Determining the Location of a Proposed Weather Station in the Sooke Water Shed using Multi-Criteria Decision Making and Suitability Analysis

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1 Introduction

Multi-criteria decision making (MCDM) has become increasingly popular in various environmental and social applications as it provides a detailed framework for analyzing complex problems (Baudry et al, 2018). MCDM is an effective method of determining suitable locations of proposed developments such as weather station facilities. Weather stations are located in networks as an increase in station density increases overall network accuracy (Stahl et al, 2006). Weather stations are typically equipped with devices to measure temperature, atmospheric pressure, humidity, wind speed, solar radiation and precipitation. When determining the location of a new weather station, there are numerous factors to consider such as elevation, slope, aspect and view shed. The optimal location of the weather station must have the functional requirements pertaining to the Environment Canada MSC installation standards, as well as constraints derived from the current existing weather network. The functional requirements of a weather station include a minimum of a 90 meter squared area, access roads for maintenance, existing electrical infrastructure if required and a suitable height to have an unobstructed line of sight for cloud and visibility measurements (Environment Canada, 2005). Meteorological variables such as air temperature and precipitation are some of the most important inputs in most environmental models (Stahl et al, 2006). Increasing weather station accuracy by using MCDM to help facilitate an optimal location decision has a far-reaching impact on the models that rely on the data that the stations provide. The purpose of the the analysis performed in this study was to use MCDM to help find an optimal location to place a new weather station in the existing network in the Sooke watershed.

2 Methods

2.1 Study Area and Data

2.1.1 Study Area

The study area encompasses the entire Sooke watershed, located northwest of the City of Victoria, approximately 30 kilometers from the city centre. The watershed converges into the Sooke Lake reservoir which is the primary water supply for approximately 350,000 people in the Greater Victoria Area (Capital Regional District, 2015). The reservoir has a total capacity of 160.32 million meters cubed, of which 92.7 million meters cubed is available for water supply (Capital Regional District, 2015). The reservoir is supplied primarily by the 8,620 hectare Sooke watershed composing of mostly forested terrain. There are 8 current weather stations in the watershed, 4 of which are weather station facilities. Figure 1 shows a small scale map of the study area and the surrounding features.

2.1.2 Data

The source for the secondary data used in this study was provided in lab and the original source is unknown. The first piece of data used was a 30x30 meter DEM of the Sooke Watershed. The other core piece of data used in the analysis was a point file containing locations of facilities within the watershed including weather stations. The large scale of the data sets allowed for the use of a Transverse Mercator projection referenced to the NAD 1983 UTM Zone 10N Coordinate System. A few additional ancillary data sets such as a roads, streams, and water bodies were used as a visual aid in the final placement decision, however they were not used as inputs in the multi-criteria model.

2.2 Analysis methods

2.2.1 Data Pre-Processing

The DEM of the Sooke watershed and the Sooke watershed facilities point file were first loaded into ArcGIS 10.5 software. A query was then performed on the facilities point file to isolate the locations of the 4 existing weather station facilities in the watershed. The ancillary roads, streams and water bodies files were also loaded into the GIS software and clipped to the extent of the study area defined by the DEM.

2.2.2 Binarization and Thresholding

Four intermediate binary surfaces were then created from the DEM and weather station locations. These surfaces were then used as inputs into the multi-criteria model in following steps.

The first binary surface created was an elevation suitability surface. A threshold of 400 meters was applied on the DEM to ensure that the new weather station would have a unobstructed line of sight for cloud and visibility measurements as required by the Environment Canada MSC installation standards. Cells less than 400 meters in elevation were classified as not suitable and cells greater than or equal to 400 meters were classified as suitable.

Secondly, a slope suitability surface was then created from the Sooke watershed DEM. The DEM was used as input into a slope analysis tool, which created a slope surface for the watershed with each cell of the raster containing a slope value. A 30 degree threshold was then applied to the slope surface to ensure that the weather station could be constructed on a semi-flat surface.

Cells greater than or equal to 30 degrees were classified as not suitable and areas less than 30 degrees were classified as suitable.

Next, an aspect suitability surface was then created from the DEM. The DEM was used as input into an aspect analysis tool, which created an aspect surface for the watershed with each cell containing an aspect value between 0-360 degrees. Since the other weather stations are located on North, South and West facing slopes, a constraint was placed on the aspect surface to ensure an East facing weather station location. An interval of 40-140 degrees was placed on the raster to meet this criteria. Cells within this interval were classified as suitable and cells outside of it were classified as not suitable.

Lastly, a view shed suitability surface was created from the DEM and extracted weather station points. The weather stations and DEM were used as input into a view shed analysis tool, which created a view shed surface for all four weather stations. A requirement of the new weather station is that is must be visible from at least one existing weather station, so if a cell was visible from at least one of the existing weather stations it was classified as suitable, otherwise it was classified as not suitable.

2.2.3 Layer Integration

The binary suitability surfaces created in Section 2.2.2 were then integrated to create a final suitability map. The four binary surfaces were weighted equally and were integrated through a multi-layer raster intersection. For an output cell to be suitable, all four corresponding input cells had to be suitable. The final suitability surface had the same binary suitable or non-suitable classification as the four inputs.

2.2.4 Site Selection

The ancillary roads, water bodies and streams files were then overlayed as a visual aid for decision making as the proposed weather station must not be located on a stream or water body and it must have road access for maintenance. A suitable location was then selected by using the visual aids, the suitability surface and standards outlined by Environment Canada.

3 Results

The final integrated suitability map with proposed location is shown in Figure 2, and the four input suitability surfaces created in Section 2.2.2 are shown in Figures 3-6. Additionally, a 3D representation of the suitability raster is shown in Figure 7. Table 1 shows the attributes of each input suitability layer and the final suitability surface, and the original attribute screenshots are shown in Figure 8. After the integration of the surfaces in 2.2.3, it was determined that there were 16493 suitable cells in the watershed for weather station placement. The aspect suitability surface had the greatest impact on the final surface as it had the least amount of suitable cells of the four input surfaces with 74416 cells. The selected optimum weather station location was determined to be approximately located at 449,513 mE, 5,383,323 mN in the north-eastern region of the watershed. This location was classified as suitable in the final output, had direct access to multiple roads and was not impeded by streams or water bodies. In addition, it is an adequate distance away from the existing weather stations to ensure optimal coverage by the weather station network in the Sooke watershed.

4 Discussion

The location selected as a result of the analysis was determined based on the criteria outlined by the Environment Canada installation guide, and the constraints imposed by the current weather station network in the Sooke watershed. There were many areas that met these criteria and were classified as suitable in the final suitability surface, however the deciding factor was the visual aids of roads, streams and water bodies as well as the distance from other weather stations. Another factor was the size of the area as it has to be large enough to contain the weather station itself, as well as secondary and protected areas required by the MSC installation standards (Environment Canada, 2005). The MCDM approach used in this study was fairly successful in determining a new weather station location, however it is very limited in its design. The biggest limitation in the MCDM approach in this study was the equal weighting, and mandatory membership of each class. When performing a multi-criteria analysis there are some parameters that are more important then others and should be weighted as such. For example, in the analysis performed in this study, elevation and slope were certainly more important than aspect and view shed as the aspect and view shed requirements are rooted in stake holder preference and do not have a substantial impact on the weather stations functionality. Furthermore, the mandatory membership of each class does not allow for any degrees of membership or fuzzy sets. This means that suitable areas are not ranked in any way and there is certainly great variance amongst them. Also, if an input cell misses the threshold by a very minor factor such as 1 degree or 1 meter it will be completely disregarded as suitable. A weighted approach does introduce new problems however, mainly that determining the weights is largely subjective and they often have little to no theoretical foundation supporting them (Malczewski, 2000).

5 Conclusion

In conclusion, the MCDM procedures performed in this study can be an effective method in helping facilitate the decision of a proposed weather station in the Sooke water shed. Multi-criteria analysis is useful in many environmental, geographical and social applications and is effective at decomposing complex problems into a manageable framework. Weighted and more mathematical involved models may result in a higher accuracy of suitability, however do to the nature of the procedure there will always be inherent uncertainty in the final result. The subjective property of determining weights, thresholds and other factors all impact the final result. In conclusion, MCDM is not enough to make complex decisions on its own, however it is an effective tool to help facilitate decisions.

6 Tables and Figures

Table 1: Table of Intermediate Binary Rasters and Final Suitability Surface

Raster Surface	Suitable Cells	Non-Suitable Cells	Total Cells
Binary View shed	91286	138000	229286
Binary Aspect	74416	154870	229286
Binary Slope	217166	12120	229286
Binary Elevation	101900	127386	229286
Final Suitability Surface	16493	212793	229286

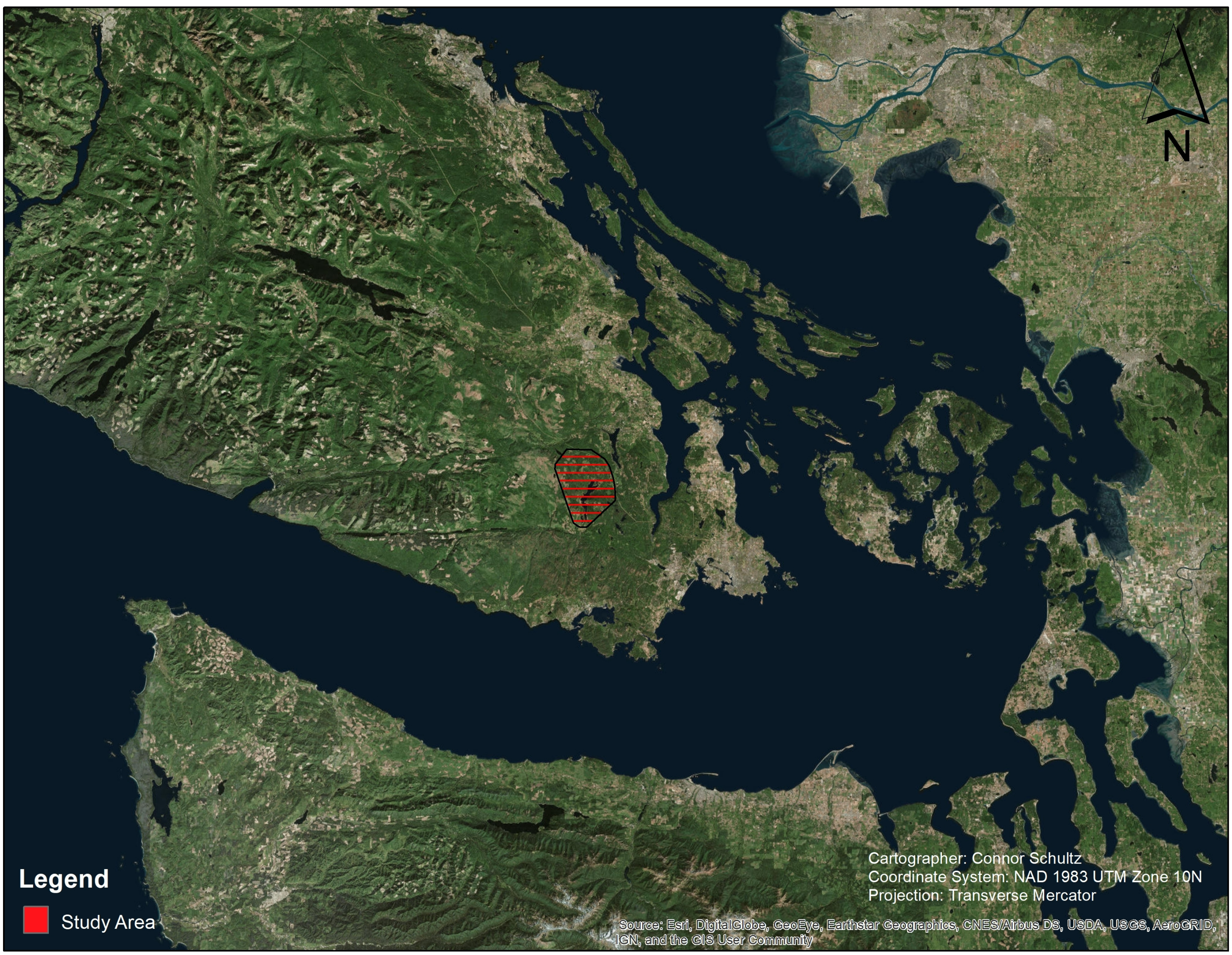

Figure 1: Study Area Map of Sooke Water Basin, Greater Victoria Area, BC, Canada

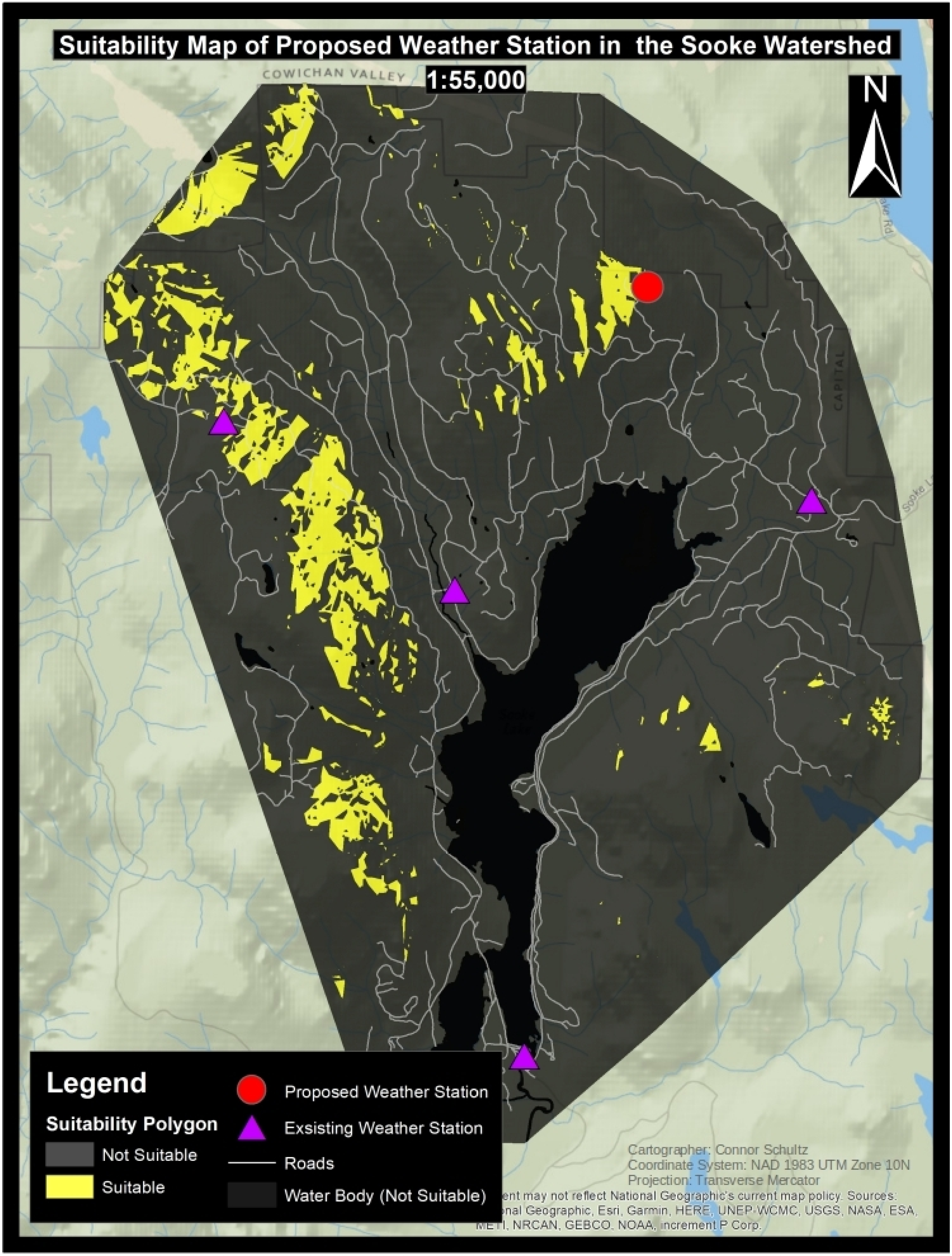

Figure 2: Final Output Map from Unweighted Suitability Analysis in the Sooke Watershed, BC, Canada

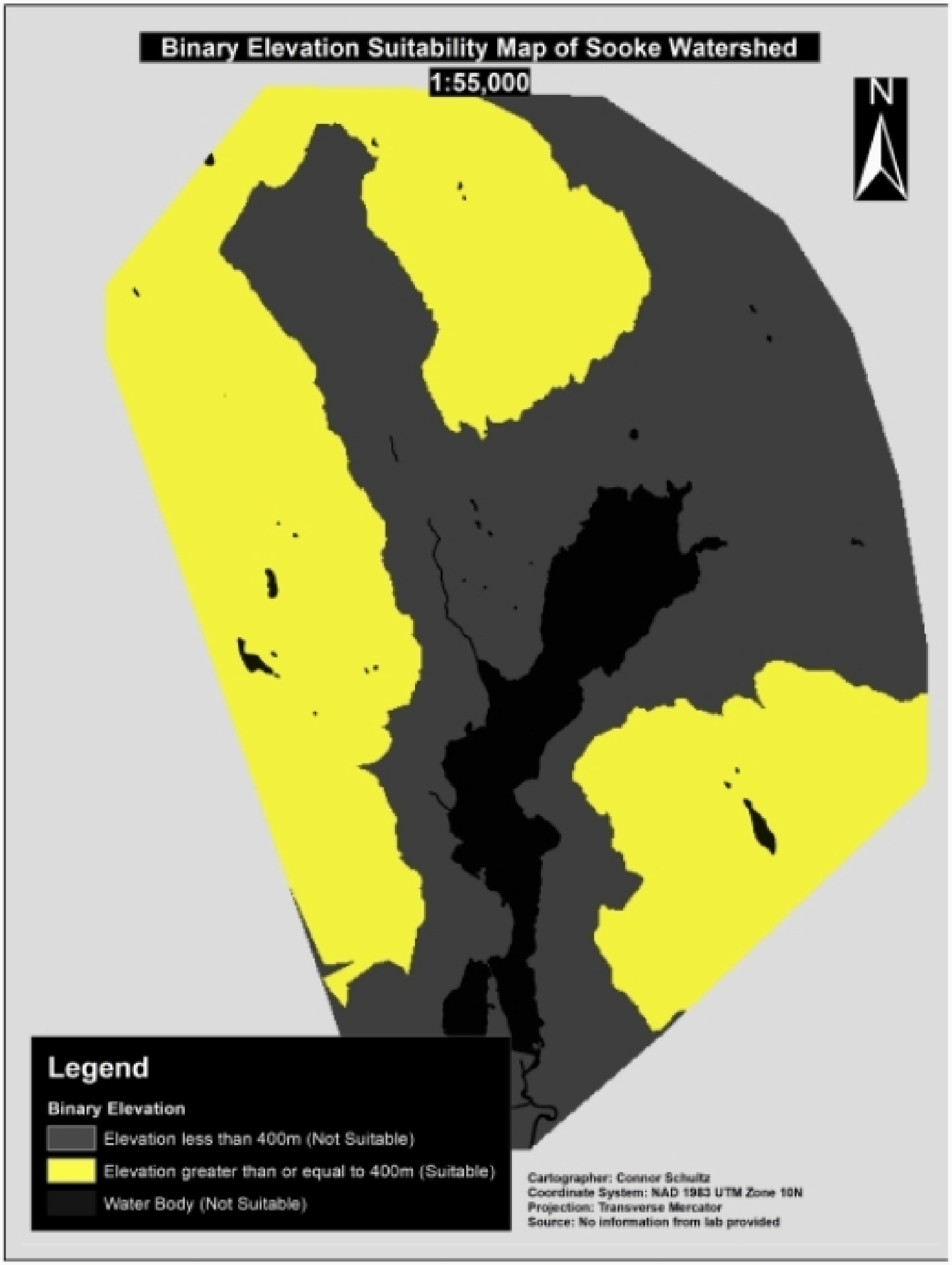

Figure 3: Binary Elevation Suitability map of Sooke Watershed using a threshold of 400 meters

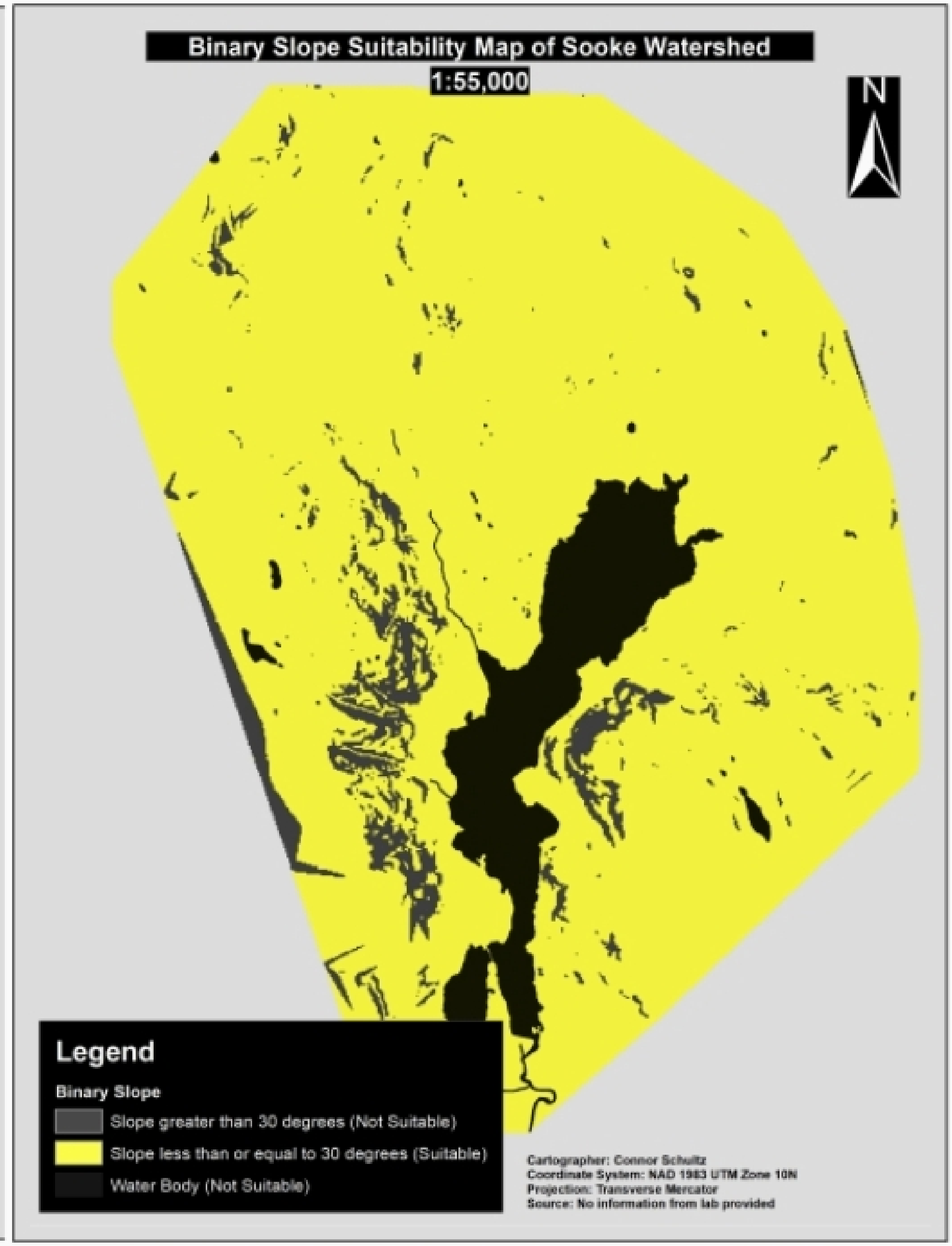

Figure 4: Binary Slope Suitability map of Sooke Watershed using a threshold of 30 degrees

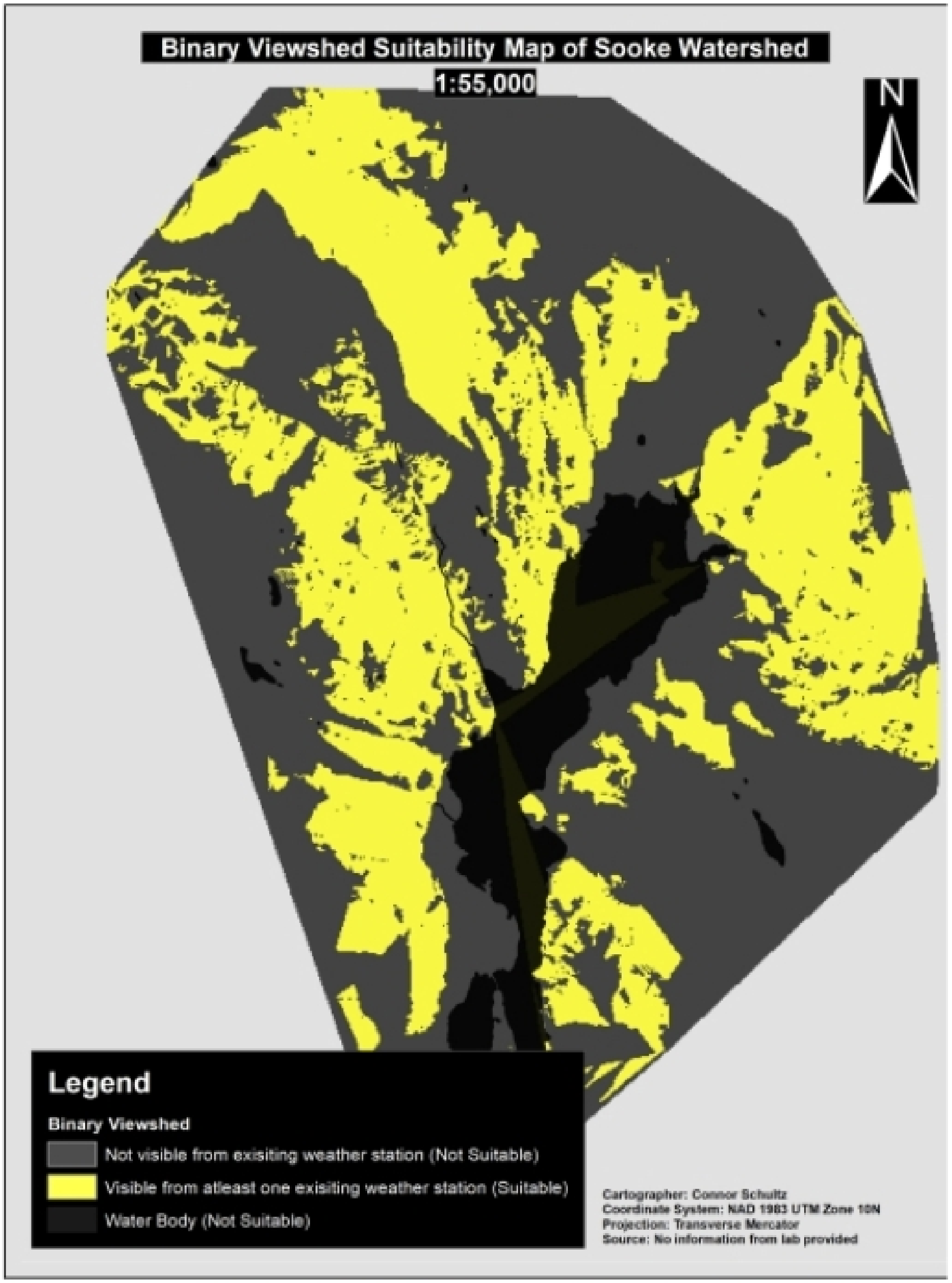

Figure 5: Binary Viewshed Suitability map of Sooke Watershed using the four existing weather stations in the area

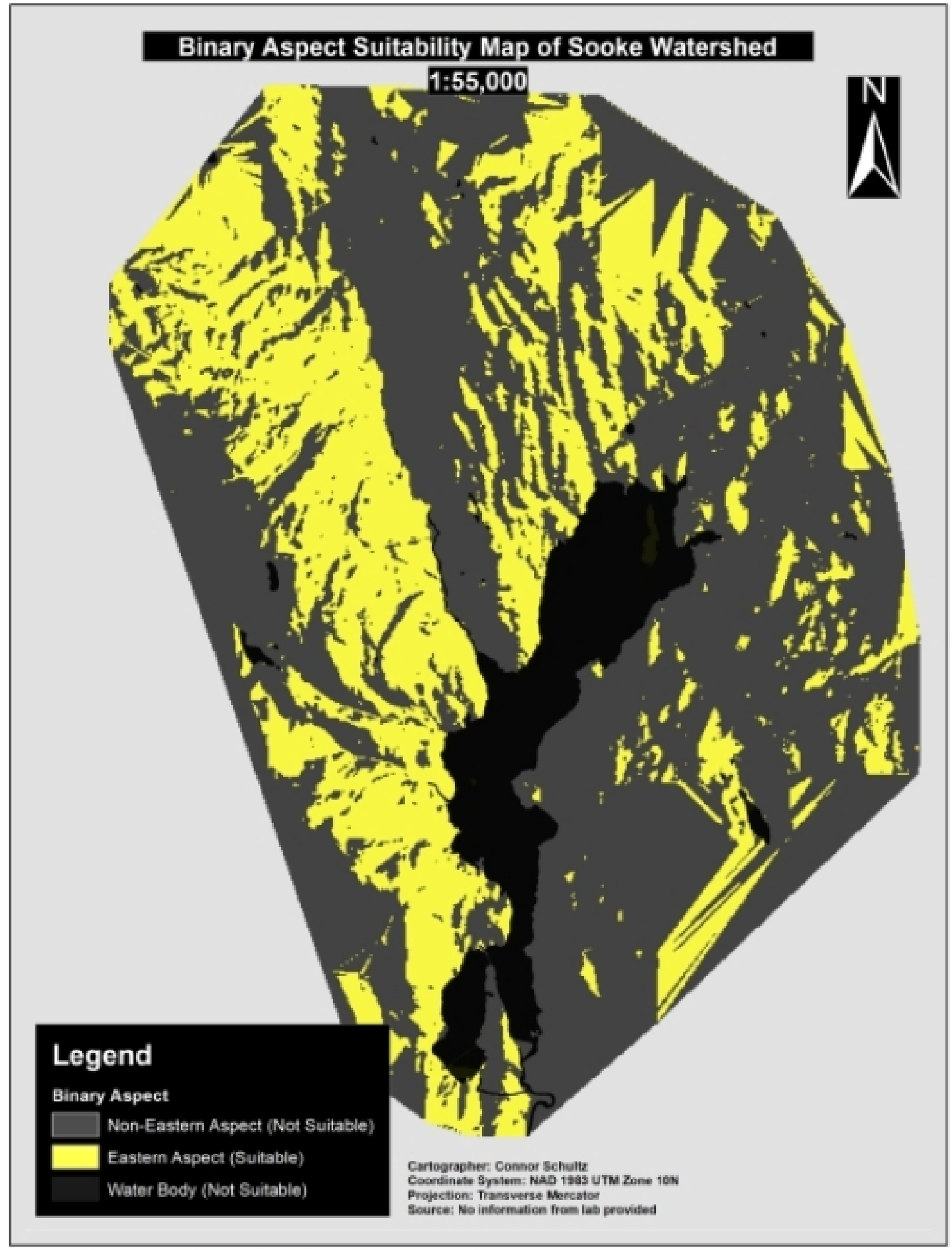

Figure 6: Binary Aspect Suitability map of Sooke Watershed using an interval of 40 – 140 degrees

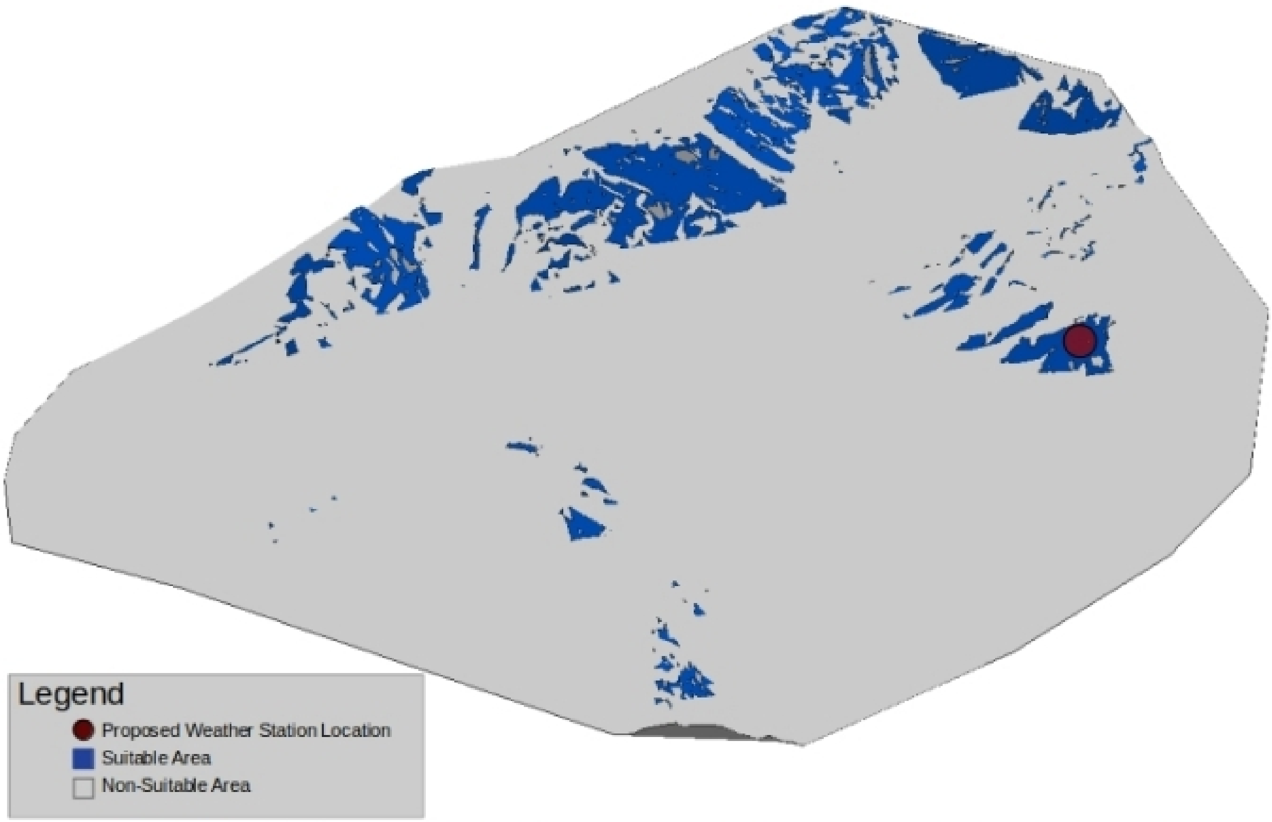

Figure 7: 3D representation of Sooke Watershed with proposed weather station location

Binary Viewshed

Rowid	VALUE	COUNT
0	0	138000
1	1	91286

Binary Slope

Rowid	VALUE	COUNT
0	0	12120
1	1	217166

Binary Aspect

Rowid	VALUE	COUNT
0	0	154870
1	1	74416

Binary Elevation

Rowid	VALUE	COUNT
0	0	127386
1	1	101900

final_output

Rowid	VALUE	COUNT
0	0	212793
1	1	16493

Figure 8: Attribute Tables from all intermediate binary rasters used in final suitability analysis and the final output table

7 References

Capital Regional District (2015, May 01). Sooke Water Supply Area (Primary Water Supply). Retrieved March 6, 2019, from https://www.crd.bc.ca/service/drinking-water/watershed-protection/sooke-water-supply-area-(primary-water-supply)

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Environment Canada (2000). *MSC Installation Standards For RCS Network Autostations* (Vol. 1.0, Draft). (n.d.).

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