USING ARCGIS PRO TO EVALUATE THE IMPACTS OF IN-STREAM BARRIERS ON FISH HABITATS

Case study: Bonneville Cutthroat Trout in the Bear River Watershed

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Introduction

In-stream structures provide myriad benefits to society. For example, reservoirs deliver drinking water, provide water for agriculture, generate hydroelectric energy, and protect our cities from flood events. Also, road crossing structures such as bridges and culverts can shorten our trips. However, these in-stream structures can negatively alter the environment of streams. For instance, diversion dams change the natural sediment regime of the streams in their upstream and downstream (Petts et al., 2005), and large dams vary the thermal patterns of the regulated downstream rivers (Olden et al., 2009). Any changes in the stream can consequently disturb the lives of the animals in that stream (Poff et al., 1997). For the GIS in Water Resources course term project, I focused on the Bear River watershed in northern Utah. I spatially analyzed the habitats for the Bonneville cutthroat trout (BCT) affected by the dams in this watershed. I used ArcGIS Pro for this spatial analysis.

In this report, I will first describe the study region and the BCTs' habitat requirements and characteristics. After that, I will explain my analysis methods on the habitats and finally conclude the report with presenting the results. In Appendix I, I will briefly elucidate the use of ArcGIS in creating the maps in this report.

Study region

The Bear River watershed is a ~7500 square miles drainage area that is shared among three states: Utah, Idaho, and Wyoming with shares of 44%, 36%, and 20%, respectively (Sehlke, 2005). The main stem of the watershed is the Bear River that originates in the Uintas mountain range at the elevation of ~13,000 feet and terminates into the Great Salt Lake at the elevation of ~ 4,211 feet (www.bearriverinfo.org). There are around 41 impoundments and small dams in the Bear River watershed, which I named and categorized based on their heights as Barriers (less than 10 feet tall), Impoundments (between 10 feet and 50 feet), and Small Dams (between 50 feet and 165 feet). Figure 1 shows the Bear River watershed and the dispersion of the dams within the watershed.

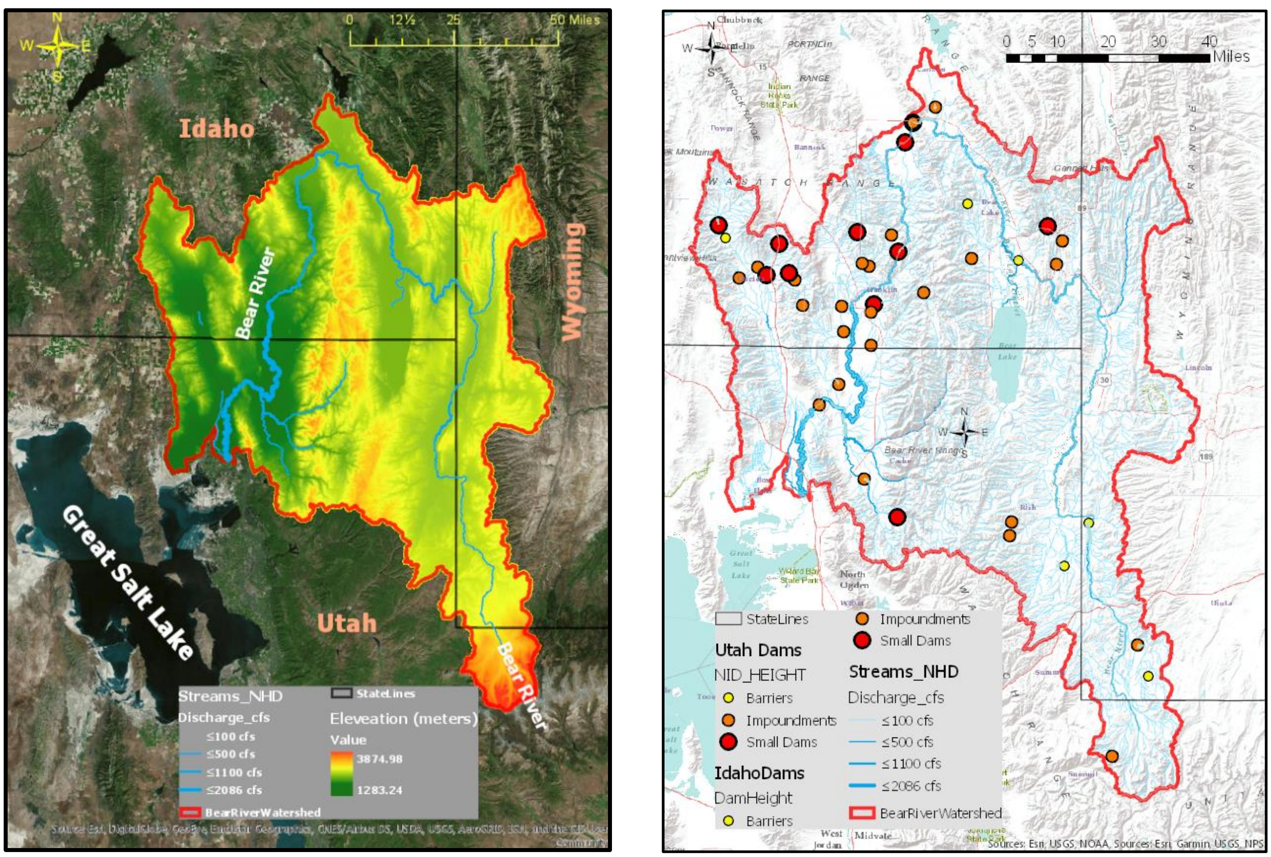


Figure 1: The Bear River watershed (left), the dispersion of the dams in the watershed (right) (Data source: hub.arcgis.com)

Bonneville cutthroat trout (BCT) habitats

The Bonneville cutthroat trout is one of the subspecies of cutthroat trout which was historically native to the Lake Bonneville, but the desiccation of this lake to the Great Salt Lake shifted the habitats of the BCTs to the Bear River watershed ([Kershner, 1995]). This subspecies typically need cold water with relatively high dissolved oxygen concentration ([Lentsch, 2000]).

A [report] by the U.S. Fish and Wildlife Service provides Habitat Suitability Index Models for cutthroat trout as suitability curves. The Suitability Index (SI) is a unit-less metric that specifies the suitability of habitat affected by any variables for fish survival, growth, and reproduction. It ranges between 0 to 1 with zero indicates no suitable habitat and one shows the best quality habitat ([Wu et al., 2006]). Figure 2 displays the historic and current ranges of the BCT habitats within the Bear River watershed.

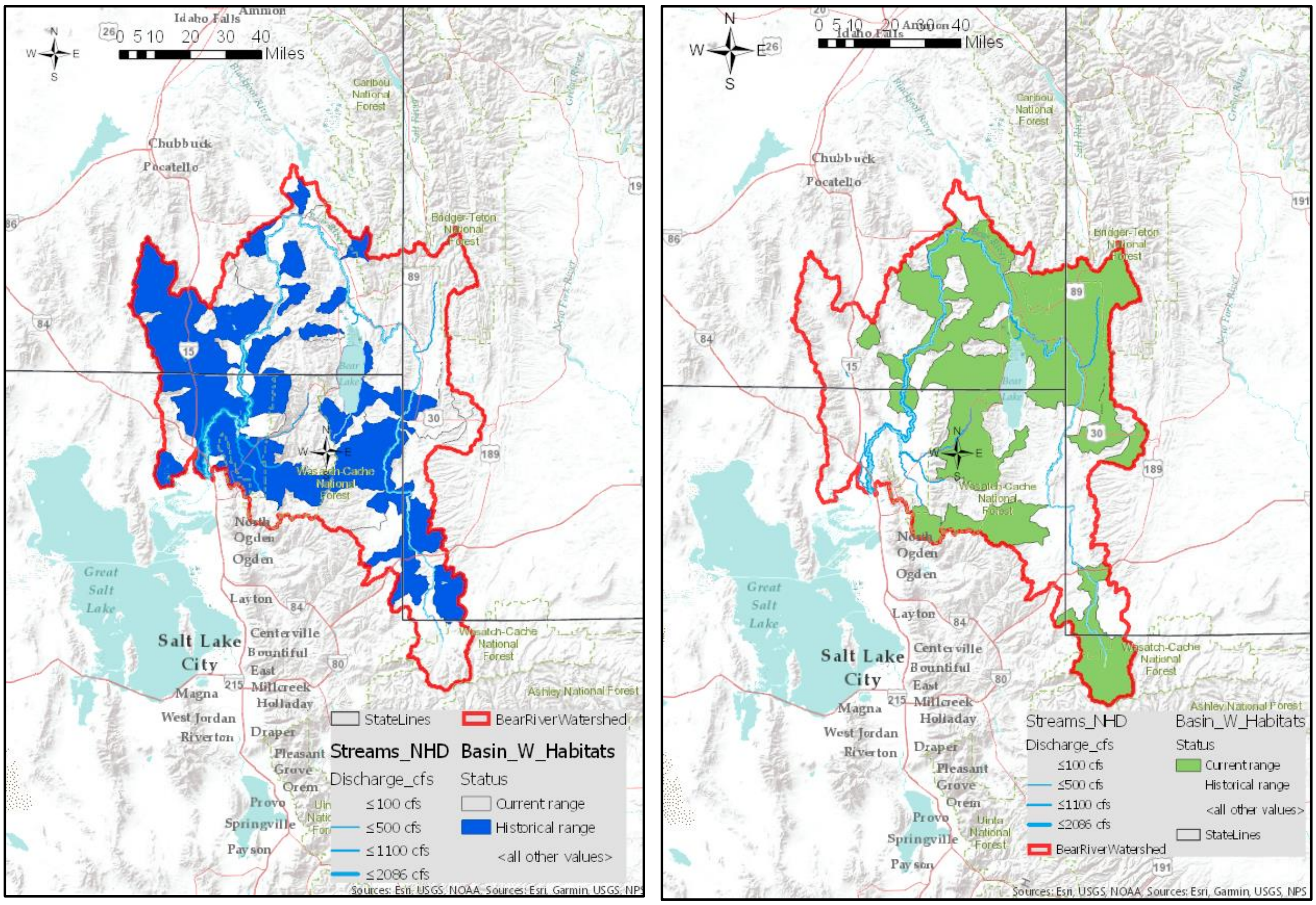


Figure 2: Historic (left map) and current (right map) ranges of the BCT (Data source: [Trout Unlimited])

BCT's habitat analysis

A suitable habitat for BCT is a complex function of stream hydraulics and geomorphological and environmental variables. Considering all these variables in a watershed-level analysis of habitat is a complicated and data-intensive task. In addition, there might be a lack of quality data in time and space. Therefore, I first searched for all reliable and available data in the Bear River watershed. I found out that I can obtain streamflow, water temperature, and channel bed gradient for the watershed from [NHDPlus] and [NorWeST] datasets. Furthermore, I noticed that I will be able to analyze the stream connectivity using ArcGIS Pro. As a result, I decided to divide the habitat analysis into two parts. In the first part, I used streamflow, channel bed gradient, and water temperature together to define fair, good, and best habitats in the watershed. In the second part, I examined the stream connectivity by calculating the stream lengths above each dam in the watershed and assumed each dam as an impassible barrier that disconnects the BCT's habitats. In the following sections, I will explain these two parts in details.

Habitat analysis based on variables

For analyzing the habitats, I first downloaded the NHDPlusV2 data for streamflow and channel bed gradient variables for the watershed. The NHDPlus dataset is an integrated suite of geospatial data products including the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), and the National Watershed Boundary Dataset (WBD) built by the US EPA Office of Water with assistance of the US Geological Survey.

For temperature data, I used NorWeST data set developed by the U.S. Department of Agriculture and the U.S. Forest Service. The Northwest Stream Temperature (NorWeST) database is a collection of temperature data from the existing data from agencies and from individual professionals that have collected temperature data in the western U.S. The NorWeST database contains over 220,000,000 temperature readings from over 22,700 stream or river sites (Isaak et al., 2017). This databases uses NHDPlus streams for presenting its temperature data. I used the mean August temperature for the period of 1993-2011 from this database to categorize BCT's habitat. Figure 3 shows the mean August stream temperature within the Bear River watershed.

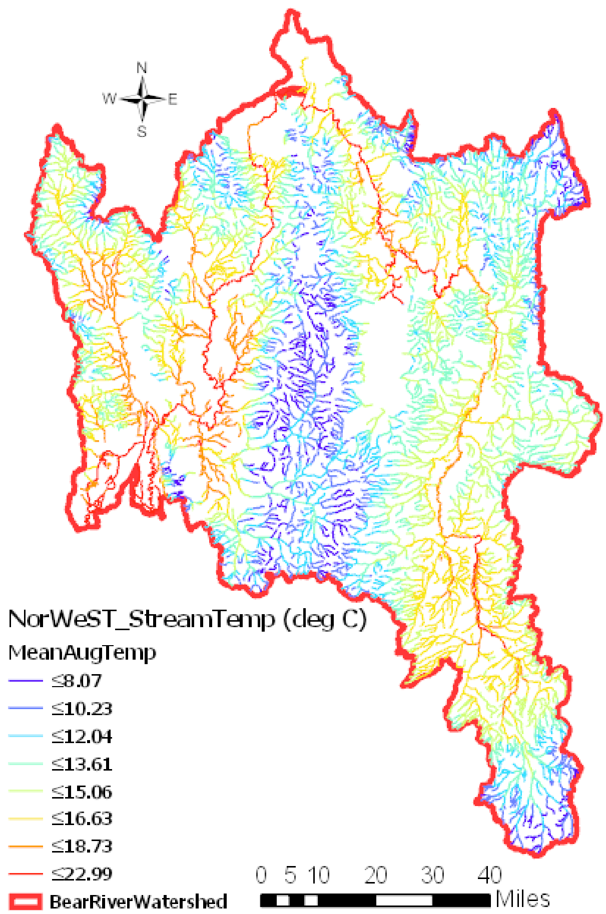


Figure 3: Mean August stream temperature (1993-2011) in the Bear River Watershed, Northern Utah (Data source: NorWeST)

I categorized the BCT's habitats into three groups of fair, good, and best by combining the streamflow, temperature, and channel bed gradient variables. Table 1 shows the definition of these categories based on the variable ranges.

Table 1: Habitat types based on the in-stream variables

Type of habitat	Streamflow ranges - Q (cfs)	Channel bed gradient (%)	August Water Temperature - T (° C)
Fair	Q > 15.0	$S_0 < 5.0$	T < 20.0
Good	Q > 40.0	$S_0 < 3.0$	T < 16.0
Best	Q > 50.0	$S_0 < 2.5$	T < 15.0

I joined the attribute tables of the NHDPlus and NorWeST datasets by their ComID (Common Identifier) in the ArcGIS environment and then used the "Select By Attributes" tool to identify and quantify the habitat types. Figure 4 illustrates the distribution of the habitat based on their types in the Bear River watershed. This data shows that as we apply more strict criteria for the habitat, they shrink. We can easily observe these shrinkages from green to grey segments in Figure 4.

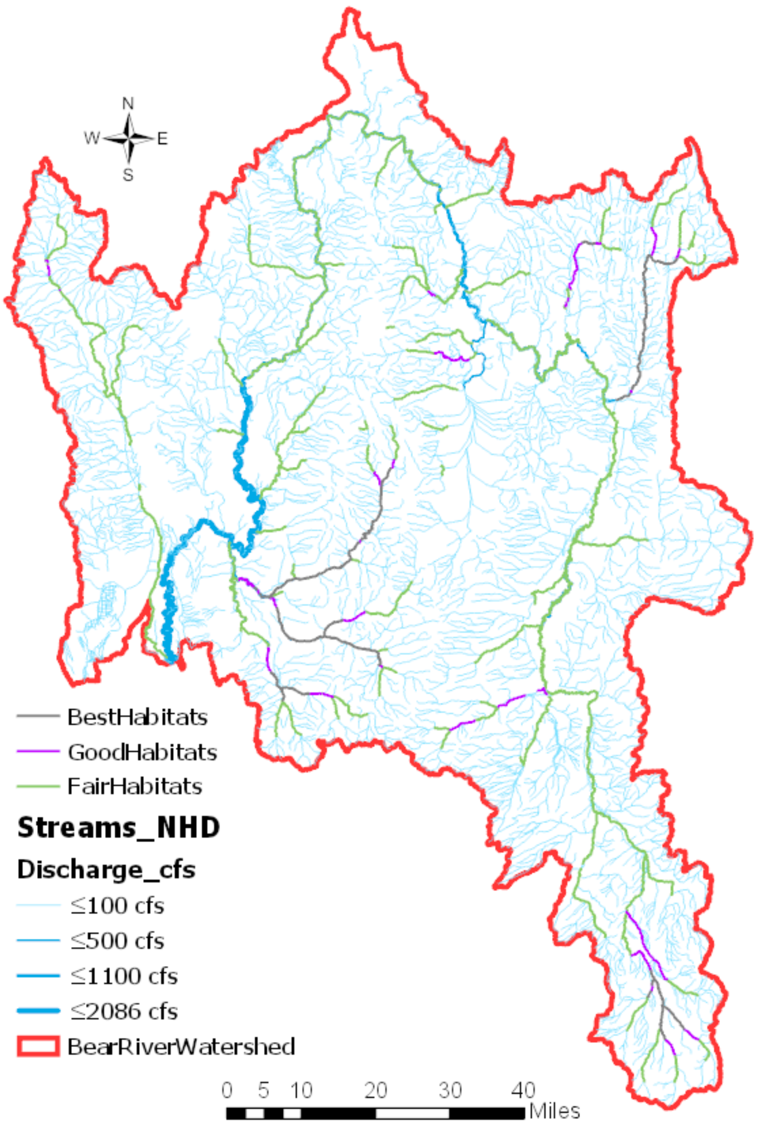


Figure 4: BCT's habitat types in the Bear River Watershed, Northern Utah

Table 2 shows the total stream lengths and their shares of the total stream lengths in the watershed for each types of habitats.

Table 2: Habitat lengths and percentage of total, based on the habitat types

Type of habitat	Streams Lengths (Km)	Total Stream Lengths of the watershed (Km)	Percentage of the total (%)
Fair	6,549	38,043	17.2
Good	1094	38,043	2.9
Best	477	38,043	1.3

Habitat analysis based on fragmentation

Dams and the impoundments that they create divide the streams into two different continuums in terms of in-stream variables such as water depth, velocity, dissolved oxygen, temperature, nutrients, and sediment regime (Granzotti et al., 2018). Beside the changes in the in-stream variables, dams and impoundments also disconnect the downstream and upstream sides of the dams which can stop fish from their natural movements. The changes in the variables and discontinuity resulted from dams can heavily impact fish species' life cycles and fragment their habitats (Compton et al., 2008).

To quantify the habitat fragmentation in the Bear River watershed, I decided to calculate the total stream length of each habitat types affected by dams. I only focused on those dams that affect habitat types. Since there are several dams in the watershed that affect the habitat types, I was looking for an automatic way to delineate the basin and stream lengths for each dam within the Bear River watershed. Therefore, I asked Dr. David Tarboton of Utah State University for suggestions. He provided and walked me through a Python code to automate the process of delineating the watersheds.

Python is an open-source, high-level, and cross-platform programming language that was introduced with ArcGIS 9.0. ArcGIS Pro uses Python 3 while other ArcGIS products uses Python 2 (pro.arcgis.com). There is a Python scripting environment in ArcGIS Pro that the codes can be written and implemented on it. For delineating the basins for the dams and calculating their total lengths in the Bear River watershed, I used the following code (mainly authored by Dr. Tarboton). This code has two parts to avoid repeatedly consuming USU's credits with the ESRI. The first part, the credit consuming part, delineates watershed. The second part provides the NHD flowlines and their lengths within the delineated watershed.

First Part of the code

```
#-------------------------------------------------------------------------------
# Name          Select Streams upstream of input points
# Description:  S
# Author:       David Tarboton and Ali Farshid
# Created:
#-------------------------------------------------------------------------------

import arcpy
import time
from arcpy import env
from arcpy.sa import *

# Set inputs
workDir=r"C:\Users\A02291464\Desktop\Ali\Fall 2018\CEE6440 GIS\Term Project\Term Project\Term Project.gdb"
myfile=r"C:\Users\A02291464\Desktop\Ali\Fall 2018\CEE6440 GIS\Term Project\Term Project\myoutput.txt"
F = open(myfile,"w")
env.workspace = workDir
env.overwriteOutput = True
arcpy.ImportToolbox("http://elevation.arcgis.com/arcgis/services;Tools/Hydrology", "hydro")
result=arcpy.agolservices.Watershed("Dams", None, None, "Meters", "FINEST", False, True)
while result.status < 4:
    print(result.status)
    time.sleep(0.2)
#print("Execution Finished")
arcpy.CopyFeatures_management(result.getOutput(0), "watershed2")
print("Watershed Written")
```

The first part of the code delineates the Bear River watershed. At the beginning I set the working directory to my term project geodatabase. Then the code imports the Hydrology toolbox for delineating the watershed. In the next step the *arcpy.agolservices.watershed ()* command uses the capability of the ArcGIS online sources to delineate the watershed by taking the dams locations as pour points with the options of "Meters" for the unit and "Finest" for the resolution. At the end of the first part, the *arcpy.CopyFeatures_management ()* command copies the generated watershed into watershed2 feature.

Second Part of the code

```
#-------------------------------------------------------------------------------
# Name          Select Streams upstream of input points
# Description:  S
# Author:       David Tarboton and Ali Farshid
# Created:
#-------------------------------------------------------------------------------

import arcpy
import time
from arcpy import env
from arcpy.sa import *

# Set inputs
workDir=r"C:\Users\labuser\Desktop\Ali\MyProject1\MyProject1.gdb"
myfile=r"C:\Users\labuser\Desktop\Ali\output.txt"
F = open(myfile,"w")
env.workspace = workDir
env.overwriteOutput = True

nwatershed=int(arcpy.GetCount_management("watershed2")[0])
for pourpointid in range(nwatershed):
    ppquery="PourPtId="+str(pourpointid+1)
    print(ppquery)
    selectwatershed=arcpy.management.SelectLayerByAttribute("watershed2", "NEW_SELECTION", ppquery, None)
    selectflowline=arcpy.management.SelectLayerByLocation("NHDPlus", "INTERSECT", selectwatershed, None,

                                                           "NEW_SELECTION","NOT_INVERT")
    outflowline="NHDSelect"+str(pourpointid+1)
    arcpy.management.CopyFeatures(selectflowline, outflowline, None, None, None, None)
    arcpy.analysis.Statistics(outflowline, "temptable","LENGTHKM SUM", None)
    tablecursor=arcpy.SearchCursor("temptable")
    fieldname="SUM_LENGTHKM"
    for row in tablecursor:
        # if you want all values in the field
        print(row.getValue(fieldname))
        #F.write("{pourpointid},{row.getValue(fieldname)}")
        F.write(str(pourpointid)+","+str(row.getValue(fieldname))+"\n")
F.close()
```

The second part of the code uses a loop to calculate the stream lengths for each dam's basin. The number of loops is equal to the number of the existing dams. The code first uses *arcpy.management.SelectLayerByAttribute ()* command to select basins within the Bear River watershed. Then it uses *arcpy.management.SelectLayerByLocation()* command to select NHDPlus flowlines which intersects with the basin. Finally, the code uses *arcpy.analysis.Statistic s ()* command to sum up the stream lengths. At the end, the code publishes the results in a text file and saves it in the original folder.

After this step, I calculated the stream lengths with Fair, Good, and Best habitats for the four major dams that greatly fragment the fish habitat. I used the "Select By Attribute" tool to select the desired habitat type within the basin. Then I copied the selected feature as a new table. Then, I opened the table and used the "Summarize" option to sum the length of the selected habitat. Table 3 shows the results of this procedure.

Table 3: Habitat lengths and percentage of total, based on the habitat types

Dame Name	Longitude	Latitude	Total U.S. Stream Length (Km)	Total Length of fragmented habitat (Km)		
				Fair Habitat	Good Habitat	Best Habitat
WOODRUFF NARROWS	**-111.01500**	**41.50500**	**1,809**	**764.7**	**244.52**	**86.4**
HYRUM	**-111.87444**	**41.62472**	**441**	**121.42**	**65.71**	**31.81**
ELKHORN	**-112.41519**	**42.30753**	**298**	**35.91**	**4.76**	**0**
WOODRUFF CREEK	**-111.31667**	**41.46667**	**97**	**26.31**	**8.69**	**0**

Conclusion

For the GIS in Water Resources course's term project, I decided to spatially analyze the BCT habitats in the Bear River watershed in northern Utah using ArcGIS Pro software. This study used the publicly available datasets to define a simple habitat representation for BCT that can be applied to the entire watershed. Analysis based on the set of streamflow, water temperature, and channel bed gradient showed that 6,549 km of the streams in the watershed are Fair habitats for the BCT. These Fair habitats include 1094 km and 477 km of Good and Best habitats, respectively. The second part of the analysis revealed that four major dams in the watershed have largely fragmented the Fair and Good habitats.

Appendix I (Step by Step Map Creation)

1. I obtained the USGS gage data from the Bear River watershed near Corinne, UT from the USGS NWIS website.
    a. USGS 10126000 BEAR RIVER NEAR CORINNE, UT
        i. Latitude 41°34'35", Longitude 112°06'00" NAD27
        ii. Box Elder County, Utah, Hydrologic Unit 16010204
        iii. Drainage area: 7,029 square miles
        iv. Datum of gage: 4,204.60 feet above NGVD29.
    b. This gage will be assumed to be the outlet of the Bear River watershed.

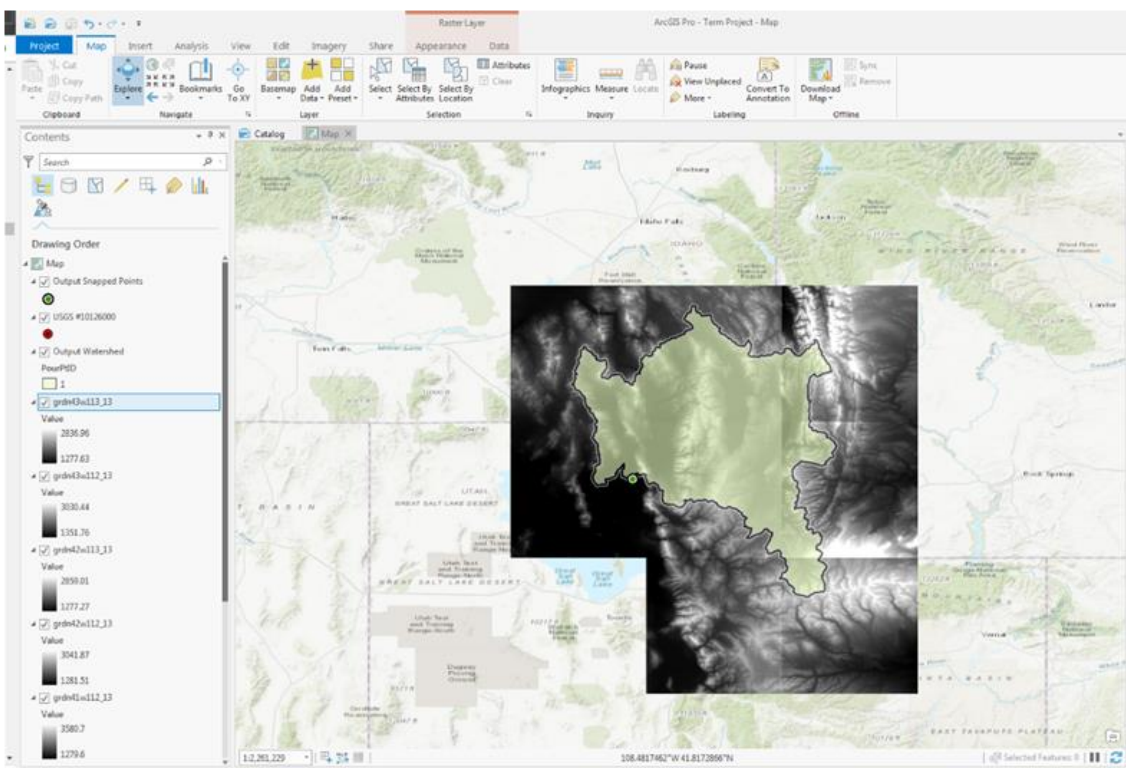
2. I computed the latitude and longitude to the USGS gage the decimal degrees as following. Then, I added it to my map.

LatDeg	LatMin	LatSec	LongDeg	LongMin	LongSec	LatDD	LongDD
41	34	35	112	6	0	41.57639	-112.1

3. I used ArcGIS online tool to delineate the Bear River watershed at Corinne, UT.

4. I downloaded 8 digital elevation models (DEMs) for this watershed from the National map website. The available data for this area was 1/3 arc-second DEM.

5. These DEMs is in 1 degree by 1 degree tiles that I merged them into a single DEM for the entire watershed.



6. These DEMs is in 1 degree by 1 degree tiles that I merged them into a single DEM for the entire watershed (I used "Mosaic to New Raster" geoprocessing tool.) It took 8 minutes and 42 seconds to complete this task.

7. Then, I used the NAD 1983 UTM Zone 12 N Coordinate System to organized my data into a consistent projection. ("Create Feature Dataset" to copy all features to a single correct projected base map)

8. Then, I extracted the merged DEM for the Bear River watershed. Before doing that, I created 1 kilometer buffer around the watershed to avoid edge effects. ("Buffer"→"Extract by Mask")
9. Before proceeding, I had to change the masked DEM to the consistent projection. ("Project Raster")

10. Then, I followed the standard procedure of: Fill pits → Flow Direction → Flow Accumulation → Define Watershed → Define stream segments → Delineate Catchments that Drain to them → Convert streams to vector → evaluate stream orders → subwatersheds draining directly to each stream gages.
    a. Fill the sinks to avoid the traps that stop water from moving.
    b. Flow Direction calculates the flow direction for each cell in the filled DEM grid based on D8 method.
    c. Flow accumulation → 181904520 cells =>
        1. The surface are of the watershed: 18,190.45 Km^2 = 7023 mi^2
        2. Surface area of the watershed from the USGS website = 7029 mi^2
    d. Stream Definition → For this watershed, the streams defined as cells with flow accumulation greater than 5,000 cells.
    e. To make sure that the streams are within the watershed entirely, I had to clip the buffer.
    f. In the next step, I created stream links. These are segments of the streams that have a unique identifier.
    g. In this step, I converted the Streamlinks and Catchments to vector representations.

11. The following tables shows the data sources that I used for this project:

Data Type	Source
River networks, watershed boundaries, streamflows	NHDPlus v2
Digital Elevation Model	The National Map
Observed and predicted stream temperatures	NorWeST Stream Temp
Gradients	NHDPlus v2
In-stream structures in Utah	Utah Division of Water Rights' website
In-stream structures in Idaho & Wyoming	ArcGIS Hub / National Inventory of Dams
BCT's habitat ranges	Trout Unlimited

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