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2019 Wetlands Delineation Study

Final Report

C-CORE Document Number
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Revision History

Version	Name	Date Of Changes	Comments
1.0	Sherry Warren Masoud Mahdianpari Thomas Puestow	03/31/2020	Submitted to Client

Distribution List

Company	Name	Number Of Copies
City of St. John's	Dave Wadden	1 electronic submission

Table of Contents

List of Tables

List of Figures

Executive Summary

This project generated the first comprehensive wetlands inventory for the City of St. John's using satellite imagery. The investigation comprised the delineation and classification of wetlands using remote sensing and the generation of a comprehensive spatial database fully compatible with the City's existing information infrastructure to store all relevant information. The following geospatial information products were generated during this study:

- A GIS data layer containing polygons of all relevant wetlands extracted from satellite imagery;
- Annotated image maps showing boundaries of wetlands at a scale of 1:25,000; and
- A GIS data layer showing connectivity between wetlands.

The wetlands inventory was generated using very-high-resolution (VHR) WorldView-4 and GeoEye-1 satellite imagery captured in August 2017 and 2018. The imagery was acquired with a nominal spatial resolution of one meter in four spectral bands (i.e. blue, green, red and near-infrared). The area of interest (AOI) comprises the municipal boundary of the City of St. John's as well as a buffer of 1 km around the municipal boundary to capture wetlands partially located within the City's jurisdiction.

The extraction of wetlands from satellite imagery required the collection of reference data for algorithm training and validation. Reference polygons of wetlands classes and uplands land cover categories were collected in the field and extracted from the imagery by means of visual interpretation. Wetlands were delineated using an object-oriented approach comprising image segmentation and classification. Wetlands Connectivity was determined by using spatial tools to derive flow paths from LiDAR data. Only wetlands covering at least 100 m^2 were retained. The final products were edited for consistency and quality controlled.

The analysis revealed the presence of 3564 individual areas of contiguous wetlands greater than 100 m^2 in the AOI. Wetlands were identified and differentiated from non-wetland land cover categories with an accuracy of 95%. When considering separate wetlands categories, the overall classification accuracy was slightly lower (91%) due to the similarities in vegetation composition in certain types of wetland.

The wetlands inventory is fully compatible with the City's existing information infrastructure and ready to be used in support of municipal decision-making and operations. Specifically, the inventory provides baseline information on the location, type and number of wetlands in a given area within the stated limits of uncertainty. In the event that a more detailed evaluation of the importance of wetlands is required, the inventory serves as a starting point for detailed field-based methods for delineation and functional assessment such as the Wetlands Ecosystem Services Protocol (WESP). Given the inherent dynamic nature of wetlands, it is recommended to evaluate land cover change in the AOI on a periodical basis. The most cost-effective approach comprises the use of multi-temporal satellite imagery in a change detection process. This analysis will highlight areas of significant change, which could subsequently be subjected to a more detailed investigation to determine the nature and impact of the change. Regular change detection should be considered every five years.

1 Introduction

This report describes the objectives, approach and results of a recent study to delineate wetlands using remote sensing technologies for the City of St. John's.

Wetlands are natural infrastructures that facilitate the interactions of soils, water, plants, and animals, thus making them one of the most productive ecosystems (Mahdianpari et al., 2017b; Mohammadimanesh et al., 2019). They play an important role in hydrological and biogeochemical cycles, significantly contribute to wildlife habitat, and offer several environmental functions, such as supporting stream flow, cooling and purifying water, sediment retention and stabilization, carbon sequestration, soil and water conservation (Mahdianpari et al., 2017a). These functions are vital in maintaining and well-being of regional, national, and global ecosystems and economics.

At the level of municipalities, an accurate knowledge of the location, type, and spatial extent of urban wetlands is critical to balance the need for development with the necessity to preserve the integrity of wetlands complexes. Decisions by municipal land use authorities have a direct impact on the aesthetics of the neighbourhood, the financial viability of a development, the health of the community, habitat, food security, and the capability of land to retain storm water. There is an increase in public awareness, engagement and environmental stewardship, and municipal councils and their stakeholders wish to be informed in more detail as to why an area can be developed, what mitigation measures may need to be put in place, which areas may need to be protected from development, or why an area is to be managed for conservation purposes or for public use.

This investigation was carried out to aid the City of St. John's in generating a comprehensive inventory of wetlands within its jurisdiction and relevant adjacent areas. It comprised the delineation and classification of wetlands using remote sensing and the generation of a comprehensive spatial database fully compatible with the City's existing information infrastructure to store all relevant information. The following geospatial information products were generated during this study:

- A GIS data layer containing polygons of all relevant wetlands extracted from satellite imagery;
- Annotated image maps showing boundaries of wetlands at a scale of 1:25,000; and
- A GIS data layer showing connectivity between wetlands.

2 Methodology

The wetlands inventory was generated using very-high-resolution (VHR) WorldView-4 and GeoEye-1 satellite imagery captured in August 2017 and 2018. The imagery was acquired with a nominal spatial resolution of one meter in four spectral bands (i.e. blue, green, red and near-infrared). The area of interest (AOI) comprises the municipal boundary of the City of St. John's as well as a buffer of 1 km around the municipal boundary to capture wetlands partially located within the City's jurisdiction. The satellite image coverage and AOI are presented in Figure 1.

Figure 1. Satellite imagery and AOI (green polygon).

Generating the wetlands inventory from VHR satellite imagery required the execution of the following major tasks:

- Identify and collect relevant ancillary data;
- Collect reference data;
- Prepare data for analysis;
- Delineate wetlands; and
- Generate final deliverables.

The extraction of wetlands from satellite imagery required the collection of reference data for algorithm training and validation. Reference polygons of wetlands classes and uplands land cover categories were collected as follows:

- Data from 111 wetlands sites previously visited in 2015 and 2017 (Mahdianpari et al., 2019);
- During a dedicated field campaign within the context of the current investigation, a total of 77 wetlands locations were visited; and
- 244 wetlands polygons and 395 polygons of uplands (i.e. land cover other than wetlands) were extracted from the satellite imagery by means of visual interpretation for areas not easily accessible in the field.

The field campaign focused on areas not covered during the 2015/2017 field visits, such as Shea Heights, the Foxtrap Access Road and the Goulds. The week-long field campaign was executed during late September 2019. Figure 2 shows the locations of all sites visited in 2015, 2017 and 2019.

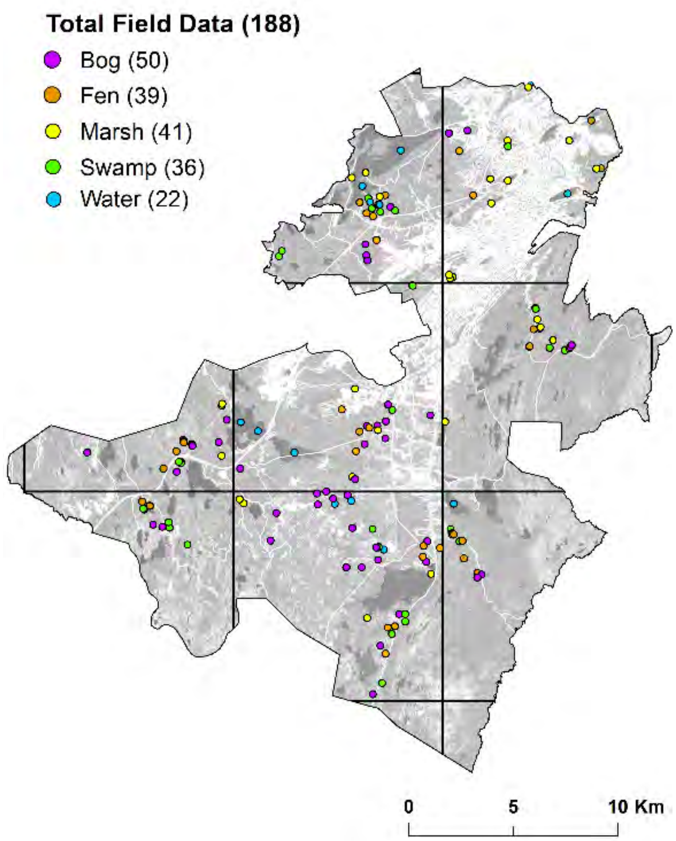

Figure 2. Locations of field data collection (2015, 2017 and 2019).

The collection of field data was governed by C-CORE's protocols for collecting ground-truth data. All wetlands were labelled using the Canadian Wetlands Classification System (Warner and Rubec, 1997). GPS co-ordinates, photographs and field notes were collected to facilitate wetlands training data preparation before classification. The major wetlands categories used include *Bog*, *Fen*, *Marsh*, *Swamp* and *Water*.

Where required, additional sub-categories (e.g. treed, shrub-covered) were defined to ensure the collection of homogeneous and representative training cases. Upon delineation, the sub-categories were subsequently merged with the appropriate major wetlands types prior to the generation of the final wetlands coverage. In addition to wetlands classes, uplands land cover categories (e.g., forest, sealed surfaces and urban green spaces) were defined to achieve an exhaustive classification of the imagery while minimizing misclassification errors. All reference datasets were geocoded and stored in a geodatabase. Statistical sampling was used to divide the reference polygons into separate datasets to be used for algorithm training (70%) and validation (30%).

During the data preparation and pre-processing stage, all satellite imagery was geometrically, radiometrically and atmospherically corrected (Mahdianpari et al., 2019). This also included the computation of additional image variables, such as the normalized difference vegetation index (NDVI), Enhanced Vegetation Index (EVI), and Green/Red Vegetation Index (GRVI). Other predictor variables included slope, digital surface models (DSM), and canopy height extracted from the LiDAR digital elevation models (DEM). All datasets were screened for quality and consistency according to C-CORE's quality assurance (QA) process.

Wetlands were delineated using an object-oriented approach comprising image segmentation and classification (Benz et al., 2004). During segmentation, the images were partitioned into groups of homogeneous pixels. For each segment, a variety of spatial, spectral and contextual characteristics (e.g., size, shape, colour, texture and arrangement) were computed in an effort to mimic the human interpretation process. Using the training data with verified wetlands information, the statistical characteristics of each predictor variable were analyzed with respect to its potential to contribute to the discrimination and delineation of wetlands. Supervised image classification was used to generate a data layer of wetlands types.

Wetlands Connectivity was determined by using spatial tools to derive flow paths from LiDAR data. These flow paths represent surface water connectivity between wetlands, waterbodies, rivers, and streams. An appropriate arrow symbology was selected to represent the direction of water movement. Existing GIS layers of waterways were overlaid on recent imagery and examined for completeness, consistency and quality. Any missing waterways were added and appropriately identified in the corresponding attribute data. Only wetlands covering at least 100 m^2 were retained. The final products were edited for consistency and quality controlled according to C-CORE's QA processes. Open geospatial consortium (OGC) metadata guidelines were followed for all geospatial datasets generated in the project. The final deliverables were generated in ArcGIS shapefile format using a NAD 1983 Modified Transverse Mercator (MTM) Zone 1 projection.

The accuracy assessments were conducted by comparing the classification map to the ecological ground truth data, held back for validation purpose, using confusion matrices. The accuracy of final product is reported in terms of overall accuracy, errors of commission and errors of omission (Congalton, 1991).

3 Results

The analysis revealed the presence of 3564 individual areas of contiguous wetlands greater than 100 m^2 in the AOI. An overview of area coverage of wetlands is presented in Table 1. With the exception of open water, bogs and fens are the most common type of wetlands in the area, with fens accounting for almost half (47%) of the area covered by vegetated wetlands. Swamps and marshes are comparatively rare, with a combined total area coverage of 10.5 km^2. The relative scarcity of marshes reflects the findings of previous assessments (Buchanan and Houlihan, 1987).

Table 1. Area coverage of wetlands in the AOI.

Wetland Category	Area Coverage [%]	Area Coverage [km^2]
Bog	18.0	13.9
Fen	28.2	21.8
Swamp	7.9	6.1
Marsh	5.6	4.4
Open Water	40.3	31.1
Total	**100.0**	**77.1**

Figure 3 shows the size distribution of individual wetlands across the AOI. The majority of wetlands are less than 5000 m^2 in size. Less than 25% of all individual wetland areas are greater than 10,000 m^2 (1 ha).

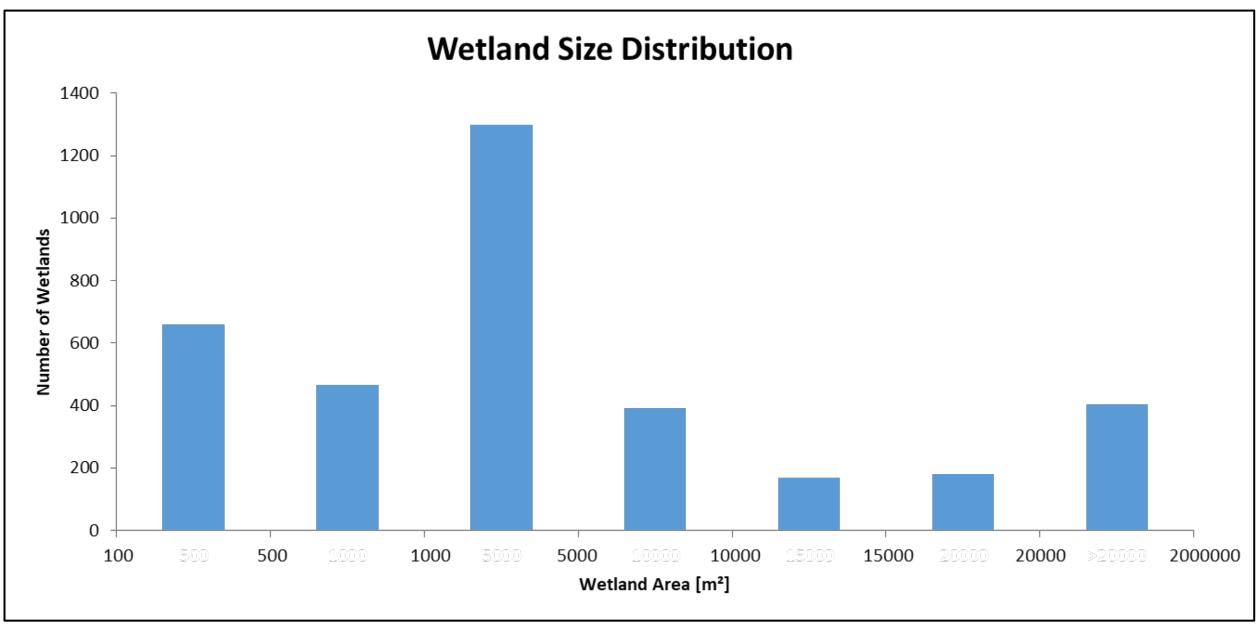

Figure 3. Wetlands size distribution.

An example of the wetlands classification superimposed over a WorldView-4 satellite image is presented in Figure 4. Individual maps showing wetlands overlaid on aerial photography at a scale of 1:25,000 are presented in Appendix A.

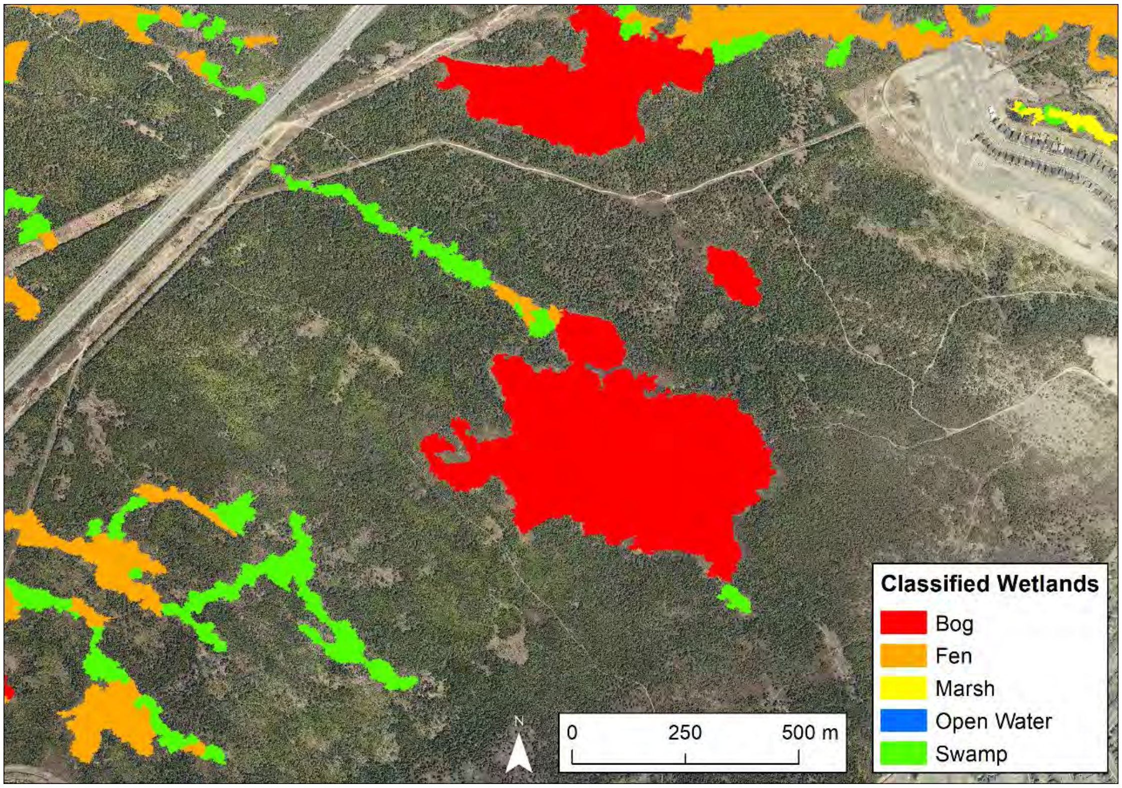

Figure 4. Example of wetlands classification overlaid on WorldView-4 imagery.

The accuracy of the classification was assessed by comparing the classification result to the reference dataset as described in Section 3. The results of the accuracy assessment are presented in Table 2.

Table 2. Accuracy and classification errors.

	Reference Data							
	Overall Accuracy: 91%	**Bog**	**Fen**	**Marsh**	**Swamp**	**Water**	**Upland**	**Error of Commission [%]**
Classification	**Bog**	**21**	2	0	0	0	1	**12**
	Fen	2	**31**	0	1	0	1	**11**
	Marsh	0	1	**12**	0	0	0	**8**
	Swamp	1	2	0	**24**	0	4	**23**
	Water	0	0	1	0	**22**	0	**4**
	Upland	0	1	0	5	0	**116**	**5**
	Error of Omission [%]	**12**	**16**	**8**	**20**	**0**	**5**	

For the purpose of this analysis, all non-wetland land cover classes were combined in a single *Upland* category. When considering separate wetlands classes as well as *Upland*, an overall classification accuracy of 91% was achieved. When all wetlands categories are combined, the accuracy with which wetlands can be differentiated from uplands vegetation increases to 95%, with a classification error of 5%.

Classification errors for individual categories ranged from 4% for *Water* to 23% for *Swamp*. The observed errors of omission and commission for *Swamp* are caused by the confusion with *Upland*. This is not surprising, as swamps are defined as forested wetlands, and the degree of wetness at the time of image acquisition cannot be extracted reliably from remotely sensed data alone. Swamps also occur as a transition between other types of wetlands classes and dry upland. Similarly, swamps are usually found in transition between waterbodies, including rivers and streams and dry upland.

The largest confusion between wetlands categories are observed for *Bog* and *Fen*, with classification errors ranging from 11 to 16%. This is again expected, as many wetlands in the AOI exhibit different stages of transition from fen-like to bog-like vegetation communities, and both categories often have similar spectral signatures.

Another source of confusion arises from the transitional nature of wetlands ecosystems. Wetland boundaries are not visible as obvious lines of demarcation in the landscape, but rather, one wetlands habitat may gradually transition into another type of wetland or upland. Not only are the boundaries of wetlands inherently fuzzy, but they can change over time, be subject to seasonal cycles or alter in response to specific weather conditions (Calhoun et al., 2017; Zedler, 2003). Depending on the vegetation composition and type of wetland, the accurate delineation of wetlands can be challenging even in the field.

4 Conclusion and Recommendations

This project generated the first comprehensive wetlands inventory for the City of St. John's using satellite imagery. More than 3000 unique wetlands were identified and differentiated from non-wetland land cover categories with an accuracy of 95%. In addition, the connectivity between wetlands was captured and the existing spatial dataset of streams was updated.

The wetlands inventory is fully compatible with the City's existing information infrastructure and ready to be used in support of municipal decision-making and operations. Specifically, the inventory provides baseline information on the location, type and number of wetlands in a given area within the stated limits of uncertainty.

In the event that a more detailed evaluation of the importance of wetlands is required, the inventory serves as a starting point for detailed field-based methods for delineation and functional assessment such as the Wetlands Ecosystem Services Protocol (WESP).

Given the inherent dynamic nature of wetlands, it is recommended to evaluate land cover change in the AOI on a periodical basis. The most cost-effective approach comprises the use of multi-temporal satellite imagery in a change detection process. This analysis will highlight areas of significant change, which could subsequently be subjected to a more detailed investigation to determine the nature and impact of the change. Regular change detection should be considered every five years.

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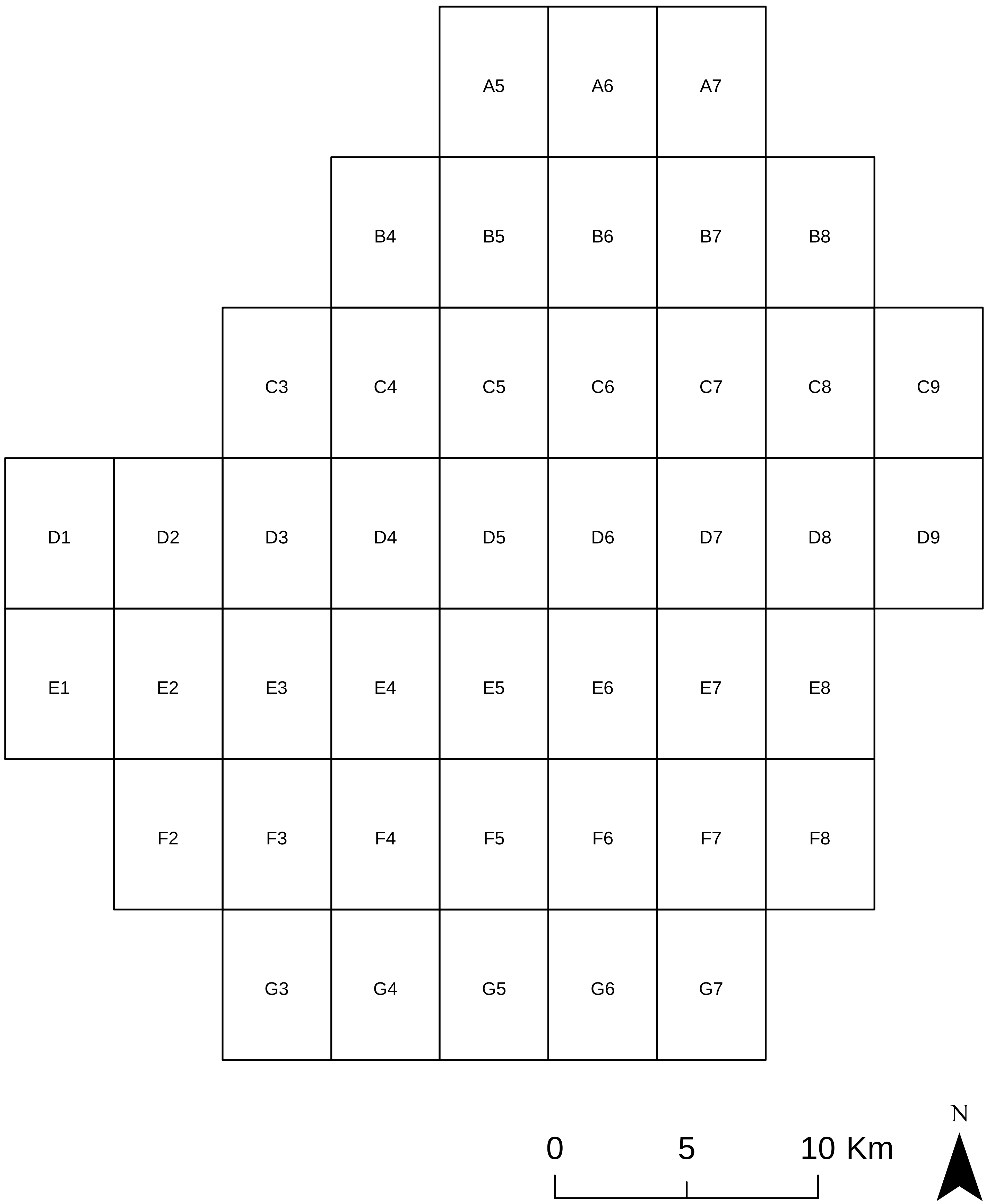
Appendix A: Wetlands Inventory Maps - 1:25,000

1: 25,000 Wetlands Inventory Index (44 grids)



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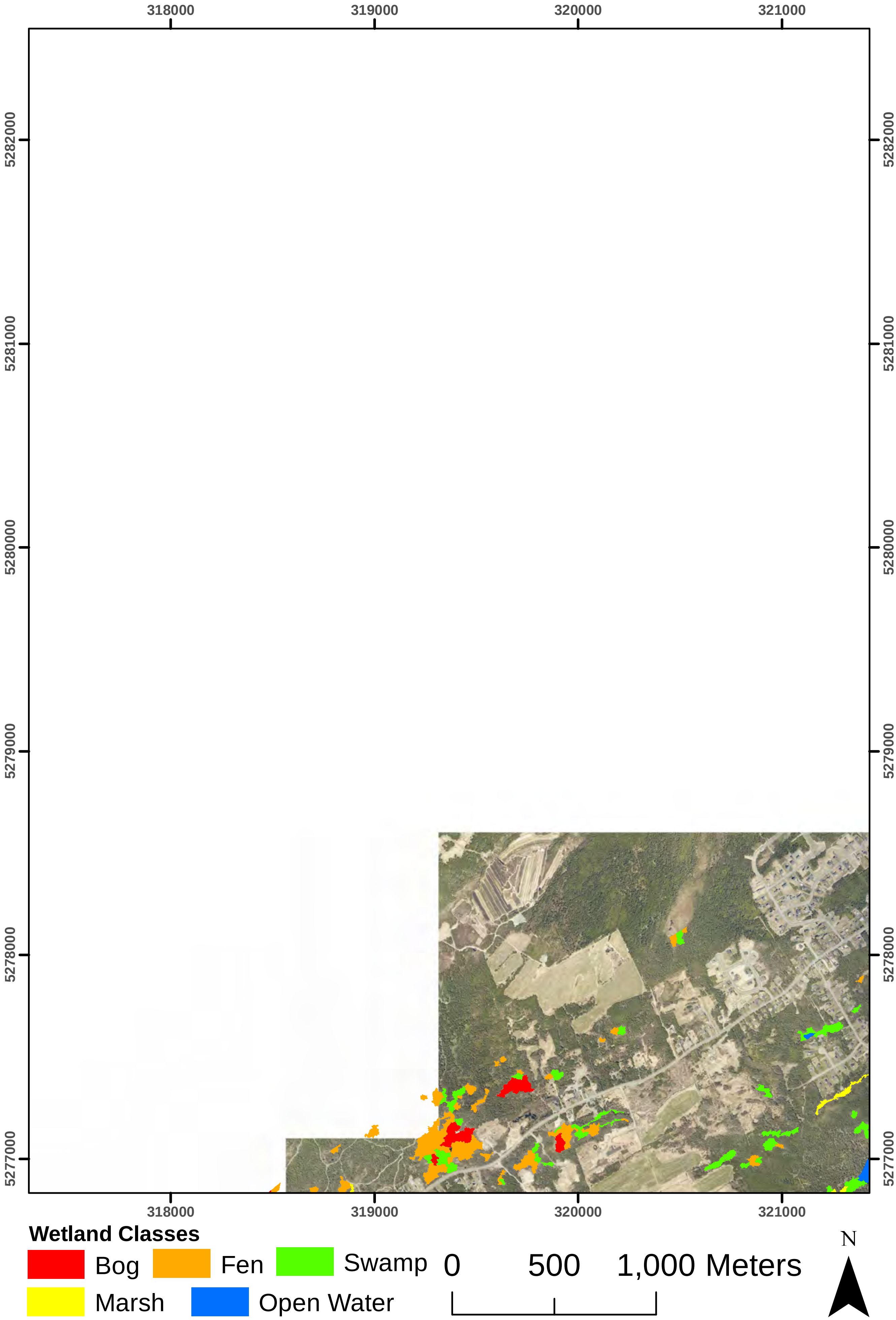
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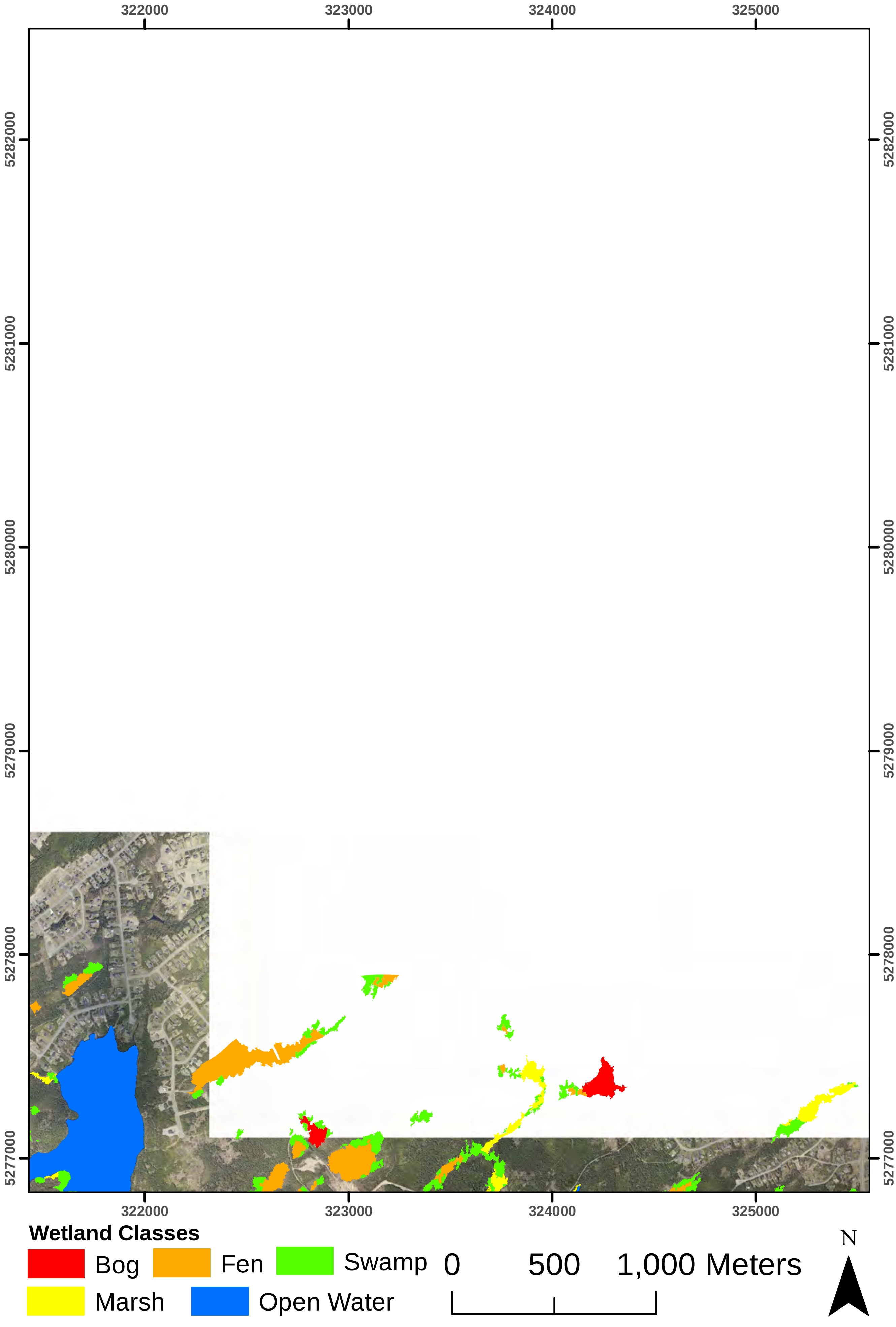

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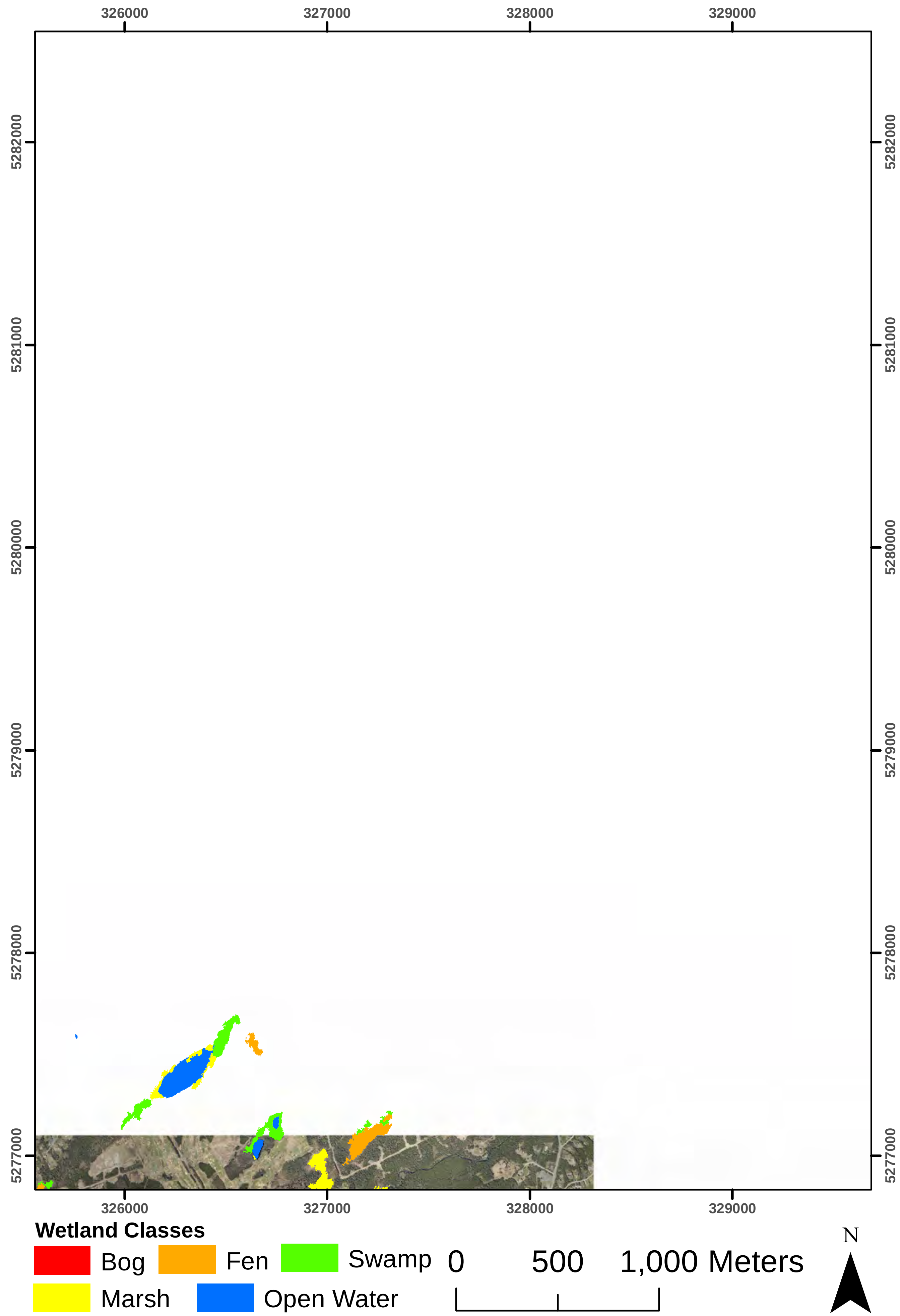
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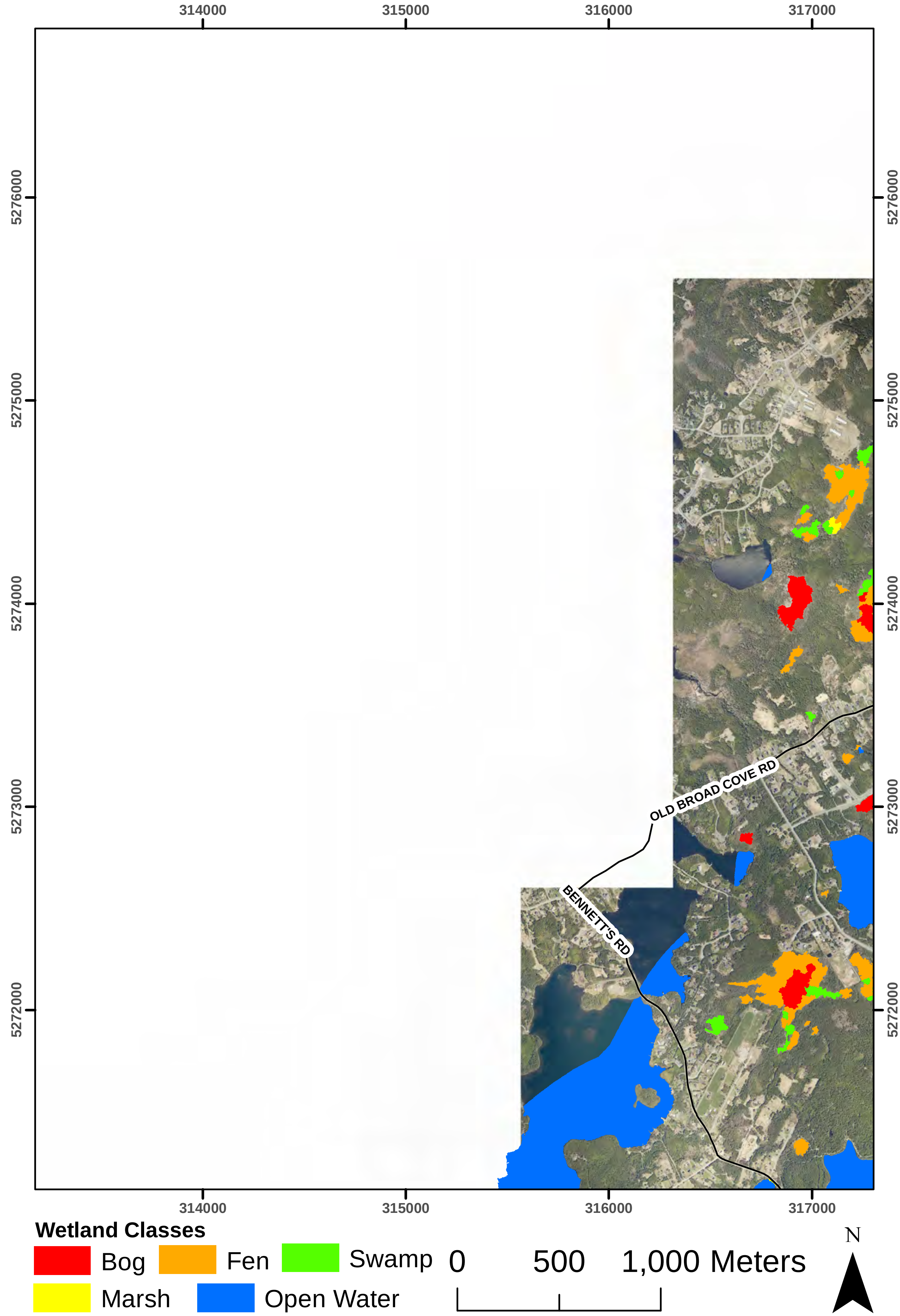

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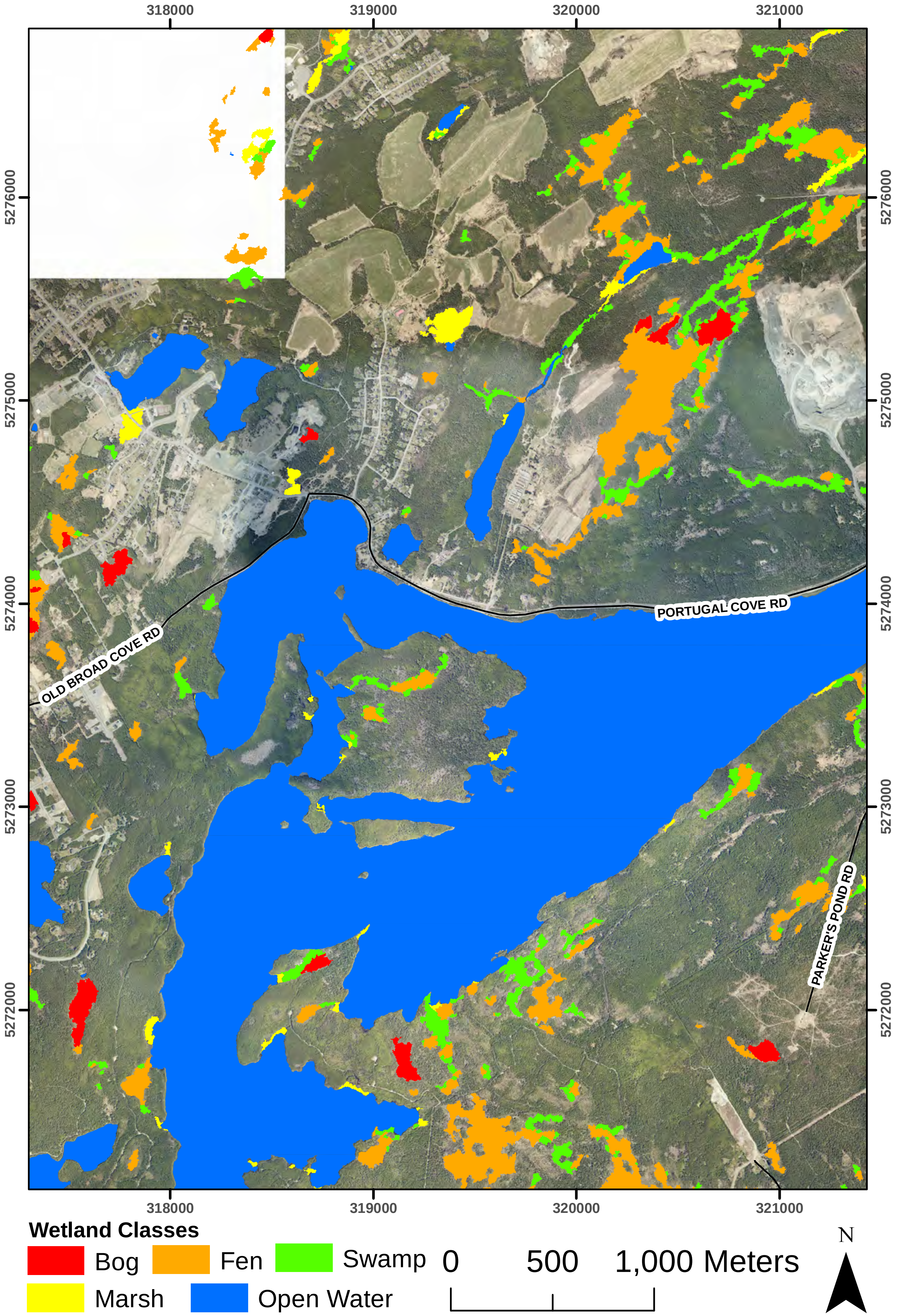
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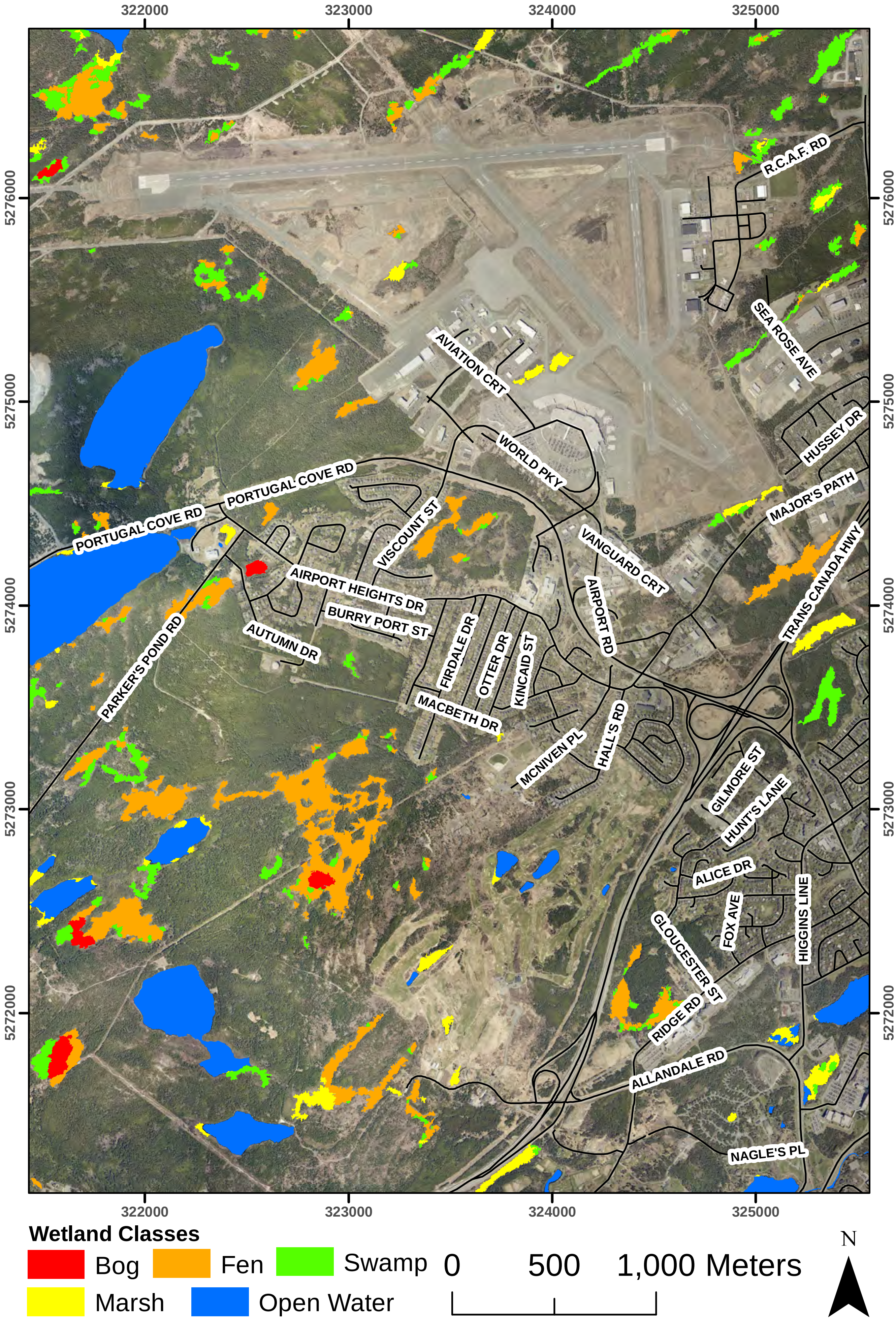

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BURRY PORT ST
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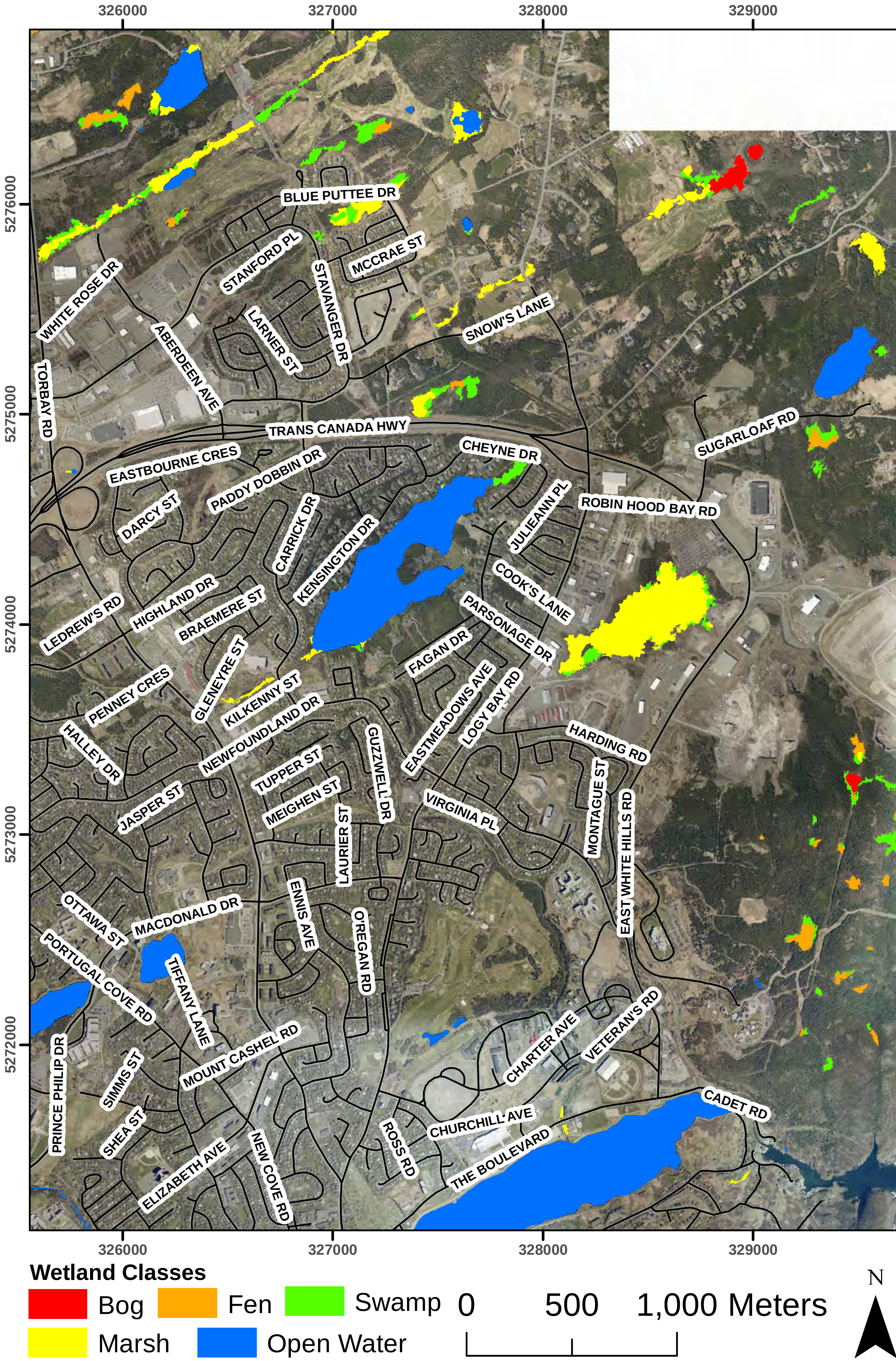
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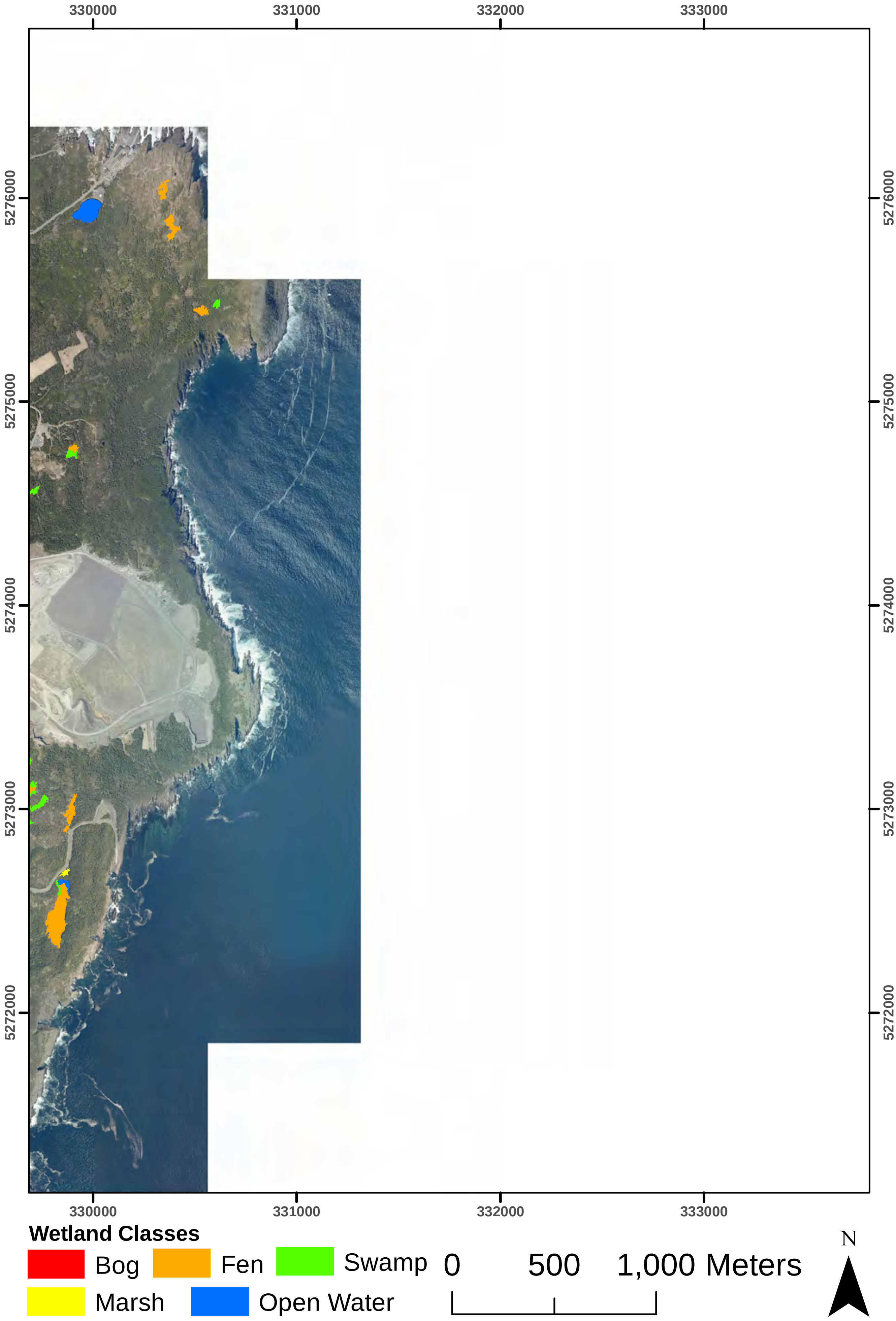
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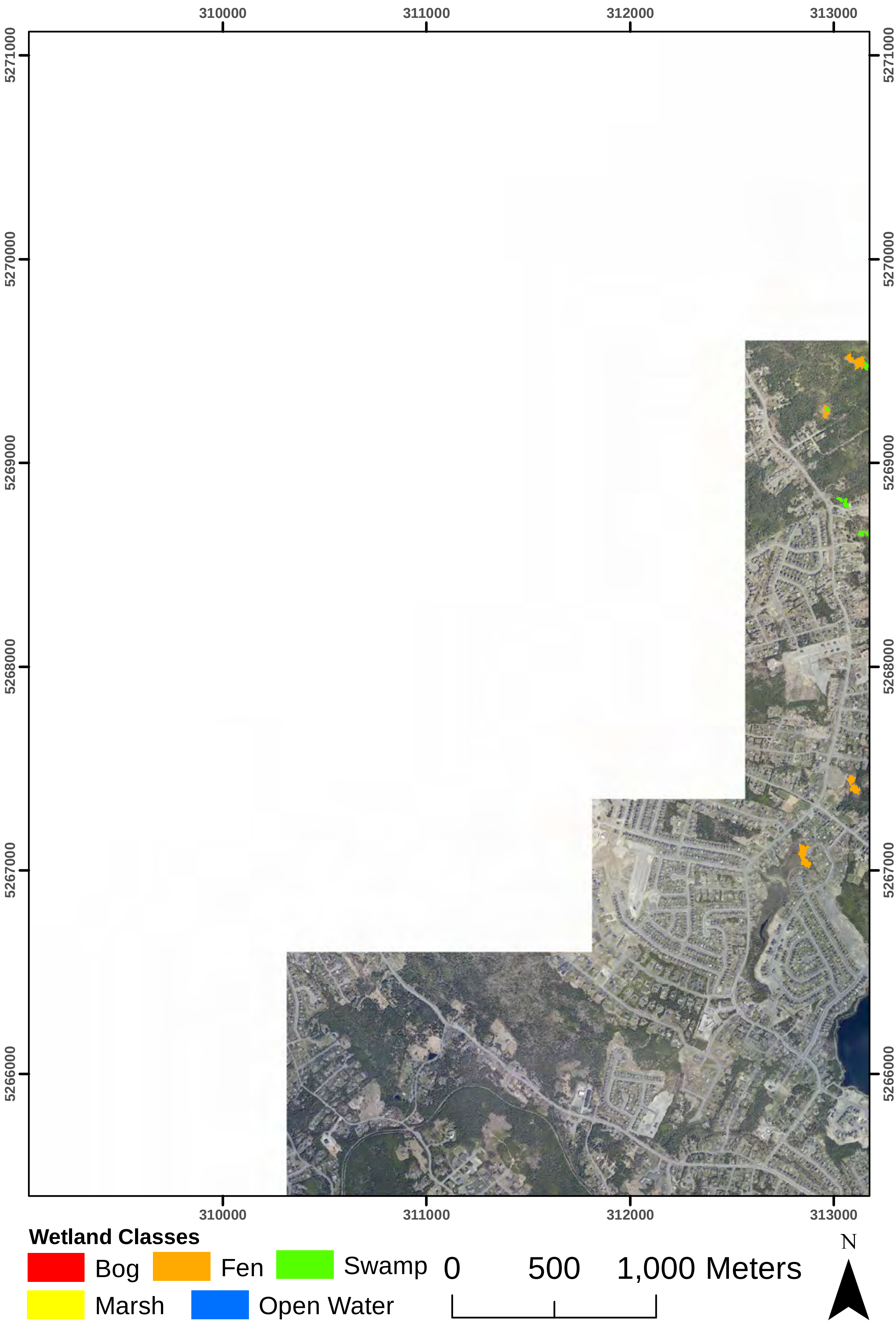

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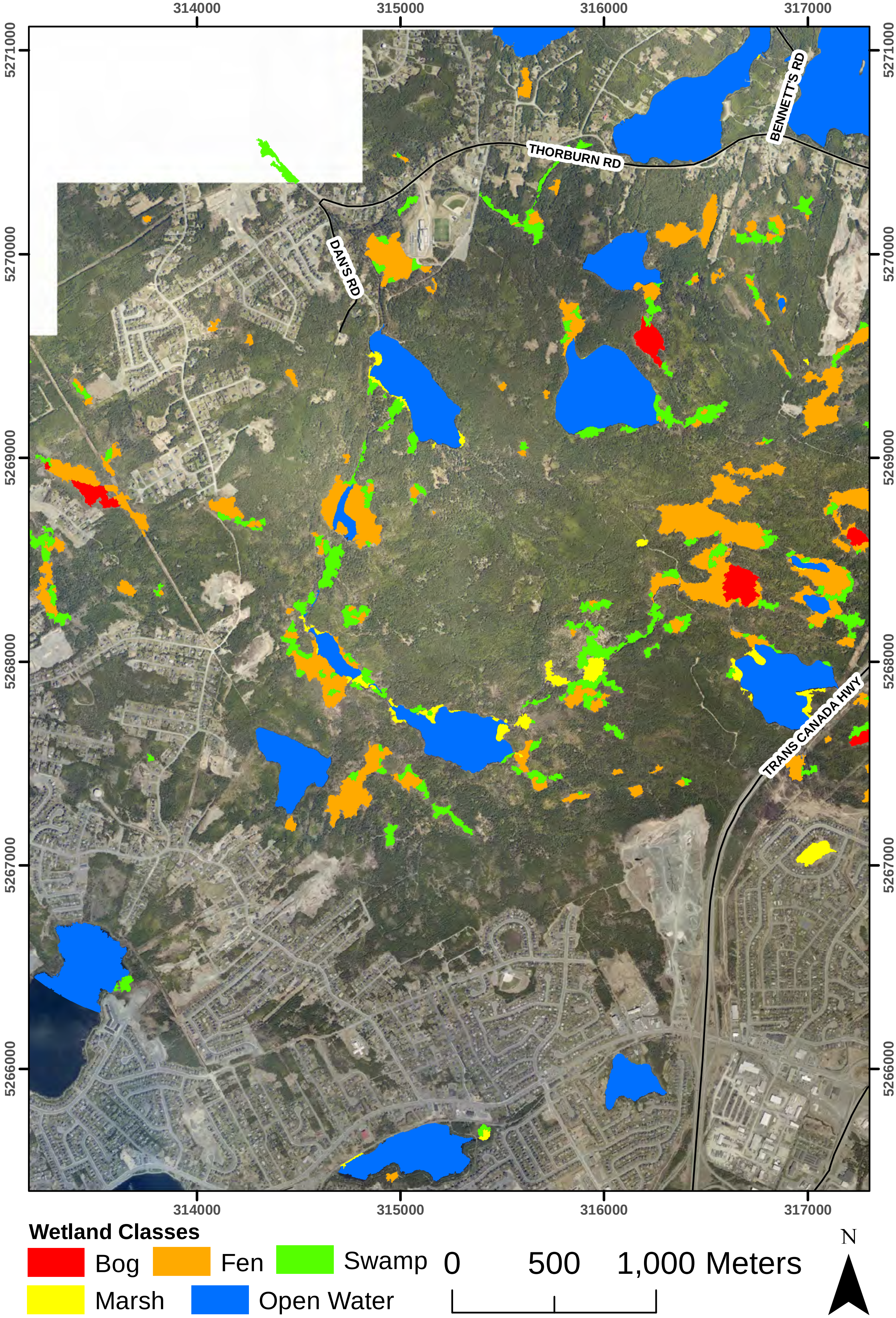
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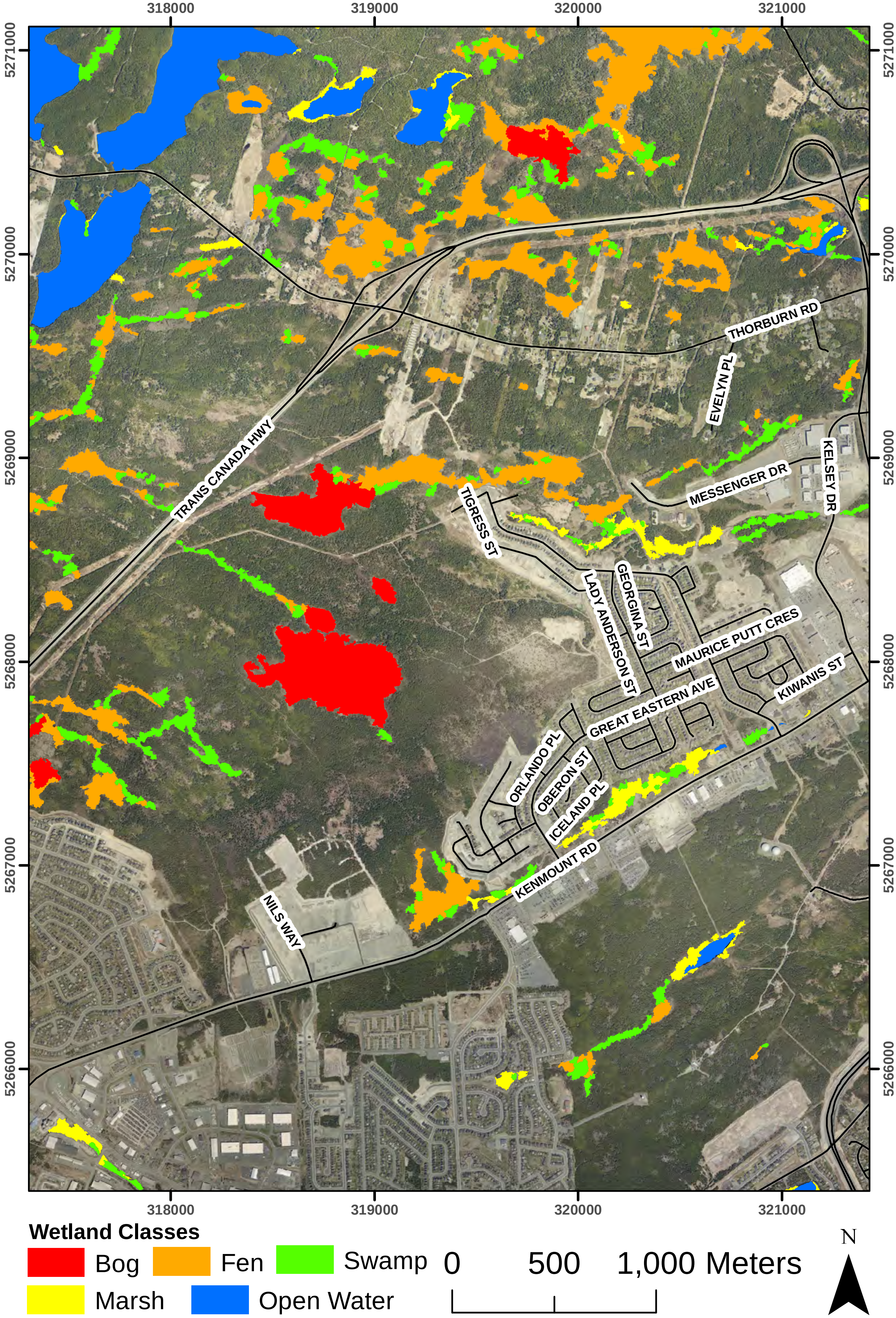
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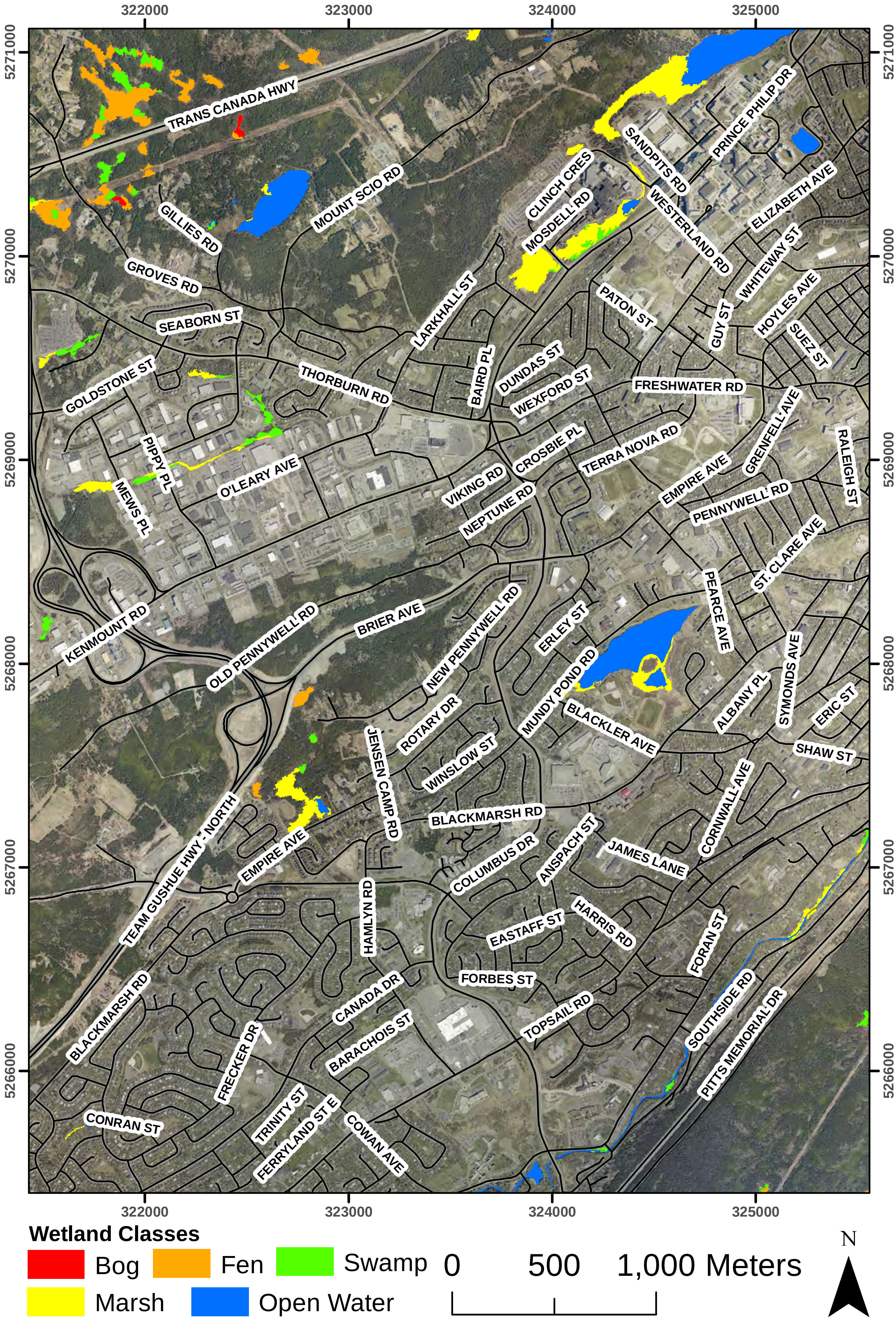
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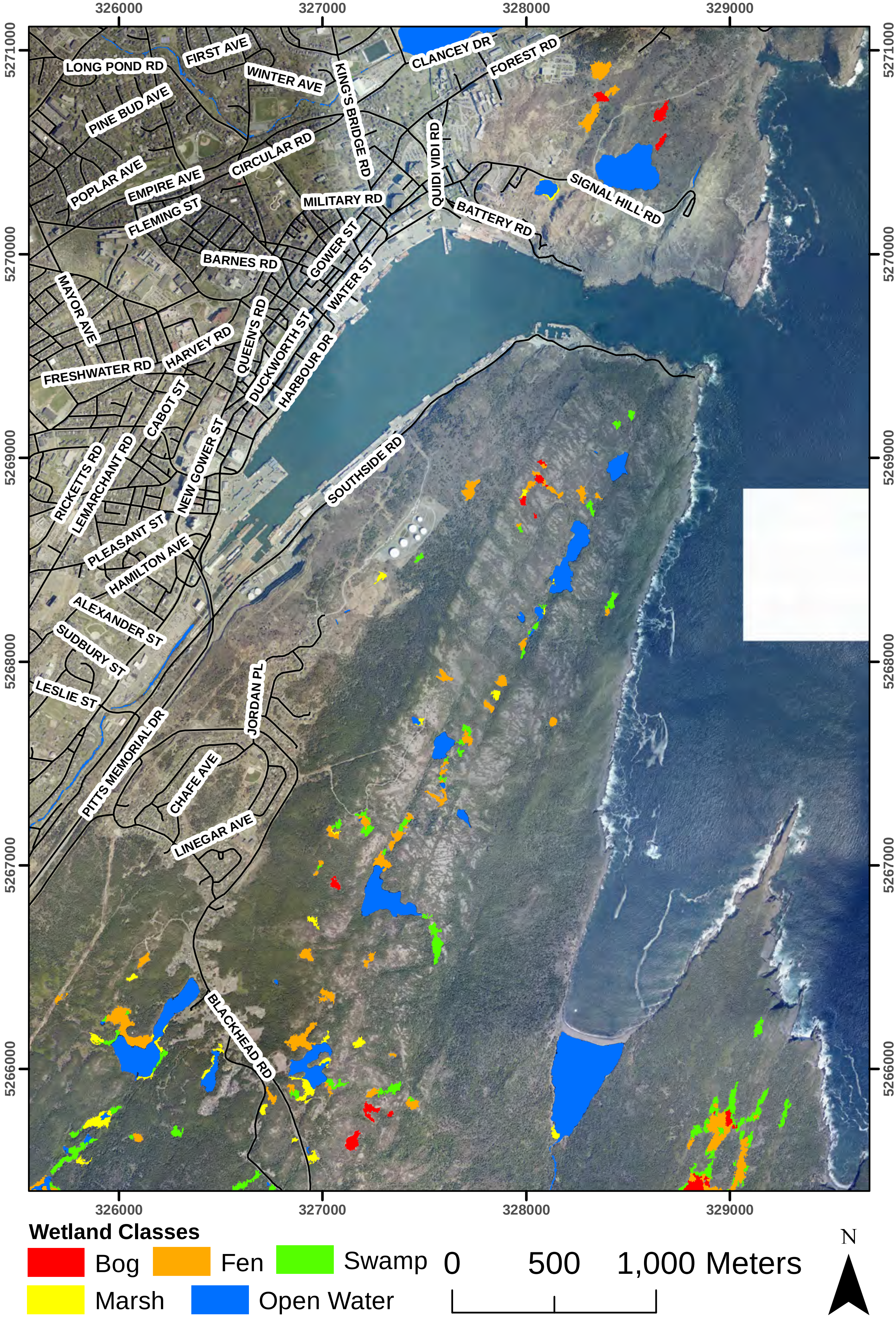
5266000
TRANS CANADA HWY
MOUNT SCIO RD
GILLIES RD
GROVES RD
SEABORN ST
GOLDSTONE ST
THORBURN RD
O'LEARY AVE
PIPPY PL
MEWS PL
KENMOUNT RD
OLD PENNYWELL RD
BRIER AVE
TEAM GUSHUE HWY - NORTH
EMPIRE AVE
BLACKMARSH RD
CONRAN ST
FRECKER DR
TRINITY ST
FERRYLAND ST E
COWAN AVE
BARACHOIS ST
CANADA DR
HAMLYN RD
JENSEN CAMP RD
ROTARY DR
WINSLOW ST
NEW PENNYWELL RD
LARKHALL ST
BAIRD PL
DUNDAS ST
WEXFORD ST
CLINCH CRES
MOSDELL RD
SANDPITS RD
WESTERLAND RD
PRINCE PHILIP DR
ELIZABETH AVE
WHITEWAY ST
HOYLES AVE
SUEZ ST
GUY ST
PATON ST
FRESHWATER RD
GRENFELL AVE
RALEIGH ST
TERRA NOVA RD
CROSBIE PL
VIKING RD
NEPTUNE RD
EMPIRE AVE
PENNYWELL RD
ST. CLARE AVE
PEARCE AVE
ERLEY ST
MUNDY POND RD
BLACKLER AVE
ALBANY PL
SYMONDS AVE
ERIC ST
SHAW ST
CORNWALL AVE
BLACKMARSH RD
COLUMBUS DR
ANSPACH ST
JAMES LANE
HARRIS RD
EASTAFF ST
FORBES ST
TOPSAIL RD
FORAN ST
SOUTHSIDE RD
PITTS MEMORIAL DR
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0 500 1,000 Meters
N

C7



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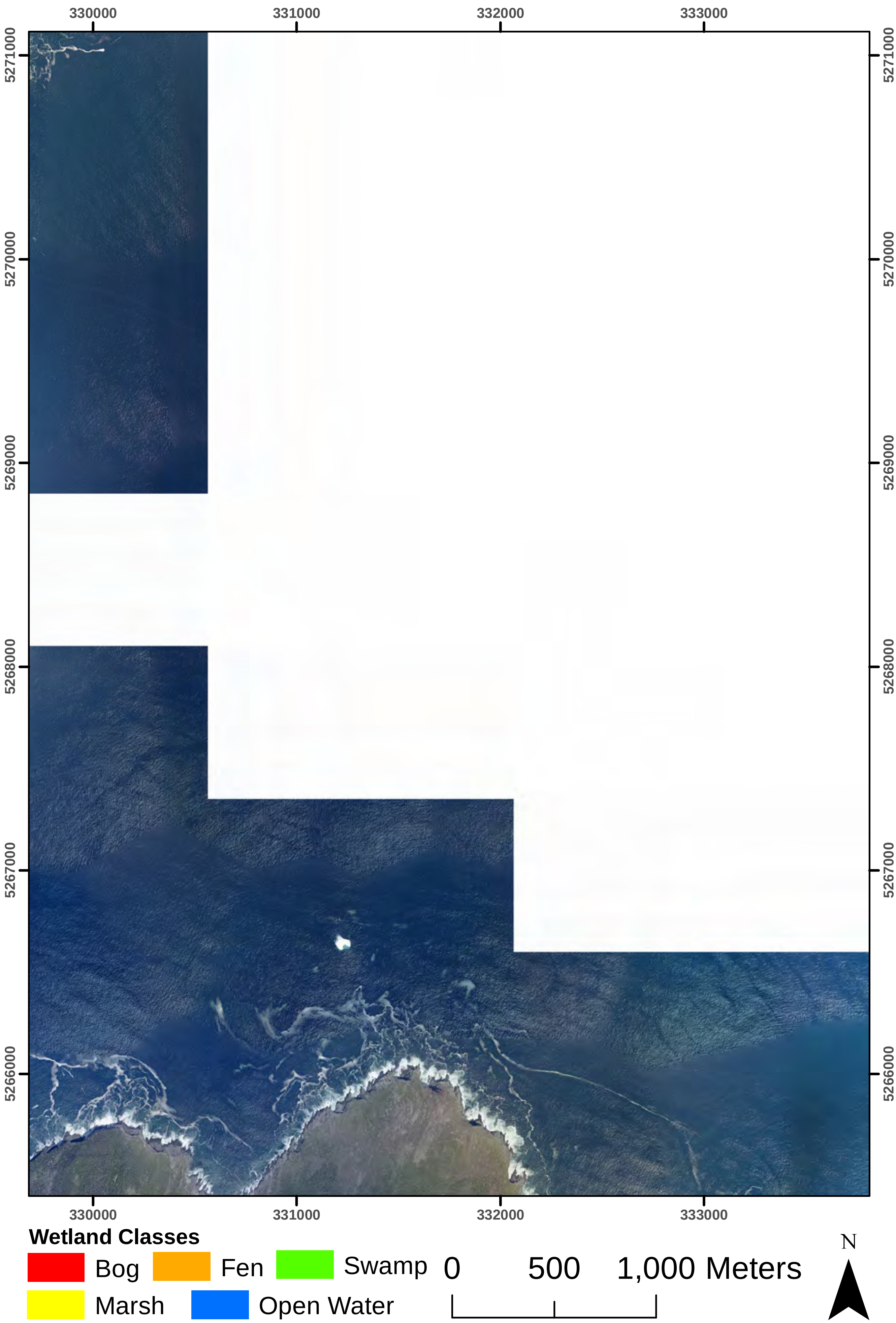
LONG POND RD
FIRST AVE
WINTER AVE
KING'S BRIDGE RD
CLANCEY DR
FOREST RD
PINE BUD AVE
CIRCULAR RD
QUIDI VIDI RD
POPLAR AVE
EMPIRE AVE
MILITARY RD
SIGNAL HILL RD
FLEMING ST
BATTERY RD
BARNES RD
GOWER ST
WATER ST
MAYOR AVE
QUEEN'S RD
DUCKWORTH ST
HARBOUR DR
HARVEY RD
FRESHWATER RD
CABOT ST
NEW GOWER ST
RICKETTS RD
LEMARCHANT RD
SOUTHSIDE RD
PLEASANT ST
HAMILTON AVE
ALEXANDER ST
SUDBURY ST
LESLIE ST
JORDAN PL
PITTS MEMORIAL DR
CHAFE AVE
LINEGAR AVE
BLACKHEAD RD
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

C8



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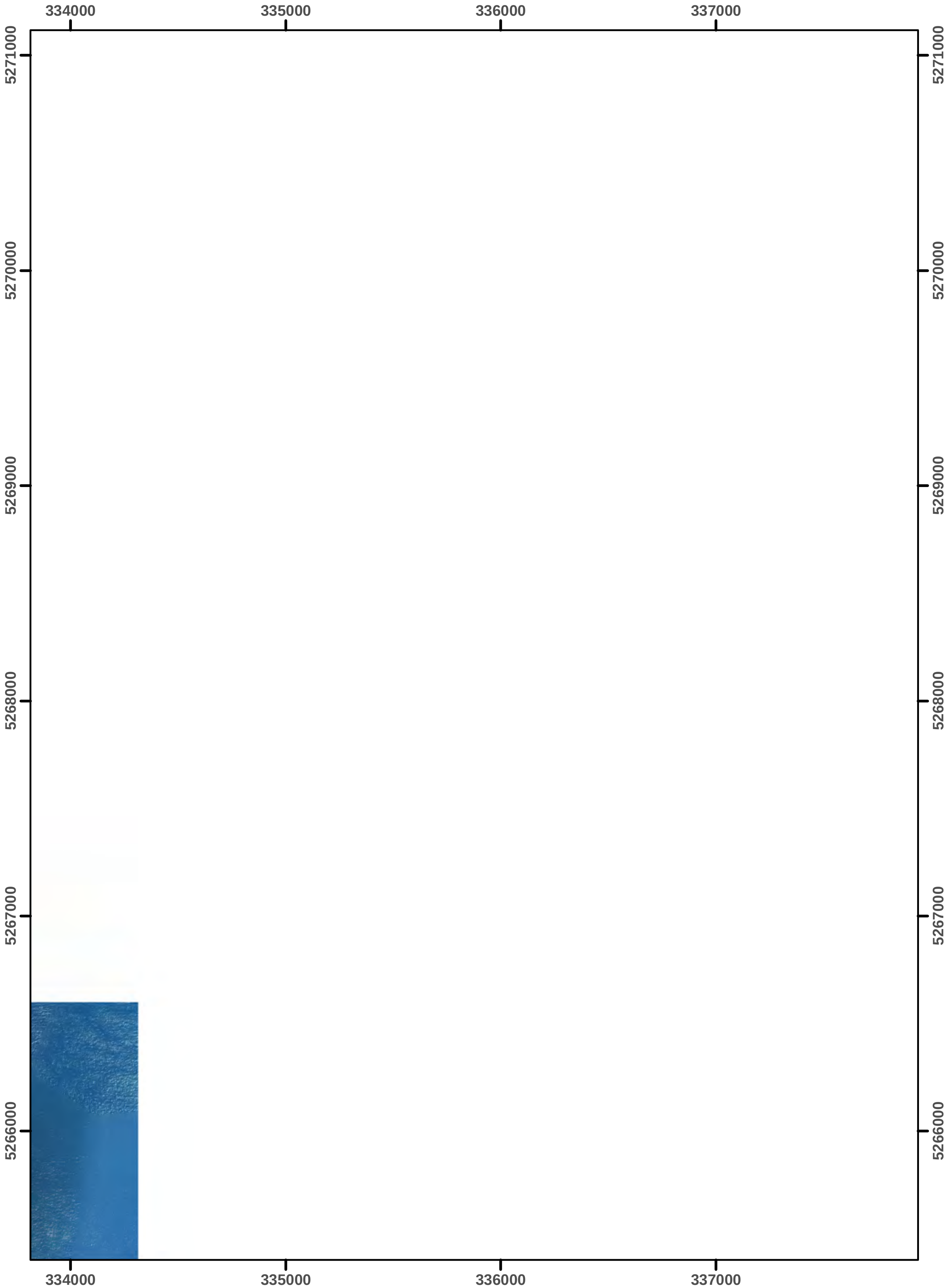
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

C9



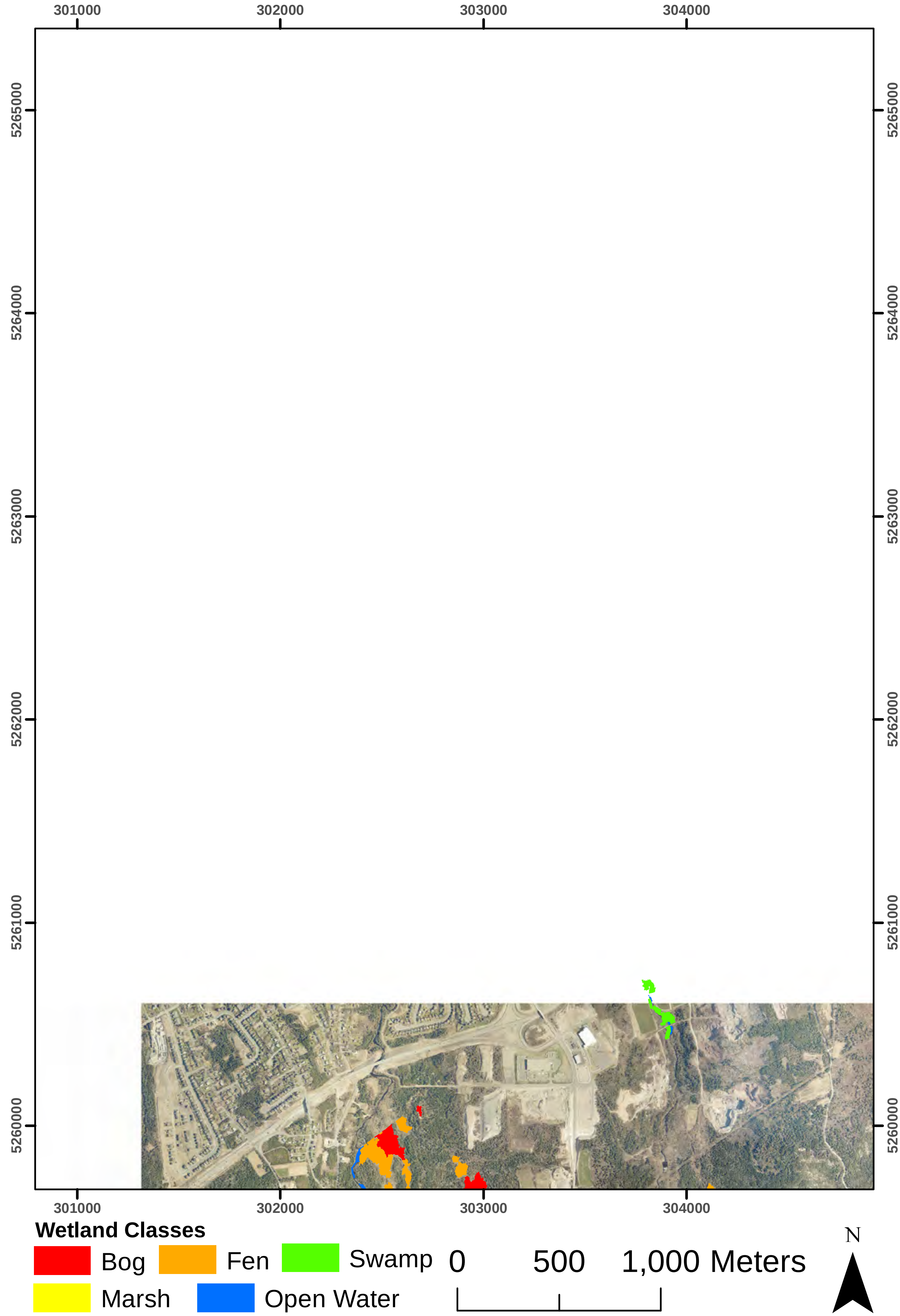
Wetland Classes

Bog
Fen
Swamp
Marsh
Open Water

0 500 1,000 Meters

N

D1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Wetland Classes
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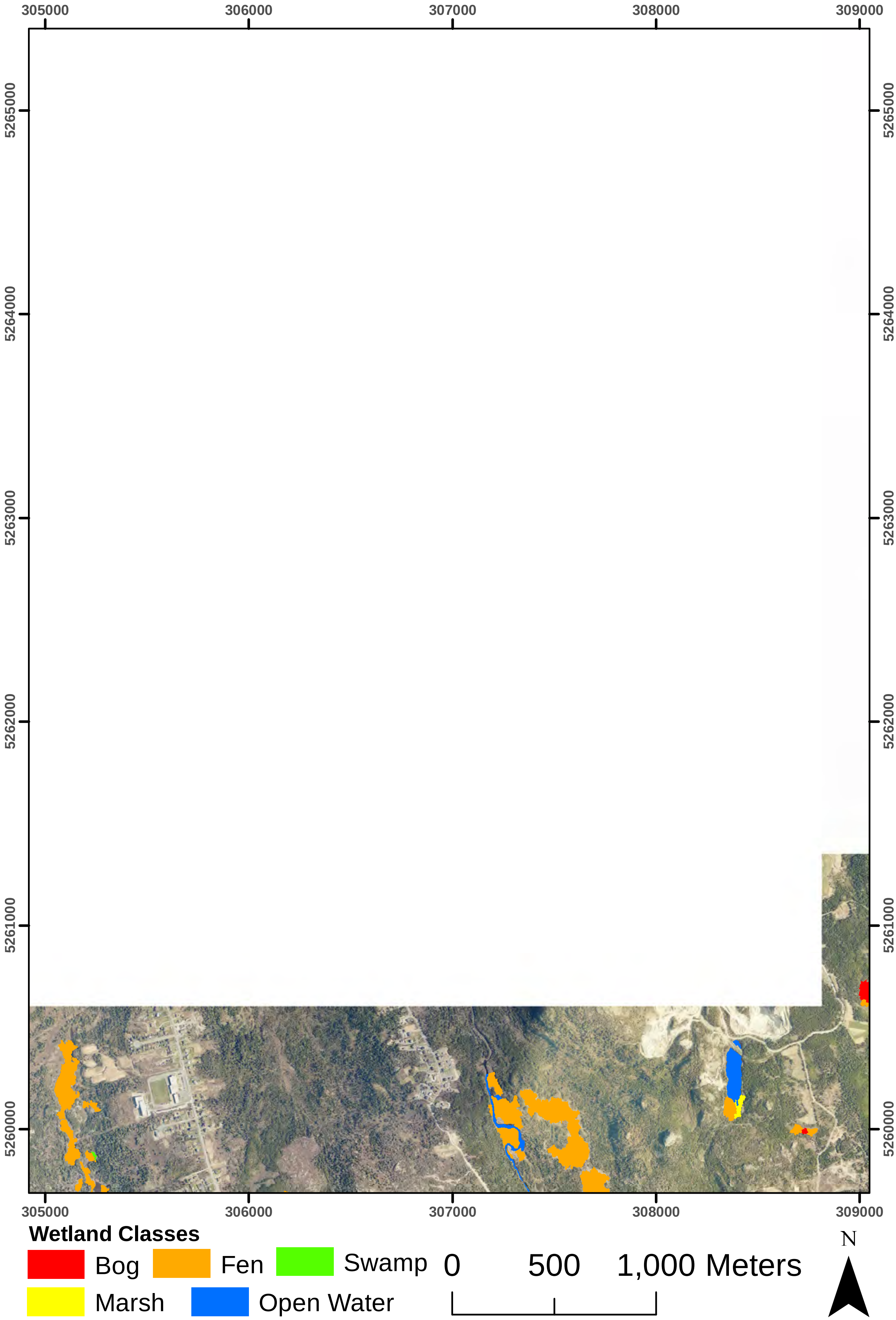
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

D2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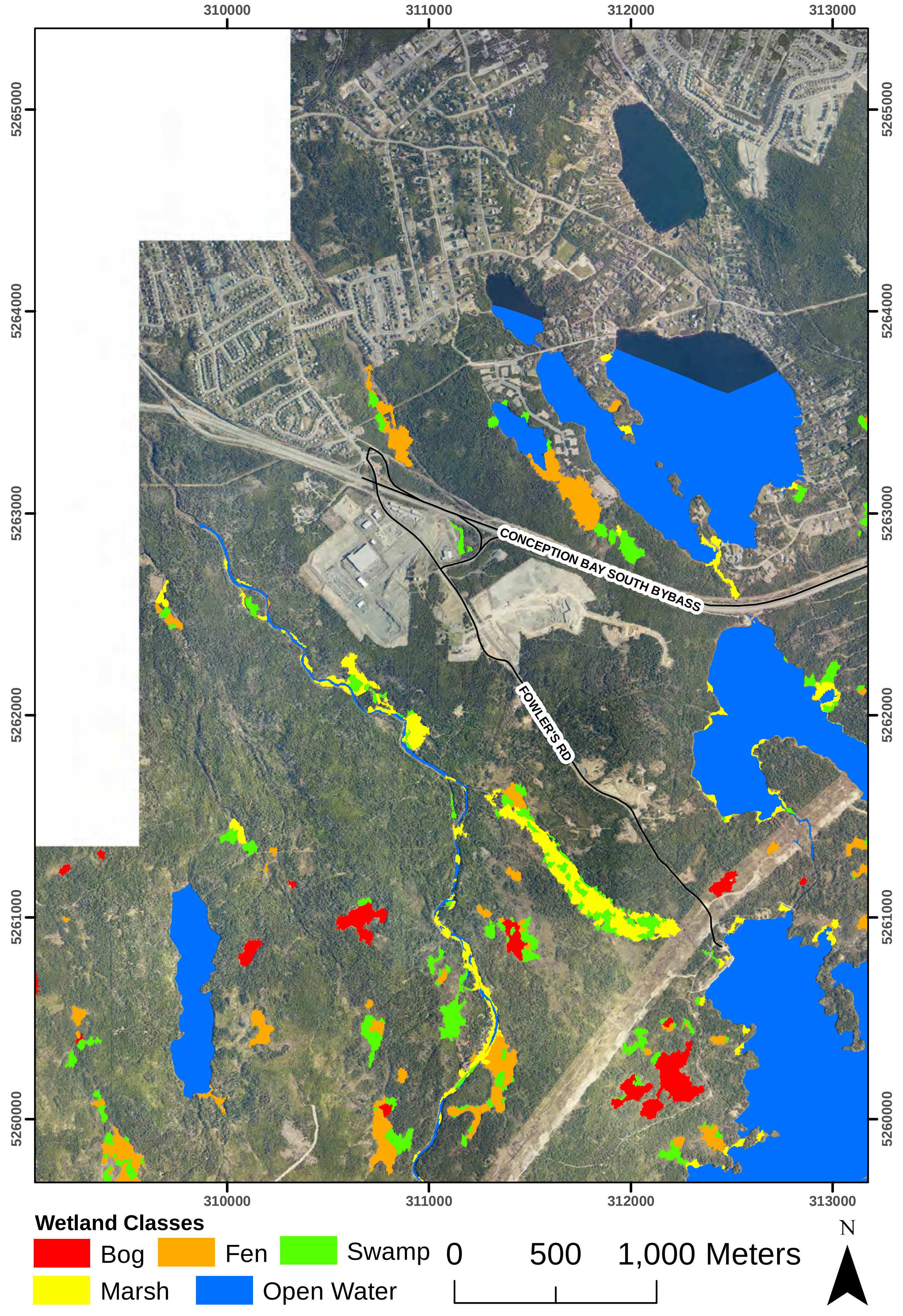
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

D3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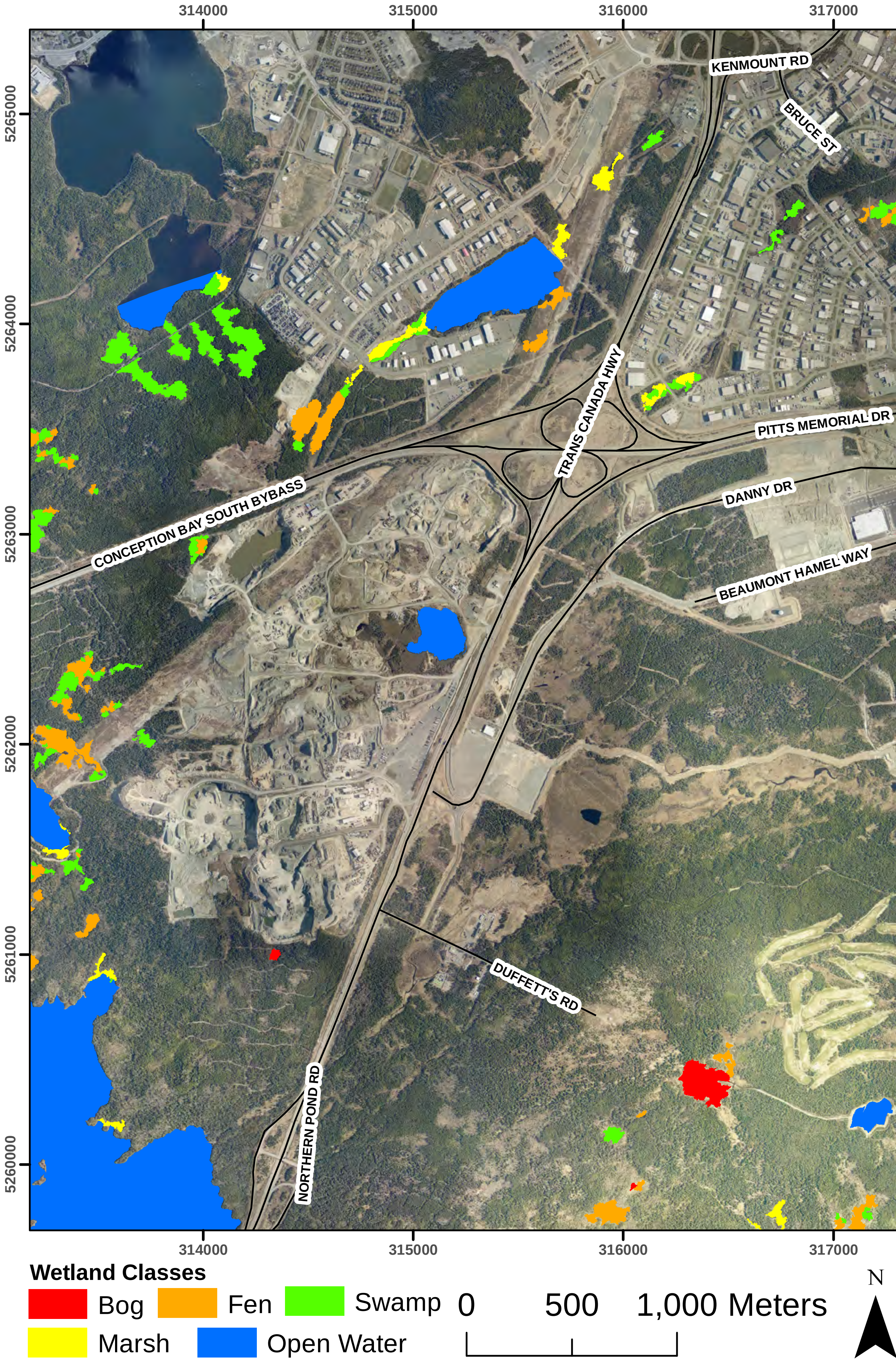
CONCEPTION BAY SOUTH BYBASS
FOWLER'S RD
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

D4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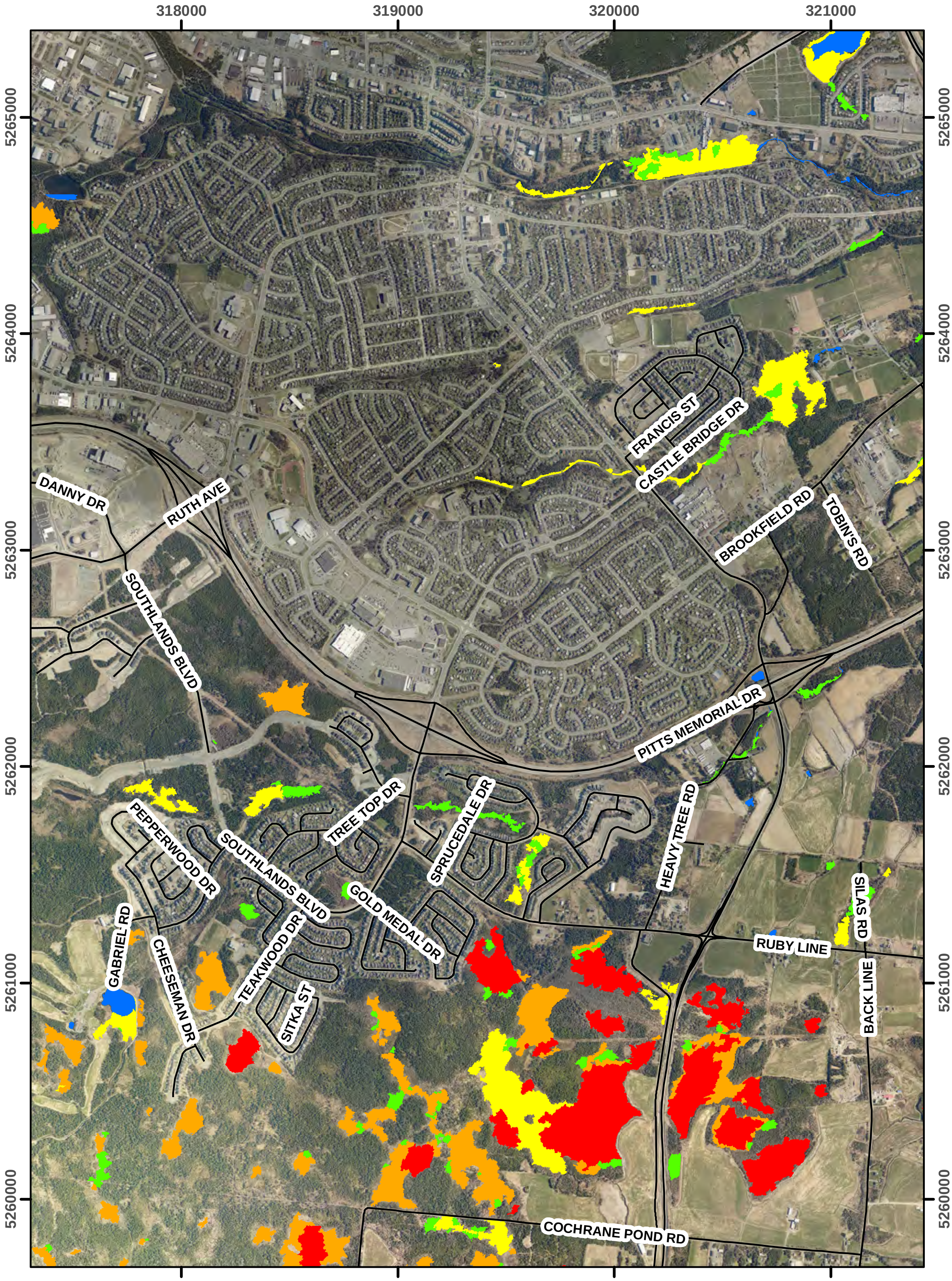
KENMOUNT RD
BRUCE ST
TRANS CANADA HWY
PITTS MEMORIAL DR
DANNY DR
CONCEPTION BAY SOUTH BYBASS
BEAUMONT HAMEL WAY
DUFFETT'S RD
NORTHERN POND RD
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

D5



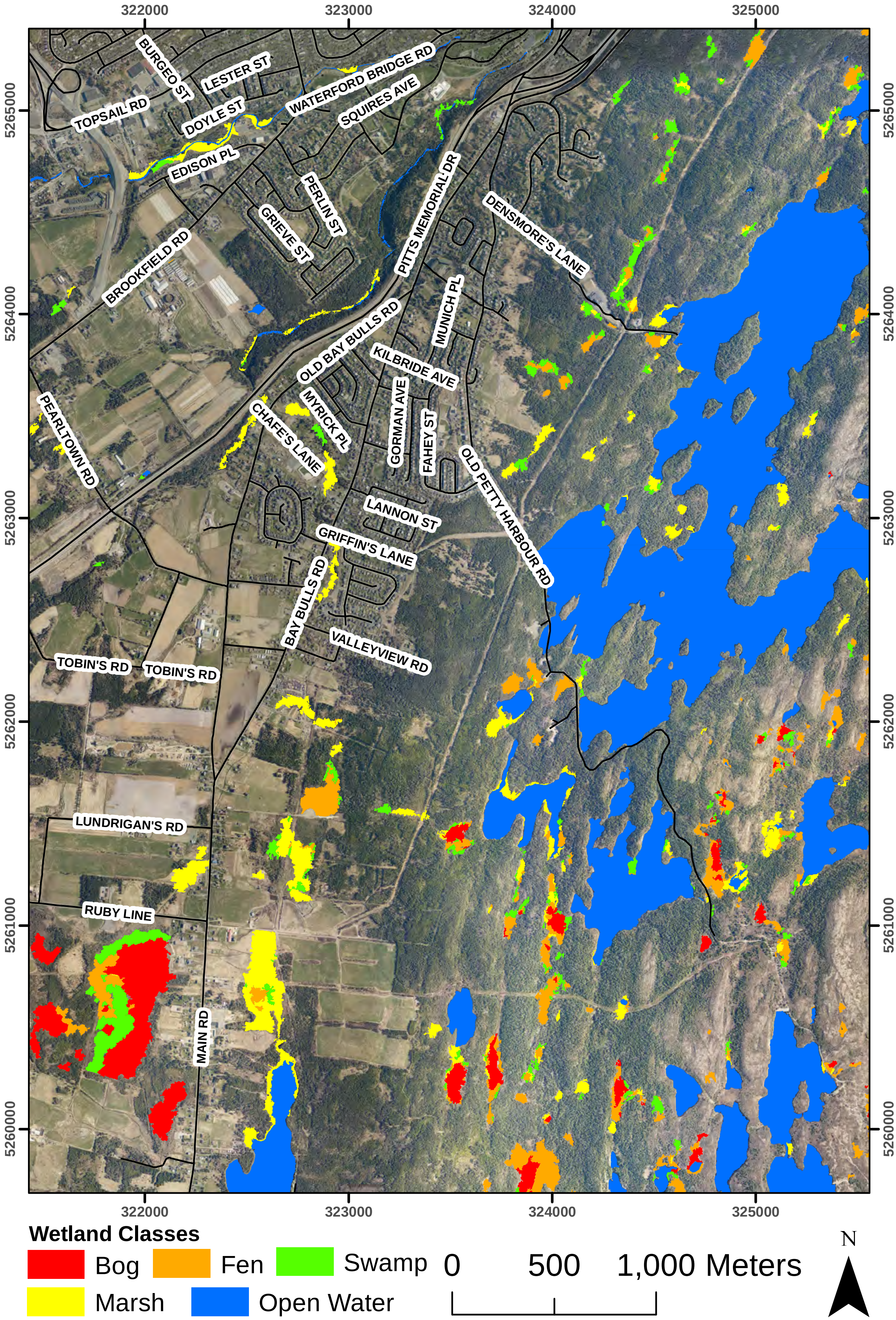
Wetland Classes

Bog Fen Swamp
Marsh Open Water

0 500 1,000 Meters

N

D6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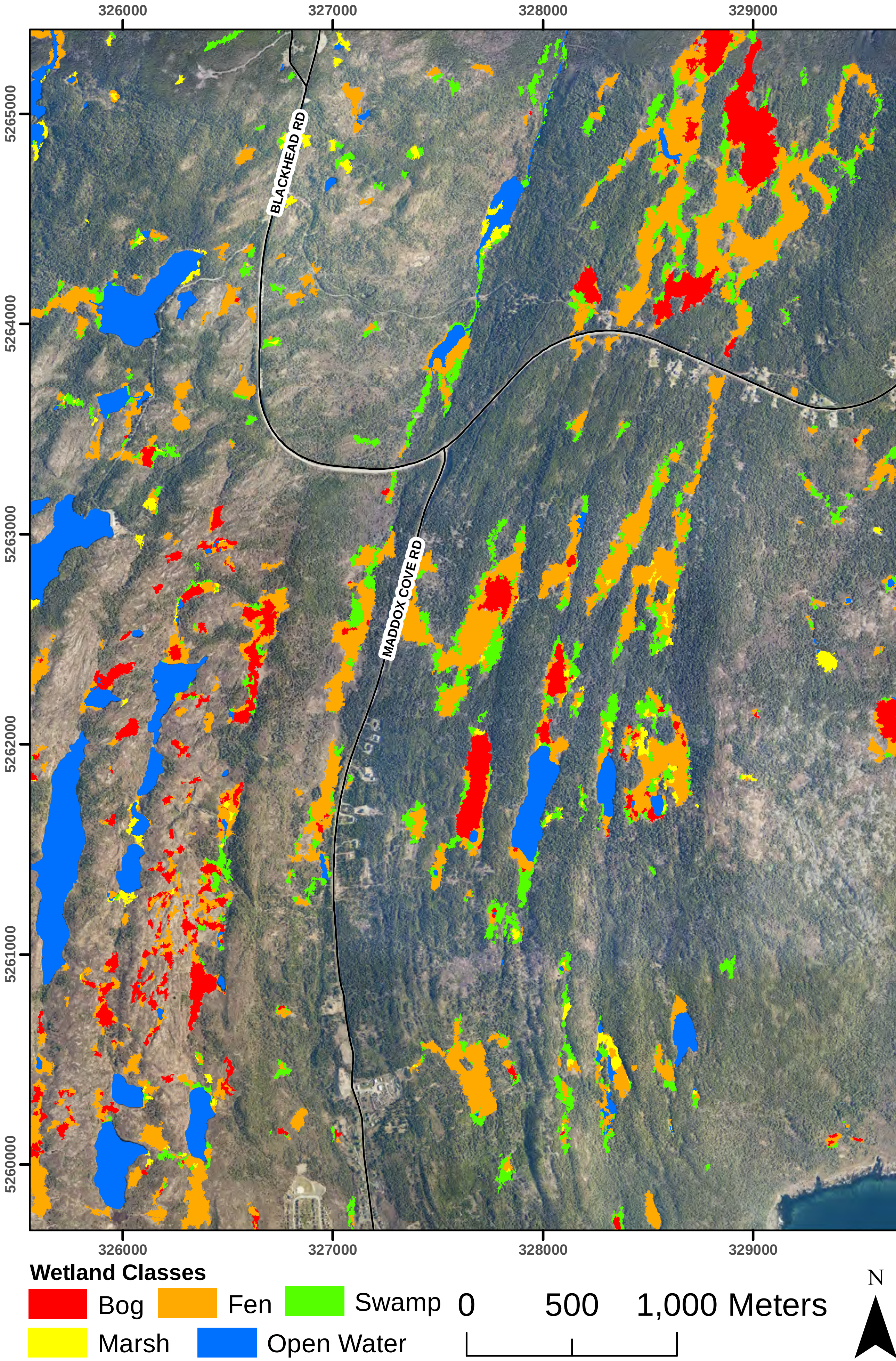
BURGEO ST
LESTER ST
WATERFORD BRIDGE RD
SQUIRES AVE
TOPSAIL RD
DOYLE ST
EDISON PL
PERLIN ST
GRIEVE ST
PITTS MEMORIAL DR
DENSMORE'S LANE
BROOKFIELD RD
MUNICH PL
OLD BAY BULLS RD
KILBRIDE AVE
PEARLTOWN RD
CHAFE'S LANE
MYRICK PL
GORMAN AVE
FAHEY ST
OLD PETTY HARBOUR RD
LANNON ST
GRIFFIN'S LANE
BAY BULLS RD
VALLEYVIEW RD
TOBIN'S RD
TOBIN'S RD
LUNDRIGAN'S RD
RUBY LINE
MAIN RD
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

D7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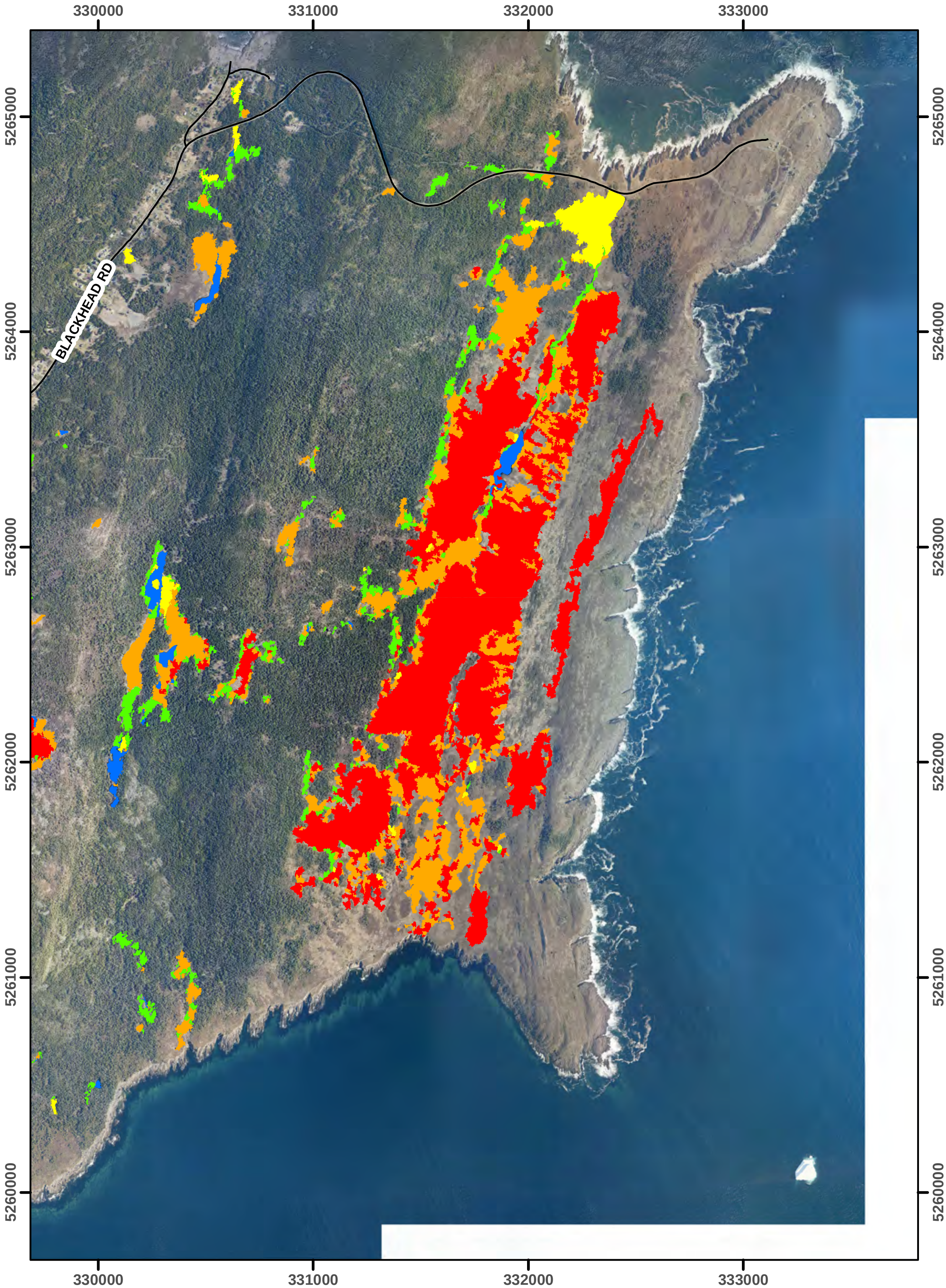
BLACKHEAD RD
MADDOX COVE RD
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

D8



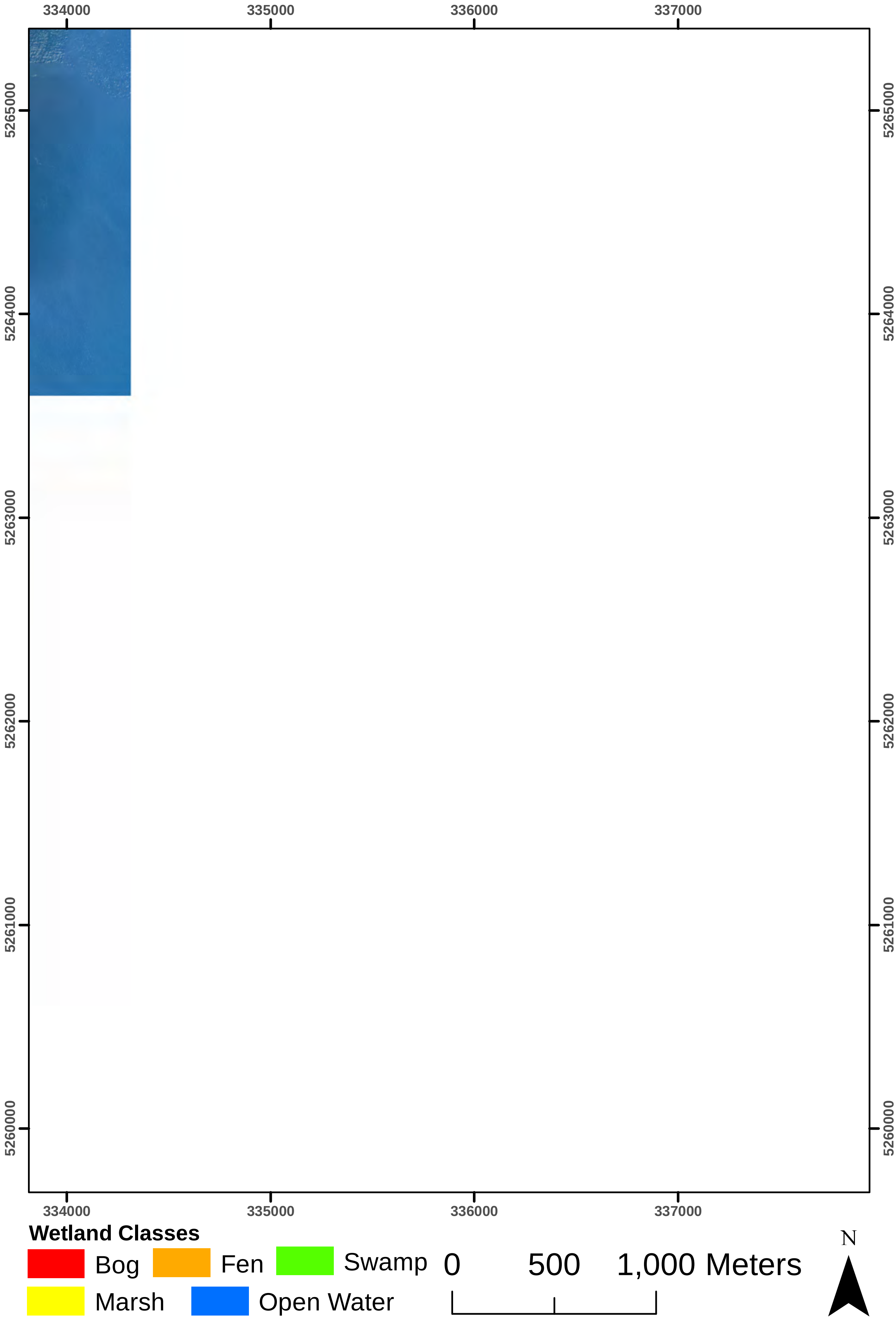
Wetland Classes

Bog Fen Swamp Marsh Open Water

0 500 1,000 Meters

N

D9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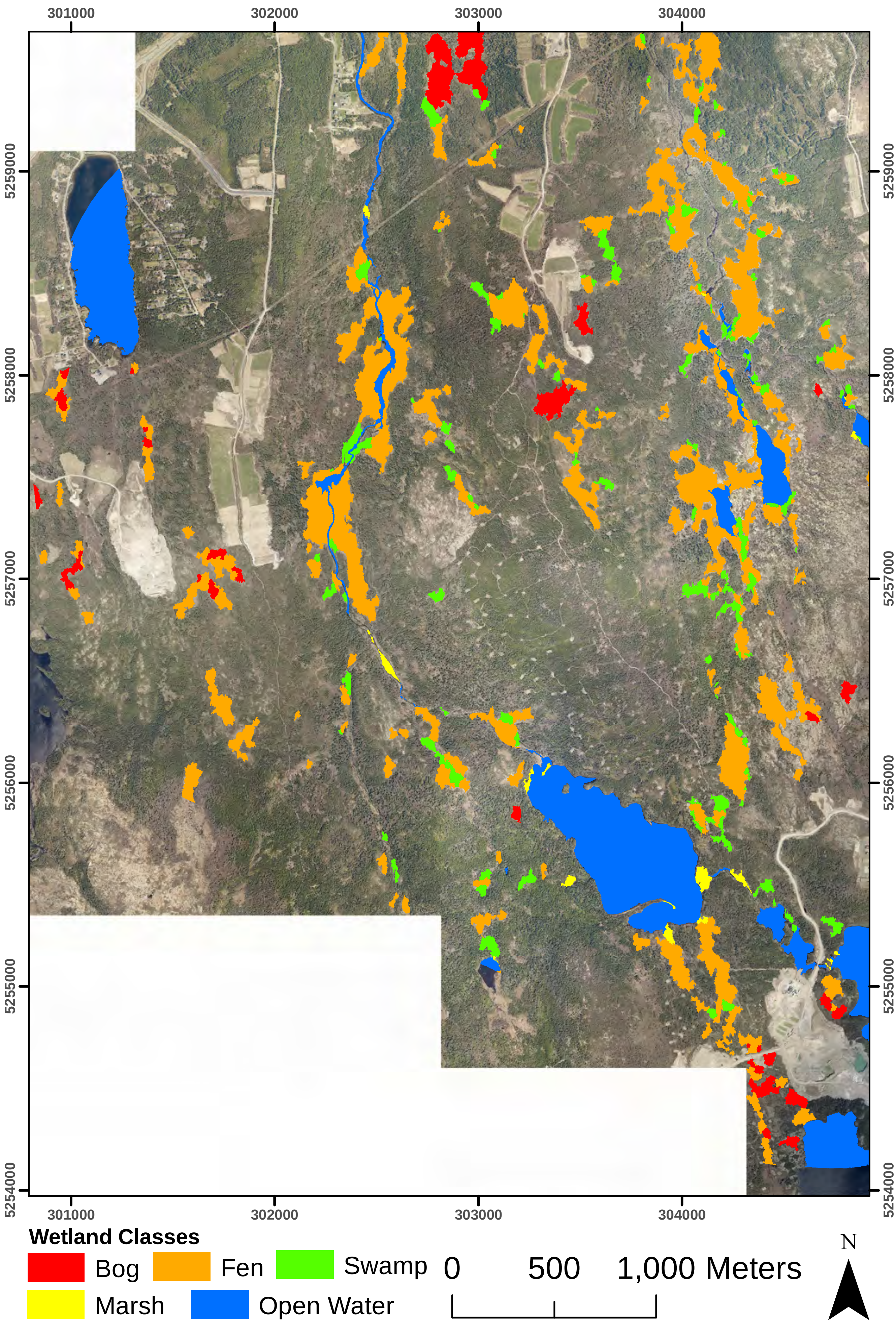
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

E1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Wetland Classes
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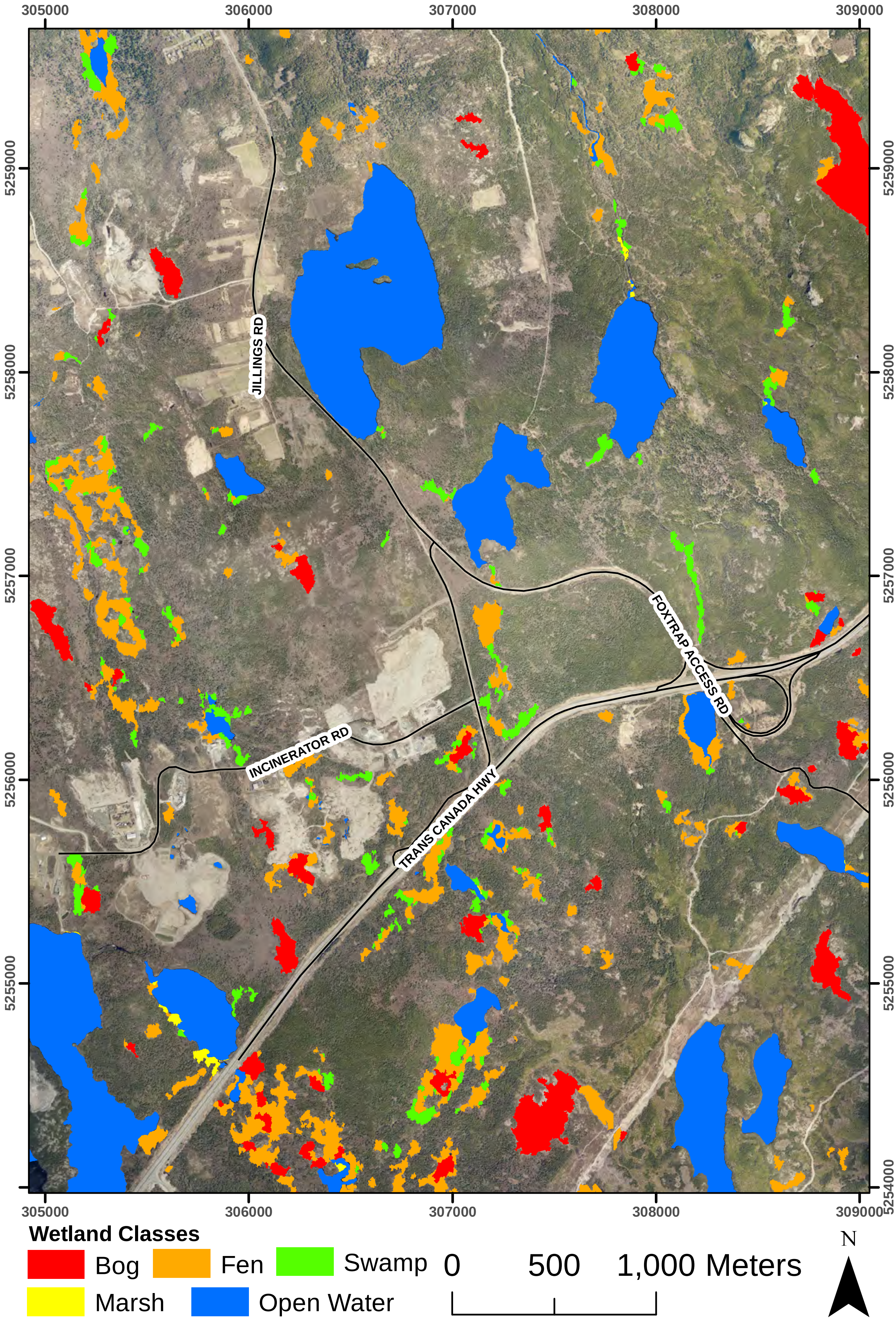
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

E2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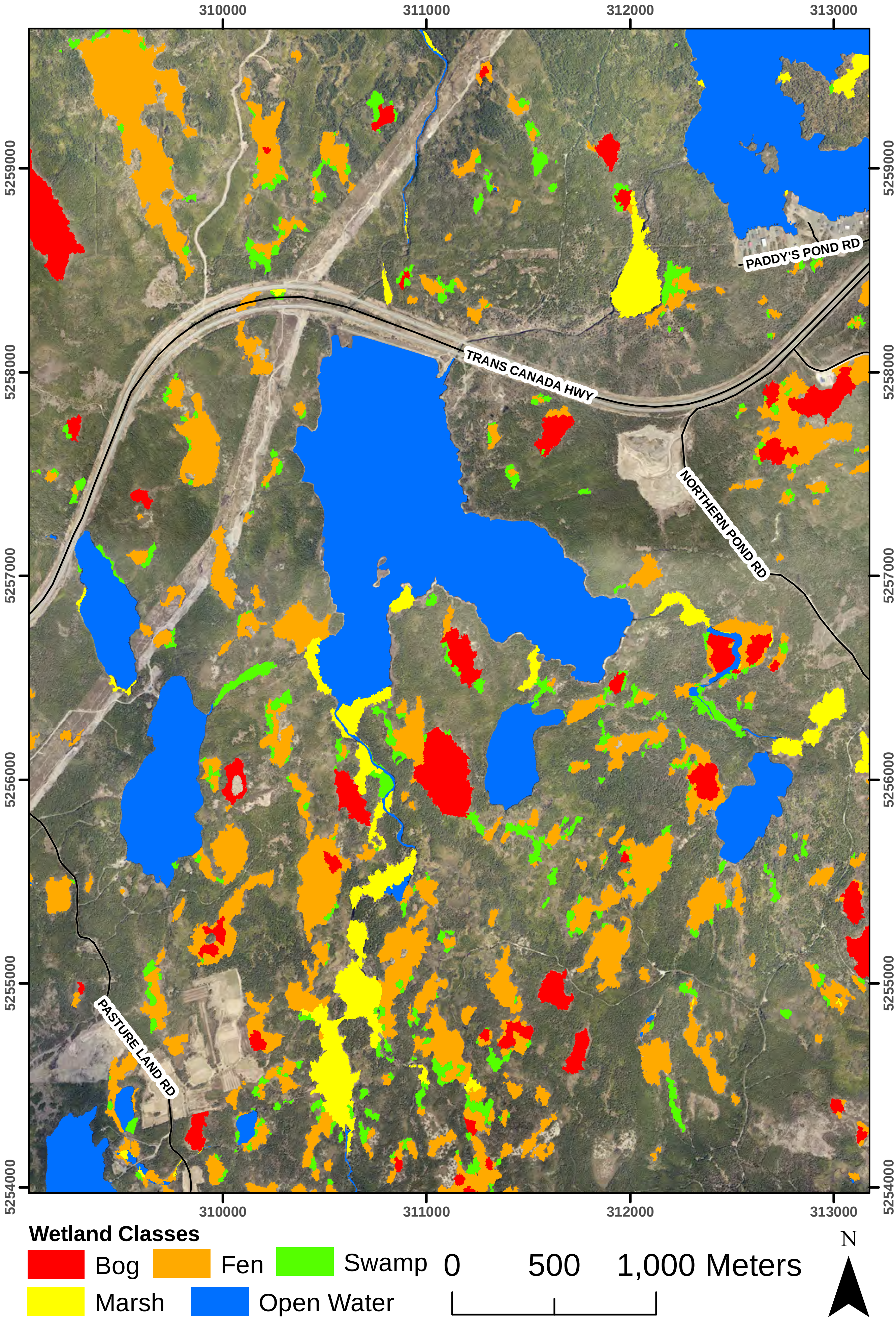
5254000
JILLINGS RD
FOXTRAP ACCESS RD
INCINERATOR RD
TRANS CANADA HWY
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

E3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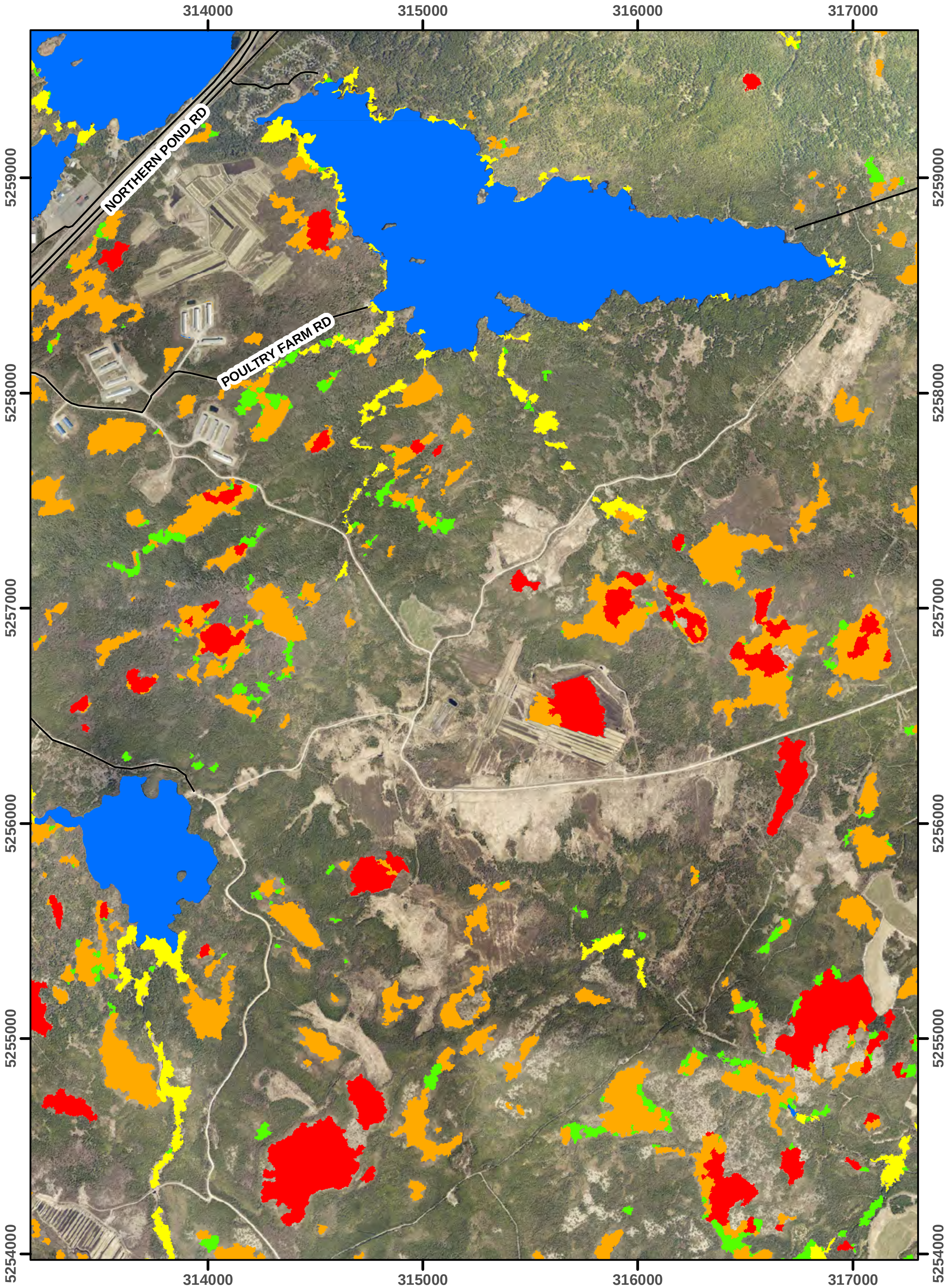
PADDY'S POND RD
TRANS CANADA HWY
NORTHERN POND RD
PASTURE LAND RD
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0 500 1,000 Meters
N

E4



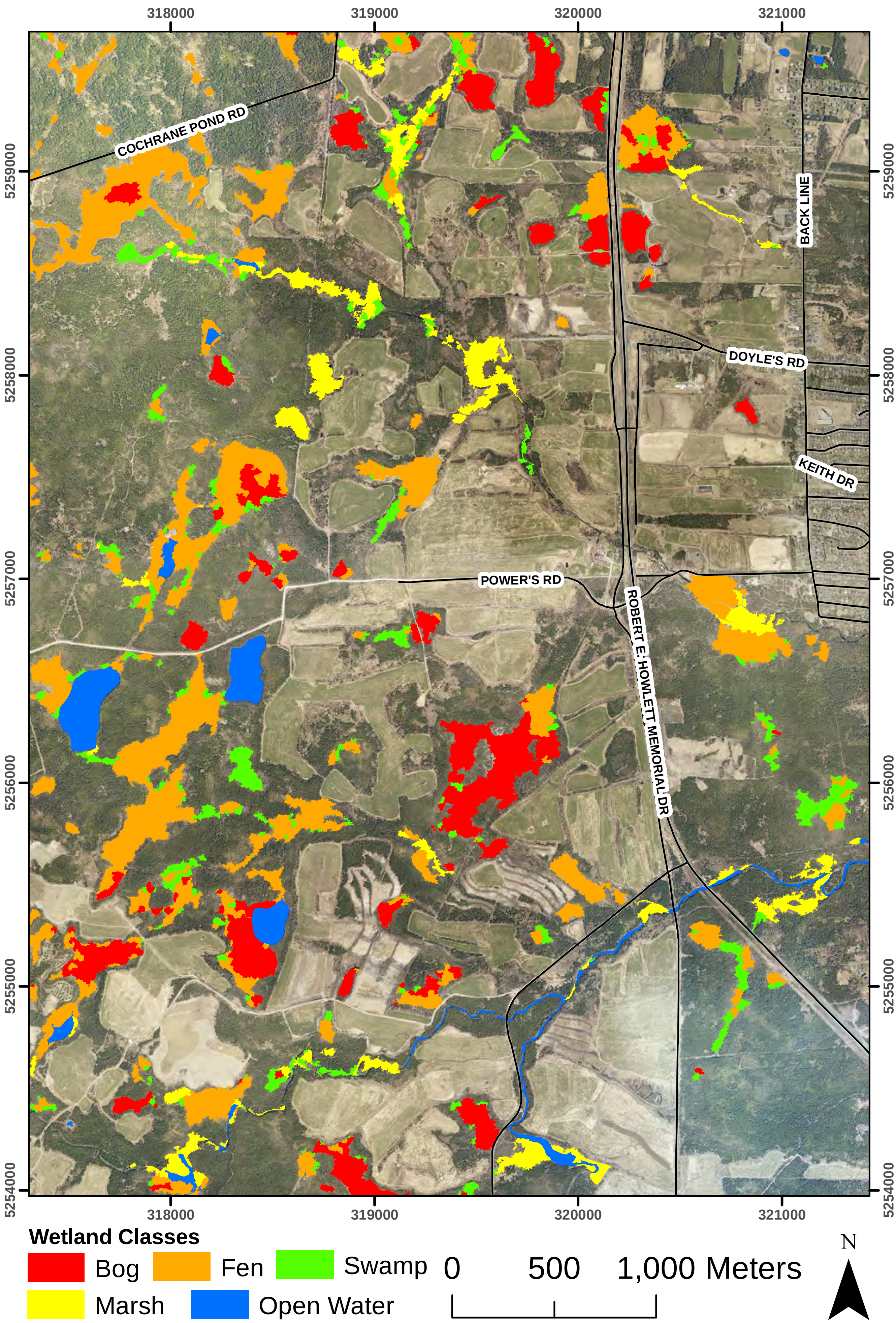
Wetland Classes

Bog Fen Swamp
Marsh Open Water

0 500 1,000 Meters

N

E5



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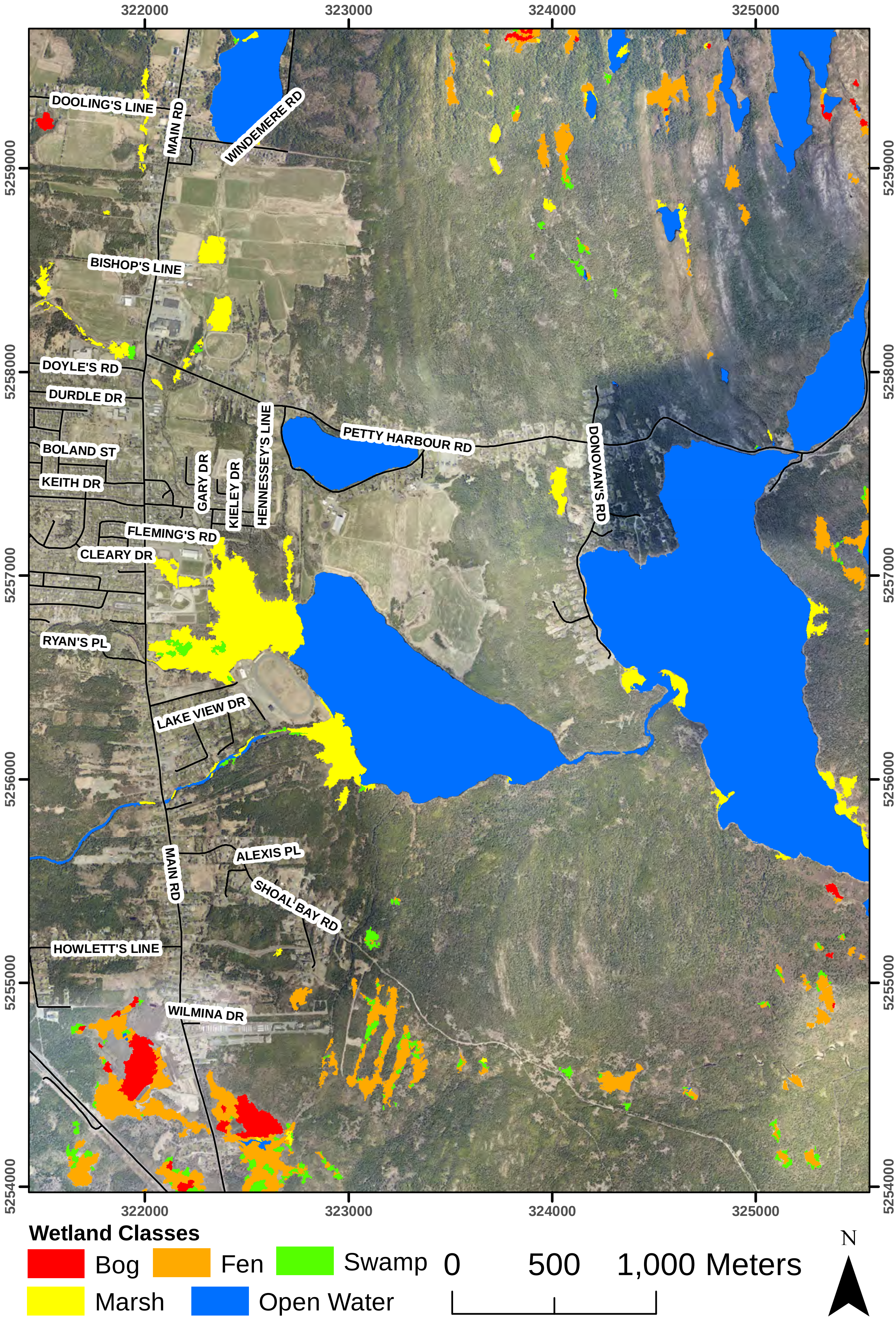
COCHRANE POND RD
BACK LINE
DOYLE'S RD
KEITH DR
POWER'S RD
ROBERT E. HOWLETT MEMORIAL DR
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

E6



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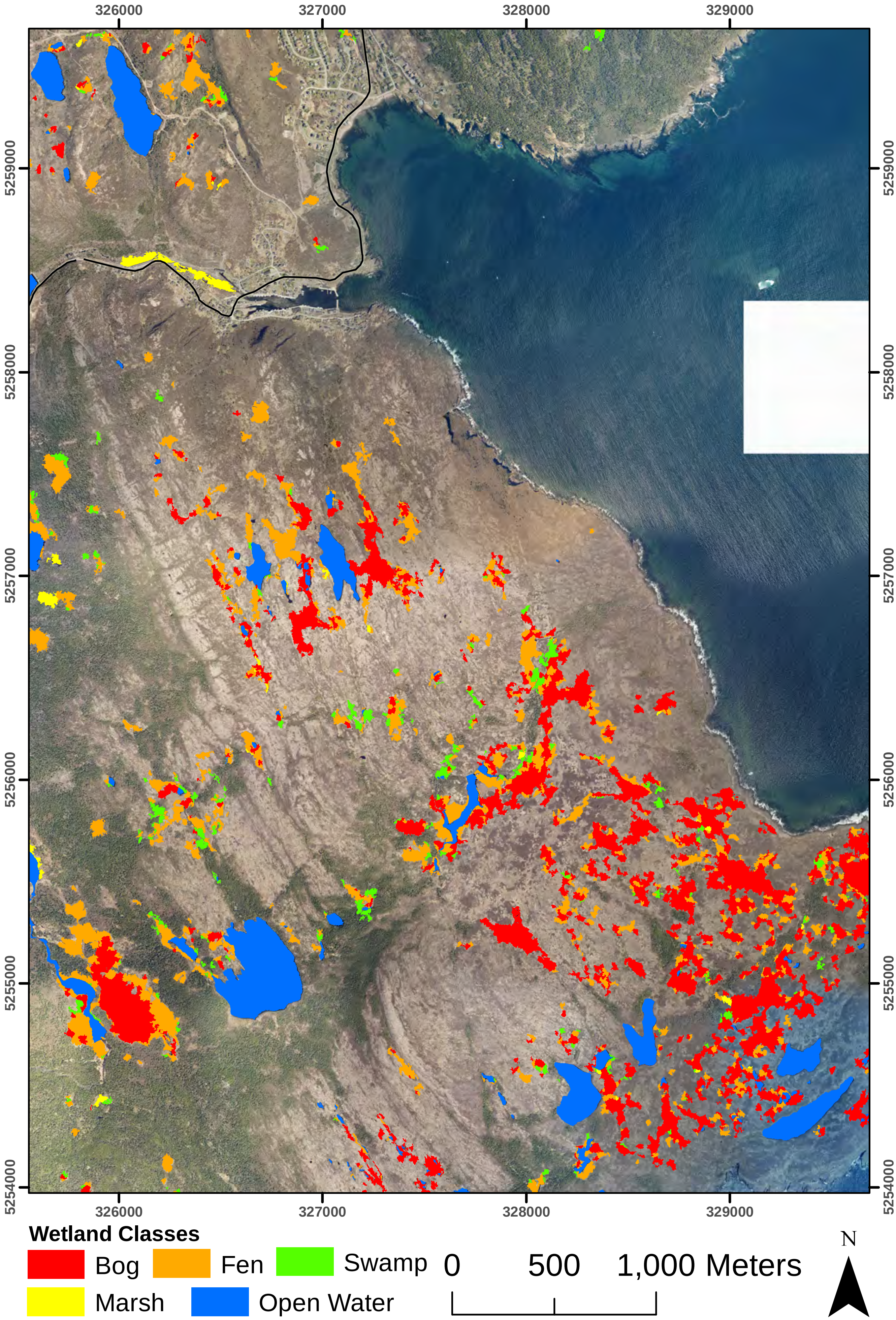
DOOLING'S LINE
MAIN RD
WINDEMERE RD
BISHOP'S LINE
DOYLE'S RD
DURDLE DR
BOLAND ST
KEITH DR
GARY DR
KIELEY DR
HENNESSEY'S LINE
PETTY HARBOUR RD
DONOVAN'S RD
FLEMING'S RD
CLEARY DR
RYAN'S PL
LAKE VIEW DR
ALEXIS PL
SHOAL BAY RD
HOWLETT'S LINE
WILMINA DR
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

E7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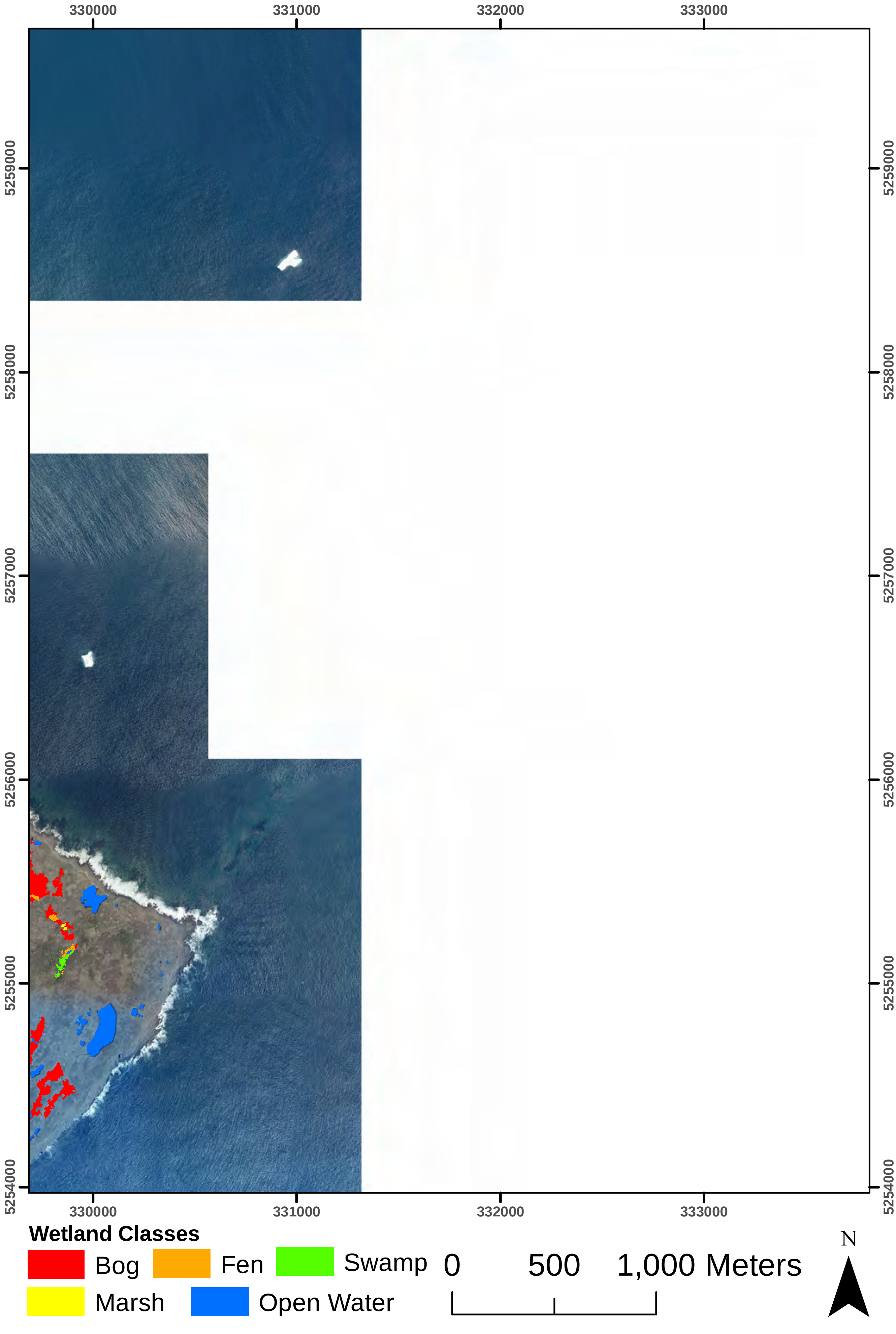
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

E8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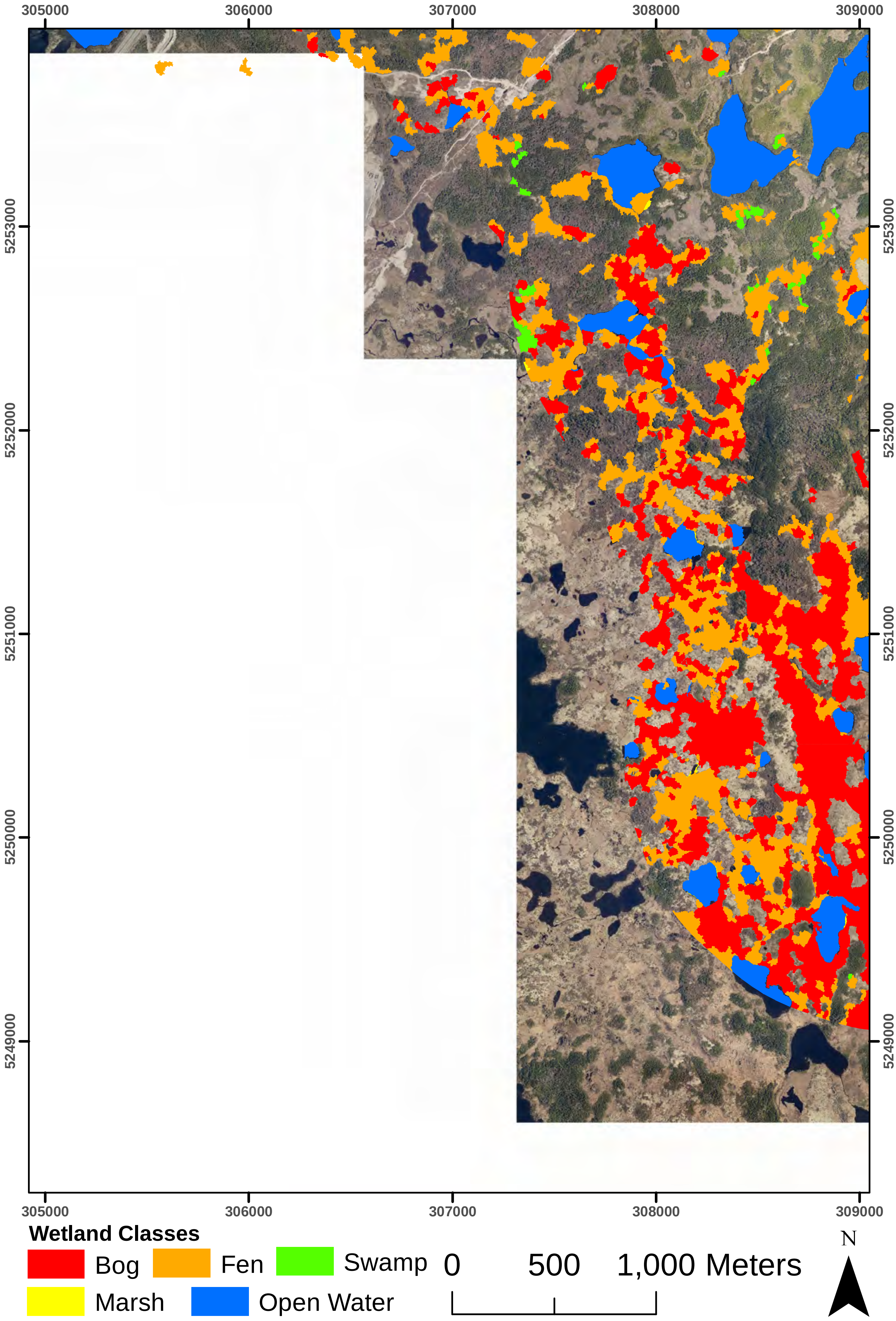
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

F2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Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
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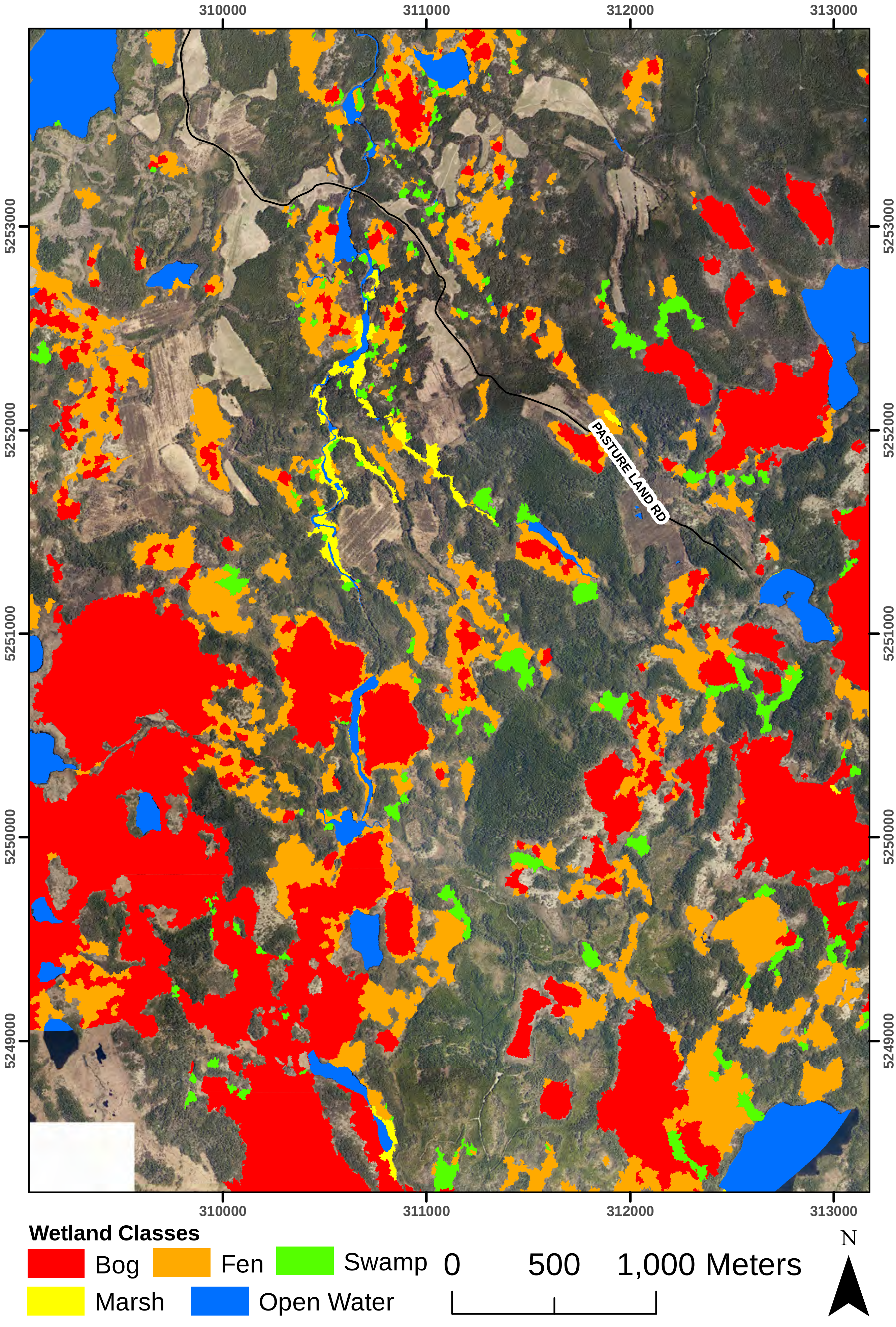
1,000 Meters
N

F3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PASTURE LAND RD
Wetland Classes
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Fen
Swamp
Marsh
Open Water
0
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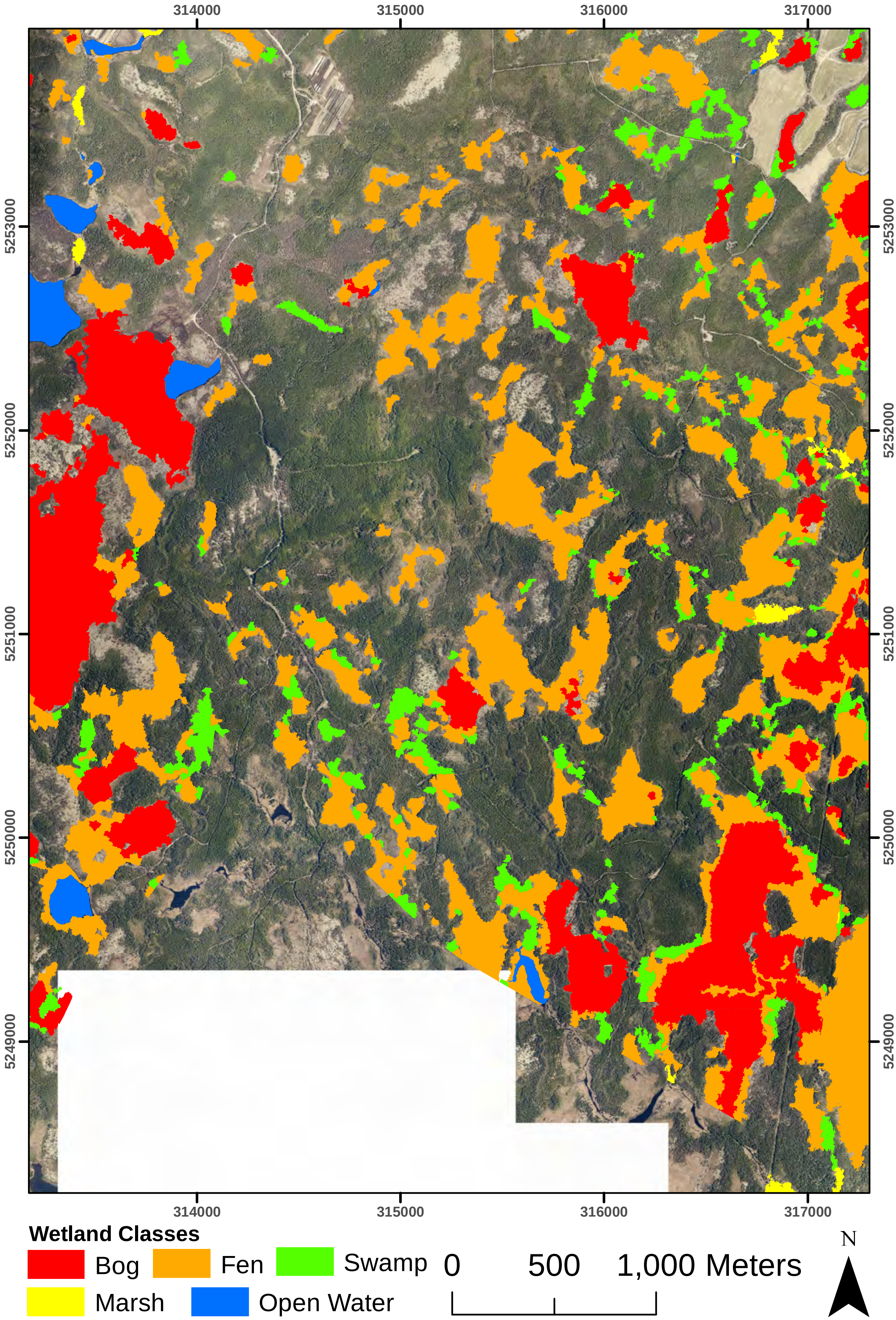
1,000 Meters
N

F4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Wetland Classes
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Fen
Swamp
Marsh
Open Water
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N

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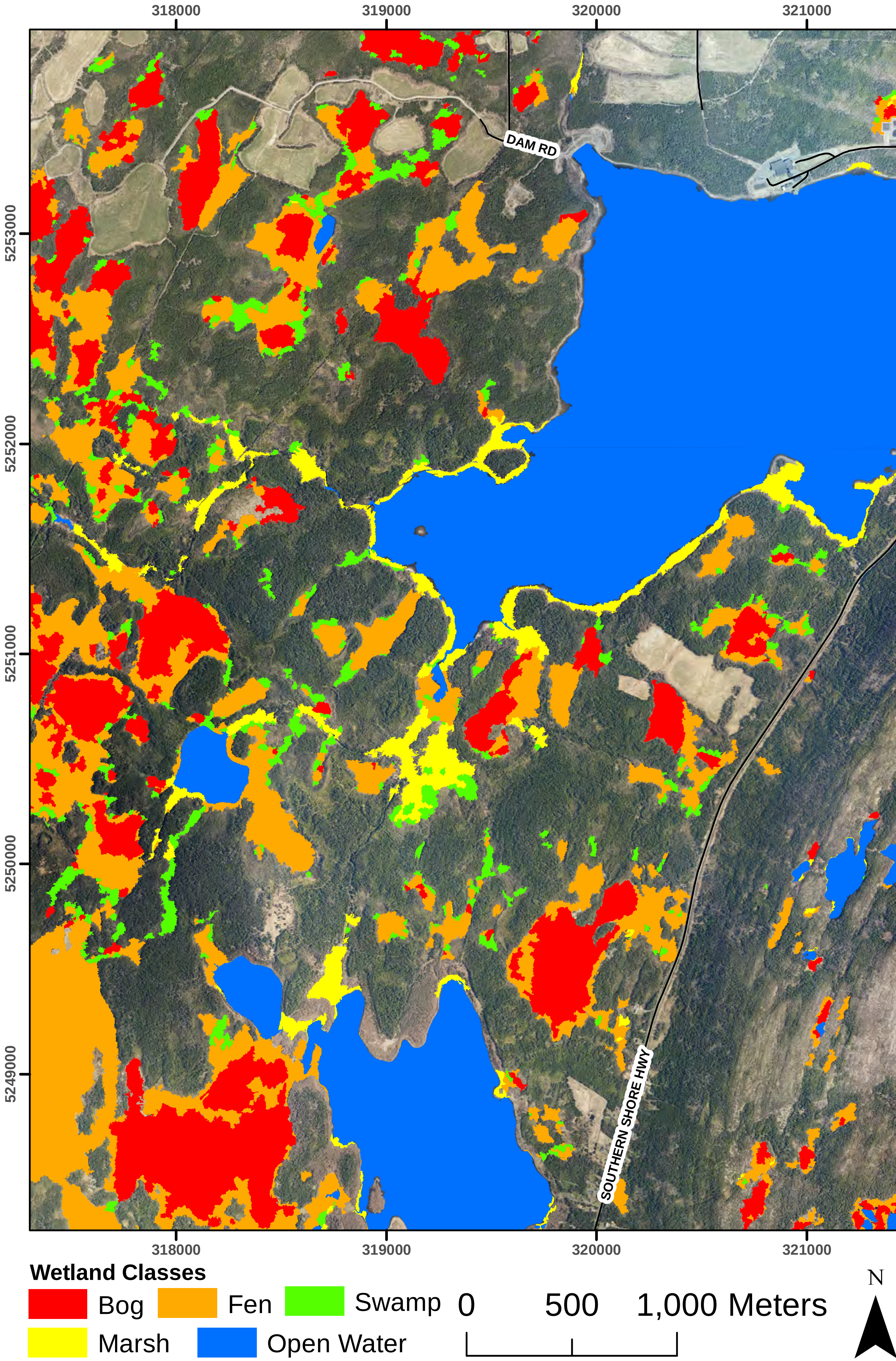
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DAM RD
SOUTHERN SHORE HWY
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
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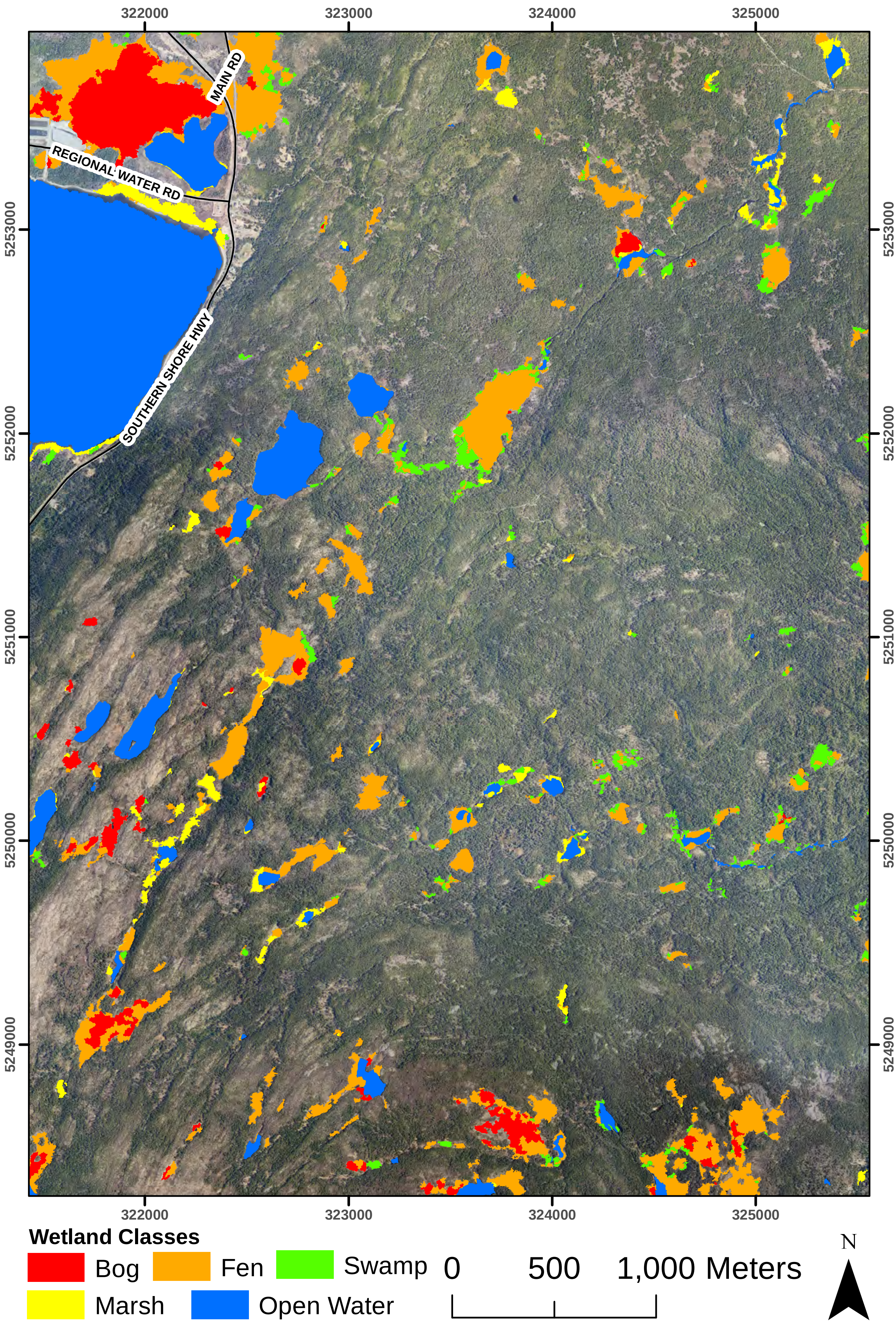
1,000 Meters
N

F6



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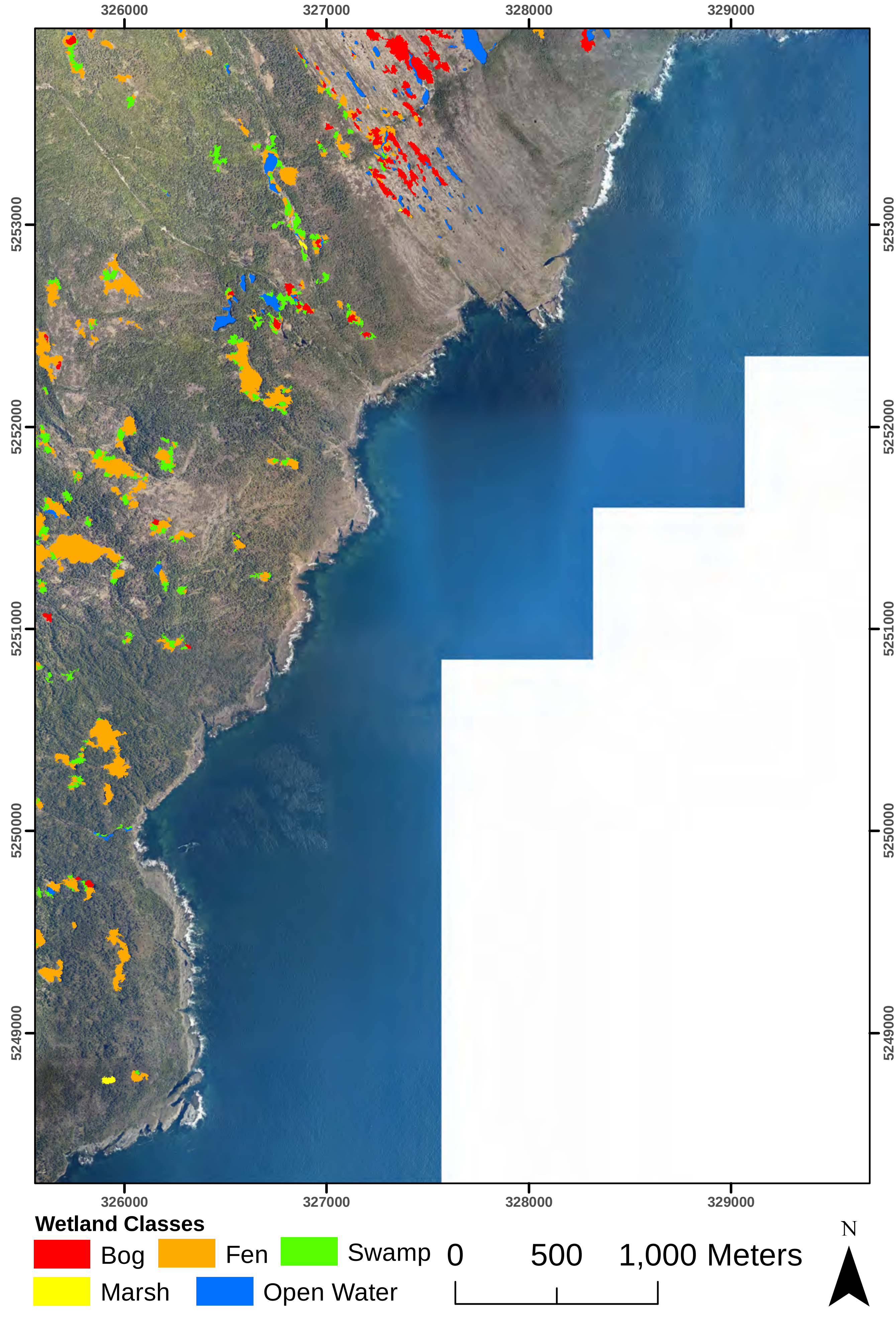
MAIN RD
REGIONAL WATER RD
SOUTHERN SHORE HWY
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

F7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Wetland Classes
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Fen
Swamp
Marsh
Open Water
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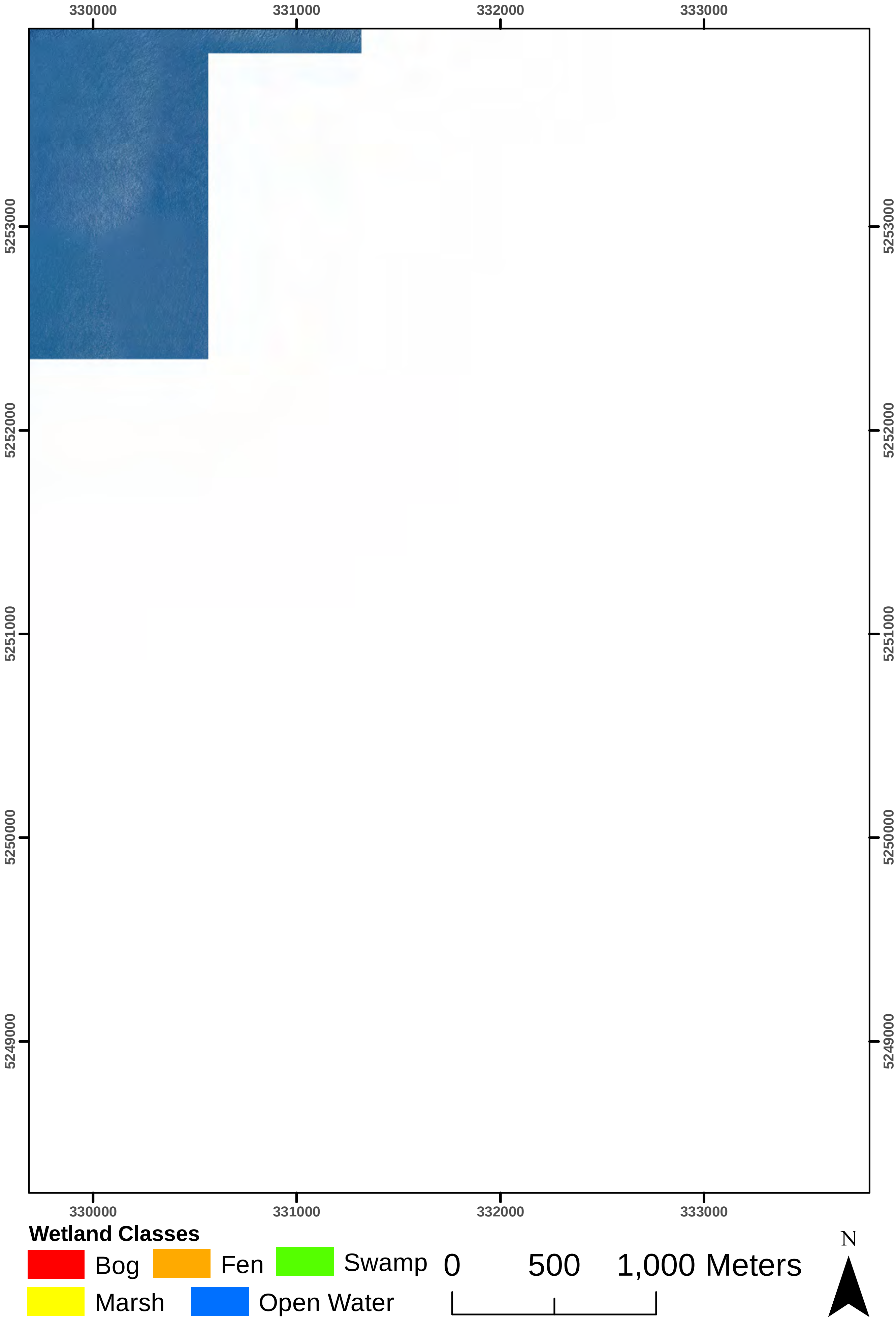
1,000 Meters
N

F8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Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
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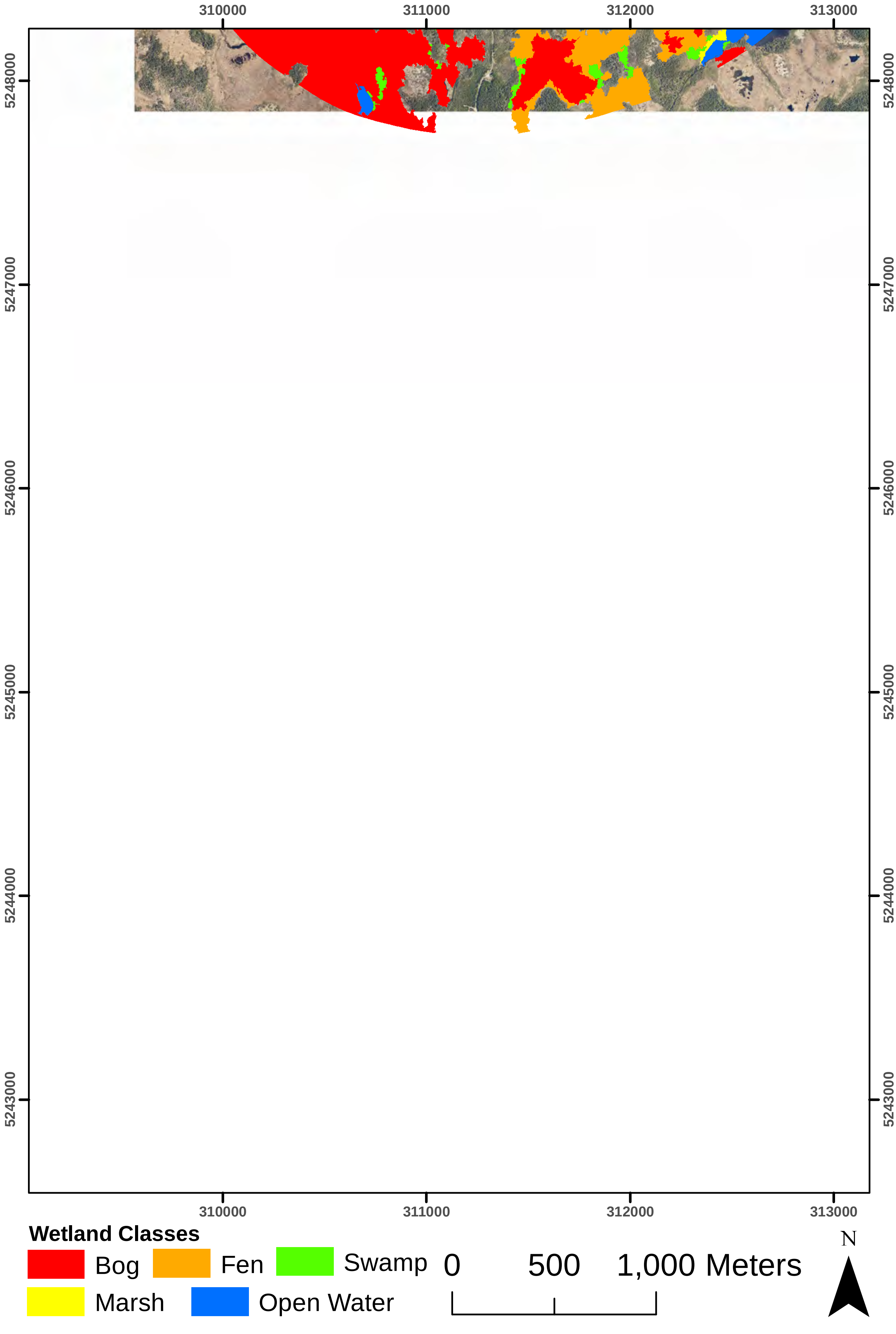
1,000 Meters
N

G3



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Wetland Classes
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Fen
Swamp
Marsh
Open Water
0
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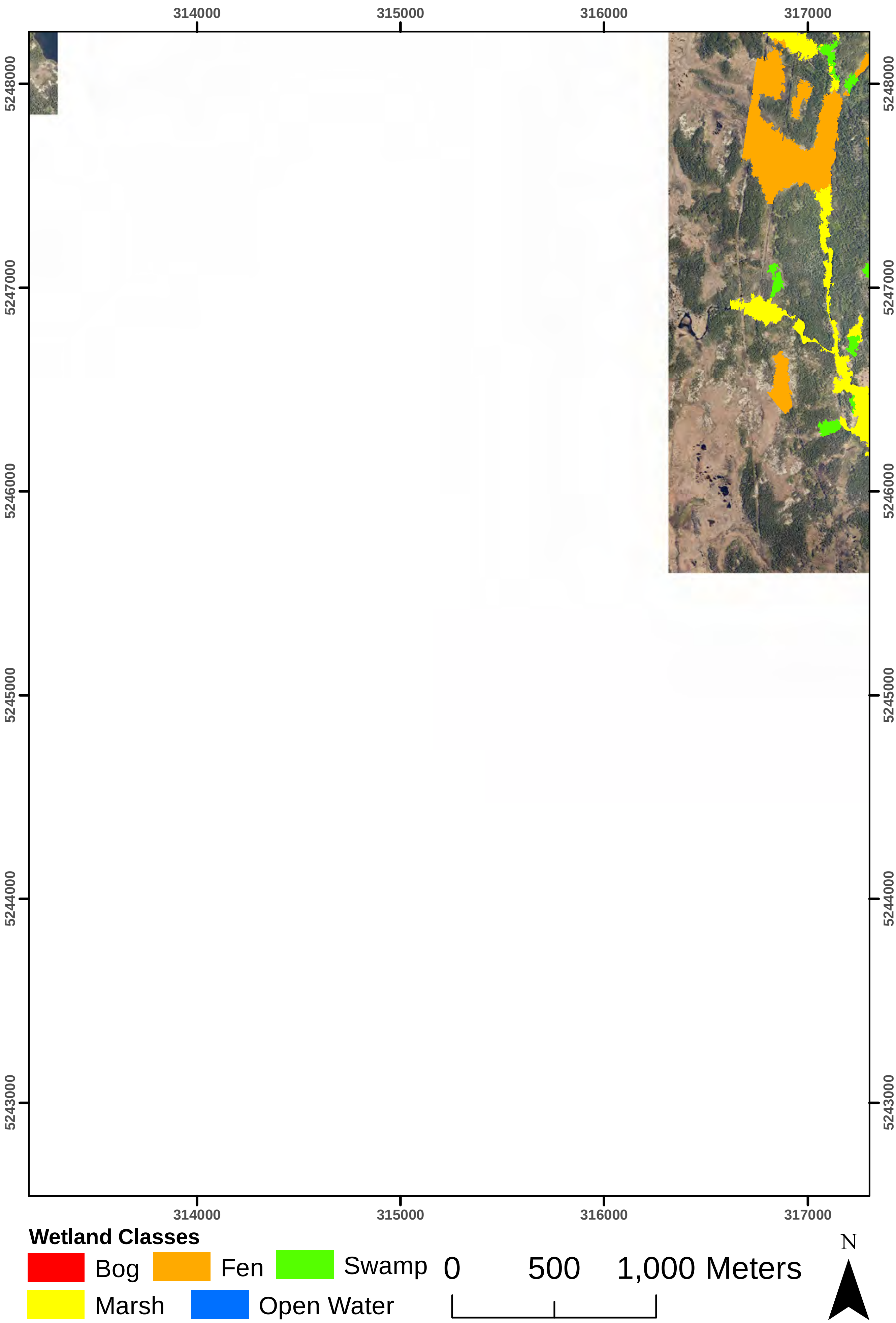
1,000 Meters
N

G4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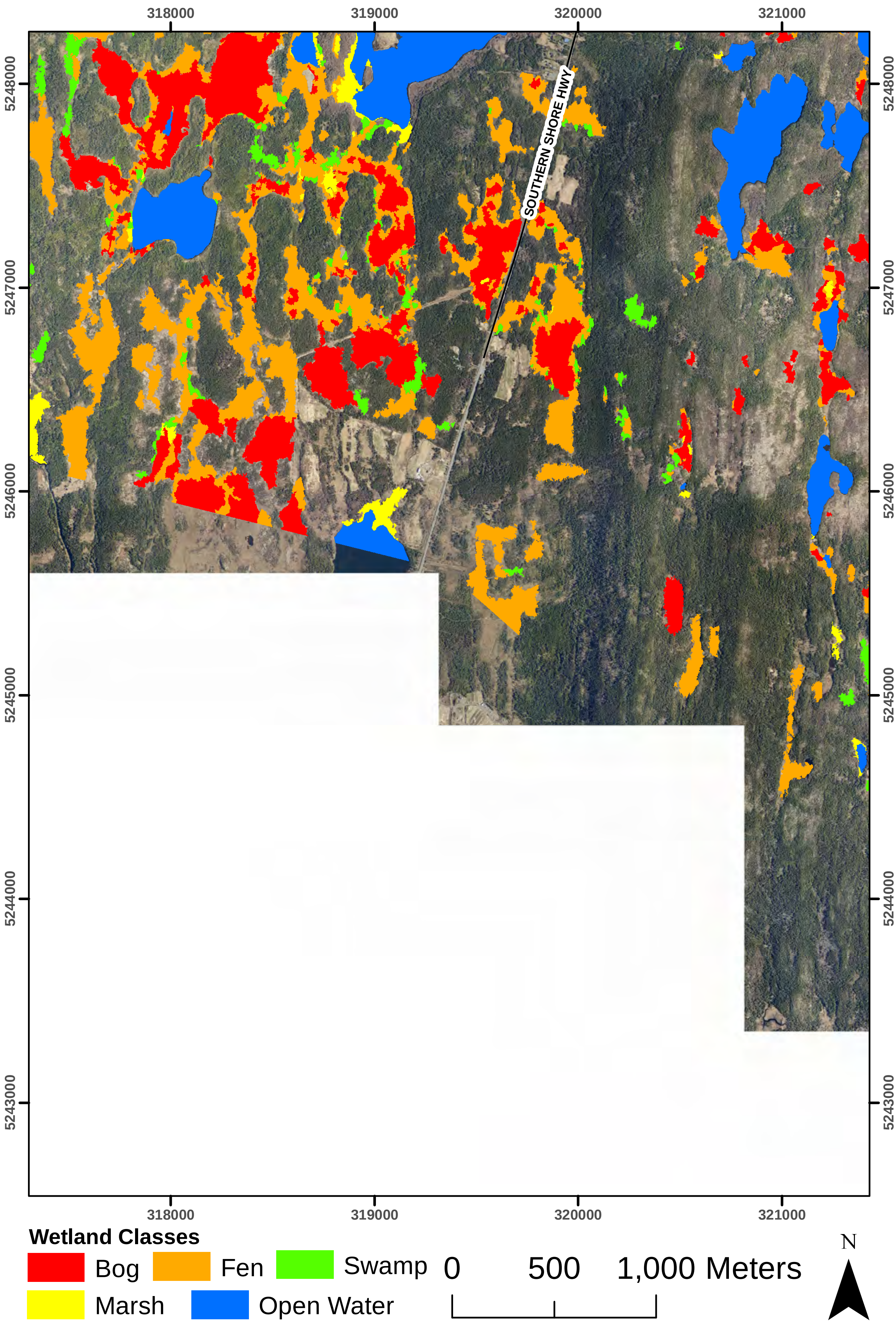
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

G5



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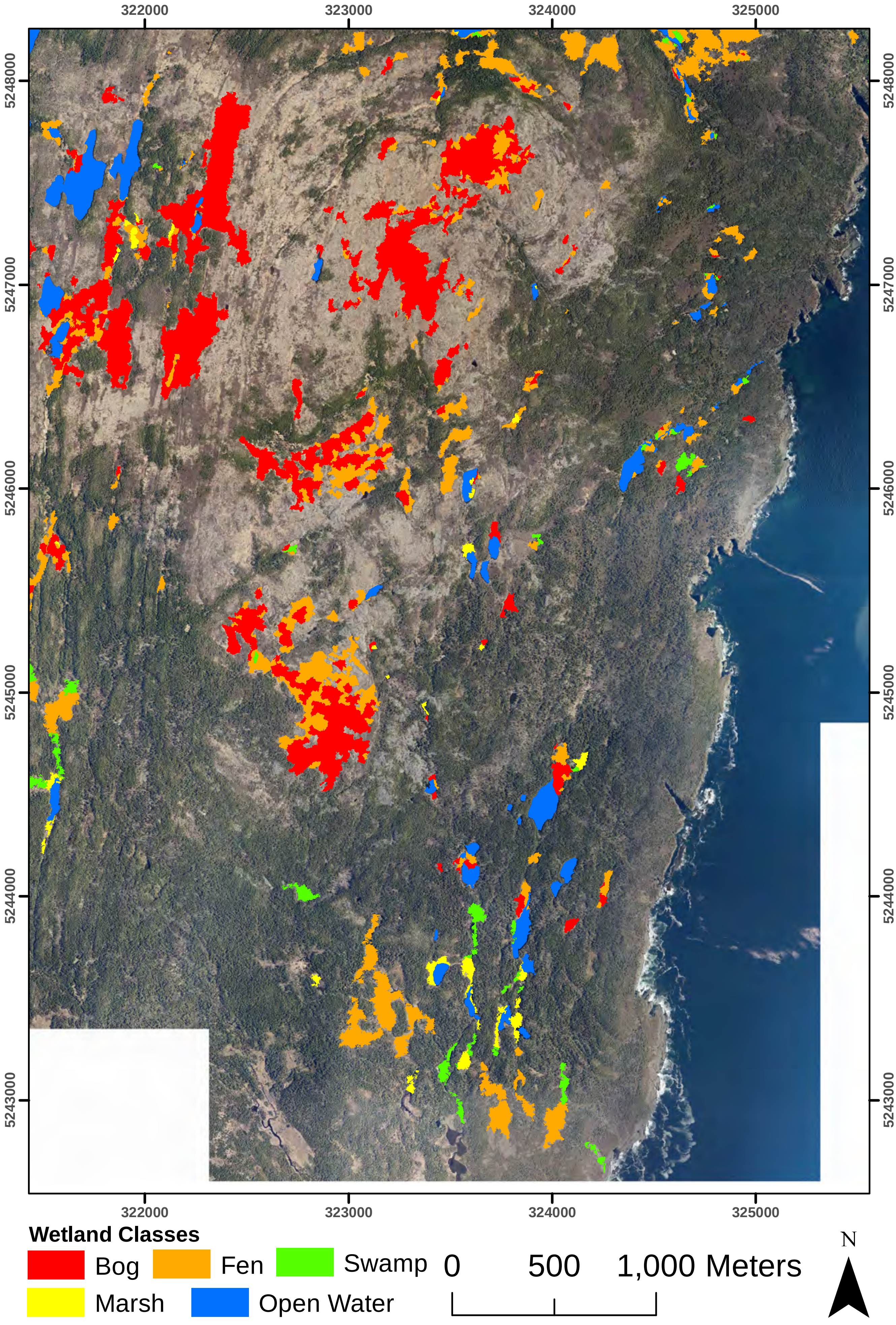
SOUTHERN SHORE HWY
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

G6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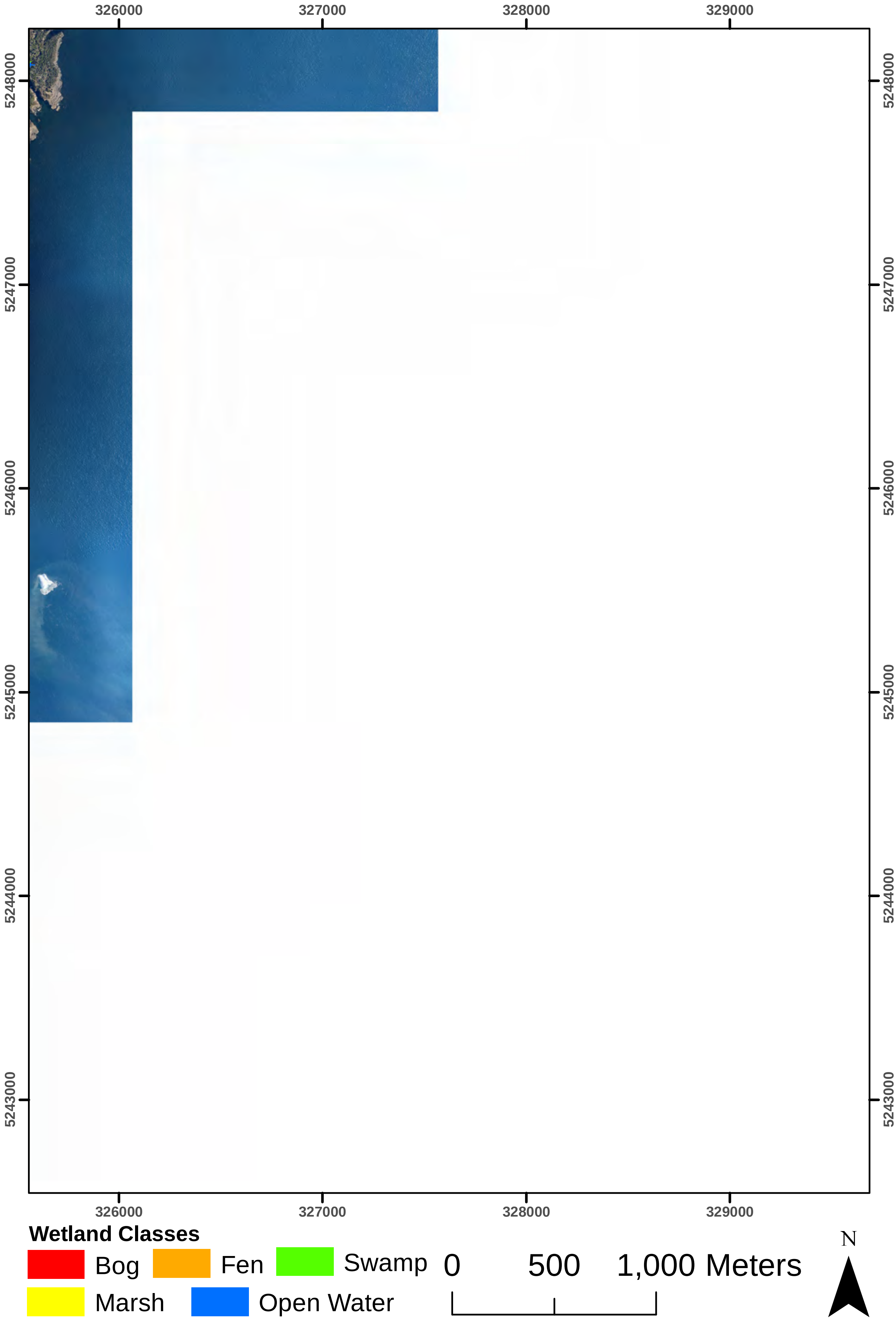
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

G7



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328000
329000
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5246000
5245000
5244000
5243000
Wetland Classes
Bog
Fen
Swamp
Marsh
Open Water
0
500
1,000 Meters
N

LAST PAGE OF DOCUMENT