication) noted that SRP removal in submersed vegetation systems is typically much greater than TP removal, with detection limit levels (5 ppb) being a typical result. Adey et al (1983) and Craggs et al (1996) reported on the development and use of an algal turf scrubber (ATS) to remove phosphorus from dilute agricultural runoff in the Everglades Agricultural Area and from a secondary wastewater effluent, respectively. The ATS system is a synthetic material on a gently sloping base over which the water to be treated is run. Total phosphorus concentration in the EAA agricultural runoff water was reduced only from 38 parts per billion (ppb) to 28 ppb. The same system applied to treat secondary effluent resulted in removal of 1.82 g/m^2/day, comparable to wetland treatment. TP concentration reduction of 40% was also similar to treatment system effectiveness.

Combined Systems

The SFWMD has evaluated or is in the process of evaluating a number of different “combined systems” to reduce phosphorus from entering the Everglades. These technologies can also be considered for removing phosphorus from field runoff resulting from dairy activities (grazing, land application, irrigation etc.) These systems include: managed wetlands with chemical pretreatment, chemical treatment with solids separation, SAV-lime rock systems, and attached algae systems. These systems were evaluated for phosphorus removal on post-BMP and post-STA water (Brown and Caldwell, 1993; South Florida Water Management District 1993). In general these systems receive relatively low phosphorus concentration waters (30 to 165 ppb) and thus, based on this research, would only be effective in treating similar levels of phosphorus down to levels less than 50 ppb. Therefore, other phosphorus removal treatment processes would have to precede these processes.

Field demonstrations on chemical treatment with filtration consistently produced water containing less than 10 ppb of phosphorus. Influent phosphorus concentrations were relatively low, approximately 20 to 150 ppb. Both alum and ferric chloride were successfully used. Other conventional and state of the art technologies that perform solids-liquid separation other than conventional filtration were investigated as follows: ballasted sand enhanced settling, magnetically enhanced settling, high rate sedimentation, microfiltration, a dolomitic lime fixed film bio-reactor, and enhanced coagulation. Of these technologies, only magnetic particle enhanced settling, ballasted sand enhanced settling, high rate sedimentation, and microfiltration significantly reduced total phosphorus concentrations. These technologies were recommended for further research prior to implementation. The remainder of the technologies were eliminated from further consideration (SFWMD, 2000).

The submerged aquatic vegetation/limerock (SAV/LR) technology is a two step process whereby submerged indigenous plants remove phosphorus from the water and is then followed by a limerock filter which further removes phosphorus. In the first step of the process, phosphorus is removed through plant biosynthesis and adsorption to (or co-precipitation with) calcium carbonate precipitates which are mediated by photosynthesis related pH increases in the water. The limerock filter removes soluble phosphorus through precipitation and removes particulate phosphorus through a filtering process. The SAV/LR system consistently removed phosphorus from an average influent level of 108 ppb down to an average of 15 ppb P. The study also investigated the effects of system hydraulic retention time, water depth, SAV harvesting and SAV treatment in series (SFWMD, 2000). Research is continuing on SAV/LR systems.

Periphyton-based treatment is process that utilizes attached algae supported over a layer of limerock to remove phosphorus. The mechanisms for phosphorus removal are essentially identical to that of the SAV/LR system. This system has constantly removed phosphorus down to levels less than 15 ppb; however, influent phosphorus levels were only slightly higher than effluent levels. It is believed that performance can be enhanced by modifying key process parameters. Therefore, research is continuing on this process and a large scale pilot project is currently underway (SFWMD, 2000).

Water Management and Reuse Techniques

Water Collection and Discharge Management

Centralized Treatment Facilities

Several private entities have proposed centralized facilities for treatment of various dairy waste streams. ILG/Aqua Envirotech (FDACS-ILGAEM, 2000) has proposed several centralized treatment facilities that would received piped waste streams from a collection of farms, similar to a municipal wastewater treatment system. These facilities would contain processes proprietary to ILG/Aqua Envirotech for waste treatment, and would produce liquid fertilizer as a final product. The economics of creating the infrastructure for this kind of operation would require close scrutiny.

A less infrastructure-intensive suggestion has been made by HydroMentia, Inc. (FDACS-HM, 2000), who has proposed construction of water hyacinth production ponds, followed by algal turf scrubbers, in sections of SFWMD main canals prior to discharge to Lake Okeechobee. The biomass harvested from these systems would potentially be used as livestock feed.

Water Retention to Reduce Net Discharges and Enhance Water Treatment

Environmental impact on receiving streams may be ameliorated, independent of any specific treatment techniques, by reducing the amount of water discharged off-farm. An effective technique for affecting this reduction is to convert some available pasture land to retention basins. These basins have been used extensively for urban stormwater management (Wanielista,1978) to provide hydraulic buffering and reduce volume and peak stormwater discharge. Depending on the size of the size of the retention and if the retained water is reused as irrigation on the farm, significantly reductions of water discharge can be obtained. An additional advantage of the hydraulic buffering and resulting flow reduction is that more efficient treatment technologies can be applied to the discharged water because of the low more constant flow that can be maintained.

Vegetated Buffers

Vegetated Buffer Strips (Filter Strips, Greenways, Riparian Zones) are naturally occurring or planted vegetated strips of land used to reduce nutrient and chemical transport from runoff and shallow groundwater flow from agricultural areas. Vegetative filters are currently a recommended BMP for removing suspended solids and nutrients from concentrated livestock runoff and edge-of-field areas. Filters are designed with adequate length and flow velocities to promote filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilization of contaminants. Vegetative filters are effective at removing P associated with detached solids, but are not as effective at removing soluble P. Design criteria for vegetative filters are found in Conservation Practice Standard, Filter Strip, Code 393 (USDA 1982) and the SCS Agricultural Waste Management Handbook. The National Resource Conservation Service has also developed specifications for a three-zone riparian forest buffer strip system which is recommended as a BMP for agricultural systems (USDA-NRCS 1995). Vegetative filters should be included as a BMP on all dairies, but cannot reduce P concentrations to desired target levels.

A comprehensive citation and subject index on various aspects of vegetated stream riparian zone water quality effects has been prepared by Correll (2001). The index contains 715 citations of research literature dealing with design, performance, and operation of vegetated (forest, grass, herbaceous) riparian buffer zones and the influences they have on the quality water received from upland areas.

Current research has shown that vegetated filter strips consisting of trees, grass, and other vegetation around agricultural fields can reduce sediment and P loads by as much as 70 percent (Mikkelsen and Gilliam, 1995). Recent research in vegetated buffers quantifies nutrient and chemical removal and attempts to determine optimal design parameters. A total phosphorus removal of 50% was observed in agricultural field experiments by Daniels et al (1996), with phosphorus removal increasing as distance traveled across the grass and riparian buffer increased. Patty et al (1996) experienced similar results with simulated rainfall over agricultural land, which showed phosphorus removal increasing from 22 to 89% as grassed buffer strip width increased. Robinson et al (1996) correlated sediment concentrations in cropland runoff with vegetated buffer width, slope, and soil infiltration capacity. A buffer width of 9 meters removed 70% of sediment, with little improvement for additional buffer width. A case study by Heathwaite et al (1998) identifies the phosphorus concentrations in runoff associated with land receiving either granular inorganic fertilizer, liquid cattle slurry, or solid cattle manure. Reduction in phosphorus varied according to land application type with a range of 98% removal from inorganic fertilizer plots and only 10% removal from slurry plots. Chaubey et al (1995) developed a model used to predict the infiltration performance of grassed buffer strips receiving runoff from poultry litter. Lim et al (1998) developed a first order exponential decay function relating buffer width, nutrient concentration, and mass transport.

Another concept that is similar to vegetative strips is the use of vegetated buffers and greenways to improve surface and groundwater quality. An example of this approach is the USEPA allowing local governments to establish natural vegetative buffers (greenways) along stream corridors in lieu of incurring other EPA enforcement actions associated with violations of the Clean Water Act (Kleckley 2000). Most of these buffers consist of trees which are planted to provide nutrient uptake, sediment screening, and stream shading. The root system in a vegetated buffer increases the permeability of the soil. As a result, surface runoff percolates into the soil resulting in less water reaching the receiving stream. Some tree species that have been utilized in these buffers include poplar, eastern cottonwood, willow, and eucalyptus. These trees have extensive root systems which can tap shallow groundwater systems and remove nitrogen, phosphorus, and other contaminants.

Stone et. al. (1998) found that ortho P concentrations in a receiving stream located downgradient from a 14,000 head hog farm had been maintained at a constant level of approximately 0.05 mg/l due to the presence of a natural riparian ecosystem consisting of pine-mixed hardwood uplands and a hardwood swamp.

Models are currently being developed to simulate the function and performance of vegetative buffers. Some of these models may be useful in helping to select appropriate design parameters for these systems. One such model is the Riparian Ecosystem Management Model (REMM) which has been developed by the USDA-ARS, Southeast Watershed Research Laboratory (SWRL) and the University of Georgia Coastal Plain Experiment Station in Tifton, Georgia (Inamdar, et. al. 1999). REMM was developed to investigate the influence of site conditions affecting the fate of sediment, nitrogen, and phosphorus in a three-zone riparian system corresponding with specifications of the U.S. Forest Service and USDA-NRCS (USDA-NRCS 1995). REMM simulates the following site conditions: climate, topography, soil characteristics, vegetation types, and management influences. The SWRL conducted an un-calibrated simulation on a Coastal Plain three-zone riparian buffer system over a 5-year period and found that water table nutrient concentrations were within one standard deviation of observed values on an annual basis. Surface runoff loads for N and P exiting the third zone (managed herbacious buffer adjacent to row crop field) were simulated to within one standard deviation of observed values. REMM appeared to model the general patterns and processes observed in the riparian ecosystem and the simulated loss/sequestration of nutrients during passage through the buffer (i.e. denitrification and plant uptake), were also similar to observed trends. Simulated values of dissolved organic P (DOP) in groundwater leaving all three zones were within one standard deviation of observed values.

Recycling of Wastewater Effluent

Recycling dairy waste water can be an effective means for reducing additional water needs, as well as reducing pollutant loading to receiving waters. The regular use of wash water ensures a reliable flow for recycling. Although the level of treatment of recycled water can be modest, some treatment is required to remove many of the entrained or dissolved pollutants including phosphorus, BOD, and nitrogen. The effluent can then be reused for wash water and other uses requiring low-quality water. Recycled water is usually mixed with make up water prior to reuse.

Like water retention, recycling of waste water is usually one element of a waste management system that includes collection, treatment, and storage components. Research to date has focused on methods of treating, storing, and mixing waste water that can then either be recycled, land-applied, or discharged. Svoboda et al. (2000), developed a sequencing batch aerobic reactor (SBAR) to provide adequate treatment to allow recycling of dairy wash water. Phosphorus removal was modest, but BOD removal was very efficient. Huang and Chiswell (2000) experimented with alum as a means of treating water sufficient for recycling, achieving phosphorus reductions of over 80%. The various treatment methods that are appropriate for recycling systems are discussed elsewhere in this document.

Several proposals have been made to integrate the production of moderate to high value aquaculture products with the dairy treatment processes to produce fish protein concentrate (FDACS-EEWD, 2000) or fish, shellfish, and crustaceans (FDACS-EAEST, 2000)

Land Application of Wastewater Effluent

Direct Land Application

Land application of wastewater from dairy operations is a common and economical method for wastewater treatment that involves application of liquid wastewater to spray fields typically using gun nozzles or sprinkler systems. The effluent is normally pretreated using a lagoon system or other means prior to land application. When managed properly, irrigation of crops with effluent reduces reliance on commercial fertilizers as a continuously available source of plant nutrients. Effluent can be beneficial to crops by providing nitrogen (N), phosphorus (P), potassium (K), and other micro-nutrients important for plant growth.

Factors for successful operation of a land application system include proper planning, design, installation , and management. Calculations for volume and rates of land application are based on nutrient uptake of crops to be grown on the land, and land area availability for rates and timing of application.

The drawback to liquid system application is that it can be complicated to manage. Also, application at rates higher than the crop nutrient uptake capacity can create a higher risk of polluting surface and ground waters. Phosphorus, which is much less soluble than nitrate-nitrogen, does not readily move with ground water to off-site receiving surface waters. It can, however, be transported to surface waters as runoff, as can other sediments and become a serious threat to surface water quality.

Field testing of the effectiveness of land application as a phosphorus removal technique provide varying results. Sweeten et al. (1995) found soil water phosphorus levels of 1 mg/L after two years of application of 54 mg/L effluent. However, soil phosphorus levels have been found to increase with increasing application rates or prolonged application periods due to its low leaching rate. Westerman et al. (1995) obtained an average of 18 mg/L in soil water after three years of application of 56 mg/L effluent, but soil water concentrations had increased significantly each year, from 3 mg/L at the end of the first year to over 30 mg/L at the end of the sampling program.

Soil Amendments to Retain Phosphorus

Soil amendments can be used to mitigate off-site impacts to water quality by further slowing phosphorus migration. Research by Daniel and Haustein (1998) has shown that phosphorus runoff from nutrient-saturated fields can be reduced when water treatment plant residuals (alum sludge) is land applied. Vallance and Adamus (2000) used spent lime at 200mg/L to reduce phosphorus concentrations in land-applied effluent from 16 to 3 mg/L. Decreased phosphorus in runoff associated with land-applied poultry litter has also been correlated with use of alum, quick lime, slaked lime, ferrous chloride, ferric chloride, ferrous sulfate, and ferric sulfate on the manure prior to land application. This treatment may also have the similar results for dairy waste water, as discussed elsewhere in this document. Matichenkov, et al (1999) found significant reduction of phosphorus in runoff when a number of soil amendments were applied to sandy soils. Among those amendments found to be most effective were silicate slags from industrial processes.

Alternative Crop Production

Proposals have been made to apply treated wastewater to crops that have high nutrient requirements and reasonable market value, which provides economic incentive for pollution abatement activities. Among the crops proposed have been turfgrass (FDACS-DBE, 2000), chestnuts and reeds (FDACS-EAS, 2000), ramie fiber (FDACS-PIAF, 2000), rapid-growth trees (FDACS-SDBM, 2000), and rice (FDACS-IFAS, 2000).

Summary and Conclusions

The literature review successfully identified most if not all of the potential technologies that could potentially reduce P loads off of Okeechobee Dairies. Of those technologies identified, only a few had the potential to reduce P levels to the targeted P concentration of 40 ug/l and for most of these the general literature provided limited cost and performance data to fully assess their utility for the South Florida dairies. The more promising technologies identified will therefore need to have a more in-depth assessment done before a final ranking of the technologies can be completed.

The identified “typical” agricultural BMPs for dairies will be able to provide further reductions of P from the dairies, but will not be able to meet the P concentration target on their own. Therefore, it is clear that other technologies, such as wetlands, bio-chemical, and chemical treatment, will be needed to reach the ultimate goal. Unfortunately, few of these more advanced technologies have been tested on dairies, particularly south Florida dairies, which limits the available data for their effectiveness and cost. The status of the available data will likely result in a high uncertainty for the cost effectiveness of some of the technologies, which means that the application of some the technologies might end up being experimentally in nature. The technologies with known low performance uncertainties may be more expensive requiring a decision for the final selection of technologies to weigh cost against potential and known performance.

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Appendix A: FDACS Innovative Technologies Process Descriptions

Responses to: RFP - Innovative Technologies for the Treatment and Management of Dairy Solids and Wastewater and Surface Water Runoff

RFP Issued by: Florida Department of Agriculture and Consumer Affairs

(Company Index Number Refers to accompanying spreadsheet)

A. Inclusive Proposals for Barn Solids, HIA, and Pasture Runoff

Company Index No.: 7

Respondent/Vendor: D B Environmental, Inc
414 Richard Rd., Rockledge, FL 32955

Process Description: Barn wash is treated in a primary lagoon. Effluent from the lagoon, HIA runoff, and pasture runoff is routed to a Submerged Aquatic Vegetation (SAV) wetland, which should discharge effluent with P-content that meets receiving stream standards. Barn solids and side stream water from the lagoon would be used, respectively, for soil amendment and irrigation in plant production units (e.g. grass). Specifics of barn solids conditioning and lagoon side stream treatment are not given.

Innovative Elements: SAV wetland

Company Index No.: 10

Respondent/Vendor: Earthworks, Inc.
623 Weatherbee Rd., Ft. Pierce, FL 34982

Process Description: Barn solids are collected by squeegee and fed to a thermophilic anaerobic digester. Digester effluent is treated in a multi-step process that includes primary separation, enzyme addition, and centrifugation. Solids from the separation process are sold or recycled on-farm as compost. Liquid from the separation process is sold or recycled on-farm as liquid fertilizer. Barn wash water, HIA runoff, and pasture runoff are routed to an anaerobic lagoon. Lagoon discharge is routed to an algae pond. Algae-containing pond discharge is routed to fish aquaculture ponds. Discharge from the aquaculture ponds is used as irrigation for plant production units (Ramie), or treated by ion exchange for discharge to receiving streams. Fish are harvested and processed in a central facility for hydrolysis to liquid protein and solid “fish fertilizer” for lawn and garden use

Innovative Elements: Thermophilic anaerobic digestion, fish aquaculture, centralized fish processing plant, ion exchange

Company Index No.: 11

Respondent/Vendor: Engineering and Applied Science, Inc
11700 N. 58th St., Ste. G, Tampa, FL 33617

Process Description: This is basically a *research proposal* to evaluate the optimum combination of processes that include anaerobic and aerobic lagoons, chemically enhanced SAV wetlands, chemical phosphorus precipitation, vegetative aquaculture with plant harvesting, and manure composting.

Innovative Elements: Chemically enhanced SAV, aquaculture

Company Index No.: 13

Respondent/Vendor: HydroMentia, Inc.
3233 SW 33rd Rd., Ocala, FL 34474

Process Description: Barn wash is routed to an aerated lagoon, followed by a settling lagoon. Settled solids are periodically removed to a composting facility. Effluent from the lagoon, along with HIA and pasture runoff, is routed to a water hyacinth production pond that is equipped with a harvest station. Effluent from the hyacinth basin flows to an algal turf scrubber system that is also equipped with a harvest station. Final effluent is suitable for irrigation, or discharge to receiving streams. Harvested biomass is transported to a physical processing system that produces a dry livestock feed. An alternative proposal is made for a regional system or systems that would treat District canal water. The alternative proposal consists of the hyacinth and algal turf scrubber systems without the lagoons and composting facilities.

Innovative Elements: Water hyacinth and algal turf scrubber systems. Regional systems as an alternative

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Company Index No.: 15

Respondent/Vendor: ILG and Aqua Envirotech Manufacturing Co., Inc
2390 NW 147th St., Miami, FL 33054 (ILG)

Process Description: Barn solids are washed to holding pits through screens. HIA and pasture runoff is routed to the same pits. Effluent from the pits is routed through coarse filtration, then through a flocculation process to fine filtration, and finally to a polishing operation. Polished effluent is routed to irrigation or discharge. Solids from the separation processes are dewatered and composted. Specifics of the type of filters used, the type of solids dewatering and handling systems proposed, and the nature of the polishing operation are not given.

Innovative Elements: Unless there are some undisclosed proprietary elements of the process, there does not appear to be anything innovative about this proposal except the suggestion for the construction of centralized facilities with wastes piped in from the farms, similar to a municipal waste water treatment plant.

Company Index No.: 19

Respondent/Vendor: Pelican Inlet Aqua Farms, Inc.
3914 SW 11th Ave., Cape Coral, FL 33914

Process Description: Barn solids are washed to a settling pond. Runoff from HIAs and pastures are routed to a holding pond. Settling pond and holding pond effluents are blended and used for irrigation of ramie fiber plant production units. Settled solids are applied as soil amendment to ramie stubble after each harvest. No information is provided about ramie water requirements or nutrient uptake versus dairy farm discharge.

Innovative Elements: Ramie production, however the proposal appears to take a very naïve approach to water and nutrient balances.

B. Partial Proposals for Barn Solids and HIA

Company Index No.: 1

Respondent/Vendor: Agrimond, LLC
8910 Astronaut Blvd., Cape Canaveral, FL 32920

Process Description: Barn solids are flushed to a sand trap, and then transported to a mechanical screening operation. Solids from the screens are routed to solids storage. Effluent from the screening operation and runoff from the HIA are routed to an aerated lagoon, to which is added a proprietary strain of bacteria. Effluent from the aerated lagoon is routed to a clarifier, where proprietary polymer is added and suspended solids are separated, thickened, and removed to solids storage. The aeration and clarification steps are similar to an activated sludge system, however the activated sludge in this process is not recycled to the aeration basin. Clarifier overflow flows to an aerobic lagoon, then to a facultative lagoon for partial nitrification and de-nitrification. Discharge water is recycled as wash water, used for irrigation, or discharged to receiving streams. Solids are removed for windrow composting.

Innovative Elements: Single pass activated sludge system, utilizing proprietary bacteria and proprietary polymer

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Company Index No.: 9

Respondent/Vendor: EA Engineering, Science, & Technology, Inc
Laurel Ct., Ste 200, 15500 New Barn Rd., Miami Lakes, FL 33014

Process Description: Barn wash and HIA runoff is screened for solids removal. Solids are composted for in-farm soil amendment. Effluent from screening is routed to an aerobic basin where phosphorus is precipitated by ferric sulfate. Settled solids are periodically removed from the basin and added to the compost process. Effluent from the treatment basin flows to an aerated aquaculture pond where several trophic levels exist simultaneously, e.g. algae and fish or filter feeding invertebrates. Marketable species are harvested from the pond. Effluent from the aquaculture pond is used for irrigation of plant production units, e.g. grasses, watercress.

Innovative Elements: Aquaculture

Company Index No.: 18

Respondent/Vendor: Madrid Engineering Group, Inc
PO Box 2506, Bartow, FL 33831

Process Description: Barn solids are washed to a facultative lagoon. Solids decomposition and clarification are facilitated by addition of liquefied activated carbon. Effluent from the lagoon is routed to one of several processing troughs that are lined with iron humate and sand. The water percolates through the sand/ iron humate mixture, where phosphorus is removed by sorption and ion exchange with the iron humate.

INNOVATIVE ELEMENTS: USE OF LIQUEFIED ACTIVATED CARBON TO ENHANCE THE BIOLOGICAL SYSTEM AND IRON HUMATE FOR PHOSPHORUS SORPTION.

Company Index No.: 22

Respondent/Vendor: Sigma Duckweed & Biomass Management, LLC
c/o Sigma Energy Engineering, Inc., 140 Spring Rd., Orinda, CA, 94563

Process Description: Barn wash and HIA runoff is routed to a facultative lagoon, where sedimentation is enhanced by polymer addition. Effluent from the lagoon is routed to an aquaculture pond stocked with duckweed. Effluent from the duckweed pond flows through limestone filters and then to irrigation of plant production units of short rotation intensive culture trees, e.g. poplar, and/or forage crops, or to receiving streams. Duckweed is harvested and processed for animal feed.

Innovative Elements: Duckweed as the aquaculture plant and short rotation intensive culture trees in the plant production units

C. Partial Proposals for HIA and Pasture Runoff

Company Index No.: 3

Respondent/Vendor: Berryman &Henigar
3200 Commonwealth Blvd., Ste. 101, Tallahassee, FL 32303

Process Description: Runoff from HIAs and pastures is routed through hydraulic structures to separate wetland cells for the HIA and the pasture streams. Runoff is pretreated by a proprietary passive polymer dosing system prior to introduction into the wetland cells. During periods of low to normal flow the two sets of wetland cells operate independently. During periods of high flow the hydraulic structures direct the pasture runoff to the HIA wetland cells and then direct the discharge from the HIA cells to the pasture wetland cells, affecting series wetland treatment under conditions of high hydraulic load. The pasture wetland cells discharge to receiving streams.

Innovative Elements: Use of proprietary passive polymer dosing to enhance wetland treatment. Use of passive hydraulic structures to affect additional wetland contact area at high flow (thoughtful, if not innovative).

Company Index No.: 6

Respondent/Vendor: Cambridge Water Technology
PO Box 1184 Gloucester, MA, 01931

Process Description: Runoff from HIAs and pastures is "preconditioned" in a magnetic field where it is treated with ferrous sulfate, polymer and magnetite. The resulting dense floc is separated from the water in a rapid settle. The magnetite is separated from the flocculated sludge magnetically and recycled. Solids are recycled on-farm as soil amendment.

Innovative Elements: Use of the magnetic separation technique to enhance solid-liquid separation in what is, essentially, a chemical phosphorus precipitation system.

Company Index No.: 8

Respondent/Vendor: DMD Group c/o Dosdourian Enterprises, Inc.
649 US Hwy. 1, Ste. B, North Palm Beach, FL 33408

Process Description: Injection of environmentally compatible grout into fields to form subsurface barrier impermeable to water, which reroutes water to areas specifically designed to be plant production units.
Innovative Elements: Subsurface barriers to route water to desired locations

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Company Index No.: 20
Respondent/Vendor: Rehberg, Bob
No address provided
Process Description: Iron humate (FeH) is used for phosphorus adsorption. No solids treatment system is proposed for the barn solids but barn water would be treated in troughs containing a mixture of sand and FeH. HIA runoff is treated in treatment basins receiving collected runoff from 10-acre tracts. The basins contain a mixture of sand and FeH. Pastures are treated by direct application of FeH to the soil. The barn troughs and HIA ponds require periodic replenishment of FeH; the pastures require periodic applications of FeH. Pasture runoff and HIA troughs discharge to receiving streams. This proposal is similar to that of Madrid Engineering Group, with the additional element of pasture soil treatment.
Innovative Elements: Use of iron humate for phosphorus adsorption

D. Partial Proposals for Barn Waste Only

Company Index No.: 4
Respondent/Vendor: Biomass Processing Technology, Inc.
4035 NW 43rd St., Gainesville, FL 32606
Process Description: Barn solids are collected by a mobile sweeping and collection device that deposits them in a holding station. The system is designed to minimize the volume of wash water. Collected solids are picked up by the contractor and transported to his central processing facility. Transported solids are processed at the facility using a proprietary process that produces fuel, animal feed, and other undefined by-products.
Innovative Elements: Full service contract removal and treatment of barn waste in a permitted facility

Company Index No.: 5
Respondent/Vendor: Bion Environmental Technologies
7921 Southpark Plaza, Ste. 200, Littleton, CO, 80120 and
HAS Engineers, 1486-A Skees Rd., West Palm Beach, FL 33411
Process Description: Barn solids are flushed to proprietary solids separation cells. Effluent from the cells is routed to an aerated facultative lagoon, then to a clarifier. Part of the clarifier effluent is recycled as flush water; the balance is routed to a biological treatment package plant. Effluent from the package plant is treated with alum and routed to a surface wetland. Effluent from the wetland is post-treated with additional alum (optional), sand filtered, and discharged to receiving streams. All solids from downstream processes are recycled back to the solids separation cells.

Innovative Elements: Proprietary solids separation cells (which are claimed to produce a soil-like material) and chemically enhanced wetlands

Company Index No.: 12

Respondent/Vendor: Environmental Processing Systems, Inc.
420 S. Dixie Hwy., Coral Gables, FL 33114

Process Description: Barn solids are flushed to a solids separator. Water overflow from the separator is routed to an undefined treatment process. Separated solids are composted in a proprietary confined-aeration container, which is a large poly bag system equipped with blowers and vented ports.

Innovative Elements: The proprietary composting system

Company Index No.: 16

Respondent/Vendor: J.A. Jones Environmental Services
8936 Western Way, Ste. 10, Jacksonville, FL 32256

Process Description: An integrated plant is built on each farm site. Barn wastes are routed to a thermophilic anaerobic digester, which has pH adjustment via lime addition. Digested solids are dewatered on a belt filter. Dewatered solids are blended with sulfuric acid (to neutralize the lime) and dry chemical additives, then granulated, then dried in a direct combustion dryer using methane from the digester. Dried product is packaged and sold as fertilizer. Filtrate from the belt filters is treated by electro-coagulation, filtered, and discharged to a receiving stream or recycled.

Innovative Elements: Package system for digestion, fertilizer production, and water treatment

Company Index No.: 21

Respondent/Vendor: RKB Enterprises, Inc.
625 Maury Ave., Norfolk, VA, 23517

Process Description: The proposal is directed specifically to manure treatment. Manure is collected in an agitated holding tank, to which is added the proprietary "Manure Mate" coagulating agent. The mixture is then routed through an "appropriate" separation process (e.g. screw press, belt filter). Dewatered solids are sent to composting, filtrate is sent to whatever is the existing water treatment system.

Innovative Elements: The proprietary coagulating agent appears to be the only innovation in this proposal.

Company Index No.: 23

Respondent/Vendor: WCI Waste Conversion Inc
Stn. C, Box 3396, Ottawa, ON, K1Y4J6

Process Description: Barn wastes are collected in a sump, and then blended in a conditioning tank with an undefined proprietary bulking and coagulating agent. The blended manure slurry is dewatered in a proprietary wiped screen conveyor-filter. Dewatered solids are conveyed to composting. Filtrate is directed to a secondary settling chamber for further solids reduction. Settled solids are recycled to the blender. Settler effluent is routed to an aeration tank and then recycled as wash or routed to irrigation.

Innovative Elements: Proprietary bulking and coagulating agent and proprietary dewatering system.

E. Partial Proposals for Pasture Runoff Only

Company Index No.: 2

Respondent/Vendor: Applied Technology & Management, Inc.
400 S. Australian Ave., West Palm Beach, FL 33401

Process Description: Vegetated swales direct pasture runoff to a collection/surge pond. Pond effluent is pumped at controlled rates to constructed surface wetlands. Wetland effluent is discharged to the receiving stream.

Innovative Elements: This appears to be a standard constructed wetland

Company Index No.: 14

Respondent/Vendor: Institute of Food and Agricultural Science (Univ. Fla.)
Indian River Research and Education Center, 2199 South Rock Rd.,
Ft. Pierce, FL 34945

Process Description: Pasture soils are treated with oxides of iron and aluminum, and limestone to promote retention of phosphorus. Runoff is routed to a "water detention zone" where both floating aquatic and emergent plants (rice) are growing. Effluent from the water detention zone is treated by ion exchange, and discharged to the receiving stream.

Innovative Elements: Soil treatment with Al and Fe oxides and limestone, and final treatment by ion exchange. The "water detention zone" appears to be a standard constructed surface wetland.

Company Index No.: 17

Respondent/Vendor: Lockhart Ag Technologies
Lake Harbor, FL 33459

Process Description: Pastureland soil is sampled on a regular grid. Soil sample analysis is used to determine the required application rates of silicate slag, dolomitic limestone, ferrous iron, or combinations thereof. The soil additives are intended to promote binding of phosphorus and reduce desorption to runoff water. The spatially variable application rates are positioned by coordinates and integrated into a computerized model of the field. In the field, a computerized application system is used in conjunction with a differential global positioning system to meter the soil additive at rates appropriate to the location in the field.

Innovative Elements: Soil additives, computerized systems for spatially distributed application rates

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Appendix B. Biological Processes used for Nutrient Removal

Biological Processes used for Nutrient Removal[1]

Process	**Effluent Quality** **Secondary**[a]	**5 mg/l BOD**	**5 mg/l TSS**	**Nitrification**	**10 mg/l nitrate N**	**3 mg/l total N**[b]	**1.0 mg/l total P**	**0.5 mg/l total P**
Activated Sludge	X	M	X	M				
Extended Aeration (oxidation ditch)	X	M	X	X	M			
A/O IM	X	M	X	M			M	
Modified Ludzack Ettinger	X	M	X	X	X			
Operationally Modified activated sludge	X	M	X	M	M		M	
PhoStrip IM	X	M	X	M	X		X	X
A^2/O IM	X	M	X	X	X		M	
Trickling Filters	X			M				
Fluidized bed	M			M	X	X		
Post-aeration anoxic tank [c]					X	X		
Two-sludge process	X	M	X	X	X	X		
Three-sludge process with chemical addition	X	M	X	X	X	X	X	X
Denitrification filters			X		X	X		
Bardenpho TM	X	M	X	X		M		
Modified Bardenpho	X	M	X	X		M	M	
Simpre IM	X	M	X	X	X	M		
Bionutre IM	X	M	X	X	X	M	M	
OWASA nitrification	X	M	X	X	M		M	
Sequencing batch reactors	X	M	X	M	X	M	M	
Phase isolation ditches	X	M	X	M	M	M	M	
Chemical addition (alum, lime, or iron salts)							X	X

[1] Taken from Water Environment Federation, 1998

X - process capable of producing effluent meeting indicated standard;

M - Process should be capable of meeting standard with proper design, acceptable influent characteristics, and/or tertiary filtration

[a] 20-30 mg/l effluent biochemical oxygen demand (BOD_5) and total suspended solids (TSS)

[b] filtration recommended to meet indicated standard

[c] requires methanol addition for denitrification

Appendix C. Performance of Municipal Wastewater Facilities Using Mineral Salts for Phosphorus Removal

Performance of Municipal Wastewater Facilities Using Mineral Salts for Phosphorus Removal [1]

Plant Type and Location	Design Flow (m^3/d)	Average Flow (m^3/d)	Chemicals	Chemical Feed Point	Chemical Dosage (mg/l as Metal Ion)	Influent TP (mg/l)	Effluent TP (mg/l)
Plug Flow AS							
Waupaca, WI	4,760	2,200	Alum	Sec. Clarifier	24.60	7.56	0.86
East Chicago, IN	75,700	59,800	Alum	Sec. Clarifier	7.70	1.93	0.38
			Polymer	Sec. Clarifier	1.00		
Mason, MI	5,700	5,000	Ferric Chloride	Prim. Clarifier	9.10	6.50	0.88
			Polymer	Prim. Clarifier	0.05		
Flushing, MI	4,400	6,000	Ferric Chloride	Sec. Biol. Process	5.30	3.40	0.48
				Sec. Biol. Process	0.15		
Appleton, WI	62,500	52,200	Ferrous Chloride	Plant Influent	16.80	10.50	0.80
Grand Ledge, MI	5,700	3,000	Ferrous Chloride	Sec. Biol. Process	5.60	4.50	0.70
Bowling Green, OH	30,300	20,100	Ferrous Chloride	Sec. Clarifier	5.20	8.40	0.75
			Polymer	Sec. Clarifier			
Kenosha, WI	106,000	90,500	Ferrous Sulfate	Prim. Clarifier	5.35	3.74	0.36
Toledo, OH	386,100	310,400	Ferrous Sulfate	Prim. Clarifier	3.60	2.76	0.35
			Polymer	Prim. Clarifier			
Clintonville, WI	3,800	2,700	Ferrous Sulfate	Sec. Clarifier	5.30	3.60	0.75
Complete Mix AS							
Thiensville, WI	900	3,300	Alum	Sec. Biol. Process	9.30	3.78	0.29
			Polymer	Sec. Biol. Process	0.82		
Two Harbors, MN	4,500	3,400	Alum	Sec. Clarifier	9.60	6.00	0.25
Escanaba, MI	8,300	7,600	Ferric Chloride	Prim. Clarifier	4.70	4.50	0.82
			Polymer	Prim. Clarifier	0.35		
Sheboygan, WI	69,600	46,600	Ferric Chloride	Sec. Clarifier	10.20	6.38	0.90
Lima, OH	70,000	15,100	Ferrous Chloride	Prim. Clarifier	13.20	3.90	0.50
			Polymer	Prim. Clarifier	0.07		
Niles, MI	22,000	12,100	Ferrous Chloride	Sec. Biol. Process	10.90	4.10	0.70
Crown Point, IN	13,600	8,700	Ferrous Chloride	Sec. Clarifier	11.00	5.50	0.70
			Polymer	Sec. Clarrfier	0.94		

Cedarburg, WI	11,400	7,600	Ferrous Sulfate	Sec. Clarifier	9.90	3.31	0.67
			Polymer	Sec. Clarifier			
Contact Stabilization AS							
Neenah, WI	5,700	4,000	Alum	Prim. Clarifier	7.70	3.50	0.70
Neenah, WI	14,800	16,700	Alum	Sec. Biol. Process	4.10	4.10	0.80
Algoma, WI	2,800	3,000	Ferric Chloride	Prim. Clarifier	33.00	3.30	0.23
			Polymer	Prim. Clarifier	0.07		
Grafton, WI	8,100	3,600	Ferrous Chloride	Prim. Clarifier	16.20	7.00	0.69
Port Washington, WI	4,700	5,800	Ferrous Chloride	Prim. Clarifier	8.50	5.90	1.00
Port Clinton, OH	5,700	6,400	Ferrous Chloride	Sec. Biol. Process	10.20	5.20	0.50
Oberlin, OH	5,700	5,700	Ferrous Chloride	Prim. Clarifier	6.40	5.90	1.00
North Olmstead, OH	34,000	21,200	Sodium Aluminate	Sec. Biol. Process	8.30	2.90	0.70
Pure Oxygen AS							
Fon du Lac, WI	41,600	26,900	Alum	Sec. Clarifier	8.50	7.20	0.73
			Polymer	Sec. Clarifier	0.75		
Extended Aeration AS							
Aurora, MN	1,900	1,700	Alum	Prim. Clarifier	16.90	2.90	0.76
Upper Allen, PA	1,800	1,200	Alum	Sec. Biol. Process	8.20	8.90	2.00
			Polymer	Sec. Biol. Process	0.37		
Corunna, Ontario	3,800	2,000	Alum	Sec. Clarifier	5.00	7.74	0.36
Saukville, WI	7,600	2,400	Ferrous Chloride	Prim. Clarifier	10.30	6.40	0.59
Plymouth, WI	6,200	5,800	Ferrous Chloride	Sec. Biol. Process	7.70	6.70	0.77
Trenton, OH	13,200	9,600	Ferrous Chloride	Sec. Biol. Process	2.56	6.10	0.65
Seneca, MD	18,900	15,100	Sodium Aluminate	Plant Influent	4.30	7.10	1.60
Step Aeration AS							
Fort Wayne, IN	227,100	170,100	Ferrous Chloride	Sec. Biol. Process	4.30	72	0.67
East Lansing, MI	71,200	42,800	Ferrous Chloride	Sec. Clarifier	5.90	5.30	0.90
			Polymer	Sec. Clarifier	0.05		
Oak Creek, WI	454,200	340,650	Ferrous Sulfate	Sec. Biol. Process	4.40	4.60	0.54
Elkhart, IN	75,700	60,200	Ferrous Sulfate	Sec. Clarifier	1.60	2.56	0.83
2-Stage Nitrification AS							
Piscataway. MD	113,600	54,900	Alum	Sec. Clarifier	8.80	6.13	0.20
			Polymer	Sec. Clarifier	3.80		
High Rate TF							
Geneva, OH	7,600	3,900	Alum	Sec. Clarifier	12.10	3.00	0.40
Colowater, MI	8,700	7,400	Ferric Chloride	Sec. Clarifier	8.30	4.10	0.88

			Polymer	Sec. Clarifier	0.10		
Oconto Falls, WI	1,900	1,400	Ferric Chloride	Sec. Biol. Process	8.81	3.67	0.45
Kendalville, IN	10,100	7,600	Ferric Chloride	Sec Biol. Process	14.70	3.63	0.35
			Polymer	Sec Biol. Process	25		
Standard Rate TF							
Willard, OH	5,100	4,800	Alum	Prim. Clarifier	6.30	52	0.82
			Polymer	Prim. Clarifier	0.14		
Elizabethtown PA	11,400	6,500	Alum	Sec. Clarifier	128	5.10	1.70
			Polymer	Sec. Clarifier	0.40		
Durana, Mi	3,000	2,700	Ferric Chloride	Prim. Clarifier	112	5.10	0.83
Sage, MI	16,700	6,400	Ferric Chloride	Prim. Clarifier	9.60	9.70	1.50
			Polymer	Prim. Clarifier	0.10		
Little Hunting Creek, VA	17,000	14,400	Ferric Chloride	Prim. Clarifier	42.50	9.30	0.20
			Polymer	Prim. Clarifier	2.80		
Bay City, MI	75,700	33,300	Ferric Chloride	Sec. Clarifier	9.50	4.60	0.50
			Polymer	Sec. Clarifier	0.29		
Colomo, MI	8,300	5,300	Ferrous Chloride	Prim. Clarifier	4.10	2.40	0.65
RBC							
Romeo. MI	6,100	3,300	Alum	Prim Clarifier	7.10	2.96	0.46
			Polymer	Prim. Clarifier	0.77		
Chesaning, MI	2,200	2,000	Ferric Chloride	Prim. Clarifier	9.00	2.60	0.60
			Polymer	Prim. Clarifier	0.40		
Negaunee, Mi	6,100	3.300	Ferric Chloride	Prim. Clarifier	7.50	2.00	0.95
			Polymer	Sec. Clarifier	1.00		
Dexter, MI	2,200	800	Ferric Chloride	Sec. Clarifier	10.20	5.11	0.46
			Polymer	Sec. Clarifier	0.50		
Hartford. MI	1,300	800	Ferrous Chloride	Prim. Clarifier	13.00	4.00	0.75
			Polymer	Prim. Clarifier	0.60		
St Jonns, MI	7,200	6,300	Ferrous Chloride	Prim. Clarifier	5.01	3.70	0.50
			Polymer	Prim. Clarifier	0.04		
Charlotte. MI	4,500	2,700	Ferrous Chloride	Prim. Clarifier	13.70	5.60	0.68
			Polymer	Sec. Clarifier	0.18		
Oxidation Ditch							
Lapeer, MI	7,000	7,200	Ferric Chloride	Sec. Clarifier	4.65	5.30	1.20
Portage, IN	13,200	8,400	Ferrous Chloride	Sec. Clarifier	9.90	6.00	1.50

[1] Taken from USEPA, 1987.
AS means activated sludge
TF means trickling filter
RBC means rotating biological contactors

Appendix D. Phosphate Precipitation Methods and Chemicals Used in Different Countries

Phosphate Precipitation Methods and Chemicals Used in Different Countries [1]

				BOD			**SS**			**Phosphorus**		
Stage of treatment	**Country**	**Number of Plants**	**Chemicals Used**	**Influent (mg/l)**	**Effluent (mg/l)**	**Removal (%)**	**Influent (mg/l)**	**Effluent (mg/l)**	**Removal (%)**	**Influent (mg/l)**	**Effluent (mg/l)**	**Removal (%)**
Pre-precipitation	Norway	1	Alum	88	7	92	111	17	85	7.9	0.5	94
	Canada	1	Lime	210	7	97	380	5	99	10.7	0.8	92
	Sweden	3	Alum	165	12	96	240	15	94	6	0.3	95
	USA	2	Ferric salts	-	-	-	-	-	-	8.1	0.8	90
Co-precipitation	Norway	1	Ferrous salts	284	8.0	97	223	10	96	7.5	0.6	92
	Norway	1	Alum	90	14	84	105	27	74	5.8	0.7	88
	Finland	30	Ferrous salts	165	20	88	170	31	82	7.3	1.8	75
	Germany	1	Alum	150	12	92	-	-	-	9.0	2.6	71
	Sweden	1	Alum	86	9	90	85	20	76	5.1	1.1	78
	Switzerland	10	Ferrous salts	201	12	94	-	-	-	6.5	0.9	86
	USA	1	Ferric salts	-	-	-	-	-	-	10	0.4	96
Post-precipitation	Canada	1	Lime	300	20	93	-	-	-	10	1.6	84
	Germany	1	Alum	175	15	91	-	-	-	11	1.8	84
	Sweden	20	Alum	150	8	95	160	20	88	6.5	0.4	94
	Sweden	8	Lime	140	12	91	135	35	74	4.8	0.8	83
	USA	1	Alum	-	-	-	-	-	-	10	0.5	95

[1] Taken from Yeoman *et al*., 1988.
SS: suspended solids
Environmental directorate: OECD, 1974, Paris