Hydrological Connection from Lake Audubon to Crab Creek

April 2012

Civil-3

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Abstract

The overall objective of this proposed study was to determine if a surface water connection between the Lake Audubon and Upper Crab Creek exists based on water quality characteristics, hydrologic modeling, and a mass water balance. This project plan describes how the study's objectives and procedures were followed along with the study's results.

Our goal as a team was to build on the previous assessment performed by the Department of Ecology in the Spring of 2009. The previous assessment was based on water quality testing visual observation and was inconclusive in the determination of surface water connection between Lake Audubon and Upper Crab Creek. However, the study strongly recommended additional water quality analysis in order to draw further conclusions. Furthermore, a surface water hydrologic model was not conducted by the Department of Ecology. It should also be noted that the Ecology study did not evaluate the underlying soils and possible infiltration that could allow a ground water connection between the two water bodies.

Hydrologic Modeling of Lake Audubon using HEC-HMS will help to determine if there is a possibility of surface water connection between the two water bodies. The model was designed to evaluate the conditions that could create a surface water connection. The project team generated a topographic map to delineate the contributing basin areas of the Lake Audubon watershed.

Water Quality testing was also performed to determine any correlation between sampling sites of the two water bodies and along the flow path. Tests were conducted on the effluent released from the WWTP, Lake Audubon, Crab Creek headwaters, and several ponds located between Lake Audubon and Upper Crab Creek.

The Mass Water Balance analysis was also performed to estimate the amount of water lost to infiltration into Lake Audubon, and evaluate the possibility of a groundwater connection. This is the extent of groundwater analysis that this project will cover due to time constraints and limited resources.

Acknowledgments

The Lake Audubon design team would like to take the time to acknowledge and show our gratitude for the people that made our design project successful and possible.

To Aimee Navickis-Brasch who was exceedingly helpful in every aspect of the project, not only in providing direction for our study but in here encouragement and thoughtful engineering decisions.

We are also thankful for the assistance of the Department of Ecology, especially Joe Joy, Jon Jones, and Cynthia Wall who supported the team throughout the year and helped us through the analysis of the project. We would also like to thank Kim Sherwood, a retired Ecology Engineer, who helped develop as well as coordinate the project between the City of Reardan and Gonzaga University.

Furthermore, we will like to thank Todd Emerson for taking time from his WSDOT job to help the team during site visits and other design aspects.

We are grateful for the City of Reardan to make our design project and would like to thank Bruce Johnson for assisting the team with site visit plans and sharing the history of the City of Reardan. Lastly, we would like to thank Dr. Sue Niezgoda as well as the chemistry department at Gonzaga University with particular thanks to Ian Joslin and Christy Watson who assisted the project team.

1.0 Introduction

1.1 Upper Crab Creek Background Information

Upper Crab Creek is located West of Lake Audubon, and crosses Highway 2, North to South. Lake Audubon is located near the headwaters of Crab Creek, but there is no documented direct outflow from the lake into Upper Crab Creek. No visible surface water connection between Lake Audubon and the upper reaches of Crab Creek was seen in the project teams two site visits (October 2011, March2012) or during the Ecology site visit in April of 2009 .

Upper Crab Creek is on the 303(d) list of impaired water bodies due to the pollutant fecal coliform, while the lower reaches of Crab Creek are listed for the following pollutants; fecal coliform, turbidity, temperature, pH, and dissolved oxygen. The Department of Ecology has indicated that dissolved oxygen, pH, and turbidity are likely also a problem in Upper Crab Creek.

In accordance with section 303(d) of the federal Clean Water Act, every state must identify polluted water bodies and submit a list to the EPA. Then a TMDL (Total Maximum Daily Load) is developed, which indicates how much pollutant can discharge to a water body and meet water quality standards. The TMDL identifies the pollutant sources and discharge limitations required to meet water quality standards and clean up the water body. This study is evaluating the possibility of Lake Audubon contributing fecal coliform to the Upper Crab Creek.

If nutrient loads from Lake Audubon exist in the upper reaches of Crab Creek it would have a significant effect on Crab Creek DO and pH values. The transport of enriched lake water into the headwaters of Crab Creek could also affect the future of the City of Reardan. If there is a pathway connection, then Reardan's WWTP may have to limit or eliminate discharges into Lake Audubon, which may affect the ecosystem that has developed.

1.2 Lake Audubon Background Information

Audubon Lake is located in close proximity to the headwaters of the Crab Creek watershed, north of Highway 2. "Lake Audubon is two hundred and seventy-seven acres of wetlands, vernal ponds, grasslands, and channeled scablands supporting more than 200 species of birds" (WWRP, 2005). The western section of Lake Audubon receives effluent year round from the Reardan WWTP (Waste Water Treatment Plant), and it is believed that the lake would dry up in the summer and fall months if it did not receive this discharge from the plant (per the City of Reardan Staff). The effluent enriches the lake water and supports the surrounding wildlife, which in turn helped transform the lake into a habitat for migratory birds and an aesthetic tourist site for the City of Reardan.

2.0 History of Reardan

Reardan Washington was established in 1882. As stated by the 2010 United States Census the population of Reardan is 571 people. The City of Reardan approximately has a land area of 0.49 square miles. The land cover surrounding the City of Reardan and Lake Audubon is primarily various agricultural crops and cattle grazed pastures.

During the early 1910's the population of Reardan peaked at around 900 people. At that time, all waste and wastewater was sent to a septic system located adjacent to the current wastewater treatment plant as well as the current location of Lake Audubon. Storm water and wastewater both traveled in the same pipes that led to the city septic system (per the City of Reardan Staff). The combination of the effluent, snowmelt, and storm water caused the septic system to overflow into the surrounding field. During the mid-1910's was the first time water was seen year round in the field. Although there was seasonal flooding in the field adjacent to the septic system, it was not until the septic system overflowed did water remain, thus creating Lake Audubon. The photograph in Figure 2.1 shows the field in question that is now know as Lake Audubon. As the photo depicts, before the septic system overflowed the field was used for a semi-professional baseball field.

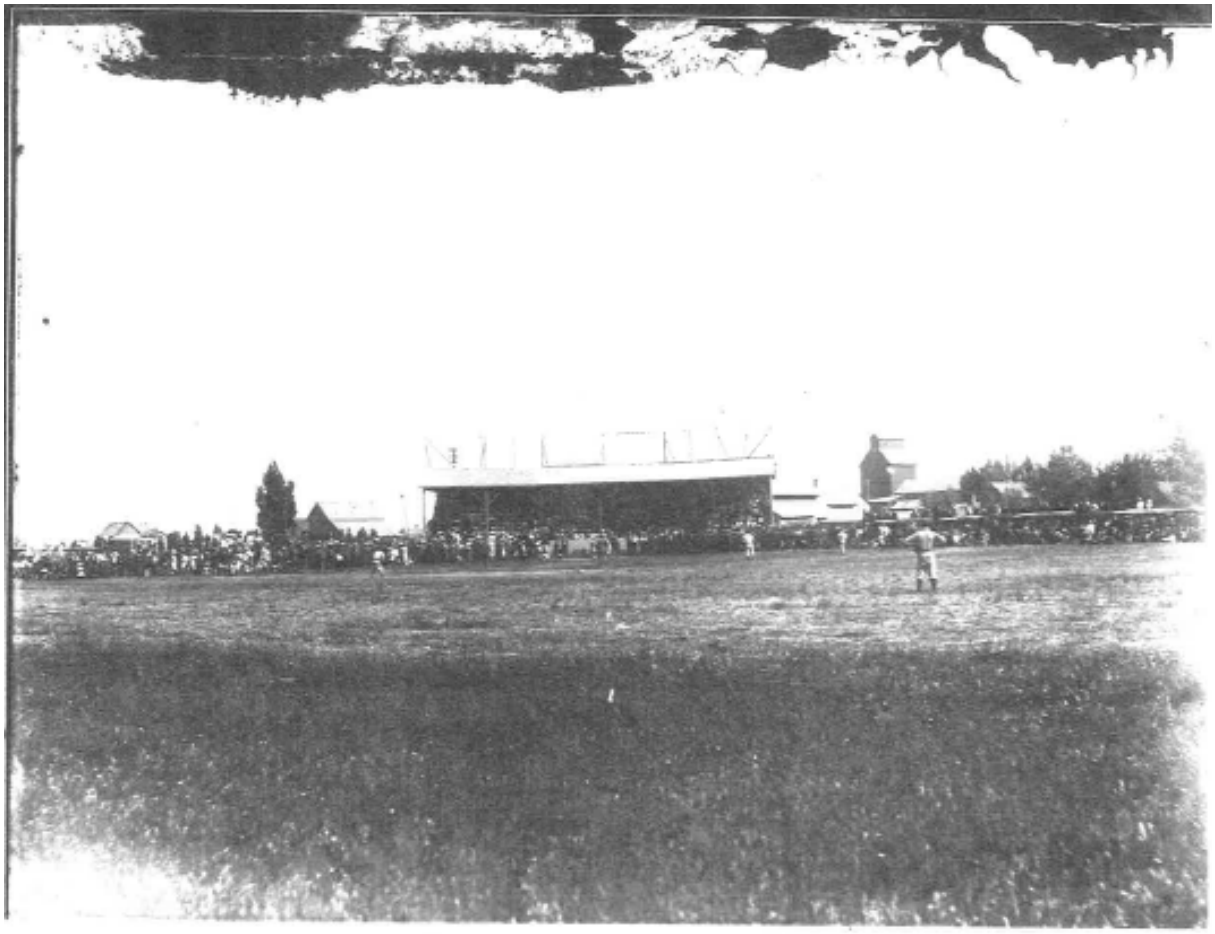


Figure 2.1 Photo of historic baseball field of what is now Lake Audubon.

In the late 1960's and early 1970's the first wastewater treatment plant was constructed. Since this time the wastewater treatment has been improved and updated. Figure 2.2 is a current aerial photo of Lake Audubon and the current wastewater treatment plant along with approximate locations of the old septic system and baseball field.

Figure 2.2 Current Photo of Lake Audubon with the current wastewater treatment plant, historic baseball field, and historic septic system depicted.

3.0 Elevation Map Development

To perform hydraulic modeling of Lake Audubon, a comprehensive elevation map of the region was developed. The elevation map was derived from existing elevation maps (provided by United States Geological Survey) as well as the survey of the site. The site survey provided a means of determining intermediate elevations of the Lake Audubon wetland watershed since the contour intervals of the USGS topographic map was too large. It should be noted that a through survey of the lake bottom was not performed. The average depth of the lake bed was determined through a brief site survey of the water surface elevations and the lake bed. The results from this survey can be seen in Table A of Appendix A.1.

3.1 Survey Site Selection

The survey was broken down into two specific regions. The first region surveyed was the eastern side of Lake Audubon. A more detailed survey was performed in the second region, which is west of Lake Audubon (between the lake and Upper Crab Creek). The elevation map limits can be seen below in Figure 3.1

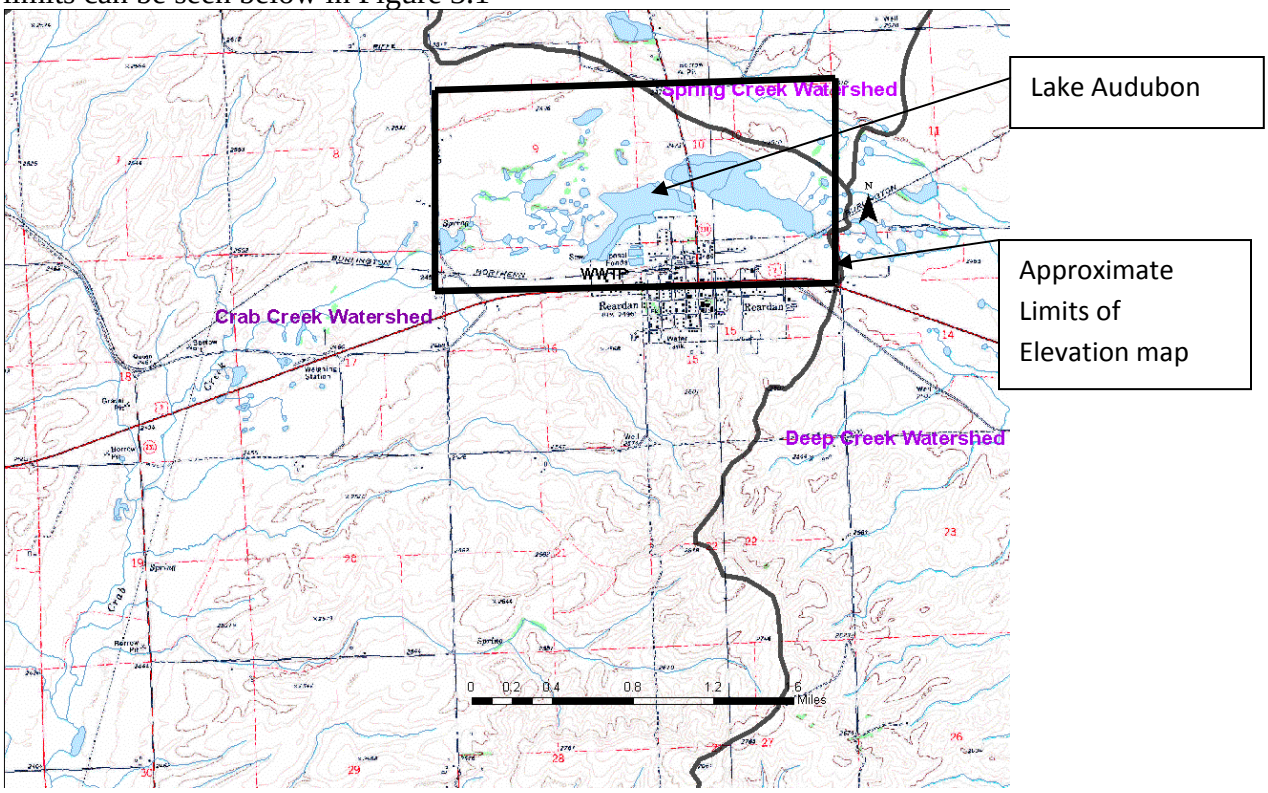


Figure 3.1 Topographic Map of Lake Audubon

3.2 Surveying Validity

Todd Emerson, a Washington State licensed surveyor oversaw the work performed to ensure valid surveying procedures.

3.3 Surveying Equipment and Procedure

The equipment utilized throughout the survey was a Topcon GPS Hiper Lite and receivers. The method of surveying performed was the base and rover method. To ensure that the surveyed data could be combined with the existing elevation maps, the surveying equipment was set based on benchmark R 204 (PID SV0949) which is defined in a NGS datasheet. See Figure 3.2. The benchmark is located at the corner of Highway 231 and Euclid Road.

Figure 3.2 Survey Crew Preparation and Bench Mark R 204

3.4 Data Collection

The existing elevation map was converted into USGS xyz data. Then the surveyed xyz data was combined with the USGS xyz data to create an accurate and comprehensive map of Lake Audubon and its surrounding area.

3.5 Verification of Elevation Map

To verify the project team's elevation map Todd Emerson reviewed the final product. A copy of the final map can be seen in Figure A.1 in Appendix A.

4.0 Delineation

The Lake Audubon watershed was delineated to determine the basin's area, slope, and channel length, which are vital variables for the hydrological model, HEC-HMS. Through the use of a USGS topographic map, three catchment basins were determined based on possible flow paths in the Lake Audubon watershed. The team was able to estimate the channel length and slope of each sub-basin manually.

Furthermore, to validate our calculations and ensure a more accurate representation of the necessary variables, an AutoCAD file of the combined USGS topographic map and the team's surveyed intermediate elevations was utilized. With AutoCAD functions including the use of polylines and other functions, areas, slopes, and channel lengths of the determined three sub-basins were calculated.

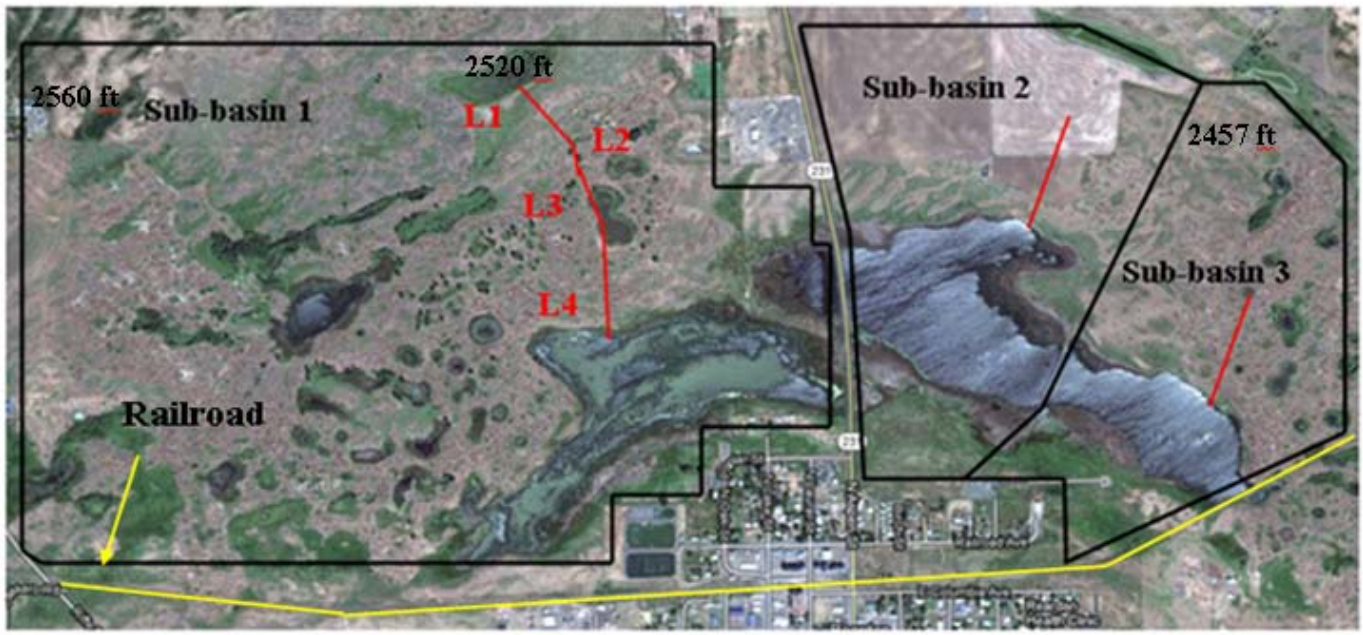


Figure 4.1 Sub-basin areas and channel lengths

4.1 Sub-basins

Sub-basin 1 is bounded by the highest elevation of 2520 feet and 2560 feet on the north, Highway 231 to the east, a railroad that runs through the City of Reardan on the south, and Riffe Rd to the west. This area includes Lake Audubon and the surrounding natural wetland.
Sub-basin 2 includes half of East Lake as depicted in Figure 4.1. The area is bounded on the north by Euclid Rd, an elevation of 2457 feet on the east, the City of Reardan to the south, and Highway 231 to the west.

Lastly, sub-basin 3 is bound by the highest elevation of 2457 to the north, the railroad to the east and south, and the City of Reardan to the west.

Table 4.1 illustrates the calculated areas, lengths, and slopes of each sub-basin. These values are used to calculate inputs for running HEC-HMS.

Table 4.1 Delineated Sub-basins

Sub-basin	Area (acres)	Length (ft)	Slope
Sub-basin 1	299		
L1		1644.5	-2.30
L2		589	-2.50
L3		780.8	-3.00
L4		3724	-0.20
Sub-basin 2	67	1075	-2.10
Sub-basin 3	102.5	2439	-1.20

To verify the results of the calculated slopes, Streamstats was utilized. A terrain profile was taken of the desired channel lengths depicted in Figure 4.1, which in turn established elevation losses and channel lengths. These are illustrated in Appendix B. Table 4.2 shows the calculated slopes determined by Streamstats. Furthermore, the values represent similar slope values that were determined manually and provide the design team a verification of the calculated slope values.

Table 4.2 Streamstats Sub-basin Slopes

Sub-basin 1	**Slope**
L1	-1.7
L3-4	-0.8
Sub-basin 2	-1.87
Sub-basin 3	-0.99

5.0 HEC-HMS Modeling

HEC-HMS is a watershed modeling system developed by the U.S. Army Corps of Engineer's Hydrologic Engineering Center that is capable of incorporating many different variables into its calculations. The watershed of interest is separated into controllable pieces by dividing the total basin area into sub-basins, reservoirs, sources, sinks, and flow paths, which have data pertaining to flow incorporated into them. A depiction of the model layout can be seen in figure 5.1.

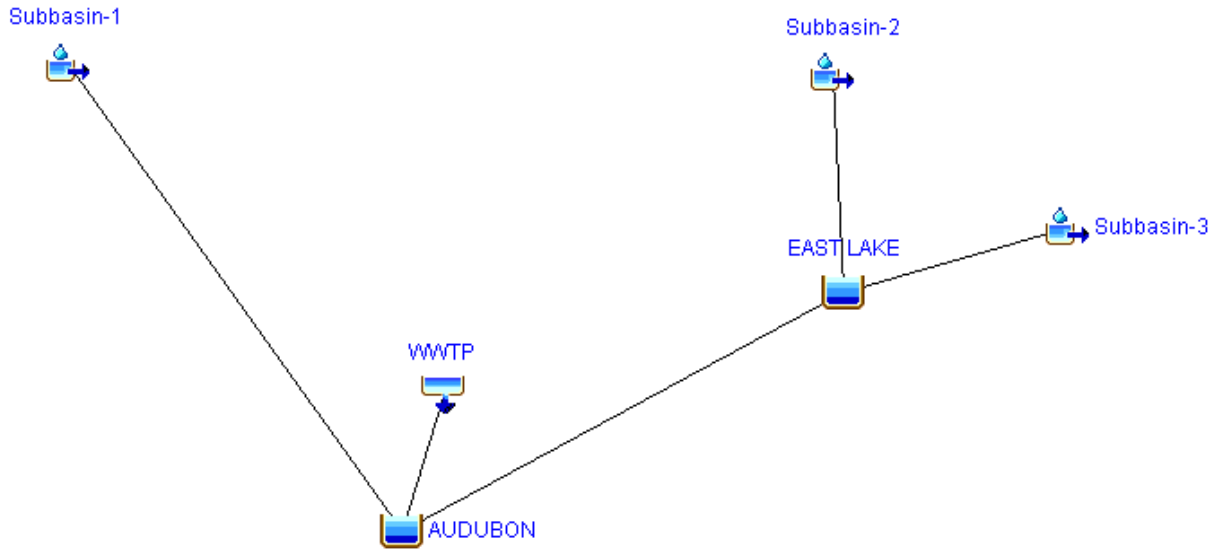


Figure 5.1Model Description

5.1 Methods

5.1.1 Sub-Basins

The Lake Audubon watershed was divided into 3 sub-basins as depicted in Figure 5.2.

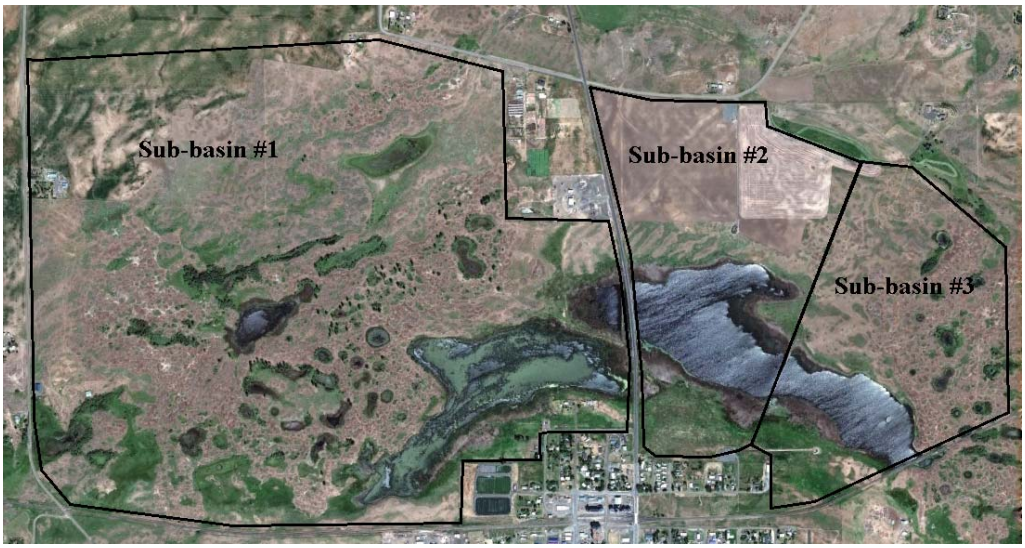


Figure 5.2 Model Sub-basins

The losses of each sub-basin were modeled using the SCS curve number approach; the soil classifications were determined using NRCS's web soil survey online software and curve numbers were selected from Table 2-2c within NRCS's TR55 (Urban Hydrology for Small Watersheds technical release). A combined curve number was calculated for each of the three sub-basins based on percentage of soil type. Combined curve number calculations, a web soil survey map depicting soil group and percentage of land area, and NRCS TR55 Table 2-2c can be seen in Appendix C. These combined curve numbers can be seen in Table 5.1.

Table 5.1Combined CN Values

Sub-basin	CN
1	78
2	80
3	68

The transform methods of each sub-basin were modeled using the SCS segmental approach to calculate time of concentrations for flow. This approach is also located within the NRCS's TR55. The segmental approach divides the total flow path into overland, shallow concentrated and channeled flow and computes a separate flow time for each using manning's n values, velocity's, and slopes. Based on the project site topography and aerial maps, it appeared runoff was conveyed to the wetland via overland sheet flow and shallow concentrated flow. The Audubon watershed lag times were computed using overland flow and shallow concentrated flow equations.

For overland flows:

$$Tt = \frac{0.007(nL)^{0.8}}{(P2)^{0.5}S^{0.4}}$$

Where: Tt = travel time (hrs)
n= Manning's roughness coefficient (NRCS TR55 table 3-1)
L = Flow path length (ft) (less than 300ft)
P2= 2-year, 24-hour rainfall (in)
S = slope of hydraulic grade line (ft/ft)

For shallow concentrated flows:

$$Tt = \frac{L}{3600V}$$

Where: Tt = travel time (hr)
L= flow length (ft)
V = average velocity (ft/s)
3600 = conversion factor from seconds to hours

Time of Concentration:

$$Tc = T_t1 + T_t2 + \cdots + T_tn$$

Lag Time is taken to be:

$$T_L = .6T_C$$

The calculations for the lag time of each sub-basin and the supporting NRCS's tables can be seen in Appendix C. The lag times for each sub-basin can be seen in Table 5.2.

Table 5. 2 Lag Times

Sub-basin	Lag Time (MIN)
1	36.55
2	12.78
3	23.66

5.1.2 East Lake Reservoir

The lake east of highway 231 was modeled as a reservoir in HEC-HMS, with a corrugated metal pipe culvert leading to Lake Audubon as its outlet structure. Values for the stage area curve and

outlet structure were obtained in the field. Typical entrance and exit coefficients for a corrugated metal culvert were selected. The stage area curve for the East Lake entity was approximated using the stage area curve for Lake Audubon, due to a lack of data pertaining to its topography. A descriptive method of how the stage area curve was generated can be seen in section 5.1.4. The outlet structure parameters can be seen in Table 5.3.

Table 5.3 East Lake Culvert Parameters

Culvert Parameter	Value
Length (ft)	40
Diameter (ft)	1.5
Inlet Elevation (ft)	2470
Entrance Coefficient	0.2
Outlet Elevation (ft)	2470
Exit Coefficient	1
Manning's n Value	0.022

5.1.3 Waste Water Treatment Plant

Reardan's WWTP was modeled as a source in HEC-HMS with a constant discharge of 0.2259 MGD (0.35014 CFS), as per the WWTP's maximum monthly design flow as stated in Reardan's National Pollutant Discharge Elimination System Waste Discharge Permit (Ecology 2010).

5.1.4 Lake Audubon

Lake Audubon was modeled as a reservoir in HEC-HMS, with an approximated broad-crested spillway at an elevation of 2475ft leading to what appears to be the most probable flow path as its outlet structure. The spillway location and elevation was determined based on observations during site visits and in review of the project site topographical map.

Elevation and area values for Lake Audubon's area curve and outlet structure were obtained in the field, and from the project site topography map. The areas at elevations 2472 ft and 2475 ft were obtained from the project sites topography map, and the areas below 2472 ft to the bottom of Lake Audubon were approximated using a depth of 7 ft and a slope of 5% obtained in the field.

Since the outlet for Lake Audubon is a natural spillway (not constructed); a larger spillway coefficient was selected to account for losses.
The stage area curve for Lake Audubon can be seen in Figure 5.1.2 and the outlet structure parameters can be seen in Table 5.1.4.

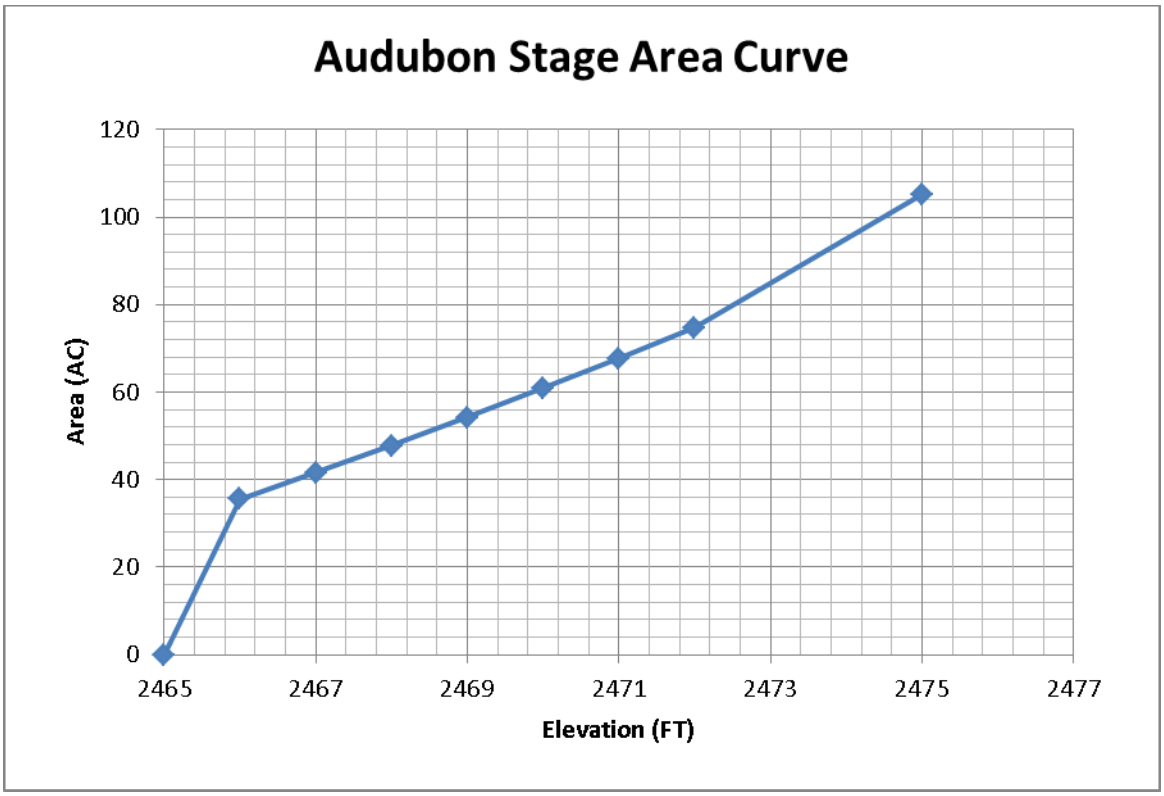


Figure 5.3 Audubon's Area vs. Elevation Curve

Table 5.4 Audubon Outlet Structure

Spillway Parameter	Value
Elevation (ft)	2475
Length (ft)	80
Coefficient	4.0

5.1.5 Most Probable Flow Path

The most probable flow path was taken to be the lowest elevation path southwest along the perimeter of Lake Audubon where initial spillage would occur and flow would be directed approximately 3178 ft toward the headwaters of Crab Creek. Additional discussion about the flow path is provided in section 9.0.

5.1.6 Meteorological Model

Precipitation was modeled using the SCS long duration design storm as described in the WSDOT Highway Runoff Manual. The 24hour 2yr, 10yr, 25yr, 50yr, 100yr, and 500yr storms were implemented into the model as different scenarios. P24 (Precipitation in inches for the 24 hour storm event) values were obtained from Isofluvial maps for the 24hour 2yr, 10yr, 25yr, 50yr, and 100yr storm events. These maps were obtained from NOAA's online database, and the 500yr P24 value was obtained from Washington State's Department of Ecology. Isofluvial maps for the 24hour 2yr, 10yr, 25yr, 50yr, and 100yr events can be seen in Appendix H.

A snowmelt modification was added to these P24 values to simulate a rain on snow event. This modification factor was calculated using the WSDOT's Snow Water Equivalent equation obtained from the 2010 WSDOT Hydraulics Manual. The maximum average monthly snow depth was obtained from the nearest gage in Davenport. The Hydraulics Manual indicates that the Snow Water Equivalent factor should be added to the 24hr 100yr storm event, however, for this study the modification factor was added to all storm event P24 values to account for all possible volume increases due to snowmelt.

Snow Water Equivalent:

$$SWE = \frac{Average\ Snow\ Depth\ (max.month\ \left(\frac{in}{day}\right))}{5}$$

SWE cannot exceed 1.5 in/day as specified by the WSDOT Hydraulics Manual. An average snow depth value of 7 in/day was obtained from the Western Regional Climate Center's Davenport gauge. Table 5.5 shows the P24 values and the modified P24 values for the 24hour 2yr, 10yr, 25yr, 50yr, 100yr and 500yr storm events.

Table 5.5 Modified P24 Values

Storm Event	24 hour rain fall depth (in)	SWE	Corrected Rain Fall Depth (in)
2yr	1.2	1.4	2.6
10yr	1.7	1.4	3.1
25yr	2	1.4	3.4
50yr	2.2	1.4	3.6
100yr	2.4	1.4	3.8
500yr	2.97	1.4	4.37

Monthly pan evaporation rates were also inputted to model Lake Audubon's and the eastern lakes evaporation. These evaporation rates can be seen in Figure 6.2 in Section 6.1.2

5.1.7 Control Specifications

The model was run using seven days in March to account for the most probable max flow volume. Rain fall depths were also increased incrementally to determine what storm event it would take to show significant discharge and stage in the flow path south west from Lake Audubon and in Lake Audubon itself. Global summaries for each storm event can be seen in the model results sections.

The initial water surface elevation of the lake was set as the representative bankfull elevation of 2472 ft. Water surface elevations from site surveys in both October and March and a survey of the centerline of Highway 231 (located between Audubon and East Lake) were used in the determination of the bankfull elevation. The results can be seen below in Table 5.6

Table 5.6 Bankfull Elevation Data

Description	Elevation (ft)
elevation of center line of highway 231	2473.2
current water surface (as of 3/28/2012)	2471.3
water surface (as of 10/18/2011)	2470.0
representative bank full elevation	2472

The representative bankfull elevation of 2472 ft was primarily chosen based on the change in the water surface elevation from the two site surveys in October and March. This change in elevation represents how the elevation of the water surface changes due to increased precipitation in the spring and winter months. The bankfull elevation is imperative in the modeling because it represents the water surface elevation that will most likely cause flooding after a storm event occurs.

5.2 Model Results

The following section shows results of the HEC-HMS model for the 24 hour 2yr, 10yr, 25yr, 50yr, 100yr, and 500yr events. The wetland was modeled assuming full conditions. An additional scenario was modeled in HEC-HMS to determine what storm event would cause significant rise in stage of Lake Audubon. It was found that a storm magnitude of almost twice the 500yr event was necessary to rise to Lake Audubon's spillway elevation of 2475 ft (a P24 value of 7in). The global summaries for the 24 hour 2yr, 10yr, 25yr, 50yr, 100yr, 500yr, and modified storm events can be seen in tables 5.7– 5.13. The storage and flow vs time graphs for Lake Audubon for all storm events can be found in Figures C.1-C.6 Appendix C.

Table 5.7 Year 24 Hour Event

2yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	39.4	01Mar2012, 08:36	26.6
Subbasin-3	0.218538	24.7	01Mar2012, 08:06	11.2
Subbasin-2	0.163069	3	01Mar2012, 16:15	3.8
EAST LAKE	0.381607	6.9	01Mar2012, 22:27	72.8
WWTP	0	0.4	01Mar2012, 00:00	4.9
AUDUBON	0.965559	0	01Mar2012, 00:00	0

Table 5.8 10 Year 24 Hour Event

10yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	62.4	01Mar2012, 08:33	37.4
Subbasin-3	0.218538	37.2	01Mar2012, 08:06	15.4
Subbasin-2	0.163069	6.4	01Mar2012, 08:27	5.9
EAST LAKE	0.381607	7.2	02Mar2012, 00:06	76.3
WWTP	0	0.4	01Mar2012, 00:00	4.9
AUDUBON	0.965559	0	01Mar2012, 00:00	0

Table 5.9 25 Year 24 Hour Event

25yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	77.5	01Mar2012, 08:33	44.3
Subbasin-3	0.218538	45.3	01Mar2012, 08:06	18.2
Subbasin-2	0.163069	9.5	01Mar2012, 08:24	7.3
EAST LAKE	0.381607	7.3	02Mar2012, 00:15	78.5
WWTP	0	0.4	01Mar2012, 00:00	4.9
AUDUBON	0.965559	0	01Mar2012, 00:00	0

Table 5.10 50 Year 24 Hour Event

50yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	87.9	01Mar2012, 08:33	49
Subbasin-3	0.218538	50.8	01Mar2012, 08:06	20
Subbasin-2	0.163069	11.8	01Mar2012, 08:24	8.3
EAST LAKE	0.381607	7.4	02Mar2012, 00:12	80
WWTP	0	0.4	01Mar2012, 00:00	4.9
AUDUBON	0.965559	0	01Mar2012, 00:00	0

Table 5.11 100 Year 24 Hour Event

100yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	98.6	01Mar2012, 08:33	53.8
Subbasin-3	0.218538	56.5	01Mar2012, 08:06	21.9
Subbasin-2	0.163069	14.2	01Mar2012, 08:21	9.4
EAST LAKE	0.381607	7.5	02Mar2012, 00:12	81.5
WWTP	0	0.4	01Mar2012, 00:00	4.9
AUDUBON	0.965559	0	01Mar2012, 00:00	0

Table 5.12 500 Year 24 Hour Event

500yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	130.5	01Mar2012, 08:30	68.1
Subbasin-3	0.218538	73.2	01Mar2012, 08:06	27.4
Subbasin-2	0.163069	21.8	01Mar2012, 08:21	12.6
EAST LAKE	0.381607	7.8	02Mar2012, 00:18	85.9
WWTP	0	0.4	01Mar2012, 00:00	4.9
AUDUBON	0.965559	0	01Mar2012, 00:00	0

Table 5.13 Modified Storm Event

100yr	DRAINAGE AREA (SQ MI)	FLOW (CFS)		VOL (AC FT)
Subbasin-1	0.583952	297	01Mar2012, 08:29	4.47
Subbasin-3	0.218538	158.9	01Mar2012, 08:04	4.69
Subbasin-2	0.163069	66.3	01Mar2012, 08:16	3.41
EAST LAKE	0.381607	9.3	02Mar2012, 00:18	4.61
WWTP	0	0.4	01Mar2012, 00:00	
AUDUBON	0.965559	0	01Mar2012, 00:00	0

It should also be noted that infiltration values were not implemented into the model, and that 0.44 acre-ft infiltrates over the seven day model run time. The equation used to determine the volume infiltrated over the seven day model period can be seen below.

This volume of infiltration was obtained by:

$$Vol = A \times I \times T$$

Where: A = Wetland Area
I = Infiltration Rate
T = Time

6.0 Lake Audubon Mass Water Balance

As a supplement to both the water quality assessment and hydraulic modeling of Lake Audubon, a Mass Water Balance was performed to evaluate the possible connectivity of Lake Audubon and Upper Crab Creek. The water mass balance had one primary goal, to determine the representative infiltration rate of the Lake Audubon. The project team performed a water mass balance on Lake Audubon based on the change in water surface elevation surveyed during the period of October 18, 2011 to March 28, 2012. During this time all inputs and outputs as well as the change in volume of the lake were quantifiable and known to the project team. Based on well data in the area ground water contribution was assumed to be zero. For a more detailed description of the ground water and well data refer to section 9.0 of the report.

The equation used for the mass water balance as well as a description of each variable can be seen below. Table 6.1 shows the method used for determining each variable used in the mass water balance. A more detailed description of how each variable was determined will be discussed in the following section of the report.

$$(dV/dt) = Q_i - Q_o + Q_c + -Q_{in} + Q_{sm} + (P \times A) - (ET \times A) - (E \times A_{water})$$

Where:
A_{plants} = area of wetland plants
A_{water} = area of open water
ET = evapotranspiration rate
E = open water evaporation rate
P = precipitation rate
Q_c = catchment runoff rate
Q_{in} = infiltration of lake bed
Q_i =input wastewater flow rate
Q_o = output wastewater flow rate
Q_{sm} = snowmelt rate
t =time
V = water storage (volume) in wetland

Table 6.1 Method for Determining Mass Water Balance Variables

Variable	Source
Area of Lake Audubon	AUTOCAD using surveyed data
Evapotranspiration Rate	Penman-Montieth method
catchment run off rate	HEC-HMS
Wetland open water evaporation rates	Pan evaporation with open water coefficient from Spokane County Regional Stormwater Manual
Effluent	City of Reardan WWTP
Change in volume of Lake	2 Separate Site Surveys
Precipitation rate	NOAA
Snow pack	NOAA
Wind	NOAA

Shown below (Figure 6.1) is schematic drawings detailing all know inputs and outputs for Lake Audubon.

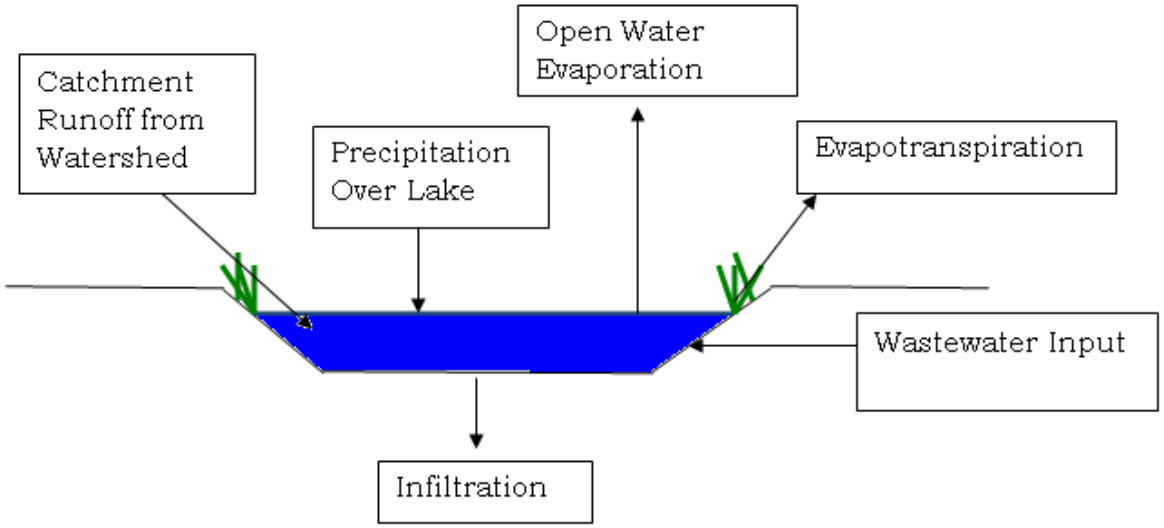


Figure 6.1 Schematic Drawing Showing Available Inputs and Outputs of Lake Audubon

6.1 Methods

6.1.1 Area of Lake Audubon

The area of the Lake Audubon was determined using the computer program AutoCad. Using the topographically map developed for the project, the area of Lake Audubon as a whole was measured. The results of the area calculations can be seen in Table 6.2. It should be noted that area of the wetland plants was estimated to be seven percent of the total wetland area based on visual observation.

Table 6.2 Areas of Lake Audubon

Description	Area (ft&2)
Lake Audubon	2,862,504.00
Wetland Plants	200,375.28
Open Water	2,662,128.72

6.1.2 Open Water Evaporation Rate

The evaporation rate for the open water of the Lake was found using the average pan evaporation rates. Due to the lack of gauge data in the area during the time of the analysis, the average pan evaporation rates were used to provide a representative rate. The average pan evaporation rates were found in the Spokane Regional Storm Water Manual. To determine the actual evaporation rate of the open water, the pan evaporation rates was multiplied by a pan coefficient. Based on previous studies of wetland evaporation rates, the pan coefficient that best represents Lake Audubon and its present conditions was found to 0.75. The results for average open water evaporation for each month can be seen below in Table 6.3.

Table 6.3 Average Open Water Evaporation

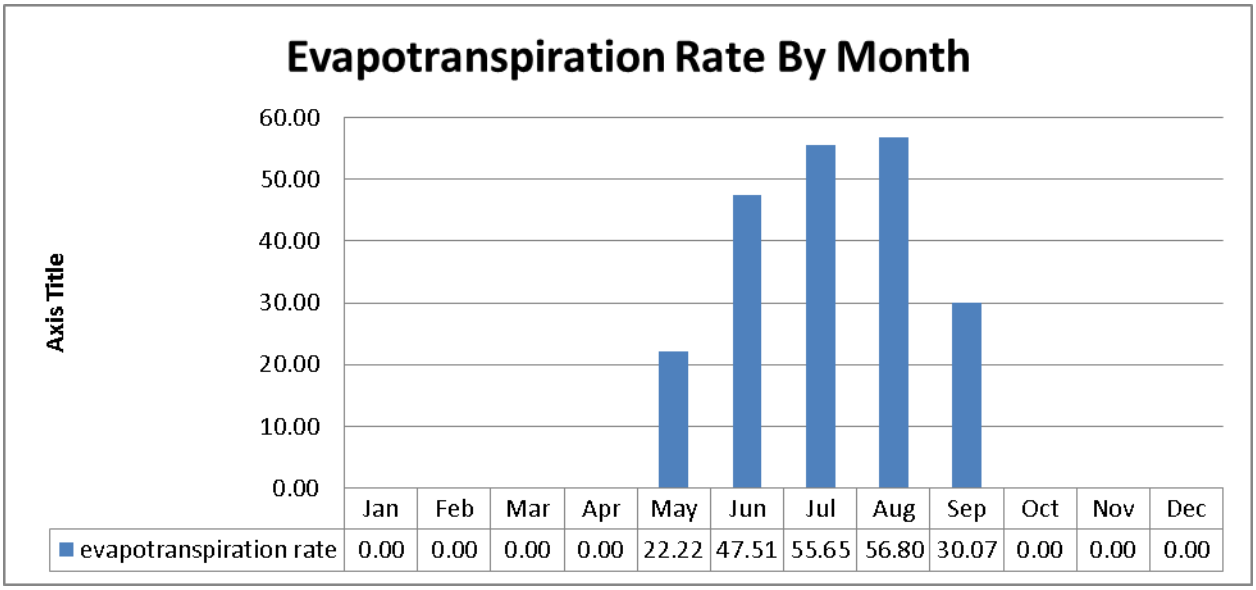
Month	Pan Evaporation (in)	Pan Coefficient	Open Water Evaporation (ft)
January	0.61	0.75	0.038
February	1.11	0.75	0.069
March	2.28	0.75	0.143
April	4.45	0.75	0.278
May	6.69	0.75	0.418
June	8.14	0.75	0.509
July	10.7	0.75	0.669
August	9.42	0.75	0.589
September	5.9	0.75	0.369
October	2.58	0.75	0.161
November	1.2	0.75	0.075
December	0.51	0.75	0.032

6.1.3 Evapotranspiration Rate

The evapotranspiration rate of Lake Audubon was determined using the FAO Penman-Monteith equation. FAO Penman-Monteith equation is the recommended as sole method for determining evapotranspiration (Crop evapotranspiration) the FAO Penman-Monteith method used actual meteorological data to determine a reference evapotranspiration rates. The FAO Penman-Monteith equation as well as the reference evapotranspiration rates can be seen in Appendix D in Figure D.1 and Table D.1 respectively.

After the reference evapotranspiration rate was determined it was multiplied by a crop coefficient to determine the evapotranspiration rate of a specified reference crop. Due to the nature of our project site the reference crop used was alfalfa. After the evapotranspiration rate for alfalfa was determined it was then determined (through the help of Robert Nolan from the

Washington Department of Ecology) that the value for evapotranspiration of a wetland was estimated to be 160% of alfalfa's evapotranspiration. The results for the evapotranspiration rate of Lake Audubon can be seen Figure 6.2. It should be noted that the values of evapotranspiration calculated (using the FAO Penman-Monteith method) for the months from October to March were found to be negligible and assumed zero in the mass water balance.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
evapotranspiration rate	0.00	0.00	0.00	0.00	22.22	47.51	55.65	56.80	30.07	0.00	0.00	0.00

Figure 6.2 Evapotranspiration Rate Estimated By Month for Lake Audubon

The Washington Department of Ecology suggested verifying the accuracy of the evapotranspiration rates by comparing our results with evapotranspiration values equal to 450 percent of the open water evaporation rates. The comparison rates can be seen below in Table 6.4. The results from the comparison show the calculated evapotranspiration values deviate slightly from the estimate of 450 percent of the open water evaporation rates. The comparison showed that the calculated values are comparative to the values suggested by the department of ecology. Therefore, the calculated evapotranspiration rates were used because they were based on actual physical and metrological characteristics of the project site during the period from October to March.

Table 6.4 Evapotranspiration Rate Comparison

Month	Calculated Evapotranspiration Rate (in/month)	450% of Open Water Evaporation (in/month)
Jan	0	2.05
Feb	0	3.74
Mar	0	7.69
Apr	14.00	15.01
May	22.06	22.57
Jun	47.50	27.47
Jul	55.65	36.11
Aug	56.79	31.79
Sep	30.07	19.91
Oct	0	8.70
Nov	0	4.05
Dec	0	1.72

6.1.4 Change in Lake Volume as a Function of Time

In order to determine the infiltration rate of the lake, the change in elevation as a function of time had to be a quantifiable value. Due to the lack of a storage gauge for the Lake, the change in volume as a function of time had to be determined from surveyed data. Using data from our project team's two site surveys the water surface elevation was determined for the both October 18, 2011 and March 28, 2012.

With the two known elevations the change in volume as a function of time was determined. The side slopes of lake were assumed to 1:1 (H:V), therefore the change in water surface elevations was multiplied by the total area of the Lake.

This resulted in a value for the change in Lake Audubon's Volume as a function of time for the period of October 18, 2011 to March 28, 2012. The results for change in Lake Volume as a function of time can be seen below in Table 6.5.

Table 6.5 Results from Change in Lake Volume as Function of Time

Date	Water Surface Elevation (ft)	
10/18/2011	2470.10	
3/28/2012	2471.40	
	Change in Volume (ft^3)	3,722,400.20
	Chang in Volume per Day (ft^3/day)	**22,236.81**

6.1.5 Catchment Runoff Rate

The inflow due to precipitation in Lake Audubon's watershed was determined using the hydrologic model HEC-HMS. HEC-HMS determined the resulting increase in volume due to precipitation using the single event model. The soils, underlying geology, land use, slope of the catchment basin, and the topography of Lake Audubon's water shed were inputs into HEC-HMS. In order to improve the accuracy of the mass water balance actual rainfall data from a nearby NOAA gauge (Davenport Washington) was used. The total rain fall depth for each month between October 2011 and March 2012 was inputted into HEC-HMS. From this the amount of volume added due to precipitation in the surrounding watershed for each month was found. The results from HEC-HMS analysis can be seen below in Table 6.6.

Table 6.6 Catchment Runoff Rate From October 18th, 2011 to March 28, 2012

Month	Rainfall (in)	Catchment Runoff Rate (ft^3)
October	0.11	0
November	0.82	34848.00
December	0.84	39204.00
January	1.11	139827.60
February	1.08	126324.00
March	2.90	1724976.00

6.2 Results

The representative infiltration rate for Lake Audubon was estimated at 0.07 inches per day using the water mass balance equation and methods listed above. The infiltration rate was determined for each month between October 18th, 2011 and March 28th, 2012. The results from this analysis can be seen below in Table 6.7. A more detailed calculation of the monthly infiltration rates can be seen in Table D.2 in Appendix D.

Table 6.7 Infiltration by Month for the Period of October 18th, 2011 to March 28th, 2012

Month	Q infiltration (ft^3)
Oct (18th-31st)	-205,265.17
Nov	71,749.13
Dec	197,045.48
Jan	344,071.90
Feb	238,855.31
Mar (1st-28th)	2,112,331.99

Using the values shown in Table 6.2.0.1the total infiltration was found for the period in question. After this value was determined the representative infiltration rate for Lake Audubon was found. The total infiltration as well as the infiltration rate can be seen bellow in Table 6.8.

Table 6.8 Total Infiltration and Infiltration Rate

Total Infiltration (ft^3)	2,758,788.64
Infiltration (in/day)	0.071

6.3 Discussion of Results

The results from the water mass balance show that an insignificant amount of water in Lake Audubon is lost due to infiltration of the lake bed. According to minimum standards for constructed stormwater wetland the permeability of a clay liner should be no greater than 0.034 inches per day. Permeability is the measure of a soils ability to transmit water; however it is representative of an infiltration rate. The calculated infiltration rate is twice the amount of maximum permeability of 0.034 inches per day. Although the values of the calculated infiltration rate and the maximum permeability differ they are both in the same general range. This helps to show that the calculated value for infiltration can be assumed to be representative of the actual infiltration. It should be noted that Lake Audubon is not a constructed wetland; therefore the value of infiltration rate is expected to differ from a constructed wetland's infiltration rate.

As with any model or analysis there is a distinct possibility of error. Throughout the analysis great care was taken to use actual quantifiable data form the period in question to ensure the results were representative to the actual conditions. However, due to the large nature of the project, some assumptions or estimates had to be made. Specifically, the estimation of the change in the Lake's volume as a function of time. Due to the limited amount of time and budget a through survey of the bottom of Lake Audubon's bed was not performed. Therefore, the volume was estimated based on the surface area and the change in the Lake's water surface level. Even with the distinct possibility of error, the results from the water mass balance are believed to be representative of the actual conditions in Lake Audubon.

7.0 Water Quality Assessment

As a corollary to hydraulic models for Lake Audubon, select water quality measurements were gauged in locations respective to a theoretical Crab Creek watershed. As an indicator for any discernible impacts from the lake within the watershed temperature, dissolved oxygen, turbidity, and pH were measured. Moreover, as the selected testing parameters represent the 303(d) listed contaminants for lower Crab Creek, continuity of contaminants between Upper and Lower Crab Creek were also considered. This objective follows from the belief that the contaminants in lower Crab Creek are also present in upper Crab Creek. The pH, temperature, turbidity and dissolved oxygen measurements taken in the field.

The scope of the Lake Audubon design project encompasses the plausibility wastewater treatment plant effluent affecting the local watershed of Crab Creek. Although limited to the probability of surface water connection, an avenue for verification lies within a chemical connection that is not limited to conditions conducive to overland flow. To distinguish between agricultural and natural contaminants that may confound chemical analysis (nutrients such as nitrogen, phosphorus, etc.) a more descriptive anthropogenic chemical such as caffeine or acetometaphin, if present in Crab Creek, implies the possibility of either groundwater or surface water connectivity.

For the Lake Audubon project, caffeine was the tracer of choice. A common test element in high-performance liquid chromatography orientation courses, the chemical is also a non-native organic compound that within the Crab Creek watershed could inevitably indicate a relationship to the treated effluent from Reardan's waste water treatment plan (WWTP).

To assess the presence and concentration of caffeine analysis of surface water samples, Gonzaga University's HPLC-MS (high performance liquid chromatography linked to a mass spectrometer) was the preferred methodology; however, with technical failures limiting results from the HPLC, a direct injection to the MS was implemented. To this end, select sampling locations throughout the Lake Audubon and upper Crab Creek watershed were collected and prepared for analysis at Gonzaga University.

The resulting pH, turbidity, dissolved oxygen, temperature, and caffeine data was then placed alongside data from a Washington Department of Ecology (Ecology) study previously conducted upon upper Crab Creek's connectivity to Lake Audubon to determine whether relationships between each water body could be discerned.

7.1 Site Selection and Schedule

As the water quality and tracer tests were conducted as a companion study to the hydrological assessment, the sampling locations were selected starting from the theoretical point source, City of Reardan's waste water treatment plant (WWTP), to the theoretical outlet at the headwaters of Crab Creek. As such, the four sampling locations began with an outflow pool from the WWTP (l), the second in Lake Audubon east of HWY 231 (2), third in an isolated pool in the Audubon basin (3), and a final location at the headwaters of Crab Creek (4). Figure 7.1 depicts the spatial representation for the sampling locations. With rising water levels from fall to spring the original sampling location for Lake Audubon (2) was moved to a more accessible location at the equalizing culvert underneath HWY231 (5). For discussion of continuity one sample was taken from a lower reach of Crab Creek, notated as sample location six (6), which is not shown in Figure 7.1. Figure 7.2 presents a more encompassing view of the Crab Creek watershed with all sampling locations (1-6) indicated.

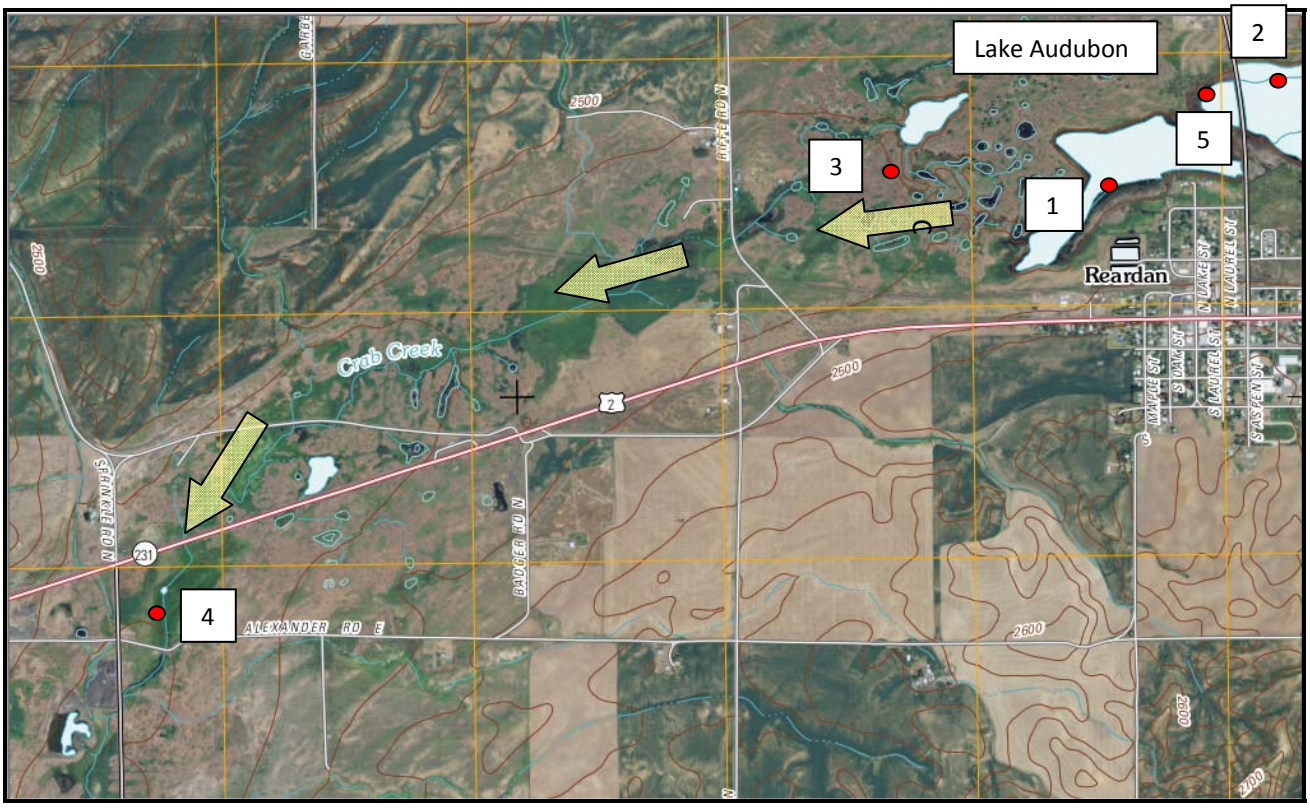


Figure 7.1. Topographic Map of Reardan w/ WQ sampling locations and flow path arrows.

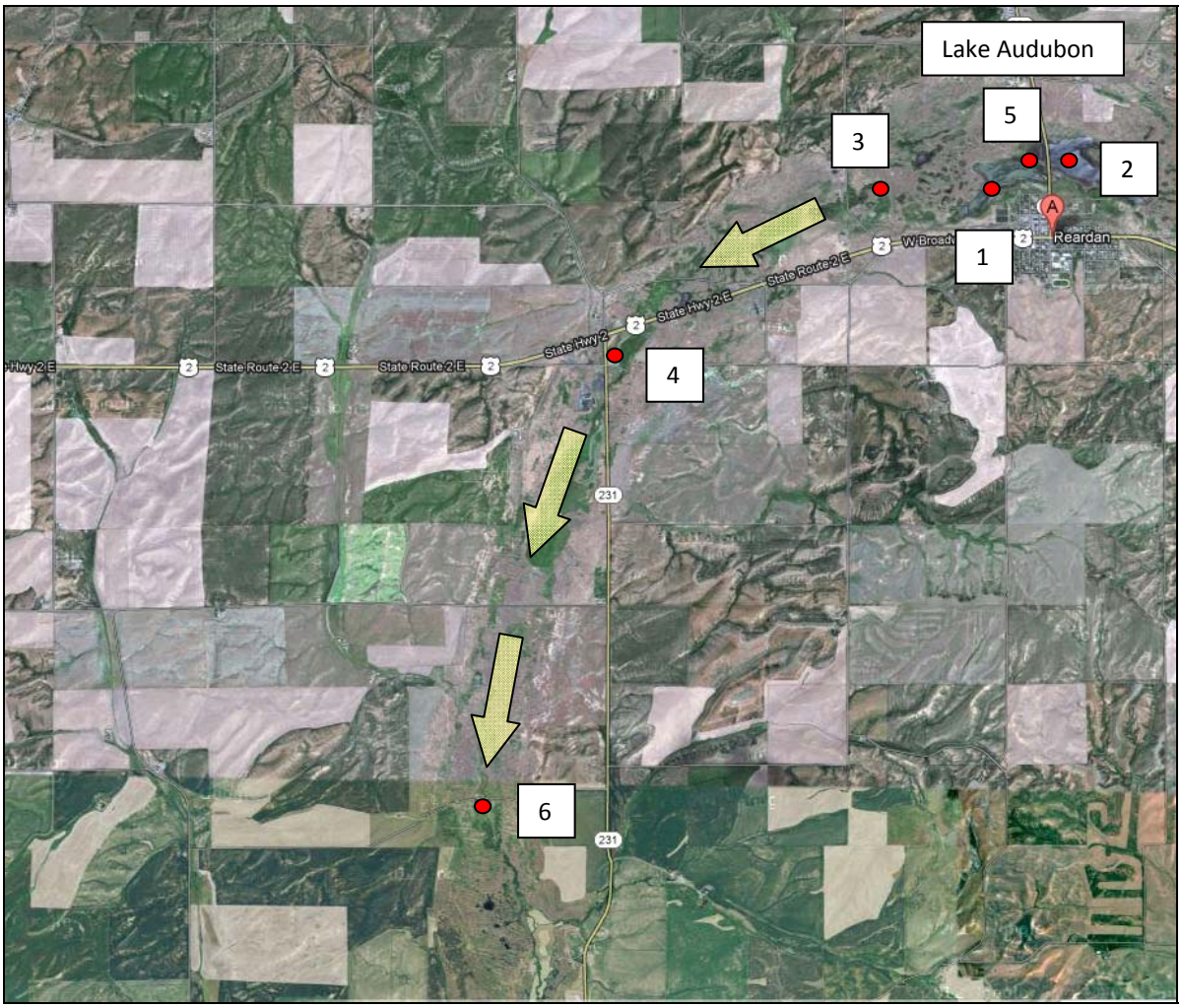


Figure 7.2. Sampling locations, 1-6, within Crab Creek watershed with flow arrows (Google Image).

Schedule

The study area was visited five times. Hourly recording thermistors were installed on October 17th, 2011. Water quality measurements were taken on November 12th, 2011 and February 24, 2012. Caffeine samples were collected on March 28th and April 12th 2012. Descriptions of the site visits are summarized in the Field Visitation for Water Sampling section that follows.

7.2 Measurement and Data Collection

Calibration of instruments and data collection methods follows the approach detailed in the quality assurance project plan (QAPP) for this project. Variations in methodology did occur, notably in the use of a direct injection into a mass spectrometer (MS) as opposed to a high performance liquid chromatography linked to mass spectrometer (HPLC-MS). Additionally, no change in methodology occurred in measurement of temperature, pH, dissolved oxygen, or caffeine sampling. Detailed modifications to measurements and data collection as compared to the QAPP can be found in Appendix E.

7.3 Field Visitations and Water Sampling Results

Field Visit October 17, 2011
During a site visit conducted on October 17, 2011 long-line thermistors relaying real-time data were installed at four selected sample locations in Crab Creek and within the proximity of Lake Audubon. The four locations gathering temperature data were also used for all other water quality tests. Long-line thermistors and installation assistance provided by Cynthia Wall of Ecology.

Photographs of site locations (1-4) are presented in Appendix F.

Field Visit November 12, 2011
Water quality tests were performed on November 12, 2011 for pH, conductivity, and dissolved oxygen (DO) by Steven Kuhlmeier and Logan Palmer. Two Extech probes, one for DO and the other for pH and conductivity, were utilized for data collection at the four locations. Turbidity samples were also collected at each site by withdrawing an aliquot of water from as close to midstream and middle depth as possible. The weather conditions at all sites were cold with light snow and minor ice forming at the slow moving portions of Crab Creek as well as the fringe of Lake Audubon.

Field Visit February 24, 2012
Water quality tests were performed on February 24, 2012 for pH, turbidity, and dissolved oxygen (DO) by Steven Kuhlmeier and Logan Palmer. Two Extech probes, one for DO and the other for pH, as well as a HACH field turbidity meter were utilized for data collection. The weather conditions of the site visit were mid- 40's with light wind and thin ice formations at the slow moving portions of Crab Creek as well as the majority of Lake Audubon.

Sampling locations deviated slightly from the prior sampling locations in that the east Lake Audubon (Site 2) location was at a higher water level and frozen; as such, samples for the east lake were taken at the HWY 231 equalizing culvert (Site 5) between the east and west ponds (Figure 1). Morning samples were taken from sampling locations 1-4 (with location 2's deviation to location 5). Afternoon samples were assessed at Site 4 (Upper Crab Creek) and 5 (equalizing culvert). The mean values for the multiple replicate measurements are summarized in Table 7.4. All sampling sites are shown in Figure 7.2.

Photographs for sampling at locations 5 and 4 on February 24th, 2012 are presented in Appendix G.

Field Visit March 28, 2012
The project team conducted sampling for caffeine analysis in the middle of western Lake Audubon, the headwaters of Crab Creek, and from the direct effluent of Reardan's municipal wastewater treatment plant (WWTP). To capture of a descriptive sample of each water source, samples were withdrawn as close to the center of flow as possible. For the headwaters of Crab Creek (location #4), as the flow constricts into a culvert underneath Alexander Rd, was the location of two samples. Lake Audubon samples were collected by the project team during measurements of lake depth in two locations in the middle of the western section of the lake

(west of location #5). WWTP discharge samples were taken from the center of flow as accessed by a manhole (location #1).

Field Visit April 12, 2012

Additional samples for caffeine analysis were collected from location #5 and location #1, the equalizing culvert dividing Lake Audubon and at the headwaters of Crab Creek respectively. The same precautions in sampling were observed as on the previous site visit.

7.4 Results and Compilation

From water quality measurements taken on the previously noted dates, a synthesized data collection was created and tabulated in Table 7.1 below. The data taken by the project team in November, 2011 and February, 2012 was then placed alongside data from a source assessment of Crab Creek conducted by Ecology in April of 2009. The raw data for sampling can be found in Appendix H. The more extensive water quality characterization covered a gambit of nutrients and metals in Crab Creek and Lake Audubon themselves as well as smaller ponds between the two. This project's study utilizes the conclusions from the previous study and compares the before mention parameters to discern a continuity of results. In relation to the compiled data in Table 7.1, continuity appears to be sustained with similar pH and conductivity values maintaining through sampling periods in Crab Creek in Lake Audubon, in both sampling location 5 and 2 compared to Ecology's Lake Audubon sampling location, continuity of pH and dissolved oxygen was observed. Conductivity values differ greatly between November and April's sampling but during sampling a considerable reddish tint at the sampling location may indicate the presence of iron oxide being of wetland or external origin. Temperature data was not recovered from field locations in sampling locations 2 and 3 as the rise in water levels inundated both thermistor ties. Pending the posting of thermistor temperature data (placed in sample locations 1 and 4) by Ecology, temperature data was not included in this report.

Table 7.1. Compiled data from three sampling periods with inclusion of related data from Ecology field study in 2009.

		April 21, 2009 Morning Sampling*	November 12, 2011 Morning Sampling	February 24, 2012 Morning Sampling	February 24, 2012 Afternoon Sampling
Sample # 1 Location (WWTP Effluent)	pH		7.99±0.01	7.93±0.23	
	Dissolved Oxygen (mg/L)		9.5±0.14	10.6±0.1	
	Conductivity (uS)		984±8		
	Temperature (C°)		0	0	
	Turbidity (mg/L)			14.2±2.2	
Sample # 2 Location (Lake Audubon, East of HWY 231)	pH	9.45	9.03±0.24		
	Dissolved Oxygen (mg/L)	10.86	11.5±0.11		
	Conductivity (uS)	908.9	4237.3±54.4		
	Temperature (C°)	13.46	n/a		
	Turbidity (mg/L)				
Sample # 3 Location (Pond, West Side Audubon Lake)	pH		8.75± 0.05	7.7±0.1	
	Dissolved Oxygen (mg/L)		10.85± 0.18	11.97±0.50	
	Conductivity (uS)		1417.5± 17.5		
	Temperature (C°)		n/a	n/a	
	Turbidity (mg/L)			76.9±0.3	
Sample # 4 Location (Head Waters of Crab Creek)	pH	7.82	8.77± 0.11	7.33±0.02	7.6±0.0
	Dissolved Oxygen (mg/L)	11.97	13.9± 0.04	6.12±0.07	9.5±0.7
	Conductivity (uS)	535.6	488± 6		
	Temperature (C°)	14.65	0	0	0
	Turbidity (mg/L)			10.9±0.5	3.3±1.2
Sample # 5 Location (Lake Audubon, Culvert Connecting East and West Lake)	pH	9.45		8.75±0.05	8.9±0.1
	Dissolved Oxygen (mg/L)	10.86		11.97±0.12	7.5±0.3
	Conductivity (uS)	908.9			
	Temperature (C°)	13.46	n/a	n/a	n/a
	Turbidity (mg/L)			6.23±0.26	6.1±0.5

* Data taken from Department of Ecology field study, referenced as HWY 231 and Audubon Lake (Joy, 2010).

7.5 Caffeine Sample Preparation

In order to consolidate and insure complete dissolution of organics within each sample, where caffeine contaminants would be seen, liquid-liquid extraction was performed for each sample. Liquid-liquid extraction operates in this instance by binding organic constituents to a volatile methyl chloride solution; which also being heavier than water separates into an extractable solution. The extracted solution can then be allowed to evaporate leaving the captured dissolved organics behind. Sample preparation was performed in Gonzaga University's unified laboratory with assistance from Ian Joslin, a laboratory assistant and student in the chemistry department. Following general guidelines for liquid-liquid extraction of caffeine described in *Introduction to Organic Laboratory Techniques: A Microscale Approach* the steps detailed in Appendix J performed (Pavia, Lampman, and et al 73-75).

7.6 Mass Spectrometry Analysis

Results from the liquid chromatography analysis (HPLC) were not possible due to mechanical failures (procedure for proposed method found in Appendix I), direct injection (demonstrated in Appendix J) into the Waters HPLC Mass Spectrometer (MS) was used as an alternative. The mass spectrometer provides a qualitative and quantitative analysis of sample constituent compounds through assessment of mass to charge ratio relative to overall abundance. With peaking instances of a particular molecular mass to charge ratio as the molecule passes the detector, for caffeine the ratio is 194, specific chemical compounds can be discerned from a sample. Running the caffeine standard solutions of prepared, through the mass spectrometer a calibration curve was created. Once identifying the specific mass to charge ratio of interest, the subsequent samples could be compared to the calibration curve for a concentration estimate for that sample time and location.

To insure samples were not contaminated between runs, a solution of 0.1% Acetonitrile was used to rinse the sampling syringe. Additionally, a rinse was run through the MS with the Acetonitrile to assure no remnants of previous samples remained.

7.7 Results of Caffeine Analysis

Plotting charge counts for each sample against the modified calibration curve provides an estimate for the concentration of caffeine in each sample in parts per billion (ppb). Respective charge counts are derived from spectrometer outputs at a mass/charge ratio of 196.03. The mass to charge ratio of 196.03 was selected as it was the descriptive peak in the standard solutions. The dissimilarity to a typical mass to charge ratio of 194 for caffeine could be explained by the protonation of caffeine during extraction or analysis due to pH changes. However, the documented protonation of caffeine during MS analysis finds the mass/charge ratio to be 195 in this scenario (Zhou, and Cook 961-966). Without a conclusive link to the identified spikes in the standard solutions and an accepted identifier for caffeine, the resulting concentrations derived for the samples will not be concluded upon. For documentation the MS direct results for the samples, blanks, and standards are displayed in Appendix K and the interpreted results with standard curves in Appendix L relative to the standard derived 196.03 mass/charge ratio.

7.8 Discussion

Comparing data derived from the mass spectrometric analysis of various samples in the Crab Creek watershed the appearance of connectivity based upon caffeine concentration could not be made. With spiked samples not demonstrating expected concentrations, even with the hypothetical protonation of caffeine, implications of losses during extraction or a lesser representation from mass spectrometry rather than a HPLC-MS configuration places the accuracy of sample data under scrutiny. As such a relationship connecting anthropogenic impacts with Crab Creek cannot be made with the data collected as verification of caffeine's presence was not verifiable. Future studies, however, could implement caffeine as an effective organic tracer in efforts to distinguish livestock fecal coliform inputs from possible human contamination.

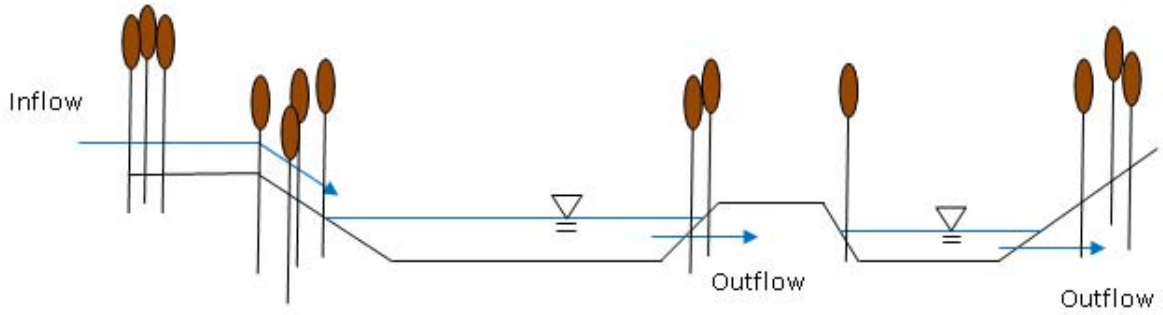
The efforts in the water quality assessment of the Crab Creek watershed provided a continuation to the more extensive water characterization provided by the Washington Department of Ecology (Ecology) study of 2010. The synopsis data compiled in Table 7.1 placing data points from the previous study with new data demonstrates a continuity of water characterization. The conclusions from the water assessment would then be in agreement with that of the previous Ecology study, that being that the observed water composition between the headwaters of Crab Creek and Lake Audubon are dissimilar (Joy, 2010).

8.0 Discussion of Additional Treatment Opportunities

8.1 Wetland

Lake Audubon is a natural wetland that has been created from effluent being discharged from the City of Reardan's WWTP. The wetland resembles that of a free water surface (FWS) that encompasses shallow water flowing over plant media. Figure 8.1 illustrates a FWS that represents a similar cross section of the Reardan site. Additionally, the natural wetland that surrounds Lake Audubon has similar characteristics of a constructed wetland. Studies have shown that the utilization and construction of wetlands have led to further treatment of effluent that has been discharged from WWTPs. The following section includes descriptions of natural processes that occur in constructed wetlands and their ability to remove contaminants, which may relate to the natural processes that takes place in the Reardan wetland. Thus, the Lake Audubon wetland may provide another possible treatment method once the effluent is discharged into the lake from Reardan's WWTP.

Figure 8.1 A cross section of Lake Audubon and surrounding wetland.



8.2 Natural Processes in Constructed Wetlands

Within constructed wetlands, physical, biological, and chemical processes break down contaminants and acts as another mechanism to treat effluent from WWTPs to improve water quality. Through biological processes, pollutants are removed by plant uptake, photodegredation, and microorganism uptake. By chemical processes, pollutants are removed through sorption, photo-oxidation, and volatilization. Sorption moves the pollutants atom charges from aqueous phases to solid phases. There are two categories of sorption that are experienced in wetlands: adsorption and precipitation. Adsorption includes the transferring of ions to soil particles while precipitation converts metals to insoluble forms. Photo-oxidation breaks down contaminants and oxidizes the compounds through sunlight and volatilization breaks down the compound and releases it into the air as a gaseous state (Norton).

8.3 Fecal Coliform Removal

One of the main parameters that affects Upper Crab Creek and is listed on the Section 303d list is fecal coliform. The following sections include literature researches of constructed wetlands that provide the design team with additional data to evaluate if there is a hydrological connection between Lake Audubon and Upper Crab Creek. This will allow the team to determine if the parameter fecal coliform affects Upper Crab Creek and if fecal coliform concentrations can be transported via surface water. The present NPDES permit limits the Reardan WWTP to discharge 50 cfu/100 mL monthly and 100 cfu/100 mL weekly of fecal coliform into Lake Audubon.

Studies of constructed wetlands compare concentrations of Total Suspended Solids, Dissolved Oxygen, fecal coliform, etc with each parameter's influent and effluent concentrations after passing through constructed wetlands. Constructed wetlands have been proven to be efficient means in reducing concentration levels of physical and chemical parameters (Hench, Bissonnette, Sexstone, etc.). There is no current data of the Lake Audubon wetland's ability to remove fecal coliform, but the Lake Audubon wetland will be modeled as a FWS/constructed wetland based on similar characteristics. The constructed wetland studies provide experimental data and results that can be compared to the natural wetland in Reardan.

8.4 Efficiency of Constructed Wetlands

As described in the previous sections, once fecal coliform is discharged into Lake Audubon, the natural wetland provides another treatment process through physical, biological, and chemical processes. The main process for removing fecal coliform within a constructed wetland is sedimentation through discrete and flocculent settling. Additionally, the root structure of plants in a wastewater wetland can also filter out fecal coliform. If further treatment took place in the natural wetland around Lake Audubon, then these two processes would most likely be the main treatment mechanisms.

In a constructed wetland, the wetland performance/efficiency in treating stormwater is generally a function of inflow, or hydraulic loading rate and detention time, which are functions of storm intensity, runoff volume, and wetland size (Birch, Fazeli, Suh). Seasons may also play a part in the efficiency of removing fecal coliform. In the *Reduction of fecal coliform levels in two created wetlands at the Olentangy River Wetland Research Park,* fecal coliform reduction was 1.5 to 2 times greater in June than in March. These differences may be due to plant coverage, temperature, and retention time of the ambient wetland. Summer months have a higher density of plant cover, which may lead to a greater ability of plants to filter out the contaminants and allow more time for sedimentation (Hinds Jr, Brown, Burns Jr)

Macrophytes, which include cattails, are rooted plants that anchor to the substrate media. The biomass of the plant slows the pathway of wastewater which in turn enhances sedimentation. The plants also uptake contaminants and the extensive root systems of these plants act as a filter. The roots also provide a surface for microorganisms to attach to where microorganisms break down pollutants (Sundaravadivel, M., and S. Vigneswaran). In constructed wetlands, cattails and bulrush are a popular aquatic plant to grow within the wetland. The Lake Audubon wetland has led to the growth of cattails and bulrush, which represents further treatment in the natural

wetland from plant uptake. These species of plants have the ability to withstand high pollutant concentrations and provide a high volume of biomass. In the *Fate of physical, chemical, and microbial contaminants in domestic wastewater following treatment by small constructed wetlands*, fecal coliform decreased in microbial densities from 8 log CFU/100 mL to 5.2 log CFU/100 mL after being discharged into a vegetated wetland system (Hench, Bissonnette, Sexstone, etc.).

Through physical, biological, and chemical processes, constructed wetlands, fecal coliform pollutants are removed at an efficiency of 70% and greater. In the *Reduction of fecal coliform levels in two created wetlands at the Olentangy River Wetland Research Park*, the study saw a monthly decrease in fecal coliform concentrations and an average removal efficiency of 80% and 72%, for wetland 1 and wetland 2, respectively (Hinds Jr, Brown, Burns Jr). Furthermore, in Removal Mechanisms in Constructed Wastewater Wetlands, the study saw removal efficiency in fecal coliform of 94% (Norton). The present NPDES permit limits the Reardan WWTP to discharge 50 cfu/100 mL monthly and 100 cfu/100 mL weekly of fecal coliform into Lake Audubon. So, if the removal efficiency of fecal coliform within constructed wetlands occurred in Lake Audubon, then these discharge limits would be greatly reduced from the natural wetland.

Figure 8.2 illustrates another opportunity for fecal coliform removal through physical, biological, and chemical processes from constructed wetlands. If the lake overflowed, then a possible overland flow along the flow path to Upper Crab Creek may occur. If possible due to high storm events, then further treatment will take place through contaminants flowing through vegetation, which will be similar to a biofiltration swale and depending on the soil conditions through infiltration.

These studies provide an estimate of the fecal coliform removal that may occur at t the natural wetland developed around Lake Audubon.

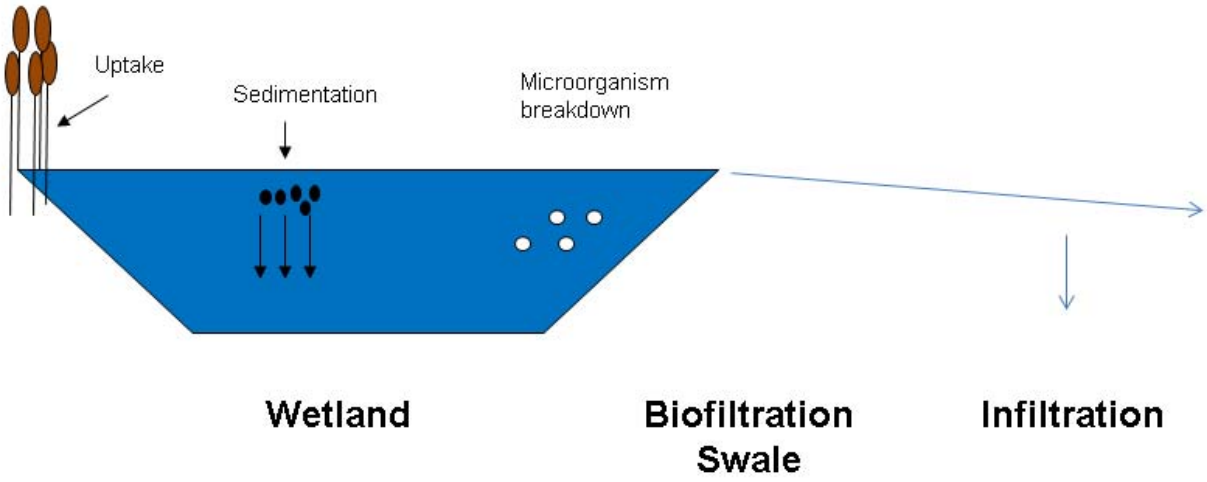


Figure 8.2 Possible Fecal Coliform removal process in the wetland and along the flow path

9.0 Soil Conditions

9.1 Hydric Soils

Hydric soils are soils that are "formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (NRCS). Under natural conditions, these soils are either saturated or inundated long enough during the growing season to support the growth and reproduction of hydrophytic vegetation.

To renew their National Pollutant Discharge Elimination System Permit, the City of Reardan must establish sufficient evidence that there is no hydrological connection between Lake Audubon and Upper Crab Creek. If evidence suggests that there is a connection, then the City of Reardan may have to limit their Wastewater Treatment Plant's discharge into Lake Audubon. This may lead Lake Audubon to dry up in the summer months since the effluent from the WWTP is a main source of water for the lake. If this takes place, then the wetland that has established at the site may be altered or destroyed. With this possibility, it is critical to understand the hydrological connection between Lake Audubon and Upper Crab Creek to determine the type of permits necessary when the current NPDES permit is renewed in 2015.

To be considered a wetland, there are three essential characteristics that must be identified: hydrophytic vegetation, hydric soils, and wetland hydrology. Hydric soils are usually the most obvious and attainable indicator of categorizing a wetland. So, to classify if the immediate area around Lake Audubon had hydric soils, the design team performed a hydric soils test. The Alpha-Alpha-Dipyridyl test determines if there is any presence of ferrous iron (Fe++) in the soils. If there is any indication of reducing conditions due to Fe oxidizing, then the soil should show a bright pink or red color when the Alpha-alpha-Dipyridyl solution is dropped on the soil. The design team unearthed soil around the lake's edge and dropped the Alpha-alpha-Dipyridyl solution on the soil. There was a small change of the soil color at first, but after vinegar was applied to the soil a distinct rust color appeared indicating ferrous iron was tied up by the carbonate. Therefore, one of the wetland's characteristics, hydric soils, was satisfied. This test procedure is approved by the Natural Resources Conservation Service.

To further the design team's determination of hydric soils and characterization of a wetland, Web Soil Survey depicted that hydric soils were present. An Area of Interest was constructed through Web Soil Survey for the immediate area around Lake Audubon. Of 1190 acres of the Area of Interest, 64.8% of the area's soils were partially hydric.

Determining that hydric soils were present within the Lake Audubon wetland, the design team was able to conclude that the soils have a very low permeability rate and a groundwater connection between Lake Audubon and Upper Crab Creek is less likely due to infiltration being low. This is illustrated in Mass Water Balance section, where a calculated infiltration rate of 0.071 in/day was determined.

9.2 Soil Characteristics

The following sections include characteristics of soils that were determined through the utilization of Web Soil Survey. The team had an Area of Interest of 1190 acres that included the surrounding area of Lake Audubon. This is illustrated in Figure 9.1 and includes the soil names in the Area of Interest. The potential flow path area that may develop from an overflow of Lake Audubon is depicted in Figure 9.1. In Table 9.1, the potential flow path includes soils 26 and 79, Cocolalla silt loam and Tucnnon-Rock outcrop, respectively. The report includes the soil's properties and qualities including its infiltration ability, drainage qualities, and the soil's attributes of an expected value of its depth to the water table, possible restrictive layers, and ability to flood. Web Soil determines these characteristics based on the general attributes of each soil.

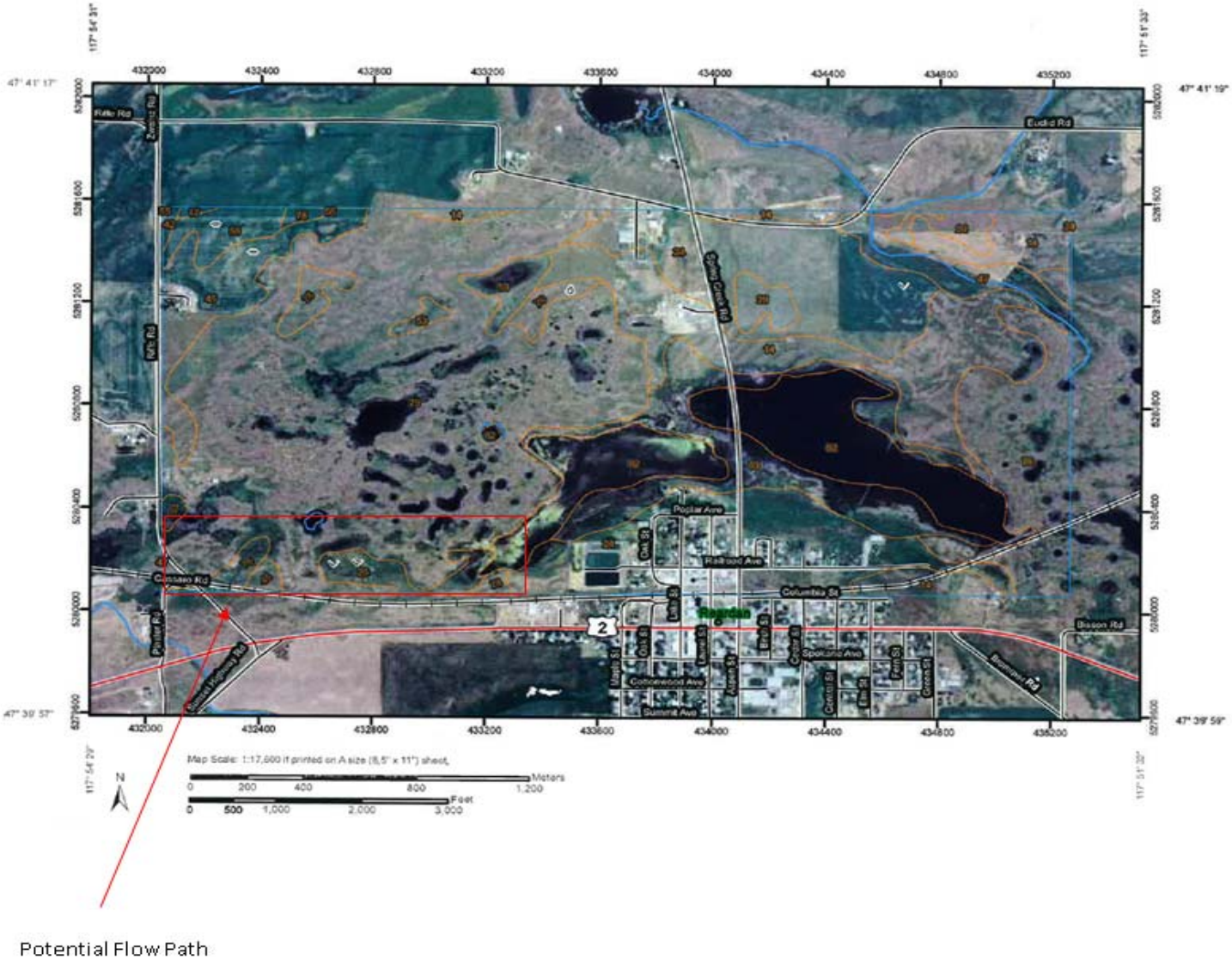


Figure 9.1 Soil Map and Potential Flow Path (Web Soil Survey)

Table 9.1 Soil Description (Web Soil Survey)

Map Unit Legend

Lincoln County, Washington (WA043)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
14	Benco cobbly silt loam, 0 to 7 percent slopes	138.5	11.6%
17	Broadax silt loam, 7 to 25 percent slopes	0.9	0.1%
24	Cheney silt loam, 0 to 5 percent slopes	213.9	18.0%
26	Cocolalla silt loam, drained	14.5	1.2%
29	Dragoon silt loam, 7 to 25 percent slopes	9.2	0.8%
42	Hanning silt loam, 7 to 25 percent slopes	1.4	0.1%
45	Kuhl cobbly silt loam, 0 to 15 percent slopes	44.2	3.7%
47	Mondovi silt loam	24.8	2.1%
53	Pedigo silt loam	96.2	8.1%
55	Reardan silt loam, 0 to 7 percent slopes	0.1	0.0%
56	Reardan silt loam, 7 to 25 percent slopes	14.3	1.2%
78	Tucannon silt loam, 0 to 5 percent slopes	25.8	2.2%
79	Tucannon-Rock outcrop complex, 0 to 15 percent slopes	494.5	41.6%
82	Water	111.7	9.4%
Totals for Area of Interest		**1,189.9**	**100.0%**

Table 9.2 depicts the soil attributes of the soils encompassing the possible flow path if water overflowed Lake Audubon. A further description of each characteristic is described in Appendix H.

Table 9.2 Soil Characteristics

Map Unit Symbol	26	79
Soil Name	Cocolalla Silt Loam	Tucannon-Rock Outcrop
Infiltration Rate	Low	Low
Drainage Class	Poorly Drained	Well Drained
Depth to Any Restrictive Layer (in)	Unknown	29.9

9.3 Soil Analysis

Based on the soil attributes determined through Web Soil Survey, the soils in the possible flow path from Lake Audubon and Upper Crab Creek present more evidence for determining a hydrological connection. Since the attributes of the soils determined by Web Soil Survey are assumptions and include characteristics of soils that are not protected by vegetation, the qualities may not be accurate and are more of a representation. With the presence of vegetation in the possible flow path, the rate of runoff and infiltration will most likely decrease due to plant uptake and the plant's biomass. Furthermore, the flooding ability of the soils will increase based on the decrease of runoff and infiltration rates and water will most likely pond in depressions that were observed on site visits. Therefore, there is a low chance of a hydrological connection between Lake Audubon and Upper Crab Creek if water was able to flow over Lake Audubon's natural spillway and travels into the possible flow path.

10.0 Conclusion

The objective of this project was to determine whether an overland connection between Lake Audubon, a receiver of treated municipal waste water, and the head waters of Crab Creek is a probable event. Further considerations in the study were made to incorporate the plausibility of infiltration into groundwater from Lake Audubon, characteristics of ambient treatment and attenuation in the modeled storm events, and a study of select water quality parameters within the Crab Creek watershed The project follows a similar study of connectivity between the two water bodies, conducted by the Washington Department of Ecology in 2009-2010. The results of that study discerned no continuity between the two water bodies, and from this conclusion this project compared and verified our findings.

The Lake Audubon HEC-HMS Model shows no surface overflow from Lake Audubon's spillway for all modeled storm events. It was determined that a storm event of almost twice the magnitude of the 24 hour 500 year event or compounded storm events would need to occur to cause an overflow from Lake Audubon, which is highly improbable. Additionally, this large storm event would cause a rise in stage of the lake east of Audubon exceeding the elevation of the center line of Highway 231, which has only been reported once or twice by a Reardan resident.

Through the implementation of a mass water balance for Lake Audubon, a low infiltration rate of 0.71 in/day was determined. This illustrates that a groundwater connection is low and this is furthered emphasized through the determination of hydric soils in the wetland. Hydric soils have the characteristic of having a soil layer that has a low permeability rate. This has provided the design team with a determination of a low probability of groundwater connection.

Using select water quality parameters as continuation of the previous and more extensive study of chemical composition of Lake Audubon and Crab Creek, this and the previous assessment found no similarities that would indicate connectivity. A further study of caffeine, an organic and anthropogenic specific tracer chemical, was conducted in attempt to discern whether human impacts exist at all in Crab Creek. Although mechanical failures and non-descriptive results yielded no conclusions to this end, it is the recommendation of this project team for further study of caffeine or other anthropogenic tracers within Crab Creek. Further study could provide an indicator of whether human waste products, as opposed to agricultural, can be attributed to the degradation of Crab Creek.

To further prove that there is little to no hydrological connection via surface water, Web Soil Survey determined soil characteristics of soils that are in the possible flow path’s area. Through observations from site visits and Web Soil Survey’s soil characteristics, if water reached the possible flow path due to a high storm event, then water would be stored in many depressions of the scabland west of Lake Audubon.

11.0 Project Schedule

The project schedule can be seen below in Table 11.1

Table 11.1 Project Schedule

Task Name	Duration	Start	Finish
Projects Announced	1 day	Wed 8/31/11	Wed 8/31/11
Teams Selected	1 day	Fri 9/2/11	Fri 9/2/11
CEDE General Meeting	1 day	Wed 9/14/11	Wed 9/14/11
Project Management	**7 days**	**Wed 9/14/11**	**Thu 9/22/11**
Determine Scope	1 day	Wed 9/14/11	Wed 9/14/11
GANTT Chart	1 day	Thu 9/15/11	Thu 9/15/11
Organizing Activities	1 day	Fri 9/16/11	Fri 9/16/11
Determine Milestones	1 day	Mon 9/19/11	Mon 9/19/11
Brainstorm Possible Solutions	1 day	Tue 9/20/11	Tue 9/20/11

Preliminary Site Visit	1 day	Thu 9/15/11	Thu 9/15/11
Weekly Meeting	1 day	Wed 9/21/11	Wed 9/21/11
Meeting with Department of Ecology	1 day	Thu 9/22/11	Thu 9/22/11
Proposal Activiites	7 days	Thu 9/22/11	Fri 9/30/11
Weekly Meeting	1 day	Wed 9/28/11	Wed 9/28/11
Proposal Due	1 day	Fri 9/30/11	Fri 9/30/11
Weekly Meeting	1 day	Wed 10/5/11	Wed 10/5/11
Literature Research	**7 days**	**Wed 10/5/11**	**Thu 10/13/11**
Case Studies	2 days	Thu 10/6/11	Fri 10/7/11
Tracer Research	2 days	Mon 10/10/11	Tue 10/11/11
Weekly Meeting	1 day	Wed 10/12/11	Wed 10/12/11
Project Data Collection	**7 days**	**Mon 10/17/11**	**Tue 10/25/11**
Surveying and Data Collection	1 day	Mon 10/17/11	Mon 10/17/11

Tabulation of Data	1 day	Tue 10/18/11	Tue 10/18/11
Analysis of Data	2 days	Wed 10/19/11	Thu 10/20/11
Description of Data Collection	2 days	Thu 10/20/11	Fri 10/21/11
Summary of Data Collection	2 days	Mon 10/24/11	Tue 10/25/11
Weekly Meeting	1 day	Wed 10/19/11	Wed 10/19/11
Permitting Analysis	**5 days**	**Mon 10/24/11**	**Fri 10/28/11**
Literature Search	3 days	Mon 10/24/11	Wed 10/26/11
Researching NPDES Permit	1 day	Thu 10/27/11	Thu 10/27/11
Permit Flow Chart	1 day	Fri 10/28/11	Fri 10/28/11
Weekly Meeting	1 day	Wed 10/26/11	Wed 10/26/11
30% Roundtable	1 day	Fri 10/28/11	Fri 10/28/11
Data Analysis	**14 days**	**Fri 10/28/11**	**Wed 11/16/11**

Water Quality Analysis	4 days	Mon 10/31/11	Thu 11/3/11
Surveying Analysis	4 days	Tue 11/1/11	Fri 11/4/11
Acquiring of Topographic Map	3 days	Mon 11/7/11	Wed 11/9/11
Developing Surveyed Points into AutoCAD	4 days	Thu 11/10/11	Tue 11/15/11
Weekly Meeting	1 day	Wed 11/2/11	Wed 11/2/11
Weekly Meeting	1 day	Wed 11/9/11	Wed 11/9/11
Meeting with Department of Ecology	1 day	Tue 11/8/11	Tue 11/8/11
Meeting with City of Reardan	1 day	Thu 11/10/11	Thu 11/10/11
Weekly Meeting	1 day	Wed 11/16/11	Wed 11/16/11
50% Report Activities	**16 days**	**Wed 11/16/11**	**Wed 12/7/11**
QAAP Developed	10 days	Wed 11/16/11	Tue 11/29/11

Powerpoint Developed	2 days	Mon 12/5/11	Tue 12/6/11
Weekly Meeting	1 day	Wed 11/23/11	Wed 11/23/11
Weekly Meeting	1 day	Wed 11/30/11	Wed 11/30/11
50% Presentation	1 day	Wed 12/7/11	Wed 12/7/11
50% Report Due	1 day	Fri 12/9/11	Fri 12/9/11
Hydrologic Modeling	**29 days**	**Fri 1/20/12**	**Wed 2/29/12**
Determing Input Variables	6 days	Fri 1/20/12	Fri 1/27/12
Testing Model	6 days	Fri 1/27/12	Fri 2/3/12
Inputing Determined Models	4 days	Wed 2/15/12	Mon 2/20/12
Weekly Meeting	1 day	Wed 1/25/12	Wed 1/25/12
Meeting with Ecology	1 day	Fri 1/27/12	Fri 1/27/12
Combining of Topographic Maps	7 days	Mon 1/30/12	Tue 2/7/12

Weekly Meeting	1 day	Wed 2/1/12	Wed 2/1/12
Water Chemistry Collection and Research	**18 days**	**Wed 2/1/12**	**Fri 2/24/12**
Caffeine Research	4 days	Wed 2/1/12	Mon 2/6/12
Acquistion of Lab Equipment	5 days	Wed 2/8/12	Tue 2/14/12
Site Visit for Additional Testing	1 day	Fri 2/24/12	Fri 2/24/12
Delineation	**5 days**	**Wed 2/8/12**	**Tue 2/14/12**
Calculating Slopes, Areas, and Channel Length	2 days	Mon 2/13/12	Tue 2/14/12
Weekly Meeting	1 day	Wed 2/8/12	Wed 2/8/12
Site Visit	1 day	Mon 2/13/12	Mon 2/13/12
Weekly Meeting	1 day	Wed 2/15/12	Wed 2/15/12
Soil Research	**7 days**	**Wed 2/15/12**	**Thu 2/23/12**
Well Logs	2 days	Wed 2/15/12	Thu 2/16/12

Soil Determination around Reardan	2 days	Fri 2/17/12	Mon 2/20/12
Research of Soil Characteristics	3 days	Tue 2/21/12	Thu 2/23/12
Water Mass Balance	**22 days**	**Wed 2/15/12**	**Thu 3/15/12**
Evapotranspiration rate	13 days	Mon 3/19/12	Wed 4/4/12
Find Precipitation Rate Data	7 days	Mon 3/19/12	Tue 3/27/12
Find Change in Volume of Lake	11 days	Mon 3/19/12	Sat 3/31/12
Determine Volume of Lake	11 days	Mon 3/19/12	Sat 3/31/12
Run Equation	5 days	Wed 3/28/12	Tue 4/3/12
Site Visit Caffeine Sampling and Testing	**1 day**	**Wed 3/28/12**	**Wed 3/28/12**
HPLC training	4 days	Wed 3/28/12	Sat 3/31/12

Caffine testing	24 days	Wed 3/28/12	Sat 4/28/12
Determining Lake Depths	1 day	Wed 3/28/12	Wed 3/28/12
Finishing Project	**44 days**	**Tue 3/6/12**	**Fri 5/4/12**
Writing Report	39 days	Tue 3/6/12	Fri 4/27/12
Preparing Presentation	34 days	Tue 4/10/12	Fri 5/25/12
Practice Presentation	1 day	Thu 5/3/12	Thu 5/3/12
Final Presentation	1 day	Fri 5/4/12	Fri 5/4/12

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Appendix A

Table A.1 Lake Bed Survey Points

Point Number	Northing	Easting	Depth to Lake Bed (ft)	Elevation of Lake Bed (ft)
1	258999.4	2365907	4.3	2467
2	259156.3	2365906	5.4	2465.9
3	259339.6	2365926	5.3	2466
4	259624.9	2366108	5.7	2465.6
5	259613	2366193	5.4	2465.9
6	259569.1	2366310	4.2	2467.1
7	259395.3	2366258	3.5	2467.8
8	259391.7	2366252	3.4	2467.9
9	258875.9	2365903	4.4	2466.9

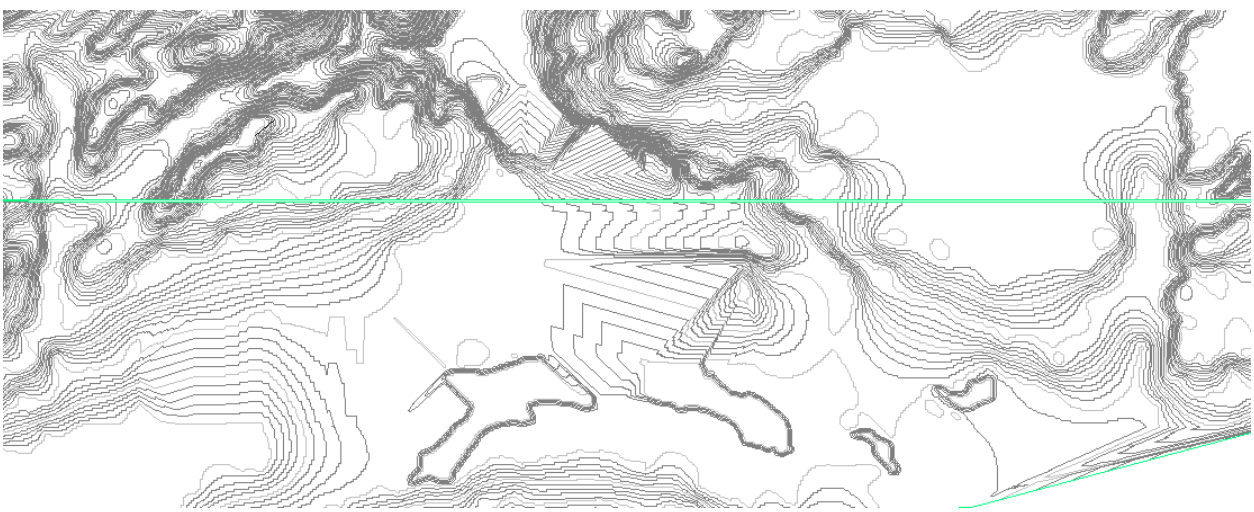
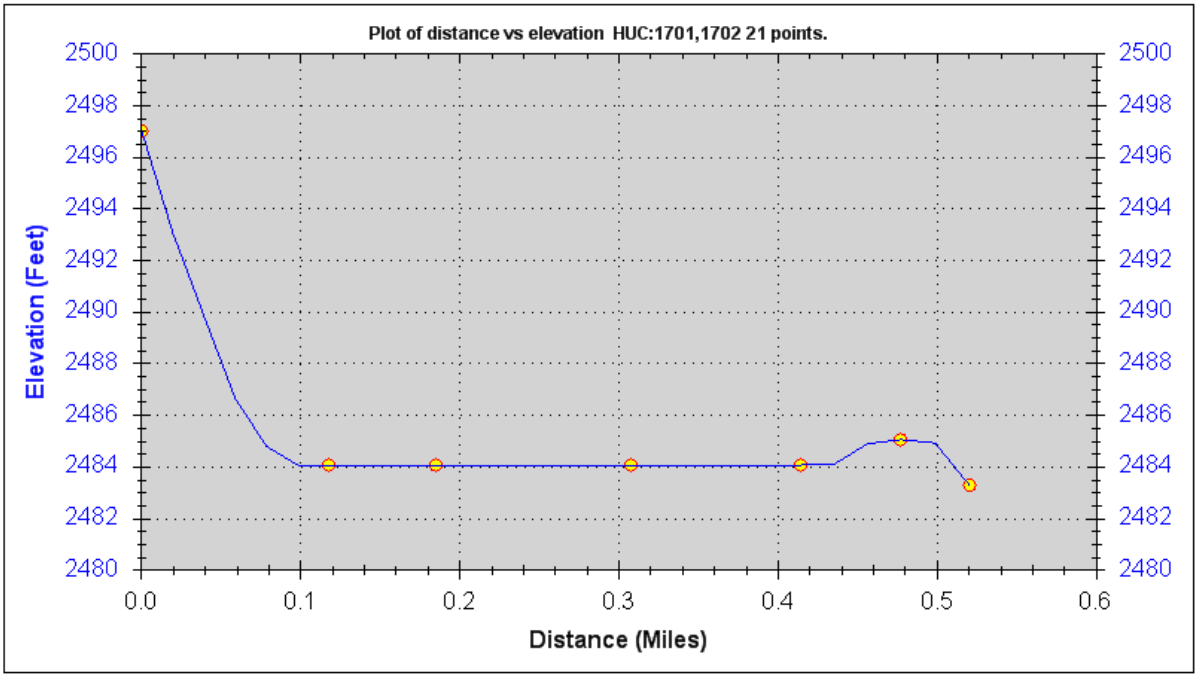


Figure A.1 Elevation Map

Appendix B



S	Z	X	Y	UserPoint
0	2497.038	633231.81	743128.74	True
0.02	2493.068	633251.91	743104.4	False
0.04	2489.852	633272.02	743080.06	False
0.06	2486.67	633292.13	743055.71	False
0.08	2484.8	633312.24	743031.37	False
0.1	2484.078	633332.35	743007.03	False
0.12	2484.078	633352.46	742982.69	True

Figure B.1 Streamstats for Sub-Basin 1

Appendix C
NRCS TR55 – Table 2-2c

Table 2-2c Runoff curve numbers for other agricultural lands [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.
2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
4 Actual curve number is less than 30; use CN = 30 for runoff computations.
5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Watercourse slope to Velocity (NRCS TR-55)

Figure 3-1 Average velocities for estimating travel time for shallow concentrated flow

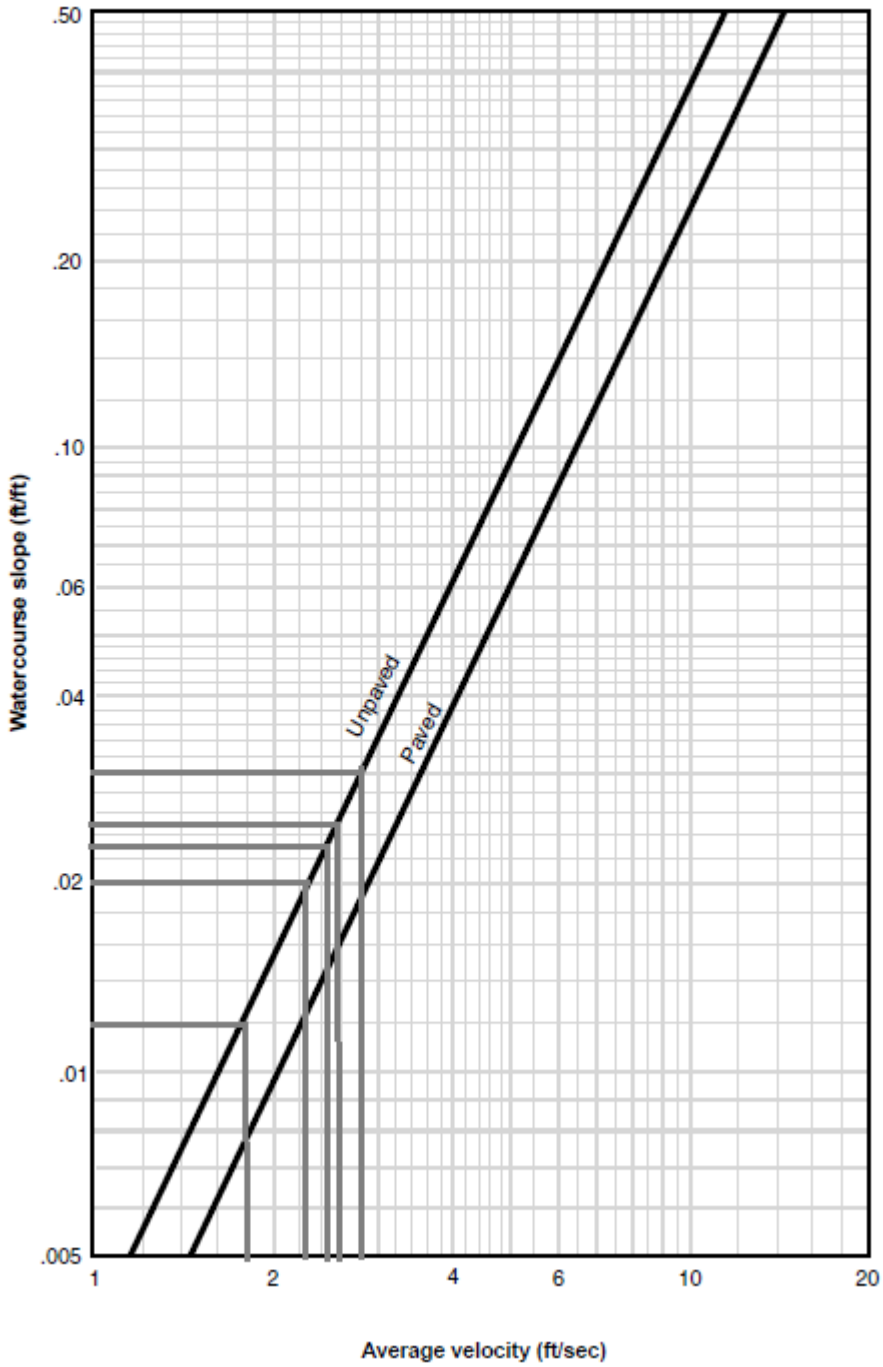


Table 3-1 Roughness coefficients (Manning's n) for sheet flow

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

[1] The n values are a composite of information compiled by Engman (1986).

[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

[3] When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Roughness Coefficients (NRCS TR-55

Area (acres) 299

Overland Flow (300ft) + Shallow Concentrated Flow

length 1 (ft)	1644.5	n	p2	L1	s	L2	V1
slope 1	-2.30%	0.05	1.2	300	0.023	1344	2.4

Shallow Concentrated Flow

length 2 (ft)	589	L3	V2
slope 2	-2.50%	589	2.6

Shallow Concentrated Flow

length 3 (ft)	750.8	L4	V3
slope 3	-3.00%	750.8	2.8

Shallow Concentrated Flow

length 4 (ft)	3724	L5	V4
slope 4	-0.20%	3724	2.2

Tt1 =	0.252168
Tt2=	0.155556
Tt3=	0.062927
Tt4=	0.074484
Tt5=	0.470202

Sum Tt=	1.015337	
in min	60.9202	
60%	36.55212	min

Sub-basin 2

Area (acres) 67

Overland Flow (300ft) + Shallow Concentrated Flow

length 1 (ft)	1045	n	p2	L1	s	L2	V1
slope 1	-2.10%	0.05	1.2	300	0.021	745	2.21

Tt1=	0.2615127
Tt2=	0.09364

sum Tt=	0.355153	
in min	21.30916	
60%	12.7855	min

Sub-Basin 3

Area (acres) 102.5

Overland Flow (300ft) + Shallow Concentrated Flow

length 1 (ft)	2439	n	p2	L1	s	L2	V1
slope 1	-1.20%	0.05	1.2	300	0.012	2139	1.8

Tf=	0.3271206
Tf=	0.3300926

sum Tf=	0.657213	
in min	39.43279	
60%	23.65968	min

Table C1Curve Number Calculations

Sub-basin #1			
CN	% of land type		Proportional CN
78	66%		51.48
70	20%		13.65
86	2%		1.29
60	1%		0.66
89	6%		4.984
100	6%		6.3
		CCN=	78.364

Sub-basin #2			
CN	% of land type		Proportional CN
65	18%		11.83
60	2%		1.32
83	11%		9.379
80	54%		42.88
100	15%		14.7
		CCN=	80.109

Sub-basin #3			
CN	% of land type		Proportional CN
64	16%		10.112
50	43%		21.45
66	5%		3.3
79	4%		3.239
84	12%		9.744
100	21%		20.6
		CCN=	68.445

*Curve Numbers of 100 represent water bodies

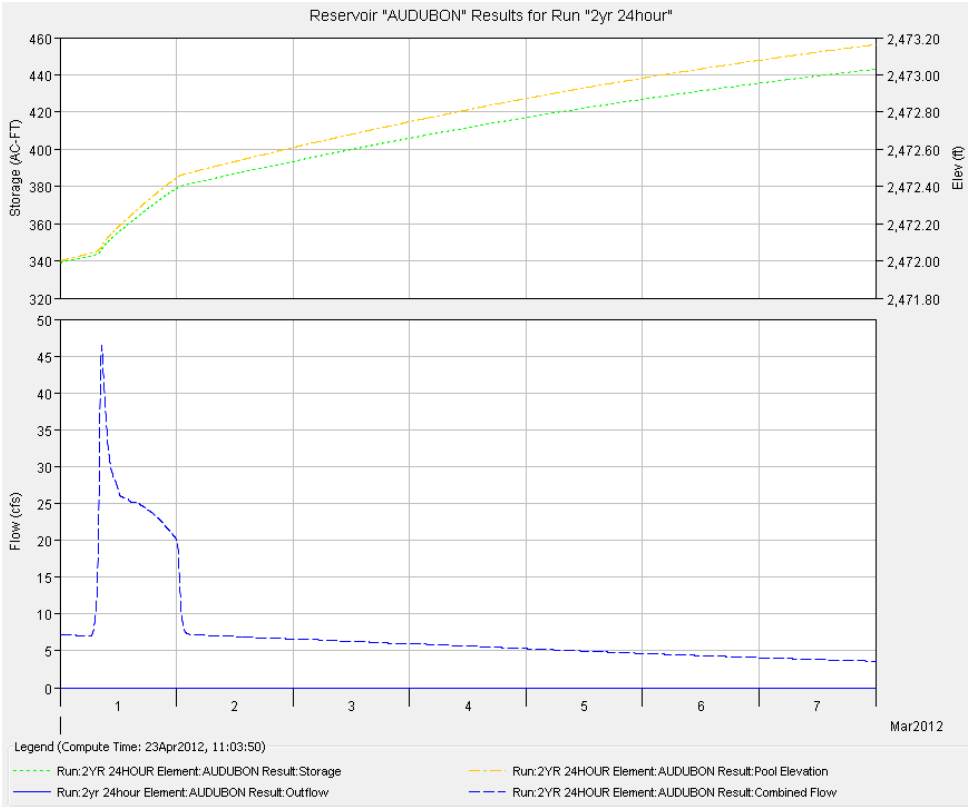


Figure C.1 2 Year Storage v Time & Flow v Time Curves

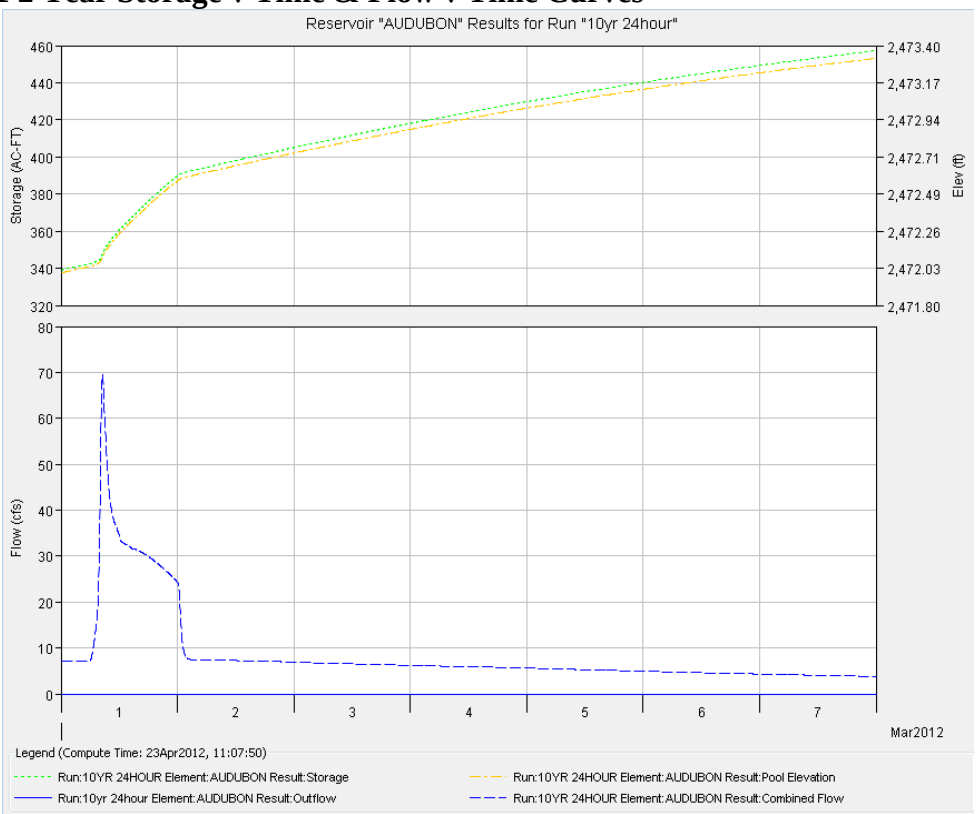


Figure C.2 10 Year Storage v Time & Flow v Time Curves

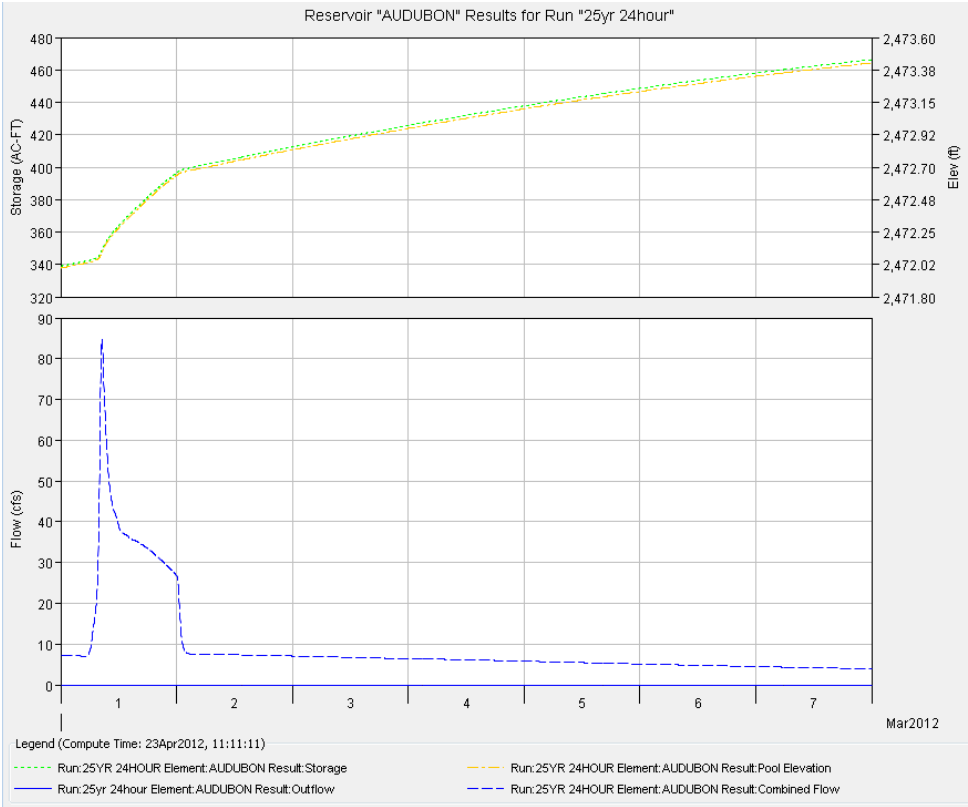


Figure C.3 Year Storage v Time & Flow v Time Curves

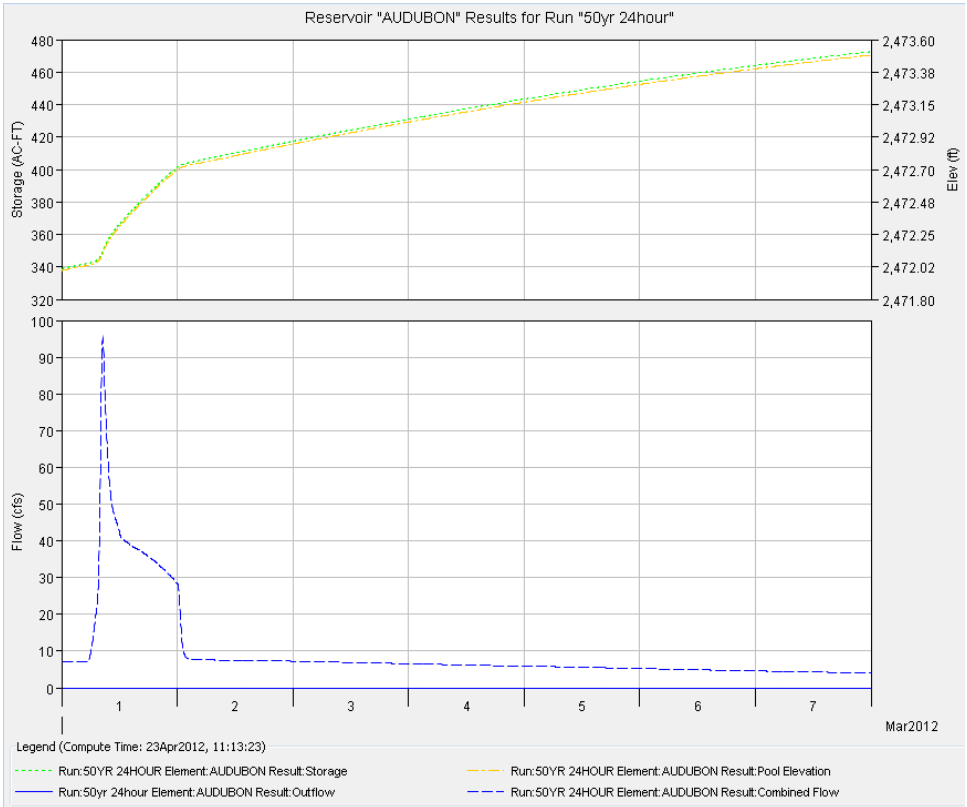


Figure C.4 50 Year Storage v Time & Flow v Time Curves

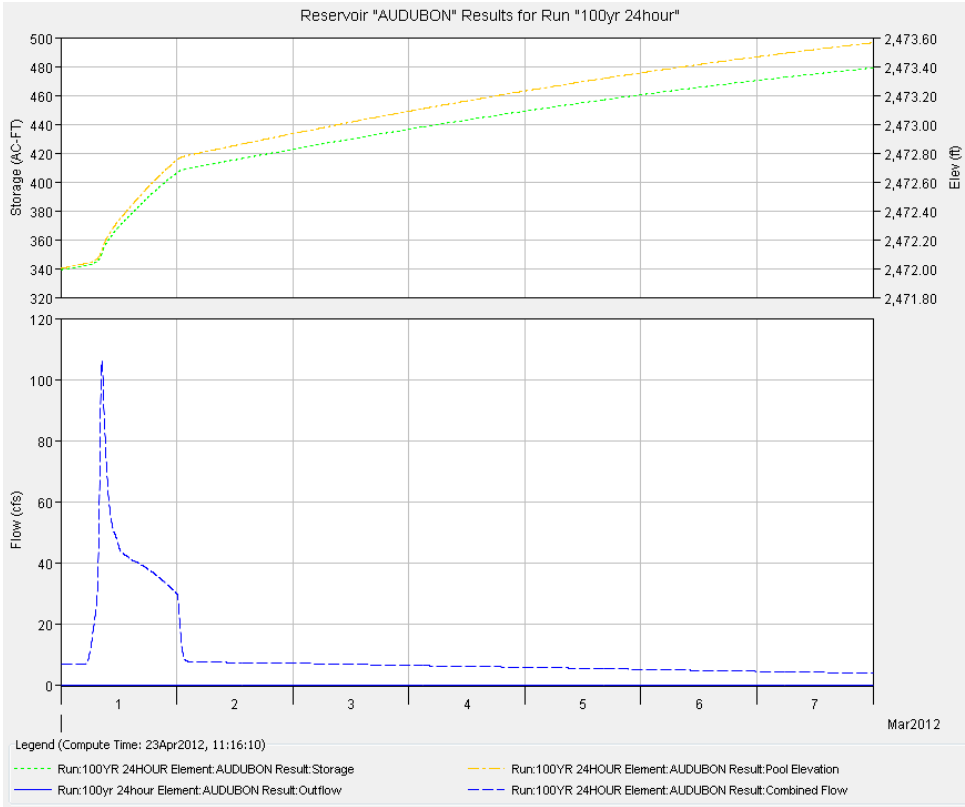


Figure C.5 100 Year Storage v Time & Flow v Time Curves

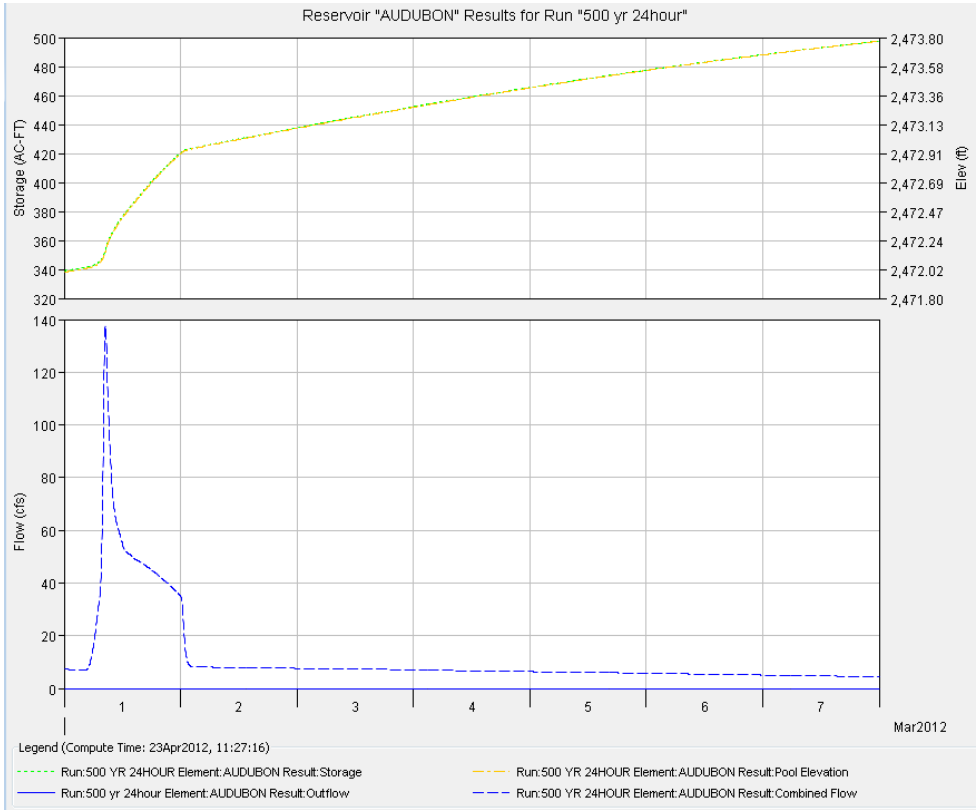


Figure C.6 500 Year Storage v Time & Flow v Storage Curves

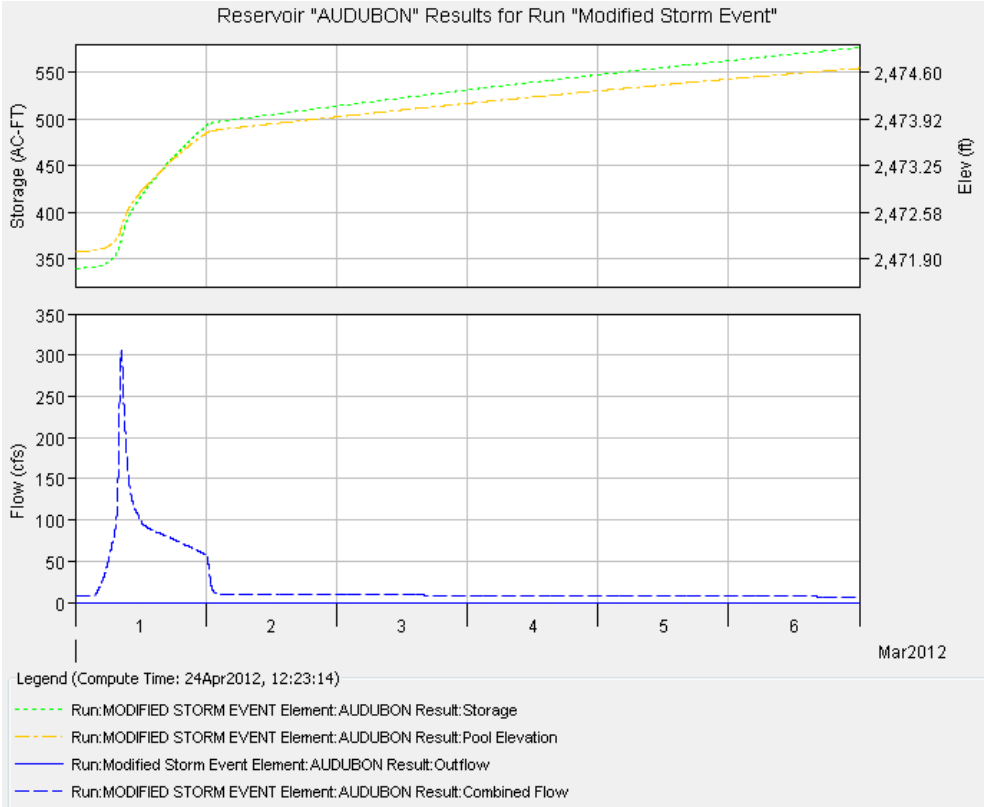

Reservoir "AUDUBON" Results for Run "Modified Storm Event"
Storage (AC-FT)
550
500
450
400
350
2,474.60
2,473.92
2,473.25
2,472.58
2,471.90
Elev (ft)
Flow (cfs)
350
300
250
200
150
100
50
0
1
2
3
4
5
6
Mar2012
Legend (Compute Time: 24Apr2012, 12:23:14)
Run:MODIFIED STORM EVENT Element:AUDUBON Result:Storage
Run:MODIFIED STORM EVENT Element:AUDUBON Result:Pool Elevation
Run:Modified Storm Event Element:AUDUBON Result:Outflow
Run:MODIFIED STORM EVENT Element:AUDUBON Result:Combined Flow

Figure C.7 .1

Appendix D

Figure D.1- FAO Penman-Monteith Equation and Variables

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

ETo reference evapotranspiration [mm day-1],
Rn net radiation at the crop surface [MJ m-2 day-1],
G soil heat flux density [MJ m-2 day-1],
T mean daily air temperature at 2 m height [°C],
u2 wind speed at 2 m height [m s-1],
es saturation vapour pressure [kPa],
ea actual vapour pressure [kPa],
es - ea saturation vapour pressure deficit [kPa],
D slope vapour pressure curve [kPa °C-1],
g psychrometric constant [kPa °C-1].

Table D.1 Reference Evapotranspiration Rates (Et_o) by Month for Lake Audubon.

	Et_o (in/month)	**Et_o (in/day)**
January	0.00	0.00
February	0.00	0.00
March	17.36	0.56
April	43.24	1.44
May	72.67	2.34
June	82.65	2.75
July	84.51	2.73
August	74.46	2.40
September	52.11	1.74
October	24.62	0.79
November	0.00	0.00
December	0.00	0.00

Table D.2 Detailed Calculations of Infiltration Rate by Month For the Period of October 18th, 2011 to March 28th, 2012.

Month	**$Q_{infiltration}$**	**PxA (ft^3)**	**Qc (ft^3)**	**Qi (ft^3)**	**(ETxA) (ft^3)**	**ExA (ft^3)**	**dV/Dt (ft^3)**
Oct (18th-31st)	-205265.17	26239.62	0.00	314626.29	0.00	249252.54	296878.54
Nov	71749.13	195604.44	34848.00	726060.67	0.00	199659.65	685104.33
Dec	197045.48	200375.28	39204.00	750262.69	0.00	84855.35	707941.14
Jan	344071.90	264781.62	139827.60	726060.67	0.00	101493.66	685104.33
Feb	238855.31	257625.36	126324.00	701858.65	0.00	184685.18	662267.52
Mar (1st-28th)	2112331.99	691771.80	1724976.00	677656.63	0.00	342641.73	639430.71
Total infiltration (ft^3)	2758788.64						
Infiltration (in/day)	0.071						

Appendix E

In addition to the procedures outlined in the quality assurance project plan the following changes were made in equipment used in field measurements with corresponding operation and calibration. General field equipment listed below with added equipment and calibration tabulated in Table E1.

General Equipment:

- HACH Field Turbidimeter
- 4 1-L Sampling Containers
- 2 gal Distilled Water/Deionized Water

Table E1. Water Quality Parameters, Equipment Model, Manufacturer, and Resolution

Parameter	Equipment	Manufacturer	Resolution
Turbidity	Field Turbidimeter	HACH	0.01 NTU

Sampling Procedures

Turbidity

Calibration: Prior to sampling the HACH field turbidity meter was calibrated by Gonzaga University's environmental lab technician. Calibration of the field turbidity meter maintains accuracy for a one month period following calibration. Field samples were evaluated within this period. Important in the sampling procedure is to ensure clean glassware so as to not provide additions impediments to analysis (glass impairments would increase turbidity reading, providing falsely high turbidity values).

Measurement: Sampling from each location multiple trials, demonstrative samples of each water body will be analyzed with the HACH field turbidity meter, values will be provided in NTU's or Nephelometric Turbidity Units.

Appendix F: Pictures of Sampling Locations (11-12-2011)

Figure F1. Discharge from WWTP, lower right left of path

Figure F2. East Lake Audubon, samples taken

Figure F3. Pond, West of Lake Audubon head waters

Figure F4. Crab Creek, just downstream from

Appendix G: Pictures of Sampling Locations (2-24-2012)

Figure G1. Lake Audubon Equalizing Culvert (Submerged)

Figure G2. Crab Creek headwaters.

Appendix H: Raw Data from Field Water Quality Assessment

Table H1. November 12, 2012 morning sampling

	Sample # 1 Location (WWTP Effluent)			**Sample # 2 Location (Lake Audubon, East of HWY 231)**				**Sample # 3 Location (Pond, West Side Audubon Lake)**				**Sample # 4 Location (Head Waters of Crab Creek)**			
Parameter	Trial #1	Trial #2	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation
pH	7.99	7.98	7.99±0.01	9.2	8.7	9.2	9.03±0.24	8.8	8.7		8.75± 0.05	8.62	8.87	8.82	8.77± 0.11
Dissolved Oxygen (mg/L)	9.64	9.36	9.5±0.14	11.6	11.35	11.55	11.5±0.11	10.75	11.1	10.7	10.85± 0.18	13.86	13.9		13.9± 0.04
Conductivity (uS)	992	976	984±8	4350	4230	4240	4237.3±54.4	1435	1400		1417.5± 17.5	494	482		488± 6
Temperature (C°)															
Turbidity (mg/L)	448	438	443±5	2175	2115	2120	2136.7±27.2	718	700		709± 9	297	291		294± 3

Table H2: February 24, 2012 Grab Samples:
A.M. Collection Run (9:15-11:00) - Overcast and Windy, mid-40's

	Sample # 1 Location (WWTP Effluent)				**Sample # 5 Location (Lake Audubon, Culvert Connecting East and West Lake)**				**Sample # 3 Location (Pond, West Side Audubon Lake)**				**Sample # 4 Location (Head Waters of Crab Creek)**			
Parameter	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation
pH	7.7	8.15	7.8	7.93±0.23	8.7	8.8		8.75±0.05	7.6	7.8		7.7±0.1	7.31	7.35		7.33±0.02
Dissolved Oxygen (mg/L)	10.7	10.5	9.5	10.6±0.1	11.8	12	12.1	11.97±0.12	12.5	12.1	11.3	11.97±0.50	6.03	6.18	6.16	6.12±0.07
Temperature (C°)																
Turbidity (mg/L)	16.3	12	8.2	14.2±2.2	6	6.6	6.1	6.23±0.26	76.6	77.1		76.9±0.3	11.3	10.4		10.9±0.5

Table H3. February 24, 2012 Grab Samples:
P.M. Collection Run (3:20-5:00) – Sun emerging and Windy, mid-40's

	Sample # 5 Location (Lake Audubon, Culvert Connecting East and West Lake)				**Sample # 4 Location (Head Waters of Crab Creek)**				**Sample #6 Location (Lower Crab Creek, Detour Road)**			
Parameter	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation	Trial #1	Trial #2	Trial #3	Mean ± standard deviation
pH	8.8	8.9	8.9	8.9±0.1	7.6	7.6		7.6±0.0	8.3	8.15	8	8.2±0.1
Dissolved Oxygen (mg/L)	7.2	7.8	6.9	7.5±0.3	8.6	9.8	10.1	9.5±0.7	9.9	11.6	10.6	10.7±0.7
Temperature (C°)												
Turbidity (mg/L)	6.6	5.6	5.5	6.1±0.5	4.4	2.1		3.3±1.2	4.1	8	3.8	5.3±1.9

Appendix I

High-Performance Liquid Chromatography (HPLC)
General procedures for collecting samples will follow guidance in field sampling from the Environmental Protection Agency (EPA) for surface waters ("Surface Water Sampling"). Following sampling HPLC analysis will be performed in relation to EPA Method 553. The application of an HPLC analysis for caffeine that is presented in EPA Method 553 where the methods for assessing benzidines and nitrogen containing pesticides is explicit in the translatability to caffeine monitoring (Behymer, Bellar, et al). The process implements a liquid-liquid extraction and HPLC to mass spectrometric analysis to quantify contaminant concentrations.

Procedure Synopsis:

- Two 1L samples will be taken from each sampling location for analysis.
- Samples will be filtered on site with 0.45μm Millipore filters with an induced pressure gradient from a Geotech hand pump.
- Using a reverse-phase chromatography column on Gonzaga University's HPLC apparatus with a UV-VIS detector, an external standard from known concentrations of caffeine was utilized to develop a calibration curve.
- Once calibrated, samples from each site were injected into the HPLC. Chromatograph output provides absorption to wavelength curves which, if caffeine is present, resembles the calibration output from standard solutions. Figure I2 below demonstrates the typical chromatograph output for caffeine absorbance. Indicators for caffeine peaking at 225 and 273 nm (Northridge: California State University).
- Concentration can then be extrapolated and resulting data from the various samples can provide insight into the possibility and nature of anthropogenic contamination within the Crab Creek watershed.

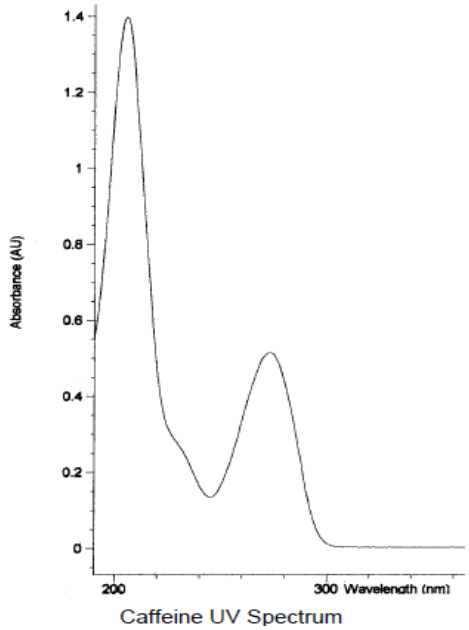


Figure I1. Caffeine Chromatogram. UV absorption vs. wavelength (Northridge: California State University).

Appendix J

Sample and Standard Preparation for direct injection into mass spectrometer

Equipment:
Five (5) extraction flasks
Methyl chloride solution
Methanol solution

- 40mL of each surface water sample were extracted with a 0.45μm, 10 mL syringe into the clean extraction flasks.
- Each sample was then washed with 20mL of methyl chloride solution shown in Figure J1.
- Following each methyl chloride wash samples were gently mixed, with care to avoid emulsifying methyl chloride and water layers.
- After mixing, the methyl chloride layer being of greater density that water settles to a lower and extractable layer in the extraction flasks.
- The methyl chloride solution and dissolved organic solution is then withdrawn from the extraction flasks.
- The procedure of washing, mixing, and extraction is performed three (3) times on each sample in increments of 20mL of methyl chloride.
- As methyl chloride is highly volatile the 60mL of extracted solution is allowed evaporate, leaving extracted organics as precipitates from each sample. Depiction of resulting precipitate in Figure J2.
- Deionized water and methanol solution at proportions of 0.4mL and 1.6mL respectively are then added to the resulting precipitates.
- Lastly, to insure dissolution of extracted precipitates, each 2mL sample is placed in a sonnicator to catalyze the process.
- Samples were then stored in the laboratory until analysis.

Figure J1. Methyl chloride sample wash

Figure J2. Resulting precipitate after methyl chloride evaporation.

Standard Preparation

As a model to compare sample results, a series of standardized caffeine solutions were prepared. Drawing from a stock caffeine solution of 3.6 μg/L six standards ranging from 0.1 ppb (0.1μg/L or 100ng/L) to 5ppb (5000ng/L) were created. The six standards (0.1, 0.25, 0.5, 1.0, 2.5, and 5.0ppb) were diluted with deionized water to desired concentrations with the addition of one blank solution, comprised of just deionized water. Standards were created with assistance from Ian Joslin in Gonzaga University's unified laboratory on March 28 and April 12, 2012. Standard solutions were selected in this range because expected concentrations of caffeine from WWTP's employing UV treatment and the survival of caffeine in surface waters has been observed in ranges of 0.03-9.5μg/L (Buerge, Thomas, and et al 691-700). Table J1 reiterates the standard solutions used for calibration.

Table J1. Standard caffeine solutions

Standard Solution Concentrations				Units (ppb or μg/L)		
0.1	0.25	0.5	1.0	2.5	5	Blank- 0

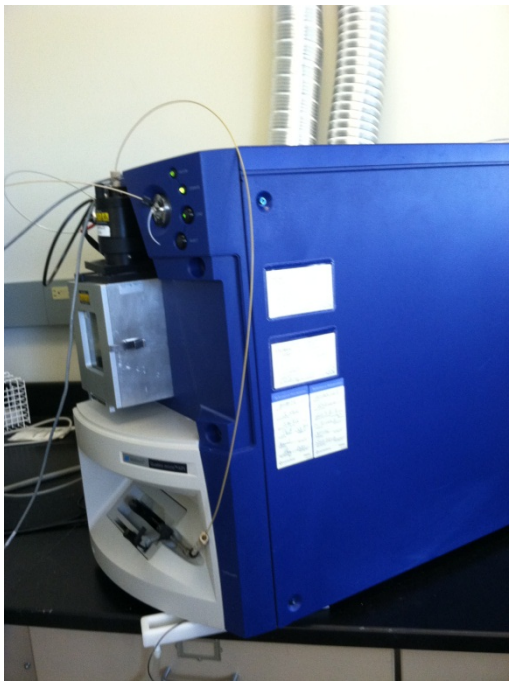


Figure J3. Mass spectrometer in operation.

Figure J4. Injected sample into mass spectrometer.

Assistance in preparing the mass spectrometer for direct injection was provided by Gonzaga University's undergraduate research coordinator and lab operator Christy Watson. The parameters related to the mass spectrometer's operation for all samples are shown in Table J2.

Table J2 Mass spectrometer operational parameters.

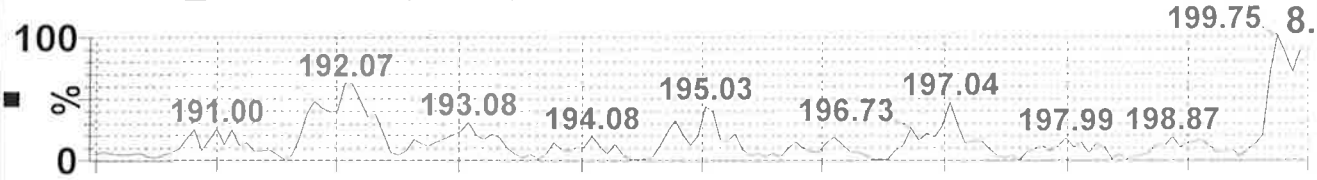
Parameter	**Value**	**Units**
Capillary	3.5	kV
Lens	0.1	V
Cone	21	V
Source Temperature	130	°C
Desolvation Temperature	500	°C
Cone Gas Flow	60	L/h
Desolvate gas flow	800	L/h

Appendix K

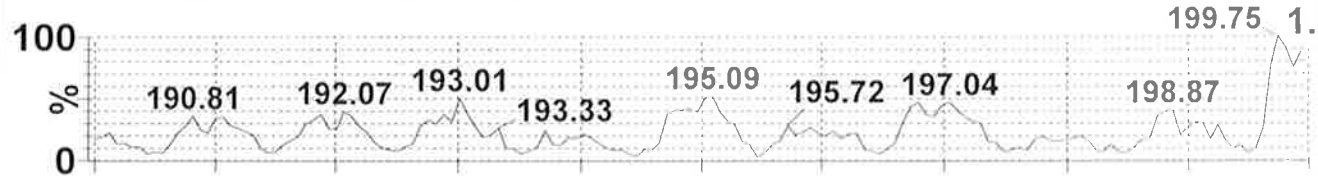
Mass spectrometer results for the samples, blanks, and standards follow on the proceeding pages.

LA2 Spiked QAA 812 19-Apr-201215:28:31

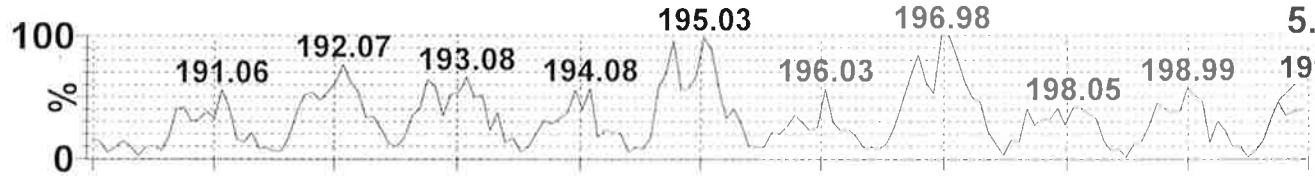
SAMPLE5_APRIL19 1 (0.018) Scan ES+ 8.75e5



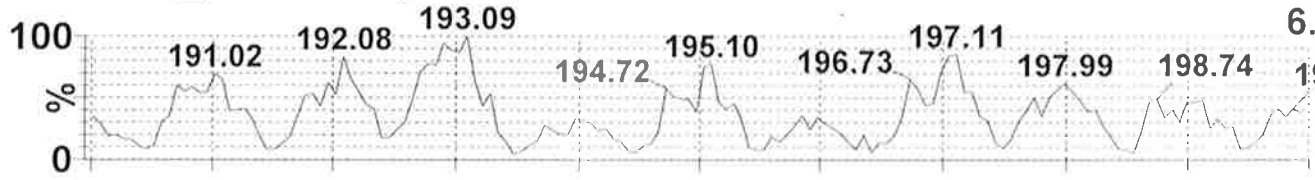
SAMPLE4_APRIL19 1 (0.018) Scan ES+ 1.08e6



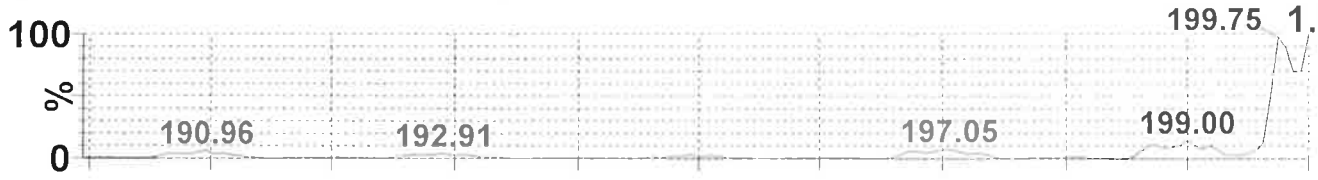
SAMPLE3_APRIL19 1 (0.018) Scan ES+ 5.53e5



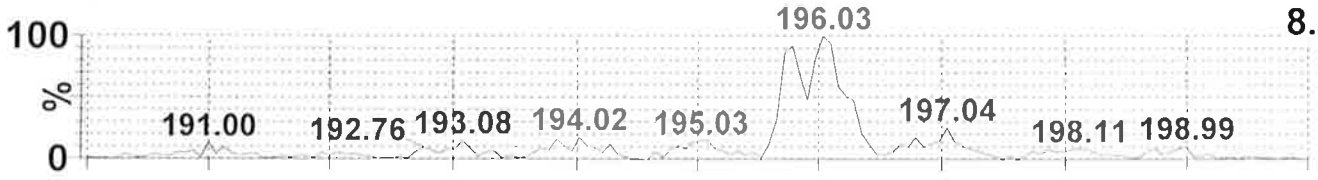
SAMPLE2_APRIL19 1 (0.018) Scan ES+ 6.63e5



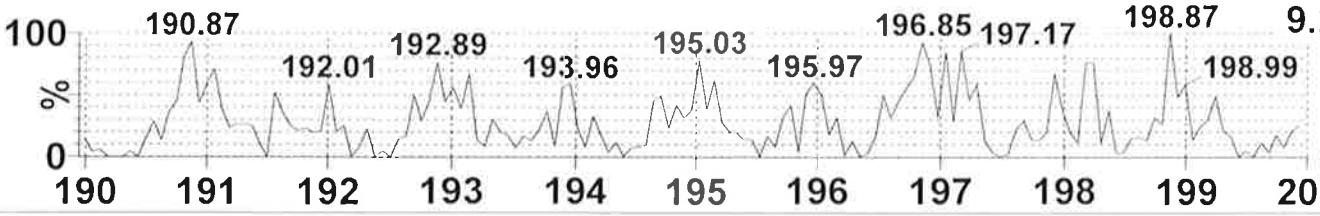
SAMPLE1_APRIL19 1 (0.018) Scan ES+ 1.39e7



STD1_APRIL19 1 (0.018) Scan ES+ 8.00e5



BLANK1_APRIL19 1 (0.018) Scan ES+ 9.27e4



Appendix L

The following are the results of mass spectrometry analysis with 196.03 as caffeine identifier.

Calibration curve: The resulting mass/charge ratio versus caffeine concentration for the standard solutions analysis is shown in Figure L1. As can be seen, solution concentrations of 0.1, 0.25, and 2.5ppb create a skewed relationship that results in a least squares fit of 31%. Removing the concentrations of 0.1 and 0.25 from the calibration curve, as the dilution to the concentration level was most susceptible to error, generated a modified calibration curve. The modified curve is shown in Figure L2 and as the relationship provides a curve with a least squares fit of 86%, allows more effective estimation of sample concentrations.

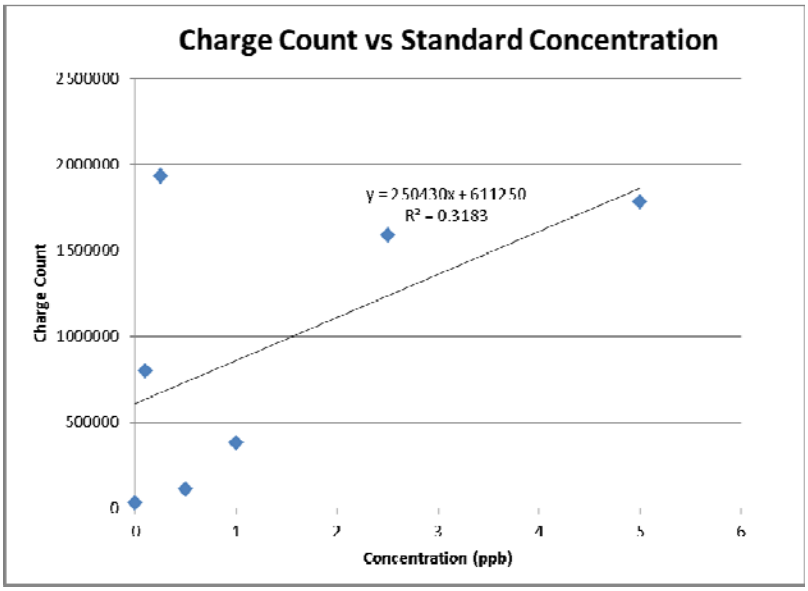


Figure L1. Calibration curve of all standard solutions as charge count vs. concentration.

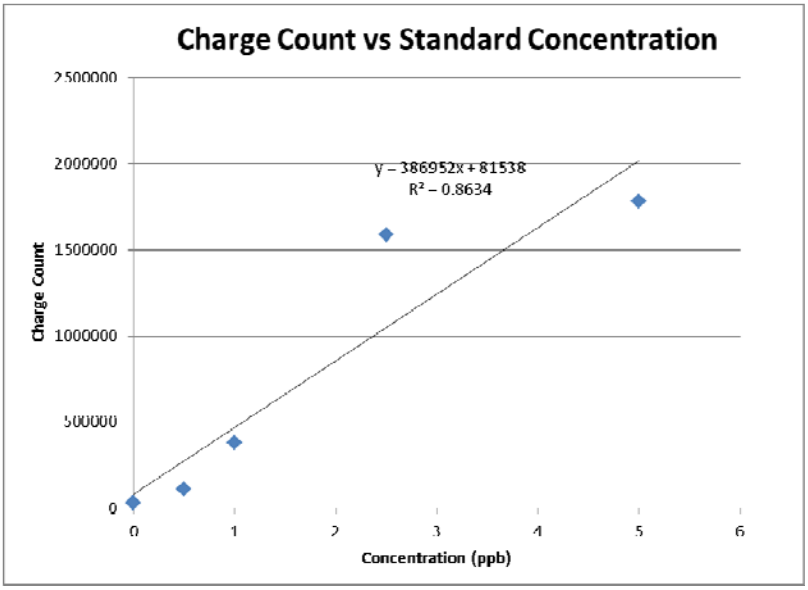


Figure L2. Modified calibration curve as charge count vs. concentration.

Results

Taking the output values from the mass spectrometer for the mass/charge peaks, charge counts could be referenced against the modified calibration curve to determine a concentration value of the identified molecule. Following 196.03 mass/charge peaks the data for both sampling runs was compiled into Table L1.

Table L1. Results of samples against modified calibration curve.

Name	Sampling Run	Charge Count (e-)	Concentration (ppb)
Sample1- LA2	2	0	-0.211
Sample2-LA1	2	0	-0.211
Sample9-LA1_S1	1	64600	-0.044
Sample8-CC2_S1	1	99600	0.047
Sample13-LA2_S1 Spiked	1	117480	0.093
Sample11-WWTP1_S1	1	127200	0.118
Sample12-WWTP2_S1	1	127380	0.118
Sample7- CC1_S1	1	131040	0.128
Sample5-LA2 Spiked	2	157500	0.196
Sample4-CC1	2	248400	0.431
Sample10-LA2_S1	1	272000	0.492
Sample3-CC2	2	337050	0.660

Appendix M

Hydrological Soil Group

The classification of the hydrological soil groups relate to the rate of water infiltration when soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long duration storms. Therefore, they are based on estimates of runoff potential.

Cocolalla silt loam has a rating of C, which describes that the soil has a slow infiltration rate when thoroughly wet and has a layer that impedes the downward movement of water or soils of moderately fine texture. This means if water from the wetland can overflow and reach the flow path, more of the volume will travel as runoff compared to infiltrating. (Web Soil Survey).

Drainage Class

The soil represented with the map symbol of 26 has a drainage class of "somewhat poorly drained." From the Soil Survey Manual, "Somewhat poorly drained: Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall" (Web Soil Survey).

The other soil of concern, 79, has a soil characteristic of being well drained**.** Well drained is described as "water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep" (Web Soil Survey).

Water Table

A water table refers to a saturated zone. To determine the water table depth in the Area of Interest, past well logs were utilized. Table M1 depicts this and the site's static levels. The site's static levels were determined through a ratio of the well log elevations and static levels equated to the site's elevations and unknown site static levels. Web Soil Survey also approximated water table depth based on the attributes of the soil. The water table depth assumptions are represented in Table M2. Since the water level was measured at different dates and a function of the underlying soil properties at that specific location, it only provides an approximate representation of the water table depth in the wetland. These serve as a verification of the calculated static levels for the wetland, which in turn were utilized to determine the infiltration rate.

Table M1

Well	Location	Date	Static Level (ft)	Elevation (ft)	Site's Static Level (ft)
1	Riffe Rd	May-93	20	2500	19.77
2	West of Riffe Rd	Oct-98	13	2460	13.06
3	South of HWY 2	Jun-99	36	2520	35.30
4	28081 Riffe Rd	Apr-04	22	2455	22.14

Table M2

Soil	Acres in AOI	Depth (ft) *
Cocolalla silt loam	16	4
Tucannon-Rock outcrop	880.3	>17

Depth to Any Soil Restrictive Layer
A restrictive layer is a nearly continuous layer that has one or more physical, chemical, or thermal properties that significantly impedes the movement of water. Examples include bedrock, dense layers, etc. According to Web Soil Survey, the depth to any impermeable layer in the area of interest of the possible flow path has no restrictive layer less than 78” and 30” for Cocolalla silt loam and Tucannon-Rock outcrop, respectively.

Flooding Frequency Class
The area of concern has an “occasional” possibility of flooding meaning that flooding occurs infrequently under normal weather conditions. This is illustrated in Figure by the soil symbol 26. Based on the soil’s attributes in the Area of Interest, Web Soil Survey determined that the soils have a 5-50% chance of flooding in any year. This illustrates that even if water was able to overflow into the potential flow path, the depressions of the flow path would create more storage area for the water output, thus creating a lower probability of a hydrological connection via surface water.

Figure M1

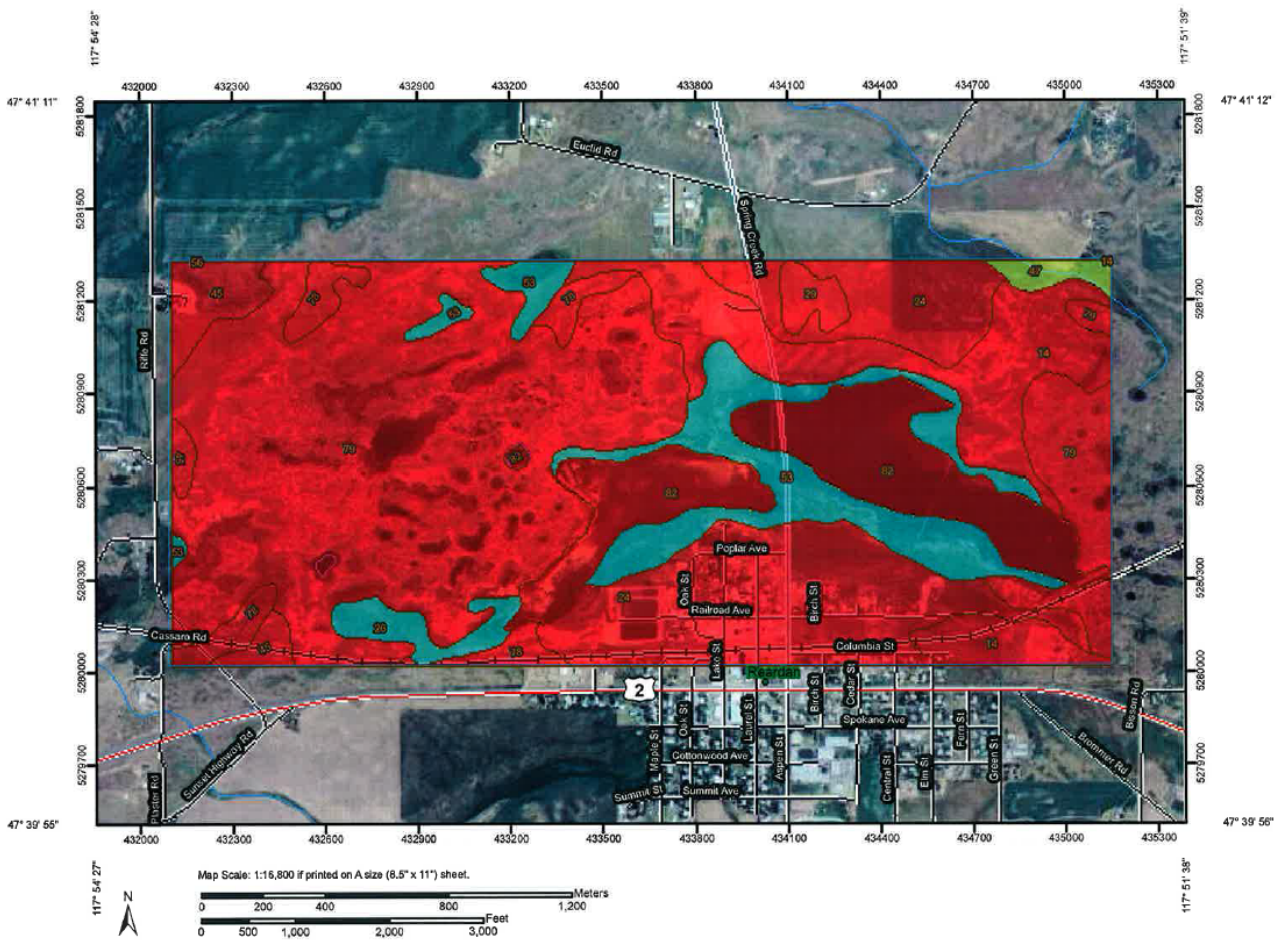


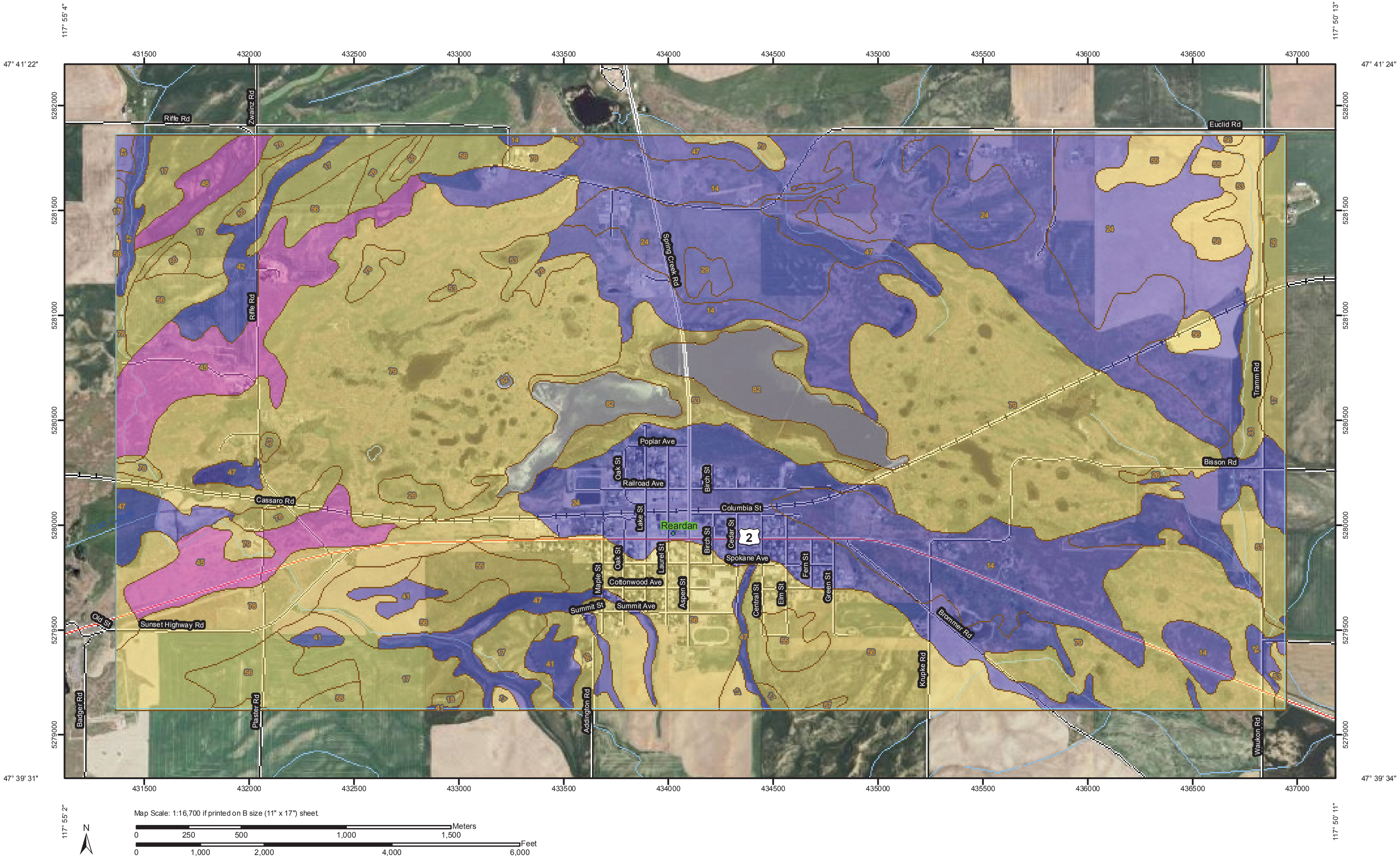
Table M3

Flooding Frequency Class

Flooding Frequency Class— Summary by Map Unit — Lincoln County, Washington (WA043)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
14	Benco cobbly silt loam, 0 to 7 percent slopes	None	107.6	10.9%
24	Cheney silt loam, 0 to 5 percent slopes	None	172.1	17.4%
26	Cocolalla silt loam, drained	Occasional	16.0	1.6%
29	Dragoon silt loam, 7 to 25 percent slopes	None	9.2	0.9%
45	Kuhl cobbly silt loam, 0 to 15 percent slopes	None	26.9	2.7%
47	Mondovi silt loam	Rare	7.9	0.8%
53	Pedigo silt loam	Occasional	92.8	9.4%
56	Reardan silt loam, 7 to 25 percent slopes	None	0.0	0.0%
78	Tucannon silt loam, 0 to 5 percent slopes	None	29.9	3.0%
79	Tucannon-Rock outcrop complex, 0 to 15 percent slopes	None	415.1	42.0%
82	Water	None	111.7	11.3%
Totals for Area of Interest			**989.1**	**100.0%**

Appendix N

Hydrologic soil groups for Lincoln county, spatial representation, is shown on the following page.


117° 55' 4"
117° 50' 13"
47° 41' 22"
47° 41' 24"
47° 39' 31"
47° 39' 34"
117° 55' 2"
117° 50' 11"
431500
432000
432500
433000
433500
434000
434500
435000
435500
436000
436500
437000
5282000
5281500
5281000
5280500
5280000
5279500
5279000
Riffe Rd
Zwainz Rd
Euclid Rd
Spring Creek Rd
Tramm Rd
Poplar Ave
Oak St
Railroad Ave
Birch St
Bisson Rd
Cassaro Rd
Columbia St
Lake St
Reardan
Cedar St
2
Spokane Ave
Laurel St
Fern St
Maple St
Cottonwood Ave
Aspen St
Green St
Central St
Elm St
Summit St
Summit Ave
Old St
Sunset Highway Rd
Bronmer Rd
Krupke Rd
Badger Rd
Plaster Rd
Addington Rd
Waukon Rd
Map Scale: 1:16,700 if printed on B size (11" x 17") sheet.
N
Meters
0
250
500
1,000
1,500
Feet
0
1,000
2,000
4,000
6,000

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Units

Soil Ratings

A

A/D

B

B/D

C

C/D

D

Not rated or not available

Political Features

Cities

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

MAP INFORMATION

Map Scale: 1:16,700 if printed on B size (11" × 17") sheet.

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for accurate map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 11N NAD83

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Lincoln County, Washington
Survey Area Data: Version 7, Jun 17, 2009

Date(s) aerial images were photographed: 6/26/2006

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Hydrologic Soil Group

Hydrologic Soil Group— Summary by Map Unit — Lincoln County, Washington (WA043)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
14	Benco cobbly silt loam, 0 to 7 percent slopes	B	524.3	13.9%
17	Broadax silt loam, 7 to 25 percent slopes	C	159.6	4.2%
18	Broadax silt loam, 25 to 40 percent slopes	C	2.1	0.1%
24	Cheney silt loam, 0 to 5 percent slopes	B	625.0	16.5%
26	Cocolalla silt loam, drained	C	18.6	0.5%
29	Dragoon silt loam, 7 to 25 percent slopes	B	9.2	0.2%
33	Emdent silt loam, drained	C	20.1	0.5%
41	Hanning silt loam, 0 to 7 percent slopes	B	28.6	0.8%
42	Hanning silt loam, 7 to 25 percent slopes	B	41.3	1.1%
45	Kuhl cobbly silt loam, 0 to 15 percent slopes	D	192.6	5.1%
47	Mondovi silt loam	B	139.8	3.7%
53	Pedigo silt loam	C	149.2	4.0%
55	Reardan silt loam, 0 to 7 percent slopes	C	95.0	2.5%
56	Reardan silt loam, 7 to 25 percent slopes	C	472.6	12.5%
57	Reardan silt loam, 25 to 40 percent slopes	C	1.7	0.0%
78	Tucannon silt loam, 0 to 5 percent slopes	C	188.4	5.0%
79	Tucannon-Rock outcrop complex, 0 to 15 percent slopes	C	997.1	26.4%
82	Water		111.7	3.0%
Totals for Area of Interest			**3,776.9**	**100.0%**