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AN ASSESSMENT OF THE HYDROLOGIC CONNECTION BETWEEN BLACKTAIL CREEK AND A RIVERINE WETLAND FOR NUTRIENTS PROCESSING POTENTIAL

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AN ASSESSMENT OF THE HYDROLOGIC CONNECTION BETWEEN BLACKTAIL CREEK AND A RIVERINE WETLAND FOR NUTRIENTS PROCESSING POTENTIAL

by

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Abstract

Silver Bow Creek (Blacktail Creek to Warm Springs Creek) is listed as impaired for nitrates, total nitrogen and total phosphorus in the Montana 2014 draft 303(d) list. Blacktail Creek, a head water to Silver Bow Creek, flows approximately 17 miles before joining Silver Bow Creek in Butte, MT. Previous studies have shown that nutrient concentrations in Blacktail Creek are significantly higher than the Montana Department of Environmental Quality (DEQ) target concentrations. In the literature, constructed (treatment) wetlands have been popularly used as an effective Best Management Practice (BMP) to process nutrients from municipal, industrial, and livestock wastewater. While there has been enough research conducted on the effectiveness of constructed (treatment) wetlands in processing nutrients, little research has been conducted on riverine wetlands that are hydrologically connected to streams. For this study we have chosen a historically excavated wetland (KOA wetland) within the flood plain of Blacktail Creek. This study investigates the hydrologic connection between Blacktail Creek and the KOA wetland as well as the nutrients removal potential of the KOA wetland. The hydrologic connection between Blacktail Creek and the riverine wetland was evaluated using two approaches: wetland inundation modeling using HEC-RAS and an analysis of water surface changes. Further validation of the HEC-RAS model is required, but this study found a limited hydrologic connection (both surface and sub-surface) from Blacktail Creek to the KOA wetland. Based on this determination it is likely that the riverine wetland currently offers limited potential for processing of Blacktail Creek's nutrients. Nutrient sampling of the riverine wetland and adjacent Blacktail Creek during the study has shown that the KOA wetland does not contribute nitrite+nitrate and may actually serve to process nitrogen, but is a potential source of phosphate to the stream. This study is significant as restoration of Blacktail Creek is ongoing and an improved understanding of the hydrologic connection between Blacktail Creek and existing riverine wetlands can potentially aid in meeting target nutrient concentrations.

Keywords: Blacktail Creek, HEC-RAS, LiDAR, ArcGIS, Nutrients, Wetlands

Dedication

This work is dedicated to my parents H. & Katy Ball for granting me so many opportunities to explore the world around me and for gently guiding me on my path in life. Without them many of my passions in life would be left unexplored and I wouldn't be where I am today.

Acknowledgements

I would like to acknowledge my Committee Chair Raja Nagisetty for his guidance, advice, advocacy and most importantly for allowing me to work on a project that he personally proposed and secured funding for. I would also like to acknowledge my advisor and committee member Kumar Ganesan for his support, understanding and for always being available to answer my questions during the last three years of meeting the requirements of a non-thesis masters of Environmental Engineering. Additionally, I'd like to acknowledge Bill Drury and Glenn Shaw for their patience and help while serving on my committee. This work has been partially funded by a Montana Tech Faculty Development Grant.

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Glossary of Terms

Term	**Definition**
BMP	Best Management Practice
HEC-RAS	Hydrologic Engineering Center's River Analysis System
ArcGIS	Environmental Systems Research Institute's Geographic Information System
HEC-GeoRAS	ArcGIS extension that facilitates extraction and export of spatial features for use in HEC-RAS
LIDAR	Light Detection and Ranging
Nutrient Pollution	Presence of excess nitrogen and phosphorus above background levels

1. Introduction

1.1. Nutrients

Nutrients, such as nitrogen (N) and phosphorus (P), are naturally occurring elements required for aquatic ecosystem function and can serve as indicators of overall surface water quality (Montana DEQ, 2014a. and USEPA, 2000). However, the presence of excess nitrogen and phosphorus above background levels in a body of water (nutrient pollution) can negatively impact aquatic ecosystem health, human health and recreational benefits (Montana DEQ, 2014a. and USEPA, 2000). Anthropogenic sources of nitrogen and phosphorus are the primary source of nutrient pollution and result in the impairment of 40% of surveyed surface waters in the United States (USEPA, 2000). Anthropogenic sources of nutrient pollution are broken into two categories: point source and nonpoint source. Point sources are discernible or distinct sources of nutrient pollution such as industrial or sanitary wastewater discharges. Nonpoint sources (NPS) are diffuse in nature and often occur due to the conveyance of nutrients to a body of water due to runoff from urban and agricultural areas (Montana DEQ, 2012).

The Montana Department of Environmental Quality (MTDEQ) regulates point source discharges of nutrients to groundwater and surface waters under the Montana Groundwater Pollution Control System (MGWPCS) and the Montana Pollutant Discharge Elimination System (MPDES) respectively (Montana EQC, 2014). The MGWPCS and MPDES programs create legally enforceable standards and regulations aimed at protecting the water quality of receiving groundwater and surface waters. MTDEQ currently addresses nonpoint source nutrient pollution under their 2012 Nonpoint Source Management Plan. The current plan outlines monitoring, education/outreach, and subsidization of control technologies as MTDEQ's primary focus for NPS nutrient pollution prevention (Montana DEQ, 2012).

In February of 2015 the Environmental Protection Agency (EPA) approved MTDEQ's proposed base numeric nutrient standards, hereafter referred to as DEQ-12A. Approval of DEQ-12A created legally enforceable standards for total N and total P concentrations (§75-5-103(2) MCA) designed primarily to protect the beneficial uses of wadeable streams/rivers of the state (Montana DEQ, 2014b). Due to limits of technology and possible economic impacts to MPDES permit holders, Montana adopted nutrient standards variances to allow for end-of-pipe variances. The nutrient standards variances, hereafter referred to as DEQ-12B, are available based on determination that a permit holder cannot meet DEQ-12A standards (Montana DEQ, 2014c). Although DEQ-12B only impacts point source discharges of nutrients, the importance of NPS nutrient pollution to meeting DEQ-12A regulations is addressed:

> "This approach should allow time for nitrogen and phosphorus removal technologies to improve and become less costly, and to allow time for nonpoint sources of nitrogen and phosphorus pollution to be better addressed." (Montana DEQ, 2014c.)

Legally enforceable standards and regulations for NPS nutrient pollution are currently not a desirable option and other means of mitigating NPS nutrient pollution are needed in order to meet DEQ-12A regulations.

1.2. Nutrient Processing by Riverine Wetlands

Naturally occurring and constructed wetlands have been shown to process and reduce nutrient concentrations of through-flowing water and are often utilized as Best Management Practices (BMPs) for mitigating nutrient pollution of streams and rivers (Harrison et al., 2014, Kadlec, 2010 and Verhoeven et al., 2006). Wetlands can serve to process nutrients from surface runoff and subsurface flow and have been shown to aid in NPS nutrient pollution processing (Harrison et al. 2014 and Verhoeven et al., 2006).

Nutrients processing by wetlands is a complex process that varies both seasonally and temporally (Verhoeven et al., 2006). Nutrients transported to wetlands can be assimilated by plants, algae, macrophytes and micro-organisms; adsorbed to sediment particles; or converted and utilized by bacteria (USEPA, 2000). Removal of N by wetlands is primarily due to denitrification by microbial activity under anaerobic conditions, resulting in the conversion of nitrate (NO_3^-) to nitrogen gas (N_2) and/or intermediates nitric oxide (NO) and nitrous oxide (N_2O) (Harrison et al., 2014, Kadlec, 2010). Assimilation of N and P by aquatic plants and microorganisms within wetlands does not result in true removal of the nutrients from the wetland, but instead acts as storage unless vegetation is harvested and removed from the wetland (Verhoeven, 2006). Phosphorus processing in wetlands occurs through sedimentation/precipitation and adsorbtion to sediments; however, mobilization of P during seasonal flooding or runoff events has shown that wetlands can act as sources of P to adjacent surface waters (Harrison et al., 2014).

Factors affecting the nutrient processing ability of riverine wetlands have been linked to the hydrological connection with nutrients, the inflowing nutrients concentration, temperature, availability of dissolved inorganic carbon and dissolved oxygen, as well as the bacterial and plant communities present within the wetland (Harrison et al., 2014, Kadlec, 2010 and Verhoeven et al., 2006).

1.3. Site Location

Blacktail Creek's headwaters originate along the continental divide in the Highland Mountains of south-west Montana and then flows northward through the Summit Valley for approximately 17 miles before joining with Silver Bow Creek in Butte, Montana (Ganesan et al., 2013). For the study we chose a riverine wetland complex bounded by Blacktail Creek to the south, Kaw/Lexington Avenue to the east, and the Butte Kampgrounds of America (KOA) to the north as shown in Figure 1. Hereafter, the wetland complex of interest will be referred to as the KOA wetland. The KOA wetland is listed under the United States Fish & Wildlife Service's (USFWS) National Wetland Inventory as a historically excavated wetland that has a surface area of 1.55 acres (USFWS, 2005). The KOA wetland complex consists of a 0.78 acre freshwater pond that is semipermanently flooded and a 0.77 acre freshwater emergent wetland that is temporarily flooded as shown in Figure 2 (USFWS, 2005). The wetland is located on land owned by the City and County of Butte-Silver Bow (BSB) and currently the KOA wetland has no upstream conveyances allowing inflow from Blacktail Creek, upgradient wetland complexes or BSB's storm water drainage system. The KOA wetland is separated from Blacktail Creek by the Blacktail Creek Trail, a paved walking/biking path, and potential overland flow must breach the walking trail to cause overland inundation of the wetland (Figure 3). The KOA wetland does have a culvert at its outlet that allows water from the wetland to discharge into Blacktail Creek. The KOA wetland is upstream of the BSB Metro Sewer & Stormwater treatment facility (WWTP) and approximately 1500 ft. upstream of the United States Geological Survey (USGS) gage station 12323240.

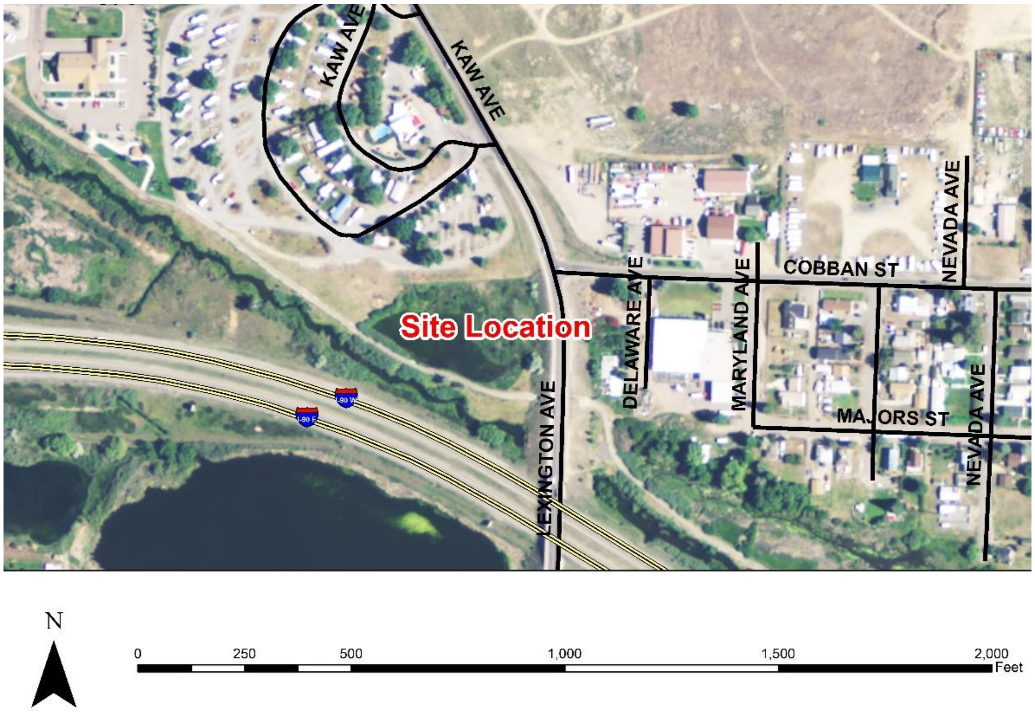

Figure 1: Site Location

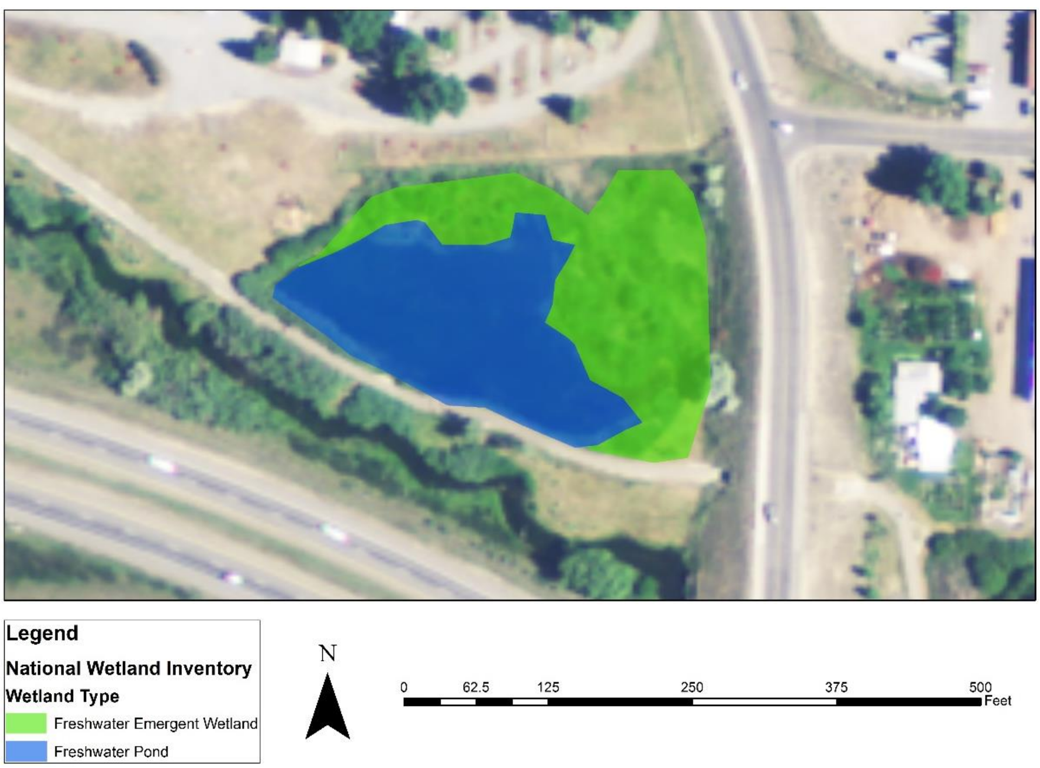

Figure 2: USFWS Wetland Classification

Figure 3: Walking Trail/Levee (facing East)

1.4. Site History

Previous studies have identified elevated nitrate concentrations in baseflow samples of Blacktail Creek upstream of the WWTP (Lafave, 2008 and Plumb, 2009). Groundwater contaminated by effluent from septic tanks, leaky municipal sewer connections, fertilizer application and domestic animal waste originating in the Summit Valley have been suggested as possible sources of the elevated nitrate concentrations observed in Blacktail Creek (Lafave, 2008 and Plumb, 2009). Currently Silver Bow Creek (Blacktail Creek to Warm Springs Creek) is listed as impaired for nitrates, total nitrogen and total phosphorus (Montana DEQ, 2014a). Average nutrient concentration reductions of 91% and 93% of total nitrogen and total phosphorus respectively are required to meet DEQ-12A standards for Silver Bow and Blacktail Creek (Montana DEQ, 2014a).

1.5. Project Hypothesis/Objectives

The overall goal of the project was to determine the effectiveness of the KOA wetland in reducing Blacktail Creek nutrient concentrations. Initially two hypotheses were proposed: that nutrient processing by riverine wetlands will be very effective in reducing nutrient loads for the Blacktail Creek reach and that potential nutrient load reduction by the riverine wetland is controlled by Blacktail Creek's hydrologic connection to the wetland. Specific objectives of the project were to assess the hydrologic connection between Blacktail Creek and the wetland; determine the nutrient processing ability of the wetland; and evaluate the effectiveness of riverine wetlands as a BMP for nutrients reduction of adjacent surface waters.

As the project progressed it was recognized that Blacktail Creek and the KOA wetland had a limited hydrologic connection for the purposes of transferring nutrients from the creek to the wetland. As a result the focus of the project shifted to identifying the current hydrologic connection between the creek and wetland, site conditions that limited the hydrologic connection and proposing ways to improve the hydrologic connection between the two. Nutrient data collected during the study period is also presented for reference purposes.

2. Methods

2.1. Hydrological Connection

The hydrologic connection between the riverine wetland and Blacktail Creek was evaluated using two approaches: wetland inundation modeling with HEC-RAS and an evaluation of measured and/or modeled water surface elevations within the KOA wetland and Blacktail Creek.

2.1.1. Wetland Inundation Modeling

Wetland inundation modeling was undertaken to model the minimum Blacktail Creek discharge required to cause areal inundation of the riverine wetland. The model was developed using three programs: ArcGIS, HEC-GeoRAS and HEC-RAS.

2.1.1.1. ArcGIS Overview

Environmental Systems Research Institute's (ESRI) ArcGIS (Arc) is a geographic information system (GIS) program that connects spatial features to data attributes (Kennedy, 2013). The Arc suite offers users various graphical user interfaces (GUIs) that allow for manipulation and visualization of spatial data and its attributes. ArcGIS version 10.2.2 was released in April, 2014 and used for the project. The GUIs utilized for the project were: ArcMap, ArcCatalog, ArcScene and HEC-GeoRAS.

Arc was utilized to develop a digital terrain model (DTM) representing the bathymetry of Blacktail Creek, KOA wetland and the surrounding floodplain for use in HEC-RAS as well as other aspects of the project. For the project a triangulated irregular network (TIN) was used create the DTM. TIN's are vector data sets that represent geographic space using continuous nonoverlapping triangles. The vertices or nodes of each triangle are formed from data points containing x-, y-, and z- values. Lines then connect each data point to form the triangles and result in the creation of a modeled surface. Creation of a TIN can also include the use of breaklines. Breaklines are used to represent distinct interruptions of a modeled surface's slope. Breaklines enforce a change in slope by not allowing triangles to cross the line (i.e. enforced as triangle edges) and can have constant z- values or vary over space. The accuracy of a TIN in modeling an existing surface is dependent on the quality and density of point data available as well as the use of breaklines.

2.1.1.1.1. Data Acquisition

The point data required for TIN creation was acquired from two sources: Butte Area One Light Detection and Ranging (LiDAR) data courtesy of the Montana Bureau of Mines & Geology (MBMG) and from Real Time Kinematic (RTK) Global Positioning System (GPS) surveying.

The Butte Area One LiDAR survey took place in the summer of 2013 via helicopter and averaged 3.25 points per square foot (35 pts/m^2). The resulting data is of higher quality and resolution than previously available topographic data sets for the area. However, due to the fact that the LiDAR survey was topographic in nature the near-infrared laser used to survey had limited success penetrating water and resulted in data gaps along Blacktail Creek and the surrounding wetlands. Due to the fact that the Butte Area One LiDAR survey generated over 40 million individual data points the data set was clipped using ArcMap to a smaller area surrounding the study location. This allowed for faster processing of the data while retaining the accuracy of the original data set.

RTK GPS surveying was undertaken on May 26th-27th of 2015 to survey bathymetric cross sections of Blacktail Creek as well as the bathymetric profile of the KOA wetland. Twenty two cross sections were surveyed perpendicular to the flow of Blacktail Creek upstream and downstream of the KOA wetland, resulting in a total of 695 survey points and an average spacing of ~56 ft. between cross sections. Surveying of the KOA wetland resulted in 409 survey points and an average spacing between points of ~0.008 points per square foot. The GPS survey points are shown below in Figure 4.

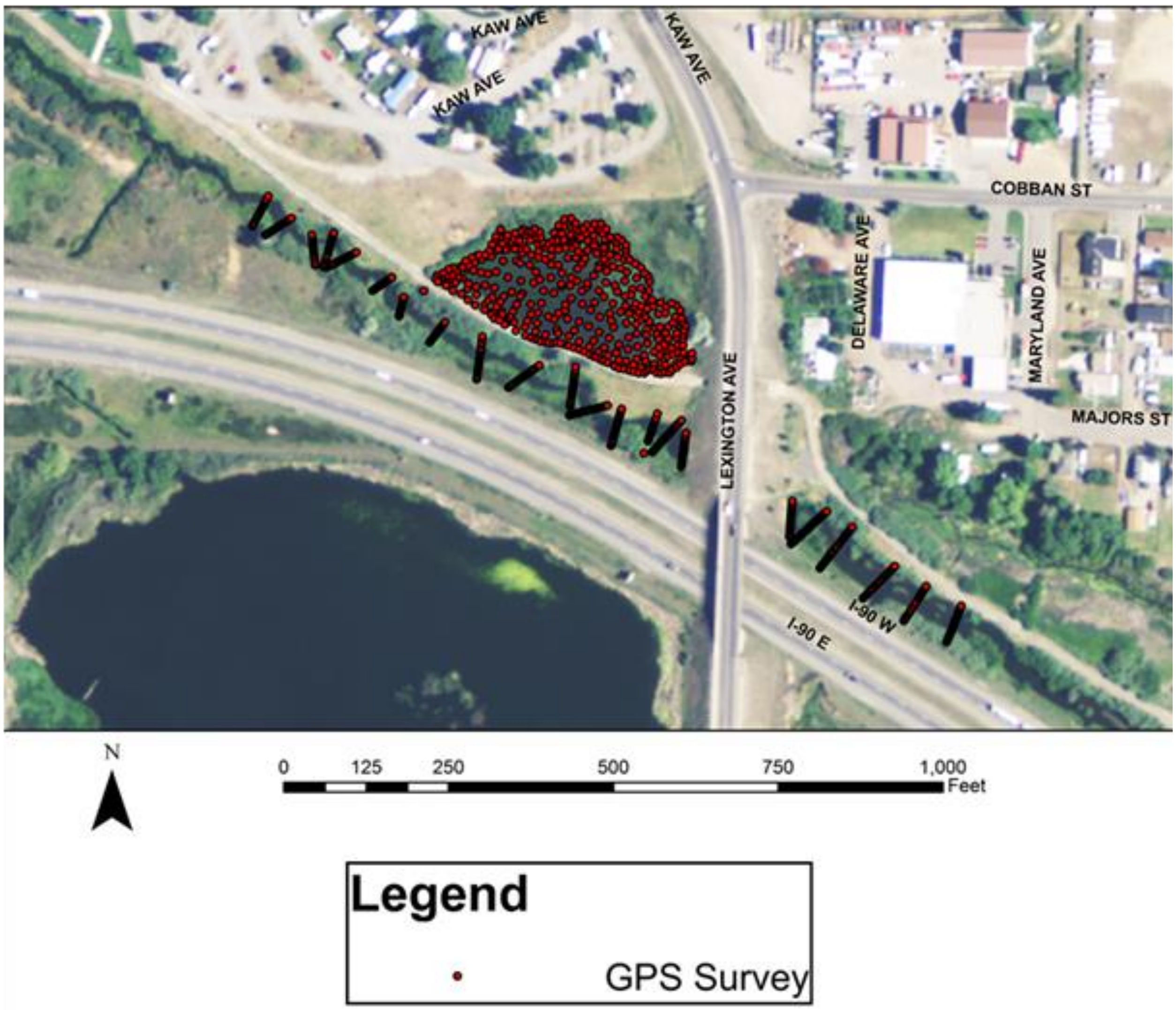

Figure 4: GPS Survey Points

During the process of building the required TIN a discrepancy in elevation was noted between the survey and LiDAR data. To determine which data set contained the elevation error the RTK GPS Survey equipment was checked using the Butte GPS Control Point (PID: QY0638). The control point is located on the south end of the Montana Department of Transportation (MDT) equipment yard in Butte and is used for GPS and vertical control. Two points were surveyed at the control point and resulted in a vertical elevation difference of +0.525 ft. above the control points orthometric elevation. The specifications of the control point are available in Appendix B: GPS Survey Control Point Specifications. All previously GPS surveyed points were then corrected by decreasing their elevation 0.525 ft. using the Adjust 3D Z tool in ArcMap.

Digital orthoimagery are georeferenced images of the earth's surface. One meter resolution 2013 Montana digital orthoimagery was available for the study location and had a horizontal accuracy of +/- 19.685 ft. (6 m.) (available at: http://geoinfo.msl.mt.gov/home/msdi/orthoimagery). The 2013 orthoimagery was utilized for visual verification of digitized features and the final TIN.

2.1.1.1.2. Data Processing

In order to create an accurate TIN, digitizing of the GPS survey data to create breaklines for the stream banks and thalweg of the study reach was undertaken using ArcScene. ArcScene allows for 3-dimensional visualization of spatial data and was utilized to digitize breaklines with z- values attributed from the physically surveyed points (Figure 5).

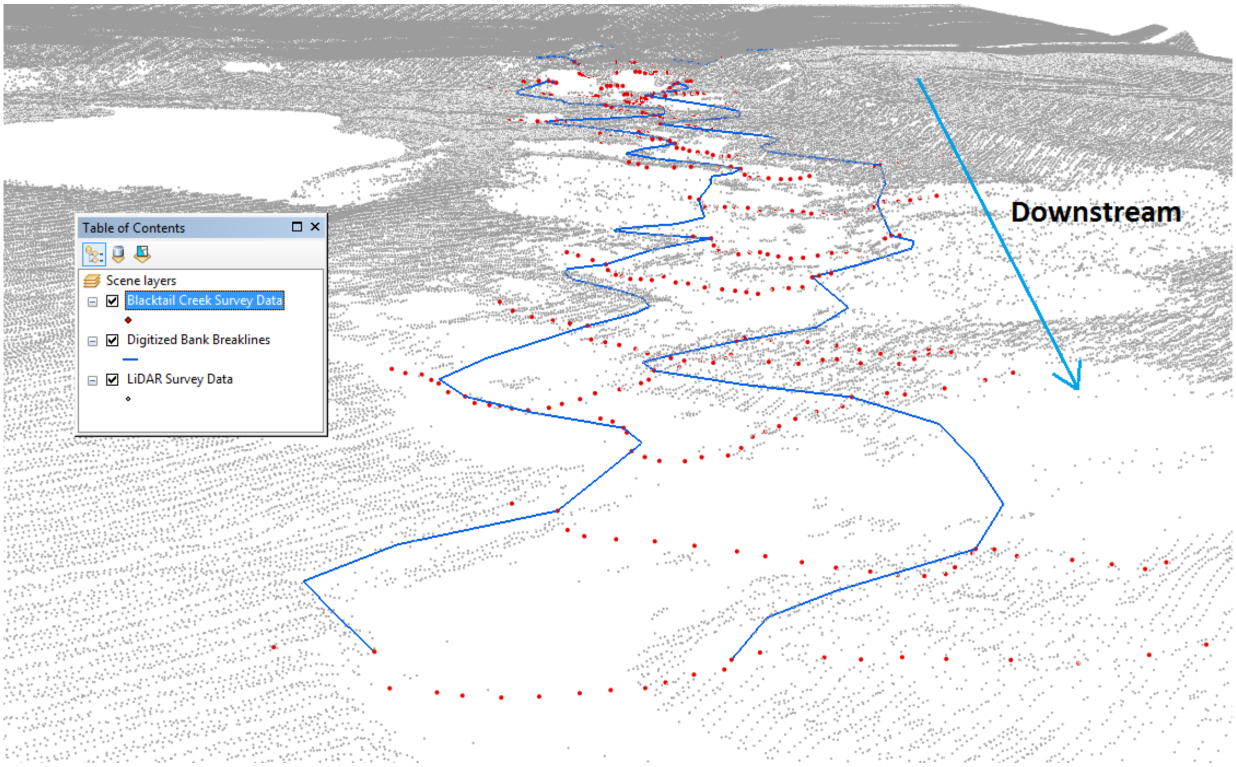

Figure 5: ArcScene Bank Breaklines Digitization

Once the breaklines were digitized, the accuracy of the LiDAR data used to build the TIN was addressed. Inaccuracies in processed LiDAR data can occur in shallow water and areas of dense vegetation, both of which occur along the banks of the study reach (NOAA, 2012). Removal of LiDAR points within the stream banks and immediately adjacent was done to remove the possibility of inaccurate data being used to build the TIN. ArcMap was used to create polygon features representing the banks of Blacktail Creek. The bank polygon features were then input into ArcMap's Buffer Tool and additional polygons representing a buffer distance of 2 ft. were created surrounding each feature. The bank polygons and buffer polygons were then used to clip (remove) any LiDAR point data located within the polygons.

Once all required data had been digitized/processed ArcMap's Create TIN tool was used to build the TIN. The input features consisted of the Blacktail Creek cross section and KOA wetland GPS survey data points, the selected LiDAR survey data points and the digitized stream bank and thalweg lines. The GPS and LiDAR data points were input as masspoints so that each data point and its respective elevation were imported as vertices or nodes of the TIN. The bank and thalweg lines were input as hardlines and acted to enforce distinct elevation changes as discussed in Section 2.1.1.1. Accuracy of the TIN was evaluated using 2013 digital orthoimagery as well as personal knowledge of the site location. The resultant TIN is shown below in Figure 6 and a zoomed in view of the TIN and study area is shown in Figure 7.

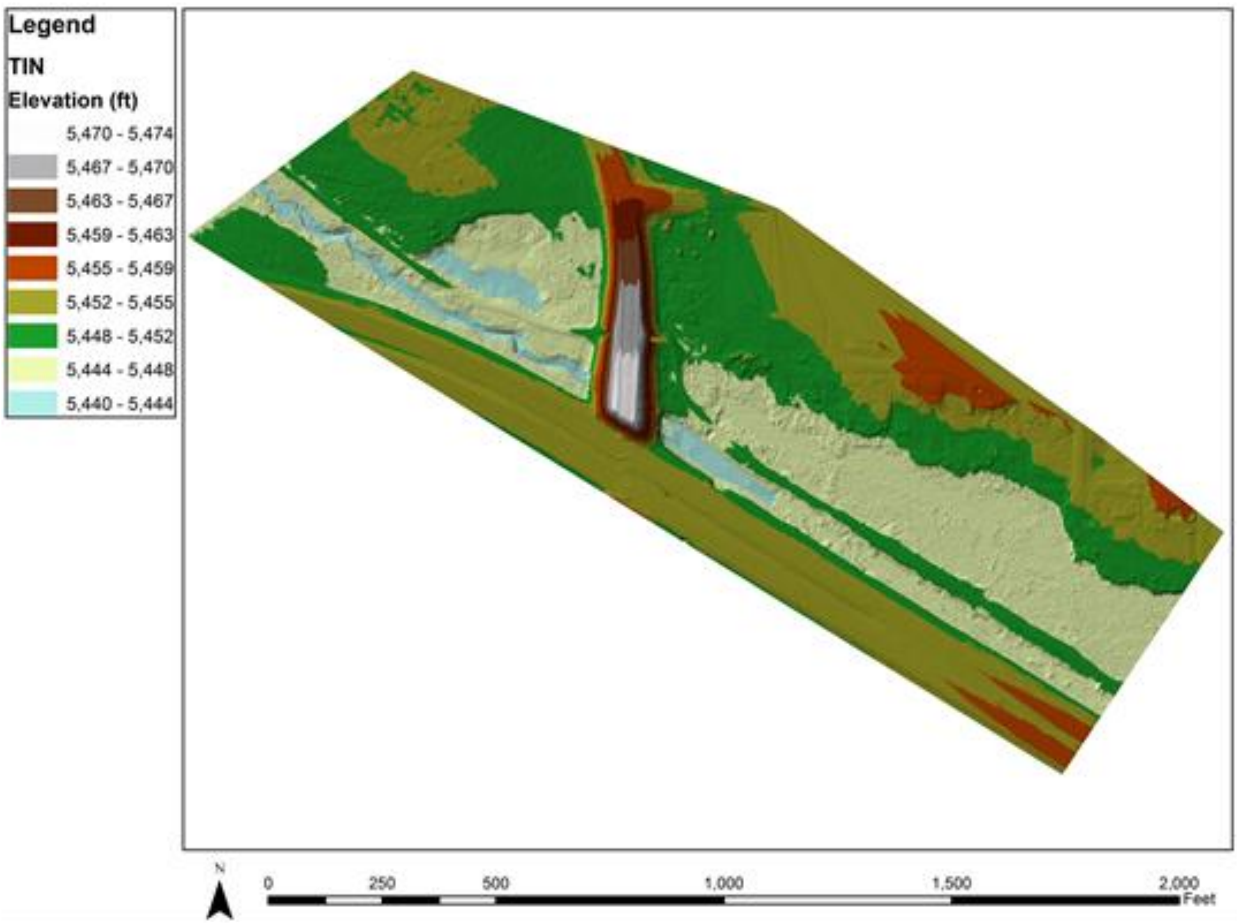

Figure 6: Final TIN

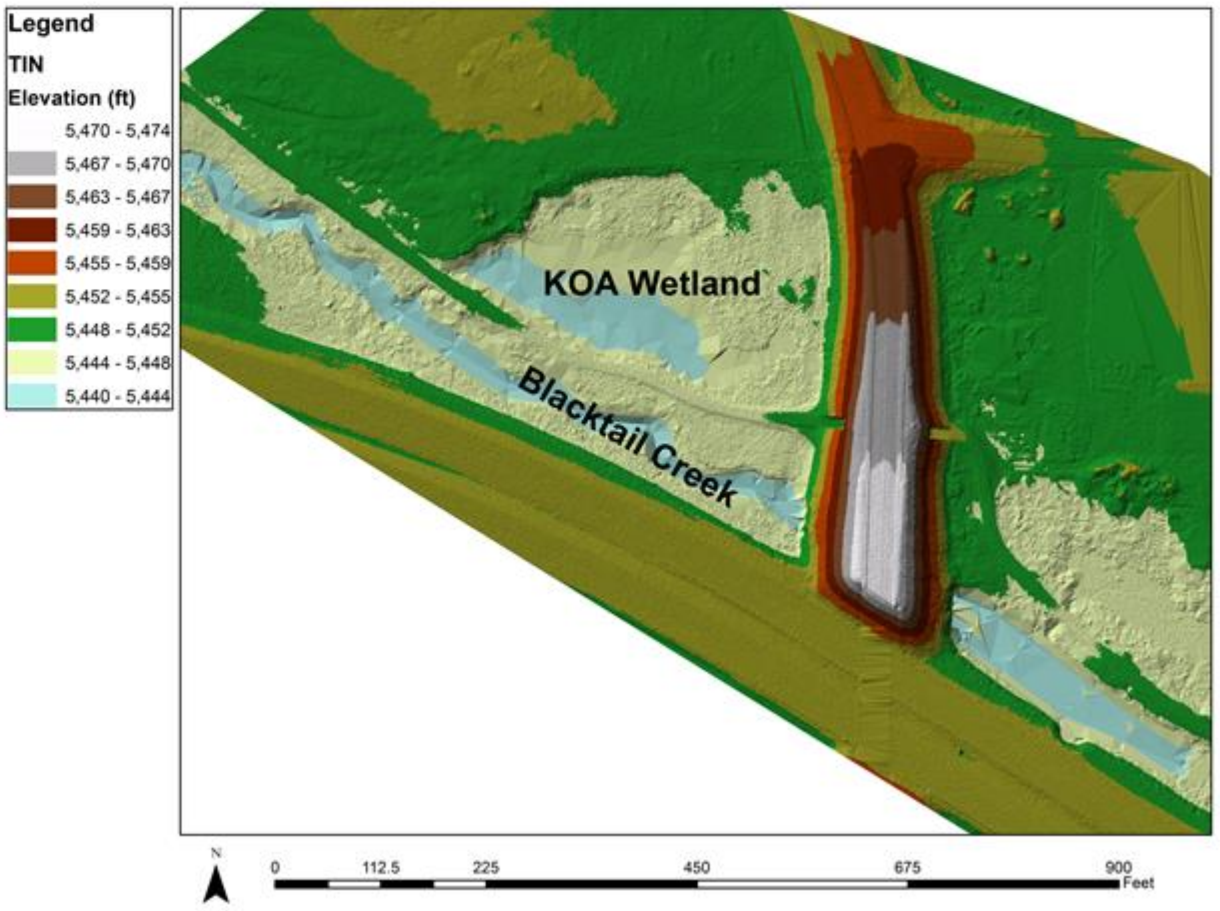

Figure 7: Final TIN Study Area

2.1.1.2. HEC-GeoRAS Overview

HEC-GeoRAS is an ArcGIS extension that was developed cooperatively by the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) and ESRI. The extension allows for the processing of geospatial data within ArcMap prior to import into the Hydrologic Engineering Center's River Analysis System (HEC-RAS) program (USACE, 2009). HEC-GeoRAS version 10.2 was used for the project.

2.1.1.2.1. Data Processing

After creation of the DTM for the study area was complete the HEC-GeoRAS extension was used in ArcMap to digitize River Analysis System (RAS) layers prior to export. All layers required for the model were created in accordance with version 4.2 of the HEC-GeoRAS User's Manual (USACE, 2009). The following RAS layers were digitized prior to export: Stream Centerline, Banks, Flowpath Centerlines, Cross Section Cut Lines, Lateral Structures and Storage Areas. All required spatial attributes for the RAS layers were determined from the previously developed TIN using HEC-GeoRAS and ArcMap.

Digitization of Cross Section Cut Lines layer was performed directly on top of the 22 GPS surveyed cross sections to ensure that the bathymetry of Blacktail Creek would be most accurately represented. Outside of the GPS surveyed points, continued digitization of Cross Section Cut Lines was done perpendicular to expected flow as needed to represent the floodplain. Similarly, digitization of the HEC-GeoRAS Banks layer was performed directly on top of the stream banks breaklines (Figure 3) previously created using ArcScene.

Two Storage Areas (SA) were created using HEC-GeoRAS to represent the KOA wetland as well as the wetland East of Kaw/Lexington Ave (hereafter referred to as the Kaw wetland). Within HEC-GeoRAS elevation-volume data was determined for the KOA and Kaw wetlands respectively. Lateral Structures were digitized adjacent to the two storage areas and represented the high ground/levee created by the paved walking trail along the north side of Blacktail Creek within the study area. Adjacent to the KOA wetland the Lateral Structure was split into two structures so as to allow for modeling of overbank inundation at the lowest point in the walking path and continued outflow through a culvert at the outlet of the wetland.

Next a Bridge/Culvert layer was digitized along the top of the Kaw/Lexington Avenue overpass to extract the deck/roadway profile from the TIN. Finally, polygon features representing ineffective flow areas were drawn on the upstream and downstream sides of the Kaw/Lexington Ave. culverts.

Once digitization of all the layers was complete an export file was created and the final steps of the inundation modeling were undertaken using HEC-RAS. Figure 8 below shows all features digitized using ArcMap and HEC-GeoRAS prior to export.

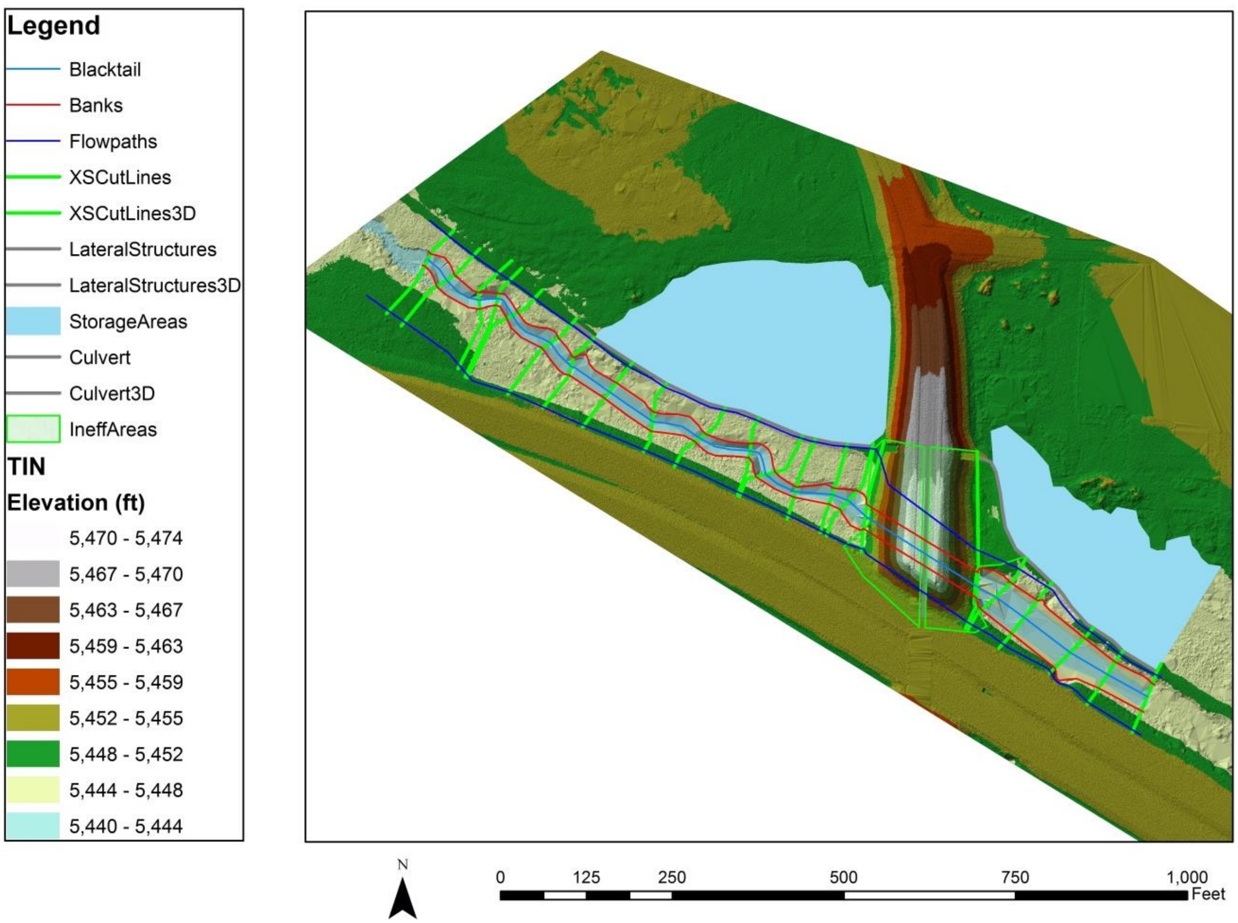

Figure 8: HEC-GeoRAS Layer Digitization

2.1.1.3. HEC-RAS Overview

HEC-RAS was developed by the USACE and initially released in 1995. HEC-RAS performs one-dimensional analysis of steady and unsteady flow river hydraulics by iterative solving of the one-dimensional energy equation (USACE, 2010a). Required inputs for HEC-RAS analysis of an existing or proposed stream design are geometric data and selected flow data.

2.1.1.3.1. Data Acquisition

Nearly all of the geometric inputs for the HEC-RAS model were determined using the HEC-GeoRAS extension for ArcGIS. The only geometric inputs that were added in HEC-RAS were the required culvert data. The culvert inputs were determined using a combination of field and ArcMap measurements.

Flow data was obtained from Montana Flood Frequency and Basin-Characteristic Data available for the Blacktail Creek USGS gage station 12323240. The compiled annual peak discharges served as a guide in selecting flows to model and are shown below in Table I (USGS, 2015).

Table I: Flood Frequency Data Adapted from USGS, 2015

Discharge (cfs)	26.00	83.00	139.00	224.00	283.00	361.00	419.00	478.00	538.00	618.00
Annual Exceedance Probability (%)	99.50	80.00	50.00	20.00	10.00	4.00	2.00	1.00	0.50	0.20
Return Interval (yr)	1.00	1.25	2.00	5.00	10.00	25.00	50.00	100.00	200.00	500.00

Manning’s “n” (roughness) coefficients for channel and overbank flow were adapted from a 2010 Federal Emergency Management Agency (FEMA) flood insurance study for Butte-Silver Bow County (FEMA, 2010). Based on the values found in the FEMA study, the average for channel and overbank (“n”=0.040 and “n”=0.060, respectively) were selected. Table II shows the range of “n” values for Blacktail Creek and Silver Bow Creek at Butte and was adapted from page 13 of FEMA, 2010.

Table II: Manning’s “n” Coefficients (adapted from FEMA, 2010)

Stream	Channel	Overbank
Blacktail Creek	**0.030-0.050**	**0.040-0.080**
Silver Bow Creek @ Butte	**0.025-0.045**	**0.045-0.065**

2.1.1.3.2. Data Processing

Once the required data had been acquired and/or pre-processed a new project was started in HEC-RAS and all data was added to the HEC-RAS model in accordance with version 4.1 of the HEC-RAS User’s Manual (USACE, 2010a).

The HEC-GeoRAS export file previously created using ArcGIS was imported under the Geometric Data GUI. United States (US) customary units were selected and river stations (RS) were rounded to whole numbers before completing the import. Figure 9 shows the imported HEC-GeoRAS geometry as displayed in HEC-RAS. After import, verification of the 22 imported cross sections’ geometric accuracy was performed by visual inspection and adjustment, as needed, of bank station locations using the Graphical Cross Section Editor. As stated previously, cross sections were drawn in HEC-GeoRAS overtop of surveyed locations and the extracted cross sections within and immediately adjacent to the banks of Blacktail Creek were represented solely by that data. Outside of the area immediately adjacent to the banks (~2 ft.) extracted cross section points were represented by survey and/or LiDAR data. Several cross sections, primarily in areas with dense vegetative cover and/or steep slopes, had discrepancies in the extracted cross section point data. Using the Graphical Cross Section Editor points not representative of the existing site conditions were removed.

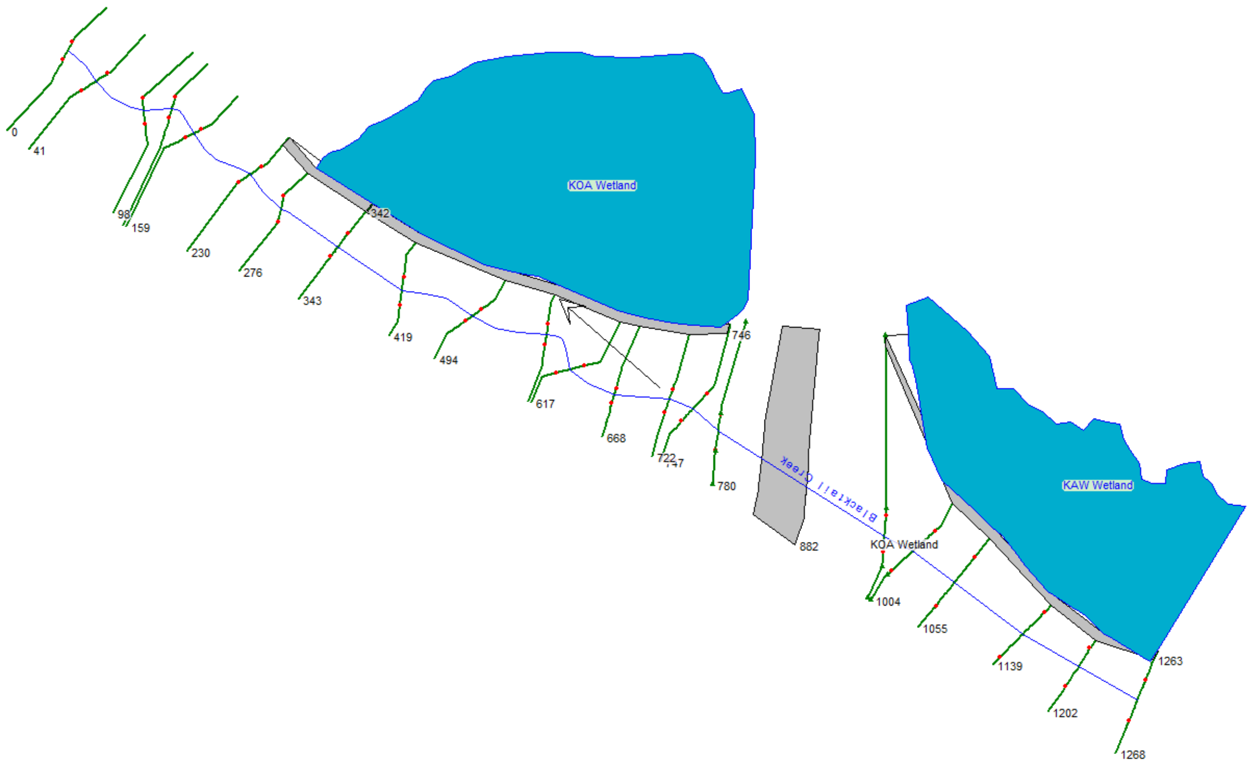

Figure 9: Imported Geometry

After verifying the geometric accuracy of the imported cross sections the Cross Sections Points Filter tool was used to filter unnecessary points from any cross section containing more than 500 points. This step was done due to HEC-RAS's limit of 500 points per cross section (USACE, 2010a). Filtering of the 22 cross sections resulted in an average of 273.7 points per cross section. Next, the selected Manning's n Values (Channel "n"=0.040 and Overbank "n"=0.060) were entered for the left overbank (LOB), channel and right overbank (ROB) of each cross section using the Edit Cross Section tool (FEMA, 2010).

Underneath Kaw/Lexington Ave. Blacktail Creek travels through two parallel pipe arch culverts. The culvert feature created in HEC-GeoRAS was imported and using the Culvert Data Editor in HEC-RAS the two culverts and their necessary inputs were entered. An Entrance Loss

Coefficient of 0.7 was selected for the culverts using Table 6-3 of the HEC-RAS Hydraulic Reference Manual and a Manning's n value of 0.03 was selected for the top of the culverts using Table 6-2 (USACE, 2010b). While surveying Blacktail Creek sediment deposition on the downstream end of the culverts was observed, while the upstream side remained relatively sediment free. Due to the lack of uniform sedimentation throughout the length of the culverts and the assumption that high flows would mobilize the sediments a Manning's n value of 0.03 was also selected for the bottom and a depth blocked of 0 was used (K. Snodgrass, personal communication, July 28, 2015). For the two cross sections upstream of the culverts and one downstream a contraction coefficient of 0.30 and an expansion coefficient of 0.50 was used. The coefficients were adjusted to model the energy loss associated with flow contraction approaching the culverts and increased flow expansion leaving the culverts.

Using the Lateral Structure Editor tailwater connections were selected for the 3 lateral structures created with HEC-GeoRAS and their respective storage areas (KOA or KAW Wetland) were set as the SA. Within the Lateral Structure Editor an 8 in. culvert was added to the furthest down gradient lateral structure using GPS survey data of the structure. The culvert was added to the HEC-RAS model to represent the existing culvert that acts as an outlet to the KOA wetland. An Entrance Loss Coefficient of 0.9 was selected for the culvert using Table 6-3 of the HEC-RAS Hydraulic Reference Manual and a Manning's n value of 0.012 for the top of the culvert was selected using Table 6-2 (USACE, 2010b). While surveying the culvert it was noted that vegetation and sediment had blocked ~1/2 of the upstream end of the 8 in. culvert. An assumption was made that the current blockage would not be mobilized due to the limited/low velocities expected within the KOA wetland. Based on this assumption a conservative Manning's n value of 0.03 was selected for the bottom of the culvert Using Table 3-1, part B. of the HEC-RAS Hydraulic Reference Manual (USACE, 2010b). Finally, the depth to use bottom n and depth blocked were set at 4 inches (0.3333 ft.).

Once all geometry data had been added and verified for accuracy steady flow data for the model was entered into HEC-RAS. A normal depth assumption was used for the model and a downstream slope of 0.00075 was used to compute normal depth for the study reach. The downstream slope was determined using surveyed water surface elevations approximately 400 ft. downstream of the last surveyed cross section. As stated previously, the USGS annual peak discharges for Blacktail Creek served as a guide in selecting flows to model. For each profile and flow rate modeled an initial water surface elevation of 5445.738 ft. was used for the KOA storage area. The initial water surface elevation value was selected for the KOA wetland as it was the average water surface elevation recorded during the study period. The KAW storage area initial water surface elevation was set to empty as no data was available for its water surface elevation. An X-Y-Z Perspective plot of the study reach at 30 cfs is shown below in Figure 10.

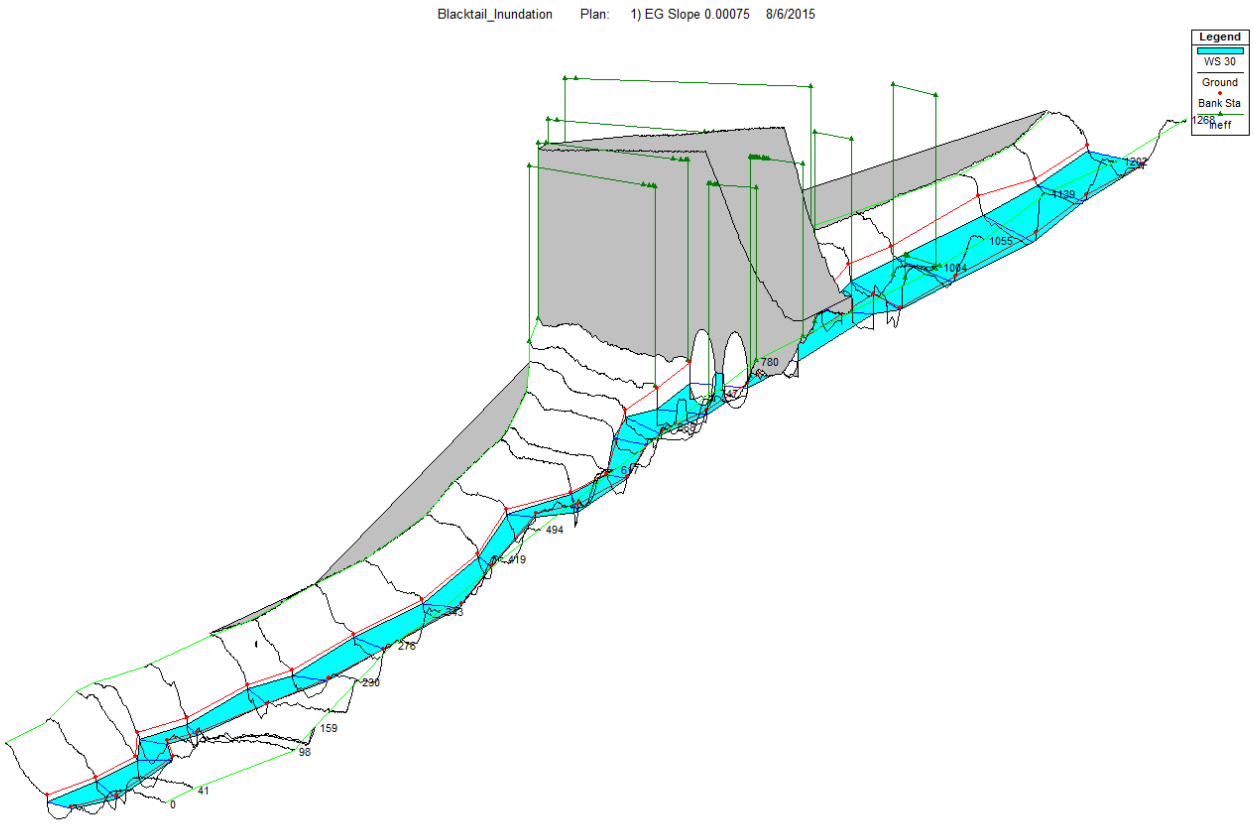

Figure 10: X-Y-Z Perspective Plot of Study Reach

2.1.2. Water Surface Evaluation

2.1.2.1. Data Collection

Submerged absolute level loggers' measure total pressure and in conjunction with a barologger can be used to record changes in the height of a water column. The project used Solinst 3001 Levelogger® Edge placed in the riverine wetland to record changes in total pressure every 5 minutes. A metal T-post was securely placed within the riverine wetland and a polyvinyl chloride (PVC) pipe was attached to the post. The level logger was placed inside of the PVC pipe and rested on a horizontal metal bolt running through the PVC pipe. The Levelogger was placed at a water depth that allowed for continued submergence throughout seasonal variations in the wetland water surface height. A Solinst 3001 Edge Barologger was placed on site as well to record changes in atmospheric pressure every 5 minutes. Using Solinst's Levelogger version 4.1.1 software, recorded data was downloaded from both instruments and barometric compensation was applied to determine the relative height of the water surface above the Levelogger. The Levelogger's location within the wetland was surveyed using RTK GPS surveying equipment to allow for wetland water surface elevation calculations. Similarly to the surveyed Blacktail Creek cross sections the Levelogger's vertical location corrected by decreasing the surveyed elevation 0.525 ft. using the Adjust 3D Z tool in ArcMap. Water surface height data was collected for the KOA wetland from 5/28/2015 to 7/28/2015.

2.1.2.2. Data Processing

Data collected from the Levelogger placed in the KOA wetland was corrected for barometric pressure using Solinst's Levelogger software and then compiled in Excel. Based on the surveyed location of the Levelogger's sensor an elevation of 5444.7387 ft. was added to the water heights recorded by the Levelogger. Discharge and gage height data for Blacktail Creek from 5/28/15 to 7/28/15 was acquired from the USGS Station downstream of the study location. The USGS gage data was available in 15 minute intervals and within Excel the VLOOKUP function was used to correlate Levelogger data for the available USGS data intervals.

2.2. Nutrients Data

2.2.1. Field Sampling

Water samples were collected following the field sampling protocols found in Appendix A: Field Sampling Protocol. Samples were collected from Blacktail Creek adjacent to the riverine wetland as well as from the head and outlet of the riverine wetland (Figure 11). Field duplicates and laboratory fortified field blanks were collected during each sampling event as well following field sampling quality assurance/quality control (QA/QC) protocols (Appendix A: Field Sampling Quality Control). Sampling events took place on April 30th, June 24th and July 8th, 2015. At the time of sampling flow measurements were taken at the Blacktail Creek sampling location using a Marsh McBirney Flo-Mate 2000.

Figure 11: Wetland Sampling Locations

2.2.2. Sample Analysis

Water samples were analyzed using a FIAlab®-2500 flow injection analyzer (FIA) or Hach® Spectrophotometer (HACH) within the permitted time post sampling as described in

Appendix A: Field Sampling Protocol. FIAlab®-2500 reagent preparation followed the procedures outlined in Appendix A: Flow Injection Analyzer Reagent Preparation Procedures. Samples were analyzed for nitrite+nitrate and phosphate and adhered to the sample analysis QA/QC protocol found in Appendix A: Sample Analysis Quality Assurance/Quality Control.

3. Results

3.1. Hydrological Connection

3.1.1. Wetland Inundation Model

After the HEC-RAS model had been verified for geometric accuracy, the USGS annual peak discharges for Blacktail Creek were used to bracket the flow at which inundation of the KOA wetland occurred. By modeling the walking path between Blacktail Creek and the KOA wetland as a lateral structure HEC-RAS produces a Lateral Structure Output table that includes a field for water exiting or entering the stream via the lateral structure. For this reason we modeled the walking path as two lateral structures to account for possible flow over the walking path as well as outflow and/or inflow from the culvert at the outlet of the wetland. Modeling showed that areal inundation, over the walking path, occurred at higher modeled flows than inflow from the creek through the wetland's outlet culvert. Inflow from Blacktail Creek through the culvert began to occur at a modeled discharge of 160 cfs. However, this connectivity does not represent true inundation and would have limited nutrient processing potential as water from Blacktail Creek that enters the KOA wetland though the culvert would likely have limited residence time and contact with potential denitrifying (anaerobic) zones of the wetland.

True areal inundation (overland flow) from Blacktail Creek to the KOA wetland first occurred at a modeled discharge of 265 cfs. The modeled inundation occurred at the lowest elevation section of the walking trail and entered the wetland approximately half-way along its length adjacent to Blacktail Creek. By entering near the midpoint of the wetland, flows entering the wetland likely have a greater potential for nutrient processing when compared with flows entering as inflow through the outlet culvert. However, further study of the wetland dynamics during these conditions is required before any conclusions about potential nutrient processing can be made.

The minimum HEC-RAS modeled Blacktail Creek discharge causing areal inundation of the KOA wetland is indicative of a limited hydrologic connection between the two. The 265 cfs minimum discharge is representative of an 8.5 year event or an annual probability of 13% that Blacktail Creek will exceed the modeled discharge (USGS, 2015). The HEC-RAS model was developed based on current conditions of the site and demonstrates a limited hydrological connection between Blacktail Creek and the KOA wetland due to the statistical rarity of flood events required to cause areal inundation. Moreover, the modeled infrequency of areal inundation events suggests that currently there is a limited potential of transfer and processing of Blacktail Creek's nutrients by the KOA wetland.

3.1.2. Wetland Water Surface

Analysis of the two months that the Levelogger was placed in the KOA wetland result in a maximum water surface elevation of 5445.9441 ft. and a minimum of 5445.6051 ft., a 4.068 inch difference in water surface elevation. The maximum water surface elevation occurred on 5/28/2015 and the minimum occurred on 7/27/15, which correspond to the first day the Levelogger was placed in the wetland and the second to last day that Levelogger data was collected for the study. Table III shows a comparison of the Levelogger and USGS Gage Station discharge data for the study period.

Table III: Data Comparison 5/28/15 to 7/28/15

	Mean	Minimum	Maximum	Range	Count
Wetland Levelogger (ft)	**5445.739**	**5445.605**	**5445.944**	**0.339**	**5787**
USGS Discharge (cfs)	**15.382**	**2.700**	**72.000**	**69.300**	**5787**

During the Levelogger study period Blacktail Creek experienced five different storm events that resulted in appreciable increases in discharge. The storm events occurred on June 4th, June 16th, June 29th, July 23rd and July 27th-28th of 2015. The events resulted in a minimum discharge increase of 8 cfs and a maximum of 43 cfs relative to Blacktail Creek's discharge prior to the storm events. The June 4th event is of particular significance as Blacktail Creek reached its highest discharge during the study period. In an 11 hour period the discharge increased from 29 cfs to 72 cfs before returning back to 32 cfs. Annually Blacktail Creek has an 85.5% probability of exceeding the June 4th discharge of 72 cfs (USGS, 2015). Figure 12 shows the Blacktail Creek discharge and KOA wetland water surface elevation data for the study period.

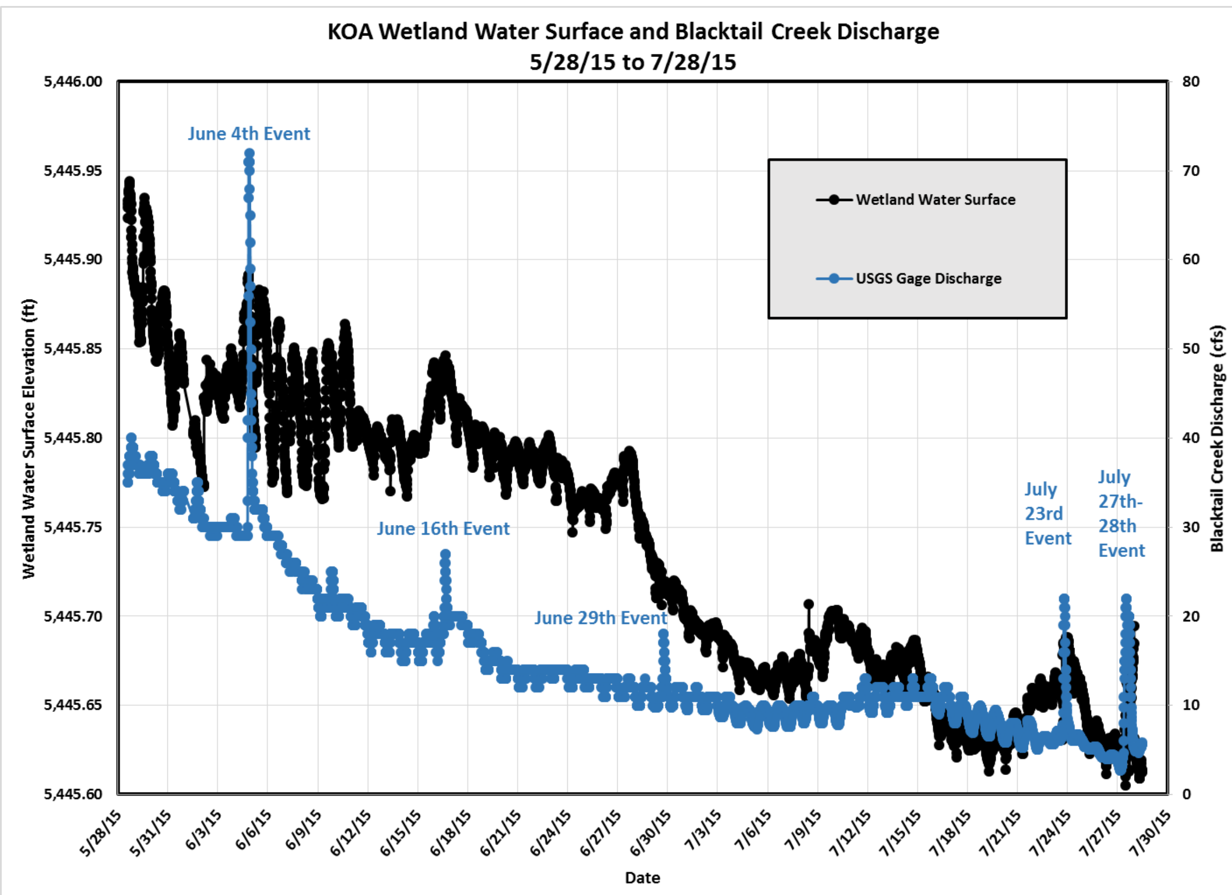

Figure 12: Study Period Chart

As stated previously the KOA wetland has no natural or man-made hydrologic connections to Blacktail Creek or the upgradient wetland complex. Upon initial inspection the KOA wetland does appear to show response to the June 4th event in the form of a 0.9 inch increase in water surface elevation (Figure 13). However, the wetland's response begins at approximately 8:30 am, while the USGS gage discharge response begins at 6:45 pm. Blacktail Creek's response coincides with the start of precipitation in the area as on June 4th rainfall is first recorded at the Weather Underground BTL/LAO weather station at 6:40 pm (Weather Underground, 2015). Based on the Levelogger data recorded, the KOA wetland's response does not appear to be linked to either the precipitation event or Blacktail Creek's highest discharge and largest increase in discharge observed during the study period. After the June 4th event no more rain was recorded in the Butte area for June 5th-7th, yet the average daily increase in the wetland's water surface elevation was 1.15 inches for those three days. The lack of correlation between the observed changes in the KOA wetland water surface elevation and Blacktail Creek's peak discharge, during the study period, is the first indicator of limited subsurface lateral flow from the creek to the wetland.

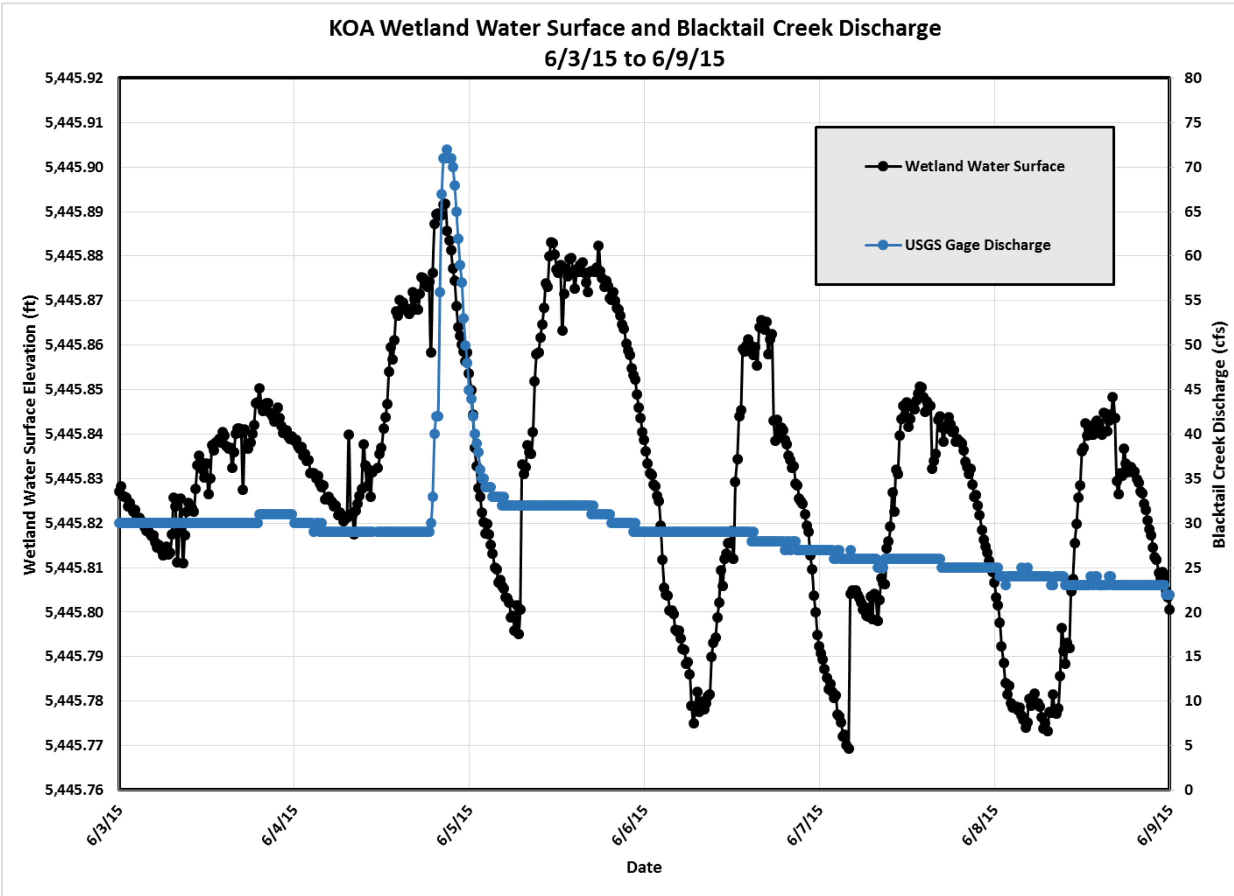

Figure 13: June 4th Event Chart

Without surveyed water surface elevations for a Blacktail Creek discharge of 72 cfs limited conclusions can be drawn about the hydraulic gradient between the creek and wetland at the time of the event. However, utilizing the HEC-RAS model and the June 4th peak discharge of 72 cfs, a maximum water surface elevation of 5445.110 ft. at the cross sections adjacent to the wetland can be estimated. During the same time period that Blacktail Creek reached 72 cfs, the Levelogger recorded wetland water surface elevation was 5445.892 ft. Figure 14 shows that even at the peak discharge for the study period the hydraulic head is 0.782 ft. higher in the KOA wetland than in Blacktail Creek. Further analysis found that a modeled discharge of 137 cfs is required to cause a Blacktail Creek water surface elevation adjacent to the KOA wetland greater than 5445.892 ft. This analysis assumes that an event causing a 90.28% increase over Blacktail Creek's June 4th discharge would not result in an increase in the KOA wetland's water surface elevation

s

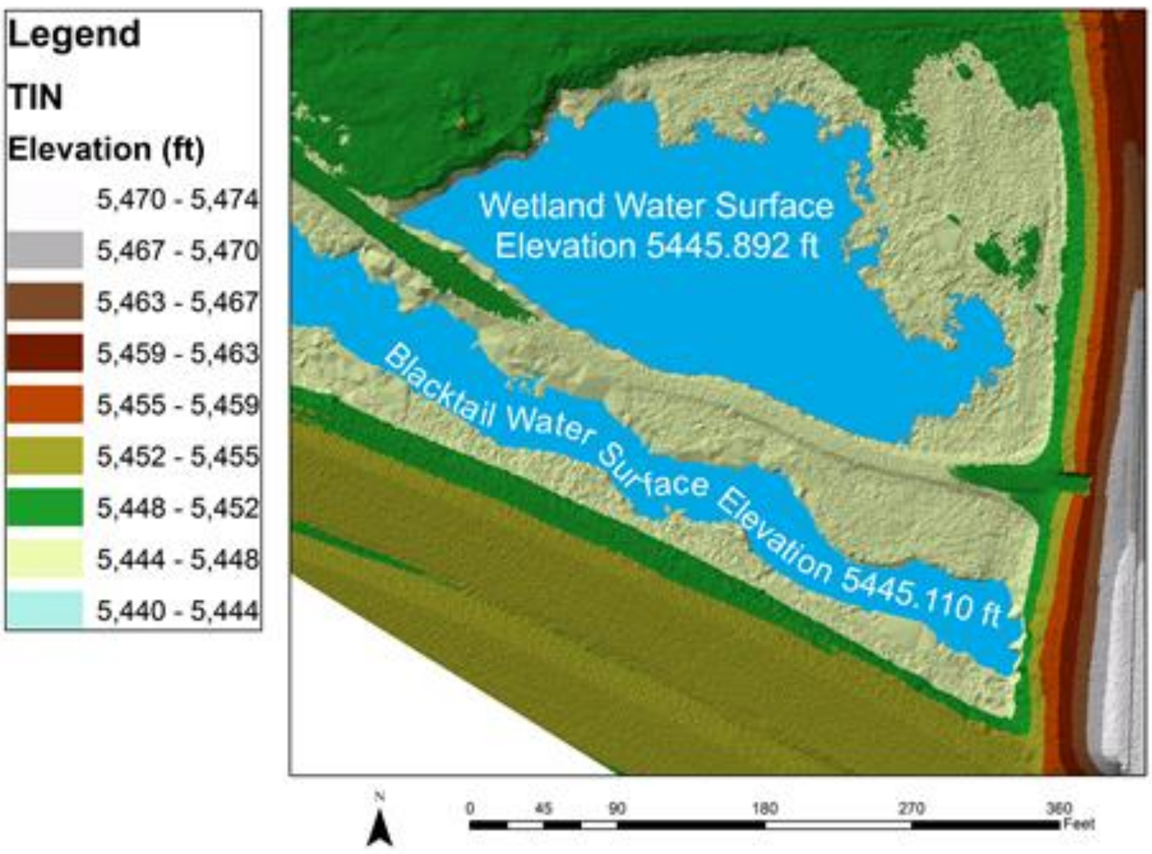

Figure 14: Blacktail Creek Max Modeled Water Surface June 4th

Further validation of the HEC-RAS model's accuracy is needed, but in conjunction with the lack of correlation between Blacktail Creek's discharge and the Levelogger's water surface elevation data it can be inferred that the current subsurface lateral hydrologic connection of the study site is from the KOA wetland to Blacktail Creek. The study's determination of a limited potential for subsurface lateral flow from the creek to the wetland further demonstrates a limited potential for processing of Blacktail Creek's nutrients by the KOA wetland.

3.2. Nutrients Data

Results from the nutrients concentrations analysis for the three sampling events are shown in Table IV and Table V below. No samples were collected or analyzed between 4/30/15 and 6/24/15 due to technical difficulties with both the FIA and HACH during that time.

Table IV: Nitrite+Nitrate Sampling Results (mg/L)

	4/30/2015		6/24/2015		7/8/2015	
Laboratory Fortified Field Blank	**0.054**	**H**	**-0.01**		**-0.01**	
Wetland Head	**0.117**	**H**	**-0.01**		**0.00**	
Wetland Head Lab Duplicate	**0.139**	**H**	**NA**		**NA**	
Wetland Outlet	**0.561**	**H**	**0.01**		**0.03**	
Wetland Outlet Field Duplicate	**NA**	**H**	**NA**		**0.03**	
Wetland Outlet Lab Duplicate	**NA**	**H**	**0.02**		**NA**	
Blacktail Creek @ KOA	**0.703**	**H**	**0.73**		**1.21**	*****
Blacktail @ KOA Field Duplicate	**0.818**	**H**	**1.31**	*****	**NA**	
Blacktail @ KOA Lab Duplicate	**NA**	**H**	**NA**		**1.20**	*****
0.2 mg/L Nitrite+Nitrate Standard	**NA**	**H**	**0.18**		**0.19**	
Marsh-McBirney Gaged Flow (cfs)	**18.900**		**12.20**		**7.60**	

H Indicates analysis was performed on the HACH
* Indicates sample value was greater than FIA analysis range

Table V: Phosphate Sampling Results (mg/L)

	4/30/2015		6/24/2015		7/8/2015	
Laboratory Fortified Field Blank	**0.034**	**H**	**-0.08**		**-0.01**	
Wetland Head	**0.377**	**H**	**0.97**		**0.18**	
Wetland Head Lab Duplicate	**0.395**	**H**	**0.94**		**NA**	
Wetland Outlet	**0.414**	**H**	**0.59**		**0.75**	
Wetland Outlet Field Duplicate	**NA**	**H**	**NA**		**0.55**	
Blacktail @ KOA	**0.385**	**H**	**0.11**		**0.25**	
Blacktail @ KOA Field Duplicate	**0.416**	**H**	**0.04**		**NA**	
Blacktail @ KOA Lab Duplicate	NA	H	NA		0.22	
0.2 mg/L Phosphate Standard	NA	H	0.22		0.18	
Marsh-McBirney Gaged Flow (cfs)	18.900		12.20		7.60	

H Indicates analysis was performed on the HACH

Although sampling was not conducted during May and the majority of June, results from all three sampling events show that the nitrite+nitrate concentration was consistently lower at the head and outlet of the wetland than that of Blacktail Creek adjacent to the KOA wetland. The results also showed that phosphate concentrations in the wetland outlet were consistently equal to or greater than the phosphate concentrations in Blacktail Creek adjacent to the KOA wetland.

4. Discussion

The primary goal of this study was to determine how effectively a riverine wetland was hydrologically connected with Blacktail Creek for the purposes of transferring nutrients from the stream to the wetland. Secondarily, the study sought to determine the nutrient processing ability of the KOA wetland for Blacktail Creek's nutrient load. Finally, the project was used as a pilot study to gain experience and understanding of the process required to model and study the hydrologic connection between Blacktail Creek and additional riverine wetlands for the purpose of nutrient removal.

The primary goal of the study has been achieved as the study determined that Blacktail Creek has a limited hydrologic connection to the KOA wetland for the purposes of transferring nutrients from the stream to the wetland. Currently the hydrologic connection and opportunity for nutrients from Blacktail Creek to enter the wetland are limited by the infrequency of modeled overland inundation and the lack of apparent subsurface lateral flow from Blacktail Creek into the wetland.

As stated above, an initial goal of the project was to assess the KOA wetland's processing of Blacktail Creek's nutrient load using the nutrients data collected during the study. However, due to the study's determination of a limited hydrologic connection between the two it is no longer valid to draw any conclusions about processing of Blacktail Creek's nutrients by the KOA wetland. Further study is required to determine the source and concentration of nutrients entering the wetland before making any conclusions about nutrient processing by the KOA wetland. This study can conclude that during the study period the KOA wetland did not serve as a source of nitrite+nitrate to Blacktail Creek, but does appear to serve as a possible source of phosphate. Further study is required understand the seasonal nutrients dynamics of the KOA wetland.

The results and understanding gained during the study have potential be useful in the design of riverine wetlands systems for Blacktail Creek nutrient processing. Proposed restoration plans for Blacktail Creek upstream of the study area are already addressing the need for increased hydrologic connections with riverine wetlands (Montana NRDP, 2015). Using the methodologies and knowledge gained by this project future restoration designs will be able to identify existing riverine wetlands that will benefit from designs improving their hydrologic connection with Blacktail Creek.

5. Limitations of the Study

Validation and/or calibration of HEC-RAS model inputs was not possible during the study period and the current model is based solely on the assumptions and inputs discussed in this paper. Further study is required to determine the model's applicability in modeling discharge and inundation of the study site as during the study period relatively low discharges were observed in Blacktail Creek. Three components of the current HEC-RAS model have been identified as possible sources of bias or inaccuracy and require further validation and/or calibration. The three components are: TIN inputs and creation, Manning's n value selection and the normal depth/downstream slope assumption.

Inherently the study and modeling of dynamic systems such as rivers and wetlands provides insight into conditions observed only during the study period. Any results and/or conclusions drawn from the project represent a relatively short period of study and should be viewed as an initial investigation into the hydrologic conditions of the site.

6. Future Work

The study's determination of a limited potential for surface and subsurface flows from Blacktail Creek to enter the KOA wetland offers several opportunities for further study. The highest priority for further study is continued validation and/or calibration of the current HEC-RAS model. Validation can best be achieved by one of two methods: visual observation of overland inundation occurring at or near the modeled discharge of 265 cfs or through the surveying of Blacktail Creek's water surface elevation at known discharges and at cross sections utilized in the HEC-RAS model. Comparison of surveyed and modeled water surface elevations should be used to validate and/or calibrate the current model.

Other areas of study recommended are to identify the current source and nutrients concentration of the KOA wetland's inflowing water. Identification of the current source of water to the wetland presents an opportunity study a hydrologically disconnected riverine wetland and more accurately assess the KOA wetland's nutrient processing ability.

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Appendix A: Blacktail Sampling QA/QC Protocol

Field Sampling Protocol

River sampling procedure

- All samples will be collected facing upriver.
- Rinse the sample bottle out three times, dumping out the water downstream of the collection site.
- Collect the sample in the part of the stream with the greatest flow velocity, at 50%-60% of the streams depth.
- Flow measurements will be taken at each site using the flow meter. Measurements will occur approximately every foot (about 20 data points), with depth and velocity being recorded.

Wetland sampling procedure

- Wetland sampling will consist of sample collection at the head of the wetland and at the outlet of the wetland.

- Sample collection at the head of the wetland will be done at a location as far from the wetland edge as safely practical.
- Rinse the sample bottle out three times, dumping out the water down gradient of the collection site.
- Prior to sample collection allow adequate time for sediments disturbed by the sampler to return to their pre-disturbance state.
- Collect the sample at a depth of 40-60% of the wetlands depth at sampling location.

- Wetland outlet sample collection will occur at the end of the pipe running from the wetland to Blacktail Creek and prior to mixing with Blacktail Creek.
- Rinse the sample bottle out three times, dumping out the water downstream of the collection site.
- Outlet flow will be estimated using a 5 gallon bucket and a stopwatch.

Sample Specifications

- At each sampling location one 500mL sample will be collected and preserved with concentrated sulfur acid (pH<2), and will be analyzed within 28 days of collection for total phosphorus, nitrate + nitrite, TKN, and ammonia.
- Acid handling protocols including protective eyewear and gloves will be adhered to while preserving samples.
- At each sampling location a 250mL bottle will be collected and a BD 30mL syringe connected to a Thermo Scientific 0.45um Nalgene Syringe Filter will be used to filter and transfer 25-50mL of the sample to a sterile 250mL bottle. Sample will be analyzed within 48 hours of collection with FIA analysis for dissolved phosphate.
- All samples will be labeled with the site name, date, what it will be sampled for, preservation method, and initials.
- All samples will be placed in a cooler with adequate ice immediately after collection and refrigerated once back at the lab.

Field Sampling Quality Control

Field Duplicates

- Allows for assessment of performance of laboratory equipment by comparison of field duplicate results.
- Collect a field duplicate for ten percent of all samples, or at least one duplicate per sampling event.
- Duplicates will be collected for each sample type (i.e. one preserved 500mL and one filtered 250mL)
- Collected simultaneously as original sample following same protocol except for being placed in separate containers.
- Assigned its own unique ID.

Field Blanks

- Minimum of one field blank prepared during each sampling event.
- Field blanks were preserved and packaged the same way as the samples.

- Field blanks were collected to evaluate whether contaminants had been introduced into the samples during the sampling event due to ambient conditions or from sample containers.
- Field blanks were made by adding DI water to the sampling container in the field.

Calibration Procedures

Marsh McBirney Flo-Mate 2000

- The Marsh McBirney Flo-Mate 2000 will be used to measure flow rate in the stream. It will be cleaned to remove any accumulation of oil on the electrode. After cleaning, the sensor will be placed in a five gallon plastic bucket of water in the field. The sensor will remains at least three inches away from the side and bottom of the bucket for 10 to 15 minutes until the water settles. Zero stability is ±0.05 ft/sec.
-

Flow Injection Analyzer Reagent Preparation Procedures

Safety

The following safety items must be worn at all times during any work in the lab:

- Long pants
- Closed-toed shoes
- Safety goggles
- Gloves
- Lab coat

Follow all other lab safety protocols during reagent preparation, as well as proper spill clean-up procedures.

Reagent Preparation

- All procedures are also described in the FIA instruction manuals located on the desktop of the FIA computer.
- All chemicals located in the upper left-hand cabinet opposite the flow injection analyzer, or the solid and liquid chemical cabinets

Ortho Phosphate Reagent Preparation Procedure

Carrier: De-ionized Water (1 Liter)

Chemicals Needed:

- 10.0 grams Ammonium molybdate tetra-hydrate (1235.81 FW)
- 0.2 grams Antimony Potassium Tartrate half-hydrate (333.94 FW)
- 40 mL concentrated H_2SO_4 acid (catalyst)
- 30 grams ascorbic acid (176.12 FW)
- 1.0 grams sodium dodecyl sulfate (288.38 FW) (surfactant)

Reagent 1: 6 mM Ammonium Molybdate

Total Solution: 1 Liter

Place acid into 800mL of DI water, mix and let cool to room temperature. Add molybdate and antimony potassium tartrate and mix until dissolved. Fill flask to the mark (1 liter). Transfer solution into a dark and airtight glass bottle for maximum longevity. This solution is stable for several weeks.

Reagent 2: Reagent Carrier Stream of 300mM Ascorbic Acid

Total Solution: 1 Liter

Place the ascorbic acid into a 1-liter volumetric flask and mix with 600 mL of DI water until dissolved. Add the sodium dodecyl sulfate and mix slowly (prevent foaming) until dissolved. Fill flask to the mark (1 liter). Transfer solution into an airtight light sensitive glass bottle for maximum longevity. This reagent degrades quickly (approximately 48 – 72 hours), so prepare fresh for each sample analysis run.

Total Phosphorus Reagent Preparation Procedure

Carrier: 1 liter de-ionized water and H_2SO_4 acid

Add 60 mL concentrated H_2SO_4 acid to 1 liter DI water. The acid is to match the total phosphate matrix

Reagent 1: 6 mM Ammonium Molybdate

- Same reagent and procedure as for ortho phosphate.

Reagent 2: Reagent Carrier Stream of 300mM Ascorbic Acid

Nitrate/Nitrite Reagent Preparation Procedure

Carrier: De-ionized Water (1 Liter)

Chemicals Needed:

- 43 grams ammonium chloride
- 20 grams sulfanilamide
- 50 ml concentrated phosphoric acid
- 0.50 grams N-1-naphthylethylenediamine dihydrochloride
- Dishwashing liquid

Reagent 1: 1.6M Ammonium Chloride Buffer (for nitrate only)

Mix 43 grams Ammonium chloride and 4 drops dishwashing liquid with DI water; make 500 ml TOTAL. Mix well and store in a dark bottle.

For nitrite, reagent 1 is not needed.

Reagent 2: Colorimetric Sulfanilamide Solution

Mix 20 grams sulfanilamide, 0.50 grams N-1-naphthylethylenediamine dihydrochloride, and 50 ml concentrated phosphoric acid with DI water to make 500 ml TOTAL. Mix well and store in a dark bottle.

Sample Analysis Quality Assurance/Quality Control

During all reagent preparation, stringent QA/QC procedures need to be followed, including:

- Analyzing a field duplicate every four samples
- Analyzing a lab duplicate every eight samples
- Analyzing a lab fortified blank (LFB) during each sample analysis run
- Analyzing a check standard at a known concentration during each sample analysis run
- Preparing standards for calibration curves using the same standard solution for all instruments
- Acid washing all glassware with DI water before use
- Only use DI water from the MBMG for reagent prep or carriers
- Use clean sample tubes, pipet tips, and trays for each sample

Appendix B: Model Inputs

GPS Survey Control Point Specifications

The NGS Data Sheet

Available here: http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=QY0638

See file dsdata.txt for more information about the datasheet.

```
PROGRAM = datasheet95, VERSION = 8.7.1
1        National Geodetic Survey,   Retrieval Date = AUGUST 11, 2015
 QY0638
************************************************************************
 QY0638  CBN          -  This is a Cooperative Base Network Control Station.
 QY0638  DESIGNATION -  BUTTE GPS
 QY0638  PID          -  QY0638
 QY0638  STATE/COUNTY-  MT/SILVER BOW
 QY0638  COUNTRY      -  US
 QY0638  USGS QUAD    -  BUTTE SOUTH (1996)
 QY0638
 QY0638                         *CURRENT SURVEY CONTROL
 QY0638
______________________________________________________________________
 QY0638* NAD 83(2011) POSITION- 45 58 04.59752(N) 112 31 03.25535(W)
ADJUSTED
 QY0638* NAD 83(2011) ELLIP HT-  1667.217 (meters)        (06/27/12)
ADJUSTED
 QY0638* NAD 83(2011) EPOCH   -  2010.00
 QY0638* NAVD 88 ORTHO HEIGHT -  1679.620 (meters)     5510.55  (feet)
ADJUSTED
 QY0638
______________________________________________________________________
 QY0638  NAD 83(2011) X  - -1,701,154.080 (meters)                   COMP
 QY0638  NAD 83(2011) Y  - -4,103,389.537 (meters)                   COMP
 QY0638  NAD 83(2011) Z  -  4,563,970.345 (meters)                   COMP
 QY0638  LAPLACE CORR    -           2.43  (seconds)
DEFLEC12B
 QY0638  GEOID HEIGHT    -         -12.42  (meters)
GEOID12B
 QY0638  DYNAMIC HEIGHT  -       1678.966 (meters)     5508.41  (feet) COMP
 QY0638  MODELED GRAVITY -    980,167.0   (mgal)                     NAVD
88
 QY0638
 QY0638  VERT ORDER      -  SECOND    CLASS II
 QY0638
 QY0638  Network accuracy estimates per FGDC Geospatial Positioning Accuracy
 QY0638  Standards:
 QY0638         FGDC (95% conf, cm)     Standard deviation (cm)     CorrNE
 QY0638            Horiz  Ellip           SD_N   SD_E   SD_h      (unitless)
 QY0638  -------------------------------------------------------------------
 QY0638  NETWORK     0.97   1.86            0.32   0.45   0.95      0.01950160
 QY0638  -------------------------------------------------------------------
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 QY0638  Click here for local accuracies and other accuracy information.
 QY0638
 QY0638
 QY0638.The horizontal coordinates were established by GPS observations
 QY0638.and adjusted by the National Geodetic Survey in June 2012.
 QY0638
 QY0638.NAD 83(2011) refers to NAD 83 coordinates where the reference
 QY0638.frame has been affixed to the stable North American tectonic plate.
See
 QY0638.NA2011 for more information.
 QY0638
 QY0638.The horizontal coordinates are valid at the epoch date displayed
above
 QY0638.which is a decimal equivalence of Year/Month/Day.
 QY0638
 QY0638.The orthometric height was determined by differential leveling and
 QY0638.adjusted by the NATIONAL GEODETIC SURVEY
 QY0638.in April 1998.
 QY0638
 QY0638.The X, Y, and Z were computed from the position and the ellipsoidal
ht.
 QY0638
 QY0638.The Laplace correction was computed from DEFLEC12B derived
deflections.
 QY0638
 QY0638.The ellipsoidal height was determined by GPS observations
 QY0638.and is referenced to NAD 83.
 QY0638
 QY0638.The dynamic height is computed by dividing the NAVD 88
 QY0638.geopotential number by the normal gravity value computed on the
 QY0638.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
 QY0638.degrees latitude (g = 980.6199 gals.).
 QY0638
 QY0638.The modeled gravity was interpolated from observed gravity values.
 QY0638
 QY0638. The following values were computed from the NAD 83(2011) position.
 QY0638
 QY0638;                     North         East     Units Scale Factor
Converg.
 QY0638;SPC MT       -   195,419.314   366,275.443   MT  0.99955719   -2 12
26.5
 QY0638;SPC MT       -   641,139.48  1,201,691.09   iFT  0.99955719   -2 12
26.5
 QY0638;UTM  12      - 5,091,605.442   382,423.574   MT  0.99976995   -1 05
28.3
 QY0638
 QY0638!             -  Elev Factor  x  Scale Factor =   Combined Factor
 QY0638!SPC MT       -   0.99973870  x   0.99955719  =   0.99929601
 QY0638!UTM  12      -   0.99973870  x   0.99976995  =   0.99950871
 QY0638
 QY0638                          SUPERSEDED SURVEY CONTROL
 QY0638
 QY0638  NAD 83(2007)-  45 58 04.59713(N)    112 31 03.25684(W) AD(2002.00) 0
 QY0638  ELLIP H (02/10/07) 1667.265  (m)                        GP(2002.00)
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 QY0638  ELLIP H (07/10/01) 1667.230  (m)                          GP(        ) 4
2
 QY0638  NAD 83(1999)-  45 58 04.59651(N)    112 31 03.25693(W)  AD(        ) B
 QY0638  ELLIP H (04/16/01) 1667.315  (m)                          GP(        ) 4
2
 QY0638  NAD 83(1992)-  45 58 04.59591(N)    112 31 03.25544(W)  AD(        ) B
 QY0638  ELLIP H (05/15/92) 1667.381  (m)                          GP(        ) 4
2
 QY0638  NAD 83(1986)-  45 58 04.58707(N)    112 31 03.23969(W)  AD(        ) 1
 QY0638  NAD 27      -  45 58 04.85190(N)    112 31 00.16420(W)  AD(        ) 1
 QY0638  NAVD 88 (03/21/94) 1679.6    (m)  GEOID93 model used    GPS OBS
 QY0638  NAVD 88 (05/28/92) 1679.7    (m)  UNKNOWN model used    GPS OBS
 QY0638  NGVD 29 (04/22/91) 1678.5    (m)  UNKNOWN model used    GPS OBS
 QY0638
 QY0638.Superseded values are not recommended for survey control.
 QY0638
 QY0638.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
 QY0638.See file dsdata.txt to determine how the superseded data were
derived.
 QY0638
 QY0638_U.S. NATIONAL GRID SPATIAL ADDRESS: 12TUR8242391605(NAD 83)
 QY0638
 QY0638_MARKER: DH = HORIZONTAL CONTROL DISK
 QY0638_SETTING: 7 = SET IN TOP OF CONCRETE MONUMENT
 QY0638_SP_SET: CONCRETE POST
 QY0638_STAMPING: BUTTE GPS 1987
 QY0638_MARK LOGO: NGS
 QY0638_MAGNETIC: N = NO MAGNETIC MATERIAL
 QY0638_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
 QY0638+STABILITY: SURFACE MOTION
 QY0638_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
 QY0638+SATELLITE: SATELLITE OBSERVATIONS - June 30, 2006
 QY0638
 QY0638  HISTORY     - Date     Condition        Report By
 QY0638  HISTORY     - 19870101 MONUMENTED       NGS
 QY0638  HISTORY     - 19900830 GOOD             NGS
 QY0638  HISTORY     - 19910814 GOOD             NGS
 QY0638  HISTORY     - 19931116 GOOD             NGS
 QY0638  HISTORY     - 19940219 GOOD             MTDOT
 QY0638  HISTORY     - 19950112 GOOD             MTDOT
 QY0638  HISTORY     - 19970806 GOOD             MTDOT
 QY0638  HISTORY     - 20010501 GOOD             NGS
 QY0638  HISTORY     - 20060630 GOOD             ADACLA
 QY0638
 QY0638                          STATION DESCRIPTION
 QY0638
 QY0638'DESCRIBED BY NATIONAL GEODETIC SURVEY 1987
 QY0638'THE STATION IS LOCATED ABOUT 1.6 KM (1.00 MI) NORTHWEST OF THE BUTTE
 QY0638'AIRPORT, ON THE SOUTH SIDE OF BUTTE, AT THE SOUTH SIDE OF THE
 QY0638'PROPERTY OF THE BUTTE DISTRICT OFFICE OF THE MONTANA STATE HIGHWAY
 QY0638'DEPARTMENT AND ALONG MEADOWLARK ROAD.
 QY0638'TO REACH THE STATION FROM THE JUNCTION OF INTERSTATE HIGHWAY 90 AND
 QY0638'HARRISON AVENUE, IN BUTTE, GO SOUTH ON HARRISON AVENUE FOR 1.84 KM
 QY0638'(1.15 MI) TO MEADOWLARK ROAD ON THE RIGHT.  TURN RIGHT AND GO WEST
FOR
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QY0638'0.72 KM (0.45 MI) TO THE HIGHWAY DEPARTMENT OFFICE ON THE RIGHT AND
QY0638'THE STATION AS DESCRIBED.
QY0638'THE STATION MARK IS A STANDARD DISK SET IN TOP OF A ROUND 16-INCH
QY0638'CONCRETE MONUMENT PLANTED 12 FEET IN THE GROUND.  IT IS 0.83 M
QY0638'(2.7 FT) SOUTHWEST OF A WITNESS POST, 1.03 M (3.4 FT) NORTHEAST OF
QY0638'ANOTHER WITNESS POST, 8.4 M (27.6 FT) EAST OF A CHAINLINK FENCE,
QY0638'13.10 M (43.0 FT) SOUTHEAST OF A POWER POLE AND FENCE CORNER, 17.6 M
QY0638'(57.7 FT) WEST OF A CURB OF THE WEST END OF A PARKING AREA AND 30.7 M
QY0638'(100.7 FT) NORTH OF THE CENTER OF MEADOWLARK ROAD.
QY0638
QY0638                          STATION RECOVERY (1990)
QY0638
QY0638'RECOVERY NOTE BY NATIONAL GEODETIC SURVEY 1990
QY0638'THE STATION IS LOCATED ABOUT 1.6 KM (0.99 MI) NORTHWEST OF THE BUTTE
QY0638'AIRPORT, AT THE SOUTH SIDE OF BUTTE, NEAR THE SOUTHERN PROPERTY LINE
QY0638'OF THE BUTTE DISTRICT OFFICE OF THE MONTANA DEPARTMENT OF HIGHWAYS
QY0638'AND ALONG THE NORTH SIDE OF MEADOWLARK ROAD.  OWNERSHIP--MTDH.
QY0638'TO REACH THE STATION FROM THE JUNCTION OF U.S. INTERSTATE HIGHWAY 90
QY0638'AND HARRISON AVENUE IN BUTTE, GO SOUTH ON HARRISON AVENUE FOR 1.84 KM
QY0638'(1.14 MI) TO MEADOWLARK ROAD ON THE RIGHT.  TURN RIGHT AND GO WEST ON
QY0638'MEADOWLARK ROAD FOR 0.72 KM (0.45 MI) TO THE MTDH OFFICE ON THE RIGHT
QY0638'AND THE STATION.
QY0638'THE STATION MARK IS SET 30.7 M (100.72 FT) NORTH OF THE CENTER OF
QY0638'MEADOWLARK ROAD, 17.6 M (57.74 FT) WEST OF A CURB AT THE WEST END OF
QY0638'A PARKING LOT, 13.10 M (42.98 FT) SOUTHEAST OF A FENCE CORNER, 8.4 M
QY0638'(27.56 FT) EAST OF A CHAIN LINK FENCE, 1.03 M (3.38 FT) NORTHEAST OF
QY0638'A WITNESS POST, 0.83 M (2.72 FT) SOUTHWEST OF ANOTHER WITNESS POST
QY0638'AND FLUSH WITH THE GROUND SURFACE.
QY0638'DESCRIBED BY C.W.W.
QY0638
QY0638                          STATION RECOVERY (1991)
QY0638
QY0638'RECOVERY NOTE BY NATIONAL GEODETIC SURVEY 1991
QY0638'THE STATION IS LOCATED ABOUT 1.6 KM (1.0 MI) NORTHWEST OF THE BUTTE
QY0638'AIRPORT, ON THE SOUTH SIDE OF BUTTE, SOUTHWEST OF THE BUTTE DISTRICT
QY0638'OFFICE OF THE MONTANA HIGHWAY DEPARTMENT AND ON THE NORTH SIDE OF
QY0638'MEADOWLARK ROAD.
QY0638'TO REACH THE STATION FROM THE JUNCTION OF INTERSTATE HIGHWAY 90 AND
QY0638'HARRISON AVENUE (EXIT 127), GO SOUTH ON HARRISON AVENUE FOR 1.84 KM
QY0638'(1.14 MI) TO A ROAD RIGHT.  TURN RIGHT AND GO WEST ON MEADOWLARK ROAD
QY0638'FOR 0.72 KM (0.45 MI) TO THE WEST END OF THE HIGHWAY DEPARTMENT
QY0638'PARKING LOT ON THE RIGHT AND THE STATION ON THE RIGHT.
QY0638'THE STATION IS A STANDARD DISK SET IN THE TOP OF A 16 FOOT (4.9 MT)
QY0638'DEEP CONCRETE MONUMENT THAT IS 14 INCHES IN DIAMETER AND RECESSED 8
QY0638'CM.  LOCATED 30.7 M (100.7 FT) NORTH OF THE CENTERLINE OF MEADOWLARK
QY0638'ROAD, 17.6 M (57.7 FT) WEST OF A CURB AT THE WEST END OF THE PARKING
QY0638'LOT, 13.1 M (43.0 FT) SOUTHEAST OF A FENCE CORNER, 8.4 M (27.6 FT)
QY0638'EAST OF A CHAIN LINK FENCE, 1.03 M (3.38 FT) NORTHEAST OF A
FIBERGLASS
QY0638'WITNESS POST AND 0.83 M (2.72 FT) SOUTHWEST OF ANOTHER FIBERGLASS
QY0638'WITNESS POST.
QY0638
QY0638                          STATION RECOVERY (1993)
QY0638
QY0638'RECOVERY NOTE BY NATIONAL GEODETIC SURVEY 1993
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QY0638'RECOVERED IN GOOD CONDITION.
QY0638
QY0638                          STATION RECOVERY (1994)
QY0638
QY0638'RECOVERY NOTE BY MONTANA DEPARTMENT OF TRANSPORTATION 1994
QY0638'RECOVERED IN GOOD CONDITION.
QY0638
QY0638                          STATION RECOVERY (1995)
QY0638
QY0638'RECOVERY NOTE BY MONTANA DEPARTMENT OF TRANSPORTATION 1995 (DRD)
QY0638'RECOVERED AS DESCRIBED.
QY0638
QY0638                          STATION RECOVERY (1997)
QY0638
QY0638'RECOVERY NOTE BY MONTANA DEPARTMENT OF TRANSPORTATION 1997 (GLT)
QY0638'RECOVERED AS DESCRIBED.
QY0638
QY0638                          STATION RECOVERY (2001)
QY0638
QY0638'RECOVERY NOTE BY NATIONAL GEODETIC SURVEY 2001 (AJL)
QY0638'RECOVERED AS DESCRIBED.
QY0638'
QY0638
QY0638                          STATION RECOVERY (2006)
QY0638
QY0638'RECOVERY NOTE BY ADAMS AND CLARK INC 2006 (GMD)
QY0638'RECOVERED IN GOOD CONDITION.

*** retrieval complete.
Elapsed Time
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