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Design of a Constructed Wetland for Wastewater Treatment and Reuse in Mount Pleasant, Utah

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DESIGN OF A CONSTRUCTED WETLAND FOR WASTEWATER TREATMENT AND REUSE IN MOUNT PLEASANT, UTAH

by

Yue Zhang

A project submitted in partial fulfillment of
the requirements for the degree

of

MASTER OF LANDSCAPE ARCHITECTURE

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ABSTRACT

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Reuse in Mount Pleasant, Utah

by

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Utah State University, 2012

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Municipalities in the Intermountain West are facing water shortages based on their current population growth projections. Utah has the second highest per-capita culinary water use in the United States. Among other cities, Mount Pleasant, Utah, is seeking innovative and cost-effective ways to reduce culinary water use. This study presents a feasibility analysis of and a design for using a free water surface constructed wetland system to treat the city's wastewater. The study further presents a cost-benefit assessment of using the treated water for landscape irrigation in the city. The study is based on an analysis of existing wastewater quality, local climatic and site biophysical conditions, and future water use projections. The proposed constructed wetland system is composed of two reactors in series: a stabilization lagoon followed by a constructed wetland. The study involves retrofitting the existing wastewater sewage lagoons and designing a constructive wetland and a storage pond for reclaimed water. The study results show that after a relatively long retention time, the overall biochemical oxygen demands will be reduced by 93.6% to 97.8% and the total suspended solids will be reduced by 87.2% to 87.9%. The treated water is sufficient to irrigate approximately 45 acres of turfgrass or 37 acres of pasture grass. In contrast to complex high-maintenance treatment systems, constructed wetlands provide ecologically-sustainable wastewater treatment. For municipalities that are facing similar challenges, this study provides an example of reducing culinary water use and achieving other sustainable development goals by reclaiming and reusing treated wastewater.

(85 pages)

PUBLIC ABSTRACT

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Constructed wetlands are engineered and managed wetland systems that are increasingly receiving worldwide attention for wastewater treatment and reclamation. Compared to conventional treatment plants, constructed wetlands are cost-effective and easily operated and maintained, and they have a strong potential for application in a small community like Mount Pleasant, a city in central Utah that has available land but technology and budget constraints.

Water is a serious concern in this area due to the local dry climate and limited freshwater resources. Reclaiming and reusing the treated wastewater would create an alternate water source for irrigation by reducing demand on potable water sources utilized for drinking water. This study introduces a constructed wetland system to Mount Pleasant for secondary treatment of their wastewater and to make the effluent water suitable for irrigation. By studying the existing wastewater quality, local climate, site condition, water policies and future demands, this study presents a model of constructed wetland for Mount Pleasant and evaluates the practicality of this model in wastewater treatment and reuse. The study results show that a constructed wetland coupled with the existing evaporation pond provides at least 87% removal of pollutants in the wastewater treatment process and that the effluent water qualifies for both agriculture and landscape irrigation. Future considerations in choosing constructed wetlands as a wastewater treatment system in other communities with needs similar to those of Mount Pleasant are highlighted in the study.

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CHAPTER I

INTRODUCTION

The rapid population growth in many municipalities in the arid and semi-arid Intermountain West region places increasing demands on limited freshwater supplies. The amount of freshwater and the balance among different users significantly affect the development of many cities, including Mount Pleasant, Utah. The population increase has increased not only the freshwater demand but also the volume of wastewater discharged. Treated wastewater appears to be the only freshwater resource that is increasing as other sources are dwindling. Next to the development of new management strategies to supply freshwater, the challenge of treating and recycling wastewater will play an important role in the water shortage problem. Use of treated water for irrigating landscapes is often viewed as one of the approaches to maximize the existing water resources and to stretch current urban water supplies (U.S. EPA, 2004a).

Moreover, sanitation is a concern with the increase in wastewater discharge. The leakage of pollutants may have significant negative impacts on the surrounding environment and threaten the ecosystem and public health. The proper treatment of wastewater before it is discharged into the environment will help to mitigate these damages.

Mount Pleasant, Utah is facing all the above problems with a scarcity of freshwater. The updated city general plan (2007 to 2017) emphasizes that water is the most serious concern for the city's future development. "Mount Pleasant's future growth will be restricted by available water. […] Based on the Central Utah Public Health

Department recommendations, Mount Pleasant has sufficient water rights to sustain a maximum population of about 4,000" (Mount Pleasant General Plan, 2007 to 2017). Mount Pleasant's 2010 census population is 3260. The population forecasts indicate that the population of Mount Pleasant will be approximately 4,444 by 2025. This means there will be a freshwater shortage in the near future if the city does not develop strategies to reclaim or reuse their water.

While the environmental and conservational benefits of wastewater reuse are obvious, the major concerns associated with wastewater reuse include effective treatment methods and processes, construction costs, additional costs of installation, and maintenance and management strategies.

Very little information is available concerning wastewater reclamation and reuse in Intermountain West municipalities, particularly small communities like Mount Pleasant. To date, the city has no effective facilities for treating wastewater discharge to meet federal or state regulations. The sewage lagoon system (1000 S, 1000 W) serves as the only "treatment" (storage) site for municipal wastewater disposal. The lagoon consists of two evaporation ponds (non-discharge retention lagoon) with a total surface area of approximately 30 acres. A large amount of water (more than 108,000 US gallons per day [USG/d]) is lost via evaporation from the ponds' open surfaces. Because of the paucity of information regarding wastewater reclamation and management in areas such as Mount Pleasant, research and designs need to be tailored to fit the local climate and site conditions and to take into consideration probable future additions. Also, the feasibility, effectiveness, and economic limits should be considered in treatment plans.

Constructed wetlands (CWs) have been proved to be “cost-effective” methods for wastewater treatment. They also provide other landscape and social benefits such as wildlife habitat, research laboratories, and recreational uses (U.S. EPA, 1999). CWs are artificial wetland systems that are designed to exploit the physical, chemical, and biological treatment processes that occur in wetlands and provide for the reduction in organic material, total suspended solids, nutrients, and pathogenic organisms. CWs emulate the natural treatment processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality (Arroyo, Ansola, & Luis, 2010). The vegetation and microbial communities in the wetlands can adapt to the wastewater inflow and utilize the various organic and inorganic pollutants during their metabolic and other life processes (Brix, 1994). Compared with the conventional treatment process, CWs provide advanced wastewater treatment that is highly valued but of low cost in terms of investment, operation, and maintenance.

How to integrate wastewater treatment processes with the landscape-featured CW poses a challenge to landscape architects. And how to wisely use and manage the irrigation water is another important consideration. This study discusses the design, performance, and management strategies of a free water surface (FWS) treatment system in Mount Pleasant for the use of treated municipal wastewater. It exploits a CW system (FWS CWs following the existing first lagoon) for municipal wastewater treatment and then uses the recycled water for irrigation and landscape water use.

The proposed project site is located on the west side of Highway #89 between 1000 South and 2000 South, 955 West and 1650 West City Street, Mount Pleasant, Utah (Figure 1). This site is currently used for a city sewage lagoon system. This system serves as the only storage site for domestic wastewater. It consists of two existing ponds with a total surface area of 30.04 acres, and two reserve ponds (which have not been constructed) that total 25 acres. The average present wastewater flow is about 237,186 (USG/d), including both black water and gray water (called “combined sewage”). This project focuses on applying a CW system for municipal wastewater treatment at the present flow rate. The impact of a future increase is considered, and the possible construction of a future expansion is also included in the assessment.

Figure 1. Site location.

The study, from a landscape architectural point of view, prescribes a multi-benefit program in managing city freshwater resources. It addresses the water-use strategy under both the current conditions and for future development. The project is intended to assist local governments in their wastewater treatment decision-making process and propose an appropriate mechanism for cleaning and reusing the wastewater. The study results could be a reference for future research and construction.

Design Regulations and Rules

The author of this study sought to take advantage of the reuse potential of the water. The benefits to suppliers of reclaimed water include greater public awareness and demand for reclaimed water and clear guidelines for reclaimed water production. Benefits to end users include increased public acceptance of the use of reclaimed water and a subsequent decrease in the demand for freshwater.

The major reason for this study is to take advantage of the reuse potential for the water. The reuse options include landscape water and irrigation use in the surrounding area. This option, using landscape irrigation close to public and other related activities, would require additional permit and regulations. This study would use two standards, EPA guidelines and Utah Administrative Code R317-3, as references.

U.S. EPA Guidelines

There are no federal regulations governing reclaimed water use, but the U.S. EPA (2004b) has established guidelines to encourage states to develop their own regulations. The primary purpose of federal guidelines and state regulations is to protect human health and water quality. To reduce disease risks to acceptable levels, reclaimed water must meet certain disinfection standards by either reducing the concentrations of constituents that may affect public health and/or limiting human contact with reclaimed water.

Based on the U.S. EPA inventory, current regulations can be divided into the following reuse categories: unrestricted urban reuse (irrigation of areas with unrestricted public access), restricted urban reuse (irrigation of areas with controllable access), agricultural reuse on food crops, agricultural reuse on non-food crops, unrestricted recreational reuse, restricted recreational reuse, environmental reuse (wetland or sustain stream flows), industrial reuse, groundwater recharge, and indirect potable reuse. Based on the study objectives, the regulations on “unrestricted urban reuse” and “agricultural reuse on food crops” should be considered in this research. Table 1 lists the U.S. EPA guidelines for urban reuse and agricultural reuse water quality.

Table 1

U.S. EPA Guidelines for Water Reuse

Reuse types	Treatment	Reclaimed water quality	Setback distance	Monitoring
Urban reuse (landscape irrigation, vehicle washing, fire protection, commercial air conditioners, etc.)	Secondary Filtration Disinfection	pH=6-9, BOD≤10mg/L, ≤2 NTU, No detectable fecal coli/100mL, 1 mg/L CL_2 residual(minimum)	50 feet to potable water wells	pH: weekly, BOD: weekly, Turbidity: continuous, Coliform: daily, Cl_2 residual-continuous
Agricultural reuse on food crop	Secondary Disinfection	pH=6-9, BOD ≤30mg/L, TSS ≤30mg/L, < 200 fecal coli/100ml, 1mg/L CL_2 residual(minimum)	300 feet to potable water wells 100 feet to areas accessible to the public (if spray irrigation)	pH: weekly, BOD: weekly, TSS: daily, Coliform: daily, Cl_2 residual-continuous
Agricultural reuse non-food crop	Secondary Filtration Disinfection	pH=6-9, BOD≤10mg/L, ≤2 NTU, No detectable fecal coli/100mL, 1 mg/L CL_2 residual(minimum)	50 ft (15 m) to potable water wells	pH: weekly, BOD: weekly, Turbidity: continuous, Coliform: daily, Cl_2 residual-continuous

Abbreviations: BOD, biochemical oxygen demands; TSS, total suspended solids; coli, coliform; CL_2, chlorine; NTU, nephelometric turbidity units.

Adapted from *Guidelines for water reuse* (pp. 167–170), 2004a, Washington, DC: U.S. Environmental Protection Agency and U.S. Agency for International Development EPA/625/R-04/108.

Utah Administrative Code

R317-3-11: Use, Land Application and Alternate Methods for Disposal of Treated Wastewater Effluents

According to the state, Type I water is required for all spray irrigation of food crops. Type I reuse activity allows human exposure and would require filtration, disinfection, and regular monitoring. The quality of treated effluent before use must meet the following standards:

- The monthly arithmetic mean of biochemical oxygen demands (BOD) shall not exceed 10 mg/L.
- The daily arithmetic mean turbidity shall not exceed 2 nephelometric turbidity units (NTU), and turbidity shall not exceed 5 NTU at any time.
- Escherichia coliform concentration shall no exceed 9 organisms/100 mL.
- A 1 mg/L total chlorine residual is recommended after disinfection and before the treated effluent goes into the distribution system.
- The pH should be continuously between 6 and 9.

Research Objectives

- To study the feasibility of building a CW in Mount Pleasant, Utah.
- To propose and design a CW system for treating and reusing municipal wastewater.
- To evaluate the pollutant removal efficiency in the proposed CW system.
- To promote sustainable management of natural resources.

CHAPTER II

LITERATURE REVIEW

Municipal Wastewater

"Wastewater" Definition

The term "wastewater" refers any water that has been used or polluted, and contains waste products. Wastewater is approximately 99% water; only 1% is a mixture of suspended and dissolved organic solids, detergent, and cleaning chemicals. "Sewage" is one kind of wastewater. It includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. Sewage treatment, or municipal wastewater treatment, is the process of removing contaminants from wastewater and household sewage. It includes physical, chemical, and biological processes to remove organic, inorganic and biological contaminants.

The typical composition of municipal wastewater (after pretreatment) most often treated in CWs contains suspended solids, organic matter, and in some instances, nutrients (especially total nitrogen) and heavy metals, as shown in Table 2 (Tchobanoglous & Burton, 1991). Domestic sewage wastewater typically contains 200 mg of suspended solids, 200 mg biochemical oxygen demands, 35 mg nitrogen, and 7 mg phosphorus per liter (Volodymyr, Sirajuddin, & Viktor, 2007).

Table 2

Contaminations Concentration in the Typical Untreated Domestic Wastewater

Parameter	Unit	Concentration		
		Weak	Medium	Strong
TS	mg/L	350	720	1,200
TDS	mg/L	250	500	850
TSS	mg/L	100	220	350
BOD	mg/L	110	220	400
COD	mg/L	250	500	1,000
TN	mg/L	20	40	85
TP	mg/L	4	8	15
Total Coliform	No/100mL	10^6~ 10^7	10^7~ 10^8	10^7~ 10^9

Abbreviations: TS, total solid; TDS, total dissolved solids; TSS, total suspended solids; BOD, biochemical oxygen demands; COD, chemical oxygen demands; TN, total nitrogen; TP, total phosphorous.

Adapted from *Wastewater engineering: Treatment disposal reuse* (p. 1820), by G. Tchobanoglous and F. L. Burton (Eds.), 1991, New York, NY: McGraw-Hill.

Wastewater Reuse and Reclamation

During the last century, the increasing demands for freshwater coupled with environmental concerns about the discharge of wastewater into ecosystems and the high cost and technology requirements of wastewater treatment have spurred processes in water reclamation and reuse. Early development stems from the land application for the disposal of wastewater, following the admonition of Sir Edwin Chadwick—“the rain to the river and the sewage to the soil” (National Research Council of the National Academies, 1996, p. 17). Such land disposal schemes were widely adopted by large cities in Europe and the United States in the 1900s.

With the development of sewerage systems, domestic wastewater was firstly considered to be reused by farms. California was the pioneer in wastewater reuse and has the most comprehensive regulations pertaining to the public health aspects of reuse. By 1910, 35 California communities were using sewer water for irrigation (Recycled Water Task Force, 2003). In 1918, the California State Board of Public Health promulgated the initial *Regulation Governing Use of Sewage for Irrigation Purpose,* pertaining to irrigation of crops with sewage effluents. In 1929, the city of Pomona, California, initiated a project using reclaimed wastewater for the domestic irrigation of lawns and gardens (Ongerth & Harmon, 1959). In 1965, the Santee, California recreational lakes, supplied with reused wastewater, were opened for swimming.

Today, as more advanced technologies are applied for water reclamation, the quality of reclaimed water can exceed conventional drinking water quality based on most conventional parameters. Water reclamation or water purification processes could technically provide water of almost any quality desired (Asano, 1998).

Conventional Wastewater Treatment

Conventional Wastewater Treatment Process

The conventional wastewater treatment process consists of a series of physical, chemical and biological processes. Typically, treatment involves three stages, called primary, secondary and tertiary treatment.

Primary treatment is used to separate and remove the inorganic materials and suspended solids that would clog or damage the pipes. Primary treatment consists of screening, grit removal, and primary sedimentation. Screening and grit removal may also be called “preliminary treatment.” Large debris, such as plastics, rags, branches, and cans are removed by the screens, while smaller coarse solids, such as sand and gravel, are settled by a grit chamber system. Then wastewater is moved into a quiescent basin, with a temporarily retention; the heavy solids settle to the bottom while the lighter solids, grease and oil float to the surface. The settled and floating pollutants are removed by sedimentation and skimming, with the remaining liquid then discharged to undergo secondary treatment. Typically, about 50% of total suspended solids (TSS) and 30% to 40% of BOD are removed in the primary treatment stage (Nelson, Bishay, Van Roodselaar, Ikonomou, & Law, 2007).

Secondary treatment removes dissolved and suspended biological matter. Typically, up to 90% of the organic matter in the wastewater can be removed through secondary treatment by a biological treatment process (U.S. EPA, 2004b). The two most common conventional methods used to achieve secondary treatment are attached growth processes and suspended growth processes. In attached growth (or fixed-film) processes, the bacteria, algae and microorganisms grow on a surface and form a biomass. Attached growth process units include trickling filters, biotowers, and rotating biological contactors. In suspended growth processes, the microbial growth is suspended in an aerated water mixture. The most common of this type of process is called “activated sludge.” This process grows a biomass of aerobic bacteria and other microorganisms that will breakdown the organic waste.

Tertiary treatment is sometimes defined as advanced treatment; it produces a higher-quality effluent than do primary and secondary treatment in order to allow discharge into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs, and others). The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality to the desired level. This advanced treatment can be accomplished by a variety of methods such as coagulation sedimentation, filtration, reverse osmosis, and extending secondary biological treatment to further stabilize oxygen-demanding substances or remove nutrients. As wastewater is purified to higher and higher degrees through such advanced treatment processes, the treated effluent can then be safely and appropriately reused.

Before the treated wastewater is discharged, a ***disinfection*** process is sometimes required. Water systems add disinfectants to kill pathogenic microorganisms. The purpose of disinfection in the treatment of wastewater is to substantially reduce the number of microorganisms in the water to be discharged back into the environment, and it is almost always the final step in the treatment process regardless of the level or type of treatment used. Common methods of disinfection include chlorine, and ultraviolet light. The treated water can be discharged into a stream, river, lagoon, or wetlands, or it can be used for landscape irrigation. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.

Advantages and Disadvantages of Conventional Treatment

Advantages. Conventional sewage treatment system requires relatively less land area and allows better control of the wastewater treatment process. For example, CWs that discharge to surface water require 4 to 10 times more land area than does a conventional wastewater treatment facility (U.S. EPA, 1988). The treatment facilities are usually operated under a well-controlled environment. Thus, the efficiency is less sensitive to the environment. This technique could produce a more consistent quality of effluent.

Disadvantages. The main disadvantage of conventional wastewater treatments is their high cost of construction and maintenance. Typically, construction costs range from one tenth to one-half of those for conventional treatment systems. For example, total capital costs of the Benton, Kentucky CW system were $260,000 (1986 dollars) compared to a 1972 estimate of $2.5 million for a comparable conventional treatment system involving chemical additives (Hammer, 1992).

Also, the operation and monitor of mechanical systems requires specialized personnel. Generally, the complexity and cost of wastewater treatment technologies increase with the quality of the effluent produced (Organization of American States, 1997).

Constructed Wetlands

History of CWs

The scientific studies on the use of CWs for wastewater treatment began in the middle of the last century. The first experiments were undertaken by Käthe Seidel in Germany in the early 1950s at the Max Planck Institute in Plön (Seidel, 1955). In her report, she discussed the possibility "of lessening the overfertilization, pollution and silting up of inland waters through appropriate plants, thereby allowing the contaminated waters to support life once more" (Seidel, Happel, & Graue, 1978, p. 2). She opines that macrophytes (e.g., *Schoenoplectus lacustris*) are capable of removing large quantities of organic and inorganic substances from polluted water. Moreover, *Schoenoplectus* spp. (bulrush) not only enriches the soil on which it grows in bacteria and humus but apparently exudes antibiotics. Bacteria and heavy metals in the polluted water are eliminated and removed by passing through the macrophytes.

Seidel's discoveries gave birth to modern CWs and stimulated the following research and applications of engineered treatment wetlands in the Western world. However, most of her studies focused on the subsurface flow (SSF) CW. The first full-scale CW was built with a FWS system in the Netherlands in 1967 (De Jong, 1976). This treatment facility was designed to clean the wastewater from a camping site with 6000 summer visitors per day.

In North American, the experimentation with FWS wetlands started with the observation of assimilative capacity in natural wetlands at the end of the 1960s and beginning of 1970s (Spangler, Sloey, & Fetter, 1976; Wolverton, 1987). Between 1967 and 1972, researchers in Chapel Hill, North Carolina began a five year study using a combination of constructed coastal ponds and natural salt marshes for the recycling and reuse of municipal wastewater (Odum, Ewel, Mitsch, & Ordway, 1977). In 1973, the first fully CW consisting of a series of constructed marshes, ponds and meadows was built in Brookhaven, New York (Kadlec & Knight, 1996). About the same time, an interdisciplinary research team at the University of Michigan began the Houghton Lake project. This is the first application of a treatment wetland in a cold climate area (Kadlec, Richardson, & Kadlec, 1975; Kadlec & Tilton, 1979). Since then, FWS CWs have been broadly used in the United States for various types of wastewater treatment.

FWS CWs

As designated by the Water Pollution Control Federation, Washington, D.C. (WPCF), CWs have two general categories: FWS and SSF. FWS CWs are designed to mimic natural wetlands, with the water flowing above the ground surface at shallow depths through a dense growth of emergent wetland plants (Kadlec & Knight, 1996). SSF on the other hand, create subsurface flow through a permeable medium, treating the wastewater beneath the surface. SSF systems are also known as root-zone systems, rock-reed-filters, and vegetated submerged bed systems. The media used (typically soil, sand, gravel or crushed rock) greatly affects the hydraulics of the system. Both types of CWs typically may be fitted with liners to prevent infiltration (U.S. EPA, 1999). They share some characteristics but are distinguished by the hydraulic grade level, macrophytes types, and direction of flow (Table 3).

Table 3
Types of Constructed Wetlands for Wastewater Treatment

	Constructed Wetlands						
Water Level	FWS				SSF		
Plants	Free-floating	Floating-leaved	Submerged	Emergent	Emergent		
Flow	Horizontal				Horizontal	Vertical	
Direction						Down flow	Up flow

Adapted from *Constructed wetlands for wastewater treatment: A review* (p. 965), by J. Vymazal, M. Sengupta, and R. Dalwani (Eds.), 2007, proceedings of the 12th World Lake Conference, India.

For the purpose of this study, only FWS CWs with emergent macrophytes and with impermeable liners (Figure 2) are considered. FWS CWs typically consist of a sequence of shallow basins and a water control structure that maintains water depth. The water depth in the FWS commonly ranges from 1 to 1.3 feet. When rooted macrophytes are used, 0.7 to 1.3 feet of soil is needed to support the roots of vegetation if the beds are sealed. FWS CWs can use emergent, submergent, free-floating, and floating-leaved macrophytes (Crites & Tchobanoglous, 1998; Vymazal, 2001).

FWS CWs function as land-intensive treatment systems. Inflow water containing particulate and dissolved pollutants slows and spreads through a large area of shallow water with emergent or submerged vegetation. Settable organics are rapidly removed through quiescent conditions, deposition, and filtration. Attached and suspended microbial growth is responsible for the removal of soluble organics. FWS CWs are very effective in removing suspended solids via filtration and sedimentation (Kadlec & Knight, 1996). Nitrogen is most effectively removed in FWS CWs by nitrification/denitrification. Ammonium is oxidized by nitrifying bacteria in aerobic zones, and nitrate is converted to free nitrogen or nitrous oxide in the anoxic zones by denitrifying bacteria.

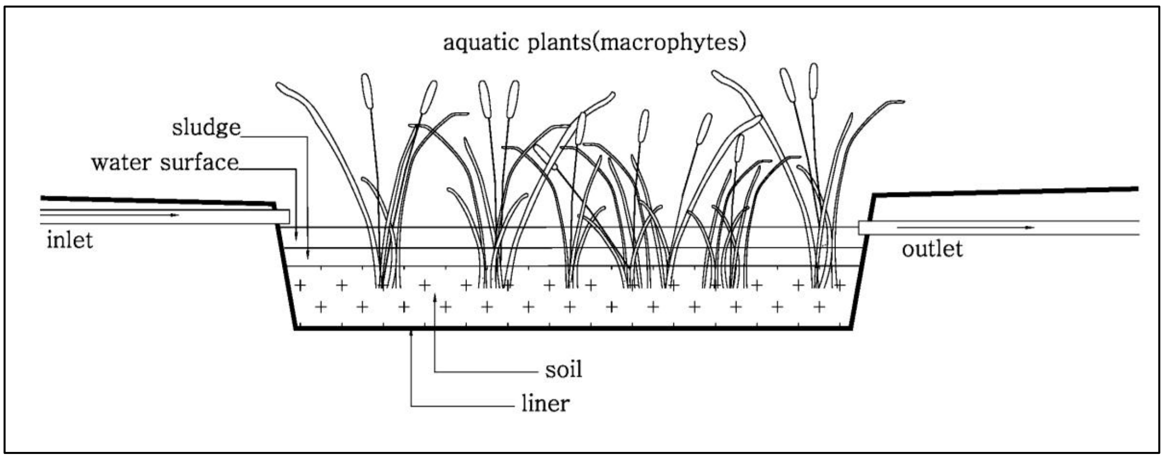

Figure 2. A graphic of a free water surface constructed wetland.

In North America FWS is the dominant type of wetlands used for wastewater treatment. Compared with the SSF wetlands, FWS CWs have both advantages and disadvantages (Table 4). Generally, FWS CWs have more landscape and greater esthetic values but require greater land area and moderate temperatures.

Table 4
Advantages and Disadvantages of Free Water Surface (FWS) Constructed Wetlands and Subsurface Flow (SSF) Wetlands

	FWS	SSF
Advantages	Lower installation and operating costs	Greater assimilation rate, less land required
	Good integration into the landscape	No visible surface flow
	More secondary benefits (such as wildlife habitat), but contamination exposure concern	More cold tolerant
	Shorter development period to reach full performance	Reduction in odor and insect problems
Disadvantages	Less cold tolerant More land required	Not attractive to wildlife, more isolated from humans

Wetland Hydrology

"Hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetland process (Mitsch & Gosselink, 2007, p. 108)." Wetland design is affected by the volume of water, its reliability and extremes, and its movement through the site (U.S. EPA, 1999). Wetland hydrology describes the input and output of water in wetland systems. It affects the composition of vegetation and species communities by acting as the main pathway via which energy and nutrients are transported.

Water enters wetlands via surface flow, precipitation, and groundwater discharge, while it flows out via surface flow, ground water recharge, and evapotranspiration (ET) (Note: Tide is not considered in this study) (Figure 3).

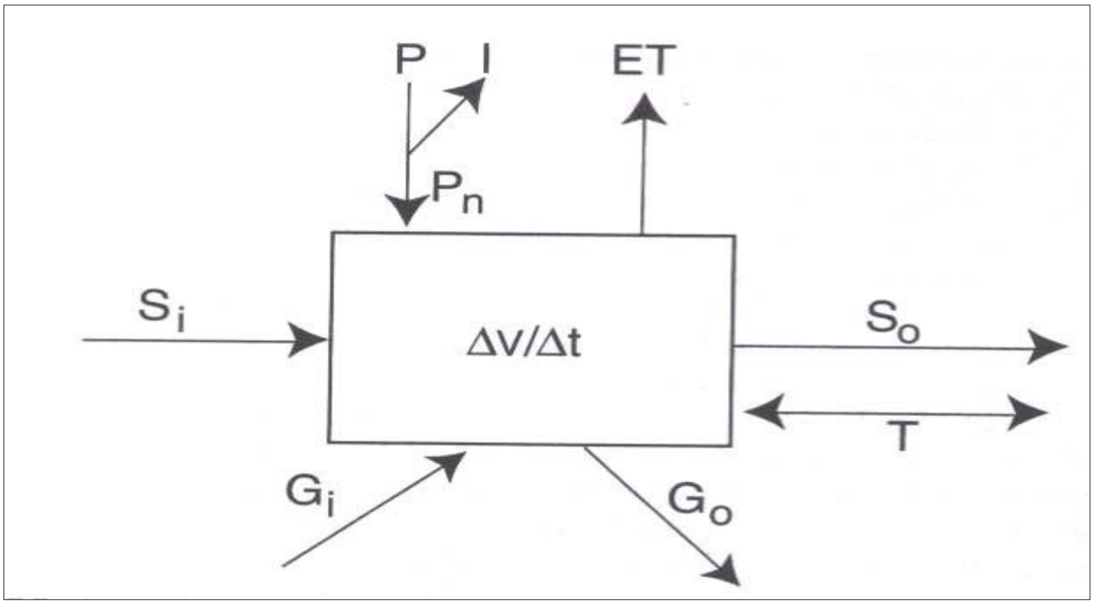

Figure 3. Wetland hydrology. From *Wetland*, 4th ed. (p. 119), by J. W. Mitsch and G. J. Gosselink, 2007, New York, NY: John Wiley & Sons.
Abbreviations: P, precipitation; I, interception; P_n, net precipitation; ET, evapotranspiration; S_i, surface inflow; S_o, surface outflow; G_i, groundwater inflow; G_o, groundwater outflow; T, tide; $\Delta V/\Delta t$, change in storage per unit time.

The wetland water budget is the total of inflows and outflows of water through a wetland. The overall water balance in a wetland is affected by climate and weather, hydro period, hydraulic residence time, hydraulic loading rate, groundwater exchange, and ET (U.S. EPA, 1999). The calculation of the wetland water balance for a FWS CW is shown in Equation 1 (Kadlec & Knight, 1996):

$$\frac{dV_w}{dt} = Q_i + Q_c + Q_{sm} - Q_o - Q_b - Q_{gw} + (P - ET)A_w \quad (1)$$

where V_w is the water volume or storage in the wetland (m^3); t is the time (day); Q_i is the wastewater inflow rate (m^3/d); Q_c is the catchment runoff rate (m^3/d); Q_{sm} is the snow melt rate (m^3/d); Q_o is the outflow rate (m^3/d); Q_b is the berm loss rate (m^3/d); Q_{gw} is infiltration to groundwater (m^3/d); P is the precipitation rate (m/d); ET is the evapotranspiration rate (m/d); and A_w is the wetland water surface area (m^2).

In constructed wetlands design, groundwater recharge or discharge (Q_{gw}) and bank loss (Q_b) can be avoided by a liner or geo-textiles. Additionally, if catchment runoff (Q_c) and snowmelt (Q_{sm}) are neglected, the water balance in Equation 1 can be simplified to Equation 2:

$$\frac{dV_w}{dt} = Q_i - Q_o + (P - ET)A_w \qquad (2)$$

In nature, wetland storage is largely variable. Factors such as wetland landscape features, conveyance capacity, and the inflow and outflow all affect the wetland water table level. Most wetlands experience a dry season and a wet season. The “dry-out” period has strong implications for the vegetative structure and ecosystem function. CWs, on the other hand, have a relatively controlled system by adjusting some form of outlet water level. Dry-out will rarely occur in CWs. Vegetation that endures continuous flooding can survive.

The wetland hydrology is critical in wastewater treatment processes because it determines the duration of water-biota interactions, and the transport of waterborne substances to the sites of biological and physical activity (Kadlec & Wallace, 2009). The longer water remains in the wetland the greater is the chance of sedimentation, adsorption, biotic processing and retention of nutrients (William, 1995). Wetland systems installed in cold climates require larger and deeper structures with a longer detention time for better pollutant removal. Wetlands should be sized in cold climates for a minimum detention time of 10 to 13 days to ensure high quality effluent (Gustafson, Anderson, Christopherson, & Alex, 2002).

Pollutant removal

Raw sewage consists of a combination of domestic and commercial wastewaters. The pollutant parameters commonly present are BOD, TSS, organic compounds, pathogens, nutrients (especially nitrogen) and heavy metals. CWs are very efficient in reducing the level of these pollutants in municipal wastewater effluents. In FWS wetlands, the removal mechanisms include flocculation, sedimentation, absorption, oxidation and anaerobic reaction. Figure 4 illustrates the most important of these processes as they occur in a FWS system. In a properly operating CW system, the concentration of in the effluent should be less than 30mg/L, TSS are less than 25 mg/L, and fecal coliform bacteria concentration is less than 10,000 colony-forming units (cfu)/100 mL (David, James, Christopherson, & Axler, 2002).

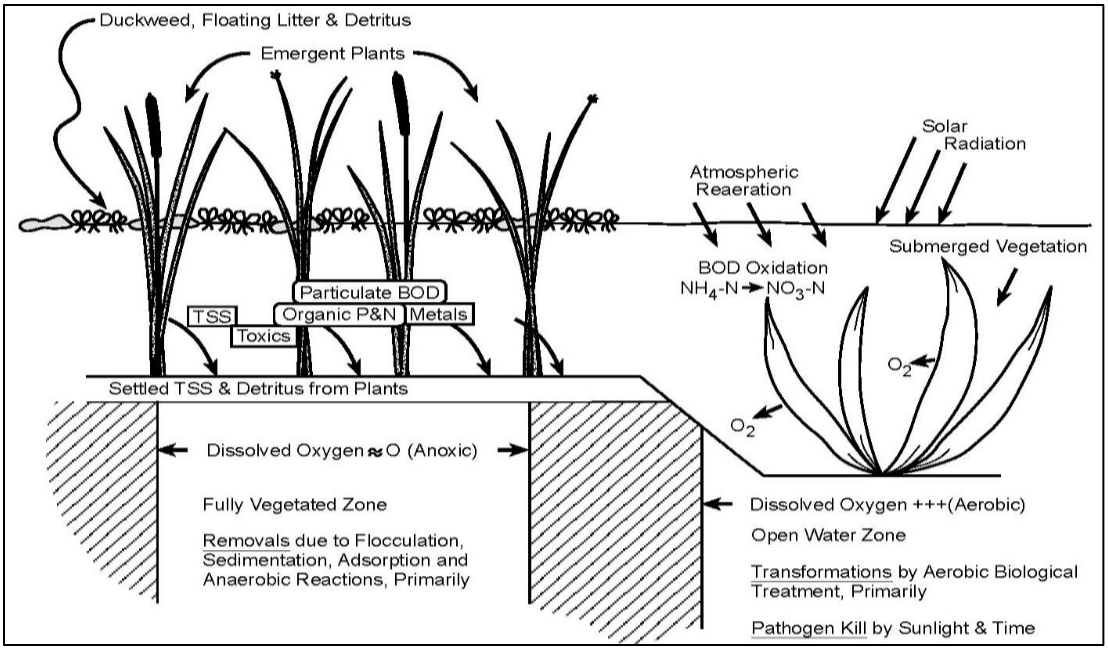

Figure 4. Mechanisms that dominate free water surface wetland systems. From *U.S. EPA manual: Constructed wetlands treatment of municipal wastewaters* (p. 44), 1999, Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development.

Biochemical Oxygen Demand (BOD_5) Removal. BOD_5 is a measure of the mass of oxygen required by aerobic organisms to decompose organic matter in the water. The standard BOD value is commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 ℃. In FWS wetlands, removal of the soluble BOD_5 is due to microbial growth attached to plant roots, stems, and leaf litter that have fallen into the water. Because algae are not present with the complete plant coverage, water surface reaeration provides the major sources of oxygen for these reactions in addition to plant translocation of oxygen from the leaves to the rhizosphere (U.S. EPA, 1980).

BOD_5 removal often approximates first-order kinetics. Based on the First Order–Reaction Kinetics–Plug Flow Approach, Reed ́s method is used to estimate BOD removal efficiency. This method is a research-based design method based on the first-order plug flow assumption for those pollutants that are removed primarily via biological processes (i.e., BOD, ammonia, and nitrate) (Knight, Ruble, Kadlec, & Reed, 1993).

BOD removal is calculated by Equation 3 (Reed, Ronald, & Middlebrooks, 1995):

$$\frac{C_e}{C_o} = e^{-K_T \times t} \tag{3a}$$

$$K_T = K_{20}\,(1.06)^{(T-20)}, K_{20} = 0.678\ d^{-1} \tag{3b}$$

where C_e is the effluent BOD (mg/L); C_o is the influent BOD (mg/L); K_T is the temperature dependent first-order areal rate constant (day^{-1}); and t is the detention time (day).

TSS Removal. The “total solid” refers to the suspended or dissolved matter. TSS are solids that can be retained by a filter. The removal of TSS from water to the wetland sediment bed is essential for both the improvement of water quality and the function of the wetland ecosystem. TSS are predominantly removed via flocculation/sedimentation and filtration/interception mechanisms (U.S. EPA, 1999). Suspended solids can also be produced within the wetland. This occurs due to the death of invertebrates, fragmentation of detritus from plants, production of plankton and microbes within the water column or attached to plant surfaces, and formation of chemical precipitates.

TSS removal processes are related to filtration and retention times. The slow flowing water allows the physical separation of TSS. The removal equation (Reed, Ronald, & Middlebrooks, 1995) below is used in FWS wetlands:

$$C_e = C_o[0.1139 + 0.00213(HLR)] \quad (4a)$$

$$HLR = \frac{Q}{A} \quad (4b)$$

where C_e is the effluent TSS (mg/L); C_o is the influent TSS (mg/L); *HLR* is the hydraulic loading rate (cm/L); *Q* is average flow rate through the system (m^3/d); and A_s is surface area of the systems (m^2).

Nitrogen Removal. Nitrogen is a serious concern in wastewater because of its role in eutrophication and toxicity to aquatic. Numerous biological and physiochemical processes in wetlands are particularly important in the transformations of nitrogen into varying biologically useful forms. Additionally, plants that require nitrogen for their growth play an active role in removing it from the wastewater.

Nitrogen removal occurs through nitrification, denitrification, ammonification, volatilization and plant uptake (Figure 5). The removal rate in a wetland is 61% through denitrification and 14% through plant biomass, and the remainder is stored in the soil (Matheson, Nguyen, Cooper, Burt, & Bull, 2002). Hence, the nitrification and denitrification processes occurring within the wetland are the major mechanisms for nitrogen removal (Vymazal, Brix, Cooper, Green, & Haberl, 1998). Vegetated zones are anaerobic, because oxygen released by hydrophytic plants is trivial compared to the oxygen demands. Therefore, nitrification unlikely to happen in VSB wetlands and highly dense vegetated zones of FWS wetlands, but can be accomplished in open-water zones. To increase the efficiency of nitrification and denitrification, a well aerated condition must be followed by the vegetated zones.

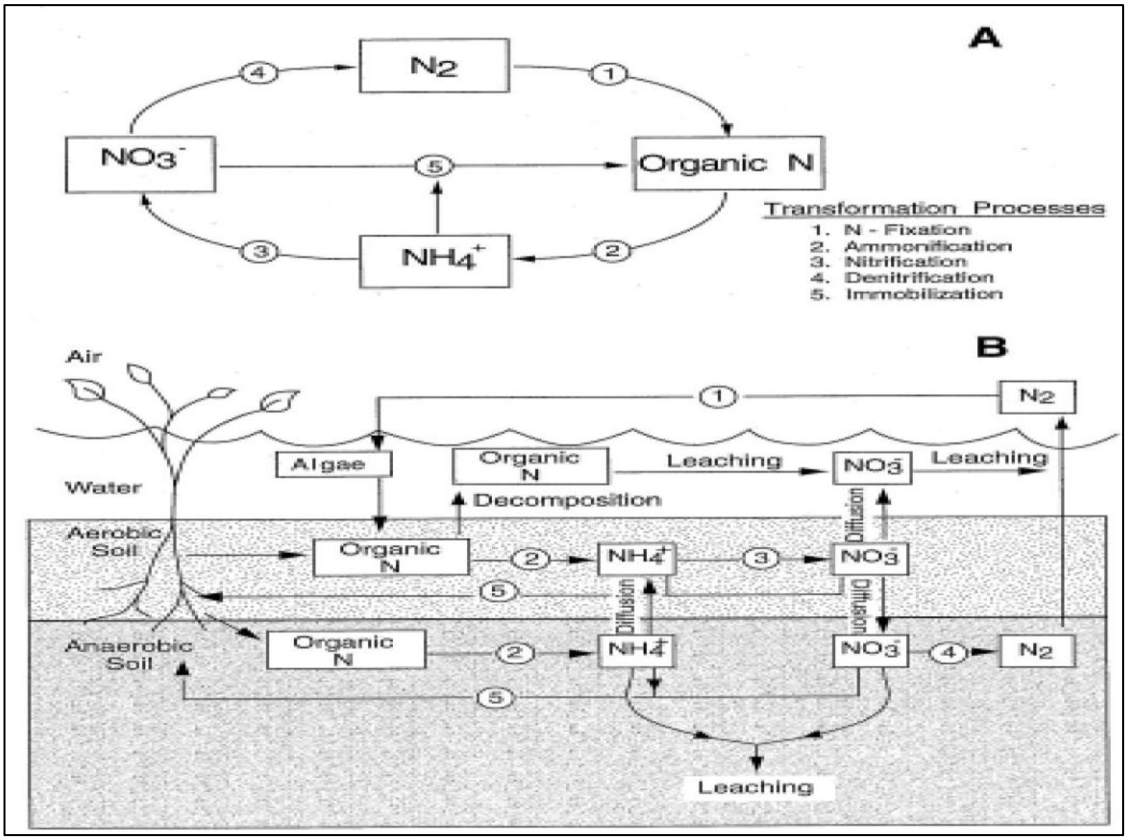

Figure 5. Nitrogen cycle in wetlands. From *Ecology of freshwater and estuarine wetland* (p. 139–140), by D. P. Batzer and R. R. Sharitz, 2006, Berkeley, CA: University of California Press.
Note. (A) shows the major transformations. (B) shows the specific nitrogen transformation processes occur in each portion of wetlands.

Like BOD removal, nitrogen removal through nitrification and denitrification is sensitive to temperature and is greatly retarded in cold temperature. The first-order decay model (Equation 5) for all pollutants is assumed (U.S. EPA, 1988). This model (Kadlec & Knight, 1996), known as the k-C* Model, is based on areal rate constants:

$$\ln \frac{(C_e - C^*)}{(C_i - C^*)} = -\frac{K_{A,T}}{q} \tag{5a}$$

$$K_{A,T} = K_{A,20}\theta^{(T-20)} \tag{5b}$$

where C_e is the amount of Nitrogen at the wetland outlet (mg/L); C_i is the amount of Nitrogen at the wetland inlet (mg/L); C^* is the background Nitrogen (mg/L); $K_{A,T}$ is the first-order areal rate constant at wetland temperature t ℃; K_{20} is the first-order areal rate constant at 20℃; q is the hydraulic loading rate (m/yr); θ is the temperature correction factor; and T is wetland water temperature (℃).

Total Phosphorus Removal. Phosphorus is one of the important nutrients that cause eutrophication in the lakes. Plants uptake phosphorus during the growing season, but the phosphorus is released back into the water during decomposition when plants die. Phosphorus can also be released in varying proportions at different times throughout the year and is cycled throughout the wetland. The predominant form is orthophosphate which can be used by algae and macrophytes. Inorganic phosphorus can also be found as polyphosphates. Municipal wastewaters may contain from 5 to 20 mg/L of total phosphorous, of which 1 to 5 mg/L is organic and the rest is inorganic. The per capita phosphorous contribution per inhabitant per day averages about 0.0048 lb/person/day (Kentucky Department of Environmental Protection, 2012).

The removal of phosphorus in wetlands is achieved through physical, chemical, and biological processes (Debusk, 1999). The physical process includes sedimentation and entrapment within the emergent macrophyte stems and attachment to plant biofilms.

Chemical methods are soil absorption and desorption. This involves soluble inorganic phosphorus moving from the pores in the soil media to the soil surface. The biological mechanism involves uptake of phosphates by microorganisms, including bacteria, fungi, and algae. The biological process is rapid but does not allow for much storage. In FWS wetlands the uptake from free floating macrophytes is more important but these plants must be harvested and replaced to maximize phosphorus removal. Typical phosphorus removal is in the 40% to 60% range (Vymazal, 2006).

CHAPTER III

DESIGN OF CONSTRUCTED WETLAND

Introduction

In semi-arid regions, an evaporation pond is a conventional means of disposing of wastewater without contaminating ground or surface waters. The wastewater disposal system is successful when the evaporation (loss) rate exceeds the precipitation (gain) rate. However, the loss of water via evaporation causes waste and places stress on water resources, especially considering the rapid growth of water demands. Moreover, the future development associated with an increasing water supply will release greater volumes of wastewater. In other words, there will be more evaporation ponds needed and more water loss in the future. Also, sanitation is a concern to the city whose wastewater treatment system is ineffective or incomplete. The leakage of pollutants can have significantly negative impacts on the surrounding environment and public health.

Mount Pleasant’s current sewage lagoon system consists of two such evaporation ponds. This system loses a significant amount of water every day via evaporation. If this amount of water could be reused, that would provide an alternative water resource, which is valuable and important to the city in light of the water shortage problem. The design of a treatment system that could render the wastewater to an acceptable discharge level at which the effluent could eventually be reused to supplement irrigation demands is a great challenge for the city. A FWS CW system is hypothesized to be a cost-effective and feasible option for Mount Pleasant’s wastewater treatment. The general concept of the proposed treatment system is that the FWS CWs could integrate well with the existing waste stabilization ponds, and the combined system could provide better municipal wastewater treatment.

A CW is a low energy-consuming ecosystem that uses natural biogeochemical cycles to remove sediments and pollutants from water. Unlike current complex high-maintenance treatment systems, it is hoped that the use of CWs will lead to more ecologically-sustainable wastewater treatment in the future. It provides advanced treatment to wastewater that has been pretreated to secondary levels. The pollutant removal efficiency is related to several factors: temperature, the size and number of wetlands, the volume and quality of influent water, and the retention time.

In this chapter, climate, site conditions, design methods, and assessment criteria for developing a proposed wetland are discussed in detail. Two regulatory sources, Utah Administrative Code R317-3 and U.S. EPA guidelines, are used and R317-3 provides the primary reference.

Climate

Mount Pleasant is a city in Sanpete Valley, central Utah, at an elevation of 5,924 feet (1,805 m). Climate in this region is characterized by large seasonal and daily temperature variations. The location typically experiences hot dry summers and cold winters. Table 5 shows Mount Pleasant's monthly normal climate data from the Moroni weather station. Temperatures reach a normal maximum of 88.2 ℉ (31.2℃) in July and a normal minimum of 12.7 ℉ (–10.7℃) in January. The normal mean temperature ranges from 69.7 ℉ (20.9℃) to 22.5 ℉ (–4.1℃).

Most of the precipitation in the San Pitch River drainage basin falls as snow in the mountains, from November to April (Robinson, 1971). The driest months in this region are from June through August, although occasionally brief thunderstorms produce intense precipitation totals. The normal annual total precipitation in Mount Pleasant is 10.94 inches. Normal annual ET in Moroni is 48.53 inches. Because Mount Pleasant does not have a weather station. Climate data from the closest station (Moroni) were used for this study (Table 5).

Table 5

Mount Pleasant City Normal Climate Conditions, Data from Moroni Station

Station Name: Moroni		Station Number: USC 00425837		Location: 39 °32' N, 111 °35' W		Years: 1981-2010
Date	Normal average temperature (°F)	Normal maximum temperature (°F)	Normal minimum temperature (°F)	Precipitation (inches)	Normal snowfall (inches)	Evapotranspiration (inches)
Jan	24.70	36.60	12.70	0.91	8.50	0.83
Feb	29.60	41.50	17.70	0.92	9.60	1.31
Mar	38.80	52.20	25.30	1.01	4.30	2.57
Apr	45.90	61.20	30.50	0.89	1.10	4.12
May	53.90	70.50	37.40	0.83	0.40	6.02
Jun	62.40	80.80	44.10	0.68	0.00	7.48
Jul	69.70	88.20	51.20	0.65	0.00	8.47
Aug	68.10	86.10	50.20	0.78	0.00	7.32
Sep	59.70	77.70	41.70	0.99	0.00	5.08
Oct	48.30	64.50	32.00	1.18	7.00	3.08
Nov	35.90	49.20	22.60	0.85	6.30	1.41
Dec	25.20	37.00	13.50	1.25	8.60	0.84
Annual	46.85	62.13	31.58	10.94	45.80	48.53

Note. Climate information is from National Climatic Data Center (NCDC).

Water Budget

In this particular study, the input water includes precipitation, snowfall, and influent, and the output includes evaporation, ET, and effluent (Figure 6). From a water balance standpoint, the input and output values should be equal. The volume of effluent water is calculated based on Equation 6:

$$Q_e = Q_i + \left(\frac{P + P_S - E - ET}{12 \times d}\right) A \times 7.48 \tag{6}$$

where Q_e is the outflow (USG/d); Q_i is the inflow (USG/d); P is the normal monthly precipitation (inches/month); P_s is the monthly snowfall converted to precipitation (inches/month); E is the monthly evaporation rate (inches/month); ET is the monthly evapotranspiration (inches/month); d is the number of days in each month; A is the pond area (ft^2); 7.48 gal/ft^3 is the conversion factor to convert volume in cubic feet to liquid volume in gallons; and 12 in/ft is the conversion factor to convert inches to feet. Because precipitation is generally measured in inches of liquid water and not in snowfall amounts, snow is usually converted into inches of water by dividing by 10. For example, 10 inches of snow is equivalent to 1 inch of rain.

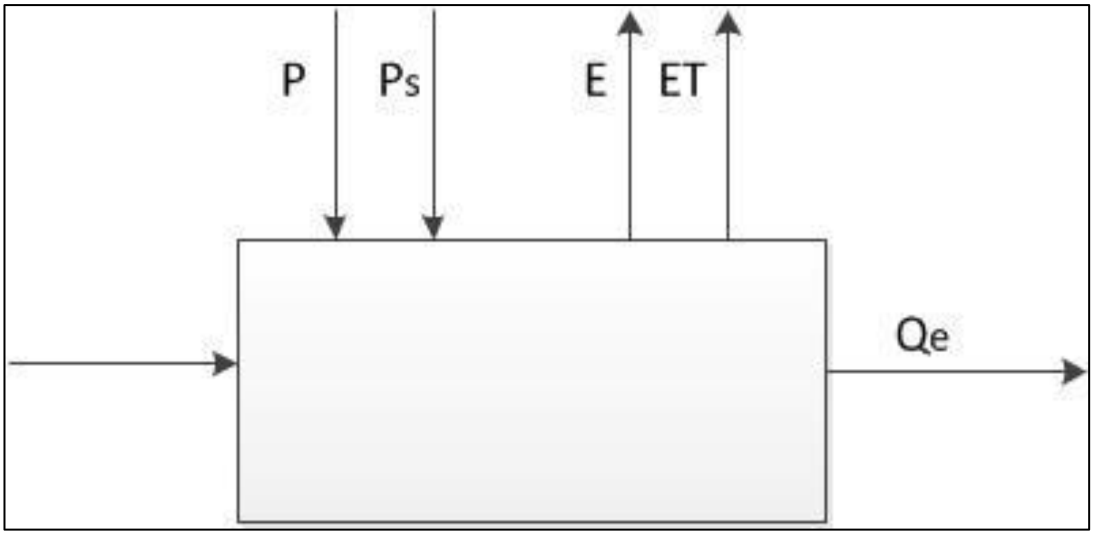

Figure 6. Components of the water budget in this study.
Abbreviations: P, precipitation; $P_{s,}$ Snow fall; E, surface evaporation; ET, evapotranspiration; Q_i , inflow; $Q_{e,}$ outflow.

Evaporation Estimates (E)

The “Class A” pan is the standardized measurement of pan evaporation rate. It is a container that is 4 feet in diameter and 10 inches in height.

The evaporation measured with this pan evaporation method represents open water in an open area, which is different from the evaporation rate in a lagoon or lake. Kohler (1954) calculated that annual lake evaporation could be estimated by applying the annual coefficient 0.7 to Class A pan evaporation.

ET Estimates

Wetland ET is the combination of water evaporation from a water surface and transpiration from wetland plants. The ET rate will greatly affect the hydraulic retention time by removing water and can concentrate the pollutants in the wastewater. Specific ET rates are difficult to be measured accurately in FWS wetlands. In wetland design, a common practice is to assume that fully vegetated FWS wetland ET rates are equivalent to 70% to 80% of Class A pan evaporation rates (Kadlec & Knight, 1996); Reed, Ronald, and Middlebrooks (1995) suggest the equivalent of 80%.

Evapotranspiration/Evaporation (ET/E) Ratio

0.7 is used in this study as the pan evaporation coefficient to calculate the evaporation rate and 0.8 is used as the ET coefficient to calculate the ET rate. Therefore, the ET/E ratio is 1.14.

Net Precipitation (P_n)

The net precipitation is the net amount of received water from the atmosphere. It is calculated by the precipitation subtract evaporation rate. Table 6 shows the net precipitation of the first lagoon.

Table 6

Estimated Evaporation Value and Net Precipitation Value (in Inches)

Station Name: Moroni			Station Number: USC 00425837				Location: 39 °32' N, 111 °35' W			Years: 1981-2010		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation	0.91	0.92	1.01	0.89	0.83	0.68	0.65	0.78	0.99	1.18	0.85	1.25	10.94
Snowfall	8.50	9.60	4.30	1.10	0.40	0.00	0.00	0.00	0.00	7.00	6.30	8.60	45.80
Evapotranspiration	0.83	1.31	2.57	4.12	6.02	7.48	8.47	7.32	5.08	3.08	1.41	0.84	48.53
Pan evaporation [a]	1.04	1.64	3.21	5.15	7.53	9.35	10.59	9.15	6.35	3.85	1.76	1.05	60.66
Evaporation [b]	0.73	1.15	2.25	3.61	5.27	6.55	7.41	6.41	4.45	2.70	1.23	0.74	42.46
Net precipitation [c]	1.03	0.73	–0.81	–2.61	–4.40	–5.87	–6.76	–5.63	–3.46	–0.82	0.25	1.38	–26.94

Note. a. Pan evaporation is calculated by dividing ET by 0.8.
b. Estimated evaporation value is calculated by multiplying pan evaporation with a pan coefficient of 0.7.
c. Net precipitation (precipitation minus evaporation) is the net gain of water from atmosphere. The negatives value means evaporation is higher the precipitation.

Design Concept

The existing two large-surface evaporation cells lose a large amount of water everyday. The proposed project suggests removal of the second pond (Pond II) to reduce the evaporation loss and building a CW system and a storage pond on the current second pond location. The first pond (Pond I) will be kept as the primary treatment pond. The wastewater from the preliminary treatment will flow into the first pond. After the retention time, the effluent will go through several CW cells to receive advanced treatment.

The system is represented as two reactors in series: a facultative lagoon followed by a constructed FWS wetland and one storage pond (Figure 7). The facultative lagoon provides primary treatment and serves as an equalization basin by moderating incoming municipal wastewater flows (Di Toro, 1975) and collecting recycled wetland effluent whenever the wetland is unable to satisfy permit limits. The chief function of the FWS wetland is to meet discharge permit requirements. The effluent water from the CW will be stored in a small-surface pond for irrigation and future use.

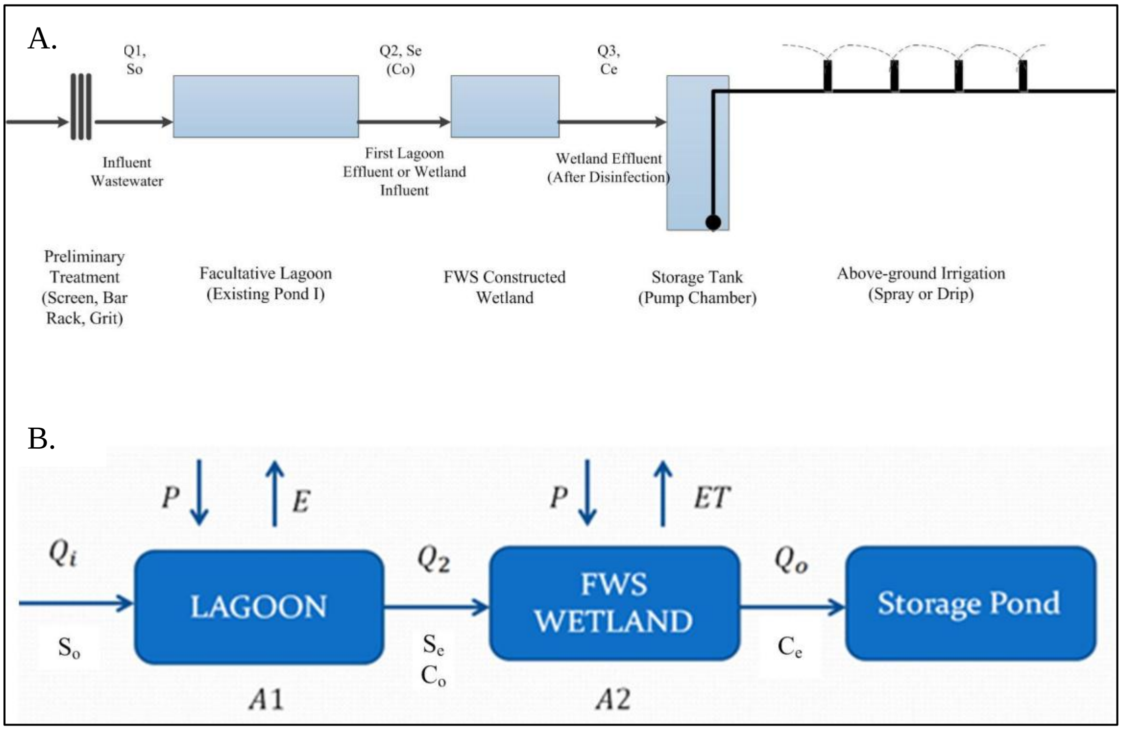

Figure 7. Schematic map of the proposed wastewater treatment system.
Note. (A) The diagram of the proposed wastewater treatment system. (B) The flow chart of the treatment process.

Site Selection

The proposed CW will replace the existing second pond and be built next to the first lagoon pond (Figure 8). From the standpoint of construction cost and feasibility, the proposed site offers the least-extensive option. Some existing infrastructure and materials could be saved or slightly adjusted to achieve future demands. Moreover, maintenance and evaluation are two major components in CW operation. Therefore, accessibility for management and monitoring has to be guaranteed. The site has an existing road system, which would also help reduce the construction cost.

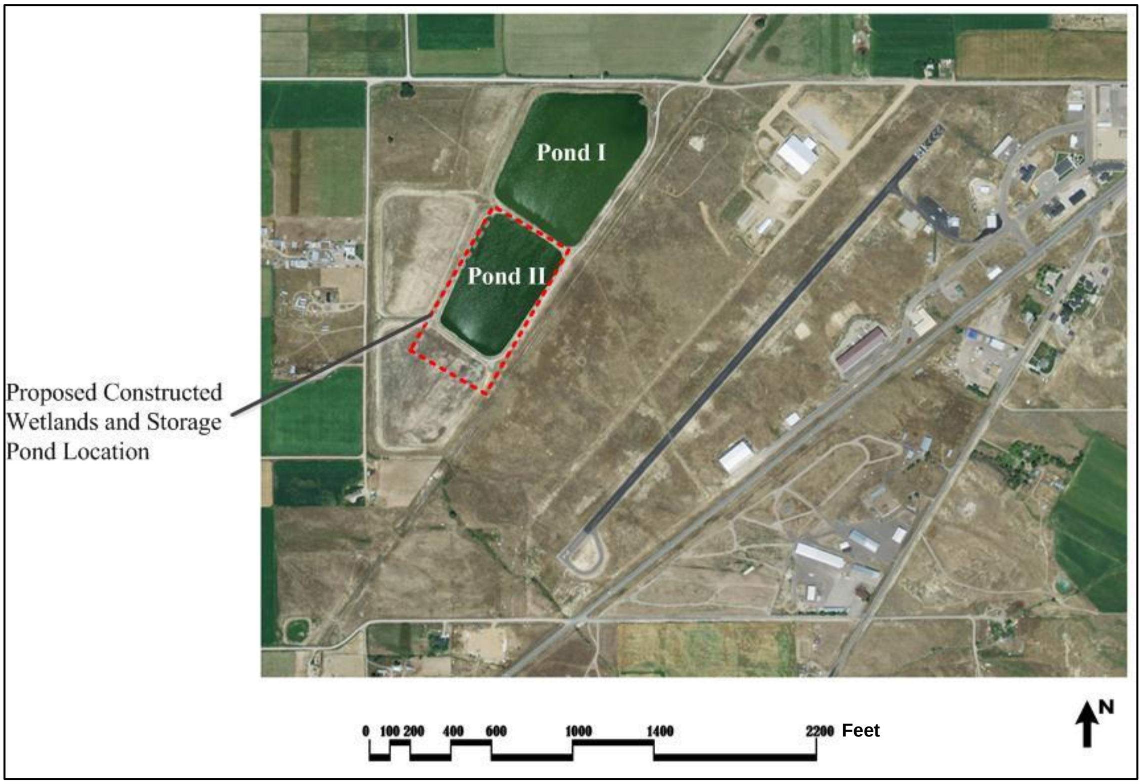

Figure 8. Proposed constructed wetland position, shown in dashed square.

Current Site Condition

The study site is located in the southwest of Mount Pleasant, along Highway #89 (latitude 39° 31′ N, longitude 111° 28′ W). The total area is around 100 acres, and there is a 3.2% west-facing slope. The highest elevation is 5,780 feet, and the lowest is in the northwest corner, at 5,738 feet (Figure 9). The site has a ground water elevation of about 98 feet. Mount Pleasant Airport is located adjacent to the east of the site. The 361-acre airport has been active since 1938, and it serves as a tie-down storage site for transient aircraft. The airport consists of one paved runway (4,260 feet long and 60 feet wide) and 10 air taxi operations. The north, south, and west sides of the study area are surrounded by private farmlands.

The existing sewage lagoon system is located in the study site. The system has been designated by the City as a non-discharge lagoon facility for storage and preliminary treatment of the daily wastewater. The average influent wastewater is about 237,157 USG (relative to the year 2011) per day. The lagoon system consists of two existing evaporation ponds and two future ponds (which have not yet been constructed). The primary cell (Pond II) is designed to maintain a minimum water depth during the summer. The pond is 745 feet by 781 feet (13.36 acres) and can hold 60 acre-feet of backup water. The secondary cell (Pond I) is designed to store all the sewage during the wet weather season. It is 745 feet by 975 feet (16.68 acres), with 88 acre-feet of backup water. Both ponds use synthetic liners.

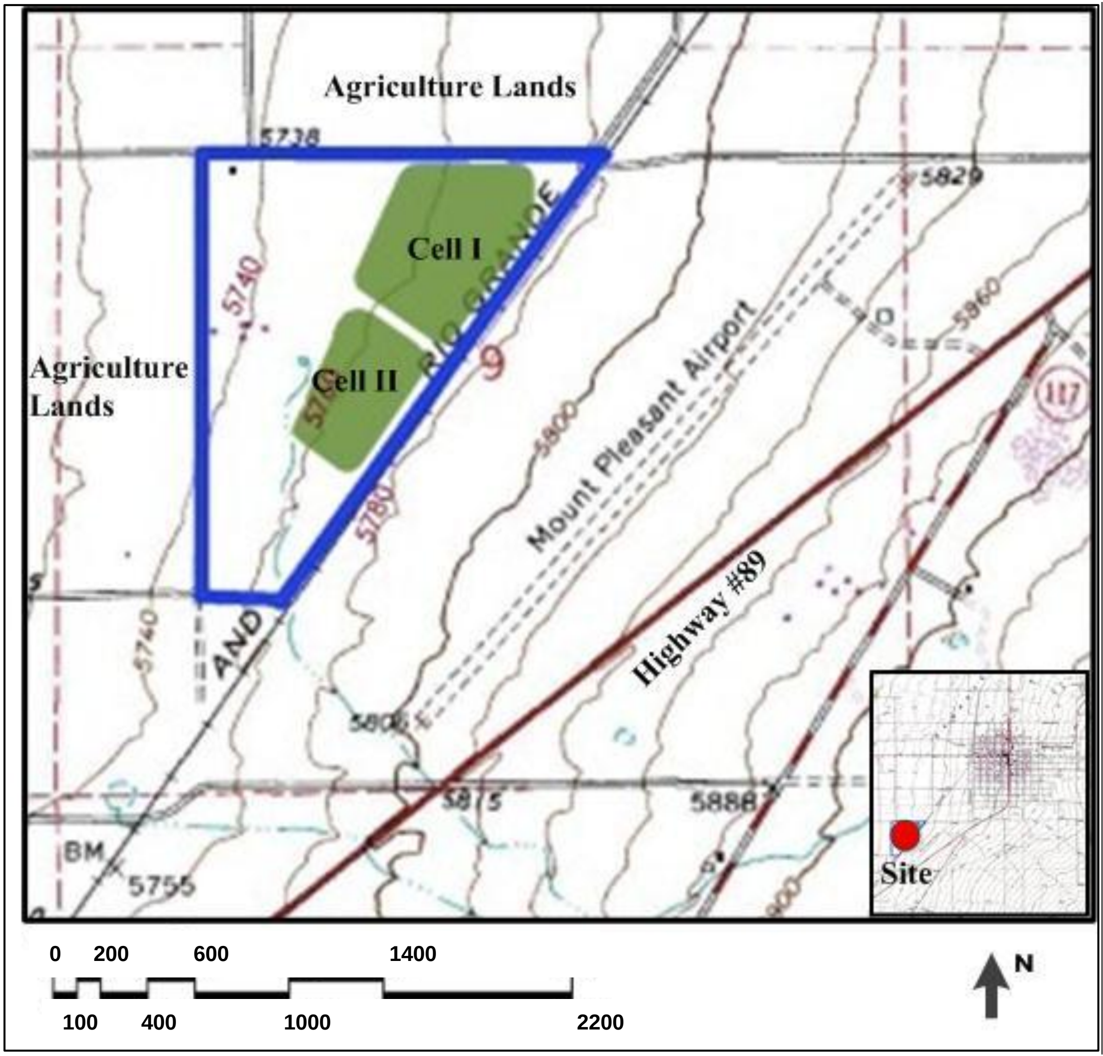

Figure 9. Current programs in the study site.

The First Lagoon Pond

As illustrated in the design concept, the existing first lagoon pond will be reserved to receive, hold, and pre-treat wastewater. The existing evaporation pond would be viewed as a primary facultative pond, which uses natural processes (sunlight and wind) to treat raw wastewater.

Flow Calculation

The estimated monthly effluent volume is calculated by Equation 6 and presented in Table 7 below.

Table 7

Estimated Results of Monthly Effluent Flow

	Average inflow (USG/m)	Net precipitation (inches)	Pond I area (sq.ft)	Water loss (cu.ft/m)	Water loss (USG/m)	Pond I outflow (USG/m)
Jan	7,422,865.91	1.03	726,375.00	62,574.18	468,054.86	7,890,920.77
Feb	6,807,959.76	0.73	726,375.00	44,414.80	332,222.74	7,140,182.50
Mar	7,001,493.12	–0.81	726,375.00	–48,954.65	-366,180.77	6,635,312.35
Apr	6,963,150.77	–2.61	726,375.00	–157,683.91	–1,179,475.62	5,783,675.15
May	7,507,386.59	–4.40	726,375.00	–266,186.17	–1,991,072.57	5,516,314.02
Jun	6,403,984.72	–5.87	726,375.00	–355,015.78	–2,655,518.04	3,748,466.68
Jul	7,033,046.85	–6.76	726,375.00	–409,266.91	–3,061,316.52	3,971,730.33
Aug	7,491,745.01	–5.63	726,375.00	–340,488.28	–2,546,852.34	4,944,892.67
Sep	7,249,553.92	–3.46	726,375.00	–209,135.47	–1,564,333.31	5,685,220.61
Oct	7,648,895.69	–0.82	726,375.00	–49,332.97	–369,010.61	7,279,885.08
Nov	7,511,716.67	0.25	726,375.00	14,905.82	111,495.54	7,623,212.21
Dec	7,513,759.90	1.38	726,375.00	83,230.47	622,563.91	8,136,323.81
Total	86,555,558.91	–26.94	726,375.00	–1,630,938.87	–12,199,422.73	74,356,136.18
Average	7,212,963.24	–2.25	726,375.00	–135,911.57	–1,016,618.56	6,196,344.68

Detention Time

According to Utah Administrative Code R317-3-10, the detention time in the facultative lagoon shall be greater than 120 days in the winter months (December, January and February) and 60 days in the summer months (Jun, July and August). The remaining months are assumed to have a 90-day retention time in this study.

BOD Removal Calculation

The BOD removal is assumed to follow first-order kinetics and the formulation for the continuous reactor assuming complete mixing. Therefore, Equation 7 is used as the kinetic model for BOD removal in the aerated lagoon, shown as follows:

$$S_e = \frac{1}{1+Kt} \cdot S_o \qquad (7)$$

where S_e is the outflow concentration (mg/L); S_o is the inflow concentration (mg/L); K is BOD reaction coefficient at temperature T (day^{-1}); t is detention time time (day).

The variation of K with respect to temperature can be determined through the relationship shown in the Equation 8 (Mara, 1976):

$$K_T = K_{20} \cdot \theta^{T-20} \qquad (8)$$

where K_T is the BOD reaction coefficient at temperature T (day^{-1}); K_{20} is the BOD removal rate at 20 ℃ (day^{-1}); θ is the temperature coefficient 1.05. For normal domestic sewage, the K_{20} value may be assumed to be 0.3 day^{-1} at 20 ℃ for primary facultative lagoon (day^{-1}) (Shilton, 2005).

Tables 8 to 10 show the calculation results from the above equation. This study uses the typical value of BOD concentration in influent wastewater, which is 200 mg/L.

Table 8

BOD Concentration in the First Lagoon Effluent in Summer Months After 60-day Retention Time

	T (°F)	T (°C)	T–20	$\theta^{(T-20)}$	K(t)	S_e (mg/L)
Jun	62.40	16.89	–3.11	0.86	0.26	12.15
Jul	69.70	20.94	0.94	1.05	0.31	10.08
Aug	68.10	20.06	0.06	1.00	0.30	10.50
Sep	59.70	15.39	–4.61	0.80	0.24	13.00

Table 9

BOD Concentration in the First Lagoon Effluent in Winter Months After 120-day Retention Time

	T (°F)	T (°C)	T–20	$\theta^{(T-20)}$	K(t)	S_e (mg/L)
Dec	25.20	–3.78	–23.78	0.31	0.09	16.28
Jan	24.70	–4.06	–24.06	0.31	0.09	16.49
Feb	29.60	–1.33	–21.33	0.35	0.11	14.58

Table 10

BOD Concentration in the First Lagoon Effluent After 90-day Retention Time

	T (°F)	T (°C)	T–20	$\theta^{(T-20)}$	K(t)	S_e (mg/L)
Mar	38.80	3.78	–16.22	0.45	0.14	15.11
Apr	45.90	7.72	–12.28	0.55	0.16	12.63
May	53.90	12.17	–7.83	0.68	0.20	10.30
Sep	59.70	15.39	–4.61	0.80	0.24	8.87
Oct	48.30	9.06	–10.94	0.59	0.18	11.88
Nov	35.90	2.17	–17.83	0.42	0.13	16.25

Constructed Wetland Design

Area

The area of the constructed wetland sell is calculated using Equations 9, as follows:

$$A_w = \left(\frac{0.0365 \times Q}{K_A}\right) \times \ln\left(\frac{C_i - C^*}{C_e - C^*}\right) \quad (9a)$$

where A_w is the required wetland area (ha); Q is the water flow rate (m^3/d); C_i is the inflow concentration (mg/L); C^* is the background concentration (mg/L) (1.0 for BOD and TSS); and C_e is the outflow concentration (mg/L); K_A is the temperature-dependent first-order areal rate constant at temperature of T. K_A can be calculated based on Equation 9(b):

$$K_A = K_{A,20} \cdot \theta^{(T-20)} \quad (9b)$$

where $K_{A,20}$ is the first-order areal rate constant at 20 ℃; $\boldsymbol{\theta}$ is the design parameter. The value of $\boldsymbol{\theta}$ and the relationship between C^* and C_i are shown in Table 11.

Table 11
Kadlec and Knight k-C Model Design Parameters*

Parameter	$K_{A,20}$	θ	C* (mg/L)
BOD	34	1.00	3.5+0.053 C_i
TSS	1000	1.00	5.1+0.16 C_i
Organic-N	17	1.05	1.5
TN	22	1.05	1.5
TP	12	1.00	0.02
Fecal coli.	75	1.00	300 cfu/100mL

Adapted from *Treatment wetlands* (p. 217), by R. H. Kadlec and R. L. Knight, 1996, Boca Raton, FL: CRC Press.

The calculation results (Table 12) show that based on the average inflow water information the proposed CW size is about 1.65 acres. However, if 1.65-acre wetland is applied the quality of effluent from November to March could not meet the irrigation standard.

Table 12

Estimated Constructed Wetland Overall Areas Based on Kadlec and Knight Model

	T (°F)	T (°C)	C* (mg/L)	C_o (mg/L)	K_T (m/yr)	Average daily inflow (m^3/d)	A (ha)	A (ac)
Jan	24.70	–4.06	4.37	16.49	8.37	963.56	3.22	7.96
Feb	29.60	–1.33	4.27	14.58	9.81	965.30	2.11	5.22
Mar	38.80	3.78	4.30	15.11	13.21	810.24	1.43	3.54
Apr	45.90	7.72	4.17	12.63	16.63	729.79	0.60	1.47
May	53.90	12.17	4.05	10.30	21.54	673.60	0.06	0.14
Jun	62.40	16.89	4.14	12.15	28.36	472.98	0.19	0.47
Jul	69.70	20.94	4.03	10.08	35.92	484.99	0.01	0.02
Aug	68.10	20.06	4.06	10.50	34.11	603.82	0.05	0.13
Sep	59.70	15.39	4.00	8.87	25.99	717.36	–0.21	–0.52
Oct	48.30	9.06	4.13	11.88	17.97	888.95	0.50	1.24
Nov	35.90	2.17	4.37	16.25	12.03	961.90	2.18	5.38
Dec	25.20	–3.78	4.36	16.28	8.51	993.53	3.19	7.88
Average	46.85	8.25	4.19	12.93	17.14	772.17	0.67	1.65

Note. The area of the constructed wetland is calculated by Equation 9.

Considering the reuse target, this study suggests a minimum size of 3.7 acres is required for current condition. In that case, from March to early November the quality of the discharged water could meet the level for irrigation usage. The discharge water from late November to February will be stored, and could not be used in irrigation. After more higher-quality water is mixed into the storage pond, the mixture then could be reused again.

Aspect Ratio (L:W)

The configuration of wetland cell is important in basin design because of its impact on flow resistance and hydraulic circuiting. There is much information in the literature on the effects of aspect ratio (length-to-width, L:W) on the performance of ponds and wetlands for pollutant removal. Kadlec and Knight (1996) suggest the aspect ratio L: W should be greater than 2:1 to ensure plug flow conditions. Mitsch and Gosselink (2007) recommend the minimum aspect ratio of 2:1 to 3:1 for surface-flow wastewater wetland. Crites, Middlebrooks, and Reed (2006) recommend 2:1 < L:W < 4:1. The U.S. EPA manual (1999) states that, in general, FWS wetlands are built with L:W ≤ 4:1 to avoid hydraulic problems.

Theoretically, long and narrow flow paths are closer to plug flow than are short and wide flow paths. However, the longer the flow path, the greater will be the resistance. A very high aspect ratio will increase the effective detention time and thus may lead to overflow problems due to gradual accumulation of vegetation litter (Kadlec & Wallace, 2009). Commonly used aspect ratios are between 2:1 and 5:1. Persson, Somes, and Wong (1999) present a relationship between hydraulic efficiency index and the aspect ratio. Their study shows that the aspect ratio should be greater than 1.88 but less than 5 so that the efficiency performance will be "satisfactory" (Figure 10).

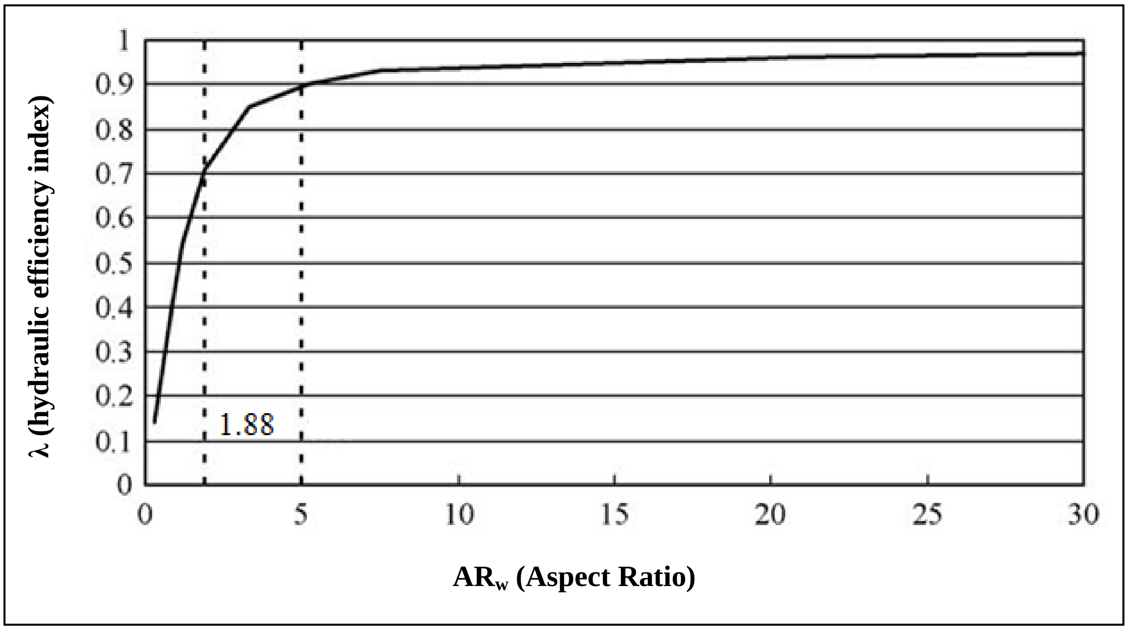

Figure 10. The relationship between the hydraulic efficiency and the aspect ratio (AR_w) of wetlands. From "Optimal design for hydraulic efficiency performance of free-water-surface constructed wetlands," by T. Su, S. Yang, S. Shi, and H. Lee, 2009, *Ecological Engineering*, *35*(8), p. 1204.
Note. The hydraulic efficiency increases with the aspect ratio increases. However, the hydraulic efficiency of the wetlands significantly improves when the aspect ratio is less than 5.

The aspect ratio for this research was assumed to be around 4:1. Based on the water surface of wetland, the total scale of wetland was designed to be 805 feet in length and 201 feet in width.

Depth

Water depth is an important physical measure for the design, operation, and maintenance of a FWS CW. The actual water depth in a FWS CW will generally not be known with a high degree of accuracy due to basin bottom irregularities (U.S. EPA, 1999). Estimated operating water depths for FWS CWs in the North American Database range from approximately 0.3 to greater than 6.5 feet with typical depths of 0.5 to 2 feet.

The maximum ice depth on a FWS wetland during the coldest winter of record would be about 6.0 inches (Byung, Sherwood, Thomas, & Patrick, 1997). If the established winter water depth is set at above 1.5 feet. of liquid treatment volume would still be available. This study assumes the operating depth is 1.5 feet.

Retention Time

The hydraulic residence time (HRT) in the wetland can be calculated with Equation 10 (Crites, Middlebrooks, & Reed, 2006):

$$t = LWyn/Q \tag{10}$$

where t is the wetland HRT (day); L is the length of wetland cell (m); W is the width of wetland cell (m); y is the depth of water in the wetland cell (1.5 feet in this study); n is the porosity, or the space available for water to flow through the wetland (typically 0.75); and Q is the average flow through the wetland (m^3/d).

Average flow (Q) is the arithmetic average between the inflow and the outflow. A conservative design might assume no seepage and adopt reasonable estimates for ET losses and rainfall gains from local records for each month of concern. This requires a preliminary assumption regarding the surface area of the wetland so the volume of water lost or added can be calculated. It is usually reasonable for a preliminary design estimate to assume that outflow equals inflow. Based on this assumption, the results show that the retention time in the designed wetland is 6.7 days.

Layout and Configuration

According to the EPA Manual, significant open water area between fully vegetated zones would achieve better effluent quality than would a fully vegetated FWS because of the aerobic transformations and removal opportunities.

The "sequential model," developed by Gearheart and Finney (1999), states that the dominant physical and biological processes occur in a sequential fashion, with one process or mechanism providing the products for the next process or mechanism. The total area required for wastewater treatment is then a sum of each distinctive area or zone responsible for a specific effluent objective. This model recognizes that the FWS CW requires a minimum of three general compartments (Figure 11). In the first zone, flocculation and sedimentation will occur. In the second zone, soluble BOD reduction and nitrification can occur. In the third zone, further reductions in TSS and associated constituents and denitrification will occur (U.S. EPA, 1999).

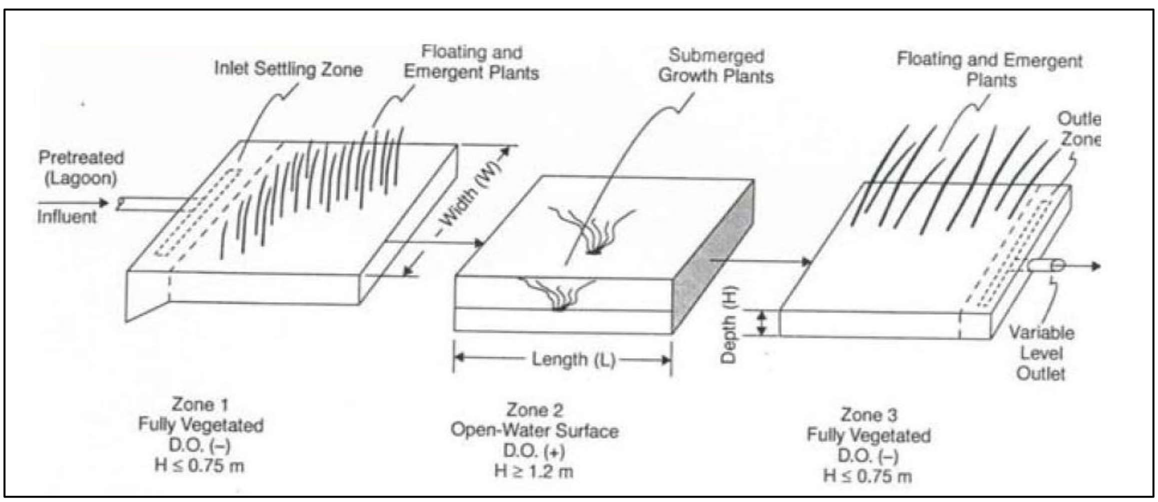

Figure11. Elements of a free water surface constructed wetland. From *U.S. EPA manual: Constructed wetlands treatment of municipal wastewaters* (p. 22), 1999, Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development.

Studies show that algal growth in Zone 2 (open-water) generally starts to occur between days 2 and 3 (United Kingdom Department of Environment, 1973). The algal growth will cause negative effects (like increasing the pH and NH_3–N, and inducing phosphorus precipitation) to the function of wetland and reduce the treatment efficiency (U.S. EPA, 1999). Therefore, the optimum sizing of this zone would be an HRT of 2 days at maximum flow, or an HRT of 3 days at average flow. The general depth in the open-water-zone is 4 feet. Therefore, the size of Zone 2 is 0.5 acres. Both Zone 1 and Zone 3 are 1.6 acres.

Large systems should have at least two trains of cells that can operate in parallel to provide flexibility for management and maintenance. Parallel cells are necessary for replanting, vegetation die-off, harvesting, leak patching or other possible operational control and some unexpected event. Moreover, multiple flow paths allow the loading rate to be manipulated to meet varying inflow water quality (Kadlec & Wallace, 2009). Thus, two parallel systems are recommended for future expansion.

Internal Cell Arrangement

The arrangement of internal components within a single wetland cell is largely implicated with the treatment efficiency. Theoretically, if the bottom of the wetland and the vegetation density can be controlled at tolerances that promote full areal contacting, the treatment can prevent poor flow distribution and maximize the efficiency of pollutant removal. In the design process, some preexisting constructions (i.e., ditches, roads, or berms) should be considered to avoid inadequate flow control in a FWS wetland. Figure

12 illustrates some general recommendations for designing a high-areal efficiency wetland cell.

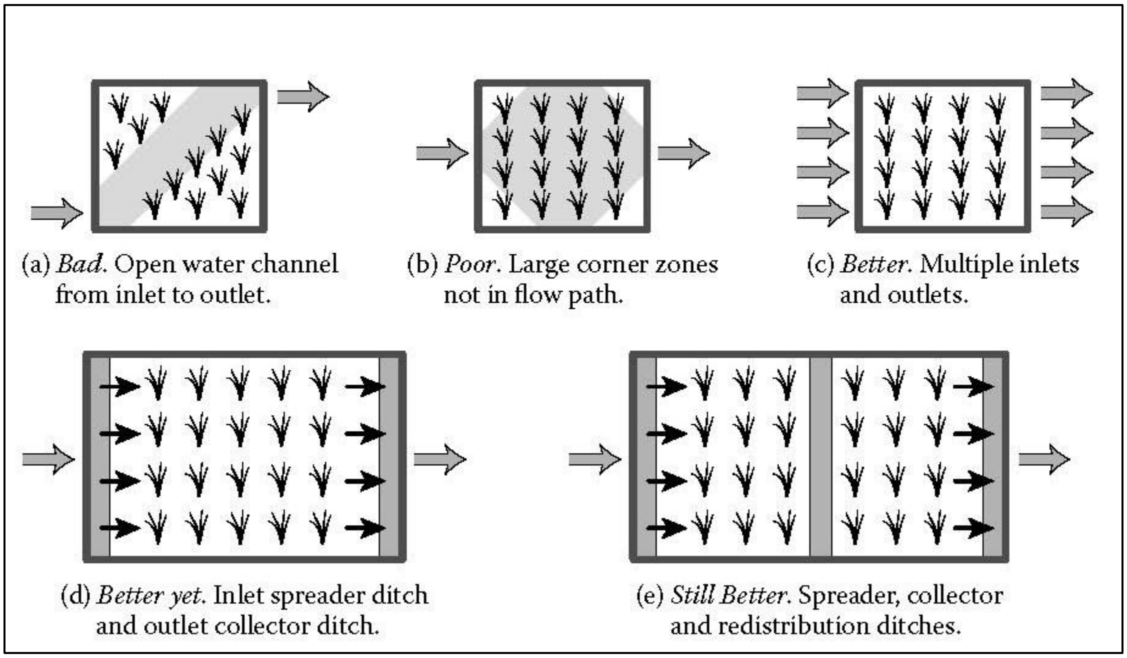

Figure 12. General recommendations for designing a high-areal efficiency wetland cell. From *Treatment wetlands*, 2nd ed. (p. 659), by R. H. Kadlec and S. D. Wallace, 2009, Boca Raton, FL: CRC Press.

Soil and Vegetation

In order to optimize soil conditions in this research wetland, the soil should be a mix of 25% of sphagnum peat moss and 75% of natural mineral soil from the site. This mixed type of soils containing both sphagnum and natural material will be effective in enhancing ion exchange and denitrification for treating the graywater (William, 2004).

This study focused on emergent aquatic species because emergent vegetation has been used frequently for wastewater treatment in wetlands (U.S. EPA, 1999). The most popular emergent vegetation includes cattails (*Typha spp.*), bulrushes (Scirpus *spp.*), and common reeds (*Phargmites australis*) (Campbell & Ogden, 1999). Cattails and bulrushes are quite common in Utah, and were chosen for the vegetation in this study. One significant distinction between cattails and bulrushes is the rooting depth of each vegetation type. The typical depth of the cattail root system is 6 to 12 inches and that of the bulrush is 24 to 48 inches (Figure 13). Based on the design depth, cattail is used in this study.

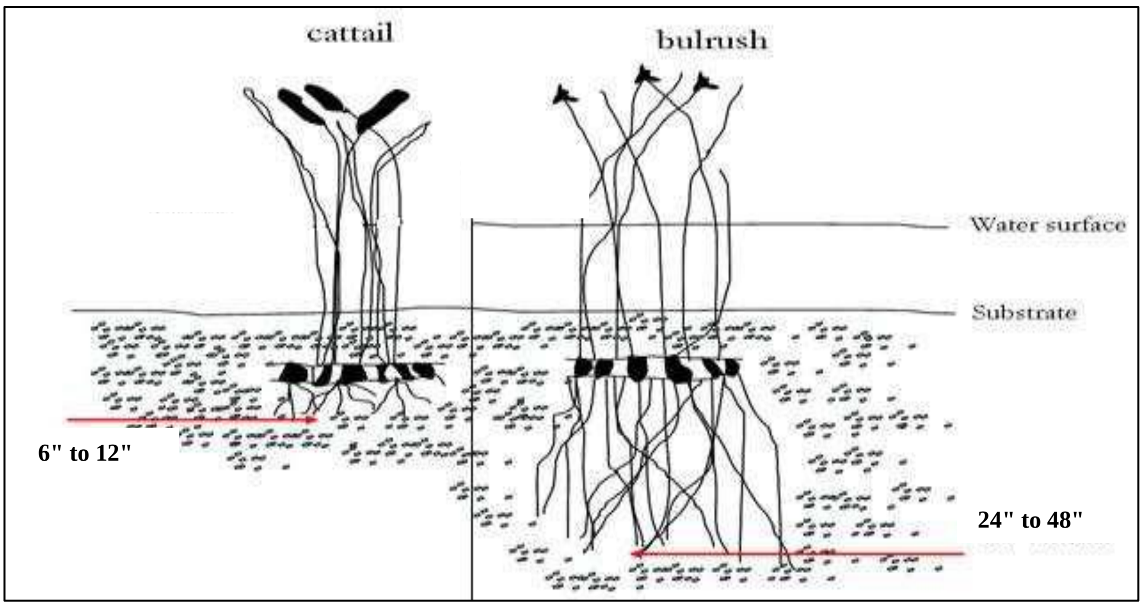

Figure 13. Soil depth for Cattail and Bulrush. Adapted from *Constructed wetlands in the sustainable landscape* (p. 103), by C. S. Campbell and M. H. Ogden, 1999, New York, NY: John Wiley & Sons.

Preparation and Liner

There are two types of wetland bottom designs: one that permits water to be infiltrated from the pond (like stormwater wetland) and one in which infiltration is restricted (like wastewater wetland). The study recommends using synthetic liners at the bottom to prevent seepage.

Preparation of the sub-grade is a crucial part of the construction process. The sub-grade should be properly compacted. Larger rocks and sharp sands should be removed to prevent ripping of the liner (U.S. EPA, 2011).

Disinfection Requirement

The goal of this study is to clean the wastewater and reuse the treated wastewater in landscape irrigation. Landscape water is mostly applied above ground and has open public access. Therefore, the wastewater must be treated to a sufficiently high level for public health standards and to reduce odors. A filtration and disinfection process is usually required before the water is stored in a holding tank for later use or just before application to the land. Ultraviolet light is becoming one of the most popular and cost-effective disinfection method.

Pollutant Removal

This study uses Kadlec and Knight k-C* model (see Equation 5) to calculate the effluent BOD concentration in the proposed CW. Table 13 illustrates the calculation results.

Table 13

Estimated Effluent BOD Concentration in the Proposed Constructed Wetland

	C_o (mg/L)	T–20 (℃)	HLR (cm/d)	t (day)	C_e (mg/L)
Jan	16.49	–24.06	6.44	6.70	12.85
Feb	14.58	–21.33	6.45	6.70	11.07
Mar	15.11	–16.22	5.41	6.70	9.84
Apr	12.63	–12.28	4.87	6.70	7.49
May	10.30	–7.83	4.50	6.70	5.73
Jun	12.15	–3.11	3.16	6.70	4.83
Jul	10.08	0.94	3.24	6.70	4.32
Aug	10.50	0.06	4.03	6.70	4.69
Sep	8.87	–4.61	4.79	6.70	5.08
Oct	11.88	–10.94	5.94	6.70	7.51
Nov	16.25	–17.83	6.42	6.70	11.48
Dec	16.28	–23.78	6.64	6.70	12.75
Average	12.93	–11.75	5.16	6.70	7.70

Note. C_o is the influent BOD concentration, which is equal to the S_o (Pond I effluent BOD concentration) in this study (mg/L); C_e is the effluent BOD concentration (mg/L); *HLR* is the hydraulic loading rate (cm/d); and *t* is the wetland HRT (day).

The BOD and TSS removal efficiency of the whole system is calculated by Equation 11:

$$\text{Removal efficiency} = (1 - C_e/C_o) \times 100\% \quad (11)$$

where C_o is the influent concentration (mg/L); and C_e is the effluent concentration (mg/L). The calculation results are shown in Table 14.

Table 14

BOD and TSS removal efficiency (%) in the entire wastewater treatment system

	BOD C_o (mg/L)	TSS C_o (mg/L)	Daily Inflow (m^3/d)	HLR (cm/d)	T–20 (°C)	BOD Removal efficiency (%)	TSS Removal efficiency (%)
Jan	200	200	963.56	6.44	–24.06	93.57%	87.24%
Feb	200	200	965.30	6.45	–21.33	94.47%	87.24%
Mar	200	200	810.24	5.41	–16.22	95.08%	87.46%
Apr	200	200	729.79	4.87	–12.28	96.25%	87.57%
May	200	200	673.60	4.50	–7.83	97.14%	87.65%
Jun	200	200	472.98	3.16	–3.11	97.59%	87.94%
Jul	200	200	484.99	3.24	0.94	97.84%	87.92%
Aug	200	200	603.82	4.03	0.06	97.65%	87.75%
Sep	200	200	717.36	4.79	–4.61	97.46%	87.59%
Oct	200	200	888.95	5.94	–10.94	96.24%	87.34%
Nov	200	200	961.90	6.42	–17.83	94.26%	87.24%
Dec	200	200	993.53	6.64	–23.78	93.63%	87.20%
Average	200	200	772.17	5.15	–11.75	96.15%	87.51%

Future Expansion

Based on the city's general plan (2007–2017), the city's current growth rates is about 2.0% per annum. In this study, the design will also consider the future expansion for the next 25 years (from 2010 to 2035) following the current growth rate. The census population in 2010 is 3,260. The build-out population forecast in 2035 would be approximately 5,349.

Per capital flow applied in the future treatment systems is designed on the basis of an annual average daily rate of flow of 100 gallons per capita per day (0.38 cubic meters per capita per day). That means in the next 25 years, there would be an additional 208,900 gallons wastewater generated per day.

In 2035, the anticipated wastewater disposal to the lagoon system will double from its current 237,138.5 USG per day. A paralleled treatment system (an aeration pond plus a CW) is recommended for future reservation. There will be more water reclaimed in the future along with the growing wastewater discharge.

Storage Pond Design

A holding tank or lagoon is another necessary component in this case, because the storage space allows operators to adjust application rates. The amount of water needed for irrigation is seasonal. Moreover, in December and January the discharged water BOD concentration (see Table 12) could not meet the state irrigation standards (BOD $\leq$10 mg/L). That amount of water needs to be stored for advanced treatment (oxidation) or future mixing. Systems may be permitted to apply wastewater only during certain months of the year, or they may be required to include subsurface drainage to help prevent runoff and erosion during wet weather.

Therefore, the tank is designed to store a minimum of 90 days of design flow. Based on a 25-year development period, the proposed holding tank should be one pond with a minimum volume of 35,649,857 USG (134,950 m^3) or two ponds with a storage volume of 17,824,930 USG (67,475 m^3) in each. Typically, a small-surface pond is recommended for reducing the loss of water from evaporation. The geographic information system (GIS) map shows that the groundwater level of this area is 98 feet. The state required a minimum separation of 4 feet between the bottom of the lagoon and the groundwater elevation. Therefore, the optimum size of a one-cell storage pond is 1.2

acres (surface area) by 92 feet (depth) if the construction difficulty and costs are not considered.

In this project, the design depth of the storage pond is 18 feet. The surface area is 3.1 acres.

System Design Maps

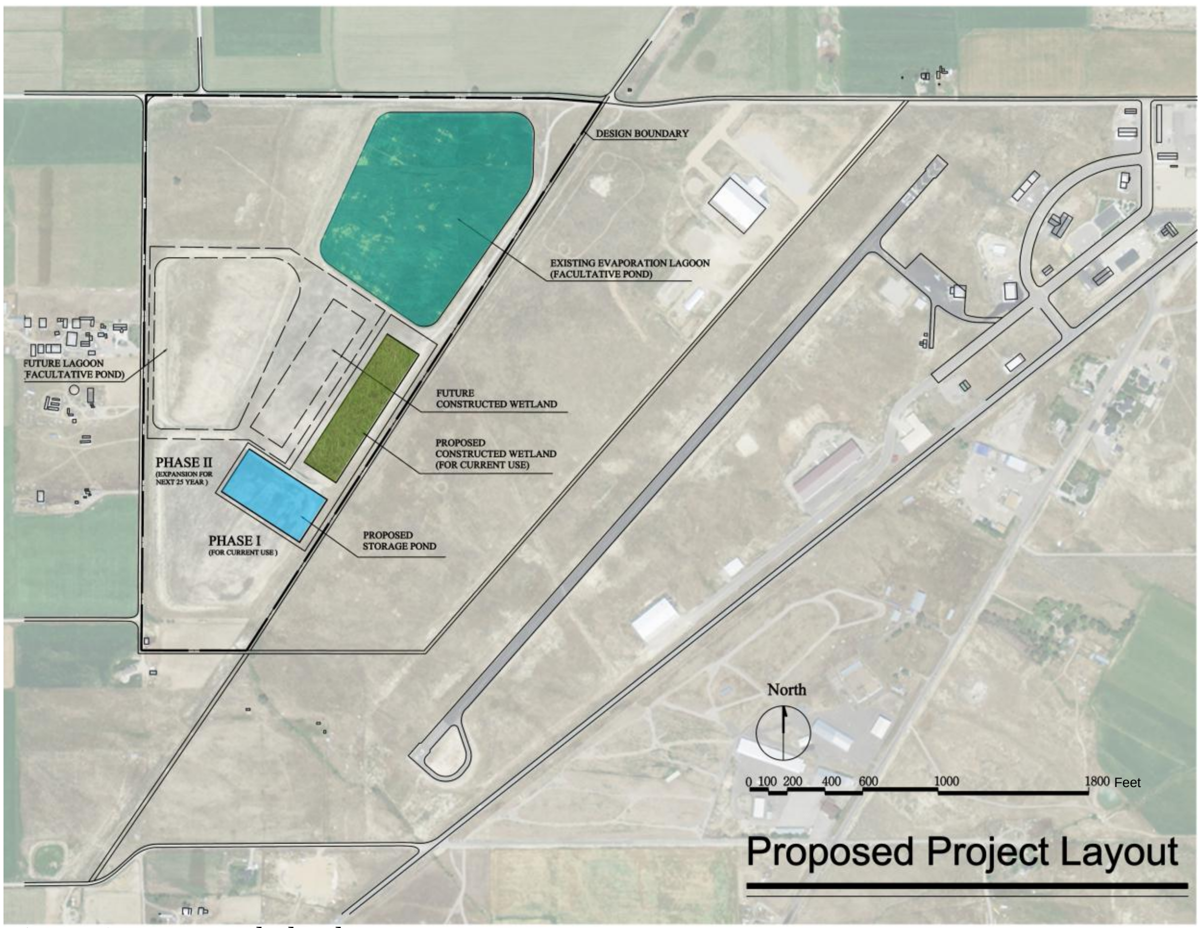

Figure 14. Proposed plan layout.

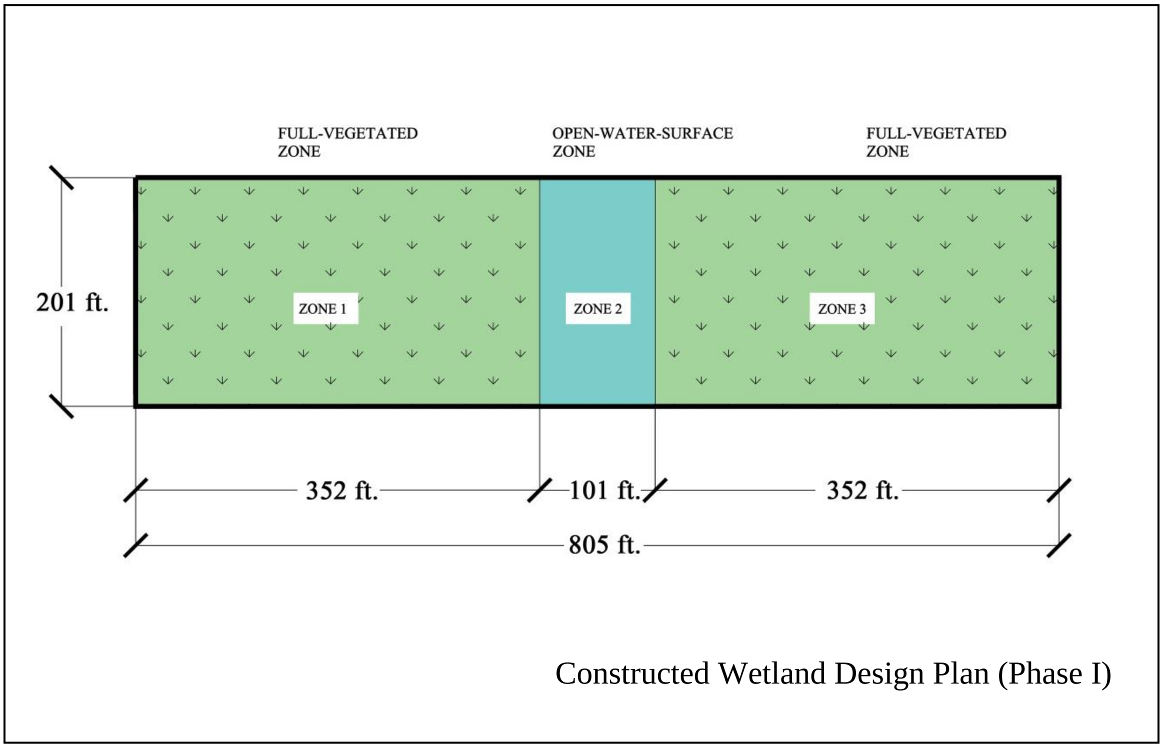

Figure 15. Design plan of the proposed constructed wetland plan based on current sewage volume.

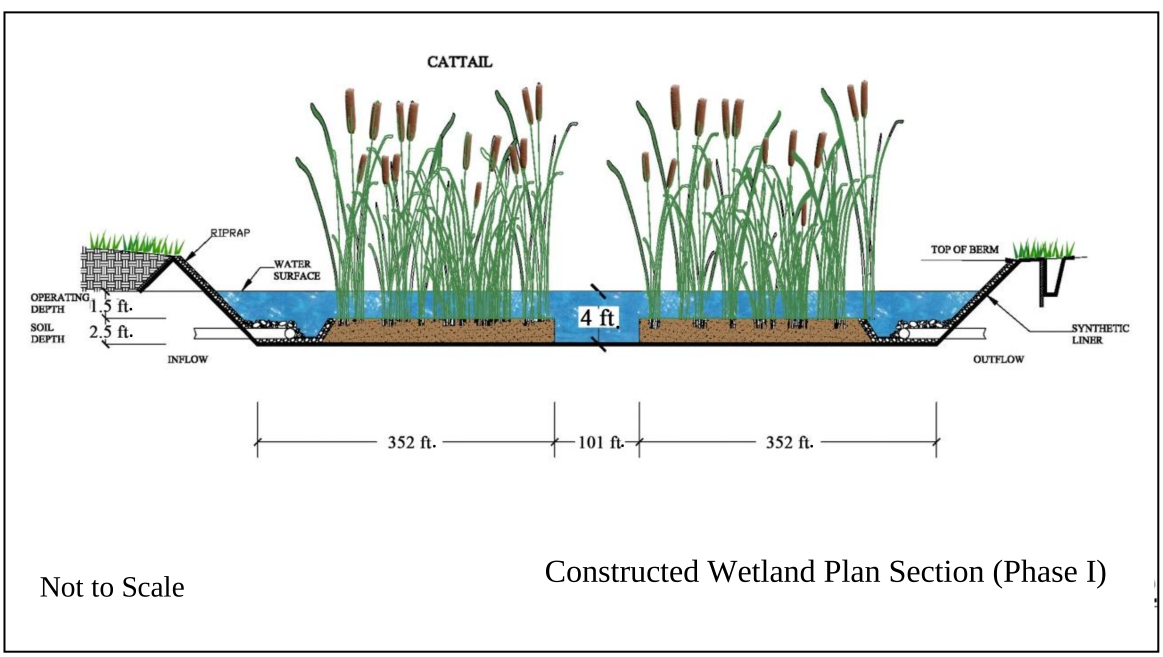

Figure 16. Plan section of the proposed constructed wetland based on current sewage volume.

Irrigation Reuse Management

Utah is ranked the second driest state in the nation. Only Nevada has less water. Natural precipitation in the Sanpete region is between 9 and 12 inches per year, and most plants used in the urban landscape have water requirements that exceed these rainfall amounts. Consequently, irrigation, particularly during the summer, is necessary to sustain a landscape in urban areas.

Reclaimed wastewater is being increasingly used for irrigation because it contains valuable nutrients required for plant growth, and has fertilization potential for agricultural crops. Domestic wastewater contains the macronutrients such as nitrogen, phosphorous, potassium, calcium and magnesium, all of which are vital to plant and soil health. However, wastewater must undergo strict treatment and disinfection to eliminate odors and destroy pathogens before it can be reused in order to protect public health and the environment.

Turf Irrigation

Water use data from cities in the Southwest show that 50% or more of domestic summer water use is used for outdoor watering. Landscape areas are very rarely planted with a single species and instead use turf, trees, and other perennials. Turfgrasses can make up a large portion of the landscape and are generally identified as high-water-use ground covers.

Turfgrass water use is affected by seasonal variations in air temperature and other weather conditions. Water use is relatively low in the spring, increases in late June through July and early August, and then decreases through the end of August into

September and October. Table 15 summarizes monthly turfgrass water use rates for various locations throughout Utah (Hill & Kopp, 2002). For example, turfgrass water use for the month of July in Mount Pleasant would be approximately 0.17 inch (100 gallons per 1,000 square feet) per day. Currently the designed treatment system would generate 195,342 gallons of water per day. That means this amount of water could at least irrigate about 1,953,000 square feet (44.8 acres) of turfgrass landscape in the hot summer season.

Table 15

Monthly and Total Seasonal Water Use Estimates (in Inches) for Turfgrass from Selected Cities in Utah

Location	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Seasonal Total
Logan	–	0.29	1.90	3.41	4.31	4.78	4.20	2.66	1.14	–	22.68
Manti	–	–	1.36	3.87	4.72	5.32	4.64	3.35	1.05	–	24.32
Moab	0.16	1.77	2.68	4.05	5.00	5.44	4.64	3.58	2.22	0.41	29.95
Salt Lake	–	0.31	1.89	3.39	4.64	5.39	4.53	2.72	1.38	–	24.26
Odgen	–	0.64	2.23	3.61	4.78	5.21	4.43	2.74	1.93	–	25.57
Park City	–	–	0.48	2.94	3.81	3.96	3.70	2.29	–	–	17.17
Pleasant Grove	–	0.31	2.19	3.70	4.56	5.22	4.25	2.94	1.50	–	24.68

Adapted from *Consumptive use of irrigated crops in Utah,* by R. W. Hill, 1994, Utah Agriculture Experiment Station Research Report No. 145. Logan, UT: Utah State University.

Agriculture Irrigation

Agricultural irrigation is the most common current water reuse practice in the United States. In 1995, 34% (340,000 m^3/d) and 63% (570,000 m^3/d) of the total volume of recycled water in California and Florida, respectively, were used for agricultural purposes (Jimenez & Asano, 2008).

In Utah, agriculture is the largest water user which requires approximately 70% of Utah’s freshwater resources (Utah Division of Water Resource). With the population growth, the demands for irrigation are increasing to satisfy the growth of food production. One strategy to address this challenge is to conserve water and improve the efficiency of water use. In this context, water reuse becomes a vital alternative resource and key element of the integrated water resource management.

Mount Pleasant wastewater treatment system is in proximity to agricultural lands. One of the major agriculture plants in this area is pastures grasses. The crop irrigation requirement, or ET, is the combination of transpiration from plant leaves plus evaporation from adjacent soil surfaces. Estimated average monthly pasture water use, or ET, for pasture in Fairfield, Pleasant Grove, and Santaquin are presented in Table 16. Since Mount Pleasant's statistics in water use are currently unavailable, projections in Table 16 rely on the data from Pleasant Grove, whose climatic conditions are similar to Mount Pleasant. Using the same method for the calculation of turfgrass, the wastewater reclaimed in this study could irrigate approximately 37 acres of pasture in the hot summer season.

Table 16
Monthly Pasture Irrigation Water Use/ET (in Inches) in Fairfield, Pleasant Grove, and Santaquin

Location	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Seasonal Total
Fairfield		0.85	3.48	5.05	5.60	4.65	3.23	0.65	23.51
Pleasant Grove	0.3	2.02	4.28	5.29	6.06	4.93	3.42	1.46	27.76
Santaquin	0.26	2.02	4.22	5.36	5.84	4.81	3.26	1.34	27.10

Adapted from *Consumptive use of irrigated crops in Utah*, by R. W. Hill, 1994, Utah Agriculture Experiment Station Research Report No. 145. Logan, UT: Utah State University.

CHAPTER IV

CONCLUSIONS AND CONTRIBUTIONS

Conclusions

Water reclamation and reuse as a sustainable strategy in water management has been attractive to communities in the Intermountain West, due to the increasing demands placed on freshwater resources driven by population growth and climate change. A properly designed municipal wastewater treatment system will facilitate water management and reuse practices. These sustainable practices will bring economical environmental benefits for future development. Compared to the conventional engineering treatment systems, wastewater stabilization ponds (WSPs) and CWs provide various advantages. They are low energy-consuming and biologically self-designing strategies and are of social and economic adherence. They also produce high-quality treated water that is suitable for almost any type of reuse.

This study demonstrates the feasibility of the combined WSPs and CWs system for municipal wastewater treatment and reclamation for Mount Pleasant. Integrating this treatment system with the original evaporation lagoons would not only improve wastewater quality but also save a large amount of water that could be used for other purposes such as irrigation. The results show that pollutant levels in the wastewater could be reduced by 87% to 97% after treatment of 6.7 days by the 3.7-acre facility currently in use. The entire system, including the existing lagoon, is 20.4 acres in size (not counting the auxiliary facilities). In the majority months (except winter), the system has the capacity to clean about 240,000 gallons of influent wastewater and discharge 198,055 gallons of 90% treated water which could irrigate over 44.8 acres of turf landscape every day.

Contributions

The contributions of this study are fourfold. First, the proposed wastewater treatment system will assist Mount Pleasant's current plan of cleaning its daily domestic wastewater through an environmental friendly manner. Second, the study tackled the pressing water shortage problems and provided a low-cost strategy which can bring multiple benefits to the City's water resource management. Third, environmental health and public health conditions are expected to be improved after the enhancement of wastewater quality. Forth, this study serves as an exemplary case for other Utah communities that are facing similar water shortage problems or lack of resources to build costly wastewater treatment plants.

Conventional wastewater treatment plants are constructed at great cost due to the high-demands on equipment, energy, and labor. Therefore, they may not be feasible for small communities such as Mount Pleasant. CWs present a viable alternative in this study, especially for small communities who have adequate land reserves while facing budgetary or technological constrains.

This study demonstrates that wetlands could be high performing in pollutant removal through the integration with the primary treatment system. As water is increasingly scarce in the Intermountain West, this study can motivate sustainable practices like such in a larger context. The study will also help informed design and decision to be made. Communities like Mount Pleasant can develop their water management strategies more wisely, according to their own needs, priorities, and water resource availability.

Limitations

There are several limitations in this study. First, there is little specific data and information available for the study site. Due to the short study time and zero budget, there is little first-hand information. Second, all the results are calculated based on equations; no pilot experiments were conducted. Third, several important factors that are related to water consumption are not included in the analysis, such as plant productivity and climate change.

Suggestions for Future Study

As discussed in the literature review, FWS CWs would benefits existing landscapes and wildlife habitats. A question which deserves future study is how to integrate landscape value and recreation needs, while serving wastewater treatment function simultaneously.

Mount Pleasant desires more recreational facilities in the future. The current lagoon system includes a large portion of the open lands and presents ample space for future growth of these facilities. The quality of the treated wastewater would be qualified for landscape irrigation and public access. Finally, a recreational wet-park could be built based on the proposed master plan.

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APPENDIX

Appendix. Mount Pleasant City Municipal Wastewater
Discharge Volume 2011–2012

Mount Pleasant City Greyline Data
From Feb/03/2011 9:10 to Feb/01/2012 12:24

Date and Time	Site 1 (Ave) (USG/min)	Time of Maximium	Site 1 (Max) (USG/min)	Time of Minimum	Site 1 (Min) (USG/min)	Interval Total (USG)
2/3/2011 12:00	174.621	2/2/2011 12:31	298.336	9:10:15 AM	84.647	248017.12
2/4/2011 12:00	175.509	2/3/2011 12:50	273.178	8:45:59 AM	84.943	252732.81
2/5/2011 12:00	174.917	2/4/2011 12:32	290.64	9:19:19 AM	78.135	251880.49
2/6/2011 12:00	176.397	2/5/2011 16:54	325.861	9:24:45 AM	66.001	254011.39
2/7/2011 12:00	167.518	2/6/2011 15:16	295.376	8:05:13 AM	63.633	241225.63
2/8/2011 12:00	182.02	2/7/2011 12:33	305.735	8:42:45 AM	71.92	262109.08
2/9/2011 12:00	171.661	2/8/2011 12:26	288.273	7:07:19 AM	67.481	247192.28
2/10/2011 12:00	172.253	2/9/2011 12:33	281.169	6:46:11 AM	75.176	248047.61
2/10/2011 20:24		POWER FAILURE		POWER DOWN		
2/10/2011 20:29		POWER FAILURE		POWER UP		
2/11/2011 12:00	171.069	2/10/2011 12:45	289.752	2/10/2011 20:29	0	245458.93
2/12/2011 12:00	165.742	2/11/2011 12:34	293.008	10:05:11 AM	67.777	238668.49
2/13/2011 12:00	162.782	2/12/2011 15:06	290.64	9:19:35 AM	70.144	234406.52
2/14/2011 12:00	173.141	2/13/2011 17:23	274.658	8:59:05 AM	73.4	249323.18
2/15/2011 12:00	180.54	2/14/2011 12:39	295.376	9:03:59 AM	74.88	259978.04
2/16/2011 12:00	164.854	2/15/2011 12:30	282.353	8:02:23 AM	61.265	237389.76
2/17/2011 12:00	168.702	2/16/2011 12:28	261.34	9:34:53 AM	70.44	242930.31
2/18/2011 12:00	168.406	2/17/2011 12:54	267.555	9:06:11 AM	65.409	242504.21
2/19/2011 11:59	165.446	2/18/2011 12:31	282.649	9:46:13 AM	69.552	238236.73
2/20/2011 12:00	177.285	2/19/2011 15:30	296.264	9:35:15 AM	63.929	255295.88
2/21/2011 12:00	163.374	2/20/2011 17:07	299.815	9:27:43 AM	59.785	235258.86
2/22/2011 12:00	165.742	2/21/2011 16:01	293.896	9:14:27 AM	59.785	238668.49

2/23/2011 12:00	158.935	2/22/2011 12:41	272.586	9:18:11 AM	61.265	228865.95
2/24/2011 12:00	158.047	2/23/2011 12:37	263.411	8:31:23 AM	58.01	227587.39
2/25/2011 12:00	163.67	2/24/2011 12:49	276.73	9:37:39 AM	70.144	235685.08
2/26/2011 12:00	161.302	2/25/2011 13:01	271.107	9:30:05 AM	57.714	232275.46
2/27/2011 12:00	165.446	2/26/2011 15:07	299.223	10:11:03 AM	55.642	238242.25
2/28/2011 12:00	163.67	2/27/2011 14:00	281.761	8:59:49 AM	60.081	235685.08
3/1/2011 12:00	162.782	12:26:55 AM	259.268	8:36:29 AM	67.481	234403.81
3/2/2011 12:00	158.343	3/1/2011 12:27	253.94	8:25:37 AM	65.705	228016.27
3/3/2011 12:00	164.262	3/2/2011 12:44	282.353	9:26:05 AM	62.449	236537.42
3/4/2011 11:45		POWER FAILURE		POWER DOWN		
3/4/2011 11:45		POWER FAILURE		POWER UP		
3/4/2011 12:00	176.989	3/3/2011 12:43	300.111	3/3/2011 18:10	0	254848.96
3/5/2011 12:00	162.782	3/4/2011 12:46	288.273	10:35:07 AM	64.817	234409.24
3/6/2011 12:00	174.325	3/5/2011 14:26	314.614	10:16:33 AM	70.144	251025.1
3/7/2011 12:00	166.926	3/6/2011 16:29	282.649	10:01:19 AM	63.041	240375.93
3/8/2011 12:00	170.773	3/7/2011 13:43	303.367	8:58:15 AM	61.857	245910.85
3/9/2011 12:00	163.078	3/8/2011 12:33	277.322	9:15:33 AM	64.817	234832.62
3/10/2011 12:00	158.343	3/9/2011 23:48	232.631	10:09:43 AM	71.92	228016.27
3/11/2011 12:00	157.751	3/10/2011 13:15	235.294	9:18:07 AM	69.848	227158.52
3/12/2011 12:00	155.383	3/11/2011 15:26	246.541	10:17:13 AM	69.552	223751.67
3/13/2011 12:00	155.087	3/12/2011 15:29	895.007	10:03:31 AM	62.153	223325.42
3/14/2011 12:00	147.392	3/13/2011 15:55	269.331	6:29:01 AM	56.234	212244.47
3/15/2011 12:00	157.455	3/14/2011 13:26	242.99	6:33:31 AM	52.978	226734.93
3/16/2011 12:00	147.096	12:15:45 AM	242.398	6:16:57 AM	54.754	211818.23
3/17/2011 12:00	153.607	3/16/2011 14:21	236.182	8:45:39 AM	67.481	221197.08
3/18/2011 12:00	150.944	11:54:39 AM	240.03	5:48:27 AM	58.01	217356.28

3/19/2011 12:00	140.585	3/18/2011 15:45	221.384	7:24:59 AM	53.274	202444.32
3/20/2011 12:00	153.015	3/19/2011 13:57	286.793	9:08:09 AM	56.53	220339.49
3/21/2011 12:00	154.199	3/20/2011 16:19	267.851	7:29:17 AM	53.866	222046.86
3/22/2011 12:00	155.383	3/21/2011 15:11	248.909	7:02:15 AM	53.57	223749.08
3/23/2011 12:00	149.76	11:41:49 AM	227.895	6:26:03 AM	53.57	215656.47
3/24/2011 12:00	148.576	3/23/2011 14:21	245.653	8:07:35 AM	61.561	213954.12
3/25/2011 12:00	151.24	3/24/2011 15:55	247.725	6:45:29 AM	53.274	217779.83
3/26/2011 12:00	151.832	3/25/2011 15:21	242.694	9:08:23 AM	58.306	218637.36
3/27/2011 12:00	155.679	3/26/2011 14:00	292.416	7:25:37 AM	54.754	224175.17
3/28/2011 12:00	161.007	3/27/2011 13:51	272.882	9:19:31 AM	68.369	231852.04
3/29/2011 12:00	158.343	3/28/2011 14:39	264.891	7:25:09 AM	59.785	228013.63
3/30/2011 12:00	151.536	3/29/2011 14:39	232.039	5:44:37 AM	52.682	218211.14
3/31/2011 12:00	147.688	3/30/2011 12:26	247.725	6:27:41 AM	51.202	212670.57
4/1/2011 12:00	146.8	3/31/2011 13:48	236.478	6:44:53 AM	57.418	211392.00
4/2/2011 12:00	141.769	4/1/2011 13:34	246.837	7:27:41 AM	58.602	204146.78
4/3/2011 12:00	149.168	4/2/2011 13:58	286.201	7:24:47 AM	52.09	214801.63
4/4/2011 12:00	169.59	4/3/2011 13:57	308.398	5:45:43 AM	56.53	244206.05
4/5/2011 12:00	157.751	11:36:03 AM	280.578	7:15:31 AM	51.498	227166.41
4/6/2011 12:00	150.944	11:34:31 AM	258.38	7:28:45 AM	50.61	217356.28
4/7/2011 12:00	155.975	11:38:39 AM	266.371	6:04:59 AM	52.682	224604.01
4/8/2011 12:00	160.711	11:37:51 AM	278.506	6:32:49 AM	60.377	231423.12
4/9/2011 12:00	159.823	4/8/2011 12:00	269.035	9:51:53 AM	66.297	230144.55
4/10/2011 12:00	163.078	4/9/2011 13:59	298.336	9:45:41 AM	60.673	234832.62
4/11/2011 12:00	167.222	4/10/2011 13:51	293.896	7:16:03 AM	60.377	240802.18
4/12/2011 12:00	166.63	11:34:23 AM	295.08	6:53:55 AM	67.185	239941.50
4/13/2011 12:00	156.567	11:24:53 AM	266.963	7:40:13 AM	59.194	225459.10

4/14/2011 12:00	160.711	11:41:13 AM	295.376	6:40:19 AM	59.785	231423.12
4/15/2011 12:00	160.415	4/14/2011 12:00	274.362	9:11:41 AM	58.306	230996.89
4/16/2011 12:00	153.015	4/15/2011 13:44	236.182	8:20:21 AM	56.53	220342.04
4/17/2011 12:00	161.598	4/16/2011 14:56	316.686	9:30:09 AM	55.05	232699.00
4/18/2011 12:00	167.222	11:40:29 AM	307.511	6:39:55 AM	53.57	240802.18
4/19/2011 12:00	171.661	11:54:15 AM	291.824	5:35:13 AM	64.521	247192.28
4/20/2011 12:00	170.773	11:36:59 AM	295.968	7:02:57 AM	69.552	245913.70
4/21/2011 12:00	159.823	11:49:57 AM	295.672	7:06:15 AM	55.346	230144.55
4/22/2011 12:00	167.814	11:57:21 AM	290.344	5:16:39 AM	70.736	241651.73
4/23/2011 12:00	159.527	4/22/2011 12:00	286.201	8:59:49 AM	64.521	229718.29
4/24/2011 12:00	164.262	4/23/2011 13:55	343.027	9:16:31 AM	54.162	236537.42
4/25/2011 12:00	173.437	4/24/2011 13:58	311.95	6:21:53 AM	57.714	249749.42
4/26/2011 12:00	174.325	11:31:37 AM	282.353	5:31:39 AM	62.449	251028.01
4/27/2011 12:00	163.374	4/26/2011 12:07	269.331	7:01:17 AM	60.081	235258.86
4/28/2011 12:00	161.007	12:56:49 AM	263.707	6:20:15 AM	65.705	231849.36
4/29/2011 12:00	158.935	11:43:07 AM	296.264	6:32:23 AM	57.714	228865.95
4/30/2011 12:00	161.598	4/29/2011 12:09	266.371	7:01:01 AM	68.073	232701.70
5/1/2011 12:00	166.334	4/30/2011 14:58	305.735	9:39:09 AM	60.673	239520.81
5/2/2011 12:00	166.334	5/1/2011 14:07	271.698	6:53:51 AM	58.898	239520.81
5/3/2011 12:00	164.558	11:51:37 AM	273.77	6:49:11 AM	59.785	236963.67
5/4/2011 12:00	157.751	5/3/2011 12:18	261.932	7:07:17 AM	56.53	227161.15
5/5/2011 12:00	158.935	11:37:09 AM	262.523	6:58:41 AM	57.714	228865.95
5/6/2011 12:00	154.791	1:56:19 AM	253.644	7:06:41 AM	57.714	222899.33
5/7/2011 12:00	154.791	5/6/2011 13:42	253.94	9:23:31 AM	66.889	222901.91
5/8/2011 12:00	170.773	5/7/2011 23:02	481.54	6:06:27 AM	71.92	245910.85
5/9/2011 12:00	183.204	5/8/2011 14:55	317.278	5:27:43 AM	69.552	263813.91

5/10/2011 12:00	179.061	5/9/2011 14:22	324.085	6:59:23 AM	60.081	257853.09
5/11/2011 12:00	164.558	12:04:35 AM	274.658	6:52:01 AM	60.673	236958.18
5/12/2011 12:00	161.894	12:57:13 AM	260.452	6:55:39 AM	61.857	233125.22
5/13/2011 12:00	158.935	1:29:39 AM	249.797	6:30:29 AM	66.001	228868.6
5/14/2011 12:00	151.536	5/13/2011 12:19	261.34	9:05:27 AM	63.337	218211.14
5/15/2011 12:00	167.814	5/14/2011 13:51	310.47	9:15:01 AM	68.073	241654.53
5/16/2011 12:00	169.59	5/15/2011 14:52	299.815	6:04:31 AM	61.265	244206.05
5/17/2011 12:00	163.078	5/16/2011 12:00	280.282	7:17:13 AM	64.225	234832.62
5/18/2011 12:00	170.182	11:38:49 AM	321.421	7:01:57 AM	67.481	245058.52
5/19/2011 12:00	175.805	11:37:19 AM	286.793	6:52:55 AM	89.678	253161.98
5/20/2011 12:00	177.877	5/19/2011 13:02	294.192	7:00:01 AM	74.88	256142.31
5/21/2011 12:00	158.047	5/20/2011 12:14	256.012	6:53:01 AM	64.817	227587.39
5/22/2011 12:00	165.446	5/21/2011 14:28	309.286	9:42:17 AM	66.593	238242.25
5/22/2011 22:18		POWER FAILURE		POWER DOWN		
5/22/2011 22:18		POWER FAILURE		POWER UP		
5/23/2011 12:00	167.518	5/22/2011 13:55	316.686	5/22/2011 22:18	0	241211.67
5/24/2011 12:00	178.765	5/23/2011 16:18	284.425	6:38:41 AM	70.736	257417.90
5/25/2011 12:00	183.204	5/24/2011 12:04	270.515	6:52:05 AM	98.853	263816.96
5/26/2011 12:00	184.092	1:39:59 AM	287.385	5:35:11 AM	100.037	265092.34
5/27/2011 12:00	166.038	5/26/2011 14:06	311.062	7:06:29 AM	67.185	239094.59
5/28/2011 12:00	164.558	5/27/2011 12:43	316.094	8:06:03 AM	67.481	236963.67
5/29/2011 12:00	179.357	5/28/2011 13:51	342.435	10:00:15 AM	88.79	258273.38
5/30/2011 12:00	169.886	5/29/2011 13:53	308.99	7:11:49 AM	66.889	244637.95
5/31/2011 12:00	178.765	5/30/2011 14:59	325.565	6:06:27 AM	64.521	257417.90
6/1/2011 12:00	154.495	5/31/2011 15:03	284.721	5:48:47 AM	66.889	222470.51
6/2/2011 12:00	145.912	6/1/2011 16:04	279.098	6:39:59 AM	58.602	210115.85

6/3/2011 12:00	135.257	6/2/2011 14:05	230.855	7:29:05 AM	57.418	194770.5
6/4/2011 12:00	144.432	6/3/2011 13:43	236.182	9:28:07 AM	58.602	207980.09
6/5/2011 12:00	137.921	6/4/2011 14:54	271.107	9:17:17 AM	49.723	198608.55
6/6/2011 12:00	138.217	6/5/2011 14:51	249.501	7:28:53 AM	55.642	199030.04
6/7/2011 12:00	141.473	6/6/2011 14:43	238.55	9:04:59 AM	50.315	203722.89
6/8/2011 12:00	144.432	11:47:15 AM	442.472	7:33:37 AM	54.754	207982.5
6/9/2011 12:00	232.039	6/8/2011 15:39	544.285	7:33:03 AM	43.803	334135.73
6/10/2011 12:00	132.298	1:22:47 AM	199.778	7:11:19 AM	54.458	190510.76
6/11/2011 12:00	133.186	6/10/2011 14:34	228.487	6:18:59 AM	49.131	191784.90
6/12/2011 12:00	141.769	6/11/2011 14:36	271.402	7:18:21 AM	55.346	204146.78
6/13/2011 12:00	142.361	6/12/2011 15:31	278.21	7:14:57 AM	51.202	204999.14
6/14/2011 12:00	138.809	6/13/2011 13:23	220.2	7:41:45 AM	48.539	199884.81
6/15/2011 12:00	137.625	1:25:15 AM	227.303	7:55:51 AM	50.019	198180.00
6/16/2011 12:00	135.849	6/15/2011 23:07	218.424	6:44:33 AM	46.763	195622.84
6/17/2011 12:00	137.625	6/16/2011 14:33	256.9	6:21:29 AM	44.099	198182.30
6/18/2011 12:00	143.248	6/17/2011 13:59	235.886	9:11:39 AM	50.019	206275.31
6/19/2011 12:00	142.065	6/18/2011 14:03	269.923	9:06:59 AM	52.386	204572.87
6/20/2011 12:00	155.679	6/19/2011 13:43	256.604	6:55:49 AM	61.265	224177.76
6/21/2011 12:00	159.231	6/20/2011 14:26	260.452	6:06:31 AM	62.745	229292.21
6/22/2011 12:00	149.76	2:00:01 AM	226.119	6:11:23 AM	60.377	215653.97
6/23/2011 12:00	141.769	6/22/2011 14:03	218.72	8:13:51 AM	56.234	204146.78
6/24/2011 12:00	153.903	6/23/2011 15:52	239.438	7:04:27 AM	69.552	221618.03
6/25/2011 12:00	151.536	6/24/2011 14:53	248.613	6:55:43 AM	60.081	218213.66
6/26/2011 12:00	156.567	6/25/2011 13:40	296.856	9:11:13 AM	67.481	225456.49
6/27/2011 12:00	156.567	6/26/2011 14:20	276.138	7:11:37 AM	65.705	225456.49
6/28/2011 11:59	154.791	6/27/2011 15:11	256.308	8:19:29 AM	64.817	222894.17

6/29/2011 12:00	152.719	6/28/2011 14:14	243.877	7:07:27 AM	65.113	219921.03
6/30/2011 12:00	155.679	6/29/2011 21:04	305.735	6/29/2011 19:58	0	224177.76
7/1/2011 12:00	153.607	6/30/2011 14:17	265.187	6:53:47 AM	65.113	221194.52
7/2/2011 12:00	150.056	7/1/2011 15:05	262.227	7:41:09 AM	65.409	216080.19
7/3/2011 12:00	161.894	7/2/2011 17:17	278.802	9:25:03 AM	65.113	233127.92
7/4/2011 12:00	172.549	7/3/2011 14:47	307.215	9:20:25 AM	63.041	248470.84
7/5/2011 12:00	168.702	7/4/2011 14:03	335.332	7:08:23 AM	58.602	242930.31
7/6/2011 12:00	173.437	7/5/2011 20:32	377.063	6:08:25 AM	64.521	249749.42
7/7/2011 12:00	154.495	7/6/2011 15:45	246.245	7:07:49 AM	62.449	222473.08
7/8/2011 12:00	157.455	7/7/2011 15:41	235.886	8:16:37 AM	65.705	226734.93
7/9/2011 12:00	152.127	7/8/2011 15:13	255.716	9:31:05 AM	66.001	219063.46
7/10/2011 12:00	163.374	7/9/2011 14:20	290.64	8:59:27 AM	73.4	235258.86
7/11/2011 12:00	160.415	7/10/2011 14:59	283.537	7:11:49 AM	61.561	230996.89
7/12/2011 12:00	245.949	7/11/2011 14:58	558.787	7:37:59 AM	58.306	354166.86
7/13/2011 12:00	151.832	7/12/2011 15:01	238.55	6:49:41 AM	61.857	218637.36
7/14/2011 12:00	147.096	7/13/2011 13:44	227.303	7:50:13 AM	57.714	211818.23
7/15/2011 12:00	150.944	7/14/2011 14:33	240.622	7:00:45 AM	60.377	217356.28
7/16/2011 12:00	145.32	7/15/2011 14:14	263.411	6:55:27 AM	62.153	209263.53
7/17/2011 12:00	143.248	7/16/2011 14:33	253.052	9:08:47 AM	61.265	206277.70
7/18/2011 12:00	151.24	7/17/2011 16:30	265.779	7:00:29 AM	64.521	217782.35
7/19/2011 12:00	155.383	7/18/2011 14:18	237.662	7:16:25 AM	62.745	223754.25
7/20/2011 12:00	152.127	7/19/2011 16:15	235.59	9:07:47 AM	59.785	219063.46
7/21/2011 12:00	150.944	7/20/2011 14:59	256.9	6:58:23 AM	67.185	217358.80
7/22/2011 12:00	150.944	7/21/2011 15:08	246.541	9:24:01 AM	64.817	217358.80
7/23/2011 12:00	154.495	7/22/2011 15:49	257.492	9:36:21 AM	70.144	222475.66
7/24/2011 12:00	145.912	7/23/2011 13:53	314.614	9:32:57 AM	56.234	210110.99

7/25/2011 12:00	150.352	7/24/2011 14:44	492.786	7:25:15 AM	64.521	216506.29
7/26/2011 12:00	159.823	7/25/2011 14:20	251.573	7:50:31 AM	74.88	230144.55
7/27/2011 12:00	165.446	12:00:49 AM	257.788	6:11:03 AM	67.777	238242.25
7/28/2011 12:00	150.352	7/27/2011 14:09	253.644	7:27:37 AM	61.561	216506.29
7/29/2011 12:00	143.84	7/28/2011 14:10	245.357	7:08:43 AM	60.081	207130.03
7/30/2011 12:00	147.096	7/29/2011 14:56	219.904	7:05:49 AM	69.256	211818.22
7/31/2011 12:00	153.607	7/30/2011 14:50	258.084	9:55:57 AM	66.889	221194.52
8/1/2011 12:00	171.661	7/31/2011 20:14	415.243	6:40:05 AM	73.992	247192.28
8/2/2011 12:00	165.446	8/1/2011 14:58	250.981	7:03:15 AM	72.808	238242.25
8/3/2011 12:00	155.679	8/2/2011 15:52	262.523	5:37:43 AM	71.032	224177.76
8/4/2011 12:00	169.59	11:48:13 AM	526.231	6:42:07 AM	65.705	244208.87
8/5/2011 12:00	254.532	8/4/2011 14:55	555.828	7:25:03 AM	71.624	366526.52
8/6/2011 12:00	257.492	8/5/2011 14:39	583.353	7:05:13 AM	81.687	370792.78
8/7/2011 12:00	157.455	8/6/2011 14:47	290.64	6:59:07 AM	72.216	226732.30
8/8/2011 12:00	158.639	8/7/2011 14:42	273.178	7:15:33 AM	68.665	228439.73
8/9/2011 12:00	163.078	8/8/2011 14:44	258.972	6:44:43 AM	76.36	234832.62
8/10/2011 12:00	164.262	8/9/2011 14:44	268.443	6:53:33 AM	79.023	236537.42
8/11/2011 12:00	151.24	8/10/2011 13:59	261.932	7:10:25 AM	65.409	217784.87
8/12/2011 12:00	150.944	8/11/2011 15:31	256.308	6:59:19 AM	68.96	217358.80
8/13/2011 12:00	145.616	8/12/2011 14:19	250.093	7:17:27 AM	59.194	209687.18
8/14/2011 12:00	147.984	8/13/2011 14:42	258.676	8:49:37 AM	65.113	213096.82
8/15/2011 12:00	158.639	8/14/2011 14:44	238.846	6:03:25 AM	76.656	228439.73
8/16/2011 12:00	156.271	8/15/2011 14:57	239.438	8:16:57 AM	70.44	225030.22
8/17/2011 12:00	154.199	8/16/2011 15:00	263.707	6:14:39 AM	67.481	222046.86
8/18/2011 12:00	157.455	1:34:53 AM	230.855	6:32:25 AM	70.736	226734.92
8/19/2011 12:00	160.415	8/18/2011 14:07	240.03	6:31:13 AM	74.584	230996.89

8/20/2011 12:00	162.19	8/19/2011 16:43	242.694	7:03:55 AM	88.198	233551.33
8/20/2011 19:12		POWER FAILURE		POWER DOWN		
8/20/2011 20:24		POWER FAILURE		POWER UP		
8/21/2011 12:00	157.751	8/20/2011 14:42	292.712	8/20/2011 20:25	0	215803.09
8/22/2011 12:00	160.119	8/21/2011 16:09	276.73	6:52:33 AM	71.032	230570.79
8/23/2011 12:00	244.765	8/22/2011 14:40	571.218	7:23:09 AM	66.297	352462.18
8/24/2011 12:00	157.751	1:18:33 AM	238.846	6:44:35 AM	72.512	227161.14
8/25/2011 12:00	158.047	1:26:57 AM	253.644	6:26:11 AM	72.808	227587.39
8/25/2011 19:15		POWER FAILURE		POWER DOWN		
8/25/2011 20:28		POWER FAILURE		POWER UP		
8/26/2011 12:00	163.078	8/25/2011 20:28	306.919	8/25/2011 20:28	0	222862.67
8/27/2011 12:00	150.944	8/26/2011 12:10	223.16	7:51:53 AM	69.848	217361.31
8/28/2011 12:00	160.119	8/27/2011 13:42	280.873	8:33:17 AM	68.073	230570.79
8/29/2011 12:00	172.549	8/28/2011 13:41	290.64	8:01:23 AM	71.032	248476.59
8/30/2011 12:00	169.294	8/29/2011 22:50	269.627	8:17:21 AM	70.736	243777.13
8/31/2011 12:00	161.598	11:44:51 AM	264.595	5:49:51 AM	73.4	232701.69
9/1/2011 12:00	215.761	8/31/2011 14:14	558.491	6:31:31 AM	69.256	310698.71
9/2/2011 12:00	160.711	9/1/2011 12:00	249.501	8:21:07 AM	63.929	231420.43
9/3/2011 12:00	152.127	9/2/2011 14:33	241.806	7:09:25 AM	66.889	219063.45
9/4/2011 12:00	155.679	9/3/2011 13:43	287.681	9:00:41 AM	66.297	224177.76
9/5/2011 12:00	151.832	9/4/2011 14:13	271.994	8:13:33 AM	58.602	218637.35
9/6/2011 12:00	187.348	9/5/2011 15:41	303.663	6:49:53 AM	61.265	269780.53
9/7/2011 12:00	167.222	11:39:41 AM	305.143	5:49:55 AM	64.817	240799.39
9/8/2011 12:00	161.894	11:54:31 AM	288.273	7:37:49 AM	61.561	233127.91
9/9/2011 12:00	158.343	11:35:03 AM	292.416	6:43:25 AM	62.153	228013.63
9/10/2011 12:00	155.087	9/9/2011 12:00	241.806	7:10:41 AM	56.826	223325.42

9/11/2011 12:00	161.894	9/10/2011 14:39	319.645	8:21:19 AM	60.673	233127.91
9/12/2011 12:00	180.244	11:50:51 AM	302.183	5:58:39 AM	64.817	259551.94
9/13/2011 12:00	169.886	11:39:37 AM	287.385	8:24:03 AM	59.49	244635.11
9/14/2011 12:00	161.894	11:52:21 AM	292.712	6:53:43 AM	55.642	233127.91
9/15/2011 12:00	172.549	11:59:05 AM	298.928	7:10:57 AM	65.705	248470.84
9/16/2011 12:00	178.765	11:41:11 AM	318.757	7:27:09 AM	72.808	257420.87
9/17/2011 12:00	196.523	9/16/2011 21:41	305.735	9:03:39 AM	86.423	282992.53
9/18/2011 12:00	166.926	9/17/2011 13:39	295.968	9:01:59 AM	61.561	240373.14
9/19/2011 12:00	173.733	11:52:03 AM	280.282	6:03:11 AM	60.969	250175.64
9/20/2011 12:00	169.886	11:47:23 AM	286.201	8:10:45 AM	58.898	244635.11
9/21/2011 12:00	157.751	11:59:23 AM	299.223	6:08:09 AM	59.49	227161.14
9/22/2011 12:00	166.334	9/21/2011 12:00	299.223	6:03:51 AM	68.073	239520.80
9/23/2011 12:00	161.302	11:52:05 AM	279.69	6:10:59 AM	70.736	232275.45
9/24/2011 12:00	153.015	9/23/2011 12:07	256.012	6:56:15 AM	59.785	220342.03
9/25/2011 12:00	162.486	9/24/2011 14:40	293.6	9:11:11 AM	64.817	233980.25
9/26/2011 12:00	175.805	9/25/2011 14:38	303.071	5:48:23 AM	62.745	253159.05
9/27/2011 12:00	172.253	9/26/2011 12:00	285.609	7:12:49 AM	64.521	248044.74
9/28/2011 12:00	161.598	11:45:19 AM	314.022	5:41:39 AM	66.297	232701.69
9/29/2011 12:00	160.119	9/28/2011 12:00	299.815	6:56:41 AM	56.826	230570.76
9/30/2011 12:00	165.446	9/29/2011 14:47	435.073	6:30:31 AM	71.032	238242.24
10/1/2011 12:00	163.966	9/30/2011 12:00	279.986	9:32:11 AM	74.288	236111.18
10/2/2011 12:00	167.814	10/1/2011 13:31	330.004	8:16:45 AM	63.929	241651.73
10/3/2011 12:00	182.612	10/2/2011 14:09	302.183	6:52:05 AM	69.256	262958.38
10/4/2011 12:00	180.54	11:37:59 AM	298.336	7:38:19 AM	68.96	259981.04
10/5/2011 12:00	164.558	11:46:41 AM	294.784	7:35:41 AM	54.162	236960.92
10/6/2011 12:00	193.563	11:47:23 AM	287.089	8:41:29 AM	97.077	278730.56

10/7/2011 12:00	177.877	10/6/2011 12:05	284.425	7:29:31 AM	73.696	256145.27
10/8/2011 12:00	175.213	10/7/2011 17:13	298.336	7:33:33 AM	57.714	252306.58
10/9/2011 12:00	176.101	10/8/2011 16:05	325.861	6:44:33 AM	78.135	253585.14
10/10/2011 12:00	182.908	10/9/2011 15:25	300.111	8:44:17 AM	69.848	263387.66
10/11/2011 12:00	176.101	10/10/2011 12:05	298.632	6:08:35 AM	63.633	253585.15
10/12/2011 12:00	169.59	11:45:45 AM	298.04	8:06:05 AM	66.001	244208.87
10/13/2011 12:00	167.518	11:55:53 AM	298.04	9:10:01 AM	69.256	241225.63
10/14/2011 12:00	163.078	10/13/2011 12:05	322.605	5:51:25 AM	58.01	234832.62
10/15/2011 12:00	155.975	10/14/2011 12:05	277.618	6:14:37 AM	63.041	224604.00
10/16/2011 12:00	179.357	10/15/2011 13:37	315.502	9:37:59 AM	85.831	258276.36
10/17/2011 12:00	196.523	10/16/2011 13:39	308.102	9:15:43 AM	86.719	282989.26
10/18/2011 12:00	168.702	10/17/2011 12:00	286.793	5:46:25 AM	63.929	242930.31
10/19/2011 12:00	171.365	10/18/2011 12:05	311.358	5:19:51 AM	80.207	246766.01
10/20/2011 12:00	159.527	10/19/2011 12:15	260.452	8:18:19 AM	63.041	229718.29
10/21/2011 12:00	161.894	10/20/2011 13:45	250.389	8:52:31 AM	66.593	233127.92
10/22/2011 12:00	162.782	10/21/2011 15:00	263.115	8:56:25 AM	66.889	234409.23
10/23/2011 12:00	161.894	10/22/2011 14:38	292.416	8:44:43 AM	68.96	233127.92
10/24/2011 12:00	171.069	10/23/2011 14:39	292.712	9:03:53 AM	64.817	246337.09
10/25/2011 12:00	177.877	10/24/2011 12:10	292.416	6:06:41 AM	76.36	256139.35
10/26/2011 12:00	167.222	11:57:37 AM	274.954	6:00:21 AM	62.449	240802.18
10/27/2011 12:00	164.262	11:51:29 AM	282.649	8:26:47 AM	66.889	236537.42
10/28/2011 12:00	161.302	10/27/2011 12:07	276.73	8:16:43 AM	66.593	232275.45
10/29/2011 12:00	160.119	10/28/2011 12:03	271.107	9:43:31 AM	63.041	230570.79
10/30/2011 12:00	178.173	10/29/2011 13:39	351.61	9:30:49 AM	75.176	256568.55
10/31/2011 12:00	172.253	10/30/2011 14:35	295.08	8:23:25 AM	65.409	248044.74
11/1/2011 12:00	178.469	11:58:23 AM	278.802	8:06:05 AM	82.871	256994.77

11/2/2011 12:00	254.236	11/1/2011 12:29	580.689	6:05:57 AM	76.656	366100.28
11/2/2011 12:23		POWER FAILURE		POWER DOWN		
11/2/2011 14:17		POWER FAILURE		POWER UP		
11/3/2011 12:00	156.271	11:56:51 AM	295.672	11/2/2011 14:17	0	207186.68
11/4/2011 12:00	237.662	11/3/2011 14:43	558.491	7:22:11 AM	74.288	342233.42
11/5/2011 12:00	168.702	11/4/2011 12:00	276.73	6:00:47 AM	87.606	242930.31
11/6/2011 12:00	178.469	11/5/2011 15:10	311.654	10:24:13 AM	63.041	256994.77
11/7/2011 12:00	174.621	11/6/2011 13:32	289.457	10:05:53 AM	69.848	251457.15
11/8/2011 12:00	262.819	11/7/2011 13:36	596.671	6:45:51 AM	70.144	378455.56
11/9/2011 12:00	163.67	11/8/2011 12:46	300.111	8:54:29 AM	63.633	235685.08
11/10/2011 12:00	160.415	11/9/2011 12:42	285.609	7:20:51 AM	70.144	230999.56
11/11/2011 12:00	162.19	11/10/2011 12:59	283.537	9:28:05 AM	76.36	233551.33
11/12/2011 12:00	158.935	11/11/2011 12:49	305.143	9:56:59 AM	64.225	228865.95
11/13/2011 12:00	171.661	11/12/2011 16:34	311.358	10:36:55 AM	66.593	247195.14
11/14/2011 12:00	180.54	11/13/2011 14:32	307.215	10:05:19 AM	70.736	259975.02
11/15/2011 12:00	167.518	11/14/2011 12:58	308.99	7:54:37 AM	61.857	241225.63
11/16/2011 12:00	166.038	11/15/2011 12:58	282.353	10:06:09 AM	68.96	239094.58
11/17/2011 12:00	163.078	11/16/2011 12:40	284.129	7:40:23 AM	74.288	234832.61
11/18/2011 12:00	167.814	11/17/2011 12:45	302.775	10:11:15 AM	74.88	241651.73
11/19/2011 12:00	170.182	11/18/2011 13:24	286.793	11:00:05 AM	89.678	245061.35
11/20/2011 12:00	169.294	11/19/2011 14:34	310.47	10:19:31 AM	62.449	243779.95
11/21/2011 12:00	161.302	11/20/2011 14:32	273.474	9:12:13 AM	61.857	232278.14
11/22/2011 12:00	173.437	11/21/2011 16:09	261.044	7:34:31 AM	70.44	249749.42
11/23/2011 12:00	155.383	11/22/2011 13:17	244.469	7:57:01 AM	60.969	223754.25
11/24/2011 12:00	160.119	11/23/2011 16:19	250.685	10:32:55 AM	69.848	230568.12
11/25/2011 12:00	151.24	11/24/2011 14:39	298.336	10:36:15 AM	65.113	217784.87

11/26/2011 12:00	159.823	11/25/2011 16:10	268.443	10:31:19 AM	72.808	230144.55
11/27/2011 12:00	163.374	11/26/2011 14:34	292.712	9:12:33 AM	67.481	235258.86
11/28/2011 12:00	167.814	11/27/2011 17:59	270.515	7:37:09 AM	66.889	241651.73
11/29/2011 12:00	166.038	11/28/2011 13:26	285.905	8:38:15 AM	65.705	239094.58
11/30/2011 12:00	157.751	11/29/2011 13:02	294.488	9:14:33 AM	57.418	227161.14
12/1/2011 12:00	159.823	11/30/2011 13:04	266.371	6:45:31 AM	70.144	230144.55
12/2/2011 12:00	165.15	12/1/2011 13:42	279.394	7:54:01 AM	72.512	237815.98
12/3/2011 12:00	166.334	12/2/2011 13:31	283.241	10:09:41 AM	78.135	239520.80
12/4/2011 12:00	167.814	12/3/2011 16:21	298.632	10:08:01 AM	68.96	241651.73
12/5/2011 12:00	166.334	12/4/2011 17:29	278.21	8:52:35 AM	65.409	239520.80
12/6/2011 12:00	169.59	12/5/2011 13:06	301.591	7:03:35 AM	69.552	244208.87
12/7/2011 12:00	171.069	12/6/2011 13:05	314.614	7:38:55 AM	79.615	246339.94
12/8/2011 12:00	176.101	12/7/2011 13:18	268.443	7:59:33 AM	84.943	253585.14
12/9/2011 12:00	164.558	12/8/2011 13:30	278.506	7:53:53 AM	68.073	236963.66
12/10/2011 12:00	163.67	12/9/2011 13:11	299.223	10:05:49 AM	67.185	235685.08
12/11/2011 12:00	167.518	12/10/2011 15:58	316.39	10:13:13 AM	63.337	241225.63
12/12/2011 12:00	168.406	12/11/2011 17:54	276.73	8:01:55 AM	68.96	242504.21
12/13/2011 12:00	170.182	12/12/2011 13:06	301.295	9:34:07 AM	69.256	245067.03
12/14/2011 12:00	162.19	12/13/2011 12:49	289.752	7:40:25 AM	67.185	233548.63
12/15/2011 12:00	167.814	12/14/2011 13:34	271.107	8:35:25 AM	69.256	241651.73
12/16/2011 12:00	165.15	12/15/2011 13:24	284.129	9:53:43 AM	67.185	237821.49
12/17/2011 12:00	172.845	12/16/2011 13:11	279.394	10:05:17 AM	74.584	248891.32
12/18/2011 12:00	162.19	12/17/2011 14:10	281.465	9:01:21 AM	68.369	233554.03
12/19/2011 12:00	168.11	12/18/2011 18:04	261.044	7:42:05 AM	77.544	242077.95
12/20/2011 12:00	181.428	12/19/2011 13:08	258.972	8:10:03 AM	102.997	261256.62
12/21/2011 12:00	185.868	12/20/2011 13:02	279.394	8:17:43 AM	82.279	267649.63

12/22/2011 8:55		POWER FAILURE		POWER DOWN		
12/22/2011 8:55		POWER FAILURE		POWER UP		
12/22/2011 12:00	178.469	12/21/2011 15:03	249.797	8:55:19 AM	0	256962.05
12/23/2011 12:00	178.173	12/22/2011 15:39	260.156	9:26:33 AM	100.925	256568.55
12/24/2011 12:00	178.765	12/23/2011 16:16	285.609	8:21:11 AM	84.055	257420.87
12/25/2011 12:00	188.827	12/24/2011 14:35	332.372	10:14:29 AM	79.615	271911.43
12/26/2011 12:00	155.679	12/25/2011 14:37	274.658	10:49:37 AM	62.745	224177.76
12/27/2011 12:00	166.926	12/26/2011 16:35	295.376	10:25:33 AM	65.113	240373.14
12/28/2011 12:00	153.903	12/27/2011 16:02	272.586	8:44:33 AM	60.377	221620.59
12/29/2011 12:00	153.015	12/28/2011 15:36	265.483	10:18:03 AM	66.297	220342.03
12/30/2011 12:00	159.527	12/29/2011 16:48	279.986	8:29:59 AM	63.337	229718.29
12/31/2011 12:00	162.486	12/30/2011 16:42	283.241	10:23:55 AM	67.481	233980.26
1/1/2012 12:00	168.11	12/31/2011 16:04	322.901	10:52:03 AM	63.929	242077.95
1/2/2012 12:00	148.28	1/1/2012 14:36	250.389	11:36:37 AM	61.561	213523.07
1/3/2012 12:00	167.222	1/2/2012 15:24	294.192	10:26:35 AM	64.521	240799.39
1/4/2012 12:00	156.271	1/3/2012 12:58	242.398	8:26:33 AM	66.593	225030.22
1/5/2012 12:00	159.527	1/4/2012 15:32	270.219	10:02:23 AM	63.337	229718.29
1/6/2012 12:00	159.823	1/5/2012 13:00	251.869	7:47:35 AM	61.561	230141.89
1/7/2012 12:00	160.415	1/6/2012 16:13	239.142	10:22:15 AM	69.848	230999.56
1/8/2012 12:00	170.773	1/7/2012 17:00	295.672	10:43:39 AM	67.185	245913.70
1/9/2012 6:37		POWER FAILURE		POWER DOWN		
1/9/2012 8:56		POWER FAILURE		POWER UP		
1/9/2012 12:00	176.693	1/8/2012 14:35	286.201	9:38:17 AM	0	229688.86
1/10/2012 12:00	168.702	1/9/2012 13:06	259.86	9:36:23 AM	66.297	242930.31
1/11/2012 12:00	159.231	1/10/2012 13:04	298.928	10:22:05 AM	59.194	229292.21
1/12/2012 12:00	167.222	1/11/2012 13:15	275.25	9:41:33 AM	71.624	240799.39

1/13/2012 12:00	164.262	1/12/2012 13:06	304.255	9:12:21 AM	60.673	236537.42
1/14/2012 12:00	166.334	1/13/2012 13:03	274.362	10:39:53 AM	67.185	239520.81
1/15/2012 12:00	170.182	1/14/2012 16:09	300.999	10:46:13 AM	61.561	245061.36
1/16/2012 12:00	161.007	1/15/2012 16:52	279.69	8:06:41 AM	60.969	231849.36
1/17/2012 12:00	173.437	1/16/2012 16:19	277.026	10:00:11 AM	66.889	249749.42
1/18/2012 12:00	167.222	1/17/2012 13:03	301.591	8:03:51 AM	70.44	240799.39
1/19/2012 12:00	159.823	1/18/2012 13:03	284.721	10:14:53 AM	63.337	230144.55
1/20/2012 12:00	160.119	1/19/2012 13:05	279.394	8:19:13 AM	64.817	230570.79
1/21/2012 12:00	158.639	1/20/2012 13:18	273.178	10:52:07 AM	56.826	228439.73
1/22/2012 12:00	223.456	10:56:33 AM	3232.856	10:47:01 AM	60.377	321776.21
1/23/2012 12:00	175.509	1/22/2012 12:33	3232.856	8:22:29 AM	64.521	252732.81
1/24/2012 12:00	168.11	1/23/2012 13:22	274.066	7:55:43 AM	73.696	242075.15
1/25/2012 12:00	165.15	1/24/2012 13:20	284.721	7:47:11 AM	60.377	237818.73
1/26/2012 12:00	155.679	1/25/2012 13:23	259.86	9:59:37 AM	60.377	224177.76
1/27/2012 12:00	168.406	1/26/2012 13:05	263.411	10:43:01 AM	80.799	242504.21
1/27/2012 14:20		POWER FAILURE		POWER DOWN		
1/27/2012 14:23		POWER FAILURE		POWER UP		
1/28/2012 12:00	161.007	1/27/2012 13:11	279.986	1/27/2012 14:24	0	231304.62
1/29/2012 12:00	173.437	1/28/2012 16:46	310.174	10:29:47 AM	67.777	249749.42
1/30/2012 12:00	167.518	1/29/2012 16:08	294.488	7:08:11 AM	70.736	241228.42
1/31/2012 12:00	170.773	1/30/2012 13:26	295.968	6:55:51 AM	68.073	245910.85
2/1/2012 12:00	160.711	1/31/2012 13:43	291.232	8:30:55 AM	63.633	231423.11