Task 4.1

Final Report

for the project entitled

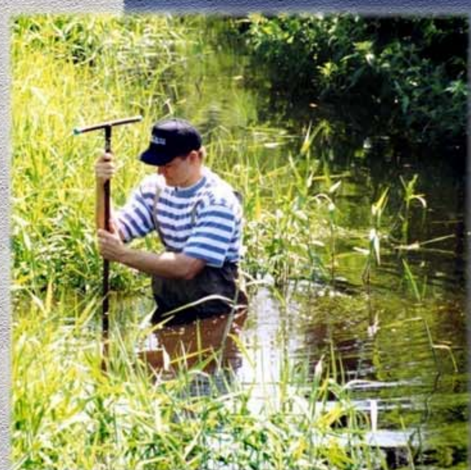
Dairy Best Available Technologies in the Okeechobee Basin

(SFWMD Contract No. C-11652)

Submitted by

SWET, Inc.

Soil and Water Engineering Technology, Inc.



In Association With

CDM, Inc
Engineering & Water Resources, Inc.
ENTEL Envirnomental Companies, Inc.
Environmental Research and Design
Mock Roos & Associates, Inc.
Royal Consulting Services, Inc.

May 31, 2008

The SWET Team

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INTRODUCTION

The purpose of the Dairy Best Available Technology project was to identify, select, monitor, and oversee the implementation of best available technologies (BATs) that would significantly reduce the export of phosphorus (P) from dairy operations into Lake Okeechobee and its tributaries. The project goal statement provides a clear and unambiguous target for success:

> *This project will result in the unbiased identification, selection, implementation, and monitoring of Best Available Technologies (BATs) that will significantly reduce P export from dairy operations into Lake Okeechobee and its tributaries and bring about the most substantial improvements in water quality in the shortest amount of time possible, while minimizing project costs and detrimental socio-economic impacts to the local region.*

This report focuses on the final results and conclusions from the project. Detailed task reports were previously developed for all of the earlier phases of the project and are available from the District, however, for clarity a brief summary of the entire project will be provided before the project results and conclusion are presented.

The project was initiated in November, 2000 and ultimately resulted in four separate edge-of-farm (EOF) treatment systems being designed, constructed, and evaluated for phosphorus removal efficiencies. Table 1 provides a summary of the various tasks that were completed for this multi-phased project. As can be seen in Table 1, the initial tasks were associated with establishing project goals and completing a detailed literature review for ranking the available technologies for reducing phosphorus loadings from dairies in the Okeechobee watershed. Based on the literature review and technical review of identified alternative technologies, stormwater retention with associated water reuse and chemical treatment of any excess water passing through the retention pond was selected as the most promising technology.

Figure 1 provides a conceptual view of the EOF system. The system is designed to collect and divert as much surface and groundwater flow as possible from the high P source areas on a dairy to a stormwater retention/detention (R/D) pond and chemically treat offsite discharges. The system has the following four major components:

1. Land source areas needing runoff treatment
2. System of ditches and dikes to collect and divert runoff to the treatment system
3. R/D pond for storing water for treatment and reuse on farm
4. Chemical treatment system for discharge from the R/D pond

The R/D pond provides some wetland treatment, but will serve primarily as a surge buffer for chemical treatment of any offsite discharge and storage for water reuse on the farm. Chemical treatment of the impoundment discharge will occur at the end of the R/D pond farthest from the inflow to reduce P concentrations as much as possible due to wetland interactions. The impoundment discharge will be injected with aluminum salts/polymers as it flows, via pump or gravity, into a sump/basin sized to ensure complete flocculation and settling prior to final discharge from the property. The chemical treatment system will operate only when the storage capacity of the system is exceeded or to recover storage capacity prior to a subsequent storm event.

TABLE 1. TASKS DESCRIPTION AND COMPLETION DATES

TASK NO	TASK / DELIVERABLES DESCRIPTION	COMPLETION DATE
1	**Development of Goals, Performance Measures and Potential Impacts**	
	1.1 Project Kick-Off Meeting	11/9/2000
	1.2 Develop Draft Goals, Potential Impacts/Performance Measures and Evaluation Method	12/2/2000
	1.3 Conduct and Submit Literature/Data Search and Summary	1/2/2001
	1.4 Submit Final Goals, Potential Impacts/Performance Measure and Evaluation Method	2/2/2001
2	**Assessment and Selection of Project Sites**	
	2.1 Ranking and Selection of Dairy Sites	2/2/2001
	2.2 Development of Landowner Agreements	4/2/2001
	2.3 Develop and Submit Draft QAPP and Monitoring Plans	6/2/2001
	2.4 Formulate Technology Alternatives and Submit Draft Report	6/2/2001
	2.5 Finalize and Submit Final QAPP and Monitoring Plans for Existing Dairy Conditions	8/2/2001
	2.6 Finalize Technology Alternatives and Submit Final Report	8/2/2001
	2.7 Complete Evaluation of Alternatives and Submit Draft Report	9/2/2001
	2.8 Develop and Submit Draft CNMPs for the Three Selected Dairies	10/2/2001
	2.9 Prepare for and Conduct One Stakeholders Meeting	10/2/2001
	2.10 Finalize the Evaluation of Alternatives and Submit Final Report	11/2/2001
	2.11 Finalize the CNMPs for the Three Selected Dairies and Submit Final Report	11/2/2001
	2.12 Governing Board Presentation	11/2/2001
3	**Implementation and Monitoring of Alternatives**	
	3.1 Farm Level P Load Monitoring	
	3.1.1 Equipment purchase (up to a total of 9 sites)	11/2/2001
	3.1.2 Install and Test Monitoring Stations (9 stations assumed)	11/2/2001
	3.1.3 Conduct Routine Field Monitoring Activities - TP (52 Biweekly trips from RPB)	9/2/2006
	3.1.4 Laboratory Analyses (assume 9 biweekly samples for 52 trips TP @$15/sam.)*	9/2/2006
	3.1.5 Labor & Lab for 9 monthly samples for 24 mo. Fecal and TSS @ $45/sample *	1/1/2005
	3.2 Preparation and Submittal of Quarterly Reports	11/2/2005
	3.2.A Amendment No. 1	12/18/2006
	3.3 Develop Draft Vendor Project Documents	1/2/2002
	3.3.A Amendment No. 1	7/2/2003
	3.4 Finalize Vendor Project Documents	3/2/2002
	3.4.A Amendment No. 1	8/1/2003
	3.5 Draft Implementation Plan for Selected Technologies	3/2/2002
	3.5.A Amendment No. 1	3/1/2004
	3.6 Draft Monitoring Plan for Selected Technologies	3/2/2002
	3.6.A Amendment No. 1	2/1/2004
	3.7 Development of the Final Implementation Plan for Selected Technologies	5/2/2002
	3.7.A Amendment No. 1	5/1/2004
	3.71 Cost of Implementing Vendor Technology	5/2/2002
	3.7.1.A Amendment No. 1	5/1/2004
	3.72 Review and Inspect Vendor Construction Activities	5/2/2002
	3.7.2.A Amendment No. 1	5/1/2004
	3.7.3 Vendor Payments	1/1/2006
	3.8 Final Monitoring Plan for Selected Technologies	5/2/2002
	3.8.A Amendment No. 1	3/1/2006
	3.8.1 Equipment Purchase (up to a total of 6 sites)	6/2/2002
	3.8.1.A Amendment No. 1	7/29/2006
	3.8.2 Install and Test Monitoring Stations	6/2/2002
	3.8.2.A Amendment No. 1	6/1/2006
	3.8.3 Conduct Routine Monitoring Activities - TP	1/1/2005
	3.8.3.A Amendment No. 1	11/1/2007
	3.8.4 Laboratory Analyses TP	6/1/2006
	3.8.4.A Amendment No. 1	11/1/2007
	3.8.5.A Lab. Analyses for 3 samp/mo for 15 mo, fecal and TSS	11/1/2007
	3.9 Prepare for and Attend Bi-annual Site Meeting (5 qtrs)	8/2/2005
	3.9.A Amendment No. 1	11/1/2007
	3.10 Prepare for and Conduct Public Workshop	11/2/2005
	3.11 Submit Workshop Minutes	12/2/2005
4	**Evaluation of Alternatives Performance**	
	4.1 Prepare and Submit Draft Final Report	3/1/2008
	4.2 Prepare for and Conduct Public Workshop	4/15/2008
	4.3 Prepare and Submit Final Report and Associated Project Data	3/15/2008
	4.4 Prepare and Submit Workshop Minutes	4/25/2008

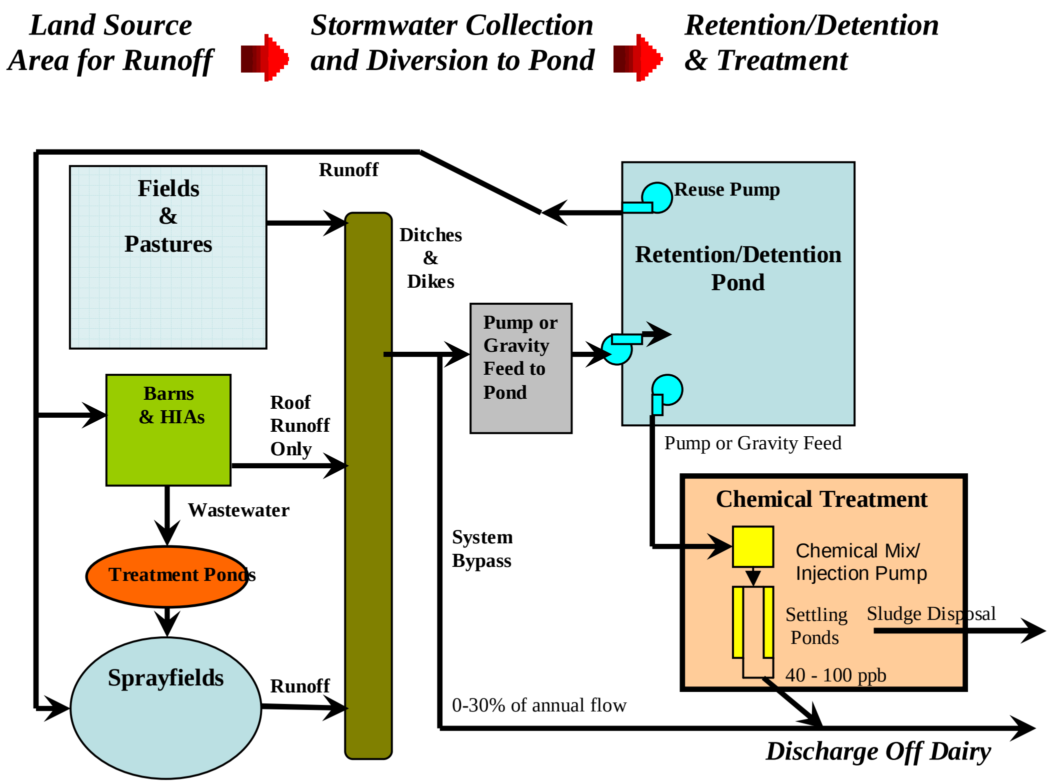


Figure 1. Conceptual Design of EOF System

While the literature review was being completed, the dairies within the Okeechobee basin were being evaluated and ranked for their participation based on their P loads, management characteristics, and willingness to participate. Three dairies were selected during the initial phase of the project and later an additional dairy was added under an amendment to the contract based on the success of the first systems. Animal nutrient management plans (ANMPs) were developed for each of the selected dairies to characterize their operations for the design/build phase of the project. Once the available technologies were prioritized and the ANMPs completed, design/build contractors were selected based on their prior experience and technical and logistical qualifications. The following design/build contractors were selected and assigned to the dairies:

Participating Dairy	Design/Build Contractor
Butler Oaks	CDM, Inc.
Davie Dairy	Environmental Research and Design, Inc.
Dry Lake Dairy	Engineering and Water Resources, Inc.
Amendment 1	
Milking R, Inc.	Royal Consulting Services

Different firms were selected for each dairy in order to spread the logistical demand for getting the designs and construction completed on schedule. Also, using multiple firms brought additional perspectives and technical skills into the project, while ensuring additional availability of firms for completing future projects.

The design criteria and budget constraint provided to the design/build firms were to design and build a retention based reuse and chemical treatment system to maximize the P removal for a set budget of $575,000 per dairy. The P reduction goal provided to firms was to achieve 40ppb P concentrations in the farm discharge water or as close to this goal as the budget would allow. Construction activities of the initial three Dairy BAT systems were completed between mid 2003 and early 2004, while the final system on Milking R, Inc. was completed in November 2006. Each firm provided unique approaches to implementing the retention based reuse and chemical treatment technology for dairy farms. The following section provides descriptions of the four systems.

DESCRIPTION OF THE FOUR CONSTRUCTED DAIRY BAT SYSTEMS

Butler Oaks Dairy EOF System

The Butler Oaks Dairy EOF system was designed and constructed by CDM, Inc. CDM's detailed design report is provided in the Task 3.7 Final Report. The dairy required significantly more diversion ditches upstream of the retention areas to separate the runoff from the low use west tract and off-farm areas from the dairy's east tract's more P-laden runoff that needed treatment. The west tract (west of County Road 721) is low use hayland and beef pastures, which was anticipated based on low P soil tests to have low P runoff. The east tract (east of County Road 721) contains the main dairy activities, including the milk center, milk herd pastures, calf barn, and the sprayfield. The flow from the west tract is also mixed with runoff from the neighboring B-4 dairy and wetlands west of the tract before coming onto the east tract. This on-flow does contain moderate P levels, but it is estimated that only about 20 percent or less of the P would be from Butler Oaks Dairy's west tract based on the land use and acreage of contributing areas. Initial design analyses considered including this inflow in the treatment system, however, the cost of the system would exceed the available budget. The system was therefore designed to treat the water from just the east tract, which is shown in Figure 2.

Because of the availability of a low-use land (woodland) on the lowest elevation portion of the dairy at its east end, the retention storage requirements were met with a gravity inflow system. Shallow water depths and quicker storage recovery in the R/D area were important for protecting the oak trees in the area. This more rapid drawdown after a storm event decreased the water reuse potential for this system. The gradients were not sufficient to gravity feed the chemical treatment system; therefore, two pumps were used to lift water into the treatment system. One of these pumps can be used to pump water into the waste storage pond for water reuse.

To collect the east tract runoff and isolate it from the bypass water from the west tract, a new treatment system collection ditch was constructed parallel to the existing south canal (Figure 2).

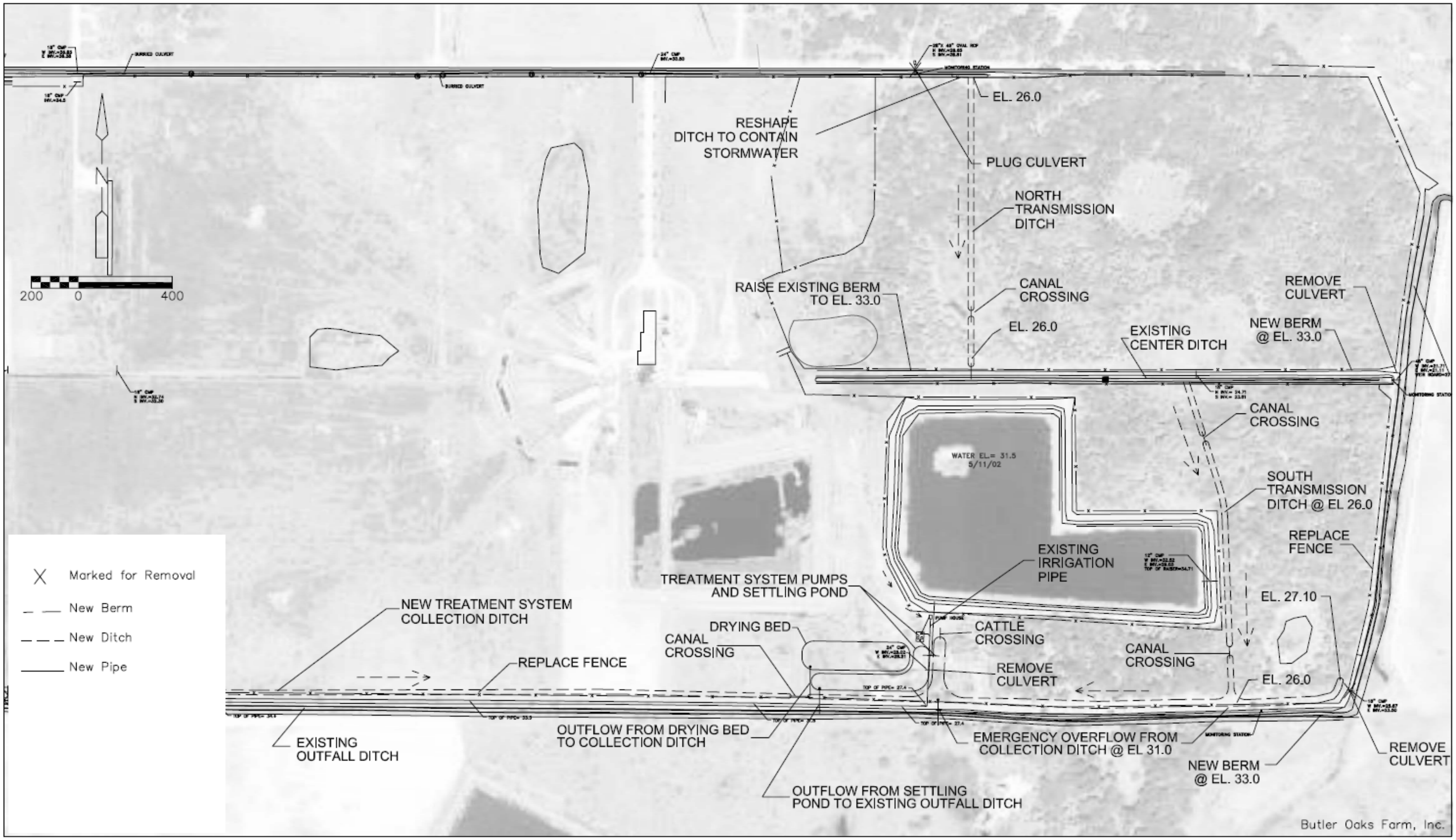


Figure 2. Layout of the Butler Dairy EOF System

This new ditch connects to the existing north/south (N/S) sprayfield ditches to collect all runoff from the irrigated fields, which receives effluent from the waste storage pond. The new treatment system collection ditch continues to flow east to the R/D area, which is then pumped through the alum treatment system. A berm was constructed around the perimeter of the R/D area. The berm has a 2-foot freeboard over the control elevation of 31.0 feet National Geodetic Vertical Datum (NGVD). Stormwater from the pastures and road on the north side of the eastern tract is diverted along the south side of Boat Ramp Road in the improved road ditch to a point just east of the existing culvert under the road. At this point, a new north/south ditch from the road ditch to the "center" ditch east of the milk barn was constructed to transfer drainage water to the "center" ditch. A culvert and flapper gate from the "center" ditch to an internal drainage ditch within the R/D area allows water from the "center" ditch to drain into the R/D area when water levels in the "center" ditch exceeds the level in the R/D pond. The water that flows to the R/D internal ditch from the center ditch is pumped either to the treatment system or to the waste storage pond for reuse via lift pumps located on the south side of the 3rd stage waste storage pond. This internal ditch is used to ensure adequate dewatering of the oaks in the R/D area.

The stormwater treatment system uses two lift pumps, alum chemical injection system, large flocculation/settling pond, and sludge de-watering area. Discharge from the settling pond is piped to the existing south boundary ditch just upstream of monitoring station 41A. An emergency overflow is located between the R/D storage area and the existing outfall canal at an elevation of 31.5 feet NGVD.

Davie Dairy EOF System

The Davie Dairy EOF system was designed and constructed by ERD, Inc. ERD's detailed design report is provided in the Task 3.7 Report. The steeper gradients along the lower section of Nubbin Slough near the property border and the wetlands within the slough limited the ability to create R/D storage. An earthen dam with three corrugated metal pipe (CMP) culverts with gate structures was constructed across the slough to create a small R/D area (Figure 3) behind the dam. The primary purpose of the earthen dam, however, was to divert water to the chemical treatment system, and not to retain water. Therefore, this system can be considered a flow-thru instead of R/D pond based system. A 4' dia. pipe extends from the slough upstream of the culvert structure to deliver water via gravity to the chemical treatment system. Although the topography allows for a gravity-fed system, the storage volume R/D storage behind the dam could only hold back about 0.3 inches of stormwater runoff. Therefore, ERD designed the chemical treatment system to handle high peak flow rates to allow the system to treat 100 percent of the runoff from storms up to 3.5 inches per day. A flowmeter was installed in the inlet pipe of the treatment pond to control the speed of the chemical feed/injector pumps in order to maintain constant chemical dosing concentrations at variable water flow rates. The chemical dosed water flows into a large flocculation/settling pond before discharging back into Nubbin Slough downstream of the diversion structure. Sludge in the flocculation/settling pond can be hydraulically pumped into above ground drying beds for sludge dewatering prior to land application.

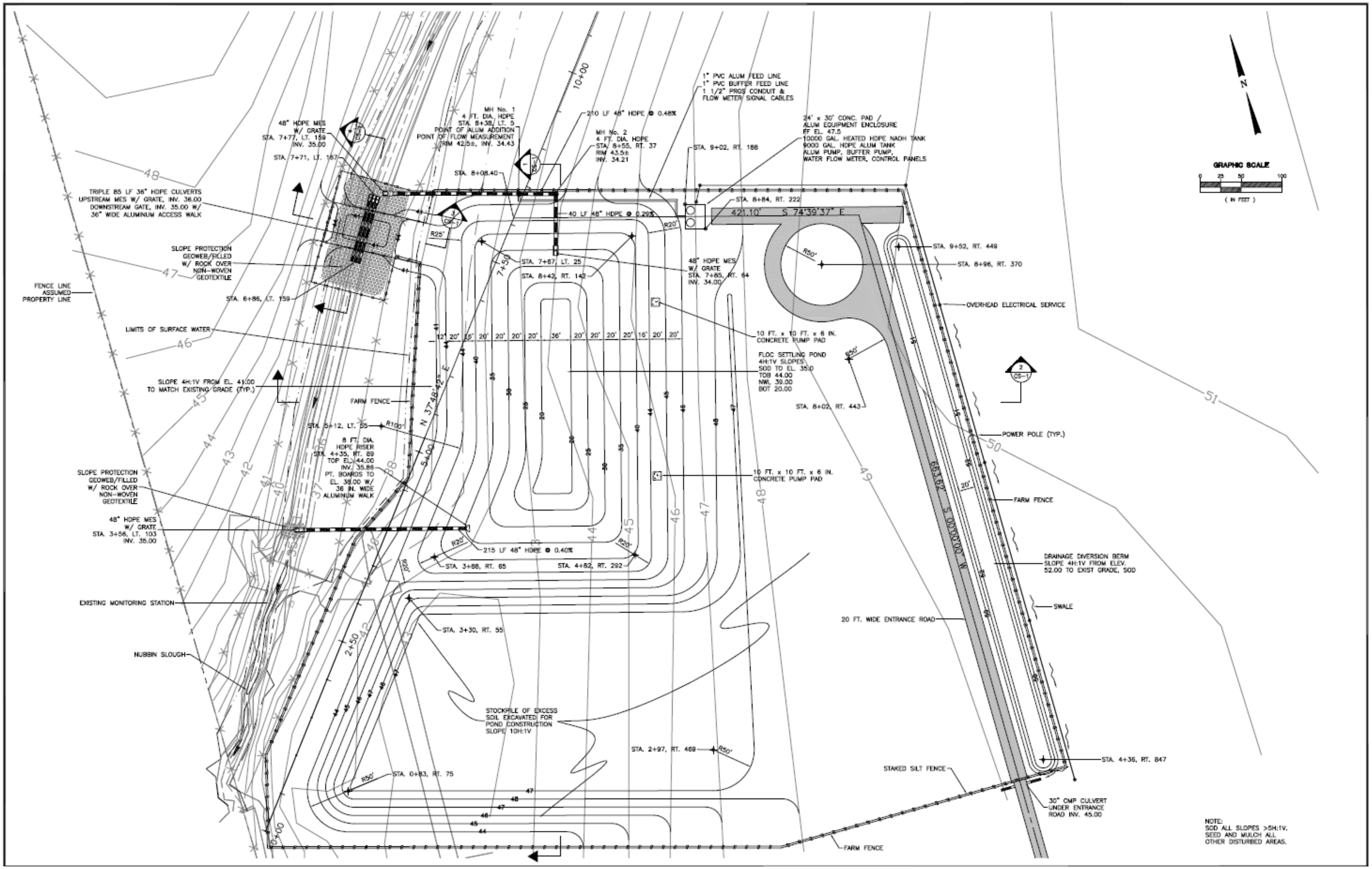


Figure 3. Layout of the Davie Dairy EOF System.

Dry Lake Dairy EOF System

The Dry Lake Dairy EOF system was designed and constructed by EWR, Inc. EWR's detailed design report is provided in the Task 3.7 Report. The Dry Lake Dairy system was a more conventional R/D pond storage type system (Figure 4). The EOF treatment system consists of a traditional aboveground surface water management system followed by chemical treatment. The system required 2,600 feet of new ditches, a 48-acre surface water impoundment, a 13,200-gallon-per-minute (gpm) lift pump, a gravity based alum feed/mixing unit, and two flocculation/settling ponds. The Dry Lake Dairy system has a unique gravity based chemical injection system. An 18-inch culvert from the R/D pond delivers water to the chemical treatment system. The culvert flow passes under a 4-foot gate (can also be used to stop flow) to create an orifice flow condition, which provides a flow signal for controlling the alum injection rate based on the stage-to-flow relationship. After alum is injected, the flow is forced through a multi-vaned flow mixer before entering the two flocculation/settling ponds. The bottoms of these ponds have under-drains which allow dewatering of sludge in the ponds during dry periods.

The Dry Lake Dairy was sold for development in 2005, so data collection ceased in December 2005. However, the retention pond and lift pump were continued to be operated by the developers through the beginning of 2007 when the pond was modified to accommodate the new ERP permitted equestrian community stormwater system .

Milking R Dairy EOF System

The Milking R Dairy EOF system was designed and constructed by Royal Consulting Services, Inc. (RCS). RCS detailed design report is provided in the Task 3.7.A. Report. The Milking R system is similar to the Dry Lake System in that it is also a conventional R/D pond storage type system (Figure 5). To deliver runoff to the EOF system, a ditch block was constructed along the northern end of the farm's north-south ditch to prevent flow from neighboring properties from entering the treatment system. The central farm ditch was improved to better deliver runoff from all parts of the farm to the R/D pond. Flashboards were installed to the top of bank elevation in an existing outflow structure on the west side of the property to redirect flow to the collection ditch running east towards the R/D pond. Runoff to the west of the previous Bion treatment system had a small lift pump installed to utilize the old Bion System Wetland for pretreatment of runoff going to the R/D pond. Two 8,000 gpm lift pumps were installed to transfer water from the collection ditch into an 87-acre R/D pond. Any excess water that discharges from the R/D pond during very wet periods is treated with alum proportional to the flowrate by the chemical injection system. The alum injection flow rate is controlled by a unique flow metering system that creates timed pulses to operate four different sized solenoid values based on the stage-to-flow relationship over the discharge structure. The treated stormwater enters a 3.1-acre flocculation/settling pond where the alum floc settles out. Treated discharges from the settling pond are then released offsite. A sludge drying bed is provided along the northwest side of the settling pond.

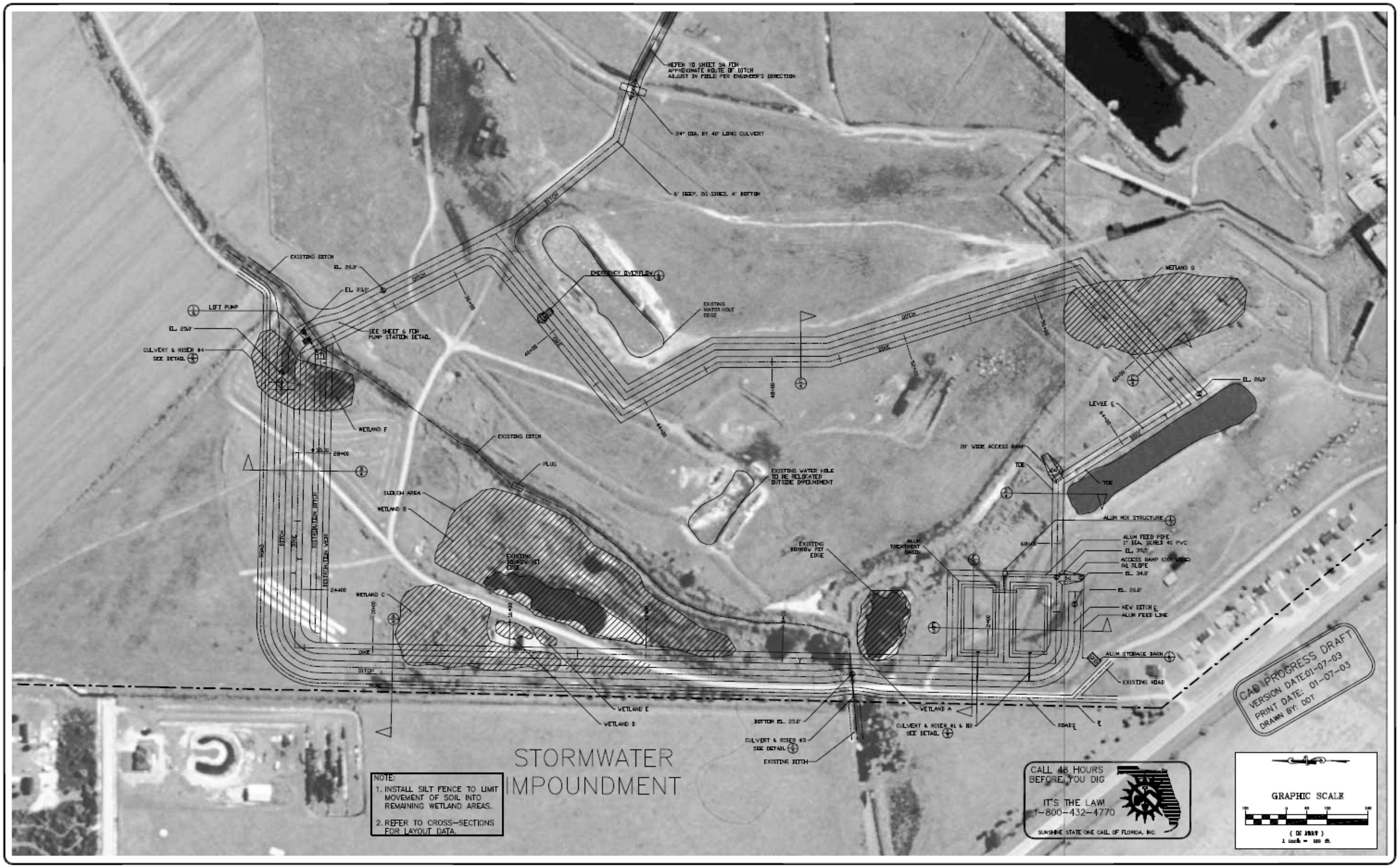


Figure 4. Layout of the Dry Lake Dairy EOF System.

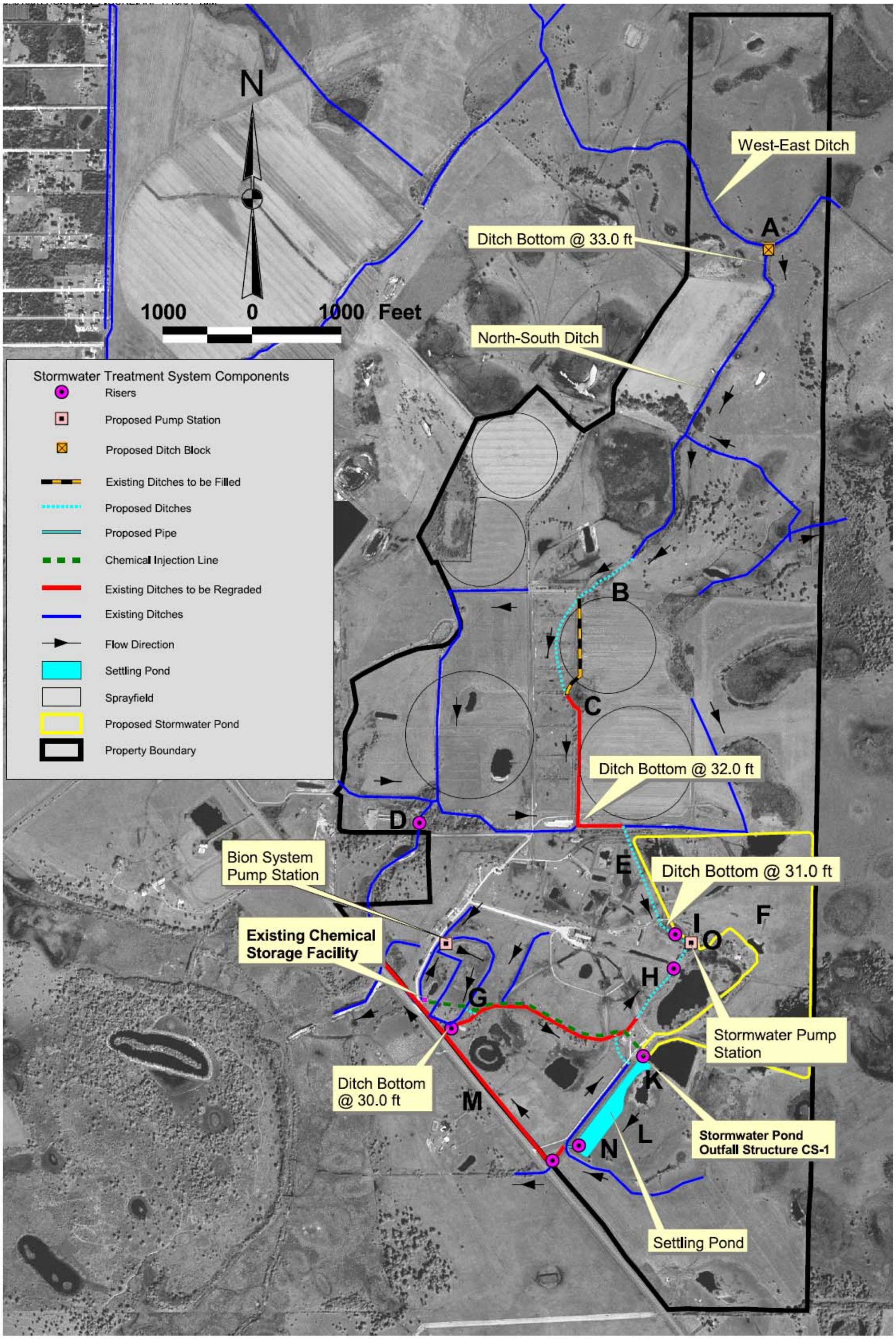


Figure 5. Layout of Milking R EOF System.

METHODOLOGY FOR EVALUATION OF P REMOVAL EFFICIENCIES

While the Dairy BAT systems were being constructed, monitoring plans for each of the systems were developed that would provide the data needed to evaluate the P removal efficiencies of each of the systems. The monitoring systems were designed to measure the flow rate and P concentrations of the inflow and outflow of the systems so that by the difference, the amount of P removal could be determined. Flows were determined by measuring water depths going over weir structures, water velocities and depths in culverts, and runtimes of lift pumps. The P concentrations were determined by using autosamplers that collected a flow proportional composite sample at the inflow and outflow points of each system. Grab samples were also collected during site visits for additional information and to provide a secondary measurement in case of sampler problems. The sampling locations for each of the systems are shown in Figures A-1 through A-4 in Appendix A.

ANALYSIS OF FLOW AND WATER QUALITY DATA FOR P REDUCTION DETERMINATION

The water quality data and downloaded velocity and depth data via cellular telemetry from the automated sampling stations were processed through the EXCEL® data management spreadsheets, which performed quality control (QC) checks and calculated the flow and P loads for each system. The spreadsheet also plotted stages, velocities, and flows for a visual inspection and validation. Multiple monitoring sites were installed at each dairy to evaluate pre-construction flow and P loads conditions entering and leaving the farms. The information was used to quantify flow and P loads for the purpose of optimizing the EOF system designs. Table 2 provides a summary of the pre-construction flow and P load monitoring data for the first three dairies only since Milking R did not have pre-construction monitoring due to addition of this dairy late in the process. In all cases, the final designed EOF systems significantly modified the drainage systems on each of the dairies so that none of the pre-construction monitoring sites/data corresponds directly with the EOF outflow (TOUT) monitoring locations. However, a reasonable adjustment was made to the pre-construction data to generally represent the conditions upstream of the EOF TOUT monitoring locations that are described later in this report for the EOF systems. For Davie Dairy no adjustment was needed because the pre-construction Davie South site was only a few hundred yards downstream of the EOF system. However, at Butler Oaks Dairy the entire flow passing through the 10D monitoring site from more natural areas upstream of the dairy was diverted around the EOF system, and therefore this flow had to be subtracted from the total farm discharge monitored at 41A. This adjustment makes clear that the P concentration off the dairy land downstream of 10D had much higher concentrations. The adjustment made for Dry Lake accounted for the fact that about 50 percent of the land that drained out through the 49A pre-construction was diverted to the EOF system which outputs to the 32B monitoring site. The adjusted pre-construction data are presented as the equivalent TOUT column in Table 2 so it can be roughly compared to the flow and P loads for the outflows from the EOF systems. However it should be noted that the flows and P loads are also highly influenced by rainfall and that the pre-construction years were a little drier than normal rainfall

Table 2. Pre-construction Monitored Flow and P Loads for Three Initial EOF System (March 2002 through March 2004)

Dairy Name		Davie Dairy			
Site Name		Davie South	Davie North	Davie East	Equiv. TOUT
Volume	(ac-in)	114060	14745	43182	114060
Runoff	(in)	45.62	46	43	45.6
Runoff	(in/yr)	27.65	27.4	26.2	27.6
Area	(ac)	2500	324	1000	2500
P	(lbs)	37894	14002	4175	37894
P	(lbs/yr)	22966	8435	2530	22966
Flow Avg P	(ppm)	1.47	4.19	0.43	1.47
Years of Data		1.65	1.66	1.65	1.65
Dairy Name		Butler Oaks Dairy			
Site Name		KREA 41A	KREA10D	Equiv. TOUT	
Volume	(ac-in)	56748	42542	14206	
Runoff	(in)	26.5	28.4	22.16	
Runoff	(in/yr)	13.84	13.8	10.8	
Area	(ac)	2141	1500	641	
P	(lbs)	30417	10612	19805	
P	(lbs/yr)	14532	5176	9661	
Flow Avg P	(ppm)	2.36	1.10	6.15	
Years of Data		2.09	2.05	2.05	
Dairy Name		Dry Lake Dairy			
Site Name		KREA 32B	KREA 49A	Equiv. TOUT	
Volume	(ac-in)	10176	8907	14808	
Runoff	(in)	26.36	29.69	27.94	
Runoff	(in/yr)	12.52	14.95	13.3	
Area	(ac)	386	300	530	
P	(lbs)	7799	9152	12558	
P	(lbs/yr)	3704	4610	5980	
Flow Avg P	(ppm)	3.38	4.53	3.74	
Years of Data		2.11	1.99	2.1	

for Butler and Dry Lake dairies, but these years were significantly wetter for Davie Dairy, particularly for 2003. These pre-construction sites were abandoned when the EOF monitoring systems were installed.

The EOF systems monitoring stations were installed in late 2003 for Davie Dairy, early 2004 for Butler Oaks Dairy and Dry Lake Dairy, and Milking R Dairy monitoring came on line in late 2005. These flow and P load results were used to estimate the overall summary (Table 3) of the estimated annual flow and phosphorus loads from the startup of each system (October 2003 for Davie Dairy and March 2004 for Butler Oaks Dairy and Dry Lake Dairy) through the end of the project (December 2007). The individual farm subtotal percentage reductions are calculated based on the flow-weighted yearly reductions.

Table 3. Summary of P Reductions for Dairy BAT Project to Date

Dairy Name	Year	P Load Reduction		% Due To Reuse/Retention
		Load (lb)	%	
Davie Dairy	2004*	559	5%	1%
	2005	480	4%	1%
	2006	536	18%	1%
	2007	138	20%	1%
	Subtotal	1713	9%	1%
Butler Oaks Dairy	2004**	3716	62%	81%
	2005	5574	78%	88%
	2006	2766	99%	82%
	2007	1383	100%	100%
	Subtotal	13439	80%	84%
Dry Lake Dairy	2004**	2295	50%	91%
	2005	3443	65%	90%
	2006	2617	94%	100%
	2007	2181	100%	100%
	Subtotal	10536	66%	93%
Milking R Dairy	2006***	882	100%	100%
	2007	2645	100%	100%
	Subtotal	3527	100%	100%
Total		**25687**	**49%**	**82%**

* Includes two months of 2003

** Started mid spring so not a complete year

*** Include one month of 2005

Table 4 provides an additional breakdown of the flow and P loads data for the various monitoring locations. The estimated flow volumes are subject to error due to equipment problems as described in the project's quarterly progress reports, but these data losses did not significantly limit the assessment of the performance of the systems and estimated error of about ±20 percent for P removal rates provided in Tables 3 and 4. Table 3 clearly shows significant reductions were achieved for the R/D pond based systems. As also can be seen, the majority of the P reductions for Dry Lake, Butler Oaks, and Milking R systems were due to water retention and reuse. The volumes pumped into the R/D ponds following the rainfall pattern except for the observed large pumping difference during 2006 between Milking R and Dry Lake. This difference was initially puzzling since these dairies neighbor each other, but then it was realized that a unique combination of three contributing factors was the likely cause. First, the Dry Lake pump station was being operated during 2006 by the developer to optimize their construction activities which significantly increased the pumping rate over those measured for Milking R. Secondary, there were significant internal drainage improvements at Milking R that increased within-farm water retention thus reducing the amount of stormwater needing to be pumped into its R/D pond, and lastly the 2006 rainfall came in an unusually well distributed pattern where very few individual events exceeded 1 inch. Such a rainfall pattern created very little runoff if on-retention was available, which was the case for Milking R.

The low P removal efficiency at Davie Dairy was due to the system's high dependency on the chemical treatment for removing P, which unfortunately only functioned approximately 20 percent of the time. The pass-thru design with essentially no retention/reuse capability is the reason for the high dependency on the chemical treatment system. The causes of the systems poor performance are discussed in the next section on operation and maintenance.

The influence of annual variations in rainfall and resulting runoff can also be seen in Table 3. It is important to note that three of the four evaluation years were below the average rainfall of 47 inches/year and therefore the observed P reductions associated with retention/reuse are higher than the long term anticipated performance of the system by an estimated 10 percent. However, year 2004 does give an insight into the performance during a wet worst case condition where approximately 15 inches of the year's above average 55 inches of rainfall came during two hurricanes, which created significant bypass conditions. Bypass water occurs when the runoff rates exceed pump capacities. Bypass water is untreated, and therefore reduces the net P removal efficiency during these periods. Even during 2004 the R/D systems had over 50% P reductions and this included the increase in bypass water at Butler Oaks due to hurricanes which caused several days of power outage at the pump station. Years 2005, 2006, and 2007 were approximately 5, 10, and 12 inches below normal rainfall, respectively, resulting in much higher P removal efficiency, particularly for the very dry year of 2007 where all three R/D systems retained 100% of the stormwater generated within the farm. The percent of P removed due to reuse/retention provides an indication of how effective water reuse and retention is compared to chemical treatment. Chemical treatment becomes more important during wet years because the amount of water needing treatment is higher. Unfortunately, for the R/D pond systems the actual P removal efficiencies of the chemical treatment systems are not correctly represented due to the high P removal for water reuse and retention. At Davie Dairy the P removal is almost entirely dependent on chemical treatment.

Table 4. Summary of Flow and P Concentration Data for Dairy BAT Treatment Monitoring Sites

Dairy Name	Davie Dairy					
Site Name	Land Flow	Retained/Reuse	ByPassed	Tin	Tout	
Volume (ac-in)	112588	65	38655	73933	73868	
Runoff (in)	45	0.03	15.46	29.6	29.5	
Runoff (in/yr)	11	0.01	3.69	7.1	7.1	
Area (ac)	2500	2500	2500	2500	2500	
P load (lbs)	19230	11	7262	12628	10915	
P load (lbs/yr)	4594	3	1735	3016	2607	
Flow Avg P (ppm)	0.74	0.74	0.81	0.74	0.64	
Years of Data	4.19	4.19	4.19	4.19	4.19	
Start Date	10/1/03	10/1/03	10/1/03	10/1/03	11/3/03	
End Date	12/7/07	12/7/07	12/7/07	12/7/07	12/7/07	
Dairy Name	**Butler Oaks Dairy**					
Site Name	Land Flow	Retained/Reuse	ByPassed	Tin	Tout	
Volume (ac-in)	20143	13794	2625	3895	3724	
Runoff (in)	38.37	26.27	5.00	7.42	7.09	
Runoff (in/yr)	10.1	6.9	1.3	2.0	1.87	
Area (ac)	525	525	525	525	525	
P load (lbs)	16837	11221	2317	3299	1081	
P load (lbs/yr)	4449	2965	612	872	286	
Flow Avg P (ppm)	3.60	3.50	3.80	3.65	1.28	
Years of Data	3.78	3.78	3.78	3.78	3.78	
Start Date	3/19/04	3/19/04	3/19/04	3/19/04	3/19/04	
End Date	12/31/07	12/31/07	12/31/07	12/31/07	12/31/07	
Dairy Name	**Dry Lake Dairy**					
Site Name	Land Flow	Retained/Reuse	ByPassed	Tin	Tmid	Tout
Volume (ac-in)	23850	12727	9357	13913	1766	1375
Runoff (in)	45	24	18	27	3.33	2.59
Runoff (in/yr)	17.8	9.5	7.0	10.8	2.30	1.74
Area (ac)	530	530	530	530	530	530
P load (lbs)	15928	8500	6249	18424	1456	415
P load (lbs/yr)	6294	3358	2469	7280	575	278
Flow Avg P (ppm)	2.87	2.87	2.87	5.70	3.55	1.33
Years of Data	2.53	2.53	2.53	2.53	2.53	2.53
Start Date	3/19/04	3/19/04	3/19/04	3/19/04	3/19/04	3/19/04
End Date	9/30/06	9/30/06	9/30/06	9/30/06	9/30/06	9/30/06
Dairy Name	**Milking R Dairy**					
Site Name	Land Flow	Retained/Reuse	ByPassed	Tin	Tmid	Tout
Volume (ac-in)	6488	6488	0	6488	0	0
Runoff (in)	6.80	6.8	0	6.80	0.00	0.00
Runoff (in/yr)	3.3	3.3	0	3.27	0.00	0.00
Area (ac)	954	954	0	954	0.00	0.00
P load (lbs)	3527	3527	0	3527	0.00	0.00
P load (lbs/yr)	1695	1695	0	1695	0.00	0.00
Flow Avg P (ppm)	2.34	2.34	0	2.34	0.00	0.00
Years of Data	2.08	2.08	2.08	2.08	2.08	2.08
Start Date	12/1/05	12/1/05	12/1/05	12/1/05	12/1/05	12/1/05
End Date	12/31/07	12/31/07	12/31/07	12/31/07	12/31/07	12/31/07

Table 5 provides the chemical treatment P removal efficiencies during operational periods except for Milking R, which never discharged due to its high retention storage. As can be seen in Table 5, chemical treatment efficiencies ranged from 58 to 98 percent with an average of about 80 percent. The Dry Lake system afforded the opportunity to run tests at different alum concentrations to field verify the jar testing data for proper dosing rates, which was 25 mg/l Al. Table 5 verifies that this dosing rate of alum appears to be about right. It is clear that if needed the chemical treatment systems will provide significant treatment. The key is that the chemical treatment systems must be in activation mode at all times.

Table 5. The Estimated Treatment Efficiency of the Three Dairy BAT Systems during Period of Operation.

Butler Dairy			Davie Dairy			Dry Lake Dairy				
Inflow	Outflow	Reduction	Inflow	Outflow	Reduction	Release	Al conc.	Inflow	Outflow	Reduction
mg/l	mg/l		mg/l	mg/l			mg/l	mg/l	mg/l	
4	0.54	87%	0.99	0.33	67%	1	35*	5	0.077	98%
1.5	0.34	77%				2	10.7	4.9	2.05	58%
						3	25.1	2.5	0.29	88%
						4	27.5	2.9	0.52	82%

* Estimated from chemical use, not directly measured

OPERATION AND MAINTENANCE OF THE FOUR EOF SYSTEMS - LESSONS LEARNED

As anticipated, a number of equipment and other operation and maintenance issues occurred during the project. In spite of these issues, however, very high P removal efficiencies were obtained for all but one of the systems. Details of these issues are presented in the quarterly status reports, but the most significant issues will be highlighted in this report with recommended solutions presented. Probably the most important lesson learned for all of the systems was that do NOT assume that the dairymen would have the time and expertise to properly operate and maintain such complex chemical injection systems, which was determined to be the primary source of failures. These failures were due to equipment malfunction and the lack of available trained technicians to remedy problems in a timely fashion. As indicated above, the Davie Dairy system was the most vulnerable to chemical injection system problems because its injection system had to work almost continuously as compared to the other three systems. The large retention systems of the other three systems greatly limited the amount of water needing treatment thus requiring only infrequent and short periods of chemical injection. The following summary of the problems that occurred at Davie Dairy highlights the issues. First, alum was not used because initial jar tests indicated that buffering with sodium hydroxide was needed to achieve required flocculation rates. Instead, an aluminum polymer (Hyper+Ion 4090) was selected. Unfortunately, this chemical created two problems; 1) it corroded the injector pump internal parts, and 2) in late 2005 it congealed in the tank requiring a three month cleanup effort. A second more expensive aluminum polymer (Hyper+Ion 1090) was then selected and installed, but unfortunately this polymer was found to produce a floc with poor settling properties when injected below optimum rates. Dosing at optimal rates was very difficult because the inflow P concentrations were highly variable ranging from 0.4 to 1.5 ppm. Other issues at this site were the flowmeter failed twice due to lightning strikes, the injector pumps by design were not able to slow to the speeds needed to inject chemicals at low flows, and the deep rectangular flocculation pond was short circuiting due to thermal clines and poor geometry. The short circuiting effectively created shorter retention times for floc sedimentation. All of these issues resulted in the injection system at Davie Dairy being non-operational approximately 80 percent of time. However, during the brief period where the system was operational with the original aluminum polymer, the Davie Dairy system was achieving over 65 percent P removal efficiencies. Butler Oaks and Dry Lake systems experienced much more limited chemical injection system problems that were mostly associated with the corrosive nature of the alum on valves and pipes. The Milking R injection was never used due to the system's high retention and water reuse, i.e. the retention pond never discharged.

The drainage ditches, culverts, and pumps generally performed well during the project. Power failures at Butler Oaks Dairy, particularly during 2004 hurricanes, presented a problem because of the electric pumps, but were quickly remedied by initially renting and then purchasing a generator. The primary issue with the pumps was the maintenance of the float control systems, which needed to be calibrated on a more routine basis.

As noted above, the chemical polymers used at Davie Dairy had congealing and floc settling problems. These problems were not observed for the alum that was used at the other three sites, Therefore it is recommended that alum be used unless significant jar testing and chemical properties data are made available to ensure the chemical's performance.

To address the observed operation and maintenance issues, the following adjustments are recommended:

1. Rigorous jar testing is conducted to determine settling rating for the potential chemical flocculent.
2. Flocculation pond designed to minimize short circuiting.
3. The chemical injection equipment is thoroughly evaluated for compatibility with the selected chemical.
4. Spare parts or replacements for the injection pumps are kept on site.
5. Build redundancy into the flow metering system associated with the chemical injection control system so that it can automatically switch to the alternative system if a failure is detected in the primary flow metering system.
6. When possible, use a mechanical or air bubbler agitator at the point of chemical injection to enhance mixing, if injection is not done into pumps or other specially designed mixing structures.
7. Conduct a thorough operation and maintenance visit for the injection system, lift pumps, and structures at least once per month.
8. Either have a field staff member complete a rigorous training program on the system or hire a professional with appropriate experience to operate and maintain the system.

ESTIMATED ANNUAL COSTS AND P REMOVAL EFFICIENCIES

The annual cost, which includes the amortized design and construction costs and the routine operation and maintenance costs are provided in Table 6. It is important to note that these costs do not include the significant contribution made by the dairies associated with the land they committed to the project for the R/D ponds and chemical treatment facilities. The operational and maintenance costs, which were also the dairies' responsibility, include chemicals, equipment replacement, repairs, and operation and maintenance (O&M) activities. The amounts of total P removed for each system are also provided in Table 6 along with the anticipated P removal efficiencies in terms of dollars per pound of P removed for just the O&M costs and then for the total system including both the amortized design and construction costs and O&M costs. It must be noted that the amount of runoff and associated P discharge occurring during the evaluation period greatly influences the P removal efficiency in terms of dollars per pound-P removed. This is the reason that the Milking R system appears to have poorer P removal efficiency than Butler Oaks and Dry Lake, when in reality all three systems would be expected to have similar performances.

Table 6. Estimated O&M Cost Per Pound of P Removed Over Period of Operation (through 12/07)

Farm	Years of Operation	Total O&M Costs ($)	Amortized Const. Costs over 15 yrs ($/yr @ 8%)	Total Annual Costs ($/yr)	Total P Removed (lbs)	P Removal Efficiency	
						O&M ($/lb-P Removed)	Total Costs ($/lb-P Removed)
Davie	4.1	$ 304,585.11	$67,177	$141,466.04	1713	$ 177.82	$338.63
Butler	3.53	$ 76,157.42	$67,177	$88,751.33	13439	$ 5.67	$23.31
Milking R	1.83	$ 10,850.01	$67,177	$73,105.96	3527	$ 3.08	$37.93
Dry Lake*	3.53	$ 6,954.04	$67,177	$69,146.97	10536	$ 0.66	$23.17

* Farmer did not record non-chemical O&M Costs

It is clear that the EOF chemical treatment systems that had R/D ponds for retention and water reuse have very good P removal efficiencies averaging about $27 per pound of P removed, which is lower than most of the other technologies evaluated. The system failures for the Davie Dairy pass-thru system resulted in an overall poor P removal efficiency of $339 per pound of P removed; however based on its performance during operational periods the pass-thru system's removal efficiencies were estimated to be in the order of $40 per pound of P removed, which is still quite good compared to other available technologies.

PERMITTING ISSUES

The primary permitting issue that had to be addressed during this project was obtaining United States Army Corps of Engineers (USACE) permits for constructing a couple of the systems' components in wetlands. USACE Nationwide Permits were obtained for the diversion structure at Davie Dairy and the R/D pond dike at the Dry Lake Dairy system. During the threatened and endangered species assessment at the Butler Oaks Dairy site, gopher tortoises were found and therefore a *Florida Fish and Wildlife Conservation Commission* permit was obtained to relocate the tortoises. Environmental resource permits (ERPs) were not needed because the dairies had Industrial Waste / NPDES permits with the Florida Department of Environmental Protection which already addressed ERP requirements. However, for future systems on other types of facilities, it is likely that an ERP or modifications to an existing ERP would be required.

CONCLUSIONS AND RECOMMENDATIONS

Four different EOF systems were constructed and evaluated for their ability to reduce P loads leaving four dairies in the northern Okeechobee watershed. Three of the EOF systems used large stormwater retention/detention (R/D) ponds to retain as much stormwater on site as possible to limit the amount of chemical treatment needed. The fourth EOF system was a flow-thru system where the majority of the stormwater was injected with a chemical flocculent and passed through a small floc settling pond prior to discharge. This flow-thru system had less than 3 percent flow reduction as compared to over 80 percent flow reduction for the other three systems and therefore was almost completely dependent on the chemical treatment system for P reductions. The R/D ponds provided flow reductions due to increased evaporation off the pond surface and the reuse of the water for irrigation. It was found that the EOF chemical systems that included R/D ponds provided excellent P removal efficiencies averaging about $27 per pound of P removed. The flow-thru design, however, was found to be more problematic creating a poorer performance than the other R/D pond based systems due to a high failure rate of its continuously on-demand chemical injection equipment and potential short circuiting in the flocculation. It is estimated, however, based on successful run periods that if more robust and redundant injection and flow metering systems are used, a more intensive O&M practices employed, and introducing internal baffling in the floc pond, then the flow-thru system would achieve P removal efficiencies in the order of $40 per pound of P removed.

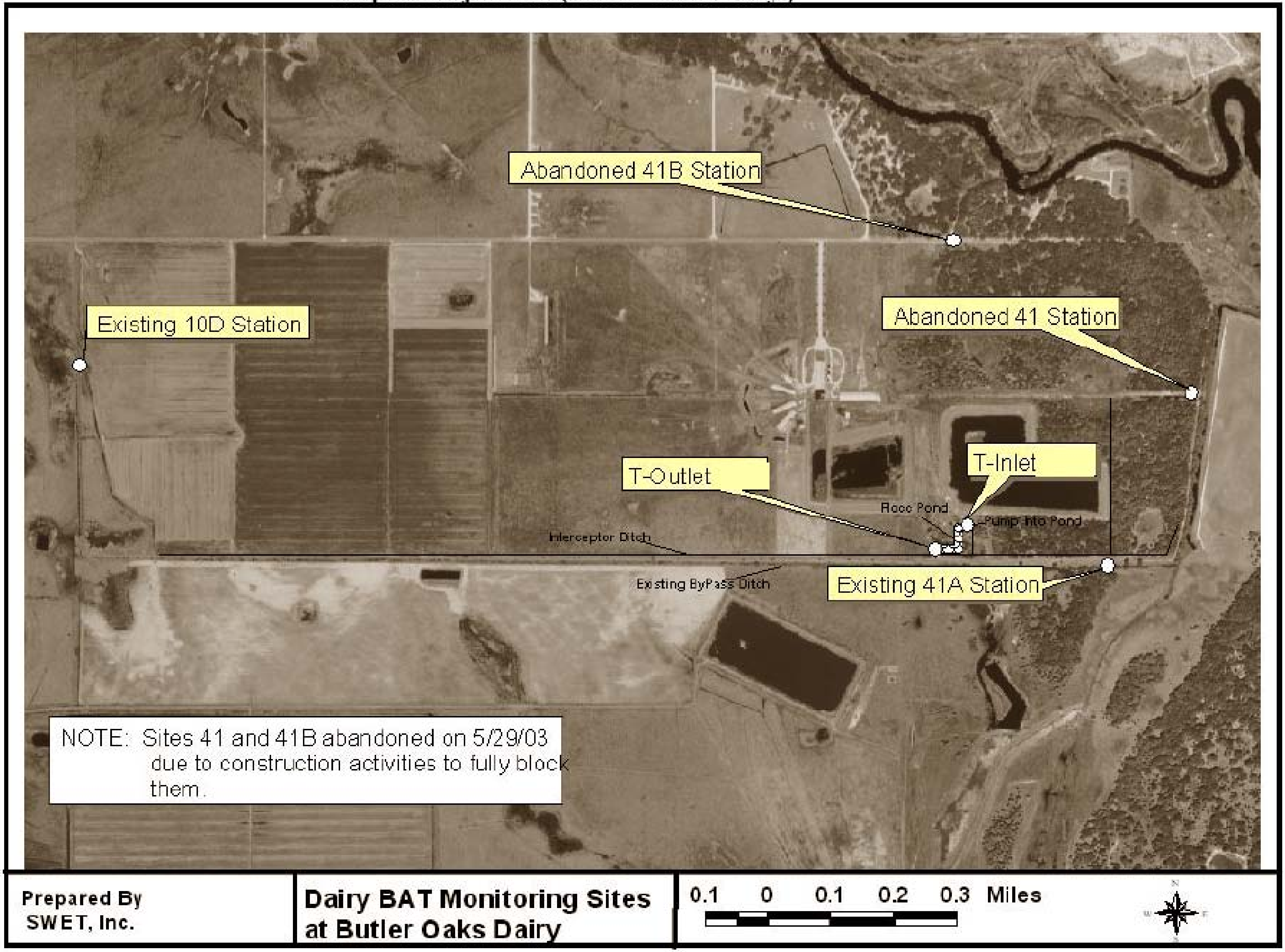
The effectiveness of the chemical flocculants was found to be highly influenced by the stormwater characteristics. The pH, hardness, and P concentration levels are the primary parameters that can influence the flocculation performance of the selected chemical flocculant, particularly associated with the floc formation rates and settling characteristics. The stormwater from the more intensive dairy pastures and sprayfields land uses were found to have significant hardness and pH levels for good floc formation; Therefore no additional buffering was required when using alum as the flocculant. However, the stormwater at the Davie Dairy system was found to have low hardness and pH levels due to a much higher fraction of its stormwater coming from offsite nondairy land uses. The lower hardness and pH levels required either chemical buffering with sodium hydroxide (NaOH) if alum was to be used or aluminum based self buffering chemicals such as Hyper+Ion compounds to obtain the required P reductions. Hyper+Ion was selected at Davie Dairy due to safety issues associated with NaOH, but was found to be particular sensitive to the inflow P concentrations as far as the settling ability of its produced floc, i.e. under dosing conditions would produce a non-settling floc. This situation creates a problem because real-time adjustments to dosing rates based on inflow characteristics is extremely difficult, particularly for P concentrations that are highly variable and hard to measure in real-time. For example, this means that if the chemical dosing rate is set for average P concentrations, then about 50 percent of the floc and associated P will pass thru the flocculation pond: or if the dosing rate is set for the maximum inflow P concentration, then overdosing will be occurring most of the time, which greatly increases costs and a potential concern for chemical pass thru. Alum floculants appear to be less sensitive to inflow P concentrations and less costly if overdosed. It is recommended that alum be used in the future unless significant scientific evidence of chemical properties and rigorous jar testing data are provided to ensure the flocculation performance and cost effectiveness of alternative chemicals.

As evidenced by the higher than anticipated equipment failure rates, particularly for the pass-thru system, it is clear that more robust and redundant equipment designs and operation and maintenance procedures are needed. Higher quality pumps and flow meters will reduce failure rates. Equipment redundancy or backup systems are also critical in order to allow treatment to continue when the inevitable equipment failures occur thus allowing repairs to be made without downtimes. Equipment redundancy can increase treatment reliability by as much as 50 percent. In addition to improved equipment quality and redundancy, a more intensive routine operation and maintenance program will be needed to ensure the reliability of these systems. If these systems are to be operated and maintained by dairy staff, then it is recommended that the staff member(s) complete a rigorous training program on the system and have full knowledge of specialists and/or manufacturers for each piece of equipment so that repairs can be completed quickly. If the dairy staff does not have the time or the technical background to adequately learn and commit to the proper operation and maintenance of their system, then it is strongly recommended that professional O&M services be contracted for their system.

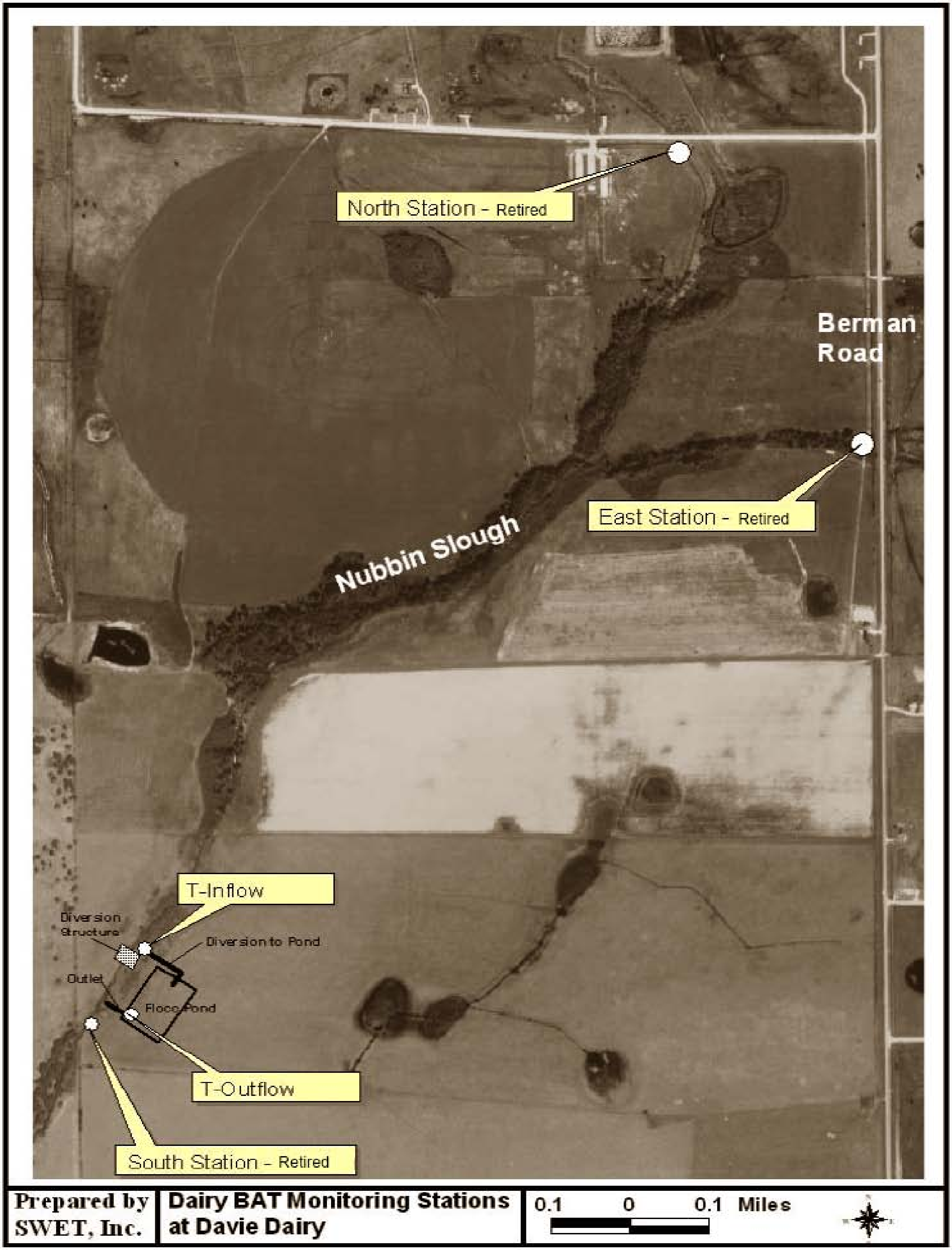
APPENDIX A

SITE MAPS OF THE FOUR DAIRY BAT TREATMENT SYSTEMS WITH MONITORING LOCATIONS

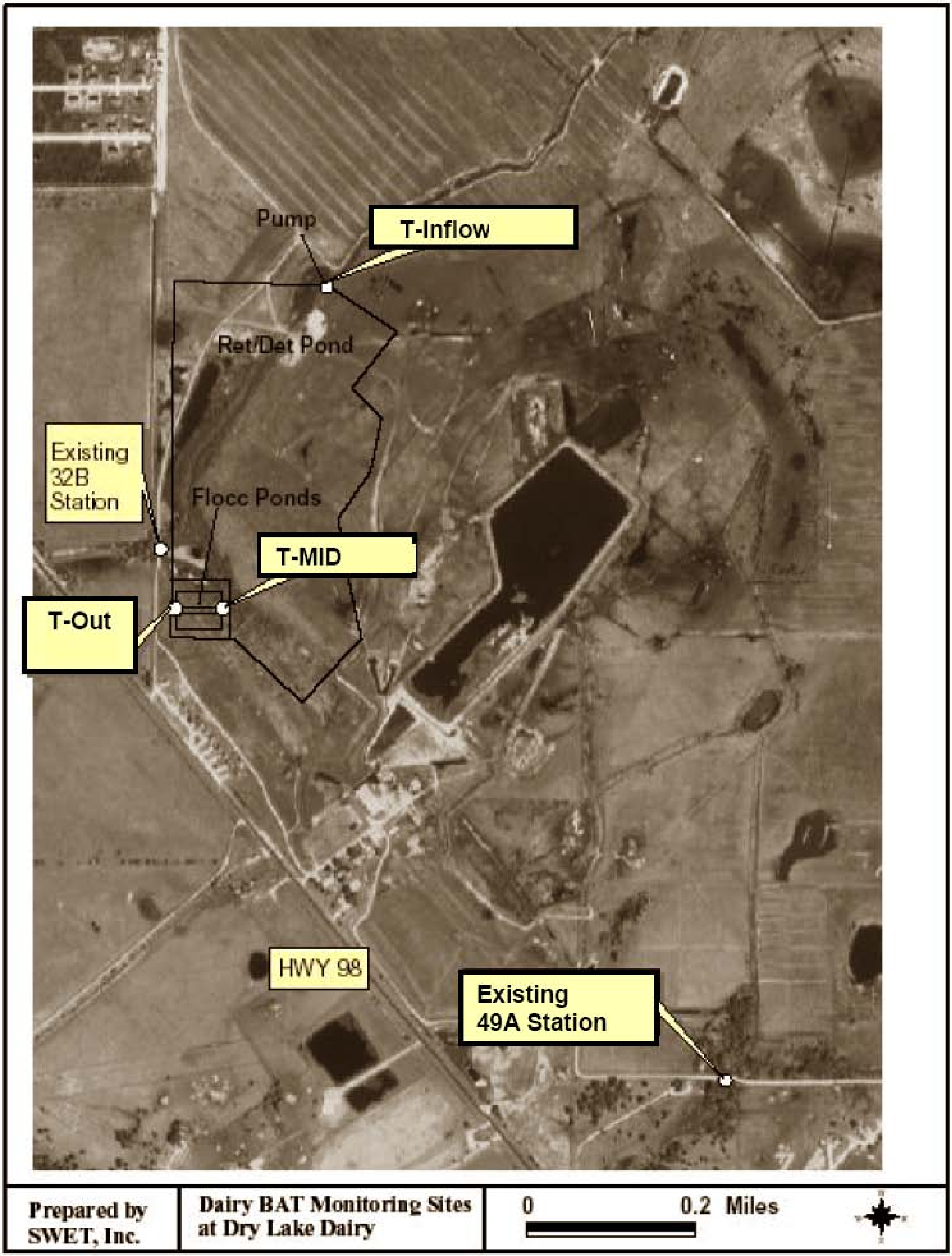
Map of Project Site (Butler Oaks Dairy.)



Map of Project Site (Davie Dairy Inc.)



Map of Project Site (Dry Lake Dairy.)



Map of Project Site (Milking R Dairy Inc.)