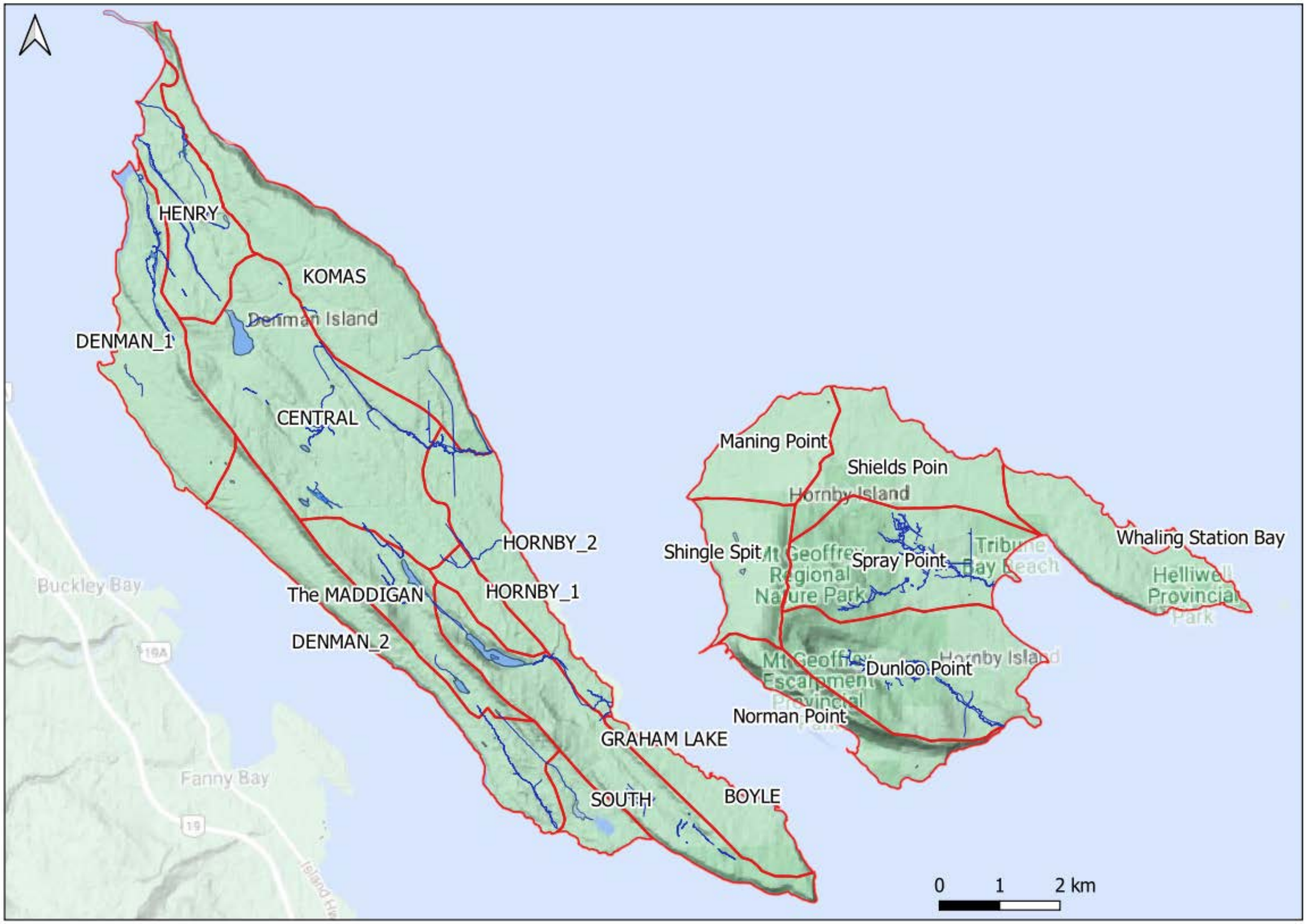
APPENDIX 2: Groundwater Management Regions

Table 1. Groundwater management regions of the Study Islands

Study Island	Groundwater Region Name	Groundwater Region ID	Groundwater Region Area (km^2)	Total Area (km^2)	GW Region Count
Denman Island	BOYLE	BL	2.38	51.58	11
	HENRY	HY	3.84		
	HORNBY_1	H1	1.12		
	HORNBY_2	H2	3.60		
	KOMAS	KS	8.32		
	CENTRAL	CL	11.14		
	SOUTH	SU	1.33		
	DENMAN_1	D1	5.43		
	DENMAN_2	D2	5.64		
	GRAHAM LAKE	GL	5.63		
	The MADDIGAN	MN	3.15		
Hornby Island	Dunloo Point	DP	6.97	29.92	7
	Spray Point	SY	6.10		
	Shields Point	SL	4.50		
	Whaling Station Bay	WS	4.09		
	Maning Point	MP	2.90		
	Shingle Spit	SS	2.90		
	Norman Point	NP	2.50		
Gabriola Island	North Degnen Bay Region	ND	2.22	52.65	11
	West Degnen Bay	WD	2.77		
	Gabriola Region	GR	12.30		
	False Narrow Region	FN	6.18		

Study Island	Groundwater Region Name	Groundwater Region ID	Groundwater Region Area (km²)	Total Area (km²)	GW Region Count
	Lock Bay Region	LB	8.30		
	Hoggan Lake Region	HL	9.02		
	Sand Region	SR	3.65		
	Descanso Bay Region	DB	3.03		
	Northumberland Channel Region	NC	1.22		
	South Descanso Bay Region	SD	1.74		
	Silva Bay Region	SB	2.22		
Galiano Island	North Galiano Spanish Hills	GAL01	2.29	58.15	21
	Dionisio Point	GAL02	1.73		
	North Georgia Strait	GAL03	1.46		
	North Trincomali Channel	GAL04	4.66		
	West Galiano	GAL05	1.92		
	East Galiano	GAL06	3.63		
	Greig Creek	GAL07	2.38		
	Central Georgia Strait	GAL08	3.36		
	Quadra Hill East	GAL09	3.15		
	Quadra Hill West	GAL10	5.04		
	South Trincomali Channel	GAL11	1.07		
	Cook Cove	GAL12	3.23		
	Finlay Lake	GAL13	3.32		
	Montague Harbour	GAL14	3.17		
	Winstanley Point	GAL15	0.62		
	Sutil Mountain	GAL16	2.11		
	Georgeson Bay	GAL17	1.90		
	Matthews Point	GAL18	0.53		
	South Galiano	GAL19	3.75		
	Cain Peninsula	GAL20	0.54		
	Murchison- Whaler Bay	GAL21	8.29		
	South Pender I	SP01	2.69	9.12	4

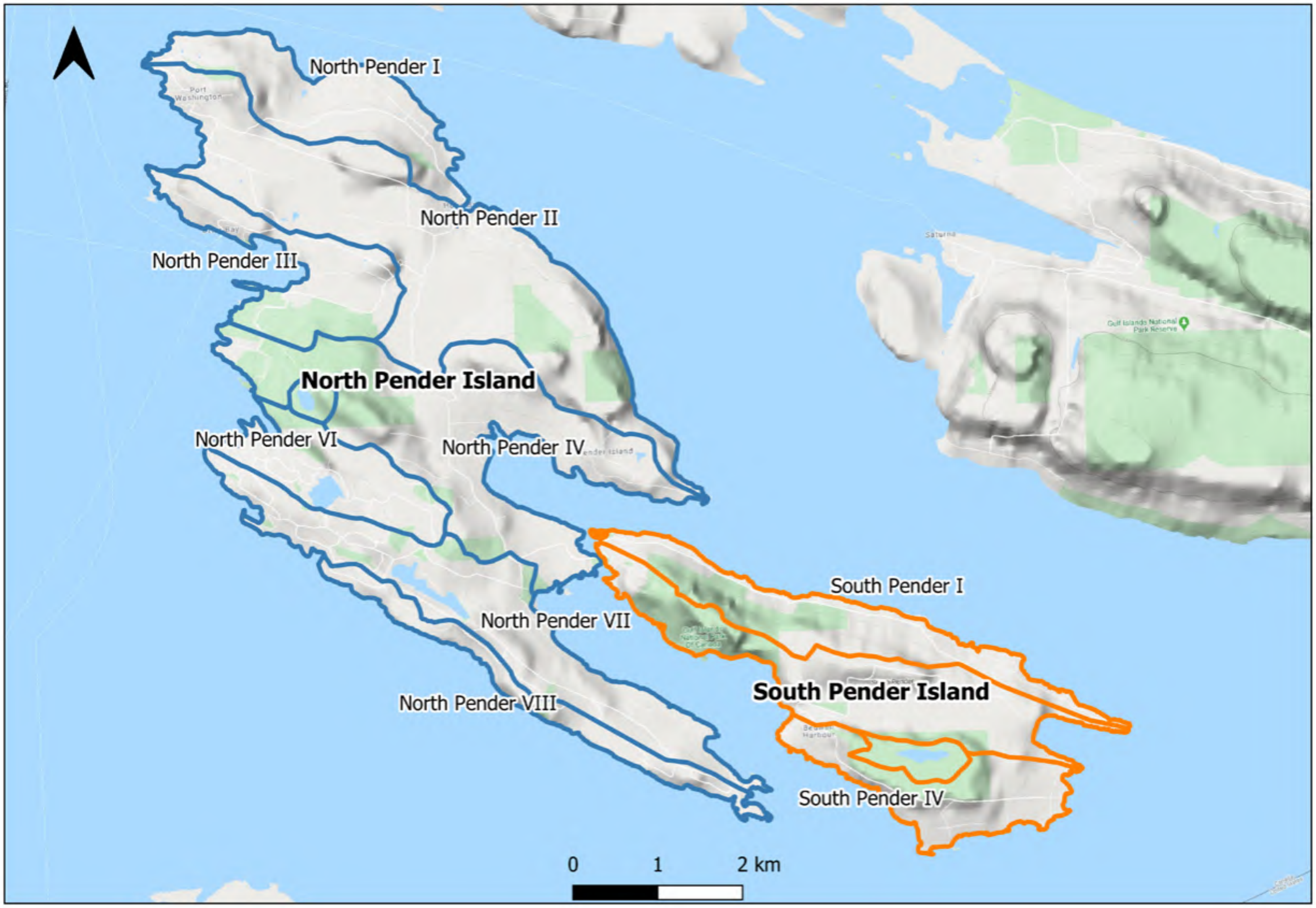
Study Island	Groundwater Region Name	Groundwater Region ID	Groundwater Region Area (km²)	Total Area (km²)	GW Region Count
South Pender Island	South Pender II	SP02	3.80		
	South Pender III	SP03	0.48		
	South Pender IV	SP04	2.15		
North Pender Island	North Pender I	NP01	2.65	27.09	8
	North Pender II	NP02	7.95		
	North Pender III	NP03	2.34		
	North Pender IV	NP04	6.15		
	North Pender V	NP05	0.23		
	North Pender VI	NP06	2.00		
	North Pender VII	NP07	4.33		
	North Pender VIII	NP08	1.44		
Saturna Island	Boot Cove	SAT01	2.66	34.25	5
	Brown Ridge	SAT02	6.70		
	Lyall Harbour	SAT03	10.39		
	Narvaez Bay	SAT04	5.94		
	Tumbo Channel	SAT05	6.56		
Mayne Island	Navy Channel Westside	MAY06	3.00	23.36	7
	Navy Channel_Eastside	MAY07	0.86		
	Center1_East	MAY02	4.28		
	Center1_West	MAY03	3.91		
	Center2_East	MAY04	5.45		
	Center2_West	MAY05	2.04		
	Georgina Pt_Hall Hill North	MAY01	3.82		
Prevost Island	Prevost Island	PRE01	6.72	6.72	1



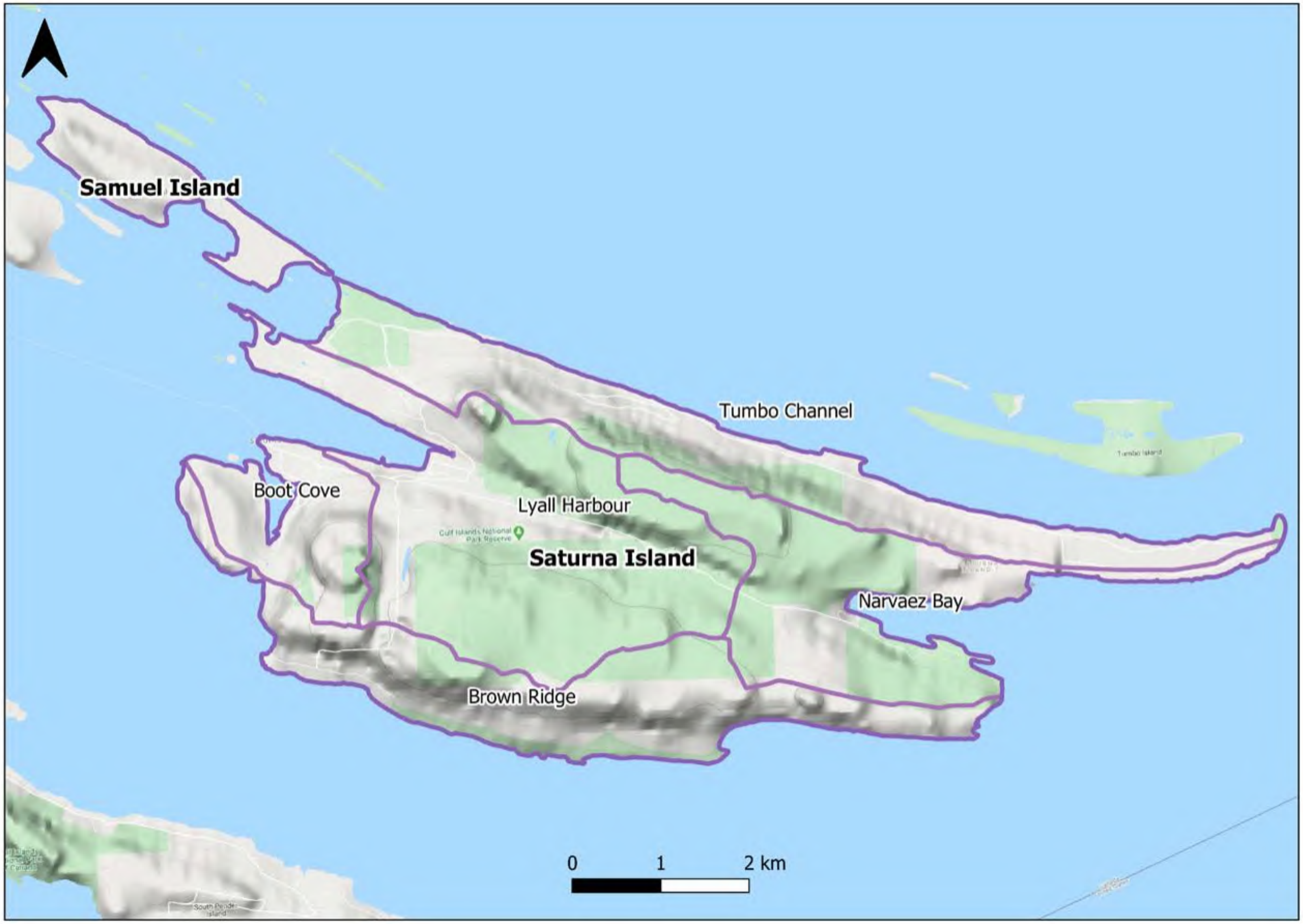
Denman and Hornby Islands

Gabriola Island

Galiano Island

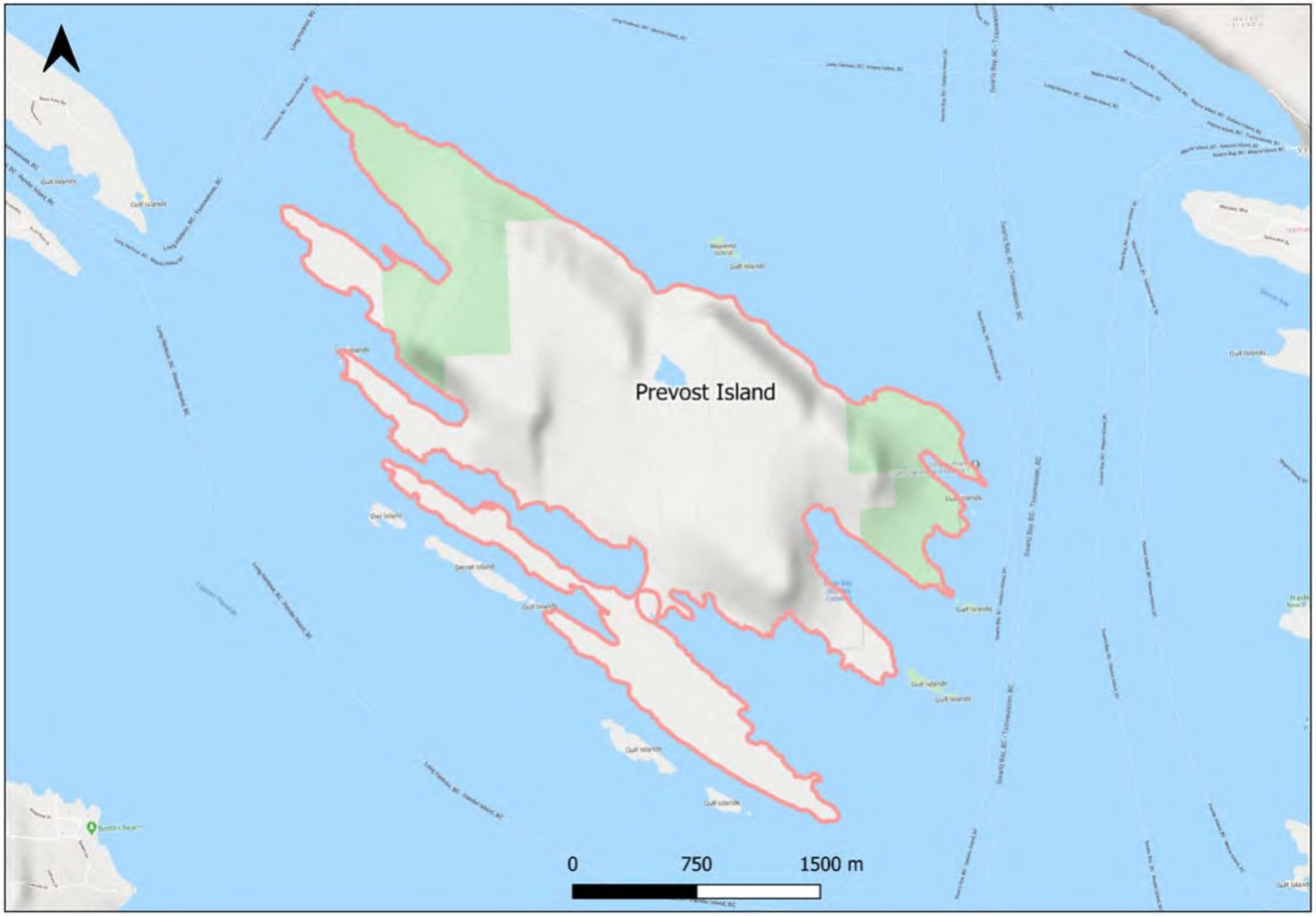


North Pender Island and South Pender Island



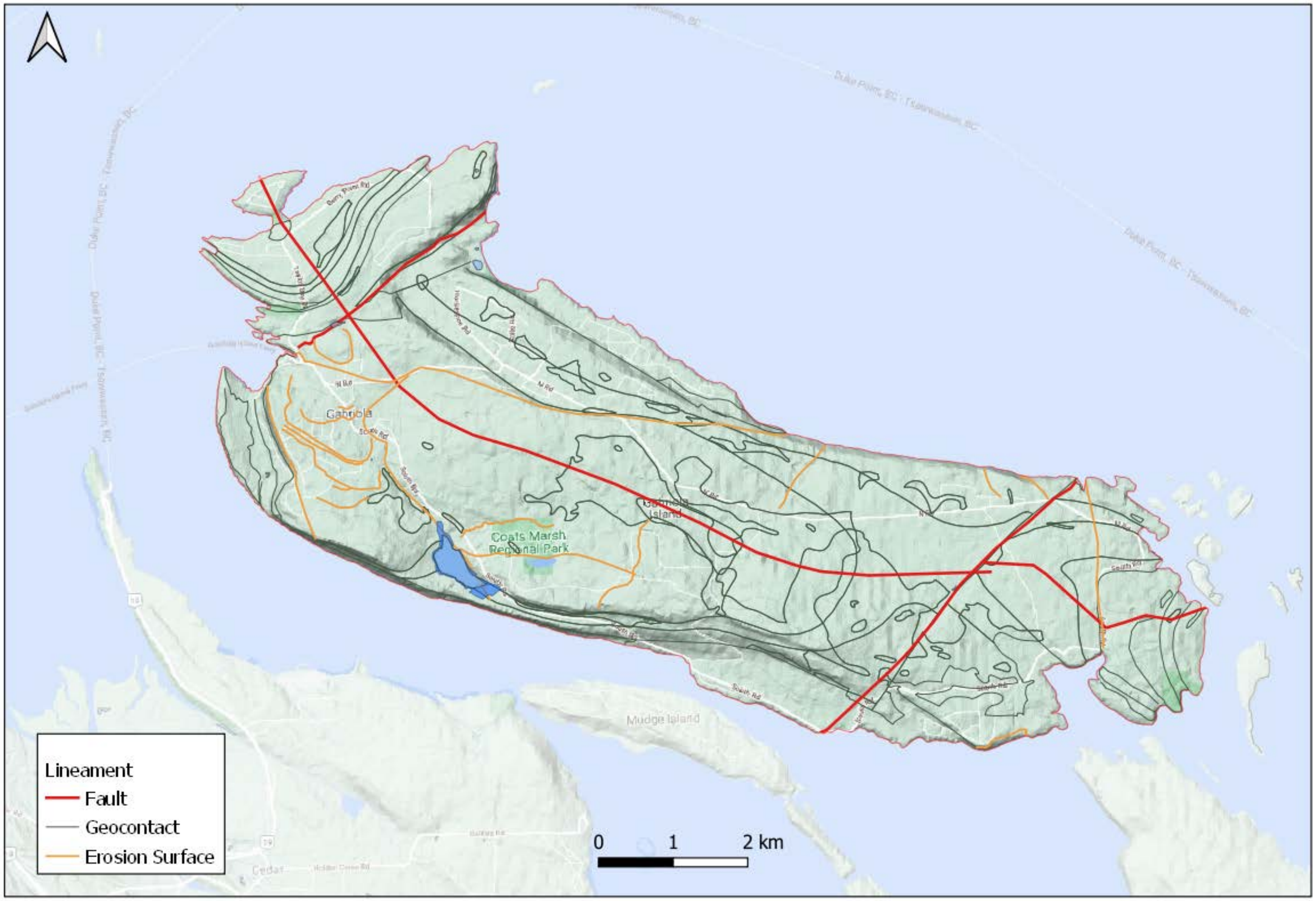
Saturna Island

Mayne Island



Prevost Island

APPENDIX 3: The Map of Delineated Lineaments for the Study Islands



Gabriola Island lineaments (faults, erosion surface and geological contacts)

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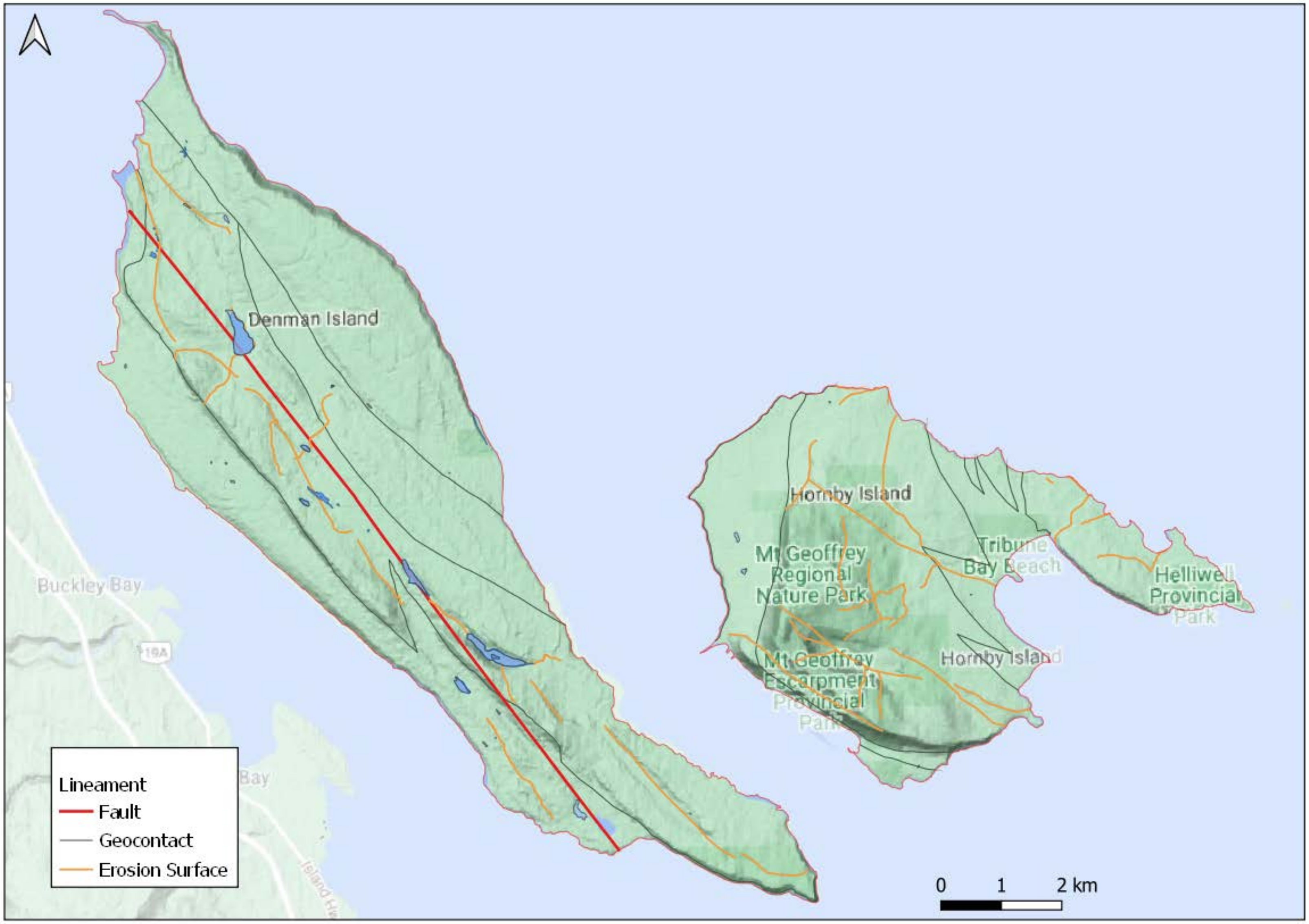
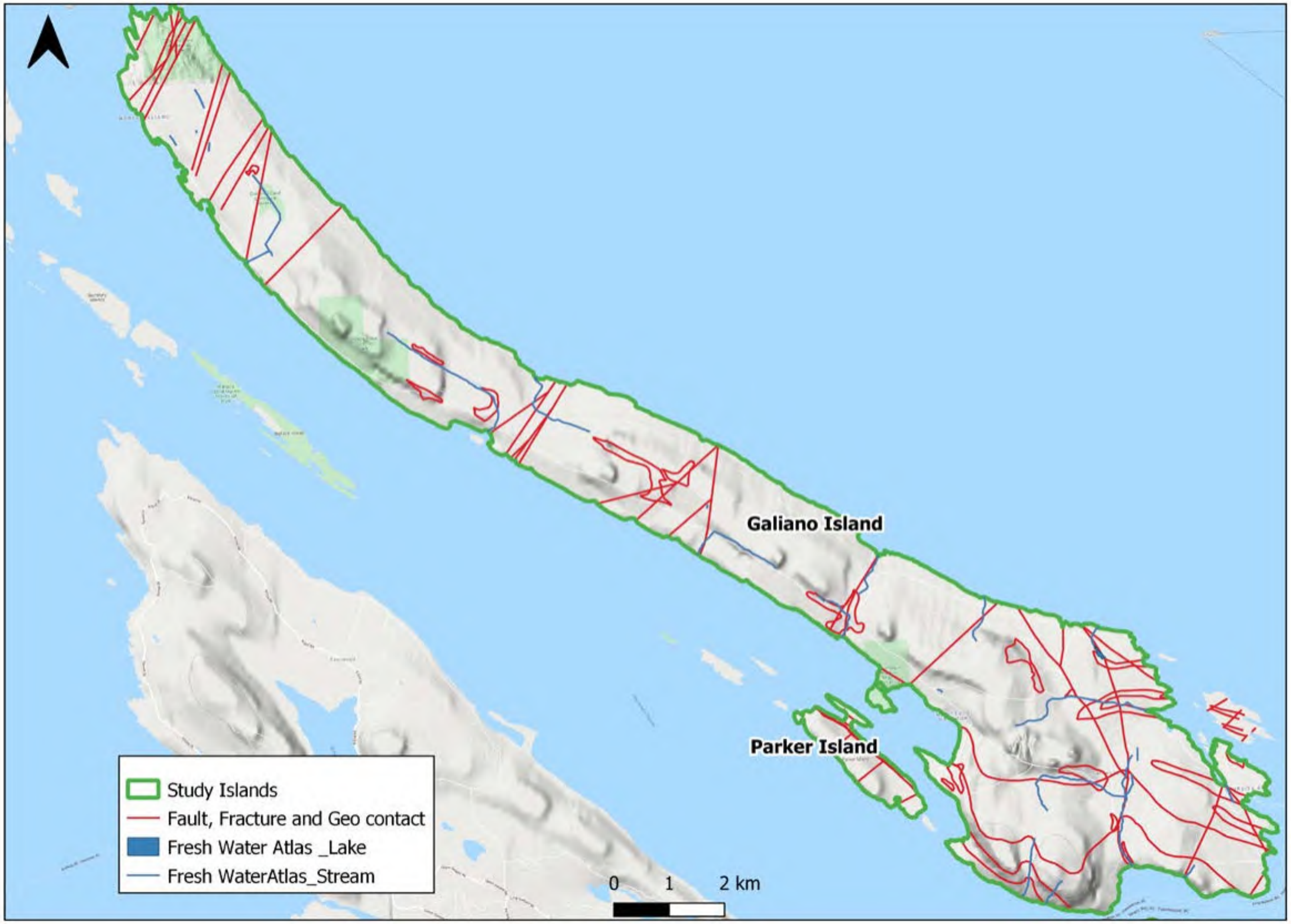
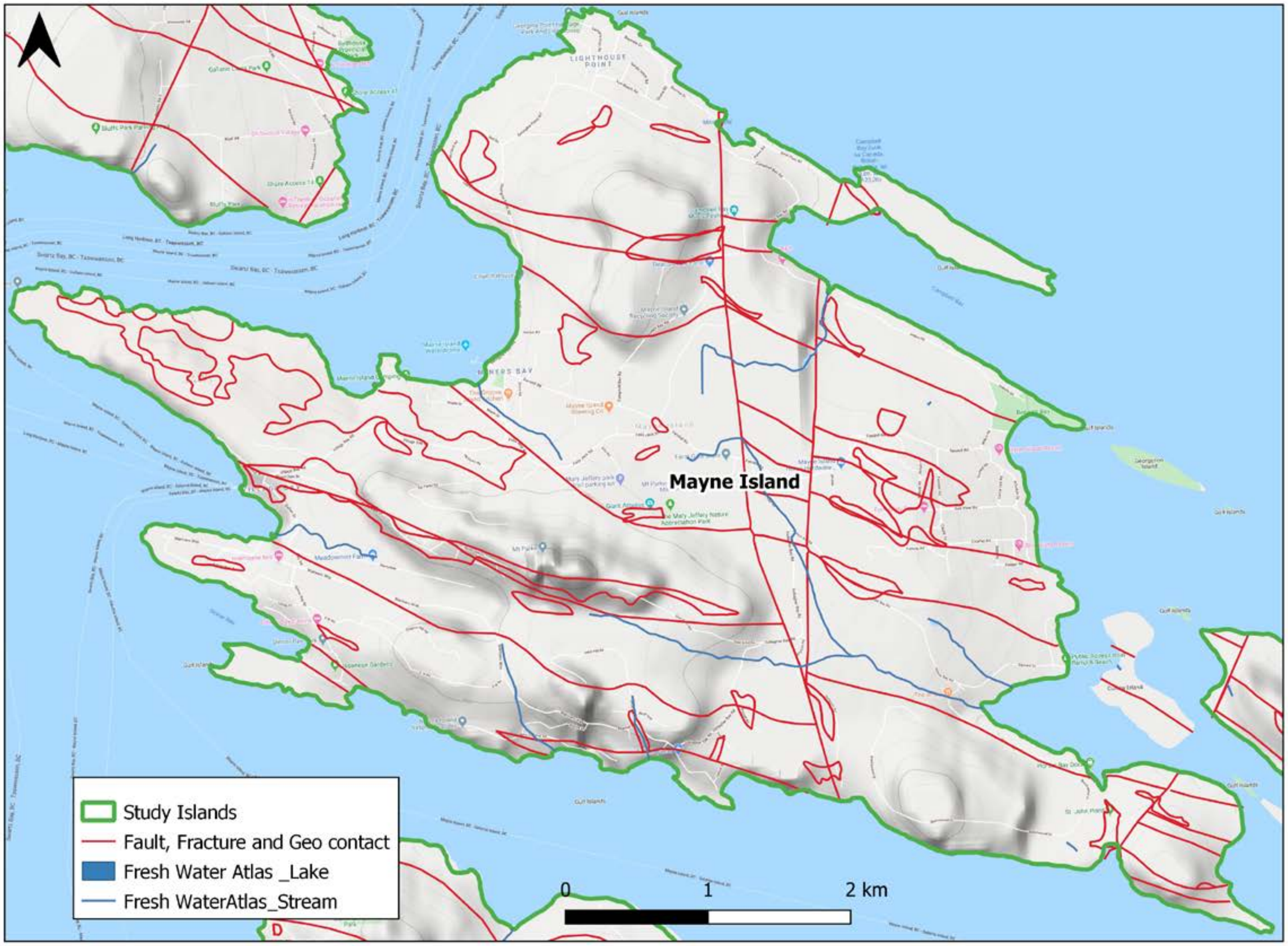


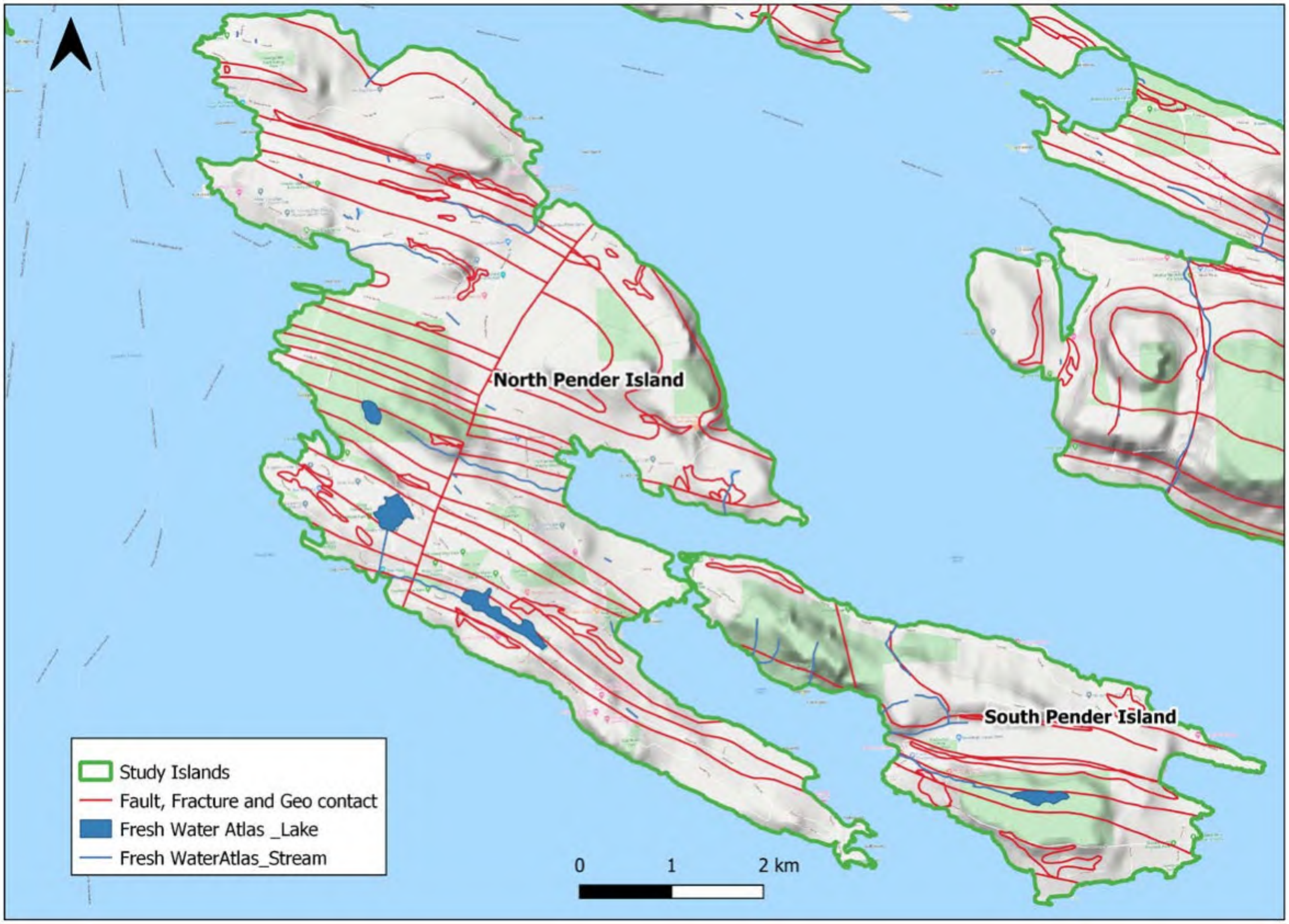
Denman and Hornby Islands lineaments (faults, erosion surface, and geological contacts)



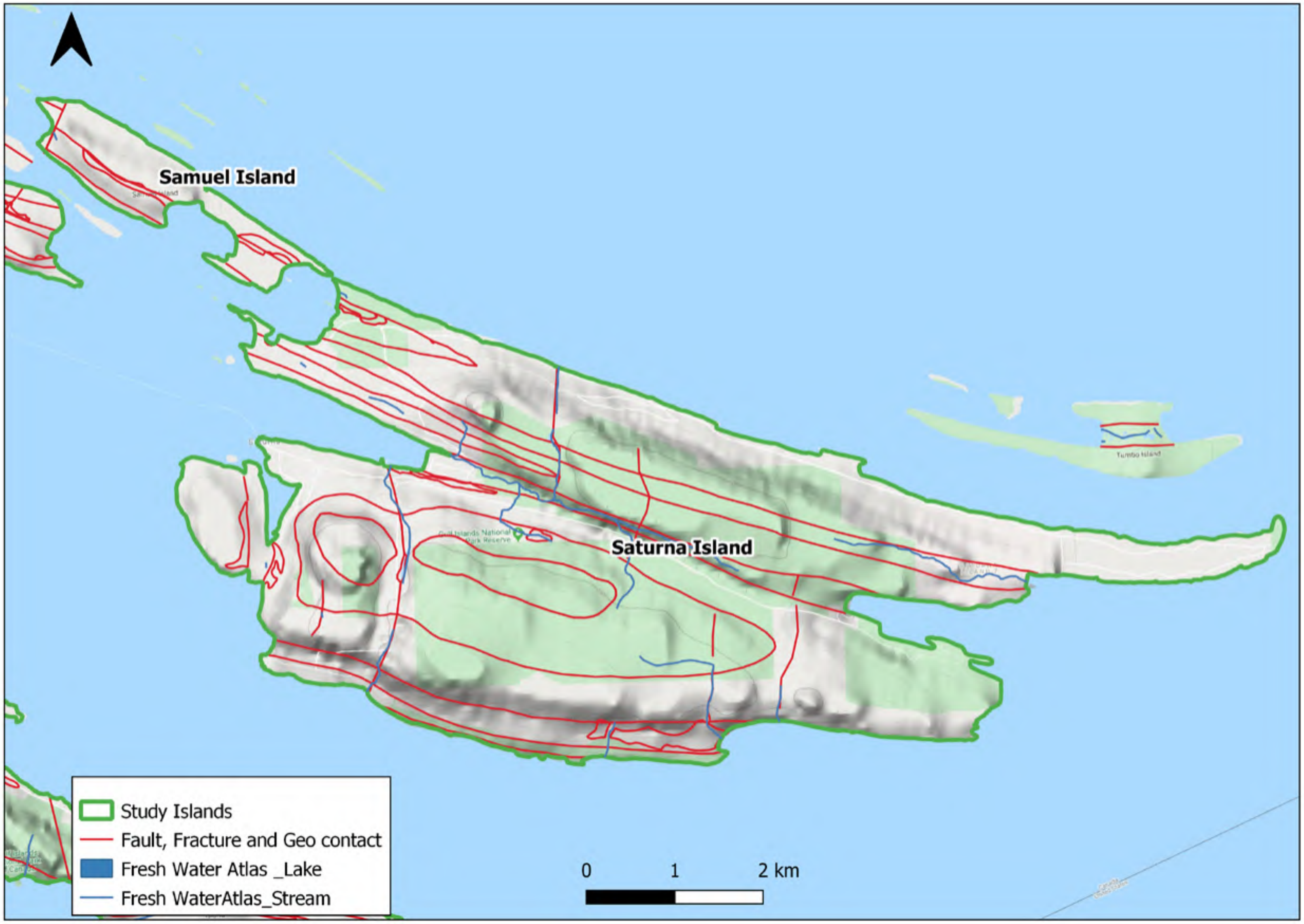
Galiano Island lineaments (faults, fractures, and geological contacts)



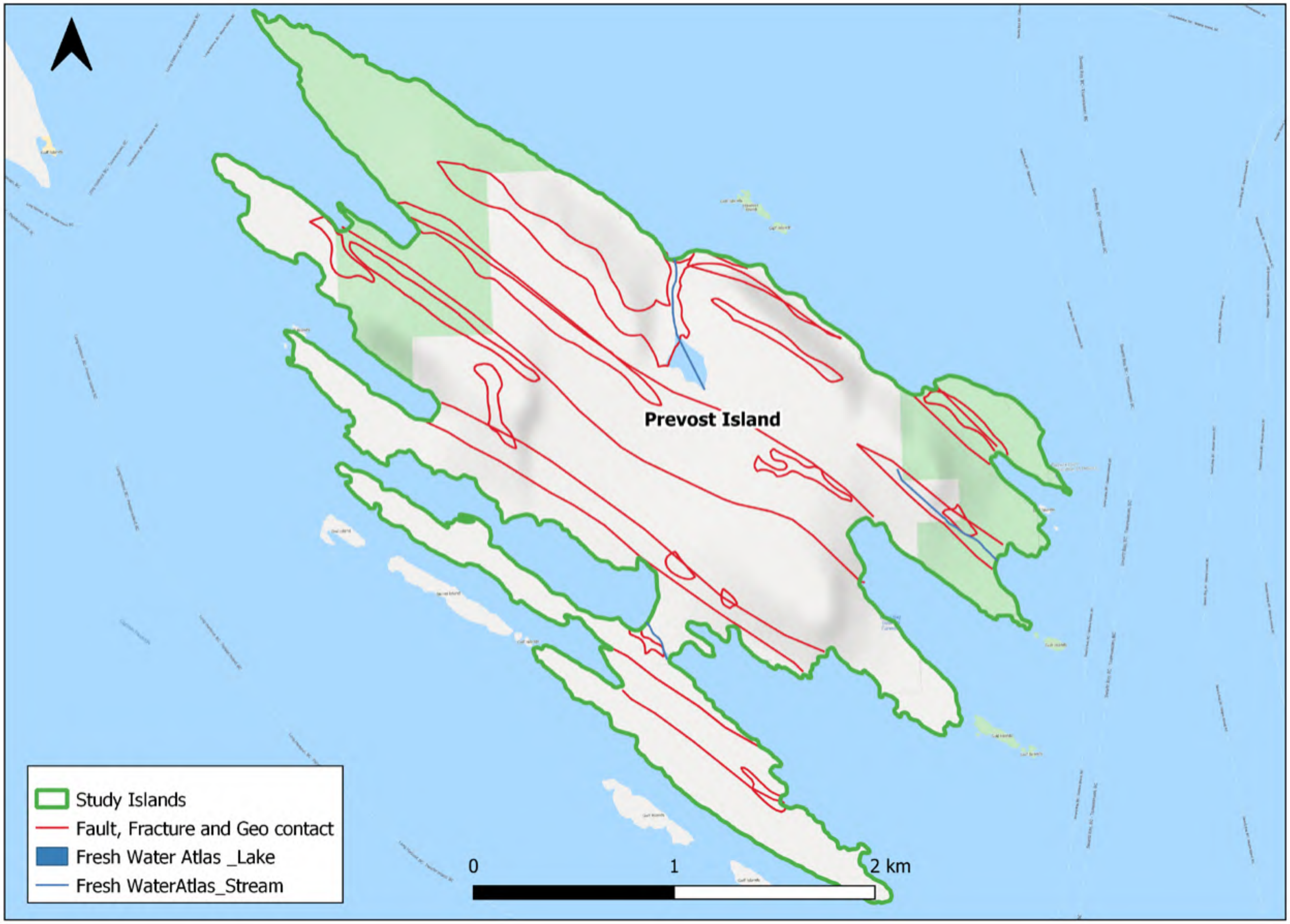
Mayne Island lineaments (faults, fractures and geological contacts)



North Pender and South Pender Islands lineament (faults, fractures and geological contacts)



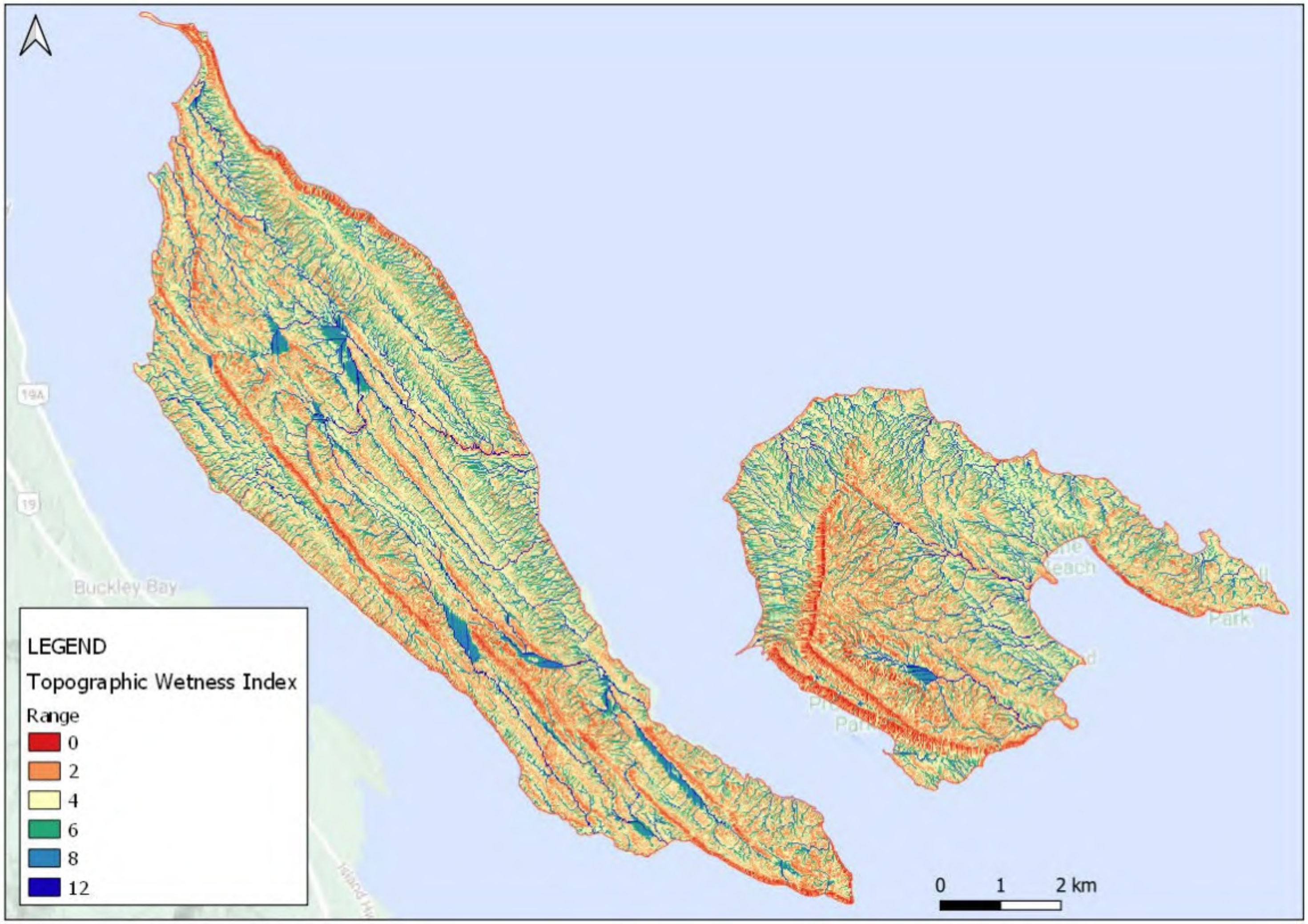
Saturna Island Lineaments (faults, fractures and geological contacts)



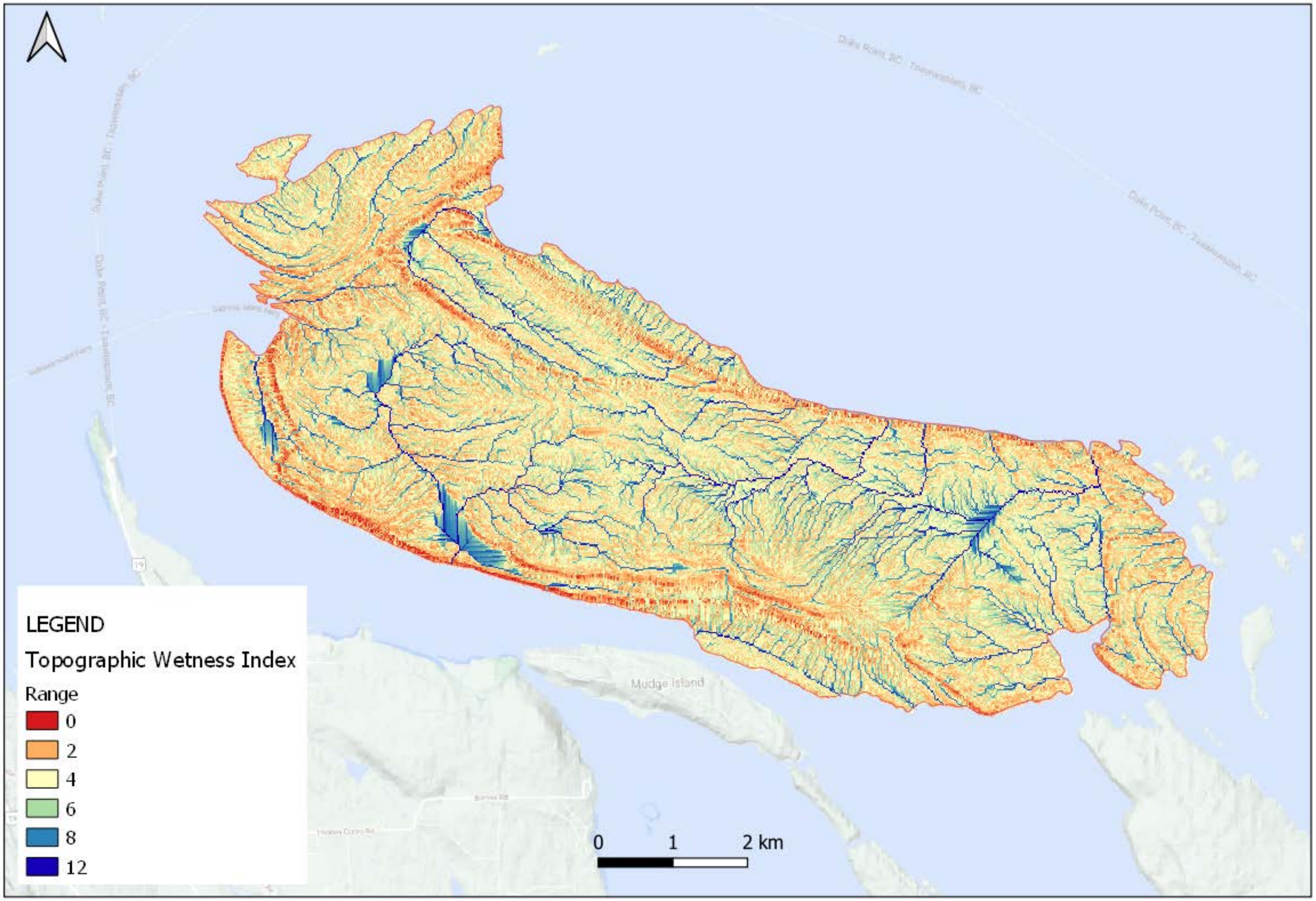
Prevost Island lineaments (faults, fractures and geological contacts)

APPENDIX 4: Topography Wetness Index (TWI) across the Study Islands

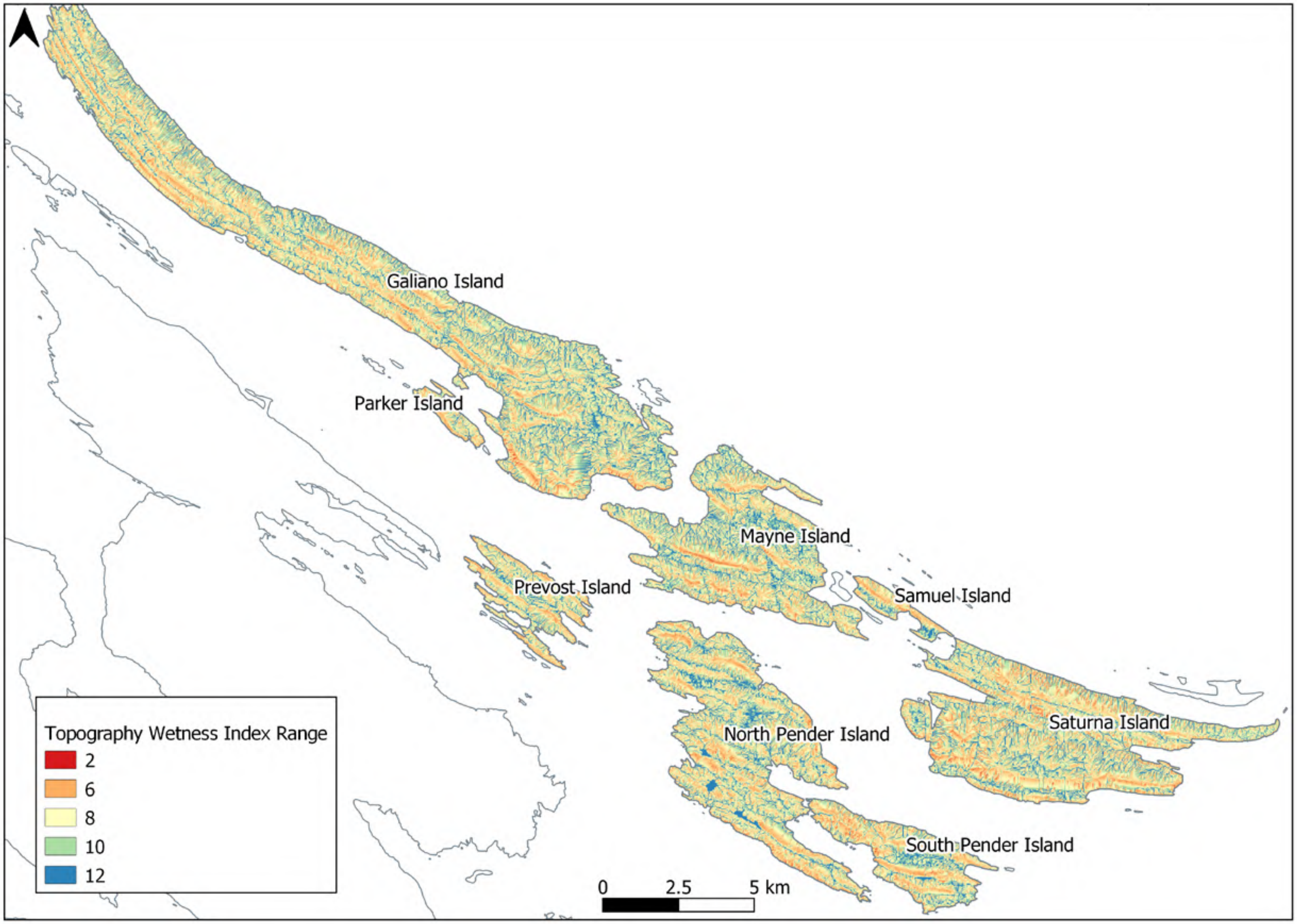
GW Solutions Inc.
Suite 24 – 4800 Island Hwy, Nanaimo, BC, V9T 1W6
Tel. (250) 756-4538 * abarroso@gwsolutions.ca



Generated Topography Wetness Index across Denman and Hornby Islands

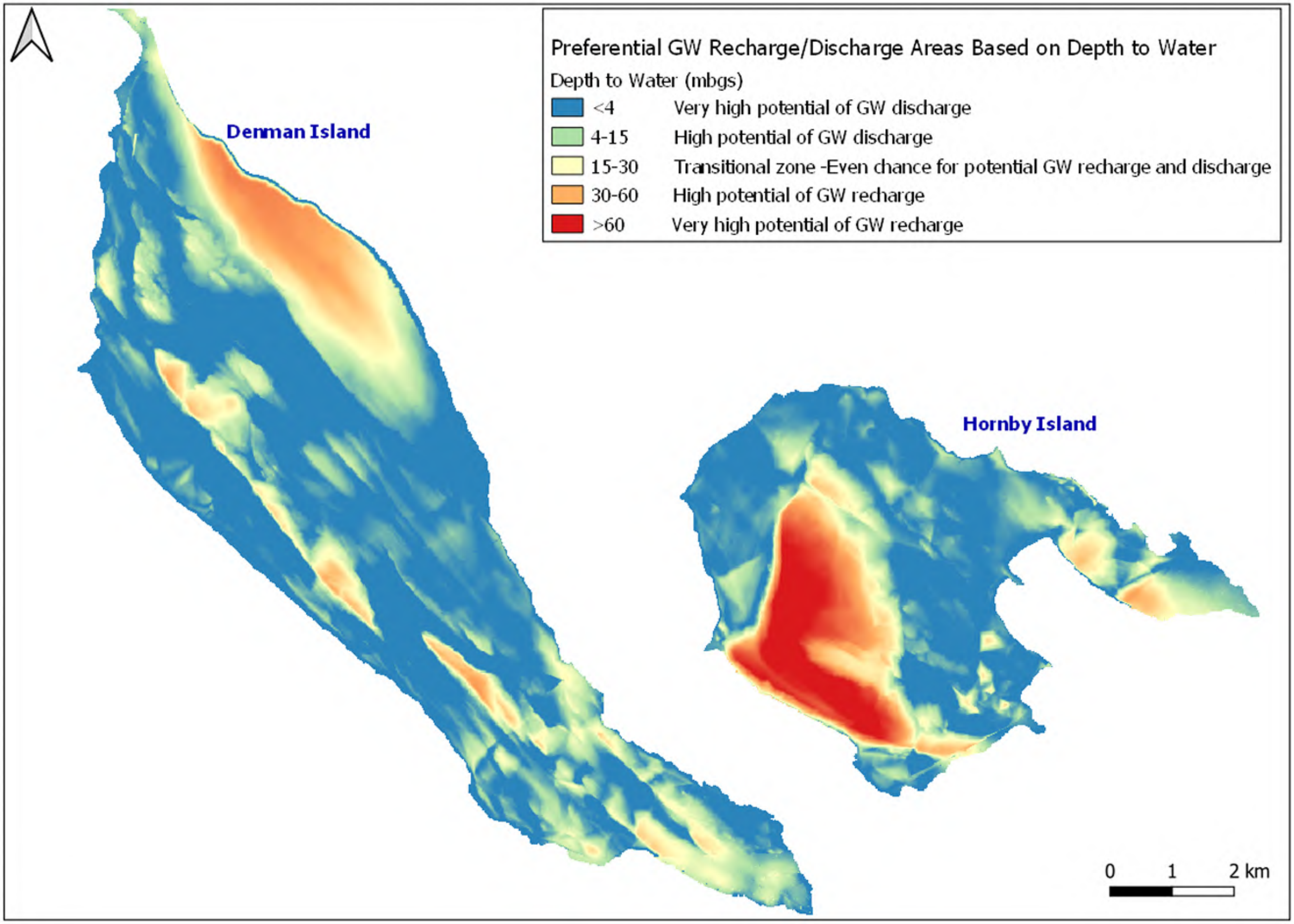


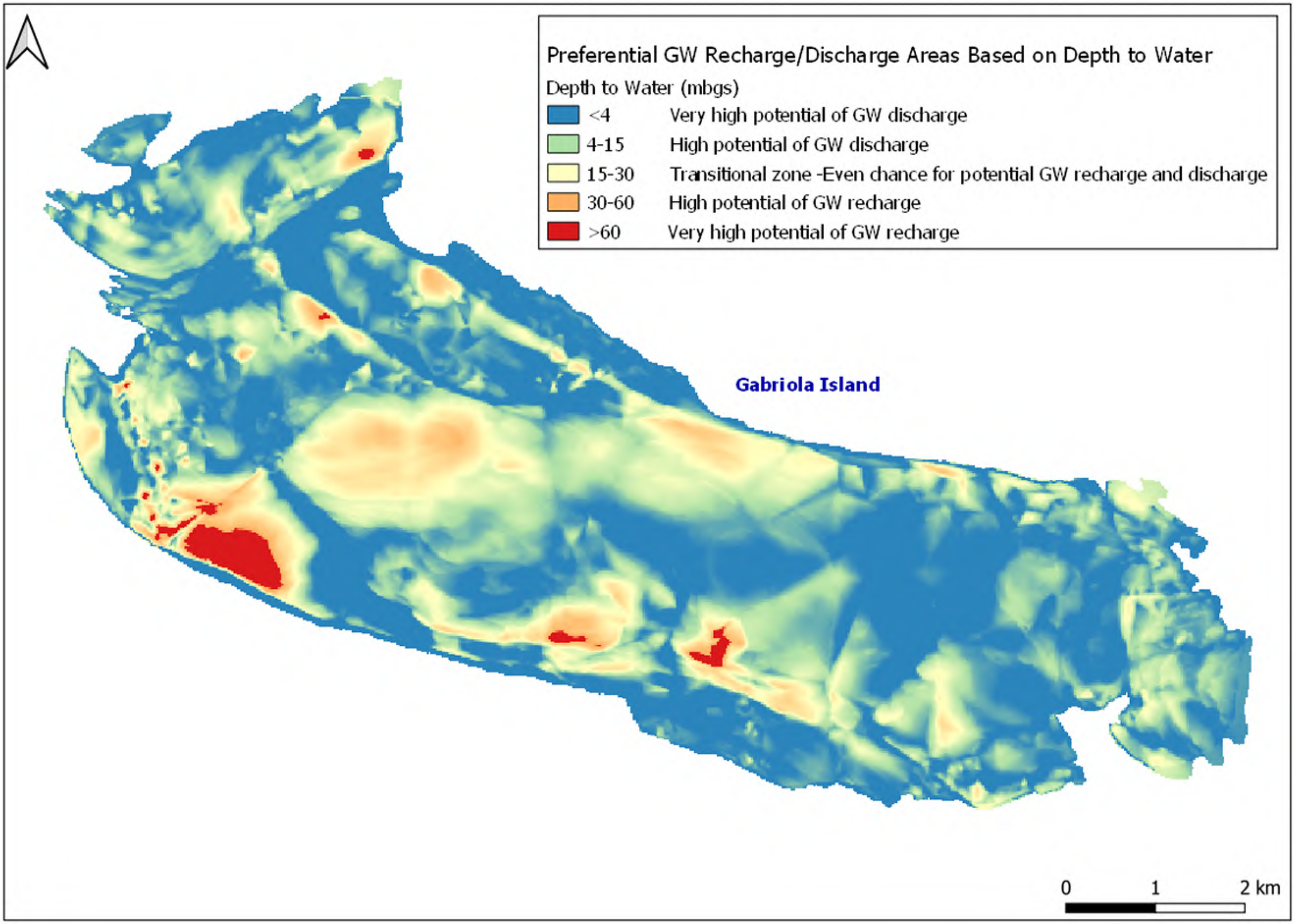
Generated Topography Wetness Index across Gabriola Island

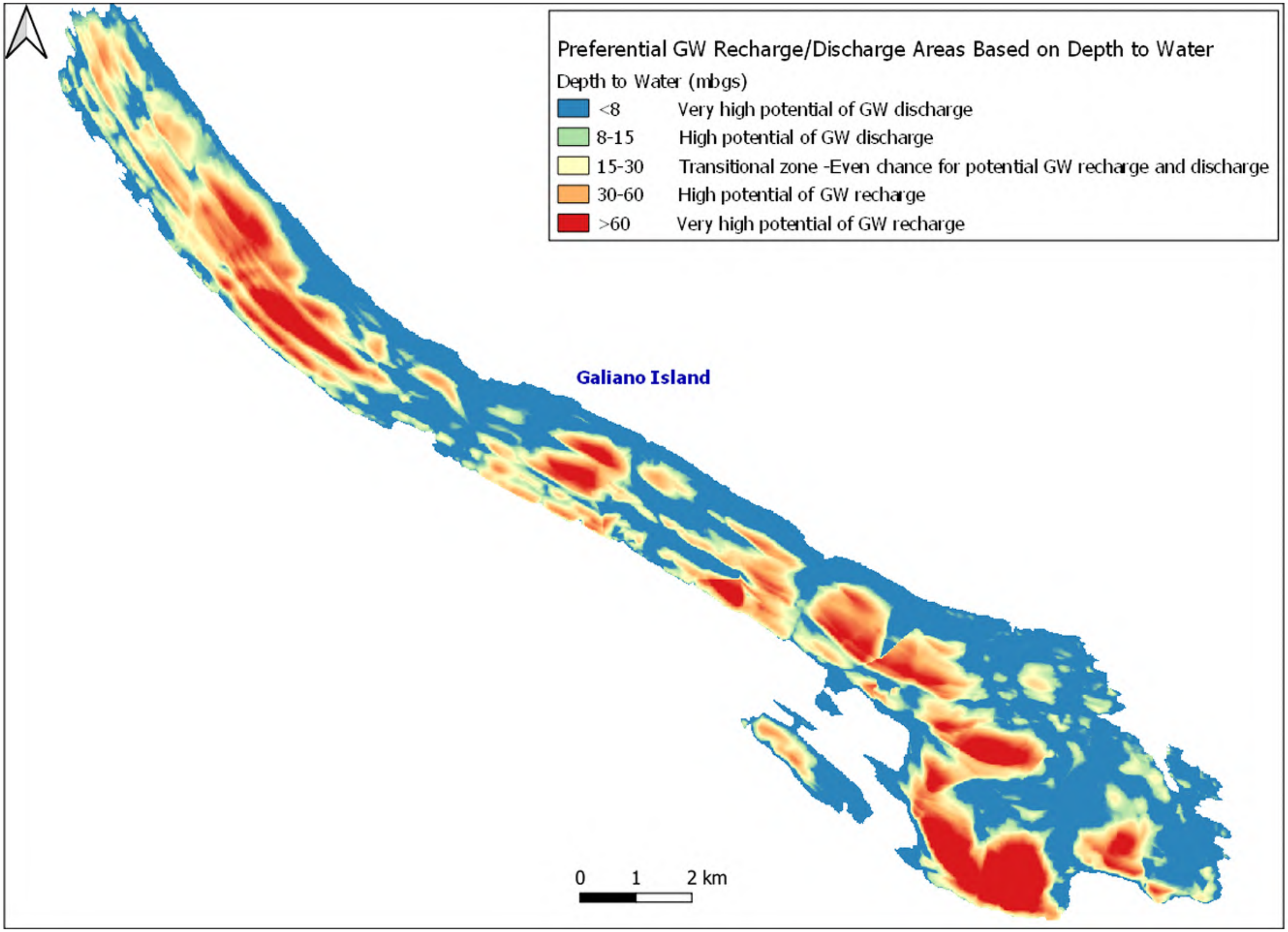


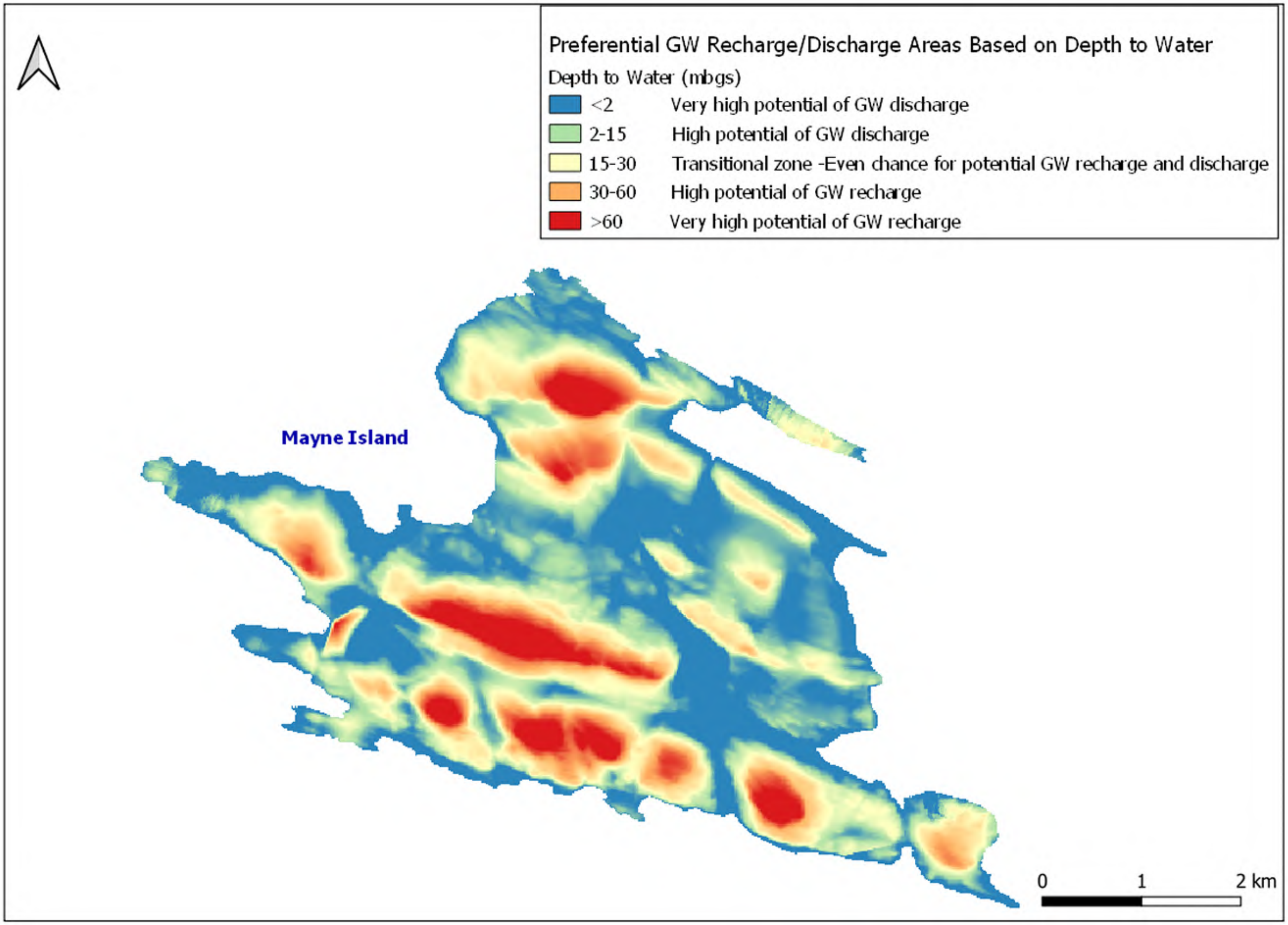
Generated Topography Wetness Index across Galiano, North Pender, South Pender, Mayne, Saturna, and Prevost Islands

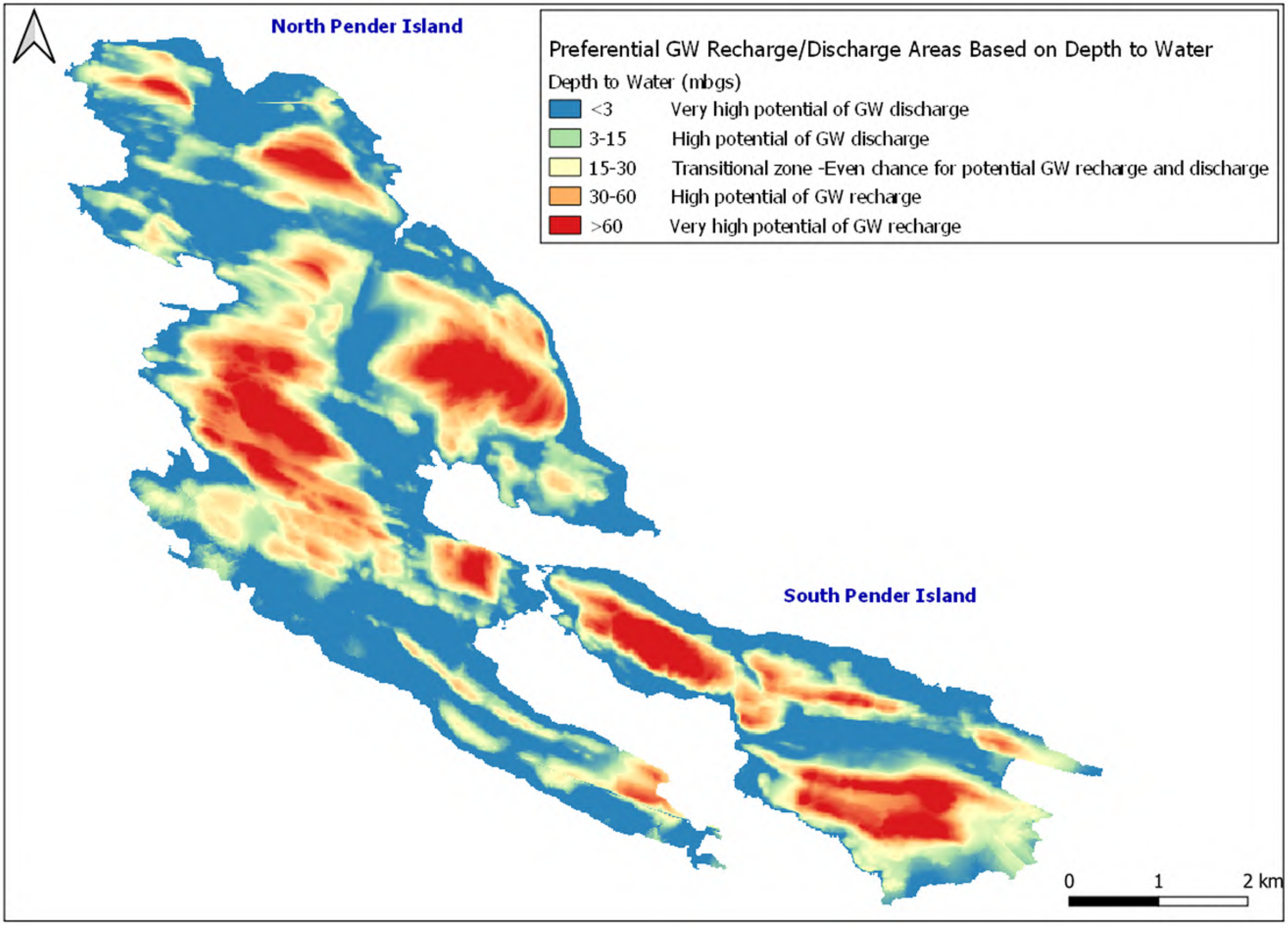
APPENDIX 5: Potential Zones for Groundwater Recharge and Discharge based on Depth to Water

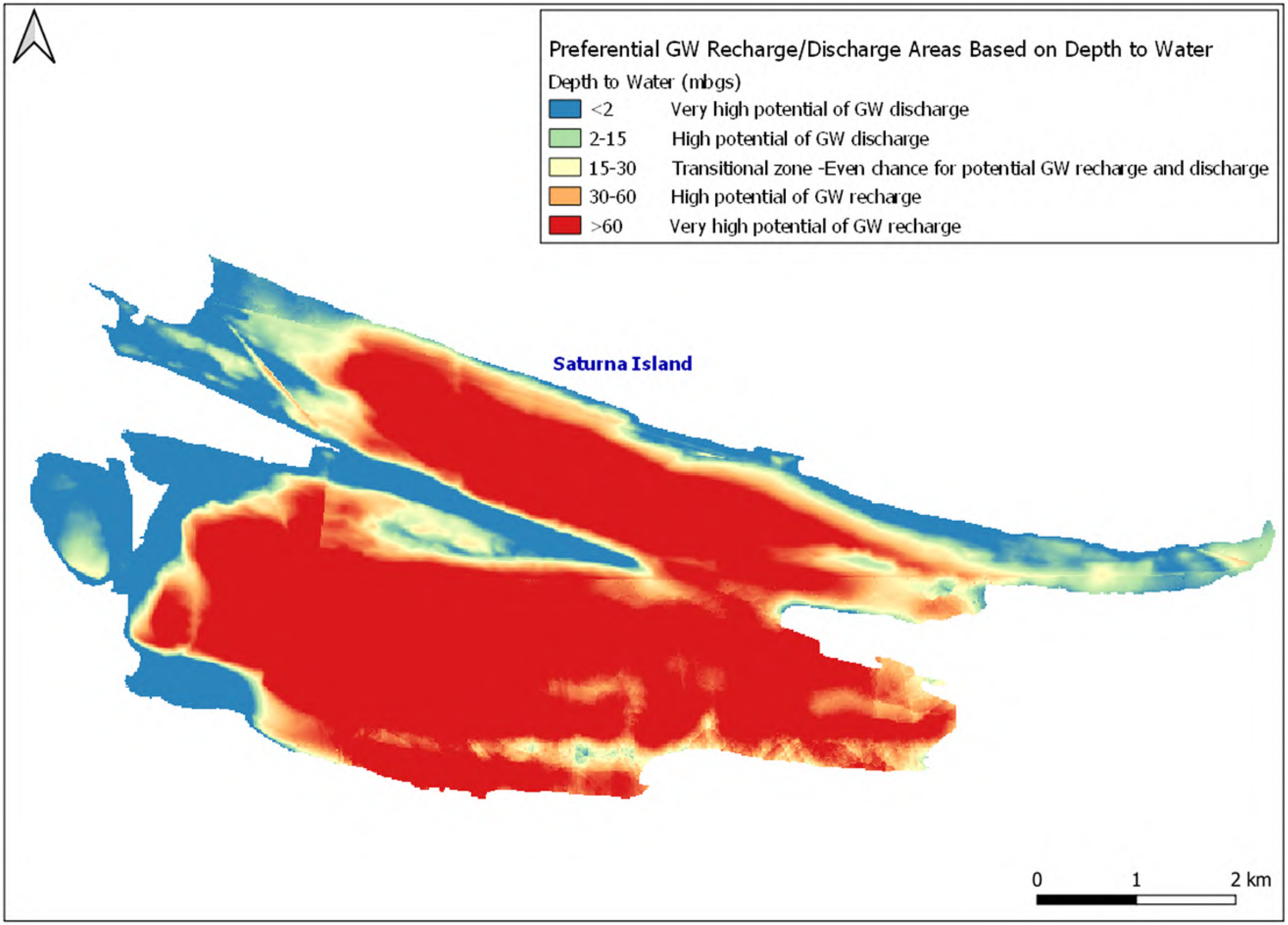

Preferential GW Recharge/Discharge Areas Based on Depth to Water
Depth to Water (mbgs)
<4 Very high potential of GW discharge
4-15 High potential of GW discharge
15-30 Transitional zone -Even chance for potential GW recharge and discharge
30-60 High potential of GW recharge
>60 Very high potential of GW recharge
Denman Island
Hornby Island
0 1 2 km


Preferential GW Recharge/Discharge Areas Based on Depth to Water
Depth to Water (mbgs)
<4 Very high potential of GW discharge
4-15 High potential of GW discharge
15-30 Transitional zone -Even chance for potential GW recharge and discharge
30-60 High potential of GW recharge
>60 Very high potential of GW recharge
Gabriola Island
0
1
2 km


Preferential GW Recharge/Discharge Areas Based on Depth to Water
Depth to Water (mbgs)
<8 Very high potential of GW discharge
8-15 High potential of GW discharge
15-30 Transitional zone -Even chance for potential GW recharge and discharge
30-60 High potential of GW recharge
>60 Very high potential of GW recharge
Galiano Island
0 1 2 km


Preferential GW Recharge/Discharge Areas Based on Depth to Water
Depth to Water (mbgs)
<2 Very high potential of GW discharge
2-15 High potential of GW discharge
15-30 Transitional zone -Even chance for potential GW recharge and discharge
30-60 High potential of GW recharge
>60 Very high potential of GW recharge
Mayne Island
0
1
2 km


North Pender Island
Preferential GW Recharge/Discharge Areas Based on Depth to Water
Depth to Water (mbgs)
<3 Very high potential of GW discharge
3-15 High potential of GW discharge
15-30 Transitional zone -Even chance for potential GW recharge and discharge
30-60 High potential of GW recharge
>60 Very high potential of GW recharge
South Pender Island
0 1 2 km


Preferential GW Recharge/Discharge Areas Based on Depth to Water
Depth to Water (mbgs)
<2 Very high potential of GW discharge
2-15 High potential of GW discharge
15-30 Transitional zone -Even chance for potential GW recharge and discharge
30-60 High potential of GW recharge
>60 Very high potential of GW recharge
Saturna Island
0
1
2 km

APPENDIX 6: Description of methodological review process for different methods of remote sensing approach

Mapping Potential groundwater discharge Based on Remote sensing approach

1 INTRODUCTION TO GROUNDWATER DISCHARGE MAPPING

Groundwater discharge can be defined as occurring when "groundwater flows upwards towards the land surface or where the water table intersects the land surface" (Sass et al., 2014). Groundwater is naturally discharged in areas of relatively lower hydraulic potential and these areas are relatively low-lying, and are located at the bottoms of linear and depressions in the topography, on the lower reaches of slopes and depressions, as well as near major breaks in the slopes. Groundwater discharge thus occurs in the lower elevations adjacent to areas of higher elevation which are the groundwater recharge areas (Toth, 1971).

Several approaches have been proposed for estimating the presence of groundwater discharge, using a variety of data sources. GW solutions reviewed several academic and public-sector methodologies to select a method for groundwater discharge estimation that could be applied to Vancouver Island and its surrounding islands. Based on its review, GW solutions selected a method for discharge estimation based on satellite-based multispectral image analysis. This method was chosen due to its ease implementation, reliance on free and publicly available data, and accuracy in identifying potential discharge zones on the landscape.

The following sections summarize the methodological review process, as well as describes the final discharge mapping process.

2 REVIEW OF DISCHARGE MAPPING METHODOLOGIES

The initial review of groundwater discharge mapping involved examining methodologies presented in Sass et al. (2014), Doody et al. (2017), Munch and Conrad (2007), Barron et al. (2014), Werner et al. (2007), and Leaney et al. (2011). Following the primary review, two methods were selected for detailed testing and implementation in the study area. These were the method of Sass et al. (2014) and Barron et al. (2014). These were selected due them relying exclusively on open-source satellite data, reporting high accuracy in their classification of potential groundwater discharge as well as showing the potential for being applicable to the study region at hand. Other methods were discarded from consideration due to a combination of low reported accuracy, untenable or unspecified assumptions, requirements for data that were unavailable, inability to use open-source analytical tools, and time constraints.

Detailed testing and implementation involved replicating methodologies and examining their results against identifiable groundwater discharge zones on Hornby, Denman and Gabriola islands. The implementation and analysis were completed using the R programming language as well as the QGIS software package. Following testing, it was decided that the methodology from Sass et al. be discarded from consideration due to an inability to access the appropriate data for employing it. The Barron et al.

2014 method thus was the chosen basis for producing the final classification of potential groundwater discharge zones. The details of each method and their implementation are discussed subsequently.

2.1 Mapping groundwater thermal signatures (Sass et al., 2014)

The theory behind the Sass et al. method is that depending on the time of the year, discharging groundwater is at a temperature that differs from the land surface. Using satellite-based thermal imagery from the Landsat mission, one can examine the surface temperature of a given study region and use this difference in thermal signatures to detect discharging groundwater. The authors employ their methodology using winter-time satellite imagery, assuming that discharging groundwater is warmer than the surface which may be covered by frost or snow. They utilize a known discharge zone – a wetland – and employ transect analysis to identify the temperature "threshold" that differentiates a discharge zone. This threshold is then applied to the entire landscape to detect discharge zones across the study region.

Given the climate of Vancouver Island, a winter-time approach similar to the authors is untenable as temperatures rarely fall below 0 degrees Celsius consistently enough for groundwater to have a warmer thermal signature. Conversely, during the dry season, groundwater is distinctly cooler than the surrounding landscape, occurring at about 10-12 degrees Celsius. The method was thus tested using summer-time satellite imagery, with the goal of identifying groundwater discharge by searching for a cool temperature signature. Known discharge zones – such as wetlands and lakes – were identified to examine whether such a signature was present.

Unfortunately, the applicability of this method was limited by the fact that the thermal satellite imagery was only available for 7pm over the study area, as a result of the satellite's orbital trajectory. Unlike for a winter-time scenario, the time of day of temperature retrieval is very important for a summer-time scenario, as temperatures for land relative to water can vary very drastically depending on the time of day (Figure 1).

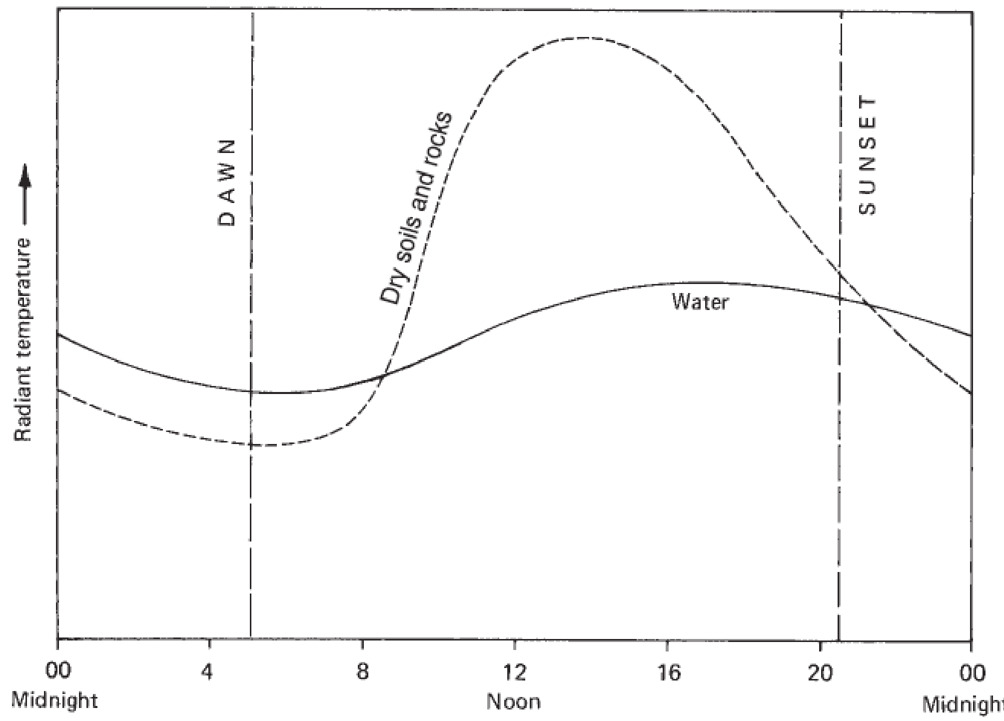


Figure 1: Generalized diurnal radiant temperature variations for soil and rocks versus water (taken from page 255 of Lillesand et al., 2015)

Since satellite-based thermal imagery detects the temperature of the surface "skin" rather than the air temperature, a late time of day retrieval in the summer would show temperatures that are quite high, since much of the land as well as the water surface has been exposed to solar radiation all day, raising its temperature to well above the ambient air temperature. Additionally, as Figure 1 illustrates, a near-sunset image of temperature would not be able to detect any strong difference between the temperature signals of moisture versus dry land on the landscape, as any discharged water would likely have been exposed to too much solar radiation to be distinctively cooler.

Ideally, for the assumptions of this method to hold in a summer-time scenario, thermal imagery would need to be obtained in the morning, prior to midday, when the temperature differences between land and moisture are likely to be highest. Several satellite missions were checked for the availability of such data, including previous Landsat missions, the ASTER mission and the Sentinel missions. None had data that were at the right time and at a resolution appropriate for this study region. As a result of this limitation, the Sass et al. (2014) method had to be discarded from further consideration.

2.2 Mapping landscape "greenness" and "wetness" (Barron et al., 2014)

The Barron et al. (2014) method was designed as part of much more comprehensive mapping of groundwater dependent ecosystems that was developed by the Government of Australia (Doody et al., 2017). The method focuses on identifying areas of potential groundwater discharge by trying to measure the optical signatures left by discharging groundwater. These features can include things such as moisture changing the appearance of the landscape either through darkening it or through encouraging vegetation to grow perennially, thereby "greening" it. Such indications of landscape "moisture" and "greenness" can be detected using satellite imagery, by relying on satellite based spectral indices. A spectral index can be understood as a mathematical manipulation on certain wavelengths of detectable light that are designed to highlight certain characteristics of the landscape, such as greenness or wetness, while minimizing other confounding effects.

A vast number of spectral indices have been defined for various use cases[1]. The authors of this method rely on the NDVI (Normalized Difference Vegetation Index) and the NDMI (Normalized Difference Moisture Index). Both are well-known methods which are widely used. The NDVI is designed to highlight the presence of dense green vegetation, or “greenness”, while the NDMI is designed to highlight the level of moisture within vegetation or soil, defined as “wetness”. By comparing landscape “greenness” and “wetness” between the wet season and the dry, it is possible to observe which parts of the landscape *preserve* their wetness and greenness between the wet and the dry season. While there are many forms in which landscape change occurs, the general idea is that those parts of the landscape that continue to be “green” and “wet” even in the dry season are likely candidates for groundwater discharge, as groundwater would be the primary source for continuing moisture supply to the surface in the dry season (excluding irrigation).

Implementing this method required multispectral satellite images for the wet and dry season over the study area, which were available for Hornby, Denman and Gabriola islands. Images were acquired from both the Landsat and the Sentinel missions, which provide freely accessible multispectral image data for analysis. Since this was the primary method chosen for discharge analysis, its methodology is discussed in greater detail in the following sections.

3 MAPPING POTENTIAL GROUNDWATER DISCHARGE

3.1 Data Acquisition and Pre-processing

Satellite image scenes for the wet and the dry season were acquired from the Landsat 8 mission[2] and the Sentinel-2 mission[3]. The data were downloaded in surface reflectance units where available, as surface reflectance processing removes confounding effects of the atmosphere on reflected radiation. Surface reflectance data were available for all the necessary images except for 1 Sentinel-2 scene. In this case, the image data were processed to surface reflectance locally using the Sen2Cor software library (ESA, 2018). The reference wet season months were chosen as January and February, while the reference dry season months were July and August.

A major issue with satellite imagery is cloud cover blocking the actual surface. Since one of the goals was to obtain imagery from the wet season, cloud cover was a significant issue for many images. Images from wet and dry seasons from 2021 up to 2016 were examined, and only those images where cloud covering was minimal were selecting. Additionally, all data were cleaned for any additional issues related to cloud cover, cloud shadows, radiometric saturation and confounding aerosol content – achieved by using the quality-assurance data that accompanies all satellite imagery downloads.

[1] An authoritative database of verified indices is maintained at https://www.indexdatabase.de/
[2] These data were downloaded from the EarthExplorer platform, found here: https://earthexplorer.usgs.gov/
[3] These data were downloaded from the SciHub Copernicus platformer, found here: https://scihub.copernicus.eu/dhus/#/home

Following image selection, cleaning and pre-processing, the data that were deemed most appropriate for the analysis were images from August 2020 (dry season), January 2019 (wet season) and January 2021 (wet season). 2 wet season images were chosen since the only cloud-free image from the Landsat archive was from January 2019 while for the Sentinel data the only cloud free image was from January 2021. All data were further verified for the proportion of low-quality pixels and it was affirmed that more than 95% of the image data in all cases was of high-quality.

3.2 Methodology

The input data were used as a basis for calculating the NDVI and NDMI for both the wet and the dry season. This resulted in 4 layers, 2 maps of the NDVI (wet and dry) and 2 of the NDMI. An example of these outputs for Gabriola island is shown in Figure 2.

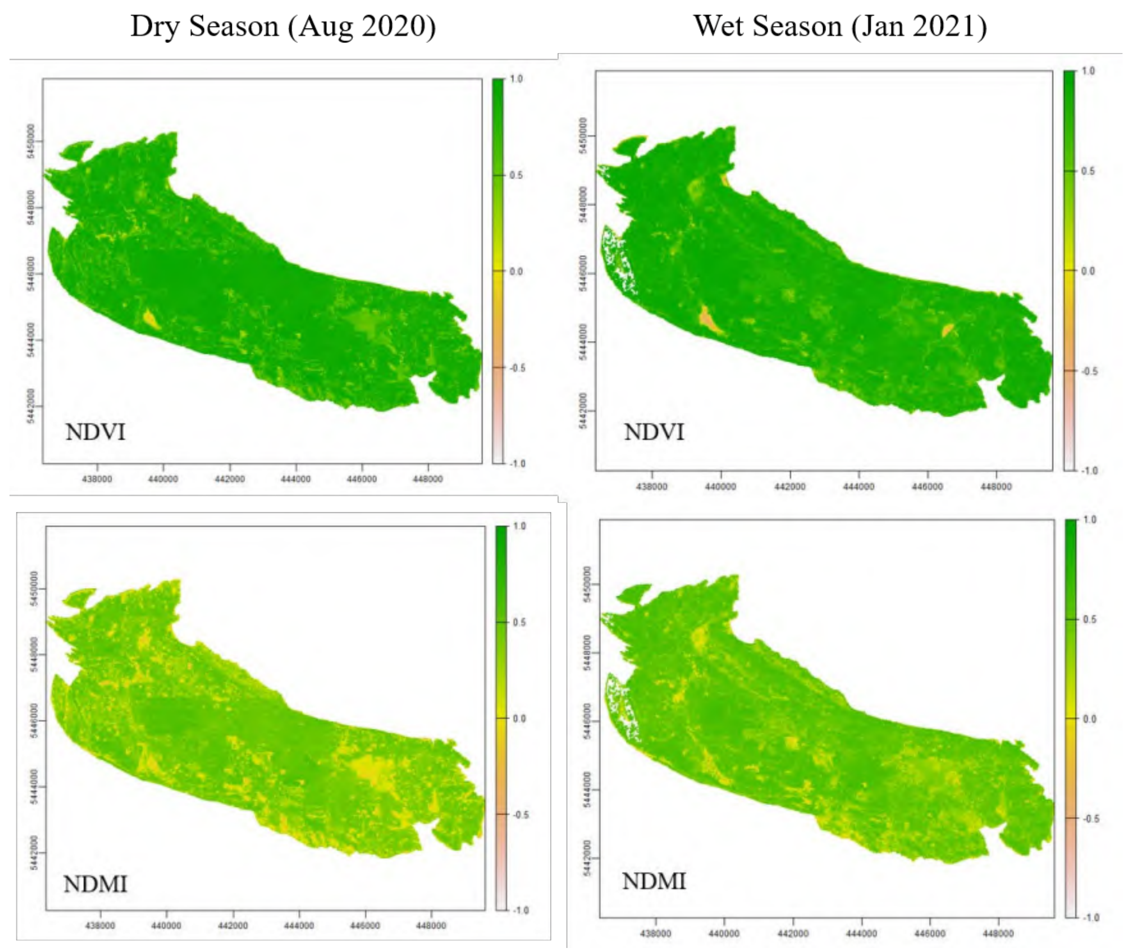


Figure 2: Wet and Dry season NDVI and NDMI for Gabriola island. It highlights that Gabriola is overall quite vegetated, but there are still discernable changes between the wet and dry season. These maps were generated using Sentinel-2 data.

Both indices range in value from -1 to 1. For the NDVI values near 1 indicate dense vegetation, while those near 0 or below indicates water. Bare soil, and non-dense vegetation tend to fall between this range. For the NDMI, values closer to 1 indicate greater vegetation moisture content.

Each dataset was cropped to the same extent, thereby allowing the data to be transformed to a tabular format in which each row represented the wet and dry season NDVI and NDWI for every pixel in the raster file. Following the method outlined in Baron et al. (2014), this tabular data became the basis for the subsequent unsupervised classification process. The chosen algorithm was the K-means method, which is common for remote sensing analyses. The algorithm operates by first randomly assigning pixels to a fixed number of groups (specified by the user), and then iteratively reclassifying pixels so as to minimize their distance to the "mean" each group. This iteration then continues until pixels are no longer being reclassified or until a threshold of maximum iterations is reached. The goal behind this approach is thus to minimize the total within-group variation, such that at the end of the classification every data point is grouped into a cluster with pixels that are more similar to each other than to data in another cluster.

An iterative process was implemented in R that tested what the optimum number of clusters should be (with optimum being defined as the clustering setup where the rate of error minimization was the greatest). Following this, the tabular NDVI and NDMI data were clustered using the K-means algorithm. This resulted in each pixel on the landscape being assigned to a group. This grouping structure could then be examined alongside the input NDVI and NDWI data using scatter plots. Figure 3 shows the groups defined by the unsupervised classification, plotted by their wet and dry season NDVI and NDWI values.

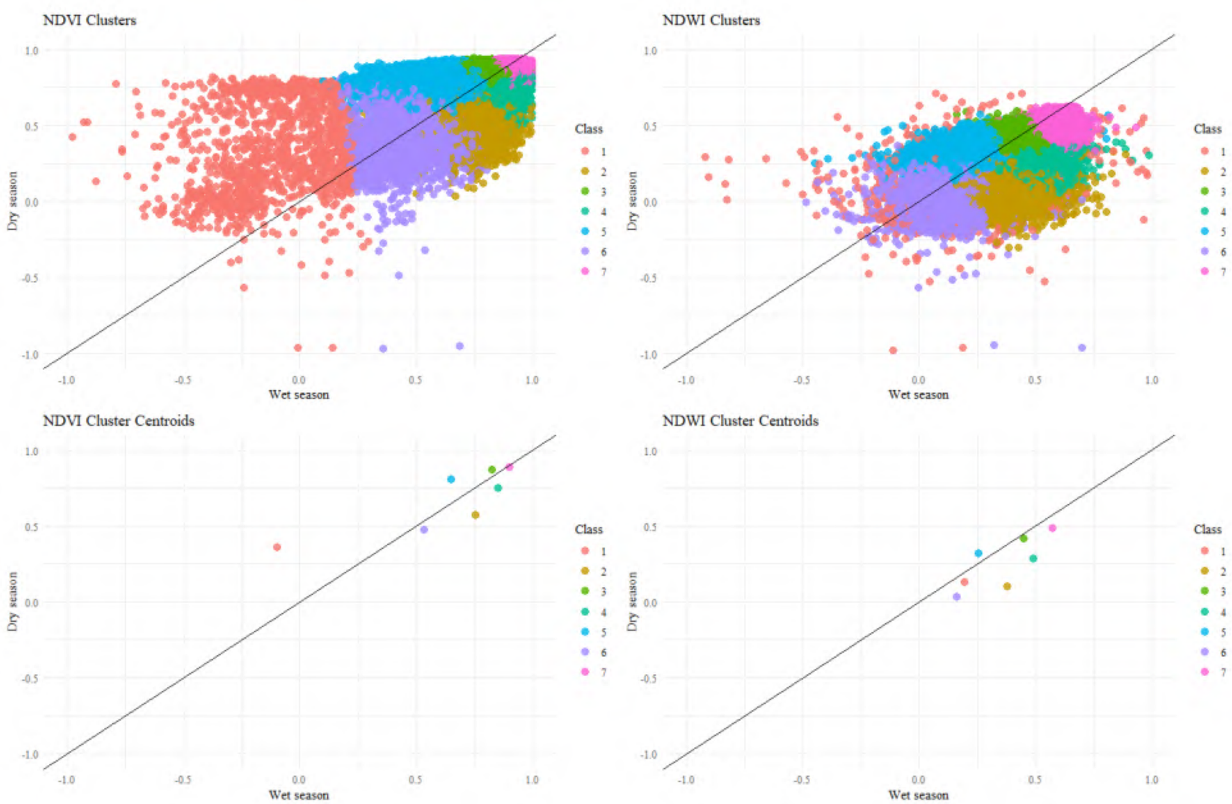


Figure 3: Scatter plots plotting pixels by their wet and dry season NDVI and NDMI, coloured by the unsupervised classification output. The plots above contain points for all pixels in the scene, while the plots below contain the "centroid" values for each group.

As is evident, the groups are generally well separated. Importantly, each group is also located in a different position relative to the black 1-to-1 line. Examining their relative location gives important clues about whether a group of pixels is a discharge zone or not. Groups where the data are largely above the line show that these pixels are wetter in the dry season relative to the wet season – a strong indication of potential groundwater discharge. Cluster number 1 (in red) is a good example of this. Conversely, groups that have positive but low NDVI and NDMI values in the wet season that do not persist in the dry season are very poor candidates for groundwater discharge, as there is no evidence for a continuing supply in the dry season. Cluster number 2 (in orange) is a good example of this. The other groups can be similarly analyzed for their potential groundwater dependency based on their locations on this plot, relying on the characteristics of the NDVI and NDMI indices.

3.3 Results: Map of potential groundwater dependent zones

Following the visual inspection of the unclassified pixels output as described above, each pixel was then reclassified into a new categorization that indicated its potential groundwater dependency. These reclassified maps were then cleaned and smoothed to generate the final classification of potential groundwater dependent zones for Hornby, Denman and Gabriola islands. These classification maps were verified using overlay images from Google Earth. It indicated that the classification correctly captured all known wetlands as well as all areas with visible signs of groundwater discharge based on the presence of dry-seasons ponds, streams and rivulets.

The final classifications of groundwater dependence potential for Hornby, Denman and Gabriola islands are presented in figures 4 and 5.

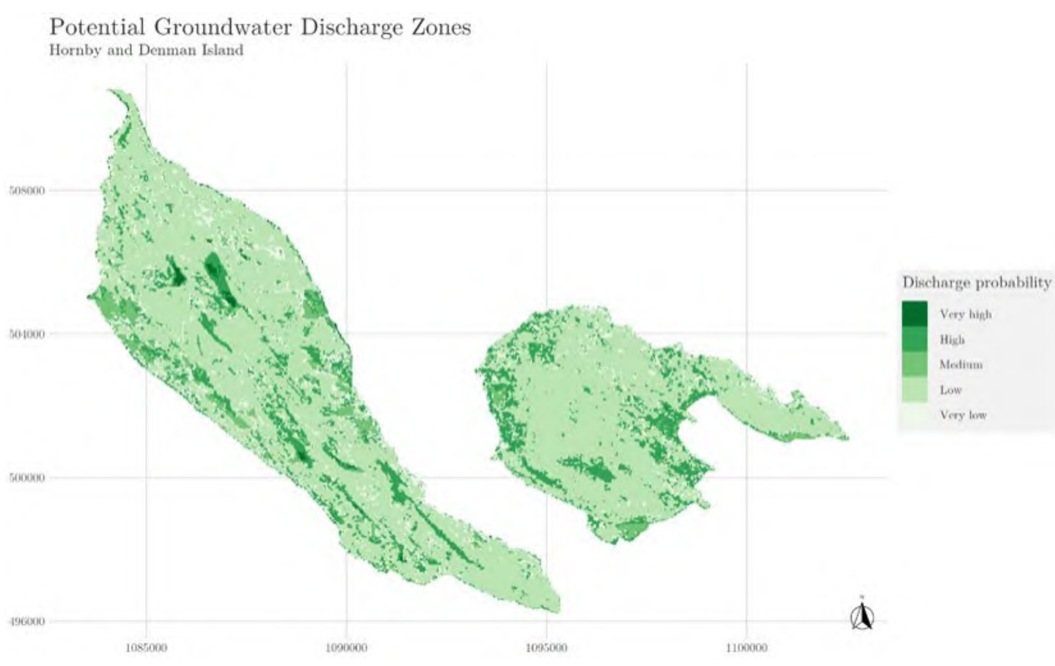


Figure 4: Classification of groundwater discharge potential on Hornby and Denman islands

Figure 5: Classification of groundwater discharge potential on Gabriola island

4 SCOPE AND LIMITATIONS

The results from this discharge mapping process relies on measuring the visible indications of greenness and wetness associated with groundwater discharge. While this is a useful proxy, it is critical to acknowledge that since what is being measured is not causal factors affecting groundwater discharge, the outputs cannot be considered as authoritative sources for identifying discharge zones. Rather, these results classify the landscape based on their *likelihood* of being discharge zones. In the absence of other streams of data, such a methodology may thus offer a good means to estimate the locations of groundwater discharge. However, verifying which parts of the landscape are indeed discharge zones necessitates that these outputs be combined with other information such as elevation, subsurface geology and the depth to the water table, in order to ascertain which identified areas meet the biophysical requirements for being zones of groundwater discharge.

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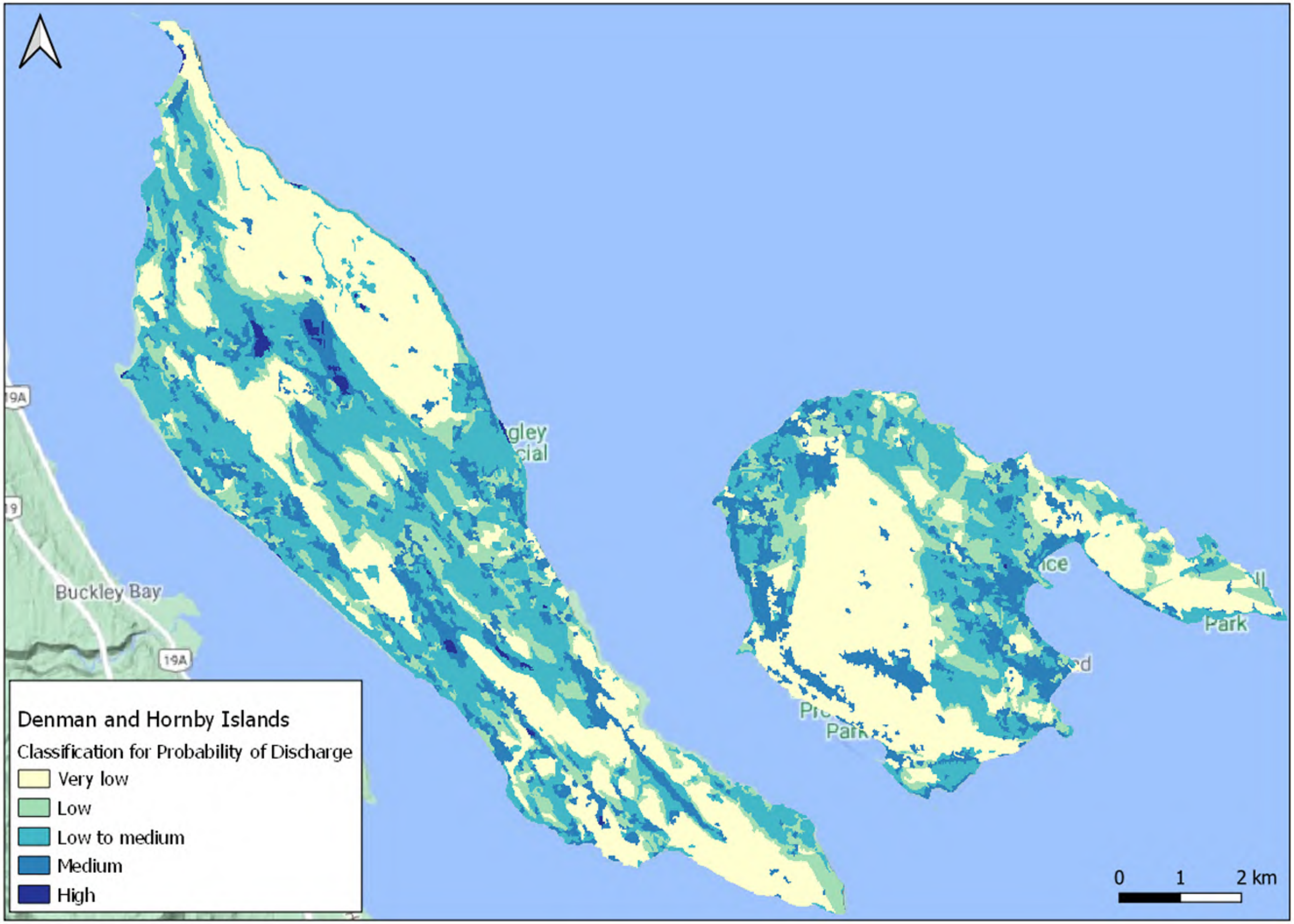
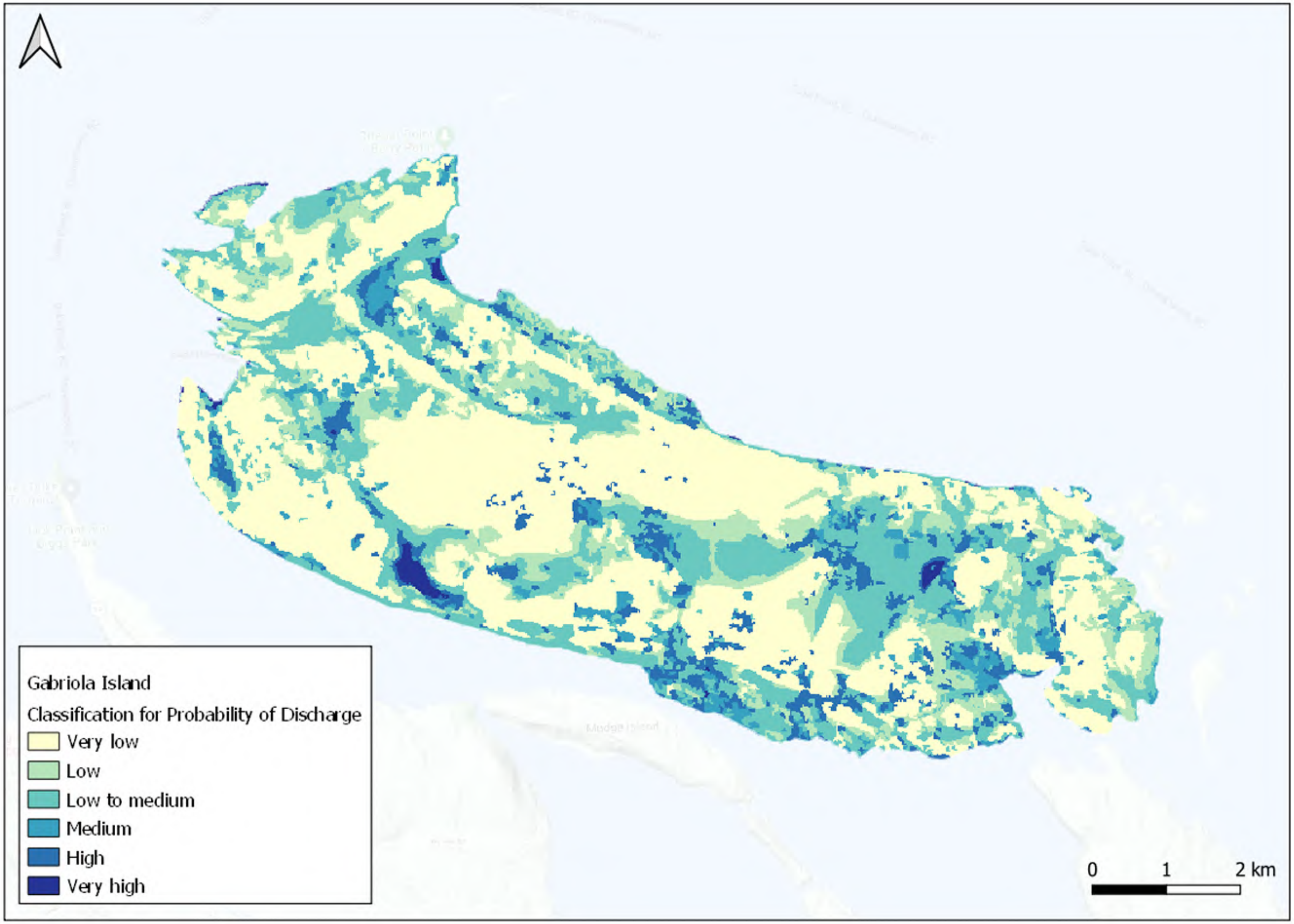
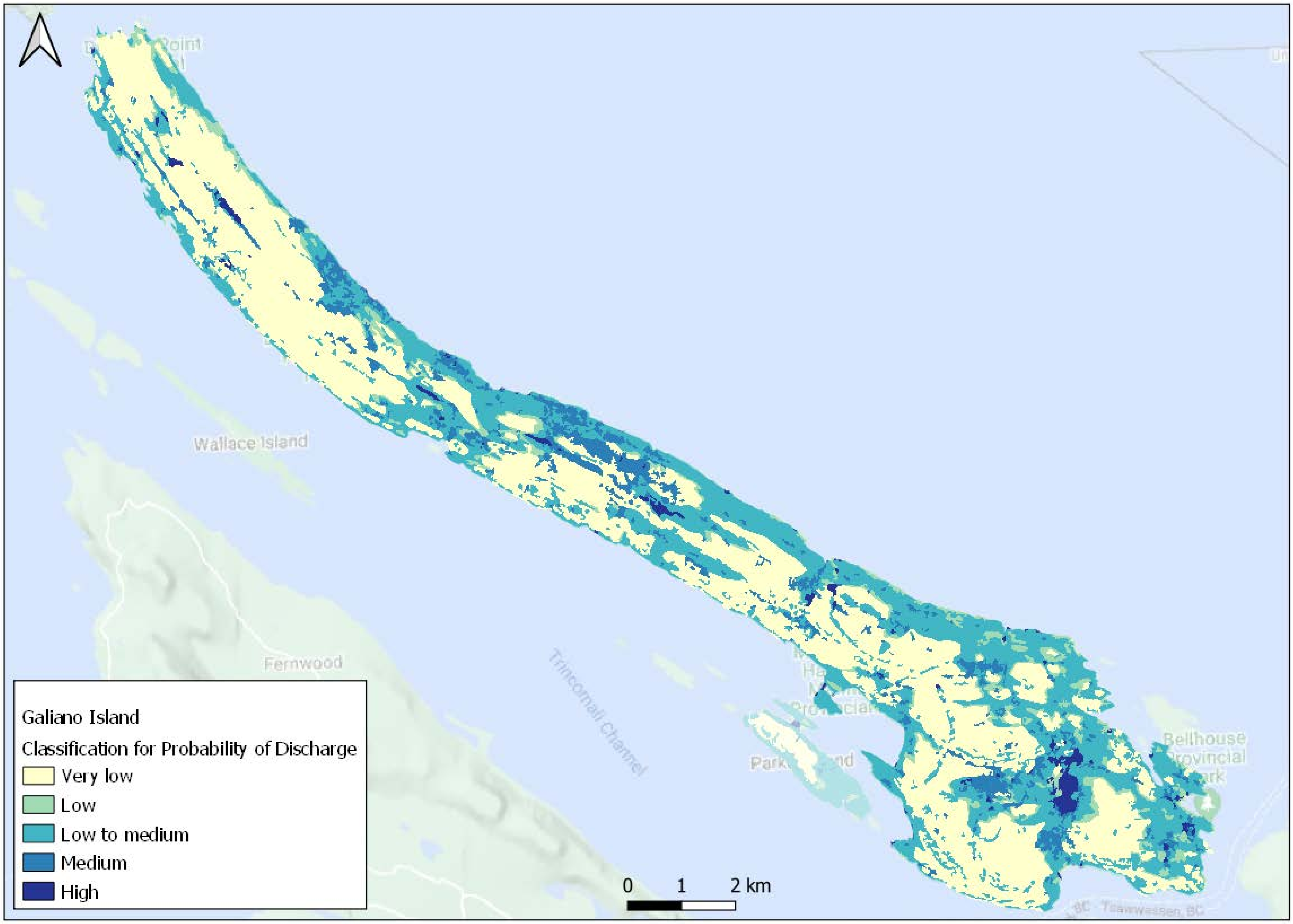
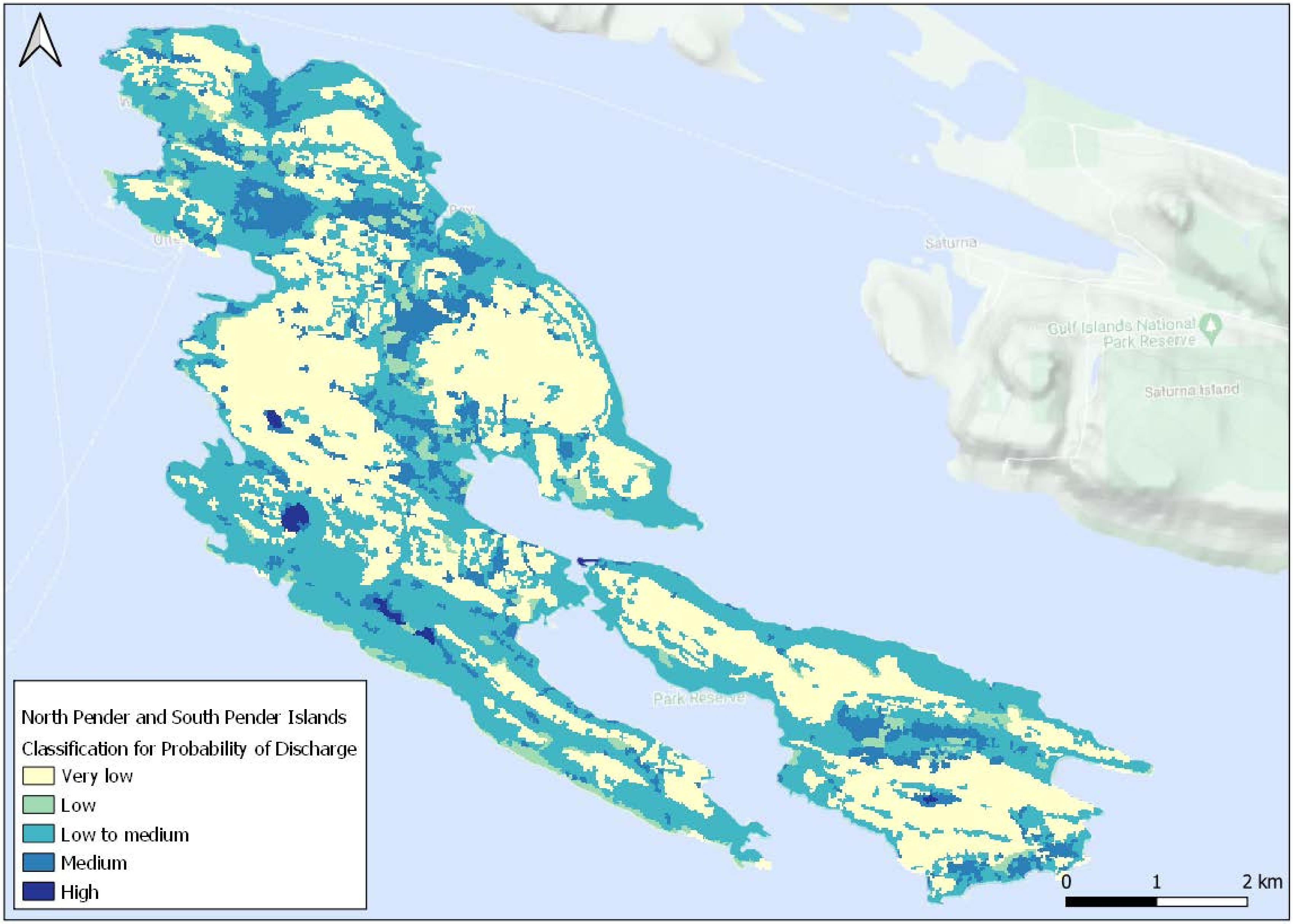
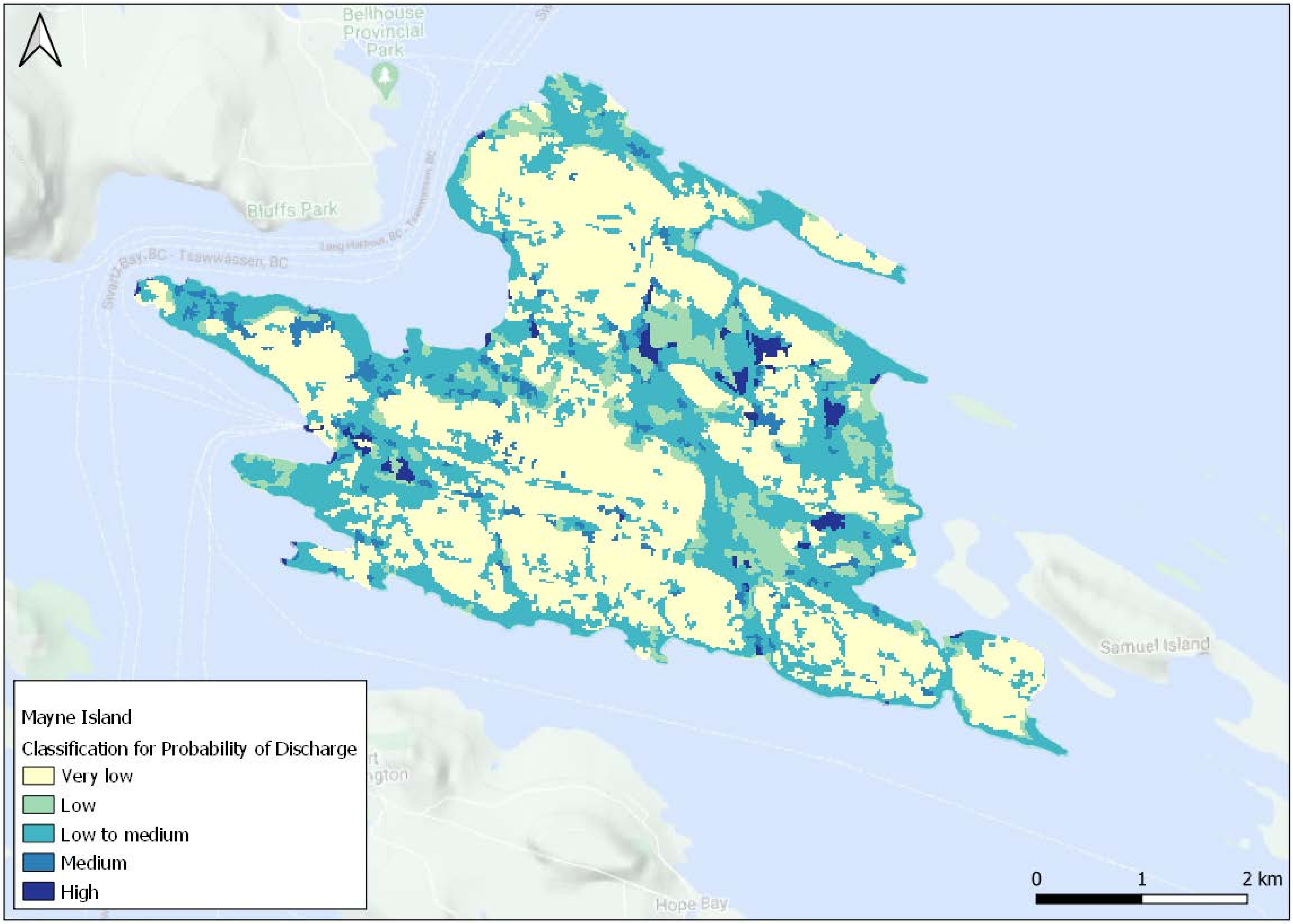
APPENDIX 7: Groundwater Discharge Probability Maps Based on NDVI and NDMI

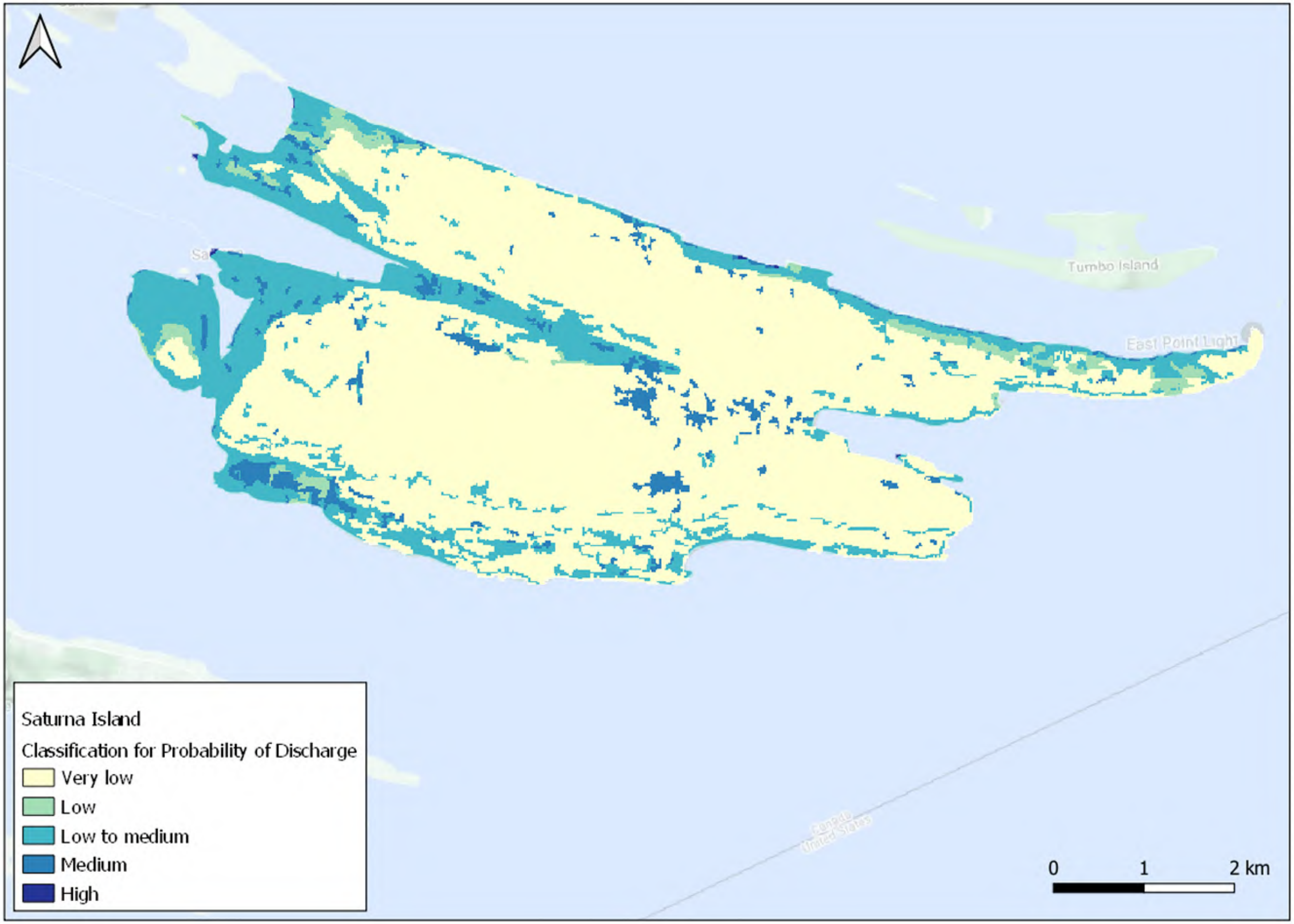

Denman and Hornby Islands
Classification for Probability of Discharge
Very low
Low
Low to medium
Medium
High
Buckley Bay
19A
0 1 2 km


Gabriola Island
Classification for Probability of Discharge
Very low
Low
Low to medium
Medium
High
Very high
0 1 2 km

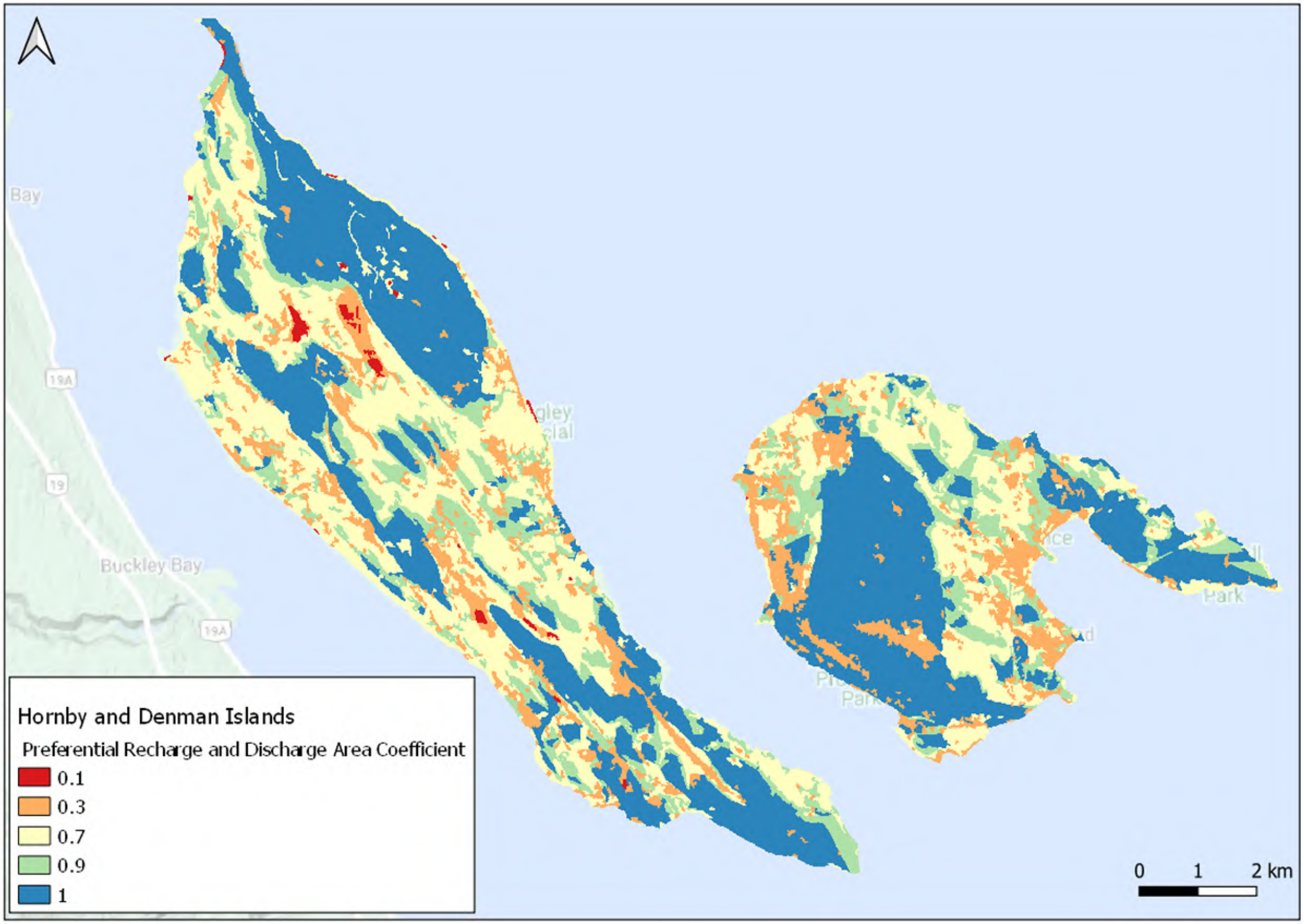

Wallace Island
Fernwood
Trincomali Channel
Bellhouse Provincial Park
0 1 2 km
Galiano Island
Classification for Probability of Discharge
Very low
Low
Low to medium
Medium
High

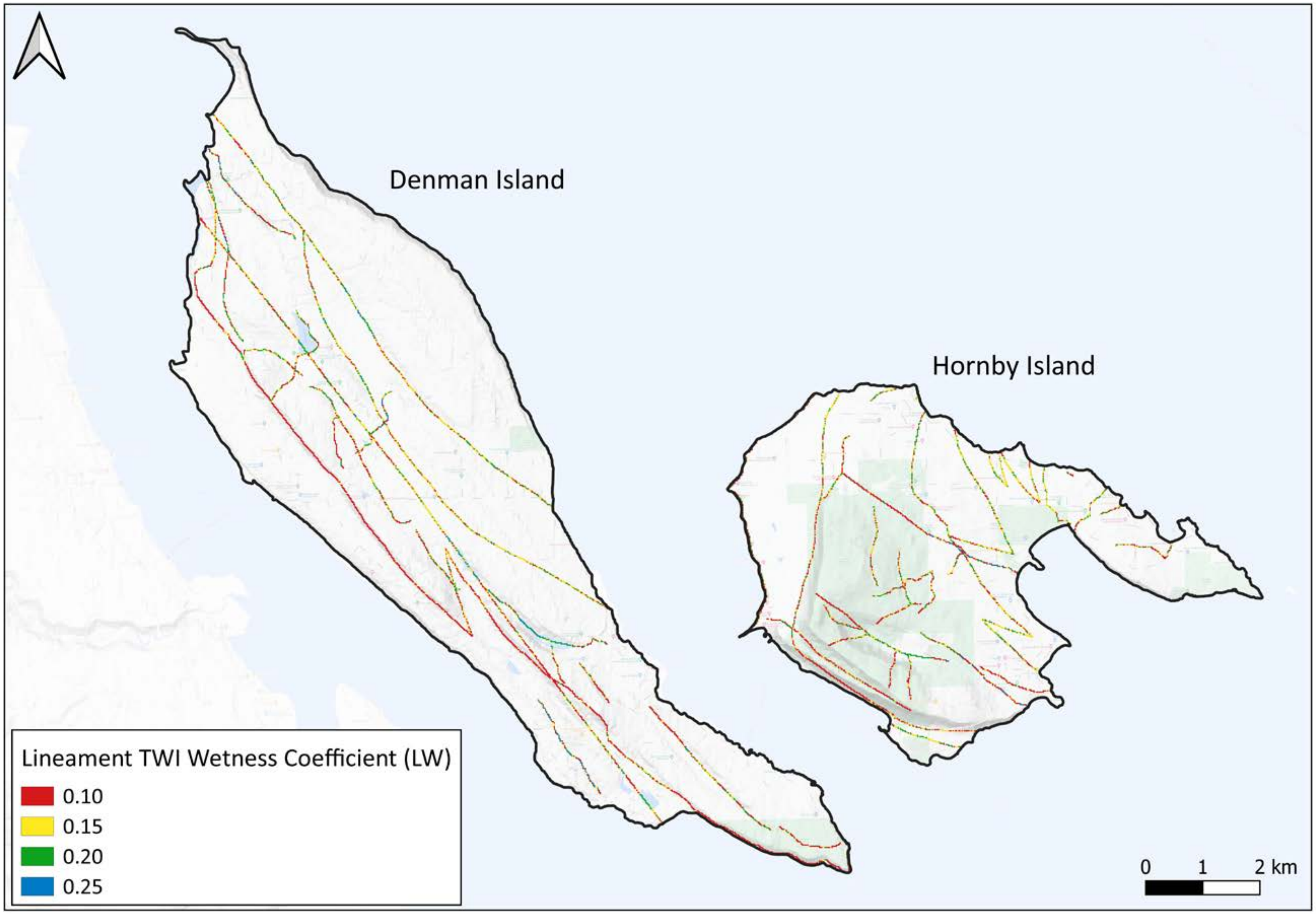

Saturna
Gulf Islands National Park Reserve
Saturna Island
Park Reserve
North Pender and South Pender Islands
Classification for Probability of Discharge
Very low
Low
Low to medium
Medium
High
0
1
2 km

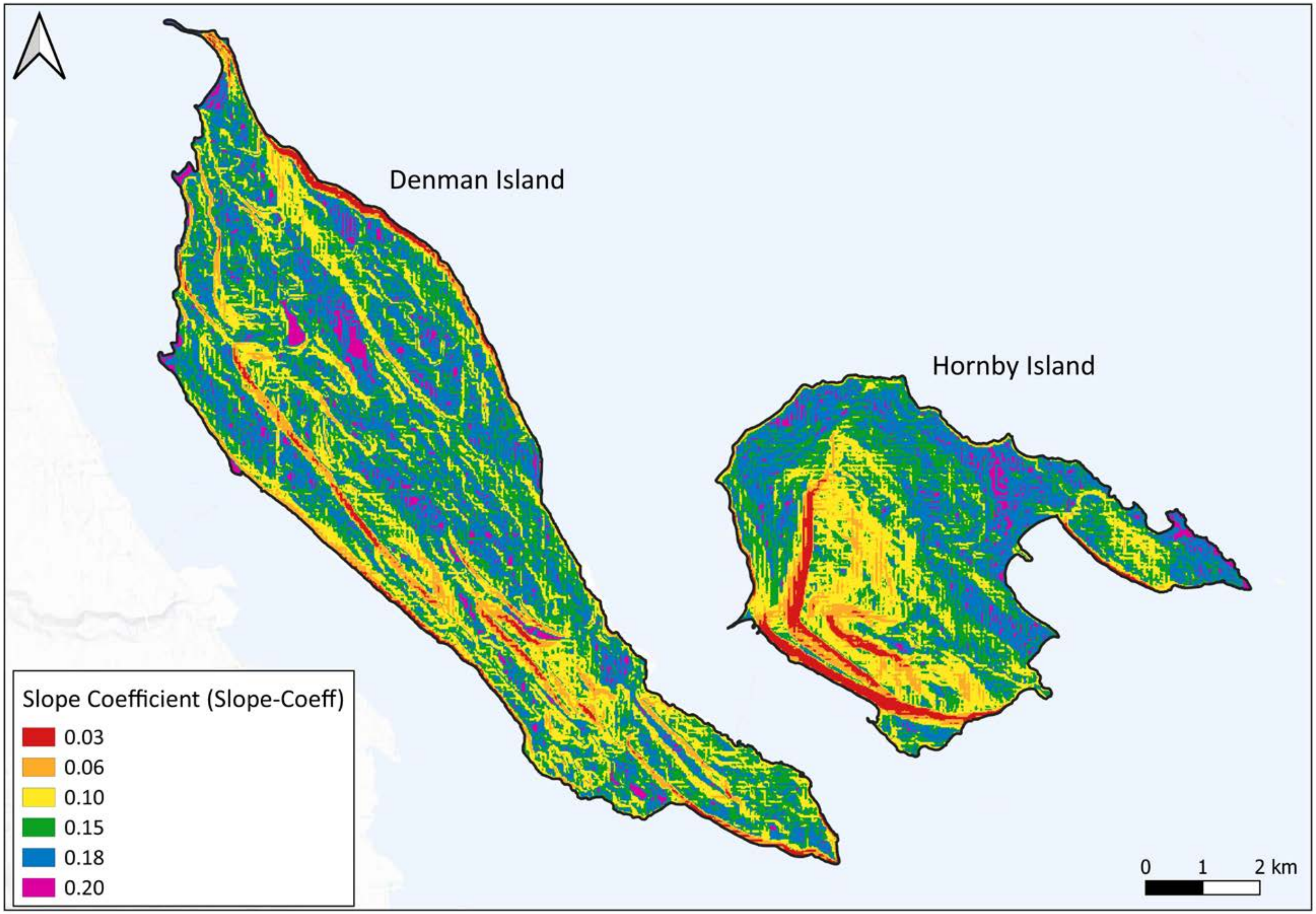

Bellhouse Provincial Park
Bluffs Park
Samuel Island
Hope Bay
Mayne Island
Classification for Probability of Discharge
Very low
Low
Low to medium
Medium
High
0
1
2 km

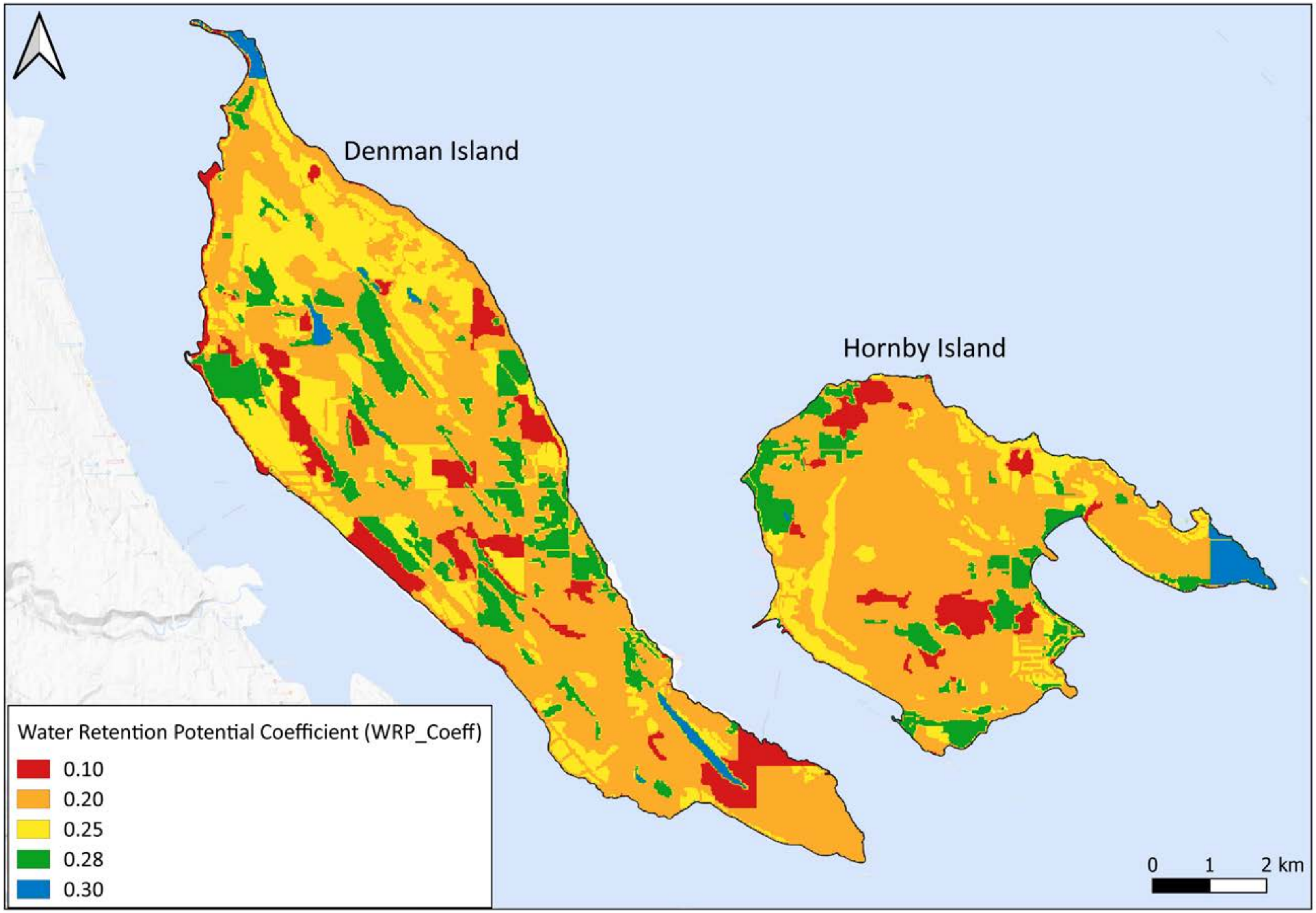

Turnbo Island
East Point Light
Saturna Island
Classification for Probability of Discharge
Very low
Low
Low to medium
Medium
High
0
1
2 km

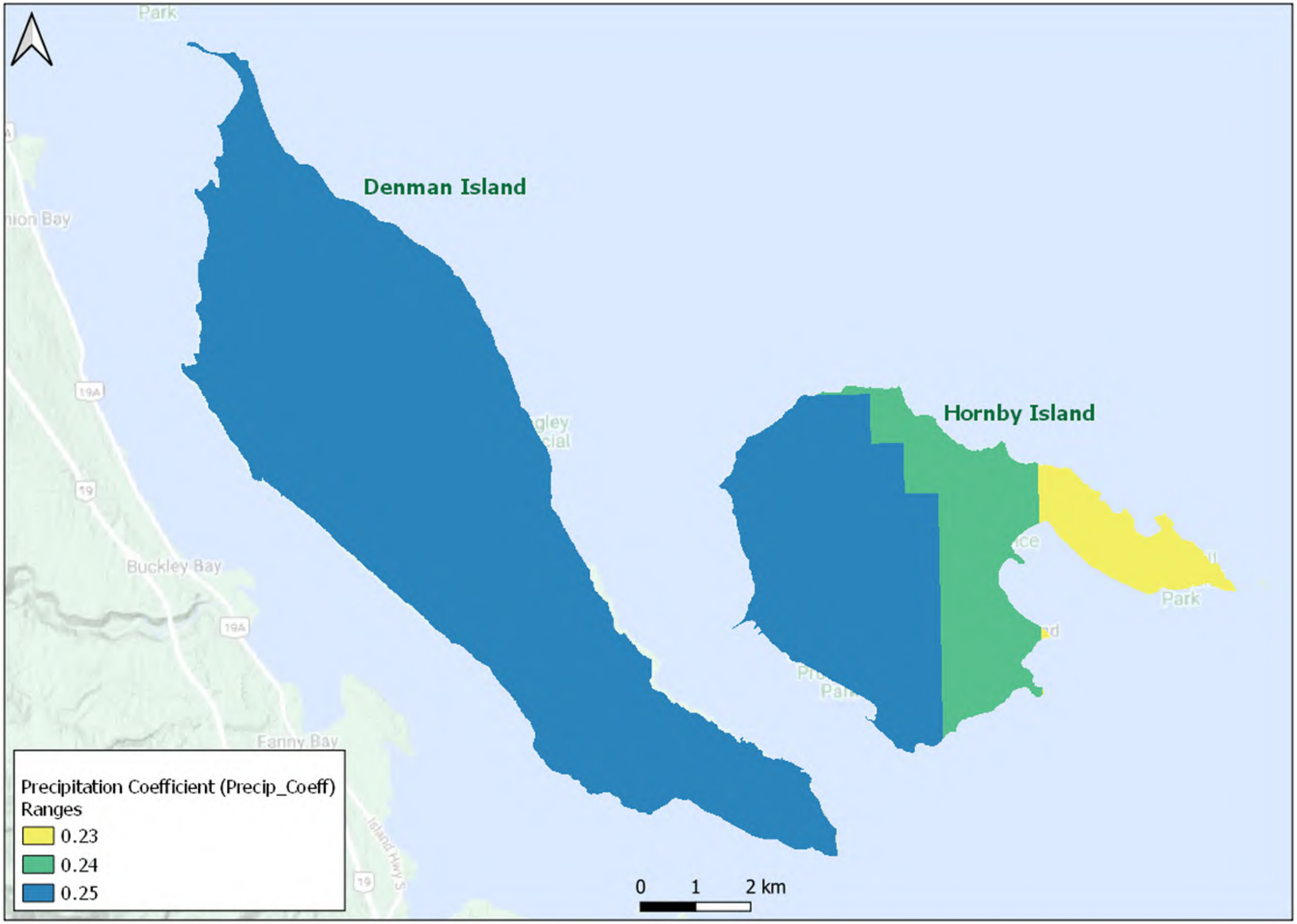
APPENDIX 8: Maps of recharge factors/coefficients across the Study Islands

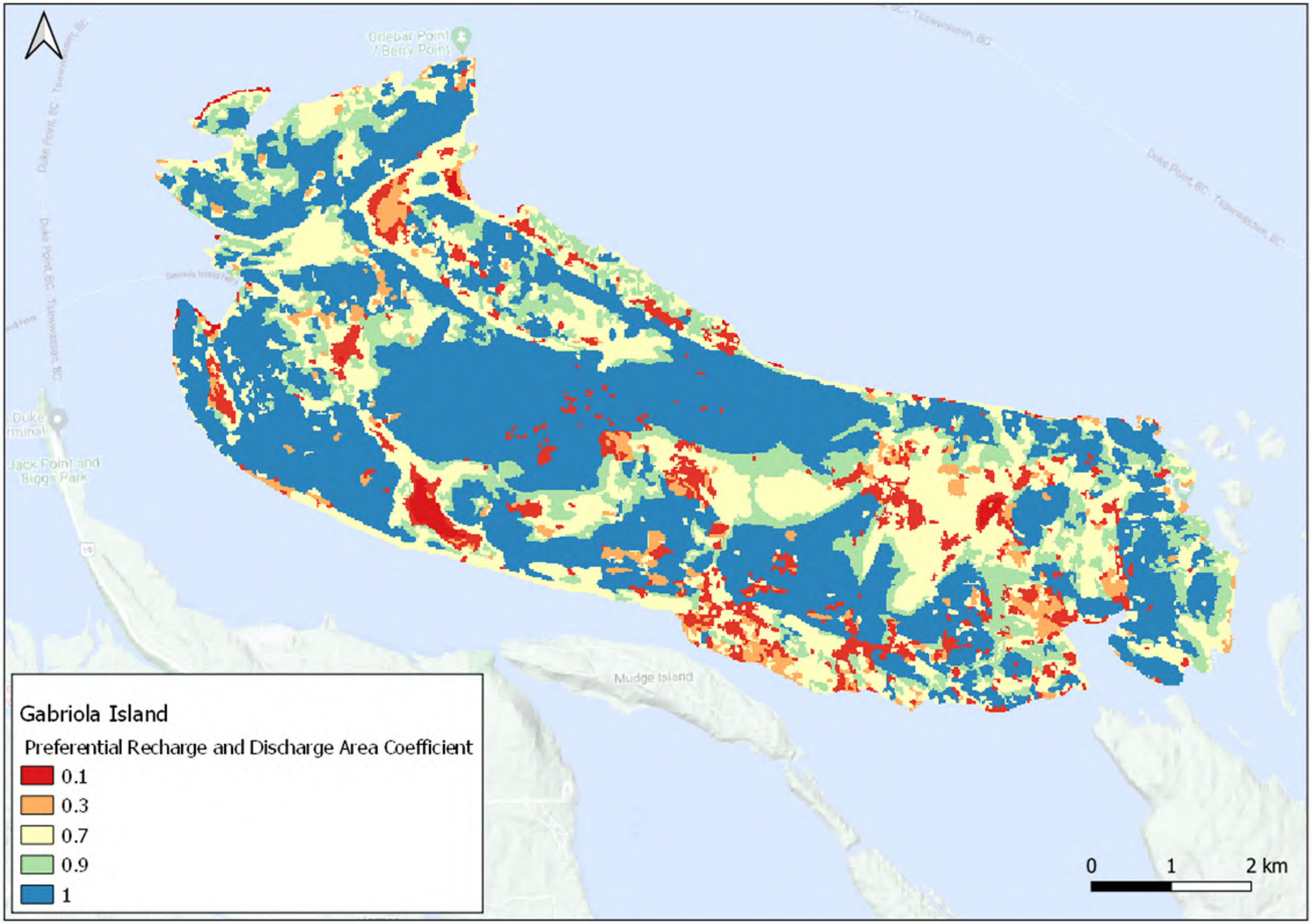

Hornby and Denman Islands
Preferential Recharge and Discharge Area Coefficient
0.1
0.3
0.7
0.9
1
0 1 2 km
Buckley Bay
Bay

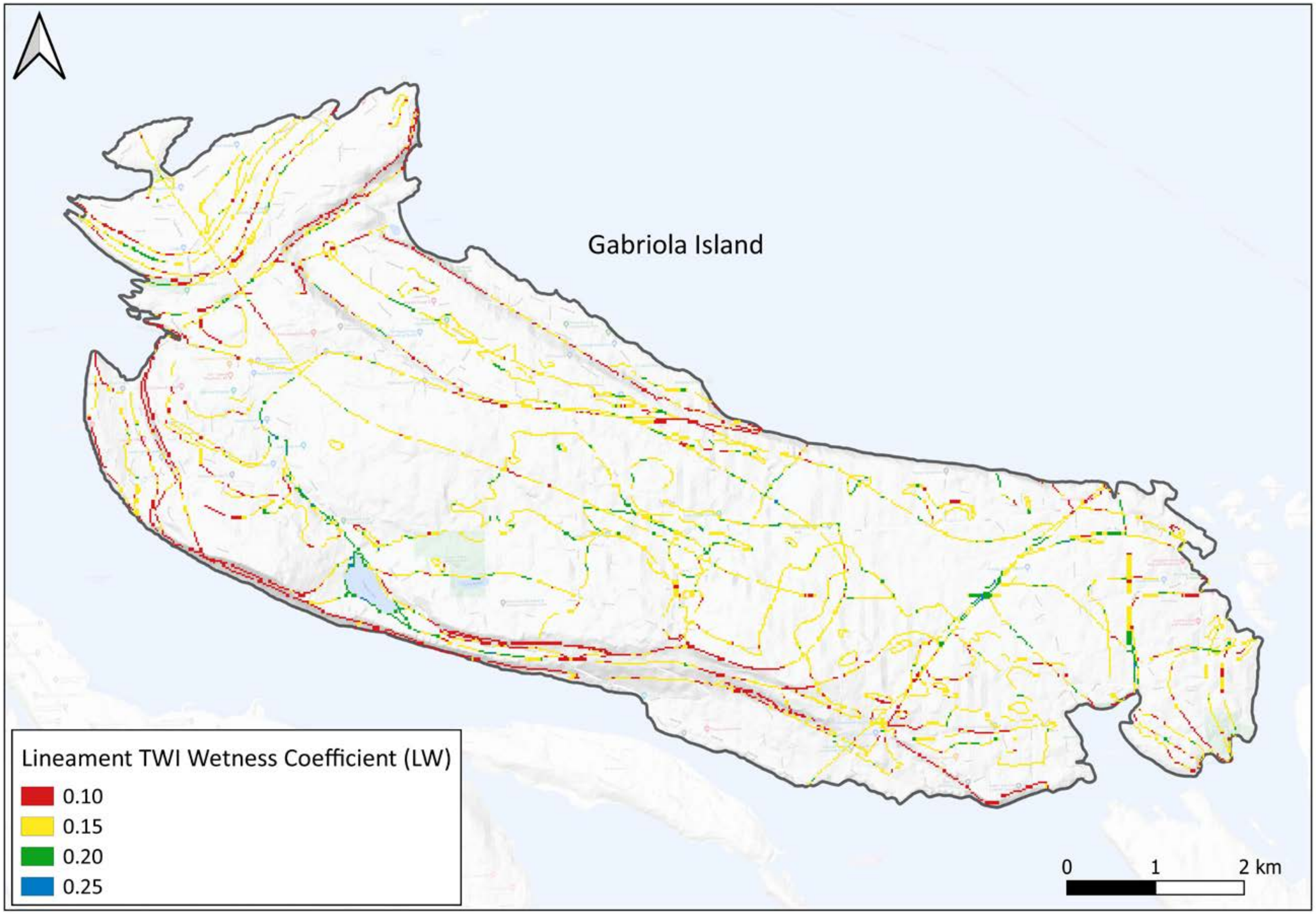

Denman Island
Hornby Island
Lineament TWI Wetness Coefficient (LW)
0.10
0.15
0.20
0.25
0 1 2 km

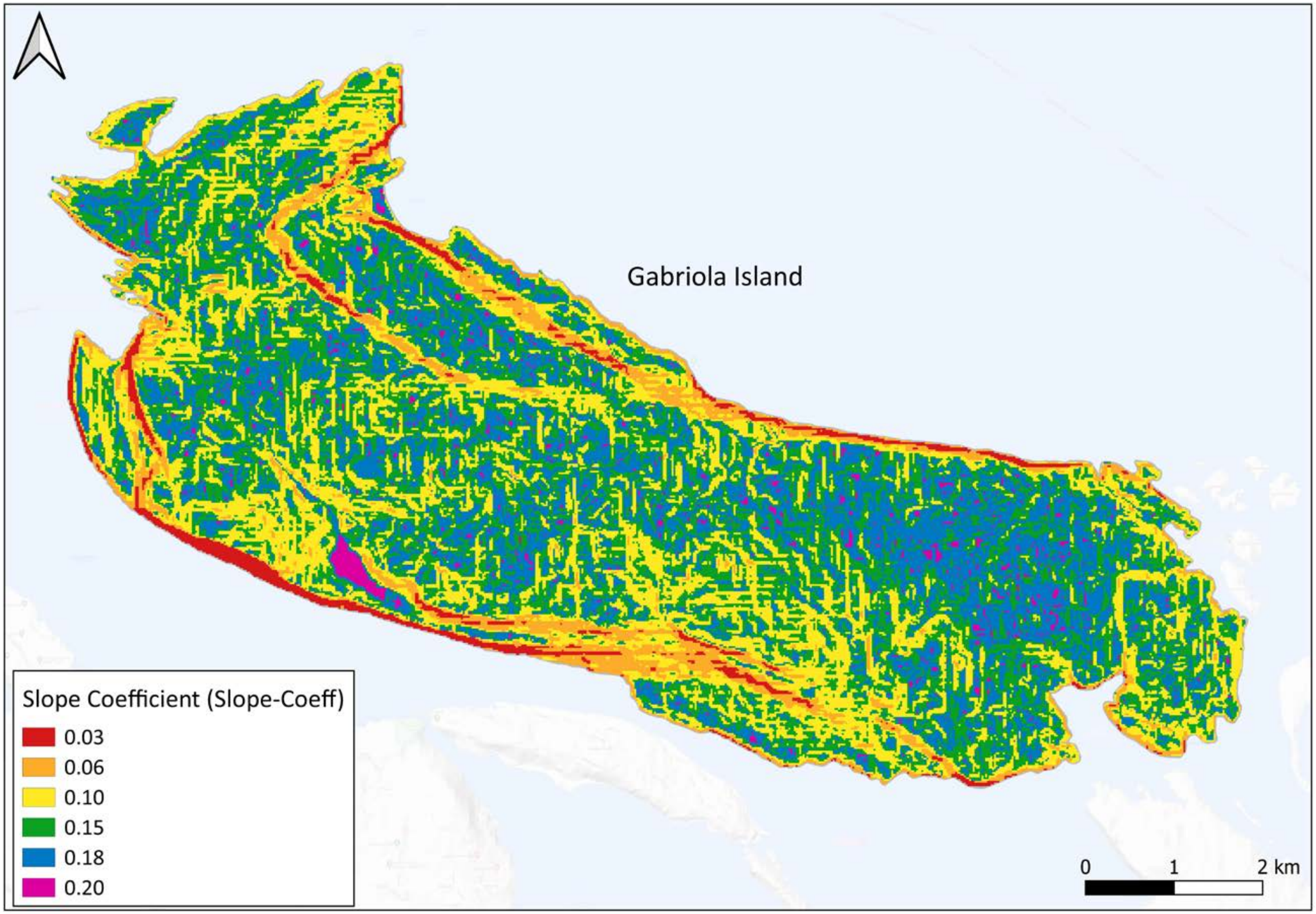

Denman Island
Hornby Island
Slope Coefficient (Slope-Coeff)
0.03
0.06
0.10
0.15
0.18
0.20
0 1 2 km

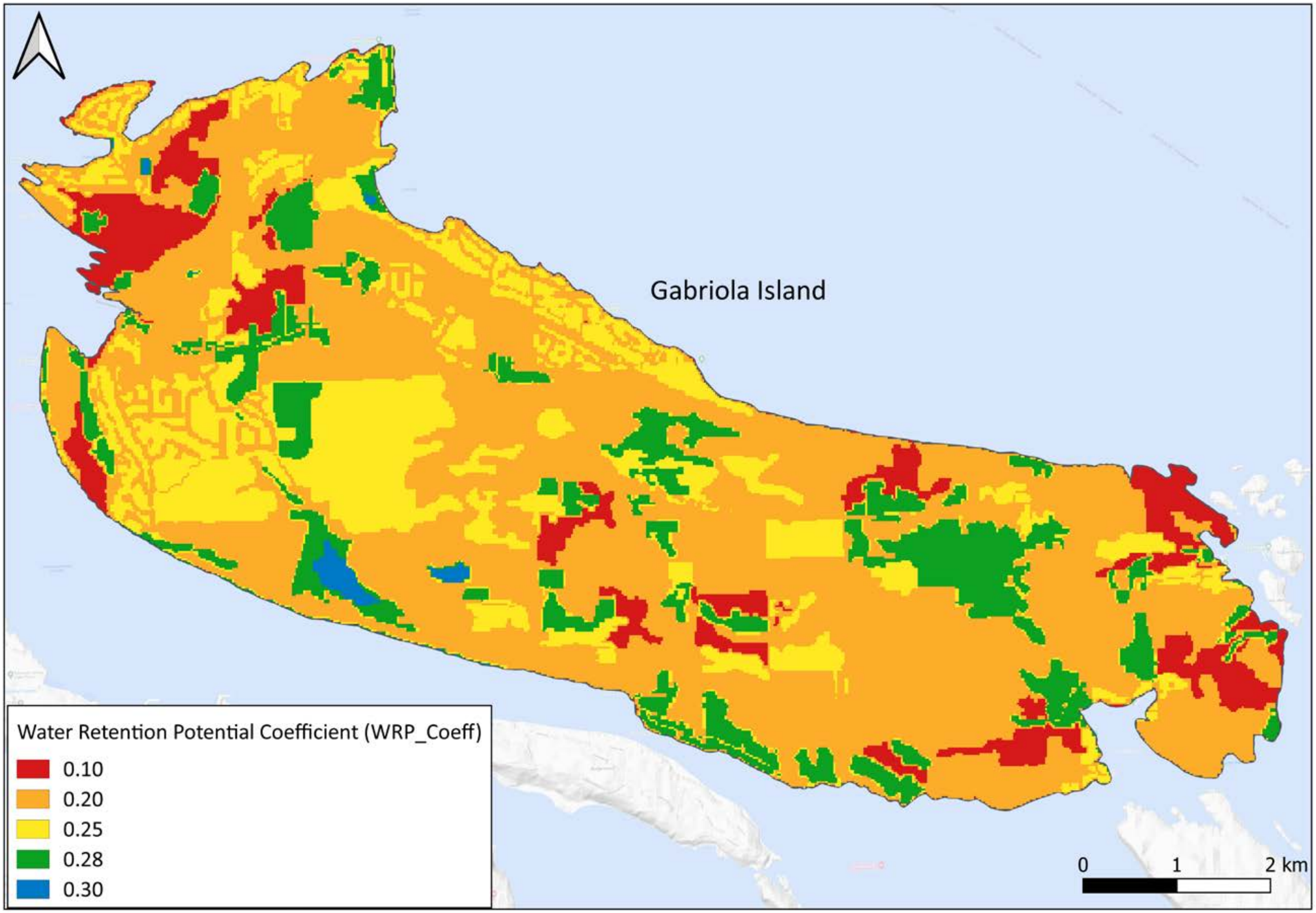

Denman Island
Hornby Island
Water Retention Potential Coefficient (WRP_Coeff)
0.10
0.20
0.25
0.28
0.30
0 1 2 km

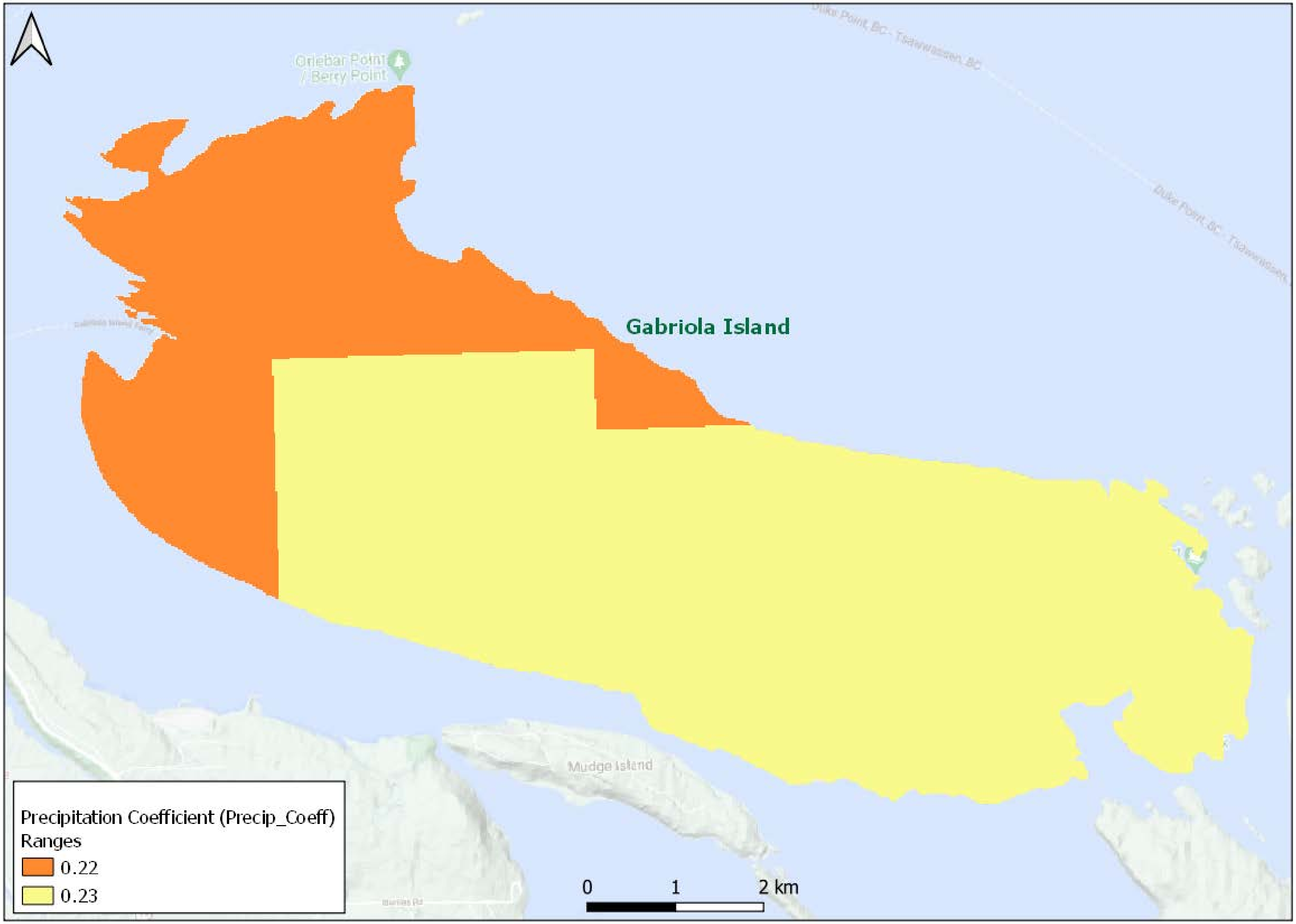

Denman Island
Hornby Island
Buckley Bay
Fanny Bay
Park
Precipitation Coefficient (Precip_Coeff) Ranges
0.23
0.24
0.25
0 1 2 km


Gabriola Island
Preferential Recharge and Discharge Area Coefficient
0.1
0.3
0.7
0.9
1
0
1
2 km
Mudge Island
Jack Point and Biggs Park
Orlebar Point / Berry Point

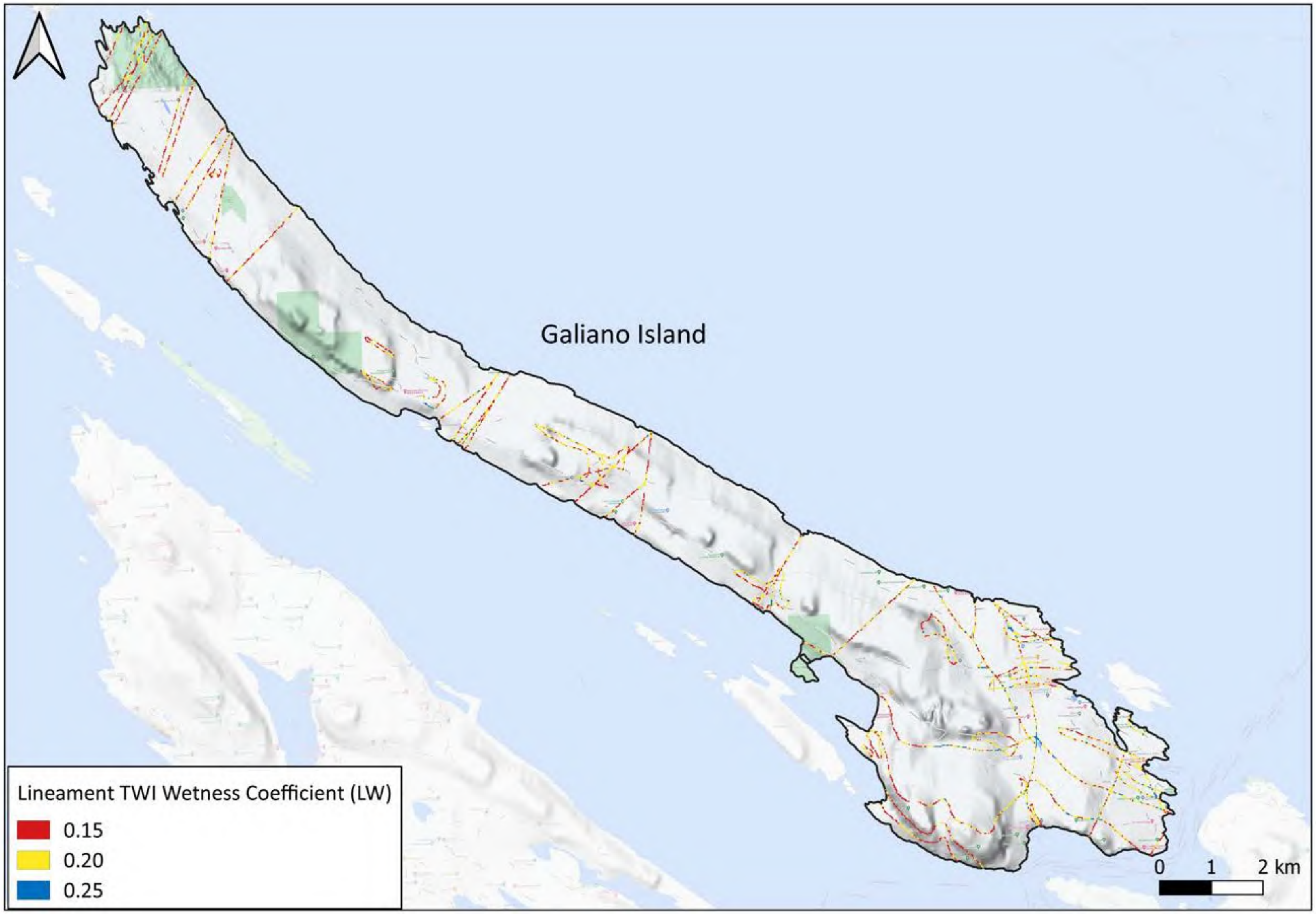

Gabriola Island
Lineament TWI Wetness Coefficient (LW)
0.10
0.15
0.20
0.25
0
1
2 km

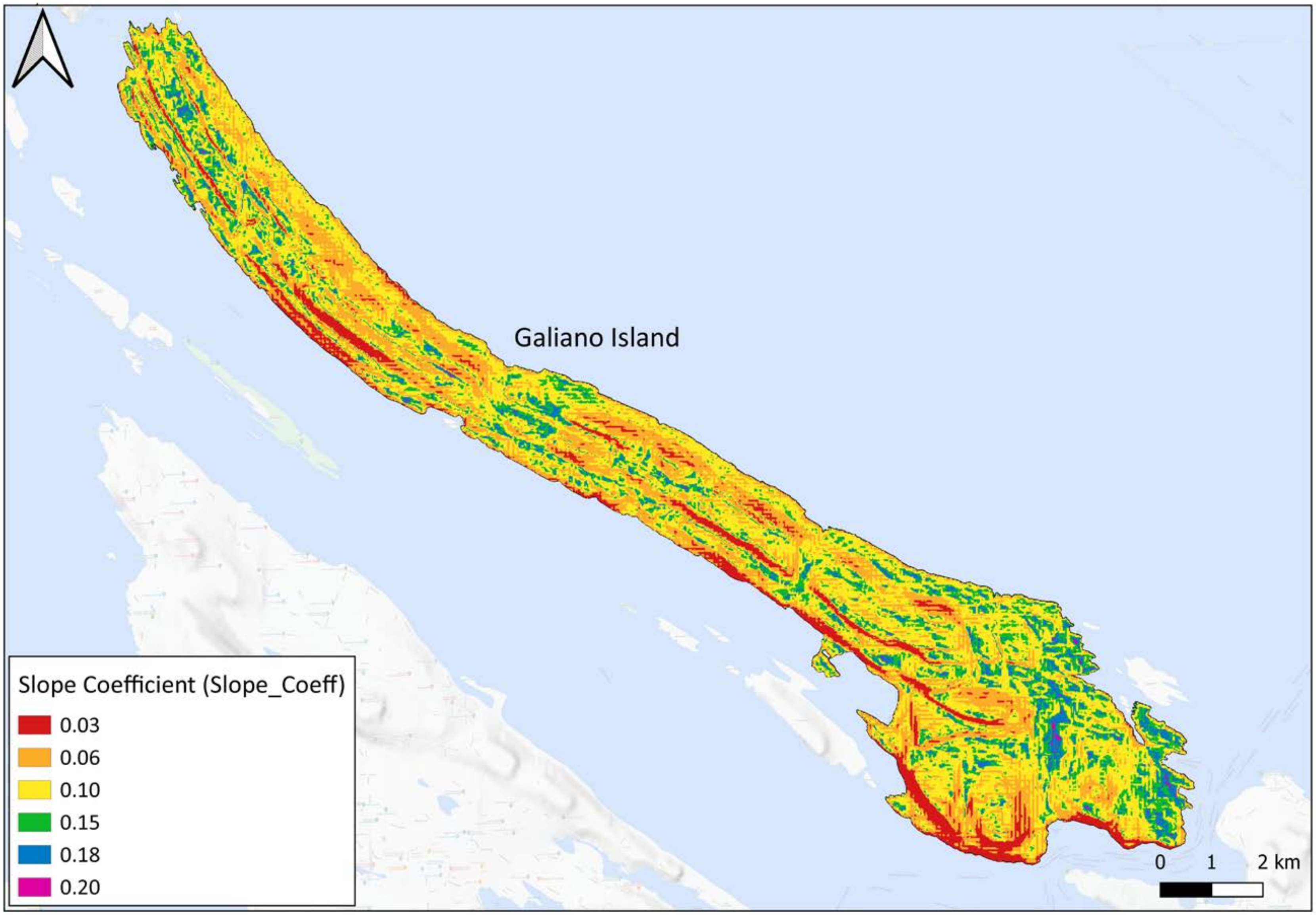

Gabriola Island
Slope Coefficient (Slope-Coeff)
0.03
0.06
0.10
0.15
0.18
0.20
0
1
2 km

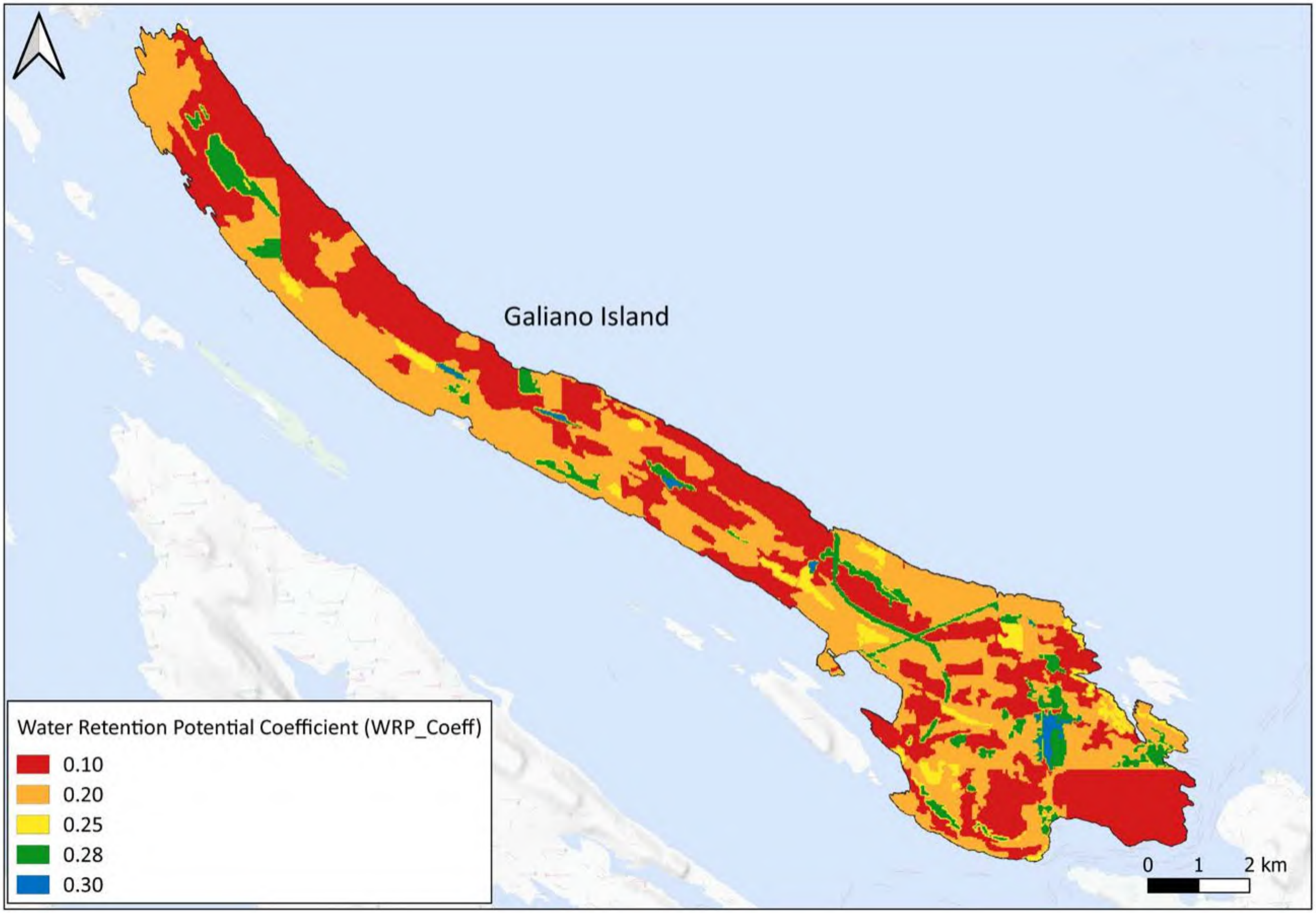

Gabriola Island
Water Retention Potential Coefficient (WRP_Coeff)
0.10
0.20
0.25
0.28
0.30
0
1
2 km

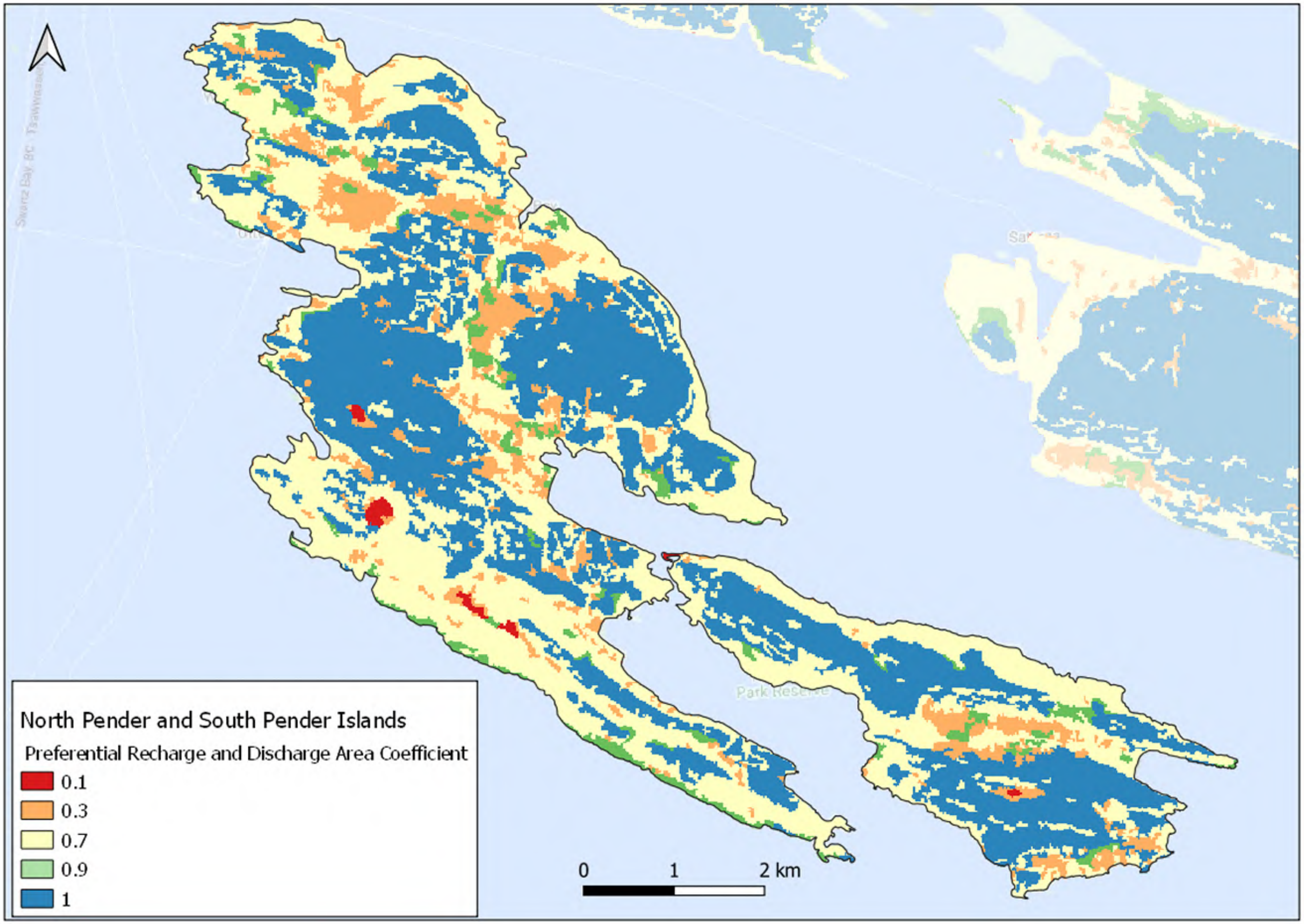

Gabriola Island
Mudge Island
Precipitation Coefficient (Precip_Coeff)
Ranges
0.22
0.23
0
1
2 km

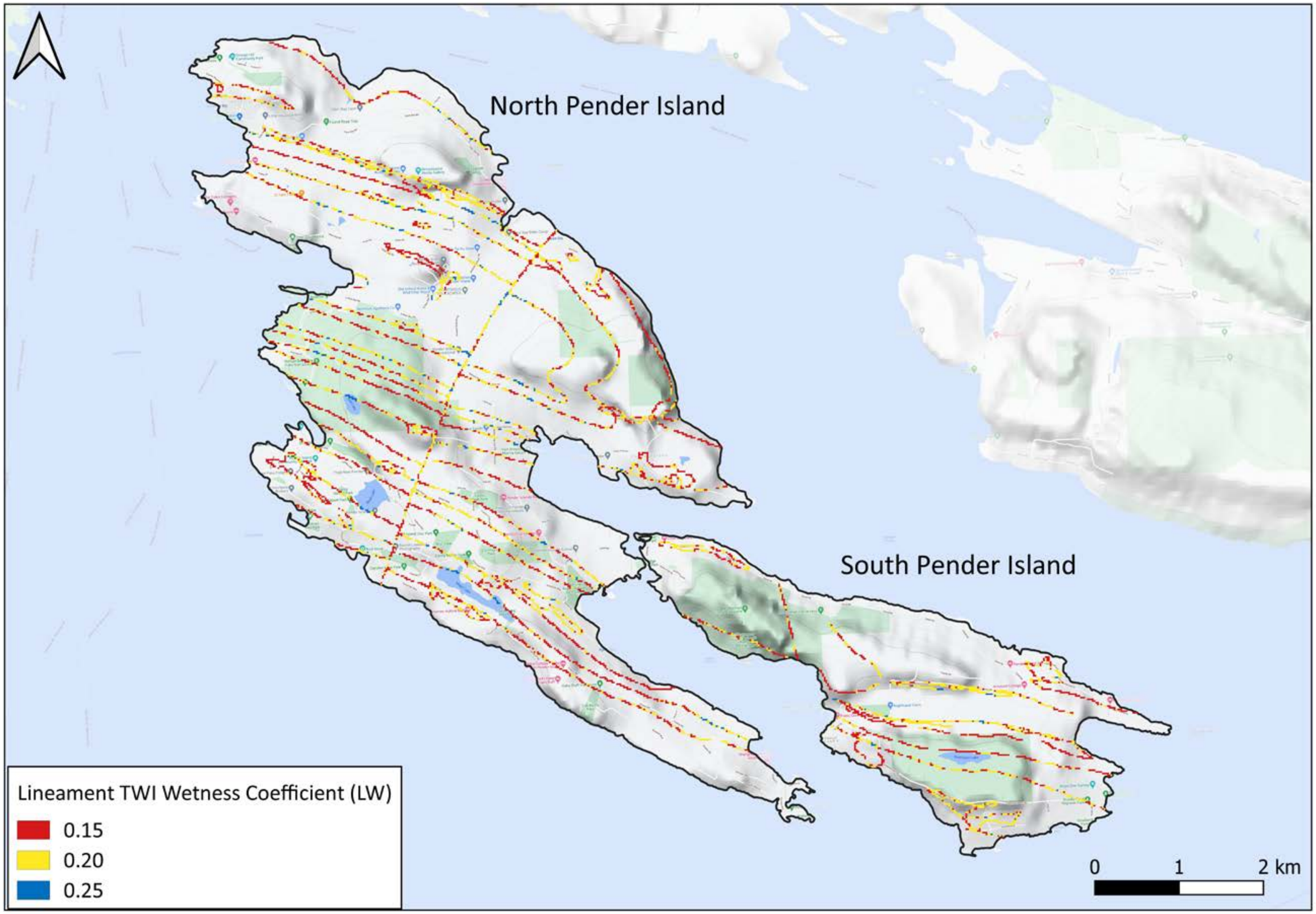

Wallace Island
Fernwood
Trincomali Channel
Parker Island
Galiano Island
Preferential Recharge and Discharge Area Coefficient
0.1
0.3
0.7
0.9
1
0 1 2 km

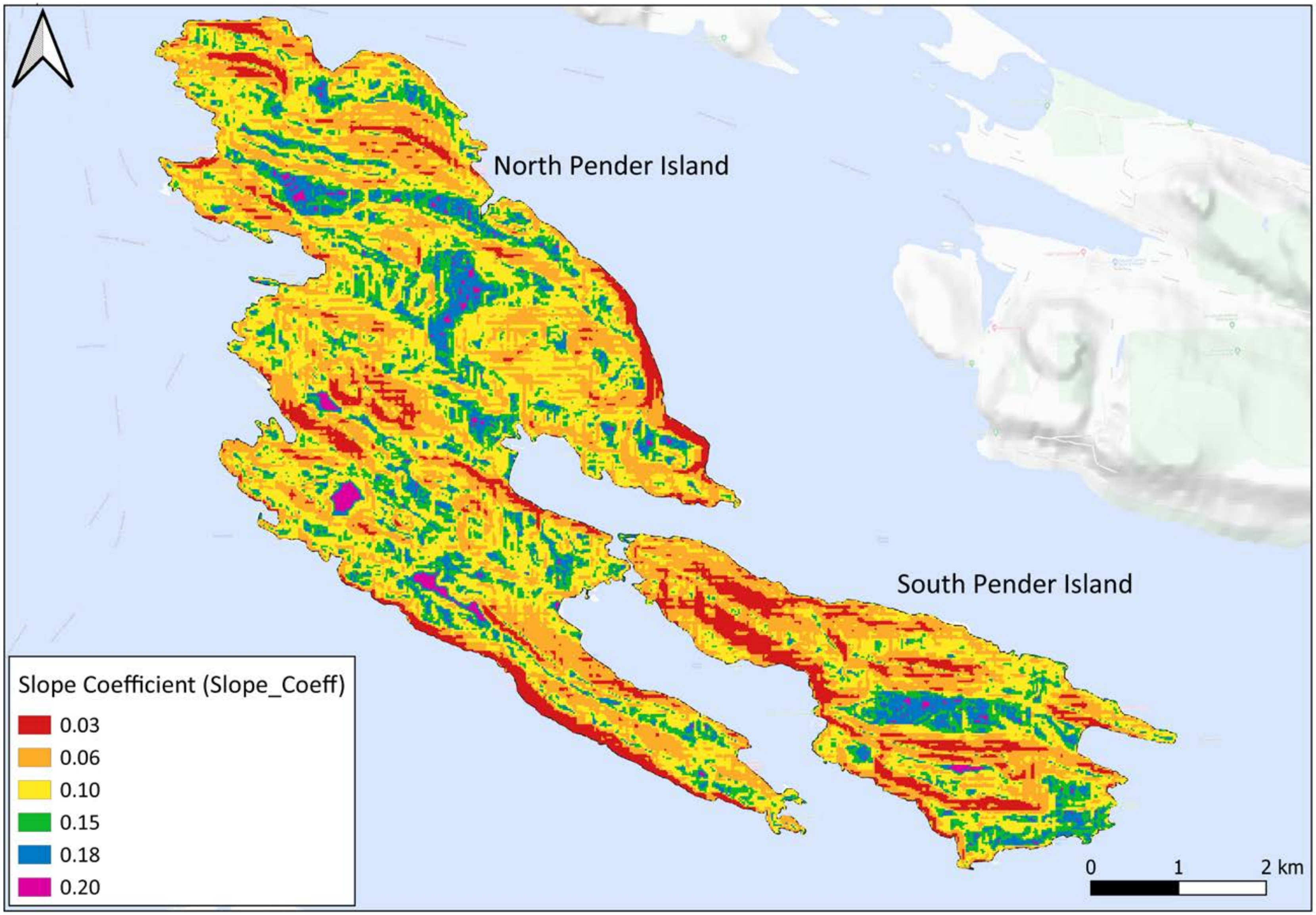

Galiano Island
Lineament TWI Wetness Coefficient (LW)
0.15
0.20
0.25
0
1
2 km

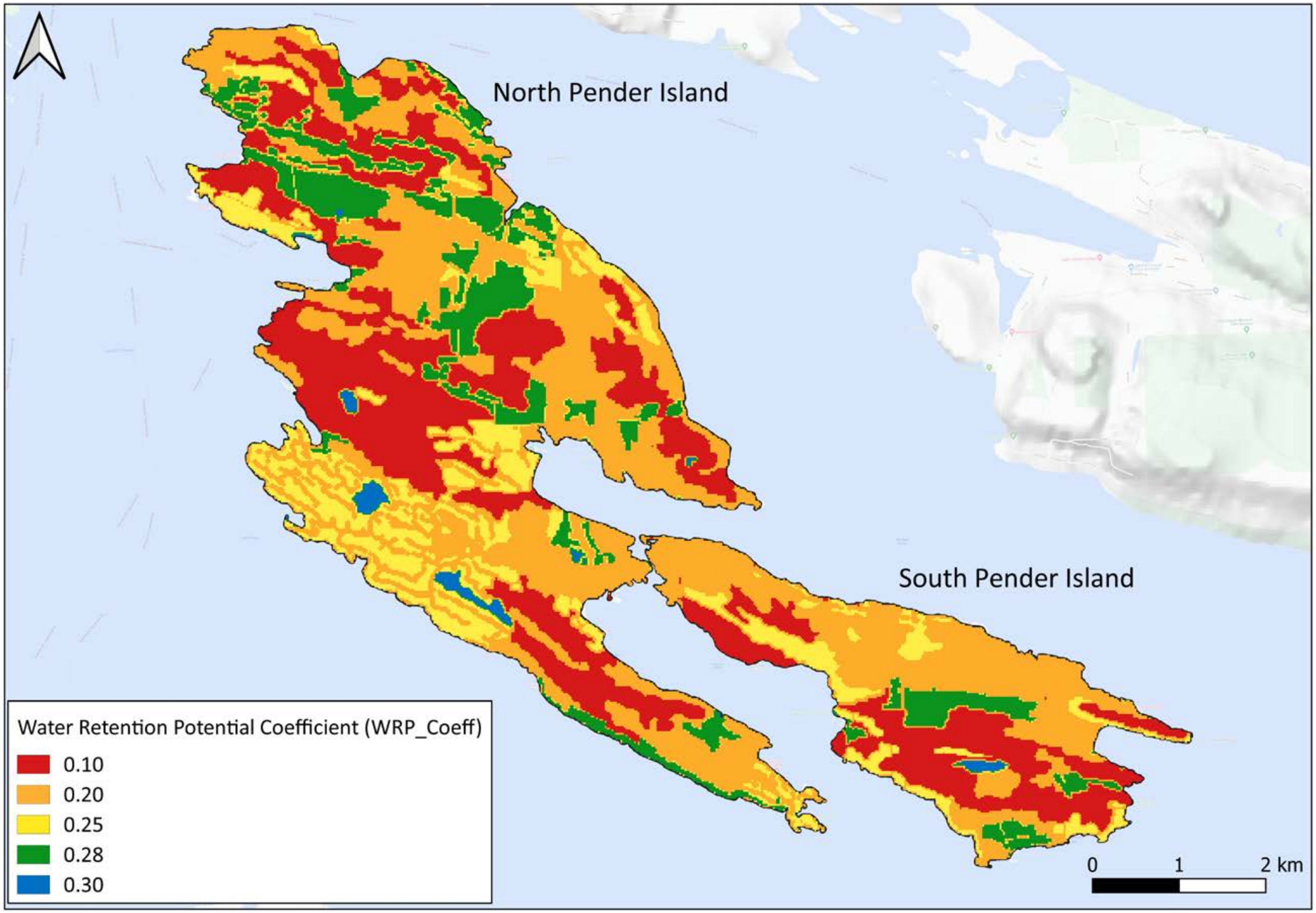

Galiano Island
Slope Coefficient (Slope_Coeff)
0.03
0.06
0.10
0.15
0.18
0.20
0
1
2 km

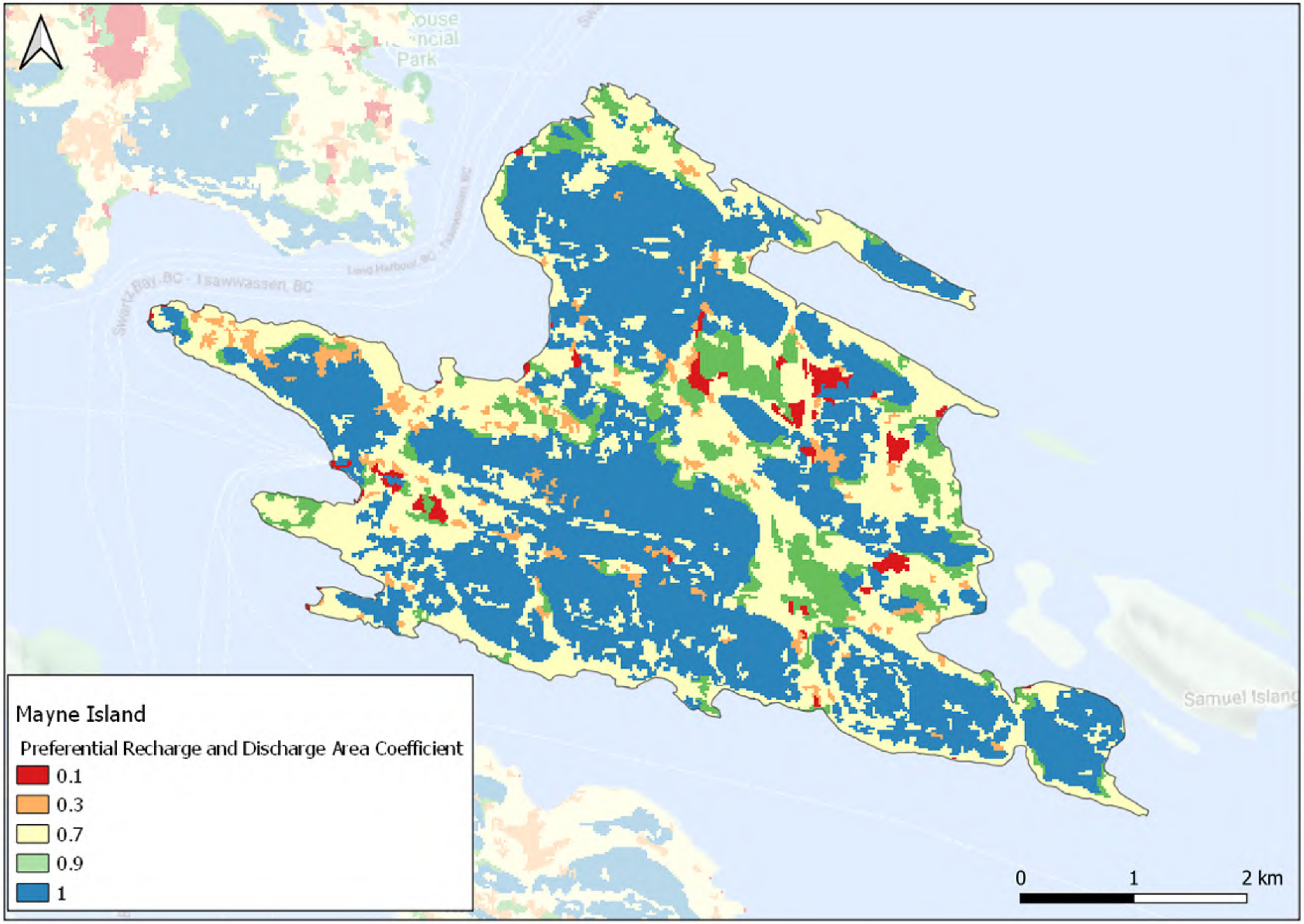

Galiano Island
Water Retention Potential Coefficient (WRP_Coeff)
0.10
0.20
0.25
0.28
0.30
0
1
2 km

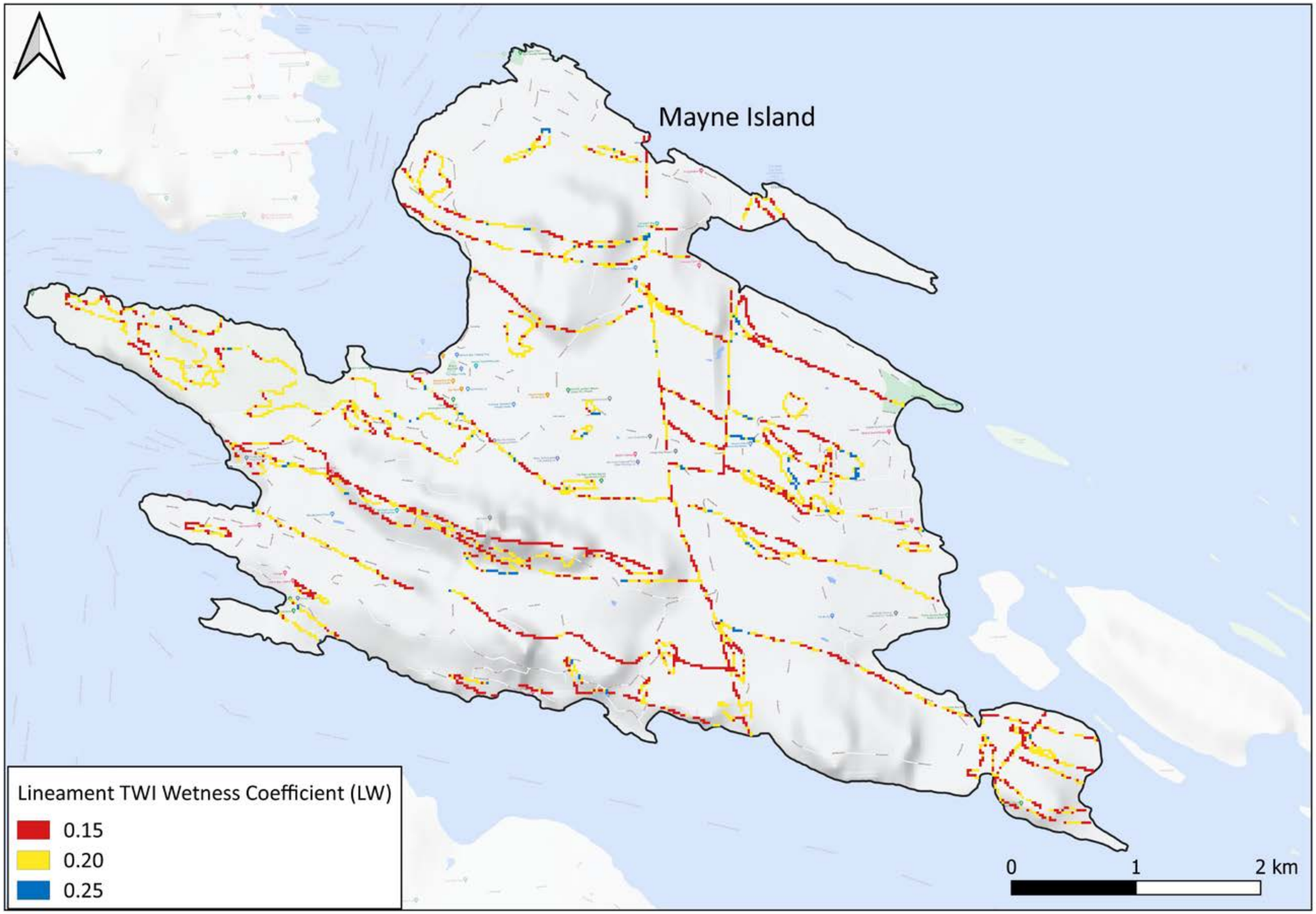

North Pender and South Pender Islands
Preferential Recharge and Discharge Area Coefficient
0.1
0.3
0.7
0.9
1
0
1
2 km


North Pender Island
South Pender Island
Lineament TWI Wetness Coefficient (LW)
0.15
0.20
0.25
0
1
2 km

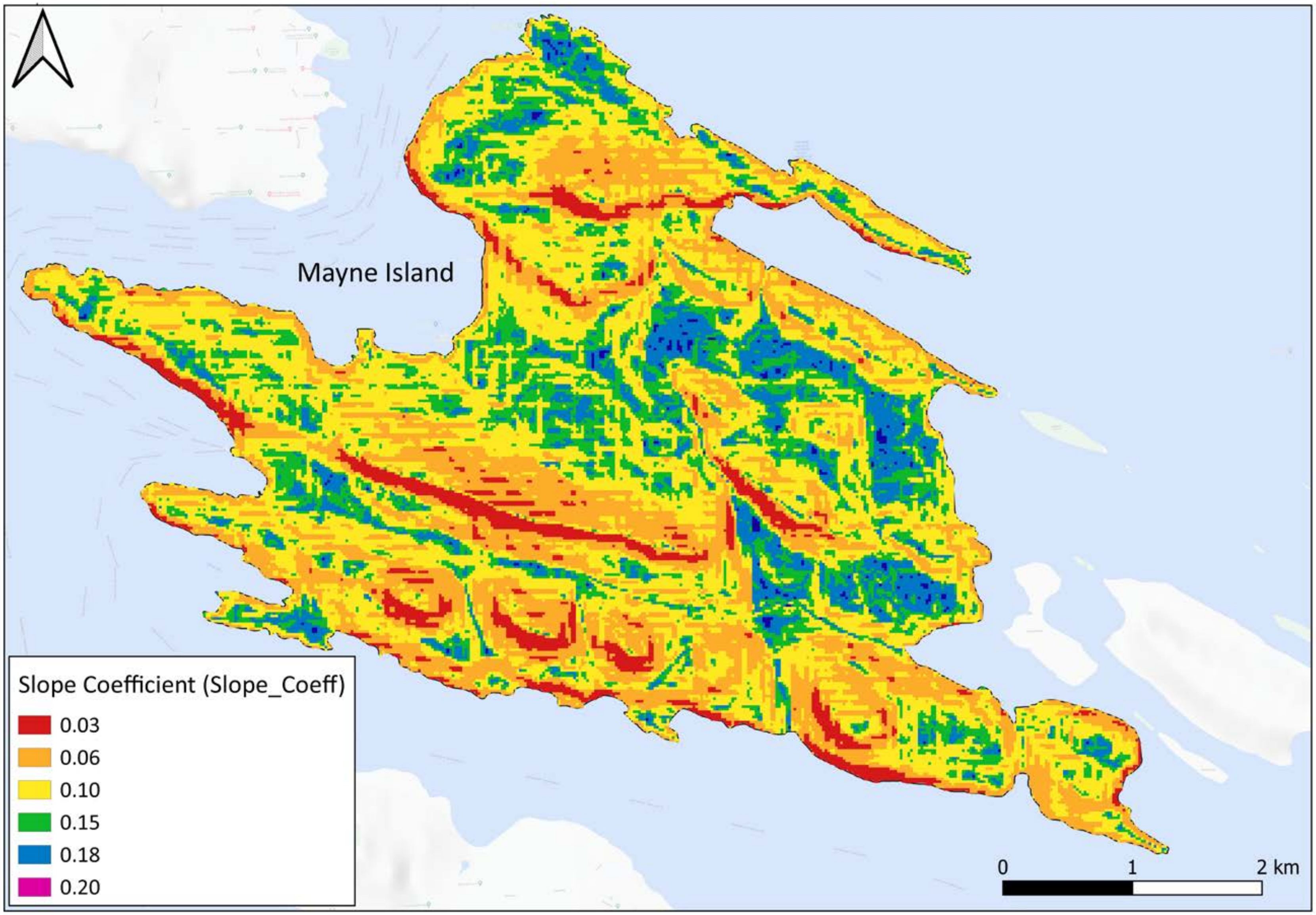

North Pender Island
South Pender Island
Slope Coefficient (Slope_Coeff)
0.03
0.06
0.10
0.15
0.18
0.20
0
1
2 km

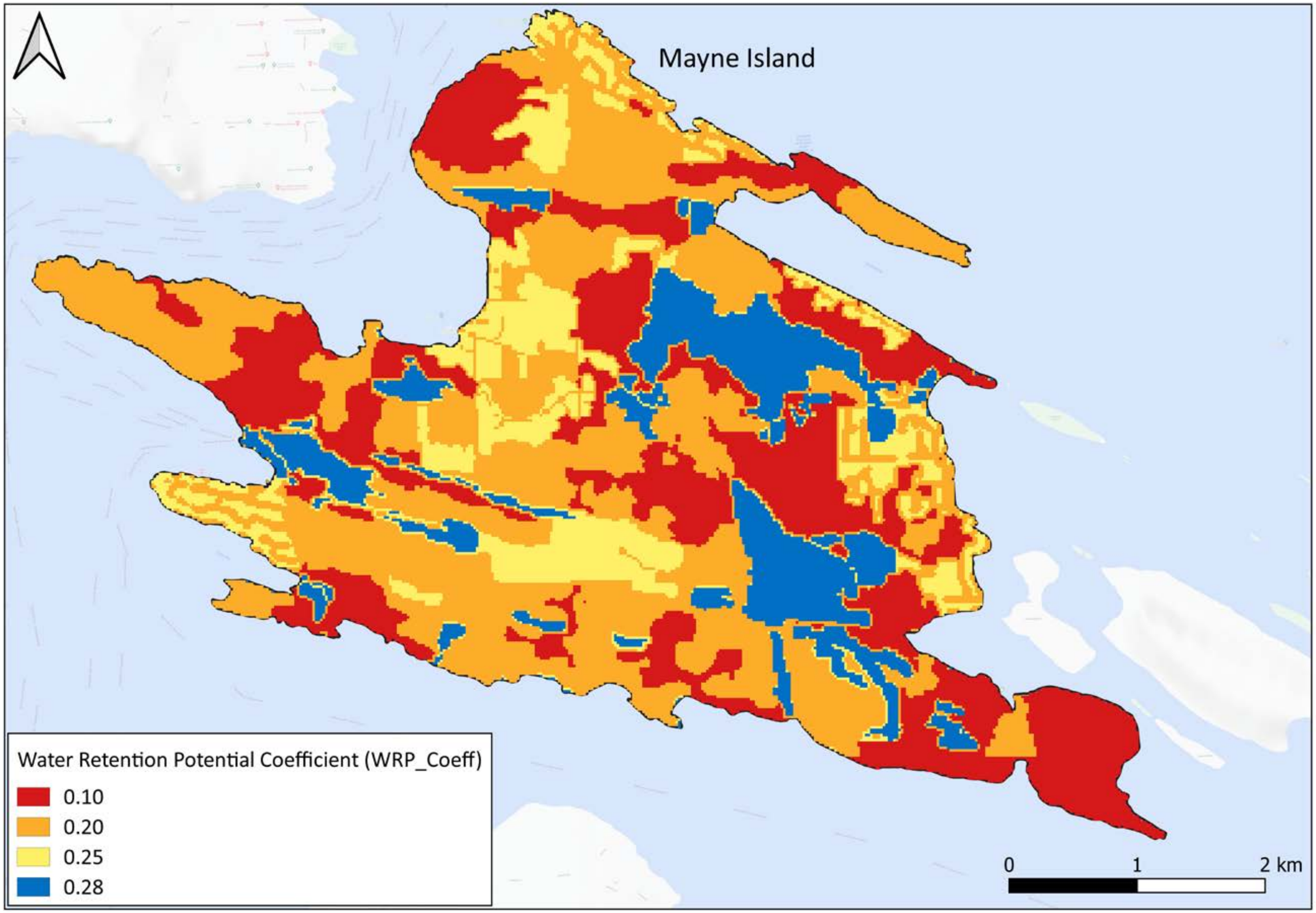

North Pender Island
South Pender Island
Water Retention Potential Coefficient (WRP_Coeff)
0.10
0.20
0.25
0.28
0.30
0
1
2 km

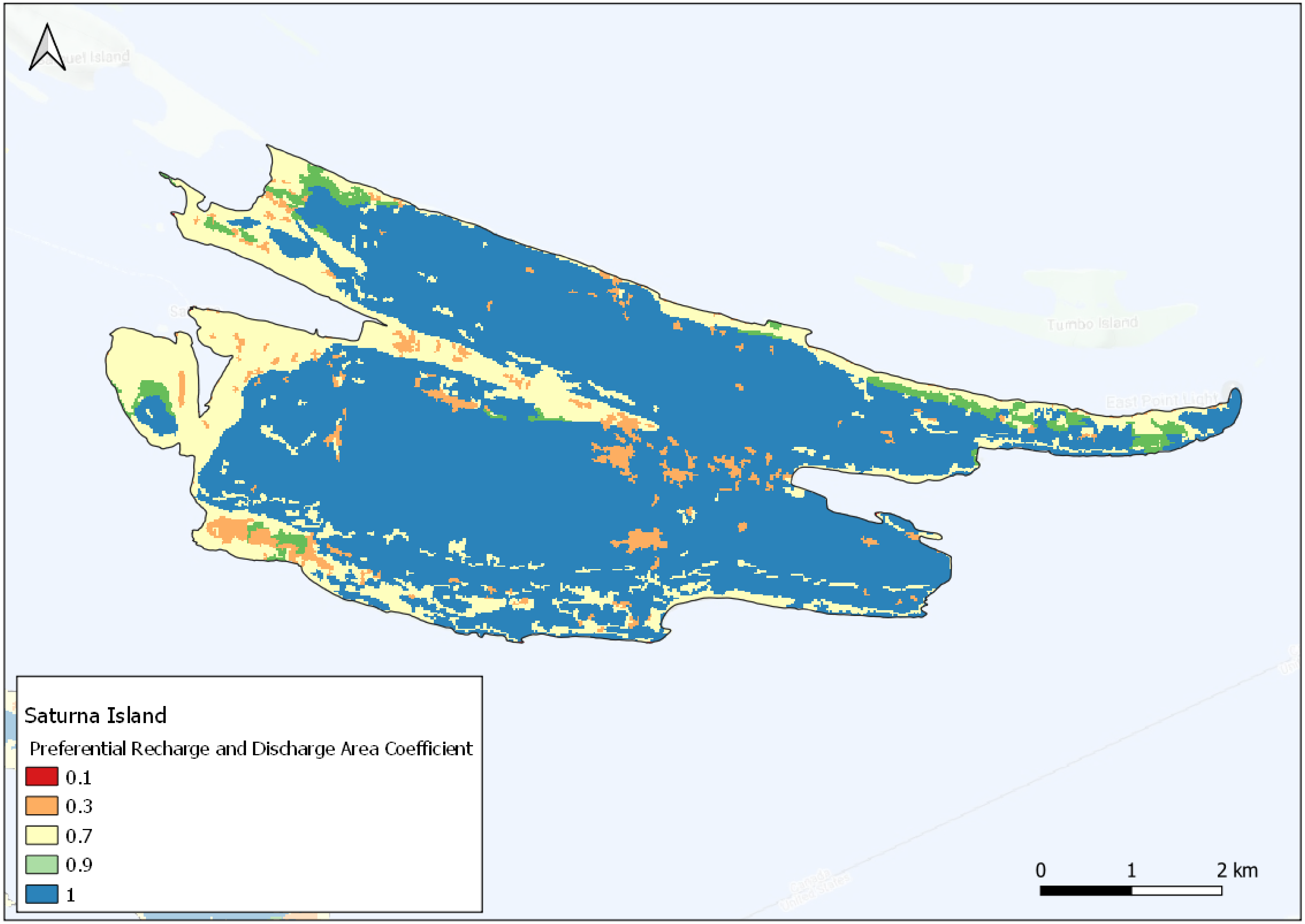

Mayne Island
Preferential Recharge and Discharge Area Coefficient
0.1
0.3
0.7
0.9
1
0
1
2 km
Samuel Island

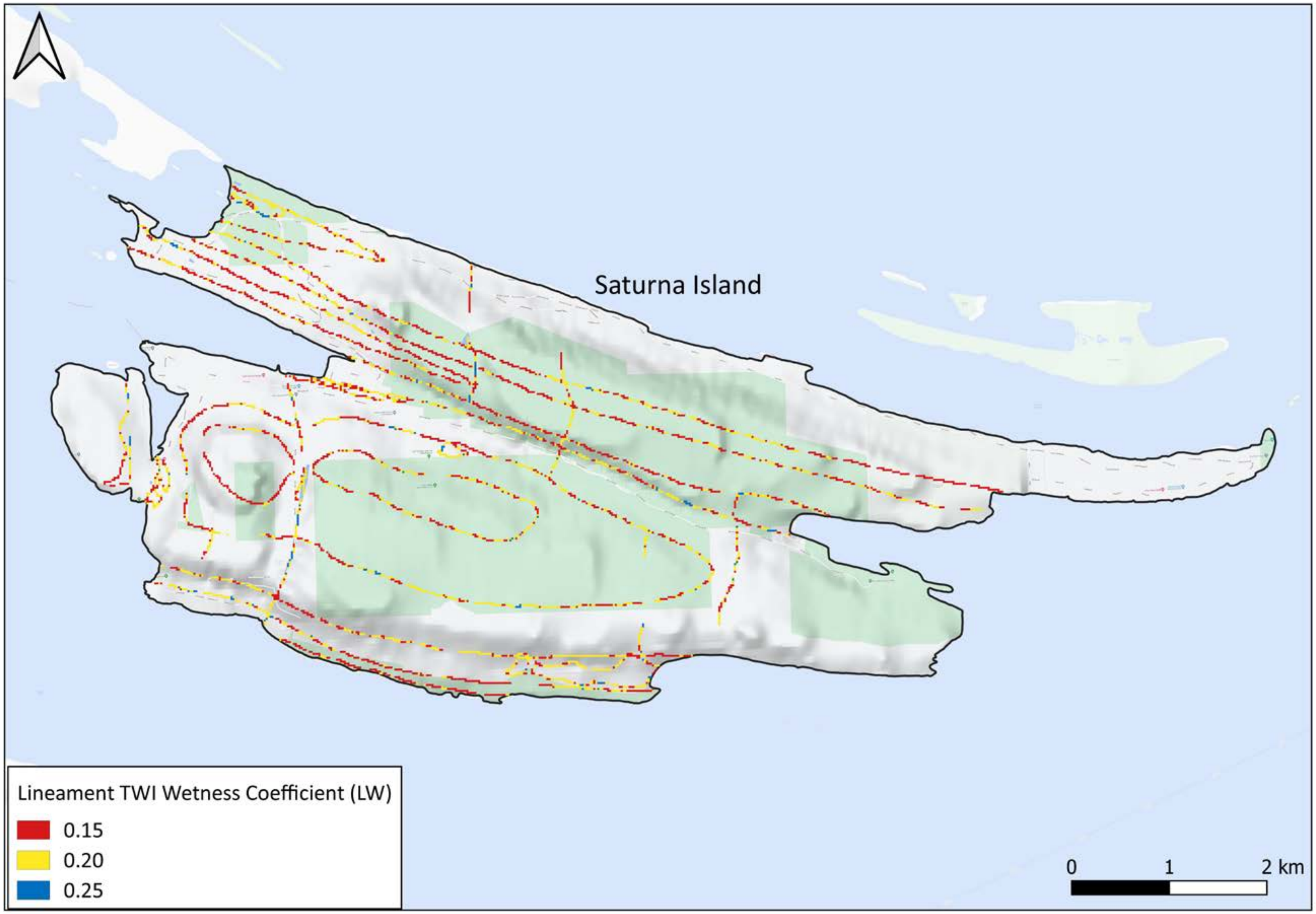


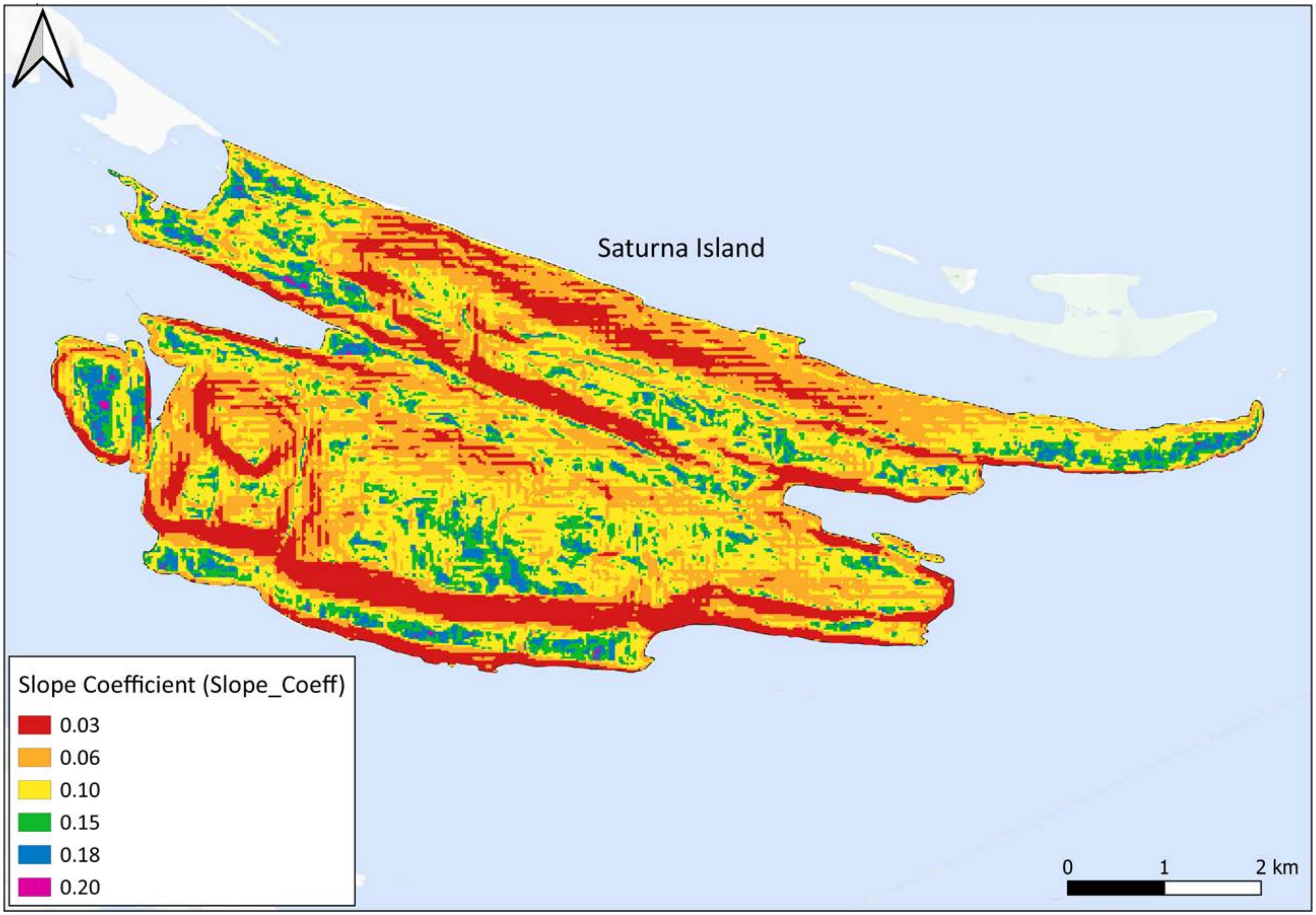
Mayne Island
Lineament TWI Wetness Coefficient (LW)
0.15
0.20
0.25
0
1
2 km

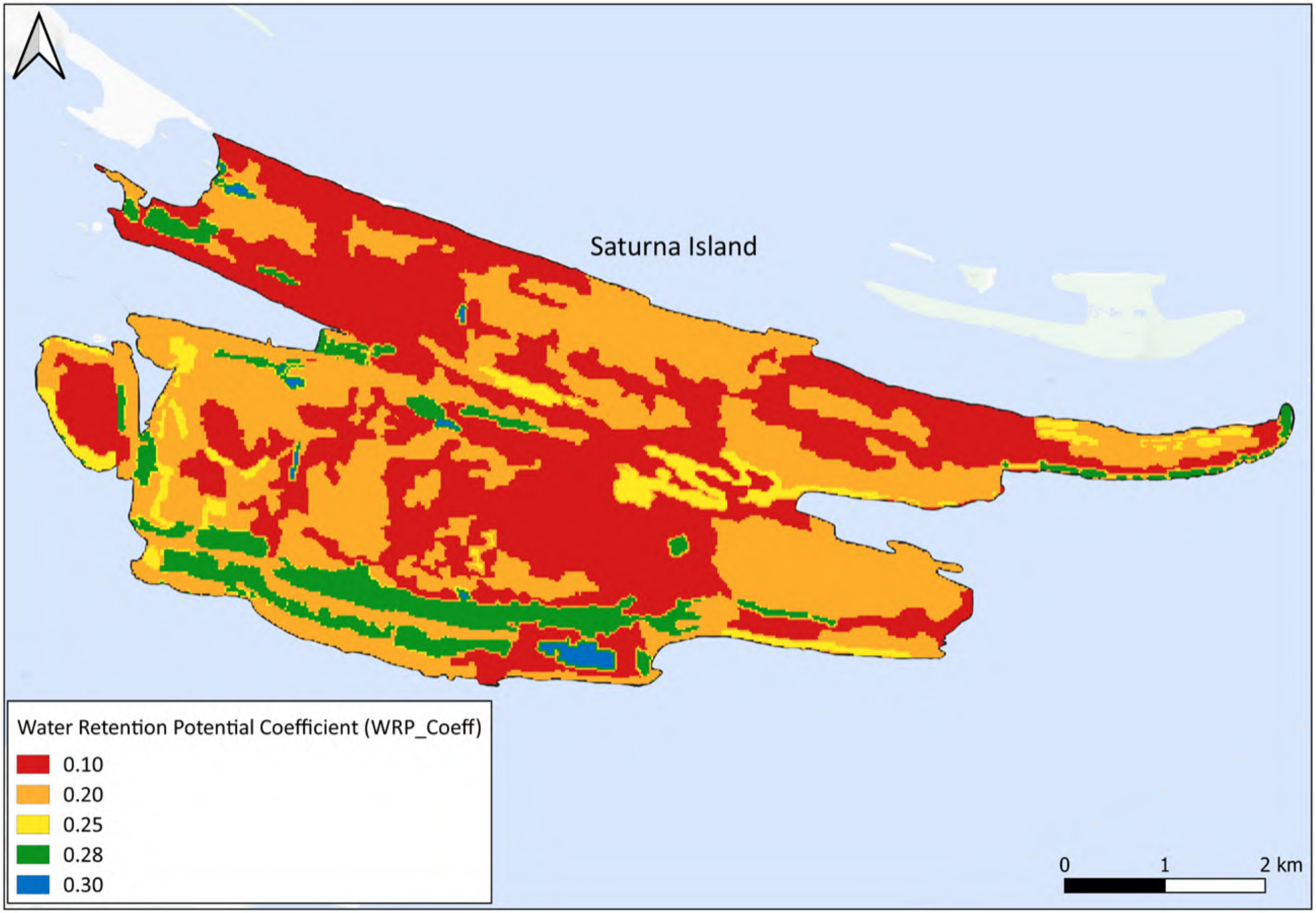

Mayne Island
Slope Coefficient (Slope_Coeff)
0.03
0.06
0.10
0.15
0.18
0.20
0
1
2 km

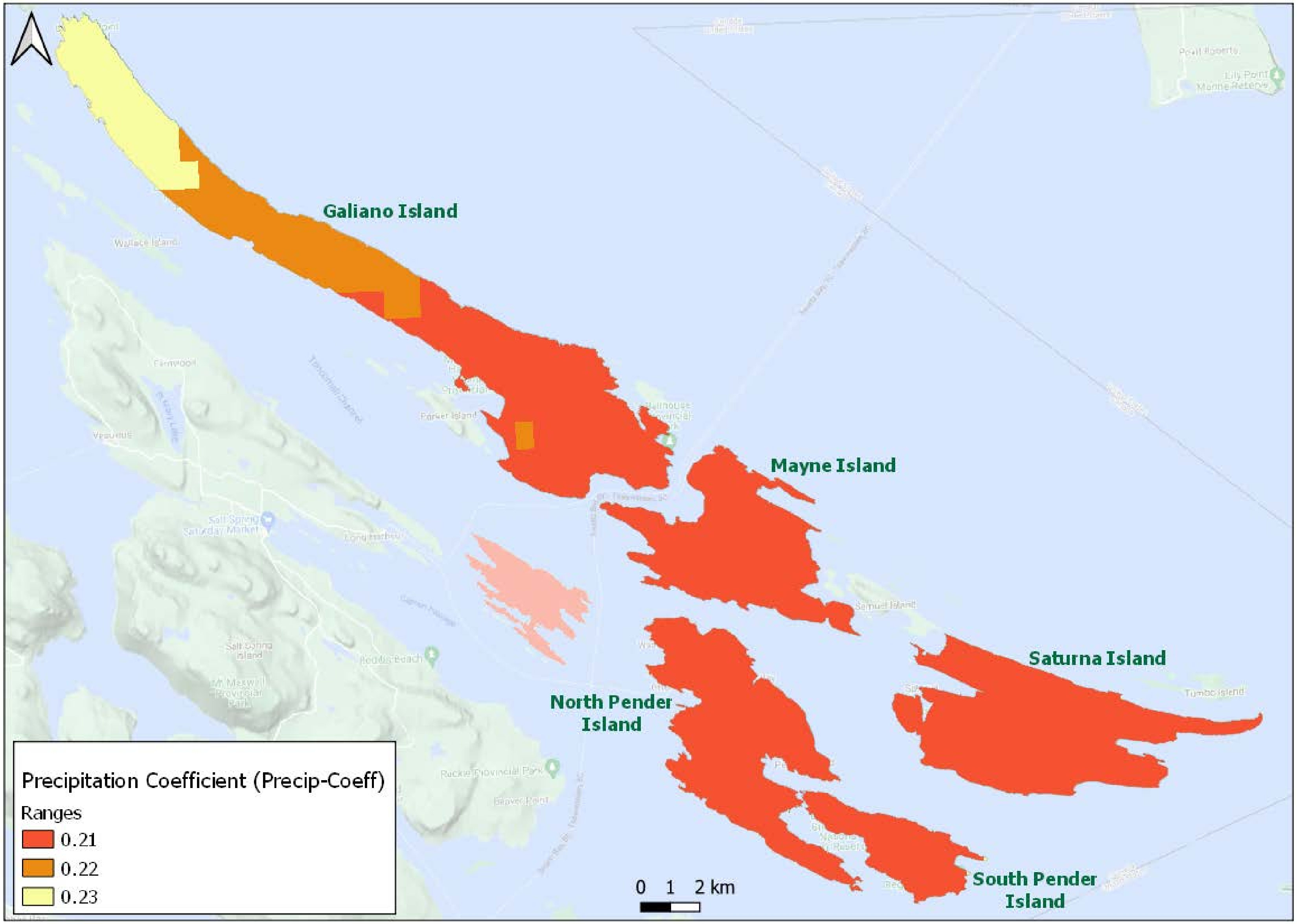

Mayne Island
Water Retention Potential Coefficient (WRP_Coeff)
0.10
0.20
0.25
0.28
0
1
2 km


Tumbo Island
Saturna Island
Preferential Recharge and Discharge Area Coefficient
0.1
0.3
0.7
0.9
1
0
1
2 km


Saturna Island
Lineament TWI Wetness Coefficient (LW)
0.15
0.20
0.25
0
1
2 km


Saturna Island
Slope Coefficient (Slope_Coeff)
0.03
0.06
0.10
0.15
0.18
0.20
0
1
2 km


Saturna Island
Water Retention Potential Coefficient (WRP_Coeff)
0.10
0.20
0.25
0.28
0.30
0
1
2 km


Galiano Island
Mayne Island
Saturna Island
North Pender Island
South Pender Island
Precipitation Coefficient (Precip-Coeff)
Ranges
0.21
0.22
0.23
0 1 2 km

DATE:	August 31, 2021
FROM:	William Shulba, P.Geo, Senior Freshwater Specialist Alex Hedley, Watershed Ecosystems Technologist, UVic Co-Op Student Local Planning Services
SUBJECT:	**Groundwater Recharge Mapping Project: Precipitation Interception Potential Manual**

BACKGROUND

Freshwater is a unique amenity in the Islands Trust Area with inherent vulnerabilities to a changing climate. Residents of the Islands Trust Area, First Nations, and British Columbians in general are experiencing climate driven freshwater vulnerabilities such as drought, wildfire, ecosystem loss, and flooding that are directly affecting livelihoods and businesses - challenging the sustainability of communities and watershed resilience.

Protection of recharge areas and preservation of groundwater resources is a commitment of Islands Trust Council. It is imperative that freshwater sustainability is a key lens through which Islands Trust planning decisions are made. To facilitate this, the Islands Trust has supported and coordinated freshwater research projects, advocated for water literacy, provided open public access to freshwater data, and coordinated with the Province on initiatives.

Water shortage issues are an ever-present concern for many individuals in the Islands Trust area. In a survey conducted in 2016, more than 40% of people indicated they have concerns about exhausting their household freshwater supply (Islands Trust, 2021). Changing precipitation patterns projections are expected to result in longer drought periods during the summer, and more intense precipitation events in the wetter seasons, resulting in a reduced quality of drinking water (Pinna Sustainability, 2020).

Climate change related issues such sea-level rise and storm surge flooding are expected to worsen the salt water intrusion issues found on the islands (Islands Trust, 2021). Even with freshwater concerns abound, mitigation for these water related issues is possible. Understanding how groundwater and freshwater resources are replenished, by way of groundwater recharge potential, is one-step towards easing these concerns.

PURPOSE

Groundwater recharge is one of the primary factors controlling limits on groundwater withdrawal (Döll & Flörke, 2005, as cited in Mohan et al., 2018). To determine the groundwater recharge potential of the Islands Trust area, multiple variables, including soil and vegetation characteristics, need to be considered (Mohan et al., 2018). Forest canopies have been known to intercept as much as 10-40% of the total rainfall (Horman et al., 1996, as cited in Murakami, 2006). As such, quantifying and mapping the influence of vegetation characteristics and their influence on precipitation interception is important for assessing groundwater recharge potential.

The purpose of this investigation on precipitation interception potential is to assess the spatial variability of interception potential in the Islands Trust area, to develop a greater understanding of groundwater recharge potential. With a greater understanding on where groundwater recharge potential is low or high, appropriate water management strategies can be developed based on this information.

OBJECTIVES

The precipitation interception potential map will be developed with the successful execution of four key objectives.

1. Perform a literature review to determine which vegetation characteristics contribute significantly to precipitation interception.
2. Using the Vegetation Resource Inventory (VRI), to asses vegetation interception characteristics that correspond to VRI attribute data available in the Islands Trust region.
3. Create a weighting scheme, that assigns importance to the VRI attributes to precipitation interception.
4. Input the VRI attributes, and associated attribute items, into a GIS with their assigned weights to create a surface representing precipitation interception potential for the Islands Trust area.

GOALS

The primary goal is to create a precipitation interception potential surface for the Islands Trust area that accurately represents real-world precipitation interception. The precipitation interception potential surface can then be combined with other groundwater recharge data to create a comprehensive groundwater recharge surface for the entirety of the Islands Trust area. The successful completion of this product will allow for more informed decisions on current and future water management strategies, supporting the Islands Trust mandate to preserve and protect.

ANALYSIS

Variables of Interception

Variables of Interception was the name given to the general forest features that were determined to be significant to rainfall interception processes. The variables of interception included 1) Canopy Closure, 2) Forest Cover Type, and 3) Herb Storage Capacity. Each of the variables of interception were assigned a weight describing their relative importance to rainfall interception. Together, these weights add up to 1.

Table 1. Variables of Interception assigned weights.

Variable of Interception	Assigned Weight
Canopy Closure	0.64
Forest Cover Type	0.26
Herb Storage Capacity	0.1

Attributes of Interception

Attributes are the VRI data categories that contribute to each of the three aforementioned variables of interception. The VRI attributes used include Label Line 4 Index Classes (for crown closure), Shrub Crown Closure, Shrub Cover Pattern, Land Cover Class Code 1, Land Cover Class Code 2, Land Cover Component Percentage 1, Land Cover Component Percentage 2, Herb Cover Type, and Herb Cover Percentage. These attributes were assigned a weight indicating their importance to the variable of interception they belong to (See Figure 1). A shapefile containing fields for attribute items and attribute item ratings is provided for each of the attributes contributing to interception.

Table 2. Canopy Closure Attributes and assigned weights.

VRI Attribute	Assigned Weight
LINE_4_CLASSES_INDEXES (Crown Closure)	0.72
SHRUB_CROWN_CLOSURE	0.14
SHRUB_COVER_PATTERN	0.14

Table 3. Forest Cover Type Attributes and assigned weights.

VRI Attribute	Assigned Weight
LAND_COVER_CLASS_CD_1	0.42
EST_COVERAGE_PCT_1	0.42
LAND_COVER_CLASS_CD_2	0.08
EST_COVERAGE_PCT_2	0.08

Table 4. Herb Storage Capacity Attributes and assigned weights.

VRI Attribute	Assigned Weight
HERB_COVER_TYPE	0.5
HERB_COVER_PCT	0.5

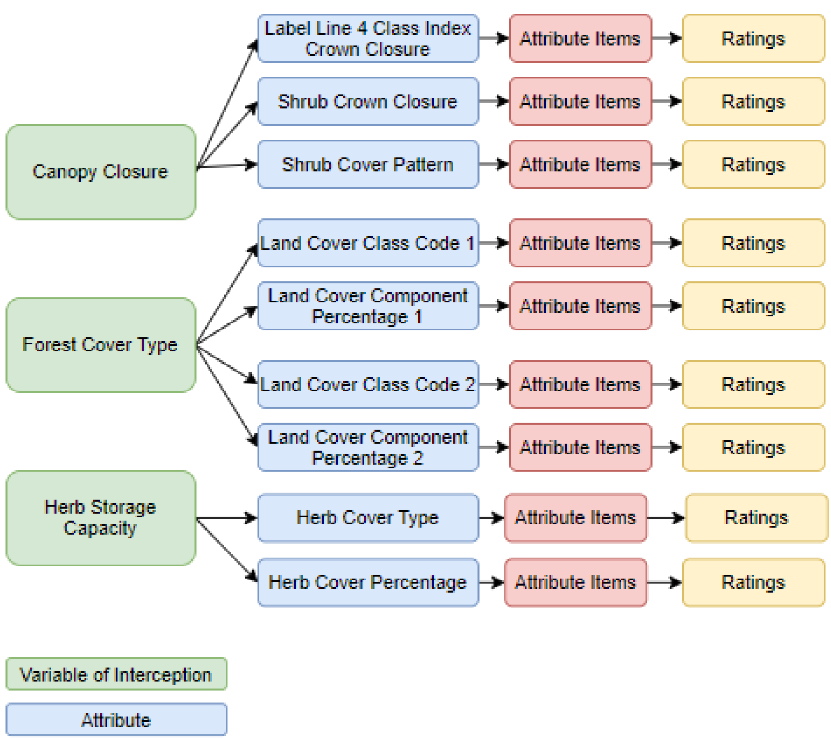


Figure 1. Flowchart describing of hierarchy of interception variables, attributes, attribute items, and ratings.

Attribute Items

Attribute items are the class codes or descriptors found within each attribute in the VRI. These include numeric and text characters. Refer to Excel document for attribute item information.

Attribute Item Ratings

Attribute item ratings are the interception values assigned to each of the attribute items found within the VRI. The attribute item ratings range between 1 and 0, with a precision of two decimal places. Refer to Excel document for attribute item rating information.

Weighting Method

Variables of interceptions and attributes were both assigned weights, which, together, add to 1. Weights were calculated using the analytical hierarchy process (AHP), which is a method that allows for pairwise comparison based on relative importance (Aragon et al., 2012). Values of 9 represent extreme importance relative to other variables or attributes, 7 indicates very strong importance, 5 indicates strong importance, 3 indicates moderate importance, and 1 indicates equal importance between variables or attributes. The importance scheme used to calculate weights can be seen below (Tables 5 to 8). The resulting weights, as well as the rating values assigned to the attribute items, can be seen in the provided Excel file.

Table 5. AHP table for weighting variables of interception.

	Canopy Closure	Forest Cover Type	Herb Storage Capacity
Canopy Closure	1	3	5
Forest Cover Type	1/3	1	3
Herb Storage Capacity	1/5	1/3	1

Table 6. AHP table for weighting VRI canopy closure attributes.

	LINE_4_CLASSES_INDEXES (Crown Closure)	SHRUB_CROWN_CLOSURE	SHRUB_COVER_PATTERN
LINE_4_CLASSES_INDEXES (Crown Closure)	1	5	5
SHRUB_CROWN_CLOSURE	1/5	1	1
SHRUB_COVER_PATTERN	1/5	1	1

Table 7. AHP table for weighting VRI forest cover type attributes

	LAND_COVER_CLASS_CD_1	EST_COVERAGE_PCT_1	LAND_COVER_CLASS_CD_2	EST_COVERAGE_PCT_2
LAND_COVER_CLASS_CD_1	1	1	5	5
EST_COVERAGE_PCT_1	1	1	5	5
LAND_COVER_CLASS_CD_2	1/5	1/5	1	1
EST_COVERAGE_PCT_2	1/5	1/5	1	1

Table 8. AHP table for weighting VRI herb storage capacity attributes.

	HERB_COVER_TYPE	HERB_COVER_PCT
HERB_COVER_TYPE	1	1
HERB_COVER_PCT	1	1

RESULTS

Precipitation Interception VRI Attributes on Hornby, Denman and Gabriola Island

Hornby, Denman and Gabriola Island are comprised of 876 polygons containing VRI data. The following list provides VRI attribute data found on these islands that are of interest to canopy precipitation interception potential. Additionally, the number of polygons containing data and total area containing data on these attributes are provided.

1. **Land Cover Class Code 1 (LAND_COVER_CLASS_CD_1):**
   Land Cover Class Code 1 data is found in 822 of 876 polygons (93.8%) on the islands. This class has data in 118.48 km^2 of the total 127.77 km^2 area of the islands (92.7%).

2. **Land Cover Component Percentage 1 (EST_COVERAGE_PCT_1):**
   Land Cover Component Percentage 1 data is found in 874 of 876 polygons (99.7%). This class has data in 126.89 km^2 of the total 127.77 km^2 area of the islands (99.3%).

3. **Land Cover Class Code 2 (LAND_COVER_CLASS_CD_2):**
   Land Cover Class Code 2 data is found in 46 of 876 polygons (5.3%). This class has data in 3.54 km^2 of the total 127.77 km^2 area of the islands (2.8%).

4. **Land Cover Component Percentage 2 (EST_COVERAGE_PCT_2):**
   Land Cover Component Percentage 1 data is found in 52 of 876 polygons (5.9%). This class has data in 4.38 km^2 of the total 127.77 km^2 area of the islands (3.4%).

5. **Label Line 4 Index Classes (LINE_4_CLASSES_INDEXES):**
   Label Line 4 Index Classes data is found in 792 of 876 polygons (90.4%). This class has data in 120.92 km^2 of the total 127.77 km^2 area of the islands (94.6%).

6. **Shrub Crown Closure (SHRUB_CROWN_CLOSURE):**
   Shrub Crown Closure data is found in 465 of 876 polygons (53.1%). This class has data in 74.61 km^2 of the total 127.77 km^2 area of the islands (58.4%).

7. **Shrub Cover Pattern (SHRUB_COVER_PATTERN):**
   Shrub Cover Pattern data is found in 465 of 876 polygons (53.1%). This class has data in 74.61 km^2 of the total 127.77 km^2 area of the islands (58.4%).

8. **Herb Cover Type (HERB_COVER_TYPE):**
   Herb Cover Type data is found in 549 of 876 polygons (62.7%). This class has data in 82.95 km^2 of the total 127.77 km^2 area of the islands (64.9%).

9. **Herb Cover Percentage (HERB_COVER_PCT):**
   Herb Cover Percentage data is found in 549 of 876 polygons (62.7%). This class has data in 82.95 km^2 of the total 127.77 km^2 area of the islands (64.9%).

DISCUSSION

The complete set of data including interception variable weights, attribute weights, attribute items, and attribute item ratings, are included in a provided Excel file. This file has six sheets, including an overview sheet with the full set of weights and ratings, a CSV data format sheet, a canopy closure data sheet, a forest cover type data sheet, a herb storage capacity data sheet, and an attribute item rating sheet.

The spatial data for attribute item and attribute item rating data is included in shapefiles. There is a separate shapefile for each island, containing attribute fields (containing the attribute items), and attribute item rating fields. A naming key for the field names is provided in the section below. Maps displaying the spatial distribution of VRI attribute data on Denman, Hornby, and Gabriola have also been provided.

Variables of Interception included:

- Canopy Closure
- Forest Cover Type
- Herb Storage Capacity

Table 9. Canopy Closure Attributes and associated items.

Descriptive Name	Attribute Name (in Excel File)	Shapefile Attribute Table Field Name (short form)	Shapefile Attribute Rating Field Name
Label Line 4 Index Classes	LINE_4_CLASSES_INDEXES (Crown Closure)	L4	L4_CRWN_R
Shrub Crown Closure	SHRUB_CROWN_CLOSURE	S_CRWN	S_CRWN_R
Shrub Cover Pattern	SHRUB_COVER_PATTERN	S_CVR_P	S_CVR_P_R

Table 10. Forest Cover Type Attributes and associated items.

Descriptive Name	Attribute Name (in Excel File)	Shapefile Attribute Table Field Name (short form)	Shapefile Attribute Rating Field Name
Land Cover Class Code 1	LAND_COVER_CLASS_CD_1	LAND_CD1	LAND_CD1_R
Land Cover Component Percentage 1	EST_COVERAGE_PCT_1	EST_PCT1	EST_PCT1_R
Land Cover Class Code 2	LAND_COVER_CLASS_CD_2	LAND_CD2	LAND_CD2_R
Land Cover Component Percentage 2	EST_COVERAGE_PCT_2	EST_PCT2	EST_PCT2_R

Table 11. Herb Storage Capacity Attributes and associated items.

Descriptive Name	Attribute Name (in Excel File)	Shapefile Attribute Table Field Name (short form)	Shapefile Attribute Rating Field Name
Herb Cover Type	HERB_COVER_TYPE	H_TYPE	H_TYPE_R
Herb Cover Percentage	HERB_COVER_PCT	H_PCT	H_PCT_R

SUMMARY

The Groundwater Sustainability Science Program's (GWSS) purpose is to provide foundational knowledge and scientific inquiry into groundwater quality, quantity, and vulnerabilities to support evidence-based decision-making. By estimating the balance between groundwater recharge and human and ecological water use and the impacts of climate change, groundwater availability assessments provide information to facilitate improved watershed protection and freshwater preservation through Islands Trust's planning services, and . Planning tools include covenants, development permit areas, zoning, density bonusing, and subdivision servicing regulations. Decisions, authorizations, approvals, and planning by other responsible agencies will be better informed through this work, directly addressing the Islands Trust object of coordinating with other governments. Data acquired through the GWSS has also extending benefits to the Islands Trust Conservancy informing regional conservation planning.

The results from the Precipitation Interception Potential has identified an ecosystem approach to determining groundwater recharge potential in the Islands Trust Area by providing an essential method into the Islands Trust Area Groundwater Recharge Potential Mapping project, part of the Groundwater Sustainability Science Program.

REFERENCES

Aragon, T. J., Dalnoki-Veress, F., & Shiu, K. (2012). *Deriving Criteria Weights for Health Decision Making: A Brief Tutorial*. https://escholarship.org/uc/item/4366g5pv#page-8

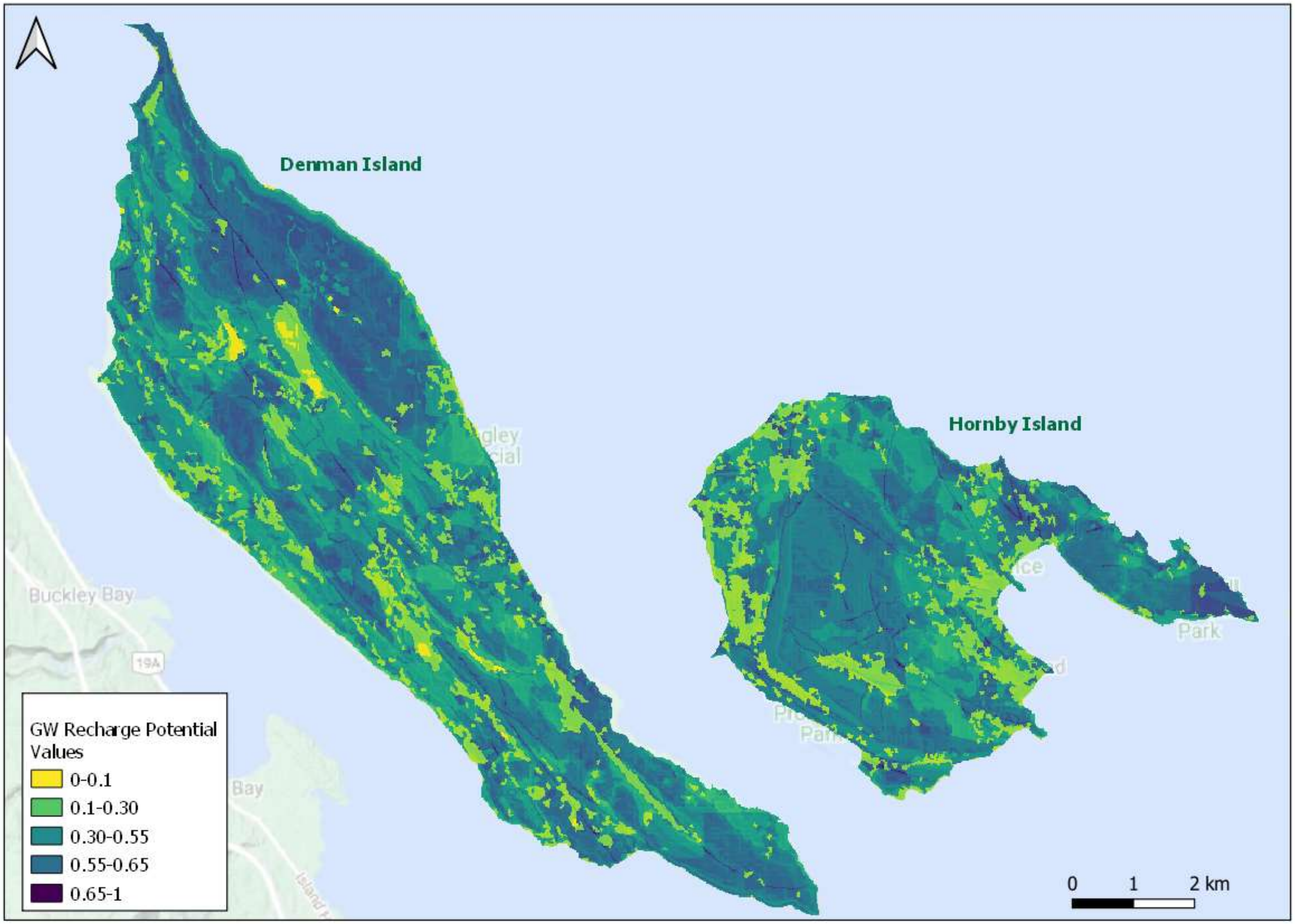
Islands Trust. (2021). *Climate change.* https://islandstrust.bc.ca/programs/climate-change/

Islands Trust. (2021). *Freshwater sustainability.* https://islandstrust.bc.ca/programs/freshwater-sustainability/

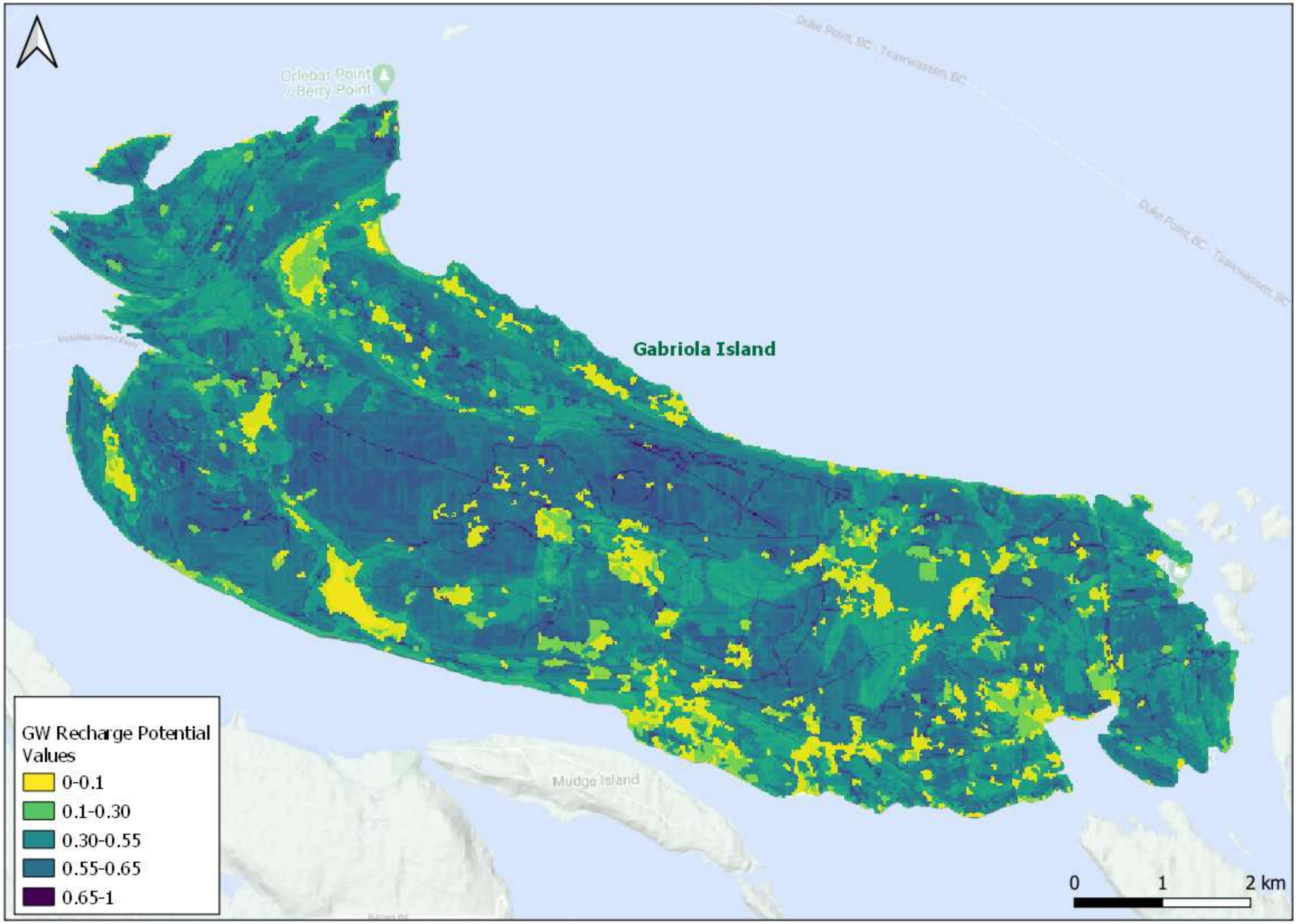
Mohan, C., Western, A. W., Wei, Y., & Saft, M. (2018). Predicting groundwater recharge for varying land cover and climate conditions – a global meta-study. *Hydrology and Earth System Sciences*, *22*, 2689–2703. https://doi.org/10.5194/hess-22-2689-2018

Pinna Sustainability. (2020). Climate projections for Islands Trust area. https://islandstrust.bc.ca/wp-content/uploads/2020/07/ITC_ClimateProjectionsReport__Final.pdf

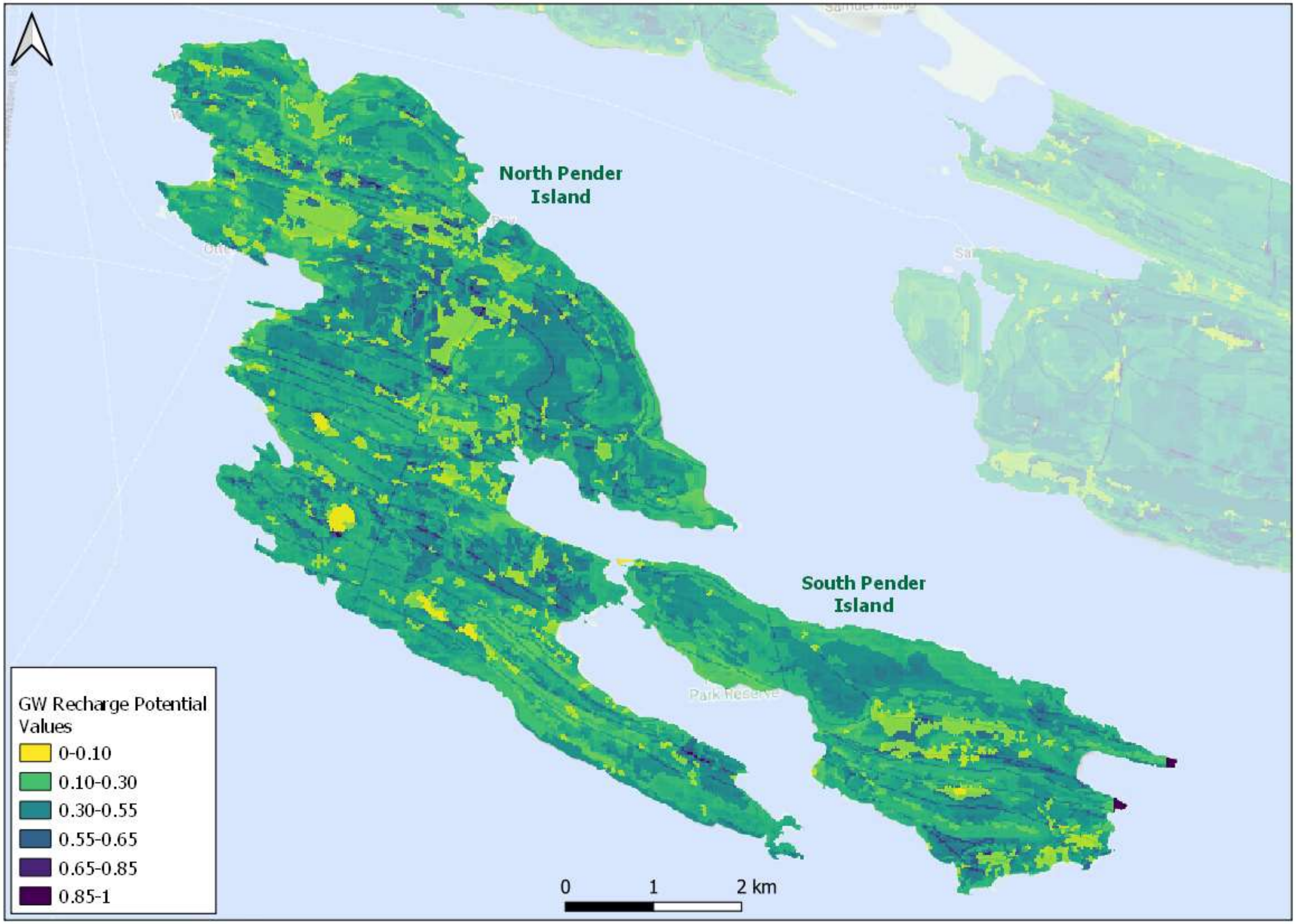
APPENDIX 10: Groundwater Recharge Potential Maps



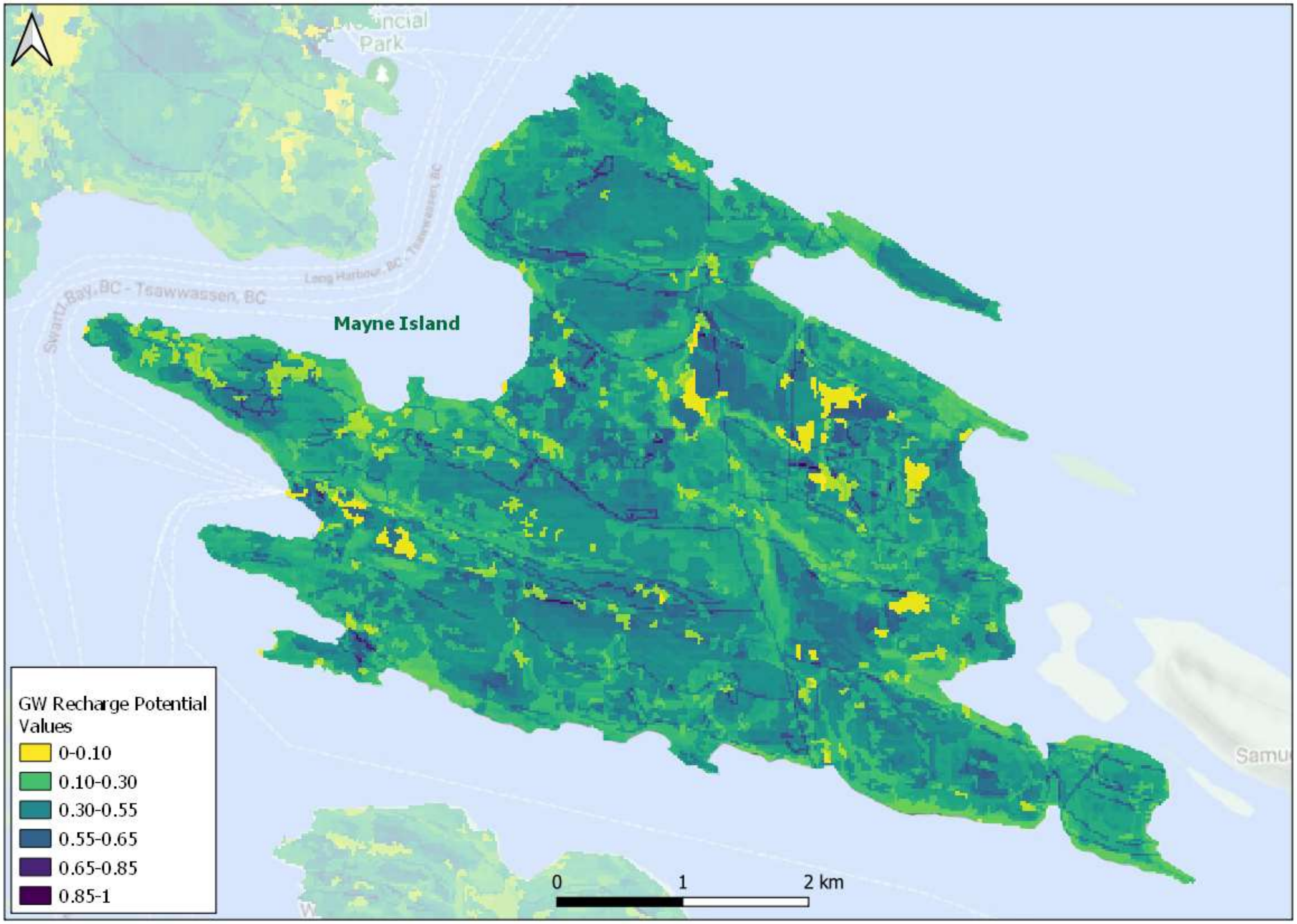
Groundwater Recharge Potential for Denman Island and Hornby Island



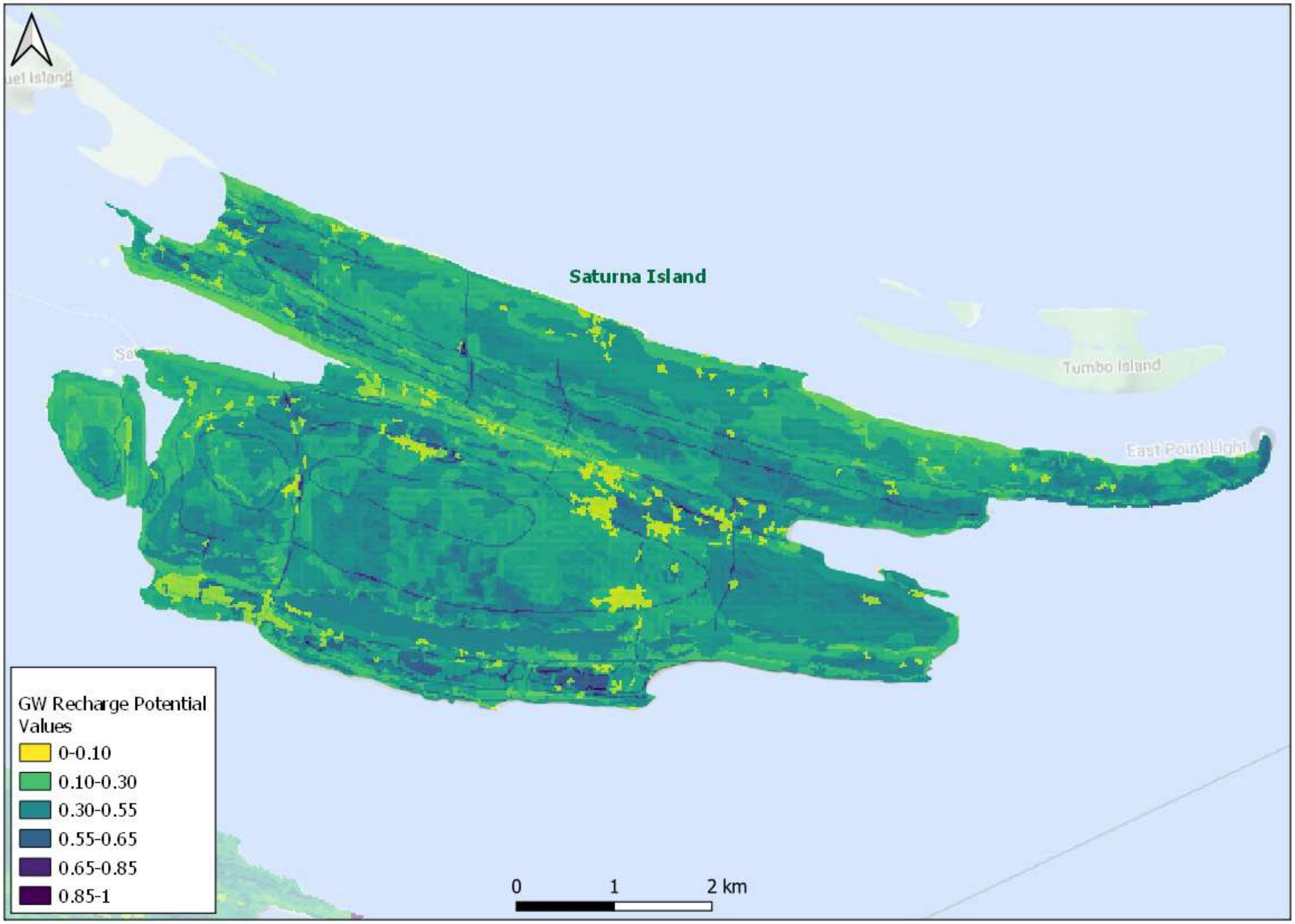
Groundwater Recharge Potential for Gabriola Island



Groundwater Recharge Potential for North Pender and South Pender Islands



Groundwater Recharge Potential for Mayne Island



Groundwater Recharge Potential for Saturna Island

Groundwater Recharge Potential for Galiano Island

APPENDIX 11: Previous Studies

Source	Study Islands	Report	Published Date	BY	FOR
EcoCat	Denman Island	Report Valens Creek Stepped-Pool Design Report for Denman Conservancy Association.pdf	Jul-01	Eakins Hydrological Consulting, D.E. Reksten Hydrologic Engineer, Clark Hydrological Services	Denman Conservancy Association, Denman Island, B.C.
		Report Preliminary Review of Groundwater Conditions and Availability, Denman Island, British Columbia.pdf	May-79	British Columbia Ministry of Environment, groundwater section, hydrology division	British Columbia Ministry of Environment, water Investigation branch
		Report Memo Update of Denman Island Report.pdf	Jun-86	Ministry of Environment	Ministry of Lands Parks and Housings
		Report Memo Site Selection Fillongley Park, Denman Island.pdf	Sep-79	Ministry of Environment	Ministry of Lands Parks and Housings
		Report Letter-report Wells at schools on Hornby and Denman Islands for School District 71.pdf	Oct-83	Pacific Hydrology Consultant LTD	McElhanney Engineering Services LTD
		Report Letter-report Pump testing of a well on Denman Island for School District No. 71.pdf	May-87	Pacific Hydrology Consultant LTD	McElhanney Engineering Services LTD
		Report Drinking Water Source Assessment Summary Report Denman Island Highways Yard.pdf	Oct-01	British Columbia Building Corporation	
		Report Construction and Testing of Observation Well WR-268-81 Contract No. 72 Denman Island, B.C..pdf	Jan-83	Groundwater Section Water Management Branch Ministry of Envi ronment	

Source	Study Islands	Report	Published Date	BY	FOR
		Report Completion report Drilling of water supply wells at schools on Hornby and Denman Island.pdf	Dec-83	PACIFIC HYDROLOGY CONSULTANTS LTD	School District No. 71 (Courtenay)
		Report British Columbia Buildings Corporation Denman Island Highways Yard Drinking water Field Assessment	Jul-01	British Columbia Buildings Corporation	
	Gabriola Island	Comparison of DRASTIC and DRASTIC-Fm methodologies.pdf	Mar-14	Vancouver Island University	Ministry of Forests Lands and Natural Resource Operations, West Coast Region, Nanaimo, British Columbia
		Report A Review of Groundwater Conditions on Gabriola Island.pdf	Aug-78	Groundwater Section Hydrology Division	Province of British Columbia, Ministry of the Environment, Water Investigations Branch
		Report Completion Report Pump Testing of Wells 1, 2, and 3 on Jenkins Subdivision Gabriola Island, B.C..pdf	Dec-71	W.L. Brown, P. Eng. R. A. Dakin p. Eng.	Gabriola Wildwood Status LTD
		Report Gabriola Island Final Report Assessment and Mapping of Streams of Gabriola Island 1997-98.pdf	Apr-98	Northern Aquatics	Heartlands Conservancy Society and Urban Salmon Habitat Program, Ministry

Source	Study Islands	Report	Published Date	BY	FOR
					of Environment, Lands and Parks (Fisheries Section)
		Report Gabriola Island Hydrochemical Data Worksheet 1 and 2 of 2.pdf	Map		
		Report Habitat of Groundwater Gabriola Island, British Columbia - Final Report.pdf	Jan-75	ROBINSON, ROBERTS & BROWN LTP.	Department of Lands, Forests and Water Resources, Water Resources Service, Groundwater Division
		Report Habitat of Groundwater Gabriola Island, British Columbia.pdf	Sep-72	ROBINSON, ROBERTS & BROWN LTP.	Department of Lands, Forests and Water Resources, Water Resources Service, Groundwater Division
		Report Memo Gabriola Island Community Plan, Fault Zones.pdf	Jun-79	Ministry of Environment, Groundwater section	Ministry of Environment, Water Investigation Branch
	Hornby Island	Report A Preliminary Groundwater Assessment of a Crown Land Parcel on Hornby Island, 1993.pdf	Oct-93	Groundwater Section Hydrology Branch Water Management Division	
		Report A Preliminary Review of Groundwater Conditions on Hornby Island, B.C..pdf	Oct-84	Groundwater Section, Water Management	

Source	Study Islands	Report	Published Date	BY	FOR
				Branch, Ministry of Envi ronment	
		Report Completion report Drilling of water supply wells at schools on Hornby and Denman Island.pdf	Dec-83	Pacific Hydrology Consultants Ltd	School District No. 71 (Courtenay)
		Report Contract 75 - Construction and Testing of Observation Wells, Coombs and Hornby Island, BC Well Nos. 287 and 288.pdf	Feb-85	Groundwater Section Water Management Branch	
		Report Groundwater Conditions on Hornby Island 1989 Update and Review.pdf	Aug-89	Groundwater Section, Water Management Branch, Ministry o f Environment	Groundwater Section, Water Management Branch, Ministry of Environment
		Report Groundwater Conditions on Hornby Island, British Columbia - 1989 Update and Review.pdf	Aug-89	Groundwater Section, Water Management Branch, Ministry o f Environment	Groundwater Section, Water Management Branch, Ministry of Environment
		Report Groundwater development proposed nine-hole golf course, Hornby Island, BC..pdf	Sep-89	W.L. Brown, P. Eng.	Arris Consultant LTD.
		Report Hornby Island Domestic Well Monitoring Study.pdf	Sep-10	Ministry of Environment, Water Stewardship Division Vancouver Island Regional Operations Branch	

Source	Study Islands	Report	Published Date	BY	FOR
		Report Hornby Island Groundwater Protection Pilot Project Phase II Report Draft.pdf	May-02	Eleanor N.M. Kneffel	Islands Trust and the Ministry of Water, Land & Air Protection
		Report Hornby Island Groundwater Protection Project Phase III Final Progress Report.pdf	Mar-04	Ron McMurtrie, Project Coordinator	Islands Trust and Regional District of Comox-Strathcona
		Report Letter Sorensen well test - Lot A, Plan 21814, Hornby Island.pdf	Apr-80	McElhanney Surveying & Engineering Ltd	Mr. E. Livingstone,
		Report Memo Preliminary Assessment of Groundwater Conditions Vacant Crown Land, Hornby Island.pdf	Mar-92	BC Environment Water Management Division	BC Environment Water Management Division
		Report Memo Site Selection, Tribune Bay Park, Hornby Island.pdf	Jul-79	BC Environment, Groundwater Section, Hydrology Division	BC Environment, Groundwater Section, Hydrology Division
		Report Preliminary Groundwater Investigation of Hornby Island.pdf	Jun-76	Groundwater Section	Groundwater Section, Hydrology Devieion
		Report Preliminary Notes on Groundwater of Hornby Island.pdf	Sep-74	E. Thorn	

Source	Report	Published Date	BY	FOR
Other Sources	HYDROLOGY ASSESSMENT HORNBY ISLAND FIRE HALL	Jul-15	H2O Environmental Ltd	Simcic and Uhrich Architects
	A PRELIMINARY GROUNDWATER ASSESSMENT OF A CROWN LAND PARCEL ON HORNBY ISLAND - 1993	Oct-93	Groundwater Section Hydrology Branch, Water Management Division	
	Geochemical evolution of groundwater on Saturna Island, British Columbia	2001	D.M. Allen.1 Department of Earth Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada. M. Suchy. Dillon Consulting, Box 978, Iqaluit, Nunavut X0A 0H0, Canada.	
	Groundwater Recharge Model for Gabriola Island	Dec-16	R. Burgess and D.M. Allen Department of Earth Sciences, Simon Fraser University	Regional District of Nanaimo
	Hydrogeology of Coats Marsh, Gabriola Island (2015—2020)			
	Hydrogeological Conceptual Model	Apr-13		
	Results of the Groundwater Geochemistry Study on Hornby Island, British Columbia	Apr-02	D.M. Allen and G.P. Matsuo Department of Earth Sciences Simon Fraser University	Islands Trust Victoria, B.C.

Source	**Report**	**Published Date**	**BY**	**FOR**
	The Hydrogeology of Salt Spring Island	Jan-15	Department of Earth Sciences Simon Fraser University	
	Water Budget Project : RDN Phase One (Gabriola, DeCourcy& Mudge Islans)	Apr-13	SRK Consulting (Canada) Inc	Regional Destrict of Nanaimo
	Characterizing Recharge to Fractured Bedrock in a Temperate Climate	2010	Canterbury University	
	Trends in groundwater levels in British Columbia	May-13	Simon Fraser University	
	Denman and Hornby Islands, Water Allocation Palns	Jul-94	Regional water management	Province Of British Columbia, Ministry Of Environment, Lands And Parks, Vancouver Island Region

Additionally, we have reviewed the following studies and sources of information:

- A Review of Groundwater Conditions Galiano Island, MoE Water Management Branch, 1983
- Pumping and Sampling of Obs. well 258 communication, MoE Water Management Branch, 1993
- Assessment of Groundwater Availability and Quality, MoE Water Management Branch, 1998
- Georgina Water Works Review, MoE Water Investigations Branch, 1968

- Drilling Construction and Testing of Observation Well WR 258-80, MoE Inventory and Engineering Branch, 1980
- Mayne Island Wells Field Study, MoE Water Management Branch, 1986
- Groundwater Potential Magic Lake Estates, MoE Water Management Branch, 1977
- Port Washington Watershed Analysis, MoE Water Investigations Branch, 1977
- Geology of North and South Pender Island, unknown, unknown (post 2002)
- Galiano Groundwater Study, Waterline Resources Inc., 2011
- Southern Gulf Islands Groundwater Sustainability Strategy, Islands Trust, 2019
- Ecocat – Provincial Database
- Henderson, James D. An ecosystem approach to groundwater management in the Gulf Islands. Calgary, 1997.