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Integration of QUAL2Kw and ArcGIS for Silver Bow Creek, Montana

By

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A non-thesis paper submitted in partial fulfillment of the
requirements for the degree of

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Abstract

The purpose of this project is to take preliminary steps towards the development of a QUAL2Kw model for Silver Bow Creek, MT. These preliminary steps include initial research and familiarization with QUAL2Kw, use of ArcGIS to fill in geospatial data gaps, and integration of QUAL2Kw and ArcGIS. The integration involves improvement of the QUAL2Kw model output through adding functionality to the model itself, and development of a QUAL2Kw specific tool in ArcGIS. These improvements are designed to help expedite and simplify the viewing of QUAL2Kw output data spatially in ArcGIS as opposed to graphically within QUAL2Kw. These improvements will allow users to quickly and easily view the many output parameters of each model run geographically within ArcGIS. This will make locating potential problem areas or “hot spots” much quicker and easier than interpreting the QUAL2Kw output data from a graph alone. The added functionality of QUAL2KW was achieved through the development of an excel Macro, and the tool in ArcGIS was developed using python scripting and the model builder feature in ArcGIS. Both the Macro and the ArcGIS tool, as well as all other pertinent data are open-source and are available for free at the MT Tech Digital Commons (http://digitalcommons.mtech.edu/grad_rschr1/).

Keywords: Silver Bow Creek, ArcGIS, QUAL2Kw, Model, Water Quality

Dedication

I wish to thank my loving fiancé Mallory for all her support and endless patience throughout the course of this project. I would also like to dedicate this to our daughter Avery Pearl Potts, who came into the world at the halfway point of my work. They have supplied me with the limitless motivation required for such an endeavor.

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1. Introduction

1.1. Site History

Butte, Montana is at the headwaters of Silver Bow Creek (SBC), which extends from Butte approximately 22 miles northwest to the Warm Springs Ponds (WSP) where it becomes the headwaters of the Clark Fork River. Butte has a rich mining history that began in the late 1880s and is continuing to the present day (Chavez & Mullen, 2012). Throughout the early history of mining in Butte, mine tailings and other mine waste were discharged directly to Silver Bow Creek (Chavez & Mullen, 2012; NRDP et al., 2005). Discharges of mine waste to SBC continued up until the 1970s (Chavez & Mullen, 2012; NRDP et al., 2005). These toxic discharges severely impacted the aquatic and riparian habitat along SBC (Chavez & Mullen, 2012; NRDP et al., 2005). In 1983, the Environmental Protection Agency (EPA) listed the Butte area including SBC as one of numerous Superfund sites in the Upper Clark Fork River Basin (UCFRB) (Chavez & Mullen, 2012). The mine tailings deposited along Silver Bow Creek were designated as the Streamside Tailings Operable Unit (SSTOU) within the comprehensive Superfund site (Chavez & Mullen, 2012).

A collaborative EPA and MT Department of Environmental Quality (DEQ) Record of Decision (ROD) was issued in 1995 that identified and outlined the site remedial strategies (Chavez & Mullen, 2012; NRDP et al., 2005). In 1999, Atlantic Richfield Company (ARCO) agreed through a legal settlement to pay \$215 million to the State of Montana for remediation and restoration work (Chavez & Mullen, 2012; NRDP et al., 2005). Approximately \$80 million of this was designated for the remediation of Silver Bow Creek with the remaining portion allocated to the UCFRB Restoration Fund (Chavez & Mullen, 2012; NRDP et al., 2005). Remediation of SBC began in 1999 and is ongoing to present day (Chavez & Mullen, 2012;

NRDP et al., 2005). In 2000, the Natural Resources Damage Program (NRDP), the Montana Department of Justice (DOJ), and the Greenway Service District (GSD) collaborated with DEQ to bring an additional restoration component that enhances the basic remediation required by Superfund (Chavez & Mullen, 2012). Since 1999 and continuing up to the present time, extensive remediation and reclamation of the mine tailings and other mine wastes as well as substantial restoration activities have considerably improved then environmental conditions along Silver Bow Creek (Chavez & Mullen, 2012; Plumb, 2009).

The removal of the toxic heavy metals in the mine tailings and other mine wastes has allowed higher forms of biota to flourish in SBC; however, excessive nutrients from the largely urbanized upper portion of the SBC watershed have created an eutrophication problem in SBC (Gammons et al., 2011; Parker et al., 2012; Plumb, 2009). Eutrophication in general refers to excessive primary productivity of aquatic plants and algae caused by an excessive input of nutrients (nitrogen and phosphorus compounds) into the system (Nimick et al., 2011; Plumb, 2009; Turner et al., 2009). Some primary production is good for the aquatic community, but eutrophication can be a problem for many reasons. Excessive plant and algal biomass can impede water travel, harm recreational areas, clog pipes, create an eyesore, and can adversely affect aquatic habitat. One of the most serious problems created by eutrophication is that it can cause large diurnal swings in water chemistry including dissolved oxygen (DO) levels, which can become depleted overnight and in the early morning (Turner et al., 2009). This problem has been well documented in SBC (Gammons et al., 2011; Parker et al., 2012; Plumb, 2009). Identifying the sources of nutrients to SBC and working to remediate and regulate those sources will likely be the next and possibly the final step in the cleanup and restoration of Silver Bow Creek.

1.2. Project Objectives

The original objectives of this project were to develop a QUAL2Kw model (discussed in section 2) of Silver Bow Creek and to predict the impacts that a planned upgrade to the Butte Metro Wastewater Treatment Plant (WWTP) would have on the water quality of SBC. Upon initial research of the QUAL2Kw model and assessment of available data, it was determined that in order to develop, calibrate, and validate a robust model, considerable amounts of field water chemistry data would need to be collected and analyzed including seasonal and diurnal samples. The budget for this project was inadequate to accomplish the required field data collection and analyses. The original objectives were modified to take the initial steps that would be required for developing a QUAL2Kw model of SBC. The steps include adding functionality to QUAL2Kw to improve the QUAL2Kw model output and using ArcGIS to fill in geospatial data gaps.

2. QUAL2Kw Overview

QUAL2Kw is a water quality model for natural environmental processes including flow dynamics, weather, morphology (to some extent), and nutrients (major ions) (Pelletier et al., 2006; Pelletier & Chapra 2008). The QUAL2Kw modeling framework is designed as an updated or “modernized” version of QUAL2E, which was released in 1987 (Brown & Barnwell, 1987). A water quality model called QUAL2K is widely used by the EPA and the Montana Department of Environmental Quality (DEQ). The current version of this model (version 2.11b8) is available to download for free from the EPA website <http://www.epa.gov/athens/wwqtsc/html/qual2k.html> or at <http://qual2k.com/>. QUAL2Kw is an expansion on QUAL2K that allows for simulation of multiple time periods or branches (Pelletier et al., 2006; Pelletier & Chapra 2008). This ability to simulate multiple branches is essential to

the goals of modeling SBC so that the output of the predicted water quality of a tributary branch can be input as a point source in the receiving branch. In the case of SBC, the effluent stream from the Butte Metro WWTP would be modeled as the point source tributary branch and SBC would be the receiving branch.

The version of QUAL2Kw used in this project is Version 5.1b5.2 (Version 5), which similarly to the QUAL2K version available through EPA is also public domain and open-source from the State of Washington Department of Ecology <http://www.ecy.wa.gov/programs/eap/models.html>. The newest version of QUAL2Kw is Version 6.0b3a1.2 (Version 6), which adds the capabilities of non-steady and non-uniform flow modeling through the use of kinematic wave flow routing, as well as transient storage zones. This latest version was recently released during fall, 2013 and is still in beta, with no documentation or known publications discussing application to natural systems. Until beta testing of Version 6 has been completed and documentation has been developed, Version 5 is recommended for use on SBC.

There are a wide variety of water quality models available, but there are numerous advantages to using QUAL2Kw for modeling SBC. As aforementioned, QUAL2Kw is open-source, which is cost-effective, but the main advantage is that the model is packaged as an Excel Workbook. This makes sharing the model very simple and quick because no special software needs to be purchased and no installation is necessary. The model program is written entirely in Visual Basic for Applications (VBA) programming language, which is Excel's Macro coding language. There is also a FORTRAN executable, which has proven to be very time efficient during multiple model runs because it is much faster than the VBA executable (seconds vs. minutes). Having a model entirely written in Excel was advantageous to this project, because it

allowed for adding to and modifying the VBA code to increase functionality with regards to data display and subsequent interpretation (discussed further in section 4).

2.1. QUAL2Kw Capabilities

QUAL2Kw version 5 is a one-dimensional, uniform, steady-flow water quality model with dynamic diurnal heat budget and water quality kinetics (Pelletier et al., 2006; Pelletier & Chapra 2008). A one-dimensional uniform model means that the model assumes the channel is well-mixed both vertically and laterally, so the output is generated as water quality parameter values for specified distances (reaches) downstream from the headwater location (i.e., the stream or river system is treated as a series of lines) (Pelletier & Chapra 2008). It must be assumed that the modeled parameters are constant across the entire width and depth of each location, which may be an acceptable assumption for a well-mixed system, but may be problematic for poorly-mixed systems with spatial variations in water chemistry. This model version also provides the option to include up to two transient hyporheic and/or surface storage zones per channel, which can add a degree of non-uniformity if so desired (Pelletier & Chapra 2008).

Producing diurnal output for each reach is very important for SBC or for similar relatively shallow and/or eutrophic water bodies (Gammons et al., 2011; Parker et al., 2012; Plumb, 2009; and Turner et al., 2009). Water bodies that are eutrophic and or have large substrate to volume ratios are more susceptible to large diurnal changes in water chemistry (Gammons et al. 2011). The diurnal heat budget allows for simulation of natural meteorological conditions that are continuously variable or repeating on a diurnal cycle. The dynamic water quality kinetics similarly allow for continuously variable or diurnally repeating simulations to allow for more accurate modeling of biogeochemical processes (Turner et al., 2009). In eutrophic systems, both attached algae (periphyton) and free-floating algae in the water column

(phytoplankton) can be important contributors to water chemistry parameters (Turner et al., 2009). Version 5 of QUAL2Kw allows for simulation of both periphyton and phytoplankton dynamics, as well as heterotrophic metabolism in the hyporheic zone and sediment diagenesis. This includes the option to simulate the preferential uptake of nutrients by periphyton with variable stoichiometry of nutrients (Nitrogen and Phosphorus species) (Pelletier et al., 2006; Pelletier & Chapra 2008).

Calibration of models is often one of the most time-consuming and difficult aspects of modeling. QUAL2Kw offers an automatic calibration option that utilizes a genetic algorithm to automatically calibrate the kinetic rate parameters (Pelletier et al., 2006). The genetic algorithm is called PIKAIA and is basically an optimization subroutine algorithm that essentially mimics natural selection to derive the optimal rate parameters and fitness of the model (Charbonneau & Knapp, 1995; Pelletier et al., 2006; Pelletier & Chapra 2008). PIKAIA is incorporated into QUAL2Kw as an Excel VBA Macro. Numerous attempts were made to utilize this Macro to calibrate a model for SBC based on data collected from a variety of sources, which would not be acceptable for true calibration, but were used in hopes of gaining a better understanding and working knowledge of QUAL2Kw. The automatic calibration using the PIKAIA genetic algorithm Macro was allowed to run for a maximum of approximately 36 hours and the Excel program locked up and crashed before any solution was ever achieved. It is uncertain, whether this is a flaw in the system or a problem with the input data, but if a SBC model is to be developed, this problem may require further attention. An Excel workbook containing the PIKAIA genetic algorithm is available for download from the State of Washington Department of Ecology's website (<http://www.ecy.wa.gov/programs/eap/models.html>), and may be useful if this issue is to be addressed during future modeling efforts.

2.2. QUAL2Kw Limitations and Data Gaps

Although QUAL2Kw has been proven to work well to simulate natural water quality processes in a variety of systems from around the globe (Camargo et al., 2010; Kannel et al., 2007; Oliveira et al., 2012; Turner et al. 2009) there are still a number of limitations. Some of the major limitations include:

1. Non-uniform mixing (2D or 3D);
2. Unsteady flow;
3. Watershed processes;
4. Reservoirs;
5. Organismal dynamics (zooplankton, macroinvertebrates, ichthyoids, etc.); and
6. Sediment adsorption/desorption.

A major limitation with regards to SBC is the inability to incorporate or model the geochemistry and/or speciation of metals. Although the entire extent of the streamside tailings have been or will be removed, which reduces the impact that metals have on SBC water chemistry, the SBC watershed and the Butte Hill are still a potential source of metals to SBC, particularly during storm runoff. Another major limitation that is specific to SBC is not a limitation of the model, but the limited availability of stream geomorphological data needed by the model.

QUAL2Kw requires the input of specific geomorphologic data that is used for calculating parameters such as slope, velocity, and travel time. The user must enter the specified reach data into the “reach” tab in the QUAL2Kw model. The user must also specify the length, upstream and downstream elevations, and the geographic coordinates of the downstream end of each reach. During the course of this work, no such data existed for SBC. The main reason for this lack of quality geospatial data for SBC is that the recent and ongoing restoration work has significantly altered the stream morphology. One of the primary goals of this project is to use

ArcGIS to generate the missing geospatial data including but not limited to: a digitized stream centerline, digitized stream reaches to be modeled, and all the corresponding coordinates, elevations, distances, slopes, and sinuosities. This objective will be discussed in more detail in section 3.2.2.

A final limitation that applies not only to SBC, but to all QUAL2Kw models is the format of the output data. QUAL2Kw output data can be viewed in tabular or graphical format within Excel. The model conveniently produces diurnal data for each pre-determined reach, and also tabulates the average, maximum, and minimum value of each parameter for each reach. The average, minimum, and maximum values of each modeled parameter are organized into three separate tabs within the model. However, for each parameter a single plot is generated, which displays the maximum, average, and minimum vales that correspond to each reach. These plots show the parameter value on the y-axis and the distance downstream on the x-axis. This type of plot allows modelers to view a 24-hr diurnal plot of specified parameters for each reach or view a plot of the average, maximum, and minimum values for each parameter as a function of distance downstream.

Although QUAL2Kw automatically generates the plots discussed above, these excel plots cannot easily be view geospatially on a map. Because the parameter values generated by the model correspond to specific geographic locations, the inability to view these values geospatially is a major limitation of the QUAL2Kw model. A primary goal of this project is to integrate QUAL2Kw with ArcGIS to address this limitation and allow the modelers to quickly and easily view any modeled parameters geospatially. This objective is discussed in detail in section 4.

3. ArcGIS

A Geographic Information System (GIS) is a system designed to improve the collection, storage, management, interpretation, and delivery of geospatial data. The first computer-based GIS was released by the Canadian Government as the Canada Geographic Information System (CGIS) in the 1960s (Price, 2014). The Environmental Systems Research Institute (ESRI) was founded in 1969 (Price, 2014). ESRI pioneered the concept of linking spatial features with attributes in a table, which is the core concept and function of modern GIS (Price, 2014). ArcGIS as we know it was first introduced by ESRI in 1999 as ArcGIS 8.0 (Price, 2014; Kennedy, 2013). ArcGIS is a geographic information system that contains various graphical user interfaces (GUIs) including, ArcMap, ArcCatalog, ArcView, and ArcScene and now ArcGIS includes a wide variety of online applications (Price, 2014; Kennedy, 2013). ArcGIS 10.1 was released in June, 2012 and is the version utilized for the work in this project.

3.1. Data Acquisition

To effectively generate the data needed to fill in the geospatial data gaps, certain data were needed. These data mainly include base layers, but also include various shapefiles, lines, and points. Reach endpoint data, and sampling locations were used to generate data for each pre-determined restoration reach.

3.1.1. Base Layers

The most versatile and highest resolution data currently available are LiDAR, which would have been ideal for this project. Unfortunately, the only LiDAR coverage available was a very small area obtained by Pioneer Technical Services, Inc. that encompasses less than 1 mile of SBC length. LiDAR is ideal because it contains imagery and high resolution elevation data in one dataset. For that reason, LiDAR files take up a large amount of file space, and are expensive

and time-consuming to obtain and process. Due to the lack of high-quality LiDAR data and the need for both high-resolution spatial data (x,y) and elevation data (z), a combination of basemaps were used and processed for this project.

3.1.1.1. Aerial Orthophotos

Aerial orthophotos are a mosaic of aerial photographs taken from airplanes or drones that have been stitched together to form one large seamless coverage. The seamless mosaic is then spatially rectified against known coordinates to ensure that coordinates and dimensions of the image are accurate and not distorted in any way, which is common in many map projections. Aerial orthophotos were obtained from the National Resource Information System (NRIS) for Montana (<http://geoinfo.montanastatelibrary.org/data/aerialphotos/>). These spatially rectified high-resolution (~1m) aerial photos were essential for this project particularly for accurate and precise stream digitization.

Due to the recent and ongoing restoration of SBC that has significantly altered the stream morphology, obtaining the most recent orthophotos was important. The primary orthophoto used for this project was mosaicked from four aerial images from 2011 that used the NAD83 HARN Montana (meters) coordinate system, to form one seamless orthophoto. This mosaicked orthophoto was “clipped” to include only the area needed for this project (i.e., the Silver Bow Creek watershed). The Clip tool in ArcGIS allows “clipping” of large files, which allows users to specify a particular area of interest and generate a smaller file from a larger file. The Clip tool helps with data management and file space usage, which can both be important factors to consider when working with ArcGIS.

Similar orthophotos from 2009 and 2005 were used in delineating tailings and in other comparisons. A large portion of the lower section of SBC, between Durant Canyon and the

Warm Springs Ponds was not yet restored or was in the process of being restored in 2011 so the 2011 orthophotos could not be used for these areas. Because of the time and effort needed to create orthophotos, the 2011 dataset was the most current orthophoto dataset available at the time of this work. Because aerial imagery is necessary for stream digitization, a set of 2013 aerial images were specially requested from NRIS. Although these images had not been orthorectified, they were carefully overlain on the 2011 orthorectified images in a transparent coverage to compare spatial accuracy. Although slight distortions were observed, which generally shifted the stream centerline to the west a maximum of approximately 1 meter, this degree of error was deemed acceptable because these images were the only option at the time to finish digitizing SBC.

3.1.1.2. Digital Elevation Model (DEM)

Digital elevation models or DEMs are digital elevation datasets. DEMs are typically formatted either as a raster, which is a grid of cells containing elevation data, or a triangular integrated network (TIN) which are composed of vectors containing elevation data (Price, 2014; Kennedy, 2013). Many of the DEMs used today were obtained through the Shuttle Radar Topography Mission (SRTM) in 2000 using a combination of single-pass synthetic aperture radar (SAR) and double-pass stereo pairs (Kennedy, 2013). All DEMs created using this method have inherent inaccuracies. DEMs generated from radar will reflect the first surface they hit, so if trees or other vegetation are present, the radar will reflect off the vegetation and the DEM will not be representative of the true ground surface. This is yet another reason LiDAR would be advantageous. DEMs generated from LiDAR penetrate through thick vegetation to accurately map the true ground surface; however, LiDAR cannot penetrate water, so mapping a streambed

or lake bottom would not be possible with LiDAR and even thick cloud coverage can prevent the collection of LiDAR data.

The typical resolution of DEMs obtained from the SRTM is 3 arc-second (~90 m), but for this project a 1/3 arc-second (~10m) DEM was obtained from the U.S. Geological Survey's (USGS) National Map Viewer (<http://viewer.nationalmap.gov/viewer/>). This DEM was derived from the National Elevation Dataset (NED) developed by the USGS and published in February 2013. This publication date does not mean that the data was acquired in 2013. The NED is a seamless mosaic of the "best available" elevation data obtained from various sources including SRTM, LiDAR, and other technologies. Once again a LiDAR DEM would have been ideal, because LiDAR can achieve resolutions down to the range of centimeters instead of meters or tens of meters obtained through the best conventional radar and stereo methods. A more recent DEM that depicts the land surface elevations during and after SBC restoration would also have been ideal, but the 10m DEM from the NED was the best elevation dataset available at the time.

The main use of the DEM for this project was simply to assign elevation data to the various Silver Bow Creek datasets. Accurate elevation data is essential when computing slopes, and slope data is used in QUAL2Kw for some of the rate kinetic equations for processes dependent on or affected by stream velocities (Pelletier et al., 2006; Pelletier & Chapra 2008). The DEMs obtained from the USGS National Map Server were imported as 4 separate approximate 1.2 gigabyte files that required additional processing before they could be used to generate SBC elevation data.

3.1.2. Silver Bow Creek GIS Data

As discussed in Section 2.2, QUAL2Kw requires specific geospatial data to be entered by the user in the "reach" tab. This reach data is an integral component of the model and it is

essential that it is accurate. Because Silver Bow Creek is a well-known stream that is part of a superfund site, it was thought that high quality GIS data would be readily available.

Unfortunately the best available GIS data from the USGS National Hydrography Dataset (<ftp://nhdftp.usgs.gov/DataSets/Staged/States/FileGDB/HighResolution/>) didn't account for the geospatial changes to SBC from the recent and ongoing restoration work even though the high resolution NHD dataset was updated in 2013. Due to the lack of high quality, up-to-date, geospatial data for SBC, the data needed for input into QUAL2Kw was developed from the best orthophoto and DEM datasets. During the process of creating GIS data for SBC, additional datasets, including 3D point files, and SBC rasters were developed, which will all be available on the MT Tech Digital Commons at http://digitalcommons.mtech.edu/grad_rsch/1/.

3.2. Data Creation and Processing

Because there was no high quality GIS data for the newly restored SBC, these data had to be created. The creation of these GIS data involved stream digitizing, which is a multi-step process in ArcGIS, and it required the addition of elevation data to the digitized stream. There are a variety of possible approaches and methods that could be used to reach the same end result of digitizing a high-resolution stream centerline that is broken up into specified reaches with elevation data assigned to each reach. The approach and methodology used for this particular project is described in the following sections.

3.2.1. Data Processing

Before any digitization of SBC data could begin, some of the base layers required pre-processing to convert them into proper formats for the tasks. The aerial orthophotos were imported as multiple images for each year, so they were mosaicked into one seamless image and clipped to cover only the square geographic area containing SBC. The clipping and mosaicking

was not necessary for the stream digitizing, but this significantly reduced the number and size of the files, which helped to save storage space and speed up other processes in ArcGIS.

Maintaining the smallest file sizes possible while working in ArcGIS substantially increases processing speeds, and reduces the incidence of problems saving and/or crashing the program.

The DEMs also required similar pre-processing, which was necessary not only to save file space, but for the processing of the SBC elevation data as well. The original DEMs were imported as four separate files that had a seam crossing SBC in multiple locations between the top of Durant canyon and the headwaters at Butte, MT. This seam would be problematic for any elevation processing of SBC because in ArcGIS it is only possible to choose to add elevation from one DEM. To manage this problem, the four DEMs were added to a mosaic, which was then converted to a raster and clipped to the same spatial extent of the aerial orthophoto mosaic. The reason for converting to a smaller raster as opposed a full size DEM was to conserve file space. During the processing of the DEMs over 20 gigabytes of file space were used, before the intermediate DEMs were deleted. All stages of the DEM use the GCS NAD83 coordinate system and the NAVD88 elevation datum (meters).

3.2.2. Stream Digitizing

The actual process of stream digitization is more tedious and monotonous than it is mentally taxing. The process of stream digitizing can be accomplished in a variety of ways, most of which were attempted during this project in an effort to decide upon and employ the most accurate method. The method used for this project was to simply use the draw tool with a straight line function (curved line was assessed, but it potentially adds erroneous sinuosity) and methodically trace the stream centerline. This was accomplished by zooming in to an optimal extent that typically ranged between 1:1,000 and 1:2,000, and using the mouse to click and trace

the approximate stream centerline. Once the edge of the computer monitor screen is reached the graphic image of the stream must be converted to a feature. This process generates many small features that represent tiny reaches of SBC, which must then undergo additional processing to create the desired streamlines and SBC data.

To create a single streamline for SBC, these many small reaches must have their endpoints snapped together using the “snap” tool. The line feature generated by the snap tool, must then be unsplit using the “unsplit line” tool. These two steps will inevitably require multiple attempts before the snapping and splitting parameters are adjusted properly. To create a SBC streamline that is separated into pre-determined reaches developed for the restoration process in the ROD, a point dataset of the reach endpoints was obtained from Pioneer Technical Services, Inc. These endpoints were located on the original SBC channel, which in many cases, was tens of meters away from the new channel location, so even this point dataset required processing. The reach endpoints were snapped to the closest location on the new digitized SBC streamline. Then the digitized streamline was split based on these new reach endpoints.

Once this dataset was developed, new distances of the restored SBC channel could be computed. Euclidean distance still needed to be measured and elevation data still needed to be added before slopes or sinuosities could be computed. Measuring the Euclidean distance was accomplished using the “distance between points” tool, and sinuosities were calculated using the field calculator function in the attribute table of the SBC streamline. Adding the elevation to the endpoints was accomplished using the “extract values to points” tool. Once the elevation of each endpoint was known, the average slope of each reach could be computed. This covers the primary datasets, but additional data was also generated during this process, which may be of value. For example, various other versions of SBC are available including three raster streamline

datasets of various cell sizes ranging from 1 foot to ten meters, and various SBC point datasets with x,y,z data are available and spacing ranges from over 1km down to 20m. These datasets contain built-in descriptions, which can be viewed under the “properties” tab in ArcGIS and are available for download from the MT Tech Digital Commons at http://digitalcommons.mtech.edu/grad_rsch/1.

Delineating the thalweg (deepest point in the channel) was discussed, but bathymetric data would be needed to accomplish this task, and the thalweg location is often dynamic and can change dramatically from a single high-flow event. Ultimately this task was not attempted; however, as mentioned in the previous paragraph, numerous datasets were generated during the process of creating the exact data desired for this project, and some of these datasets may have value for other projects related to SBC. A polygon of SBC that delineates both the left and right banks was also created, which is of no use for a one-dimensional model like QUAL2Kw, but may be of value for a two-dimensional or quasi-two-dimensional model like HEC-RAS. All of the digital data used, processed, or generated during this project will be publically available through the MT Tech Library’s Digital Commons at the following URL: http://digitalcommons.mtech.edu/grad_rsch/1/.

4. Integration of QUAL2Kw and ArcGIS

The purpose of the integration of ArcGIS and QUAL2Kw is to expedite and simplify the display of QUAL2Kw data in ArcGIS so that output parameters, which represent water quality at specific locations, can be viewed at those locations on a map. Exporting, reformatting, importing, choosing coordinate systems, converting to features, and changing other display options are a general simplification of the steps required to view just one QUAL2Kw output parameter from just one model run in ArcGIS. Streamlining or automating this process would

allow modelers to quickly and seamlessly pull the proper data from QUAL2Kw, display it on a map, and change the symbology to a quantified color ramp so that modeled data can easily be interpreted and correlated to actual field locations. To accomplish this integration, a variety of methods were considered and assessed. The final integration was accomplished with an Excel Macro developed with Visual Basic for Applications (VBA) coding, and with an ArcGIS tool developed using ArcGIS Model Builder and Python scripting.

4.1. Tool Development

Initially, with limited knowledge of ArcGIS Model Builder and no knowledge of the Python coding language used by ArcGIS, it was thought that the entire functionality of the tool could be contained in ArcGIS. Through researching and learning the basics of Python, and attempting to complete the tool solely within the ArcGIS platform, it was eventually determined, that additional pre-formatting of the QUAL2Kw output data would be needed prior to use in ArcGIS. Use of MATLAB was initially considered, but the desire to avoid the requirements of any additional software made the application of MATLAB impractical. The process of simply reformatting the QUAL2Kw output to a format used by ArcGIS was first attempted using queries in Microsoft Access, but this idea was also eventually abandoned for the simpler and more practical approach of using a Macro in Excel.

4.1.1. QUAL2Kw Macro

A very important step in the process of viewing QUAL2Kw output data in ArcGIS is the reformatting of the QUAL2Kw Excel tabular data. This task can be tedious and time-consuming because ArcGIS has very specific requirements with regards to how tables are formatted, and QUAL2Kw output tabulated data do not meet many of the formatting requirements of ArcGIS. Automating this reformatting process can save considerable amounts of time, if QUAL2Kw data

are to be viewed in ArcGIS. This automation process is a very important step because when a table is entered into ArcGIS, only the top row can be used as headings, and this row cannot contain any special characters or spaces. The QUAL2Kw output tabular data have multi-row headings that begin on the 7th row from the top and some of these headings contain spaces and/or special characters. The ArcGIS Export macro requires the ArcGIS_Export template Excel workbook, which already contains properly formatted column headings in the top row. The Macro copies all the modeled data from each of the QUAL2KW output tabs (average, minimum, and maximum) as well as the latitude and longitude data from the reach tab and pastes it into the ArcGIS_Export template. To avoid overwriting the template, the Macro also automatically saves the exported data in whatever folder the QUAL2Kw workbook is save in renames it with same file name the user entered in the QUAL2K (1) tab (cell B9) with a .xlsx file extension. The automation of this process can save considerable amounts of time for modelers who would like to view their QUAL2Kw output data geographically in ArcGIS.

Using a Macro in Excel is an ideal approach for a number of reasons. The entire QUAL2Kw model can be run using Macros by clicking the “Run VBA” macro button, so adding one more macro to export the desired output data and properly format it for use in ArcGIS requires the least amount of additional effort for the modeler. Once the model has been run, the modeler can simply click the “ArcGIS Export” button to run the macro. This eliminates the requirement of opening or even installing MATLAB, Microsoft Access, of any other software. The “ArcGIS Export” Macro can be stored within the QUAL2Kw model or it can be shared as an external Macro. This Macro was created using the developer suite in Excel and the macro code can be viewed in Appendix A.

4.1.2. ArcGIS Model Builder

As mentioned in the previous section, it was initially thought that the entire process could be accomplished using ArcGIS Model Builder. After some preliminary research and attempts, it was realized that reformatting the desired output tables from QUAL2Kw would be needed prior to any application in ArcGIS. ArcGIS model builder was used to automate the process of adding the properly formatted average, minimum, and maximum values of QUAL2Kw output data to the ArcMap, and joining it with three copies of the SBC dataset that was used to generate the reach data for QUAL2Kw. Accomplishing these tasks manually is not a difficult task, but it would take considerably more steps and therefore more time. The only problem with model builder is that its capabilities are limited to the use of existing tools and functions. Where model builder leaves off, Python scripting can be employed to truly customize an ArcGIS tool. The tool developed using model builder was exported as Python scrip so that additional python scripting could be used to enhance the model builder tool and to develop a custom tool with user-selectable input parameters.

4.1.3. Python Scripting

Python is a programming language developed by Guido van Rossum at the Centrum voor Wiskunde en Informatica (CWI) in the Netherlands and was first released in 1991 (Zandbergen, 2013). Python is free and open-source (FOSS) and is available for download at the website <https://www.python.org/>, but it is automatically installed with ArcGIS because Python is the programming language of ArcGIS. The version of Python used with ArcGIS 10.1 is Python 2.7.2, although python version 3.4.0 was released on March 17, 2014 (Python website). All of the ArcGIS work and Python scripting for this project has been accomplished using ArcGIS 10.1 and Python 2.7.2.

As discussed in Section 3, ArcGIS is composed of GUIs which are used to accomplish a multitude of various tasks and process. If these GUIs were not functioning, the same tasks could be accomplished through the use of a command line interface and using programming code. Python is the coding language of ArcGIS. Python allows automation of tasks within ArcGIS, that may be cumbersome, repetitive, or time-consuming using the regular GUIs. Python script was used to add functionality to the ArcGIS tool, which was developed using model builder. Python script was written to automate the display of the data as a categorized, quantified, generic color ramp after it has been imported using model builder. These display options can easily be manipulated in ArcGIS, so no additional python scripting was developed to further adjust the display. Python script was also essential for converting the script output from model builder into a custom tool within ArcGIS. With these Python additions to the model builder tool, the tool now has user-selectable input parameters, which allows for any file naming conventions as opposed to very specific file pathnames that would otherwise be needed.

4.2. Final Tool Capabilities

When the functionality of the Excel Macro and the ArcGIS tool are combined, QUAL2Kw model output data can be quickly and efficiently viewed within ArcGIS with the click of two buttons. The current Excel Macro has the capabilities of converting the average, maximum, and minimum parameter values corresponding to the geospatial model output from QUAL2Kw into a format that can be readily entered into ArcGIS with no previous GIS data required. The current ArcGIS tool can then add the properly formatted QUAL2Kw output data for SBC and join it with the Silver Bow Creek streamline that was used to generate the QUAL2Kw reach data, and then display the first parameter in the table as a categorized, quantified color ramp. The ArcGIS tool cannot currently be used for applications other than

Silver Bow Creek; however, beta testing of an ArcGIS tool that can be used for any QUAL2Kw application is currently underway, and may be released in the future.

5. Discussion

The primary goal of this project was to prepare initial data for the development of a robust QUAL2Kw model of SBC and to enhance the QUAL2Kw model output. Through the creation of the missing geospatial data as well as the creation of additional potentially useful GIS data, and the development of an operational Excel Macro and ArcGIS tool that help to integrate the two programs, the primary goals of this project have been achieved. Improvement of the ArcGIS tool so that it can be used for any QUAL2Kw application, is being considered. This improvement will require additional python scripting that after adding the excel table, automatically displays the x,y data, designates the proper coordinate system, and converts the features to a layer. If these steps can be achieved, then the python script that displays the data could be combined with the script that runs that process to form a fully functional tool for any QUAL2Kw application. Unlike the current tool, this tool would not require any additional GIS data to already be entered into ArcGIS.

6. Future work

One of the primary goals of this project was to prepare initial data for the development of a robust QUAL2Kw model of Silver Bow Creek. The completion of that objective opens up a perfect opportunity for the continuation of this project by collecting the necessary field water chemistry data, and then developing a robust QUAL2Kw water quality model. The collection of diurnal water chemistry data for at least two different flow regimes (high flow and low flow) and/or seasonal conditions (spring/fall), for at least two locations (upstream headwaters and a representative downstream location) would be the minimum amount of field data needed to

calibrate and validate a model. More data may be needed if calibration or validation is difficult, and more available data for calibration and validation should theoretically allow for the development of a more robust model. Even though it is likely too late to model the Butte Metro Wastewater Treatment Plant upgrade before it goes into effect, a robust SBC QUAL2Kw model could still be valuable for predicting responses to future land use changes, climate change, or other possible scenarios. With various agencies and companies connected to SBC, there may be considerable interest and/or funding available for just such an endeavor.

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Appendix A: QUAL2Kw Data

All QUAL2Kw data are available through the MT Tech Library's Digital Commons at the following URL: http://digitalcommons.mtech.edu/grad_rschr/1/

The Visual Basic for Applications (VBA) code for the ArcGIS Export macro is included below:

```

Sub ArcGIS_Export()
'
' ArcGIS_Export Macro
' Exports reach data and water quality data (avg, min, & max) to ArcGIS_Export template
and formats for use in ArcGIS.
'
' Keyboard Shortcut: Ctrl+Shift+E
Dim name As Variant
Dim wb As String

wb = ActiveWorkbook.Path
name = Range("z1").Value
ActiveWindow.ScrollWorkbookTabs Sheets:=31
ActiveWindow.ScrollWorkbookTabs Sheets:=15
Sheets("WQ Output (1)").Select
ActiveWindow.SmallScroll Down:=-3
Range("A11").Select
ActiveWindow.SmallScroll Down:=-9
Range("A9:AP1009").Select
Selection.Copy
Windows("Q2Kw_ArcGIS_Export.xlsx").Activate
Sheets("Avg").Select
ActiveWindow.SmallScroll Down:=-9
Range("G2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Windows("Q2Kw.xlsm").Activate
Sheets("WQ Min (1)").Select
Range("A9:AF1009").Select
Application.CutCopyMode = False
Selection.Copy
Windows("Q2Kw_ArcGIS_Export.xlsx").Activate
Sheets("Min").Select
Range("G2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Windows("Q2Kw.xlsm").Activate
Sheets("WQ Max (1)").Select
ActiveWindow.SmallScroll Down:=-18

```

```

Range("A9:AF1009").Select
Range("AF9").Activate
Application.CutCopyMode = False
Selection.Copy
Windows("Q2Kw_ArcGIS_Export.xlsx").Activate
Sheets("Max").Select
Range("G2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Windows("Q2Kw.xlsm").Activate
ActiveWindow.SmallScroll Down:=-15
Range("C986").Select
ActiveWindow.ScrollWorkbookTabs Position:=xlFirst
Sheets("Reach (1)").Select
Range("A10:F1010").Select
Application.CutCopyMode = False
Selection.Copy
Windows("Q2Kw_ArcGIS_Export.xlsx").Activate
Sheets("Avg").Select
Range("A2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Sheets("Min").Select
Range("A2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
Sheets("Max").Select
Range("A2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False
ActiveWorkbook.SaveAs filename:=wb & "\" & name & ".xlsx", FileFormat:=51,
CreateBackup:=False
End Sub

```

Appendix B: GIS Data

All digital GIS data are available through the MT Tech Library's Digital Commons at the following URL: http://digitalcommons.mtech.edu/grad_rsch/1/