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Alternative Futures Analysis of Farmington Bay Wetlands in the Great Salt Lake Ecosystem

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Executive Summary

Introduction

The Farmington Bay wetlands are an integral part of the Great Salt Lake Ecosystem. The wetlands support the delivery of a wide range of ecosystem services including support for avian habitat and control of excess nutrient pollutants. The principal risks posed to the wetlands are the conversion to upland development, degradation from pollutants and change in freshwater availability.

Purpose, Objectives and Approach

An Alternative Futures Analysis (AFA) was conducted to demonstrate how models can be used to evaluate landscape design scenarios developed for the Farmington Bay area of the Great Salt Lake. Scenarios were developed which featured the design of a conservation "future" focused on a set of wetland protection, restoration, and conservation practices. The conservation design was contrasted with scenarios that reflect current day wetland management practices and an extrapolation of those practices into the future. Each of the future scenarios was described in context with the average water level elevation of the Great Salt Lake and a high water level elevation (4,200 feet and 4,212 feet, respectively). In addition, a set of wetland "templates" was developed and embedded into each scenario to aid scenario design and evaluation. Each template represents a typical cluster or complex of wetlands with a dominate wetland class: impoundment wetlands, playa wetlands and fringe/emergent wetlands. Evaluation of the scenarios was based on risks to avian habitat support caused by degradation in wetland abundance, distribution, and condition. The evaluation entailed the use of four ecological modeling approaches. A wetland landscape profile was developed to track change in wetland abundance, by class, across the scenarios. A Geographic Information System (GIS) based avian wetland habitat assessment (AWHA) was developed to predict the availability of suitable avian habitat. The ArcView Generalized Watershed Loading Function (AVGWLF) model was calibrated to predict nutrient loads to the wetlands. A wetland cellular water quality model was developed to evaluate nutrient retention in impoundment class wetlands. No specific analysis was conducted to determine the effects of nutrient loads on the ecological condition of receiving wetlands.

Major Significance

The development and demonstration of the evaluation models was the key objective of the study and the results are presented in detail. The interpretation of those results, in terms of setting wetland management goals for the study area, is purposely kept general in nature. New scenario development and community-based planning can take advantage of this first iteration of scenarios and evaluation models. For example, general project results reveal that most (97%) of wetlands in the study area are located within an elevation band of 4,200 feet to 4,217 feet. Results from the AFA show a dramatic loss of wetlands in the Plan Trend 4,212 feet and the Conservation 4,212 feet scenarios. The Plan Trend scenarios observe the greatest decline in the most suitable category of avian habitat for three bird groupings: migratory shorebirds, migratory waterbirds, and migratory waterfowl.

The Conservation 4,200 scenario protects the most wetland acreage and highest category of suitable avian habitat. The Plan Trend 4,200 scenario observes the greatest decline in the highest class of suitable avian habitat. A substantial increase in watershed loading of nutrients delivered to all the templates for the Conservation and Plan Trend scenarios was predicted using the AVGWLF model. Results from this model indicate that total phosphorus and total nitrogen loads delivered to the templates from the Jordan River watershed are heavily influenced by the two major point sources in the Jordan Basin. The wetland water quality model predicted a removal efficiency of 74% for phosphorus, and -11% for sediment for Impoundment class wetlands. The approach used for this project, incorporating GIS based evaluation models and including an Alternative Futures Analysis, is a transparent way of organizing and communicating complex scientific information to a diverse group of stakeholders and improving communication among the stakeholders.

The authors of this report encourage examination of the methods and results produced by this research project. Our hope is that lessons learned will be applied in renewed effort toward envisioning ways to sustain and improve the health of the Great Salt Lake Ecosystem.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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Acknowledgements

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Acronyms

AFA	Alternative Futures Analysis
AMSL	Above Mean Sea Level
APEL	American Pelican
APWA	American Public Works Association
ASCE	American Society of Civil Engineers
AVGWLF	ArcView Generalized Watershed Loading Function
AWHA	Avian Wetland Habitat Assessment Model
DCDCED	Davis County Department of Community and Economic Development
DEM	Digital Elevation Model
EWRI	Environmental and Water Resources Institute
FEMA	Federal Emergency Management Administration
FHWA	Federal Highway Administration
GIS	Geographic Information System
GSL	Great Salt Lake
GWLF	Generalized Watershed Loading Function
HGM	Hydrogeomorphology
HLR	Hydrologic Loading Rate
IWS	Institute for Watershed Sciences
KLSCP	K, LS, and CP (factors used in the Universal Soil Loss Equation)
LBCR	Long Billed Curlew
MEA	Millennium Ecosystem Assessment
MGSG	Migratory Shorebirds
MGWB	Migratory Waterbirds
MGWF	Migratory Waterfowl
N	Nitrogen
NCSH	Nesting Colonial Shorebirds
NCWB	Nesting Colonial Waterbirds
NPS	Nonpoint Source
NRMRL	National Risk Management Research Laboratory
NWI	National Wetland Inventory
P	Phosphorous
PER	Perimeter Expansion Rate
POTW	Publicly Owned Treatment Works
PSIE	Pennsylvania State Institutes of the Environment
SLCPZ	Salt Lake County Planning & Zoning Division Department of Community Development
SLCWRPR	Salt Lake County Water Resources Planning and Restoration
SNPL	Snowy Plover
SSURGO	Soil Survey Geographic (Database)
STORET	STOrage and RETrieval (System for Water Quality Data)
TMDL	Total Maximum Daily Load
TP	Total Phosphorous
TSS	Total Suspended Solids

USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
USGS	US Geological Service
USLE	Universal Soil Loss Equation
UTDEQ	Utah Department of Environmental Quality
UTDNR	Utah Department of Natural Resources
UTDOT	Utah Department of Transportation
UTDWQ	Utah Division of Water Quality
UTDWRe	Utah Division of Water Resources
UTDWRi	Utah Division of Water Rights
WAQSP	Water Quality Stewardship Plan
WERF	Water Environment Research Foundation

1.0 INTRODUCTION

1.1 Problem Statement

The Farmington Bay wetlands provide essential habitat for migratory shorebirds, waterfowl, and waterbirds from both the Pacific and Central flyways of North America (Paul and Manning, 2002). The valued wetland resource is at risk from encroaching development along the Wasatch Front. Current trends toward intensification of land uses and increasing water uses are likely to continue as future projections of population growth in Davis County and Salt Lake County are realized. An average annual population increase of 2.0% and 1.9% was projected for the counties, respectively, between 2005 and 2020 (DCDCED, 2005; SLCWRPR, 2008; SLC, 2009). If population growth rates continue as forecast, then there will be significant impact to the quantity and quality of wetlands surrounding Farmington Bay.

For example, effluent from nine Publicly Owned Treatment Works (POTWs) discharge to waterbodies and wetlands adjacent to Farmington Bay. Pollution from this type of discharge has been shown to be detrimental to the function and health of wetlands (Mitsch and Gosslink, 2000). The problem is exacerbated by continued wetland loss resulting from upland development. Future growth projections for the area signify an increase in pollutant loading, additional impacts to wetland hydrology, and more wetland loss due to urban land conversion.

At present, the condition and vulnerability of the Farmington Bay wetlands is not well understood. Efforts are underway to assess the nutrient enrichment problem affecting the Farmington Bay wetlands (Hoven and Miller, 2009). The effects of groundwater flow disruption also have been studied (Bishop et al., 2009) and other work is underway to prioritize habitat areas in need of protection (D. Paul, Avian West, personal communication). State and local environmental managers will benefit from this new information if it can be structured in a way that helps integrate and guide ongoing wetland management activities. An integrated strategy that protects both wetland quantity and quality is a prerequisite for promoting and sustaining the delivery of ecosystem services, including avian use support.

1.2 Objective

This research project was conducted to develop a way of forecasting and quantifying the cumulative effect of management practices on the future management of wetland ecosystem services. The study is focused on wetland support for biodiversity, and specifically examined management risks to the avian habitat. Retention, recovery, and removal of excess nutrients by the wetland resource were also analyzed. No specific analysis was conducted to determine the effects of nutrient loads on the ecological condition of receiving wetlands. It was beyond the scope of the project. Future efforts to determine the effects of nutrient loads on the ecological condition of receiving wetlands will likely involve the systematic monitoring and assessment of wetlands in the project area over time. Information about the development and deployment of a wetland-monitoring program for the Great Salt Lake can be found on the Utah Department of Environmental Quality website (http://www.deq.utah.gov/Issues/gslwetlands/index.htm).

The study's design is structured around use of the Alternative Futures Approach (AFA) developed by Carl Steinitz (1990). The AFA has been applied to a variety of temporal landscape change assessments throughout the United States (Steinitz, et al., 2002). Toth (2002) applied a similar approach in the Wasatch Front region of Utah. AFA is a planning framework developed to help communities consider their options for managing land and water use. This type of planning helps communities articulate and understand the relationships between and consequences of different decision or management scenarios.

An AFA project generates a collection of alternative landscape design scenarios for a geographical area. The scenarios are illustrated on maps by showing future land use. Plan trend scenarios depict future land use based on assumed implementation of current day management practices into the future. Conservation-based scenarios depict future land use based on assumed implementation of a plausible set of innovative protection, restoration, and treatment practices. Once developed, AFA design scenarios are modeled and evaluated with respect to a set of ecological endpoints or outcomes. In this project, the ecological outcomes of water quality and avian habitat use are interpreted as forecasts of ecosystem services. The application of evaluation models, to a hypothetical set of landscape design scenarios, demonstrates how the models can be used in community planning projects within the Great Salt Lake ecosystem. The evaluation models are the major product of this research project.

2.0 METHODS

2.1 Alternative Future Approach

The Alternative Futures Approach served as the study framework for this research project. The AFA consists of six levels of inquiry. Each level is distinguished with a design-type question. The questions helped guide the development and evaluation of scenarios for managing Farmington Bay wetlands in context with their surrounding environment. Individual analytical tasks were completed with the objective of answering each of the questions. Subsections within this Methods section and the remaining sections of the report correlate with a specific design question.

The six design questions used to structure the AFA are:

(a*) How should the landscape be described? How does the landscape operate?*
See Section 2.2: Study Area

(b) *By what actions might the current representation of the landscape be altered?*
See Section 2.3: Scenarios and Templates

(c) *How does one judge whether the current state of the landscape is working well?*
See Section 2.4: Ecosystem Services

(d) *What predictable differences might the changes cause?*
See Section 3.0: Results

(e) *"How is a decision to change or conserve the landscape to be made?*
Section 4.2: Setting Wetland Goals

To complete the use of AFA, each of the design questions is addressed a second time in the Discussion section of this report. The flow of that discussion presents the question and topics in reverse order. In this manner, the discussion sets the stage for a second iteration of the AFA. The second iteration can be conducted by government officials and community stakeholders interested in sustaining the delivery of ecosystem services associated with Farmington Bay wetlands.

2.2 Study Area Description

The study area consists of the contributing watersheds and shorelands of Farmington Bay. Farmington Bay is a large inlet located in the southeastern quadrant of Great Salt Lake (GSL). Farmington Bay is located northwest of Salt Lake City and includes parts of Salt Lake County and Davis County (Figure 1). The major geographical features of the study are: The Great Salt Lake, the Jordan River Watershed, and the Farmington Bay Wetlands.

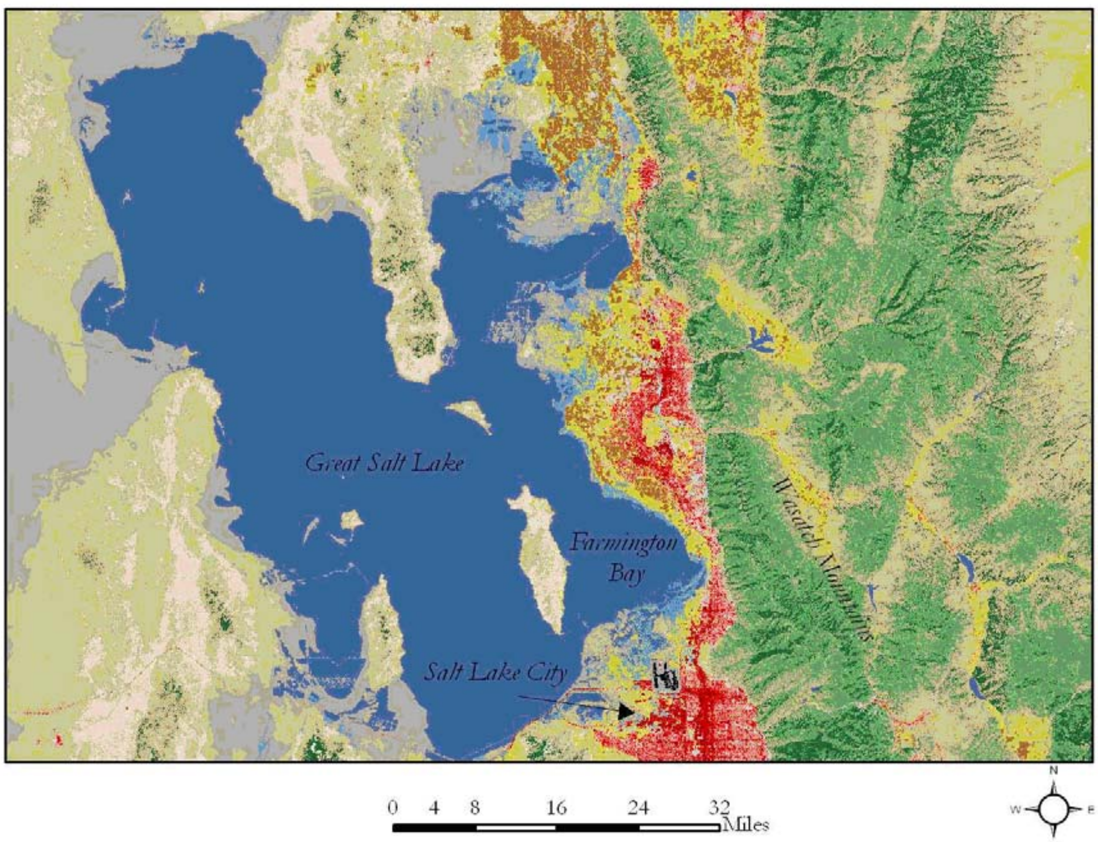


Figure 1. Great Salt Lake Eco-region and Farmington Bay, NLCD 2001.

The Great Salt Lake

The GSL is the largest saline lake in North America and the fourth largest in the world. It measures approximately 128 kilometers at its greatest length, 2,414 square kilometers in area, and 4 meters in average depth. The GSL is a terminal lake of recent geologic age (approximately 13,000 years old). It is a remnant of Lake Bonneville, a pluvial Pleistocene lake. The Great Salt Lake ecosystem includes 161,880 hectares (approximately 400,000 acres) of wetlands in addition to other associated uplands and drainage systems.

Its large surface area and low topographical relief make the Great Salt Lake very sensitive to climate-related fluctuations. Long-term patterns and trends in the rise and fall of the lake level are difficult to predict, although lake level is essentially determined by the balance between inflows and outflows. Inflows come from three major rivers (Bear River, Weber River, and Jordan River) and precipitation. The only outflow is evaporation. Evaporation is sensitive to lake area, which changes with lake level according to the bathymetry. Evaporation is also sensitive to salinity, which changes the lake surface saturation vapor pressure. Salinity changes with lake volume as the total salt load in the lake becomes concentrated or diluted (Mohammed, 2006). The level of the Great Salt Lake has fluctuated dramatically over the years; the lowest water surface elevation in recent history was about 4,191 feet above mean sea level (AMSL), and the highest elevation was approximately 4,212 feet AMSL in 1986 (UTDNR, 2000). In Farmington Bay, even small fluctuations in elevation can create drastic changes in the landscape. Figure 2 displays the difference in lake level between 1988 and 2003.

1988 **2003**

Figure 2. Level of Great Salt Lake in 1988 and 2003 (Miller and Hoven, 2007).

In recent years, the lake level has dropped significantly due to persistent drought in the region. Nevertheless, the lake-level continues to fluctuate erratically. Local, county, and state managers are kept mindful of the potential impacts associated with lake level fluctuation. Figure 3 displays a hydrograph for the Great Salt Lake for the period 1992 – 2008.

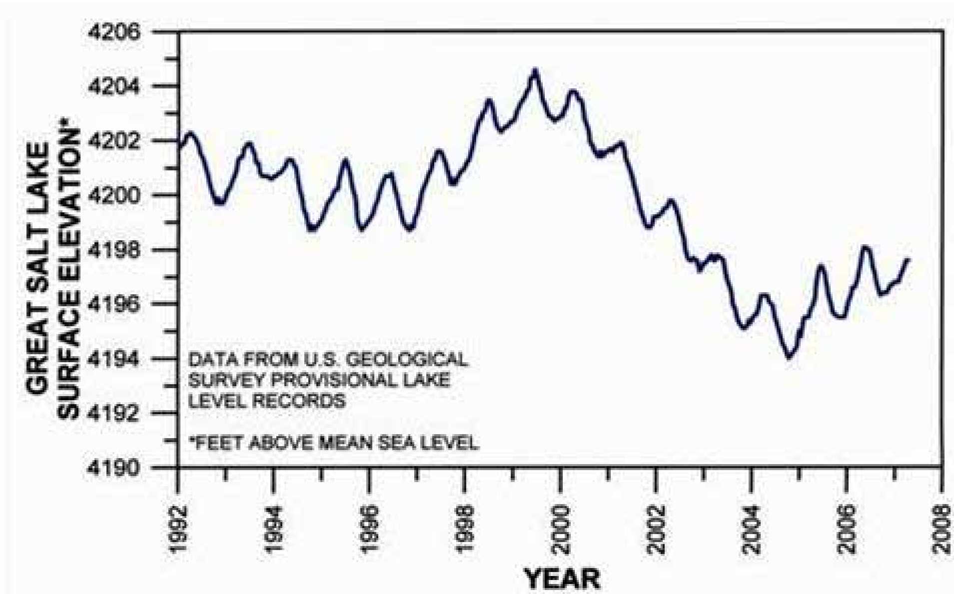


Figure 3. Hydrograph depicting Great Salt Lake surface elevation fluctuation at the South Arm from 1992-2008, USGS 2008.

Jordan River Watershed

Figure 4 displays the Jordan River Watershed and its conveyances. The Jordan River originates at the north end of Utah Lake, where a pumping station has been used to regulate its flow. It flows north past the Turner Dam, where water is diverted into a series of canals. The Jordan River is then impounded and diverted in numerous locations for agricultural irrigation and municipal and industrial purposes (CH2MHILL, 2005). The river continues north into the Salt Lake City metropolitan area, where the outflows of the Central Valley Water Reclamation Facility and South Valley Water Reclamation Facility are introduced to the river. The majority of the flow is eventually diverted to the Surplus Canal. The remaining flow of the Jordan River disperses into impounded wetlands located in the southeast portion of Farmington Bay.

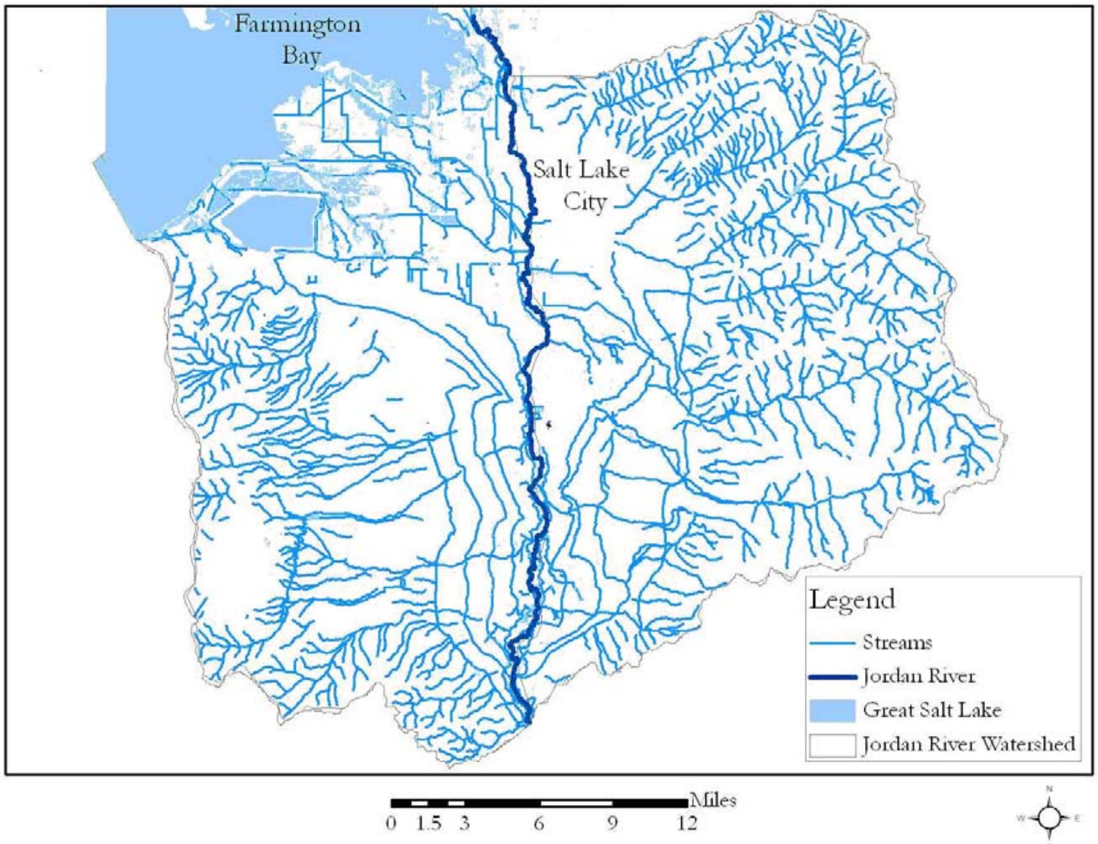


Figure 4. Jordan River basin and conveyances.

As the Jordan River flows through its watershed and into Farmington Bay, the river receives water from many streams flowing down from the Wasatch and Oquirrh mountain ranges. It also receives water from sources outside of the basin via several aqueducts and canals.

Farmington Bay Wetlands

The Farmington Bay wetlands are part of a shorelands environment that is defined by elevation. The upland boundary for the shorelands is 4,230 feet, and the lowland boundary is 4,200 feet above mean sea level (AMSL). Although the lowland boundary will change with the rise and fall of lake level, 4,200 feet is considered the historical average lake level. It serves as a boundary for our study area. See Appendix A for details on how these boundaries were quantified for the AFA.

The wetlands of the Farmington Bay receive runoff and treated effluent from the Salt Lake and Davis County areas, and stream flows from the Jordan River and local canyons (Myers and Miller, 2007). The contributing tributaries in Davis County all originate from the Wasatch Range. They are Baird Creek, Kays Creek, and Holmes Creek, and they comprise the majority of drainage area for the eastern wetlands in Farmington Bay. The Davis County drainage basins are presented in Figure 5.

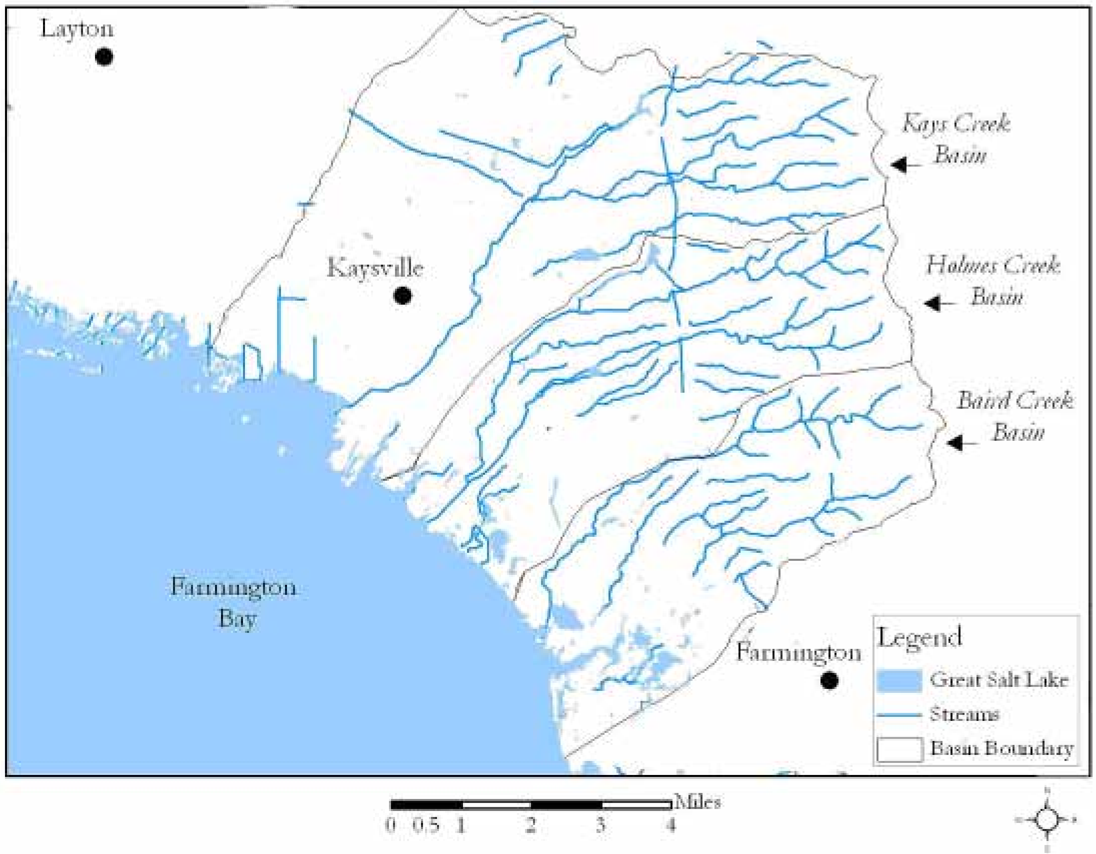


Figure 5. Baird Creek, Holmes Creek, and Kays Creek basins and conveyances.

The hydrology of the shorelands environment is deltaic in structure, but highly altered. All streams draining to Farmington Bay have been altered for agricultural and urban uses. Flow is predominately conveyed to and through the shorelands area in a series of canals and drainage ditches. The classes of wetlands that have developed in response to the drainage network vary in terms of their hydrogeomorphology (HGM) and vegetation. Many of the wetland systems have been impounded for waterfowl management uses.

A functional wetland classification system was generated to reflect the highly variable and dynamic conditions of the landscape. The classification system takes into account the HGM and vegetation characteristics of individual wetland patches. It also factors the abundance, distribution, and condition of those patches within the larger shorelands context and in relationship to the delivery of ecological services.

The four wetland classes developed for the study are: fringe, impoundment, playa, and emergent. The wetlands were mapped by spatially organizing and reclassifying individual 2008 National Wetland Inventory (NWI) data (USFWS, 2008). The reclassification is displayed in Figure 6.

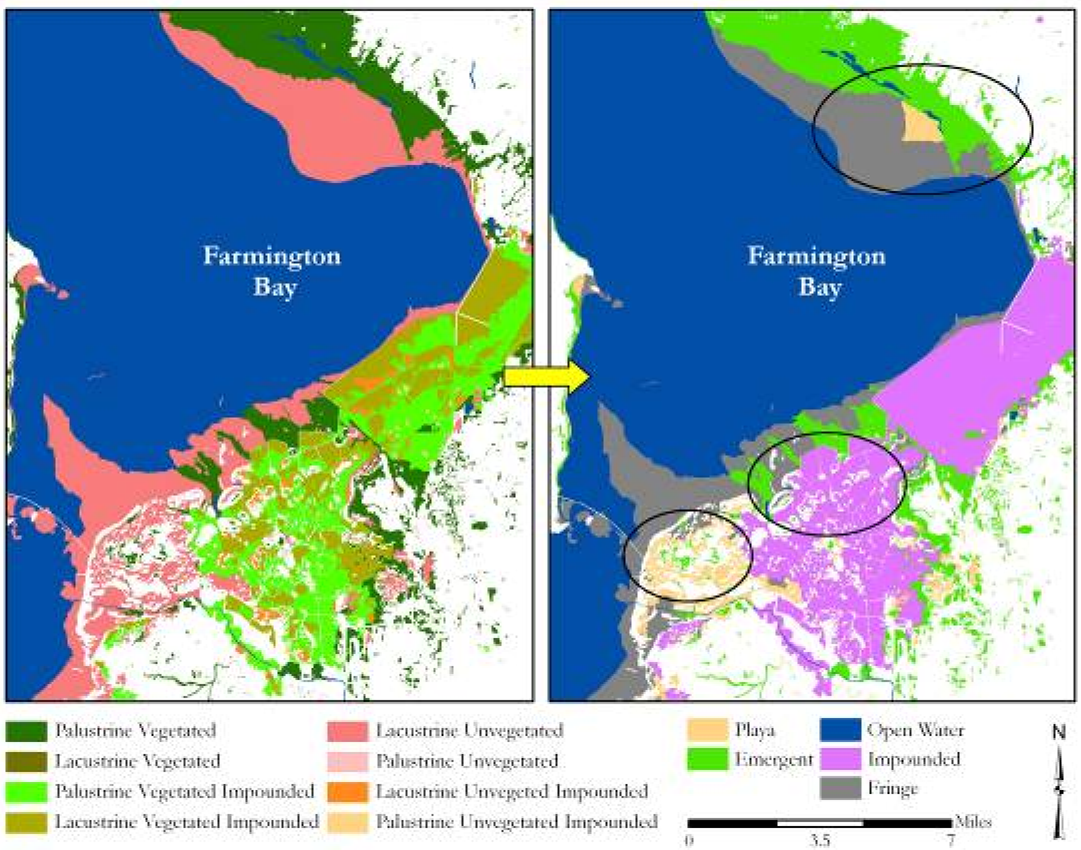


Figure 6. Functional wetland classification based on the 2008 NWI data.
*The black ovals represent the general location of each template. The final functional wetland classification is defined and represented on the right map panel as follows: White = (upland); Purple = Impounded; Gray = Fringe; Dark Blue = Open water; Green = Emergent; and Peach = Playa.

Playa wetlands are classified by NWI data as palustrine unconsolidated shore. Playas generally occur in topographic depressions (i.e., closed elevation contours) allowing for an accumulation of surface water. Fringe wetlands are classified by NWI data as lacustrine emergent, lacustrine aquatic bed, and lacustrine unconsolidated shore. Fringe wetlands are adjacent to lakes, where the water elevation of the lake maintains the water table in the wetland. The boundary of the fringe wetlands in Farmington Bay is the edge of the seasonally flooded zone, as identified by NWI data. The emergent wetlands are classified by NWI as palustrine emergent. Emergent wetlands are generally found in association with the discharge of groundwater to the land surface or sites with saturated overflow with no channel formation. The predominant source of water is groundwater or interflow discharging at the land surface. The impoundment wetlands are a conglomerate of all NWI wetland classes in the Farmington Bay region that are controlled by engineered structures. Appendix B presents a more detailed discussion of the base-line NWI classification.

2.3 Management Scenarios and Template Descriptions

The project team developed five scenarios and three templates for the project. Each scenario is a mapped representation of land use across the study area, including wetland management practices within the shorelands of Farmington Bay. The set of scenarios depict the current landscape setting and four alternative visions of the future.

Each future scenario reflects a common set of urban growth and water use/availability projections for broader study area. The scenarios diverge relative to specific wetland and habitat management assumptions directed within the Farmington Bay shorelands. The assumptions are correlated to variables with the evaluation models used in the study. The future scenarios selected for this project are as follows: a) Plan Trend 4,200; average lake level ; b) Conservation 4,200; average lake level; c) Plan Trend 4,212; high lake level and d) Conservation 4,212; high lake level

The templates are a representation of "typical" landscape patches that are common across the set of scenarios. They are presented as functional units of the landscape. The templates are used to analyze how different classes of wetland patches along the shorelands respond to the management practices assumed in the broader scenarios. The three templates are: a) Impoundment Template, b) Fringe/Emergent Template, and c) Playa Template.

2.3.1 Current Scenario 2003

The current scenario is a baseline for measuring the cumulative effects of land use and water use change, as predicted for each future scenario. Data from the year 2003 were the most readily available for the past ten years; therefore 2003 was the year selected for the Current Scenario. Figure 7 presents a map of current land use and wetland class that characterize the current scenario.

For Salt Lake County, current water availability estimates were obtained for the Jordan River Watershed from the 2005 CH2MHILL's Flow and Return Study conducted for the Recycled Water Coalition (CH2MHILL, 2005). Annual estimates of ground and surface water withdrawals for different uses (e.g., municipal, agricultural) were obtained from publically available state and county reports (UTDNR, 1997; SLCWRPR, 2008; SLC, 2009). Assignment of withdrawals for the different months was based on observed weather patterns, stream flows, and seasonality of water usage.

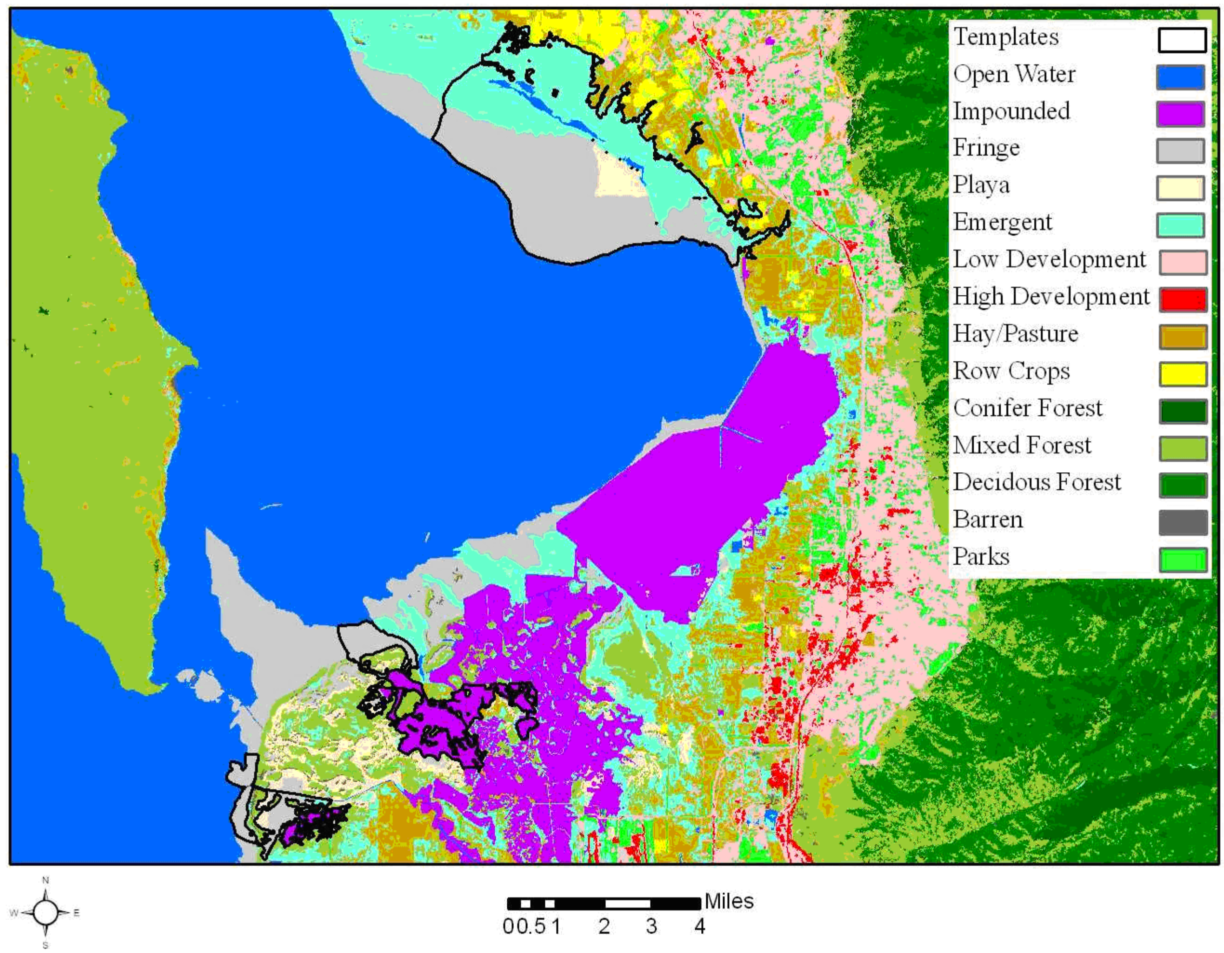


Figure 7. Current Scenario: Land Use and Wetland GIS Layers.

Point source discharge data were obtained from the EPA STORET database (USEPA, 1996; 2006a). Turner Dam flows and irrigation canal flows were obtained from the Utah Division of Water Rights (UTDWRi, 2005). Measured monthly data were used where available and typically included: 1) canals with measured flow data and 2) point source dischargers.

In Davis County, annual estimates of water imported via the Davis Aqueduct were obtained from the Utah Geological Survey. It was assumed that the majority of this imported water was used for agriculture and that a certain amount would return to streamflow after irrigation. The basins in Davis County also contain one major point source, and data for flows and concentrations of nutrients and sediment from that facility were obtained from the EPA STORET database (USEPA, 1996; 2006a).

2.3.2 Future Scenarios

The four alternative future scenarios are based on land use projections for the year 2030. Those projections are available from development planning agencies in Salt Lake and Davis Counties. For example, Salt Lake County has produced estimates of land use change based on population projections to the year 2030 (WAQSP, 2009). These data were used in this study to adjust land use in the entire Jordan River Basin. Land Use adjustments were further adjusted using proposed changes presented by the Northwest Quadrant Master plan (SLCPZ, 2007).

Also, all four alternative future scenarios are based on the same set of assumptions about future water availability in 2030. Water availability reflects the flow return projections from wastewater treatment plants, groundwater discharge, municipal and industrial discharges, inputs from canal diversions and other withdrawals.

Future projected flow estimates from Salt Lake County wastewater treatment plants were obtained from the County and included an additional facility in Riverton (SLCWRPR, 2008). Future projected withdrawals for various uses in the year 2030 were estimated based on information from multiple sources (Utah Water Data Book, 1997 and CH2MHILL, 2005).

In Davis County, point source flow data were altered for the future scenarios based on population projections from the Central Davis Sewer District 2008 Operating Budget (CDSD, 2007). Assumptions were not made regarding future nutrient concentrations in wastewater flows.

2.3.3 Plan Trend 2030 Scenarios

Figure 8 presents a map of land use and wetland class that characterizes the Plan Trend scenario. The Plan Trend scenarios characterize the future landscape under two different water level elevations for the Great Salt Lake. One elevation is 4,200 feet. It is the average lake level and reflects associated landscape conditions. The other elevation is 4,212 feet. It is the highest lake level elevation. The two scenarios are called Plan Trend 4,200 and Plan Trend 4,212. Each of the Plan Trend scenarios assumes that current policies and development/conservation trends will continue into the future (Baker, et al. 2004). The Plan Trend scenarios were constructed based on projected population growth, land use change, increase in flow delivery and nutrient loads, and a decrease in the quantity of upland wetlands. For the Plan Trend scenario, wetlands and associated "interior habitat" above 4,212 feet elevation were removed from the land use data layer. Interior habitat is described in the next Section and Appendix C. Wetlands between the 4,212 feet and 4,217 feet elevation are assumed to be at risk from conversion, and are likewise converted within the scenario to upland land use. The design assumption is that "lost" wetlands will be replaced with a mix of low-density development and parks. Below 4,212 feet elevation, wetlands are assumed generally safe from development. The design assumption regarding loss of Plan Trend wetlands in the 4,212-4,217 feet elevation zone takes into account that the Federal Emergency Management Administration (FEMA) has established a critical elevation line for planning around Farmington Bay at 4,217 feet (SLCPZ, 2008). Development below 4,217 feet poses risk of significant damage to property, persons, and structures as lake levels increase and recede. Based on FEMA's evaluation, Salt Lake County and, to a lesser extent, Davis County adheres to a "no build" zone below 4,217 feet. For purposes of the Plan Trend scenario, the assumption is that development adapts to that restriction through engineering practices (e.g., elevated floodplain filling). The other design assumption is that the current extent of the invasive plant, *Phragmites*, will increase by a perimeter rate of 5 meters per year. The assumption is based on an average of perimeter expansion rate (PER) values (Phelps, 2005).

Phragmites is an invasive species that has been monitored and actively managed in the Farmington Bay wetlands. Appendix C presents additional information about *Phragmites*.

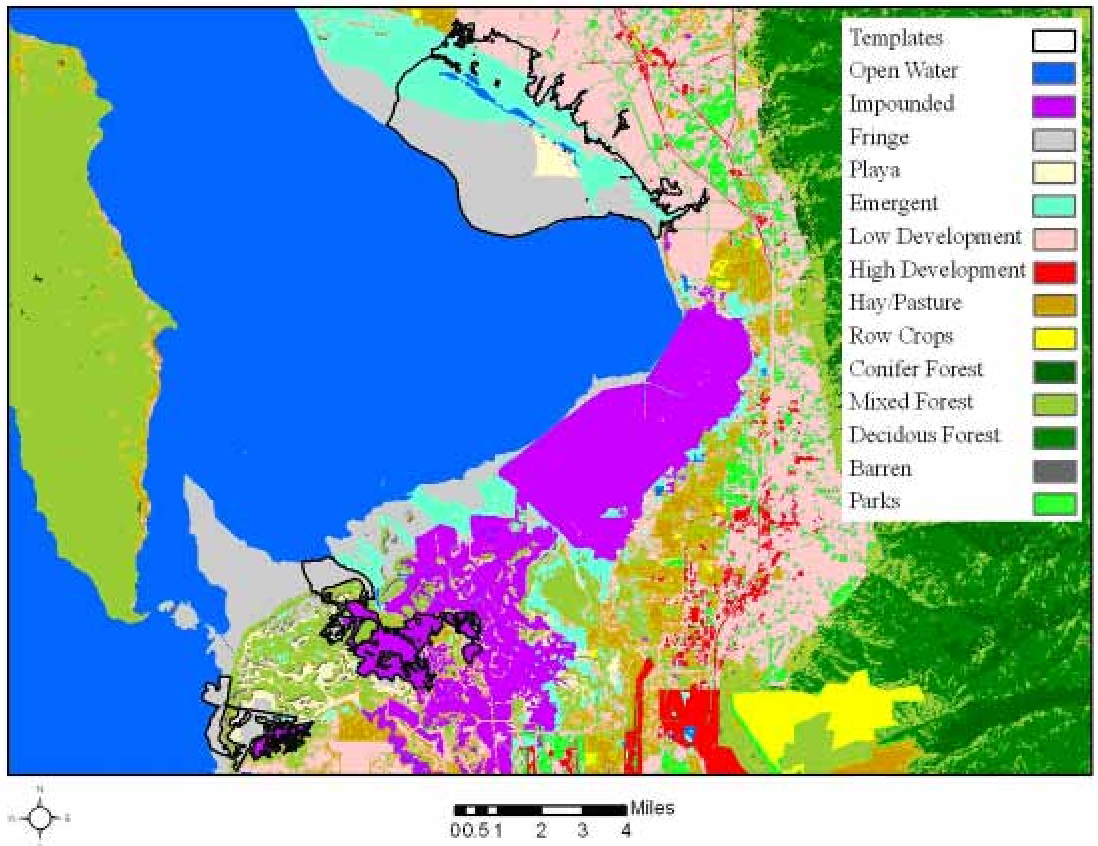


Figure 8. Plan Trend 4,200 Lake-level Scenario: Land Use and Wetland GIS Layers. Wetlands are removed above 4,212 and replaced with low-density development.

2.3.4 Conservation 2030 Scenarios

Figure 9 presents a map of land use and wetland class that characterize the Conservation scenario. A Conservation scenario assumes a priority emphasis on ecosystem protection and restoration strategies that are realistic and feasible for all stakeholders (Baker, et al., 2004).The Conservation scenarios focus on restoration and conservation of wetlands. The Conservation scenarios (“4,200” and “4,212”) use the same land use and water use assumptions for Salt Lake County and Davis County as presented in the Plan Trend scenario. Those assumptions reflect the use of conventional management practices to manage population growth. However, the Conservation scenario differs notably from the Plan Trend scenario in that certain wetlands are categorically designated for conservation and restoration. The Conservation Scenario identifies all natural wetlands below 4,217 feet as critical lands for protection and restoration. The Scenario also assumes that there will be no net loss in the quantity and quality of wetlands above 4,217 feet elevation within the shorelands area (i.e., between 4217 feet and 4230 feet elevation).

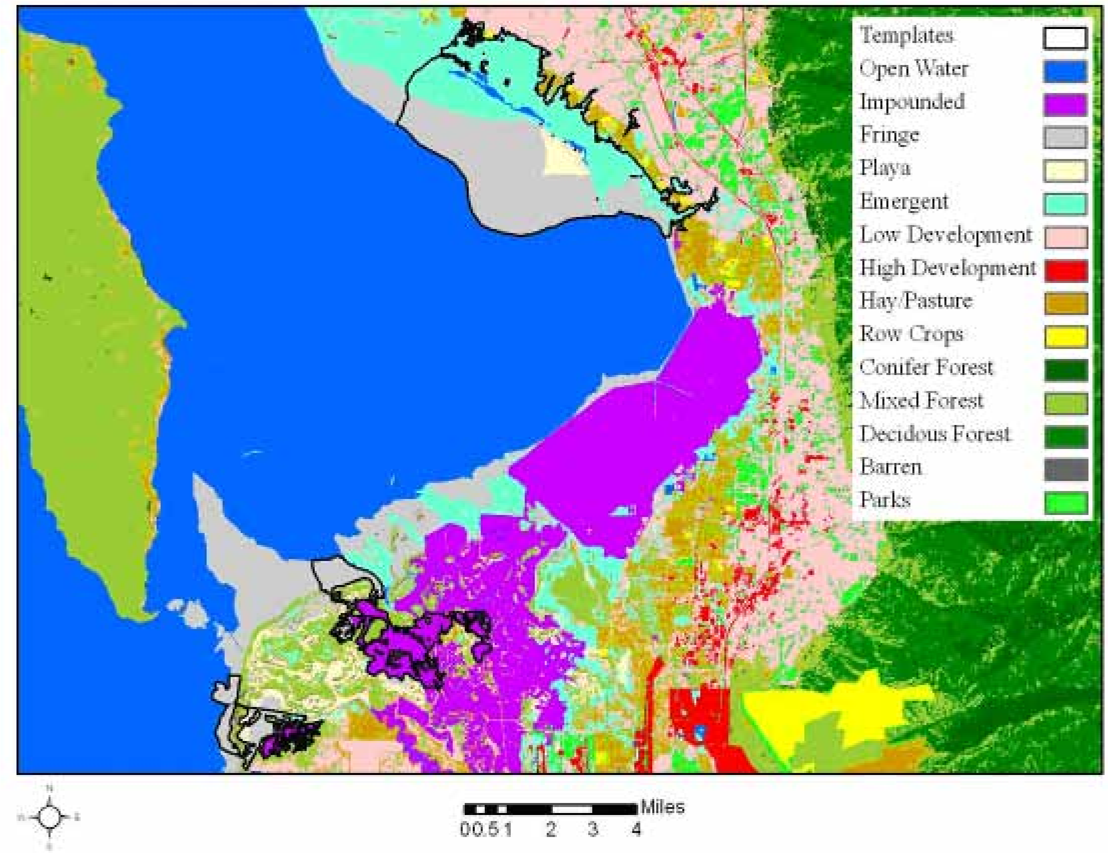


Figure 9. Conservation 4,200 Lake-level Scenario: Land Use and Wetland GIS Layers.
Low density development increases, but wetlands above 4,217 are not removed.

The "no net loss" design assumption includes provision for the restoration of wetlands and associated habitat in the shorelands area to offset wetland degradation and conversion. An assessment of potential restoration opportunity was performed to identify areas suitable for restoration under the Conservation scenarios. Those mapped areas provide the resource capacity needed to sustain the no net loss design.

Rules for locating restoration opportunities were established prior to development of the GIS methodology. A full description of those mapping rules, along with the methodology and representation of the GIS datasets used to create the restorations opportunity map, can be found in Appendix C. GIS variables selected to identify potential restoration opportunities are: 30-meter buffer around all conveyances, wetland class, hydric soils, interior habitat, and *Phragmites*. The categories of restoration opportunities are as follows: Public or Private High Potential, Public or Private Potential, *Phragmites* Removal Potential, and presence of Hydric Soils. These are the areas identified in the Conservation scenario. The restoration opportunity map is shown in Figure 10.

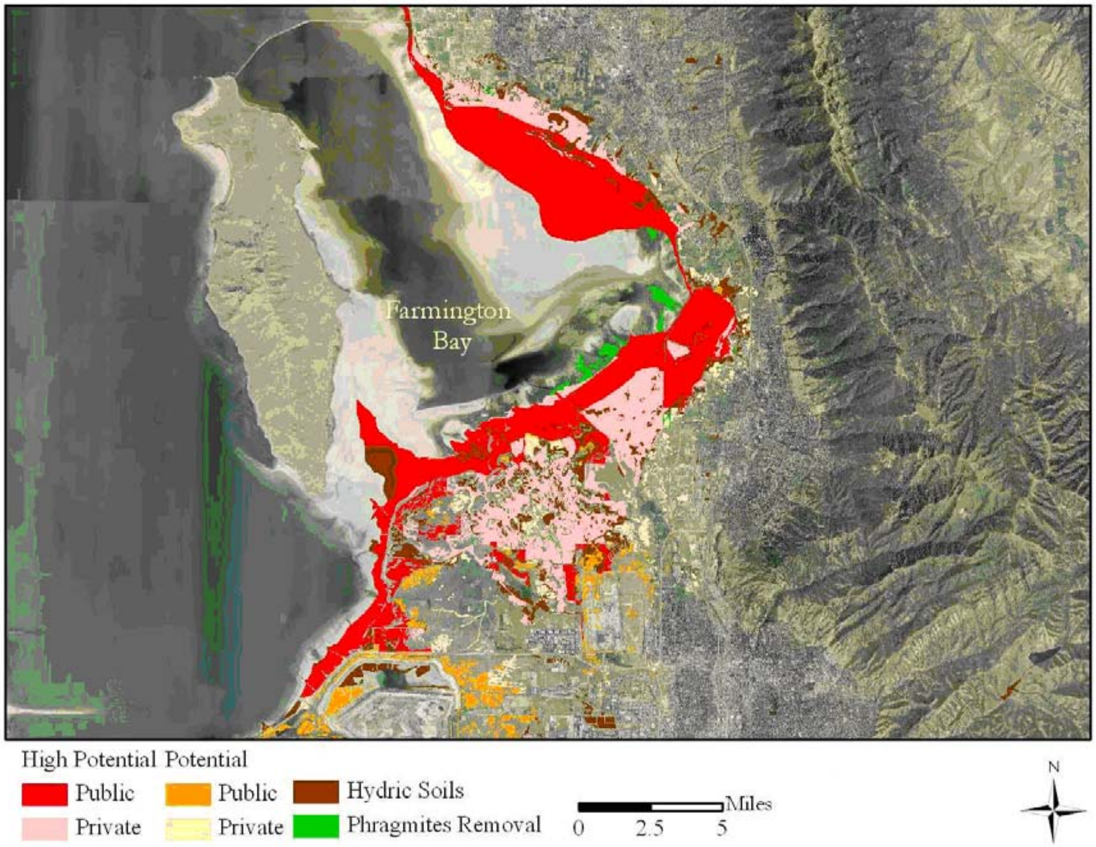


Figure 10. Potential restoration opportunity.

High potential restoration opportunity is mapped as areas they have been “screened” to take into account the following factors: 30-meter buffer around flow conveyances, all-hydric soils, interior habitat of at least 30 meters, and not categorized as seasonally or permanently flooded wetlands by NWI data. Potential restoration opportunity is mapped as all-hydric or partially-hydric soils and not categorized as seasonally or permanently flooded wetlands in NWI. Any wetlands or areas immediately adjacent to wetlands that have *Phragmites* are considered potentially restorable and therefore fall into the potential *Phragmites* removal class. Any areas that display all-hydric or partially-hydric soils are noted as having a hydric-soils potential for restoration opportunity.

2.3.5 2030 Lake Level Rise Scenarios

For both the Conservation and Plan Trend scenarios, the effects of a lake level rise to 4,212 feet were taken into account. FEMA flood assessment GIS data, along with a digital elevation model (DEM), were used to produce a simulation of lake level rise to 4,212 feet. That simulation allowed for an evaluation of wetland acreage change resulting from higher lake water levels. Figures 11 and 12 depict the lake level rise scenarios. In Figures 11 and 12, the open water (blue) of the 4,212 Scenarios inundates the wetlands along the lake shore when compared to the 4,200 scenarios (see Figures 7, 8, and 9). The Conservation 4,212 Scenario (Figure 12) shows more emergent wetlands then the 4,212 Plan Trend scenario (Figure 11).

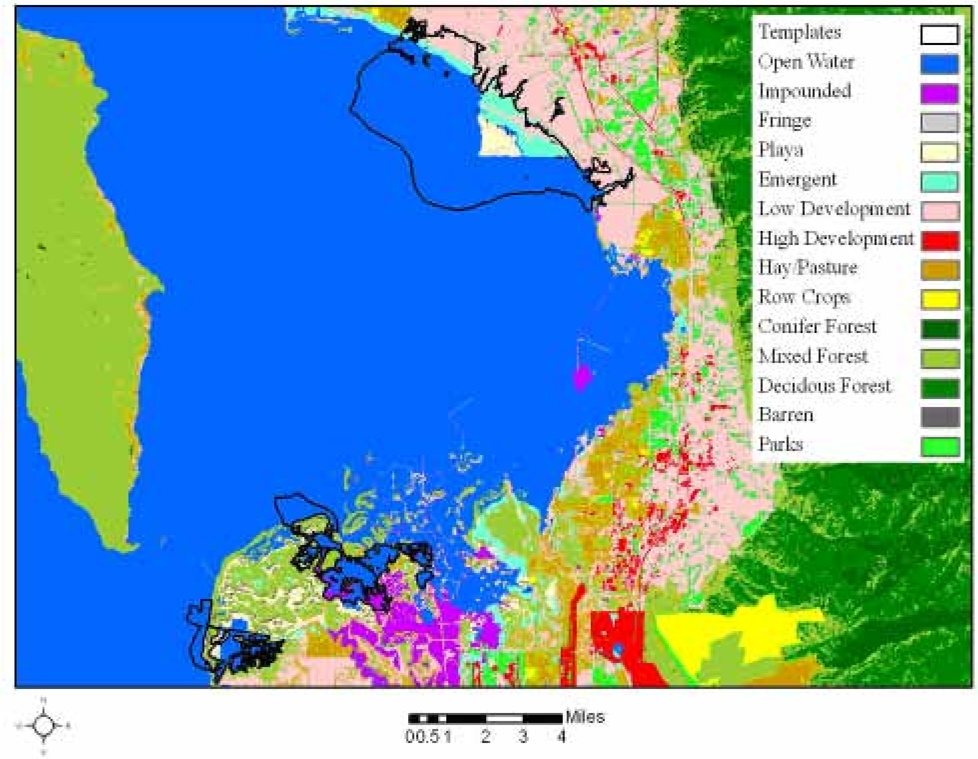


Figure 11. Plan Trend 4,212 Lake-level Scenario: Land Use and Wetland GIS Layers. Wetlands are removed above 4,217 and replaced with low density development. Open water is increased to 4,212 feet.

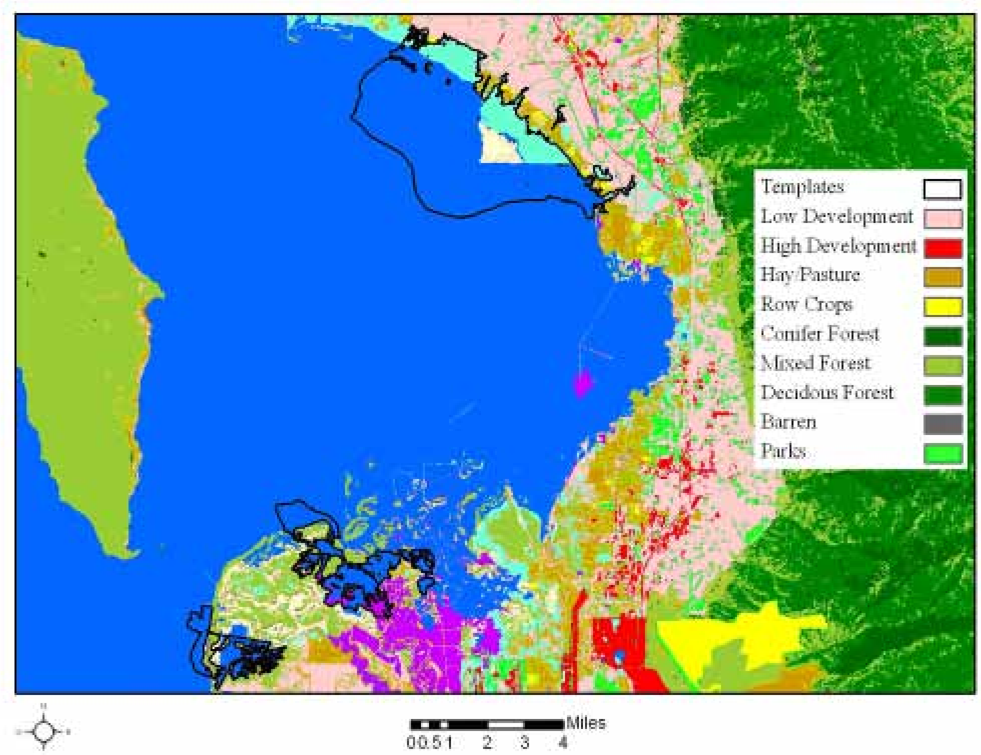


Figure 12. Conservation 4,212 Lake-level Scenario: Land Use and Wetland GIS Layers. Low-density development increases, but wetlands above 4217 are not removed. Open Water is increased to 4,212 feet.

2.3.6 Study Templates

The templates are a representation of "typical" landscape patches that are common across the set of Farmington Bay shorelands scenarios. They are presented as functional units of the landscape. The templates are used to analyze how different classes of wetland patches along the shorelands respond to the management practices assumed in the broader scenarios. The name of each template corresponds to the dominate class of wetland within the template.

The boundaries of a template were identified using the following criteria: A complex of wetlands, fed by a conveyance, with an established entry point, a delineated drainage basin, a hydrology connected by surface waters, and with a down-gradient boundary defined by the edge of the temporally flooded lacustrine unconsolidated shoreline zone at 4,200 feet AMSL (the Great Salt Lake surface elevation). Templates were selected with guidance from the project team based on data availability and whether or not the area was a typical example of occurrence of wetland complex types (e.g., impoundment, fringe, playa).

2.3.6.1 Impoundment Template

Figure 13 displays the Impoundment template. The "Impoundment" template is a 2,230-acre wetland complex consisting of a string of several diked units located primarily within the boundaries of the Ambassador Duck Club. The major conveyance delivering flows to this template is the Ambassador Cut, which carries diverted water from the Jordan River via the Surplus Canal, through the template and into Farmington Bay. Flows to the Ambassador cut are first subjected to a series of dams, diversions, and wetlands. There is a flow gauge with minimal data on the Ambassador cut. Impoundments are critical for controlling high flows, administering water rights allocations, and managing habitat for migratory waterfowl.

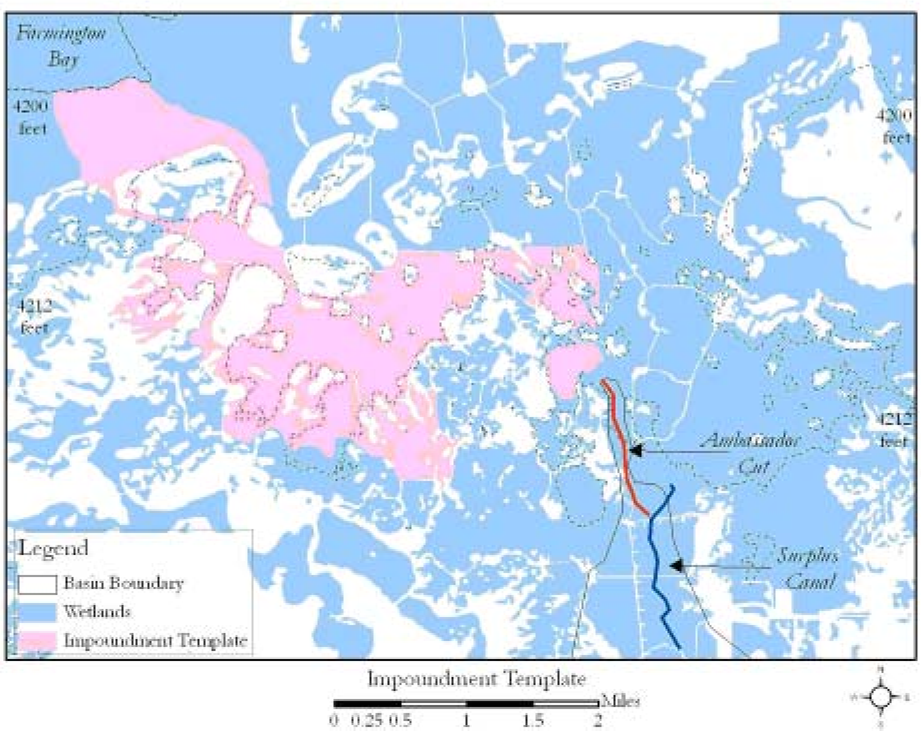


Figure 13. Impounded template, associated wetlands, basin boundary, and conveyances.

2.3.6.2 Fringe/Emergent Template

The “Fringe/Emergent” template is a large, 10,922-acre complex of wetlands located on the eastern shore of Farmington Bay. The fringe template is comprised mainly of lacustrine wetland types on the southwestern edge of the template. Moving up slope, the Fringe template becomes dominated by emergent class wetlands. Three major conveyances deliver flows to this template (i.e., Baird Creek, Holmes Creek, and Kays Creek). The Central Davis Sewer District is located at the outflow of Baird Creek into the Farmington Bay wetlands. The Central Davis Sewer District is a publicly owned collection system and treatment plant serving the Farmington, Fruit Heights, and Kaysville areas. Also located in this template is the 4,000-acre Great Salt Lake Shorelands Preserve. There are no observed flow gauges on the creeks. Figure 14 displays the Fringe/Emergent template.

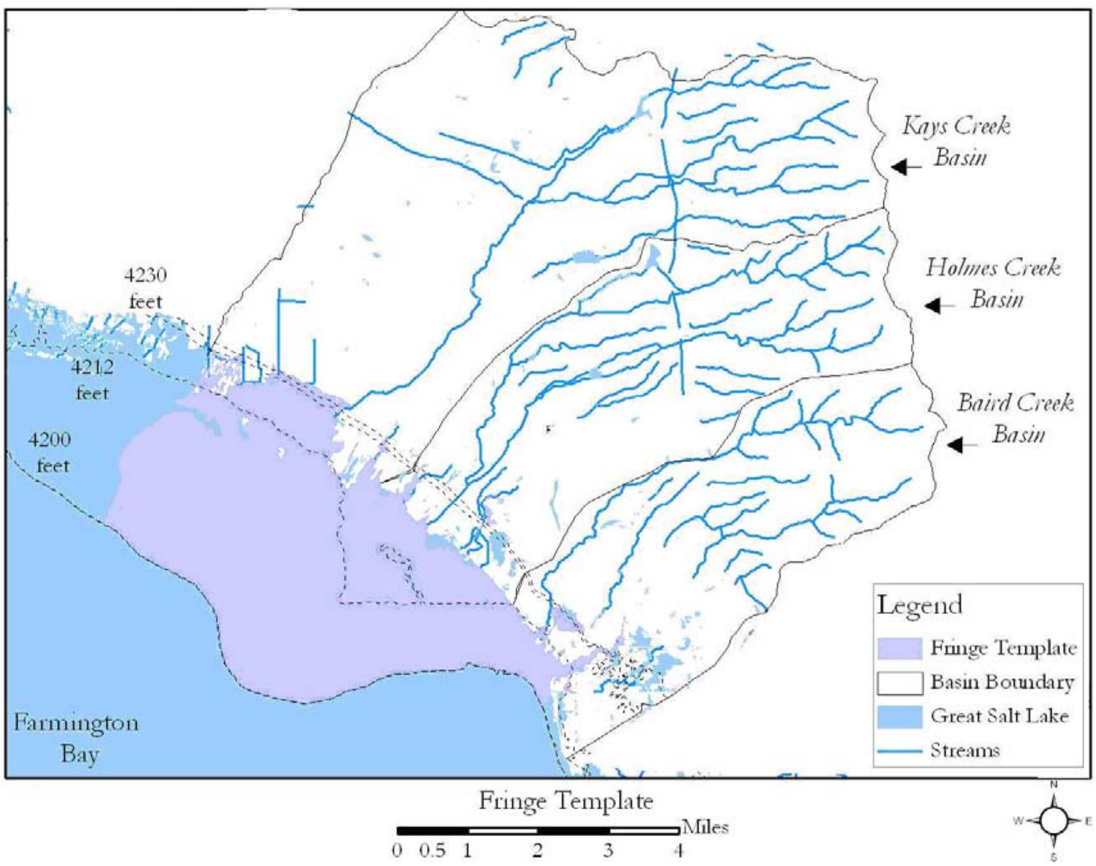


Figure 14. Fringe/Emergent template, associated wetlands, basin boundaries, and conveyances.

2.3.6.3 The Playa Template

Figure 15 displays the Playa template. The “Playa” template is a 1,167-acre wetland complex located in the northwest corner of Salt Lake County, just north of Interstate 80. The major conveyances delivering flows to this template is the North Pointe Consolidated Canal and the Goggin Drain. Both structures carry diverted water from the Jordan River and flow into the Great Salt Lake at the Kennecott Mitigation wetlands. The gauge on the Goggin Drain is located approximately 7 miles downstream from the Surplus Canal, 3.3 miles north of Saltair, and 7.2

miles north of Magna. The Goggin Drain carries natural drainage and surplus water spilled from canals, with an annual mean flow of 245 cubic feet per second. The maximum recorded discharge of the Goggin Drain is 1,850 cubic feet per second on June 10, 2006. In many years, there were periods of time with no observed flow (USGS, 2008).

Playa class wetlands represented in the template are shallow depressional systems that have highly variable hydric periods. Playa wetlands can fluctuate from dry and wet throughout the entire year. A Playa can be vegetated or non-vegetated. If vegetated, the cover type will depend on frequency of inundation with saline water. The wetlands in this template are managed by the Inland Sea Shorebird Preserve. Water level fluctuation within the wetlands is controlled to support their use by migratory shorebirds and waterbirds.

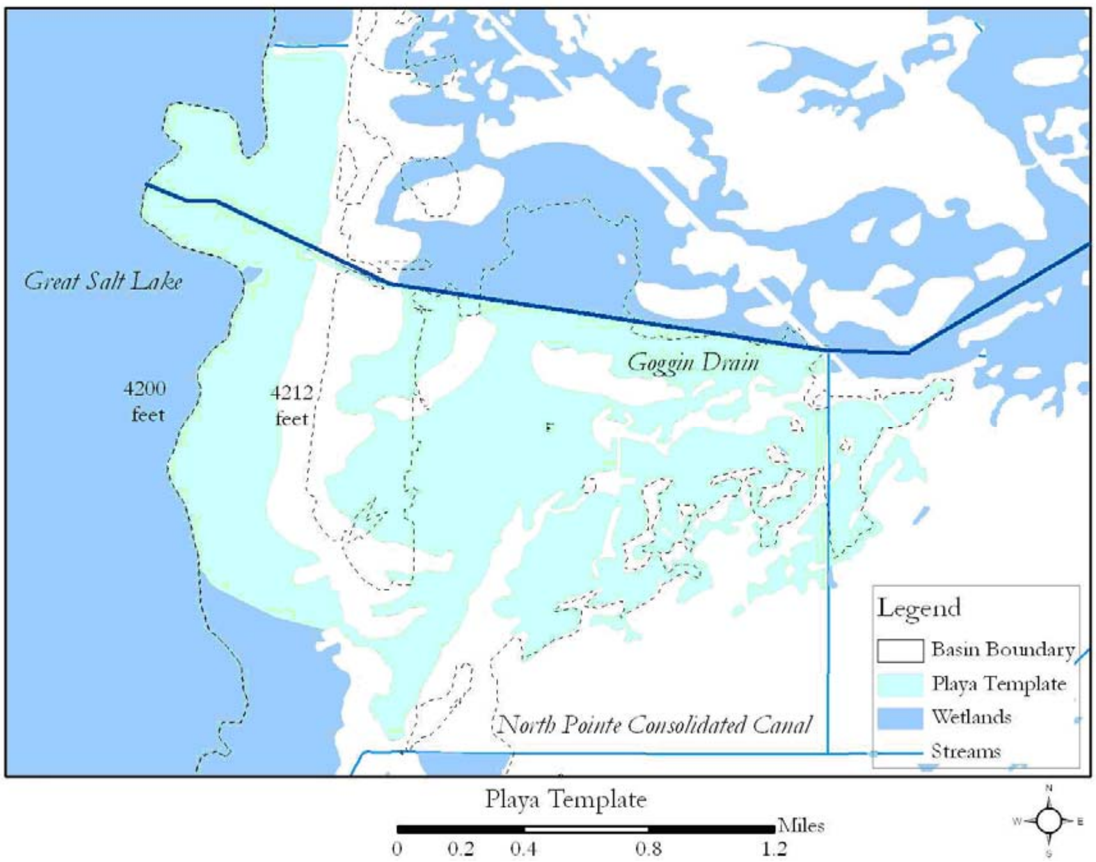


Figure 15. Playa template, associated wetlands, basin boundary, and conveyances.

2.4 Ecosystem Services and Evaluation Models

The Millennium Ecosystem Assessment (MEA, 2005) provides a comprehensive discussion and analysis of the wetland ecosystem services. The MEA also provides rationale for using ecosystem services as an endpoint for strategies aimed at the wise management and use of wetlands. For purposes of this study, we focused on two specific services attributed to Farmington Bay wetlands: (1) Support for avian habitat and (2) control of excess nutrients and pollutants. These two services were selected in response to perceived community concern about human well-being and their consideration for the intrinsic value of avian species and associated ecosystems. The two services were also selected to help develop a better understanding of the interplay between ecosystem services.

2.4.1 Ecosystem Service - Support for avian habitat

Farmington Bay wetlands currently provide important avian habitat as assessed by surveys of bird presence and use. They support approximately one million breeding shorebirds and several million transients. Snowy Plovers (*Charadrius alexandrinus*), American Avocets (*Recurvirostra americana*), Black-necked Stilts (*Himantopus mexicanus),* and Long-billed Curlews (*Numenius americanus)* use the Farmington Bay wetlands for nesting and migratory purposes. Huge numbers of transients, including a large percentage of the world's adult Wilson's Phalaropes (*Phalaropus tricolor*), large numbers of Red-necked Phalaropes (*P. lobatus*), Long-billed Dowitchers (*Limnodromus scolopaceus*), Western Sandpipers (*Calidris mauri*), and Marbled Godwits (*Limosa fedoa*) use these wetlands (Orning et al. 2006). The abundance, distribution, and condition of various types of wetland patches that are correlated with specific avian life history uses (e.g. nesting grounds, foraging and staging areas for migratory shorebirds and waterbirds) are additional measures of habitat suitability and availability. Wetland managers in Farmington Bay have historically utilized the existing topography and water management of the Jordan River to manage shorebird and waterbird habitat with water control structures and impoundment wetlands. The diverse shorebird habitats of Farmington Bay include: 1) large saline lake systems primarily of importance to post-breeding and migrant shorebirds, 2) complex freshwater marshes of importance to breeding and migrating shorebirds, 3) vast upland areas near wetlands, providing critical breeding habitat to several species, and 4) agricultural fields that serve both as breeding and foraging sites. Additional shorebird habitat is provided periodically by a vast array of ephemeral wetlands and playas, numerous human-made impoundments, and riparian areas (Orning et. al. 2006).

An Avian Wetland Habitat Assessment Model (AWHA) was developed to help formalize relationships about expected bird use based on the abundance and distribution of wetland habitat types. Wetland landscape profiles were developed as part of the AWHA. A wetland landscape profile is way of tallying and reporting the abundance of wetland classes within a defined area. The theory behind using wetland landscape profiles is that the abundance, distribution, and condition of wetlands in the landscape reflect the broad scale of processes that sustain ecosystems (Bedford 1996, Bedford 1998, Gwin 1999, Johnson 2005). Those same processes factor into the delivery of ecosystem services. The wetland landscape profiles that were developed for the AWHA can be viewed as a coarse index of wetland support for avian habitat, one of the key ecosystem services provided by these wetlands.

Lastly, a nutrient and sediment transport model was calibrated for the study area to develop an understanding of pollutant risk posed to wetland habitats. The AWHA model and watershed transport model are described in the following sections.

2.4.1.1 Development of the Avian Wetland Habitat Assessment (AWHA) Model

The Avian Wetland Habitat Assessment (AWHA) is a GIS-based model developed for this project to evaluate the availability of suitable avian habitat in Farmington Bay under a variety of future scenarios. The model framework combines GIS data and *a priori* knowledge to apply spatial weights indicating the availability of different classes of suitable habitat for various bird groupings. GIS data that represent different anthropogenic and environmental variables are used to predict where a particular species is most likely to be located on the landscape.

The first phase of the spatial analysis involved establishing the indicative variables of species distribution. Variables were assigned a spatial weight commensurate with their influence on the distribution of a particular bird grouping on the landscape. For instance, the presence of *Phragmites* may be an indicator of poor habitat for some species, but it may not be an indicator of poor habitat for another species. Variables used to determine the preferred location of a species in the landscape can have a gradient of influence. Therefore, the weight is considered "fuzzy" (i.e., not confined to Boolean classification, where there is either a "1" value assigned for presence or a "0" value assigned for absence).

For each species, a particular variable may also hold a greater or lesser importance when compared to another variable. Consequently, not only is a weight assigned for each variable as an indicator for a particular species, but the variables are also weighted in relation to each other. This secondary weight is referred to as variable strength. Local avian experts assisted with the preliminary assignment of weights to the variables. The GIS raster, vector and imagery datasets used to develop AWHA were obtained from the following sources: Utah Department of Environmental Quality, Utah Department of Transportation, Ducks Unlimited, and SWCA Environmental Consultants. Figure 16 depicts an example of the raster datasets created using the weighted variables as determined by the local GSL experts based on best professional judgement. These data layers, when combined, yield maps of habitat suitability. These maps are used to describe the current and predicted species distributions across the Farmington Bay wetlands. The highest index value (5) represents the highest class of suitable habitat available in the template. As the index trends toward lower values (1), the scores are decreasing and the habitat is progressively "less suitable". Figure 17 presents the variables weighting system and raster calculation applied to estimate avian habitat. Figures 18, 19, and 20 display the resulting avian habitat suitability index for Migratory Shorebirds, Migratory Waterfowl, and Migratory Water birds. A summary of the data matrices, variables, and processes used for the development of AWHA is presented in Appendix D. It should be emphasized that the habitat index produced by this model does not indicate the presence or absence of a species. Rather, the model predicts the change in the highest class of suitable habitat available for each bird grouping under conditions set by the future scenarios that were defined as part of the AFA. All proportional results evaluate the departure of each future scenario from the current scenario. The lower classes of habitat suitability could be similarly evaluated; however, this analysis focuses solely on the highest class of habitat suitability.

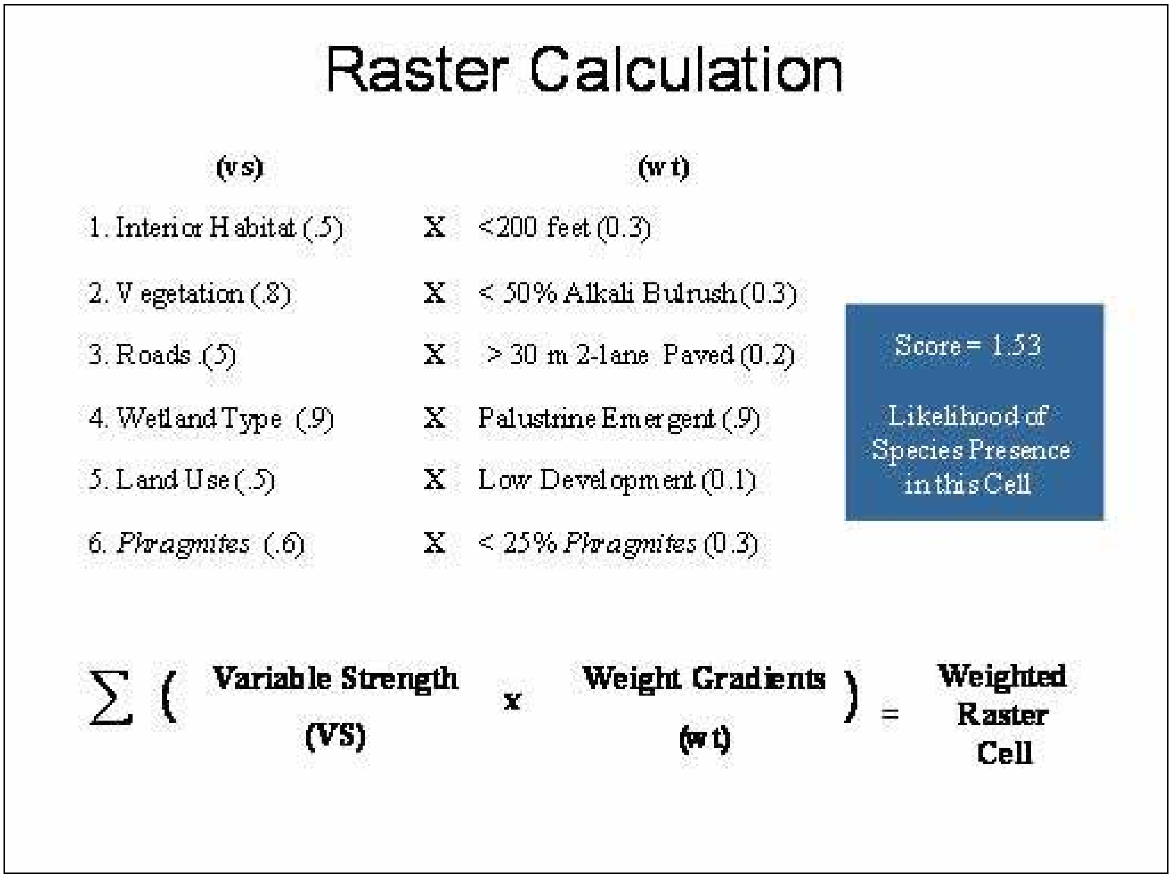


Figure 16. Example of raster datasets that represent variables used to calculate availability of suitable habitat. The final value of the weighed raster cell is calculated by summing the products of weighted variable strengths (1-6).

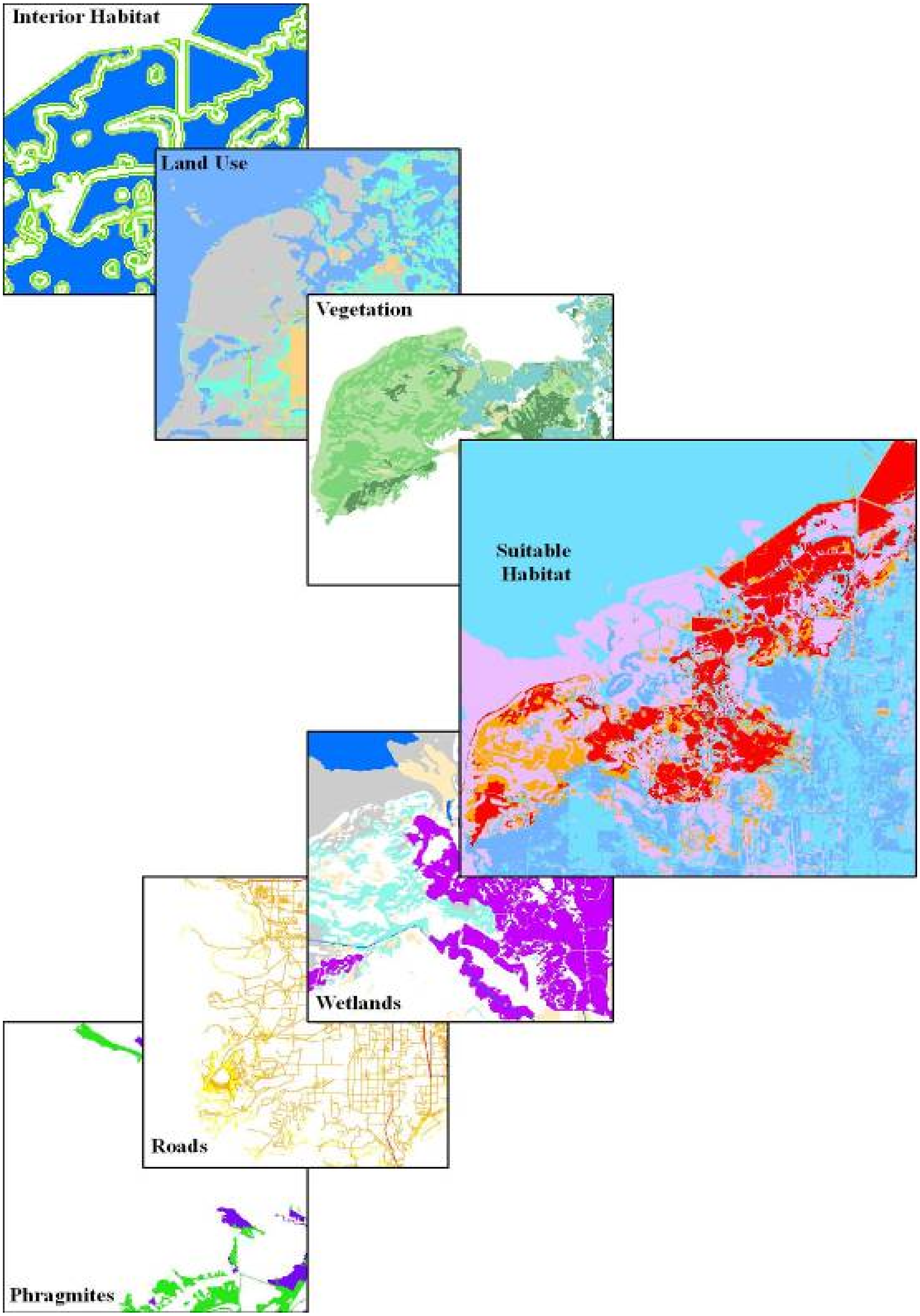


Figure 17. Variable weight hierarchy: Variables are assigned a “strength” (VS).
Which relates the variables to one another, and a weight (wt) to grade levels within each variable.

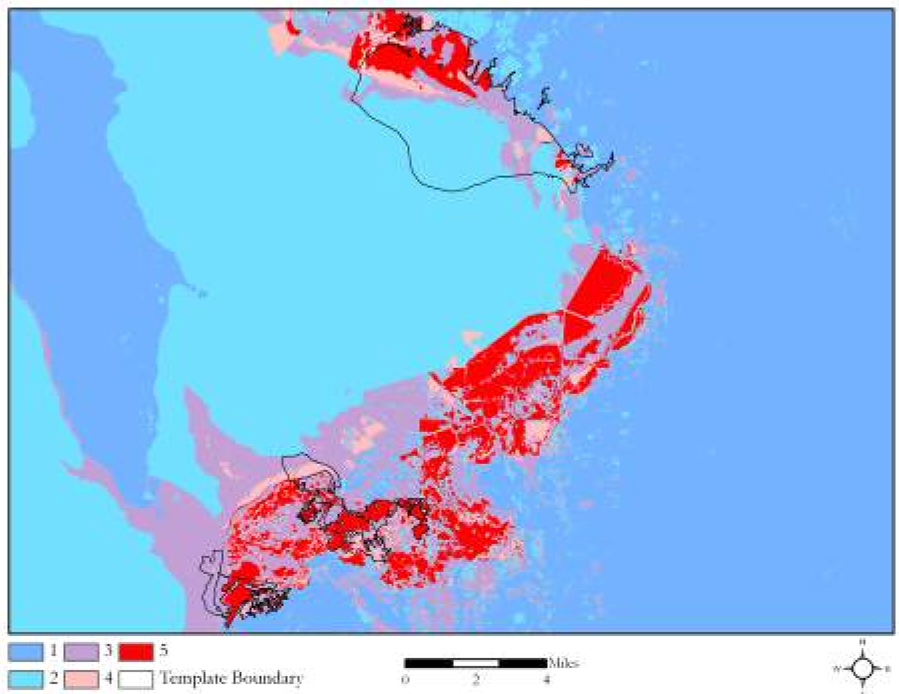


Figure 18. Suitable Migratory Shorebird habitat available in total study area under current scenario conditions. Red (#5) represents highest availability ranking.

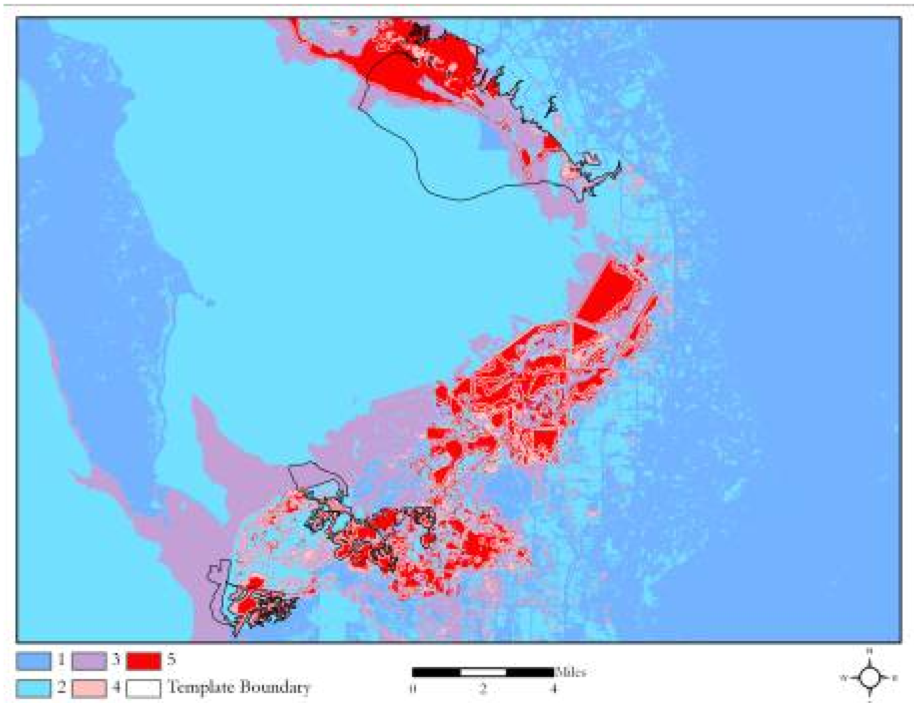


Figure 19. Suitable Migratory Waterfowl habitat available in total study area under current scenario conditions.

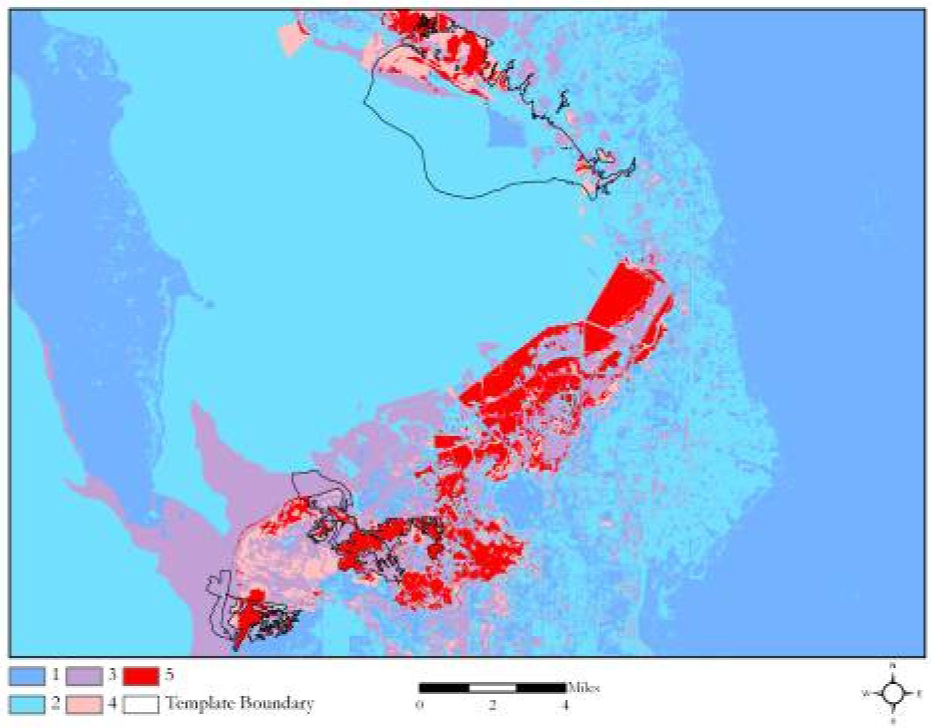


Figure 20. Suitable Migratory Waterbird habitat available in the total study area. Under current scenario conditions.

2.4.1.2 Calibration of the AVGWLF Model for the Jordan River Basin

An ArcView-enabled, enhanced version of the Generalized Watershed Loading Function (GWLF) Model was used to model nutrient and sediment transport for the Jordan River Basin. The objective of this modeling was to build understanding about the risks posed by the delivery of pollutants to wetlands and avian habitat. The AVGWLF model is an ArcView-enabled, enhanced version of the Generalized Watershed Loading Function (GWLF) Model originally developed by Haith and Shoemaker (1987). The original GWLF model was developed in the state of New York to simulate runoff, sediment, and nutrient (nitrogen and phosphorus) loadings from a watershed with various land uses, soil distributions, and management practices. The enhanced AVGWLF model was developed by Dr. Barry Evans at Pennsylvania State University for use by the Pennsylvania Department of Environmental Protection. It has been used by numerous state and federal agencies for simulating watershed processes and allocating pollutant loadings among various sources. The final calibrated model allowed the outputs of water flow, sediment, and nutrients being delivered to the Farmington Bay wetlands from the various sources throughout the watershed to be simulated. Based on these known sources of present-day loading, various future scenarios can be modeled in AVGWLF to predict future loads in the wetlands due to various changes in the watershed. Figure 21 displays a screen-capture of the AVGWLF application in an Arc GIS user window.

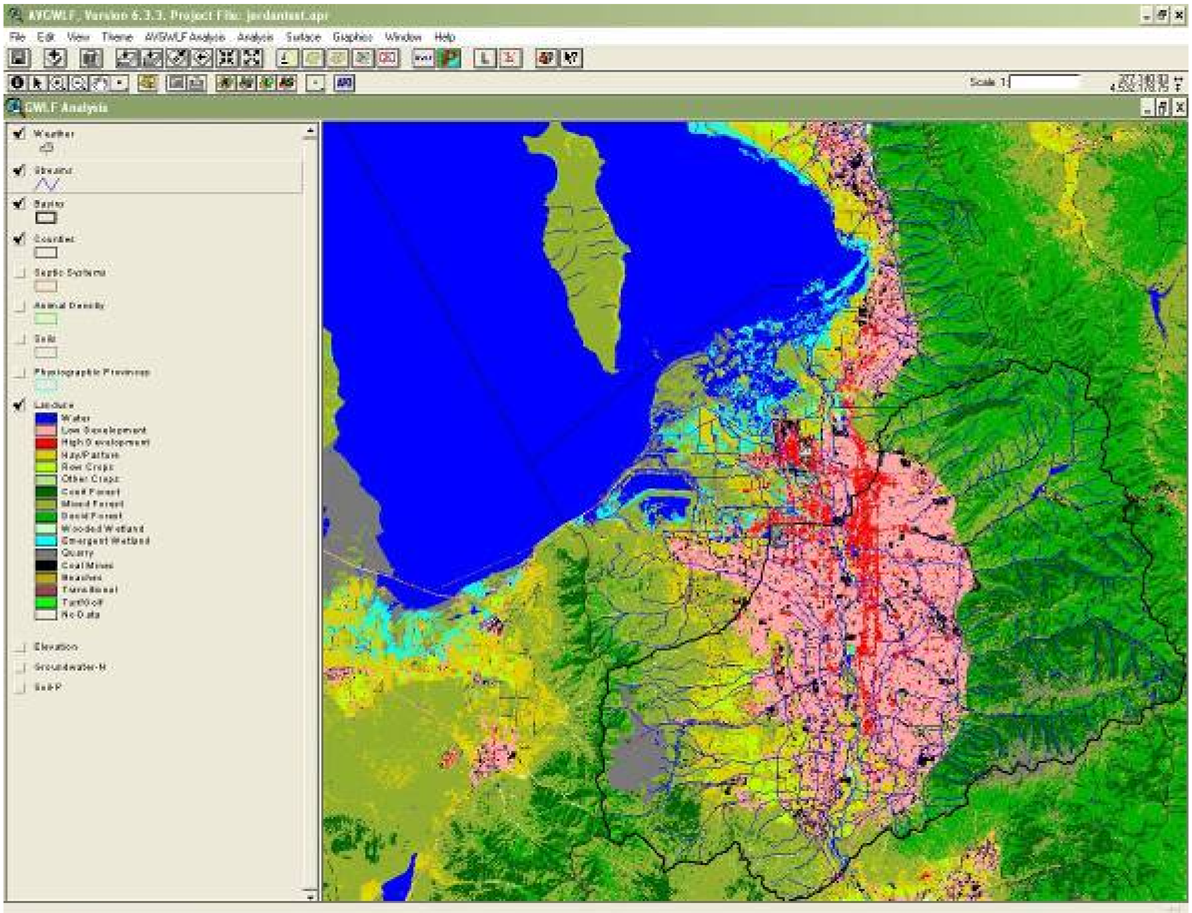


Figure 21. Screen-Capture of Jordan River ArcView Generalized Watershed Loading Function (AVGWLF).

Model calibration was performed for the period 1995-2005. During this task, adjustments were iteratively made in various model parameters until a "best fit" was achieved between simulated and observed stream flow and sediment and nutrient loads. Based on the calibration results, revisions were made in various AVGWLF routines to alter the manner that model input parameters were estimated. Statistical evaluations of the accuracy of flow and load predictions were made. Appendix E presents a more detailed discussion of the calibration results and statistics.

Yearly estimates of ground and surface water withdrawals for different uses (e.g., municipal and agricultural) were obtained from publically available state and county reports (UTDNR, 1997; SLCWRPR, 2008). These yearly estimates were spread out among the 12 months of the year and over the 11 years of simulation (1995-2005) based on best professional judgment. Observed weather patterns, stream flows, and seasonality of water usage were taken into account. All point source discharge data were obtained from the US EPA STORET database (USEPA, 1996; 2006a). Turner Dam flows, as well as irrigation canal flows, were obtained from the Utah Division of Water Rights (UTDWRi, 2008). Daily flow data for the Surplus Canal gauge were obtained from the USGS National Water Information System (USGS, 2008). Corresponding water quality data were obtained from EPA's STORET database (USEPA, 1996; 2006a**)**. To derive historical nutrient loads, standard mass balance techniques were used. First, the in-stream nutrient concentration data and corresponding flow rate data were used to develop load (mass) versus flow relationships for each watershed. Using the daily stream flow data obtained from the USGS, daily nutrient loads for the 1995-2005 periods were computed for the watershed using the appropriate load versus flow relationships. Loads computed in this fashion were used as the "observed" loads against which model-simulated loads were compared.

During this process, adjustments were made to various model input parameters to obtain a "best fit" between the observed and simulated data. With respect to stream flow, adjustments were made for evapotranspiration and "lag time" (i.e., groundwater recession rate) for subsurface flow. For nutrient loads, changes were made to the estimates for subsurface nitrogen and phosphorus concentrations. For sediment loads, revisions were made to the estimates of stream bank erosion. Further information regarding the calibration of AVGWLF can be found in Appendix E.

2.4.1.3 Calibration Statistics

For the monthly comparisons of actual data and model results, mean R^2 values of 0.86, 0.80, 0.94, and 0.90 were obtained for flow, sediment, phosphorus, and nitrogen, respectively. Considering the inherent difficulty in achieving optimal results across all measures (along with the potential sources of error), these results are very good. The monthly Nash-Sutcliffe coefficients of 0.86, 0.80, 0.92, and 0.74 were high considering that they approach their respective R^2 values. A detailed description of the statistical analysis for the AVGWLF calibration is presented in Appendix E.

2.4.2 Ecosystem Service-Assessing GSL Wetland Retention of Nutrients

The Farmington Bay wetlands buffer the effects of watershed nutrient loading (UTDNR, 2000; Hoven et al, 2006; UTDEQ, 2008; SLCWRPR, 2008; Bishop et al, 2009; SLC, 2009). Since 2004, the Utah Division of Water Quality has been characterizing the wetland ecosystems of Farmington Bay. They have also been assessing the potential effects of nutrient loads from publicly-owned treatment works (POTWs) and other natural and anthropogenic sources on the assimilative capacity of the Farmington Bay wetlands (UTDEQ, 2008). However, no similar research to quantify nutrient retention by these wetlands was available at the time the current study was conducted. Natural wetlands have been shown to "buffer" the impacts of nutrient delivery to a lacustrine system (Coveney et al, 2002). However, there is a limit to a natural wetland's capacity for retaining nutrients (Richardson and Qian, 1999). It has also been demonstrated that wetland nutrient retention efficiency can be reduced as nutrient loads increase above a certain threshold (Richardson and Qian, 1999). Furthermore, when considering phosphorus, it has been demonstrated that once a natural wetland is saturated, unacceptable amounts of phosphate can actually be exported from a wetland that was once effective at retaining nutrients (Qian and Richardson, 1997b; Richardson and Qian, 1999).

An important ecosystem service provided by wetlands is water quality improvement through pollutant retention. A large volume of water is diverted from the Jordan River and into various wetland complexes before reaching Farmington Bay. This water has nutrient and sediment loads associated with it, and the wetland complexes in Farmington Bay are assumed to provide a certain amount of treatment to these loads. Understanding the capacity of the Farmington Bay wetlands to retain nutrients and sediment is necessary for a quantitative valuation of this particular ecosystem service. As a practical first step to analyze the assimilative capacity of GSL wetlands, a rudimentary wetland cellular water quality model was developed was developed for GSL impounded wetlands based on a first-order removal rate calculation:

$$C_{out} = C_{in}\, e^{(-k/HLR)}$$

C_{out} = concentration of outflow pollutant, mg/l

C_{in} = concentration of inflow pollutant, mg/l

k = pollutant removal rate constant, m/yr

HLR = hydraulic loading rate (Q/A), m/yr

Q = annual runoff (i.e., surface water inflow rate), m^3/yr

A = wetland surface area, m^2

As shown in Figure 22, ten individual wetland cells were identified within the Impoundment Wetland Template (Template Description – See Section 2.3.6.1). The cellular water quality model equation was applied to each cell to simulate phosphorus and sediment retention. The Impoundment Template was chosen as a demonstration site due to its configuration in the landscape and the availability of water quality and flow data from the US EPA STORET database (USEPA, 1996; 2006a). These observed data were used to calibrate the wetland water quality model for conditions specific to the Impoundment Template. A detailed discussion of the development and calibration of the wetland cellular water quality model is presented in Appendix F.

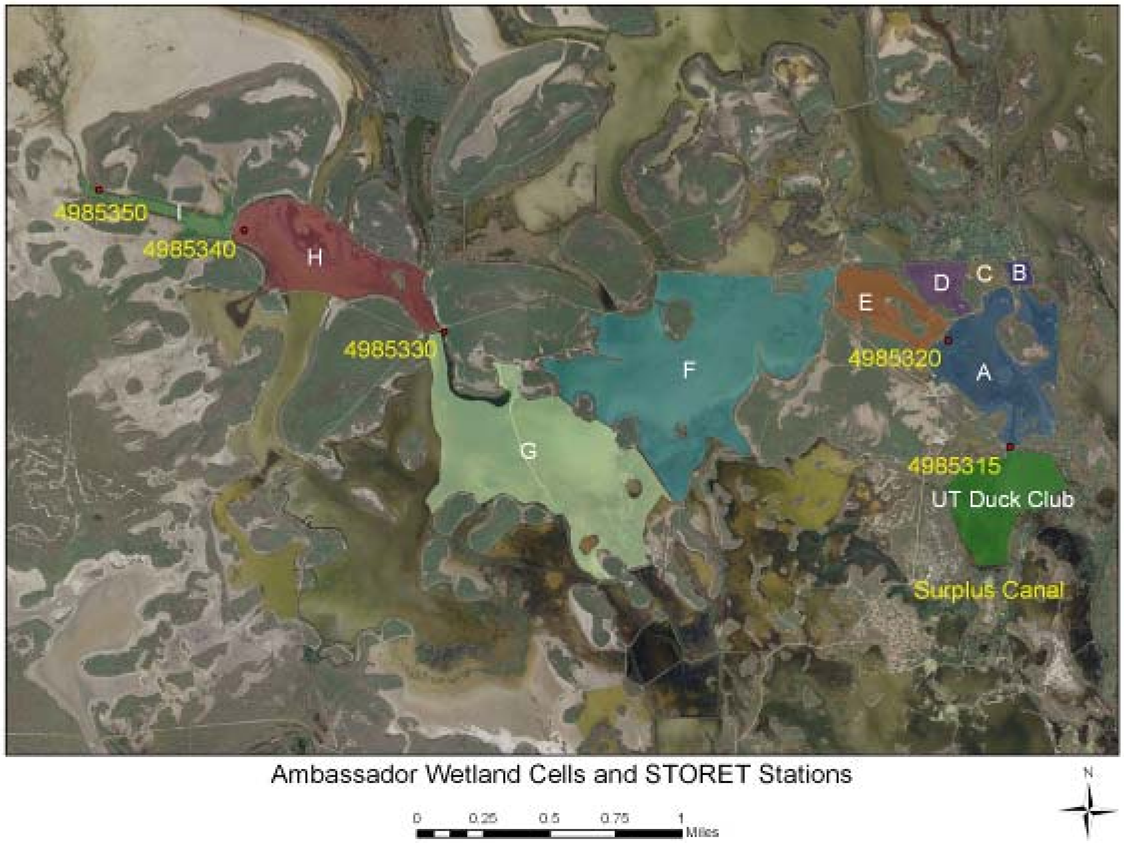


Figure 22. Ambassador Wetland cells and STORET stations.
Located within the boundary of the Impounded Template.

The AVGWLF watershed-loading model was used to simulate nutrient and sediment delivery to the Impoundment Template. This watershed loading was applied as the initial input to the wetland cell model. Output concentrations were calculated for each cell using the first-order removal rate equation described above. The wetland cells are arranged in such a way that output concentrations for one cell serve as the input concentrations for the following cell. This approach was used to simulate nutrient retention in the Impoundment Template for the baseline condition as well as for various future watershed-loading scenarios. The approach is transferrable to other wetland templates that have relatively well defined boundaries. Flow and water quality data is necessary in order to calibrate the model for each template, as wetland retention rates vary widely and are site-specific.

3.0 RESULTS

Study results are presented in four sections. The first section (3.1) describes data from analysis of wetland acreage differences among the scenarios and associated templates. Section 3.2 describes how differences in wetland acreage among the scenarios and templates affect the availability of suitable habitat for migratory waterfowl, shorebirds, and waterbirds. Section 3.3 presents predicted trends in nutrient and sediment pollutant loading to wetlands based on the AVGWLF model. The last section (3.4) presents results from the cellular water quality model for the impoundment wetlands.

3.1 Wetland Landscape Profiles

The wetland landscape profiles for the total study area and for each template are presented in the following tables, charts, and narrative. Figure 23 displays the acreage of wetlands, as distributed in each elevation zone for the Current Scenario. The majority (76%) of wetland acreage is located in the zone from 4,200 to 4,212 feet, which spans the range of the historical average water level elevation to the high water level elevation. Changes to land use or land cover in this elevation range will have the greatest effect on wetland landscape profiles. Wetland acreage decreases in elevation zones that exceed the high water level. The 4,212 - 4,217 feet zone accounts for 21% of wetland acreage, the 4,217 - 4,220 feet zone accounts for 2%, and the 4,220 - 4,230 feet zone accounts for the remaining 1%.

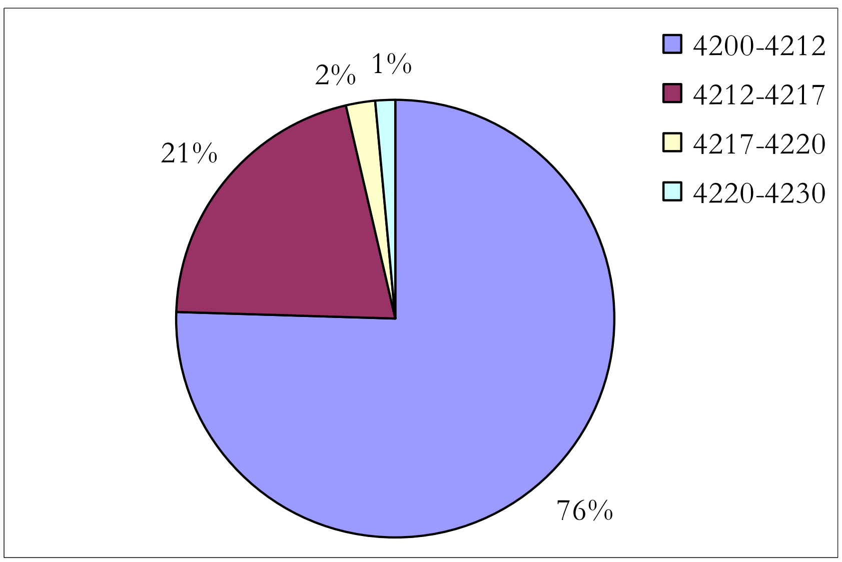


Figure 23. Distribution of total wetland acres among elevation zones.

Figure 24 and Table 1 display the wetland landscape profiles for the total study area, with wetlands distributed by wetland functional class. Wetland acreage is lost for all wetland classes under each scenario. For both lake elevations, 4,200 feet and 4,212 feet, the total wetland acreage lost is less for the Conservation scenario, 16% and 14% respectively, as compared to the Plan Trend scenario. The Conservation 4,200 and Plan Trend 4,200 scenarios are the most protective of the Fringe wetland class and least protective of the Impounded and Emergent wetland classes respectively. The Conservation 4,212 and Plan Trend 4,212 scenarios are the most protective of the Playa wetland class and least protective of the Fringe wetland class.

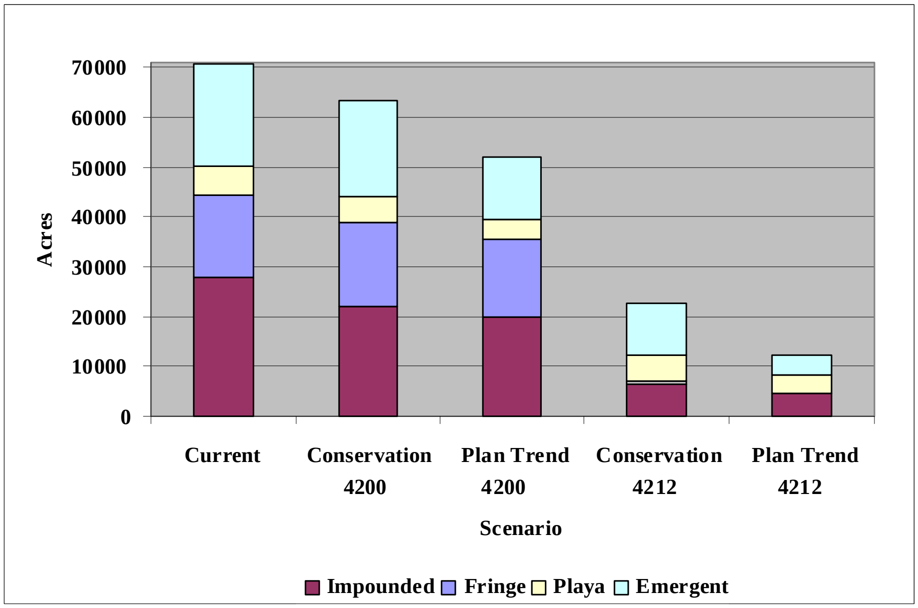


Figure 24. Wetland landscape profile for the Total study area.

Table 1. Proportional analysis of wetland acreage for the total Farmington Bay study area.

Total wetland acreage for each wetland class under different scenarios					
Wetland Class	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Impounded	27722	22182	19929	6569	4609
Fringe	16893	16530	15709	612	99
Playa	5602	5322	3667	5169	3531
Emergent	20532	19320	12916	10377	4191
Total Wetland	70749	63354	52221	22727	12430
Percent change for each wetland class under different scenarios					
Impounded	-	-20%	-28%	-76%	-83%
Fringe	-	-2%	-7%	-96%	-99%
Playa	-	-5%	-35%	-8%	-37%
Emergent	-	-6%	-37%	-49%	-80%
Total Wetland	-	-10%	-26%	-68%	-82%

Figure 25 and Table 2 display the proportional wetland landscape profiles for the Fringe/ Emergent template. When assessing the change to wetland acreage in the Fringe/Emergent, Playa, and Impoundment wetland templates separately (Figs. 25-27 and Tables 2-4), Conservation 4,200 and Plan Trend 4,200 are the most protective of the Fringe wetland class for all three templates, consistent with the total study area results. Conservation 4,212 and Plan Trend 4,212 are the most protective of the Playa wetland class and least protective of the Fringe wetland class for all three templates, consistent with the total study area results. For all three templates, the Conservation scenario results in less wetland acreage lost as compared to the Plan Trend scenario.

In summary, the Conservation scenario leads to less wetland acreage loss than the Plan Trend scenario at both the 4,200 feet and 4,212 feet lake elevations for the three templates and the total study area. At the 4,200 feet lake elevation, the Fringe wetland class is the most protected and at the 4,212 feet lake elevation, the Playa wetland class is the most protected for all three templates and the total study area for either scenario.

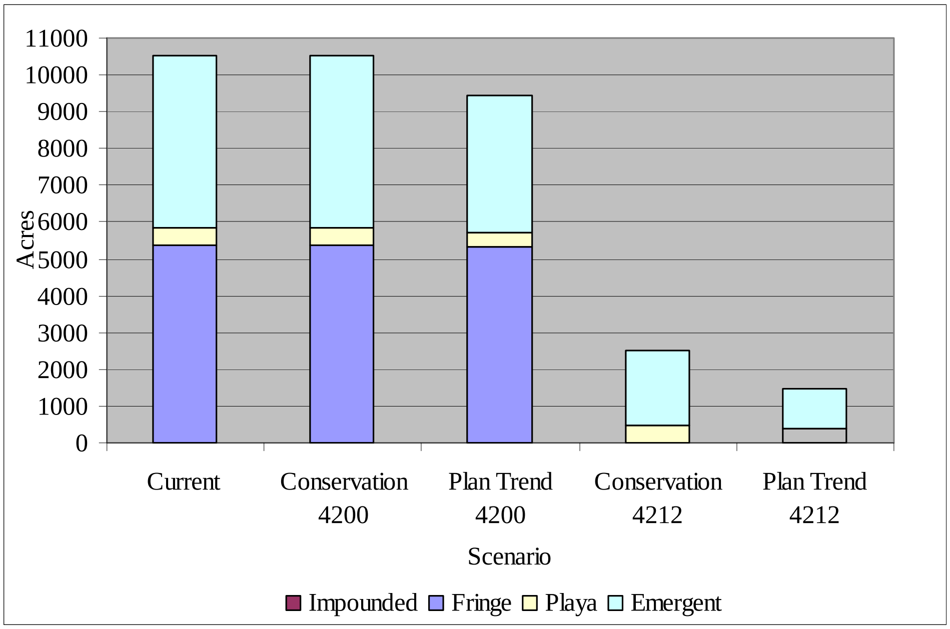


Figure 25. Wetland landscape profile for the Fringe/Emergent template.

Table 2. Proportional analysis of wetland acreage for the Fringe/Emergent template.

Total wetland acreage for each wetland class under different scenarios					
Wetland Class	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Impounded	1	0	0	0	0
Fringe	5365	5360	5311	2	2
Playa	470	470	413	460	404
Emergent	4706	4687	3717	2056	1081
Total Wetland	10542	10517	9441	2518	1487
Percent change for each wetland class under different scenarios					
Impounded	-	-100%	-100%	-100%	-100%
Fringe	-	0%	-1%	-100%	-100%
Playa	-	0%	-12%	-2%	-14%
Emergent	-	0%	-21%	-56%	-77%
Total Wetland	-	0%	-10%	-76%	-86%

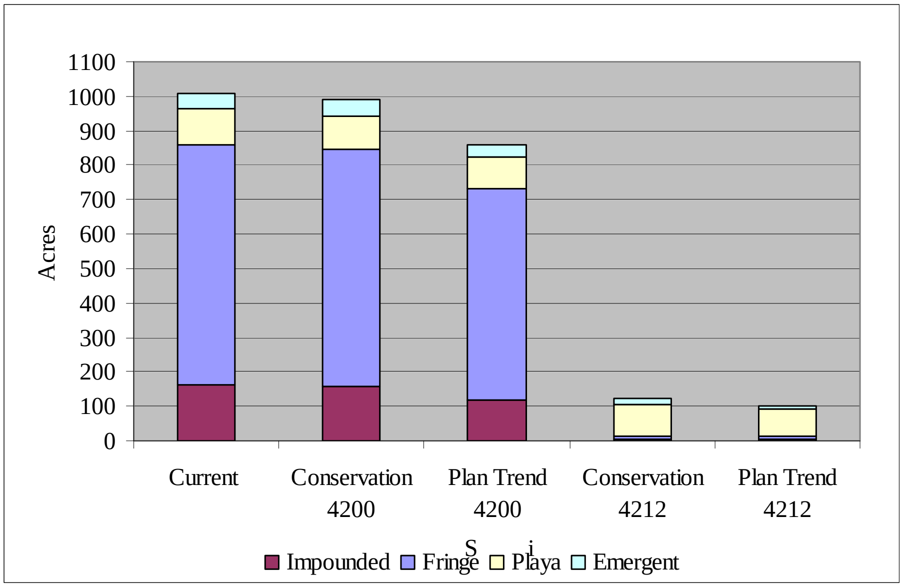


Figure 26. Wetland landscape profile for the Playa template.

Table 3. Proportional analysis of wetland acreage for the Playa template.

Total wetland acreage for each wetland class under different scenarios					
Wetland Class	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Impounded	162	157	120	6	4
Fringe	697	687	613	9	7
Playa	103	99	90	92	83
Emergent	48	47	37	14	8
Total Wetland	1010	990	860	121	102
Percent change for each wetland class under different scenarios					
Impounded	-	-3%	-26%	-96%	-98%
Fringe	-	-1%	-12%	-99%	-99%
Playa	-	-4%	-13%	-11%	-19%
Emergent	-	-2%	-23%	-71%	-83%
Total Wetland	-	-2%	-15%	-88%	-90%

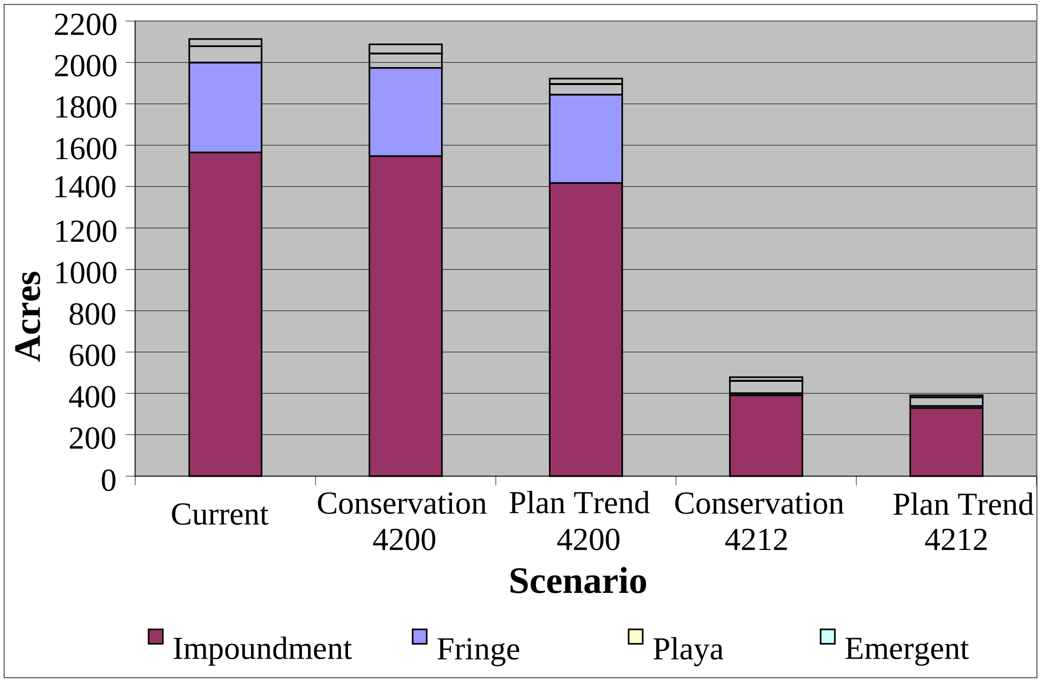


Figure 27. Wetland landscape profile for the Impoundment template.

Table 4. Proportional analysis of wetland acreage for the Impoundment template.

Total wetland acreage for each wetland class under different scenarios					
Wetland Class	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Impounded	1567	1544	1421	393	333
Fringe	432	430	422	5	3
Playa	75	72	54	67	49
Emergent	38	38	29	11	7
Total Wetland	2112	2084	1926	476	392
Percent change for each wetland class under different scenarios					
Impounded	-	-1%	-9%	-75%	-79%
Fringe	-	0%	-2%	-99%	-99%
Playa	-	-4%	-28%	-11%	-35%
Emergent	-	0%	-24%	-71%	-82%
Total Wetland	-	-1%	-9%	-77%	-81%

3.2 Avian Wetland Habitat Assessment

The results of the avian wetland habitat assessment for total study area and for each template are presented in the following tables, charts, and narrative. Figure 28 displays an example of the spatial analysis performed for migratory shorebirds in the Fringe/Emergent template. The highest index value (5) represents the highest class of suitable habitat available in the template. Class 5 indicates areas where the maximum combination of the six weighted variables sums to yield the highest scores. As the index trends towards lower values (1), the scores are decreasing and the habitat is progressively "less suitable". Further interpretation of these results is presented in Section 4.0 (Discussion and Conclusions).

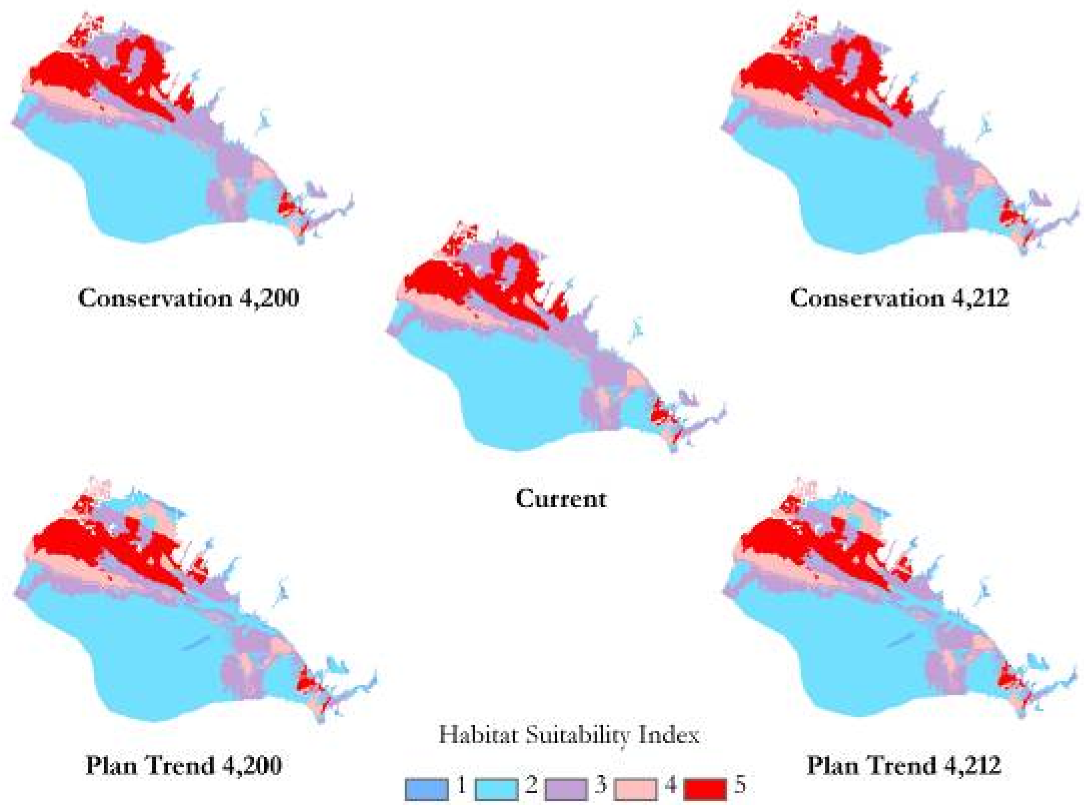


Figure 28. The above map displays the highest class of suitable habitat for Migratory Shorebirds available under various future scenarios in the Fringe/Emergent Template.

Figure 29 and Table 5 display the change in the acreage of the most suitable habitat for each bird group for the total study area. Habitat is lost for all bird groups under each scenario at the 4,200 feet elevation. There is a 2% increase in suitable habitat acreage for the Migratory Waterfowl bird group under the Conservation 4,212 scenario.

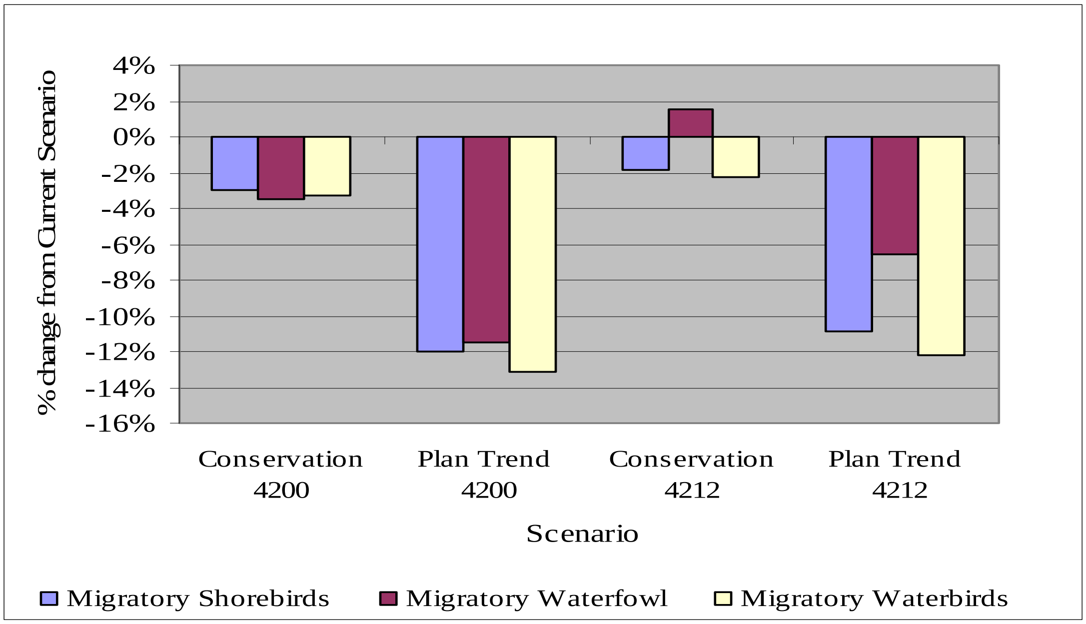


Figure 29. Proportional analysis of the most suitable habitat class for the Total study area.

Table 5. Change in habitat availability for each future scenario for the Total study area.

Total acreage of most suitable habitat for each bird group under different scenarios					
Bird Group	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Migratory Shorebirds	16285	15796	14323	15980	14515
Migratory Waterfowl	12536	12102	11100	12734	11710
Migratory Waterbirds	14135	13667	12286	13811	12412
Change in most suitable habitat acres for each bird group under different scenarios					
Migratory Shorebirds	-	-489	-1962	-305	-1770
Migratory Waterfowl	-	-434	-1437	197	-826
Migratory Waterbirds	-	-468	-1849	-324	-1723
Percent change in most suitable habitat for each bird group under different scenarios					
Migratory Shorebirds	-	-3%	-12%	-2%	-11%
Migratory Waterfowl	-	-3%	-11%	2%	-7%
Migratory Waterbirds	-	-3%	-13%	-2%	-12%

Suitable habitat changes across the three wetland templates (Figs. 30-32 and Tables 6-8, below) show habitat loss for all bird groups at the Conservation 4,200 and Plan Trend 4,200 scenarios. Increases in suitable habitat for migratory waterfowl in the Fringe/Emergent and Playa templates account for the sole increase in habitat for the Conservation 4,212 scenario in the total study area analysis. Despite modest increases in suitable habitat for migratory waterfowl and migratory waterbird groups at the 4,212 feet lake elevation, the overall trend is decreasing habitat suitability for each scenario.

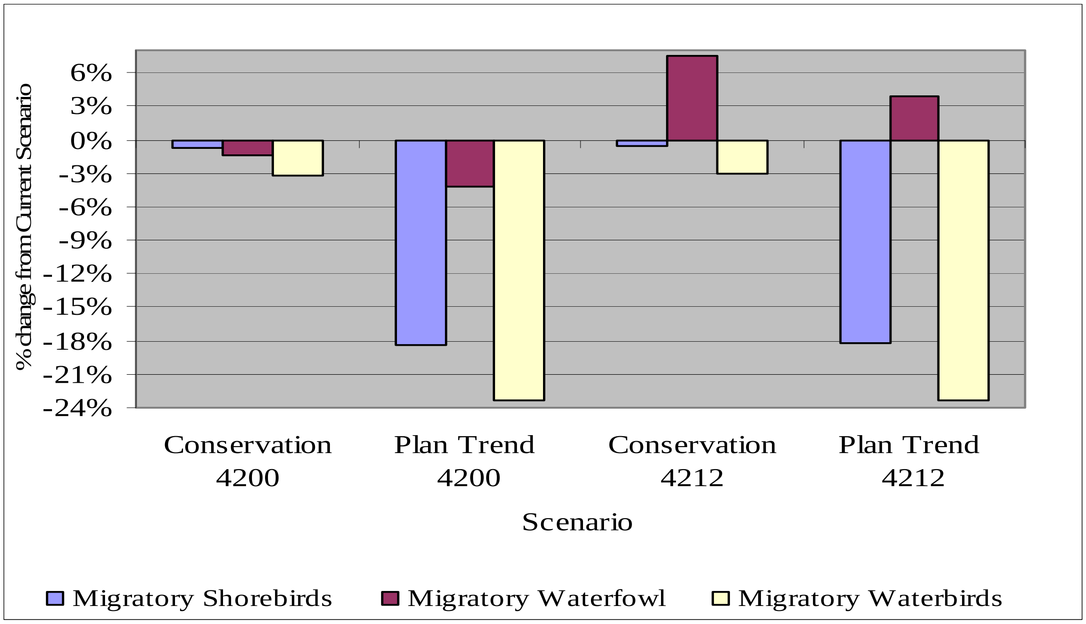


Figure 30. Proportional analysis of the most suitable habitat class for the Fringe/Emergent template.

Table 6. Change in habitat availability for each future scenario for the Fringe/Emergent template.

Total acreage of most suitable habitat for each bird group under different scenarios					
Bird Group	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Migratory Shorebirds	1847	1833	1509	1838	1511
Migratory Waterfowl	918	905	880	987	953
Migratory Waterbirds	2754	2667	2112	2669	2112
Change in most suitable habitat acres for each bird group under different scenarios					
Migratory Shorebirds	-	-14	-339	-10	-336
Migratory Waterfowl	-	-12	-38	69	35
Migratory Waterbirds	-	-87	-642	-85	-641
Percent change in most suitable habitat for each bird group under different scenarios					
Migratory Shorebirds	-	-1%	-18%	-1%	-18%
Migratory Waterfowl	-	-1%	-4%	7%	4%
Migratory Waterbirds	-	-3%	-23%	-3%	-23%

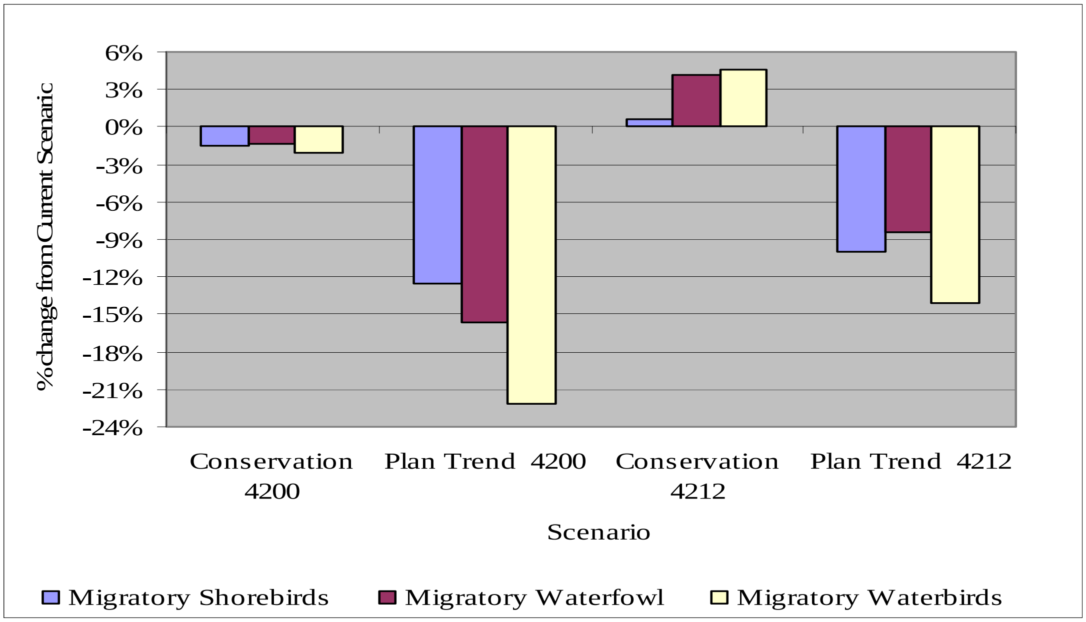


Figure 31. Proportional analysis of the most suitable habitat class for the Playa template.

Table 7. Change in habitat availability for each future scenario for the Playa template.

Total acreage of most suitable habitat for each bird group under different scenarios					
Bird Group	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Migratory Shorebirds	384	378	335	386	345
Migratory Waterfowl	307	302	259	320	281
Migratory Waterbirds	270	265	211	283	232
Change in most suitable habitat acres for each bird group under different scenarios					
Migratory Shorebirds	-	-6	-48	2	-38
Migratory Waterfowl	-	-4	-48	13	-26
Migratory Waterbirds	-	-6	-60	12	-38
Percent change in most suitable habitat for each bird group under different scenarios					
Migratory Shorebirds	-	-2%	-13%	1%	-10%
Migratory Waterfowl	-	-1%	-16%	4%	-8%
Migratory Waterbirds	-	-2%	-22%	5%	-14%

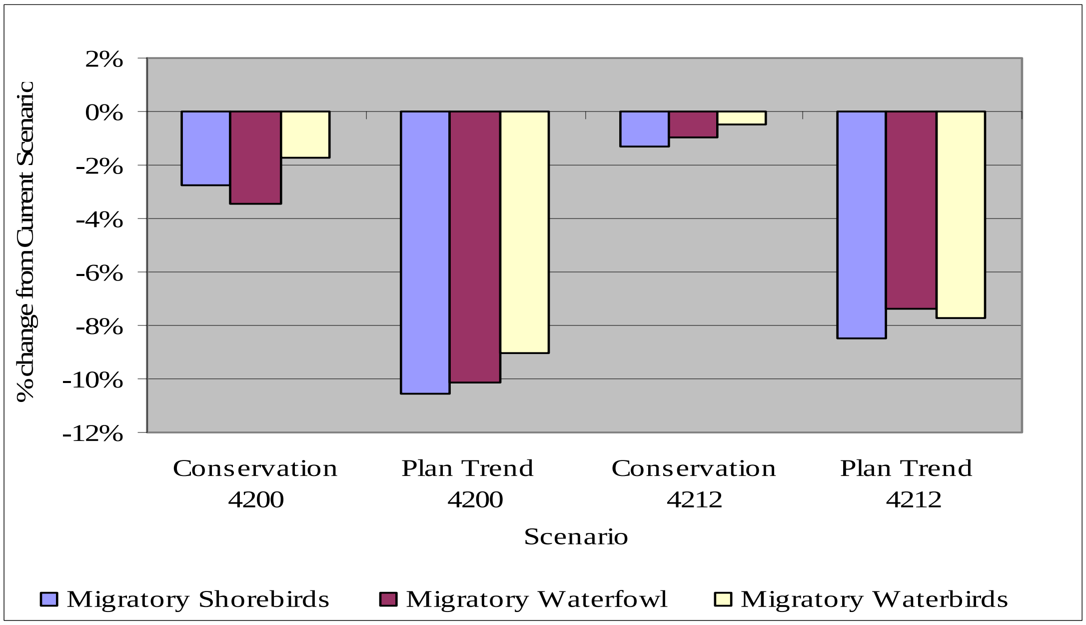


Figure 32. Proportional analysis of most suitable habitat class for the Impounded template.

Table 8. Change in habitat availability for each future scenario for the Impounded template.

Total acreage of most suitable habitat for each bird group under different scenarios					
Bird Group	4,200			4,212	
	Current	Conservation	Plan Trend	Conservation	Plan Trend
Migratory Shorebirds	1077	1047	963	1063	986
Migratory Waterfowl	971	937	872	961	899
Migratory Waterbirds	844	830	768	840	779
Change in most suitable habitat acres for each bird group under different scenarios					
Migratory Shorebirds	-	-30	-114	-14	-91
Migratory Waterfowl	-	-34	-99	-9	-72
Migratory Waterbirds	-	-15	-76	-4	-65
Percent change in most suitable habitat for each bird group under different scenarios					
Migratory Shorebirds	-	-3%	-11%	-1%	-8%
Migratory Waterfowl	-	-3%	-10%	-1%	-7%
Migratory Waterbirds	-	-2%	-9%	-1%	-8%

3.3 AVGWLF Watershed Loading Model

The AVGWLF model was calibrated for current conditions in order to provide estimates of future watershed loading of nutrients and sediment under various scenarios. Figure 33 displays the monthly flows and loads for an average year in the Jordan River basin (1995-2005). Field monitored sediment transport for the Jordan River basin is reported here as Total Suspended Solids (TSS).Figures 34, 35, and 36 and Tables 9, 10, and 11 display the loads by source for the Jordan River basin.

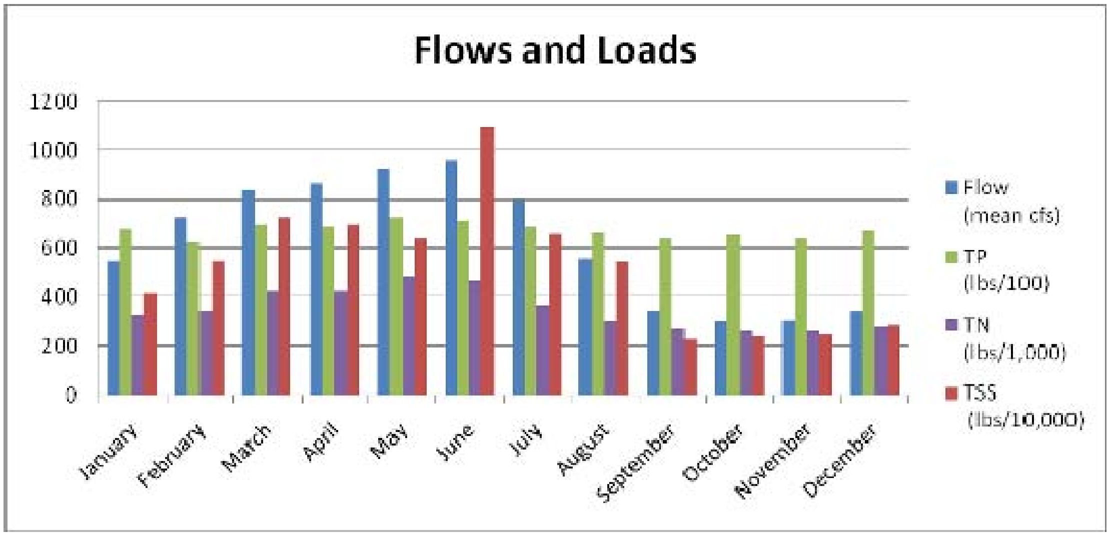


Figure 33. Mean Monthly Flows and Loads in the Jordan River.

Table 9. Phosphorus Loads-By-Source.

Source	TP (lbs/yr)
Point Sources	804,230
Turner Dam & Canals	64,132
Hay/Pasture	328
Cropland	359
Forest	272
Developed Open Space	561
Quarry/Barren Land	1,287
Low Intensity Development	1,682
High Intensity Development	3,890
Stream Bank	450
Septic Systems	190
Groundwater	4,690
Wetlands	4
Unpaved Roads	2
TOTAL	**882,077**

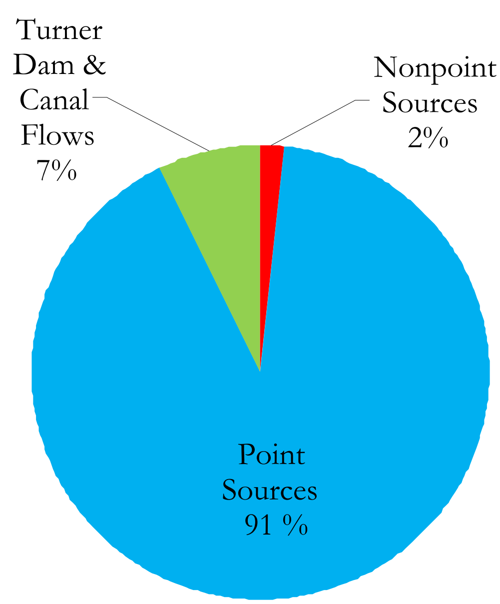


Figure 34. Phosphorus Loads By Source.

Table 10. Nitrogen Loads By Source.

Source	TN (lbs/yr)
Point Sources	2,436,212
Turner Dam & Canals	1,355,373
Hay/Pasture	2,456
Cropland	2,457.7
Forest	2,246
Developed Open Space	1,057
Quarry/Barren Land	5,953
Low Intensity Development	10,093
High Intensity Development	35,716
Stream Bank	1,022
Septic Systems	2,216
Groundwater	853,644
Wetlands	128
Unpaved Roads	15.5
TOTAL	4,708,589

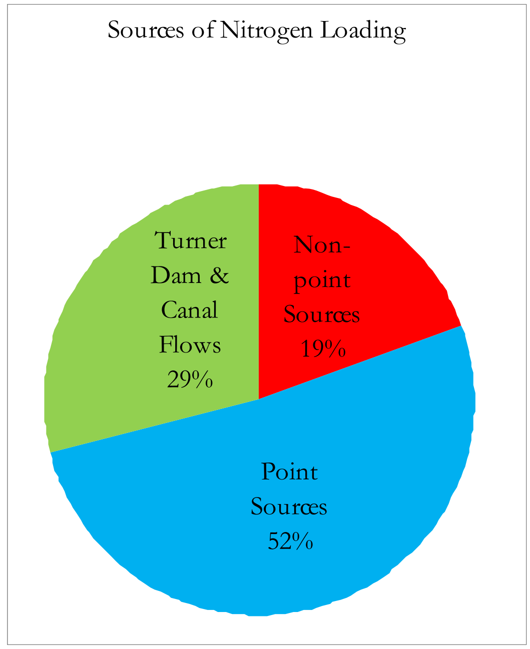


Figure 35. Nitrogen Loads By Source.

Table 11. Sediment Loads By Source.

Source	**TSS (lbs/yr)**
Turner Dam & Canals	61,202,881
Hay/Pasture	27,976.7
Cropland	123,789.6
Forest	363,255.7
Developed Open Space	32,231.6
Quarry/Barren Land	1,976,841
Low Intensity Development	93,344
High Intensity Development	12,941
Stream Bank	20,438,355
Wetlands	331
Unpaved Roads	2,755.8
TOTAL	**84,274,702**

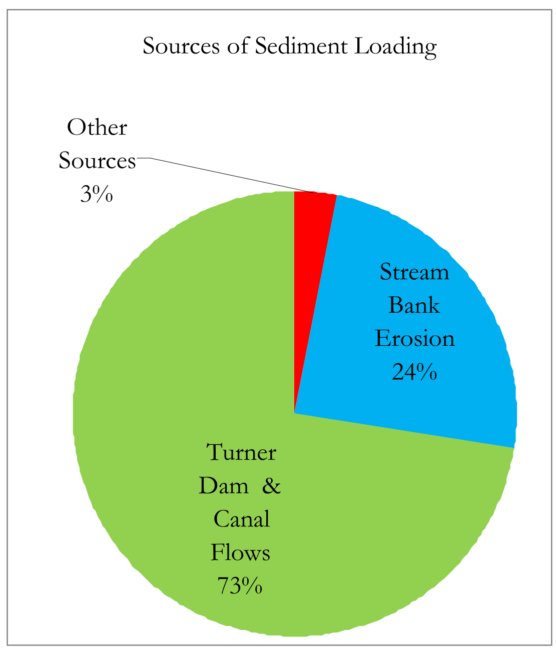


Figure 36. Sediment Loads By Source.

Flows and loads of sediment, phosphorus, and nitrogen were modeled for six sub-basins draining to the Farmington Bay wetlands under current conditions using the data and assumptions previously described (see Appendix E). Table 12 displays the net-modeled flows and loads for the current scenario after accounting for all withdrawals and extractions.

Table 12. Current Scenario Model Output: net loads after withdrawals and extractions.

Basin	Flow	Total Phosphorus		Total Nitrogen		Sediment	
	Cfs	mg/l	pounds	mg/l	pounds	mg/l	pounds
Jordan	628.3	0.69	859,723	3.40	4,213,152	51.03	63,165,452
Impoundment	34.95	0.79	54,291	3.86	266,054	28.28	1,947,677
Playa	299.13	0.83	486,290	4.08	2,403,814	39.49	23,273,750
Total Fringe	37.07	0.77	56,562	5.36	391,118	8.18	597,118
Baird	16.87	1.68	55,656	9.84	326,976	4.46	148,334
Holmes	7.63	0.02	284	1.58	23,829	11.32	170,143
Kays	12.57	0.03	621	1.63	40,311	11.25	278,640

In the Current scenario, the Goggin Drain flows and loads are almost entirely dependent on flows and loads leaving the Jordan River at the Surplus Canal diversion. The Jordan River, in turn, is heavily influenced by the two major point sources in the Jordan Basin. Model results show that Total nitrogen (TN) and Total Suspended Solids (TSS) both increase and decrease on a monthly basis along with flow. In contrast, Total Phosphorus (TP) loading remains relatively constant throughout. This information suggests that TP is derived predominately from point source discharge since environmental flows seem not to affect TP loading. Thus, conditions in the Goggin Drain appear to be heavily influenced by the Jordan Basin point source dischargers. Sediment loads derive largely from streambank erosion in the Jordan Basin and Turner Dam canal flows entering the Jordan Basin.

Future scenario nutrient and sediment loading

Table 13 displays the modeled flows and loads for the six sub-basins under the two future scenarios. Figure 37 presents the change in delivered watershed loads estimated for the Jordan River and for the Davis County sub-basins for the Plan Trend and Conservation scenarios. Tables 14 and 15 describe the change in watershed loadings for each scenario and template.

Table 13. Percent change in loads from current conditions under future scenarios.

Basin	Total Phosphorus		Total Nitrogen		Sediment	
	Plan Trend	Conservation	Plan Trend	Conservation	Plan Trend	Conservation
Jordan	50%	50%	24%	24%	-8%	-9%
Impoundment	36%	34%	15%	6%	18%	15%
Playa	38%	38%	18%	17%	39%	39%
Total Fringe	33%	26%	27%	20%	-3%	-5%
Baird	33%	26%	32%	24%	17%	13%
Holmes	16%	13%	0%	-3%	-2%	-3%
Kays	21%	17%	0%	-3%	-15%	-16%

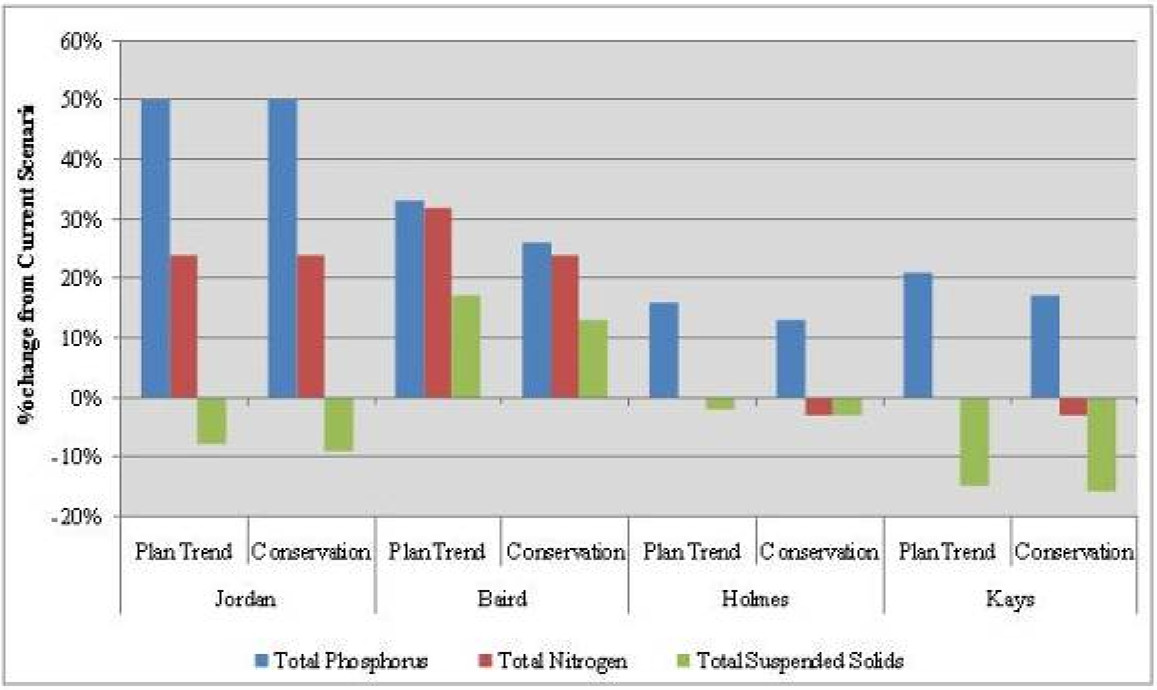


Figure 37. Percent Change of basin delivered loads from the Jordan River basin and the Davis County sub-basins under Plan Trend and Conservation scenarios.

Table 14. Plan Trend Future Scenario Watershed Loading: percent change indicates change in loading from Current scenario.

Basin	Flow	Total Phosphorus			Total Nitrogen			Sediment		
	cfs	mg/l	pounds	% change	mg/l	pounds	% change	mg/l	pounds	% change
Jordan	713.2	0.92	1,293,884	50%	3.72	5,231,031	24%	41.17	57,842,230	-8%
Impoundment	40.4	0.92	73,937	36%	3.57	307,127	15%	28.35	2,307,498	18%
Playa	402.8	0.85	671,585	38%	3.57	2,830,445	18%	40.89	32,449,376	39%
Total Fringe	37.7	0.70	75,362	33%	5.05	494,950	27%	11.48	577,899	-3%
Baird	19.0	2.02	74,280	33%	11.68	430,957	32%	4.99	173,542	17%
Holmes	7.2	0.03	331	16%	1.66	23,739	0%	15.33	167,314	-2%
Kays	11.4	0.04	752	21%	1.81	40,255	0%	14.12	237,043	-15%

Table 15. Conservation Future Scenario Watershed Loading: percent change indicates change in loading from Current scenario.

Basin	Flow	Total Phosphorus			Total Nitrogen			Sediment		
	cfs	mg/l	pounds	% change	mg/l	pounds	% change	mg/l	pounds	% change
Jordan	711.2	0.92	1,293,590	50%	3.73	5,222,649	24%	41.24	57,777,645	-9%
Impoundment	39.7	0.93	72,740	34%	3.61	282,282	6%	28.72	2,347,832	15%
Playa	401.7	0.85	671,086	38%	3.57	2,821,833	17%	40.97	32,417,914	39%
Total Fringe	37.7	0.96	71,201	26%	6.29	467,547	20%	7.62	566,136	-5%
Baird	19.0	1.87	70,153	26%	10.82	405,570	24%	4.49	168,258	13%
Holmes	7.2	0.02	321	13%	1.62	23,058	-3%	11.58	164,953	-3%
Kays	11.4	0.03	727	17%	1.73	38,919	-3%	10.33	232,924	-16%

Tables 16, 17, and 18, display the wetland retention for the sub-basins under the three scenarios. The retention rates of individual wetlands were not changed for the different scenarios. Only the amount of wetland available to retain nutrients and sediments was changed. Nutrient retention by the wetlands located in the upper portions of the Jordan River basin was negligible because those wetlands comprise a negligible percentage of the total basin area. Wetland retention rates were estimated from literature values compiled by the project team into a wetland BMP database. Much of the information summarized in the database is available from the International Stormwater Best Management Practices Database (ISBMP, 2008).

Table 16. Current scenario wetland retention of nutrients and sediment.

Basin	Estimated % of Basin that drains through a wetland	Basin Wetland Retention (lbs)		
		TP	TN	Sediment
Ambassador Cut	95%	501	15,782	41,226
Goggin Drain	29%	116	1,757	7,253
Total Fringe	14%	3937	29,447	24,380
Baird	13%	3869	24,196	5,560
Holmes	18%	28	2,513	9,000
Kays	12%	40	2,738	9,820

Table 17. Plan Trend scenario wetland retention: percent change indicates change in wetland retention from the Current scenario.

Basin	Estimated % of Basin that drains through a wetland	Basin Wetland Retention					
		TP		TN		Sediment	
		lbs	% change	lbs	% change	lbs	% change
Ambassador Cut	95%	1,079	115%	22900	45%	51,500	25%
Goggin Drain	2%	17	-85%	171	-90%	617	-91%
Total Fringe	7%	797	-80%	7696	-74%	11,280	-54%
Baird	2%	750	-81%	4617	-81%	920	-83%
Holmes	13%	23	-18%	1757	-30%	6,320	-30%
Kays	6%	23	-41%	1322	-52%	4,040	-59%

Table 18. Conservation scenario wetland retention: percent change indicates change in wetland retention from the Current scenario.

Basin	Estimated % of Basin that drains through a wetland	Basin Wetland Retention					
		TP		TN		Sediment	
		lbs	% change	lbs	% change	lbs	% change
Ambassador Cut	95%	971	94%	20927	33%	48,590	18%
Goggin Drain	29%	218	88%	2216	26%	8,047	11%
Total Fringe	14%	4955	26%	35087	19%	23,180	-5%
Baird	13%	4877	26%	30012	24%	6,260	13%
Holmes	18%	32	13%	2432	-3%	8,800	-2%
Kays	12%	46	17%	2643	-3%	8,120	-17%

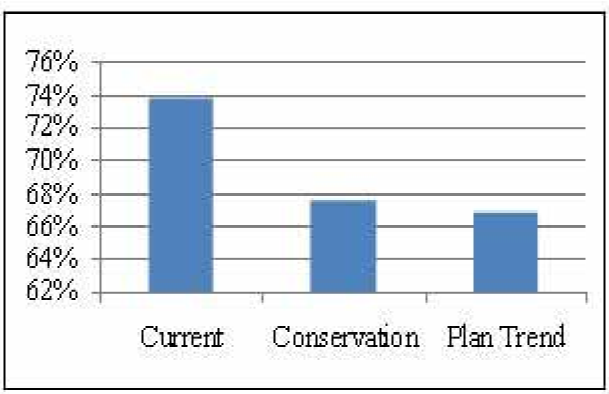
3.4 Nutrient retention capacity of impoundment wetlands

The calibrated wetland cellular water quality model for the "Impoundment" template performed well for a newly tested approach. The predicted removal efficiency for phosphorus was 74% and -11% for sediment removal. Table 19 displays the predicted vs. observed values for each cell in the template under current watershed loading conditions. The model was calibrated to approximate outflow concentrations at Cell I by using an average pollutant removal rate constant in all cells. See Appendix F for further discussion of model development and calibration.

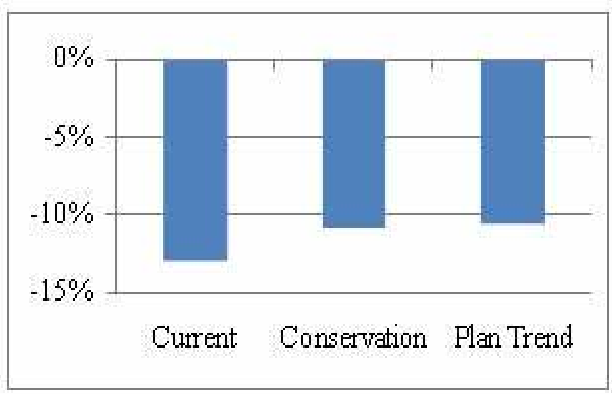
Figure 38 below displays the predicted retention of Total Phosphorus and Sediment in the Impounded template as predicted by the Wetland Cellular Water Quality Model for each scenario. Figure 39 presents the spatial framework generated for the model. Figure 40 and Figure 41 below display the calibrated results for cells that had observed data, as well as the predicted results for cells without data.

Table 19. Predicted vs. Observed Removal Efficiencies: Impoundment Template, NA=Not Available.

Wetland Cell	TP Outflow (mg/l)		Sediment Outflow (mg/l)	
	Predicted	Observed	Predicted	Observed
Utah Duck Club	0.48	0.44	28	23
A	0.45	0.65	28	23
B	0.44	NA	28	NA
C	0.44	NA	28	NA
D	0.43	NA	28	NA
E	0.41	NA	28	NA
F	0.26	NA	30	NA
G	0.21	0.22	30	29
H	0.17	0.16	31	41
I	0.13	0.14	31	33



Total Phosphorous



Sediment

Figure 38. Retention of Total Phosphorous and Sediment modeled for the Impoundment template under three future watershed-loading scenarios.

As can be observed in Figure 40, Cell A is particularly notable as it is the only cell that appears to export phosphorus (the concentration is higher than the previous cell's concentration). This could be due to a number of factors, including groundwater inputs, unidentified surface inputs, differences in soil or vegetation type, and saturation of the cell with phosphorus. There is also an overall increase in sediment concentration in the Impoundment template wetlands, although the first two cells remove a small amount of sediment. Cell H is particularly notable for its large increase in sediment concentration between the inlet and the outlet. It is likely that there is an unknown surface input here (see Appendix F). The overall increase in sediment concentration could be due to pulsing flows that re-suspend deposited sediments or to unidentified surface inflows carrying additional sediment.

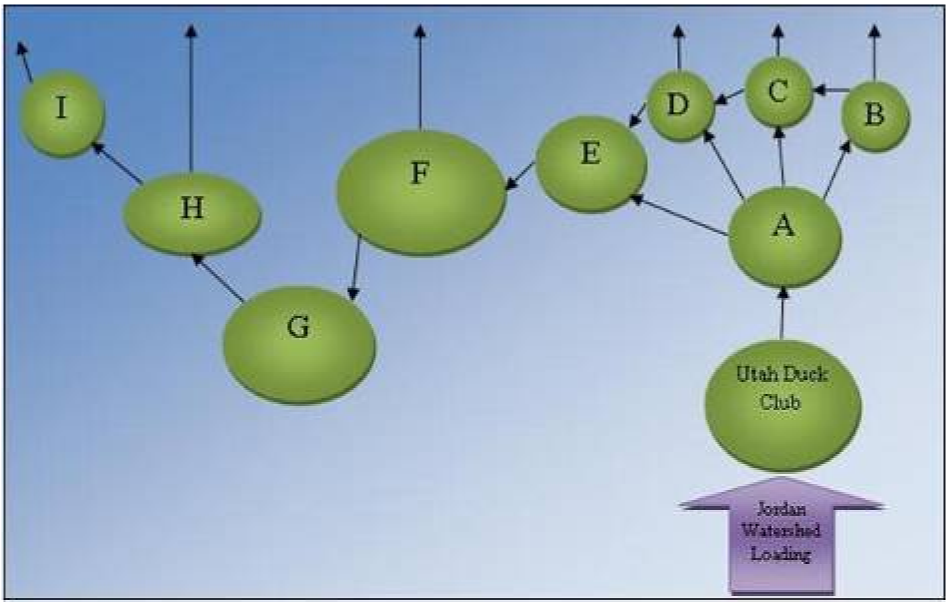


Figure 39. Impoundment Conceptual Framework.

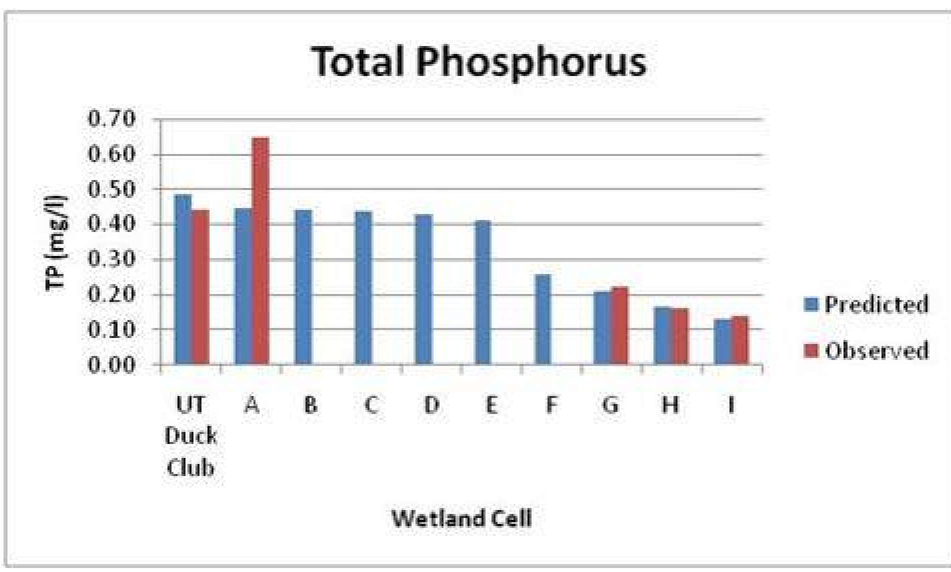


Figure 40. Observed and Simulated Results for Total Phosphorous.

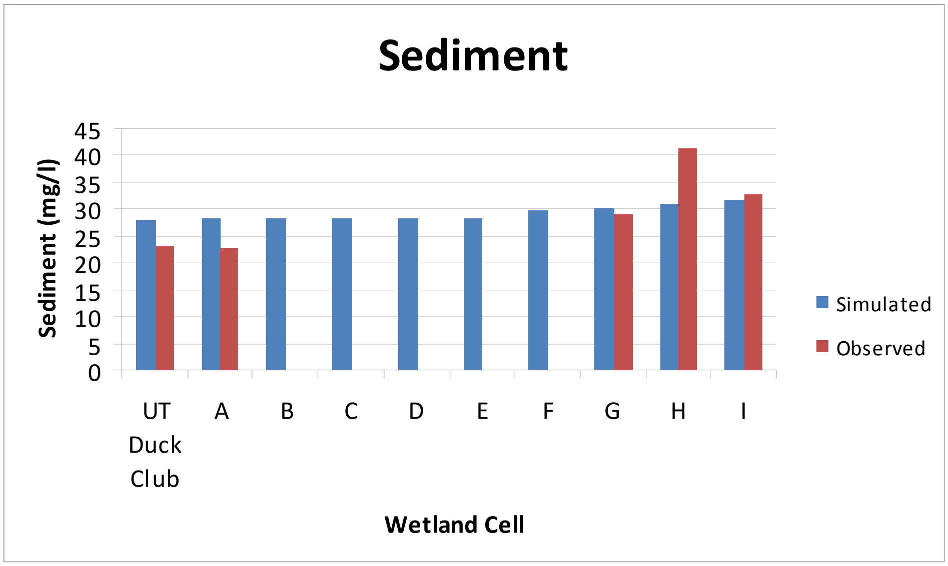


Figure 41. Observed and Simulated Results for Sediment

Table 20 displays the results of model runs for the template under the current scenario and two future scenarios. “TP in” and “Sediment in” are AVGWLF model outputs and serve as the inputs, or watershed loading to the impoundment template. “TP out” and “Sediment out” are the concentrations leaving the wetland template and entering Farmington Bay.

Table 20. Wetland Cellular Water Quality Model Results.

Scenario	TP in	TP out	Sediment in	Sediment out
Current	0.51	0.13	27.81	31.43
Conservation	0.57	0.18	21.19	23.49
Plan Trend	0.56	0.18	20.76	22.96

4.0 DISCUSSION AND CONCLUSIONS

The main objective to this study was to demonstrate use of the Alternative Futures Approach for wetland protection and conservation planning for Farmington Bay of the Great Salt Lake. An outcome of the study is an analysis of evaluation models that can be used in that approach. This discussion provides an interpretation of how study results can be used to set wetland management goals for Farmington Bay and the Great Salt Lake. A detailed analysis of the evaluation models used in the study is found in the appendices of this report.

4.1 Setting Wetland Goals – Connecting Results to a Decision-Making Framework

This research project focused on use of the AFA to compile, organize, and analyze technical information. The desired outcome of study was to produce information that will help inform decisions and build strategies for conserving the landscape that supports the wetlands of Farmington Bay. This discussion sets the stage for the technology transfer of methods and results to project partners working to protect the Great Salt Lake Ecosystem and its valued wetlands. The discussion is guided by the same "questions" listed at the beginning of major section of this report, except the questions are presented in reverse order.

4.1.1 Decision Making: Landscape Change and Conservation

Landscape ecology and information technology have matured together as a powerful toolkit for ecosystem analysis and goal setting. Conceptually, the conservation of natural processes is the ecological foundation of restoration planning, implementation and the evaluation of project success. Those processes, such as flowing water, produce physical structure within the environment. The structure helps to support life. Life is sustained because the flow of water and materials through the structure is not impeded beyond levels to which it has evolved and adapted to (i.e. life history or ecological "niche"). Decisions to change or conserve the landscape should be made reflective of these relationships.

Along these lines, public and private investments made to protect the Great Salt Lake Ecosystem and its valued wetlands continue to grow. However, stress on the Ecosystem likewise continues to increase due to the intensification of land use, increasing demand for water and climate change. Environmental managers are challenged to develop ways of keeping pace with the rate of landscape degradation and associated loss of ecosystem services.

Looking at the problem from the ground up reveals a basic fact: Project-by-project environmental review by communities leaves too little time and money for regulatory, conservation and development to adequately plan and assess land and water use. Monitoring is frequently inadequate to reveal problems or trigger corrective actions. Looking down from the landscape level reveals a path toward problem reconciliation. The path follows upon a strategic scaling-up of project planning through environmental program integration. Such integration can be guided through consideration and adoption of explicit ecosystem management goals for the wetlands and associated habitats of the Great Salt Lake. Those goals can be developed through an open community process that examines a plausible set of Alternative Futures. Once established, the goals are used to guide decisions about how to conserve or change the environmental landscape.

4.1.2 Predicting Change: Understanding the Consequences of Management Decisions

The choice to adopt environmental goals as a guide for decision-making can be influenced by a number of factors. This AFA provides insight about the consequences of a choice in actions or scenarios. Key to that type of analysis is the development and calibration of evaluation models that are applied to a set of design scenarios. The water quality models, avian use model and wetland landscape profiles used in the project all show promise as useful tools in a future community-based application of the AFA.

Project results also provide a starting point for the design of a more elaborate conservation scenario. For example, future conservation design can take into account the following results from this study:

(1) The wetland landscape profiles for the total study area, under conditions set by all future scenarios, predict a reduction of acreage in each class of wetland landscape as described by the templates.

(2) The most notable difference between the Conservation and the Plan Trend scenarios at both the 4,200 and 4,212 feet elevations, occurs in the Emergent and Playa wetland classes. The Conservation scenario protects approximately 30% more wetlands than the Plan Trend for both classes.

(3) The AWHA model predicts that availability of the most suitable category of habitat for each bird grouping will decrease in all of the future scenarios for the total study area except for Migratory Waterfowl in the Conservation 4,200 scenario.

(4) The Wetland Cellular Water Quality model predicts that, for the system as a whole, the impoundment wetlands in the Farmington Bay shoreland area will remove phosphorus and export sediment, which is consistent with observed data. However, discrepancies in removal efficiencies for individual wetlands within the impoundment template indicate that there are unaccounted sources of phosphorus and sediment in the present model. A better conceptual model and more data would improve the reliability of the Wetland Cellular Water Quality model predictions.

(5) All future scenarios show a large increase in watershed loading of both Total Phosphorus and Total Nitrogen in the evaluated sub-basins. The results are attributed to the overwhelming influence of the point sources and loads entering the Jordan River at Turner Dam. Changes in the land use of the sub-basins do not affect loads from these two sources.

These results suggest that the conservation scenario designed for the study was not sufficiently robust to address the risk of loss in the delivery of ecosystem services of interest. A more rigorous analysis of plausible protection, conservation, and treatment practices is needed. At the same time, better information about the effectiveness of those practices will be needed to guide their deployment and justify their cost.

<u>4.1.3 Predicting Change: Designing Plausible Scenarios Representing the Landscape Based on Past and Innovative Practices</u>

Each of the project's future scenarios reflects the cumulative outcome of environmental policy, practices, and individual project decisions. Experience gained during the project revealed that at least three environmental management "workstreams" influence the abundance, distribution, and condition of wetlands in the project area. Each workstream represents a cadre of environmental professionals and their community partners working with clear intent to protect and conserve the Great Salt Lake and its associated habitats.

The most profound influence on the wetland landscape is produced by practitioners with the job of conservation delivery. Both private and public wildlife managers have over many decades worked to control the abundance, distribution, and condition of wetlands in the project area to optimize the resource for avian use. Another influential group of practitioners are those involved in the federal Clean Water Action Section 404 regulatory program. The interplay between agency regulators, resource agency staff, public and private development interests, and environmental consultants leads to permit decisions that control the rate of conversion of wetlands to uplands. The third workstream involves the work of water quality managers. Both private and public water quality managers play a pivotal role in attempting to protect the wetlands of the Great Salt Lake from degradation caused by pollution and pollutants.

The design of the Plan Trend and Conservation Scenarios used in this study present two different examples of the way these workstreams function in the project area. The Plan Trend Scenarios (like the Current Scenario) assume that each workstream operates independent from one and another. In contrast, the Conservation Scenarios are organized around a common set of mapped wetland restoration opportunities. The only way that the opportunity can be fully realized is through cross-program collaboration that is guided by a common set of environmental goals.

For example, the AFA reveals that the risk of wetland loss or degradation can be correlated to resource occurrence within different elevation strata controlled by Great Salt Lake level. Wetlands located below 4212' elevation are primarily at risk of degradation from nutrient loads in their receiving waters. Wetlands located between 4212 - 4217 feet are confronted with the combined risk of pollutant degradation and conversion to upland development. Wetlands above 4217 feet are at high risk of conversion to uplands. A conservation scenario designed to manage this pattern of risk will need to be much more explicit than described in this study.

However, that scenario can build on the results of the study by more specifically describing the coordinated placement and design of protection, restoration, and treatment practices within the three project templates. The scenario also can articulate how environmental policy is coordinated across programs and authority to ensure the delivery of those practices. The types of practices include:

1. Wetland protection and preservation,
2. Wetland restoration
3. Aquatic buffer conservation
4. Flow conveyance conservation ("conservation pool")
5. Constructed wetland treatment systems
6. Waste water treatment system technological upgrades.

The types of environmental programs and authorities needed to coordinate the delivery of those management practices include:

- The Great Salt Lake Ecosystem Program, including state wildlife conservation programs
- Utah's State Water Quality Management Program
- Great Salt Lake Comprehensive Management Planning Program
- The federal Clean Water Act Section 404 Regulatory Program
- Salt Lake City Corporation, Salt Lake County, Davis County Community Development and Public Works Departments
- Private, corporate and not-for-profit community-based conservation programs

One type of innovative environmental initiative that might serve as a catalyst to align the authorities and practices is a water quality-trading program. Water quality trading is based on the premise that pollutant sources in a watershed can face very different costs to control the same pollutant. Trading programs allow facilities facing higher pollution control costs to meet their regulatory obligations by purchasing environmentally equivalent (or superior) pollution reductions from another source at lower cost, thus achieving the same water quality improvement at lower overall cost (USEPA, 2003).

The commissioning of a study on the feasibility of building a water quality-trading program to serve portions of the Great Salt Lake may be an attractive idea for several reasons. The primary reason for considering a trading program is that constructing or restoring wetlands, in addition to traditional abatement technologies, have a demonstrated capacity to reduce sediment or nutrient loadings, while also supporting habitat and other ecosystem services (USEPA, 2007 a, b). Lessons learned from wetland compensatory mitigation banking and the study of conservation delivery programs can provide added clarity about the opportunities and challenges using wetland construction and restoration to meet multiple program objectives (Rafini and Robertson, 2005; Gleason et al., 2008). There are many economic considerations that will have to be studied before incorporating wetlands in a water quality-trading program (Heberling et al, 2007).

4.1.4 Evaluating the Current State of the Landscape

Perhaps the largest information gap encountered during this AFA was the limited amount of monitoring and assessment data on Farmington Bay wetlands and their associated habitats. Such data is needed to build an understanding, with known certainty, about how changing wetland abundance, distribution, and condition affect the delivery of valued ecosystem services. The data also can be used to build and implement the assessment framework used to set environmental goals, integrate programs, prioritize projects and practices, and report on the cumulative environmental effectiveness of management actions, including water quality crediting and trades.

The US EPA has provided to states technical guidance on the implementation of wetland monitoring and assessment programs (USEPA, 2006b). Part of the guidance describes use of a three-level assessment strategy. The strategy describes an integrated use of landscape-scale, rapid and intensive assessment protocols for evaluating whether a wetland landscape is "working well" or not. This AFA demonstrated how landscape-scale information (i.e., wetland landscape profiles) can be a valuable tool for guiding wetland management decisions. As each new level of assessment comes on line, the certainty of environmental predictions, forecasts, and effectiveness reporting will increase. A study of the feasibility of expanding the scope of wetland monitoring and assessment in Farmington Bay and across the broader Great Salt Lake is a prerequisite for alternative analysis work in the region.

4.1.5 Describing How the Landscape Functions

As mentioned above, the AFA demonstrated how broad-scale assessment information can be organized and used to describe management scenarios. The project also demonstrated the use of environmental modeling to forecast the possible consequences of those scenarios. Field level monitoring and assessment information is used to strengthen the technical efficacy of those landscape assessment and modeling approaches. Additional research is also needed to build the scientific underpinnings and complete the science portfolio of tools needed to describe the functioning of the Farmington Bay wetland landscape and explain how it works. A specific set of recommendations about how to improve the next iteration of Farmington Bay Wetland AFA are presented in section 5.0.

5.0 Model Performance and Recommendations for Improvements

5.1 Recommendations for the Wetland Landscape Profiles

In all templates, the playa wetlands are the least affected by lake-level rise, although this result is somewhat misleading. Certain areas of Farmington Bay display a topography that is too flat for the 10-meter digital elevations model (DEMs) to adequately represent the effects of lake-level rise. It is probable that a higher percentage of topographical depressions are located below 4,212 feet than is currently represented by the 30 meter DEM used for this study. Therefore, it is also possible that the playa wetlands in all templates could be flooded and subsequently transformed to fringe or semi-permanent and permanently flooded lacustrine class in a scenario with a lake-level of 4,212 feet. To improve the wetland scale profiles, it is recommended that a more detailed elevation dataset be obtained and processed. The most promising strategy for obtaining a refined elevation dataset involves the processing of available Light Detection and Ranging (LIDAR) remote sensing data.

Considering the recent trend towards drier conditions in the Great Salt Lake eco-region, it would be advantageous to develop future scenarios that consider lake level and water table decline. In recent years, the lake has dropped well below the average lake level of 4,200 feet. Additional research on lake-level fluctuation patterns and groundwater interactions would improve predictions of future impacts to the current wetland landscape profile for Farmington Bay. Bishop et al. (2008) conducted a study on groundwater, ranging from the Wasatch Range in Davis County to the palustrine wetlands of the Eastern Shore of Farmington Bay. This research suggested how vegetative changes in the palustrine fringe wetlands could be realized as water withdrawals increase and lake level fluctuates. Mohammed (2006) evaluated the complex variables controlling the Great Salt Lake level.

It is recommended that the 2008 NWI data used in the functional classification be evaluated for accuracy. For this study, several errors in classification were noted and corrected by the research team. Errors in the NWI data typically fell into one of two categories: 1) misclassification of unconsolidated bottom and aquatic bed in the impounded wetland classes, or 2) misclassification of lacustrine wetlands, possibly associated with inaccurate representation of bathymetry.

5.1.1 Avian Wetland Habitat Assessment (AWHA) Performance

AWHA represents the "first cut" of a spatial modeling methodology that can be easily modified with both updated GIS data and revised variables and weights. The model functioned well in ArcGIS and produced logical results, which are in-line with the overall expectations for habitat suitability in Farmington Bay. Efforts are already underway to refine this preliminary modeling assessment. Utah Department of Natural Resources has funded a research project to improve and validate the methodology developed for the AWHA model. The variables and weights used for this project will be closely evaluated and revised as necessary to produce refined results. An analysis of this framework's potential to predict presence or absence of bird species and/or habitat abundance will be evaluated using various spatial statistics. The goal of the new project is that a validated model will be applied to the entirety of the eastern shore of the GSL for identification of wetland habitat areas for multiple bird groupings. By utilizing the resulting species-specific, statistically validated habitat data, managers will be able to prioritize the development of conservation and management strategies for wetland units.

5.1.1.1 Recommendations for AWHA

A number of revisions can be made to produce more accurate results for the AWHA spatial model. The most imperative revision may be the utilization of a higher quality elevation dataset. As previously stated, the current elevation data layer (10 meter DEM) is inadequate for representing the low relief displayed in the Farmington Bay topography, particularly for the Playa template in the "Northwest Quadrant". Refined elevation data will result in a more accurate representation of water depth in the Fringe and Playa wetlands, while also potentially allowing for a more precise evaluation of management scenarios in the Impoundment wetlands.

Watershed loading variables can potentially be included in an evaluation of suitable habitat in the Farmington Bay wetlands. Estimates of nutrient (nitrogen and phosphorous) loads, sediment loads, and conveyance flow rates were delivered to the wetlands using the AVGWLF watershed loading model. These three watershed-loading variables (flow, nutrients, and sediment) were weighted for potential use in the avian model; however, no GIS data was identified to adequately spatially represent the variables. A recommendation for future work is to explore the feasibility of creating spatial datasets to support these additional watershed-loading variables. Including the effects of watershed loads on habitat suitability would enhance model predictions. For example, under higher nutrient loading conditions, *Phragmites* will out-compete alkali bulrush, causing a loss of forage. All of the conveyances eventually output to the Fringe wetlands. Increased nutrients may be particularly problematic for Migratory Waterbirds, which use the Fringe wetlands for foraging. Another example is that increased conveyance flows might boost the functional habitat acreage in the playa wetlands, particularly during high-flow events. Overbank flows give rise to sheet-flow and create new foraging habitat outside of the standard boundaries of the wetlands.

5.1.2 AVGWLF Performance

The utility of models such as AVGWLF lies in their ability to predict watershed loading with reasonable accuracy in the presence of limited data. The AVGWLF data preparation and calibration used for this study could be valuable for managers interested in estimating nutrient and sediment loads for a variety of endpoints. The model and the supporting data could be transferred for use in other parts of north-central Utah with relative ease through the incorporation of local data or knowledge regarding the watershed budget (inputs and outputs).

During the calibration process, adjustments were made to the various input parameters to obtain a “best fit” between the observed and simulated data. One of the challenges to calibrating a model is to optimize the results across all model outputs. In the case of AVGWLF, the outputs are stream flow and sediment, nitrogen, and phosphorus loads. As with any watershed model such as GWLF, it is possible to focus on a single output measure (e.g., sediment or nitrogen) in order to improve the fit between observed and simulated loads. Focusing on one model output, however, can lead to less acceptable results for other measures. Consequently, it is sometimes difficult to achieve very high correlations across all model outputs. In spite of this limitation, it was determined that highly consistent results were obtained for the calibration site.

The AVGWLF watershed-loading model allows for a monthly and annual analysis of nutrient and sediment loads by source. This analysis shows that flows and loads in the Jordan River Basin are largely influenced by point source dischargers and Turner Dam releases. When the Turner Dam releases enter the Jordan River, water is diverted from the river almost immediately by many canals. These canals remain within the basin and, along with the Turner Dam flows in the river itself, carry a large amount of water, sediment, and nutrients. There are two major point source dischargers located above the surplus canal in the Jordan River Basin. These facilities are the Central Valley Wastewater Treatment Plant and South Valley Waste Water Treatment Plant. The treatment plants represent the largest contributors of phosphorus and nitrogen to the Surplus canal and Goggin Drain.

It should be noted that additional, related studies are currently underway or being completed in the Jordan River watershed. Of particular interest are the *Jordan River Total Maximum Daily Load Project* (TMDL) (SLC, ongoing) and the recently completed *Salt Lake County Water Quality Stewardship Plan* (SLC, 2009). Preliminary analyses from the Jordan River TMDL study are summarized in the *Jordan River Water Quality Total Maximum Daily Load Assessment* (UTDWQ, 2005). Various segments of the Jordan River are listed by Utah DEQ as being impaired for dissolved oxygen, temperature, total dissolved solids, and *E. coli*. The referenced 2005 water quality assessment provides analyses for all of these parameters and identifies phosphorus as the primary cause of the dissolved oxygen impairment.

The Jordon River TMDL project team is currently developing a water quality model (QUAL2K) to assess the impacts of various sources of phosphorus in the Jordan River watershed on dissolved oxygen levels. Preliminary source assessments indicate that publically owned treatment works (POTWs) contribute 79% of the phosphorus load in the Jordan River (Utah Division of Water Quality, 2008). While this figure differs somewhat from the estimate of 91% in the AFA, it must be noted that two very different watershed boundaries were used in these studies. The AFA used a boundary with an outlet at the Surplus Canal diversion, commonly referred to as 2100 South, while the TMDL study is using a watershed boundary with an outlet at the Great Salt Lake. The larger drainage area in the TMDL study predictably results in a large increase in surface runoff, decreasing the relative proportion of phosphorus loading attributed to POTWs.

The reasons for using different watershed boundaries in the two analyses are related to the different goals of each analysis. The TMDL study is being conducted in a regulatory environment. It is intended to identify all sources of impairment in the Jordan River watershed. Based on an understanding of these sources of impairment, the TMDL study will formulate a restoration strategy that will allow for the attainment of water quality standards in all segments of the river. The AFA, on the other hand, was a research project with the goal of simulating watershed conditions and resultant nutrient loads to the Farmington Bay wetlands under alternative future scenarios. Identification of sediment and nutrient sources was necessary to estimate future loadings due to population increases and land use change. The chosen watershed boundary facilitated estimation of flow, sediment, and nutrients delivered to the playa and impoundment wetland templates via the Surplus Canal.

It is important to use long-term datasets when analyzing water quality data in systems with highly variable climatic and human influences, such as the Jordan River watershed. Assessing pollutant sources under drought conditions will result in overestimation of point source contributions, while source assessment under very wet conditions will result in overestimation of non-point source contributions. Consequently, a ten-year period (1995-2005) was chosen for analysis, which included both wet and dry conditions. Inclusion of a drought period in the analysis is appropriate given that future climate in the Jordan River watershed is expected to be drier than present day conditions (Cromwell et al., 2007). Water quality data presented in the Jordan River Water Quality TMDL Assessment (UTDWQ 2005) and Salt Lake County Water Quality Stewardship Plan (SLC 2009) are consistent with the water quality data obtained for this project. These reports also provide guidance on the selection of other important watershed data including water use, population, and land use.

5.1.2.1 Recommendations for AVGWLF

In the Farmington Bay sub-basins, there is a large amount of variability in flows due to intense management of the basin's water resources. As a result, variability in the predicted nutrient and sediment loads correlates with variability in the flow. Due to this large, month-to-month variability, a number of assumptions were necessary when calibrating and running the model. This was particularly true for the withdrawal amounts in the basins. The project team made all efforts to obtain data from private, local, state, and federal databases to support this calibration and the subsequent modeling. If higher quality data is available, it could be incorporated into the model to produce updated results.

Monthly conveyance flow inputs should be better quantified using a hydrologic model. It is recommended that a hydrologic model for the shoreland conveyances be developed to evaluate scenarios of flow and runoff in canals. Flow simulations in the shorelands would be very useful for improving the data inputs to the AVGWLF model and for estimating nutrient loads to the wetlands. Calibration of a hydrologic model would help with future management decisions regarding water use and flow.

Calibrating a hydrologic model would require a comprehensive understanding of the current management strategies for individual conveyance flows and water rights in the shorelands. The conveyance system in the shorelands is complex and difficult to quantify. Canal flows are regulated based on water rights and are, therefore, erratic. The temporal variability of the canal flows poses the greatest challenge for modeling hydrologic processes in the shoreland. Therefore, documenting water rights and conveyance delivery under different flow regimes should be the first step in the development of a hydrological model. Assessing current water management strategies in both the shorelands and the drainage basins would help to ensure that as water availability decreases in the future, water distribution will continue to sustain the wetlands.

Land use estimates are based solely on the maps provided in the Salt Lake County Watershed-Water Quality Stewardship Plan report (SLC, 2009). Procurement of the actual land use GIS files is recommended to further improve the watershed loading estimates. Additional information regarding localized development (such as CAD or GIS data representations for the Northwest Quadrant master plan) would be useful to better estimate specific changes in the future.

Additional watershed analysis should be performed on the following stream networks: a) the lower portion of the Jordan River Basin that delivers water to the Jordan River below the Surplus Canal diversion; b) the lower Jordan River drainage sub-basins, which include wastewater treatment facilities serving Salt Lake City; c) the Davis County drainage basins that delivers nutrients and flows to the Utah State Impoundments south of Baird Creek; and d) all drainage basins north of Kays Creek that discharge into Farmington Bay.

5.1.3 Recommendations Wetland Cellular Water Quality Model

The wetland water quality model requires wetland cells with relatively well-defined boundaries, initial flow estimates, and known flow pathways between cells, and a pollutant removal rate constant. Pollutant removal rate constants are highly variable among sites and even among individual cells. Concentration estimates are thus desirable in order to calibrate the model. However, if unavailable, these values can be obtained from the literature. This calculation is applied to each cell in the template with the outflow concentration of one cell serving as the inflow concentration in the next cell. The hydrologic loading rate (HLR) will differ for each cell based on the area of the cell and the flow rate.

The impoundment template was selected for modeling because it had readily available data and relatively well-defined cell boundaries. The resulting phosphorus removal rate of 74% corresponds with the observed values. The model simulated phosphorus retention for the template as a whole very well. Cell A has an observed export of phosphorus that was not accounted for in the model. This may suggest that wetlands that receive sustained nutrient loading can reach a threshold for nutrient retention. It is possible that this is occurring in Cell A, though more investigation is necessary to confirm this. Phosphorus export could also be explained by a number of other mechanisms including alternating wet and dry periods, or re-suspension of sediment phosphorus due to pulsing flows.

The model is simplified in that it disregards many components of nutrient cycling in wetlands. However, the model performs well at characterizing the retention of nutrients. After further development and improvement, the approach presented for this project could be transferred to other impounded wetland areas. While the utility of models lay in their ability to simulate systems where data is lacking, the collection of additional water quality data will always result in a better model calibration. For example, additional nutrient and sediment data can be used to better calibrate a nutrient decay model for the various classes of wetlands found in the Farmington Bay shorelands. This would allow the establishment of more relevant nutrient retention coefficients.

6.0 SUMMARY

An “Alternative Futures Analysis” was conducted to demonstrate how models can be used to evaluate landscape design scenarios developed for the Farmington Bay area of the Great Salt Lake. Scenarios were developed which featured the design of a conservation “future” focused on a set of wetland protection, restoration, and conservation practices. The conservation design was contrasted with scenarios that reflect current day wetland management practices and an extrapolation of those practices into the future. Each of the future scenarios was described in context with the average water level elevation of the Great Salt Lake and a high water level elevation (4,200 feet and 4212 feet, respectively). In addition, a set of wetland “templates” was developed and embedded into each scenario to aid scenario design and evaluation. Each template represents a typical cluster or complex of wetlands with a dominant wetland class and they included: Impoundment wetlands, playa wetlands and fringe/emergent wetlands Evaluation of the scenarios was based on risks to avian habitat support caused by degradation in wetland abundance, distribution and condition. The evaluation entailed the use of four ecological modeling approaches. A relatively simple wetland landscape profile was developed to track change in wetland abundance, by class, across the scenarios. A Geographic Information System (GIS) based avian wetland habitat assessment (AWHA) was developed to predict the availability of suitable avian habitat. The ArcView Generalized Watershed Loading Function (AVGWLF) model was calibrated to predict nutrient loads to the wetlands. A wetland cellular water quality model was developed to evaluate nutrient retention in impoundment class wetlands.

Project results reveal that most (97%) of wetlands in the study area are located within an elevation band of 4,200 feet to 4,217 feet. Results from futures analysis show a dramatic loss of wetlands for all templates embedded in the Plan Trend 4,212 Scenario and the Conservation 4,212 Scenario. The Plan Trend Scenarios observe the greatest decline in the most suitable category of avian habitat for three bird groupings: Migratory Shorebirds, Migratory Waterbirds, and Migratory Waterfowl. The Conservation 4,200 Scenario protects the most wetland acreage and highest category of suitable avian habitat. The Plan Trend 4,200 Scenario observes the greatest decline in the highest class of suitable avian habitat. A substantial increase in watershed loading of nutrients delivered to all the templates for the Conservation and Plan Trend scenarios was predicted using the AVGWLF model. Results from this model also indicate that total phosphorus and total nitrogen loads delivered to the templates from the Jordan River watershed are heavily influenced by the two major point sources in the Jordan Basin. The wetland cellular water quality model predicted a removal efficiency of 74% for phosphorus, and -11% for sediment for impoundment class wetlands.

The approach used for this project, incorporating GIS based evaluation models and including an “Alternative Futures Analysis”, is a transparent way of organizing and communicating complex scientific information to a diverse group of stakeholders and improving communication among stakeholders.

The authors of this report encourage examination of the methods and results produced by this research project. Our hope is that lessons learned will be applied in renewed effort toward envisioning ways to sustain and improve the health of the Great Salt Lake Ecosystem.

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8.0 APPENDICES

8.1 APPENDIX A. SHORELAND ELEVATION ZONES

Several elements of this study relied on the use of a lake-level fluctuation simulation. The low relief of elevation in Farmington Bay makes determining the proper location of the lake-shore (meander-line) particularly important for assessing the acreage of wetlands, assessing restoration opportunity, and identifying avian habitat. The elevation product used for this study was a 10 meter USGS DEM obtained in 9 coverage quads from the Utah State Geographic Information Database (SGID). The 9 quads were merged to a single coverage and 1 foot contours were interpolated. The contours were clipped to the study area.

The location of the lakeshore meander-line is quite important when evaluating wetland acreages in and around Farmington Bay. With even a one foot change in lake level, open water in Farmington Bay can increase by thousands of acres. Generalized shoreland elevation zones were established to better evaluate notable elevation thresholds occurring in the landscape as well as to more clearly report acreage data associated with lake-level fluctuation and upland management decisions.

The current scenario lake level for this study was established at the historical average of 4,200 feet. Elevations below 4,200 feet are considered open lake-water. The high lake level was established at 4,212 feet based on the historical high. Wetlands between 4,212 feet and 4,217 feet were denoted as significant. These wetlands are protected from development by zoning and local building practices. The Federal Emergency Management Administration (FEMA) has established a critical elevation line for planning around Farmington Bay at 4,217 feet (SLCPZ, 2008). Any development below that line could result in significant damage to property, persons, and structures as lake levels increase and recede. FEMA 100-year flood assessments provide the most adequate information regarding the effects of lake level rise on both the wetlands and on Salt Lake and Davis County infrastructure. Wetlands located between 4,217 feet and 4,220 feet are considered significant. The spatial complexity and diversity of wetland types is pronounced despite encroaching development and the diminished water table. Above 4,220 feet, wetland acreage and complexity are reduced. Wetlands in that zone are at high risk for conversion to upland for development purposes. Figure A1 displays the shoreland elevation zones established for this study.

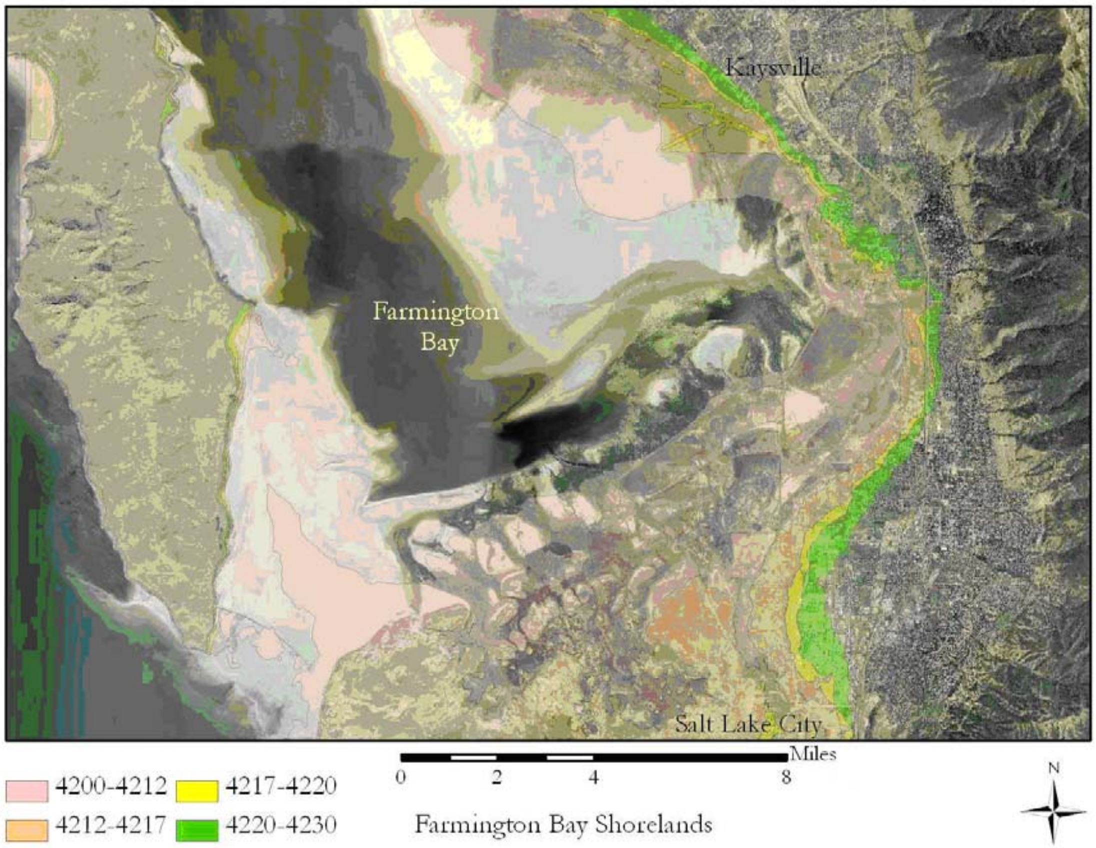


Figure A1. Shoreland Elevation Zones.

8.2 Appendix B. 2008 National Wetlands Inventory

National Wetlands Inventory

Although the wetlands were generalized into functional complexes, the original polygon data were from the 2008 NWI classification. The following paragraphs describe the NWI wetland types employed for this functional classification. Riverine and Lacustrine Limnetic (deep-lake water) wetlands were present in the landscape, but not included in this analysis or described below.

The Lacustrine System

[L] The "Lacustrine" System includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergent vegetation, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 hectares (20 acres). The majority of lacustrine wetlands located in and around Farmington Bay are generally described as Littoral. Littoral wetlands extend from the lake-shore boundary to approximately 2 meters (6.6 feet) below annual low water or to the maximum extent of non-persistent emergents; if these grow at depths greater than 2 meters.

The Palustrine System

[P] The Palustrine System includes all non-tidal wetlands dominated by trees, shrubs, emergent vegetation, mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean derived salts is below 0.5 ppt. Wetlands lacking such vegetation are also included if they exhibit all of the following characteristics: 1) are less than 8 hectares (20 acres); 2) do not have active wave-formed or bedrock shoreline features; 3) have during low water a depth less than 2 meters (6.6 feet) in the deepest part of the basin, and 4) salinity due to ocean-derived salts of less than 0.5 ppt.

Hydrogeomorphic conditions of both the Lacustrine Littoral system and the Palustrine system can be classified using NWI as follows:

1. [UB] Unconsolidated Bottom - Includes all wetlands and deepwater habitat with at least 25% cover of particles smaller than stones (less than 6-7 cm), and a vegetative cover less than 30%.

2. [US] Unconsolidated Shore - Includes all wetland habitats having the following three characteristics:
   a. unconsolidated substrates with less than 75% areal cover of stones, boulders, or bedrock;
   b. less than 30% areal cover of vegetation other than pioneering plants; and
   c. any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, seasonal-tidal, temporary-tidal, or artificially flooded.

Vegetation conditions of both the Lacustrine Littoral system and the Palustrine system can be classified using NWI as follows:

1. [AB] Aquatic Bed - Includes wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years. Aquatic beds generally occur in water less than 2 meters (6.6 feet) deep and are placed in the Littoral Subsystem (if in a Lacustrine System).

2. [EM] Emergent - Characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants.

Impounded areas of the Lacustrine Littoral system and the Palustrine system can be identified with the [h] modifier and are referred to as "Diked or Impounded". These wetlands are created or modified by a man-made barrier or dam, which obstructs the inflow or outflow of water. Originally, "Diked" and "Impounded" were described as separate modifiers (Cowardin et al. 1979). They have been combined in the NWI classification due to photo-interpretation limitations.

According to USFWS NWI Staff, when the NWI was ground-truthed, the new photography was compared to the old project data. In most cases, it appeared that conditions were very similar in relation to water levels and hydrology. The old photography was color infrared and the new photography was black and white, but for the most part, they correlated fairly well. The old photography was taken in 1981, which was prior to the flooding events that occurred during the period of 1983-1986. The new photography was taken during 1997-1998. Actual months were not available at the time of this analysis. The contour scheme used on the lake for both mapping efforts is shown below. Since the lake was originally contoured manually and subsequently digitized using topographic maps, changes were not made to this portion of the data except where obvious changes occurred (vegetation, fill, road construction, etc.). Most of these changes occurred within the L2USC area (Kevin Bon, USFWS, personal communication).

Contour Interval	**Classification**
4,195 - 4,200	**L2USC**
4,194 - 4,195	**L2UBF**
4,191 - 4,194	**L2UBG**
4,189 - 4,191	**L2UBH**
< **4,189**	**L1UBH**

8.3 Appendix C. Restorations Opportunity Assessment

Parameters for locating restoration opportunities on the Farmington Bay landscape were established prior to development of the actual GIS methodology. The rules were purposefully kept separate from the analyses of valuable avian habitat and nutrient loading so as not to introduce bias into the assessment. Furthermore, the rules are designed to be simple. They are based on data that are easily obtainable and a GIS that is easily replicable. Rules governing the designation of areas as a “high potential” or “potential” restoration opportunity were developed. The rules defining each category of restoration potential are described below.

Public or Private High Potential Restoration Opportunity

A wetland must meet the following spatial criteria to be identified as presenting a “high potential restoration opportunity”:

1. Must intersect a “30 meter buffer” around conveyances. Intersection of 30 Meter Conveyance Buffer is an indicator of high restoration potential because of the conveyance’s ability to deliver managed flows to the wetland.
2. Must exhibit “All-hydric” soils. All-hydric soils are an indicator of areas that may contain existing wetlands or suitable for wetland restoration.
3. Must possess “Interior Habitat” of at least 30 meters from wetland edge. Interior Habitat is defined as areas with no major roads, train tracks, power lines, or developed structures.
4. Must not be categorized in NWI as L2USC. These are seasonally flooded lacustrine, non vegetated wetlands that are typically found below 4,200 feet.

Public or Private Potential Restoration Opportunity

A wetland must meet two or more of the following spatial criteria to be identified as presenting a “potential restoration opportunity”:

1. Must exhibit “All-hydric” or “Potentially-hydric” soils. All-hydric soils are an indicator of areas that may contain existing wetlands or suitable conditions for wetland restoration. Potentially hydric soils are an indicator of areas with less certainty of wetland occurrence and restoration potential.
2. Must not be categorized as L2USC. These are seasonally flooded lacustrine, non vegetated wetlands that typically are found below 4,200 feet and cannot be easily managed.

Phragmites Removal Potential

Any wetlands or areas immediately adjacent to wetlands that have *Phragmites* are considered potentially restorable. Wetlands with *Phragmites* can include upland areas or seasonally flooded areas. The removal of *Phragmites* will increase the habitat value of wetlands and adjacent areas. Statistics about *Phragmites* and restoration opportunity are reported separately from the other potential restoration categories.

Restorations Opportunity GIS Methodology

The Restorations Opportunity assessment map is derived from a standard overlay analysis using the following GIS data sets: Salt Lake and Davis County Parcel Data; Interior Habitat; SSURGO soils data; *phragmites*; conveyance and water rights data; 2008 USFWS National Wetlands Inventory (NWI); and Elevation Zone Assessment. The remainder of this appendix summarizes how these data sets were incorporated into the restoration opportunity assessment.

Parcel Evaluation

The presence of public or private lands is an important indicator of areas most viable for conservation or restoration activities. Public lands include those that are owned by the county, state, or federal government. Wetlands in these areas would provide the most immediate opportunity for restoration and conservation, as there would likely be fewer barriers for obtaining these wetlands. For this study, public lands also included areas currently protected and managed by organizations such as the Audubon Society and the Kennecott Copper Corporation Mitigation Wetlands. Private lands include all other categories of private ownership and acreage in the shorelands and are mainly comprised of the several duck clubs within the project area. For both private and public lands, individual tax parcel polygons were merged in the GIS into the appropriate public or private category based on the "ownership" attribute. Figure C1 presents the parcel evaluation completed for the restorations opportunities assessment.

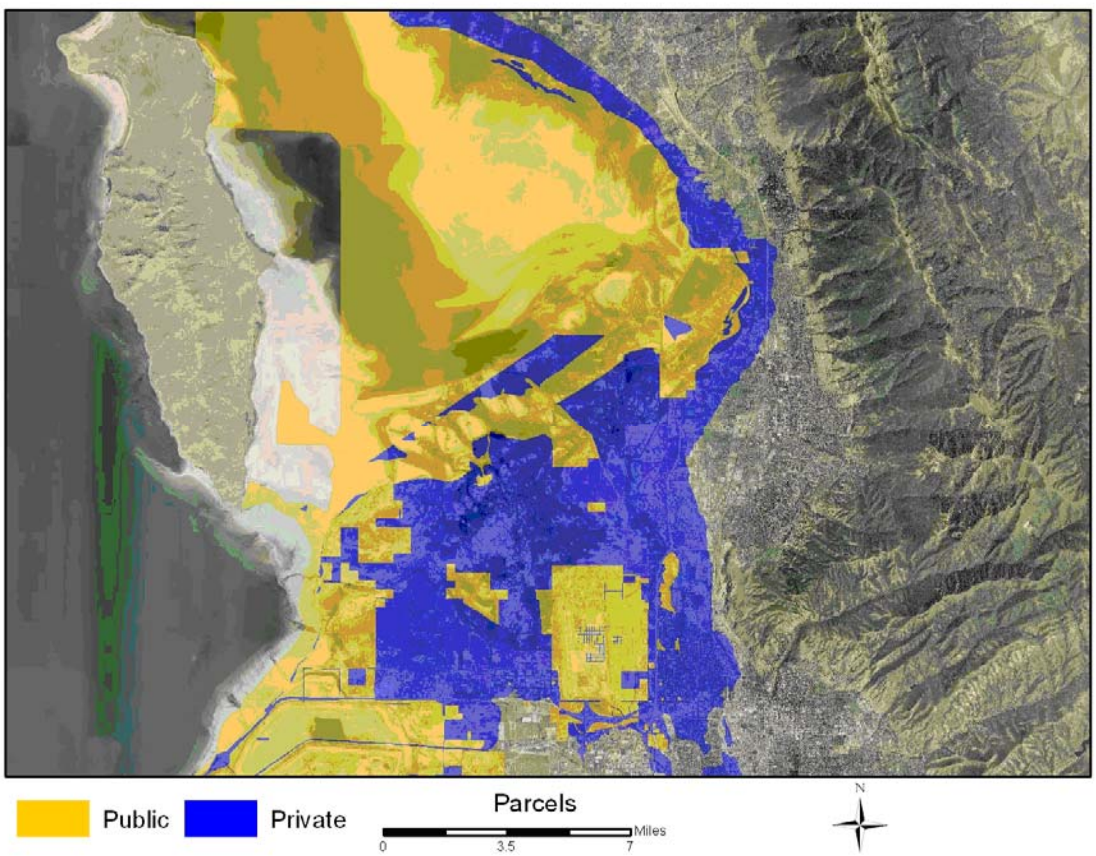


Figure C1. Parcel Evaluation.

Interior Habitat

Interior Habitat is described as non-fragmented areas with no major roads, train tracks, or developed structures that can interfere with the movements and activities of avian species. The framework for this methodology was developed by Frontier Corporation (Providence, Utah) for the Brigham City and Perry City Special Area Management Plan Project (BCSAMP, 2006). An initial 15 meter buffer was applied to the NWI wetlands layer to identify adjacent roads or railroad tracks. Then, gaps between wetland polygons of less than 60 meters were filled creating larger wetland complexes. The 60-meter buffer value was chosen based on the existence of 100 foot (30 meters) right-of-way widths for arterial roads and railroad tracks in this area. By filling the gaps created by these right-of-ways, the artificial separation of the wetland complexes by roads and railroads is eliminated. Once this initial step of identifying areas of un-fragmented wetland complexes was complete, interior buffers of 0 meters, 30 meters, 60 meters, and greater than 60 meters were applied to the resulting wetland complex polygons to "trim" back the interior habitat at 30 meter intervals. Areas of less than 0.05 acres were not assessed for this analysis. Figure C2 displays an example of creating and applying interior buffers to wetland complexes.

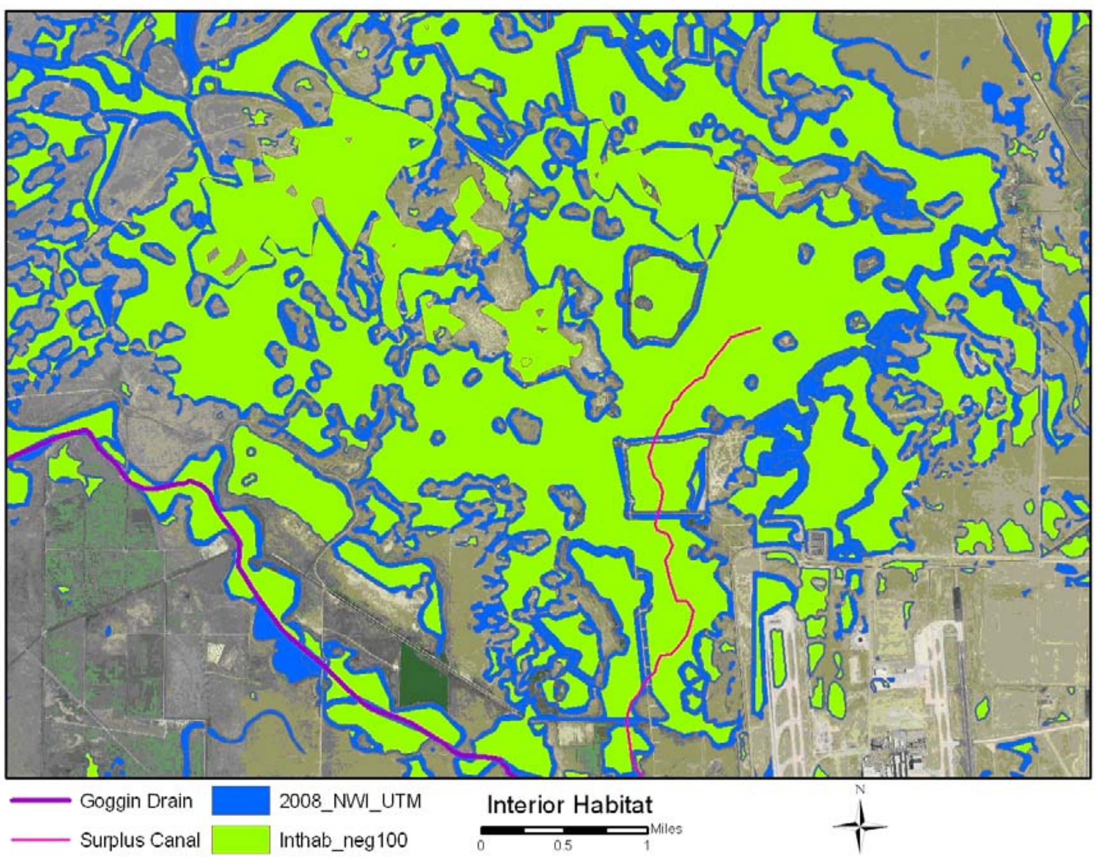


Figure C2. Interior Habitat with Interior Buffers.

Hydric Soils Classification

The SSURGO datasets for Davis County and Salt Lake County were obtained and reformatted to identify all hydric and partially hydric soils for the restorations opportunity assessment. SSURGO soil data were downloaded in a Microsoft Access database. The following steps were undertaken in Microsoft Access to adequately format and organize the SSURGO soils data for the various aspects of this project:

1. Create a new table parameter denoted by a unique Component Key
2. Group the required soil parameters
3. Create a new table with data for the first and second highest soil layer
4. Join data from highest soil layer table to the data from the second highest soil layer
5. Compute the K effective factor analogously

The resulting horizon table has a total number of records equal to the total number of unique Component Keys from the original C horizon table. The newly created table was then connected to soil survey boundaries. For the restorations opportunity map, the “Hydric Classification” field was used to reclassify the soil survey polygons and to identify All-Hydric and Partially Hydric soils. The resulting map is presented in Figure C3.

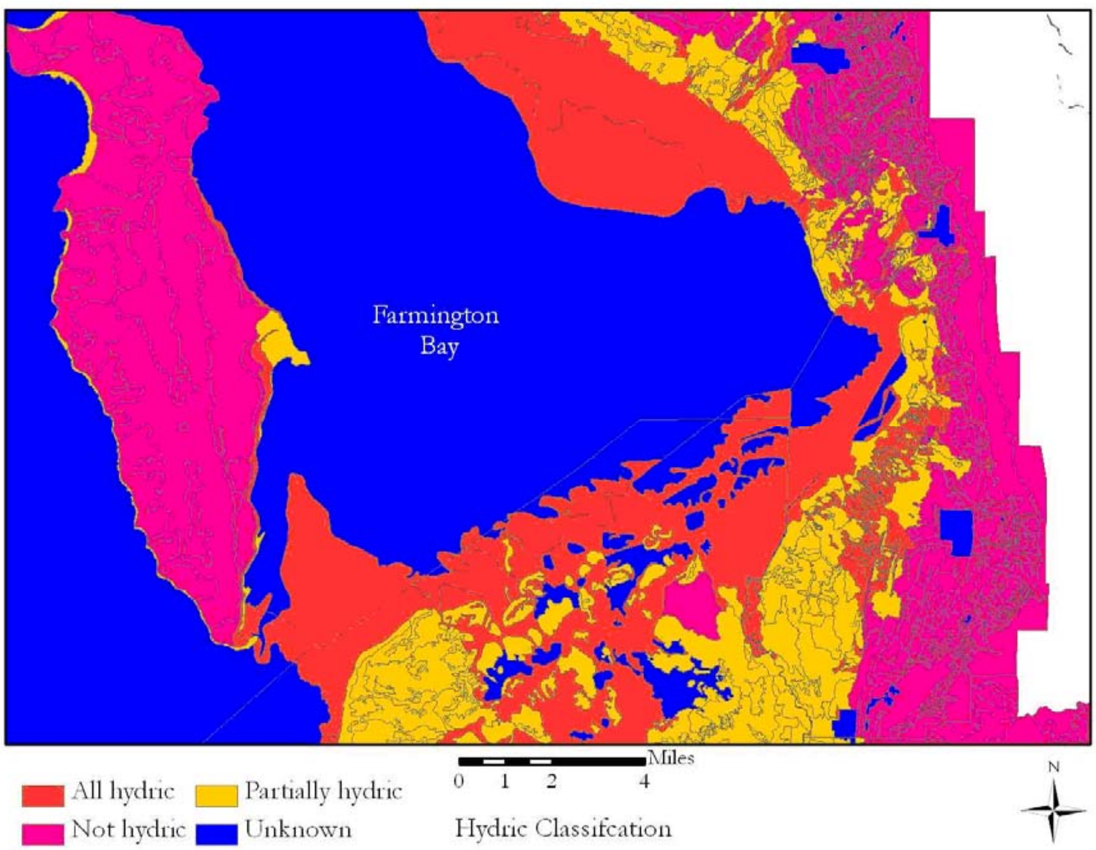


Figure C3. Hydric Soils Classification.

Conveyance and Water Rights Data

Although the 1:24,000 NHD stream data is sufficient for evaluating the streams and conveyances of the Jordan River watershed and in Davis County, these coarse spatial data are inadequate for an accurate assessment of the complex conveyance system at work in the shoreland wetlands. For an evaluation of how water and nutrient delivery may be altered in the future, it was first necessary to digitize the conveyances in the shorelands in greater detail than was offered by the NHD. Using 2006 aerial imagery, a refined shorelands conveyance layer was created for this project. The updated conveyance layer also incorporated water-rights information where available. These data were obtained from Dick Gilbert, Ambassador Duck Club, and Anne Neville, Kennecott Copper Corporation and documented in a GIS. Water rights information is important for understanding the monthly and seasonal patterns of flow being delivered to the shoreland wetlands. The data compiled for this analysis are incomplete and were not used to assess restoration opportunity. However, a future documentation of shoreland water rights in a GIS would be valuable for such an assessment. An example of these data is presented in Figure C4 below.

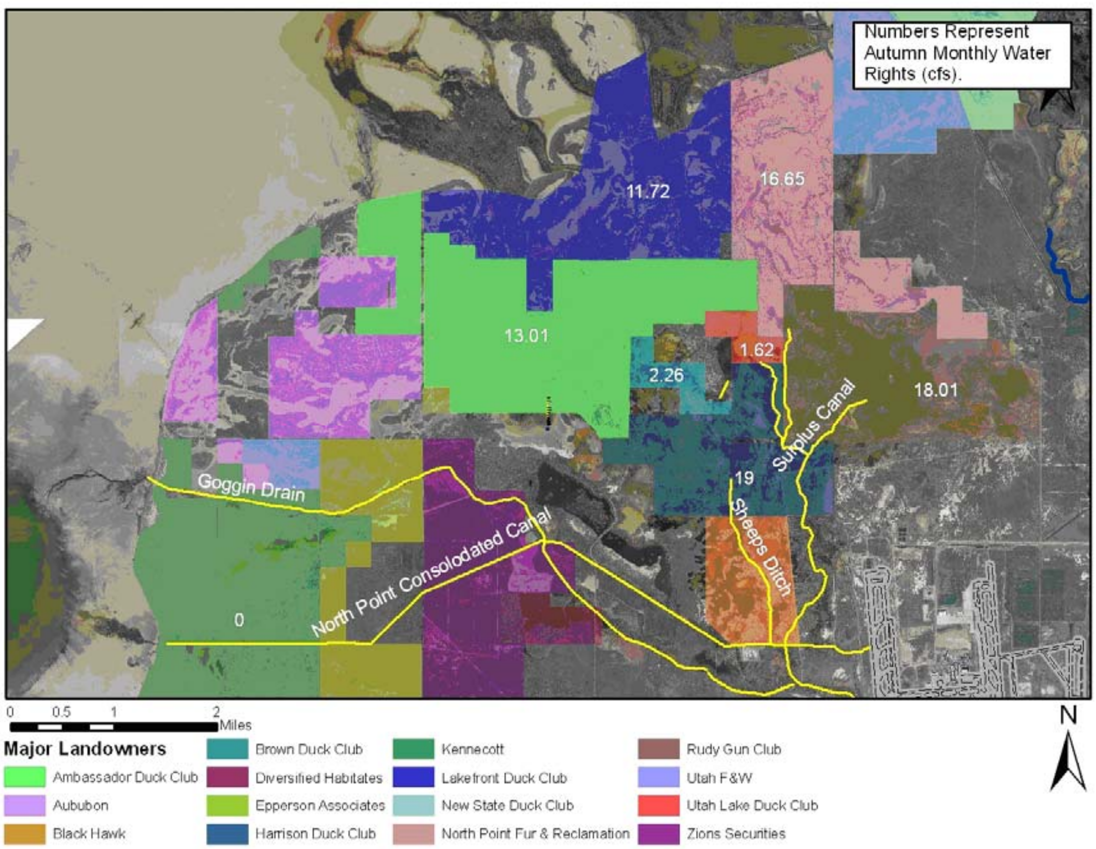


Figure C4. Example of Shoreland Conveyances and Water Rights.

Presence of Phragmites

The 2008 Ducks Unlimited Vegetative Cover (DU, 2008) and the 2006 Salt Lake County Special Area Management Plan Functional Assessment (Hoven et al, 2006) vegetative cover provided *Phragmites* distribution data. The difference in time periods for these data sets introduces error into the size estimates of independent *Phragmites* colonies; however, these were the best data available for the Farmington Bay area. Figure C5 displays the merged *Phragmites* polygon data. For the future scenarios, a growth Perimeter Expansion Rate (PER) of 5 meters per year was applied based on an average of the standard *Phragmates* PER range (.2 m – 10 m per year) presented in Phelps (2006).

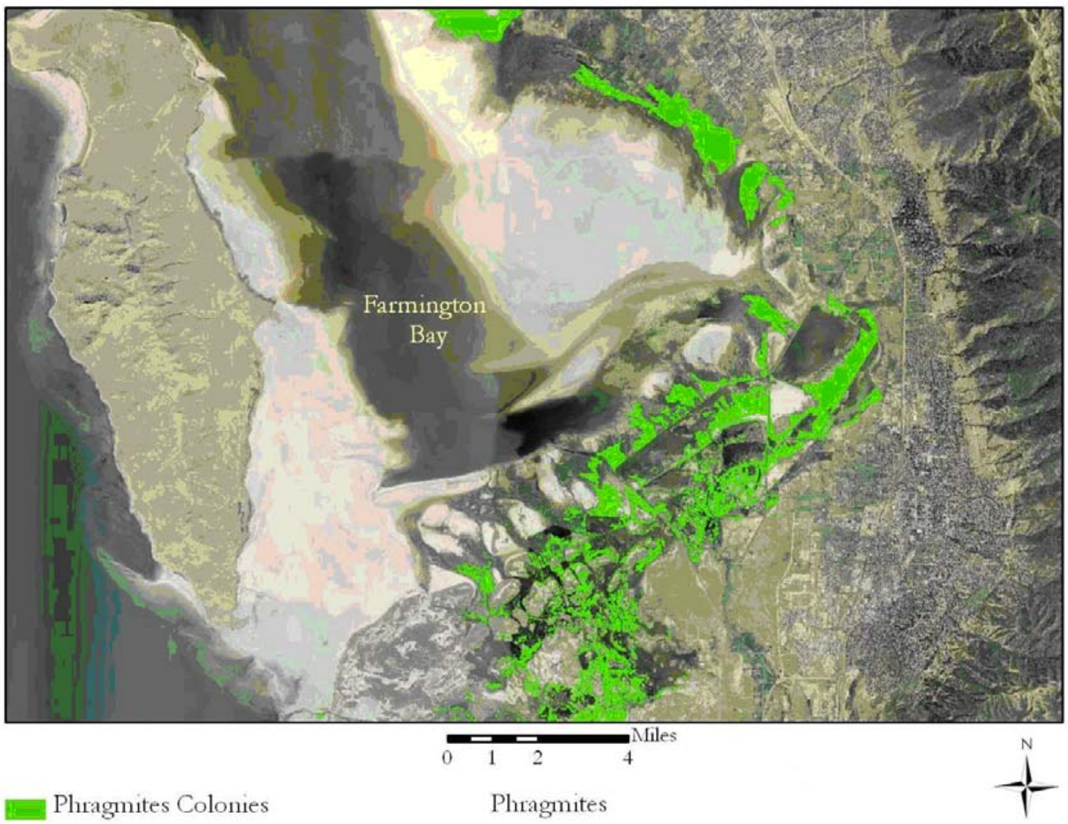


Figure C5. Phragmites Presence.

NWI Wetlands

The 2008 NWI wetlands layer was used as a base map to join the other variable data for the restorations opportunity assessment. For more information on the NWI classification employed for this study, see Appendix B.

Elevation Zone Assessment

Elevations zones identified as having significant management potential were identified using a 3D simulation of lake-level-rise. For more information on significant elevation zones, see Appendix A.

8.4 APPENDIX D. METHODOLOGY FOR THE AVIAN WETLAND HABITAT ASSESSMENT (AWHA)

Avian Wetland Habitat Assessment (AWHA) is a predictive tool developed to assess the capabilities of various wetland types around Farmington Bay to provide suitable habitat for migratory shorebirds, migratory waterfowl, and migratory water birds. The foundation of this approach is a decision support system. It includes “rules” for assessing viable wetland habitat. The rules were developed for noteworthy avian species or groups of species located on the landscape. Rules are based on the influence of significant environmental and anthropogenic variables, as identified by local wetland and ornithological experts using *a priori* knowledge. That knowledge was used to determine species distribution within a landscape. The expert panel consisted of Don Paul (Avian West), Dr. John Cavitt (Weber state University), and Dr. Heidi Hoven (Institute of Watershed Sciences).

The methodology involves the following steps: 1) selecting appropriate variables that determine the presence of a species on the Farmington Bay landscape; 2) assigning a numerical strength to each variable with respect to other variables for each species; 3) assigning weights for describing the spatial effect of a particular controlling variable; 4) applying the weighted variables to GIS raster data independently for each species; and 5) performing raster calculations to create maps denoting habitat value based on five natural breaks of classification. Natural break classification indicates the relative quality of a habitat’s value compared to the values of the entire dataset.

Selecting Variables

The first step of this analysis involves establishing the dependent and independent variables. The dependent variable is the presence or absence of a species. The independent variables are the anthropogenic and environmental variables that most strongly determine where a particular species will be located. For this study, the main independent variables are: proximity to *Phragmites* colonies, wetland habitat as denoted by National Wetland Inventory (NWI) types, , and depth of interior habitat, proximity to roads and highways, proximity to developed land use types, and the presence of key vegetative cover. Furthermore, for the template scale future scenarios analysis, nutrient loading and conveyance flow delivery as predicted from AVGWLF were added to the spatial assessment.

Assigning a Variable Strength and Weight to Each Variable

A preliminary assignment of variable strength was undertaken to establish an autonomous influence of each independent variable for each species. The variables are assigned different strengths that reflect their relative importance when compared to one another as determined by the experts. In order to estimate the importance of each independent variable to the distribution of a species, spatial weights were established for the raster cells. A common method of assigning raster values is Boolean Classification. In Boolean Classification, a pixel is assigned a value of either “true” (1) or “false” (0), based on whether or not the value of a variable at that location exceeds a specified threshold. In situations where uncertainty in the precise delineation of a threshold value exists, applying Boolean Classification may unnecessarily discard intermediate values of a variable that are still relevant to the analysis. This analysis relies on datasets, such as avian occurrence data, with imprecise boundaries. Zadeh’s fuzzy set theory (Zadeh, 1965, 1990a, and 1990b) offers an alternative approach that accommodates situations where the inclusion or exclusion of an element within a set or class is subject to imprecision.

Fuzzy set theory yields values that range from 0 to 1 based on derived relative weights for suitable variables (Banai, 1993).

Table D1 below displays an example of the workbook used to weigh the variables. Table D2 displays the final weighted variable matrix for all bird groupings completed for this analysis. This matrix was completed for eight avian groupings several times during the summer of 2008 by a panel of local avian and wetland experts.

Migratory Waterfowl (MGWF) and Migratory Waterbirds (MGWB) were analyzed for this AFA analysis. The other groupings that were weighted, but not analyzed for the AFA are as follows: Nesting Colonial Shorebirds (NCSH), Nesting Colonial Waterbirds (NCWB), Long Billed Curlew (LBCR), American Pelican (APEL), and Snowy Plover (SNPL). The initial variable strengths and weights changed depending on the feasibility of producing desired data in ArcView in an efficient manner. Variable strengths and weights also changed as the experts become more familiar with the process and sought to represent more adequately these indicators. Caveats associated with the suitability of a variable to represent (or not represent) a particular species were documented in the matrix. The weighting system is designed on a scale from 0-1, with 1 denoting the most positive indication of suitable habitat for a bird grouping.

Table D1. Variable Strength and Weights Worksheet for One Bird Grouping.

Base Variable for Habitat Suitability Index					
Variable-	**Variable Strength**	**GIS**	**Fuzzy Operator**	**Weight (0-1)**	**Final GIS**
Description	*(Vs)*	*Value*	*GIS Descriptor*	*(Wt) G*	*values*
Wetland Type	0.50	0.00	Non-wetland	0.00	0.00
		1.00	Open Water	1.00	0.50
		2.00	Impounded	1.00	0.50
		3.00	Playa	0.50	0.25
		4.00	Fringe	0.50	0.25
		8.00	Emergent	1.00	0.50
Vegetation	1.00	1.00	Open Water	1.00	1.00
		3.00	75 Akali Bulrush	0.20	0.20
		4.00	75 Cattail/Bulrush	0.00	0.00
		6.00	50-75 Alkali Bulrush	0.20	0.20
		7.00	Playa Mudflat Unvegetated	1.00	1.00
		8.00	Playa Mudflat Vegetated	0.40	0.40
		9.00	Mixed Emergent	1.00	1.00
		10.00	Upland	1.00	1.00
		11.00	Tamarisk	0.00	0.00
		13.00	River/Channel	0.30	0.30
		0.00	Other	0.00	0.00
Phragmites	0.10	2.00	Greater than 75% *Phragmites*	1.00	0.10
		1.00	Between 51-75% *Phragmites*	0.00	0.00
		0.00	No *Phragmites*	0.00	0.00
Interior Habitat	0.60	0.00	Zero Interior Habitat	0.00	0.00
		1.00	Interior habitat 0- 100 from edge	1.00	0.60
		2.00	Interior habitat 100 from edge	0.50	0.30
		3.00	Interior habitat 200 from edge	0.50	0.30
		4.00	Interior habitat 300 + from edge	1.00	0.60
Roads	0.10	1.00	Four-Lane Highway	1.00	0.10
		2.00	Two-lane Paved Road	0.00	0.00
		3.00	Near Grade; Dirt Roads; Trails	0.30	0.03
		0.00	No roads	0.50	0.05
Land Use	0.60	1.00	High Development Areas	0.00	0.00
		2.00	Low Development Areas	0.00	0.00
		3.00	Golf Courses/Turf Areas	0.00	0.00
		4.00	Row Crops	0.00	0.00
		5.00	Forested Areas	1.00	0.60
		7.00	Hay/Pasture or Scrub Shrub	0.00	0.00
		8.00	Open Space/Barren Land	0.00	0.00
		12.00	Barren Land	0.30	0.18
		13.00	Turf Grass/Golf	0.00	0.00

Table D2. Final matrix of weights for all bird groupings.

Base Variable for Habitat Suitability Index										
Value	Variable	Descriptor	Mgsh	Ncsh	Mgwf	Mgwb	Ncwb	Lbcr	Apel	Snpl
0.00	Wetland	Non-Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	Wetland	Lacustrine Types	0.50	0.50	0.50	0.50	0.50	0.00	0.50	0.00
2.00	Wetland	Impounded	0.50	0.50	0.50	0.50	0.50	0.50	0.00	0.50
3.00	Wetland	Fringe	0.25	0.25	0.50	0.25	0.50	0.00	0.50	0.00
4.00	Wetland	Playa	0.25	0.25	0.25	0.00	0.50	0.00	0.00	0.00
8.00	Wetland	Emergent	0.50	0.50	0.50	0.25	0.50	0.00	0.00	0.00
1.00	Vegetation	Open Water	1.00	1.00	1.00	0.90	0.90	0.00	0.70	0.00
3.00	Vegetation	75 Alkali Bulrush	0.20	0.00	0.80	0.00	0.72	0.00	0.00	0.00
4.00	Vegetation	75 Cattail/Bulrush	0.00	0.00	0.60	0.00	0.72	0.00	0.00	0.00
6.00	Vegetation	50-75 Alkali Bulrush	0.20	0.00	0.80	0.00	0.72	0.00	0.00	0.00
7.00	Vegetation	Playa Mudflat Unveg	1.00	0.60	0.80	0.90	0.63	0.80	0.00	1.00
8.00	Vegetation	Playa Mudflat Veg	0.40	0.40	0.80	0.00	0.36	0.80	0.00	0.00
9.00	Vegetation	Mixed Emergent	1.00	0.00	1.00	0.36	0.90	0.00	0.00	0.00
10.00	Vegetation	Upland	1.00	0.00	0.70	0.90	0.27	1.00	0.00	0.00
11.00	Vegetation	Tamarisk	0.00	0.00	0.20	0.00	0.27	0.00	0.00	0.00
12.00	Vegetation	River Channel	0.30	0.00	0.30	0.00	0.45	0.00	0.35	0.00
0.00	Vegetation	Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	*Phragmites*	na	0.10	0.10	0.30	0.30	0.60	0.00	0.00	0.30
1.00	*Phragmites*	50-75	0.00	0.00	0.09	0.00	0.42	0.00	0.00	0.00
2.00	*Phragmites*	75-100	0.00	0.03	0.15	0.00	0.60	0.00	0.00	0.00
0.00	I. Habitat	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	I. Habitat	1-100	0.60	0.06	0.80	0.18	0.14	0.04	1.00	0.21
2.00	I. Habitat	100-200	0.30	0.06	0.40	0.24	0.21	0.12	1.00	0.21
3.00	I. Habitat	200-300	0.30	0.06	0.40	0.30	0.49	0.20	1.00	0.28
4.00	I. Habitat	300+	0.60	0.06	0.80	0.42	0.70	0.32	0.10	0.56
0.00	Roads	none	0.10	0.50	0.40	0.30	0.20	0.20	0.00	0.40
1.00	Roads	4 lane	0.00	0.10	0.08	0.06	0.04	0.00	0.00	0.12
2.00	Roads	2 lane	0.03	0.05	0.08	0.06	0.04	0.00	0.00	0.12
3.00	Roads	dirt/path	0.05	0.25	0.16	0.15	0.08	0.16	0.00	0.32
1.00	Land Use	Open Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	Land Use	Low Dev	0.00	0.00	0.21	0.48	0.00	0.00	0.00	0.00
3.00	Land Use	High Dev	0.00	0.00	0.14	0.80	0.03	0.00	0.00	0.00
4.00	Land Use	Row Crop	0.00	0.00	0.56	0.48	0.00	0.00	0.00	0.00
5.00	Land Use	Hay/Past	0.60	0.10	0.49	0.80	0.00	0.64	0.00	0.00
7.00	Land Use	Coniferous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.00	Land Use	Mixed Forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.00	Land Use	Deciduous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	Land Use	Wood Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.00	Land Use	Emer Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.00	Land Use	Barren Land	0.18	0.02	0.00	0.00	0.06	0.48	0.00	0.18
13.00	Land Use	Turf Grass/Golf	0.00	0.00	0.49	0.16	0.00	0.00	0.00	0.00

Raster Calculation

In map algebra, operators and functions evaluate expressions only for input cells that are spatially coincident with the output cell. Therefore, rasters of an equal scale and pixel dimension must be created to hold the weighted variables. For each of the independent variables, a 30 meter by 30 meter raster was produced from raw vector and raster data to support the raster calculations.

Once weighted avian occurrence values for the presence of a bird grouping were established, these data were spatially joined to the independent variable raster datasets, resulting in weighted rasters for each species. Raster calculation in map algebra was used to apply the calculation in Figure B.1 for the all scenarios.

Habitat Value Maps

The results are maps for each species grouping denoting areas of high and low habitat value on the Farmington Bay landscape. The highest index value (5) represents the "most suitable" habitat available in the template and, in effect, displays the maximum combination of weights for all variables indicating suitable habitat. As the index trends towards lower values (1), the combinations of weights are decreasing and the habitat is viewed progressively as "less suitable". It must be emphasized that the habitat index produced by this model does not implicate "poor-quality" or "low value" habitat and therefore absence of a species. Rather, the model seeks to assess changes in the availability of the most suitable habitat based on the weighted variables. The AWHA analysis was undertaken only for Migratory Shorebirds, Migratory Waterbirds, and Migratory Shorebirds due to limited resources and time availability. Landscape predications were preformed for these three bird groupings. The below list displays the general steps for connecting variable weights to the raster datasets and to produce maps and proportional results:

1. Join weighted variable data to the appropriate GIS raster coverage
2. Export as a new raster (preserving the weights)
3. For each variable, create a bird grouping raster
4. Sum the variable weights for each group using Map Algebra
5. Reclassify the resulting raster calculation into 5 Natural Break (Jenks) classes
6. If the model run is for a Future scenario, import Current scenario classification
7. Save reclassified raster to create a final reporting file
8. Load template boundary
9. Convert template boundary to raster
10. Extract by mask using the template boundary raster
11. Calculate acres
12. Create graphs

8.5 APPENDIX E. CALIBRATION OF THE AVGWLF MODEL IN THE JORDAN RIVER BASIN

The AVGWLF model was calibrated for the Jordan River watershed in Salt Lake County, Utah for the purpose of quantifying the flow, sediment, and nutrients currently being delivered to the Farmington Bay wetlands from the various sources throughout the watershed. Multiple future scenarios were also modeled in AVGWLF to determine the resultant loads expected in the Farmington Bay wetlands as a result of land use and water use changes in the watershed.

Model calibration was performed for the period 1995-2005 at the Surplus Canal diversion. Stream flow was calibrated to the combined Jordan River and Surplus Canal flows at USGS gage 10170490. Total Phosphorus and Suspended Sediment concentrations were obtained from STORET station 4992320 in the Surplus Canal, while Total Nitrogen concentrations were obtained from USGS gage 10171000 in the Jordan River immediately below the Surplus Canal diversion. To derive historical nutrient loads, standard mass balance techniques were employed. First, the in-stream nutrient concentration data and corresponding flow rate data were utilized to develop load (mass) versus flow relationships for each watershed for the period in which historical water quality data were obtained. Using the daily stream flow data obtained from USGS, daily nutrient loads for the 1995-2005 period were subsequently computed for the watershed using the appropriate load versus flow relationship (i.e., "rating curves"). Loads computed in this fashion were used as the "observed" loads against which model-simulated loads were compared.

During this process, adjustments were made to various model input parameters for the purpose of obtaining a "best fit" between the observed and simulated data. As the AVGWLF model uses empirically derived relationships to simulate watershed processes, adjustments were necessary to better reflect conditions specific to the Jordan River basin. With respect to stream flow, adjustments were made that decreased the amount of the calculated evapotranspiration. Based on watershed-specific conditions and the modelers' previous experience, these values were deemed too high. With respect to nutrient loads, changes were made to the estimates for sub-surface nitrogen and phosphorus concentrations. The empirically derived estimates were not correctly representing these parameters in the Jordan River basin. With regard to sediment, revisions were made to the sediment "a" factor, which reflects the erodibility of stream banks. This value was decreased due to the large number of hardened canals in the basin. The erosivity coefficients were decreased based on the differences exhibited between these values in western versus eastern regions of the U.S.

As a result of the relatively large amount of anthropogenic influence in the Jordan River watershed, it was necessary to "externalize" a number of the model components in order to more accurately simulate yearly variations in monthly loading and flow. AVGWLF uses monthly averages for the entire period of simulation to estimate the effects of point source loadings and withdrawals. However, in the Jordan River basin, point source loadings and withdrawals are highly variable from year to year. Thus, flows and loads from these two components were calculated in a spreadsheet and added to (point sources) or subtracted from (withdrawals) the AVGWLF output for each month during the entire period 1995-2005. This method proved invaluable to the calibration procedure, as the largest contributors of flow, sediment, and nutrient loading in the Jordan River basin are entirely under human control.

To assess the correlation between observed and predicted values, two different statistical measures were utilized: 1) the Pearson product-moment correlation (r^2) coefficient and 2) the

Nash-Sutcliffe coefficient. The r^2 value is a measure of the degree of linear association between two variables, and represents the amount of variability that is explained by another variable (in this case, the model-simulated values). Depending on the strength of the linear relationship, the r^2 can vary from 0 to 1, with 1 indicating a perfect fit between observed and predicted values. Like the r^2 measure, the Nash-Sutcliffe coefficient is an indicator of "goodness of fit," and has been recommended by the American Society of Civil Engineers for use in hydrological studies (ASCE, 1993). With this coefficient, values equal to 1 indicate a perfect fit between observed and predicted data, and values equal to 0 indicate that the model is predicting no better than using the average of the observed data. Therefore, any positive value above 0 suggests that the model has some utility, with higher values indicating better model performance. In practice, this coefficient tends to be lower than r^2 for the same data being evaluated.

Adjustments were made to the various input parameters for the purpose of obtaining a "best fit" between the observed and simulated data. One of the challenges in calibrating a model is to optimize the results across all model outputs (in the case of AVGWLF, stream flows, as well as sediment, nitrogen, and phosphorus loads). As with any watershed model like GWLF, it is possible to focus on a single output measure (e.g., sediment or nitrogen) in order to improve the fit between observed and simulated loads. Isolating on one model output, however, can sometimes lead to less acceptable results for other measures. Consequently, it is sometimes difficult to achieve very high correlations (e.g., r^2 above 0.90) across all model outputs. Given this limitation, it was felt that very good results were obtained for the calibration site.

For the monthly comparisons, mean r^2 values of 0.86, 0.80, 0.94, and 0.90 were obtained for flow, sediment, phosphorus, and nitrogen, respectively. When considering the inherent difficulty in achieving optimal results across all measures as discussed above (along with the potential sources of error), these results are quite good. The sediment load predictions were less satisfactory than those for the other outputs, and this is not entirely unexpected given that this constituent is usually more difficult to simulate than nitrogen or phosphorus. Nitrogen and phosphorus predictions were very accurate due to the availability of data for the two large WWTPs in the basin, which are the largest contributors of nutrients to the river.

The monthly Nash-Sutcliffe coefficients of 0.86, 0.80, 0.92, and 0.74 were very high considering that they approach their respective r^2 values, which is often difficult in studies of this kind. As described earlier, this statistic is used to iteratively compare simulated values against the mean of the observed values, and values above zero indicate that the model predictions are better than just using the mean of the observed data. In other words, any value above zero would indicate that the model has some utility beyond using the mean of historical data in estimating the flows or loads for any particular time. As with r^2 values, higher Nash-Sutcliffe values reflect higher degrees of correlation than lower ones.

Figures E1, E2 and E3 below present a representation of the calibration results for a ten year time period, 1995- 2005.

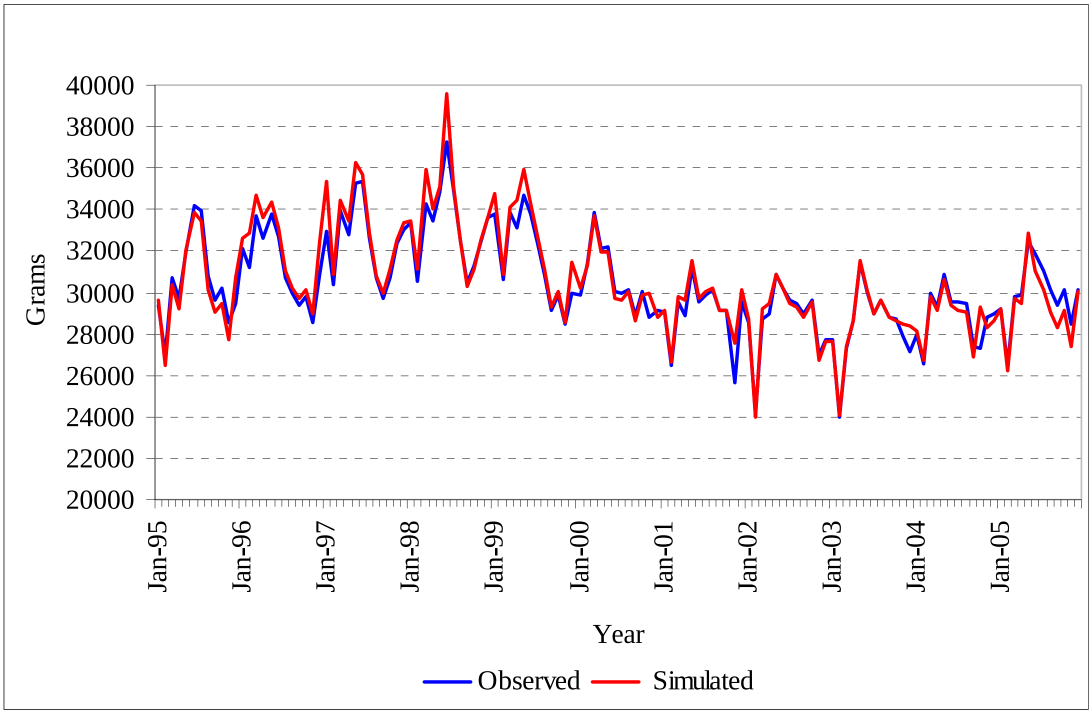


Figure E1. Comparison of Observed and Simulated Watershed Loading to the Surplus Canal for Total Phosphorous.

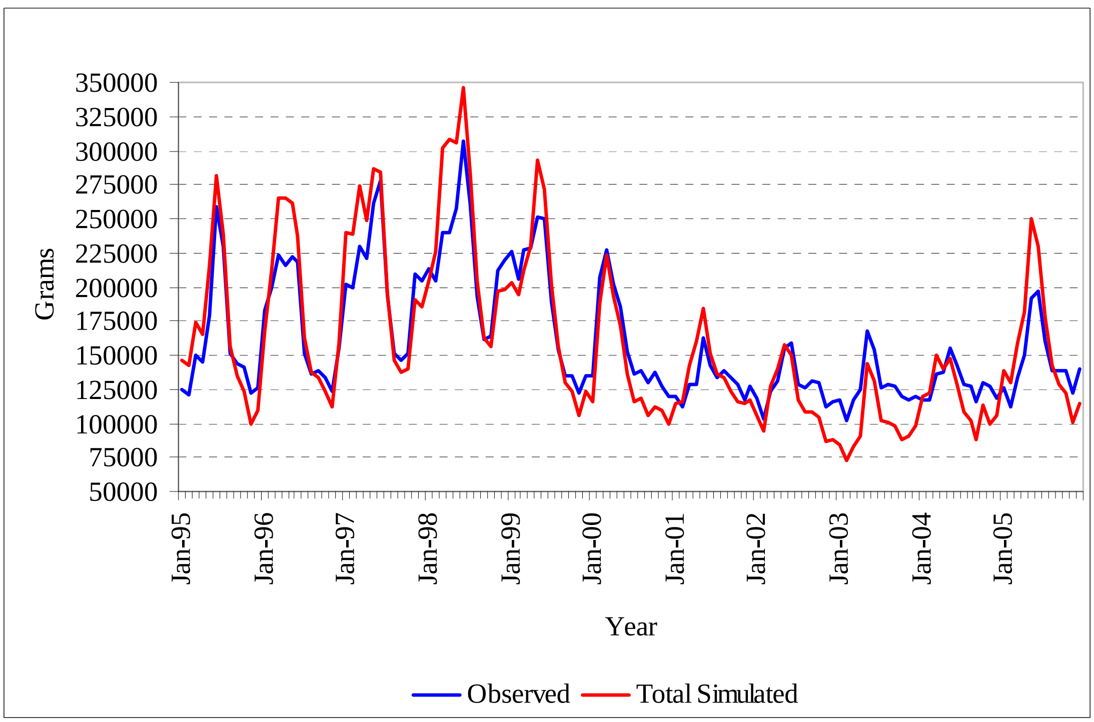


Figure E2. Comparison of Observed and Simulated Watershed Loading to the Surplus Canal for Total Nitrogen.

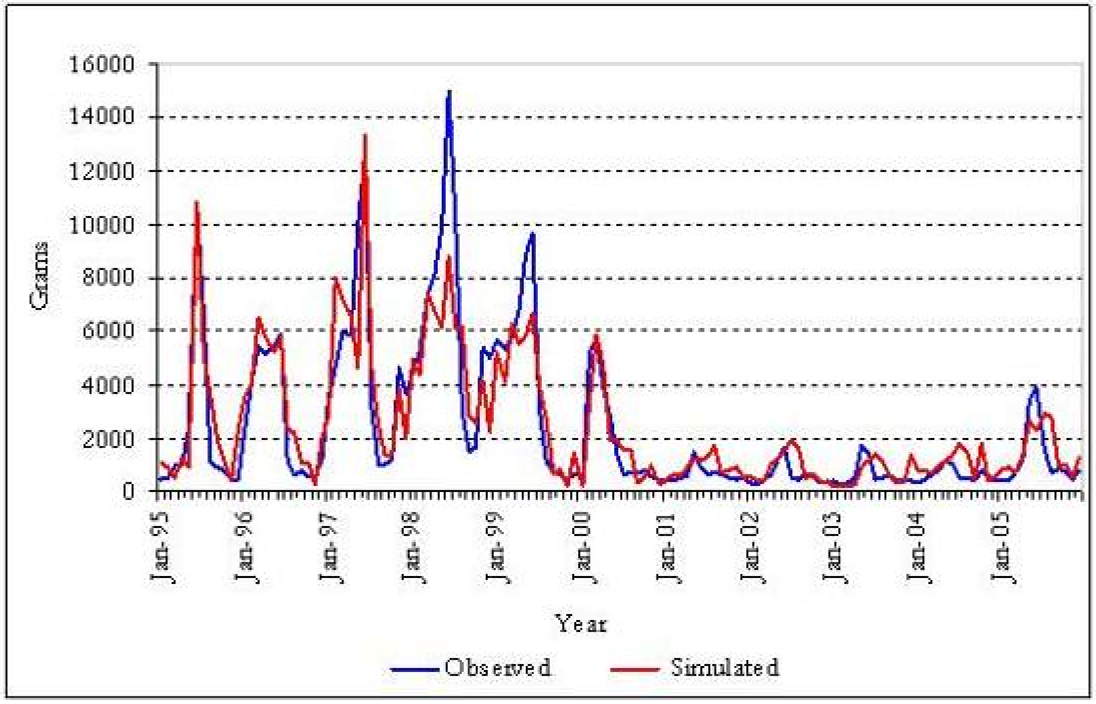


Figure E3. Comparison of Observed and Simulated Watershed Loading to the Surplus Canal for Total Suspended Solids.

AVGWLF Model: Jordan River Basin

Using data for the time period 1995-2005, the calibrated AVGWLF model was used to estimate flow, sediment, nitrogen, and phosphorus loading to the Surplus Canal. Table E1 provides the sources of data used for the AVGWLF modeling analysis. Adjustments made to these data sources were discussed above. Screenshots of the AVGWLF model with input values are shown in Figures E4 and E5. Screenshots of model output are shown in Figures E6 through E8. These figures do not include point source data, as this was simulated outside of the AVGWLF watershed model. Additional explanation of model parameters and processes is available in the AVGWLF Users Guide (Evans, 2008).

Table E1. Information Sources for AVGWLF Model Parameterization.

WEATHER.DAT file	
Data	**Source or Value**
Precipitation and Temperature	Historical weather data from Salt Lake City, UT and Provo, UT National Weather Service Stations
TRANSPORT.DAT file (See Figure 13.1.2)	
Data	**Source or Value**
Basin size	GIS/derived from basin boundaries
Land use/cover distribution	GIS/derived from land use/cover map
Curve numbers by source area	GIS/derived from land cover and soil maps
USLE (KLSCP) factors by source area	GIS/derived from soil, DEM, & land cover
ET cover coefficients	GIS/derived from land cover (adjusted)
Erosivity coefficients	GIS/derived from physiography map (adjusted)
Daylight hrs. by month	Computed automatically for state
Growing season months	Input by user
Initial saturated storage	Default value of 0 cm
Initial unsaturated storage	Default value of 10 cm
Recession coefficient	Calculated using standard hydrograph separation techniques
Seepage coefficient	Default value of 0
Initial snow amount (cm water)	Default value of 0
Sediment delivery ratio	GIS/based on basin size
Sediment “a” factor	GIS/empirically derived (adjusted)
Soil water (available water capacity)	GIS/derived from soil map
NUTRIENT.DAT file (See Figure 13.1.3)	
Data	**Source or Value**
Dissolved N in runoff by land cover type	Default values by land cover type
Dissolved P in runoff by land cover type	Default values by land cover type
N/P concentrations in manure runoff	Default values (from GWLF Manual)
N/P buildup in urban areas	Default values (from GWLF Manual)
N and P point source loads	Derived from EPA STORET database
Background N/P concentrations in GW	Derived from background N map (adjusted)
Background P concentrations in soil	Derived from soil P loading map
Background N concentrations in soil	Based on map in GWLF Manual
Months of manure spreading	Input by user
Population on septic systems	Derived from census tract maps for 2000
Per capita septic system loads (N/P)	Default values (from GWLF Manual)

Data that were critical to the model calibration, but simulated outside of AVGWLF, include Turner Dam and canal flows and concentrations, point source flows and concentrations, and withdrawal amounts. Turner Dam and canal data were obtained from the Utah Division of Water Rights, (UTDWRi, 2008). Point source data were obtained from the US EPA STORET database (USEPA, 2006a). Yearly estimates of ground and surface water withdrawals for different uses (e.g., municipal, agricultural) were obtained from publically-available state and county reports (UTDWRe, 1997; SLC, 2009). These yearly estimates were then split among the 12 months of the year for the 11 years of simulation (1995-2005) based on best professional judgment and taking into consideration observed weather patterns, stream flows, and seasonality of water usage. Figures E4 though E8 and Tables E2 though E6 present the results of the AVGWLF modeling.

AVGWLF Model Simulation Results

Figure E4. AVGWLF Input Transport File.

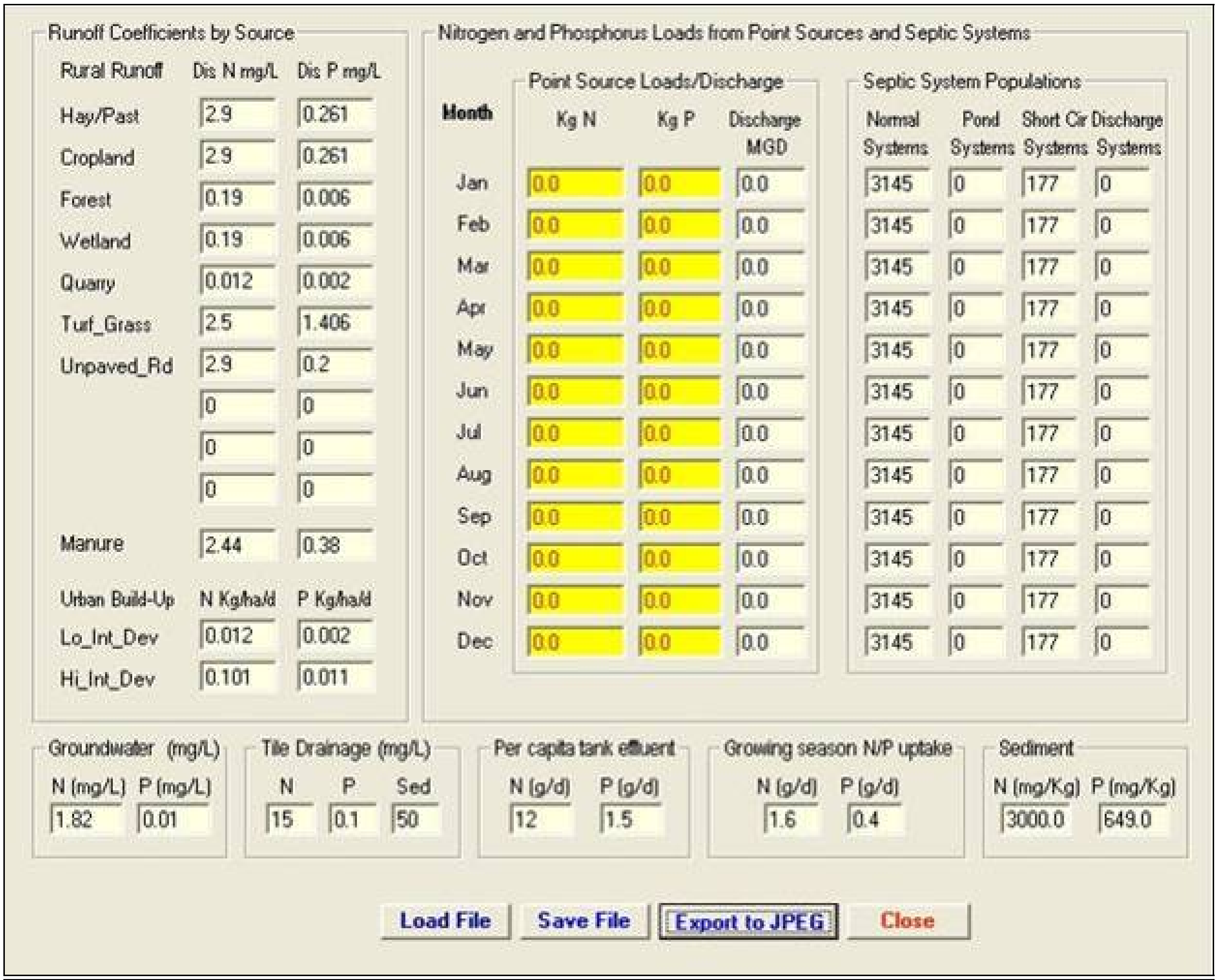
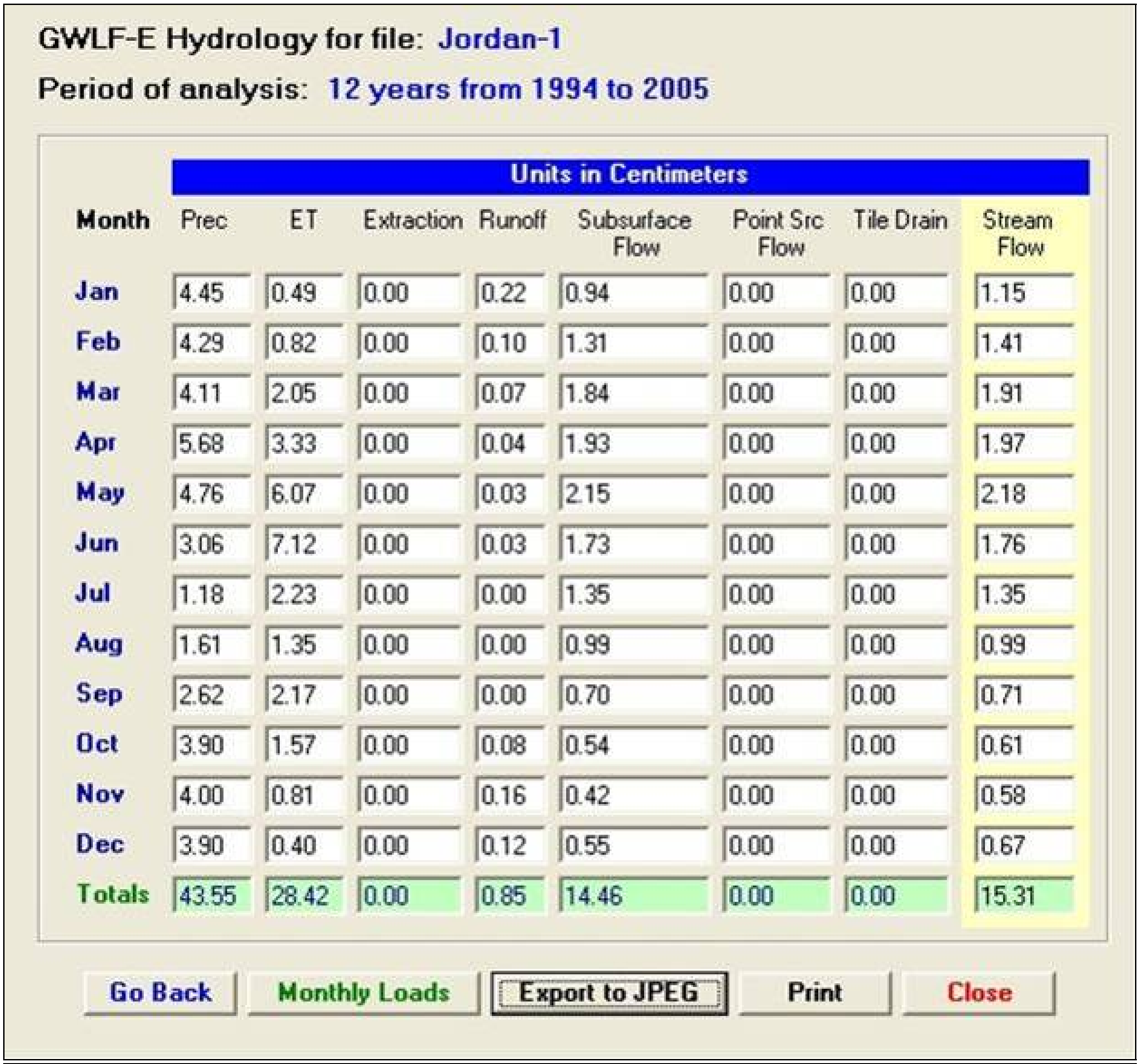


Figure E5. AVGWLF Input Nutrient File.

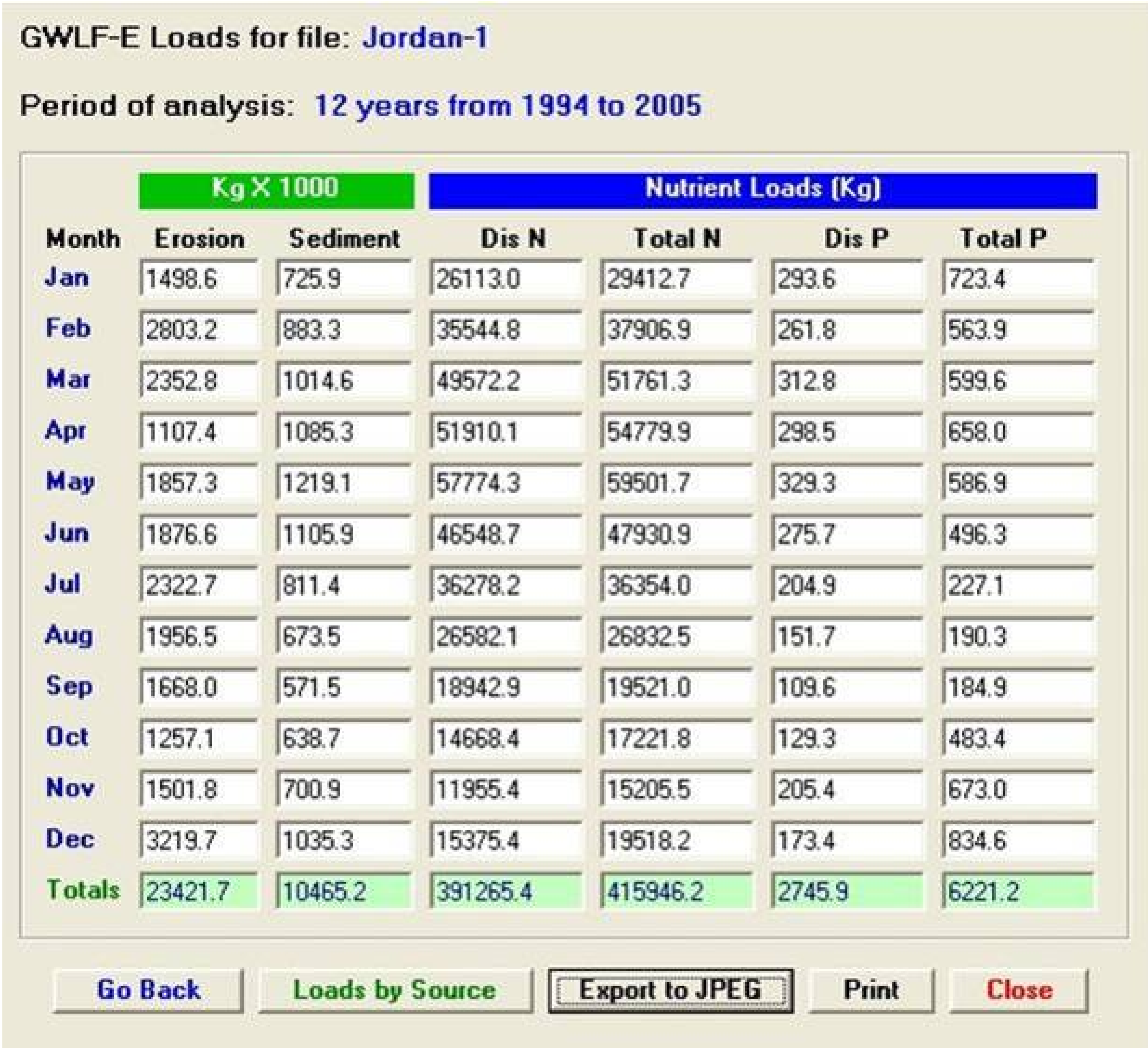


GWLF-E Hydrology for file: Jordan-1

Period of analysis: 12 years from 1994 to 2005

	Units in Centimeters							
Month	Prec	ET	Extraction	Runoff	Subsurface Flow	Point Src Flow	Tile Drain	Stream Flow
Jan	4.45	0.49	0.00	0.22	0.94	0.00	0.00	1.15
Feb	4.29	0.82	0.00	0.10	1.31	0.00	0.00	1.41
Mar	4.11	2.05	0.00	0.07	1.84	0.00	0.00	1.91
Apr	5.68	3.33	0.00	0.04	1.93	0.00	0.00	1.97
May	4.76	6.07	0.00	0.03	2.15	0.00	0.00	2.18
Jun	3.06	7.12	0.00	0.03	1.73	0.00	0.00	1.76
Jul	1.18	2.23	0.00	0.00	1.35	0.00	0.00	1.35
Aug	1.61	1.35	0.00	0.00	0.99	0.00	0.00	0.99
Sep	2.62	2.17	0.00	0.00	0.70	0.00	0.00	0.71
Oct	3.90	1.57	0.00	0.08	0.54	0.00	0.00	0.61
Nov	4.00	0.81	0.00	0.16	0.42	0.00	0.00	0.58
Dec	3.90	0.40	0.00	0.12	0.55	0.00	0.00	0.67
Totals	43.55	28.42	0.00	0.85	14.46	0.00	0.00	15.31

Figure E6. Simulated Hydrology Transport Summary.



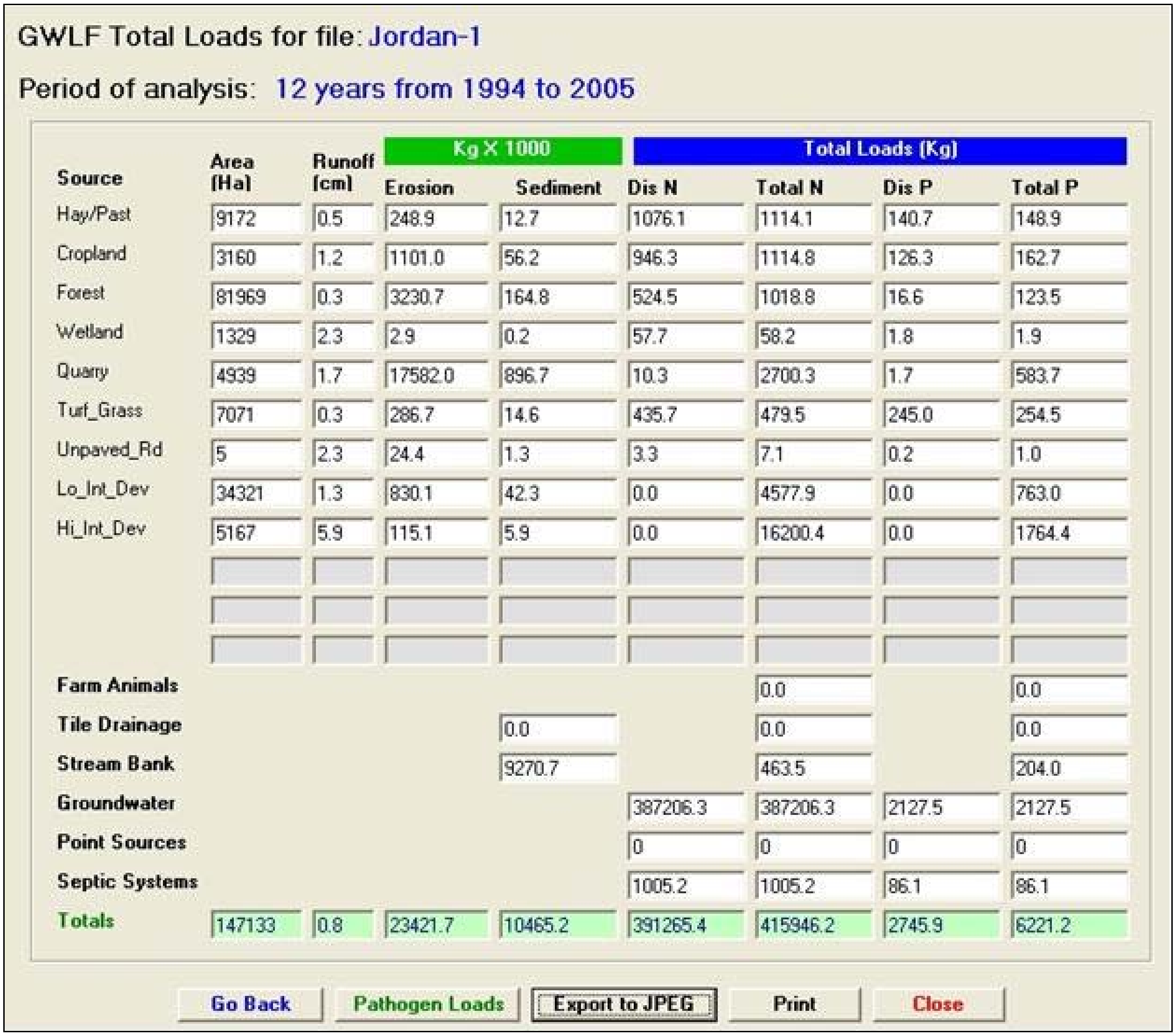
GWLF-E Loads for file: Jordan-1

Period of analysis: 12 years from 1994 to 2005

	Kg X 1000		Nutrient Loads (Kg)			
Month	Erosion	Sediment	Dis N	Total N	Dis P	Total P
Jan	1498.6	725.9	26113.0	29412.7	293.6	723.4
Feb	2803.2	883.3	35544.8	37906.9	261.8	563.9
Mar	2352.8	1014.6	49572.2	51761.3	312.8	599.6
Apr	1107.4	1085.3	51910.1	54779.9	298.5	658.0
May	1857.3	1219.1	57774.3	59501.7	329.3	586.9
Jun	1876.6	1105.9	46548.7	47930.9	275.7	496.3
Jul	2322.7	811.4	36278.2	36354.0	204.9	227.1
Aug	1956.5	673.5	26582.1	26832.5	151.7	190.3
Sep	1668.0	571.5	18942.9	19521.0	109.6	184.9
Oct	1257.1	638.7	14668.4	17221.8	129.3	483.4
Nov	1501.8	700.9	11955.4	15205.5	205.4	673.0
Dec	3219.7	1035.3	15375.4	19518.2	173.4	834.6
Totals	23421.7	10465.2	391265.4	415946.2	2745.9	6221.2

Go Back | Loads by Source | Export to JPEG | Print | Close

Figure E7. Simulated Nutrient Transport Summary.



GWLF Total Loads for file: Jordan-1

Period of analysis: 12 years from 1994 to 2005

Source	Area (Ha)	Runoff (cm)	Kg X 1000 Erosion	Kg X 1000 Sediment	Total Loads (Kg) Dis N	Total Loads (Kg) Total N	Total Loads (Kg) Dis P	Total Loads (Kg) Total P
Hay/Past	9172	0.5	248.9	12.7	1076.1	1114.1	140.7	148.9
Cropland	3160	1.2	1101.0	56.2	946.3	1114.8	126.3	162.7
Forest	81969	0.3	3230.7	164.8	524.5	1018.8	16.6	123.5
Wetland	1329	2.3	2.9	0.2	57.7	58.2	1.8	1.9
Quarry	4939	1.7	17582.0	896.7	10.3	2700.3	1.7	583.7
Turf_Grass	7071	0.3	286.7	14.6	435.7	479.5	245.0	254.5
Unpaved_Rd	5	2.3	24.4	1.3	3.3	7.1	0.2	1.0
Lo_Int_Dev	34321	1.3	830.1	42.3	0.0	4577.9	0.0	763.0
Hi_Int_Dev	5167	5.9	115.1	5.9	0.0	16200.4	0.0	1764.4
Farm Animals						0.0		0.0
Tile Drainage				0.0		0.0		0.0
Stream Bank				9270.7		463.5		204.0
Groundwater					387206.3	387206.3	2127.5	2127.5
Point Sources					0	0	0	0
Septic Systems					1005.2	1005.2	86.1	86.1
Totals	147133	0.8	23421.7	10465.2	391265.4	415946.2	2745.9	6221.2

Figure E8. Simulated Total Loads by Source.

Table E2: Jordan River Land Use Acreage Distribution.

Land Use Category	Acres	% of Drainage Basin
Open Water	613	0.20%
Agriculture	30,475	8.40%
Hay & Pasture	22,667	6.20%
Cropland	7,808	2.20%
Developed Land	97,594	26.80%
Low Intensity	84,819	23.30%
High Intensity	12,775	3.50%
Forest	202,542	55.60%
Wetlands	3,283	0.90%
Quarry/Barren Land	12,191	3.30%
Developed Open Space	17,473	4.80%
TOTAL	**364,171**	**100%**

Table E3. Simulated Phosphorus Loading Allocations; pounds per year.

Source	Total Phosphorus (lbs/yr)
Point Sources	804,230
Turner Dam & Canals	64,132
Hay/Pasture	328
Cropland	359
Forest	272
Developed Open Space	561
Quarry/Barren Land	1,287
Low Intensity Development	1,682
High Intensity Development	3,890
Stream Bank	450
Septic Systems	190
Groundwater	4,690
Wetlands	4
Unpaved Roads	2
TOTAL	**882,077**

Table E4. Simulated Sediment Loading Allocations; Pounds per year.

Source	(lbs/yr)
Turner Dam & Canals	61,202,881
Hay/Pasture	27,976.70
Cropland	123,789.60
Forest	363,255.70
Developed Open Space	32,231.60
Quarry/Barren Land	1,976,841
Low Intensity Development	93,344
High Intensity Development	12,941
Stream Bank	20,438,355
Wetlands	331
Unpaved Roads	2,755.80
TOTAL	**84,274,702**

Table E5. Simulated Total Nitrogen Loading Allocations; Pounds per year.

Source	Total Nitrogen (lbs/yr)
Point Sources	2,436,212
Turner Dam & Canals	1,355,373
Hay/Pasture	2,456
Cropland	2,457.70
Forest	2,246
Developed Open Space	1,057
Quarry/Barren Land	5,953
Low Intensity Development	10,093
High Intensity Development	35,716
Stream Bank	1,022
Septic Systems	2,216
Groundwater	853,644
Wetlands	128
Unpaved Roads	15.5
TOTAL	**4,708,589**

Table E6. Mean Annual Loadings to the Surplus Canal.

Parameter	Total Inputs	Total Extractions	Net Totals
Flow (acre-feet)	574,416	119,187	455,229
Sediment (lbs)	84,274,702	21,109,250	63,165,452
Total Phosphorus (lbs)	882,077	22,354	859,723*
Total Nitrogen (lbs)	4,708,589	495,436	4,213,153

* Accounts for 6% stream attenuation

8.6 Appendix F. Wetland Water Quality Model

Wetland ecosystems provide numerous environmental services in the greater landscape of which they are a part. In addition to providing valuable wildlife habitat, water quality improvement is considered one of their more important functions. In recognition of this important function, many studies have been conducted to examine the nutrient retention efficiencies of constructed wetlands created to treat wastewater effluent from treatment plants (Kadlec and Knight, 1996; Carleton et al., 2001; Kivaisi, 2001; Tanner, 2001; Vymazal, 2005, Jordon, 2007). Fewer studies, however, have examined nutrient retention efficiencies in natural wetlands (Fisher & Acreman, 2004), and fewer still have examined sediment retention in natural wetland systems. Nutrient and sediment retention in natural wetlands are much more difficult to quantify than in constructed wetlands due to variability in flows, vegetation types, soils, and because they were not constructed with the goal of water quality improvement in mind (Newbold, 2002).

The three primary controlling variables acting on nutrient and sediment retention in constructed wetlands are the area of the wetland, flow rate of water entering the wetland, and concentration of pollutant in the inflowing water (Newbold, 2002). While other biological, chemical, and physical variables influence retention rates, the three primary controlling variables can be used to predict removal efficiencies with a reasonable degree of accuracy in constructed wetlands using a first-order removal rate (Newbold, 2002). The following equation is an example of a first-order removal rate calculation:

$$C_{out} = C_{in}\, e^{(-k/HLR)}$$

Cout	*concentration of outflow pollutant, mg/l*
Cin	*concentration of inflow pollutant, mg/l*
k	*pollutant removal rate constant, m/yr*
HLR	*hydraulic loading rate (Q/A), m/yr*
Q	*annual runoff (i.e., surface water inflow rate),* m^3/yr
A	*wetland surface area,* m^2

A calibrated wetland water quality model for a demonstration site in the impoundment template was produced based on a first-order removal rate. The impoundment wetland template is particularly well-suited to application of the first-order removal rate calculation described above because it contains a number of wetland “cells” that can be analyzed independently or in series. Each cell contains relatively defined boundaries, allowing for determination of an estimated acreage in which pollutant retention may be occurring. Flow estimates between the cells are also available and this, combined with inflow concentration data, allows for the development of a model based on the first-order removal rate calculation. The US EPA STORET database contains a limited amount of flow, total phosphorus, and total suspended solids data for the Ambassador Duck Club wetland impoundment. Estimates were obtained from local sources or were inferred from the data for flow rates in cells that were not represented in the STORET database. Table F1 display the STORET data used and the locations of the sampling stations.

Table F1. STORET data used in model development.

STORET Data (Mar. - Sept. 2003 - 2007)			
Station	Avg. Flow (cfs)	Avg. TP (mg/l)	Avg. TSS (mg/l)
4985315		**0.44**	**23.23**
4985320	3.60	0.65	22.84
4985330	**8.25**	**0.22**	**29.08**
4985340	1.97	0.16	41.39
4985350		**0.14**	**32.62**

Figures F1 and F2 display the configuration of the 10 cells identified within the impoundment template and their respective flow paths, phosphorus, and sediment concentrations. The Jordan watershed loading is the Jordan River water that is diverted to the Surplus Canal and routed to the Ambassador Duck Club. This loading has been simulated with the calibrated AVGWLF watershed model and can be adjusted for future conditions in the Jordan River watershed. For example, the AVGWLF model was used to simulate watershed loading under two different future conditions of land use described in other sections of this report. The outputs of these future scenario watershed modeling exercises can be used as the inputs to the wetland water quality model, allowing for a prediction of future nutrient retention.

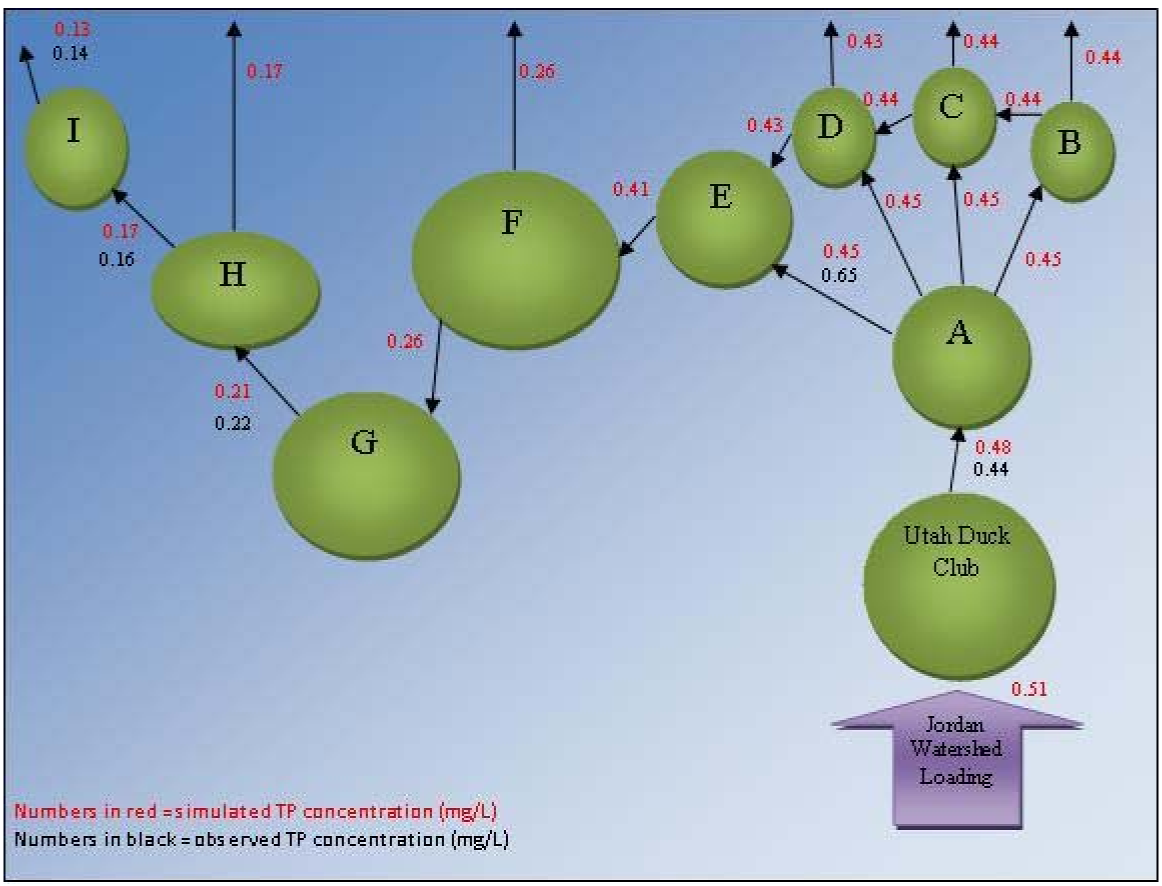


Figure F1. Impoundment Template Wetland Cells with Simulated (red) and Observed (black) TP Concentrations (mg/L).

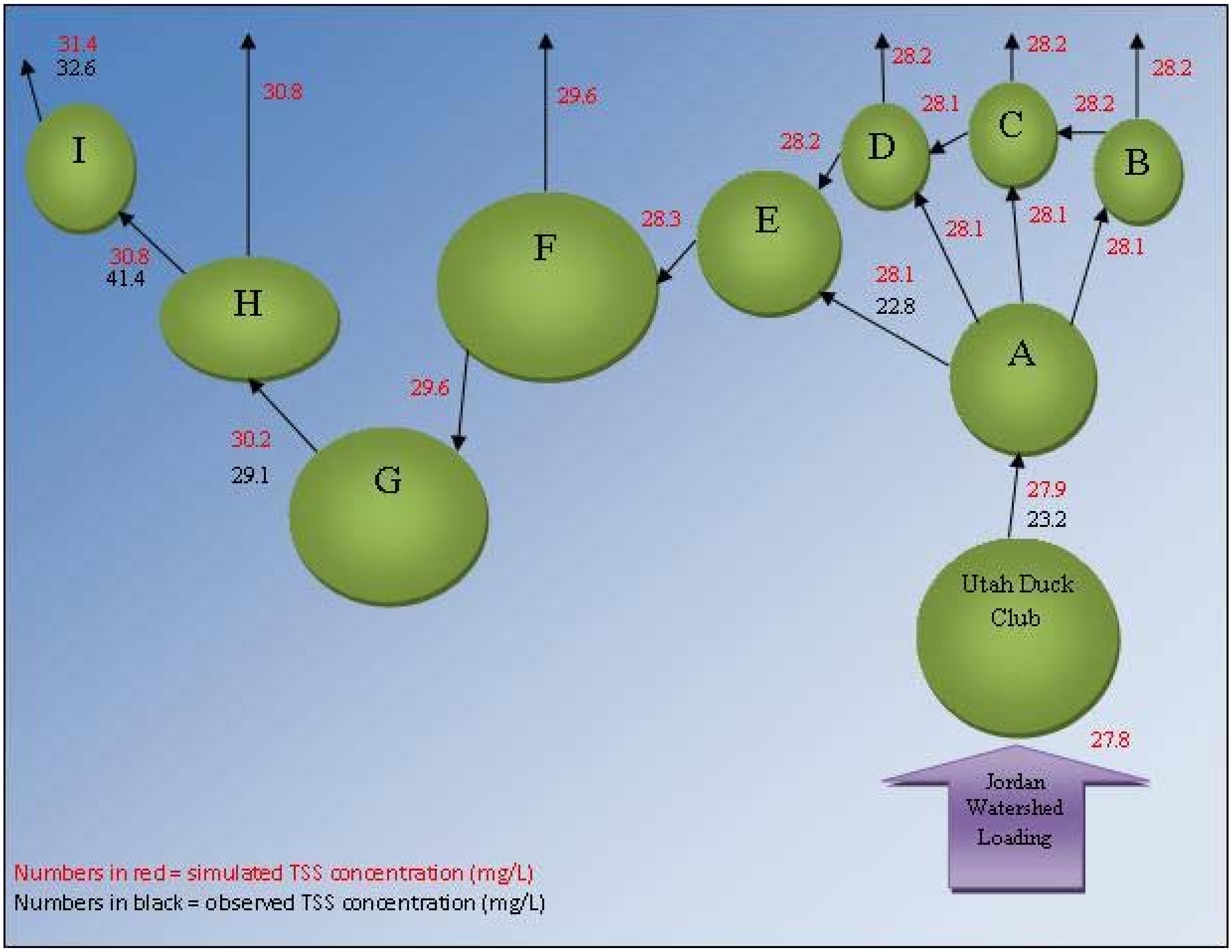


Figure F2. Impoundment Template Wetland Cells with Simulated (red) and Observed (black) TSS Concentrations.

Data limitations necessitated different data types be used in the calibration and prediction phases of sediment water quality modeling. As shown in Table F1, total suspended solids (TSS) data was used for calibration but during predictive modeling, AVGWLF simulated suspended sediment data. There is a qualitative difference in the two measures (see Gray et al. 2000), primarily that TSS is a component of the more inclusive suspended sediment measure. AVGWLF simulates "true" sediment, whereas most monitoring data is for total suspended solids (TSS). In reality, the total sediment load is usually by far the largest component of the TSS load in any given stream. An example of an exception to this general trend may be the case where many wastewater treatment plants are discharging organic loads to a slow-moving stream in a flat landscape where both upland erosion and stream channel erosion are minimal. Suspended sediment monitoring data is preferable for model calibration, but is not usually available (and was not available for the Jordan River). However, given the topography and the "flash flooding" nature of the watershed surrounding the Jordan River, it can be assumed that the TSS load was predominantly contributed by sediment (Barry Evans, Pennsylvania State University, personal communication). The model was calibrated to TSS monitoring data, which is what is typically done in watershed modeling projects, even though it is not always ideal. So, in this report when we are talking about model results we are referring to sediment, however, when the monitoring data we used to calibrate the model was TSS (by necessity).

Calculated rate constants were averaged for each pollutant (phosphorus and sediment) so that they could be applied to each of the wetland cells in the first-order removal rate calculation. An average removal rate constant of 3.28 was calculated for total phosphorus (TP) and a rate constant of -0.3 was calculated for total suspended solids (TSS). The TP average rate constant does not include the calculated value for cell A, as it was grossly misrepresentative of the template as a whole. Outflow concentrations for each cell were simulated using the calibrated first-order equation.