HYDROLOGICAL RIPARIAN ZONE MAPPING

Sponsor: MINISTRY OF FORESTS/WATER, LAND AND RESOURCE STEWARDSHIP

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Program: ADVANCED DIPLOMA IN GIS APPLICATIONS

2023-2024

VANCOUVER ISLAND UNIVERSITY

PRACTICUM SUMMARY REPORT

Contents

A. PROJECT OBJECTIVE

Background: Riparian zones are areas of rich vegetation found surrounding lakes, rivers, streams, and wetlands. They form transitional ecosystems between aquatic and terrestrial environments, sharing characteristics from both systems. Riparian zones fulfill numerous ecological roles, including maintaining water quality and temperature, filtering pollutants from runoff, and preserving aquatic ecosystems. The root systems of riparian vegetation contribute to bank stability, mitigate erosion, and play a crucial role in minimizing flood risks for adjacent communities.

Motivation: In recent years, rising water temperatures have significantly affected aquatic ecosystems, attributed to factors such as climate change and the modification of riparian ecosystems due to various human activities. Riparian vegetation plays a pivotal role in directly influencing aquatic ecosystems by providing shade, thereby maintaining cooler water temperatures. Additionally, the vegetation, along with its debris and insects that fall into the water, serves as a vital food source for fish. Establishing a defined riparian zone stands out as one of the most effective strategies for conserving aquatic ecosystems, as it helps safeguard the riparian vegetation surrounding water bodies.

Objectives: Studies have demonstrated a close relationship between riparian ecosystems and their associated flood zones (Abood, 2012) (Dingaroğlu, 2015). Building upon these findings, this study aims to explore the feasibility of a comprehensive approach that integrates LiDAR (Light Detection and Ranging) technology and ESRI ArcGIS Pro tools to delineate hydrological riparian zones. The primary objective is to derive high-resolution digital elevation models (DEMs) based on LiDAR data and utilize advanced spatial analyses to identify and characterize detailed depression zones. Additionally, the study seeks to provide insights that support the development of hydrologically meaningful riparian zones, thereby contributing to the conservation of lake ecosystems.

Sponsor: This study was sponsored by the Research Section of West Coast Natural Resource Region team at Ministry of Forests/Water, Land and Resource Stewardship (MoF/WLRS). This team is responsible for implementing research projects on fluvial and ad fluvial populations of native trout and char in the West Coast Region. Two of their research projects: ‘Forestry/climate change impacts to headwater streams and downstream reaches’ and ‘An examination of small lakes and riparian forests in the South Coast of BC,’ work towards understanding climate change impacts to headwater streams, downstream reaches, lakes, and wetlands. Due to climate change and modification of riparian zones, water bodies may experience shifts in water temperature and discharge, changes to productivity and disruptions to nutrient exchange between riparian and aquatic ecosystems. The results from this study would be used in these research projects.

B. WORK COMPLETED

This practicum consisted of the following tasks:

Task Name	Estimated/New
1. Pre-process data	Estimated
2. Delineate Lake Riparian Zone	
3. Delineate Stream Riparian Zone	
4. Compare Riparian Zone	
5. Process Habitat Data	
6. Update Existing Tool	
7. Prepare Methods Document	
8. Log daily tasks	
9. Prepare research paper materials	New

Detailed summary of each task:

1. Pre-Process Data

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	Easy	Moderate	Time Consuming

This task involved acquiring raw LiDAR files for lakes and streams, a total of approximately 600 files from LiDAR BC portal and processing to a file format compatible for further analysis. Initially, ArcGIS tool Convert LAS used for this conversion process, required 4 hours to convert 20 LiDAR files. To reduce the time consumption, a python script (Fig.1) was written to automate this task. This method allowed working with ArcGIS Pro while the python script executed in the background. However, this method also required 4 hours to convert 20 LiDAR files. To address this challenge, a new tool FME (Feature Manipulation Engine), was used to perform LiDAR file conversion. The FME script required less than 1 hour to convert 20 LiDAR files. The transformer shown in the Fig.1 was used to convert multiple .laz files in to .las files required to derive DEM. Of the three tools namely ArcGIS Pro, Python, and FME used for LiDAR file conversion, the FME tool provided the most efficient and quick execution.

```
pys > las.py > ...
import os
import arcpy
fldr=r"C:\viu\giscoursework\591\Practicum\LeewardIslandMtnRgn\LIM"
sr = arcpy.SpatialReference(3005)

for file in os.listdir(fldr):
    if file.endswith(".laz"):
        in_las=os.path.join(fldr,file)
        arcpy.conversion.ConvertLas(in_las, fldr, 'SAME_AS_INPUT',7,
        'NO_COMPRESSION' , [ 'REARRANGE_POINTS'])

arcpy.management.CreateLasDataset(fldr, fldr+r"\LIM.lasd","NO_RECURSION","", sr,
"COMPUTE_STATS","RELATIVE_PATHS","NO_FILES","","","")
```

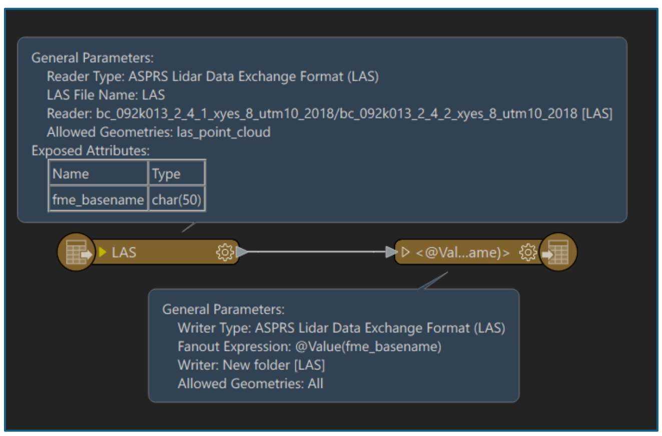


Figure 1: Python script to convert LiDAR files, FME script to convert LiDAR files.

2. Delineate Lake Riparian Zone

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	Moderate	Difficult	Scale increased beyond estimation

Study Area

This study was conducted on small lakes within the West Coast and South Coast Natural Resource Regions of British Columbia (Fig.2). Lakes ranging from 5-1000 Hectares in size were categorized based on Ecosection within the study area, refined by the availability of LiDAR data, and 10% of the total count were chosen for this study. A diverse selection of 6 lakes (Fig.3), representing varied relief conditions, were utilized as a sample set for a deep-dive analysis to construct a model using Model Builder. This model was subsequently scaled to delineate depression-based riparian zones for 248 lakes (Fig.3) within the study area.

Figure 2: Natural Resource Regions of BC

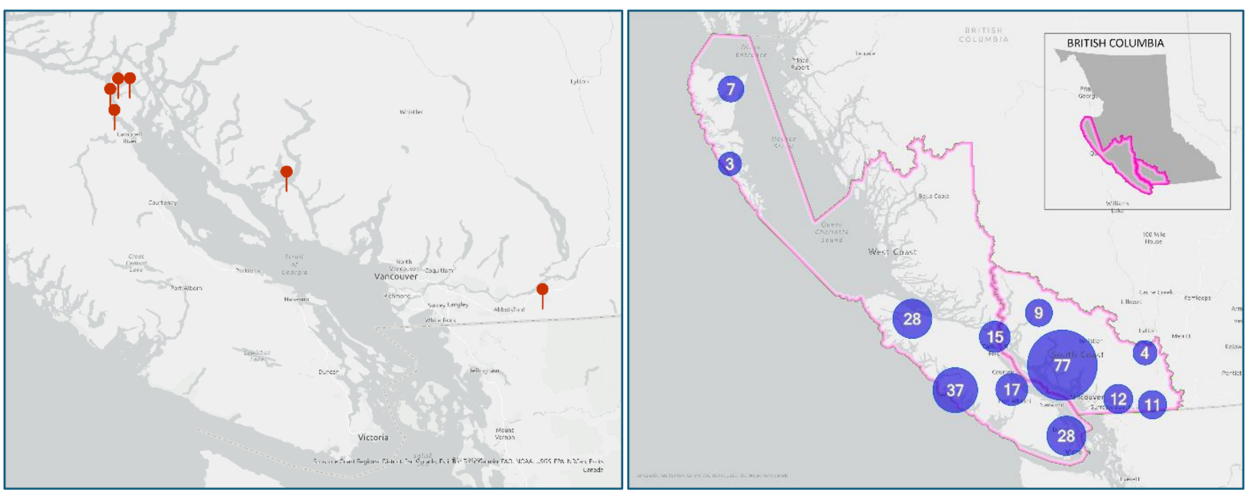


Figure 3: Sample set of 6 Lakes, Study Area 248 Lake Locations.

LiDAR Processing

Data for specific lakes within the study area were acquired by selecting appropriate map tiles and downloading the corresponding LiDAR files. For visualization purposes, the downloaded data needed to be converted to a format compatible for viewing on ArcGIS Pro map view. In instances where lakes span multiple map tiles, the Create LAS Dataset tool was used to combine multiple las files into a single .lasd file. The NAD 1983 CSRS BC Environment Albers coordinate system was used in this study.

LiDAR-based DEM

The DEM was extracted from the LiDAR dataset by applying LAS Filter to select the ground classification code. Then, LAS Dataset to Raster with Elevation value field was utilized to generate a DEM with a 1-meter spatial resolution. Further processing of the DEM was done by applying Focal statistics and Raster Calculator to identify null values and replace them with the average elevation value within a rectangular window. This smoothed DEM (Fig.4) served as the input for calculating depression zones.

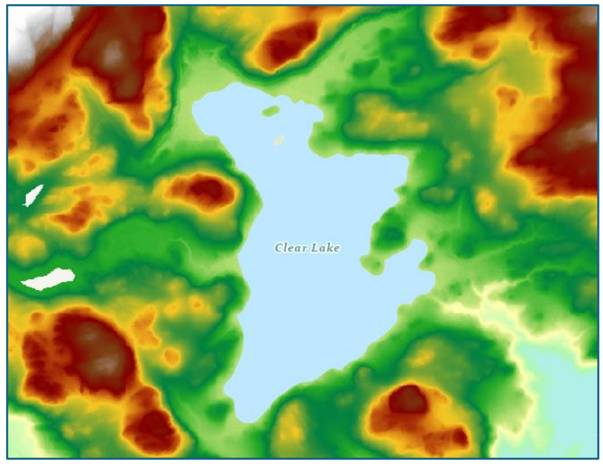


Figure 4: Digital Elevation Model

Terrain Depression

The Depression Evaluation Arc Hydro for Pro tool (Dingaroğlu, 2015) was used to extract depression cells from the DEM. This built-in Python script tool conducted various computations, including filling sinks in the DEM, identifying depressions, extracting flow direction, drainage area, depression watersheds, and ultimately applying zonal statistics to generate a depression grid. The depression cells thus extracted provide an overview of depression areas surrounding the lake. Refer to the Fig.5 illustrating depression cells highlighted in red.

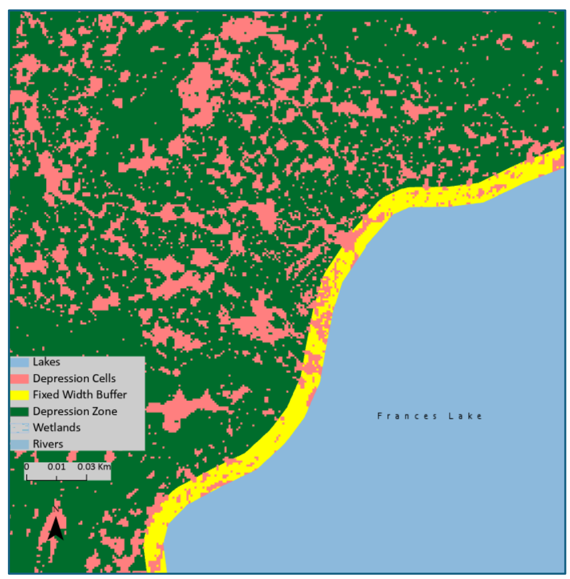


Figure 5: Depression cells around lake.

The Extract Smooth Depression DEM tool generates a smooth depression zone around the identified depression cells using two key parameters: depression minimum size and depression buffer distance. The depression minimum size parameter enables users to set a minimum threshold for the number of cells required to define a depression area. A depression as small as 1 meter by 1 meter, or a single cell, could potentially be considered noise and might not accurately represent a depression area.

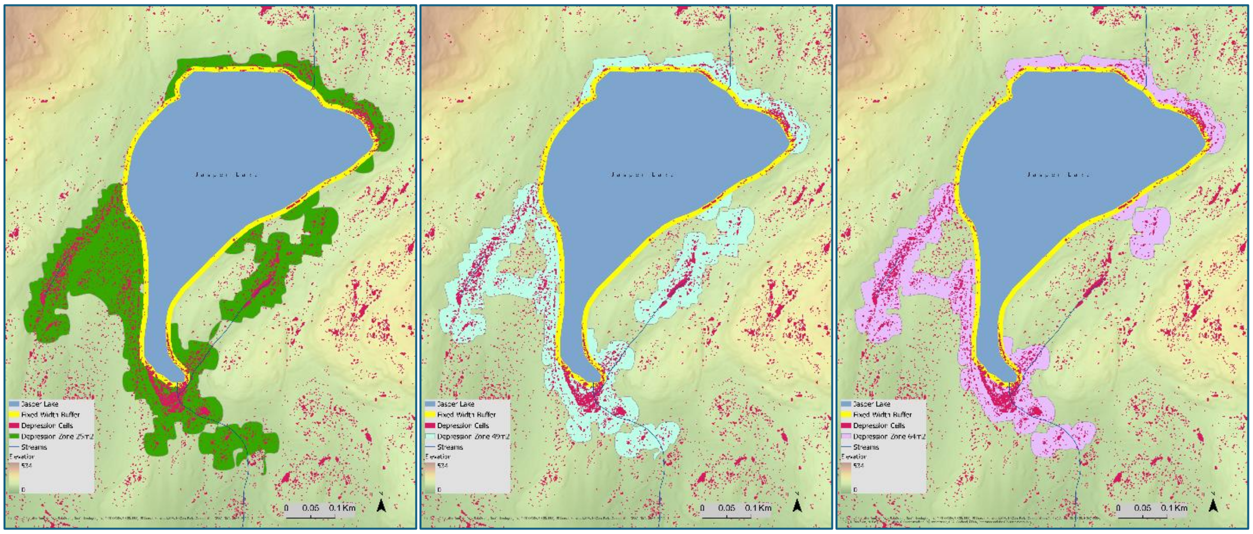


Figure 6: Depression Zone Comparison between minimum size of 5, 7, and 8 cells.

Previous studies, such as Dingaroğlu (2015), defined a depression area larger than one cell (60 m^2). However, utilizing a LiDAR-based DEM with a spatial resolution of 1m, enables extraction of depression areas as small as $1m^2$. Through a comparison of different thresholds (Fig.6), including 5 cells ($25m^2$), 7 cells ($49m^2$), and 8 cells ($64m^2$), it was determined that a minimum size of 5 continuous cells adequately captures a depression area large enough to support riparian vegetation.

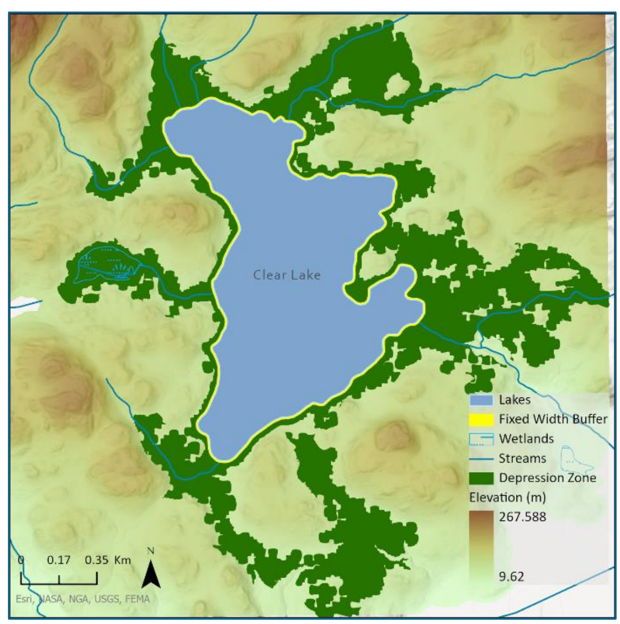


Figure 7: Smooth Depression Zone representing Riparian Zone around the lake.

<u>Riparian Depression Zone</u>

The final riparian depression zone polygon (Fig.7) was created by selecting depression polygon features in proximity to the lake, aggregating the selected polygon features, and using Bezier interpolation to smooth the polygon edges.

The varying width of a depression zone was measured using transect (Abood, 2012) and spatial join tool. The depression zone around lakes were compared to the lake shore elevation to understand the correlation between variations in the depression zone width and terrain elevation. The Feature to Line tool was used to convert the depression zone polygon to a line feature. The Transect tool was used to build transects every 10m on the depression zone line feature. The spatial join tool was used to measure the distance from each transect to the lake polygon. Further details are provided in the explanation below (Fig 8).

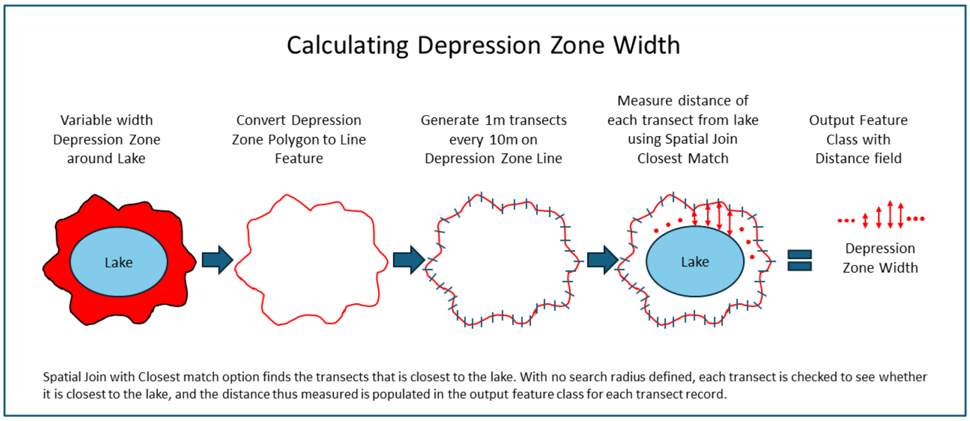


Figure 8: Depression zone width calculation process.

Average elevation of the lake shore was derived from the 1m DEM using zonal statistics (Fig 9).

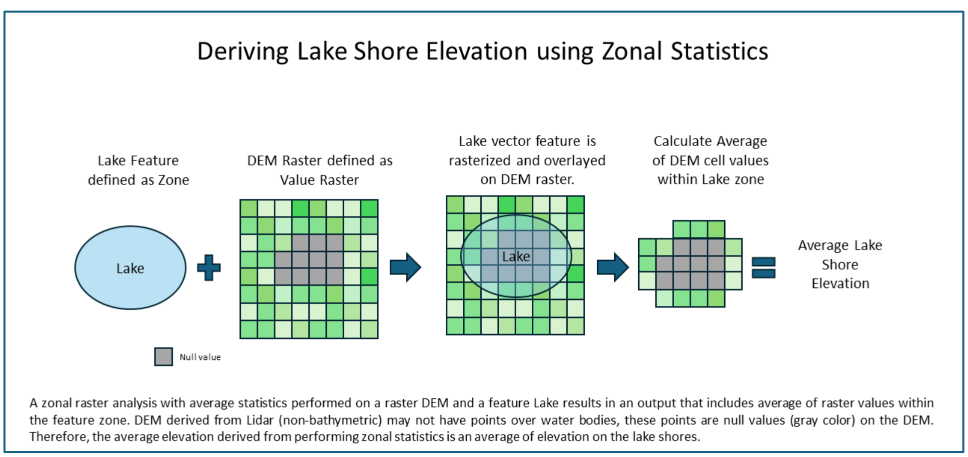


Figure 9: Lake Shore Elevation calculation process.

Lake Riparian Model

The Lake Riparian Depression Zone model was built using Model Builder (Fig.10). Three different versions of the lake model using advanced spatial analysis tools, hydrology tools in ArcGIS Pro, and Arc Hydro tools were explored. After detailed review of results from each model, the following model was finalized.

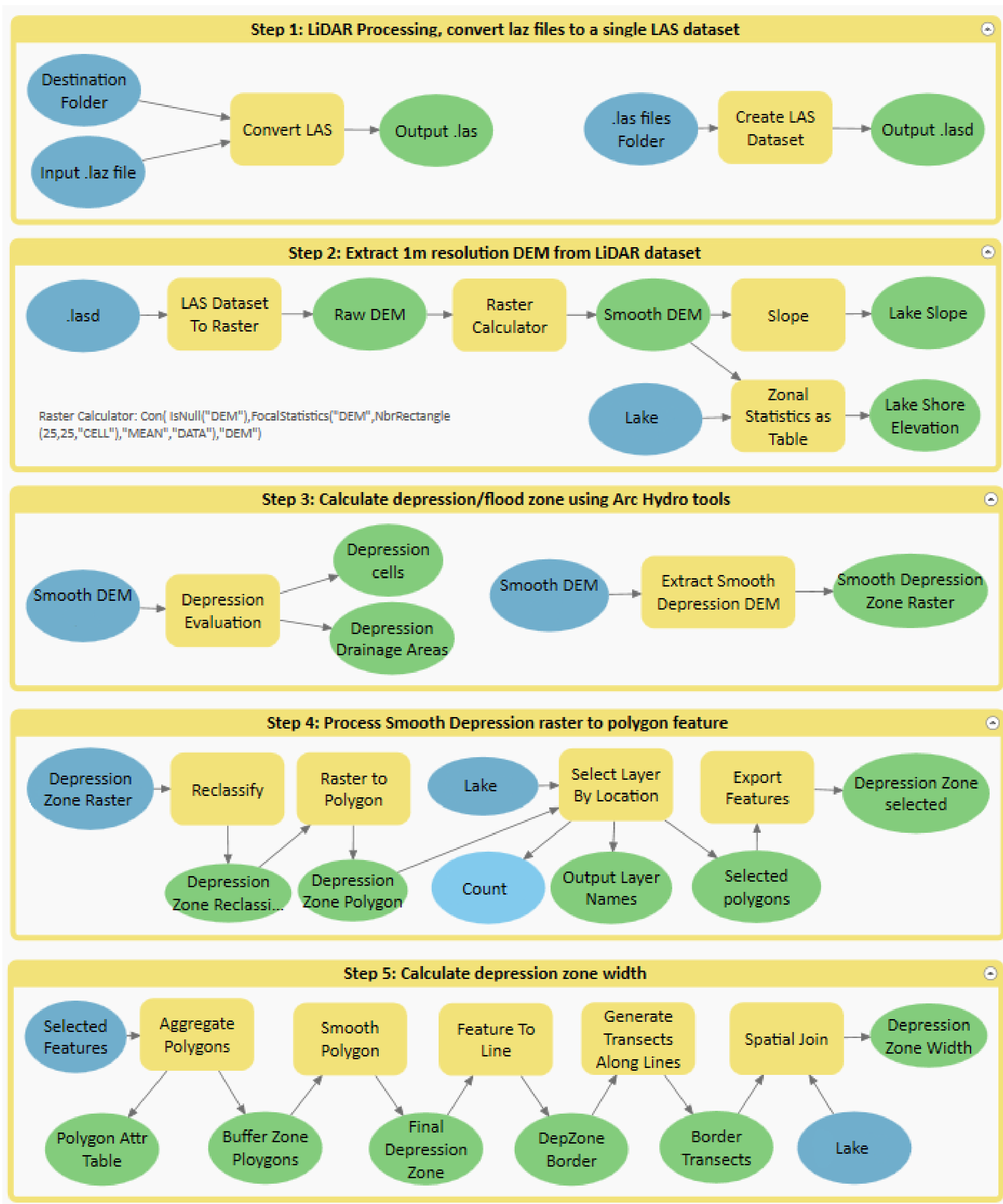


Figure 10: GIS Model to delineate hydrological riparian zone.

ArcGIS Help documentation and depression zone methodology as described in (Abood, 2012) and (Dingaroğlu, 2015) were used to develop and refine this model. The detailed process with settings on each tool were explained in the methods document (Refer to Attachments). The model involved a 5-step process to derive riparian zones from LiDAR data. Overview of the steps is as follows:

- Step 1: Process multiple LiDAR files to a single LiDAR dataset.
- Step 2: Extract 1m resolution DEM from LiDAR dataset.
- Step 3: Derive depression zone using Arc Hydro tools.
- Step 4: Process smooth depression zone to polygon feature.
- Step 5: Derive smooth riparian zone and calculate depression zone width.

Lake Riparian Zone Results

The results from the deep-dive analysis on a sample set of 6 lakes (Fig.11) indicates a clear trend between average width of depression zones and the average elevation of lake shores. Lakes with low shore elevation tend to exhibit wider depression zones in contrast to lakes with higher shore elevations. The model, applied to over 248 lakes within the study area, revealed consistent patterns demonstrating an inverse relationship between lake shore elevation and depression zone width (Fig.12).

Name	Average Depression Zone Width (m)	Average Lake Shore Elevation (m)
Jasper Lake	96.06	258.41
Darkwater Lake	122.39	186.43
Lost Lake	156.88	166.78
Clear Lake	333.45	57.29
Cultus Lake	477.16	45.78
Ruby Lake	433.90	21.20

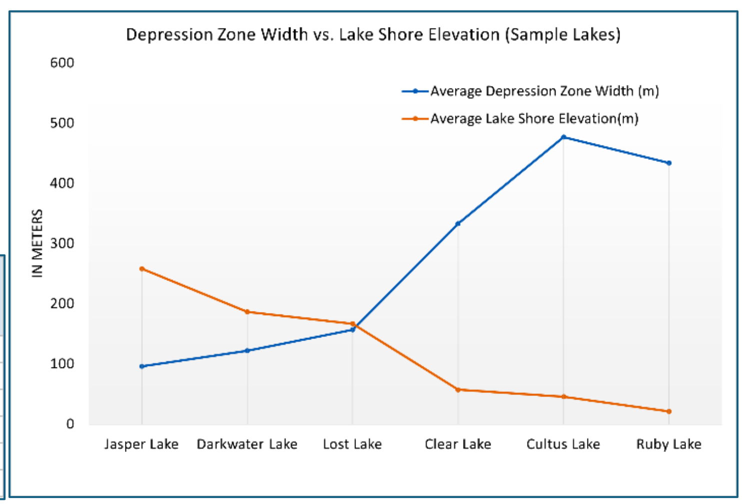


Figure 11: Sample 6 Lakes Riparian Zone Results

Ecosection	Average Depression Zone Width (m)	Average of Lake Shore Elevation (m)
Nw. Cascade Ranges	48.40	1515.61
Central Pacific Ranges	84.44	1287.15
Leeward Pacific Ranges	84.65	1692.22
Southern Pacific Ranges	136.28	1084.52
Outer Fjordland	231.30	48.54
Georgia Lowland	245.38	66.11
Queen Charlotte Ranges	279.19	127.34
Strait of Georgia	309.64	61.87
Windward Island Mountains	406.57	55.94
Skidegate Plateau	490.07	82.27
Fraser Lowland	546.89	125.51
Northern Island Mountains	570.21	161.68
Leeward Island Mountains	617.45	68.68
Southern Gulf Islands	675.66	57.44
Nanaimo Lowland	700.86	41.95
Queen Charlotte Lowland	719.84	59.72
Nahwitti Lowland	730.80	65.72

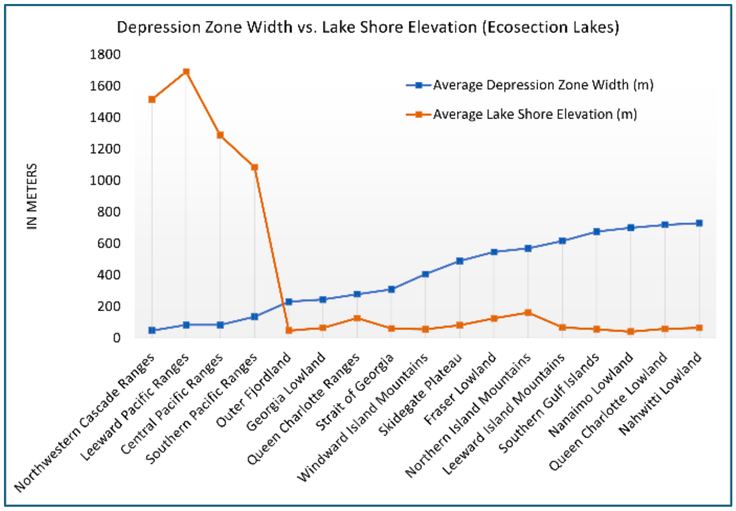


Figure 12: Ecosection 248 Lakes Riparian Zone Results

The average depression zone width from each Ecosection within the study area were aggregated into three classes—narrow, moderate, and large (Fig.13).

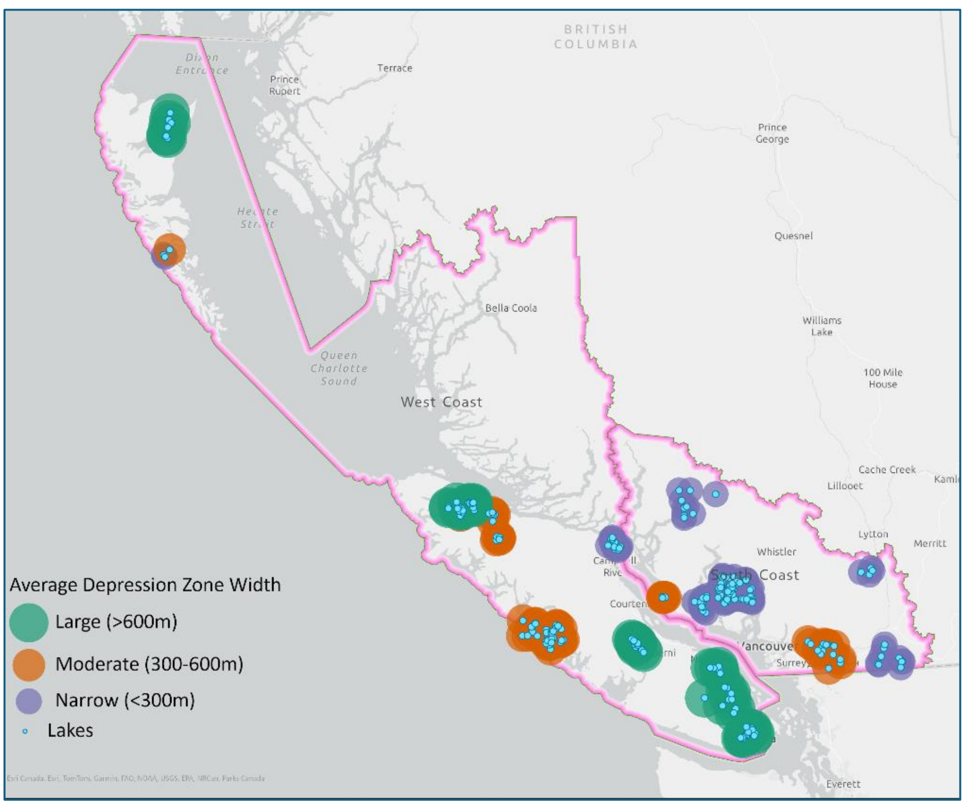


Figure 13: Riparian Zone Width in 3 broad categories in the study area.

3. Delineate Streams Riparian Zone

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	Moderate	Moderate	Number of streams selected for the study was within estimation

Study Area

This study explores the feasibility of integrating LiDAR and advanced spatial analysis tools to extract depression zone around headwater streams and downstream reaches. Streams around 23 climate stations were selected for this study (Fig.14). Selected locations include 9 upstream, 9 downstream, and 5 reference climate stations.

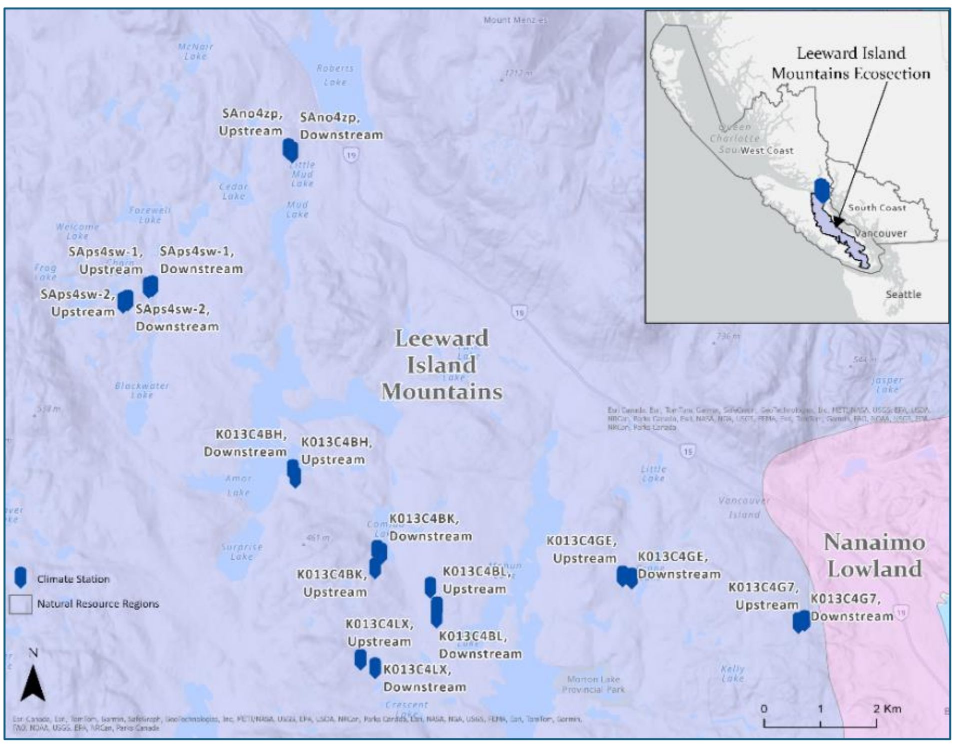


Figure 14: Streams study locations.

LiDAR Processing

Map tiles for the study locations were selected and corresponding Lidar files were downloaded. Stream locations under restricted LiDAR were acquired from sponsor in las format. Multiple las files were stitched into one LiDAR dataset file and the coordinate system NAD 1983 CSRS BC Environment Albers was selected.

Using the point spacing value from input LiDAR files, optimal resolution for DEM was determined. DEM optimal resolution= approximately 4 times point spacing value = 1m.

<u>LiDAR-based DEM</u>

Filtered LiDAR dataset with ground classification code, and a cell size/spatial resolution of 1m were selected on the LAS Dataset to Raster tool to extract the DEM. Raster Calculator tool was used to remove null data values in the DEM using focal statistics. A formula was applied to identify null values in the DEM and apply average value from nearby cells using a rectangular window. The DEM thus prepared for each stream location was used in the subsequent steps to extract streams and determine depression zones around the streams.

<u>Stream Definition</u>

DEM derived from LiDAR may have small imperfections that are often errors due to the resolution of the data or rounding of elevations to the nearest integer value. These imperfections also called as sinks, are cells with an undefined drainage direction (Fig.15); no cells surrounding it are lower (Planchon, 2002) (Tarboton, 1991). DEM with filled sinks ensures proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous (Mark, 1988). Therefore, using the Fill DEM tool, sinks were identified and filled.

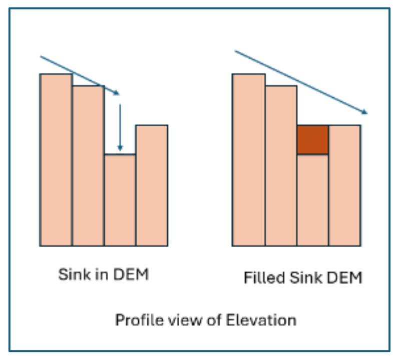


Figure 15: Sinks in DEM

The filled DEM was used to determine the direction of flow from every cell in the raster. The Flow Direction tool with D8 method was used to determine the direction of flow by the direction of steepest descent, or maximum drop from each cell (Jenson, 1988). The flow direction raster (Fig.16) thus obtained is an integer raster where values represent 8 possible directions of flow from a cell.

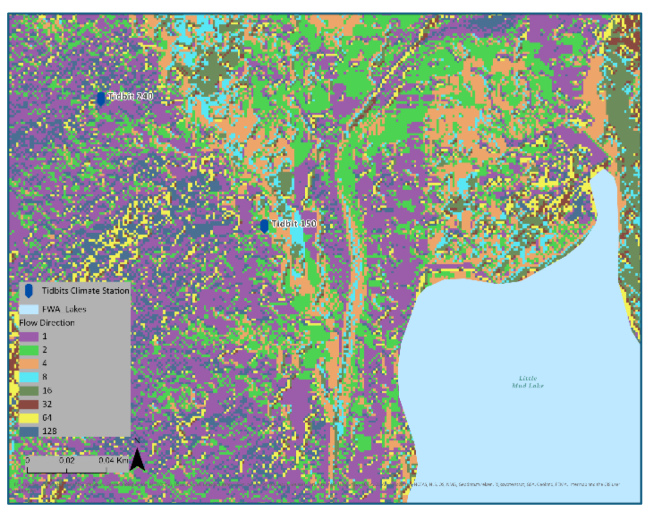


Figure 16: Flow Directions

The flow direction raster was used to calculate accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. Cells with a high flow accumulation are areas of concentrated flow and were used to identify stream channels. With flow accumulation raster, the number of upslope cells that flow into each cell was determined. In the example image below (Fig.17), cells where value was 0 represent ridges and high slope whereas value of 737980 represents a stream channel with maximum flow. Therefore, stream network (Fig.17) was defined using the flow accumulation raster and a threshold value of 1% of maximum flow accumulation value.

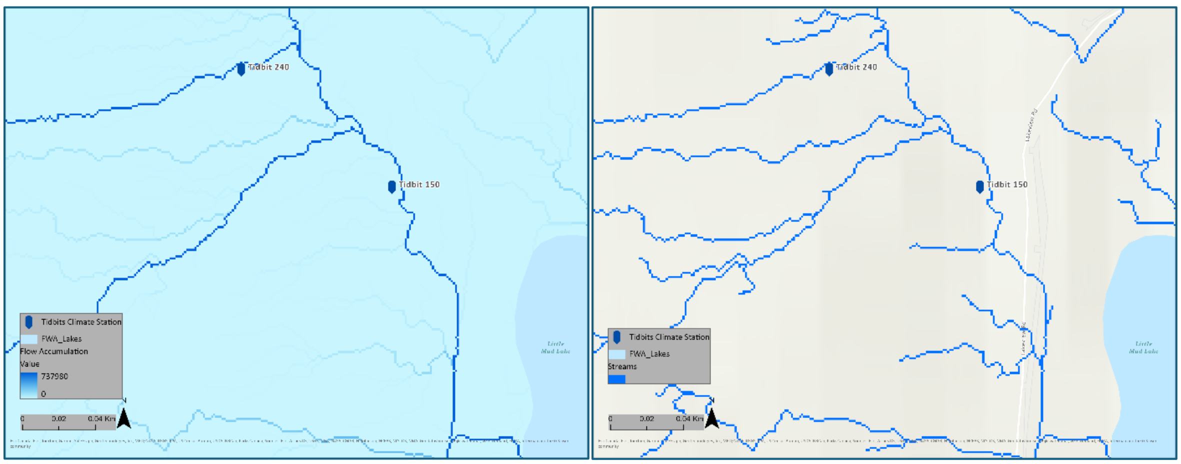


Figure 17: Flow Accumulation and Stream Raster

In this example, maximum flow accumulation is 737980 and 0.01*737980=7379. Cells with more than 7379 cells flowing into them were assigned the value 1, and a stream raster was extracted. See image showing stream raster (Fig.17) extracted from flow accumulation raster. Stream raster thus extracted was converted into line feature for further analysis. Watersheds or drainage basins were delineated by analyzing flow direction raster to find all sets of connected cells that belong to the same drainage basin.

<u>Terrain Depression</u>

The depression evaluation tool was used to extract depression cells (Fig.18) from the DEM using several internal computations such as filling sinks in the DEM, extracting flow direction, drainage area, depression zone watershed, and finally applying zonal statistics to generate a depression polygon. The Extract Smooth Depression DEM tool was used to create a smooth depression zone around the depression cells derived in previous step. A methodology similar to lake riparian zone model was applied to derive depression zones around the streams. A minimum of 5 cells of depression cells was selected as the threshold to define smooth depression zone. A depression as small as 1 meter by 1 meter, or a single cell, could potentially be considered noise and might not accurately represent a depression area.

Previous studies, such as Dingaroğlu (2015), defined a depression area larger than one cell (60 m^2). However, utilizing a LiDAR-based DEM with a spatial resolution of 1m, enables extraction of depression areas as small as $1m^2$. Through a comparison of different thresholds, including 5 cells ($25m^2$), 7 cells ($49m^2$), and 8 cells ($64m^2$) (Fig.19), it was determined that a minimum size of 5 continuous cells adequately captures a depression area large enough to support riparian vegetation.

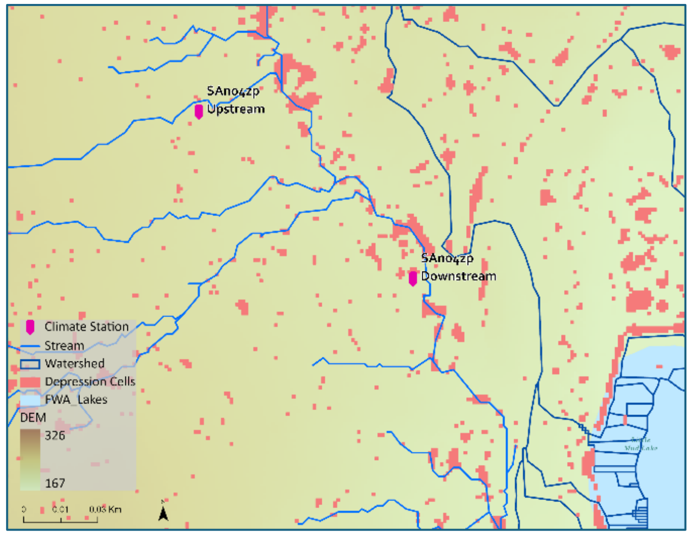


Figure 18: Depression cells around streams.

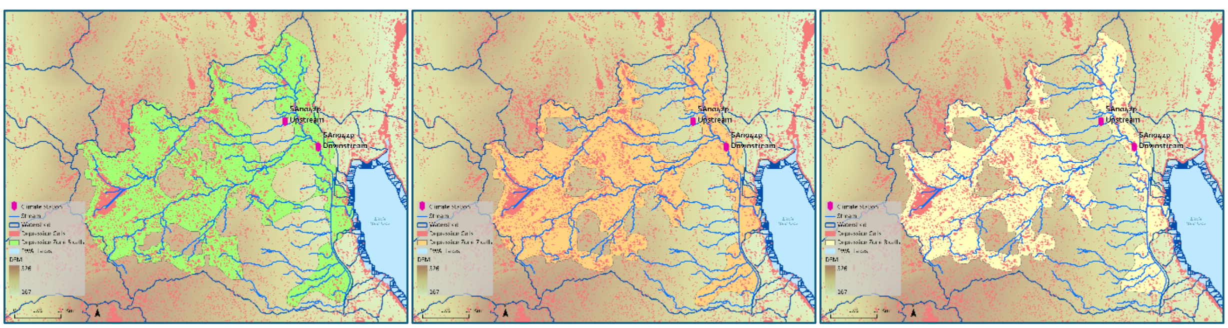


Figure 19: Depression Zone Comparison between minimum size of 5, 7, 8 cells.

Smooth depression zone (Fig.20) thus derived was reclassified and converted to polygon feature for further analysis. Depression polygon features that intersect streams of interest were selected and clipped to be within the stream watershed to extract stream depression polygon. The depression polygon thus extracted was aggregated and smoothed using Bezier interpolation.

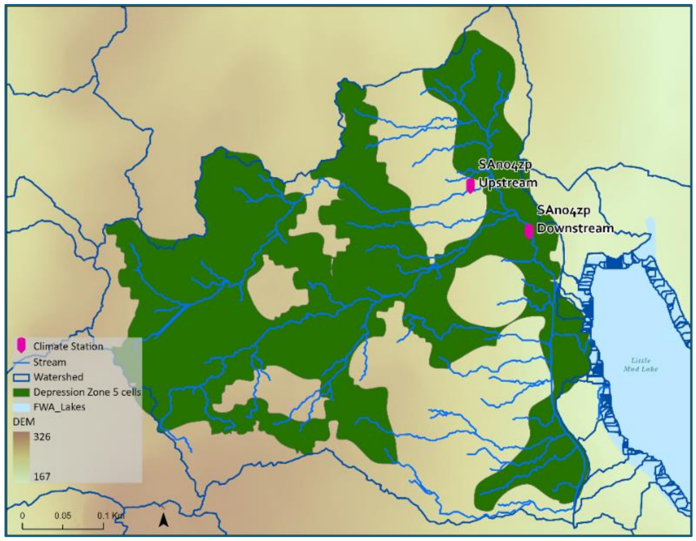


Figure 20: Smooth Depression Zone representing Riparian Zone around the streams.

<u>Riparian Depression Zone</u>

The varying width of the depression zone around streams was measured using transect tool (Abood, 2012). The depression zone was converted to a line feature, transects were generated every 5m on the depression line feature, and spatial join tool was used to measure the distance between the stream feature and the transects. Further details are provided below (Fig 21). The distance thus measured was used as the depression zone width for further analysis.

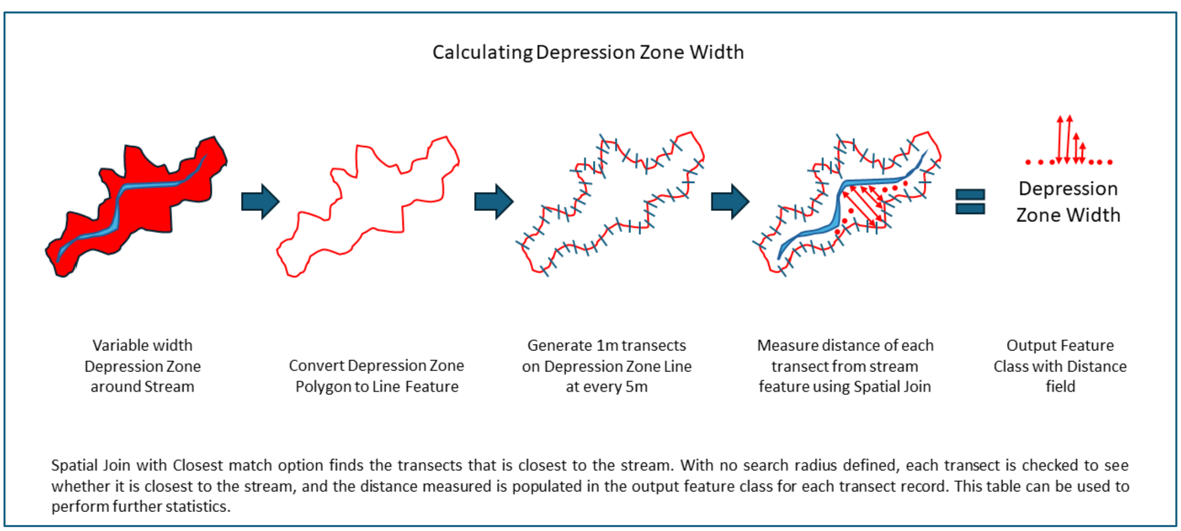


Figure 21: Depression Zone width calculation process.

Stream shore elevation can be calculated using smooth DEM and zonal statistics. The zonal statistics tool internally converted the stream feature in to stream raster and performed raster overlay analysis to extract average shore elevation around the stream. Further details are provided below (Fig 22).

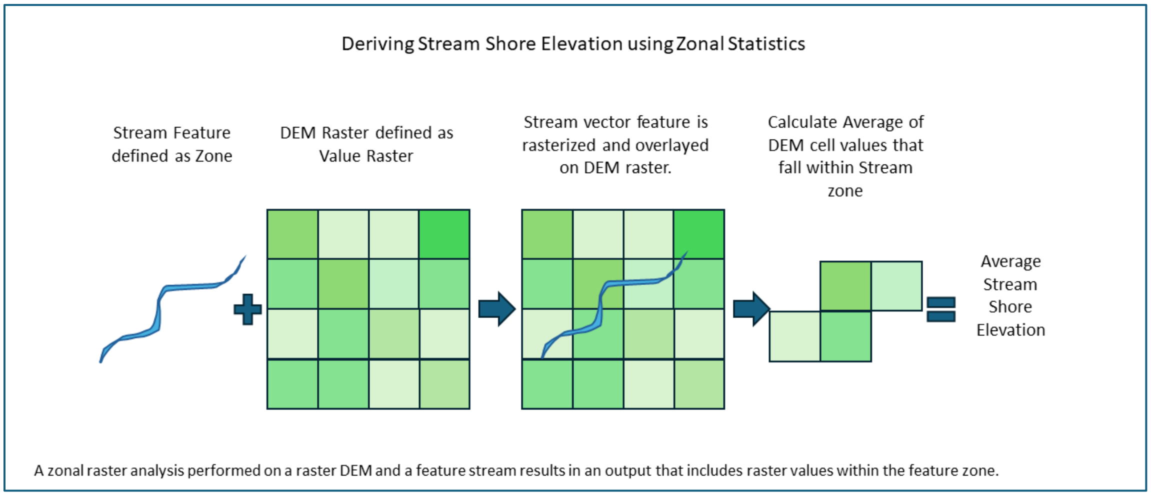


Figure 22: Stream shore elevation calculation process.

<u>Stream Riparian Model</u>

The Stream Riparian Depression Zone model was built using Model Builder (Fig.23).

The model presents a 4-step process of deriving hydrological riparian zone from LiDAR data.

- Step 1: Process LiDAR files to 1 m resolution DEM.
- Step 2: Fill sinks in DEM, derive flow direction, flow accumulation, define streams, and watershed boundaries.
- Step 3: Extract depression cells from DEM and smooth depression zone around the streams.
- Step 4: Derive smooth depression zone representing riparian zone, measure variable width of depression zone, and measure stream shore elevation.

The detailed process with settings on each tool were explained in the methods document. ArcGIS Help documentation and depression zone methodology as described in (Abood, 2012) and (Dingaroğlu, 2015) were used to build this model.

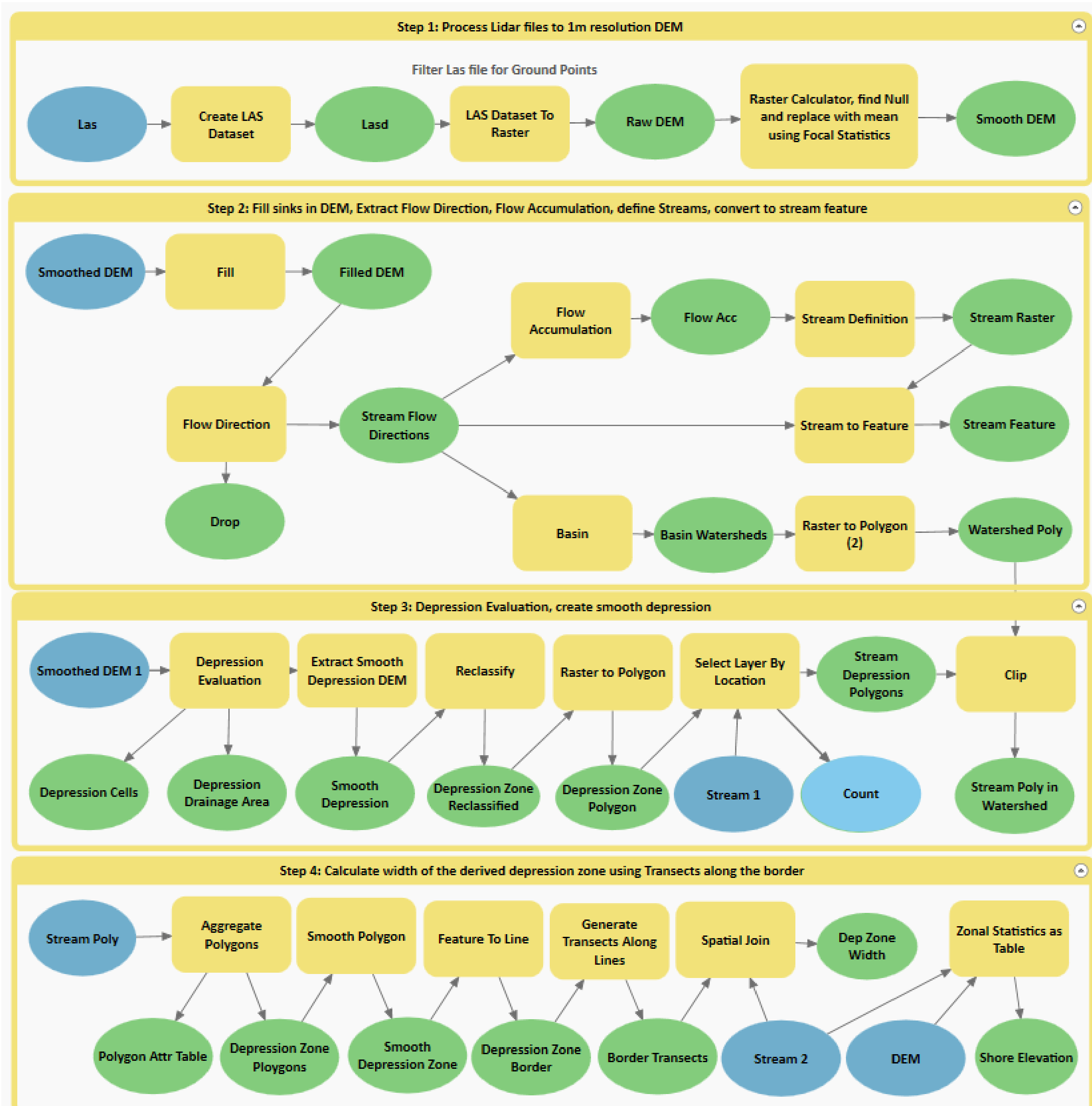


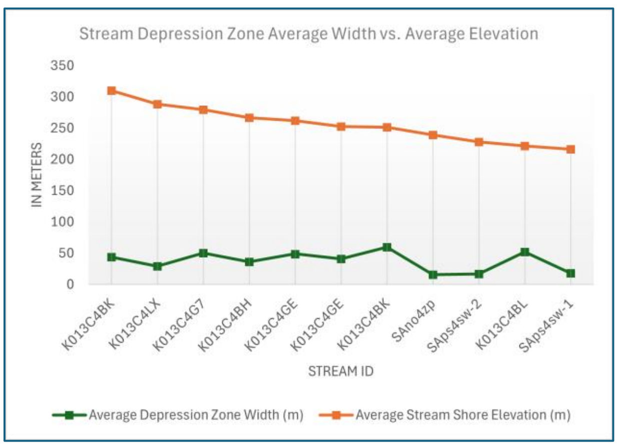
Figure 23: Stream Riparian Zone Model

<u>Stream Riparian Zone Results</u>

The results from the analysis (Fig.24) showed that depression zone around the streams ranges from 10m to 60m. Comparing the average depression zone width with stream shore elevation (Fig.25) showed a low correlation between elevation and depression zone width. This is because the study area selected included 23 climate stations within the same Ecosection Leeward Island Mountains with approximately same stream shore elevation ranges. Refer to the chart (Fig.25) visualizing the stream depression zone width around each stream location within the study area.

Block/Stream ID	Location	Tidbit id	Average Depression Zone Width (m)	Average Stream Shore Elevation (m)
K013C4BK	Upstream	48	43.78	310.40
K013C4LX	Upstream, Downstream	29-52	29.36	288.44
K013C4G7	Upstream, Downstream	11-45	50.45	279.73
NA	Reference	12	30.26	274.08
NA	Reference	13	33.39	270.97
K013C4BH	Upstream, Downstream	34-16	36.17	266.72
K013C4GE	Upstream	540	48.87	262.35
K013C4GE	Downstream	300	41.09	252.47
K013C4BK	Downstream	43	59.62	251.59
SAno4zp	Upstream, Downstream	150-240	15.94	239.05
SAps4sw-2	Upstream	530	16.69	228.19
K013C4BL	Upstream, Downstream	18-26-46	52.06	221.33
SAps4sw-1	Upstream	470	18.21	216.14
SAps4sw-2	Downstream	600	15.47	208.08
NA	Reference	21-44	52.25	200.81
SAps4sw-1	Downstream	140	11.55	191.93

Figure 24: Average Depression Zone Width



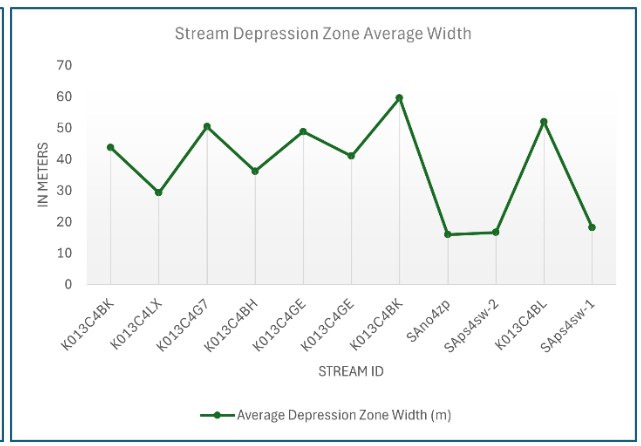


Figure 25: Average depression zone width vs. average stream shore elevation, Average depression zone width for each stream location.

Ortho Imagery Overlay

The stream depression zones derived from the analysis were overlaid on ortho imagery collected by the sponsor for a visual comparison (Fig.26) of the habitat around the streams.

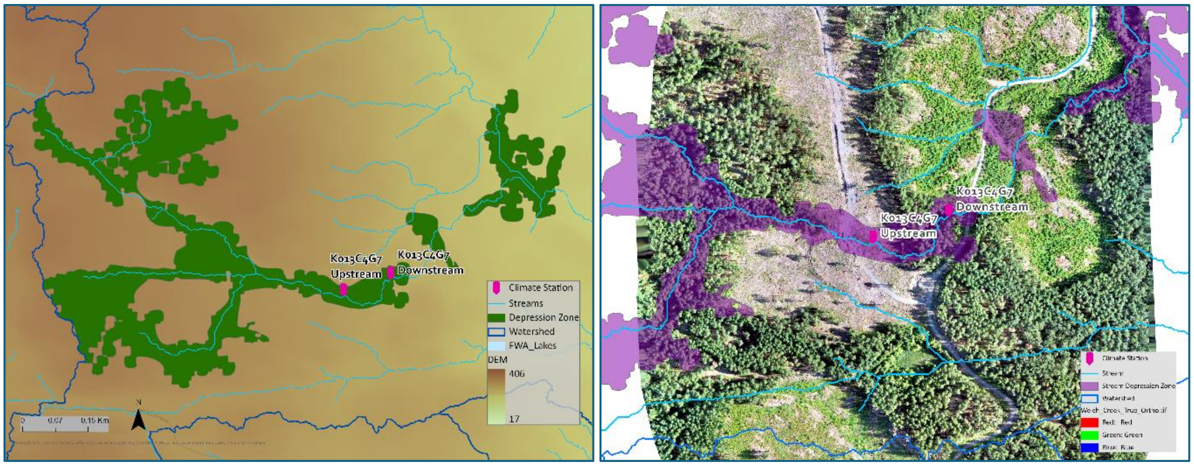


Figure 26: Visual comparison of derived riparian zone vs. ortho imagery overlay.

4. Compare Riparian Zones.

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	Moderate	Moderate	Performed with tasks 2 and 3.

This task involving visual comparison of fixed-width buffer and variable-width buffer and statistical comparison of elevation and depression zone width was performed along with tasks 2 and 3. Refer to the example (Fig.27) for a visual comparison of fixed-width buffer shown in yellow and variable-width riparian zone shown in dark green.

Refer to results from task 2 and task 3 for statistical comparisons.

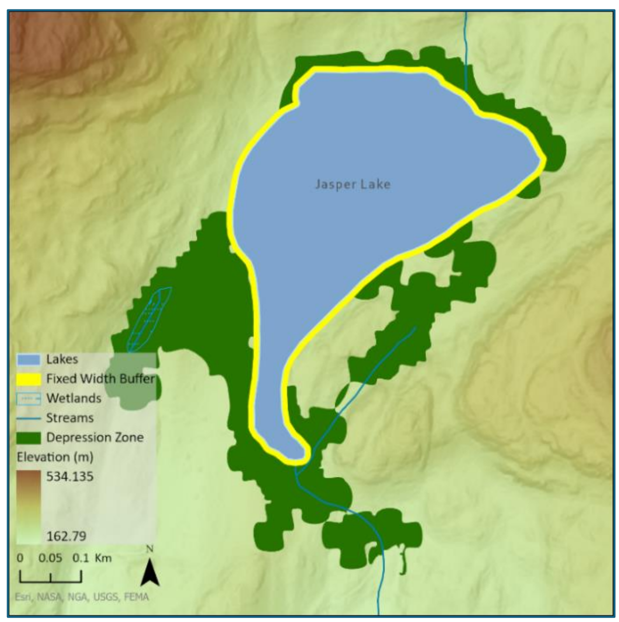


Figure 27: Visual comparison of derived riparian zone vs. fixed width buffer zone.

5. Process Habitat Data

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
0%	Easy	-	Removed from scope

6. Update Existing Tool

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
0%	Easy	-	Removed from scope

After discussions with the sponsor, tasks 5 and 6 remained unaddressed due to time constraints. Instead of these tasks a new task (Task 9) of preparing research materials determined to be of higher priority and value add for the sponsor was added to scope.

7. Prepare Methods Document

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	Moderate	Moderate	Required detailed screen captures of settings used in the model

This task entailed providing a comprehensive explanation of the analysis process, including the selected settings for each tool, accompanied by screen captures for clarity. An overview of the steps was outlined to offer a quick understanding of the process involved in deriving riparian zones from the LiDAR dataset. For example, a detailed comparison was conducted among depression zones derived using 5, 7, and 8 cells for lakes and streams. Visual comparisons indicated that the depression zone derived using 5 cells i.e. 5m x 5m = 25m^2, represented an inundation large enough for riparian vegetation growth and covered a significant portion of the lake shore intended for preservation. Furthermore, comparisons of fill depth of depression cells around the lake revealed that the depression zone with 5 cells included depressions with the highest fill depth. Consequently, a minimum depression size of 5 cells was adopted for deriving depression zones around lakes. The methods document encompasses such detailed explanations of the settings selected for this study, ensuring replicability of the analysis process.

8. Log Daily Tasks

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	Easy	Easy	10-15min spent daily summarizing

This task involved summarizing daily tasks performed during the practicum. The task log document was updated daily and shared with the sponsor through a shared folder.

9. Prepare Research Paper Materials

Degree of Completion	Estimated Level of Effort	True Level of Effort	Comments
100%	-	Difficult	Time consuming, rework

This new task involved high level of diligence and iterative process of review and rework. This involved reviewing manuscripts, proof-reading method of procedure followed in the study, and assembling materials defending the decisions made during the analysis phase.

For example, to derive meaningful statistics from the analysis, several metrics were explored. Initially, slope statistics were computed to investigate the correlation between the width of depression zones and the slope of lake shores. However, this metric was eventually discarded as the comparison between the average slope around the lake shore and the width of depression zones failed to reveal a discernible trend. Subsequently, lake shore elevation and depression zone width were compared, and this comparison revealed a clear trend. Furthermore, depression zone area and lake size were compared to identify any relationship between the two variables. Average Lake depth and average perimeter of lakes in the study area were calculated and integrated in the research paper. Additionally, wetlands intersecting depression zone were examined to identify wetlands excluded when employing fixed-width buffers.

To visually depict the study area, maps were generated, illustrating the locations of lakes overlaid on the natural resource regions and Ecosection of BC's West Coast and South Coast. Additionally, to provide comprehensive insights, a total of 78 2-D maps and 15 3-D maps were meticulously created, each representing the results obtained from every Ecosection, which will be included in the forthcoming research paper.

C. DELIVERABLES

Deliverables outlined in the proposal are listed as 'Estimated' and deliverables added to the scope during the practicum are listed as 'New' in the following table. Deliverables relating to unaddressed tasks i.e. Task 5, and 6 from the workplan are listed as incomplete and those related to completed tasks are listed as complete.

#	Deliverable	Estimated/New	Complete
1	Riparian Buffer Zone Delineation model (Lake)	Estimated	Yes
2	Hydrologically derived buffer zone for lakes		Yes
3	Map comparing derived vs. legislated buffer zone		Yes
4	Processed habitat data (Lake)		No
5	Riparian Buffer Zone Delineation model (Stream)		Yes
6	Hydrologically derived buffer zone for streams		Yes
7	Map comparing derived vs. legislated buffer zone		Yes
8	Processed habitat data (Stream)		No
9	Updated tool		No
10	Method of procedures (Lakes, Streams)		Yes
11	Geodatabase		Yes
12	Research Paper Material	New	Yes
13	Statistical analyses workbook		Yes

The contents of some of the deliverables are as follows:

- Sample Lakes Results geodatabase: for each of the 6 lakes; smooth DEM, depression zone, depression zone width, study area locations, fixed-width buffer, depression cells, and depression zone comparison layers.
- Ecosection Lakes Results geodatabase: for each of the 18 Ecosections; depression zone, depression zone width, study area lakes, fixed-width buffer, and depression cells.
- Stream Results geodatabase: For each of the 23 stream locations; DEM, flow directions, flow accumulations, watersheds, streams, depression cells, depression zone, depression zone width, and study area locations.
- Model Builder (atbx) files: Lake Riparian Zone Model, Streams Riparian Zone Model

- Statistical analysis workbook: spreadsheets with list of small lakes in study area, lakes with LiDAR data available, lakes selected for the study, depression zone width distribution, lake depth, depression zone area, depression cells fill depth comparison, charts showing results distribution.
- Maps: 78 maps representing 5 lakes from each Ecosection in the study area, 15 3D maps representing 5 lakes from 3 lake shore elevation ranges (low, mid, high).

D. PROJECT ASSESSMENT

Assessment: Tasks related to the sponsor's research projects as defined in the proposal were accomplished beyond estimated expectations. Valuable feedback and support from research fish biologist and geospatial services coordinator enriched the study's outcomes. The utilization of innovative approaches and collaborative efforts contributed significantly to a productive completion of this practicum. Key strengths of this study include the integration of LiDAR and GIS techniques to delineate riparian zones, building a generic model that could be scaled to a large study area, and providing a visual as well as a statistical comparison of fixed-width buffers to variable-width buffer. This study can be further improved by including habitat assessments and land cover classification around lakes and streams to gain better insights into riparian zones.

Challenges: Several challenges arose during this study, notably the constraints posed by limited laptop resources for processing large LiDAR files exceeding 100GB. Additionally, ArcGIS Pro software allowed for execution of model to delineate riparian zones across a maximum of 10 lakes at a time. This prolonged the process of delineating riparian zones for 248 lakes. Acquiring DEM for each Ecosection proved to be labor-intensive and time-consuming task. Furthermore, rigorous review and research were essential in preparing research materials, necessitating an iterative process of spatial analysis, map layout preparation, manuscript review, and statistical analysis. Developing a GIS model and adapting it to a larger study area required extensive brainstorming. Analyzing statistics such as lake shore slope, elevation, area, and depth, while exploring potential correlations with the variable width of the depression zone, demanded considerable effort in preparing a statistical comparison.

Scope for Improvement: Reflecting on this project, given the opportunity, I would improve time efficiency by leveraging server infrastructure to perform LiDAR file batch processing and parallel execution of GIS models over a larger number of lakes.

Learnings: In this project, I leveraged my research skills to delve into the nuances of the subject matter and derive methodologies from research papers and journal publications. By adapting existing research, refining processes, I developed spatial analysis models to suit our research objective. I had the opportunity to explore and acquire proficiency in new tools and techniques such as FME and Arc Hydro, applying Python scripts, and integrating LiDAR with advanced hydrology spatial analysis to delineate riparian zones around lakes and streams. Studying the ecological functions of riparian zones, their relationship with surrounding terrain and flood zones, highlighted GIS's pivotal role in ecosystem conservation. Continuously engaging in learning, actively seeking feedback, and honing skills while adapting to evolving tools and technologies proved invaluable throughout this practicum. This experience instilled a sense of confidence, knowing that the skills cultivated through ADGISA, and the practicum can be readily applied to future career opportunities.

E. RECOMMENDATIONS

The sponsor stands to benefit from integrating the findings of this study into their research projects. The deliverables included ArcGIS toolbox file and geodatabase of all the spatial layers created during the analysis process facilitating easy import into the software for visualizing, modifying, and replicating the study. Moreover, the methods document provides a detailed explanation of the analysis process, facilitating the duplication of this procedure in alternative study areas.

Key Findings from the study: The Lake Riparian Zone results suggest that lakes with low shore elevations typically support wider depression zones conducive for riparian vegetation growth. The Stream Riparian Zone results suggest that depression-based riparian zones can be derived for headwater streams and downstream reaches. This observation emphasizes the potential connections of hydrologically derived depression zone and riparian ecosystems. Moreover, the results accentuate the feasibility of adopting a comprehensive methodology that integrates LiDAR technology with ESRI GIS tools for delineating hydrologically meaningful riparian zones. This study introduces an innovative tool to derive variable-width riparian zones, enhancing our ability to assess riparian ecosystems, offering valuable insights that can inform conservation strategies aimed at preserving lake ecosystems and their associated biodiversity.

Future Work: Continued evaluation and refinement of this tool are essential steps towards achieving sustainable land management practices and ensuring resilient riparian ecosystems. The Stream/Lake Riparian Models can be enhanced by gathering supplementary information from satellite imagery. This includes integrating soil characteristics, riparian vegetation data, and inundation levels through satellite image classification, flood height assessments, and evaluations of aquatic habitat conditions. To further enrich the model, spectral indices can be derived from satellite images to incorporate temporal insights into land cover changes, moisture levels, water turbidity, and vegetation health surrounding lakes. A comprehensive approach will enable a more holistic understanding of riparian zone dynamics and facilitate informed decision-making in ecosystem conservation and management efforts.

F. ATTACHMENTS

Story map, All Deliverables OneDrive Folder, Deliverables are also attached as a zipped folder with this report.

G. REFERENCES

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