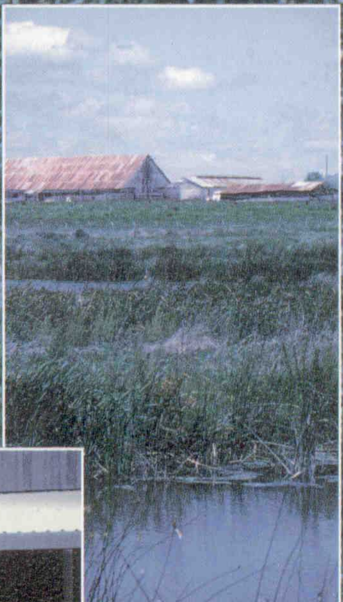
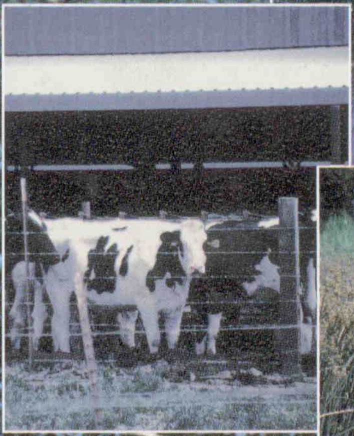
Constructed Wetlands

for Livestock Wastewater Management





Literature Review, Database, and Research Synthesis

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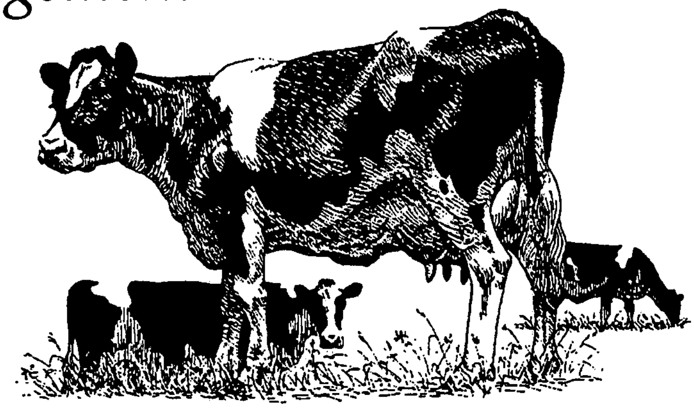

Literature Review, Database, and Research Synthesis

Prepared for

Gulf of Mexico Program, Nutrient Enrichment Committee

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and

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Prepared by

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and

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Abbreviations and Acronyms

A&M	Agricultural and Mechanical
ANN	annual average
ARS	Agricultural Research Service
ASWCC	Alabama Soil and Water Conservation Committee
BOD_5	5-day biochemical oxygen demand
°C	degrees Celsius
CAFO	confined animal feeding operation
col	colony
cm	centimeters
CO_2	carbon dioxide
COD	chemical oxygen demand
CURB	Clean Up Rural Beaches
CWF	constructed wetland filter
d	day
DO	dissolved oxygen
DT	deep trench
EPA	U.S. Environmental Protection Agency
FAP	floating aquatic plant
FC	fecal coliforms
ft^3	cubic feet
FWS	free water surface
g	grams
GMP	Gulf of Mexico Program
ha	hectares
HDPE	high-density polyethylene
HLR	hydraulic loading rate

Abbreviations and Acronyms, Continued

kg	kilograms
L	liter
LSU	Louisiana State University
LTM	long-term
LWDB	Livestock Wastewater Treatment Wetland Database
m, m^2, m^3	meters, square meters, cubic meters
µmhos	micromhos
mg	milligrams
min	minute
mL	milliliter
MOEE	Ministry of the Environment and Energy
N	nitrogen
NADB	North American Treatment Wetland Database
NCASI	National Council of the Paper Industry for Air and Stream Improvement
NH_3-N	ammonia-nitrogen
NH_4-N	ammonium-nitrogen
NO_2-N	nitrite-nitrogen
NO_3-N	nitrate-nitrogen
NRCS	Natural Resources Conservation Service, formerly the Soil Conservation Service (SCS)
OMAF	Ontario Ministry of Agriculture and Food
ORG-N	organic nitrogen
ortho-P	ortho-phosphorus
P	phosphorus
PO_4-P	phosphate phosphorus
PSWCD	Piedmont Soil and Water Conservation District
SF	surface flow

Abbreviations and Acronyms, Continued

SSF	subsurface flow
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
TVA	Tennessee Valley Authority
U.S.	United States
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
VSS	volatile suspended solids
yr	year

SECTION 1

Introduction

In general, the agricultural community has not been required to meet the strict surface water discharge regulations imposed on municipalities and industries. This is rapidly changing as water courses and water bodies affected by farming operations continue to receive high levels of nutrients and bacteria that originate from manure storage areas, manure storage tank overflows, feedlot runoff, milkhouse washwater discharges, and aquaculture pond discharges. Throughout the United States (U.S.) and Canada, agricultural wastewater streams are increasingly being viewed by regulators and the general public as sources of pollution that are contaminating aquatic habitat, drinking water, and recreational waters. Discharge permit requirements for livestock facilities have been promulgated by the U.S. Environmental Protection Agency (U.S. EPA, 1995).

Through an awareness of sustainable farming practices, the livestock industry has generally followed the practice of recycling to the soil the valuable nutrients and water contained in animal manures and in washwater and runoff. No surface discharges are allowed for most facilities. However, there are uncontrolled discharges of nutrients that enter surface water and groundwater. Best management practices can be implemented to reduce the wastewater volume and concentration to the lowest possible level that is economically and practically achievable. Covered manure storage areas, high pressure/low volume hoses and nozzles for washing stalls, routing adjacent uncontaminated stormwater flows around manure storage areas, and water recycling where practical will assist in reducing the discharge of contaminants. Once the best management practices are in place, any flow that might enter surface water or groundwater (for example, direct discharge to a water course, stormwater runoff carrying ponded wastewater or waste material spread on an open area) can be treated to reduce the potential for water contamination. As effluent limitations become more restrictive, innovative technologies may offer new and affordable methods of treatment prior to discharge.

Constructed treatment wetlands provide one approach to meet these growing challenges. Treatment wetlands reduce many typical pollutants in agricultural, industrial, and municipal effluents, such as 5-day biochemical oxygen demand (BOD_5), suspended solids, nutrients, and metals. Constructed wetlands rely on the naturally occurring energies of the sun and wind to aid plant growth and to provide carbon and oxygen for the anaerobic and aerobic processes carried out by microbial populations. Compared with many conventional technologies that rely on inputs of concentrated fossil fuels, treatment wetlands rely on the environment and its naturally occurring energies.

Agricultural researchers and innovative owners in the U.S. and Canada are investigating the use of constructed treatment wetlands to manage livestock effluent quality. Many state and federal agriculture departments are holding workshops and training sessions to provide their staff with an understanding of wetland treatment capabilities and design principles and are piloting wetland treatment alternatives. Since about 1990, at least 68 full-scale and pilot-scale constructed wetland treatment systems have been installed in the U.S. and Canada for the treatment of high strength livestock wastewater.

Gulf of Mexico Program (GMP)

The Gulf of Mexico Program (GMP) was established in 1988 as an inter-governmental, community-based program with funding from the U.S. Environmental Protection Agency (EPA) and matching funds from public and private partners to study factors affecting the ecological and economic viability of the Gulf of Mexico. The Nutrient Enrichment Committee of the GMP is interested in ways to reduce the potential for eutrophication of the near shore waters of the Gulf. Historical impairment and degradation of the rivers and estuaries in the Gulf of Mexico region are partially due to contaminant loadings from agricultural operations, both point source discharges from intensive livestock and aquaculture operations and non-point source agricultural land runoff. The GMP Constructed Wetlands Project was initiated in response to the need to define practical alternatives to reduce contaminant loadings to the Gulf of Mexico.

In 1995, the GMP sponsored efforts by the Alabama Soil and Water Conservation Committee (ASWCC) and the National Council of the Paper Industry for Air and Stream Improvement (NCASI) on the GMP Constructed Wetland Project. The purpose of the project is to document the effectiveness of constructed treatment wetlands for providing cost-effective on-farm wastewater management and for alleviating the high nutrient loading problem in the Gulf of Mexico.

During the project definition phase, the team determined that the quantity of useful project data for constructed wetlands treating livestock wastewaters from just the states in the Gulf of Mexico drainage area was limited. For that reason, the literature review and summary of design and operation data were expanded to include all of the U.S. and Canada. The project goals were to (1) compile information on wetlands constructed to treat livestock (cattle, dairy, swine, poultry, fish, and other animals raised in concentrated farming operations) wastewater, (2) present the findings in a widely distributed report and at a technical workshop, and (3) develop a public outreach and education brochure. Each of these tasks is described in more detail below.

Report

The GMP Constructed Wetland Project report presents the results of a comprehensive review of the constructed treatment wetland technology for reducing nutrient and other pollutant loadings from livestock wastewaters. The project team reviewed literature and collected information on the use of constructed wetlands for treating livestock wastewaters and developed a database of design and operational data from these systems. This report summarizes available information into a comprehensive assessment of the current status of the technology.

Workshop

Texas Agricultural and Mechanical (A&M) University sponsored a technical workshop from May 15 to 18, 1996, in Fort Worth, Texas, on the use of constructed treatment wetlands for treating livestock wastewaters. The workshop included a field trip to several constructed treatment wetlands in the Fort Worth area. The GMP Constructed Wetland Project team presented its findings at the workshop and prepared papers that were included in the conference proceedings (Borer et al., 1996; Knight et al., 1996; Pries et al., 1996; Payne et al., 1996). Regional, state, and federal agricultural and environmental engineers and researchers also presented their findings and shared their experiences. Presenters included staff from the Natural Resources Conservation Service (NRCS), EPA, regional universities, private consultants, and owners of treatment wetlands. The proceedings from this workshop contain up-to-date information on the status of this natural treatment technology as it relates to the livestock industry. Conference participants and readers of the proceedings will be able to apply this technology with greater confidence to their wastewater streams and climatic conditions.

Brochure

A brochure for public outreach and education on the use of constructed wetlands for on-farm wastewater management is being developed to help agricultural managers consider the advantages and disadvantages of constructed treatment wetlands to meet their environmental protection goals. The brochure is intended to help educate the farming community and the public about the use of treatment wetlands as part of livestock wastewater management. It will provide methods for estimating the required wetland size and cost, highlight the advantages of using constructed wetlands for on-farm waste management, and provide information from existing systems. The research synthesis and design guidance report will be referenced for additional information.

Scope of this Report

This report provides the findings of the information gathering and design performance review aspects of the project. An overview (Section 2) provides a background on wetlands and their water quality improvement potential, discusses several types of engineered wastewater treatment wetlands, gives a historical perspective on treatment wetland systems (some have been in use since the 1910s), and discusses the North American Treatment Wetland Database (NADB) that was used as the template for data collection and analysis.

A literature review (Section 3) was conducted to collect the available monitoring and design data on the livestock wastewater treatment wetlands. This review included general literature; symposia proceedings; and published and unpublished papers documenting the use of treatment wetlands for dairy, cattle feedlot, swine, poultry, and aquaculture wastewaters. The literature review also yielded the names and affiliations of the authors and co-authors who were contacted to provide up-to-date information on their projects. A list of requested information, a questionnaire, and brief description of the GMP Constructed Wetland Project were sent to each potential participant. The replies from these sources provided the data that were summarized in the Livestock Wastewater Treatment Wetland Database (LWDB) described in Section 4 of this report. The database includes information on treatment wetland sites, systems, cells, monitoring and operational data, key contacts for each site, and published literature.

Analysis of the LWDB provided the basis for the design and operation guidance that was prepared for livestock wastewater treatment wetlands (Section 5). For example, wastewaters were characterized to determine hydraulic and contaminant loading rates for different wastewater streams and climatic conditions. The experiences of sites with and without pretreatment were evaluated. As part of the operation guidance, this report discusses establishing realistic water quality goals and taking into account treatment efficiencies under varying climatic and loading conditions. The report also provides information on site selection, data collection, land area requirement calculations, design considerations for ranges of climatic conditions, types of wetland vegetation, plant establishment, and operation and maintenance.

A bibliography (Section 6) provides the reader with the background literature for this report. The complete LWDB is included in electronic format and contains the data collected at each of the research sites in North America. Summaries of data in the North American and Livestock Wastewater Treatment Wetland Databases are provided in Appendices to this report.

Two companion documents and several technical papers have also been prepared through the GMP Constructed Wetland Project. These additional documents include:

- a revised treatment wetland design guidance manual for use by the NRCS;
- a pamphlet for use by ranchers and farmers who are interested in learning more about constructed wetlands for treating their livestock wastewaters;
- four technical papers based on these reports, and presented at the Second National Workshop on Constructed Wetlands for Animal Waste Management at Fort Worth, Texas, May 15 to 18, 1996.

SECTION 2

Treatment Wetland Overview

This section provides background on the development of the treatment wetland technology. The following text describes the natural ability of wetlands to clean water, introduces the types of treatment wetland systems, reviews the historical use of wetlands for water treatment, and discusses the NADB, which is a database on treatment wetlands in the U.S. and Canada.

Benefits of Using Wetlands

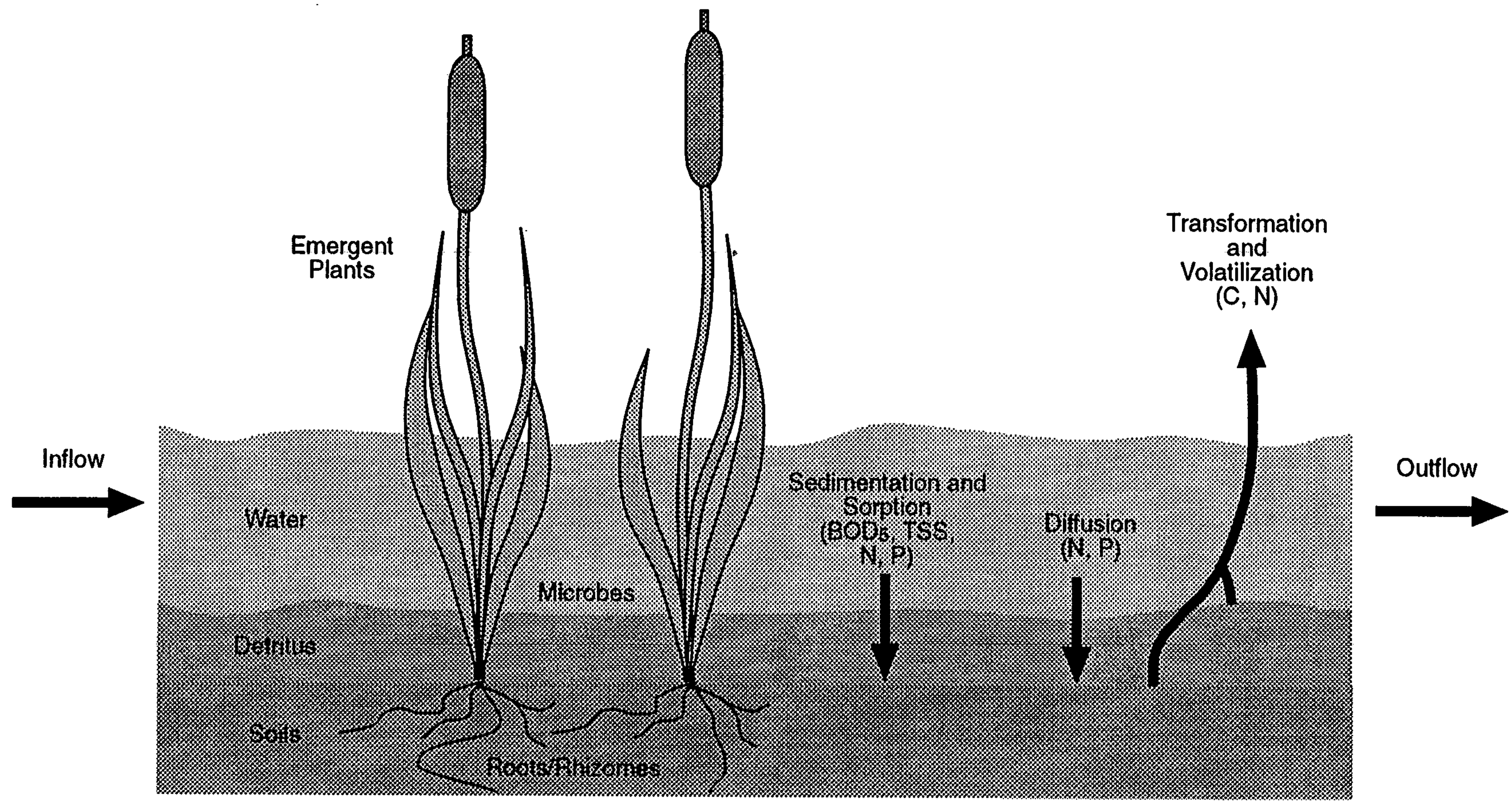
Wetlands are unique ecosystems. Natural wetlands are typically located in depressions in the landscape, along the banks of flooded areas (lakes, rivers, and streams), or in areas that have soils with low permeability. Natural wetlands are distinguished by the presence of communities of rooted plant species adapted to life in saturated soils.

Constructed wetlands can be built as shallow basins in almost any landscape as long as enough water is supplied to allow wetland vegetation to survive. Wetland flora and fauna thrive in conditions that are saturated with water during part or all of the year. Wetland plants are adapted to survive despite soil oxygen shortage when the plant roots and a portion of the stems are submerged in water.

Because of their access to abundant water, wetlands have a higher rate of biological activity than most ecosystems, and they transform many of the common pollutants in conventional wastewater into harmless by-products or essential nutrients that can be used for additional biological productivity (Mitsch and Gosselink, 1993; Kadlec and Knight, 1996). Wetlands rely on their land area and the associated natural energies and services from the sun, wind, soil, plants, microbes, and animals to reduce the contaminant concentration of the waters that pass through them (Figure 2-1). Many harmful and undesirable contaminants are removed and do not move farther downstream, reducing or eliminating the impact on sensitive aquatic life that might be adversely affected. This capability to transform and/or hold contaminants makes wetlands an attractive alternative to conventional treatment systems that consume fossil fuels and chemicals, produce troublesome sludges, and rely on labor intensive processes to treat wastewater flows.

Constructed wetlands are being considered more frequently for addressing water quality issues due to increased awareness by regulators and the general public of the benefits that wetlands can provide to society and nature. These benefits include water pollution control; restoration of a portion of the historical wetlands that have been lost to agriculture and development; wildlife habitat for local wetland species of birds, animals, reptiles and amphibians; and opportunities for school groups to study wildlife that depend on wetland ecosystems for survival.

FIGURE 2-1
Wetland Processes to Improve Water Quality



Types of Treatment Wetlands

Treatment wetlands are used to manage municipal, industrial, and agricultural wastewaters and stormwater. Municipal wastewaters include domestic and commercial wastewaters pretreated in lagoons, septic tanks, or conventional primary and secondary processes (screening, primary settling, trickling filters, and activated sludge). Industrial wastewaters discharged to wetlands for advanced treatment include food processing wastes, textile wastes, chemical facility and refinery wastes, leachates, cooling tower blowdown waters, and pulp and paper effluents. Livestock production wastewaters discharged to treatment wetlands include stormwater runoff from feedlots; wastewater from swine, dairy, and poultry facilities; and aquaculture discharges. In addition, wetlands receive point and nonpoint runoff from cities, malls, residential developments, agricultural lands, and watersheds.

There are four basic types of treatment wetlands: natural wetlands and constructed wetlands, surface flow (SF), subsurface flow (SSF), and floating aquatic plant (FAP) systems (Figure 2-2). Each type of wetland is briefly described below.

Natural Wetlands

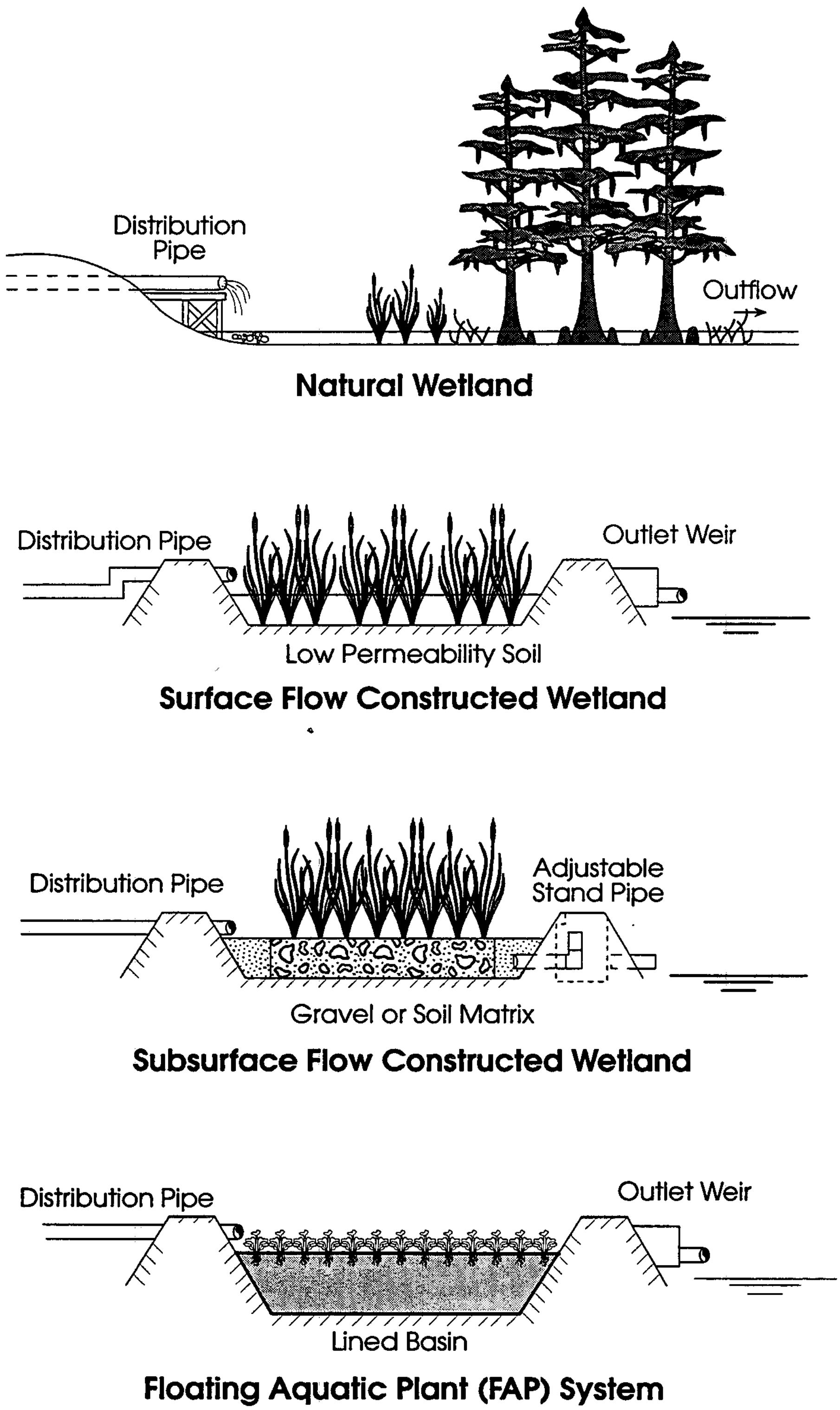
Natural wetlands have been used for the treatment and disposal of secondary wastewater effluent for many years. Many discharges to natural wetlands exist nationwide. While most of these systems were not designed for wastewater and stormwater treatment, studies of some natural wetlands led to an understanding of the natural ability of wetland ecosystems to assimilate pollutants and to the design of new natural water treatment systems.

The proper use of a natural wetland system for the treatment of secondary wastewater or stormwater involves a number of considerations. Research indicates that matching hydraulic loads to the hydroperiod requirements and tolerances of the dominant wetland vegetation species reduces the potential for vegetation changes. However, a significant increase in nutrient loading may result in a reduction in plant diversity. Optimal treatment occurs when the pretreated water flow is well-distributed throughout the wetland and travels through as sheet flow. Ideally, alternative discharge areas or "treatment cells" are used to reduce the hydraulic and nutrient loadings that might otherwise affect the vegetation community in the treatment cells.

Monitoring the performance of natural wetlands for water quality enhancement is ongoing. The data collected to date demonstrate that through careful design some natural wetlands can consistently and cost-effectively provide advanced treatment of wastewater and stormwater constituents without unacceptable environmental changes. Well known natural treatment wetlands in the U.S. include Houghton Lake, Michigan, and the Carolina Bays near Myrtle Beach, South Carolina. These systems were "engineered" from the standpoint of pretreatment and sizing to control mass loading; selection of the most adapted natural wetland plant communities for use; and design of elaborate inlet distribution piping.

At high organic and nutrient loadings, some natural wetlands may be significantly degraded. Plant species are likely to shift to herbaceous marsh species such as cattails (*Typha* spp.). Livestock wastewaters would typically require extensive pretreatment before discharge to natural wetlands.

FIGURE 2-2
Types of Engineered Treatment Wetlands



Surface Flow (SF) Constructed Wetlands

SF constructed wetlands are shallow impoundments planted with emergent, rooted vegetation. These wetlands can be planted manually or naturally colonized by volunteer plant communities. Some SF wetlands are dominated by cattails (*Typha* sp.) or bulrushes (*Scirpus* sp.), while others contain more diverse plant communities.

Unlike a natural wetland system in which hydrology is largely fixed by the tolerance limits of the existing plant community, a constructed SF wetland can be designed to regulate water depth and residence time, two of the important factors in treatment wetland design. Also, the design of constructed wetland systems can feature parallel cells or cells in series. Such a system can be operated to rotate discharge points or to use slightly different treatment capabilities of the various available plant species groups. Constructed wetlands have relatively low construction, operation, and maintenance costs compared with conventional treatment technologies.

The emergent plants of SF wetlands are not harvested to remove nutrients. Rather, the natural assimilative capacity of the microbial flora (bacteria and fungi) that attach to the living plants and to the dead submerged plant material (litter) provides efficient and reliable removal of biodegradable organics and nitrogen (ammonia and nitrate). Metals and phosphorus can be sequestered in plant materials and wetland sediments. Because much of the treatment that occurs in wetlands is from microbial action rather than plant uptake, these systems continue to function during winter, but at a slower rate. In colder climates, snow and ice cover provide an effective temperature buffer that allows continued activity. Also, long-term wetland removal rates do not decline with wetland age.

Because of their adaptability to receiving a wide range of wastewater loadings, their lower construction cost, and their relative ease of management compared to other constructed wetlands, SF wetlands are typically used for livestock wastewater treatment and are the focus of this report.

Subsurface Flow (SSF) Constructed Wetlands

SSF wetlands are gravel- or soil-based systems in which wastewater passes through a porous substrate rather than above the substrate. Emergent wetland plants are grown on the surface of the bed with the roots penetrating into the saturated, porous media. The large surface area resulting from the media and the plant roots provides ample sites for microbial activity. Many of the same emergent plant species are used with SF and SSF systems. When treating an equivalent volume of flow, gravel-based SSF wetlands may use less acreage than SF constructed wetlands.

SSF wetland systems have an advantage in cooler climates because so much of the treatment occurs below the ground surface. Thus, these systems are less affected by cold air temperatures. Also, gravel-based SSF systems have less potential for odor and mosquito problems than SF wetlands. When properly designed, gravel-based wetland systems have high efficiency rates for removing biodegradable organic matter and nitrate-nitrogen from wastewaters.

Major disadvantages of SSF constructed wetland systems include their tendency for plugging and overall system costs, which can be five times more than a SF system for a certain pollutant mass removal. Because of high solid and organic loadings in most livestock wastewaters and the resulting potential for plugging and high system costs, SSF wetlands are not being seriously considered for this application and are not covered further in this report.

Floating Aquatic Plant Systems

Several different FAP systems have been used for wastewater treatment. These systems most commonly use floating aquatic species such as duckweed (*Lemna* sp. or *Spirodela* sp.) or water hyacinths (*Eichornnia crassipes*). This vegetation takes up nitrogen, phosphorus, and metals, which can be physically removed by plant harvesting. In addition, microbes attached to plant roots assimilate biochemical oxygen-demanding substances and suspended solids, nitrify ammonium-nitrogen (NH_4-N) to nitrate-nitrogen (NO_3-N), and denitrify NO_3-N to nitrogen gas without harvesting. FAP systems reduce phytoplanktonic algal populations by shading them from available sunlight.

Intensively managed FAP systems can meet low effluent limits for nutrients without using chemical additions. Since a limited number of FAP systems are currently operating, not much information is available on the design, cost, and performance of these systems, making it difficult to compare FAP systems to other treatment wetland technologies.

Compared to SF wetlands, FAP systems have lower reaction rates, higher construction and operation costs, more sensitivity to cold temperatures, and more susceptibility to plant pests and pathogens. Polyculture systems that use a combination of floating aquatic plant species offer an alternative with less intensive pest management requirements. Also, FAP systems that use greenhouse enclosures in colder climates can be considered for small applications.

FAP systems are little different from lagoons for many of their treatment properties and are not covered further in this report.

Historical Perspective

Natural wetlands have been used as convenient wastewater discharge sites for as long as sewage has been collected. Examples of old natural wetland sites that began receiving wastewater flows in the early 1900s are found in Massachusetts (1912), Ontario (1919), Wisconsin (1923), and Florida (1939). Increasingly over the past 40 years, natural and constructed wetlands have been studied to determine the potential for water quality improvement.

Early research efforts include Seidel and Kickuth's work with SSF laboratory tests in Germany. Beginning in 1952, they investigated the use of bulrush plants for dairy wastewater treatment and removal of phenols. Soil-based SSF wetlands are still the most common application of this technology outside North America. In the United States, SSF wetlands using gravel substrates have been promoted in several southern states. SF constructed and natural wetlands for advanced treatment of municipal wastewaters were built throughout North America during the 1970s, 1980s, and 1990s.

Examples of early treatment wetland research efforts in North America include the following:

- Municipal effluent treatment and recycling using constructed estuarine ponds and natural salt marshes in North Carolina between 1967 and 1972
- Natural salt marshes for removal of heavy metals and organics in Massachusetts between 1971 and 1975
- Natural freshwater wetlands for polishing of municipal secondary effluent in Michigan in the mid-1970s
- Effects of fish processing waste in a freshwater marsh in Louisiana in the early 1970s
- Cypress wetlands recycling municipal wastewaters in Florida between 1973 and 1977
- A natural marsh wetland for assimilation of agricultural drainage and municipal wastewater nutrients in Iowa in the late 1970s
- Natural marsh wetlands receiving agricultural drainage waters for nutrient removal in southeast Florida from 1976 to 1982
- Numerous research efforts in the early 1980s for treatment of municipal wastewater in California, Saskatchewan, and Ontario.

In the 14 states in Regions IV and V, the EPA found 324 swamp discharges of municipal or industrial effluents in the mid-1980s. Monitoring at some of these sites found that water quality improvement was typical of most tested wetlands. Investigations continue to be carried out in many regions of the U.S. and Canada for treatment of a wide range of contaminants in numerous wetland system types.

Early full-scale applications of natural and constructed SF treatment wetlands for municipal wastewater discharges include systems in Michigan (1972, 1976, and 1978), California (1973), Florida (1977), Wisconsin (1979), Arizona (1980), California (1987), and South Carolina (1987). Industrial applications are located in North Dakota (oil refinery runoff and pretreated wastewater, 1975) and Mississippi (pulp and paper mill wastewater, 1991). Urban stormwater treatment wetlands are found in California (1984). Agricultural applications include Iowa (1930s), Florida (1993), and the systems covered in this report. Numerous wetlands have been constructed to treat acid mine leachates. In total, more than 400 natural and constructed treatment wetlands in North America receive municipal, industrial, agricultural, or stormwater discharges.

The findings from many of these treatment wetland systems have been presented at conferences that focused on natural treatment systems. Since 1976 more than 20 major conferences and many lesser ones worldwide addressed treatment wetlands (Table 2-1). This is an indication of the high level of interest in this technology.

During the past decade, environmental awareness has broadened the focus of water pollution control to include non-point sources. As a result, the agricultural community in North America has actively pursued source controls to prevent the movement of high strength wastewater to surface and groundwater. Contaminated flows not controlled at the source require some treatment. Constructed treatment wetlands for treating high strength livestock wastewater have been shown to greatly reduce pollutant loads and, in many cases, offer a lower cost treatment than conventional lagoon pumpout systems (Hughes et al., 1996). Only during the past 5 to 10 years has this technology been investigated seriously for treatment

TABLE 2-1
Listing of Major Treatment Wetland Conferences

Date	Location	Description
May 1976	Ann Arbor, MI	Freshwater Wetland and Sewage Effluent Disposal (Tilton et al., 1976)
February 1978	Tallahassee, FL	Environmental Quality Through Wetlands Utilization (Drew, 1978)
November 1978	Lake Buena Vista, FL	Wetland Functions and Values (Greeson et al., 1978)
July 1979	Higgins Lake, MI	Freshwater Wetland and Sanitary Wastewater Disposal (Sutherland and Kadlec, 1979)
September 1979	Davis, CA	Aquaculture Systems for Wastewater Treatment (Bastian and Reed, 1979)
June 1981	St. Paul, MN	Wetland Values and Management (Richardson, 1981)
June 1982	Amherst, MA	Ecological Considerations in Wetlands Treatment of Municipal Wastewaters (Godfrey et al., 1985)
July 1986	Orlando, FL	Aquatic Plants for Water Treatment and Resource Recovery (Reddy and Smith, 1987)
June 1988	Chattanooga, TN	Constructed Wetlands for Wastewater Treatment (Hammer, 1989)
August 1988	Arcata, CA	Wetlands for Wastewater Treatment and Resource Enhancement (Allen and Gearheart, 1988)
September 1989	Tampa, FL	Wetlands: Concerns and Successes (Fisk, 1989)
September 1990	Cambridge, UK	Constructed Wetlands in Water Pollution Control (Cooper and Findlater, 1990)
September 1990	Show Low, AZ	Municipal Wetlands (City of Show Low Public Works Department)
June 1991	Arlington, VA	Created and Natural Wetlands in Controlling Non-Point Source Pollution (Olson, 1992)
October 1991	Pensacola, FL	Constructed Wetlands for Water Quality Improvement (Moshiri, 1993)
July 1992	Pinetop-Lakeside, AZ	Effluent Reuse and Constructed Wetlands (Arizona Hydrological Society Summer Seminar)
September 1992	Columbus, OH	INTECOL Wetlands Conference (Mitsch, 1994)
December 1992	Sydney, Australia	Wetland Systems in Water Pollution Control (Pilgram, 1992)
November 1994	Guangzhou, China	4th International Conference on Wetland Systems for Water Pollution Control (IAWQ, 1994)
April 1994	Lafayette, IN	Constructed Wetlands for Animal Waste Management (DuBowy and Reaves, 1994)
July 1995	Fayetteville, AR	Animal Waste and the Land-Water Interface (Steele, 1995)
September 1995	Tampa, FL	Versatility of Wetlands in the Agricultural Landscape (Campbell, 1995)
May 1996	Fort Worth, TX	Constructed Wetlands for Animal Waste Management (DuBowy, 1996)

of livestock wastewater discharges, even though treatment wetlands have been widely used to treat municipal and industrial wastewater for many decades.

In the U.S., the NRCS and many universities, and in Canada the provincial Conservation Authorities and Ministries of Agriculture have been the frontrunners of treatment wetland technology for the agriculture industry. For example, in Kentucky, more than 20 full-scale treatment wetland systems have been installed since about 1992 with assistance from the NRCS. A long-term monitoring program is underway to track the performance of these systems. Several universities including Auburn University, Purdue University, Oregon State University, Texas A&M University, North Carolina State University, and the University of Connecticut have carried out extensive testing on treatment wetlands. Some of these sites have as many as 16 separate systems that were operated at several water depths, varying hydraulic and nutrient loading rates, and are vegetated with a variety of plant species.

Across southern Ontario, Canada, the Conservation Authorities have installed nine treatment wetland systems since 1993 and anticipate preparing a report in 1997 that will provide guidance for the future direction of this technology in that province. In Nova Scotia, Canada, the Department of Agriculture and Marketing sponsored a 3-day workshop in fall 1994 during which the Department of Agriculture and Marketing engineers attended a training course on the theory and design of treatment wetland systems. Following the seminar, three treatment wetland systems were designed over the next 2 days of the workshop and constructed the following spring. Monitoring of these systems will provide design information for future installations.

Considerable published data exist on the design, construction, and early years of operation of many of the agricultural treatment wetlands. As these systems mature and steady-state data become available, findings should be analyzed and published to provide further design and operational guidance. The development of the treatment wetland technology for the agricultural industry reflects the collective efforts of scientists and engineers who have designed and studied pilot- and full-scale wetland treatment systems. Historical studies, full-scale projects, published literature, and conferences have been key to the technology's development by providing the scientific basis for the treatment wetland technology.

North America Treatment Wetland Database (NADB)

The use of wetlands for treatment of wastewaters is an emerging technology in North America and worldwide. These wetland systems have a wide variety of engineering designs, wetted areas, flow rates, inflow water qualities, plant communities, hydrologic regimes, effluent limitations, and monitoring requirements. Until recently, an engineer or regulator considering the use of wetland technology for a specific treatment application had to search through a myriad of information to determine wetland surface area and pretreatment levels necessary to achieve effluent criteria. Several handbooks (Kadlec and Knight, 1996; Davis, 1995; Reed et al., 1995; USDA SCS, 1992; Cooper and Findlater, 1990; WPCF, 1990; and EPA, 1988) provide useful syntheses of existing knowledge concerning the design of new wetlands; however, the existing quantity of data from operational wetland treatment systems is growing so fast that handbooks will be outdated unless new empirical results are organized in the form of electronic databases. Efforts are in progress to summarize and assess the SF treatment wetland technology (CH2M HILL, in preparation) and to update the 1988 EPA constructed treatment wetland design manual.

Information on the effects of wetlands on water quality and the effects of these wastewaters on wetland biota has been collected from many operational treatment wetland systems. This information was widely scattered in scientific journal articles, monitoring reports to agencies, consultant reports, and private databases. A framework to record and update this expanding knowledge was necessary to make information available to engineers and scientists nationwide to eliminate duplication of effort and to continue to refine the empirical design equations now in use.

A wetland treatment system database project was initiated in 1991 and ended in 1993. The NADB has cataloged existing information from 206 natural and constructed wetland treatment systems and operational records for major water quality parameters, summarizing the data into a consistent, unified database. Appendix A provides a summary of the wetlands in the NADB. The NADB has been widely distributed to the engineering, scientific, and regulatory communities, and the preliminary data were reported in summary form (Knight et al., 1993a and b). The electronic files are available from the EPA; the contact is Mr. Don Brown in Cincinnati, Ohio, at (513) 569-7630 (NADB, 1993).

The NADB provides the most comprehensive wetland treatment system data summary currently available. Proposed future expansion of the database contents and additional analysis of the data collected in this format will add to the widespread usefulness of this product for the engineering, scientific, and regulatory communities.

Types of information included in the NADB include locations, climatic factors, populations served, capital and operating costs, design considerations, operating data for water quality, biota, permit conditions, existing reports and literature, and key contact people for each system. These data are cataloged into seven linked data files using dBASE IV software.

At each wetland treatment site, a single system with an inflow and outflow or multiple, parallel systems with discrete outflow points may be present. Most of the existing wetland treatment systems in North America meeting several general requirements are included in this Phase II effort. These systems include wetlands receiving municipal wastewater, industrial wastewater, and stormwater, generally more than 100,000 gallons per day (378 cubic meters per day [m^3/d]) except for some pilot-scale systems.

The primary purpose of the wetland treatment database effort was to develop a summary of existing information that could be expanded to accommodate additional information in the future. Operational data for inflow and outflow rates and constituent concentrations were averaged on a seasonal basis. A summary of the average SF and SSF treatment wetland operational performance data is provided in Table 2-2. Design and operational data that affect assimilation rates were also summarized for each system to allow regression analysis and the refinement of existing empirical design equations. Memo files were included to record data quality, anecdotal system design information, and interpretation of performance trends.

Another goal of the wetland treatment database was to provide an academic research tool for scientific investigations of wetland ecology. The database provides a detailed data repository for the physical, chemical, and biological processes of treatment wetlands. This knowledge may help direct new research efforts. The database has proven useful for

TABLE 2-2
Summary of North American Treatment Wetland Operational Performance for Systems Receiving Municipal and Industrial Wastewaters and Stormwaters*

Parameter	Type[a]	Average Concentration (mg/L)			Average Mass (kg/ha/d)[b]		
		In	Out	Eff (%)	Loading	Removal	Eff (%)
BOD_5	SF	30.3	8.0	74	7.2	5.1	71
	SSF	27.5	8.6	69	29.2	18.4	63
	All	29.8	8.1	73	10.9	7.5	68
TSS	SF	45.6	13.5	70	10.4	7.0	68
	SSF	48.2	10.3	79	48.1	35.3	74
	All	46.0	13.0	72	16.8	11.9	71
NH_4-N	SF	4.88	2.23	54	0.93	0.35	38
	SSF	5.98	4.51	25	7.02	0.62	9
	All	4.97	2.41	52	1.46	0.38	26
NO_2 + NO_3-N	SF	5.56	2.15	61	0.80	0.40	51
	SSF	4.40	1.35	69	3.10	1.89	61
	All	5.49	2.10	62	0.99	0.54	55
ORG-N	SF	3.45	1.85	46	0.90	0.51	56
	SSF	10.11	4.03	60	7.28	4.05	56
	All	4.01	2.03	49	1.71	0.95	56
TKN	SF	7.60	4.31	43	2.20	1.03	47
	SSF	14.21	7.16	50	9.30	3.25	35
	All	8.11	4.53	44	2.99	1.29	43
TN	SF	9.03	4.27	53	1.94	1.06	55
	SSF	18.92	8.41	56	13.19	5.85	44
	All	9.67	4.53	53	2.98	1.52	51
O-P	SF	1.75	1.11	37	0.29	0.12	41
	SSF	ND	ND	ND	ND	ND	ND
	All	1.75	1.11	37	0.29	0.12	41
TP	SF	3.78	1.62	57	0.50	0.17	34
	SSF	4.41	2.97	32	5.14	1.14	22
	All	3.80	1.68	56	0.73	0.22	31

*Kadlec and Knight, 1996.

[a]SF = Surface Flow, SSF = Subsurface Flow.
[b]kg/ha/d x 0.892 = lb/ac/d.
ND = No data.
Eff (%) = Efficiency of concentration reduction or mass removal.
TSS = Total suspended solids.
NO_2 + NO_3-N = Nitrite plus nitrate nitrogen.
ORG-N = Organic nitrogen.
TKN = Total Kjeldahl nitrogen.
TN = Total nitrogen.
O-P = Ortho phosphorus.
TP = Total phosphorus.
mg/L = Milligrams per liter.
kg/ha/d = Kilograms per hectare per day.

calibration and verification of a variety of pollutant reduction models (Kadlec and Knight, 1996).

A third goal of the wetland treatment database was to help establish some standardization of monitoring and reporting in wetland treatment systems nationwide. Currently, permits require widely variable reporting requirements for wetlands receiving wastewater, and researchers frequently omit key water quality parameters from monitoring or pilot programs. Examination of the operational data in the database provides permit writers and researchers with an understanding of the normal variability of water quality in wetland treatment system discharges and an appreciation of the difficulty of interpreting data from wetlands with insufficient information. Apparent data gaps can help to focus attention on new issues and direct monitoring efforts to ensure that key information is collected.

The database format used for the GMP livestock wastewater treatment wetlands project is patterned after that of the NADB with slight modifications to reflect the applicability of the database to the agriculture industry. Additional fields that were developed to input data included types of livestock, numbers of animals, agricultural category (dairy, cattle, swine, poultry, and aquaculture), and additional monitoring and mass balance parameters including conductivity, total dissolved solids, volatile suspended solids, chemical oxygen demand, temperature, and pH (see Section 4 for details).

SECTION 3

Livestock Wastewater Treatment Wetland Literature Review

A literature review was carried out to document the existing use of constructed wetlands designed to treat high strength livestock wastewaters. The documents that were reviewed provided design, monitoring, and performance data; operations and maintenance requirements; and opinions and findings that will lead to improved performance of these and other wetland systems in the future. The authors of the documents were also contacted by the project team and asked to provide summarized information for the database.

Summary of Literature Review

Several general observations were made during the literature review. The use of constructed wetlands is a recent alternative for treating concentrated livestock wastewaters. The papers that were reviewed were published in 1990 or later, and almost 80 percent of them were written in 1994 and 1995. The earliest use of a constructed wetland for animal wastewater that was cited in the literature was in 1930 on a farm in Iowa (Brenton, 1994). The remaining wetland systems that were reviewed began operating after 1989, with 90 percent of them starting to treat wastewater since 1992. Most systems reviewed did not report discharging the wetland effluent offsite, although visits to several sites by the authors of this report indicate that discharges are occurring. Final effluent disposal is intended to be through evaporation, discharge of the effluent into sod infiltration areas onsite, or disposal by spray irrigation onto nearby fields. A recent survey of several water quality regulatory agencies in the south indicates that no agency allows discharges of agricultural wastes to surface waters. (Payne et al., 1996)

Many of the operations have source controls in the form of a covered manure storage area to reduce the organic loading on the treatment wetland and divert uncontaminated stormwater runoff around the wetland (Hayman and Maaskant, 1994; Neely, 1995).

The control of hydraulic and nutrient loading rates to the treatment wetland systems varied from site to site. Pilot systems such as Oregon State University's systems (Skarda et al., 1994) were treating a small portion of the total waste flow and were able to maintain uninterrupted flow through the site's wetland systems throughout the summer by continuing to pump wastewater from the wastewater lagoon. Full-scale systems that were in a climate with high evapotranspiration rates, low rainfall rates, and/or low wastewater flow rates experienced partially or completely dry periods during the summer months, stressing the wetland vegetation (Gerrits, 1994; Holmes et al., 1995; Natzke, 1995; Adams, 1994).

In a majority of cases where wastewater was not pretreated before discharge to the wetland, or where the pretreatment system was not routinely cleaned and solids overflowed to the wetland, up to the first third of the first wetland cell had considerable buildup of solids (Neely, 1995; Reaves, 1995). The solids accumulation can lead to system failure by reducing the effectiveness of the treatment wetland by smothering the roots and killing the plants; covering the detritus that provides substrate for microbial growth; by reducing the hydraulic retention time. Emergent wetland plants will not survive under extremely anaerobic soil conditions which occur in some highly loaded treatment wetlands.

In view of the regulatory restrictions governing discharges of livestock wastewaters to surface waters, it is evident that the effluent from most constructed wetlands must be collected and recycled as flush water, and any excess must be irrigated to the land. For systems used to treat wastewaters from confined animal feeding operations with large volumes of liquid waste, a major advantage of wetlands will be to greatly reduce the amount of load needed at the irrigation site. Another advantage will be to reduce odors at these sites (Payne et al., 1996).

Treatment wetland systems must be shown to be reliable so that livestock producers are more receptive to using them. Continued research is considered by authors to be necessary to determine treatment efficiencies, optimum loading rates, life expectancy, seasonal treatment variations, and design criteria (Skarda et al., 1994).

A number of symposia, conferences, and workshops have provided researchers a venue to share information concerning the use of wetlands for treating concentrated livestock wastewaters (see Table 2-1). Proceedings from these conferences were the source of many of the papers reviewed below.

Review of Treatment Systems

The LWDB contains information for 38 dairy and eight cattle system sites, 19 swine system sites, two aquaculture system sites, and one poultry system site. The following review of published treatment wetland performance includes sites for which operational and monitoring data were available. Site numbers following system names refer to site designations in the LWDB.

Dairy Farm and Cattle Feedlot Applications

The GMP constructed wetland literature review located information for a total of 46 dairy and cattle operations that are using constructed wetlands to treat high strength runoff. Of these, 37 systems had operational and monitoring data. Waste management systems were designed and constructed for herd sizes ranging from 25 (Nova Scotia) to 330 (Maine) dairy cows and up to 7,000 head of cattle in a feedlot operation. The average reported herd size was 85 head. All of the dairy wastewater treatment wetlands in the database are surface flow systems. Most systems are rectangular in shape. The exceptions are the Ontario systems that are sinuous with high length-to-width ratios (Hayman and Maaskant, 1994).

DePere - David Gerrits Farm (Site Number 523)

Holmes et al. (1992) described the design and construction of a wetland system in a cold climate (Greenbay, Wisconsin) for the treatment of milking center wastewater. The site had four wetland systems, each divided into three cells. Two of the wetland systems were to receive wastewater that had passed through a settling/floatation tank while the other two systems were to receive untreated wastewater. The effect of pretreatment on treatment efficiencies was evaluated and reported in subsequent papers. Startup problems were encountered when filling the cells. The water level in all cells dropped below the tops of the coffer dams indicating leakage problems with the systems. The leaks were sealed, and the project continued.

Operating descriptions and monitoring data for the Greenbay, Wisconsin, systems were reported in several papers (Holmes, 1994; Holmes et al., 1994; Holmes et al., 1995). During the first winter, difficulties were experienced with delivering the wastewater to the wetland cells. A construction error, excavating and plumbing during the winter, and inadequate winterization caused the system to freeze downstream of the flow distributor during winter 1993. Construction and operation deficiencies were remedied in spring 1993. Because of a very wet spring in 1993, the wetland plants sprouted very well. During much of the summer and fall, the system did not discharge water, and the downstream cells frequently had no standing water. This condition stressed the wetland vegetation. During fall 1993, a weather station was installed with data logging capabilities, wetland plant populations were counted, and wetland cells were repaired and prepared before winter. Operation went well during winter 1994, and wastewater flows were delivered without difficulty.

Data presented in the papers show a greater concentration reduction efficiency for chemical oxygen demand (COD), BOD_5, total phosphorus (TP), and total Kjeldahl nitrogen (TKN) by the treatment wetland that received non-pretreated wastewater. Although the wetland system that received the pretreated wastewater showed a lower reduction efficiency, the COD and BOD_5 inflow concentrations were more than 40 percent lower, and the TP and TKN concentrations were more than 20 percent lower. Overall, the final effluent water quality in the system receiving pretreated wastewater was better than final effluent from the system receiving non-pretreated wastewater. The authors concluded that the treatment wetlands improved water quality. The reduction in concentration from inlet to third cell discharge for the parameters monitored in 1993 are in Table 3-1.

TABLE 3-1
Concentration Reductions, DePere-David Gerrits Farm, 1993

	Reduction in Concentration without Pretreatment			Reduction in Concentration with Pretreatment		
Parameter	Inflow (mg/L)	3rd Cell Outflow (mg/L)	Percent Reduction	Inflow (mg/L)	3rd Cell Outflow (mg/L)	Percent Reduction
COD	488	114	77	275	86	69
BOD_5	168	17	90	97	15	84
TP	16.9	2.8	83	13.5	2.4	82
TKN	19.8	5.2	74	14.7	4.4	70

It was noted that wetland plants showed no signs of stress in response to the strength of the milkhouse washwater.

Two reports (Gerrits, 1994; Natzke, 1995) presented findings of the adaptability of wetland plants at the Greenbay, Wisconsin, constructed wetland location. A plant count was made of the three dominant species (softstem bulrush [*Scirpus validus*], river bulrush [*Scirpus fluviatilis*], and giant burreed [*Sparganium eurycarpum*]), and the survival rate of each was determined from cell to cell and from one year to the next. In her paper, Gerrits reported that the vegetation in the first cell of each system was growing well. However, the plants in the following two cells showed a sharp decline in vegetation growth likely due to the lack of moisture. Natzke noted similar patterns the following year and observed considerable stress in the vegetation after 2 consecutive years of summer drought conditions.

Softstem bulrush was the dominant plant in all cells in 1995 with a dramatic (74 percent) reduction in the population in the second cells and a further reduction in population in the third cells. River bulrush was the next dominant species in 1995 and showed trends similar to the softstem bulrush, although the population changes were not as dramatic. No giant burreed plants were found in the first cell of any of the systems in 1995 in spite of the scant presence of these plants in previous years. Subsequent cells had small populations of this plant. Population statistics were presented for the years 1990 to 1995. Natzke reported that there was no indication that the wetland plants preferred either the pretreated or the untreated wastewater.

Oregon State University (Site Number 514)

Oregon State University received EPA funding to summarize the results of the design and construction of six wetland demonstration/research systems (see Figure 3-1) built south of the university dairy barns (Gamroth and Moore, 1993). The project was designed to determine the effects of hydraulic and nutrient loading rates, vegetation type (including cattail [*Typha latifolia*] and hardstem bulrush [*Scirpus acutus*]), and deep zone areas on removal rates. These systems were designed to receive a small percentage of the total wastewater flow generated by the livestock operation. Consequently, the hydraulic and nutrient loading rates were maintained at the design levels, and dilution of the wastewater ensured that maximum rates and concentrations would not be exceeded. Nutria (*Myocastor coypus*), a rodent native to South America, created problems for this wetland site in the early stages of operation by destroying most of the plants and burrowing into the berms. A fence that extended 5 centimeters (cm) into a shallow trench was erected around the site and was reported to be successful in excluding nutria.

Performance data from the Oregon State University wetland systems showed an increase in removal efficiencies from the first year of operation to the second year (Table 3-2). Table 3-3 presents average concentrations and percent reductions during warm and cold periods. Reductions were generally higher during warmer weather. Improvements in treatment efficiency were not noted for systems with deep center sections, nor for different mixes of plant populations (Skarda et al., 1994; Moore et al., 1995). This study demonstrated that wetland cells with a 7-day detention time remove between 45 and 70 percent of the major pollutants in dairy flush water and up to 95 percent of the fecal coliforms.

Crum Farm (Site Number 518)

Data from a 0.1-hectare (ha), two-cell treatment wetland that receives dairy barn waste and stormwater runoff in Frederick County, Maryland, showed overall improvement in water quality (Cronk et al., 1994). However, Cronk et al. reported high wetland influent wastewater concentrations. For example, the average inflow wastewater concentrations in the latter half of 1994 for TSS (4,900 mg/L), BOD_5 (6,450 mg/L), and TP (80 mg/L) likely

FIGURE 3-1
Plan View of Oregon State Treatment Wetland System

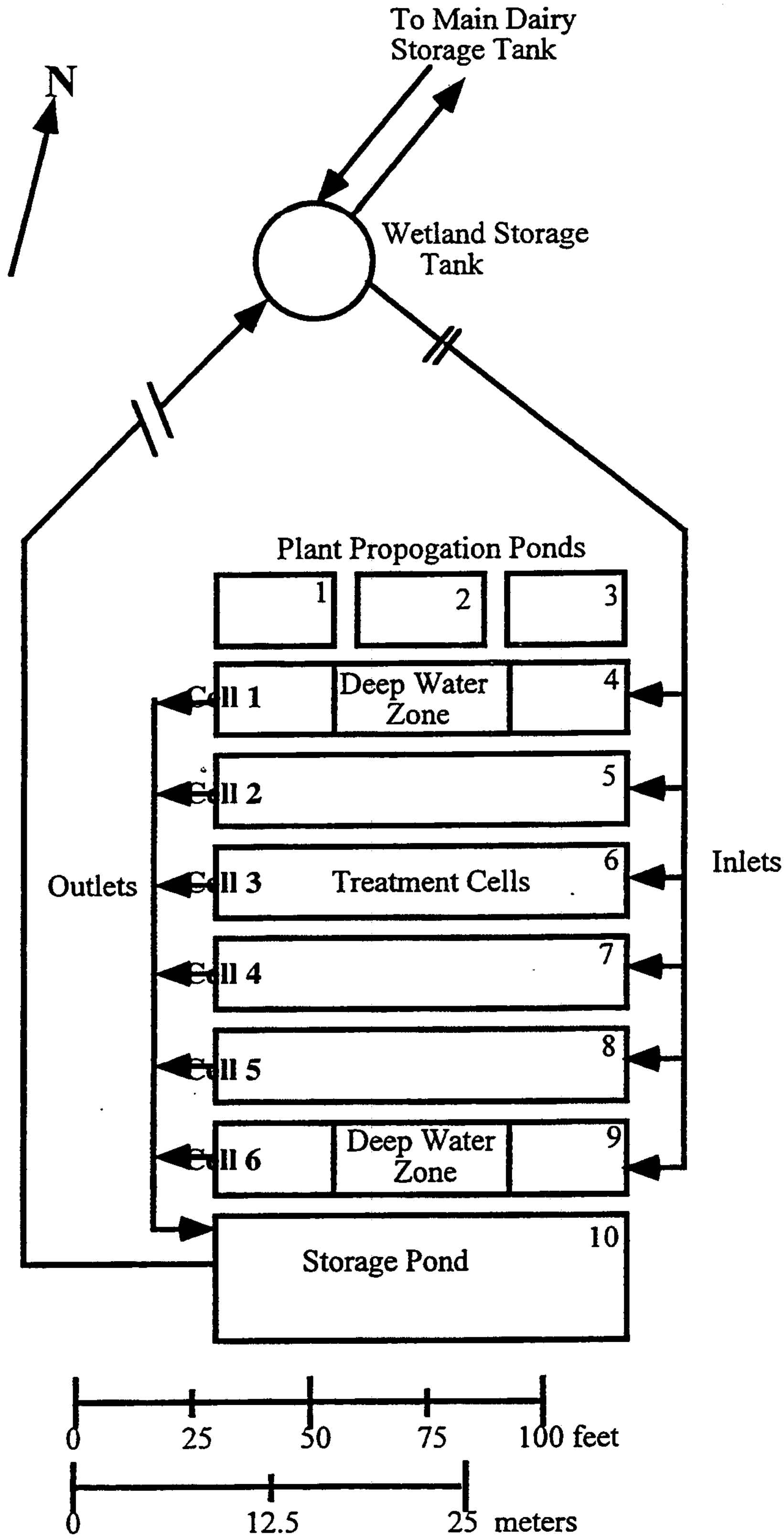


TABLE 3-2
Concentration Reductions, Oregon State University Treatment Wetland

Parameter	Percent Reduction	
	First Year	Second Year
Fecal coliforms (FC)	80 to 90	89 to 95
BOD_5	40 to 50	59 to 72
TKN	50 to 55	59 to 72
COD	40 to 50	53 to 65
TP	40 to 50	54 to 69
TSS	40 to 50	43 to 56

TABLE 3-3
Comparison of Average Concentrations and Percent Change during Warm and Cold Seasons for the Oregon State University Treatment Wetland Systems

Parameter (mg/L unless otherwise specified)	Average Concentration		Percent Reduction
	Inflow	Outflow	
BOD_5 (W)	981	290	70
BOD_5 (C)	471	208	56
COD (W)	2,812	1,245	56
COD (C)	1,686	896	47
NH_3+NH_4-N (W)	166	82	51
NH_3+NH_4-N (C)	88	52	41
Org-N (W)	225	109	52
Org-N (C)	117	68	42
TP (W)	44.9	22.7	50
TP (C)	20.6	12.4	40
PO_4-P (W)	---	---	---
PO_4-P (C)	4.9	1.9	61 (only 8 samples)
TSS (W)	748	144	81
TSS (C)	336	140	58
DO (W)	2.72	0.15	94
DO (C)	5.14	0.28	95
Fecal coliforms (W) (col/100 mL)	907,000	78,000	91
Fecal coliforms (C) (col/100 mL)	1,520,000	211,000	86
pH (W) (standard units)	7.43	7.14	4
pH (C) (standard units)	7.50	7.10	5
Water temperature (W) (°C)	12.9	12.1	-
Water temperature (C) (°C)	7.6	7.3	-
Total Solids (W)	3,329	1,736	48
Total Solids (C)	1,586	958	35

C = Cold season (November - March)
W = Warm season (April - October)

resulted in the high effluent concentrations from systems 1 and 2 of 990 and 4,820 mg/L for TSS, 2,030 and 2,730 mg/L for BOD_5, and 160 and 50 mg/L for TP, respectively. Cronk et al.
the latter half of 1994 for TSS (4,900 mg/L), BOD_5 (6,450 mg/L), and TP (80 mg/L) likely resulted in the high effluent concentrations from systems 1 and 2 of 990 and 4,820 mg/L for TSS, 2,030 and 2,730 mg/L for BOD_5, and 160 and 50 mg/L for TP, respectively. Cronk et al. noted that these were not acceptable discharge levels. Establishing good vegetation cover at this site was difficult. All vegetation (cattail [*Typha latifolia*]) in the first cell and two thirds of the vegetation (cattail) in the second cell that had been planted in summer 1993 had died by the fall of the first year of operation. Cell 1 was replanted with softstem bulrush the following year since it was considered to be a hardier plant. In that same year, cell 2 had a 10 percent cover of cattail, 50 percent cover of duckweed (*Lemna* spp.) and a 20 percent cover of barnyard grass (*Eichinochloa crusgalli*).

3M Farm (Site Number 519)

In Kent County, Maryland, a 0.12-ha treatment wetland system was monitored as part of a college research program (Adams, 1994). The Adams paper focused on the role of wetlands in the environment and how they can be used to prevent the transport of non-point source pollutants into the Chesapeake Bay. The system was planted with cattail (*Typha latifolia*), pickerel weed (*Pontederia cordata*), and bulrush (*Scirpus* spp.) in the late fall; a few plants survived. Nitrate and ammonia concentrations were reduced by 89 percent and 75 percent, respectively. An exception was in July and August 1994 after a dry spell in June 1994 when most of the vegetation died off and began to decompose, releasing nutrients into the water. The nitrate concentration dropped off through the wetland in the fall but increased again in November and December 1994, likely due to shallow water conditions and the resident duck population. During this period, the ammonia removal efficiency and dissolved oxygen (DO) concentrations also decreased. The pH values through the wetland system remained circumneutral with the exception of the late summer when the pH dropped following the dry spell in June. The wetland was 80 percent dominated by grasses including barnyard grass (*Eichinochloa crusgalli*) and panic grass (*Panicum dichotomiflorum*) with the remainder of the vegetation being velvet leaf (*Abuttilon theophrasti*), bigseed smartweed (*Polygonum pennsylvanica*), cattail (*Typha latifolia*), and spike rush (*Eleocharis quadrangulata*).

Kentucky Projects (Site Numbers 527, 531, 532, 533, 534, 535, 536, 537, 538, 540, and 541)

In Kentucky, a team made up of representatives from the Kentucky Division of Water and Conservation and the NRCS visited 11 treatment wetlands that were constructed to treat high strength dairy wastewater. The team prepared a document summarizing its findings (Neely, 1995). The herd sizes on the dairy farms ranged from 35 head to 150 head of Holstein cows. The treatment wetlands ranged in size from 0.0019 ha to 0.056 ha. None of the sites had any lagoons upstream of the wetland system and only two systems incorporated solids settling basins for pretreatment. Poor vegetation cover (an average of 35 percent) in the wetland cells was reported at most locations. The recommendations as of spring 1995 were as follows:

- Wastewater flow to 73 percent of the systems required some form of pretreatment
- 64 percent required water level control in the wetland cells
- 73 percent required re-establishment of the wetland vegetation
- 36 percent required reseeding of the filter strip vegetation
- 54 percent required installation of a filter distribution system

- 27 percent required additional cells/storage
- 18 percent required additional filter area
- 18 percent required no corrective action

Indiana Projects (Site Numbers 524 and 529)

Reaves (1995) monitored several treatment wetland systems. The dairy in Lagrange County, Indiana, had three wetland cells in parallel covering a total of 0.11 ha (Reaves et al., 1994a; Reaves, 1995). In the first year of operation, the following range of concentration reductions were reported:

• BOD_5	62 to 81 percent
• Reactive phosphate	62 to 89 percent
• TP	49 to 78 percent
• NH_4-N	50 to 70 percent
• TKN	36 to 57 percent
• Dissolved solids	up to 39 percent
• Nitrites (NO_2-N)	up to 100 percent
• NO_3-N	up to 100 percent
• TSS	65 percent

Fecal coliform reductions were greatest during the summer months but reductions were reported throughout the year. The wetland vegetation cattail [*Typha latifolia*] was grazed by cattle several times during the year. The vegetation never recovered, leaving the deeper areas free of emergent vegetation. Reed canary grass (*Phalaris arundinacae*) established a monoculture in the shallow zones. Algal blooms developed in the open water areas with increased suspended solids in the effluent. Cattle deposited waste along the entire run of the cells, resulting in a very low residence time for some of this waste. Infrequent cleaning of the solids settling pad resulted in a mean influent TSS of 15,700 mg/L. This affected the inflow concentration to the wetland of all parameters, which were typically at least one order of magnitude higher than those reported elsewhere in the literature. The solids accumulation of up to 10 cm in the front third of the treatment cells occurred during the first year of operation, reducing the system's treatment efficiency and leading to the system's eventual failure.

Reaves monitored a second dairy system in Kosciusko County, Indiana, that began operating in spring 1994 and was monitored through 1995. The dairy is upgradient from a major lake, causing concern that the operation was adversely impacting the lake's water quality. A manure pit was used for solids reduction upstream of the two-cell constructed wetland. Seepage water from a manure stack pad and yard runoff also entered the wetland. The inflow concentrations of the parameters measured in 1994 were extremely low due to the pumping out and the subsequent slow filling of the manure tank. The next year, the values were more typical. Table 3-4 shows the 1995 average concentrations from cell 1 influent to cell 2 discharge.

During the late summer, the first cell went dry from lack of rainfall. The standing water in the second cell had a hydraulic residence time of approximately 100 days, and most constituents were reduced to near background levels. Poor wetland performance in early spring during cool temperatures and slow microbial metabolism coincided with the highest

TABLE 3-4
Pollutant Concentration, Kosciusko County, Indiana, Treatment Wetland

Parameter	Cell 1 Inflow		Cell 2 Outflow
	Septic Manure Pit	Yard Runoff	
BOD_5 (mg/L)	910.3	94.0	67
Reactive phosphate (mg/L)	47.3	23.6	10
TP (mg/L)	25.3	9.7	4.2
NH_4-N (mg/L)	242.1	148.7	26.2
TKN (mg/L)	215.3	139.9	30.4
TN (mg/L)	215.3	141.6	30.7
NO_2-N (mg/L)	0.0	0.0	0.6
NO_3-N (mg/L)	0.0	7.9	0.6
TSS (mg/L)	483.4	106.4	66.4
FC (col/100 mL)	236	58	11

col = Colony
mL = Milliliter

rainfall and thus highest loading rates. Upstream storage of wastewater flows was recommended to allow for discharge of the wastewater during periods of higher microbial activity and lower precipitation periods. Reaves concluded that farmers must be aware of the limitations of constructed treatment wetland systems if they are to be an effective waste management tool.

University of Connecticut - Kellogg Dairy Research Facility (Site Number 521)

A treatment wetland system was constructed at the University of Connecticut (Neafsey and Clausen, 1994) with a pretreatment settling/floatables area, three parallel cells with three subcells totaling 0.037 ha, and a 27-day residence time. This system required a high-density polyethylene (HDPE) liner. The cells were planted with cattail (*Typha* spp.), common reed (*Phragmites*), and three square bulrush (*Scirpus americanus*). Table 3-5 shows that contaminant mass reduction varied greatly between seasons.

Piscataquis River (Site Number 528)

A 0.04-ha, four-cell wetland was constructed at a 330-head Holstein cow farm in north-central Maine to determine the effectiveness of wetlands in cold climates (Doll et al., 1994; Holmes et al., 1995). The system was designed for a loading rate of 73 kg/ha day and a 20-day detention time. Construction was completed in fall 1993. Design methodology and calculations for the wetland were presented, but performance data were not reported.

Brenton Cattle (Site Number 525)

In Iowa, a constructed wetland was used to reduce contaminant loadings from cattle feedlot stormwater runoff to surface water. A 47-ha, two-cell treatment wetland was constructed at

TABLE 3-5
Seasonal Performance, University of Connecticut Treatment Wetland System

Parameter	Percent Mass Retention	
	Before Plant Senescence	After Plant Senescence
TKN	99.6	55.3
NH_4-N	97.2	-253
NO_3+NO_2-N	93.1	83.6
TP	99.3	44.9
TSS	97.8	55.3
FC	99.9	99.9
BOD_5	99.1	56.6

a 7,000-head cattle finishing facility. The first cell was built in the 1930s on a pasture and hay field. The second cell was constructed in the late 1960s downgradient from the first on similar land. The wetland system received stormwater runoff from more than 800 ha of crop and pasture lands. Table 3-6 presents the system's concentration reductions. With the exception of phosphorus, all data reported for the wetland system effluent showed better water quality than the receiving stream (Brenton, 1994).

TABLE 3-6
Concentration Reductions, Brenton Cattle Treatment Wetland System

Parameter	Inflow Concentration	Outflow Concentration	Percent Reduction
FC (col/100 mL)	143	25.5	82
TP (mg/L)	0.61	0.12	80
BOD (mg/L)	278.6	20.1	93
TKN (mg/L)	50.8	16.5	68
NH_4-N (mg/L)	9	3.3	63
NO_3-N (mg/L)	39.2	10.8	72
TSS (mg/L)	521.6	50.8	90
Turbidity (mg/L)	336.8	42.3	87

Nowicki Farm (Site Number 526)

A 0.05-ha, two-cell treatment wetland was constructed in Alberta, Canada, in 1995 to treat feedlot runoff. After operation begins, the wastewater flow will be pretreated in a manure settlement area, an anaerobic pond, and a storage and facultative pond. Discharge from the facultative pond to the parallel wetland cells will be regulated. Excess flow will be routed via swales around the wetland and discharge into the creek. The wetland will be filled batchwise using a manual valve. Treated water will be discharged to a holding pond that will allow for recycling of water in the case of high nutrient loads or summer drought conditions. A complete sampling and operating program has been established for the system. Planting of the wetland vegetation is scheduled for 1996 (Amell, 1995).

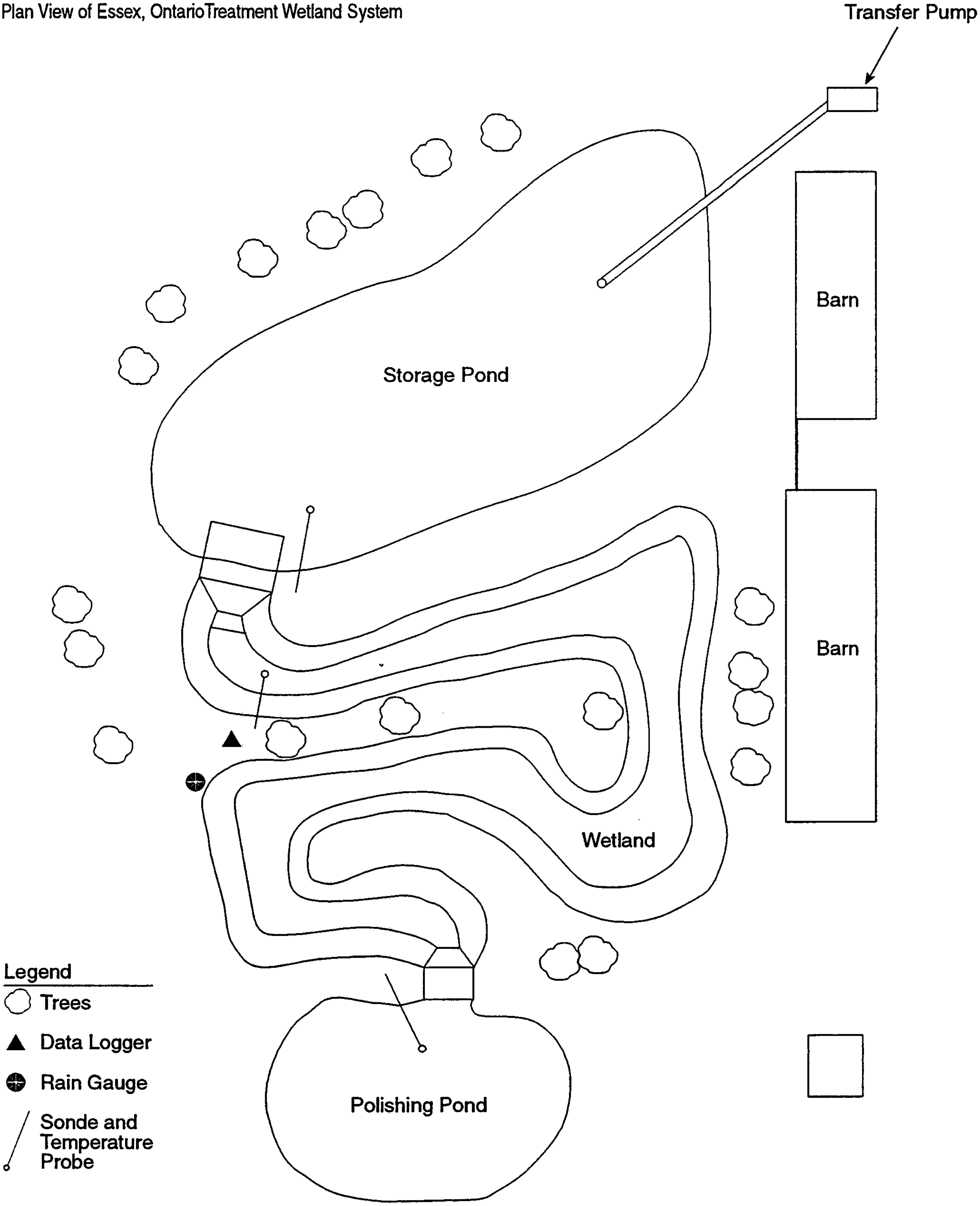
Ontario, Canada (Site Numbers 501 through 509)

Several treatment wetland systems in Ontario, Canada, treat dairy or cattle barnyard runoff as part of a province-wide research project to determine the practicality and treatment effectiveness of these systems for livestock wastewater treatment. Designs have incorporated runoff holding ponds, vegetated marsh treatment cells that are sinuous in shape, and water quality polishing cells. Several systems have similar designs to allow for comparison under Ontario's range of soil and climatic conditions. The monitoring program includes bacterial and chemical parameters in the groundwater, surface water, and bottom sediments; surface water levels; relative humidity; water temperature; rainfall; vegetation; macroinvertibrates; and wildlife. These systems will allow for an assessment of treatment efficiencies, management requirements, and economic benefits to Ontario farmers, and will further the development of low cost alternatives for the farming community to protect water quality. One of the data from published treatment systems (Site 502, Fullerton Township, Perth County, Ontario) shows good reductions in bacteria (approximately three orders of magnitude) and nutrients (TP in 1994 decreased from approximately 25 mg/L to less than 4 mg/L) through the summer (Maaskant and Hayman, 1995).

Site 501 in Essex, Ontario was constructed on the Malder Valley farm in fall 1993 to treat barnyard runoff and milkhouse washwater wastes from a dairy operation. The Essex design consists of a holding pond (see Figure 3-2) followed by a serpentine wetland treatment cell that discharges into a final holding pond. Source controls to reduce the contaminant loading to the treatment wetland include a covered manure storage that was constructed to reduce rainwater runoff from the manure and an exercise yard that was paved and curbed with concrete and sloped to drain to a central catchbasin. Barnyard runoff and approximately 200 gallons per day of milkhouse washwater are directed to a sump and then pumped to a 50,000 cubic foot (ft^3) sedimentation basin/facultative pond. The pond was designed to pretreat the wastewater by providing anaerobic conditions and allowing solids to settle, thus reducing the solids, BOD_5, nitrogen, and total phosphorus loading to the wetland. It also provides storage during the nondischarge period of approximately 6 months. The pond was sized for a 100-year storm combined with washwater produced on a daily basis. Removal of sediment from the pond is possible when required with standard liquid manure handling equipment or a backhoe.

The single wetland cell at the Malder Valley farm has a surface area of about 600 m^2 (0.15 ac) and is serpentine in shape with an aspect ratio of about 24:1. During the growing season, stored wastewater is discharged at a controlled rate to the wetland cell using an inground weir structure. This weir also controls the liquid level in the sedimentation basin. The wastewater flows through shallow zones vegetated with cattail (*Typha latifolia*), water plantain (*Alisma triviale*), arrowhead (*Sagittaria latifolia*), flowering rush (*Butomus umbellatus*), softstem bulrush (*Scirpus validus*), and duckweed(*Lemna* spp.) that are separated by deep zones vegetated with duckweed, bur-reed (*Sparganium eurycarpum*), hornwort (*Ceratophyllum demersum*), and sedge (*Carex* spp.). The vegetation was transplanted to the

FIGURE 3-2
Plan View of Essex, OntarioTreatment Wetland System



wetland cell from roadside ditches in spring 1994. Monitoring equipment was installed in fall 1993 and spring 1994. A clay soil overburden at the site negated the requirement for a liner. After excavation, the native soil was compacted to reduce the potential for the wastewater percolating into the subsoil.

Table 3-7 summarizes monitoring data collected at the Essex Treatment Wetland during the first 9 months of operation, April to December 1994. Monitoring data from May to November 1995 are presented in Table 3-8. These data are typical of early operating results reported by others.

TABLE 3-7
Essex, Ontario, Treatment Wetland Monitoring Data, Average Concentrations for April to December 1994

Parameter (mg/L unless otherwise specified)	Average Wetland Inflow Concentration	Average Wetland Outflow Concentration	% Concentration Reduction
BOD_5	357	202	43
TSS	1,596	48	97
NO_3-N	0.19	0.12	37
TKN	119	17.5	85
TP	25	3.9	84
Dissolved P	11.5	2.3	80
Conductivity (μmhos/mL)	3,091	1,225	60
Chloride	293	182.5	38
Fecal coliform (col/100 mL)	1,030,000	11,999	99
E. coli (col/100 mL)	220,600	11,343	95

TABLE 3-8
Essex, Ontario, Treatment Wetland Monitoring Data, Geometric Mean Concentrations for May to November 1995

Parameter (mg/L unless otherwise specified)	Transfer Pump to Storage Pond	Wetland Inflow Concentration	Wetland Outflow Concentration	% Reduction
BOD_5	487	68	26	62
NH_3-N	50	12	2.4	80
Total PO_4	26	12	3.7	69
TSS	332	151	104	31
E.coli (col/100 mL)	149,267	1,208	409	66

Hernando (Site Number 600)

A wetland was constructed to treat dairy wastewater on a dairy farm in Desoto County, Mississippi, in 1990 (Cooper et al., 1993; Cooper et al., 1995). Construction was provided by the U.S. Department of Agriculture (USDA) NRCS and the Agricultural Research Service (ARS). The wetland consisted of three parallel systems each with a single cell. Researchers from the NRCS, ARS, and University of Mississippi monitored the wetland for 36 months. Water quality parameters monitored included BOD_5, COD, flow, TSS, total dissolved solids (TDS), ortho-P, TP, NH_4-N, NO_3-N, chlorophyll, and total coliforms. The researchers found that the treatment wetland reduced concentrations by the following average percentages:

- Suspended solids — 60 percent
- Dissolved solids — 22 percent
- Ortho-P — 42 percent
- TP — 53 percent
- NH_4-N — 82 percent
- BOD_5 — 75 percent
- COD — 63 percent
- Chlorophyll — 78 percent
- Total coliforms — 89 percent

NO_3-N increased by 14 percent, apparently as a result of the high reduction in NH_4-N. This apparent nitrification of NH_4-N to NO_3-N was likely the result of fairly dilute wastewater concentrations and resulting aerobic conditions in the wetlands.

During 1992-1993, a cell was added to the first wetland system. The new cell was the same size as the original cells and received effluent from the first cell. The researchers found that the additional cell increased the treatment potential for all parameters measured. The results included a 23 percent reduction in conductivity, a 20 percent increase in dissolved oxygen, a 20 percent reduction in total solids, a 27 percent additional reduction in dissolved solids, a 37 percent reduction in ortho-P, and a 23 percent additional reduction in TP. NH_4-N, and NO_3-N were reduced by an additional 13 and 52 percent, respectively.

Newton, Mississippi (Site Number 602)

A constructed wetland designed to treat dairy wastewater has been operating in Newton, Mississippi, since 1989 (Cathcart et al., 1990; Davis et al., 1992). This particular treatment wetland was a collaborative effort by Mississippi State University, the USDA NRCS, and the Newton County Water Conservation District. The treatment wetland consists of six wetland systems, each comprised of a long and a short wetland cell. These treatment systems receive wastewater and surface runoff that have been pretreated in a two-stage lagoon system. Of the 12 cells in the wetland, 10 of the cells were originally planted with emergent aquatic macrophytes, and one system (with two cells) is used as a control.

The researchers monitored the effectiveness of this treatment wetland by measuring the reduction of BOD_5, NH_4-N, ortho-P, TP, TDS, and TSS on a weekly to biweekly schedule. They also monitored temperature, DO, and flow rate at the influent and effluent locations of each cell in each system. The data collected by the researchers showed BOD_5 removals ranging from 39 to 64 percent in the first stage treatment with slight improvement in the second stage (26 to 88 percent). Influent wastewater DO concentrations averaged 3.4 mg/L, indicating a relatively dilute wastewater, and wetland effluent DO concentrations were between 0 and 1 mg/L. The average reduction of NH_4-N was 45 percent. The researchers suggested that increases in the efficiency of ammonia oxidation to nitrate may have been inhibited by the low initial DO levels into the systems. This result was also evidenced by the steep removals of the limited available oxygen in the system. The researchers concluded that the wetland may have been overloaded even though a rather conservative loading rate was applied and that low DO levels seemed to have had a distinct effect on the treatment efficiency. The researchers noted that ammonia reductions were minimal when calculations were made using concentrations alone, but if mass balance calculations were used, ammonia reduction was evident.

McMichael Dairy and Key Dairy, Georgia (Site Numbers 607 and 613)

The Piedmont Soil and Water Conservation District (PSWCD) selected two dairies (McMichael and Key) near Eatonton, Georgia, to evaluate the use of constructed wetlands for treating dairy wastes (Howard, 1991; Surrency, 1993). The wetland systems, initiated in 1987, treated washdown water from milking facilities and other specific dairy wastes. The Key Dairy has had a lagoon system operating for several years and directly discharges to the treatment wetlands. This wetland system consists of three equally sized cells with a total area of 0.35 ha. The McMichael Dairy system is receiving pond water temporarily while the newly constructed lagoon fills with wastewater. The McMichael Dairy system consists of three treatment wetland cells with a total area of 0.29 ha.

Quarterly water quality monitoring of the lagoon and wetland systems began in July 1990. Parameters measured include NH_4-N, NO_3-N, TKN, TP, total organic carbon (TOC), and TSS. The researchers report a TN and TP reduction of 90 and 80 percent, respectively, at Key Dairy during intermittent wetland discharge during the first year. The researchers note decreased treatment during active wetland discharge (caused by rain events) to include reductions of more than 65 percent in TN and TP. The researchers explain the periods of intermittent wetland discharge (warm weather months) as a result of increased evapotranspiration. First year data on TSS at the Key Dairy treatment wetland indicate a 74 to 98 percent reduction. Overall, the Key Dairy effectively treated nitrogen and phosphorus wastewater components during both wet and dry seasons during the first year, but the wetland system eventually failed due to excessive solids loading (Hoke Howard, pers. comm.).

Louisiana State University and University of Southwestern Louisiana (Site Numbers 609 and 610)

Two treatment wetlands in Louisiana have recently been built to treat dairy and feedlot runoff wastes at dairy research farms. The first wetland project was constructed in 1993 at the Louisiana State University (LSU) dairy farm complex (Chen et al., 1995a). This project is designed to evaluate constructed FAP systems for the improvement of dairy lagoon wastes and consists of three systems each with a single cell. The cells are planted with water hyacinth (*Eichhornia crassipes*), duckweed (*Lemna* sp.)/emergent plants, and black willow (*Salix nigra*)/duckweed, respectively. The water hyacinth and duckweed/ emergent plant systems have cell sizes of approximately 0.2 ha. The black willow/duckweed system is approximately 0.4 ha. The water hyacinth and duckweed/emergent plant systems are monitored for removal efficiency of TSS, BOD_5, TKN, TP, fecal coliforms, and other parameters. The researchers report mean TSS removal efficiencies of 77 percent (duckweed) and 85 percent (water hyacinth); mean BOD_5 reductions of 76 and 79 percent; nitrogen removal efficiencies of 62 and 64 percent; and insignificant removals of phosphorus in both systems monitored. The researchers also report a one order of magnitude reduction in fecal coliforms. DO concentrations have remained below 2.0 mg/L during the study period. Chen et al. (1995b) also note that water hyacinths grew well during March and November and that duckweed grew well and covered the water surface during most of the year.

The other Louisiana system was built in 1994 at the University of Southwestern Louisiana dairy farm complex. The wastewater from the 150-cow herd is pretreated in a two-stage lagoon system with a combined surface area of 0.97 ha (Chen et al., 1995b). Three treatment wetland systems were constructed to treat the discharge from the lagoon systems. The first wetland system consists of three SSF cells, the second consists of four deep trench (DT) cells, and the third consists of four free water surface (surface flow [SF]) cells. The SSF system contains rock media and can be operated in series or parallel. The SF system is designed as a shallow pond system and is planted with emergent aquatic vegetation or crops. The DT system consists of very narrow, deep cells that are planted with tall emergent macrophytes around the edges. Since the systems are designed as a research and demonstration project, each system is oversized to allow flexibility in amounts and rates of wastewater addition and treatment.

Union County, Kentucky (Site Number 548)

A small treatment wetland in Union County, Kentucky, was built to reduce livestock losses resulting from drowning in the existing anaerobic lagoons at the farm (50-head herd) in the Green River area of western Kentucky (Trejo, 1993). This new treatment system consists of a dry stack pad and two constructed treatment wetland cells. The combined area of the wetland cells is 0.34 ha. The first cell is planted with cattails (*Typha* sp.), and the second cell is planted with freshly dug common reed *(Phragmites australis)*. The stack pad waste is directly routed to the treatment wetland. NO_3-N, phosphorus, and fecal coliforms are monitored at the influent and effluent ends of each cell. The author found very high removal rates of fecal coliforms from the first cell and significant removals from the second cell when the wetland received influent. NO_3-N reductions were found to be best during the summer months with limited reductions during the fall. The author attributes this decrease in removal efficiency to the senescence of the emergent macrophytes within the cells. The author also found significant reductions in phosphorus throughout the study period.

Swine Wastewater Treatment Applications

The GMP constructed wetland literature review located information for 19 swine operations that are using constructed wetlands to provide secondary treatment of lagoon supernatant with a total of 58 systems. Of those, 25 systems had operational and monitoring data. In most cases, swine wastes are collected using flush water from solid floor barns and paved lots or directly from grated flooring in farrowing or nursery barns (USDA SCS, 1992). Land application has been the most widely used disposal method for liquid swine waste but has had many problems including excessive odor, high solids content, and high nutrient concentrations (Hunt et al., 1995). The use of anaerobic and anaerobic/aerobic lagoon treatment has become a necessary step in the treatment process to limit the potential for overloading land application systems and to provide adequate primary treatment.

Constructed treatment wetlands are now becoming a viable option for secondary treatment of these highly enriched lagoon effluents. Swine waste lagoon supernatants appear to range between the waste characteristics of beef/dairy and poultry. The average NH_4-N level for anaerobic lagoon supernatant is 219 mg/L, which is much less than poultry lagoon supernatants (USDA SCS, 1992). The use of wetlands to treat swine waste lagoon discharges could reduce pollution of local water resources.

Sand Mountain, Alabama (Site Number 604)

One of the first constructed wetlands to treat swine wastewater was constructed in 1988 at the Sand Mountain Experiment Station at Crossville, Alabama (McCaskey et al., 1994; Hammer et al., 1993). This system is a combination of five systems, each with two in-series SF cells. Influent wastewater is a combination of lagoon effluent and water from a nearby farm pond. The combined treatment area of all of the cells is 3,600 square meters (m^2). Operational monitoring began in November 1990 with the collection of water samples from various stations throughout the waste treatment process, and has continued through the date of this report.

During the initial 11-month sampling period, BOD_5 influent concentrations ranged from 19.2 to 99.0 mg/L. Effluent concentrations varied from 4.9 to 17.6 mg/L. The researchers reported an average BOD_5 removal rate of 90.4 percent throughout the entire treatment wetland. Suspended solids influent concentrations varied greatly between the systems. The researchers observed increased removal of suspended solids in a wet meadow located immediately downstream of the wetland system. The overall average removal rate of suspended solids from the treatment wetland was 91.4 percent, but removal was somewhat enhanced by a wet meadow system (open vegetated channel) downstream of the wetland cells. The researchers found that fecal coliform reductions were evident after the first series of cells for all systems and that no significant additional reductions were found in the effluent from the second series of cells. Although the second series provided limited fecal coliform removal, the wet meadow system provided further removals of about 38 percent. The entire wetland as a whole reduced fecal coliform bacteria by 99.4 percent. Fecal streptococci was reduced significantly in both the first and second cell series and had limited removal in the wet meadow system. The treatment wetland averaged overall a 98.4 percent reduction of fecal streptococci. Researchers also found that NH_4-N and TKN removals benefited from the additional treatment in the second series of wetland cells. TP removals exhibited similar patterns of reduction, including significant removals in the second cell series. Removal rates were 75.9 percent for TP, 91.4 percent for TKN, and 93.6 percent for NH_4-N.

In summary, the researchers found that the treatment potential of the wetland was not affected by the type of vegetation in the cells. Also, they found significant reductions of TKN, NH_4-N, TP, and fecal streptococci in the second series of wetland cells, while reductions in suspended solids, BOD_5, and fecal coliform bacteria were augmented by the wet meadow system.

Kentucky (Site Numbers 527, 531 through 535, 537 through 550)

A team made up of representatives from the Kentucky Division of Water and Conservation and the NRCS visited seven Kentucky treatment wetlands that were constructed to treat high strength swine wastewater (Neely, 1995). The herd sizes on the swine farms ranged from 140 to 11,020 animals. The wetlands ranged in size from 0.041 ha to 4.9 ha. Five of the sites pretreated the swine wastewater flow using anaerobic lagoons upstream of the wetland system. The other two systems incorporated a holding pond for pretreatment. Good vegetation cover in the wetland cells, on average 70 percent, was reported at all but one location where 0 percent coverage was reported. After the initial assessment of the swine wetland systems in spring 1995, it was determined that three of the seven systems required no corrective action. Of the remaining four systems, three required water level control, three required re-establishment of wetland vegetation, one required reseeding of the filter strip vegetation, one required installation of a filter distribution system, one required additional cells/storage, and one required additional filter area.

Pontotoc, Mississippi (Site Number 601)

A constructed treatment wetland/vegetation strip has been operating since 1991 at the Pontotoc Ridge/Flatwoods Branch Experiment Station of the Mississippi State University (Cathcart et al., 1994). This system treats wastewater from an existing two-stage lagoon system that receives wastes from a hog farrowing house at the research facility. The wetland consists of two systems, each with a wetland cell and one vegetative strip in series. The vegetation in the wetland cells consists of a combination of cattail (*Typha latifolia)* and water chestnut (*Trapa nutans).*

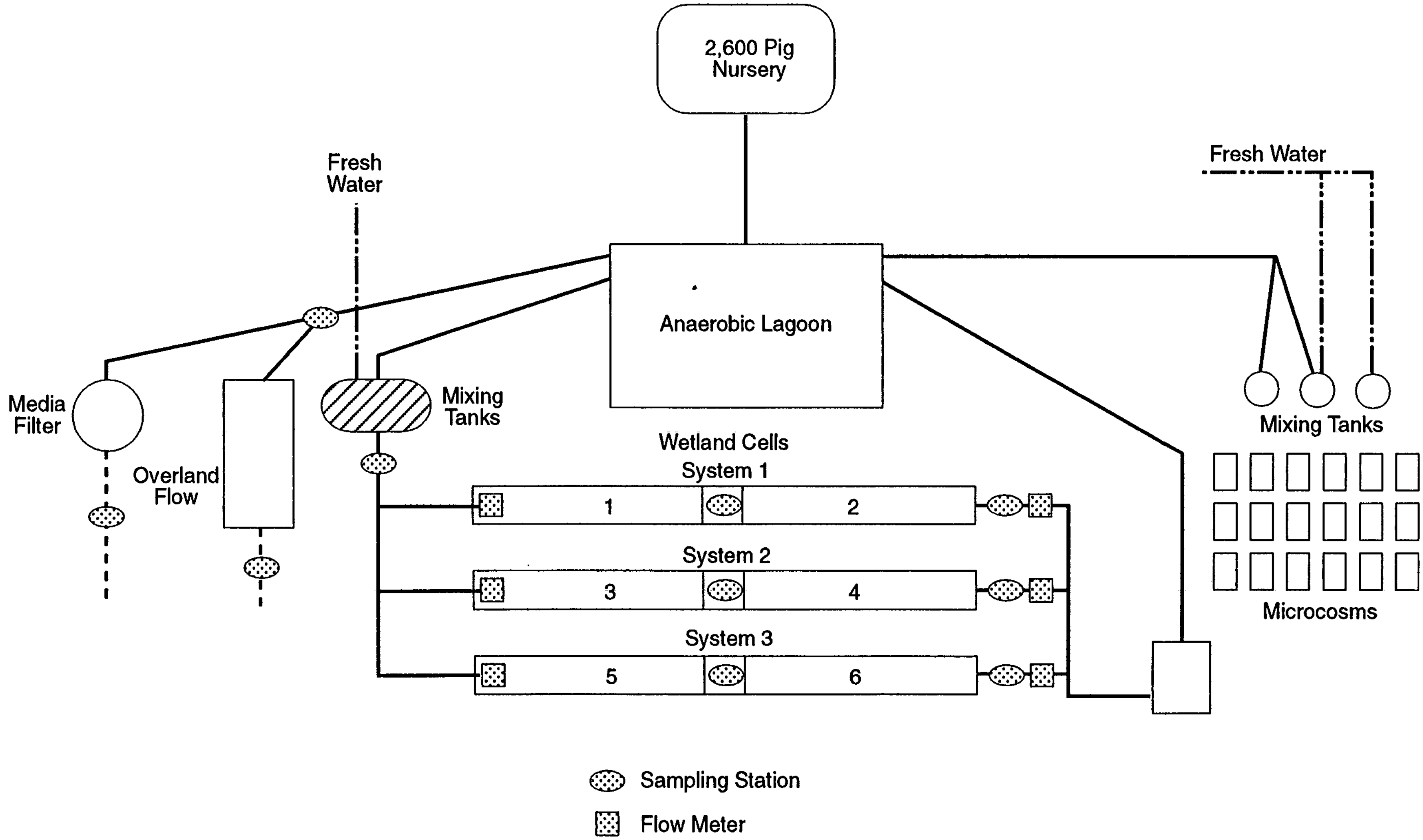
Operational monitoring began in April 1992. Monitoring parameters included DO, flow rate, water temperature, BOD_5, TSS, NH_4-N, NO_3-N, TKN, ortho-P, TP, and fecal coliforms. The researchers found an 11 percent decrease in hydraulic flows through the wetland cells. DO concentrations were somewhat higher in the effluent than the influent, perhaps because of the use of a marsh/pond/marsh design for the wetland cells. Removal rates from the wetland cells accounted for an approximately 40 percent reduction in TP, a 52 percent reduction in BOD_5, a 65 percent reduction in suspended solids, and a 70 percent reduction in NH_4-N. The researchers also found that organic nitrogen represented a relatively small fraction of the overall nitrogen content. NO_3-N was nearly absent, suggesting low nitrification or high denitrification rates in the treatment wetlands.

Duplin County, North Carolina (Site Number 612)

In 1993, a treatment wetland was constructed in Duplin County, North Carolina, to evaluate the use of constructed wetlands to treat swine wastes in the Southeastern Coastal Plain. The research effort was divided among researchers at the USDA-NRCS Coastal Plains Soil, Water, and Plant Research Center and researchers at North Carolina State University (Hunt et al., 1993; Hunt et al., 1994a; Hunt et al., 1994b; Hunt et al., 1995; Szogi et al., 1994; Szogi et al., 1995a; Szogi et al., 1995b; Humenik et al., 1995). The wetland consisted of three systems, each with two cells in series (Figure 3-3). The systems each contained a different combination of emergent vegetation. System 1 contained softrush *(Juncus effusus)* in the first cell and bulrush *(Scirpus* spp.*)* in the second cell, system 2 contained giant burreed *(Sparganium americanum)* in the first cell and cattail *(Typha* spp.*)* in the second cell. The third set of cells contained soybean (*Glycine max*) in the first cell and rice *(Oryza sativa)* in the second cell.

The researchers used a diluted waste inflow from an anaerobic lagoon system. NH_4-N inflows ranged from 22 to 90 mg/L. Mass removals of NH_4-N by the wetlands in all systems was high (96 to 99 percent) with a low loading rate of 3 kg of nitrogen per hectare per day for the first year. The researchers found that as the loading rate increased, removal efficiencies decreased in the softrush/bulrush and giant burreed/cattail systems. Mean

FIGURE 3-3
Plan View of Duplin County Treatment Wetland System



NO_3-N inflow concentrations were usually low (<3 mg/L) because of the anaerobic conditions in the lagoon. NO_3-N outflow concentrations fluctuated due to decreases or increases in microbial respiration and in oxygen solubility. Influent ortho-P concentrations ranged from 6 to 12 mg/L in the first year of operation. With the lower loading rate of the first year, ortho-P removals ranged from 90 to 97 percent for all systems. As expected, efficiencies dropped as loading rates increased. In conclusion, the researchers felt that an oxidative step such as an overland flow and media filter would be beneficial for increased, sustainable nitrogen and phosphorus removal.

Delmarva Farms, Maryland (Site Number 520)

A treatment wetland system was built at a 900-swine operation in Worchester County, Maryland, in late summer 1994 (Baldwin and Davenport, 1994). It was installed in response to an agreement by the State of Maryland and the other states in the Chesapeake Bay watershed to reduce nutrient loadings to the Bay. The 0.73-ha system has a 13-day residence time. The wastewater is pretreated in an anaerobic lagoon and a sand filter, and a portion of the flow is discharged to the wetland. The wetland effluent is recycled through the swine operation and used for flush water. The remainder of the lagoon effluent is spray irrigated. A compacted clay liner in the wetland controls seepage. Although the paper does not discuss water quality improvements, it does provide comprehensive operation and maintenance plan that includes a vegetation establishment plan, a water quality monitoring list, sampling procedures, and a wetland management plan (Baldwin and Davenport, 1994).

Purdue University (Site Number 530)

An experimental constructed wetland project for swine waste treatment is underway at the Purdue University Animal Science Research Center in Indiana. This site has 16 parallel unlined cells and is designed to treat process wastewater from a swine waste lagoon. The system design; experimental plan; and the monitoring plan of cell influent, effluent, and groundwater quality are outlined in a report (Reaves et al., 1994b).

The cells were tested at three hydraulic loading rates and two operating depths. Treatment efficiencies and vegetation performance were compared to determine the optimum system operating parameters for a treatment wetland in northern Indiana. Data collected during the first year of operation indicate that a depth of 15 cm and a 14-day hydraulic retention time provide better water treatment for the climate. Table 3-9 presents influent concentrations and percent reductions under this operating scenario.

TABLE 3-9
Concentration Reductions, Purdue University Treatment Wetland System

Parameter	Inflow Concentration	Percent Reduction
BOD_5 (mg/L)	116	58.6
Total fecal coliforms (col/100 mL)	78	97.4
TP (mg/L)	14.5	26.1
TN (mg/L)	497.4	29.8
TSS (mg/L)	122.6	60

During the first year of operation, greater reductions of TN and TP were noted in the unvegetated cell when compared to the vegetated cells with the same hydraulic loading rate and depth. The reduction in the TN concentration may have been due, in part, to the higher DO concentration in the unvegetated cell, resulting from algal growth which would allow higher nitrification rates. The open cell appeared to exhibit greater rates of chemical precipitation, thus reducing the TP concentration in the cell. In the late summer, water was removed for spray irrigation from the storage lagoon that was used as the wastewater source. At that time, the ammonia concentration rose from about 200 mg/L to more than 1,000 mg/L. Several plant species died off following this increase. Only the broad leaf cattail (*Typha latifolia*) and the softstem bulrush (*Scirpus validus*) survived the change in concentration. Percent vegetation cover and plant vigor were better in shallow treatment systems for most of the growing season. Plants growing in shallow water were better able to tolerate increased ammonia loading in late summer. However, plants survived mild freezes better at greater water depths (Reaves et al., 1995).

The groundwater impacts from the Purdue wetland system were evaluated. The unlined cells were constructed in mesic soil. Before system startup, lithium tracer was used to determine the level of leakage before system startup and showed potential for groundwater contamination from some of the cells. Preliminary results from a detailed groundwater monitoring system indicate that unlined constructed wetland cells in native soils are not contaminating groundwater. Compaction of suitable mesic soils should enable more cost-effective construction. Reaves notes that further testing is warranted to supplement these preliminary results.

Poultry Applications

Increases in high-yield, confined poultry production has led to an emphasis on poultry waste management (Rogers et al., 1995). Because most poultry facilities are confined and intensively managed for high yield production, manure and associated wastes are also confined and collected over small areas. The waste from laying hen facilities are often accumulated as mounded dry litter beneath the cages. However, wet systems are common and involve collecting wastes by flushing wastes from alleys under the cages to an anaerobic lagoon.

The GMP constructed wetland literature review located information for one poultry farm using constructed wetlands to provide secondary treatment of lagoon supernatant. A primary consideration of wetland treatment of poultry waste is its very high nutrient content. Average NH_4-N concentrations of anaerobic lagoon supernatants range from 270 mg/L to 550 mg/L depending on the type of lagoon (USDA SCS, 1992). For wetlands to treat poultry wastes, low-nutrient flush water augmentation is necessary to dilute the influent wastewater and maintain a successful treatment wetland.

Auburn, Alabama (Site Number 605)

A treatment wetland for poultry waste management was built at the Auburn University Poultry Unit in Auburn, Alabama, in 1992 (Rogers et al., 1995). This wetland consisted of three parallel systems each with two cells in-series cells; and two smaller parallel systems (series 4 and 5) which were small versions of the larger systems. The two small cells were not planted but were installed with wooden dowels used as substrate for microorganisms. The large-scale systems were planted with a variety of monotypic stands of emergent vegetation. The wetland was operated and monitored from August 1993 to June 1994. The study was shortened due to an inadequate supply of wastewater (Rogers, 1995).

The overall treatment performance of the Auburn wetlands was measured by the reduction of COD, BOD_5, NH_4-N, and TKN (Rogers et al., 1995). COD removals increased in both the vegetated and dowel systems, with sharper increases in removal from the dowel systems. BOD_5 levels increased in the vegetated systems and exhibited increased removals in the dowel systems. Rogers et al. (1995) thought that the possibility of decomposing vegetation in the vegetated systems may have added to the organic matter load in these systems. The researchers also proposed that the senescence of the plants in the vegetated systems may have decreased the attachment area for optimal microbiological treatment processes, whereas the dowel systems maintained this area. Similar results were found for NH_4-N and TKN removal. The spring season exhibited decreases in treatment of these N parameters, again related to the loss of oxygen which in turn may have decreased the nitrification rate among the vegetated systems. This effect was not present in the dowel systems (Rogers et al., 1995).

Rogers (1995) notes that the lack of wastewater may have disrupted the system and compromised the data. The researcher also states that the data collected should serve as a preliminary investigation into the use of wetlands to treat poultry wastes.

Aquaculture Applications

Aquaculture is the husbandry of food organisms in aquatic systems and has become a viable agricultural practice in the United States and worldwide (Stickney, 1994; Stickney, 1996). The U.S. aquaculture industry has expanded at an annual rate of almost 20 percent since 1980, with the 1990 U.S. harvest valued at nearly $1 billion (Zachritz and Jacquez, 1993). Coupled with the substantial growth of the aquaculture industry, the need for efficient and cost-effective aquaculture waste management is necessary. At least two aquaculture treatment wetland systems are currently in operation in North America, and operational and monitoring data were available for both systems.

The development of intensive aquaculture industries in the U.S. depends on the availability of high quality water supplies and more stringent management of pollutant discharges both within and from fish production ponds (Anderson et al., 1992). Alternative, closed cycling aquaculture waste treatment will become necessary for most production facilities around the world. Constructed treatment wetlands offer a viable treatment technology that is both low cost and effective under a wide range of climatic and environmental situations.

New Mexico State University (Site Number 611)

A pilot-scale wetland system was constructed at the Southwest Technology Development Institute's geothermal greenhouse complex at the New Mexico State University (Zachritz and Jacquez, 1993). This aquaculture system is a high-density finfish culture system that incorporates geothermal water for heating and as a culture medium. The system is of a raceway design enclosed in a large greenhouse. A constructed wetland filter (CWF) is connected to the process and is designed to reduce suspended solids, COD, and excess TN. The CWF is a small SSF treatment wetland that receives 21.9 liters per minute (L/min) of wastewater and has a surface area of 4.0 m^2. The substrate is 5 to 8 cm rock, and the system is planted with bulrush (*Scirpus californicus*). This system has been operated under various hydraulic loading rates and media types. The manuscript describing this system did not report operational data. The researchers note that controlled discharge requirements will limit continued development of high volume flow-through systems, and that closed, recirculating systems will become more common in the future.

Purvis, Mississippi (Site Number 603)

An aquaculture wastewater treatment wetland was built in 1990 as a demonstration project to evaluate catfish aquaculture practices at a facility in Purvis, Mississippi, owned by Mr. Truman Roberts (Anderson et al., 1992). The wetland consists of two systems each linked to a production pond. The first system has two cells, and the second system has four cells.

The researchers monitored NH_4-N, TSS, TP, COD, NO_3-N, and DO in both systems and also monitored soil characteristics in the second system. During year two, photosynthetic indices were monitored as an estimate of algal biomass. Reductions in NH_4-N reached 50 percent on several occasions during the study. The first system was effective in reducing COD, total phosphate, and TSS. COD reduction fluctuated seasonally, from a 75 percent reduction in February 1991 to only a 2 percent reduction in April 1992. The second system had wide variations in COD influent and effluent concentrations, but overall the system exhibited an increase in COD. TOC was measured only twice during the study period and reflected the results found with COD removals in system one and increases in system two. Total phosphate was reduced by more than 35 percent in system one, but not reduced in system two. TSS were reduced by 40 percent in system one, but system two removed insignificant amounts. The researchers explained that a lack of a vigorous aquatic plant community caused poor performance in system two.

SECTION 4

Livestock Wastewater Treatment Wetland Database

The NADB was developed to store and retrieve information about all types of treatment wetlands (NADB, 1993; Knight et al., 1993a and b). The format for the NADB was modified slightly to accommodate the unique characteristics of the livestock wastewater treatment wetland systems reviewed in this report. Because all of these data were summarized in similar data formats, it will be relatively easy in the future to combine and separate data for various types of analyses.

For this report, new data analyses were limited to the LWDB. This section presents the following information on the LWDB:

- Database structure
- Database contents
- Design summary
- Performance summary
- First-order model reaction rates

Database Structure

Six database files with data pertinent to the use of North American wetlands for treatment of high strength livestock wastewaters were developed with Access software. This electronic document is known as the LWDB to distinguish it from the NADB.

LWDB files have names that reflect their contents (within the eight-letter DOS limitation): *sites, systems, cells, operate, literat,* and *people*. Separate database files were developed because of the hierarchical nature of the data (that is, one site may have several systems, and one system may have multiple cells). Separate files reduce the need for repetitive (overlapping) data. A brief description of each database file follows below, with file details (field names, field type, field size, units, and codes) provided in Appendix B.

Unique wetland site numbers were assigned to each system. The inherent value of any particular number is meaningless; its purpose was to ensure that information about each site remained distinct throughout the tables and that these various database files could be cross-referenced.

The *sites* file ties basic information about each site, such as site name, state, community, and EPA region, to its particular site number. There are 65 fields containing 239 characters in the table. The "checkoff" fields are the smallest, with a width of one character. Checkoff fields contain an X to indicate that information for a particular parameter exists in the six files.

The *systems* database file describes each system at a site. Systems are defined as wetland treatment areas that have separate outflow monitoring stations. A system can have a single cell with inflow and outflow performance data, or it can have multiple cells arranged in series. Information entered here includes site name and number, system name and number, total number of cells, origin, hydrologic type, and design area in ha and flow in m^3/d. There are 22 fields and 197 characters in the *systems* file.

The *cells* file contains design information for each cell in a system, including site number, system number, cell number, hydrologic type, plant species names for resident vegetation, and cell length and width. Cells are wetland areas that are clearly delineated from other treatment areas by dikes or uplands and that have recognizable inlet and outlet points. There are 33 fields and 364 characters in the *cells* database file.

The *operate* file is the largest of the six linked database files, both in terms of number of records and character widths. It contains all operational data for each separate system or cell at a specific site for a specific time period. Efforts were made to provide average data on a seasonal basis, though data for monthly, annual, or other time periods also were included. Measurements for BOD_5, TSS, TKN, NH_4-N, NO_3-N, TN, organic nitrogen, TP, dissolved phosphorus, DO, fecal coliforms, conductivity, TDS, volatile suspended solids (VSS), and COD may be entered here. All concentrations are provided in units of mg/L.

Hydraulic loading rates (cm/d) and mass balances (kg/ha/d) were computed as follows and entered in the *operate* file:

HD_LD_RATE (cm/d)	=	(INFLOW (m3/d)* 0.01) / AREA_WET (ha)
SUPER_VELO (m/d)	=	AV_FLOW (m3/d)/ (WIDTH (m) * DEPTH (cm/100))
DETEN_TIME (d)	=	(void fraction * AREA (m^2) * DEPTH (cm/100)) / AV_FLOW (m3/d)
MB_XXX_IN (kg/ha/d)	=	(CN_XXX_IN (mg/L) * (INFLOW (m3/d)/ 1000)) / AREA_WET (ha)
MB_XXX_OUT (kg/ha/d)	=	(CN_XXX_OUT (mg/L) * (OUTFLOW (m3/d)/ 1000)) / AREA_WET (ha)
MB_XXX_EFF (%)	=	((MB_XXX_IN - MB_XXX_OUT) / (MB_XXX_IN) * 100
CN_XXX_EFF (%)	=	((CN_XXX_IN (mg/L) - CN_XXX_OUT (mg/L)) / CN_XXX_IN) * 100

There are 110 fields and 904 characters in the *operate* file.

The *literat* file contains selected references to literature documents for systems included in the six database files. Up to three individual authors can be entered, allowing for their selective retrieval. There are 14 fields and 508 characters in the *literat* file.

The *people* file is the smallest of the seven files in terms of numbers of fields available. One name per record was entered. A coded field ties the recorded individual to his or her involvement with the wetland treatment system, such as researcher, engineer, designer, or operator. There are 13 fields and 325 characters in the *people* file.

Database Contents

The LWDB includes 68 sites with a total of 135 separate systems and 278 individual cells. These numbers reflect that most sites have multiple systems and that most individual systems have multiple cells. Multiple cells in a system may function in series or in parallel.

Eighty-four percent of the cells in the LWDB are SF, and the remainder are SSF or other. Cell areas range from 0.0002 to 25.1 ha. Length to width ratios vary from 0.5:1 to 60:1. Eighty-five percent of the cells are identified as marsh vegetation and 10 percent as other. The remaining cells have floating aquatic plants, open water, shrub, or unknown vegetation types.

Design water depth varies from 0.3 cm to 120.0 cm with an average of 38 cm. Bottom slopes vary from 0 to 2.0 percent with an average of 0.7 percent.

The most common vegetation species planted in the animal waste treatment wetlands in North America are cattail (*Typha* spp.) and bulrush (*Scirpus* spp.). Other plant species that are frequently planted include common reeds (*Phragmites* spp.) and miscellaneous sedges and grasses.

Table 4-1 lists the sites and systems in the LWDB. All of these systems are constructed wetlands. Table C-1 in Appendix C summarizes design data for the individual cells.

Of the treatment wetland sites in the LWDB, 38 receive dairy farm wastewaters, 19 receive wastewaters from swine operations, eight receive cattle feeding wastewaters, two are aquaculture systems, and one is a poultry farm operation. Livestock wastewater treatment wetlands occur throughout the U.S. in most EPA regions (all but regions 2, 8, and 9) and throughout Canada. Region 4 (southeastern U.S.) has the most sites and systems, followed by Canada (Figure 4-1).

The LWDB includes operational data from 48 treatment wetland systems with a total of 1,390 individual records that include data for multiple parameters. Table C-2 in Appendix C summarizes the wetland long-term (LTM) and annual average (ANN) operational performance data. An analysis of these data is provided below.

The LWDB includes 89 citations to scientific journal articles, system design and data reports, and other documents related to the wetland systems. These literature citations, listed and sorted by site number, should be consulted for more detailed information on each system in the database.

In some cases, no published information is available for operating wetland systems. For these systems, the best sources of more information are (1) the operator or system manager, (2) a researcher working with the system, or (3) the system engineer who will know design considerations and may be involved in performance assessment. Table C-3 in Appendix C lists key contacts for each wetland site included in the LWDB. Other contact people may exist for that site but are not included for space considerations; the complete database contains all contact names and addresses obtained and should be consulted for more details.

Design Summary

Design data are summarized below for system age, area, flow, hydraulic loading rate, length-to-width ratio, depth, slope, and vegetation.

System Age

The use of wetlands for treating concentrated animal wastes is a relatively new idea. Figure 4-2 provides a summary of the startup dates for animal waste wetlands in the database. The oldest recorded systems are Brenton Cattle in Iowa in 1930 and the Newton, Sand Mountain, and Hattiesburg, Mississippi, systems in 1989. The majority of the other systems started operating in 1993 and 1994. Only a few systems are represented from 1995

TABLE 4-1
Wetland Sites and Systems in the Livestock Wastewater Treatment Wetland Database

Site No.	Site Name	System Name	Country	EPA Region	State	Community	Wastewater Code [a]	Hydrologic Type [b]	System Area (ha)	Design Flow (m^3/d)
519	3M Farm, MD	3M	USA	3	MD	Kent County	DAI	FWS	0.121	10.90
531	Adair Co.#1, KY	Adair Co.#1	USA	4	KY	Adair Co.	DAI	FWS	0.032	
532	Adair Co.#2, KY	Adair Co.#2	USA	4	KY	Adair Co.	DAI	FWS	0.036	
542	Allen Co., KY	Allen Co.	USA	4	KY	Allen Co.	SWI	FWS	3.700	
605	Auburn Poultry, AL	Auburn Poultry 1	USA	4	AL	Auburn	POU	FWS	0.040	
605	Auburn Poultry, AL	Auburn Poultry 2	USA	4	AL	Auburn	POU	FWS	0.040	
605	Auburn Poultry, AL	Auburn Poultry 3	USA	4	AL	Auburn	POU	FWS	0.040	
605	Auburn Poultry, AL	Auburn Poultry 4	USA	4	AL	Auburn	POU	FWS	0.000	
605	Auburn Poultry, AL	Auburn Poultry 5	USA	4	AL	Auburn	POU	FWS	0.000	
606	Auburn Swine, AL	Swine Unit	USA	4	AL	Auburn	SWI	FWS	0.004	
525	Brenton Cattle , IA	Brenton Cattle	USA	7	IA	Dallas Center	CTL	FWS	47.000	
543	Butler Co.#1, KY	Butler Co.	USA	4	KY	Butler Co.	SWI	FWS	4.900	
549	Butler Co.#2, KY	Butler Co.#2	USA	4	KY	Butler Co.	SWI	FWS	4.800	
533	Casey Co.#1, KY	Casey Co.#1	USA	4	KY	Casey Co.	DAI	FWS	0.056	
534	Casey Co.#2, KY	Casey Co.#2	USA	4	KY	Casey Co.	DAI	FWS	0.004	
535	Casey Co.#3, KY	Casey Co.#3	USA	4	KY	Casey Co.	DAI	FWS	0.002	
516	Cobb Farm, PA	Cobb	USA	3	PA	Bradford County	DAI	FWS	0.012	0.47
536	Crittenden Co., KY	Crittenden Co.	USA	4	KY	Crittenden Co.	DAI	FWS	0.074	
615	Crittenden Co., KY	Dairy	USA	4	KY	Union and Crittenden Co.s	DAI	FWS	0.340	
518	Crum Farm, MD	Crum	USA	3	MD	Frederick County	DAI	FWS	0.112	3.48
523	David Gerrits Farm, WI	David Gerrits Farm 1	USA	5	WI	De Pere	DAI	FWS	0.009	0.29
523	David Gerrits Farm, WI	David Gerrits Farm 2	USA	5	WI	De Pere	DAI	FWS	0.009	0.29
523	David Gerrits Farm, WI	David Gerrits Farm 3	USA	5	WI	De Pere	DAI	FWS	0.009	0.29
523	David Gerrits Farm, WI	David Gerrits Farm 4	USA	5	WI	De Pere	DAI	FWS	0.009	0.29
512	David Thompson Farm, N_S	David Thompson Farm	Canada		NS	Picton County	DAI	FWS	0.095	10.80
520	Delmarva Farms , MD	Delmarva	USA	3	MD	Worchester County	SWI	FWS	0.728	102.60
550	Dogwood Ridge, KY	Dogwood Ridge	USA	4	KY	Dogwood Ridge	SWI	FWS	3.800	
612	Duplin, NC	Juncus/Scirpus	USA	4	NC	Duplin Co.	SWI	FWS	0.024	
612	Duplin, NC	Rice System	USA	4	NC	Duplin Co.	SWI	FWS	0.012	
612	Duplin, NC	Soybean System	USA	4	NC	Duplin Co.	SWI	FWS	0.012	
612	Duplin, NC	Sporgonium/Typha	USA	4	NC	Duplin Co.	SWI	FWS	0.024	
501	Essex County, ONT	ERCA Wetland #1	Canada		ONT	Maidstone Township	DAI	FWS	0.060	
522	Guy Thompson Farm, PEI	Guy Thompson Farm	Canada		PEI	Dunstaffnage	DAI	FWS	0.151	
505	Hamilton-Wentworth, ONT	NPCA Wetland #2	Canada		ONT	Glanbrook Township	DAI	VSB		
603	Hattiesburg, MS	Pond I	USA	4	MS	Purvis	AQU	FWS	1.240	
603	Hattiesburg, MS	Pond II	USA	4	MS	Purvis	AQU	FWS		
600	Hernando, MS	Hernando 1	USA	4	MS	Hernando	DAI	FWS	0.040	

TABLE 4-1 (CONTINUED)
Wetland Sites and Systems in the Livestock Wastewater Treatment Wetland Database

Site No.	Site Name	System Name	Country	EPA Region	State	Community	Wastewater Code[a]	Hydrologic Type[b]	System Area (ha)	Design Flow (m^3/d)
600	Hernando, MS	Hernando 2	USA	4	MS	Hernando	DAI	FWS	0.020	
600	Hernando, MS	Hernando 3	USA	4	MS	Hernando	DAI	FWS	0.020	
515	Hickok Veal, PA	Hickok	USA	3	PA	Bradford County	CTL	FWS	0.138	3.03
544	Hopkins Co., KY	Hopkins Co.	USA	4	KY	Hopkins Co.	SWI	FWS	0.930	
513	Ken Hunter Farm, N_S	Ken Hunter Farm	Canada		NS	Inverness County	DAI	FWS	0.067	5.00
613	Key Dairy, GA	Key Dairy	USA	4	GA	Eatonton	DAI	FWS	0.350	
617	La Franchi, CA	La Franchi	USA	9	CA	Santa Rosa	DAI	FWS	0.104	54.50
610	Louis. St. Univ., LA	Black Willow	USA	6	LA	Baton Rouge	DAI	FWS	0.405	
610	Louis. St. Univ., LA	Duckweed/Emergent plant	USA	6	LA	Baton Rouge	DAI	FWS/OTH	0.202	
610	Louis. St. Univ., LA	Water hyacinth	USA	6	LA	Baton Rouge	DAI	OTH	0.202	
510	Lucky Rose Farm, IN	Lucky Rose Farm	USA	5	IN	Scott County	SWI	FWS/OTH	0.984	
545	McLean Co.#1, KY	McLean Co.#1	USA	4	KY	McLean Co.	SWI	FWS	0.650	
546	McLean Co.#2, KY	McLean Co.#2	USA	4	KY	McLean Co.	SWI	FWS	0.280	
547	McLean Co.#3, KY	McLean Co.#3	USA	4	KY	McLean Co.	SWI	FWS	0.121	
607	McMichael Dairy, GA	McMichael Dairy	USA	4	GA	Eatonton	DAI	FWS	0.290	
527	Mercer Co., KY	Mercer Co.	USA	4	KY	Mercer Co.	DAI	FWS	0.142	
517	Moyer Farm, PA	Moyer	USA	3	PA	Luzerne County	DAI	FWS	0.006	0.57
611	New Mexico State, NM	Aquaculture filter	USA	6	NM		AQU	FWS	0.000	
602	Newton, MS	Newton 1	USA	4	MS	Newton	DAI	FWS	0.020	
602	Newton, MS	Newton 2	USA	4	MS	Newton	DAI	FWS	0.020	
602	Newton, MS	Newton 3	USA	4	MS	Newton	DAI	FWS	0.020	
602	Newton, MS	Newton 4	USA	4	MS	Newton	DAI	FWS	0.020	
602	Newton, MS	Newton 5	USA	4	MS	Newton	DAI	FWS	0.020	
602	Newton, MS	Newton 6	USA	4	MS	Newton	DAI	FWS	0.020	
524	Norwood Farms, IN	Norwood Farms 1	USA	5	IN	Lagrange County	DAI	FWS	0.037	0.75
524	Norwood Farms, IN	Norwood Farms 2	USA	5	IN	Lagrange County	DAI	FWS	0.037	0.75
524	Norwood Farms, IN	Norwood Farms 3	USA	5	IN	Lagrange County	DAI	FWS	0.037	0.75
526	Nowicki Farm, ALB	Nowicki Farm	Canada		AB	Vegreville	CTL	FWS	0.048	
514	Oregon State University, OR	Oregon State University 1	USA	10	OR	Corvallis	DAI	FWS	0.088	5.40
514	Oregon State University, OR	Oregon State University 2	USA	10	OR	Corvallis	DAI	FWS	0.088	5.40
514	Oregon State University, OR	Oregon State University 3	USA	10	OR	Corvallis	DAI	FWS	0.088	5.40
514	Oregon State University, OR	Oregon State University 4	USA	10	OR	Corvallis	DAI	FWS	0.088	5.40
514	Oregon State University, OR	Oregon State University 5	USA	10	OR	Corvallis	DAI	FWS	0.088	5.40
514	Oregon State University, OR	Oregon State University 6	USA	10	OR	Corvallis	DAI	FWS	0.088	5.40
502	Perth County, ONT	UTRCA Wetland #1	Canada		ONT	Fullarton Township	DAI	FWS/OTH	0.090	
528	Piscataquis River, ME	Piscataquis River	USA	1	ME		DAI	FWS	0.037	1.90
601	Pontotoc, MS	Pontotoc 1	USA	4	MS	Pontotoc	SWI	FWS	0.160	

TABLE 4-1 (CONTINUED)
Wetland Sites and Systems in the Livestock Wastewater Treatment Wetland Database

Site No.	Site Name	System Name	Country	EPA Region	State	Community	Wastewater Code [a]	Hydrologic Type [b]	System Area (ha)	Design Flow (m^3/d)
601	Pontotoc, MS	Pontotoc 2	USA	4	MS	Pontotoc	SWI	FWS	0.160	
530	Purdue University, IN	A1	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.45
530	Purdue University, IN	A2	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.45
530	Purdue University, IN	A3	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.45
530	Purdue University, IN	A4	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.45
530	Purdue University, IN	B1	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	B2	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	B3	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	B4	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	C1	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	C2	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	C3	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	C4	USA	5	IN	Montmorenci	SWI	FWS	0.002	0.90
530	Purdue University, IN	D1	USA	5	IN	Montmorenci	SWI	FWS	0.002	1.80
530	Purdue University, IN	D3	USA	5	IN	Montmorenci	SWI	FWS	0.002	1.80
530	Purdue University, IN	D4	USA	5	IN	Montmorenci	SWI	FWS	0.002	1.80
504	Region of Niagara, ONT	NPCA Wetland #1	Canada		ONT	West Lincoln Township	CTL	FWS	0.000	
506	Region of Ottawa-Carlton, ONT	RVCA Wetland #1	Canada		ONT	Oxford-on-Rideau Township	CTL	FWS	0.024	
508	Region of Peel, ONT	MTRCA Grassed Strip #1	Canada		ONT	Town of Caledon	CTL	FWS		
507	Russel County, ONT	SNRCA Wetland #1	Canada		ONT	Russell Township	DAI	FWS		
500	Saint-Felicien, QUE	Zoo de Saint-Felicien (III)	Canada		QUE	Saint-Felicien	CTL	VSB/OTH	0.246	
500	Saint-Felicien, QUE	Zoo de Saint-Felicien (IV)	Canada		QUE	Saint-Felicien	CTL	VSB/OTH	0.471	
604	Sand Mountain, AL	Sand Mountain 1	USA	4	AL	Crossville	SWI	FWS	0.072	
604	Sand Mountain, AL	Sand Mountain 2	USA	4	AL	Crossville	SWI	FWS	0.072	
604	Sand Mountain, AL	Sand Mountain 3	USA	4	AL	Crossville	SWI	FWS	0.072	
604	Sand Mountain, AL	Sand Mountain 4	USA	4	AL	Crossville	SWI	FWS	0.072	
604	Sand Mountain, AL	Sand Mountain 5	USA	4	AL	Crossville	SWI	FWS	0.072	
503	Simco County #1, ONT	NVCA Wetland #1	Canada		ONT	Essa Township	DAI	FWS/OTH		
509	Simco County #2, ONT	SSRAP Grassed Strip #1	Canada		ONT	Springwater Township	CTL	FWS		
539	Spencer Co., KY	Spencer Co.	USA	4	KY	Spencer Co.	DAI	FWS	0.039	
614	Texas, TX	S.W.A.M.P. project	USA	6	TX	Stephenville	DAI	FWS	0.166	
608	Tifton, GA	Tifton 1	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 10	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 11	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 12	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 13	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 14	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 15	USA	4	GA	Tifton	SWI	OTH	0.012	

TABLE 4-1 (CONTINUED)
Wetland Sites and Systems in the Livestock Wastewater Treatment Wetland Database

Site No.	Site Name	System Name	Country	EPA Region	State	Community	Wastewater Code [a]	Hydrologic Type [b]	System Area (ha)	Design Flow (m^3/d)
608	Tifton, GA	Tifton 16	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 17	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 18	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 2	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 3	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 4	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 5	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 6	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 7	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 8	USA	4	GA	Tifton	SWI	OTH	0.012	
608	Tifton, GA	Tifton 9	USA	4	GA	Tifton	SWI	OTH	0.012	
529	Tom Brothers Farm, IN	Tom Brothers	USA	4	IN	Kosclusko County	DAI	FWS	0.186	
521	U of Connecticut, CT	Kellogg Dairy Research Facility	USA	1	CT	Storrs	DAI	FWS	0.037	2.66
548	Union Co., KY	Swine	USA	4	KY	Union and Crittenden Co.s	SWI	FWS	0.100	
548	Union Co., KY	Union Co.	USA	4	KY	Union Co.	SWI	FWS	0.122	
609	Univ. of SW Louis., LA	Deep Trench	USA	6	LA	Lafayette	DAI	FWS	0.010	
609	Univ. of SW Louis., LA	Free Water System	USA	6	LA	Lafayette	DAI	FWS	0.020	
609	Univ. of SW Louis., LA	Subsurface Flow	USA	6	LA	Lafayette	DAI	OTH	0.012	
540	Warren Co., KY	Warren Co.	USA	4	KY	Warren Co.	DAI	FWS	0.012	
541	Washington Co., KY	Washington Co.	USA	4	KY	Washington Co.	DAI	FWS	0.027	
537	Wayne Co.#1, KY	Wayne Co.#1	USA	4	KY	Wayne Co.	DAI	FWS	0.028	
538	Wayne Co.#2, KY	Wayne Co.#2	USA	4	KY	Wayne Co.	DAI	FWS	0.017	
511	Wayne White Farm, N_S	Wayne White Farm	Canada		NS	Greenfield	SWI	FWS	0.433	7.60
	Average								0.591	6.34
	Median								0.027	0.90
	Maximum								47.000	102.60
	Minimum								0.000	0.29

Notes:
All treatment wetlands are constructed systems.

[a]Wastewater Code
AQU = aquaculture
CTL = cattle feeding
DAI = dairy
POU = poultry
SWI = swine

[b]Hydrologic Type
FWS = free water system
OTH = other
VSB = veg. subm. bed

FIGURE 4-1
Distribution of Engineered Agricultural Wetlands in the LWDB

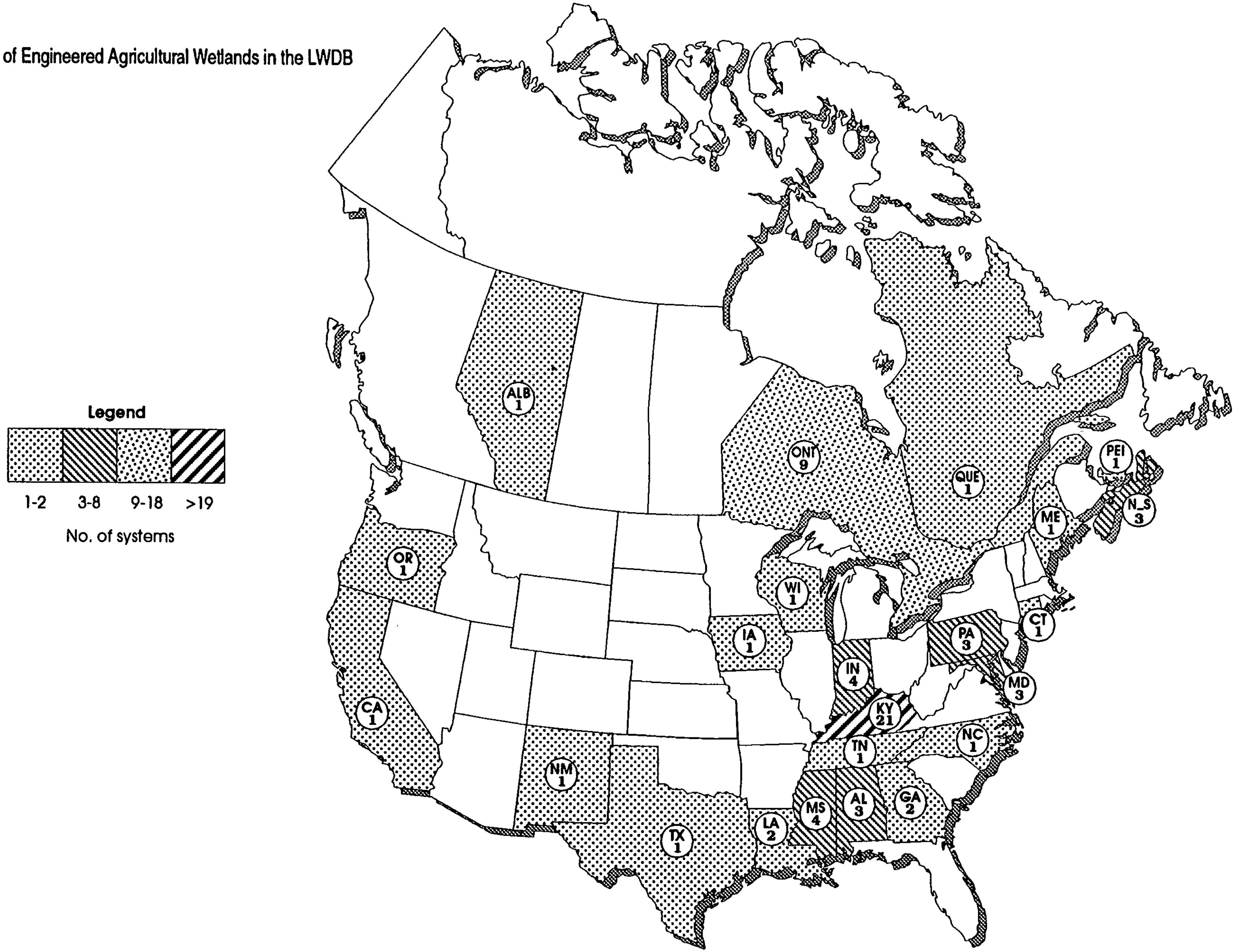
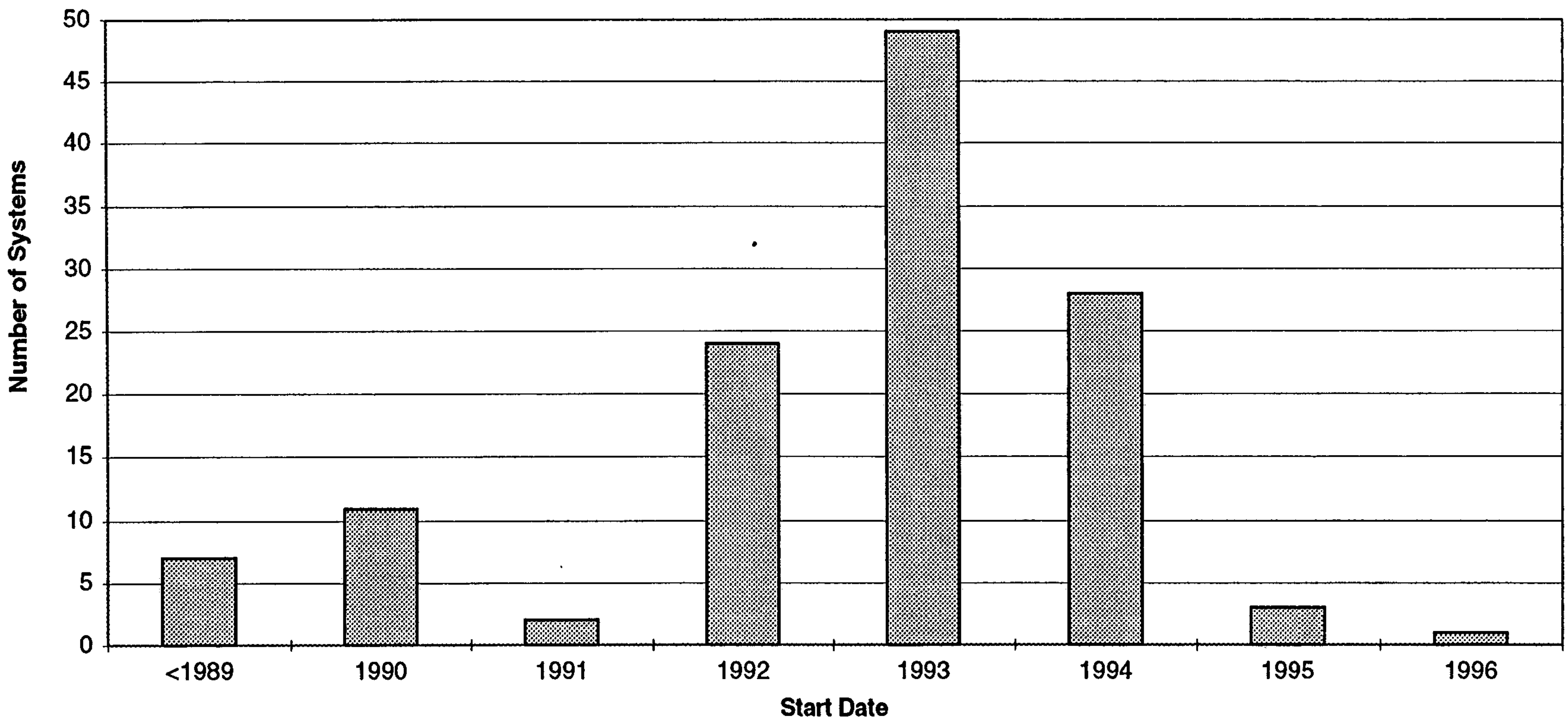


FIGURE 4-2
Starting Dates of Livestock Wastewater Wetland Treatment Systems



and 1996, primarily because these systems were too new to be discovered through the literature review.

Treatment Wetland Area

The majority of the wetlands engineered for livestock wastewater treatment are small (Figure 4-3), with an average system area of 0.6 ha and a median size of 0.03 ha (Table 4-1). The majority of the swine, poultry, and dairy treatment wetland systems are less than 0.1 ha. Most of the Kentucky swine systems are larger than 1 ha. The only large animal waste wetland system in the LWDB is the Brenton Cattle system in Dallas Center, Iowa, with an area of about 47 ha.

The average treatment wetland cell area is 0.3 ha, and the median cell area is only 0.02 ha (see Table C-1 in Appendix C). Many of these systems were designed for research purposes and not as full-scale installations.

System Design Flow

Only a few systems reported design flow, and most of these systems had a design flow of less than 10 m^3/d (Figure 4-4). The swine waste wetland at Delmarva Farms in Maryland reported the highest design flow (103 m^3/d).

Hydraulic Loading Rate

The hydraulic loading rate, q, is defined as the inlet flow (Q_i) divided by the wetland area (A):

$$q = Q_i/A \qquad (4\text{-}1)$$

where: q = hydraulic loading rate, m/d

Q_i = inlet flow rate, m^3/d

A = wetland area, m^2

Hydraulic loading rate is frequently reported in units of cm/d. Figure 4-5 summarizes the actual operational hydraulic loading rates reported in the LWDB. The average hydraulic loading rate for the treatment wetlands in the database was 4.7 cm/d, and the median was 3.9 cm/d. Average hydraulic loading rates for specific waste categories were 5 cm/d for dairy, 5.5 cm/d for poultry, and 3.8 cm/d for swine. Only two experimental cells at Newton, Mississippi, had operational hydraulic loading rates greater than 10 cm/d. The Hernando, Mississippi, and Kellog Wetland in Connecticut, both treating dairy wastewaters, had operational hydraulic loading rates less than 1 cm/d.

Length-to-Width Ratio

Length-to-width ratios were reported for 206 wetland cells. The average ratio was 6.5:1, and the median ratio was 5.1:1. The minimum ratio was 0.5:1 and the maximum was 60:1 at the Region of Ottawa-Carlton system in Ontario.

FIGURE 4-3
Size Distribution of Livestock Wastewater Treatment Wetlands

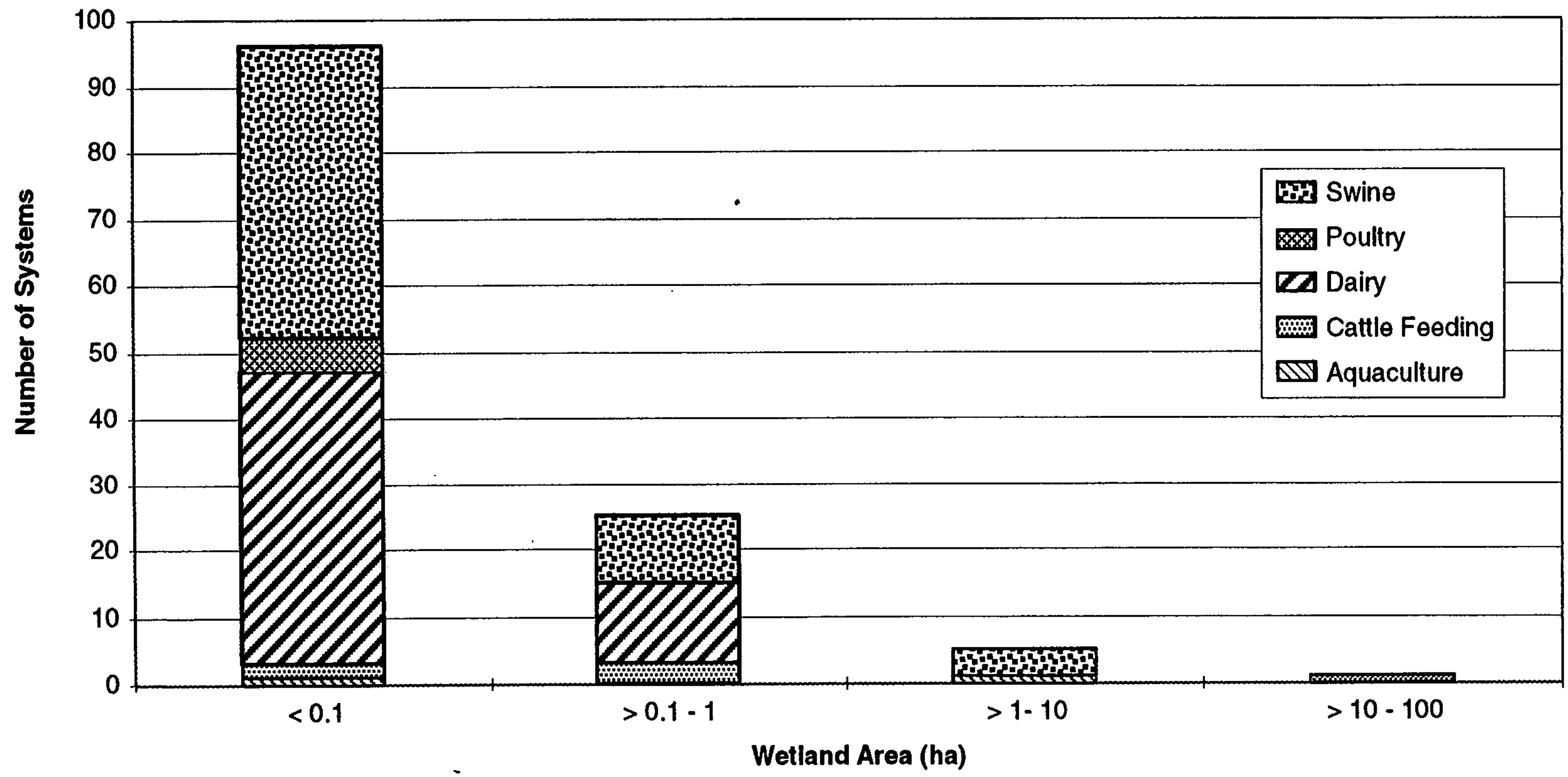


FIGURE 4-4
System Design Flow (m^3/d) for Livestock Wastewater Treatment Wetlands

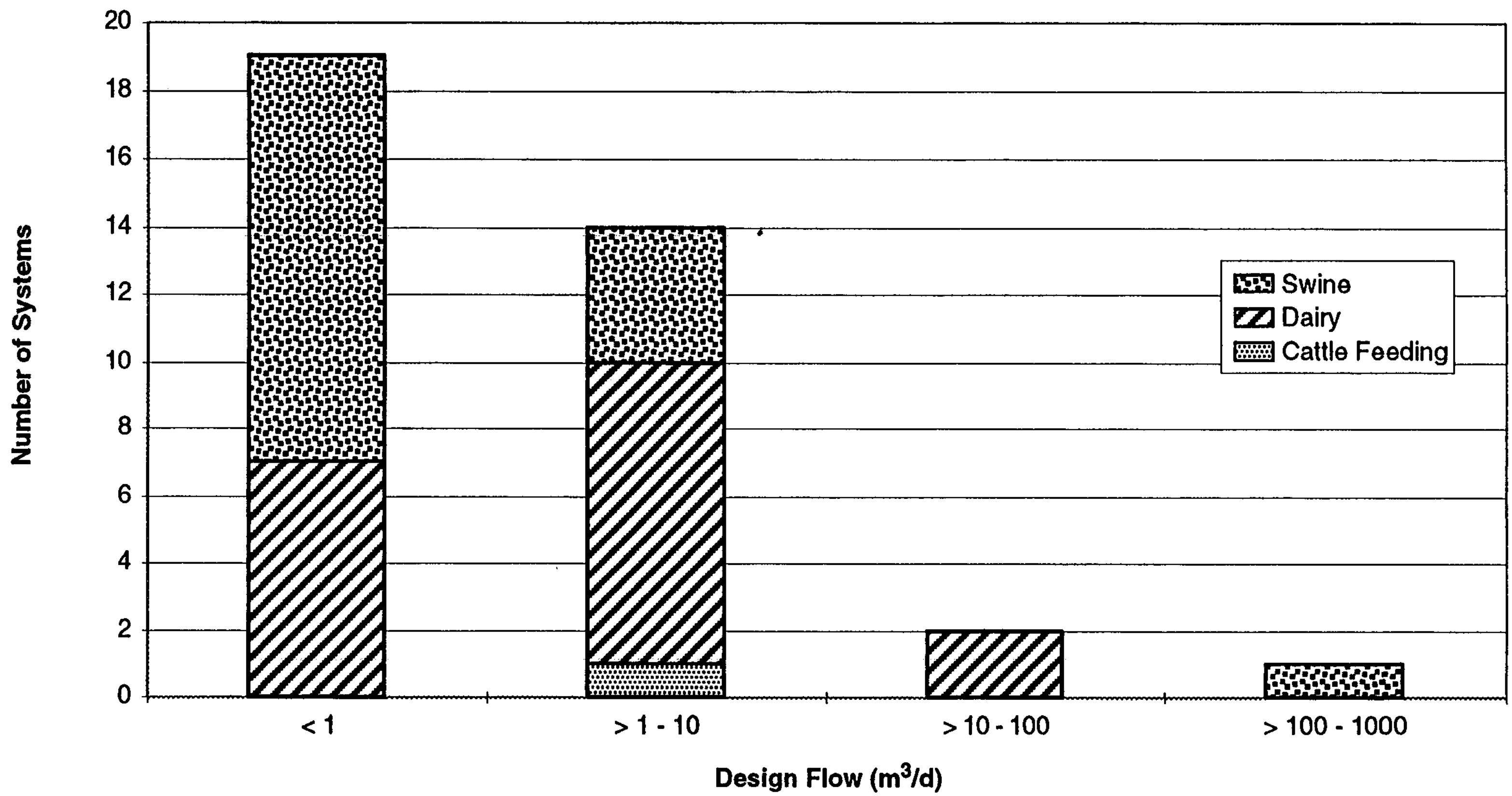
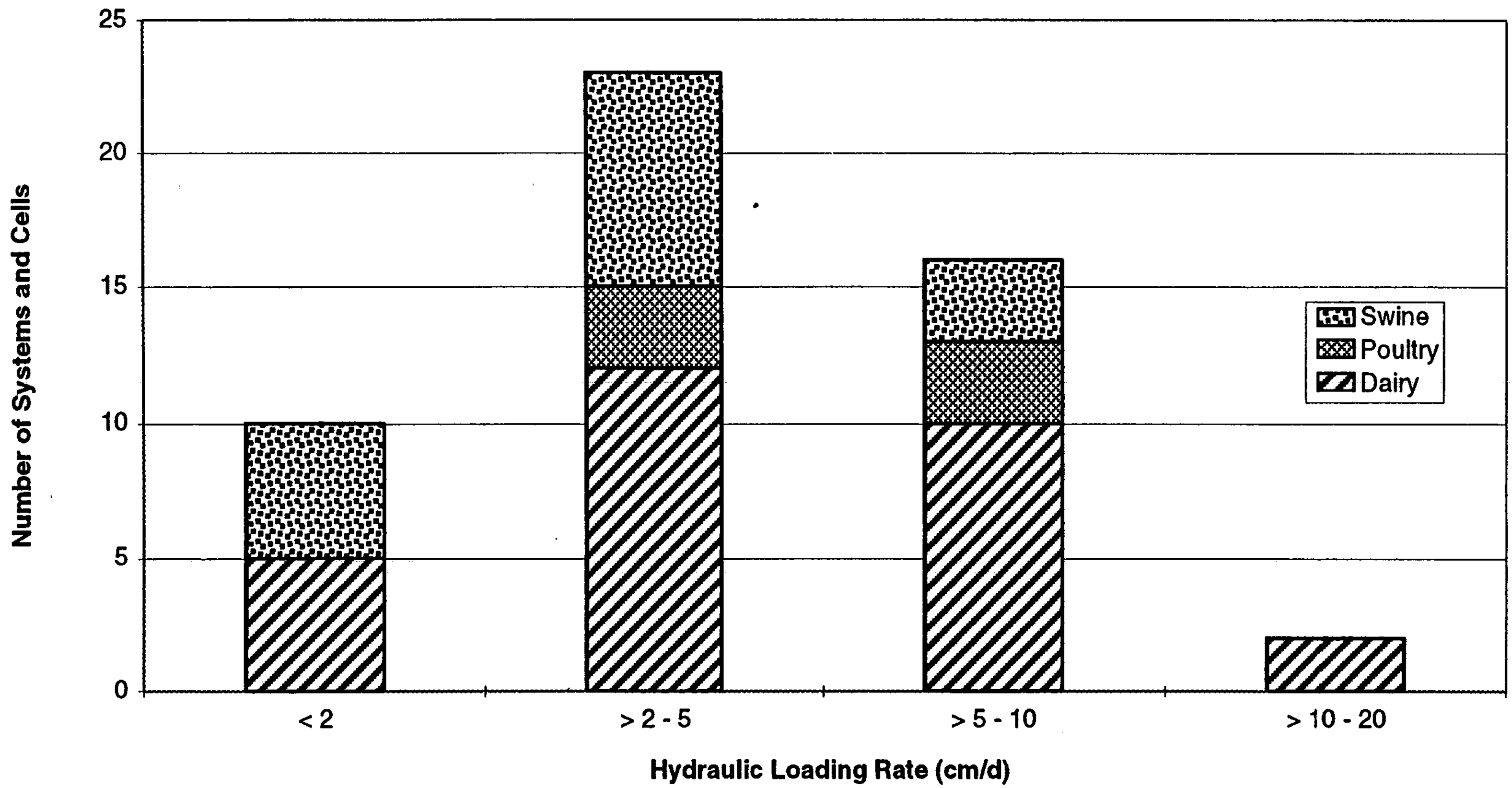


FIGURE 4-5
Hydraulic Loading Rates for Livestock Wastewater Treatment Wetlands



Design Water Depth

Design water depth information was available for 168 wetland cells (Table C-1). The average design depth was 38 cm, and the median was 30 cm. The minimum depth was less than 1 cm, and the maximum design depth was 120 cm. These are design depths including both shallow and deep zones in treatment wetland cells. Operational water depths in emergent marsh areas are typically 30 cm or less.

Bottom Slope

Cell bottom slope was reported for 83 cells (Table C-1). The average slope in the direction of flow was 0.7 percent, and the median slope was 0.5 percent. The minimum design slope was 0 percent, and the maximum was 2 percent.

Vegetation

Figure 4-6 and Table C-4 (in Appendix C) summarize the treatment wetland plant species used for different categories of animal wastes. The most commonly used plant species, in order of their occurrence in treatment wetland cells, were cattails (*Typha* spp.), bulrush (*Scirpus* spp.), and common reed (*Phragmites australis*).

Performance Summary

Operational data from the LWDB are summarized in Tables 4-2 and C-2 (in Appendix C) and in Figure 4-7 for BOD_5, TSS, TKN, NH_4-N, NO_3-N, TN, ORG-N, TP, DP, FC, conductivity, TDS, VSS, COD, temperature, and pH. Only one annual or long-term average was used for each wetland treatment system in the database to derive the summary performance statistics in Table 4-2. These statistics are global values and do not necessarily reflect the performance capability of any single system. Carefully designed and operated treatment wetlands would be expected to exceed these performance expectations, while systems with less than optimal plant communities, flow distribution, or water depth control might perform at lower levels.

Five-Day Biochemical Oxygen Demand

BOD_5 is a measure of the particulate and solid organic matter that can be microbially decomposed in 5 days in the presence of oxygen. Units are in mg/L of oxygen consumed in the decomposition process.

Average inflow and outflow BOD_5 concentrations for the LWDB were 263 and 93 mg/L, for an average concentration reduction efficiency of 65 percent. Median BOD_5 inflow and outflow concentrations were 81 and 31 mg/L for an efficiency of 62 percent. The maximum average inlet BOD_5 was 3,162 mg/L at the University of Connecticut Kellogg farm receiving dairy wastes. Table 4-2 shows average inflow and outflow BOD_5 concentrations and concentration reduction efficiencies for different waste types in the LWDB.

Figure 4-8 summarizes the observed relationship between BOD_5 mass loading and treatment wetland outflow concentration. A simple regression equation fitted to these data allows the estimation of the average BOD_5 wetland outlet concentration C_2 based on the inlet concentration (C_1):

$$C_2 = 0.766\, C_1^{\,0.878} \qquad (4\text{-}2)$$

FIGURE 4-6
Dominant Plant Species for Wetlands in the LWDB

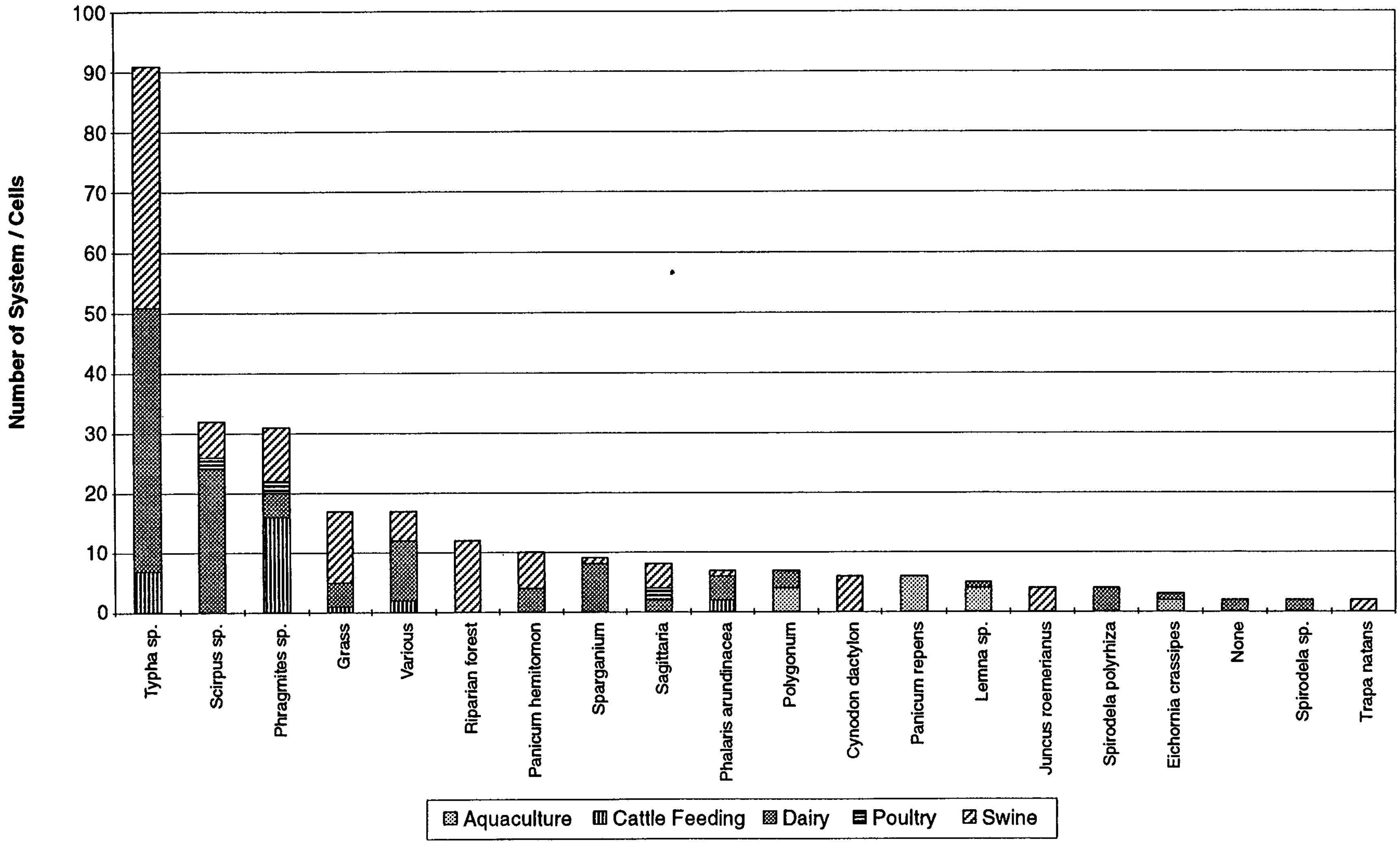


TABLE 4-2
Average Treatment Wetland Performance for Removal of BOD_5, TSS, NH_4-N, and TN

Wastewater Type	Average Inflow Concentration (mg/L)	Average Outflow Concentration (mg/L)	Average Concentration Reduction (%)
BOD_5			
Cattle feeding	113	22	80
Dairy	404	129	68
Poultry	153	115	25
Swine	81	33	59
TSS			
Cattle feeding	291	55	81
Dairy	914	432	53
Swine	107	49	54
NH_4-N			
Cattle feeding	5.1	2.2	57
Dairy	74.3	30	59.6
Poultry	74.0	59.2	20
Swine	203.6	110.6	46
TN			
Dairy	129.2	47.7	63
Poultry	89.0	69.7	22
Swine	373.3	210.8	44

FIGURE 4-7
Average Concentration Reductions for Wetlands in the LWDB

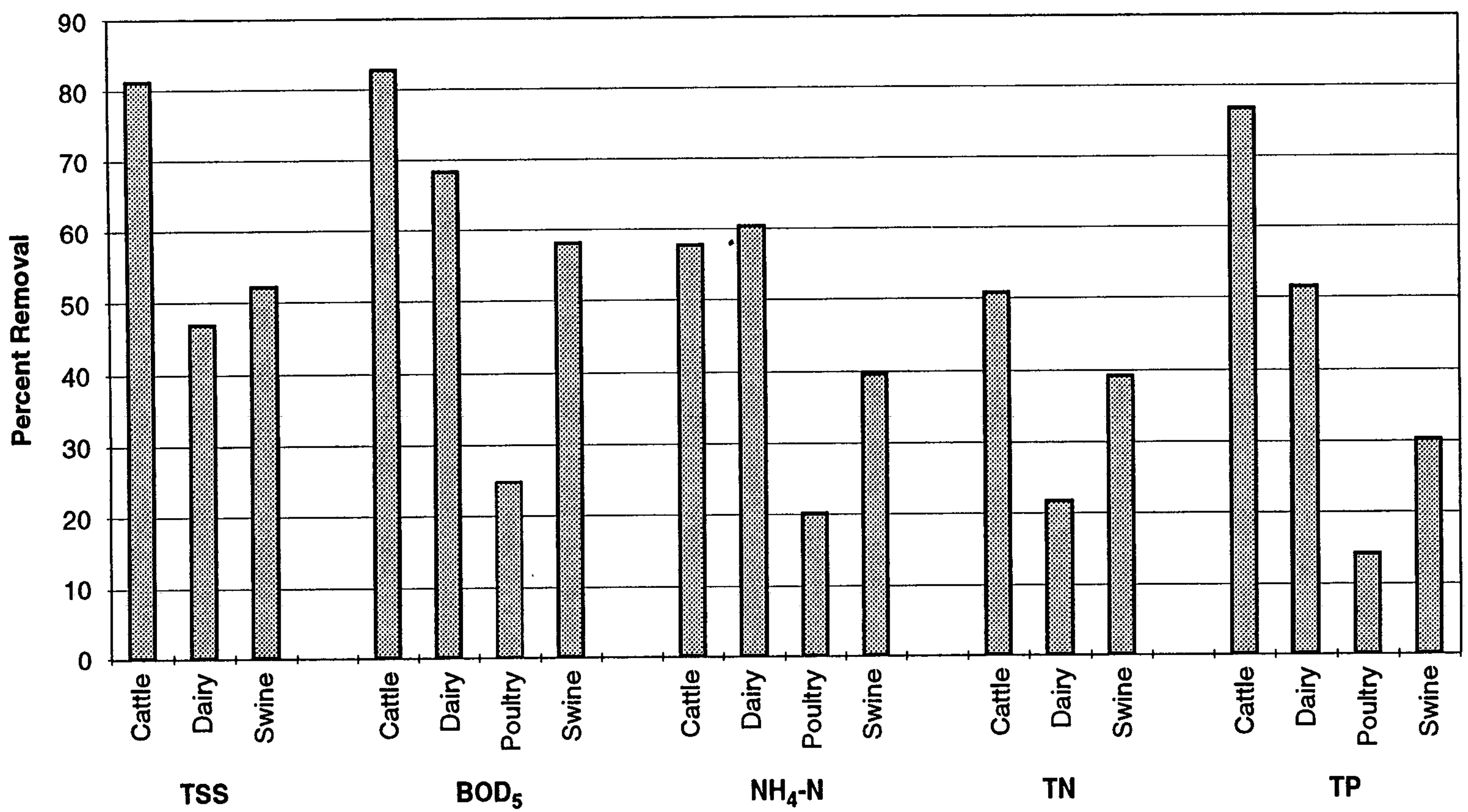
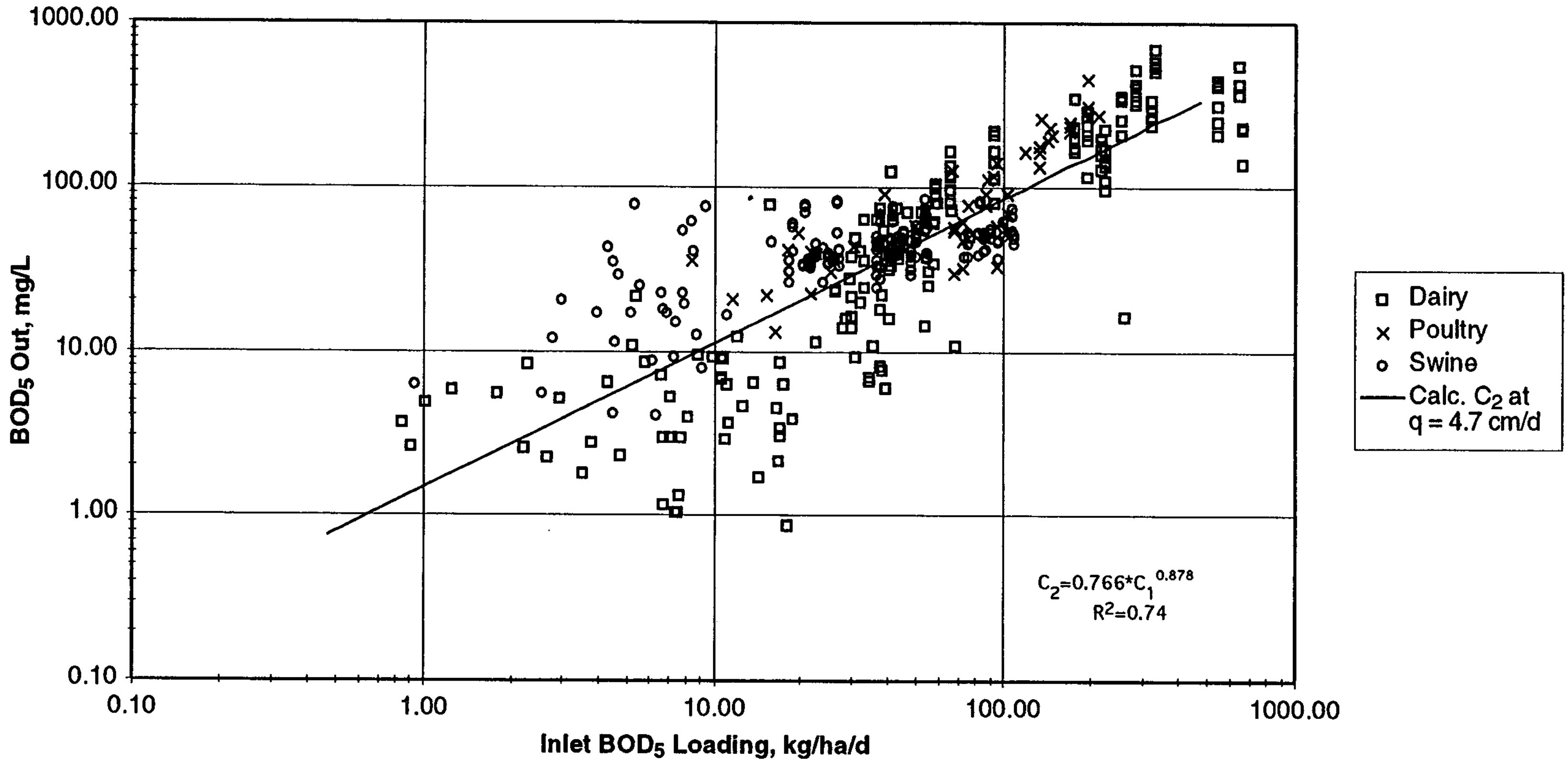


FIGURE 4-8
Relationship between BOD_5 Mass Loading and Outfall Concentration for Data in the LWDB



$R^2 = 0.74$

$C_1 = 1$ to 1,679 mg/L

$C_2 = 1$ to 682 mg/L

Based on the value of $R^2 = 0.74$, it is noted that this relationship does not explain a large amount of the variability in outlet BOD_5 concentrations, and should be used with caution.

Total Suspended Solids

TSS is a measure of the solid matter in a water sample that is retained by a specific filter. TSS may contain organic matter that can contribute to BOD_5 and inorganic minerals such as sand or clay.

Average inflow and outflow TSS concentrations for the LWDB were 585 and 273 mg/L, for an average concentration reduction efficiency of 53 percent. Median TSS inflow and outflow concentrations were 118 and 51 mg/L for a reduction efficiency of 57 percent. The maximum average inlet TSS was 11,300 mg/L at Norwood Dairy Farms in LaGrange, Tennessee. Table 4-2 shows average TSS inflow and outflow concentrations and concentration reduction efficiencies for different waste types in the LWDB.

Figure 4-9 summarizes the observed relationship between TSS mass loading and treatment wetland outflow concentration. A simple regression equation fitted to these data allows the estimation of the average TSS wetland outlet concentration C_2 based on the inlet concentration (C_1) and the average inlet hydraulic loading rate (q):

$$C_2 = 2.334\, C_1^{0.582}\, q^{0.227} \qquad (4\text{-}3)$$

$R^2 = 0.30$

$C_1 = 4$ to 1,270 mg/L

$C_2 = 2$ to 641 mg/L

$q = 0.3$ to 49 cm/d

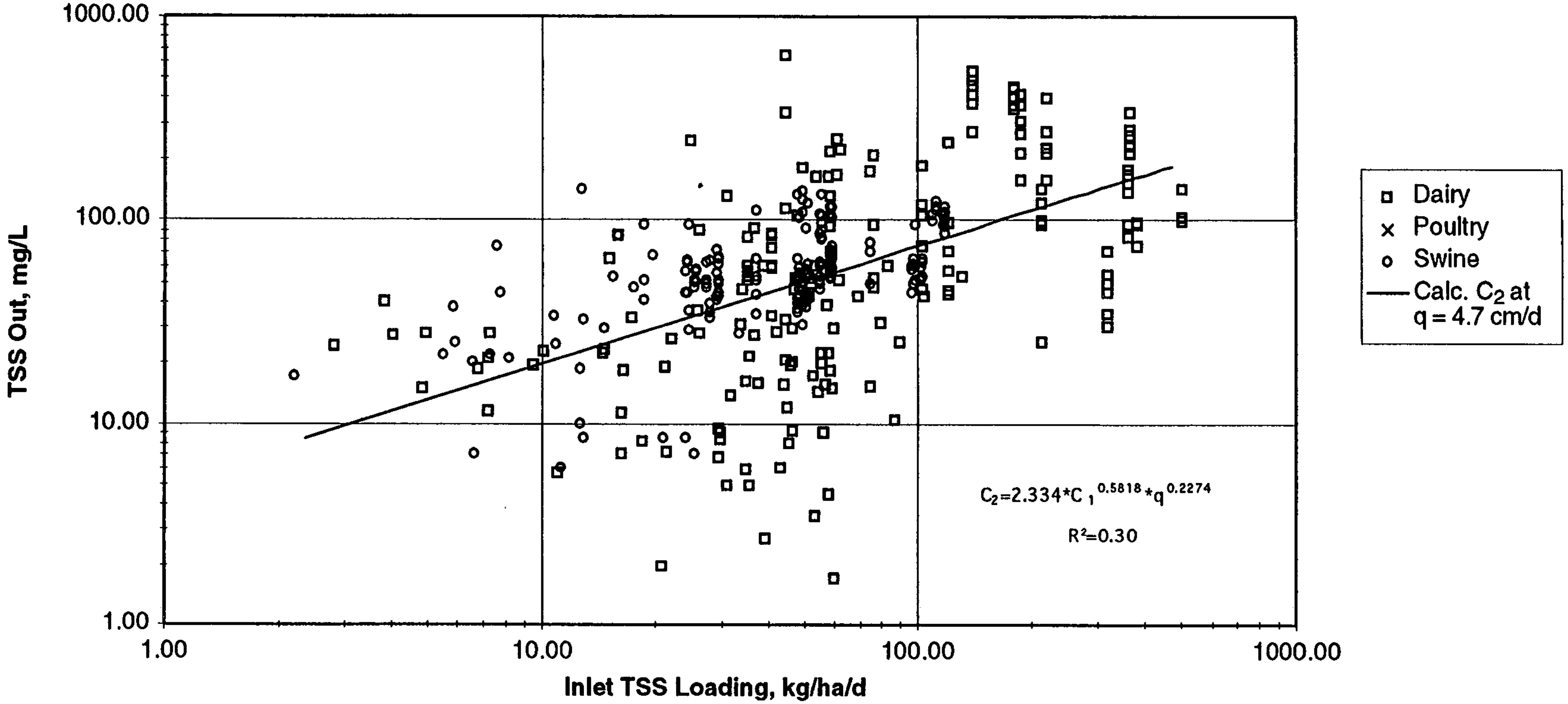
This relatively poor fit indicates that wetland outlet TSS concentrations cannot be accurately predicted based on inflow concentration or hydraulic loading rate.

Nitrogen

Several forms of nitrogen are important in concentrated animal wastewaters. The major forms are (1) organic nitrogen in proteins, amino acids, and urea; (2) NH_4-N, which derives principally from mineralization of organic nitrogen forms; and (3) NO_2-N and NO_3-N, which are formed when NH_4-N is nitrified in the presence of oxygen. Total nitrogen is the sum of organic N, NH_4-N, and NO_2-N + NO_3-N. The sum of organic and NH_4-N is measured analytically as TKN. All of these nitrogen forms have been measured in livestock wastewater wetlands and are reported in the LWDB. Table C-2 in Appendix C summarizes these results.

The majority of the TKN in most of the livestock wastewater systems in Table C-2 is in the ammonium form. At the Auburn poultry system, ammonium averaged 84 percent of the

FIGURE 4-9
Relationship betweenTSS Mass Loading and Outfall Concentration for Data in the LWDB



TKN. At LSU, the ammonium fraction was 73 percent. At Pontotoc, the fraction was 86 percent, and at Sand Mountain, Alabama, the ammonium fraction averaged 82 percent.

The average inlet and outlet ammonium nitrogen concentrations for all of the systems in Table C-2 were 122.2 and 63.7 mg/L and reduction efficiency was 48 percent. The median values were 59.8 and 18.9 mg/L for an efficiency of 68 percent. Table 4-2 shows average NH_4-N concentration reductions for different wastewater types.

NO_3-N concentrations were generally low at most sites. Average inflow and outflow concentrations were 3.6 and 2.3 mg/L for an average concentration reduction efficiency of 35 percent. The median concentration was reduced from 1.1 to 0.9 mg/L.

Average total nitrogen inflow and outflow concentrations were 254.1 and 147.5 mg/L for an average concentration reduction efficiency of 42 percent. Median concentrations were 273.6 and 98.9 mg/L for a concentration reduction efficiency of 64 percent. Table 4-2 shows average total nitrogen inflow and outflow concentrations and reduction efficiencies for different animal waste types.

Figure 4-10 summarizes the observed relationship between NH_4-N mass loading and treatment wetland outflow concentration. A simple regression equation fitted to these data allows the estimation of the average NH_4-N wetland outlet concentration C_2 based on the inlet concentration (C_1) and the average inlet hydraulic loading rate (q):

$$C_2 = 0.682\, C_1^{\,0.874}\, q^{\,0.319} \qquad (4\text{-}4)$$

$R^2 = 0.87$

$C_1 = 3$ to 1,122 mg/L

$C_2 = 0.6$ to 951 mg/L

$q = 0.3$ to 48 cm/d

Figure 4-11 summarizes the observed relationship between TN mass loading and treatment wetland outflow concentration. A simple regression equation fitted to these data allows the estimation of the average TN wetland outlet concentration C_2 based on the inlet concentration (C_1) and the average inlet hydraulic loading rate (q):

$$C_2 = 0.358\, C_1^{\,1.016}\, q^{\,0.226} \qquad (4\text{-}5)$$

$R^2 = 0.81$

$C_1 = 21$ to 1,127 mg/L

$C_2 = 4$ to 958 mg/L

$q = 0.3$ to 7.8 cm/d

Phosphorus

Animal wastes typically contain organically-bound phosphorus and dissolved inorganic phosphorus. These organic and inorganic forms can be analyzed together as total

FIGURE 4-10
Relationship between NH_4-N Mass Loading and Outfall Concentration for Data in the LWDB

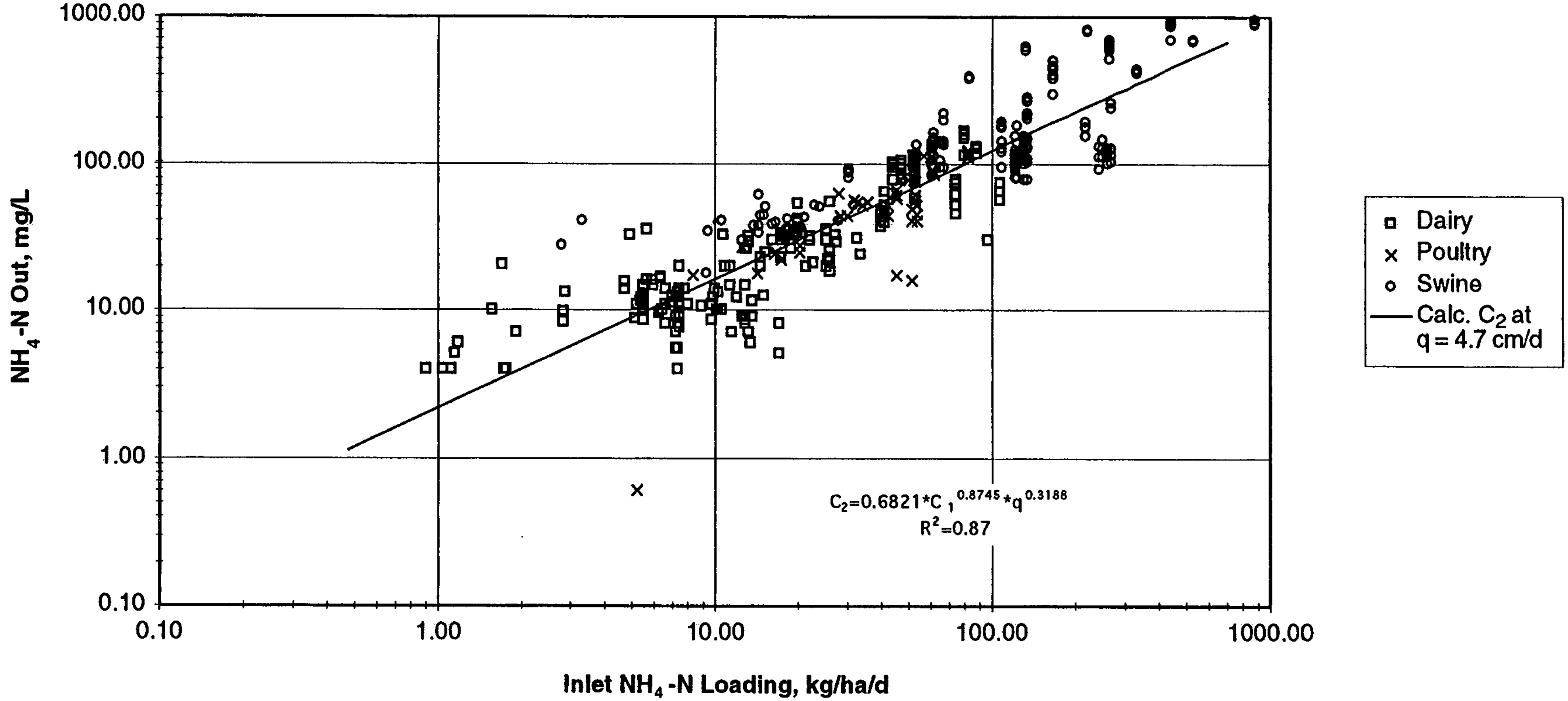
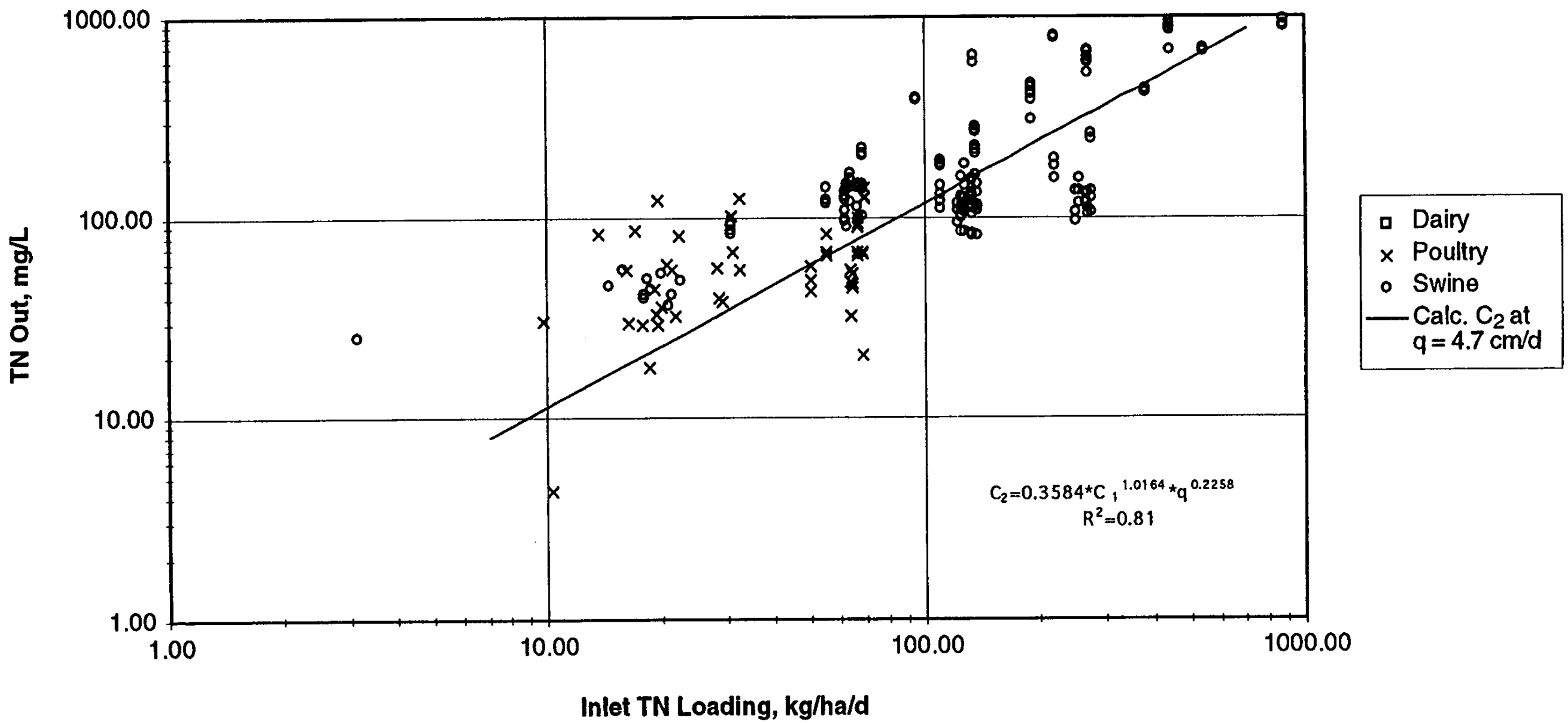


FIGURE 4-11
Relationship between TN Mass Loading and Outfall Concentration for Data in the LWDB



phosphorus. Both total phosphorus and dissolved phosphorus are reported in the LWDB and in Table C-2 in Appendix C.

Average inflow and outflow TP concentrations for the LWDB were 24.3 and 14.1 mg/L, for an average concentration reduction of 42 percent. Median TP inflow and outflow concentrations were 20.3 and 13.4 mg/L for an average reduction of 34 percent.

Figure 4-12 summarizes the observed relationship between TP mass loading and treatment wetland outflow concentration. A simple regression equation fitted to these data allows the estimation of the average TP wetland outlet concentration C_2 based on the inlet concentration (C_1) and the average inlet hydraulic loading rate (q):

$$C_2 = 0.511\, C_1^{\,1.008}\, q^{\,0.170} \qquad (4\text{-}6)$$

$R^2 = 0.70$

$C_1 = 3.5$ to 107 mg/L

$C_2 = 0.6$ to 92 mg/L

$q = 0.3$ to 7.8 cm/d

Based on the value of $R^2 = 0.70$, it is noted that this relationship does not explain a large amount of the variability in outlet TP concentrations, and should be used with caution

Fecal Coliforms

Fecal coliforms are a component of wastewaters derived from warm-blooded animals and are used as an environmental indicator of the potential for pathogenic contamination. Fecal coliform densities in raw wastewaters are typically high and can be reduced before wetland discharge by pretreatment or dilution. Inlet fecal coliform densities in the LWDB are highly variable, ranging from a system average of one to a high of 1,030,000 col/100 mL in one dairy system. The average wetland reduction for fecal coliforms was from 160,477 to 13,424 col/100 mL for an efficiency of 92 percent. The median concentrations were 1,742 col/100 mL and 55 col/100 mL for a reduction efficiency of 97 percent.

Salts

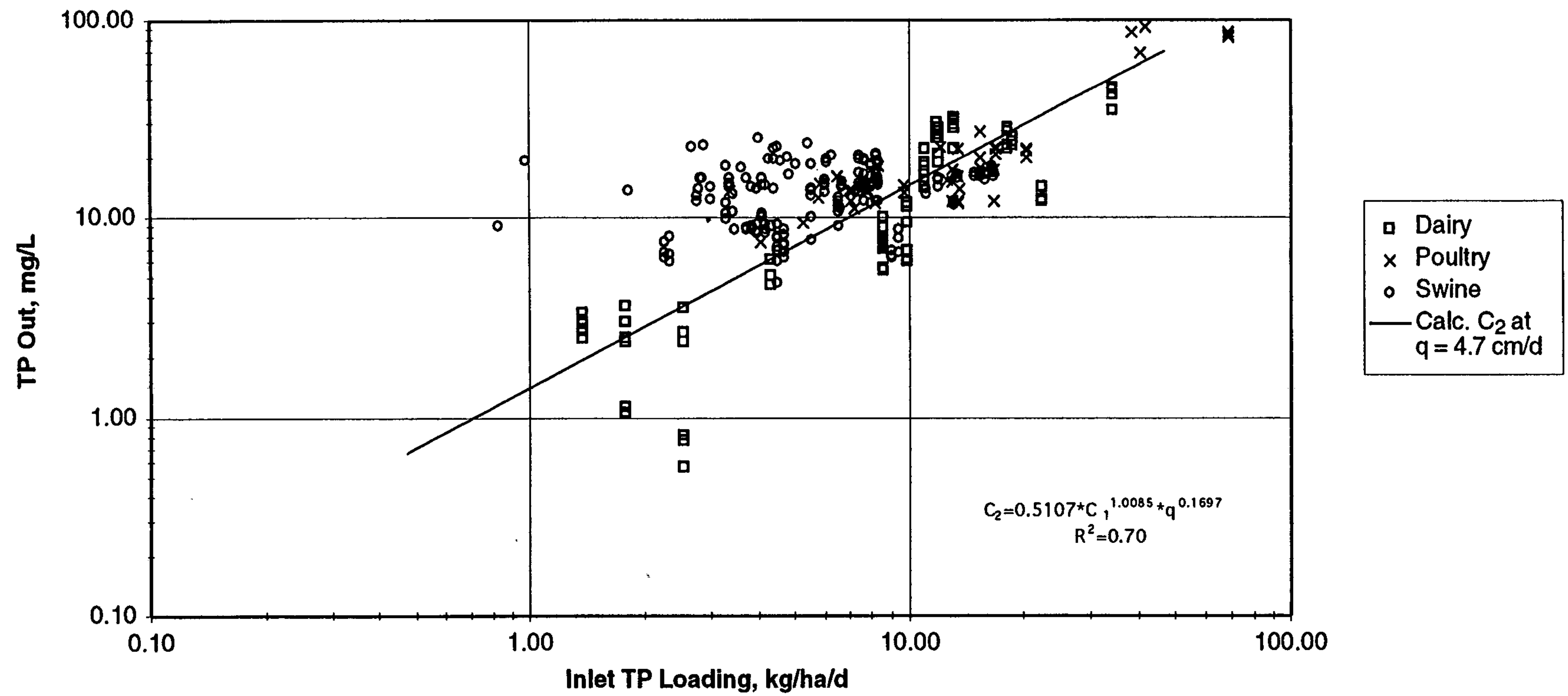
The general salt content of concentrated animal wastewaters can be surmised by measuring conductivity and total dissolved solids (Table C-2). Treatment wetlands have little effect (other than dilution or concentration by net precipitation) on concentrations of these environmentally conservative parameters. Average concentration reduction efficiencies were 21 percent for conductivity and 15 percent for TDS.

Other Parameters

Temperature data were reported for some of the treatment wetland systems. The typical effect of the wetland on water temperature is an approach to ambient air temperature. The net effect on most dates was a decrease of about 1 degree Celsius (°C).

Average wetland inlet pH values ranged from 6 to 8.4 units. In most cases, pH changed very little between the inlet and outlet wetland stations.

FIGURE 4-12
Relationship between TP Mass Loading and Outfall Concentration for Data in the LWDB



Dissolved oxygen concentrations are typically below saturation in wetland surface waters. This observation was true in the concentrated livestock wastewater treatment wetlands with low dissolved oxygen at both the wetland inlet and outlet. The average dissolved oxygen concentration declined from 2.5 to 1.6 mg/L for the systems listed in Table C-2 in Appendix C.

Few data were reported for changes in COD through treatment wetlands. Average concentrations decreased from 1,004 to 536 mg/L for a reduction efficiency of 47 percent. The highest average COD reduction occurred for dairy wastes from 2,003 to 946 mg/L for an efficiency of 53 percent; COD in poultry wastewater for one site declined from 405 to 290 mg/L for an efficiency of 28 percent during the year of startup.

Figure 4-13 summarizes the observed relationship between COD mass loading and treatment wetland outflow concentration. A simple regression equation fitted to these data allows the estimation of the average COD wetland outlet concentration C_2 based on the inlet concentration (C_1) and the average inlet hydraulic loading rate (q):

$$C_2 = 1.042\, C_1^{\,0.851}\, q^{\,0.259} \quad (4\text{-}7)$$

$R^2 = 0.89$

$C_1 = 49$ to 3,810 mg/L (g/m^3)

$C_2 = 34$ to 2,172 mg/L (g/m^3)

$q = 0.7$ to 6.5 cm/d

First-Order Model Reaction Rates

Typical treatment wetland concentration profiles decline over distance from the inlet in an approximately exponential pattern (Figure 4-14). Pollutant concentrations follow this pattern over time in batch experiments and with distance from inlet to outlet. Some pollutant concentrations decline to near-zero values while others level off to some background concentration.

The simplest model that summarizes this behavior is a first-order reaction with a zero order return (Kadlec and Knight, 1996):

$$J = k(C - C^*) \quad (4\text{-}8)$$

where:

J	=	constituent reduction rate, grams per square meter per year (g/m^2/yr)
k	=	first order rate constant, m/yr
C	=	constituent concentration, mg/L (g/m^3)
C*	=	background constituent concentration, mg/L (g/m^3)

FIGURE 4-13
Relationship between COD Mass Loading and Outfall Concentration for Data in the LWDB

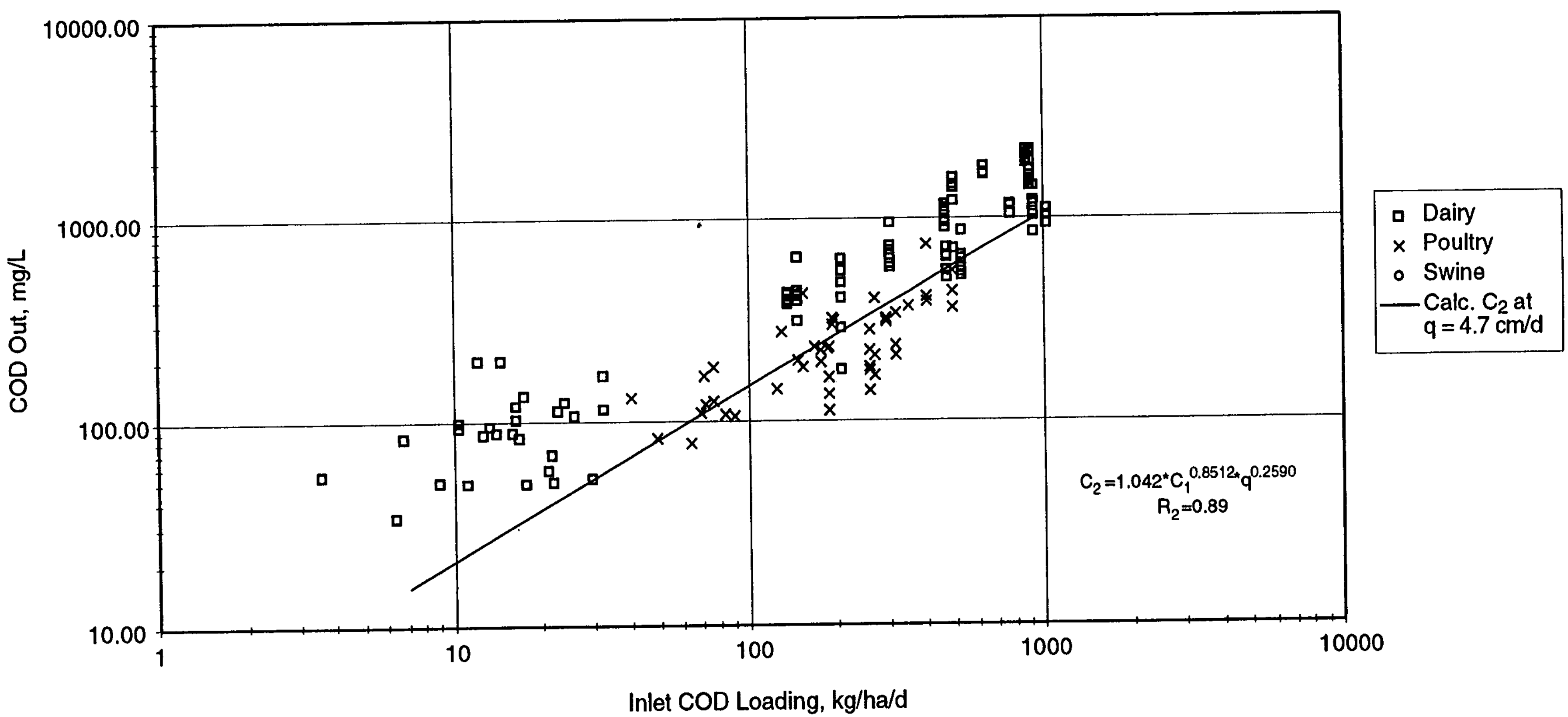
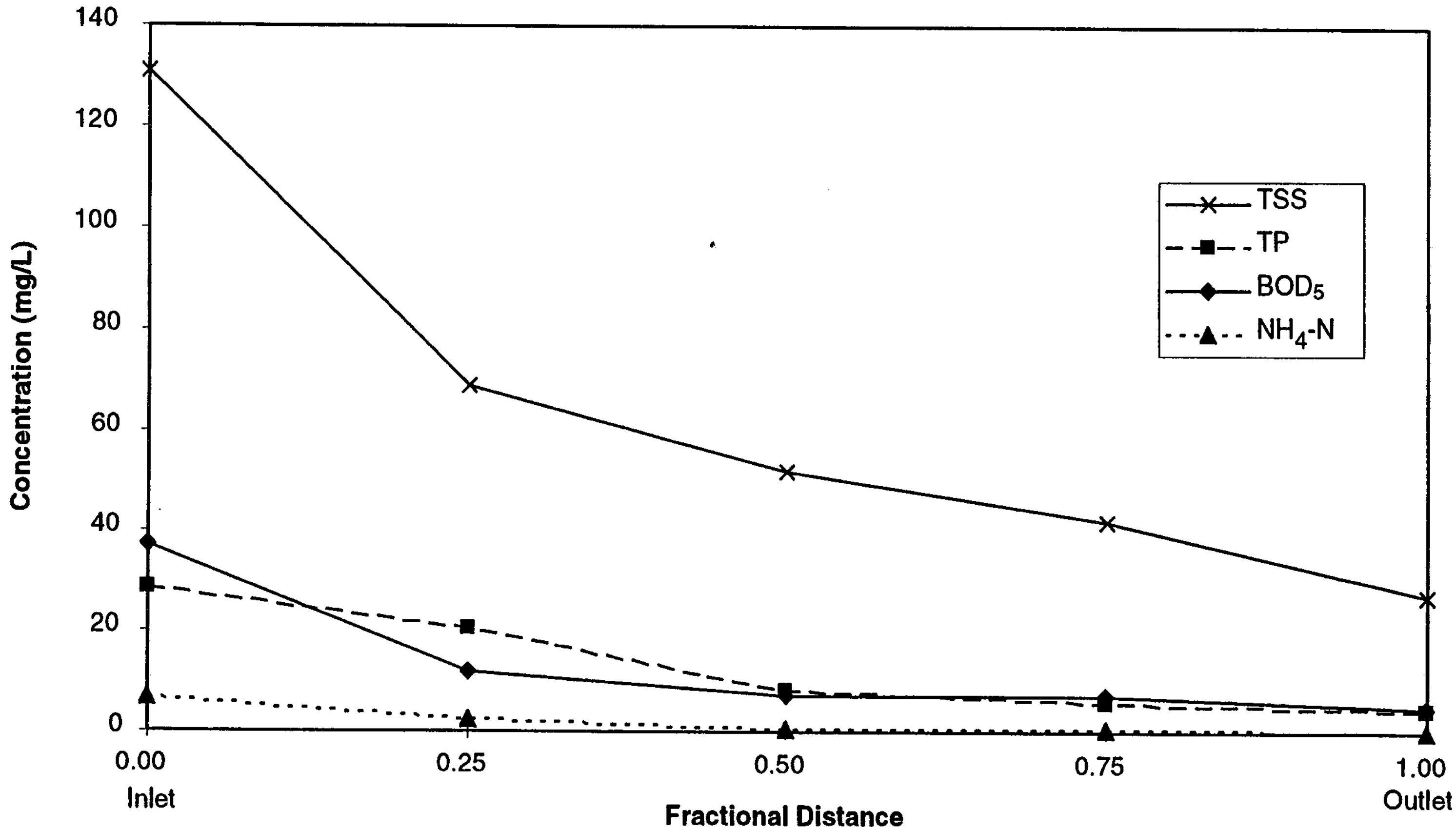


FIGURE 4-14
Mean Concentration Profiles at the Hernando, Mississippi, Dairy Treatment Wetland for the Spring 1992 Operating Period



The plug flow integration of equation 4-8 is presented below (Kadlec and Knight, 1996).

$$\ln \frac{C_2 - C^*}{C_1 - C^*} = -\frac{k}{q} \qquad (4\text{-}9)$$

where:

C_1 = inlet concentration, mg/L

C_2 = outlet concentration, mg/L

q = hydraulic loading rate, m/yr

The area-based rate constant in Equation 4-8 is often regrouped to define a volumetric rate constant:

$$k_v = \frac{k}{\varepsilon h} \qquad (4\text{-}10)$$

where:

k_v = first order volumetric rate constant (yr^{-1} or/d^{-1})

ε = porosity (unitless)

h = water depth (m)

For the volumetric case, Equation 4-9 can be modified as:

$$\ln \frac{C_2 - C^*}{C_1 - C^*} = -k_v \tau \qquad (4\text{-}11)$$

where:

τ = nominal detention time (d)

τ = $h\varepsilon/q$

Either k or k_v can be used to represent a data set or be used in design. However, the use of k_v requires the accompanying information on water depth (h) because of the depth dependence indicated in Equation 4-10. Treatment wetland data from municipal systems indicate that volumetric coefficients decrease with increasing water depth (h) and that area-based coefficients are nearly independent of water depth (Kadlec and Knight, 1996). For this reason, values of k are summarized in this report. Additional research and data analysis will need to be conducted to examine the dependence or independence of k and k_v on depth in treatment wetlands receiving concentrated livestock wastewaters.

While treatment wetland hydraulic efficiency is typically intermediate between complete mix and plug flow (approximated by three complete-mix tanks in series [Kadlec 1994]), the area-based, first-order rate constant k derived using Equation 4-9 is conservative. As long as k values in Equation 4-9 are used to predict treatment wetland performance for a wetland at least as efficient hydraulically as the typical system used to generate the rate constant, these rate constants can be used for design (see Section 5).

The area-based, first-order rate constant derived using Equation 4-9 is typically based on time-averaged data to eliminate variability due to short-term variation of inflow and outflow quality and changing flow patterns. For this report, monthly or longer averaging periods were used for data analysis.

Water temperature is known to affect some treatment wetland rate constants. This effect can be modeled as a modified Arrhenius equation as follows (Kadlec and Knight, 1996):

$$k_T = k_{20}\theta^{T-20} \qquad (4\text{-}13)$$

where:

k_{20}	=	k at 20°C, m/yr
k_T	=	k at T°C, m/yr
θ	=	theta value, dimensionless
T	=	water temperature, °C

A spreadsheet routine (solver on Excel) can be used to simultaneously solve for k_{20}, C*, and θ values that minimize the sum of squares between actual and predicted C_2 when a detailed treatment wetland data set is available. For the concentrated animal waste treatment wetlands represented in the LWDB, sufficient data were available to make these estimates only for systems at Auburn, Alabama; Newton and Pontotoc, Mississippi; Purdue, Indiana; and Corvallis, Oregon.

Biochemical Oxygen Demand

Table 4-3 summarizes the values of $k_{20\,BOD}$, C^*_{BOD}, and θ_{BOD} derived from concentrated livestock wastewater treatment wetlands. The average $k_{20\,BOD}$ was 22 m/yr with individual system values ranging from 7 to 68 m/yr. C^*_{BOD} could not be accurately determined from these high concentration data sets and an estimate of 8 mg/L was used for model calibration. Temperature had slight positive effect on the first order rate constant for BOD_5 with an overall average value of $\theta_{BOD} = 1.03$. The range of estimated θ values was from 0.94 to 1.07. Kadlec and Knight (1996) reported an average k_{BOD} from systems in the NADB as 34 m/yr with $C^* = 3.5 + 0.053C_1$ where C_1 = inlet BOD concentration. Based on data from numerous treatment wetlands receiving municipal and industrial wastewater flows, θ_{BOD} was reported as approximately 1.00 (no temperature effect).

Total Suspended Solids

Table 4-4 provides a summary of the estimated K-C* model parameter values for TSS from the LWDB. The average $k_{20\,TSS}$ was 21 m/yr with individual system values ranging from 3 to 51 m/yr. A C^*_{TSS} value of 20 mg/L was used for model calibration. Temperature had little effect on TSS reduction in the LWDB treatment wetlands ($\theta_{TSS} = 1.01$). Kadlec and Knight

TABLE 4-3
BOD_5 Rate Constants from the Livestock Wastewater Treatment Wetland Database

Site	System	Average HLR (m/yr)	BOD5 In (mg/L)	BOD5 Out (mg/L)	k20	C*	θ
Auburn Poultry Waste, AL	1	23.6	177	88	23	8 **	1.06
	2	23.6	177	103	18	8 **	1.07
	3	23.6	177	95	13	8 **	1.00
Newton Dairy Waste, MS	1	24.2	50	12	43	2	1.07
	2	20.3	50	20	22	8 **	1.03 **
	3	23.4	50	6	65	2	0.94
	4	20.8	50	6	68	8 **	1.04
	5	22.4	50	16	30	8 **	1.03 **
Oregon State University Dairy Waste, OR	1	14.4	737	229	18	8 **	1.02
	2	14.4	737	234	26	8 **	1.03
	3	14.4	737	255	25	8 **	1.05
	4	14.4	737	293	25	8 **	1.06
	5	14.4	737	286	17	8 **	1.04
	6	14.4	737	218	32	8 **	1.07
Pontotoc Swine Waste, MS	1	4.8	49	23	7	2	1.03 **
	2	5.6	46	27	8	15	1.03 **
Purdue University Swine Waste, IN	A1	7.1	115	45	8	8 **	1.04
	A2	7.1	115	43	9	8 **	1.02
	A3	7.1	113	37	9	8 **	1.02
	A4	7.1	115	40	9	8 **	1.04
	B1	14.3	115	52	14	8 **	1.03
	B2	14.3	115	51	13	8 **	1.01
	B3	14.3	113	50	13	8 **	1.01
	B4	14.3	115	51	14	8 **	1.04
	C1	14.3	115	41	20	14	1.03 **
	C2	14.3	115	50	13	8 **	1.00
	C3	14.3	115	45	15	8 **	1.01
	C4	14.3	115	43	17	8 **	1.02
	D1	28.6	115	47	31	8 **	1.03
	D3	28.6	115	56	24	8 **	1.03
	D4	28.6	115	53	26	8 **	1.02
Average		16.4	226	84	22	7	1.03
Median		14.4	115	50	18	2	1.03
Maximum		28.6	737	293	68	15	1.07
Minimum		4.8	46	6	7	2	0.94
Count		31	31	31	31	31	31
Standard Deviation		6.9	256.9	87.5	14.4	6.1	0.0

** Values fixed in model
HLR = Hydraulic loading rate.

TABLE 4-4
TSS Rate Constants from the Livestock Wastewater Treatment Wetland Database

Site	System	Average HLR (m/yr)	TSS In (mg/L)	TSS Out (mg/L)	k20	C*	θ
Newton Dairy Waste, MS	1	24.2	99	43	36	20 **	1.04
	2	20.3	99	43	26	20 **	1.04
	3	22.8	90	55	20	20 **	1.01 **
	4	20.8	84	23	51	20 **	1.01 **
	5	22.4	89	28	44	18	0.98
Oregon State University Dairy Waste, OR	1	14.4	545	170	30	20 **	1.06
	2	14.4	545	172	33	20 **	1.05
	3	14.4	545	148	45	20 **	1.08
	4	14.4	545	178	36	20 **	1.07
	5	14.4	545	191	26	20 **	1.05
	6	14.4	545	164	21	20 **	1.01 **
Pontotoc Swine Waste, MS	1	5.0	98	31	13	20 **	1.01 **
	2	5.2	96	35	11	20 **	1.01 **
Purdue University Swine Waste, IN	A1	7.1	133	67	6	20 **	0.99
	A2	7.1	133	49	10	20 **	1.02
	A3	7.1	147	48	11	20 **	1.02
	A4	7.1	133	44	12	20 **	1.01
	B1	14.3	133	57	16	20 **	0.99
	B2	14.3	133	64	13	20 **	0.98
	B3	14.3	147	107	5	20 **	1.01 **
	B4	14.3	133	67	12	20 **	0.98
	C1	14.3	133	52	17	20 **	0.98
	C2	14.3	133	112	3	20 **	1.01 **
	C3	14.3	133	50	18	20 **	0.98
	C4	14.3	133	52	17	20 **	0.99
	D1	28.6	133	76	17	20 **	0.96
	D3	28.6	133	84	14	20 **	0.96
	D4	28.6	133	80	17	20 **	0.98
Average		15.6	213	82	21	18	1.01
Median		14.3	133	60	17	18	0.99
Maximum		28.6	545	191	51	18	1.08
Minimum		5.0	84	23	3	18	0.96
Count		28	28	28	28	28	28
Standard Deviation		6.8	177.8	51.8	12.4	0.0	0.0

** Values fixed in model

(1996) reported that k_{TSS} is highly variable for different waste types and not affected by temperature (θ_{TSS} = 1.00).

Nitrogen

Apparent rate constants were calculated for ammonium N reduction in treatment wetlands (Table 4-5). These rate constants may be lower than actual NH_4^+-N rate constants that incorporate the sequential transformation of organic N to NH_4^+-N. The average estimated value of $k_{20\,AN}$ equals 10 m/yr with individual system values ranging from -1 to 26 m/yr. A C^*_{AN} value of 3 mg/L was used for model calibration. Temperature does have an effect on the removal rate of NH_4^+-N with an average value of θ_{AN} = 1.05. Kadlec and Knight (1996) reported an average $k_{20\,AN}$ of 18 m/yr with a C^*_{AN} of about zero and θ_{ON} = 1.04.

Total nitrogen rate constants were estimated at three sites: Auburn Poultry, Pontotoc Swine, and Purdue Swine. Table 4-6 summarizes these parameter estimates. The average $k_{20\,TN}$ was 14 m/yr with individual system estimates ranging from 5 to 32 m/yr. A C^*_{TN} value of 10 mg/L was used for model calibration. The average effect of temperature on the TN rate constant was estimated as θ_{TN} = 1.06. Kadlec and Knight (1996) reported an average of 22 m/yr for $k_{20\,TN}$ from systems in the NADB with C^*_{TN} = 1.5 mg/L and θ_{TN} = 1.05.

Total Phosphorus

Total phosphorus parameter values were estimated at four treatment wetland sites (Table 4-7). The average value of $k_{20\,TP}$ was 8 m/yr with a range of estimated values from 2 to 18 m/yr. A C^*_{TP} value of 2 mg/L was used for model calibration. The average effect of temperature on the TP rate constant was estimated as θ_{TP} = 1.05 with a range of estimates from 0.99 to 1.14. Kadlec and Knight (1996) reported an average $k_{20\,TP}$ from the NADB as 12 m/yr with C^*_{TP} = 0.02 mg/L and θ_{TP} = 1.0.

Comparison to Other Treatment Wetlands

Kadlec and Knight (1996) have estimated values of k_{20}, C*, and θ for selected wetlands including some sites in the NADB (Table 4-8). Values of several of these estimated rate constants are higher than those derived from livestock wastewaters:

- BOD_5 — 34 m/yr versus 22 m/yr
- Ammonium N — 18 m/yr versus 10 m/yr
- Total N — 22 m/yr versus 14 m/yr
- Total P — 12 m/yr versus 8 m/yr

It is important to note that values for k_{20}, C*, and θ extracted from insufficient (poorly "conditioned") data sets may lead to unrealistic parameter estimates. Ideal data sets include a broad range of inlet concentrations and hydraulic loading rates over long enough time periods to allow consistent wetland performance as indicated by stable outflow concentrations. None of the data sets available for this report was truly ideal for full calibration of the k-C* model.

Also, it is likely that under highly-loaded conditions, other parameters, not included in the model, may limit reaction rates. Dissolved oxygen limitations have been suggested as a

TABLE 4-5
NH4-N Rate Constants from the Livestock Wastewater Treatment Wetland Database

Site	System	Average HLR (m/yr)	NH4-N In (mg/L)	NH4-N Out (mg/L)	k20	C*	θ
Auburn Poultry Waste, AL	1	23.6	84	54	16	3 **	1.10
	2	23.6	84	42	26	3 **	1.12
	3	23.6	84	49	18	3 **	1.11
Newton Dairy Waste, MS	1	24.2	17	13	7	2	1.05 **
	2	20.3	17	16	-1	3 **	1.05 **
	3	22.8	17	17	0	3 **	1.05 **
	4	20.8	18	17	3	3 **	1.05 **
	5	22.4	18	18	-1	3 **	1.05 **
Oregon State University Dairy Waste, OR	1	14.4	125	67	7	7	0.99
	2	14.4	125	66	10	3 **	0.99
	3	14.4	125	72	10	3 **	1.01
	4	14.4	125	74	11	3 **	1.03
	5	14.4	125	69	8	3 **	1.02
	6	14.4	125	59	12	3 **	1.03
Pontotoc Swine Waste, MS	1	4.8	113	36	15	3 **	1.05 **
	2	5.6	112	39	17	3 **	1.05 **
Purdue University Swine Waste, IN	A1	7.1	422	264	5	3 **	1.04
	A2	7.1	422	254	5	3 **	1.04
	A3	7.1	328	97	9	3 **	1.00
	A4	7.1	422	264	4	3 **	1.04
	B1	14.3	422	290	8	3 **	1.06
	B2	14.3	422	278	9	3 **	1.06
	B3	14.3	328	117	15	3 **	1.01
	B4	14.3	422	301	7	3 **	1.05
	C1	14.3	422	268	10	3 **	1.07
	C2	14.3	422	199	15	3 **	1.05
	C3	14.3	422	258	11	3 **	1.09
	C4	14.3	422	259	11	3 **	1.08
	D1	28.6	422	272	20	3 **	1.09
	D3	28.6	422	285	17	3 **	1.08
	D4	28.6	422	291	16	1	1.09
Average		16.3	240	142	10	3	1.05
Median		14.4	125	74	10	2	1.05
Maximum		28.6	422	301	26	7	1.12
Minimum		4.8	17	13	-1	1	0.99
Count		31	31	31	31	31	31
Standard Deviation		6.9	171.2	112.1	6.2	2.7	0.0

** Values fixed in model

TABLE 4-6
TN Rate Constants from the Livestock Wastewater Treatment Wetland Database

Site	System	Average HLR (m/yr)	TN In (mg/L)	TN Out (mg/L)	k20	C*	θ
Auburn Poultry Waste, AL	1	23.6	101	59	19	10 **	1.08
	2	23.6	101	47	32	10 **	1.11
	3	23.6	101	58	20	10 **	1.09
Pontotoc Swine Waste, MS	1	5.0	129	47	21	10 **	1.07
	2	4.3	130	40	13	10 **	1.03
Purdue University Swine Waste, IN	A1	7.1	434	270	5	10 **	1.04
	A2	7.1	434	261	5	10 **	1.04
	A3	7.1	336	104	9	10 **	1.01
	A4	7.1	434	269	5	10 **	1.04
	B1	14.3	434	295	8	10 **	1.06
	B2	14.3	434	285	9	10 **	1.06
	B3	14.3	336	124	15	10 **	1.01
	B4	14.3	434	306	7	10 **	1.05
	C1	14.3	434	265	11	10 **	1.07
	C2	14.3	434	207	15	10 **	1.04
	C3	14.3	434	264	11	4	1.08
	C4	14.3	434	265	11	10 **	1.08
	D1	28.6	434	277	21	10 **	1.09
	D3	28.6	434	289	18	10 **	1.08
	D4	28.6	434	298	17	10 **	1.09
Average		15.4	344	202	14	4	1.06
Median		14.3	434	264	12	4	1.07
Maximum		28.6	434	306	32	4	1.11
Minimum		4.3	101	40	5	4	1.01
Count		20	20	20	20	20	20
Standard Deviation		8.1	140.3	103.8	6.8	0.0	0.0

** Values fixed in model

TABLE 4-7
TP Rate Constants from the Livestock Wastewater Treatment Wetland Database

Site	System	Average HLR (m/yr)	TP In (mg/L)	TP Out (mg/L)	k20	C*	θ
Auburn Poultry Waste, AL	1	23.6	34	22	18	6	1.06
	2	23.6	34	24	12	2 **	1.14
	3	23.6	34	23	12	2 **	1.10
Oregon State University Dairy Waste, OR	1	14.4	30	15	11	2	1.03
	2	14.4	30	15	10	3	0.99
	3	14.4	30	15	10	3	0.99
	4	14.4	30	17	13	6	1.02
	5	14.4	30	17	10	4	1.02
	6	14.4	30	13	18	3	1.05
Pontotoc Swine Waste, MS	1	4.8	30	18	6	2 **	1.05 **
	2	5.3	29	17	7	2 **	1.05 **
Purdue University Swine Waste, IN	A1	7.1	17	10	5	2 **	1.06
	A2	7.1	17	10	6	2 **	1.07
	A3	7.1	20	14	3	2 **	1.05 **
	A4	7.1	17	10	6	2 **	1.07
	B1	14.3	17	15	2	2 **	1.03
	B2	14.3	17	15	2	2 **	1.06
	B3	14.3	20	16	3	2 **	1.05 **
	B4	14.3	17	15	2	2 **	1.05 **
	C1	14.3	17	13	5	2 **	1.07
	C2	14.3	17	11	8	2 **	1.04
	C3	14.3	17	13	4	2 **	1.11
	C4	14.3	17	12	6	2 **	1.03
	D1	28.6	17	14	7	2 **	1.05
	D3	28.6	17	14	7	2 **	1.07
	D4	28.6	17	14	7	2 **	1.09
Average		15.2	23	15	8	4	1.05
Median		14.3	19	15	7	3	1.06
Maximum		28.6	34	24	18	6	1.14
Minimum		4.8	17	10	2	2	0.99
Count		26	26	26	26	26	26
Standard Deviation		7.0	6.9	3.5	4.4	1.4	0.0

** Values fixed in model

TABLE 4-8
Parameter Estimates For Area-Based, First-Order Model with Background for Surface Flow Treatment Wetlands*

Parameter	Estimated Values		
	k_{20} (m/yr)	C* (mg/L)	θ
BOD_5	34	3.5 + 0.053 C_1[a]	1.00
TSS [b]	1,000	5.1 + 0.16 C_1[a]	1.00
Organic N	17	1.50	1.05
Ammonium N	18	0.00	1.04
Total N	22	1.50	1.05
Total P	12	0.02	1.00

*Kadlec and Knight, 1996.
[a]C_1 = inflow concentration (mg/L)
[b]Rough unsubstantiated estimate, very waste specific

factor affecting performance of a number of the livestock wastewater treatment wetlands in the LWDB. The next generation model will need to be calibrated with data sets that include dissolved oxygen concentrations and atmospheric reaeration rates.

C* values for livestock wastewaters were higher than those for other wastewater sources. These high C* estimates are likely an artifact of the very high pollutant loadings for the livestock wetland pilot studies. θ values were similar between the two data sets for TSS, ammonium N, and total N. The θ values estimated for BOD and TP were higher than the values published previously for municipal treatment wetlands. At the present time, design of livestock wastewater treatment wetlands should rely on data and model parameters from the most similar systems available and on best professional judgement. Additional data collection and analyses will be required to provide increased certainty concerning performance of livestock wastewater treatment wetlands. Section 5 of this report provides a summary of preliminary recommended values for the parameters k and C* to use for sizing livestock wastewater treatment wetlands.

Summary

Constructed and natural wetlands are being used to treat a variety of wastewater sources including wastewaters from concentrated livestock operations. This technology is relatively new for agricultural applications; however, at least 68 separate systems are currently being operated or were operated in the past. The livestock industry has the distinct advantage of being able to draw upon the considerable data available from other treatment wetland applications. The development and analysis of the LWDB and the NADB have indicated that a number of the principal pollutants typical of livestock wastewaters are removed in treatment wetlands at about the same rate as these constituents in other wastewater types. Thus, recently published design equations in Kadlec and Knight (1996) can be applied to the preliminary design of wetlands treating livestock wastewaters. Conservative parameter values are recommended until additional data analysis is complete. Increasing knowledge about removal rate constants, background concentrations, and temperature effects on removal should be a goal of ongoing and future research in this field. Also, more complex, multi-parameter models should be developed to incorporate obvious effects of dissolved oxygen, pH, plant populations, and other environmental factors on treatment wetland performance.

SECTION 5

Livestock Wastewater Treatment Wetland Design and Operation Guidance

Characteristics of Livestock Wastewater

The *Agricultural Waste Management Field Handbook* (USDA NRCS, 1992), the engineering standards of the American Society of Agricultural Engineers (1985), and other technical books and publications provide detailed information on average volumes of manure (feces and urine) and average production rates of certain contaminants produced by different types of livestock. Average manure volumes and concentrations of as-excreted nitrogen, phosphorus, and BOD_5, taken from the USDA NRCS handbook, are summarized in Tables 5-1, 5-2, 5-3, and 5-4.

TABLE 5-1
Swine: As-Excreted Values of Wastewater Constituents

Constituent	Units*	Growers 18.1 to 99.8 kg (40 to 220 lbs)	Replacement Gilts	Sows: Gestation	Sows: Lactation	Boars	Nursing / Nursery Pigs 2.7 to 18.1 kg (6 to 40 lbs)
Mass	kg/d	28.8	14.9	12.3	27.2	9.3	48.1
	(lb/d)	(63.4)	(32.8)	(27.2)	(60.0)	(20.5)	(106)
Volume	m^3/d	0.028	0.015	0.012	0.027	0.009	0.048
	(ft^3/d)	(1.0)	(0.53)	(0.44)	(0.96)	(0.33)	(1.70)
Nitrogen	kg/d	0.19	0.11	0.09	0.21	0.07	0.27
	(lb/d)	(0.42)	(0.24)	(0.19)	(0.47)	(0.15)	(0.60)
Phosphorus	kg/d	0.07	0.04	0.03	0.07	0.23	0.11
	(lb/d)	(0.16)	(0.08)	(0.063)	(0.15)	(0.05)	(0.29)
BOD_5	kg/d	0.94	0.49	0.38	0.91	0.30	1.54
	(lb/d)	(2.08)	(1.08)	(0.83)	(2.00)	(0.65)	(3.40)

* Units per 454 kg (1,000 lbs) of animal weight
Source: USDA SCS, 1992

TABLE 5-2
Dairy: As-Excreted Values of Wastewater Constituents

Constituent	Units*	Cow		Heifer
		Lactating	Dry	
Mass	kg/d	36.3	37.2	38.6
	(lb/d)	(80.00)	(82.00)	(85.00)
Volume	m^3/d	0.037	0.037	0.037
	(ft^3/d)	(1.30)	(1.30)	(1.30)
Nitrogen	kg/d	0.20	0.16	0.14
	(lb/d)	(0.45)	(0.36)	(0.31)
Phosphorus	kg/d	0.032	0.023	0.018
	(lb/d)	(0.07)	(0.05)	(0.04)
BOD_5	kg/d	0.73	0.54	0.59
	(lb/d)	(1.60)	(1.20)	(1.30)

* Units per 454 kg (1,000 lbs) of animal weight
Source: USDA SCS, 1992

TABLE 5-3
Beef: As-Excreted Values of Wastewater Constituents

Constituent	Units*	Feeder 340 to 499 kg (750 to 1,100 lbs)		Yearling 205 to 340 kg (450 to 750 lbs)	Cow
		High Forage Diet	High Energy Diet		
Mass	kg/d	26.81	23.22	26.40	28.58
	(lb/d)	(59.10)	(51.20)	(58.20)	(63.00)
Volume	m^3/d	0.027	0.023	0.026	0.028
	(ft^3/d)	(0.95)	(0.82)	(0.93)	(1.00)
Nitrogen	kg/d	0.14	0.14	0.14	0.15
	(lb/d)	(0.31)	(0.30)	(0.30)	(0.33)
Phosphorus	kg/d	0.05	0.043	0.045	0.054
	(lb/d)	(0.11)	(0.094)	(0.10)	(0.12)
BOD_5	kg/d	0.62	0.62	0.59	0.54
	(lb/d)	(1.36)	(1.36)	(1.30)	(1.20)

* Units per 454 kg (1,000 lbs) of animal weight.
Source: USDA SCS, 1992

TABLE 5-4
Poultry Layers: As-Excreted Values of Wastewater* Constituents

Constituent	Unit**	Layer Hen
Mass	kg/d	27.4
	(lb/d)	(60.5)
Volume	m^3/d	0.026
	(ft^3/d)	(0.93)
Nitrogen	kg/d	0.38
	(lb/d)	(0.83)
Phosphorus	kg/d	0.14
	(lb/d)	(0.31)
BOD_5	kg/d	1.68
	(lb/d)	(3.70)

*Waste from most poultry facilities is handled as dry material. Waste from laying hens is often handled in liquid form; thus, waste characteristics for only the layers are shown in this table.
**Units per 454 kg (1,000 lbs) of animal weight.
Source: USDA SCS, 1992

Liquid wastes from confined animal feeding operations (CAFOs) include manure, contaminated water, and other liquids and solids that enter the waste stream, such as spilled milk and feed, bedding, animal hair, feathers, and broken eggs. Contaminated water includes flushwater used to remove wastes and clean houses and milking facilities, spilled drinking water, runoff from open lots and buildings, and direct precipitation on lagoons and other open waste storage facilities. In many cases, the volume of contaminated water in liquid systems is much greater than the volume of manure.

The amount of water added for waste management is an important consideration for the design of traditional treatment and storage systems and is also important in the design of constructed wetlands. The system designer must identify all sources of freshwater entering the system and account for volumes involved. The major sources will be flushwater to remove manure from alleys and barns, water for cleaning milking and milk processing facilities, rainfall runoff from roofs and open lots, and direct precipitation on waste storage facilities.

Flow rates for flushing and washdown operations are often estimated on the basis of the size of flush tanks and the number of flushes or the flow rate of pumps and hours pumped per day. In addition, the area of roofs and open lots must be determined, and the monthly or annual volumes of rainfall runoff determined from rainfall data and runoff curves.

Water usage can vary considerably from one operation to another, depending on such factors as type of buildings, method of flushing, and the overall level of management. Some useful guides have been developed to assist in planning and designing waste management systems for livestock.

Approximately 0.13 liters per second (L/s) (2 gpm) of water per 45.4 kg (100 lbs) of animal weight can be used for estimating the volume of flushwater used in swine and poultry layer facilities, while 40 to 50 gallons per cow per day can be used to predict flushing requirements for freestall alleys at dairies (Overcash et al., 1983). Tipping buckets, siphon tanks, and drop side tanks have capacities ranging from 250 to 1,000 gallons. The frequency of daily flushing will determine total volumes used.

Table 5-5 provides more detailed information on volumes typically used in various facets of dairy operations. Table 5-6 gives recommended flush rates for swine facilities based on type of swine. Both tables are adapted from Midwest Plan Service information (1983).

TABLE 5-5
Volume of Milkhouse and Parlor Wastes

Washing Operation	Water Volume		Volume Per
	Liters	Gallons	
Bulk tank			
Automatic	140 to 230	50 to 60	wash
Manual	115 to 150	30 to 40	
Pipeline			
In parlor*	240 to 475	75 to 125	wash
Pail milker	115 to 150	30 to 40	wash
Miscellaneous equipment	115	30	day
Cow preparation			
Automatic (estimated average)	7.6	2	wash per cow
Manual	0.95 to 1.9	0.25 to 0.50	
Milkhouse floor	40 to 75	10 to 20	day
Parlor floor without flushing	150 to 285	40 to 75	day
Parlor and holding area with flushing			
Parlor only	75 to 115	20 to 30	cow / day
Parlor and holding area	95 to 150	25 to 40	
Holding area only	40 to 75	10 to 20	

TABLE 5-6
Minimum Total Daily Flush Volumes for Swine

Swine Type	Flush Volume	
	L/head	Gal/head
Sow and litter	130	35
Pre-nursery pig	8	2
Nursery pig	15	4
Growing pig	40	10
Finishing pig	60	15
Gestating sow	95	25

Livestock Wastewater Pre-Treatment Requirements

The principal pretreatment practices used in the management of liquid wastes include lagoons, storage ponds and tanks, and solids separators.

Anaerobic lagoons are actual "treatment" systems, designed to reduce pollutant loads. They contain storage volumes for treatment based on volatile solids loading; settled sludge for some multi-year design period; and temporary storage resulting from the displacement of lagoon liquid by manure, bedding, and all sources of contaminated water during a given design period, typically 90 to 180 days. At the end of this temporary storage period, a volume of lagoon supernatant must be removed equivalent to the volume of material added during the design period. The supernatant is usually applied to the land at the recommended agronomic rate for a given crop. While the temporary storage volume may be removed and refilled several times a year, the treatment volume remains fixed, and the sludge storage volume is renewed only at the end of a lengthy storage period (for example, 5 to 10 years).

The waste storage pond simply collects all manure and miscellaneous by-products (water, bedding, etc.) for a specified period, after which the contents are pumped or hauled to fields as fertilizer. Waste storage ponds are not typically discharged to another treatment process. If the storage pond is the initial pretreatment component, the effluent it produces would have higher concentrations of most pollutants than lagoon effluent; therefore, a constructed wetland would not normally be used to treat waste storage pond effluent. However, if a wetland is used to treat lagoon effluent, the effluent from the wetland could be stored in a waste storage pond awaiting final application to the land.

Lagoon supernatant is typically the most dilute form of wastewater compared to storage ponds and settling basins. The supernatant is dilute because a large fraction of solids and phosphorus will have settled, and much of the nitrogen and organic material will have been biologically converted to gaseous forms and released to the atmosphere, and also because the system will have been diluted by rainfall, especially in high rainfall areas. Table 5-7 shows ranges and average concentrations of selected pollutants for wastewater treated in

TABLE 5-7

Range of Concentrations of TKN, NH_4-N, BOD_5, and TSS in Anaerobic Lagoon Supernatant

Wastewater Type	Reference	TKN (mg/L)	NH_4-N (mg/L)	BOD_5 (mg/L)	TSS (mg/L)
Poultry	1	60 to 6,500	35 to 3,500	40 to 1,500	650 to 8,300
	2	4.9 to 1,197	113 to 179*	21 to 4611	
	3	230 to 3,000	98 to 3,360		
Dairy	1	75 to 1,750	50 to 720	80 to 1200	1,160 to 47,000
	2	75 to 1,183	97 to 574*		
Swine	1	30 to 3,040	140 to 1,100	230 to 1,300	1,400 to 9,200
	2	10.6 to 1,523	318 to 601*	3.5 to 5,688	
	4	210 to 695	130 to 510		

References:
1. Overcash et al. (1983)
2. Barker et al. (1990)
3. Payne et al. (1985)
4. Payne (1996)

*Authors presented values as percent of COD; ranges presented here are percent of average COD.

anaerobic lagoons. The table illustrates that, even after treatment, the concentrations of pollutants in this type of wastewater can be exceptionally high. Yet, lagoon effluent, because of its low strength relative to other livestock wastewater sources, is a likely candidate for further treatment in a constructed wetland.

It is evident from the table that the concentration of nitrogen, BOD, and suspended solids vary greatly between lagoons. It is also evident that lagoons with high strength wastes would require more dilution before being allowed to discharge to a constructed wetland. Based on average data presented in the *Agricultural Waste Management Handbook* (USDA SCS, 1992), it would appear that the values at the lower and upper ranges shown in the above table are unusually low and unusually high, respectively.

Despite the fact that some lagoons have concentrations of certain constituents high enough to kill plants in a constructed wetland, the supernatant in animal waste lagoons is still a dilute wastewater compared with that of waste storage ponds and slurry pits. Lagoons with moderately high concentrations of pollutants may provide enough pretreatment to allow discharge to a wetland, depending on the tolerance level of the selected plants. Those lagoons at the extreme upper end of the concentration scale would probably need further dilution to allow discharge to a wetland for additional treatment.

Solids separators collect solids and pass the liquid portion to another treatment or storage process. Separators have varying degrees of efficiency in removing both solids and other constituents, depending on such factors as hydraulic residence time for settling basins and screen size for screen type separators. However, a typical range of efficiencies for all types of separators is 40 to 60 percent. Nutrient removals usually are less than the percentages for solids removal. The solids from settling basins must be removed according to the design requirements or else treatment efficiency will drop considerably. The effluent from some separator units may be effectively treated in constructed wetlands.

Purpose of Constructed Wetlands for Livestock Wastewater Management

As already noted, most liquid wastes are ultimately irrigated or hauled to the land as fertilizer, regardless of the type of pretreatment method used. This approach seeks maximum utilization of the nutrient resources and, on the surface, appears to be the most logical approach to livestock waste management. However, there are instances in which this approach cannot be employed or, possibly, should not be employed. The following situations, summarized from Miller et al. (1996), Hughes et al. (1996), and Payne et al. (1996), illustrate how a constructed wetland could be effectively used after a pretreatment facility:

1. *Nutrient reduction*: The livestock producer must have enough land to spread the pretreated wastewater at recommended agronomic rates for a given crop. If 30 hectares are needed and only 20 are available, the producer must either convert to a crop that can use more nutrients or risk contaminating surface and groundwater by over-applying wastes on too limited a land area. In some cases, the conversion to a different crop would not be possible due to changes required in factors such as equipment and labor and to economic and market considerations. If the cropping system cannot be changed, the next alternative would be to provide additional treatment components to reduce the

nutrient load so that wastes could still be applied on the land available.

The literature review provided in Section 3 of this report and the data analysis in Section 4 indicate that constructed wetlands have the capability to provide significant reductions of concentrations of TN and TP prior to final disposal. Thus, a constructed wetland can be used to reduce both nitrogen and phosphorus loads. If land application rates for the final application site are based on nitrogen, the land area requirements can be reduced substantially with proper design of the constructed wetland. If rates must be based on phosphorus, land area for ultimate spreading can be reduced but such reductions will not be as large as for nitrogen-based rates. State regulatory requirements may determine which application rates are to be used.

2. ***Pollutant reductions:*** Discharge of treated livestock wastewater is usually not an option. A survey of 13 states (Payne et al., 1996) indicated that only four might allow a discharge of livestock wastewater after treatment in a constructed wetland, but the producer must have a discharge permit and the effluent must meet National Pollution Discharge Elimination System (NPDES) or more stringent state discharge limits. Since constructed wetlands provide high removal efficiencies for BOD_5, TSS, fecal bacteria, and nitrogen, the use of constructed wetlands to treat fairly dilute livestock wastewaters could result in pollutant concentrations that meet NPDES or state limits throughout the year.

3. ***Odor control:*** Odors from the application of lagoon or storage pond wastes may cause problems with neighbors. However, since effluent from constructed wetlands is relatively odorless compared with wastes from pretreatment facilities, the wetland effluent can be stored in a collection pond and then irrigated to the final land application site without creating nuisance odors.

4. ***Economics:*** A wetland treatment system will reduce total nutrient loads and, therefore, reduce the amount of land needed at the application site. This, in turn, can reduce the amount of time spent hauling or irrigating. It can also allow for the use of smaller and more cost-effective spreading equipment. Although a small amount of land might be taken out of production through installation of the wetland, capital expenses for equipment could be greatly reduced (Hughes et al., 1996). In addition, the loss of the nutrient value can also be considered. Each system must be evaluated on its own merits to determine if the installation of a constructed wetland will provide an economic advantage.

5. ***Reduced labor:*** A constructed wetland may also decrease labor costs by reducing the time to set up and move irrigation equipment. A wetland may allow the producer to install and operate a simple solid set irrigation system, which requires less labor to operate than a traveling gun or center pivot.

6. ***Aesthetics and wildlife enhancement:*** The constructed wetland can be an attractive addition to the farm enterprise and will provide habitat for some wildlife. These may be highly desirable features for the conservation farmer, and they may also be a benefit in enhancing the livestock enterprise in the eyes of neighbors. In general, wildlife enhancement will require additional wetland and pond area beyond what is necessary for water quality treatment.

Wetland Design Guidance

Sizing the Wetland

Design criteria for livestock waste constructed wetlands were initially formalized by the USDA Soil Conservation Service (SCS, now the Natural Resources Conservation Service [NRCS]) in a document entitled *Constructed Wetlands for Agricultural Waste Treatment* (USDA NRCS, 1991). This document outlined two methods for designing constructed wetlands for treating livestock wastes, discussed below:

NRCS Presumptive Method

This method is based on areal loading of BOD to the wetland. It may be used where a livestock facility is planned or built but laboratory analyses on the wastewater characteristics can be obtained. The method "presumes" that the animals produce a known amount of BOD and that the loss of BOD in the pretreatment process (usually a lagoon) can be estimated. Using this information, the designer estimates the final amount of BOD produced per year in the pretreatment effluent and sizes the wetland on the basis of 58 kg BOD_5/ha/d (65 lbs/ac/d). This areal loading rate was expected to achieve the "minimum treatment objective" of 30 mg/L BOD_5 in the wetland effluent; hence, discharge of the effluent was anticipated.

NRCS Field Test Method

This method is based on having laboratory data on average BOD_5 concentrations from the effluent of the pretreatment facility. This information, along with average temperature data, is used in an equation (Reed et al., 1988) to determine the hydraulic residence time needed to obtain a given effluent BOD concentration. Once the hydraulic residence time is thus determined, the designer applies this information to another equation involving water depth and water column porosity to determine the surface area of the wetland.

Two factors should be considered when evaluating the NRCS requirements for constructed wetlands:

1. When NRCS initially prepared their Technical Requirement on constructed wetlands, they did so knowing that little information was available on this type system for animal wastes. Thus, they set treatment goals related to discharge limits for BOD_5, TSS and NH_4-N to standardize design procedures and to allow the agency to have a basis for comparing the results from one system to another. The establishment of limits at or below the typical NPDES discharge limits was not intended to promote the discharge of wastewater but, rather, to serve as a benchmark and to promote consistency in design throughout the country. The fact that NRCS did not make their guidance document an Engineering Standard was because not enough information was available to establish standards for this practice. In fact, it was felt that the results derived from systems developed under the Technical Requirements would ultimately lead to an Engineering Standard. NRCS is to be commended for taking the lead in establishing preliminary guidelines in what was then a fledgling technology and for providing funding to gather data on a number of projects nationwide.

2. The NRCS guidance did indicate that effluent could be discharged only if appropriate federal, state, and local permit requirements were satisfied. Otherwise, the wetland effluent must be collected in a storage pond and held until it could be land applied or recycled. No thought was given at that time to determining the total nutrient load desired at the final land application site, then establishing nutrient discharge concentrations and designing a wetland according to those needs. Only after a number of systems were installed and data gathered did it become apparent that design could be based on nutrient needs at the land application site and not necessarily on discharge limits (Payne et al., 1996). Such an approach is discussed later in this report.

3. Use of the NRCS Field Test Method to size the wetland may lead to erroneous results. As noted above, an equation is used to first determine the hydraulic detention time required to achieve a given reduction in pollutant concentration. Influent and desired effluent concentrations and average water temperature must be entered into this equation. The hydraulic detention time thus determined is then used in another equation to size the wetland. The sizing equation is as follows:

$$SA = t / (d \times p/q) \tag{5-1}$$

where:

SA = surface area (ft^2)
t = hydraulic residence time (days)
d = average water depth (ft)
p = porosity of the wetland or the ratio of plants to total water volume (values range from 0.86 to 0.95, depending on the type of plants involved)
q = flow rate (ft^3/day)

It would appear that the surface area of the wetland could be reduced, using this volumetric design approach, by simply increasing the depth of water. This could be a problem for at least two reasons: (a) the average depth of a wetland is difficult to determine with accuracy because of the obstructions caused by the varying thickness of the litter layer and because of the general inability to construct a wetland to precise design requirement, and (b) performance data have shown that volumetric rate constants, as used in the NRCS Field Test Method, are inversely proportional to depth, and, consequently, the rate of treatment efficiency decreases with depth (Kadlec and Knight, 1996).

k-C* Model

An alternative to using the NRCS guidance is to use an areal loading equation developed by Kadlec and Knight (1996):

$$A = -(Q/k)\ln([C_o - C^*]/[C_i - C^*]) \tag{5-2}$$

where:

A = area of the constructed wetland (m^2)
Q = annual flow (m^3/yr)
k = rate constant (m/yr)
C_i = inflow concentration (mg/L)
C_o= outflow concentration (mg/L)

C^* = background concentration (mg/L)

This approach is based on the fact that living and dead material, which constitute the bottom litter below the waterline, serve as substrate for microbial growth and that the biofilm in this region is responsible for a significant fraction of the treatment processes in the wetland. In addition, performance data show that areal rate constants are, in fact, relatively constant with depth, unlike the volumetric rate constants noted above.

The values for k, the first order area-based rate constant, are sensitive to temperature for some pollutants (Kadlec and Knight, 1996). Equation 4-10 from Section 4 is reproduced here for use in wetland sizing:

$$k_T = k_{20}\,\theta^{(T-20)} \qquad (5\text{-}3)$$

where:

k_T = rate constant at temperature T °C (m/yr)

k_{20} = rate constant at 20°C (m/yr)

θ = theta (dimensionless)

T = water temperature (°C)

Values of θ have been estimated by Kadlec and Knight (1996) for a variety of treatment wetlands and in Section 4 of this report based on existing livestock treatment wetland data sets.

Table 5-8 presents recommended parameter values for sizing of treatment wetlands for livestock wastewater management. These values are preliminary and are based on the central tendency of the livestock wastewater wetland data sets presented in Figures 4-8 to 4-13. As more data become available in the future from existing and new wetland systems, parameters for this model may change. The designer is advised to carefully review data presented in Section 4 of this report and in the electronic database to adjust the estimated wetland size as appropriate to meet any specific site constraints.

TABLE 5-8
Parameter Values Recommended for Use in the k-C* Model for Sizing of Livestock Wastewater Treatment Wetlands
These values are preliminary and may be revised as additional data analyses are completed.

Parameter	k_{20} (m/yr)	C^* (mg/L)	θ
BOD_5	22	8	1.03
TSS	21	20	1.01
Ammonium N	10	3	1.05
Total N	14	10	1.06
Total P	8	2	1.05

Equations 5-2 and 5-3 can be used in situations where the producer has less land than would be required with direct lagoon pumpout (Payne et al., 1996). Land area at the final application site could be determined on the basis of either nitrogen or phosphorus using rate constants and estimated background concentrations for these two constituents. In this approach, the ratio of land available to that required for direct pumpout is applied to the nutrient concentration of the lagoon effluent to determine the outflow concentration needed. This information is used to size the wetland. This procedure is presented in detail by Payne et al. (1996). An example calculation is provided for illustration.

Example:

Assume a 2,000-head swine finishing operation using 7.57 m^3/day (2,000 gal/day) of flush water and a lagoon with a surface area of 61 x 61 m (200 x 200 ft). Average annual lagoon output from direct precipitation (less evaporation), flush water, and manure displacement is 7,750 m^3/yr (273,680 ft^3/yr). Average N concentration in the lagoon is 200 mg/L. Nitrogen available per year after treatment in the anaerobic lagoon is calculated to be 5,010 kg/yr (11,040 lbs/yr) and the land area needed for direct pumpout, based on a crop requirement of 168 kg/ha/yr (150 lbs/ac/yr), is 29.8 ha (73.6 ac). Actual land area available for spreading the treated wastewater is 16.2 ha (40 ac). The recommended wetland rate constant, k_{20}, for TN is 14 m/yr, and the background concentration, C*, is 10 mg/L.

The wetland area needed to reduce the nitrogen enough so the wastewater can be applied to only 16.2 ha is determined as follows:

1. Calculate the ratio of land *available* for irrigation to land area *required* for direct application:

   16.2/29.8 = 0.54

2. Apply this fraction to the average N concentration in the lagoon (C_i) to determine the desired outlet concentration (C_o).

   C_o = 200 mg/L x 0.54 = 108 mg/L

3. Apply these values to the original wetland sizing equation to determine wetland area, A.

   A = - (7,750/14) ln ([108.8 - 10]/[200 - 10])

   A = 362 m^2 (3,900 ft^2)

4. Assuming a desired length-to-width ratio of 4:1, the basic dimensions would be

   9.5 x 38 m (31 x 125 ft)

A total of 362 m^2 (0.09 ac) of treatment wetland would be required to reach the 108 mg/L TN goal on an annual average basis in a climate with an annual average temperature of 20°C. For conservative design it is realized that the treatment wetland will operate at a slower rate for TN reduction during cold weather, and that outflow concentrations will be subject to some variability. This example may be continued by looking at the effect on wetland area by assuming the wetland will function at a rate dictated by the minimum monthly temperature of 8°C and assuming $\theta_{TN} = 1.06$:

Determine the value for $k_{8°C}$:

$k_{8°C} = (14)(1.06)^{(8-20)}$

$k_{8°C} = 7.0$ m/yr

Recalculate the required treatment wetland area, A:

$A = -(7{,}750/7.0) \ln([108-10]/[200-10])$
$A = 733 \text{ m}^2 \ (7{,}890 \text{ ft}^2)$

Thus 733 m^2 (0.18 ac) of treatment wetland would be a conservative estimate of the area necessary to offset about 13.6 ha (33.6 ac) of additional crop irrigation area.

Section 4 of this report analyzed the existing set of data from livestock wastewater treatment wetlands to predict rate constants (k_{20}) and background concentrations (C^*) and θ values applicable to various waste types. These values are tentative and are subject to revision when new data on livestock wastewater systems are developed. Additional detailed information on flows into and out of the wetlands along with the associated nutrient concentrations is needed to confirm or modify the rate constants and background concentrations for different animal species.

Planning Considerations

A number of factors must be considered in the development of every wastewater management system. Listed below are some of the important factors to consider when a constructed wetland is a component of the system. The items are listed below with brief explanations. Professional, trained engineers, soil scientists, agronomists, and others should be consulted on site-specific details and methodologies.

1. **Site selection:**

   Jurisdictional wetlands: The site selected for a constructed wetland for wastewater treatment should not be located in any part of a jurisdictional wetland. A professional opinion from NRCS is essential on this point.

   Floodplains: The site should not be in an area that floods more frequently than that caused by the 50-year, 24-hour storm, unless it can be adequately protected. Consideration should also be given to the impact of restricting streamflow if the structure is placed in a floodplain. State regulations may require more stringent restrictions.

   Soils: The underlying soils at the site should contain a relatively high fraction of clay to prevent seepage. Sandy subsoils should be avoided unless an adequate compacted layer of clay or artificial liner can be added; or if adequate pretreatment is provided. Soils classified as sand, sandy loam, and sandy clay are ideally suited as topsoil for growing

Shallow soils can pose problems during construction as well as problems related to seepage.

Topography: The lay of the land is important, with level or nearly level slopes desired. All wetland cells should be level from side-to-side. If the land has considerable slope in the lengthwise direction, it may be necessary to install several cells in series, which will add to the cost of construction, the overall size, and the maintenance and management requirements.

Land area: The wetted surface area of the wetland, as determined by appropriate equations, may be half of the total area required. If the land is sloping, additional cells and embankments will be needed (see design requirements below). If the wetland cannot be permitted for discharge, additional land will be needed for a collection basin. An adequately sized basin will be needed for irrigation and recycling purposes.

Surface and groundwater: The proximity of the system to nearby streams and to shallow groundwater should be evaluated for possible impacts in the event of discharge or overtopping of embankments.

2. **Regulatory requirements:** State water quality regulators will determine if the wetland can be permitted for discharge under NPDES, state, or water conservation district requirements. If permitting is allowed, the owner must be fully aware of any requirements for monitoring and the costs of obtaining and maintaining permits. If the system is not allowed to discharge, the owner must plan on having a storage pond to collect the wetland effluent for irrigation and/or recycling as flushwater.

3. **Water budget:** A monthly water budget is essential to account for all water (wastewater and freshwater) entering and leaving the system from all sources on a monthly basis. The water budget allows the planner to determine (1) if sufficient water will be available to sustain plant life during dry seasons, (2) if special storage requirements will be needed in pretreatment to contain all sources of water during the dormant or cold seasons, and (3) how water must be managed throughout all seasons. Table 5-9 lists some of the inputs and outputs that must be considered in developing a water budget.

TABLE 5-9
Factors to Consider in Developing a Monthly Water Budget for a Livestock Wastewater Management System Having a Constructed Wetland

Inputs	Outputs
Flush water (fresh or recycled)	Evapotranspiration of plants
Manure, bedding, other solid wastes that displace lagoon water	Evaporation from the pretreatment unit
Rainfall on the pretreatment unit	Irrigation
Runoff from roofs, lots, embankments	Recycled water
Rainfall on the constructed wetland	

4. **Water management:** During initial planning, it is necessary to determine if water will be available to the wetland during startup and all seasons thereafter. During winter, all input may need to be stored in the temporary storage component of the pretreatment unit to ensure that sufficient water is retained for release throughout the growing season (see discussion on lagoons under pretreatment requirements).

   If wetland effluent will be stored rather than discharged, the size of the downstream storage pond must be determined. Sufficient size will be needed to efficiently manage the irrigation component. Pumping requirements for both irrigation and recycling as flushwater must be considered.

   Appropriate pipes and fittings will be needed to properly manage the wastewater. Ideally, the release mechanisms will be designed to be self operating most of the time. Water management also includes maintaining water control structures and piping systems to ensure that pipes and valves remain unclogged and proper water levels are maintained.

Design Requirements

The constructed wetland should have at least two parallel cells to allow one to be closed for maintenance while the other remains in operation. The number of cells in series (in the lengthwise direction) will be determined by the topography of the site, as noted below.

The slope of the cells should be flat in the cross-flow direction (side to side) and as flat as possible in the direction of flow (lengthwise). A very shallow slope from end to end will allow for drainage of the cell, but even a shallow slope will result in increased depth in a relatively short distance. For instance, a cell with a slope of 0.5 percent and a water depth of 15.2 cm (6 in) at the upper end will have a water depth of 30.4 cm (12 in) in just 26 m (100 ft). Therefore, unless the downstream vegetation can tolerate a water depth of 30.4 cm of water, an additional cell with a lower bottom elevation would need to be added downstream. The addition of downstream cells will be determined not only by the need for drainage slope but also by the overall topography of the site. Thus, if the site is naturally sloping, additional cells will normally be necessary.

Length-to-width ratios should generally be between 1:1 and 10:1. The USDA NRCS (1991) guidelines suggest an overall length-to-width ratio for the system of 4 to 1. Research data indicate that higher ratios do not materially affect performance, and construction cost increases dramatically at higher ratios (Kadlec and Knight, 1996). Effective inlet and outlet flow distribution across the width of cells is considered more important than length-to-width ratios greater than 1:1.

Embankments between cells should be wide enough to mow and maintain. A top width of at least 2.6 m (10 ft) is desirable to inhibit burrowing animals from creating channels between cells or possibly draining a cell through an outside embankment. Suggested minimum side slopes from the top of the embankment to the bottom of each cell is 2 horizontal to 1 vertical.

Water control structures are an important component of design. Consideration must be given to plugging of orifices and weirs and to managing water depths in each cell. A variety of control methods are possible and should be designed individually by an experienced engineer.

Wetland Vegetation Types

The treatment wetland designer has only limited control over the internal biological details of wetland cell design. Through initial plant establishment and continuing water level control, the overall qualitative species composition and density of wetland plants can be controlled to a limited degree. An understanding of types of plants that occur in treatment wetlands and their growth requirements is helpful in system design and operation.

Algae

Algae are an inevitable part of a treatment wetland biological system. Depending on the structure of the treatment wetland, algae can be the dominant biological community, but, in most cases, algae remain an ancillary and usually unplanned element of most treatment wetlands. Even though algae might not be used as a primary vegetative component, they can provide important biogeochemical cycling in treatment wetlands.

The major ecological groups of algae include filamentous algae, periphyton, benthic algae, and planktonic algae. Filamentous algal mats are often the dominant form of algae in wetland systems. These algae can directly control DO and carbon dioxide (CO_2) concentrations through photosynthetic processes and indirectly cause shifts in the system's pH through changes in DO and CO_2 (Kadlec and Knight, 1996). Algal populations are dynamic with very high population growth rates; under certain environmental conditions, algal populations can explode in numbers and density and significantly influence effluent water quality. Since algae have a relatively rapid turnover rate, long-term nutrient deposition and retention through algal cycling is limited, but short-term nutrient retention and transformation can be affected by algal populations in the wetland system.

Macrophytes

Wetland macrophytes are vascular plants that are readily visible without the use of magnification. This group includes macroalgae populations and all other higher plants. Vascular plants differ from algae through their internal organization of tissues resulting from specialized cells. Macrophytes are categorized by a variety of ecological growth forms including submerged aquatic plants, floating aquatic plants, emergent herbaceous plants, and emergent woody plants, all important in treatment wetland technologies. Table 5-10 lists useful information for many of the plant species utilized in treatment wetland systems.

Submerged Aquatic Plants

Submerged aquatic plants grow in the water column in lakes, streams, and deeper wetlands. These macrophytes are an important ecological component when they occur in wetland systems because they are confined to the water column. Through photosynthesis, they can release large quantities of dissolved oxygen directly into the water column and, in turn, promote organic decomposition and nitrification. Unlike some forms of algae, submerged aquatic plants do not typically add to significant increases in suspended solids, and can offer an effective vegetative component to deeper areas of treatment wetlands.

TABLE 5-10
Typical Aquatic and Wetland Plant Species that are Used in Constructed Wetlands*

Plant Species	Common Name	Growth Form	Persistence	Growth/Spread Rate	Vegetative Growth Method	Spacing	Propagules	Habitat	Shade Tolerance	Wildlife Benefits	Water Regime	Salinity Tolerance
Acer negundo	Box elder	Tree	Perennial, deciduous	Fast, 4.5 to 6 m in 5 yrs			Container	Forested wetlands	Full sun	Songbirds, waterbirds, small mammals	Irregular to regular inundation or saturation	Fresh water, resistant to salt water
Acer rubrum	Red maple	Tree	Perennial, deciduous	Medium to fast, 5 to 7 m in 10 yrs			Seed, whip, bare root	Fresh marsh, swamp, alluvial woods	Partial shade	Gamebirds, songbirds, browsers	Irregular to seasonally inundated or saturated	Fresh water, < 0.5 ppt
Acorus calamus	Sweet flag	Emergent, herbaceous	Perennial, nonpersistent	Moderate, 15 cm/yr	Rhizome	0.3 to 0.9 m O.C.	Rhizome, bare root plant	Fresh to brackish marshes	Partial shade	Waterfowl, muskrat	Regular to permanent inundation, <15 cm	Fresh to brackish water, <10 ppt
Alnus serrulata	Smooth alder	Shrub	Perennial, deciduous	Rapid, 60 cm/yr			Container	Fresh marshes and swamps	Full sun	Songbirds, gamebirds, ducks, woodcock, blackbirds, beaver	Seasonal to regular inundation, up to 7 cm	Fresh water, < 0.5 ppt
Carex spp.	Sedges	Emergent, herbaceous	Perennial, nonpersistent	Slow to rapid	Rhizome	0.15 to 1.8 m O.C.	Seed, bare root plant	Fresh marshes, swamps, lake edges	Full shade to full sun	Rails, sparrows, snipe, songbirds, ducks, moose	Irregular to permanent inundation, <15 cm	Fresh water, <0.5 ppt
Cepahlanthus occidentalis	Buttonbush	Shrub	Perennial, deciduous	Medium, 30 to 60 cm/yr			Seedling, bare root plant	Fresh marshes, swamps, edge of ponds	Full shade to full sun	Ducks, deer, rails, blackbirds, muskrats, beaver	Irregular to permanent inundation, up to 90 cm	Fresh water, tolerates infrequent salt water
Ceratophyllum demersum	Coontail	Submerged aquatic	Perennial	Rapid	Fragmentation		Whole plant	Lakes, slow streams		Ducks, coots, geese, grebes, swans, marshbirds, muskrats	Regular to permanent inundation, 0.3 to 1.5 m	Fresh water, <0.05 ppt
Cyperus esculentus	Chufa	Emergent herbaceous	Perrenial, nonpersistent	Rapid	Rhizome		Seed, tuber	Fresh marshes, wet meadows	Full sun	Waterfowl, songbirds, small mammals	Irregular to regular inundation, <0.3 m	Fresh water, <0.5 ppt
Eichhornia crassipes	Water hyacinth	Non-rooted floating aquatic	Perennial, nonpersistent	Rapid	Stolons		Whole plant	Fresh water ponds and sluggish streams	Full sun	Coots, cover for invertebrates and fish	Permanent inundation	Fresh water, < 0.5 ppt
Hydrocotyle umbellata	Water-pennywort	Emergent to floating, herbaceous	Perennial, nonpersistent	Rapid	Stolons or rhizomes		Bare root plant, whole plant	Shorelines, shallow marshes	Partial shade	Wildfowl, waterfowl	Regular to permanent inundation,<30 cm	Fresh water, <0.5 ppt
Iris versicolor	Blue flag	Emergent, herbaceous	Perennial, nonpersistent	Slow, <60 cm/yr	Bulb	0.15 to 0.45 m O.C.	Seed, bulb, bare root plant	Marshes, wet meadows, swamps	Partial shade	Muskrat, wildfowl, marshbirds	Regular to permanent inundation, <15 cm	Fresh to moderately brackish water
Juncus effusus	Soft rush	Emergent, herbaceous	Perennial, persistent	Slow, <6 cm/yr	Rhizome	0.15 to 0.45 m O.C.	Seed, rhizome, bare root plant	Marshes, shrub swamps, wet meadows	Full sun	Wildfowl, marshbirds, songbirds, waterfowl	Regular to permanent inundation, <30 cm	Fresh water, <0.5 ppt
Lemna minor	Common duckweed	Non-rooted floating aquatic	Perennial, nonpersistent	Rapid	Fragmentation		Whole plant	Lakes and ponds	Partial shade	Ducks, gallinules, coots, rails, geese, beaver, muskrat, small mammals	Permanent inundation	Fresh water, <0.05 ppt
Nuphar luteum	Spatterdock	Rooted floating to emergent, herbaceous	Perennial, nonpersistent	Slow, <6 cm/yr	Rhizome	0.15 to 0.45 m O.C.	Bare root plant	Marshes, swamps, ponds	Partial shade	Ducks, muskrat, fish	Regular to permanent inundation, up to 1.8 m	Fresh to infrequent brackish water

TABLE 5-10 (CONTINUED)
Typical Aquatic and Wetland Plant Species that are Used in Constructed Wetlands*

Plant Species	Common Name	Growth Form	Persistence	Growth/Spread Rate	Vegetative Growth Method	Spacing	Propagules	Habitat	Shade Tolerance	Wildlife Benefits	Water Regime	Salinity Tolerance
Nymphea odorata	Fragent water lily	Rooted floating aquatic	Perennial, nonpersistent		Rhizome		Bare root seedling	Ponds and lakes	Partial shade	Cranes, ducks, beaver, muskrat, moose	Permanent inundation, 0.3 to 0.9 m	Fresh water, <0.05 ppt
Nyssa sylvatica	Black gum	Tree	Perennial, deciduous	Slow	Suckers		Seed, bare root plant	Forested wetlands, swamps	Partial shade	Ducks, woodpeckers, songbirds, aquatic furbearers	Irregular to permanent inundation	Fresh to infrequent brackish water
Phragmites australis	Common reed	Emergent, herbaceous	Perennial, persistent	Rapid, > 30 cm/yr	Rhizome	0.6 to 1.8 m O.C.	Bare root plant	Fresh to brackish marshes, swamps	Full sun	Songbirds, marshbirds, shorebirds, aquatic furbearers	Seasonal to permanent inundation, up to 60 cm	Fresh to brackish water, up to 20 ppt
Pontederia cordata	Pickerelweed	Emergent herbaceous	Perennial, nonpersistent	Moderate, 15 cm/yr	Rhizome	0.3 to 0.9 m O.C.	Rhizome, bare root plant	Fresh to brackish marshes, edges of ponds	Partial shade	Ducks, muskrat, fish	Regular to permanent inundation, up to 30 cm	Fresh to moderately brackish water, up to 3 ppt
Populus deltoides	Eastern cottonwood	Tree	Perennial, deciduous	Fast, 1.2 to 1.5 m/yr			Bare root plant, container	Forested wetlands	Full sun	Gamebirds, songbirds, waterfowl, aquatic furbearers, browsers	Seasonal inundation or saturation	Fresh to infrequent brackish water
Potamogeton nodosus	Long-leaved pond weed	Rooted submerged aquatic	Perrenial, nonpersistent	Rapid	Rhizome	0.6 to 1.8 m O.C.	Seed, bare root plant	Streams, lakes, ponds		Waterfowl, marshbirds, shorebirds, aquatic furbearers, moose, fish	Regular to permanent inundation, 0.3 to 1.8 m	Fresh water, <0.05 ppt
Quercus bicolor	Swamp white oak	Tree	Perennial, deciduous	Fast, 0.4 to 0.6 m/yr			Bare root plant, container	Forested wetlands	Partial shade	Waterfowl, marshbirds, shorebirds, gamebirds, songbirds, mammals	Irregular to seasonal inundation or saturation	Fresh to infrequent brackish water
Rosa palustris	Swamp rose	Shrub	Perennial, deciduous				Container	Fresh marshes, shrub swamps	Full sun	Songbirds, gamebirds	Irregular to regular soil saturation	Fresh water, < 0.5 ppt
Sagittaria latifolia	Duck potato	Emergent, herbaceous	Perennial, nonpersistent	Rapid, > 30 cm/yr	Runners, tubers	0.6 to 1.8 m O.C.	Tuber, bare root plant	Fresh marshes, swamps, edge of ponds	Partial shade	Ducks, swans, rails, muskrats, beaver	Regular to permanent inundation, up to 60 cm	Fresh water, <0.5 ppt
Salix nigra	Black willow	Tree	Perennial, deciduous	Fast, 0.9 to 1.8 m/yr	Suckers		Bare root, container	Fresh marshes, swamps	Full sun	Gamebirds, ducks, songbirds, woodpeckers, aquatic mammals	Irregular to permanent inundation	Fresh water, < 0.5 ppt
Scirpus acutus	Hardstem bulrush	Emergent, herbaceous	Perennial, persistent	Rapid	Rhizome	0.9 to 1.8 m O.C.	Seed, rhizome	Fresh to brackish marshes	Full sun	Ducks, geese, swans, cranes, shorebirds, rails, snipe, muskrats, fish	Regular to permanent, up to 90 cm	Fresh to brackish water
Scirpus americanus	Olney's bulrush	Emergent, herbaceous	Perennial, semi-persistent	Rapid, > 30 cm/yr	Rhizome	0.6 to 1.8 m O.C.	Rhizome, bare root plant	Brackish and alkali marshes	Full sun	Ducks, geese, swans, cranes, shorebirds, rails, snipe, muskrats, fish	Regular to permanent inundation, up to 30 cm	Fresh to brackish water, up to 15 ppt

TABLE 5-10 (CONTINUED)
Typical Aquatic and Wetland Plant Species that are Used in Constructed Wetlands*

Plant Species	Common Name	Growth Form	Persistence	Growth/Spread Rate	Vegetative Growth Method	Spacing	Propagules	Habitat	Shade Tolerance	Wildlife Benefits	Water Regime	Salinity Tolerance
Scirpus cyperinus	Wool grass	Emergent, herbaceous	Perennial, persistent	Moderate, 15 cm/yr	Rhizome	0.3 to 0.9 m O.C.	Rhizome, bare root plant	Fresh marshes, wet meadows, sloughs, swamps	Full sun	Ducks, geese, swans, cranes, shorebirds, rails, snipe, muskrats, fish	Irregular to seasonal inundation	Fresh water, < 0.5 ppt
Scirpus validus	Soft stem bulrush	Emergent, herbaceous	Perennial, persistent	Rapid, > 30 cm/yr	Rhizome	0.6 to 1.8 m O.C.	Rhizome, bare root plant	Fresh and brackish marshes	Full sun	Ducks, geese, swans, cranes, shorebirds, rails, snipe, muskrats, fish	Regular to permanent inundation, up to 30 cm	Fresh to brackish water, up to 5 ppt
Sparganium eurycarpum	Giant burreed	Emergent, herbaceous	Perennial, nonpersistent	Rapid, > 30 cm/yr	Rhizome	0.6 to 1.8 m O.C.	Seed, rhizome, bare root plant	Marshes, swamps, pond shorelines	Partial shade	Ducks, swan, geese, beaver, muskrat,	Regular to permanent inundation, up to 30 cm	Fresh water, <0.5 ppt
Taxodium distichum	Bald cypress	Tree	Perennial, deciduous	Medium, 0.3 to 0.6 m/yr			Seed, bare root, container	Fresh water swamps, pond and lake margins	Partial shade	Perching and nesting site for birds	Irregular to permanent inundation	Fresh water, <0.5 ppt
Typha angustifolia	Narrow-leaved cattail	Emergent, herbaceous	Perennial, persistent	Rapid, > 30 cm/yr	Rhizome	0.6 to 1.8 m O.C.	Rhizome, bare root plant	Fresh and brackish marshes, pond edges	Full sun	Geese, ducks, muskrats, beaver, blackbirds, fish	Irregular to permanent inundation, up to 30 cm	Fresh to brackish water, up to 15 ppt
Typha latifolia	Broad-leaved cattail	Emergent, herbaceous	Perennial, persistent	Rapid, > 30 cm/yr	Rhizome	0.6 to 1.8 m O.C.	Rhizome, bare root plant	Fresh marshes, pond margins	Full sun	Geese, ducks, muskrats, beaver, blackbirds, fish	Irregular to permanent inundation, up to 30 cm	Fresh water, <0.5 ppt

*Adapted with modifications from Thunhorst (1993).

Floating Aquatic Plants

Floating aquatic plants have been incorporated in treatment wetland systems for many years. A variety of species are used in wetland applications including water hyacinth (*Eichhornia crassipes*), duckweed species (*Lemna* spp., *Spirodela* spp., *Wolffia* spp., and *Wolfiella* spp.), water ferns (*Azolla caroliniana* and *Salvinia rotundifolia*), and water lettuce (*Pistia stratiotes*). Other common rooted species that may exist in a floating form include pennywort (*Hydrocotyle* spp.), water lilies (*Nymphaea* spp.), frog's bit (*Limnobium spongia*), spatterdock (*Nuphar* spp.), and pondweeds (*Potemogeton* spp.). In constructed treatment wetlands, floating aquatic plants serve as both a structural surface for the attachment of microbes and periphyton and as a biological component for treatment of wastewater. The floating aquatic plants with root systems can extend their roots from 10 to 60 cm into the water column depending on the wastewater characteristics. The smaller floating aquatic plants primarily serve as a shading layer to discourage unwanted planktonic algal blooms in the open or deep water microhabitats. These smaller plants provide nutrient uptake and transformation and can significantly influence temperature and dissolved oxygen concentrations in the underlying water column.

Many of the floating aquatic plants used in treatment wetlands have relatively high growth and nutrient uptake rates and rapid vegetative and, to a lesser extent, sexual reproduction rates. In most cases, management of floating aquatic plant treatment wetlands includes a harvesting plan. Since these plants accumulate large amounts of biomass and nutrients, harvesting or removing the plants from the wetland cells is necessary to achieve effective waste treatment in the wetland system. Problems may arise when dealing with disposal of the harvested plants. Composting, land application as a green manure, use as livestock fodder, landfilling, and methane generation have been alternatives used to dispose of harvested plant biomass.

Emergent Herbaceous Plants

Emergent herbaceous plants are rooted in the soil and have plant structures that extend above the surface of the water during inundated periods. The herbaceous nature of these plants includes non-woody structures that allow the plant to stand upright without the support of surrounding waters. For these plants to survive and thrive in aquatic or wetland environments, they have developed extensive adaptations to maintain normal growth and reproduction. These adaptations include lenticels (small openings through the leaves and stems) that allow air to move in and out of the plant; vascular or aerenchymous tissue that allows gaseous diffusion or air convection through the length of the plant; adventitious roots that allow absorption of gases and plant nutrients directly from the water column; and extra physiological tolerance to chemical by-products resulting from growth in the anaerobic soil environment (Kadlec and Knight, 1996).

A wide range of emergent herbaceous plant species are used in constructed treatment wetlands. The most common emergent herbaceous aquatic plants in treatment wetlands are cattails (*Typha* spp.), bulrush (*Scirpus* spp.), and common reed (*Phragmites australis*). These three groups of plants are similar in their tolerance of a wide range of water qualities, including salinity; their ability to grow under continuously flooded conditions; and their production of large quantities of biomass, which maintain plant structure during the non-growing season and provide carbon to augment microbial energy cycles.

Bulrush species have been widely used in livestock wastewater constructed treatment wetlands. The large bulrush species include *S. validus*, *S. californicus*, and *S. acutus*. These species form dense stands with large numbers of round stems that maintain upright positions for 1 to 2 years. Other species of *Scirpus* include the three-square stem varieties such as *S. americanus* (*olynei*), *S. fluviatilis*, and *S. robustus* that offer flexibility in tolerance of salinity and are attractive to various species of wildlife.

The performance of herbaceous aquatic plants in constructed treatment wetlands has only recently been studied. A variety of planted and naturally colonizing herbaceous aquatic macrophytes might exist in any given treatment wetland, and, in fact, polytypic stands of vegetation are better than monotypic stands for the wetland's ecological balance. When monotypic stands of cattail or bulrush have been studied, research has indicated no clear advantage of using a specific plant species for reducing BOD_5, TSS, TN, and TP in treatment wetlands.

Woody plants are separated into three categories: shrubs, trees (canopy and subcanopy), and woody vines. The distinguishing characteristics of woody vegetation include plants that contain bark, non-leafy vascular structures, extended, long-term growth, and decay resistant tissues. In general, woody plants are larger that emergent herbaceous aquatic macrophytes and will shade out small plant species.

A variety of woody plants can be used in treatment wetlands. In the southeast, the most commonly planted woody species include cypress (*Taxodium* spp.), willow (*Salix* spp.), ash (*Fraxinus* spp.), and gum (*Nyssa* spp.). In the north, species of willow along with spruce (*Abies* spp.), birch (*Betula* spp.), and alder (*Alnus serrulata*) are commonly used.

Woody plants can provide habitat variety useful to wildlife species. For example, shrubs and trees provide nesting areas and perches for a birds that use wetlands. Several wetland tree species provide berries, fruit, or other mast important to the ecological pathways of the wetland.

Plant Establishment and Maintenance

Problems with successful plant establishment include insufficient soil moisture, excessive water depths, inadequate soil preparation, damaged plant material, inadequate plant spacing, inappropriate plant methods, and bad timing. Other aspects of wetland vegetation maintenance are not as simple as initial plant establishment. Perpetuating the dominance of desired species, maintaining desired plant cover density, and excluding undesirable plant species are all complex, problematic goals that cannot always be achieved.

Plant Sources

In recent years, commercial supplies of wetland plant material have become relatively common. Regulations requiring entities that remove or manipulate wetlands to mitigate for the wetland losses have created a high demand for live, healthy plants for revegetation. Most commonly used plants for treatment wetlands can be purchased for planting or can be harvested locally from existing roadside ditches or pond margins. Depending on the morphology of individual plants, the plant can be purchased as a bare-root seedling, a sterile propagule from a micropropagation laboratory, a senesced root or rhizome, a potted seedling, or an individual taken from an established stand. Some wetland plant species can be established from seed. Seeds can be planted by hand broadcasting or automated broadcasting with the use of a tractor.

Another method of establishing plants in a newly constructed wetland is reliance on volunteer colonization from an existing or imported seed bank. Most constructed treatment wetlands require some type of organic soil augmentation for successful plant establishment, and removing a layer of soil from another existing wetland and evenly distributing the soil throughout the newly constructed wetland will allow the natural seed "bank" in the existing soil to germinate and establish the vegetation in the new treatment wetland.

The most common form of plant seedlings are bare-root propagules. Bare-root seedlings are easily planted in the field using a small shovel, trowel, or dibble. The survival rate of bare-root seedlings is significantly higher than for field-germinated seeds and can be generally maintained at 80 percent or higher with healthy plant stock and an adequate moisture regime. Since bare-root stock has already had a sufficient period of initial growth, successful planting can lead to a rapid plant cover development.

Field-harvested plants, in some cases, offer the most successful option for planting treatment wetlands. Field-harvested plants can be collected from nearby retention ponds, roadside ditches, and canals and planted in suitable substrate in the newly constructed wetland. Planting field-harvested plants may be more difficult than planting bare-root propagules due to the size differences of the plants. Planting can be accomplished by using a shovel or post-hole digger to bury all roots and associated belowground structures. Care should be taken to limit stresses to the plants such as extreme shifts in temperature, moisture, and light. Field-harvested plants may have advantages over nursery grown stock. These advantages include larger roots, rhizomes, and/or corms for energy storage, which will allow the plant to produce aboveground structures faster once they are planted; adaptations to the local environmental conditions through the genetic conditioning that the species has evolved in the particular locale; and the incorporation of other volunteer wetland plant species in the soil associated with the plant roots.

Plant Establishment

Wetland plants have various environmental adaptations as part of their normal routines of germination, growth, reproduction, and senescence/decay. A general understanding of these components of plant biology is important in planning and operating treatment wetlands.

Most emergent wetland plants produce seeds that germinate and initially develop best in wet but unflooded loamy soils. Excessive flooding will kill most wetland plant seedlings. Tight, clayey soils may be inhospitable for root development and aeration for some plant species. Highly drained sandy soils and gravel may not provide adequate moisture for initial plant development. Rapid development of herbaceous wetland plants in constructed wetlands is normally accomplished through adequate spacing of healthy plants into moist loamy to sandy soils, followed by very gradual increases in water levels during plant establishment. Rapid increases in water levels within newly planted treatment wetlands may kill the plantings.

Plants require nutrients in proper proportions for healthy growth. The major nutrients required for plant growth are carbon (typically supplied from atmospheric or dissolved carbon dioxide, 29 to 50 percent by dry weight), potassium (0.4 to 5 percent), nitrogen (1.5 to

4 percent), calcium (0.2 to 8 percent), sulfur (0.1 to 1.6 percent), and phosphorus (0.1 to 0.6 percent). The two major nutrients most likely to limit plant growth in wetlands are phosphorus and nitrogen, respectively. While most livestock wastewaters supply adequate quantities of these limiting nutrients, some industrial or runoff (agricultural) wastewaters do not provide ample nutrition for wetland plant growth. Nutrient supplements may be required for rapid plant development and for sustained wetland plant growth. Soil tests during pre-design can be used to identify fertilization requirements for rapid plant establishment. In addition, wetland plants require a number of minor nutrients for normal growth and development. Some essential plant micronutrients include magnesium, iron, manganese, boron, zinc, copper, and molybdenum. In a few instances, plant micronutrients must be added to wetlands to provide adequate plant growth.

Wetland plant species have a variety of growth strategies that provide competitive advantages in their natural habitats. Emergent herbaceous marsh species in temperate climates generally grow vegetatively within a single growing season to a maximum total standing live biomass in late summer or early fall. This biomass may represent multiple growth and senescence periods for individual plants during the growing season or a single emergence of plant structures. Standing senesced biomass may provide attachment sites for microbial species important in wetland treatment performance throughout the annual cycle, but is also important for maintaining root viability under flooded, winter conditions. The litter that does not decompose is added to the soil column as new organic matter and may result in a significant loss pathway for some relatively conservative elements such as phosphorus and metals (Kadlec and Knight, 1996).

Other plant species have longer growth cycles. Woody plants may live for many years under certain hydrologic regimes and can provide long-term storage and sequestering of plant nutrients in wetlands. It is important to note that almost without exception, long-term sequestration of nitrogen and phosphorus in plant uptake is not a significant component of the total loss of these elements in treatment wetlands. Their losses are explained more by the fact that these elements are quickly cycled through the growing and dying plant communities in most treatment wetlands and are available with excess plant carbon for microbial transformations (TN) or are buried with accreting peat soils (TP).

Operation and Maintenance Requirements

Water Levels

The wetland must remain wet during all seasons. During hot, dry months when evapotranspiration rates are high, water may enter the upper end of the wetland but not reach the lower end. In this situation, plants in the downstream end of the wetland can be stressed or killed and treatment can be adversely affected. Thus, the owner must ensure that water levels in all cells are maintained except for limited short periods, even if additional water must be added to the system. Additional water can come from the pretreatment unit or be pumped to the lower cells from the downstream holding pond. It may also be advantageous to divert additional roof water into the pretreatment unit during the summer months. All of these options should be considered and accounted for when the water budget is developed during initial planning.

Water Control Structures

Pipes, valves, flow control orifices, weirs and other fixtures must be checked on a regular basis for plugging. Floating solids, small turtles, and other debris have been known to enter piping systems from the pretreatment unit and block flows to wetlands. In addition, struvite, a crystalline substance often associated with livestock wastewater recycle lines, can gradually build up on the walls of pipelines and restrict flows. Thus, regular inspection of water conveyance and control structures is essential to ensure proper flows and the maintenance of proper water level elevations in the cells.

Embankments

Regular mowing of embankments ensures a neat appearance of the wetland and allows for ease of inspection of the entire system. The owner should regularly inspect embankments for damage from rodents such as muskrats and nutria. These and other types of animals can reduce or decimate healthy stands of certain types of wetland vegetation. In addition, burrows can create safety hazards for personnel and equipment. In severe situations, wire mesh or other impediments may be needed to thwart rodent activity.

SECTION 6

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Appendix A
Summary of Treatment Wetlands in the North American Treatment Wetland Database (NADB)

TABLE A-1
Summary of Treatment Wetlands in the NADB*

Site Name	City	State	Wastewater Source [a]	Origin [b]	Hydrologic Type [c]	Wetland Area (ha)	Vegetation Type [d]	Number of Cells	Design Flow (m^3/d)	Construction Cost ($)	Design HLR (cm/d)	Cost/ Area ($/ha)
Andrews	Andrews	SC	MUN	NAT	SF	185.0	FOR	1	7,193		0.39	
Apalachicola	Apalachicola	FL	MUN	NAT	SF	63.7	SHB	1	3,785		0.59	
Arcata	Arcata	CA	MUN	CON	SF	15.2	MAR	6	8,781	514,600	5.79	33,909
Arlington	Arlington	SD	MUN	CON	SF	3.4	MAR	1	643		1.87	
Armour	Armour	SD	MUN	CON	SF	3.4	MAR	1				
Armstrong Slough	South Florida	FL	STO	NAT	SF	12.1	MAR	1	41,880		34.61	
Bellaire	Bellaire	MI	MUN	NAT	SF	66.3	FOR	5	2,445		0.37	
Belle Fourche	Belle Fourche	SD	MUN	CON	SF	29.3	MAR	13	1,893		0.65	
Benton	Benton	KY	MUN	CON	SF	3.0	MAR	2	2,800		9.33	
Bethel	Bethel	MO	MUN	CON	SF	0.3	MAR		57		1.69	
Biwabik	Biwabik	MN	MUN	NAT	SF	40.5	FOR	1	1,060	934,000	0.26	23,062
Brandt	Brandt	SD	MUN	CON	SF	1.0	MAR	1				
Bridgewater	Bridgewater	SD	MUN	CON	SF	2.0	MAR	2				
Brillion	Brillion	WI	MUN	NAT	SF	156.0	MAR	1	5,400		0.35	
Bristol	Bristol	SD	MUN	CON	SF	1.0	MAR	1				
Brookhaven	Brookhaven	NY	MUN	CON	SF	0.5	MAR	7	114		2.34	
Buenaventura Lakes	Buenaventura Lakes	FL	MUN	NAT	SF	68.0	FOR	2	3,029		0.45	
Canistota	Canistota	SD	MUN	CON	SF	4.6	MAR	1				
Cannon Beach	Cannon Beach	OR	MUN	NAT	SF	7.0	FOR	2	1,174	1,274,000	1.68	182,000
Cargill/Frank Lake	High River	ALB,CAN	IND	NAT	SF	1,093.0	MAR	1	5,300	8,150,000	0.05	7,457
Central	Central	SC	MUN	NAT	SF	31.6	FOR	1	4,543		1.44	
Chancellor	Chancellor	SD	MUN	CON	SF	1.0	MAR	1				
Clear Lake	Clear Lake	SD	MUN	CON	SF	2.3	MAR	1				
Clermont	Clermont	FL	MUN	NAT	SF	0.6	MAR	3	42		0.71	
Cobalt	Cobalt	ONT,CAN	MUN	CON	SF	0.0	MAR	1	17		1.83	
Cypress Domes	Gainesville	FL	MUN	NAT	SF	1.6	FOR	2	114		0.73	
Des Plaines	Wadsworth	IL	OTH	CON	SF	10.1	MAR	4	4,635	3,375,000	4.58	333,169
Doland	Doland	SD	MUN	CON	SF	1.1	MAR	1				
Drummond	Drummond	WI	MUN	NAT	SF	6.0	HYB	1	300	25,000	0.50	4,167
Eden	Eden	SD	MUN	CON	SF	0.3	MAR	1				
Ethan	Ethan	SD	MUN	CON	SF	2.8	MAR	2				
Eureka	Eureka	SD	MUN	CON	SF	16.3	HYB	4	1,045	470,000	0.64	28,767
Everglades Nutr. Removal	West Palm Beach	FL	OTH	CON	SF	1,406.0	MAR	4	636,208	14,000,000	4.52	9,957
Fontanges	Fontanges	QUE,CAN	OTH	NAT	SF	0.5	MAR	2	280		5.60	
Fort Deposit	Fort Deposit	AL	MUN	CON	SF	6.0	MAR	2	900	374,000	1.50	62,333
Geddes	Geddes	SD	MUN	CON	SF	0.8	MAR	1				
Great Meadows	Concord	MA	MUN	NAT	SF	22.0	MAR	1	2,000		0.91	
Gustine	Gustine	CA	MUN	CON	SF	9.6	MAR	24	3,785	882,000	3.94	91,875
Gustine	Gustine	CA	MUN	NAT	SF	0.3	MAR	1				
Hamilton Marshes	Hamilton Township	NJ	MUN	NAT	SF	500.0	MAR	3				
Hay River	Hay River	NWT,CAN	MUN	NAT	SF	47.0	MAR	1	1,000		0.21	

TABLE A-1 (CONTINUED)
Summary of Treatment Wetlands in the NADB*

Site Name	City	State	Wastewater Source [a]	Origin [b]	Hydrologic Type [c]	Wetland Area (ha)	Vegetation Type [d]	Number of Cells	Design Flow (m^3/d)	Construction Cost ($)	Design HLR (cm/d)	Cost/ Area ($/ha)
Hayward	Hayward	CA	MUN	CON	SF	58.7	MAR	5	75,720		12.90	
Hidden Lake	Orlando	FL	STO	NAT	SF	3.0	FOR	1				
Hillsboro ND	Hillsboro	ND	IND	CON	SF	33.0	MAR	9	5,678	1,600,000	1.72	48,485
Hillsboro OR	Hillsboro	OR	IND	CON	SF	35.7	MAR	17		185,000		5,182
Hilton Head Plantation	Hilton Head Plantation	SC	MUN	NAT	SF	36.5	FOR	1	1,893		0.52	
Houghton Lake	Houghton Lake	MI	MUN	NAT	SF	79.0	MAR	2	6,360	500,000	0.81	6,329
Hoven	Hoven	SD	MUN	CON	SF	11.5	HYB	7	360		0.31	
Huron	Huron	SD	MUN	CON	SF	133.5	MAR	3	9,465		0.71	
Hurtsboro	Hurtsboro	AL	MUN	NAT	SF	0.2	MAR	2	56		3.50	
Incline Village	Incline Village	NV	MUN	CON	SF	173.3	MAR	8	5,000	5,000,000	0.29	28,855
Ironbridge	Orlando	FL	MUN	CON	SF	494.0	HYB	17	75,720	21,020,000	1.53	42,551
Island Lake	Longwood	FL	STO	NAT	SF	42.0	MAR	1				
Jasper	Jasper	FL	MUN	NAT	SF	24.0	FOR	1				
Johnson City	Johnson City	TX	MUN	CON	SF	0.5	MAR	9	114		2.28	
Kadoka	Kadoka	SD	MUN	CON	SF	5.0	MAR	2				
Kimball	Kimball	SD	MUN	CON	SF	6.5	MAR	1				
Kinross (Kincheloe)	Kinross	MI	MUN	NAT	SF	110.0	MAR	1	450		0.04	
Lake Apopka Wetlands Flwy	Apopka	FL	OTH	CON	SF	750.0	MAR	2	733,536		9.78	
Lake Cochrane San	Lake Cochrane San	SD	MUN	CON	SF	0.6	MAR	1				
Lake Jackson	Tallahassee	FL	STO	CON	SF	2.3	MAR	3				
Lake Preston	Lake Preston	SD	MUN	CON	SF	7.8	MAR	1				
Lakeland	Lakeland	FL	MUN	CON	SF	498.0	MAR	7	52,704		1.06	
Lakeside	Lakeside	AZ	MUN	CON	SF	38.0	MAR	7	1,540	286,600	0.41	7,542
Leaf River	New Augusta	MS	IND	CON	SF	0.4	MAR	3	699		17.92	
Listowel Artificial Marsh	Listowel	ONT,CAN	MUN	CON	SF	0.9	MAR	7	154		1.78	
Mandan (Amoco)	Mandan	ND	IND	CON	SF	16.6	MAR	11	2,650	250,000	1.60	15,060
Martin	Martin	SD	MUN	CON	SF	2.8	MAR	1				
Mays Chapel	Cockeysville	MD	STO	CON	SF	0.2	MAR	1	160	27,800	6.68	115,833
Mcintosh	Mcintosh	SD	MUN	CON	SF	3.7	HYB	3	223	530,000	0.60	142,358
Mellette	Mellette	SD	MUN	CON	SF	2.5	HYB	3	124		0.50	
Minot	Minot	ND	MUN	CON	SF	13.6	MAR	4	20,818	475,000	15.33	34,980
Monticello	Monticello	FL	MUN	CON	SF	188.6	HYB	14	3,785		0.20	
Moodna Basin	Harriman	NY	MUN	CON	SF	0.3	MAR	2	114		3.75	
Mt Angel	Mt Angel	OR	MUN	CON	SF	4.0	MAR		7,570	350,000	18.71	86,484
Mt.View Sanitary District	Martinez	CA	MUN	CON	SF	37.0	MAR	3	5,300	90,000	1.43	2,432
Murdo	Murdo	SD	MUN	CON	SF	2.4	MAR	2				
Norwalk	Norwalk	IA	MUN	CON	SF	11.7	MAR	2	1,160		0.99	
Onida	Onida	SD	MUN	CON	SF	2.8	MAR	1				
Orange County	Orlando	FL	MUN	HYB	SF	89.0	HYB	2	13,251	2,900,000	1.49	32,584
Pembroke	Pembroke	KY	MUN	CON	SF	0.9	HYB	1	340		3.66	

TABLE A-1 (CONTINUED)
Summary of Treatment Wetlands in the NADB*

Site Name	City	State	Wastewater Source [a]	Origin [b]	Hydrologic Type [c]	Wetland Area (ha)	Vegetation Type [d]	Number of Cells	Design Flow (m^3/d)	Construction Cost ($)	Design HLR (cm/d)	Cost/Area ($/ha)
Plankinton	Plankinton	SD	MUN	CON	SF	1.9	MAR	1				
Poinciana	Poinciana	FL	MUN	NAT	SF	46.6	FOR	1	1,325		0.28	
Pottsburg	Jacksonville	FL	MUN	NAT	SF	100.0	FOR	1	14,040		1.40	
Prariewood San	Prariewood San	SD	MUN	CON	SF	0.5	MAR	1				
Presho	Presho	SD	MUN	CON	SF	1.9	MAR	1				
Reedy Creek	Lake Buena Vista	FL	MUN	NAT	SF	82.2	FOR	3	20,066		2.44	
Reliance	Reliance	SD	MUN	CON	SF	0.3	MAR	1				
Richmond	Richmond	CA	IND	CON	SF	36.0	MAR	2	16,000		4.44	
Richton	Richton	MS	MUN	CON	SF		MAR	2	1,325			
Rosholt	Rosholt	SD	MUN	CON	SF	1.6	MAR	1				
Roslyn	Roslyn	SD	MUN	CON	SF	0.6	MAR	1				
Santa Rosa	Santa Rosa	CA	MUN	CON	SF	4.1	HYB	5	7,570		18.69	
Sea Pines	Sea Pines	SC	MUN	NAT	SF	20.0	MAR	1	3,786		1.89	
Seneca Army Depot	Seneca Army Depot	NY	MUN	OTH	SF	2.5	MAR	1	950		3.80	
Show Low	Show Low	AZ	MUN	CON	SF	54.2	MAR	8	5,299	146,750	0.98	2,708
Silver Springs Shores	Silver Springs Shores	FL	MUN	CON	SF	21.0	MAR	2	3,786		1.80	
Sisseton	Sisseton	SD	MUN	CON	SF	102.8	MAR	1	2,033		0.20	
Spencer	Spencer	SD	MUN	CON	SF	1.4	MAR	1	246		1.79	
St. Joseph	St. Joseph	MN	STO	NAT	SF	18.6	MAR	2	900		0.48	
Stickney	Stickney	SD	MUN	CON	SF	0.9	MAR	2	257		2.89	
Tabor	Tabor	SD	MUN	CON	SF	0.5	MAR	2				
Tripp	Tripp	SD	MUN	CON	SF	2.7	MAR	2				
University of Florida	Gainesville	FL	MUN	NAT	SF	33.0	MAR	1	7,500		2.27	
USDA-NSCS	Orono	ME	OTH	CON	SF		MAR	1		22,500		
Vereen	Little River	SC	MUN	NAT	SF	229.0	FOR	3	9,466	4,233,000	0.41	18,485
Vermontville	Vermontville	MI	MUN	CON	SF	4.6	MAR	4	380	395,000	0.83	85,870
Volga	Volga	SD	MUN	CON	SF	6.1	MAR	2	825		1.36	
Wakonda	Wakonda	SD	MUN	CON	SF	1.6	MAR	1				
Waldo	Waldo	FL	MUN	NAT	SF	2.6	FOR	1	226		0.87	
Wall Lake San	Wall Lake San	SD	MUN	CON	SF	0.4	MAR	2				
Wessington	Wessington	SD	MUN	CON	SF	0.5	MAR	1				
West Jackson County	Ocean Springs	MS	MUN	CON	SF	22.7	MAR	7	6,057		2.67	
White Lake	White Lake	SD	MUN	CON	SF	1.5	MAR	2				
Wildwood	Wildwood	FL	MUN	NAT	SF	204.0	FOR	3	3,786		0.19	
Willow Lake	Willow Lake	SD	MUN	CON	SF	9.7	MAR	6	246		0.25	
Albany	Albany	LA	MUN	CON	HYB	0.1	MAR	2	132		12.00	
Cottonwood	Cottonwood	AL	MUN	CON	HYB	0.4	MAR	1	587	156,800	14.68	392,000
Crowley	Crowley	LA	MUN	CON	HYB	17.0	MAR	7	13,248	1,660,000	7.79	97,647
Degussa Corp.	Theodore	AL	IND	CON	HYB	0.9	MAR	11	2,040	265,000	22.92	297,753
Iselin	Iselin	PA	MUN	CON	HYB	0.2	MAR	3	45	500,000	2.07	2,272,727
Pelahatchie	Pelahatchie	MS	OTH	CON	HYB	2.6	MAR	5	2,157		8.20	

TABLE A-1 (CONTINUED)
Summary of Treatment Wetlands in the NADB*

Site Name	City	State	Wastewater Source [a]	Origin [b]	Hydrologic Type [c]	Wetland Area (ha)	Vegetation Type [d]	Number of Cells	Design Flow (m^3/d)	Construction Cost ($)	Design HLR (cm/d)	Cost/ Area ($/ha)
Shelbyville	Shelbyville	MO	MUN	CON	HYB	0.2	MAR	4	280		17.28	
Terry	Terry	MS	MUN	CON	HYB	0.5	MAR	3	378	190,000	7.27	365,385
Benton	Benton	KY	MUN	CON	SSF	1.5	MAR	1	341		2.34	
Benton	Benton	LA	MUN	CON	SSF	0.5	MAR	1	1,173	262,000	24.44	545,833
Bradford	Bradford	AR	MUN	CON	SSF	1.1	MAR	2	757	335,430	6.69	296,316
Bradley	Bradley	AR	MUN	CON	SSF	0.6	MAR	4	1,135	145,000	19.46	248,714
Carlisle	Carlisle	AR	MUN	CON	SSF	4.3	MAR	4	3,255	335,430	7.49	77,199
Carville	Carville	LA	MUN	CON	SSF	0.3	MAR	1	568	100,000	21.85	384,615
Clarendon	Clarendon	AR	MUN	CON	SSF	0.8	MAR	4	2,650	318,600	32.55	391,400
Denham Springs	Denham Springs	LA	MUN	CON	SSF	6.2	MAR	3	11,355	1,500,000	18.46	243,902
Dessau Mobile Home Park	Pflugerville	TX	MUN	CON	SSF	0.2	MAR	2	568		27.04	
Dierks	Dierks	AR	MUN	CON	SSF	0.5	MAR	2	871	164,758	18.56	351,296
Doyline	Doyline	LA	MUN	CON	SSF	0.3	MAR	1	416		14.86	
Eudora	Eudora	AR	MUN	CON	SSF	1.3	MAR	2	2,271	639,619	17.04	479,834
Foothills Village	Loudon Co.	TN	MUN	CON	SSF	0.1	MAR	2	67		6.70	
Foreman	Foreman	AR	MUN	CON	SSF	1.0	MAR	4	908	354,252	8.85	345,275
Gillett	Gillett	AR	MUN	CON	SSF	0.9	MAR	4	454	229,180	4.79	241,751
Greenleaves Subdivision	Mandeville	LA	MUN	CON	SSF	0.4	MAR	1	564	523,553	12.67	1,176,524
Gurndon	Gurndon	AR	MUN	CON	SSF	1.7	MAR	2	3,255	377,411	18.87	218,789
Hammond	Hammond	LA	OTH	CON	SSF	0.1	MAR	1	329	120,000	26.11	952,381
Hardin	Hardin	KY	MUN	CON	SSF	0.6	MAR	2	378		5.91	
Haughton	Haughton	LA	MUN	CON	SSF	0.6	MAR	1	1,324		21.35	
Hornbeck	Hornbeck	LA	MUN	CON	SSF	0.0	MAR	1	231	123,870	25.67	1,376,333
Johnson City	Johnson City	TX	MUN	CON	SSF	0.1	MAR	2	114		10.36	
Kingston Power Plant	Kingston	TN	MUN	CON	SSF	0.3	MAR	4	76	81,000	2.92	311,538
Lewisville	Lewisville	AR	MUN	CON	SSF	0.7	MAR	2	1,514	113,000	21.63	161,429
Lockesburg	Lockesburg	AR	MUN	CON	SSF	0.3	MAR	2	568	112,600	17.97	356,329
Mandeville	Mandeville	LA	MUN	CON	SSF	2.6	MAR	3	5,678	1,000,000	21.75	383,142
Marion	Marion	AR	MUN	CON	SSF	2.5	MAR	8	3,785		15.39	
Mayo Peninsula	Ann Arundel Co.	MD	MUN	CON	SSF	1.5	MAR	4	2,990		19.54	
McNeil	McNeil	AR	MUN	CON	SSF	0.3	MAR	2	57	90,756	1.80	287,203
Mesquite	Mesquite	NV	MUN	CON	SSF	1.9	MAR	3	1,514	515,000	7.97	271,053
Monterey	Monterey	VA	MUN	CON	SSF	0.0	MAR	1	76		33.04	
Ola	Ola	AR	MUN	CON	SSF	0.4	MAR	4	757	425,360	17.81	1,000,847
Paris Landing	Paris Landing State Park	TN	MUN	CON	SSF	0.2	MAR	1	284		18.93	
Pembroke	Pembroke	KY	MUN	CON	SSF	0.5	MAR	1	340		6.30	
Phillips High School	Bear Creek	AL	MUN	CON	SSF	0.2	MAR	1	76	36,266	3.74	178,650
Prescott	Prescott	AR	MUN	CON	SSF	0.8	MAR	2	3,217		37.94	
Provencal	Provencal	LA	MUN	CON	SSF	0.1	MAR	1	344	152,860	24.57	1,091,857
Rector	Rector	AR	MUN	CON	SSF	1.3	MAR	5	1,325		9.92	

TABLE A-1 (CONTINUED)
Summary of Treatment Wetlands in the NADB*

Site Name	City	State	Wastewater Source [a]	Origin [b]	Hydrologic Type [c]	Wetland Area (ha)	Vegetation Type [d]	Number of Cells	Design Flow (m^3/d)	Construction Cost ($)	Design HLR (cm/d)	Cost/ Area ($/ha)
Roswell	Roswell Correctional Ctr.	NM	MUN	CON	SSF	0.0	MAR	1	15		37.50	
Shelbyville	Shelbyville	MO	MUN	CON	SSF	0.0	MAR	1	280		68.29	
Sibley	Sibley	LA	MUN	CON	SSF	0.2	MAR	1	492	48,000	23.43	228,571
Smackover	Smackover	AR	MUN	CON	SSF	2.7	MAR	6	1,892	800,000	7.08	299,401
Swifton	Swifton	AR	MUN	CON	SSF	0.4	MAR	2	416	165,200	9.71	385,082
Thornton	Thornton	AR	MUN	CON	SSF	0.3	MAR	1	378		13.36	
Tuckerman	Tuckerman	AR	MUN	CON	SSF	2.1	MAR	4	852	283,500	4.12	137,222
Utica, North	Utica	MS	MUN	CON	SSF	0.7	MAR	2	341		4.67	
Utica, South	Utica	MS	MUN	CON	SSF	0.9	MAR	2	442		4.80	
Waldo	Waldo	AR	MUN	CON	SSF	0.6	MAR	4	1,325	248,267	21.82	409,007
Natural Wetlands		Average				97.7		2	5,422	2,573,714	2.18	35,687
		Maximum				1,093.0		5	41,880	8,150,000	34.61	85,870
		Minimum				0.2		1	42	25,000	0.04	2,708
		Median				40.5		1	2,737	1,274,000	0.65	18,485
		Std. Dev.				198.0		0	8,378	2,861,492	6.24	44,169
		Count				35		35	30	7	30	3
Constructed SF		Average				56.0		4	35,856	2,518,774	3.83	58,494
		Maximum				1406.0		24	733,536	21,020,000	18.71	333,169
		Minimum				0.0		1	17	22,500	0.20	2,432
		Median				3.4		2	1,963	470,000	1.78	32,584
		Std. Dev.				192.9		4	138,131	5,264,840	5.03	76,644
		Count				79		80	48	21	47	23
Constructed SSF		Average				1.2		3	1,444	363,903	16.08	478,147
		Maximum				17.0		11	13,248	1,660,000	68.29	2,272,727
		Minimum				0.0		1	15	36,266	1.80	77,199
		Median				0.5		2	568	255,134	15.12	348,286
		Std. Dev.				2.4		2	2,409	377,130	11.63	447,592
		Count				56		56	56	34	56	34

*Kadlec and Knight, 1996

[a] Wastewater Source:
IND - Industrial.
MUN - Municipal.
OTH - Other.
STO - Stormwater.

[b] Origin:
CON - Constructed.
HYB - Hybrid.
NAT - Natural.

[c] Hydrologic Type:
HYB - Hybrid.
SF -Surface flow.
SSF - Subsurface flow.

[d] Vegetation Type
FOR - Forested.
HYB - Hybrid.
MAR - Marsh.
SHB - Shrub.

Appendix B
Field Structure of the Livestock Wastewater Treatment Wetland Database (LWDB)

Table B-1
Site Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
1	SITE	Number (Double)	8		
2	SITE_NAME	Text	30		
3	COMMENTS	Memo	-		
4	COUNTRY	Text	8		
5	EPA_REGION	Number (Double)	8		
6	STATE	Text	5		
7	COMMUNITY	Text	25		
8	TOT_SYST	Number (Double)	8		Total # of systems at the site
9	TOT_CELL	Number (Double)	8		Total # of cells at the site
10	AVE_TEMP	Number (Double)	8	deg C	
11	AN_RAIN	Number (Double)	8	cm	
12	LAKE_EVAP	Number (Double)	8	cm/yr	
13	SRCE_OF_WW	Text	3		See CODE list
14	NON_WWUSES	Text	30		
15	SITE_POPL	Number (Double)	8		
16	OPER_SEASN	Text	3		See CODE list
17	FORM_PRTRT	Text	3		See CODE list
18	SI_DES_FLO	Number (Double)	8	m3/da	
19	BOD	Text	1		Checkoffs #19-31 are parameters
20	COD	Text	1		existing in the seven databases
21	TSS	Text	1		
22	VSS	Text	1		
23	TKN	Text	1		
24	N_NH4	Text	1		
25	N_NO3	Text	1		
26	N_ORG	Text	1		
27	N_TOT	Text	1		
28	P_DSV	Text	1		
29	P_TOT	Text	1		
30	DO	Text	1		
31	F_COLIF	Text	1		
32	E_COLI	Text	1		
33	HYDROLOGY	Text	1		
34	VEG	Text	1		
35	NOT_USED	Text	1		
36	SULFAT_IDE	Text	1		
37	REDOX	Text	1		
38	TDS	Text	1		
39	T_SOLIDS	Text	1		
40	SODIUM	Text	1		
41	POTASS	Text	1		
42	COND	Text	1		
43	TURB	Text	1		
44	ALK	Text	1		
45	PH	Text	1		
46	CHLRD	Text	1		
47	METAL_COMM	Text	1		
48	METAL_TOXC	Text	1		
49	SYNTH_ORGA	Text	1		
50	PESTICIDE	Text	1		
51	HERBICIDE	Text	1		

Table B-1 (continued)
Site Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
52	NON_FEC_BA	Text	1		
53	VIRUS	Text	1		
54	TEMP	Text	1		
55	VEG_BIOMAS	Text	1		
56	VEG_CHEM	Text	1		
57	LIT_BIOMAS	Text	1		
58	LIT_CHEM	Text	1		
59	SED_BIOMAS	Text	1		
60	SED_CHEM	Text	1		
61	INVERTEBRT	Text	1		
62	VERTEBRT	Text	1		
63	OR_REC_DAT	Date/Time	8		Original record date
64	ED_REC_DAT	Date/Time	8		Edited record date
65	EDIT_COMM	Memo	-		

Codes

Coded field:	SRCE_OF_WW	Code:	AGR	agricultural
			MUN	municipal
			STO	stormwater
			IND	industrial
			OTH	other
			UNK	unknown
Coded field:	OPER_SEASN	Code:	ANN	annual
			GRO	growing
			VAR	variable
			OTH	other
			UNK	unknown
Coded field:	FORM_PRTRT	Code:	PRI	primary
			SEC	secondary
			ADS	adv. secondary
			TER	tertiary
			FAC	facultative
			NON	none
			OTH	other
			UNK	unknown

Table B-2
System Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
1	SITE	Number (Double)	8		
2	SITE_NAME	Text	30		
3	SYSTEM	Number (Double)	8		
4	SYSTEM_NAM	Text	35		
5	WASTE_CODE	Text	3		See CODE list
6	SYS_POPL	Number (Double)	8		
7	POPL_UNITS	Text	8		
8	NUM_CELL	Number (Double)	8		
9	ORIGIN	Text	3		See CODE list
10	HYDRL_TYPE	Text	3		See CODE list
11	AREA	Number (Double)	8	ha	
12	SY_DES_FLO	Number (Double)	8	m3/da	
13	VEG_TYPE	Text	3		See CODE list
14	START_DATE	Number (Double)	8	year	
15	END_DATE	Number (Double)	8	year	
16	CAP_COST	Number (Double)	8		
17	CAP_YEAR	Number (Double)	8		
18	OM_COST	Number (Double)	8		
19	OM_YEAR	Number (Double)	8		
20	OR_REC_DAT	Date/Time	8		Original record date
21	ED_REC_DAT	Date/Time	8		Edited record date
22	EDIT_COMM	Memo	-		

Codes

Coded field:	WASTE_CODE	Code:	COM	combined
			TXT	textile
			PLP	pulp and paper
			CHM	chemical
			NPS	non-point source
			DAI	dairy
			CTL	cattle feeding
			AQU	aquaculture
			SWI	swine
			POU	poultry
			MLK	milk wash
Coded field:	ORIGIN	Code:	CON	constructed
			NAT	natural
			OTH	other
			UNK	unknown
Coded field:	HYDRL_TYPE	Code:	VSB	veg. subm. bed
			FWS	free water system
			HYB	hybrid
			OTH	other
			UNK	unknown

Table B-2 (continued)
System Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
	Coded field:	VEG_TYPE	Code:	MAR	marsh
				SHB	shrub
				OPW	open water
				FOR	forest
				FAP	floating aq. plants
				HYB	hybrid
				OTH	other
				UNK	unknown

Table B-3
Cell Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
1	SITE	Number (Double)	8		
2	SITE_NAME	Text	30		
3	SYSTEM	Number (Double)	8		
4	SYSTEM_NAM	Text	35		
5	CELL	Text	7		
6	COMMENTS	Memo	-		See CODE list
7	HYDRL_TYPE	Text	3		
8	AREA_WET	Number (Double)	8	ha	Wetted Area
9	AREA_TOTL	Number (Double)	8	ha	Area including berms
10	VEG_TYPE	Text	3		See CODE list
11	VEG_SPEC_1	Text	30		
12	VEG_SPEC_2	Text	30		
13	VEG_SPEC_3	Text	30		
14	LENGTH_WET	Number (Double)	8	m	Length of wetted basin
15	WIDTH_WET	Number (Double)	8	m	Width of wetted basin
16	DEPTH_MAX	Number (Double)	8	cm	Average water depth at max water level
17	SLOPE	Number (Double)	8	%	Bed slope (average)
18	SUBSTRATE	Text	20		
19	VSB_GSIZE	Number (Double)	8	cm	VSB: gravel size
20	VSB_BTHICK	Number (Double)	8	m	VSB: bed thickness
21	VSB_BSLOPE	Number (Double)	8	%	VSB: bottom slope
22	VSB_TSLOPE	Number (Double)	8	%	VSB: top slope
23	ASPECT_WET	Number (Double)	8		Length-to-width ratio
24	ISLAN_AREA	Number (Double)	8	ha	Area of islands
25	PCT_ISLAND	Number (Double)	8	%	Percent wetland area in islands
26	#_ISLANDS	Number (Double)	8		
27	DEEP_AREA	Number (Double)	8	ha	Area greater than 1.0 m depth
28	PCT_DEEP	Number (Double)	8	%	Deep/shallow areas as percent
29	#_DP_ZONES	Number (Double)	8		No. of separate deep zones
30	EDGE/AREA	Number (Double)	8	m/m2	Total wet edge divided by wet cell area
31	OR_REC_DAT	Date/Time	8		Original record date
32	ED_REC_DAT	Date/Time	8		Edited record date
33	EDIT_COMM	Memo	-		

CODES

Coded field:	HYDRL_TYPE	Code:	VSB	veg. subm. bed
			FWS	free water system
			OTH	other
			UNK	unknown
Coded field:	VEG_TYPE	Code:	MAR	marsh
			SHB	shrub
			OPW	open water
			FOR	forest
			FAP	floating aq. plants
			HYB	hybrid
			OTH	other
			UNK	unknown

Table B-4
Operation Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
1	SITE	Number (Double)	8		
2	SITE_NAME	Text	30		
3	SYSTEM	Number (Double)	8		
4	SYSTEM_NAM	Text	35		
5	CELL	Text	7		
6	COMMENTS	Memo	-		
7	TIMEPERIOD	Text	16		
8	NO_OF_DAYS	Number (Double)	5	da	Number of days in time period
9	AV_FLOW	Number (Double)	8	m3/da	
10	INFLOW	Number (Double)	8	m3/da	
11	OUTFLOW	Number (Double)	8	m3/da	
12	OTHER_FLOW	Number (Double)	8	m3/da	
13	SUPER_VELO	Number (Double)	8	m/da	
14	DEPTH	Number (Double)	8	cm	Measured average water depth
15	AREA_WET	Number (Double)	8	ha	
16	DETEN_TIME	Number (Double)	8	da	
17	HD_LD_RATE	Number (Double)	8	cm/da	Average for time period
18	PRECIPITAT	Number (Double)	8	cm/timeperiod	Total for time period
19	MB_BOD_IN	Number (Double)	8	kg/ha/da	Average for time period
20	MB_BOD_OUT	Number (Double)	8	kg/ha/da	
21	MB_BOD_EFF	Number (Double)	8	%	
22	MB_TSS_IN	Number (Double)	8		
23	MB_TSS_OUT	Number (Double)	8		
24	MB_TSS_EFF	Number (Double)	8		
25	MB_TKN_IN	Number (Double)	8		
26	MB_TKN_OUT	Number (Double)	8		
27	MB_TKN_EFF	Number (Double)	8		
28	MB_NH4_IN	Number (Double)	8		
29	MB_NH4_OUT	Number (Double)	8		
30	MB_NH4_EFF	Number (Double)	8		
31	MB_NO3_IN	Number (Double)	8		
32	MB_NO3_OUT	Number (Double)	8		
33	MB_NO3_EFF	Number (Double)	8		
34	MB_TN_IN	Number (Double)	8		
35	MB_TN_OUT	Number (Double)	8		
36	MB_TN_EFF	Number (Double)	8		
37	MB_OGN_IN	Number (Double)	8		
38	MB_OGN_OUT	Number (Double)	8		
39	MB_OGN_EFF	Number (Double)	8		
40	MB_TP_IN	Number (Double)	8		
41	MB_TP_OUT	Number (Double)	8		
42	MB_TP_EFF	Number (Double)	8		
43	MB_DP_IN	Number (Double)	8		
44	MB_DP_OUT	Number (Double)	8		
45	MB_DP_EFF	Number (Double)	8		
46	MB_COND_IN	Number (Double)	8		
47	MB_COND_OUT	Number (Double)	8		
48	MB_COND_EFF	Number (Double)	8		
49	MB_TDS_IN	Number (Double)	8		
50	MB_TDS_OUT	Number (Double)	8		
51	MB_TDS_EFF	Number (Double)	8		
52	MB_VSS_IN	Number (Double)	8		
53	MB_VSS_OUT	Number (Double)	8		
54	MB_VSS_EFF	Number (Double)	8		
55	MB_COD_IN	Number (Double)	8		
56	MB_COD_OUT	Number (Double)	8		
57	MB_COD_EFF	Number (Double)	8		
58	CN_BOD_IN	Number (Double)	8	mg/L	Average for time period
59	CN_BOD_OUT	Number (Double)	8	mg/L	
60	CN_BOD_EFF	Number (Double)	8	%	
61	CN_TSS_IN	Number (Double)	8		
62	CN_TSS_OUT	Number (Double)	8		
63	CN_TSS_EFF	Number (Double)	8		
64	CN_TKN_IN	Number (Double)	8		
65	CN_TKN_OUT	Number (Double)	8		
66	CN_TKN_EFF	Number (Double)	8		
67	CN_NH4_IN	Number (Double)	8		

Table B-4
Operation Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
68	CN_NH4_OUT	Number (Double)	8		
69	CN_NH4_EFF	Number (Double)	8		
70	CN_NO3_IN	Number (Double)	8		
71	CN_NO3_OUT	Number (Double)	8		
72	CN_NO3_EFF	Number (Double)	8		
73	CN_TN_IN	Number (Double)	8		
74	CN_TN_OUT	Number (Double)	8		
75	CN_TN_EFF	Number (Double)	8		
76	CN_OGN_IN	Number (Double)	8		
77	CN_OGN_OUT	Number (Double)	8		
78	CN_OGN_EFF	Number (Double)	8		
79	CN_TP_IN	Number (Double)	8		
80	CN_TP_OUT	Number (Double)	8		
81	CN_TP_EFF	Number (Double)	8		
82	CN_DP_IN	Number (Double)	8		
83	CN_DP_OUT	Number (Double)	8		
84	CN_DP_EFF	Number (Double)	8		
85	CN_DP_CODE	Text	3		See CODE list
86	CN_DO_IN	Number (Double)	8		
87	CN_DO_OUT	Number (Double)	8		
88	CN_DO_EFF	Number (Double)	8		
89	CN_FC_IN	Number (Double)	8		
90	CN_FC_OUT	Number (Double)	8		
91	CN_FC_EFF	Number (Double)	8		
92	CN_COND_IN	Number (Double)	8		
93	CN_COND_OUT	Number (Double)	8		
94	CN_COND_EFF	Number (Double)	8		
95	CN_TDS_IN	Number (Double)	8		
96	CN_TDS_OUT	Number (Double)	8		
97	CN_TDS_EFF	Number (Double)	8		
98	CN_VSS_IN	Number (Double)	8		
99	CN_VSS_OUT	Number (Double)	8		
100	CN_VSS_EFF	Number (Double)	8		
101	CN_COD_IN	Number (Double)	8		
102	CN_COD_OUT	Number (Double)	8		
103	CN_COD_EFF	Number (Double)	8		
104	TEMP_IN	Number (Double)	8		
105	TEMP_OUT	Number (Double)	8		
106	PH_IN	Number (Double)	8		
107	PH_OUT	Number (Double)	8		
108	OR_REC_DAT	Date/Time	8		Original record date
109	ED_REC_DAT	Date/Time	8		Edited record date
110	EDIT_COMM	Memo	-		

Codes

Coded field:	CN_DP_CODE	Code:	AVP	avail.phosphorus
			ORP	ortho phosphorus
			TDP	total diss. phosphorus
			SRP	sol. react. phosphorus
			OTH	other
			UNK	unknown

Computations

HD_LD_RATE	=	INFLOW * 0.01 / AREA_WET (ha)
SUPER_VELO	=	AV_FLOW / (WIDTH (m) * DEPTH (cm * 100))
DETEN_TIME	=	(void fraction * AREA (m2) * DEPTH (cm * 100)) / AV_FLOW
MB_XXX_IN	=	(CN_XXX_IN * (INFLOW / 1000)) / AREA_WET (ha)
MB_XXX_OUT	=	(CN_XXX_OUT * (OUTFLOW / 1000)) / AREA_WET (ha)
MB_XXX_EFF	=	(MB_XXX_IN - MB_XXX_OUT) / MB_XXX_IN * 100
CN_XXX_EFF	=	(CN_XXX_IN - CN_XXX_OUT) / CN_XXX_IN * 100

Table B-5
People Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
1	SITE	Number (Double)	8		
2	SITE_NAME	Text	30		
3	LAST_NAME	Text	12		
4	FIRST_NAME	Text	12		
5	ORGANIZATN	Text	60		
6	ADDRESS	Text	150		
7	PHONE	Text	17		
8	FAX	Text	17		
9	ROLE	Text	3		See CODE list
10	COMMENTS	Memo	-		
11	OR_REC_DAT	Date/Time	8		Original record date
12	ED_REC_DAT	Date/Time	8		Edited record date
13	EDIT_COMM	Memo	-		

Codes

Coded field:	ROLE	Code:	R&D	research & develop.
			ENG	eng. design or study
			CON	construction of design
			MON	performance monitoring
			OPR	operator
			MAN	manager
			TBS	troubleshooting
			OTH	other
			UNK	unknown

Table B-6
Literature Records in the LWDB

Field	Field Name	Type	Size	Units	Notes
1	SITE	Number (Double)	8		
2	SITE_NAME	Text	30		
3	LAST1	Text	15		
4	FIRST1	Text	15		
5	LAST2	Text	15		
6	FIRST2	Text	15		
7	LAST3	Text	15		If >3 authors, use "et al."
8	FIRST3	Text	15		
9	TITLE	Text	180		
10	YEAR	Text	4		
11	CITATION	Text	180		
12	OR_REC_DAT	Date/Time	8		Original record date
13	ED_REC_DAT	Date/Time	8		Edited record date
14	EDIT_COMM	Memo	-		

Appendix C
Summary of Data in the Livestock Wastewater Treatment Wetland Database (LWDB)

TABLE C-1
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type[a]	Cell Area (ha)	Vegetation Type[b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio[c]	Cell Depth (cm)	Cell Slope (%)
3M Farm, MD	3M	1	FWS	0.1208	MAR	92.0	13.2	7.0	21.0	0.1
Adair Co.#1, KY	Adair Co.#1	1	FWS	0.0320	MAR	42.7	7.6	5.6	25.4	
Adair Co.#2, KY	Adair Co.#2	1	FWS	0.0361	MAR	39.6	9.1	4.4	15.2	
Allen Co., KY	Allen Co.	1	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	2	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	3	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	4	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	5	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	6	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	7	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	8	FWS		MAR				25.4	
Allen Co., KY	Allen Co.	9	FWS		MAR				25.4	
Auburn Poultry, AL	Auburn Poultry 1	1	FWS	0.0167	MAR	30.5	5.5	5.5	100.0	
Auburn Poultry, AL	Auburn Poultry 1	2	FWS	0.0167	MAR	30.5	5.5	5.5	100.0	
Auburn Poultry, AL	Auburn Poultry 2	1	FWS	0.0167	MAR	30.5	5.5	5.5	100.0	
Auburn Poultry, AL	Auburn Poultry 2	2	FWS	0.0167	MAR	30.5	5.5	5.5	100.0	
Auburn Poultry, AL	Auburn Poultry 3	1	FWS	0.0167	OPW	30.5	5.5	5.5	100.0	
Auburn Poultry, AL	Auburn Poultry 3	2	FWS	0.0167	OPW	30.5	5.5	5.5	100.0	
Auburn Poultry, AL	Auburn Poultry 4	1	FWS	0.0002	OTH	3.4	0.6	5.7	30.0	
Auburn Poultry, AL	Auburn Poultry 4	2	FWS	0.0002	OTH	3.4	0.6	5.7	30.0	
Auburn Poultry, AL	Auburn Poultry 5	1	FWS	0.0002	OTH	3.4	0.6	5.7	30.0	
Auburn Poultry, AL	Auburn Poultry 5	2	FWS	0.0002	OTH	3.4	0.6	5.7	30.0	
Auburn Swine, AL	Swine Unit	1	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	2	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	3	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	4	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	5	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	6	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	7	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	8	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	9	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	10	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	11	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	12	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	13	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	14	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	15	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	16	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
Auburn Swine, AL	Swine Unit	17	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	18	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	19	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Auburn Swine, AL	Swine Unit	20	FWS	0.0002	MAR	3.1	0.6	5.1	30.0	
Brenton Cattle , IA	Brenton Cattle	1	FWS	25.1000	MAR				61.0	
Brenton Cattle , IA	Brenton Cattle	2	FWS	21.9000	MAR					
Butler Co.#1, KY	Butler Co.	1	FWS		MAR				50.8	
Butler Co.#1, KY	Butler Co.	2	FWS		MAR				50.8	
Butler Co.#1, KY	Butler Co.	3	FWS		MAR				50.8	
Butler Co.#1, KY	Butler Co.	4	FWS		MAR				50.8	
Butler Co.#1, KY	Butler Co.	5	FWS		MAR				50.8	
Butler Co.#2, KY	Butler Co.#2	1	FWS	2.4000	MAR					
Butler Co.#2, KY	Butler Co.#2	2	FWS		MAR					
Butler Co.#2, KY	Butler Co.#2	3	FWS		MAR					
Butler Co.#2, KY	Butler Co.#2	4	FWS		MAR					
Casey Co.#1, KY	Casey Co.#1	1	FWS	0.0557	MAR	45.7	12.2	3.7	5.1	
Casey Co.#2, KY	Casey Co.#2	1	FWS	0.0037	MAR	6.1	6.1	1.0	61.0	
Casey Co.#3, KY	Casey Co.#3	1	FWS	0.0019	MAR	6.1	3.0	2.0	61.0	
Cobb Farm, PA	Cobb	1	FWS	0.0059	MAR	24.4	2.4	10.0		
Cobb Farm, PA	Cobb	2	FWS	0.0059	MAR	24.4	2.4	10.0		
Crittenden Co., KY	Crittenden Co.	1	FWS	0.0744	MAR	30.5	12.2	2.5	30.5	
Crittenden Co., KY	Crittenden Co.	2	FWS	0.0744	MAR	30.5	12.2	2.5	30.5	
Crittenden Co., KY	Dairy	1	FWS	0.1700	MAR	80.2	21.3	3.8		
Crittenden Co., KY	Dairy	2	FWS	0.1700	MAR	80.2	21.3	3.8		
Crum Farm, MD	Crum	1	FWS	0.0557	MAR	61.0	9.1	6.7	15.0	0.0
Crum Farm, MD	Crum	2	FWS	0.0557	MAR	61.0	9.1	6.7	15.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 1	1	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 1	2	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 1	3	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 2	1	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 2	2	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 2	3	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 3	1	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 3	2	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 3	3	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 4	1	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 4	2	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0
David Gerrits Farm, WI	David Gerrits Farm 4	3	FWS	0.0028	MAR	23.2	1.2	19.0	10.0	0.0

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
David Thompson Farm, N_S	David Thompson Farm	1	FWS	0.0952	MAR	38.1	27.4	1.4	0.3	
Delmarva Farms , MD	Delmarva Farms	6	FWS		MAR					
Delmarva Farms , MD	Delmarva Farms	1	FWS		MAR					
Delmarva Farms , MD	Delmarva Farms	2	FWS		MAR					
Delmarva Farms , MD	Delmarva Farms	3	FWS		MAR					
Delmarva Farms , MD	Delmarva Farms	4	FWS		MAR					
Delmarva Farms , MD	Delmarva Farms	5	FWS		MAR					
Dogwood Ridge, KY	Dogwood Ridge	1	FWS	0.1660	MAR	49.7	33.4	1.5		
Dogwood Ridge, KY	Dogwood Ridge	2	FWS	0.4090	MAR	106.1	38.5	2.8		
Dogwood Ridge, KY	Dogwood Ridge	3	FWS	1.2710	MAR	449.6	28.3	15.9		
Dogwood Ridge, KY	Dogwood Ridge	4	FWS	0.4900	MAR	381.3	12.9	29.7		
Dogwood Ridge, KY	Dogwood Ridge	5	FWS	0.2900	MAR	225.7	12.9	17.6		
Dogwood Ridge, KY	Dogwood Ridge	6	FWS	0.3700	MAR	287.9	12.9	22.4		
Dogwood Ridge, KY	Dogwood Ridge	7	FWS	0.2400	MAR	186.8	12.9	14.5		
Dogwood Ridge, KY	Dogwood Ridge	8	FWS	0.2700	MAR	210.1	12.9	16.4		
Dogwood Ridge, KY	Dogwood Ridge	9	FWS	0.3000	MAR	233.5	12.9	18.2		
Duplin, NC	Juncus/Scirpus	1	FWS	0.0120	MAR	33.5	3.6	9.3	<15	0.2
Duplin, NC	Juncus/Scirpus	2	FWS	0.0120	MAR	33.5	3.6	9.3	<15	0.2
Duplin, NC	Rice System	1	FWS	0.0120	MAR	33.5	3.6	9.3	<15	0.2
Duplin, NC	Soybean System	1	FWS	0.0120	MAR	33.5	3.6	9.3	<15	0.2
Duplin, NC	Sporgonium/Typha	1	FWS	0.0120	MAR	33.5	3.6	9.3	<15	0.2
Duplin, NC	Sporgonium/Typha	2	FWS	0.0120	MAR	33.5	3.6	9.3	<15	0.2
Essex County, ONT	ERCA Wetland #1	1	FWS	0.0600	MAR	120.0	5.0	24.0	30.0	0.3
Guy Thompson Farm, PEI	Guy Thompson Farm	1	FWS	0.1510	MAR	76.2	19.8	3.8	30.0	0.0
Hamilton-Wentworth, ONT	NPCA Wetland #2	1	VSB		MAR				100.0	
Hamilton-Wentworth, ONT	NPCA Wetland #2	2	VSB		MAR				100.0	
Hattiesburg, MS	Pond I	1	FWS	0.5500	MAR					
Hattiesburg, MS	Pond I	2	FWS	0.6900	MAR					
Hattiesburg, MS	Pond II	1	FWS		MAR					
Hattiesburg, MS	Pond II	2	FWS		MAR					
Hattiesburg, MS	Pond II	3	FWS		MAR					
Hattiesburg, MS	Pond II	4	FWS		MAR					
Hernando, MS	Hernando 1	1	FWS	0.0200	MAR	24.4	6.1	4.0		
Hernando, MS	Hernando 1	2	FWS	0.0200	MAR	24.4	6.1	4.0		
Hernando, MS	Hernando 2	1	FWS	0.0200	MAR	24.4	6.1	4.0		
Hernando, MS	Hernando 3	1	FWS	0.0200	MAR	24.4	6.1	4.0		
Hickok Veal, PA	Hickok	1	FWS		MAR				10.0	
Hickok Veal, PA	Hickok	2	FWS		MAR				10.0	

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
Hickok Veal, PA	Hickok	3	FWS		MAR				10.0	
Hickok Veal, PA	Hickok	4	FWS		MAR				10.0	
Hickok Veal, PA	Hickok	5	FWS		MAR				10.0	
Hickok Veal, PA	Hickok	6	FWS		MAR				10.0	
Hopkins Co., KY	Hopkins Co.	1	FWS	0.2300	MAR	61.0	38.1	1.6	30.5	
Hopkins Co., KY	Hopkins Co.	2	FWS	0.2300	MAR	61.0	38.1	1.6	30.5	
Hopkins Co., KY	Hopkins Co.	3	FWS	0.2300	MAR	61.0	38.1	1.6	30.5	
Hopkins Co., KY	Hopkins Co.	4	FWS	0.2300	MAR	61.0	38.1	1.6	30.5	
Ken Hunter Farm, N_S	Ken Hunter Farm	1	FWS	0.0670	MAR	36.6	36.6	1.0		1.0
Key Dairy, GA	Key Dairy	1	FWS	0.1171	MAR	91.4	12.8	7.1		
Key Dairy, GA	Key Dairy	2	FWS	0.1171	MAR	91.4	12.8	7.1		
Key Dairy, GA	Key Dairy	3	FWS	0.1171	MAR	91.4	12.8	7.1		
La Franchi, CA	La Franchi	1	FWS	0.1010	MAR	68.6	15.2	4.5	91.0	0.1
Louis. St. Univ., LA	Black Willow	1	FWS	0.4047	SHB/FAP					
Louis. St. Univ., LA	Duckweed/Emergent plant	1	FWS/OTH	0.2035	FAP/MAR					
Louis. St. Univ., LA	Water hyacinth	1	OTH	0.2035	FAP					
Lucky Rose Farm, IN	Lucky Rose Farm	1	FWS	0.6210	MAR	230.0	27.0	8.5	15.0	
Lucky Rose Farm, IN	Lucky Rose Farm	2	FWS	0.3625	OTH	145.0	25.0	5.8		
McLean Co.#1, KY	McLean Co.#1	1	FWS	0.3300	MAR	61.0	53.3	1.1	30.5	
McLean Co.#1, KY	McLean Co.#1	2	FWS	0.3300	MAR	61.0	53.3	1.1	30.5	
McLean Co.#2, KY	McLean Co.#2	1	FWS	0.1400	MAR	45.7	31.1	1.5	25.4	
McLean Co.#2, KY	McLean Co.#2	2	FWS	0.1400	MAR	45.7	31.1	1.5	25.4	
McLean Co.#3, KY	McLean Co.#3	1	FWS	0.6100	MAR	26.5	22.9	1.2	30.5	
McLean Co.#3, KY	McLean Co.#3	2	FWS	0.6100	MAR	26.5	22.9	1.2	30.5	
McMichael Dairy, GA	McMichael Dairy	1	FWS	0.0870	MAR	68.6	12.8	5.4		
McMichael Dairy, GA	McMichael Dairy	2	FWS	0.1170	MAR	91.4	12.8	7.1		
McMichael Dairy, GA	McMichael Dairy	3	FWS	0.0870	MAR	68.6	12.8	5.4		
Mercer Co., KY	Mercer Co.	1		0.0222	MAR	24.4	9.1	2.7		
Mercer Co., KY	Mercer Co.	2		0.0222	MAR	24.4	9.1	2.7		
Mercer Co., KY	Mercer Co.	3	FWS	0.0977	MAR	53.4	18.3	2.9		0.0
Moyer Farm, PA	Moyer	1	FWS	0.0064	MAR					
New Mexico State, NM	Aquaculture filter	1	FWS	0.0004	MAR	3.3	1.2	2.8	91.0	
Newton, MS	Newton 1	1	FWS	0.0130	MAR	30.0	4.5	6.7		
Newton, MS	Newton 1	2	FWS	0.0067	MAR	15.0	4.5	3.3		
Newton, MS	Newton 2	1	FWS	0.0130	MAR	30.0	4.5	6.7		
Newton, MS	Newton 2	2	FWS	0.0067	MAR	15.0	4.5	3.3		
Newton, MS	Newton 3	1	FWS	0.0130	MAR	30.0	4.5	6.7		
Newton, MS	Newton 3	2	FWS	0.0067	MAR	15.0	4.5	3.3		

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
Newton, MS	Newton 4	1	FWS	0.0130	MAR	30.0	4.5	6.7		
Newton, MS	Newton 4	2	FWS	0.0067	MAR	15.0	4.5	3.3		
Newton, MS	Newton 5	1	FWS	0.0130	MAR	30.0	4.5	6.7		
Newton, MS	Newton 5	2	FWS	0.0067	MAR	15.0	4.5	3.3		
Newton, MS	Newton 6	1	FWS	0.0130	OPW	30.0	4.5	6.7		
Newton, MS	Newton 6	2	FWS	0.0067	OPW	15.0	4.5	3.3		
Norwood Farms, IN	Norwood Farms 1	1	FWS	0.0366	MAR	61.0	6.1	10.0	30.0	1.0
Norwood Farms, IN	Norwood Farms 2	1	FWS	0.0366	MAR	61.0	6.1	10.0	30.0	1.0
Norwood Farms, IN	Norwood Farms 3	1	FWS	0.0366	MAR	61.0	6.1	10.0	30.0	1.0
Nowicki Farm, ALB	Nowicki Farm	1	FWS	0.0240	MAR	40.0	6.0	6.7	15.0	1.0
Nowicki Farm, ALB	Nowicki Farm	2	FWS	0.0240	MAR	40.0	6.0	6.7	15.0	1.0
Oregon State University, OR	Oregon State University	1	FWS	0.0203	MAR	26.7	5.5	4.9	30.0	0.1
Oregon State University, OR	Oregon State University	2	FWS	0.0203	MAR	26.7	5.5	4.9	30.0	0.1
Oregon State University, OR	Oregon State University	3	FWS	0.0203	MAR	26.7	5.5	4.9	30.0	0.1
Oregon State University, OR	Oregon State University	4	FWS	0.0203	MAR	26.7	5.5	4.9	30.0	0.1
Oregon State University, OR	Oregon State University	5	FWS	0.0203	MAR	26.7	5.5	4.9	30.0	0.1
Oregon State University, OR	Oregon State University	6	FWS	0.0203	MAR	26.7	5.5	4.9	30.0	0.1
Perth County, ONT	UTRCA Wetland #1	1	OTH		OTH					
Perth County, ONT	UTRCA Wetland #1	2	FWS		MAR					
Perth County, ONT	UTRCA Wetland #1	3	OTH		OPW					
Piscataquis River, ME	Piscataquis River	1	FWS	0.0093	MAR	15.3	6.1	2.5	10.0	
Piscataquis River, ME	Piscataquis River	2	FWS	0.0093	MAR	15.3	6.1	2.5	10.0	
Piscataquis River, ME	Piscataquis River	3	FWS	0.0093	MAR	15.3	6.1	2.5	10.0	
Piscataquis River, ME	Piscataquis River	4	FWS	0.0093	MAR	15.3	6.1	2.5	10.0	
Pontotoc, MS	Pontotoc 1	1	FWS	0.0400	MAR	33.0	12.0	2.8	12.0	
Pontotoc, MS	Pontotoc 2	1	FWS	0.0400	MAR	33.0	12.0	2.8	12.0	
Purdue University, IN	A1	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	A2	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	A3	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	A4	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	B1	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	B2	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	B3	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	B4	1	FWS	0.0023	MAR	7.3	3.0	2.4	15.0	0.5
Purdue University, IN	C1	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5
Purdue University, IN	C2	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5
Purdue University, IN	C3	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5
Purdue University, IN	C4	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
Purdue University, IN	D1	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5
Purdue University, IN	D3	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5
Purdue University, IN	D4	1	FWS	0.0023	MAR	7.3	3.0	2.4	30.0	0.5
Region of Niagara, ONT	NPCA Wetland #1	1	FWS	0.0111	OTH					
Region of Niagara, ONT	NPCA Wetland #1	2	FWS		MAR					
Region of Niagara, ONT	NPCA Wetland #1	3	FWS		MAR					
Region of Ottawa-Carlton, ONT	RVCA Wetland #1	1	FWS		MAR	120.0	2.0	60.0	20.0	0.5
Region of Peel, ONT	MTRCA Grassed Strip #1	1	FWS		OTH					
Russel County, ONT	SNRCA Wetland #1	1	FWS		MAR					
Saint-Felicien, QUE	Zoo de Saint-Felicien III	1	OTH	0.0157	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien III	2	OTH	0.0157	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien III	3	OTH	0.0157	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien III	4	OTH	0.0157	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien III	5	OTH	0.0204	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien III	6	OTH	0.0204	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien III	7	VSB	0.0724	MAR				90.0	1.2
Saint-Felicien, QUE	Zoo de Saint-Felicien III	8	VSB	0.0724	MAR				90.0	1.2
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	1	OTH	0.0431	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	2	OTH	0.0431	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	3	OTH	0.0431	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	4	OTH	0.0431	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	5	OTH	0.0431	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	6	OTH	0.0431	MAR				90.0	
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	7	VSB	0.1060	MAR				90.0	1.2
Saint-Felicien, QUE	Zoo de Saint-Felicien IV	8	VSB	0.1060	MAR				90.0	1.2
Sand Mountain, AL	Sand Mountain 1	1	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 1	2	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 2	1	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 2	2	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 3	1	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 3	2	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 4	1	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 4	2	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 5	1	FWS	0.0360	MAR	51.2	7.0	7.3		
Sand Mountain, AL	Sand Mountain 5	2	FWS	0.0360	MAR	51.2	7.0	7.3		
Simco County #1, ONT	NVCA Wetland #1	1	FWS		MAR		2.0			
Simco County #1, ONT	NVCA Wetland #1	2	FWS		OTH		2.0			
Simco County #2, ONT	SSRAP Grassed Strip #1	1	FWS		OTH					

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
Spencer Co., KY	Spencer Co.	1	FWS	0.0390	MAR	32.0	12.2	2.6	5.1	
Texas, TX	S.W.A.M.P. project	1	FWS	0.0280	MAR	30.5	9.1	3.4	45.0	0.0
Texas, TX	S.W.A.M.P. project	2	FWS	0.0280	MAR	30.5	9.1	3.4	45.0	0.0
Texas, TX	S.W.A.M.P. project	3	FWS	0.0280	MAR	30.5	9.1	3.4	45.0	0.0
Texas, TX	S.W.A.M.P. project	4	FWS	0.0280	MAR	30.5	9.1	3.4	45.0	0.0
Texas, TX	S.W.A.M.P. project	5	FWS	0.0280	MAR	30.5	9.1	3.4	45.0	0.0
Texas, TX	S.W.A.M.P. project	6	FWS	0.0280	MAR	30.5	9.1	3.4	45.0	0.0
Texas, TX	S.W.A.M.P. project									
Tifton, GA	Tifton 1	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 10	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 11	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 12	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 13	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 14	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 15	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 16	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 17	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 18	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 2	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 3	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 4	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 5	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 6	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 7	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 8	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tifton, GA	Tifton 9	1	OTH	0.0120	OTH	30.0	4.0	7.5		2.0
Tom Brothers Farm, IN	Tom Brothers	1	FWS	0.0906	MAR	64.6	14.0	4.6	23.0	0.3
Tom Brothers Farm, IN	Tom Brothers	2	FWS	0.0959	MAR	68.5	14.0	4.9	23.0	0.3
U of Connecticut, CT	Kellogg Dairy Research Facility	1	FWS	0.0123	MAR	36.6	3.4	10.9	23.0	
U of Connecticut, CT	Kellogg Dairy Research Facility	2	FWS	0.0123	MAR	36.6	3.4	10.9	23.0	
U of Connecticut, CT	Kellogg Dairy Research Facility	3	FWS	0.0123	MAR	36.6	3.4	10.9	23.0	
Union Co., KY	Swine	1	FWS	0.0340	MAR	18.6	18.3	1.0		
Union Co., KY	Swine	2	FWS	0.0340	MAR	18.6	18.3	1.0		
Union Co., KY	Swine	3	FWS	0.0340	MAR	18.6	18.3	1.0		

TABLE C-1 (CONTINUED)
Design Information for Cells in the Livestock Wastewater Treatment Wetland Database

Site Name	System Name	Cell No.	Hydrologic Type [a]	Cell Area (ha)	Vegetation Type [b]	Cell Length (m)	Cell Width (m)	Cell L:W Ratio [c]	Cell Depth (cm)	Cell Slope (%)
Union Co., KY	Union Co.	1	FWS	0.0410	MAR	21.9	18.6	1.2	20.3	
Union Co., KY	Union Co.	2	FWS	0.0410	MAR	21.9	18.6	1.2	20.3	
Union Co., KY	Union Co.	3	FWS	0.0410	MAR	21.9	18.6	1.2	20.3	
Univ. of SW Louis., LA	Deep Trench	1	FWS	0.0050	OPW	16.8	3.0	5.6	120.0	
Univ. of SW Louis., LA	Deep Trench	2	FWS	0.0045	OPW	16.8	2.7	6.2	120.0	
Univ. of SW Louis., LA	Free Water System	1	FWS	0.0095	MAR	19.1	5.0	3.8	60.0	
Univ. of SW Louis., LA	Free Water System	2	FWS	0.0100	MAR	17.1	5.9	2.9	60.0	
Univ. of SW Louis., LA	Subsurface Flow	1	OTH	0.0046	UNK	5.2	8.8	0.6	60.0	
Univ. of SW Louis., LA	Subsurface Flow	2	OTH	0.0038	UNK	4.5	8.5	0.5	60.0	
Univ. of SW Louis., LA	Subsurface Flow	3	OTH	0.0036	UNK	5.2	6.9	0.8	60.0	
Warren Co., KY	Warren Co.	1	FWS	0.0116	MAR	12.8	9.1	1.4	61.0	
Washington Co., KY	Washington Co.	1	FWS	0.0271	MAR	16.5	16.5	1.0	20.3	
Wayne Co.#1, KY	Wayne Co.#1	1	FWS	0.0279	MAR	22.9	6.1	3.8	5.1	
Wayne Co.#1, KY	Wayne Co.#1	2	FWS	0.0279	MAR	22.9	6.1	3.8	5.1	
Wayne Co.#2, KY	Wayne Co.#2	1	FWS	0.0166	MAR	18.3	9.1	2.0	15.2	
Wayne White Farm, N_S	Wayne White Farm	1	FWS	0.4334	MAR	77.4	65.8	1.2	30.0	
Average						40.6	8.6	6.5	37.8	0.7
Median						30.0	5.5	5.1	30.0	0.5
Minimum						3.1	0.6	0.5	0.3	0.0
Maximum						449.6	65.8	60.0	120.0	2.0
Count						206	208	206	168	83

Notes:

[a]Hydrologic Type
VSB = veg. subm. bed
FWS = free water system
OTH = other

[b]Cell Vegetation Type
FAP = floating aquatic
MAR = marsh
OPW = open water
OTH = other
SHB = shrub
UNK = unknown

[c]Cell Length to Width Ratio

TABLE C-2
Summary of Operational Data in the LWDB

Site Name	System Name	Cell	Time Period	Days	Years	Waste Code [a]	Average Flow (m^3/d)	Inflow (m^3/d)	Outflow (m^3/d)	Super Velo (m/d)	Depth (cm)	Area (ha)	Detention Time (d)	Hold Rate (cm/d)	BOD In (mg/L)	BOD Out (mg/L)
Auburn Poultry, AL	Auburn Poultry 1	1	ANN 93/94	244	0.7	POU	8.94	10.34	7.54	5.4	30	0.0160		6.5	177	122
Auburn Poultry, AL	Auburn Poultry 1	2	ANN 93/94	244	0.7	POU	6.88	7.54	6.23	4.2	30	0.0160		4.7	122	88
Auburn Poultry, AL	Auburn Poultry 2	1	ANN 93/94	244	0.7	POU	8.66	10.34	6.98	5.3	30	0.0160		6.5	177	129
Auburn Poultry, AL	Auburn Poultry 2	2	ANN 93/94	244	0.7	POU	6.33	6.98	5.67	3.8	30	0.0160		4.4	129	103
Auburn Poultry, AL	Auburn Poultry 3	1	ANN 93/94	244	0.7	POU	8.79	10.34	7.24	5.3	30	0.0160		6.5	177	139
Auburn Poultry, AL	Auburn Poultry 3	2	ANN 93/94	244	0.7	POU	6.71	7.24	6.19	4.1	30	0.0160		4.5	139	95
Auburn Poultry, AL	Auburn Poultry 4	1	ANN 93/94	244	0.7	POU									177	129
Auburn Poultry, AL	Auburn Poultry 4	2	ANN 93/94	244	0.7	POU									129	117
Auburn Poultry, AL	Auburn Poultry 5	1	ANN 93/94	244	0.7	POU									177	126
Auburn Poultry, AL	Auburn Poultry 5	2	ANN 93/94	244	0.7	POU									126	104
Brenton Cattle , IA	Brenton Cattle	1	LTM 92/93	428	1.2	CTL					1	21.9000			277	33
Brenton Cattle , IA	Brenton Cattle	2	LTM 92/93	428	1.2	CTL					1	21.9000			33	19
Crittenden Co., KY	Dairy	1	ANN 92	274	0.8	DAI						0.1700				
Crittenden Co., KY	Dairy	2	ANN 92	274	0.8	DAI						0.1700				
David Gerrits Farm, WI	David Gerrits Farm 1&2	1	ANN 93	182	0.5	DAI	0.95			7.8	10	0.0028	3.0	3.4	168	14
David Gerrits Farm, WI	David Gerrits Farm 1&2	2	ANN 93	182	0.5	DAI	0.95			7.8	10	0.0028	3.0	3.4	14	10
David Gerrits Farm, WI	David Gerrits Farm 1&2	3	ANN 93	182	0.5	DAI	0.95			7.8	10	0.0028	3.0	3.4	10	15
David Gerrits Farm, WI	David Gerrits Farm 3&4	1	ANN 93	182	0.5	DAI	0.95			7.8	10	0.0028	3.0	3.4	97	14
David Gerrits Farm, WI	David Gerrits Farm 3&4	2	ANN 93	182	0.5	DAI	0.95			7.8	10	0.0028	3.0	3.4	14	
David Gerrits Farm, WI	David Gerrits Farm 3&4	3	ANN 93	182	0.5	DAI	0.95			7.8	10	0.0028	3.0	3.4		17
Duplin, NC	Juncus/Scirpus	1	LTM 93/94	365	1.0	SWI						0.0120				
Duplin, NC	Juncus/Scirpus	2	LTM 93/94	365	1.0	SWI						0.0120				
Duplin, NC	Rice System	1	LTM 93/94	365	1.0	SWI						0.0120				
Duplin, NC	Soybean System	1	LTM 93/94	365	1.0	SWI						0.0120				
Duplin, NC	Sporgonium/Typha	1	LTM 93/94	365	1.0	SWI						0.0120				
Duplin, NC	Sporgonium/Typha	2	LTM 93/94	365	1.0	SWI						0.0120				
Essex County, ONT	ERCA Wetland #1	1	ANN 94	182	0.5	DAI					30				357	202
Hernando, MS	Hernando 1	1	LTM 91-92	532	1.5	DAI		1.44				0.0200		0.7	37	13
Hernando, MS	Hernando 1	4	LTM 91-92	532	1.5	DAI		1.44				0.0200		0.7	11	10
Hernando, MS	Hernando 2	2	LTM 91-92	532	1.5	DAI		1.44				0.0200		0.7	36	9
Hernando, MS	Hernando 3	3	LTM 91-92	532	1.5	DAI		1.44				0.0200		0.7	37	11
Key Dairy, GA	Key Dairy	T:1-3	ANN 90	92	0.3	DAI										
Louis. St. Univ., LA	Black Willow	1	LTM 93/95	819	2.2	DAI									74	18
Louis. St. Univ., LA	Duckweed/Emergent plant	1	LTM 93/95	819	2.2	DAI									74	14
Louis. St. Univ., LA	Water hyacinth	1	LTM 93/95	819	2.2	DAI									74	17
Mercer Co., KY	Mercer Co.	1	ANN	365	1.0	DAI									452	158
Newton, MS	Newton 1	1	LTM 91/92	720	2.0	DAI	8.06	8.67	7.41			0.0130		6.7	56	34
Newton, MS	Newton 1	2	LTM 91/92	720	2.0	DAI	7.54	6.94	12.02			0.0070		9.9	28	21
Newton, MS	Newton 2	1	LTM 91/92	720	2.0	DAI	7.50	7.75	7.34			0.0130		6.0	56	37
Newton, MS	Newton 2	2	LTM 91/92	720	2.0	DAI	6.76	6.15	7.89			0.0070		8.8	34	28
Newton, MS	Newton 3	1	LTM 91/92	720	2.0	DAI	7.65	8.04	7.54			0.0130		6.2	58	29
Newton, MS	Newton 3	2	LTM 91/92	720	2.0	DAI	7.04	7.58	7.21			0.0070		10.8	27	19
Newton, MS	Newton 4	1	LTM 91/92	720	2.0	DAI	7.42	8.24	6.67			0.0130		6.3	59	32
Newton, MS	Newton 4	2	LTM 91/92	720	2.0	DAI	5.01	5.67	5.59			0.0070		8.1	33	21
Newton, MS	Newton 5	1	LTM 91/92	720	2.0	DAI	8.23	8.04	8.55			0.0130		6.2	58	26
Newton, MS	Newton 5	2	LTM 91/92	720	2.0	DAI	8.28	9.79	7.45			0.0070		13.4	22	22
Newton, MS	Newton 6	1	LTM 91/92	720	2.0	DAI	7.70	8.52	6.83			0.0130		6.6	51	28
Newton, MS	Newton 6	2	LTM 91/92	720	2.0	DAI	6.87	6.93	15.67			0.0070		9.9	38	16
Norwood Farms, IN	Norwood Farms 1	1	LTM 93/94	730	2.0	DAI									2497	692
Norwood Farms, IN	Norwood Farms 2	1	LTM 93/94	730	2.0	DAI									2775	711
Norwood Farms, IN	Norwood Farms 3	1	LTM 93/94	730	2.0	DAI									3181	755
Oregon State University, OR	OregonState University	1	LTM 93/94	730	2.0	DAI	5.80	5.80		3.5	30	0.0147	7.6	3.9	616	182
Oregon State University, OR	OregonState University	2	LTM 93/94	730	2.0	DAI	5.80	5.80		3.5	30	0.0147	7.6	3.9	678	211
Oregon State University, OR	OregonState University	3	LTM 93/94	730	2.0	DAI	5.80	5.80		3.5	30	0.0147	7.6	3.9	678	233
Oregon State University, OR	OregonState University	4	LTM 93/94	730	2.0	DAI	5.80	5.80		3.5	30	0.0147	7.6	3.9	678	264
Oregon State University, OR	OregonState University	5	LTM 93/94	730	2.0	DAI	5.80	5.80		3.5	30	0.0147	7.6	3.9	678	275
Oregon State University, OR	OregonState University	6	LTM 93/94	730	2.0	DAI	5.80	5.80		3.5	30	0.0147	7.6	3.9	678	218
Perth County, ONT	UTRCA Wetland #1	1	LTM 93/95	913	2.5	DAI					25				400	30
Pontotoc, MS	Pontotoc 1	1	LTM 92/93	487	1.3	SWI	4.46	5.09	3.84	3.0	12	0.0400		1.3	49	23
Pontotoc, MS	Pontotoc 2	1	LTM 92/93	487	1.3	SWI	6.05	6.15	5.95	3.6	14	0.0400		1.5	46	27
Purdue University, IN	Purdue	A1	LTM 94/95	730	2.0	SWI	0.45			1.0	15	0.0023	7.7	2.0	115	43
Purdue University, IN	Purdue	A2	LTM 94/95	730	2.0	SWI	0.45			1.0	15	0.0023	7.7	2.0	115	42
Purdue University, IN	Purdue	A3	ANN 95	365	1.0	SWI	0.45			1.0	15	0.0023	7.7	2.0	113	37
Purdue University, IN	Purdue	A4	LTM 94/95	730	2.0	SWI	0.45			1.0	15	0.0023	7.7	2.0	115	39
Purdue University, IN	Purdue	B1	LTM 94/95	730	2.0	SWI	0.90			2.0	15	0.0023	3.8	3.9	115	51
Purdue University, IN	Purdue	B2	LTM 94/95	730	2.0	SWI	0.90			2.0	15	0.0023	3.8	3.9	115	50
Purdue University, IN	Purdue	B3	ANN 95	365	1.0	SWI	0.90			2.0	15	0.0023	3.8	3.9	113	50
Purdue University, IN	Purdue	B4	LTM 94/95	730	2.0	SWI	0.90			2.0	15	0.0023	3.8	3.9	115	50
Purdue University, IN	Purdue	C1	LTM 94/95	730	2.0	SWI	0.90			1.0	30	0.0023	7.7	3.9	115	40
Purdue University, IN	Purdue	C2	LTM 94/95	730	2.0	SWI	0.90			1.0	30	0.0023	7.7	3.9	115	49
Purdue University, IN	Purdue	C3	LTM 94/95	730	2.0	SWI	0.90			1.0	30	0.0023	7.7	3.9	115	44

TABLE C-2 (CONTINUED)
Summary of Operational Data in the LWDB

Site Name	System Name	Cell	Time Period	Days	Years	Waste Code[a]	Average Flow (m^3/d)	Inflow (m^3/d)	Outflow (m^3/d)	Super Velo (m/d)	Depth (cm)	Area (ha)	Detention Time (d)	Hold Rate (cm/d)	BOD In (mg/L)	BOD Out (mg/L)
Purdue University, IN	Purdue	C4	LTM 94/95	730	2.0	SWI	0.90			1.0	30	0.0023	7.7	3.9	115	42
Purdue University, IN	Purdue	D1	LTM 94/95	730	2.0	SWI	1.80			2.0	30	0.0023	3.8	7.8	115	46
Purdue University, IN	Purdue	D3	LTM 94/95	730	2.0	SWI	1.80			2.0	30	0.0023	3.8	7.8	115	55
Purdue University, IN	Purdue	D4	LTM 94/95	730	2.0	SWI	1.80			2.0	30	0.0023	3.8	7.8	115	53
Region of Ottawa-Carlton, ONT	RVCA Wetland #1	1	SUM 95	91	0.2	CTL									30	13
Sand Mountain, AL	Sand Mountain 1	1	LTM 90/92	405	1.1	SWI									54	29
Sand Mountain, AL	Sand Mountain 1	2	LTM 90/92	405	1.1	SWI									29	19
Sand Mountain, AL	Sand Mountain 2	1	LTM 90/92	405	1.1	SWI									54	14
Sand Mountain, AL	Sand Mountain 2	2	LTM 90/92	405	1.1	SWI									14	9
Sand Mountain, AL	Sand Mountain 3	1	LTM 90/92	405	1.1	SWI									54	13
Sand Mountain, AL	Sand Mountain 3	2	LTM 90/92	405	1.1	SWI									13	13
Sand Mountain, AL	Sand Mountain 4	1	LTM 90/92	405	1.1	SWI									64	16
Sand Mountain, AL	Sand Mountain 4	2	LTM 90/92	405	1.1	SWI									16	13
Sand Mountain, AL	Sand Mountain 5	1	LTM 90/92	405	1.1	SWI									64	15
Sand Mountain, AL	Sand Mountain 5	2	LTM 90/92	405	1.1	SWI									15	6
Tom Brothers Farm, IN	Tom Brothers	1	LTM 94/95	730	2.0	DAI									424	65
Tom Brothers Farm, IN	Tom Brothers	2	LTM 94/95	730	2.0	DAI									88	40
U of Connecticut, CT	Kellogg	T: 1-3	ANN 94/95	365	1.0	DAI	1.88	1.88	0.36	0.8	23	0.0340	41.6	0.6	3162	1357
Union Co., KY	Swine	1	ANN 92	274	0.8	SWI						0.0340				
Union Co., KY	Swine	2	ANN 92	274	0.8	SWI						0.0340				
Union Co., KY	Swine	3	ANN 92	274	0.8	SWI						0.0340				
Univ. of SW Louis., LA	Deep Trench	1	ANN 94/95	365	1.0	DAI					120	0.0050			14	10
Univ. of SW Louis., LA	Deep Trench	2	ANN 94/95	365	1.0	DAI					120	0.0045			10	11
Univ. of SW Louis., LA	Free Water System	1	ANN 94/95	365	1.0	DAI					60	0.0095			14	7
Univ. of SW Louis., LA	Free Water System	2	ANN 94/95	365	1.0	DAI					60	0.0095			7	9
Univ. of SW Louis., LA	Subsurface Flow	1	ANN 94/95	365	1.0	DAI					60	0.0050			14	8
Univ. of SW Louis., LA	Subsurface Flow	2	ANN 94/95	365	1.0	DAI					60	0.0038			8	5
Univ. of SW Louis., LA	Subsurface Flow	3	ANN 94/95	365	1.0	DAI					60	0.0035			5	8
Average							4.20	6.41	7.15	3.5	30	0.62	6.9	4.7	263	93
Median							5.40	6.93	7.21	3.5	30	0.01	7.6	3.9	81	31
Minimum							0.45	1.44	0.36	0.8	1	0.00	3.0	0.6	5	5
Maximum							8.94	10.34	15.67	7.8	120	21.90	41.6	13.4	3181	1357
Count							48	31	21	36.0	47	72	28.0	52.0	86	86

[a]Waste Code

DAI = dairy
CTL = cattle feeding
SWI = swine
POU = poultry

TABLE C-2
Summary of Operational Data in the LWDB

Site Name	System Name	Cell	Time Period	TSS In (mg/L)	TSS Out (mg/L)	TKN In (mg/L)	TKN Out (mg/L)	NH_4 In (mg/L)	NH_4 Out (mg/L)	NO_3 In (mg/L)	NO_3 Out (mg/L)	TN In (mg/L)	TN Out (mg/L)	OGN In (mg/L)	OGN Out (mg/L)	TP In (mg/L)	TP Out (mg/L)	DP In (mg/L)	DP Out (mg/L)
Auburn Poultry, AL	Auburn Poultry 1	1	ANN 93/94			100.7	74.5	84.1	68.3	0.44	0.12	101.2	74.6	16.68	6.17	33.72	25.68		
Auburn Poultry, AL	Auburn Poultry 1	2	ANN 93/94			74.5	58.8	68.3	54.3	0.12	0.30	74.6	59.1	6.17	4.93	25.68	21.74		
Auburn Poultry, AL	Auburn Poultry 2	1	ANN 93/94			100.7	62.0	84.1	56.3	0.44	0.67	101.2	62.7	16.68	5.77	33.72	25.85		
Auburn Poultry, AL	Auburn Poultry 2	2	ANN 93/94			62.0	45.9	56.3	41.8	0.67	0.78	62.7	46.6	5.77	4.01	25.85	23.87		
Auburn Poultry, AL	Auburn Poultry 3	1	ANN 93/94			100.7	71.2	84.1	63.4	0.44	0.15	101.2	71.4	16.68	7.82	33.72	25.73		
Auburn Poultry, AL	Auburn Poultry 3	2	ANN 93/94			71.2	56.6	63.4	49.3	0.15	1.10	71.4	57.6	7.82	7.23	25.73	22.50		
Auburn Poultry, AL	Auburn Poultry 4	1	ANN 93/94			100.7	93.2	84.1	66.0	0.44	0.15	101.2	93.3	16.68	27.18	33.72	27.95		
Auburn Poultry, AL	Auburn Poultry 4	2	ANN 93/94			93.2	78.7	66.0	66.4	0.15	0.09	93.3	78.8	27.18	12.28	27.95	31.53		
Auburn Poultry, AL	Auburn Poultry 5	1	ANN 93/94			100.7	81.9	84.1	65.8	0.44	0.14	101.2	82.0	16.68	16.13	33.72	25.60		
Auburn Poultry, AL	Auburn Poultry 5	2	ANN 93/94			81.9	70.9	65.8	59.9	0.14	0.13	82.0	71.0	16.13	10.96	25.60	27.09		
Brenton Cattle , IA	Brenton Cattle	1	LTM 92/93	522	60	50.8	22.2	8.5	1.8	32.58	9.92					0.54	0.14		
Brenton Cattle , IA	Brenton Cattle	2	LTM 92/93	60	51	22.2	16.5	1.8	2.6	9.92	11.00					0.14	0.12		
Crittenden Co., KY	Dairy	1	ANN 92							69.61	7.78					91.11	6.91		
Crittenden Co., KY	Dairy	2	ANN 92							7.78	7.07					6.91	1.55		
David Gerrits Farm, WI	David Gerrits Farm 1&2	1	ANN 93			19.8	6.5									16.90	8.10		
David Gerrits Farm, WI	David Gerrits Farm 1&2	2	ANN 93			6.5	6.8									8.10	5.80		
David Gerrits Farm, WI	David Gerrits Farm 1&2	3	ANN 93			6.8	5.2									5.80	2.80		
David Gerrits Farm, WI	David Gerrits Farm 3&4	1	ANN 93			14.7	7.2									13.50	7.70		
David Gerrits Farm, WI	David Gerrits Farm 3&4	2	ANN 93			7.2	15.0									7.70	10.20		
David Gerrits Farm, WI	David Gerrits Farm 3&4	3	ANN 93			15.0	4.4									10.20	2.40		
Duplin, NC	Juncus/Scirpus	1	LTM 93/94					34.8	11.5	1.20	5.85							7.50	5.25
Duplin, NC	Juncus/Scirpus	2	LTM 93/94					16.8	3.3	3.85	3.90							5.00	3.55
Duplin, NC	Rice System	1	LTM 93/94					13.0	0.3	0.80	0.10							2.00	0.20
Duplin, NC	Soybean System	1	LTM 93/94					34.8	13.0	1.20	0.80							7.50	2.00
Duplin, NC	Sporgonium/Typha	1	LTM 93/94					34.8	10.8	1.20	4.85							7.50	4.38
Duplin, NC	Sporgonium/Typha	2	LTM 93/94					10.8	4.0	4.85	1.83							4.38	2.03
Essex County, ONT	ERCA Wetland #1	1	ANN 94	1596	48	119.3	17.5	0.2	0.1							25.00	3.90	11.50	2.30
Hernando, MS	Hernando 1	1	LTM 91-92	137	44			6.5	0.4	0.05	0.04					13.47	3.27	6.70	1.87
Hernando, MS	Hernando 1	4	LTM 91-92	47	55			1.2	0.4	0.26	0.03					5.72	1.27	4.21	0.28
Hernando, MS	Hernando 2	2	LTM 91-92	109	56			6.1	0.3	0.07	0.05					14.44	3.78	6.88	2.79
Hernando, MS	Hernando 3	3	LTM 91-92	125	47			7.5	1.2	0.06	0.26					14.22	5.72	7.01	4.21
Key Dairy, GA	Key Dairy	T:1-3	ANN 90									211.5	47.6			42.33	10.64		
Louis. St. Univ., LA	Black Willow	1	LTM 93/95	204	45	105.2	28.8	76.8	22.0					28.04	7.85	36.73	21.58		
Louis. St. Univ., LA	Duckweed/Emergent plant	1	LTM 93/95	204	42	105.2	20.6	76.8	19.1					28.04	9.43	36.73	26.22		
Louis. St. Univ., LA	Water hyacinth	1	LTM 93/95	204	53	105.2	36.6	76.8	31.1					30.08	4.75	36.73	23.16		
Mercer Co., KY	Mercer Co.	1	ANN	1132	408	107.5	123.8	32.8	10.3							71.60	47.10	26.50	15.00
Newton, MS	Newton 1	1	LTM 91/92	96	58			15.1	15.2									30.34	35.73
Newton, MS	Newton 1	2	LTM 91/92	37	42			13.9	10.7									32.95	28.10
Newton, MS	Newton 2	1	LTM 91/92	96	66			15.1	15.1									30.34	33.08
Newton, MS	Newton 2	2	LTM 91/92	41	50			13.5	10.8									30.26	29.24
Newton, MS	Newton 3	1	LTM 91/92	88	39			15.6	19.3									31.55	36.32
Newton, MS	Newton 3	2	LTM 91/92	32	45			18.4	13.5									32.64	33.14
Newton, MS	Newton 4	1	LTM 91/92	87	49			15.5	17.4									31.78	34.91
Newton, MS	Newton 4	2	LTM 91/92	54	32			17.3	12.1									33.42	33.19
Newton, MS	Newton 5	1	LTM 91/92	100	60			15.1	18.7									31.72	35.89
Newton, MS	Newton 5	2	LTM 91/92	20	29			17.9	13.6									32.07	34.40
Newton, MS	Newton 6	1	LTM 91/92	96	57			13.4	14.1									28.45	31.05
Newton, MS	Newton 6	2	LTM 91/92	93	56			9.6	14.6									38.17	23.58
Norwood Farms, IN	Norwood Farms 1	1	LTM 93/94	8207	4922	807.8	199.7	547.4	117.3	12.40	4.39					69.86	31.41	54.22	19.44
Norwood Farms, IN	Norwood Farms 2	1	LTM 93/94	11300	4867	743.6	208.3	524.8	138.7	2.22	2.64					78.92	27.91	58.81	19.07
Norwood Farms, IN	Norwood Farms 3	1	LTM 93/94	8397	5049	918.0	230.9	561.5	122.4	8.65	5.16					69.91	28.65	53.91	19.16
Oregon State University, OR	OregonState University	1	LTM 93/94	476	111	147.8	71.0	108.2	53.5							25.79	12.45		
Oregon State University, OR	OregonState University	2	LTM 93/94	507	140	157.7	78.4	116.0	58.5							27.85	13.70		
Oregon State University, OR	OregonState University	3	LTM 93/94	507	127	157.7	80.3	116.0	62.5							27.85	13.56		
Oregon State University, OR	OregonState University	4	LTM 93/94	507	135	157.7	86.1	116.0	64.5							27.85	15.24		
Oregon State University, OR	OregonState University	5	LTM 93/94	507	162	157.7	89.6	116.0	65.8							27.85	15.85		
Oregon State University, OR	OregonState University	6	LTM 93/94	507	135	157.7	74.6	116.0	55.3							27.85	12.84		
Perth County, ONT	UTRCA Wetland #1	1	LTM 93/95	500	40	150.0	20.0	0.1	0.1	0.33	0.14					30.00	3.00		
Pontotoc, MS	Pontotoc 1	1	LTM 92/93	96	31	131.8	46.9	112.5	35.8	0.00	0.07	129.2	47.0	13.11	6.63	29.29	18.19	22.17	16.82
Pontotoc, MS	Pontotoc 2	1	LTM 92/93	93	34	129.7	39.3	112.2	38.9	0.00	0.37	129.7	39.6	9.22	5.49	28.70	16.71	21.55	15.72
Purdue University, IN	Purdue	A1	LTM 94/95	134	66	416.3	249.8	405.5	244.6	1.06	5.02	416.6	251.1			17.47	10.29	16.19	9.25
Purdue University, IN	Purdue	A2	LTM 94/95	134	49	416.3	240.3	405.5	234.8	1.06	3.41	416.6	241.3			17.47	9.81	16.19	9.00
Purdue University, IN	Purdue	A3	ANN 95	147	48	335.8	104.4	327.7	97.4	0.13	0.37	335.8	104.4			20.27	14.43	18.90	13.35
Purdue University, IN	Purdue	A4	LTM 94/95	134	44	416.3	249.0	405.5	244.2	1.06	2.18	416.6	249.6			17.47	9.80	16.19	8.90
Purdue University, IN	Purdue	B1	LTM 94/95	134	58	416.3	271.6	405.5	267.0	1.06	2.35	416.6	272.3			17.47	15.72	16.19	14.62
Purdue University, IN	Purdue	B2	LTM 94/95	134	63	416.3	262.1	405.5	256.4	1.06	2.36	416.6	262.7			17.47	15.53	16.19	14.52
Purdue University, IN	Purdue	B3	ANN 95	147	107	335.8	123.9	327.7	116.5	0.13	0.57	335.8	124.0			20.27	16.26	18.90	15.31
Purdue University, IN	Purdue	B4	LTM 94/95	134	66	416.3	283.8	405.5	279.3	1.06	2.81	416.6	284.6			17.47	15.48	16.19	14.41
Purdue University, IN	Purdue	C1	LTM 94/95	134	53	416.3	242.1	405.5	239.7	1.06	2.04	416.6	242.7			17.47	13.35	16.19	12.43
Purdue University, IN	Purdue	C2	LTM 94/95	134	112	416.3	188.2	405.5	181.0	1.06	3.83	416.6	189.3			17.47	10.88	16.19	10.02
Purdue University, IN	Purdue	C3	LTM 94/95	134	51	416.3	239.6	405.5	234.7	1.06	3.39	416.6	240.4			17.47	13.52	16.19	12.29

TABLE C-2 (CONTINUED)
Summary of Operational Data in the LWDB

Site Name	System Name	Cell	Time Period	TSS In (mg/L)	TSS Out (mg/L)	TKN In (mg/L)	TKN Out (mg/L)	NH_4 In (mg/L)	NH_4 Out (mg/L)	NO_3 In (mg/L)	NO_3 Out (mg/L)	TN In (mg/L)	TN Out (mg/L)	OGN In (mg/L)	OGN Out (mg/L)	TP In (mg/L)	TP Out (mg/L)	DP In (mg/L)	DP Out (mg/L)
Purdue University, IN	Purdue	C4	LTM 94/95	134	53	416.3	241.4	405.5	236.3	1.06	0.84	416.6	241.6			17.47	12.68	16.19	11.64
Purdue University, IN	Purdue	D1	LTM 94/95	134	78	416.3	252.4	405.5	247.6	1.06	2.81	416.6	253.2			17.47	14.08	16.19	13.08
Purdue University, IN	Purdue	D3	LTM 94/95	134	86	416.3	265.7	405.5	262.4	1.06	0.87	416.6	266.0			17.47	14.19	16.19	12.98
Purdue University, IN	Purdue	D4	LTM 94/95	134	81	416.3	274.0	405.5	268.3	1.06	2.18	416.6	274.7			17.47	14.07	16.19	13.23
Region of Ottawa-Carlton, ONT	RVCA Wetland #1	1	SUM 95			27.2	20.0									5.30	1.69		
Sand Mountain, AL	Sand Mountain 1	1	LTM 90/92	112	22	86.9	39.0	74.4	35.6					12.55	3.35	45.90	22.95		
Sand Mountain, AL	Sand Mountain 1	2	LTM 90/92	22	20	39.0	24.8	35.6	14.0					3.35	10.75	22.95	18.90		
Sand Mountain, AL	Sand Mountain 2	1	LTM 90/92	112	16	86.9	13.9	74.4	13.5					12.55	2.90	45.90	21.15		
Sand Mountain, AL	Sand Mountain 2	2	LTM 90/92	16	27	13.9	6.0	13.5	3.2					2.90	2.50	21.15	14.20		
Sand Mountain, AL	Sand Mountain 3	1	LTM 90/92	112	19	86.9	23.1	74.4	14.7					12.55	8.45	45.90	29.95		
Sand Mountain, AL	Sand Mountain 3	2	LTM 90/92	19	19	23.1	9.2	14.7	5.4					8.45	3.75	29.95	11.60		
Sand Mountain, AL	Sand Mountain 4	1	LTM 90/92	105	35	69.8	18.5	54.7	12.8					15.10	5.70	25.80	11.90		
Sand Mountain, AL	Sand Mountain 4	2	LTM 90/92	35	42	18.5	11.9	12.8	6.9					5.70	5.00	11.90	10.60		
Sand Mountain, AL	Sand Mountain 5	1	LTM 90/92	105	19	69.8	18.9	54.7	13.8					15.10	5.10	25.80	10.60		
Sand Mountain, AL	Sand Mountain 5	2	LTM 90/92	19	18	18.9	4.8	13.8	2.4					5.10	2.40	10.60	5.30		
Tom Brothers Farm, IN	Tom Brothers	1	LTM 94/95	279	74	113.8	75.9	119.1	77.5	1.54	4.98	114.2	77.1			13.87	6.81	8.11	5.53
Tom Brothers Farm, IN	Tom Brothers	2	LTM 94/95	69	42	61.9	18.2	64.5	13.8	0.67	0.76	62.1	18.4			7.08	2.76	6.14	2.19
U of Connecticut, CT	Kellogg	T: 1-3	ANN 94/95	800	240	104.1	70.2	20.3	80.1	0.36	0.08					28.18	22.58		
Union Co., KY	Swine	1	ANN 92							8.51	6.16					42.06	18.83		
Union Co., KY	Swine	2	ANN 92							6.16	6.71					18.83	14.44		
Union Co., KY	Swine	3	ANN 92							6.71	5.00					14.44	4.80		
Univ. of SW Louis., LA	Deep Trench	1	ANN 94/95	55	54	14.0	11.9	7.9	7.0	2.51	0.89					7.78	8.87		
Univ. of SW Louis., LA	Deep Trench	2	ANN 94/95	54	62	11.9	12.1	7.0	9.1	0.89	0.44					8.87	6.97		
Univ. of SW Louis., LA	Free Water System	1	ANN 94/95	55	41	14.0	10.1	7.9	7.0	2.51	0.95					7.78	7.38		
Univ. of SW Louis., LA	Free Water System	2	ANN 94/95	41	17	10.1	21.1	7.0	11.1	0.95						7.38	7.07		
Univ. of SW Louis., LA	Subsurface Flow	1	ANN 94/95	59	38	13.8	11.2	8.7	9.3	2.02	0.25					7.32	7.70		
Univ. of SW Louis., LA	Subsurface Flow	2	ANN 94/95	33	19	11.8	9.8	8.2	6.8	0.31	0.34					8.24	8.02		
Univ. of SW Louis., LA	Subsurface Flow	3	ANN 94/95	19	37	9.8	11.8	6.8	7.9	0.34	0.52					8.02	6.02		
Average				585	273	174.4	86.8	122.2	63.7	3.59	2.32	254.1	147.5	13.93	7.46	24.29	14.08	20.73	15.55
Median				118	51	100.7	56.6	59.8	18.9	1.06	0.89	273.6	98.9	13.11	5.77	20.27	13.35	16.19	13.29
Minimum				16	16	6.5	4.4	0.1	0.1	0.00	0.03	62.1	18.4	2.90	2.40	0.14	0.12	2.00	0.20
Maximum				11300	5049	918.0	283.8	561.5	279.3	69.61	11.00	416.6	284.6	30.08	27.18	91.11	47.10	58.81	36.32
Count				70	70	71.0	71.0	86.0	86.0	58.00	57.00	30.0	30.0	25.00	25.00	81.00	81.00	46.00	46.00

[a]Waste Code

DAI = dairy
CTL = cattle feeding
SWI = swine
POU = poultry

TABLE C-2

Summary of Operational Data in the LWDB

Site Name	System Name	Cell	Time Period	DO In (mg/L)	DO Out (mg/L)	FC In (mg/L)	FC Out (mg/L)	COND In (mg/L)	COND Out (mg/L)	TDS In (mg/L)	TDS Out (mg/L)	VSS In (mg/L)	VSS Out (mg/L)	COD In (mg/L)	COD Out (mg/L)	TEMP In (deg. C)	TEMP Out (deg. C)	pH In (SU)	pH Out (SU)
Auburn Poultry, AL	Auburn Poultry 1	1	ANN 93/94									393	284	476	259			7.20	7.29
Auburn Poultry, AL	Auburn Poultry 1	2	ANN 93/94									284	273	259	187			7.29	7.42
Auburn Poultry, AL	Auburn Poultry 2	1	ANN 93/94									393	346	476	304			7.20	7.28
Auburn Poultry, AL	Auburn Poultry 2	2	ANN 93/94									346	763	304	198			7.28	7.38
Auburn Poultry, AL	Auburn Poultry 3	1	ANN 93/94									393	306	476	320			7.20	7.42
Auburn Poultry, AL	Auburn Poultry 3	2	ANN 93/94									306	283	320	219			7.42	7.59
Auburn Poultry, AL	Auburn Poultry 4	1	ANN 93/94									393	518	476	438			7.12	7.30
Auburn Poultry, AL	Auburn Poultry 4	2	ANN 93/94									518	406	438	352			7.30	7.36
Auburn Poultry, AL	Auburn Poultry 5	1	ANN 93/94									393	379	476	350			7.12	7.28
Auburn Poultry, AL	Auburn Poultry 5	2	ANN 93/94									379	301	350	278			7.28	7.37
Brenton Cattle , IA	Brenton Cattle	1	LTM 92/93			143	38												
Brenton Cattle , IA	Brenton Cattle	2	LTM 92/93			38	25												
Crittenden Co., KY	Dairy	1	ANN 92			346	2												
Crittenden Co., KY	Dairy	2	ANN 92			2	0												
David Gerrits Farm, WI	David Gerrits Farm 1&2	1	ANN 93																
David Gerrits Farm, WI	David Gerrits Farm 1&2	2	ANN 93																
David Gerrits Farm, WI	David Gerrits Farm 1&2	3	ANN 93																
David Gerrits Farm, WI	David Gerrits Farm 3&4	1	ANN 93																
David Gerrits Farm, WI	David Gerrits Farm 3&4	2	ANN 93																
David Gerrits Farm, WI	David Gerrits Farm 3&4	3	ANN 93																
Duplin, NC	Juncus/Scirpus	1	LTM 93/94																
Duplin, NC	Juncus/Scirpus	2	LTM 93/94																
Duplin, NC	Rice System	1	LTM 93/94																
Duplin, NC	Soybean System	1	LTM 93/94																
Duplin, NC	Sporgonium/Typha	1	LTM 93/94																
Duplin, NC	Sporgonium/Typha	2	LTM 93/94																
Essex County, ONT	ERCA Wetland #1	1	ANN 94			1030000	11999												
Hernando, MS	Hernando 1	1	LTM 91-92	2.26	1.12			307	213	338	257					19.28	17.36	7.01	6.18
Hernando, MS	Hernando 1	4	LTM 91-92	1.59	5.22			274	166	308	199					17.41	14.76	6.19	7.09
Hernando, MS	Hernando 2	2	LTM 91-92	2.94	1.85			338	239	358	260					19.72	17.13	6.93	6.16
Hernando, MS	Hernando 3	3	LTM 91-92	2.72	1.59			340	274	362	308					19.60	17.41	6.88	6.19
Key Dairy, GA	Key Dairy	T:1-3	ANN 90																
Louis. St. Univ., LA	Black Willow	1	LTM 93/95	1.97	1.77			1745	1028			145	25			22.60	20.70	7.43	7.12
Louis. St. Univ., LA	Duckweed/Emergent plant	1	LTM 93/95	1.97	1.41			1745	1070			145	23			22.60	21.41	7.43	6.88
Louis. St. Univ., LA	Water hyacinth	1	LTM 93/95	1.97	1.31			1745	1132			145	39			22.60	20.06	7.43	7.46
Mercer Co., KY	Mercer Co.	1	ANN	0.60	0.80														
Newton, MS	Newton 1	1	LTM 91/92		1.00					730	685						17.73		
Newton, MS	Newton 1	2	LTM 91/92	0.26	0.39					703	603					21.45	20.16		
Newton, MS	Newton 2	1	LTM 91/92		0.34					730	673						17.59		
Newton, MS	Newton 2	2	LTM 91/92	0.19	0.17					690	604					20.82	19.91		
Newton, MS	Newton 3	1	LTM 91/92		0.58					727	669						16.84		
Newton, MS	Newton 3	2	LTM 91/92	0.53	0.31					677	587					20.38	19.31		
Newton, MS	Newton 4	1	LTM 91/92		0.75					733	711						17.36		
Newton, MS	Newton 4	2	LTM 91/92	0.45	0.29					688	604					20.41	19.05		
Newton, MS	Newton 5	1	LTM 91/92		0.80					744	722						17.23		
Newton, MS	Newton 5	2	LTM 91/92	0.61	0.49					691	596					20.06	18.06		
Newton, MS	Newton 6	1	LTM 91/92		3.39					691	657						21.36		
Newton, MS	Newton 6	2	LTM 91/92	4.04	2.91					781	656					24.18	24.65		
Norwood Farms, IN	Norwood Farms 1	1	LTM 93/94				52			5530	4815								
Norwood Farms, IN	Norwood Farms 2	1	LTM 93/94				55			6165	4787								
Norwood Farms, IN	Norwood Farms 3	1	LTM 93/94				52			5940	4930								
Oregon State University, OR	OregonState University	1	LTM 93/94	4.65	0.21	833538	82025	1851	1327					1901	808			7.47	7.17
Oregon State University, OR	OregonState University	2	LTM 93/94	4.65	0.16	979486	85797	2059	1467					2023	929			7.46	7.07
Oregon State University, OR	OregonState University	3	LTM 93/94	4.65	0.10	979486	88273	2059	1533					2023	945			7.46	7.00
Oregon State University, OR	OregonState University	4	LTM 93/94	4.65	0.39	979486	110938	2059	1540					2023	972			7.46	7.07
Oregon State University, OR	OregonState University	5	LTM 93/94	4.65	0.23	979486	126485	2059	1614					2023	1064			7.46	7.12
Oregon State University, OR	OregonState University	6	LTM 93/94	4.65	0.24	979486	135668	2059	1516					2023	957			7.46	7.20
Perth County, ONT	UTRCA Wetland #1	1	LTM 93/95																
Pontotoc, MS	Pontotoc 1	1	LTM 92/93	2.86	4.35											18.94	17.76		
Pontotoc, MS	Pontotoc 2	1	LTM 92/93	3.57	5.94											19.26	20.11		
Purdue University, IN	Purdue	A1	LTM 94/95			126	17	4614	3728									8.26	8.10
Purdue University, IN	Purdue	A2	LTM 94/95			126	7	4614	3671									8.26	8.03
Purdue University, IN	Purdue	A3	ANN 95			175	20	5128	3659									8.39	8.39
Purdue University, IN	Purdue	A4	LTM 94/95			126	11	4614	3675									8.26	8.04
Purdue University, IN	Purdue	B1	LTM 94/95			126	9	4614	3872									8.26	8.14
Purdue University, IN	Purdue	B2	LTM 94/95			126	16	4614	3778									8.26	8.11
Purdue University, IN	Purdue	B3	ANN 95			175	40	5128	4135									8.39	8.52
Purdue University, IN	Purdue	B4	LTM 94/95			126	16	4614	3957									8.26	8.14
Purdue University, IN	Purdue	C1	LTM 94/95			126	7	4614	3676									8.26	8.13
Purdue University, IN	Purdue	C2	LTM 94/95			126	0	4614	3233									8.26	8.82
Purdue University, IN	Purdue	C3	LTM 94/95			126	9	4614	3703									8.26	8.23

TABLE C-2 (CONTINUED)
Summary of Operational Data in the LWDB

Site Name	System Name	Cell	Time Period	DO In (mg/L)	DO Out (mg/L)	FC In (mg/L)	FC Out (mg/L)	COND In (mg/L)	COND Out (mg/L)	TDS In (mg/L)	TDS Out (mg/L)	VSS In (mg/L)	VSS Out (mg/L)	COD In (mg/L)	COD Out (mg/L)	TEMP In (deg. C)	TEMP Out (deg. C)	PH In (s.u.)	PH Out (s.u.)
Purdue University, IN	Purdue	C4	LTM 94/95			126	7	4614	3745									8.26	8.18
Purdue University, IN	Purdue	D1	LTM 94/95			126	23	4614	3900									8.26	8.23
Purdue University, IN	Purdue	D3	LTM 94/95			126	21	4614	3983									8.26	8.26
Purdue University, IN	Purdue	D4	LTM 94/95			126	15	4614	3930									8.26	8.24
Region of Ottawa-Carlton, ONT	RVCA Wetland #1	1	SUM 95																
Sand Mountain, AL	Sand Mountain 1	1	LTM 90/92			175164	3005												
Sand Mountain, AL	Sand Mountain 1	2	LTM 90/92			3005	1760												
Sand Mountain, AL	Sand Mountain 2	1	LTM 90/92			175164	2530												
Sand Mountain, AL	Sand Mountain 2	2	LTM 90/92			2530	4307												
Sand Mountain, AL	Sand Mountain 3	1	LTM 90/92			175164	3798												
Sand Mountain, AL	Sand Mountain 3	2	LTM 90/92			3798	1366												
Sand Mountain, AL	Sand Mountain 4	1	LTM 90/92			175164	2438												
Sand Mountain, AL	Sand Mountain 4	2	LTM 90/92			2438	2421												
Sand Mountain, AL	Sand Mountain 5	1	LTM 90/92			175164	1894												
Sand Mountain, AL	Sand Mountain 5	2	LTM 90/92			1894	3808												
Tom Brothers Farm, IN	Tom Brothers	1	LTM 94/95	1.54	3.75	120	35	1874	1351							16.15	16.11	7.45	7.54
Tom Brothers Farm, IN	Tom Brothers	2	LTM 94/95	2.71	5.38	19	5	1219	1005							15.50	17.25	7.49	7.61
U of Connecticut, CT	Kellogg	T: 1-3	ANN 94/95			28800	1265	226	589							12.68	12.69	6.00	7.30
Union Co., KY	Swine	1	ANN 92			3	0												
Union Co., KY	Swine	2	ANN 92			0	0												
Union Co., KY	Swine	3	ANN 92																
Univ. of SW Louis., LA	Deep Trench	1	ANN 94/95			3716	1884					45	39					7.27	7.38
Univ. of SW Louis., LA	Deep Trench	2	ANN 94/95			1884	227					39	28					7.38	6.86
Univ. of SW Louis., LA	Free Water System	1	ANN 94/95			3716	1599					45	25					7.27	7.18
Univ. of SW Louis., LA	Free Water System	2	ANN 94/95			1599	3143					25	13					7.18	
Univ. of SW Louis., LA	Subsurface Flow	1	ANN 94/95			3367	3188					47	27					7.07	6.91
Univ. of SW Louis., LA	Subsurface Flow	2	ANN 94/95			3253	3426					24	16					7.08	7.14
Univ. of SW Louis., LA	Subsurface Flow	3	ANN 94/95			3426	875					16	33					7.14	7.46
Average				2.53	1.57	160477	13424	2974	2345	1452	1228	224	206	1004	536	19.65	18.42	7.54	7.50
Median				2.48	0.80	1742	55	2059	1614	703	656	215	156	476	351	19.89	17.75	7.43	7.38
Minimum				0.19	0.10	0	0	226	166	308	199	16	13	259	187	12.68	12.69	6.00	6.16
Maximum				4.65	5.94	1030000	135668	5128	4135	6165	4930	518	763	2023	1064	24.18	24.65	8.39	8.82
Count				24.00	30.00	48	51	31	31	19	19	20	20	16	16	18.00	24.00	48.00	47.00

[a]Waste Code

DAI = dairy
CTL = cattle feeding
SWI = swine
POU = poultry

TABLE C-3
List of Contacts for Livestock Wastewater Treatment Wetlands

Site Name	Last Name	First Name	Role[a]	Organization	Address	Phone
3M Farm, MD	Baldwin	Ann	ENG	USDA - NRCS	122 Speer Rd., Suite 4, Chestertown, MD, 21620	410-778-3765
Adair Co.#1, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Adair Co.#2, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Allen Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Auburn Poultry, AL	Hill	David	R&D	Auburn University	Agricultural Engineering Dept. Auburn University, AL 36849-5417	334-844-4180
Auburn Swine, AL	Hill	David	R&D	Auburn University	Agricultural Engineering Dept. Auburn University, AL 36849-5418	334-844-4180
Brenton Cattle , IA	Brenton	William	MAN	Brenton Brothers Inc.	1415 Walnut St., PO Box 190, Dallas Centre, Iowa, 50063-0190	515-992-3403
Butler Co.#1, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Butler Co.#2, KY	Bankson	Dwain	MAN	Pig Improvement Company (PIC)	3033 Nashville Road, PO Box 348, Franklin, KY 42135-0348	502-586-9224
Casey Co.#1, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Casey Co.#2, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Casey Co.#3, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Crittenden Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Crittenden Co., KY	Trejo(Shely)	Lisa R.	R&D	NRCS	PO Box 322 West Paducah, KY 42086	502-665-5944
Crum Farm, MD	Baldwin	Ann	ENG	USDA - NRCS	122 Speer Rd., Suite 4, Chestertown, MD, 21620	410-778-3765
David Gerrits Farm, WI	Holmes	Brian	ENG	University of Wisconsin-Madison	Department of Agricultural Engineering, 460 Henry Mall, Madison, Wisconsin, 53706	608-262-3310
David Thompson Farm, N_S	Cochrane	Laurie	ENG	Department of Agriculture and Marketing	PO Box 550, Truro, Nova Scotia, Canada, B2N 5E3	902-893-6568
Delmarva Farms , MD	Baldwin	Ann	ENG	USDA - NRCS	122 Speer Rd., Suite 4, Chestertown, MD, 21620	410-778-3765
Dogwood Ridge, KY	Bankson	Dwain	MAN	Pig Improvement Company (PIC)	3033 Nashville Road, PO Box 348, Franklin, KY 42135-0348	502-586-9224
Duplin, NC	Humenik	F.J.	R&D	North Carolina State University	P.O. box 7625 Biological and Agricultural Engineering Dept. North Carolina State Univ. Raleigh, NC 27695-7625	919-515-6767
Essex County, ONT	Hermans	Paul	ENG	Essex Region Conservation Authority	360 Fairview Avenue West, Essex, Ontario, N8M 1Y6	519-776-5209
Guy Thompson Farm, PEI	DeHaan	Ron	ENG	Prince Edward Island Department of Agriculture, Fisheries, and Forestry	PO Box 1600, Charlootetown, PEI, C1A 7N3	902-368-5642
Hamilton-Wentworth, ONT	Attema	Chris	ENG	Niagara Peninsula Conservation Authority	2358 Centre St., Allenburg, Ontario, L0S 1A0	905-227-1013

TABLE C-3 (CONTINUED)
List of Contacts for Livestock Wastewater Treatment Wetlands

Site Name	Last Name	First Name	Role[a]	Organization	Address	Phone
Hattiesburg, MS	Thomas	Ronnie	R&D	NRCS	Room 323 Fed. Building Hattiesburg, MS 39401	601-544-4511
Hernando, MS	Cooper	Charles	ENG	ARS-National Sedimentation Laboratory	National Sedimentation Laboratory PO Box 1157 Oxford, Miss. 38655	601-232-2935
Hopkins Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Ken Hunter Farm, N_S	Cochrane	Laurie	ENG	Department of Agriculture and Marketing	PO Box 550, Truro, Nova Scotia, Canada, B2N 5E3	902-893-6568
La Franchi, CA	Lanier	Alicia	ENG	CH2M Hill	P.O. Box 492478, Redding, CA 96049-2478	916-243-5831
Louis. St. Univ., LA	Malone	Ron	R&D	LSU	Dept. of Civil and Environmental Engineering LSU Baton Rouge, LA 70803-6405	504-388-8666
Lucky Rose Farm, IN	McLoud	Philip	ENG	Natural Resources Conservation Service	6013 lakeside Blvd, Indianapolis, Indiana 46278	317-290-3217
McLean Co.#1, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
McLean Co.#2, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
McLean Co.#3, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
McMichael Dairy, GA	Surrency	D.	R&D	NRCS	USDA NRCS Box 13 Federal Building Athens, GA 30601	706-546-2114
Mercer Co., KY	Thom	William	ENG	University of Kentucky	Department of Agronomy, N122, ASC N, U of K, Lexington, KY, 40546-0091	606-257-4633
New Mexico State, NM	Zachritz, II	W.H.	R&D	New Mexico State University		
Newton, MS	Cathcart	Thomas	R&D	Mississippi State University	Agricultural and Biological Engineering PO Box 9632 Mississippi State, MS 39763	601-325-3282
Norwood Farms, IN	Reaves	Richard	ENG	3D-Environmental	781 Neeb Road Cincinnati, OH 45233-41125	513-922-8199
Nowicki Farm, ALB	Amell	Bernard	ENG	IMC Consulting Group Inc.	500-1122-4th St. SW Calgary, Alberta, Canada, T2R 1M1	403-269-9769
Oregon State University, OR	Moore	James	ENG	Oregon State University	Bioresource Engineering, Corvallis, OR, 97331-3906	503-737-6299
Perth County, ONT	Maaskant	Karen	ENG	Upper Thames River Conservation Authority	R.R.#6 London, Ontario, N6A 4C1, Canada	519-451-2800
Piscataquis River, ME	Rock	Chet	ENG	University of Maine	5711 Boardman Hall, Civil and Environmental Engineering, University of Maine, Orono, USA, 04469-5711	207-581-2170
Pontotoc, MS	Cathcart	Thomas	R&D	Mississippi State University	Agricultural and Biological Engineering PO Box 9632 Mississippi State, MS 39762	601-325-3282
Purdue University, IN	Reaves	Richard	ENG	3D-Environmental	781 Neeb Road Cincinnati, OH 45233-41125	513-922-8199
Region of Niagara, ONT	Attema	Chris	ENG	Niagara Peninsula Conservation Authority	2358 Centre St., Allenburg, Ontario, L0S 1A0	905-227-1013

TABLE C-3 (CONTINUED)
List of Contacts for Livestock Wastewater Treatment Wetlands

Site Name	Last Name	First Name	Role[a]	Organization	Address	Phone
Region of Ottawa-Carlton, ONT	Davidson	Terry	ENG	Rideau Valley Conservation Authority	Box 599, 1127 Mill St., Manotick, Ontario, Canada, K4M 1A5	613-692-3571
Region of Peel, ONT	Weselan	Ann Marie	ENG	Metro Toronto Region Conservation Authority	5 Shoreham Dr., Downsview, Ontario, Canada, M3N 1S4	416-661-6600
Russel County, ONT	Kollaard	William	ENG	Alfred College	31 St. Paul St., Box 580, Alfred, K0B 1A0	613-984-2948
Saint-Felicien, QUE	Villeneuve	Rejean	ENG	Les Consultants RSA	925 avenue du Pont Nord, Alma, Quebec, G8B 7B6	418-668-3373
Sand Mountain, AL	McCaskey	Thomas	R&D	Auburn University	Dept. of Animal and Dairy Sciences Auburn University Auburn, AL 36849	334-844-1518
Simco County #1, ONT	Peacock	Mark	ENG	Nottawasaga Valley Conservation Authority	RR#1, Angus, Ontario, Canada, L0M 1B0	705-424-1479
Simco County #2, ONT	Wesson	Byron	ENG	Nottawasaga Valley Conservation Authority	RR#1 Angus, Ontario, Canada, L0M 1B0	705-424-7425
Spencer Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Texas, TX	Kenimer	Ann L.	R&D	Texas A&M University	Dept. of Ag Engineering Texas A&M University 201 Scoates Hall College Station, TX 77843-2117	409-845-3677
Tifton, GA	Hubbard	Robert	R&D	USDA-ARS	Southeast Watershed Research Laboratory PO Box 946 Tifton, GA 31793	912-386-3462
Tom Brothers Farm, IN	Reaves	Richard	ENG	3D-Environmental	781 Neeb Road Cincinnati, OH 45233-41125	513-922-8199
U of Connecticut, CT	Clausen	John	ENG	University of Connecticut	Department of Natural Resources Management & Engineering, College of Agriculture & Natural Resources, Box U-87, Room 308, 1376 Storrs Rd, Storrs, CT 06269-4087	203-486-2840
U of Connecticut, CT	Newman	Jana	ENG	University of Connecticut	Department of Natural Resources Management & Engineering, College of Agriculture & Natural Resources, Box U-87, Room 308, 1376 Storrs Rd, Storrs, CT 06269-4087	203-486-0138
Union Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Univ. of SW Louis., LA	Malone	Ron	R&D	LSU	Dept. of Civil and Environmental Engineering LSU Baton Rouge, LA 70803-6405	504-388-8666
Warren Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Washington Co., KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Wayne Co.#1, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Wayne Co.#2, KY	Neely	David	ENG	NRCS	Suite 110, 771Corporate Dr., Lexington, KY 40503-5479	606-224-7360
Wayne White Farm, N_S	Cochrane	Laurie	ENG	Department of Agriculture and Marketing	PO Box 550, Truro, Nova Scotia, Canada, B2N 5E3	902-893-6568

[a] Role of Contact Person
R&D = research & development
ENG = eng. design or study
MAN = manager

TABLE C-4
Dominant Plant Species for Sites in the Livestock Wastewater Treatment Wetland Database

		Number of Cells by Wastewater Type					
Plant Species	**Common Name**	**Aquaculture**	**Cattle Feeding**	**Dairy**	**Poultry**	**Swine**	**Total**
Typha spp.	cattail		7	44		40	91
Scirpus spp.	bulrush			24	2	6	32
Phragmites spp.	common reed		16	4	2	9	31
Grass			1	4		12	17
Various			2	10		5	17
Riparian forest						12	12
Panicum hemitomon	maidencane			4		6	10
Sparganium spp.	bur-reed			8		1	9
Sagittaria spp.	arrowhead			2	2	4	8
Phalaris arundinacea			2	4		1	7
Polygonum spp.	smartweed	4		3			7
Cynodon dactylon						6	6
Panicum repens	torpedograss	6					6
Lemna spp.	duckweed	4		1			5
Juncus roemerianus	needlerush					4	4
Spirodela polyrhiza	giant duckweed			6			6
Eichornia crassipes	water hyacinth	2		1			3
None				2			2
Trapa natans	water chestnut					2	2

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