Wetland Classification with Imagery, Area, and Volume in Saskatchewan.

Phalen, Daniel

Introduction

Wetlands and Drainage

Wetlands play an important and beneficial role on the landscape but are often seen as a nuisance or burden to agricultural producers. Wetlands add costs to cropping operations by adding overlap, increasing fuel and maintenance costs, and reducing the speed of machinery while also leaving land left uncultivated. There is an economic incentive for producers to drain or fill wetlands and this can lead to adverse outcomes. Wetlands offer societal value by retaining water, reducing erosion and downstream flooding, improving water quality, and providing habitat for wildlife. Despite the economic and environmental importance of wetlands, little is known about the proportion of wetlands in Saskatchewan which fall within various permanence classes. In this project, 6358 wetlands were classified into permanence classes using historical and recent satellite imagery, and a subset of 1787 wetlands were analyzed in 3D using LiDAR to determine volume.

Stewart and Kantrud System of Wetland Classification

Wetland classification was done using the Stewart and Kantrud system of wetland classification (S&K). S&K was developed in the northern prairies in the Central Lowland and Great Plains, covering a large portion of southern Saskatchewan. S&K divides wetlands into five progressive classes, as well as two others for alkali and fen ponds, though alkali and fen ponds were not used in this report. These classes list common traits associated with wetland permanence and depth at the deepest part of the wetland. The five classes as well as some common characteristics are listed below:

Class I – Ephemeral Pond	A wetland-low-prairie zone dominates the deepest part of the wetland. The soil is porous in this area therefore bottom seepage is rapid resulting in a short duration of surface water.
Class II – Temporary Pond	A wet-meadow zone dominates the deepest part of the wetland. Water seepage is fairly rapid in this zone and surface water is usually maintained for a few weeks after the spring snowmelt and occasionally for several days after a heavy rain.
Class III – Seasonal Pond or Lake	A shallow-marsh zone dominates the deepest part of the wetland. This area often maintains surface water during the spring and early summer but are often dry in late summer and fall.
Class IV – Semi-permanent Pond or Lake	A deep-marsh zone dominates the deepest part of the wetland. This area typically maintains surface water throughout the summer and typically into fall and winter.
Class V – Permanent Pond or Lake	A permanent open water zone dominates the deepest part of the wetland. This area maintains fairly stable water levels throughout the year.

Wetlands often contain multiple zones. A Class V wetland will have a permanent open water zone in the deepest area, but will usually contain rings of deep-marsh, shallow-marsh, wet-meadow, and wetland-low-prairie zones around it.

Policy Development

The Water Security Agency (WSA) is the government of Saskatchewan's water management organization. Since 2015, the WSA has been implementing the Agricultural Water Management Strategy which contains regulations, legislation, and policies to support responsible drainage. In addition to these changes, the WSA has been supporting research and analysis on the landscape to better understand the mechanisms driving drainage and the impacts of the drained wetlands. Understanding the prairie pothole landscape is key to creating effective policy. This report will help WSA understand the distribution of wetland classes across the province as well as provide a better estimate to the volume of water that they hold.

Methods

Locations

This report looked at five locations, all of which are in Saskatchewan. Landscape slope, soil type, and surficial geology classification was retrieved from the Canadian Soil Information Service (CanSIS). Original wetland data was retrieved from the ADAM database managed by the WSA, originally sourced from the Ducks Unlimited Wetland Database. Wetland attributes largely remained the same from the ADAM database but some were modified, wetland delineations were changed as needed, many wetlands were added, impact classes were occasionally changed when they appeared incorrect, and wetland class was added for most of the wetlands.

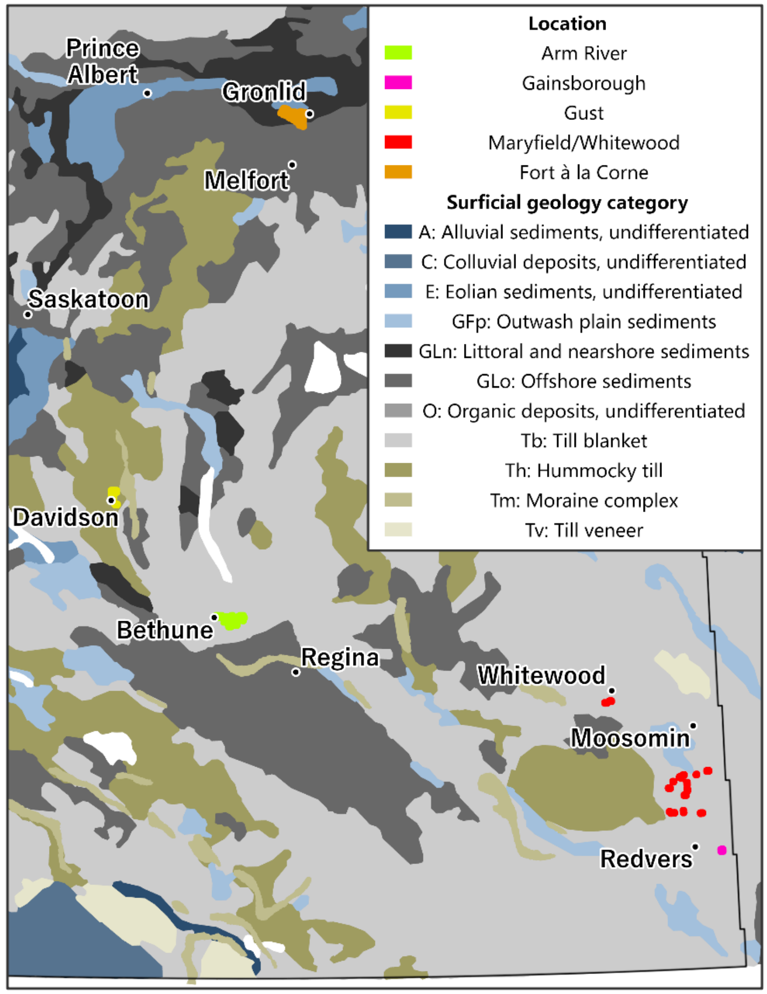


Figure 1 – Report locations and surficial geology

Gainsborough ■

The Gainsborough area is in southeast Saskatchewan, East of the town or Redvers and flows into the Gainsborough Creek. The area is approximately 960 acres in a black soil zone with a slope class of 3 and a surficial geology of morainal plain.

Arm River ■

The Arm River area is in south central Saskatchewan, east of the town of Bethune and consists of two neighboring drainage networks that flow into the Arm River. The area is approximately 7,600 acres in a dark brown soil zone with a dominant slope class of 4 and a surficial geology of morainal undulating. The area contains 58 buried culverts which act as drainage flow controls.

Fort à la Corne ■

The Fort à la Corne area is in central Saskatchewan, north of Melfort, and drains into Carrot River. The area is approximately 14,340 acres in a dark grey soil with some 2 and 3 slope classes but predominantly class 4 and 5 and a surficial geology of glaciolacustrine and glaciolacustrine delta.

Maryfield/Whitewood ■

The Maryfield/Whitewood area is a selection of land over 23 quarter sections scattered around the communities of Maryfield and Whitewood in southeast Saskatchewan. The total field area is 4,030 acres in a mostly morainal landscape.

Gust

The Gust area is in south central Saskatchewan, bordering the town of Davidson, and draining into Iskwao Creek. The area is approximately 7,700 acres in a dark brown soil zone with some 1 and 4 slope classes but predominantly class 2 and 3 and a surficial geology that is mostly glacial lacustrine plain.

Methodology

Wetland Classification

Wetlands were classified using remote sensing and the S&K. The imagery made available was the WSA historical imagery database as well as four sets of historical imagery, three from 1979 and one from 1986. In addition, there was "Sask SPOT 1.5m 2016" and FlySask Ortho Images from 2008-2011, 2012-2016, and 2017-2021.

Class I and II wetlands were lumped together into one category as the distinction was not needed. Using the S&K system, we reviewed imagery for the wetlands looking for permanent open water zones (Class V), a deep-marsh zone (Class IV), a shallow-marsh zone (Class III), and if none of these were present, wetlands were labelled Class II.

Figure 1 below shows examples of each class of wetland using different sets of imagery and in different locations. Note that Class II and III have a different scale than IV and V.

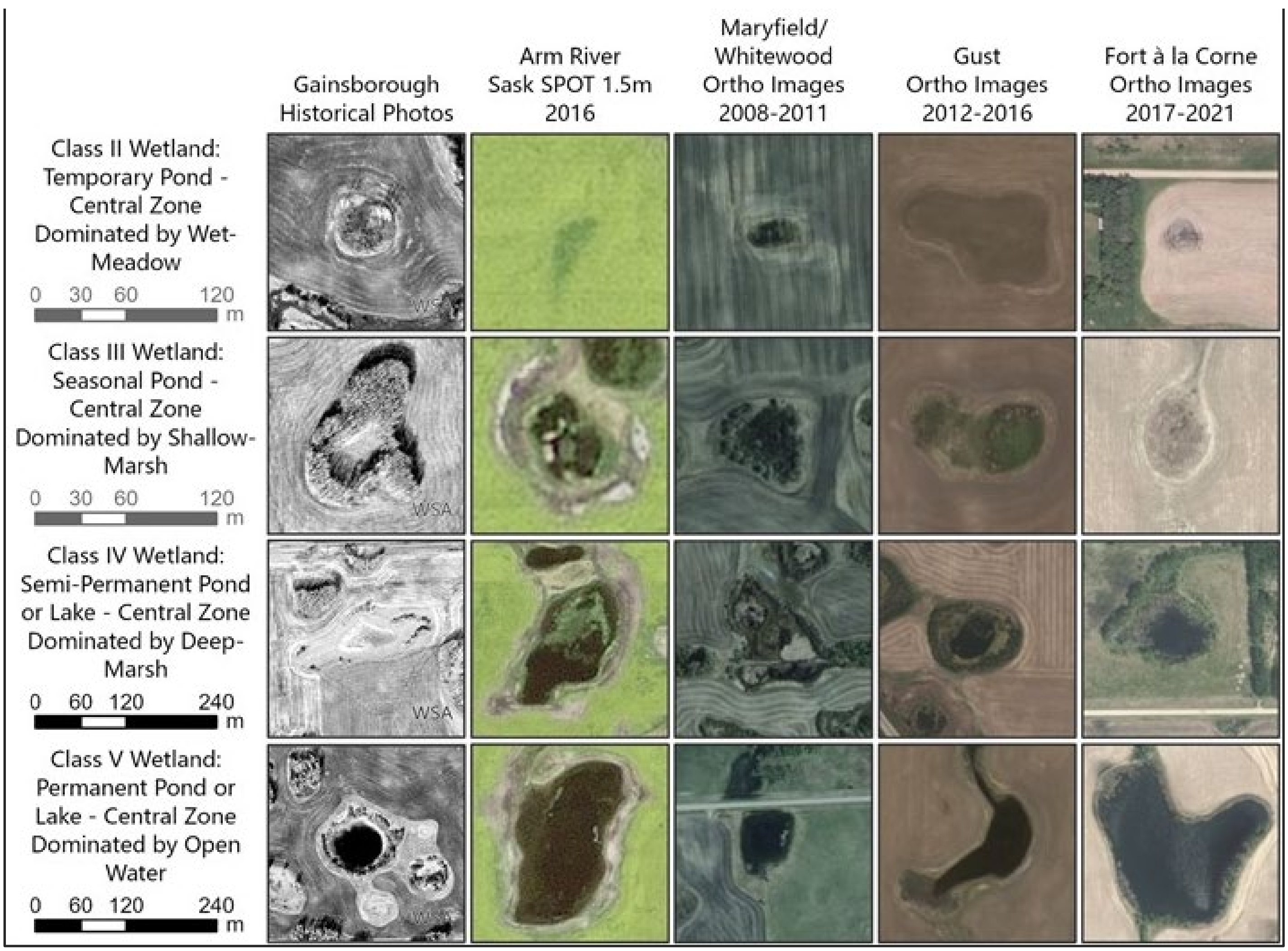


Figure 2 – Wetland classification examples in various regions and using various imagery sources

Volumetric Analysis

Wetland volumes were calculated using LiDAR provided by the WSA and using ESRI ArcGIS Pro's Cut and Fill tool. This tool provides two metrics used in analysis, fill area and fill volume. The Cut and Fill tool calculates these metrics by allowing the user to add a plane in 3D geometry and then calculates the volume between the plane and the ground surface below. The tool also provides the area of the plane that is above the ground surface. This is shown in Figure 3 with ground elevation exaggerated 5x to better illustrate.

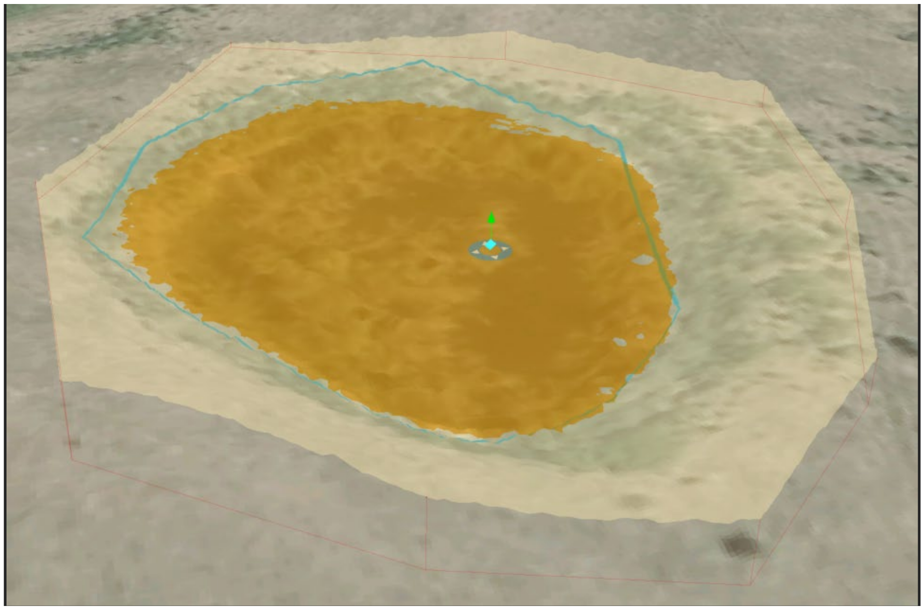


Figure 3 – A Cut and Fill plane across a wetland used to calculate volume and area.

Using LiDAR, cut and fill polygons were delineated well beyond the extent of the wetland and then with reference to the previous wetland delineation as well as two selected sets of imagery, the plane was adjusted to the top of the wetland's wet-meadow zone. These planes were then exported into a shapefile and paired to the original wetland layers.

Wetland Delineation and Attributes

The wetlands and associated values in this report are based on the historical wetland coverage. Currently drained wetlands were included and delineated based on historical imagery and LiDAR.

Wetland shapefiles were provided by WSA for the areas in this report and the attribute "Wetland_class" was added for shapefiles which did not have that attribute column. Additional attributes were added to the dataset from the Cut and Fill tool. The attributes relevant to the work done are:

Attribute	Content	Definition	Notes
OBJECTID	Integer (0, 1, 2, 3…)		Used to ID wetlands
Impact	0	Intact	Not drained, not farmed
	1	Partly Drained	Drained but still contains significant amounts of water
	2	Farmed	Not drained, but shallow enough that land can still be cropped most years
	3	Constructed	Man-made wetland (Dugouts)
	5	Completely Drained	Completely Drained
Site	Text		Locations described in this report
Acres	Float		Size of wetland polygons
Wetland_class	2	Class I/II Wetland	
	3	Class III Wetland	
	4	Class IV Wetland	
	5	Class V Wetland	
Volume	Double		Estimated volume of the wetland based on LiDAR and imagery.
Varea	Double		Surface area above the wetland volume
Ratio	Number		Added in Excel. =Varea/Volume
Area Dif %	Percentage		Added in Excel. Relative size of WSA polygon and new area delineated in volume analysis.

Table 1 – Relevant wetland attributes

Results

Overview by Location

In the 7,600 acres of the Arm River area, 1,997 wetlands were delineated (regardless of impact code) and classified for a total combined area and volume of 1,110 acres and 1,600 dam^3. An average wetland in the location has an area and volume of 0.56 acres and 0.80 dam^3. Wetlands historically covered of 14.61% and an average section has 168 wetlands.

Fort à la Corne has the largest and deepest wetlands in this report and has a significant amount of them. In the 14,340 acres of the Fort à la Corne location, there were 2,318 wetlands were delineated and classified for a total combined area and volume of 4,300 acres and 7,025 dam^3. An average wetland in the location has an area and volume of 1.85 acres and 3.03 dam^3. Wetlands historically covered 29.98% of the area and an average section has 103 wetlands.

The Gainsborough location had relatively small wetlands by area but were quite deep resulting in the highest ratio of Class V wetlands. In the 960 acres of the Gainsborough area, 379 wetlands were delineated and classified for a total combined area and volume of 188 acres and 235 dam^3. An average wetland in the Gainsborough location has an area and volume of 0.5 acres and 0.62 dam^3. Wetlands historically covered 19.57% of the area and an average section has 253 wetlands, the highest density in the report.

		Arm River	Gainsborough	Fort à la Corne	Gust	Maryfield / Whitewood
Wetland Count	Class I/II	1113	215	1358	266	776
	Class III	718	79	476	106	304
	Class IV	127	38	273	27	112
	Class V	39	47	211	9	61
	Total	1997	379	2318	411	1253
Total Volume (dam^3)	Class I/II	115	15	238	46	75
	Class III	555	42	422	180	127
	Class IV	253	44	911	126	188
	Class V	677	133	5454	276	190
	Total	1600	235	7025	628	580

Table 2 – Wetland distributions by location

Gust has the second largest average wetland, but that is due to a smoother landscape resulting in much fewer class I, II, and III wetlands. In the 7,700 acres of the Gust area, 408 wetlands were delineated and classified with a total combined area and volume of 560 acres and 628 dam^3. An average wetland in the location has an area and volume of 1.37 acres and 1.53 dam^3. Wetlands historically covered 7.27% of the area and an average section has 34 wetlands. These numbers are without three dammed water bodies which would add another 141 acres and 303 dam^3. These dammed bodies likely sit upon large natural wetlands, though not nearly the size they are now.

The Maryfield/Whitewood area did not have LiDAR available for volumetric analysis, the wetland formulas in figure 12 were used to calculate volume. In the 4,030 acres of the Maryfield/Whitewood area, 1,253 wetlands were delineated and classified for a total area of 552 acres and 580 dam^3. An average wetland in the location has a size and volume of 0.44 acres and 0.46 dam^3. Wetlands historically covered 13.71% of the area and an average section has 199 wetlands.

Class Distribution and Size

There is a consistent ratio of Class I/II wetlands in this report with Arm River at the low end at 55.7% and Gust at the high end with 64.7%. Class III wetlands range from 36% in Arm River to 20.5% in Fort à la Corne and there is a general trend that with more Class IV and V wetlands, you see less Class III wetlands. This is shown well by comparing Arm and Gust to Gainsborough and Fort à la Corne. Class IV wetlands range from 6.4% in Arm River to 11.8% in Fort à la Corne. Class V wetlands range from 2% in Arm River to 12.4% in Gainsborough.

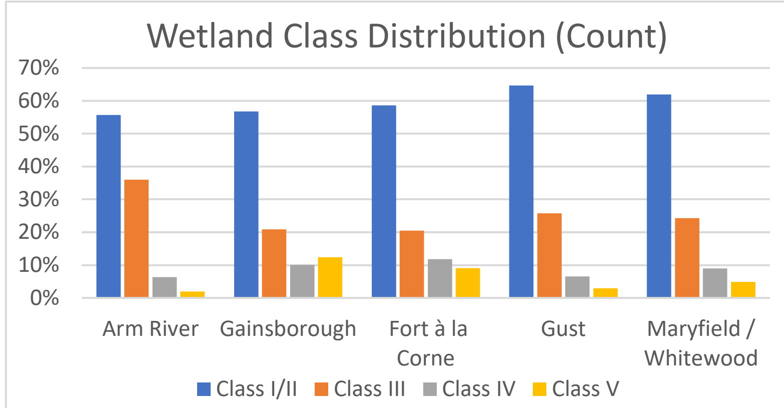


Figure 4 – Wetland distributions by location

In Figure 4, wetlands were classified by size and counted at 0.5 acre increments. In all locations, wetlands under 0.5 acres dominated the landscape in terms of count. There was significant variance with Gust being the lowest percentage at 55.2% and Arm River being the highest at 79.1%. Distribution of larger wetlands varies significantly. Arm River, Gainsborough, and Maryfield/Whitewood all have less than 2.4% of wetlands being larger than 3 acres while Gust and Fort à la Corne both have more than 8.4% of wetlands larger than 3 acres.

In Figure 5, wetlands were classified by size and total area. While the count of wetlands is highly skewed towards small wetlands, the total area is much more distributed with a very large tail, and it varies drastically by location. Wetlands over 10 acres contain more than 47% of the total wetland area in both Gust and Fort à la Corne. Looking at wetland area in wetlands larger than 3 acres again, the wetlands which represented less than 2.4% of the count in Arm River, Gainsborough, and Maryfield/Whitewood now contains an average percentage of 26.9% of the total wetland area. Fort à la Corne and Gust have 72% and 67.2% of wetland area in wetlands greater than 3 acres in size.

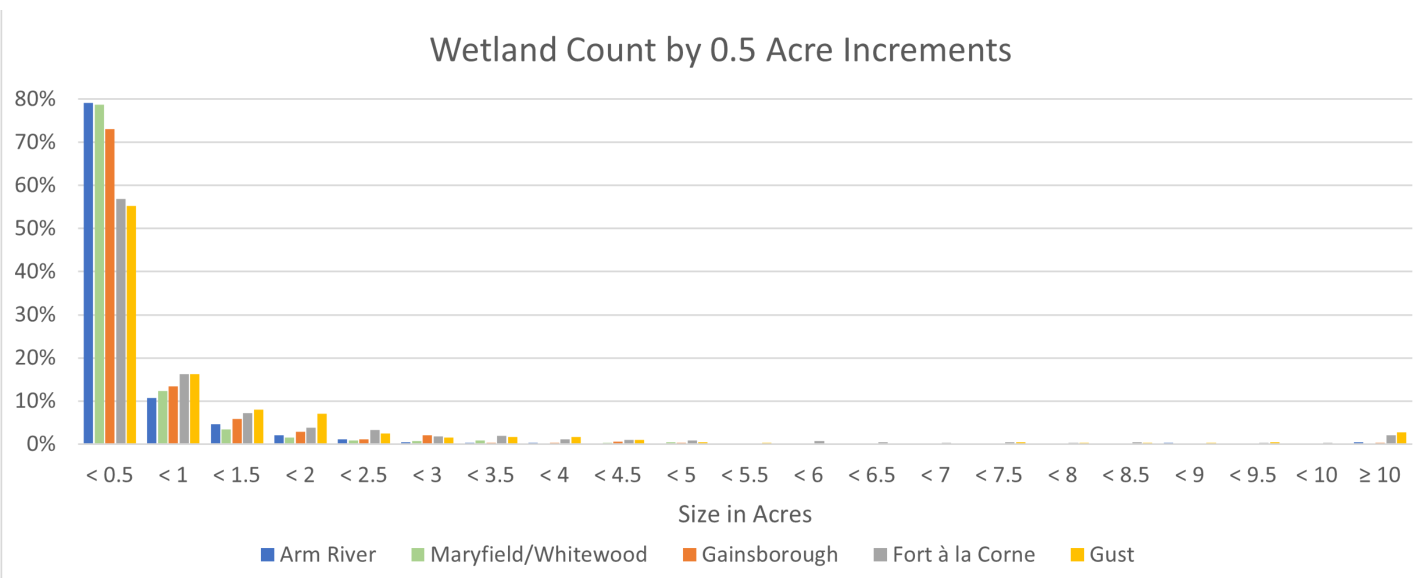


Figure 5 – Wetland count by 0.5 acre increments

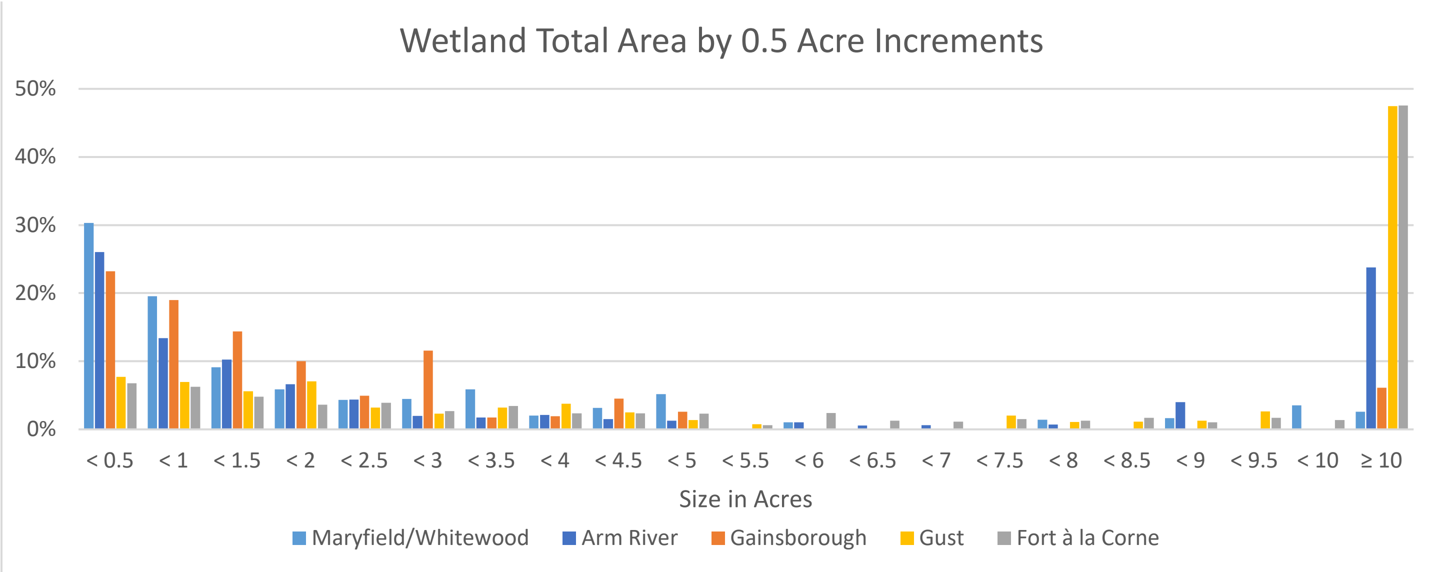


Figure 6 – Wetland total area by 0.5 acre increments

Wetland Permanence by Size

The values and figures stated in this section are from weighted data so that all locations have the same impact on the distributions. For graphs on individual locations, please see the appendix. Small wetlands, less than 0.5 acres, are dominated by Class I/II wetlands and in terms of count, they make up an average of 76% of the less than 0.5 acre wetlands. Beyond this size, class I/II wetlands quickly fall off. Between 0.5 acres and 2.5 acres, Class III wetlands are dominant. They make up an average of 39% in this range and then more slowly fall off. Class IV wetlands are not dominant at any size, aside from a couple outliers from 5.5 > 6 acres and 7.5 > 8.5 acres. Class IV wetlands are spread across the size range of 0 > 10 acres but are most common in the < 3 acre range where 84% of Class IV wetlands exist. Class V wetlands are usually the dominant class at a size of 4 acres or larger but really dominate the wetlands greater than 10 acres. Class V wetlands make up 43% of wetlands from 4 to 10 acres and 72% of the wetlands greater than 10 acres.

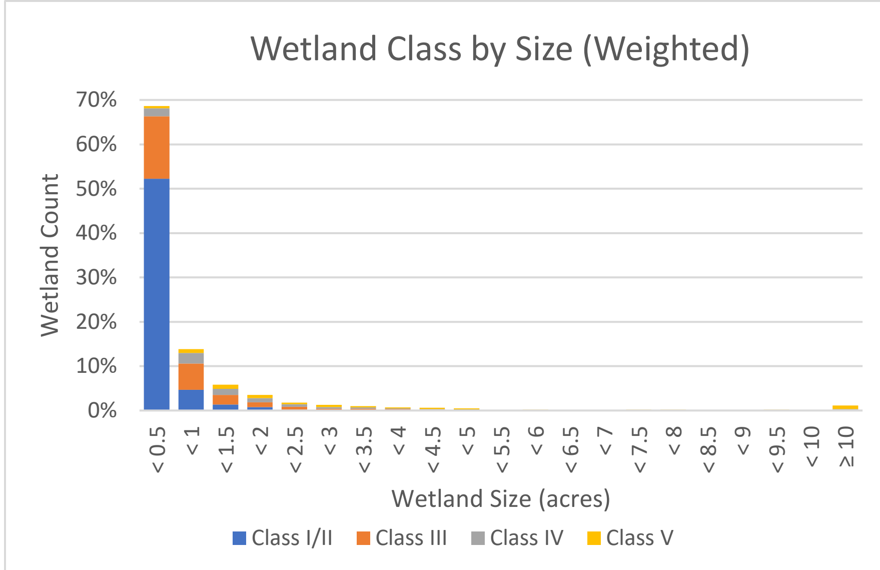
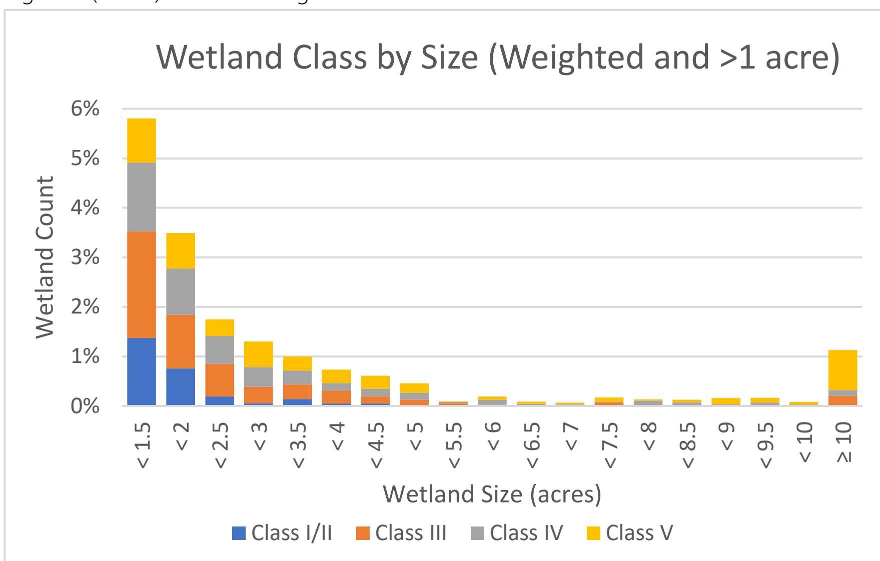


Figure 7 (Above) – Distribution of Wetland Class by Size

Figure 8 (Below) – Subset of Figure 7 to Illustrate middle size distributions



Impact codes and wetland class/size

There are four impact codes that make up almost all wetlands in the locations observed and are named intact, farmed, partly drained, and completely drained. Class I/II wetlands are mostly farmed (60%) or completely drained (28%) with most of the remaining being intact (12%). Class III wetlands are about equally likely to be completely drained (35%) or intact (34%) and another large portion are farmed (23%) with the remainder being partially drained (8%). Class IV wetlands have highest ratio of intact wetlands (43%), 27% completely drained, 25% partially drained with the remaining farmed. Class V wetlands are 41% intact, the largest ratio partially drained (37%), and most of the rest being completely drained (22%).

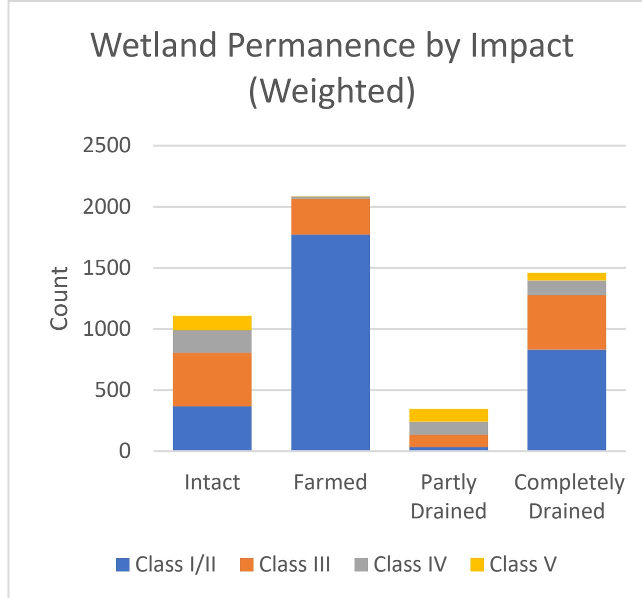


Figure 9 – Wetland Permanence by Impact Code

Wetland impacts were also compared to size and for the following paragraph, percentages are the percent within class and average percentage refers to the average of the percentages of each size, and therefore are not weighted based on acres. The smallest wetlands were most likely to be farmed with 48% of the area of wetlands under 0.5 acres being farmed and 17% for wetlands between 0.5 and 1 acres. There were no farmed wetlands larger than 4 acres. Wetlands were fairly consistently drained based on size and averaged 29% of all percentages. Going from small to large wetlands, there is not much of a trend with 26%, 36%, 29%, 31%, 34%, 13%, and so forth until getting to greater than 10 acres where 37% are drained. This is not the case for partly drained wetlands where small wetlands are very unlikely to be partly drained. The average percentage is 30% and from small to large goes 4%, 14%, 19%, 23%, 42%, 36% after which it averages 35%. The remaining intact wetlands, with an average percentage of 35%, are slightly less common in small wetlands but remain fairly consistent, percentages going from small to large are 22%, 33%, 39%, 38%, 42%, 41%, and so forth until getting to greater than 10 acres where 26% are intact.

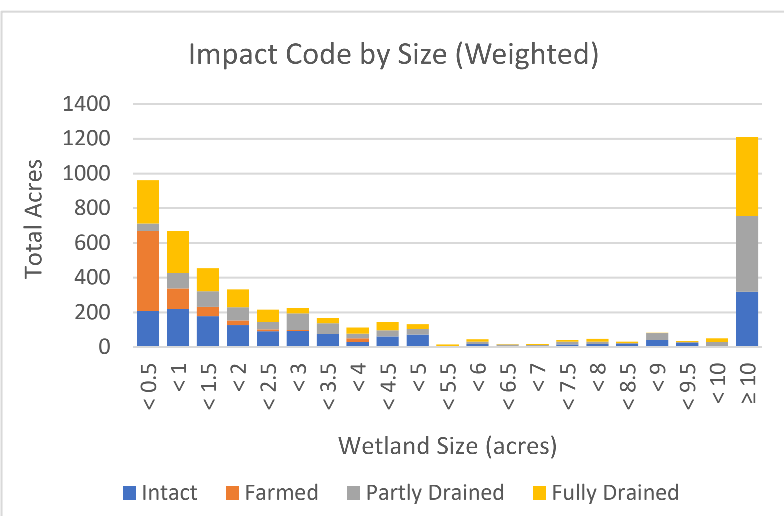


Figure 10 – Total area by impact code by size. Weighted to 1000 acres per location

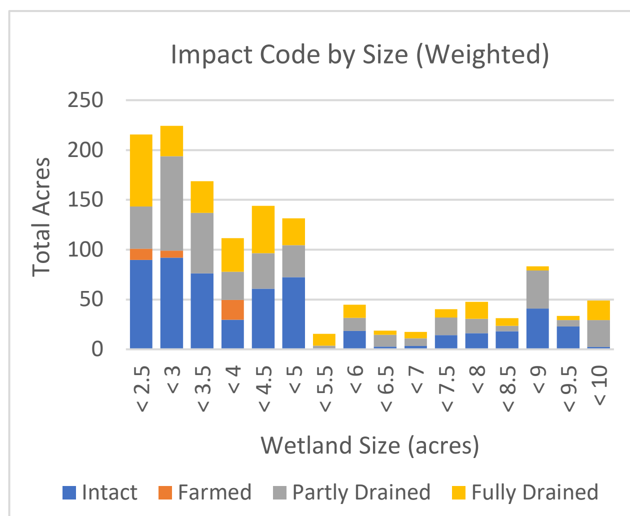


Figure 11 – Subset of Figure 10 to better show 2 to 10 acres bins

Volume

Volume by Location and Permanence

The wetland volume data is a set of 1787 wetlands from Arm River, Gainsborough, Gust, and Fort à la Corne. Subsets of the wetland polygons were used to reduce the number of Class I/II and III wetlands through random number generation. While the full set of wetland polygons were looked at to use in Class IV and V volume analysis, many were not able to be calculated properly. This is due to many of the large wetlands having significant amounts of water when the LiDAR was flown. This resulted in many higher class wetlands having to be skipped over as the volume would not be representative of reality. To apply volume data to the locations, the average volume of Class I/II wetlands for each area was multiplied by the count of wetlands. The same was done for Class III wetlands. Because samples were random and almost all in the subset were used, there should not be a selection bias. This is not true for Class IV and V wetlands because of the low sample sizes and inconsistency with water, especially in the larger and deeper wetlands. Class IV and V wetland volumes were estimated using the formula's $v=(a/x)*4.04686$ and $v=((a*622.115)^{1.118568})/1000$ respectively where v is in dam^3, a is acres, and x is the slope of the line of best fit from the scatterplots with the relative location in the appendix. Maryfield/Whitewood area used the slope from the scatterplot for all wetlands as it did not have LiDAR and therefore volume data available, the rest used their respective slopes for Class IV wetlands.

		Arm River	Gainsborough	Fort à la Corne	Gust	Maryfield / Whitewood
Average Volume	Class I/II	0.10	0.07	0.18	0.17	0.10
	Class III	0.77	0.54	0.89	1.70	0.42
	Class IV	2.70	1.10	3.20	4.86	1.68
	Class V	17.37	2.84	25.85	30.65	3.12
Total Volume (dam3)	Class I/II	115	15	238	46	75
	Class III	555	42	422	180	127
	Class IV	253	44	911	126	188
	Class V	677	133	5454	276	190
	Total	1600	235	7025	628	580
Percent Volume	Class I/II	6.8%	6.4%	3.4%	7.2%	12.9%
	Class III	32.8%	18.3%	6.0%	28.5%	22.0%
	Class IV	20.3%	18.0%	12.5%	20.7%	32.3%
	Class V	40.1%	57.4%	78.0%	43.6%	32.8%

Table 3 – Wetland Volume by Location and Permanence

While the distribution of volume varies greatly between locations, average percentages are 7.3% for Class I/II, 21.5% for Class III, 20.8% for Class IV, and 50.4% for Class V wetlands.

Plotting Wetland Volume by Area

Volumes were input in scatterplots to view trends and distributions. The formulas of the lines of best fit are improved ways of estimating wetland volume using just area over a single formula. Wetlands of Class II and Class V can have similar areas but vary drastically in volume. Using the formulas in Figure 6, wetlands of ½ hectare (1.24 acres), Class I/II wetlands would be 0.66 dam, Class III wetlands would be 1.08 dam, Class IV wetlands would be 1.63 dam, and a Class V wetland would be 1.68. Class IV and Class V wetlands are estimated to be similar in small wetlands due to using a Power function for Class V wetlands but start diverging with larger wetlands.

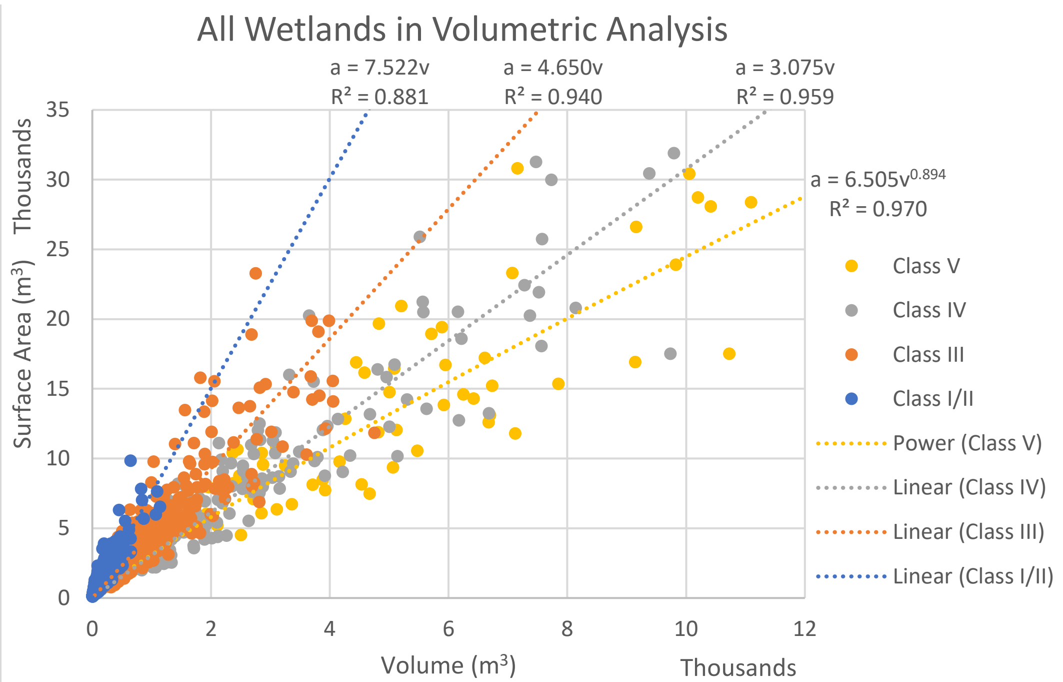


Figure 12 – Plotting wetlands by surface area and volume by class

In addition to calculating wetland volumes, the slope of the line of best fit also defines the average depth of a wetland. On average, a wetlands average depth for a Class I/II wetland is 1 / 7.522 or 13cm, a Class III wetland is 22cm, and a Class IV is 33cm deep. These are the average depths, but by using a truncated cone formula, we can estimate maximum depths with different sized bottoms. For a full cone shape, class I/II gets a depth of 39cm, class III gets 64cm, and class IV gets 96cm. For a truncated cone where the bottom area is 1/5 of the surface area, we get depths of 33cm, 53cm, and 80cm. Since Class V has a power line of best fit, a 0.5ha conical wetland will have a depth of 99cm and at 3ha, you get a depth of 1.25m and truncated with 1/5 ratio, you get 83cm and 1.04m. The estimated depth will continue to increase with size.

Limitations

It is important to note that the wetland classification was done by remote sensing and no ground truth was done. As a result, there may be a systemic error in classification which may change the distribution of wetland classes and the data derived from wetland classes and other attributes. Taking several sample spots and doing a ground truth, you could determine approximate accuracies and alter the data accordingly.

LiDAR also is not very reliable for large and deep wetlands as typically will have water and dense vegetation cutting off volume in the bottom. Many Class V wetlands were skipped over because they had too much water sitting in them, and this also gave a selection bias where the wetlands measured were shallower or drained. This was also very problematic in Class IV wetlands in the Gainsborough area as this LiDAR was flown likely in the wettest period of all the LiDAR samples.

Appendix

Figure 13 -22 are location specific counts of wetland permanence by size.

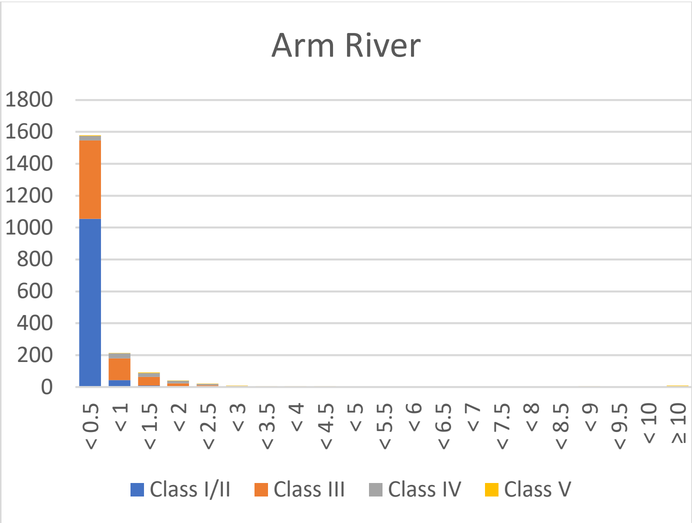


Figure 13

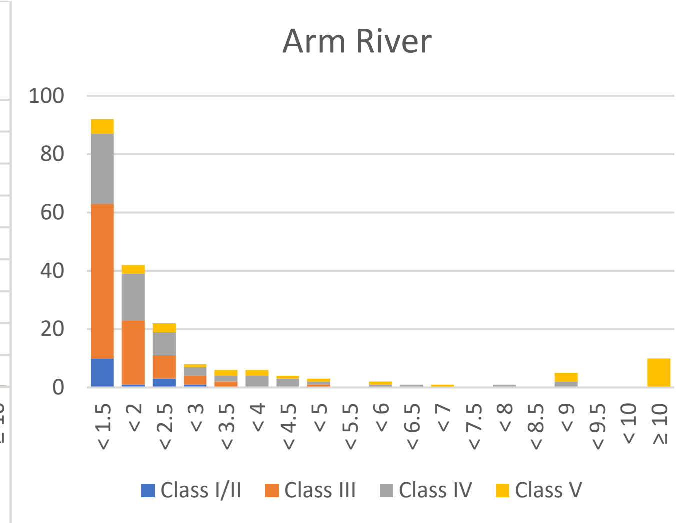


Figure 14

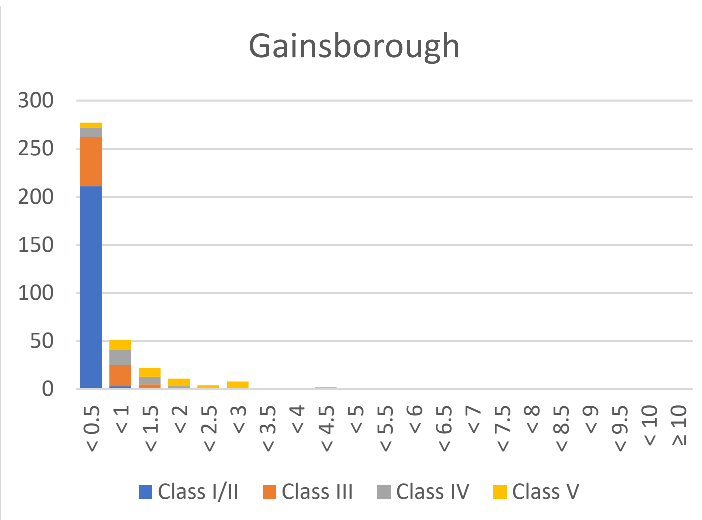


Figure 15

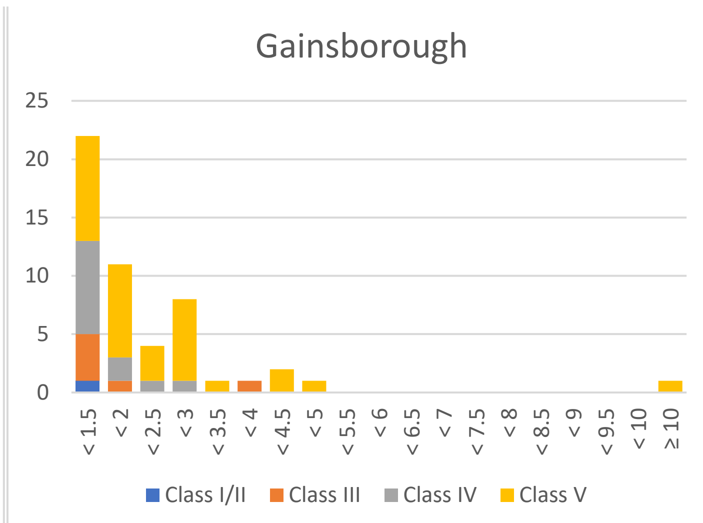


Figure 16

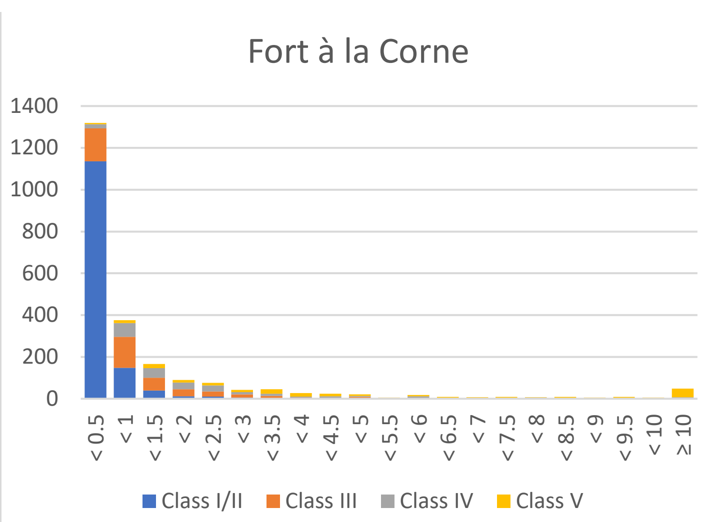


Figure 17

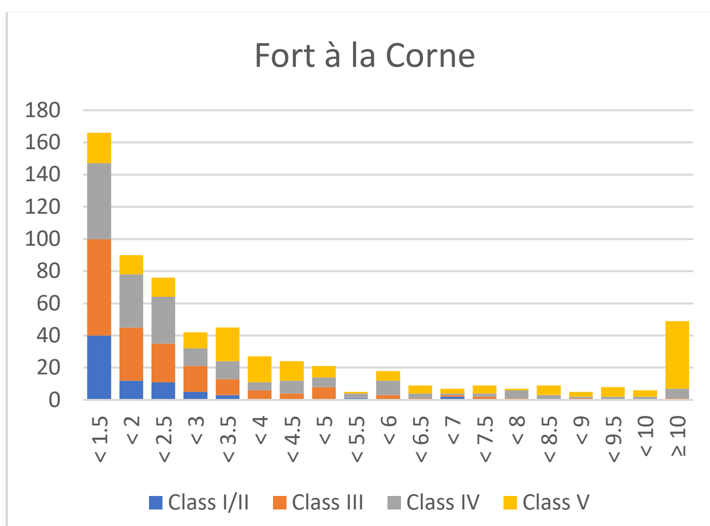


Figure 18

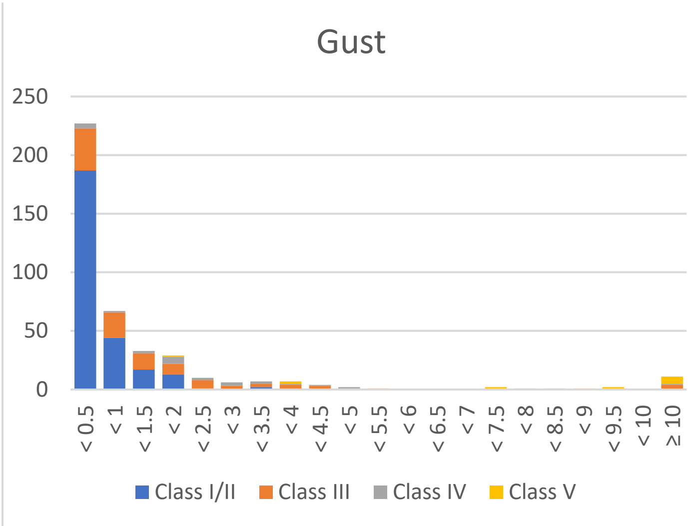


Figure 19

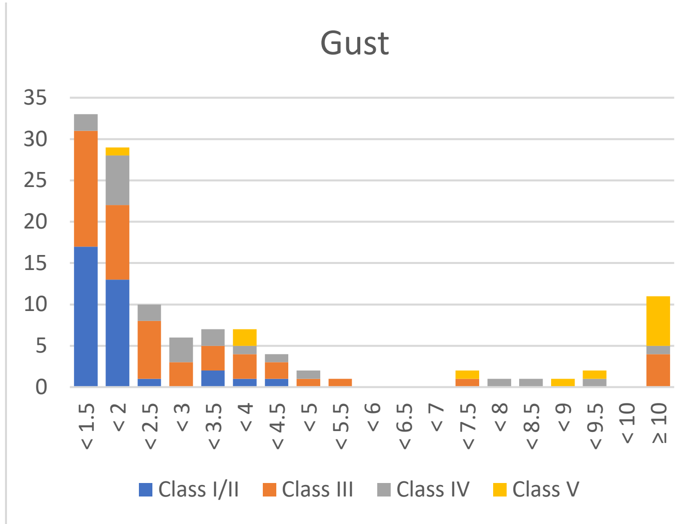


Figure 20

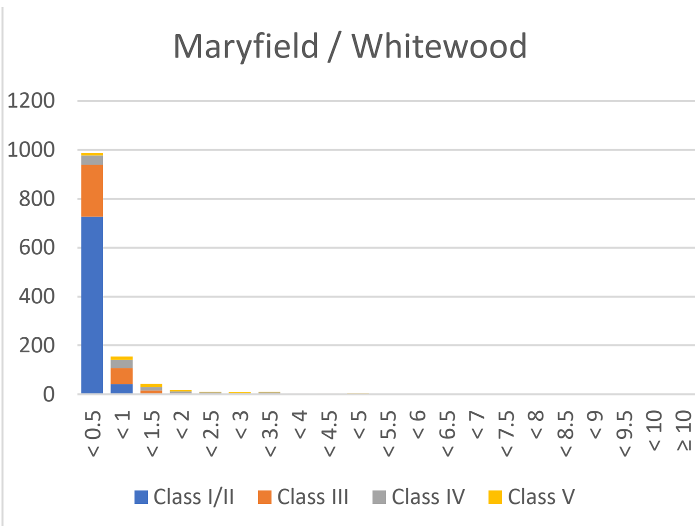


Figure 21

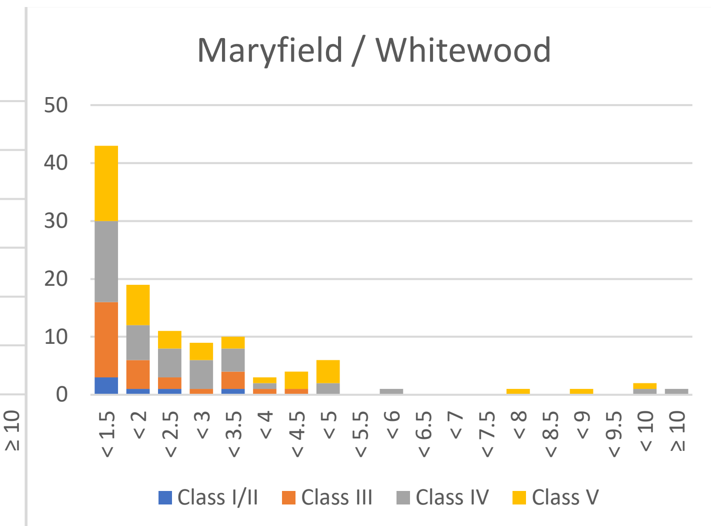


Figure 22

Figures 23 – 27 location specific counts by Impact Code

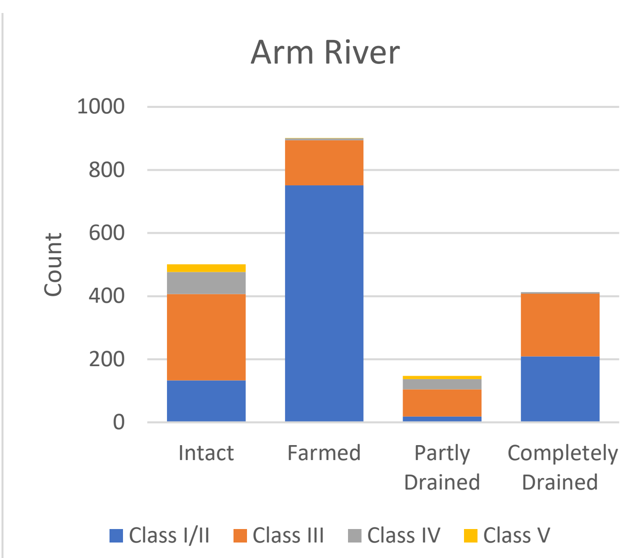


Figure 23

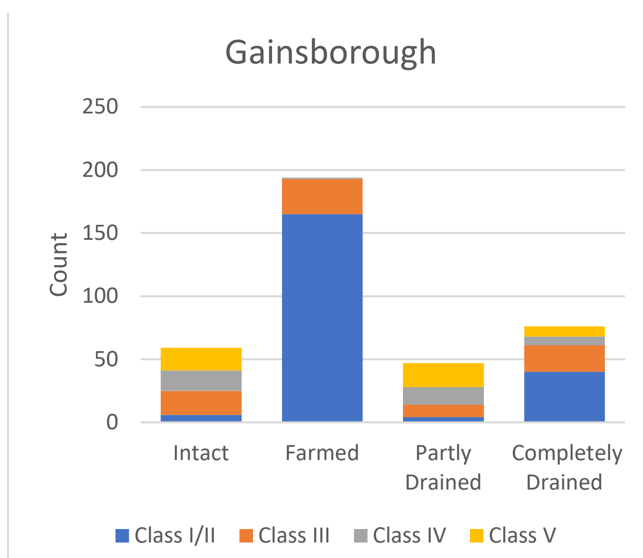


Figure 24

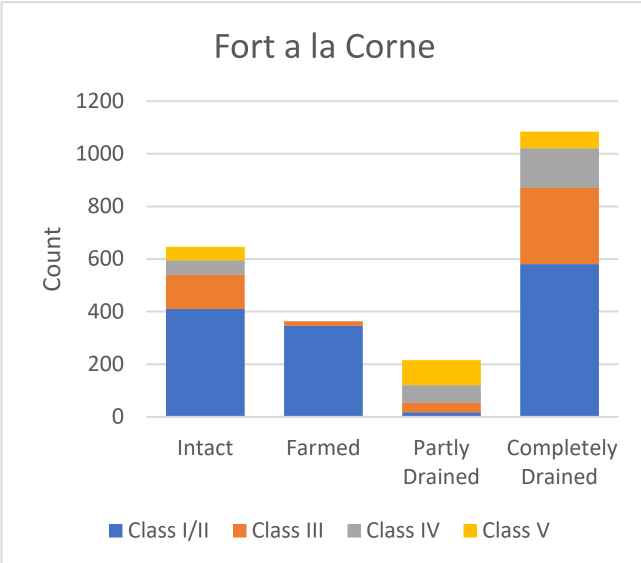


Figure 25

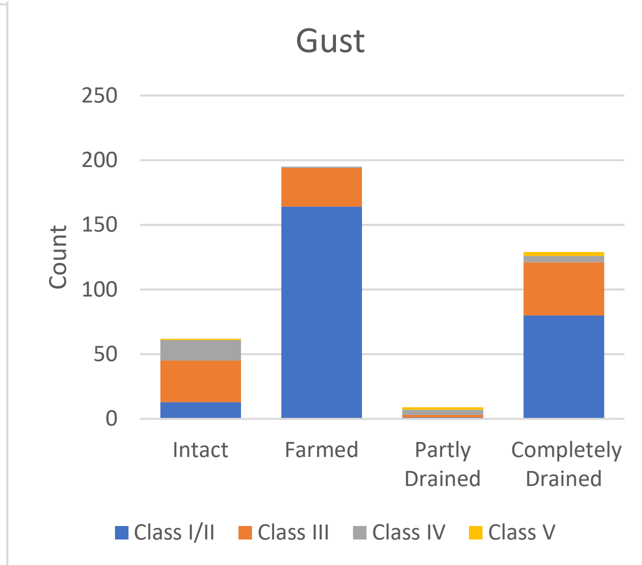


Figure 26

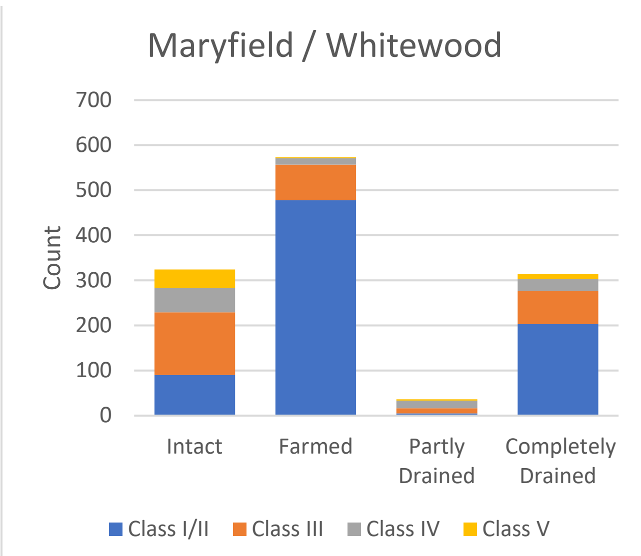


Figure 27

Figure 28 – 32 are location specific total area by size and Impact Code

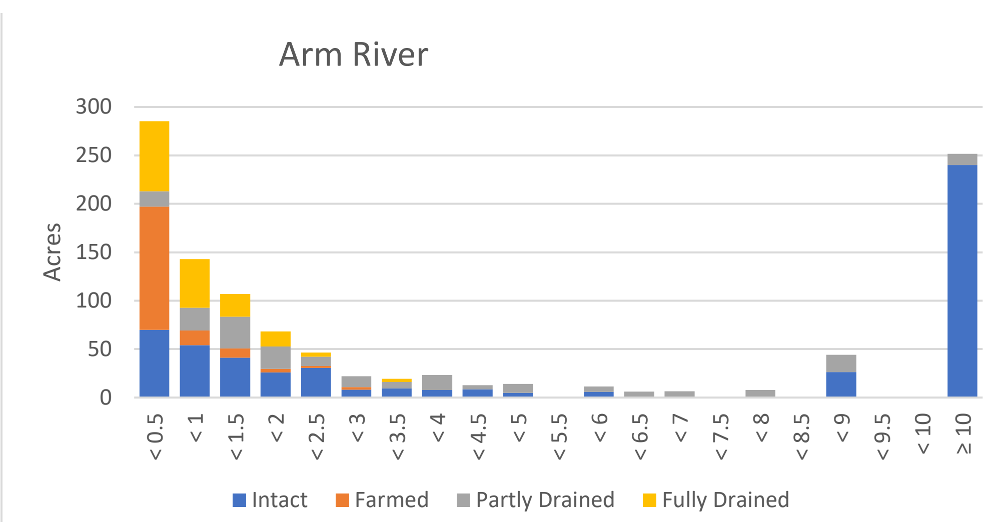


Figure 28

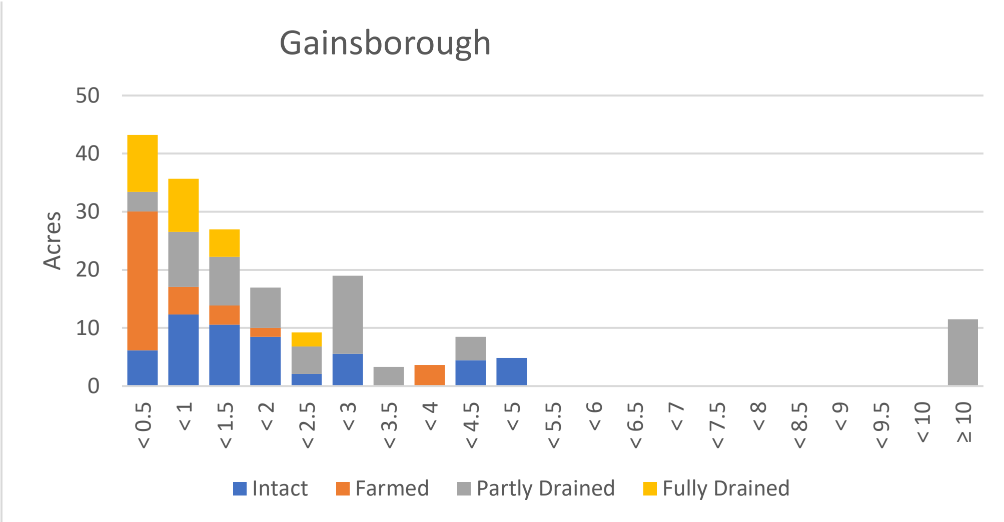


Figure 29

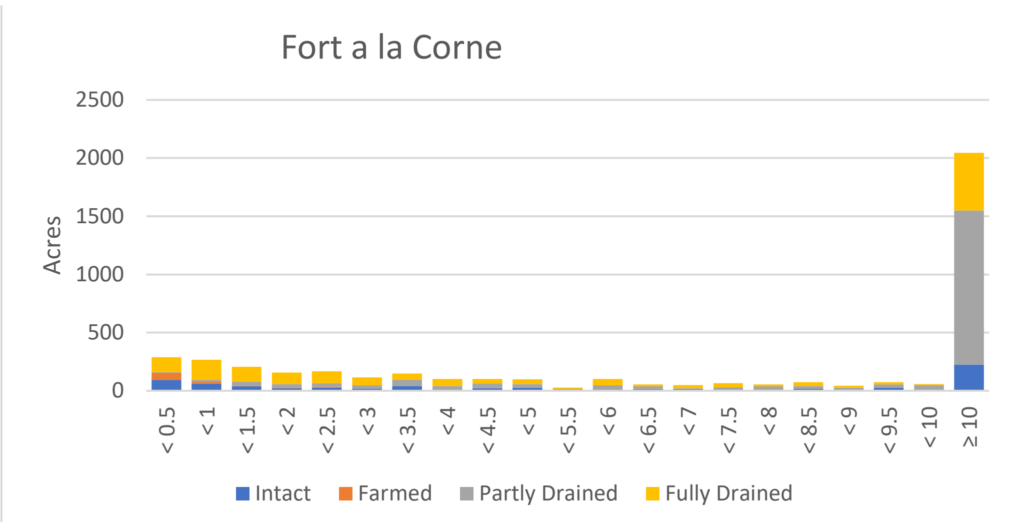


Figure 30

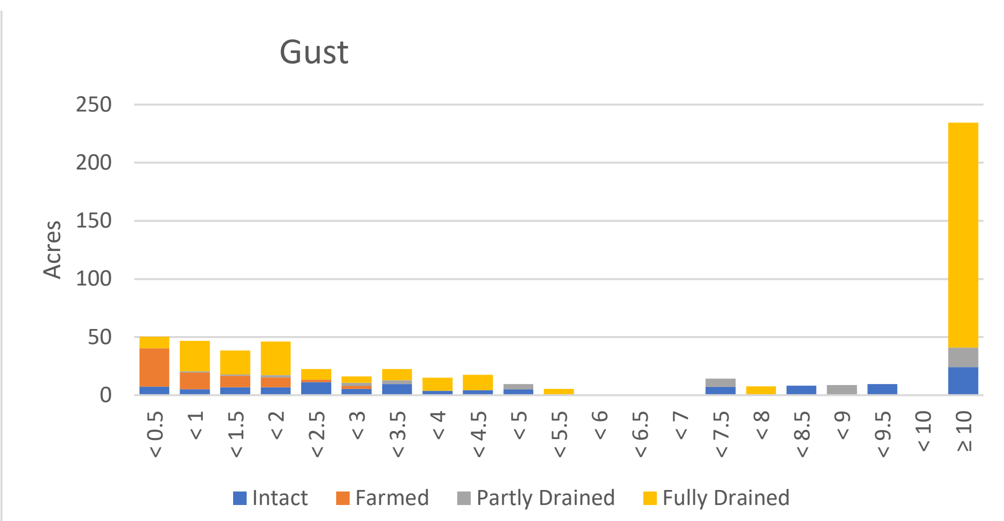


Figure 31

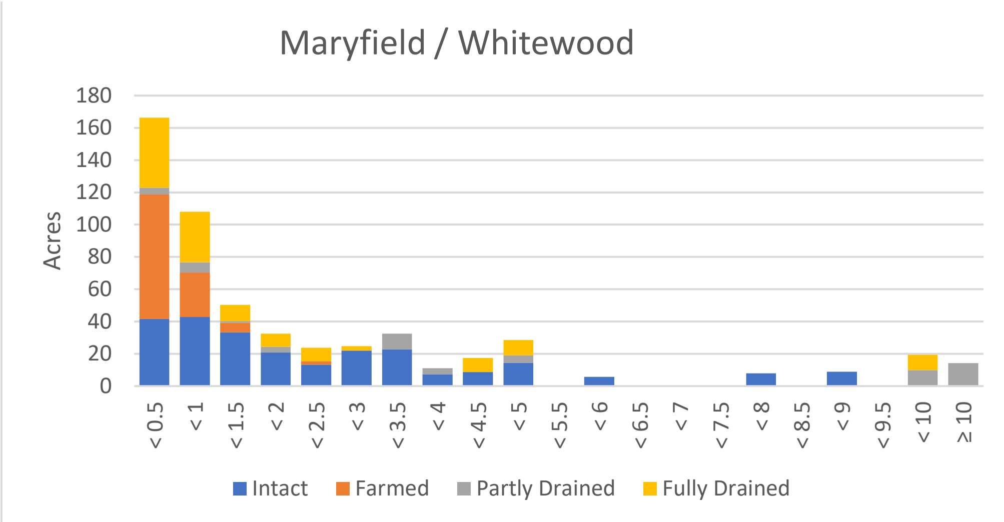


Figure 32

Figure 33 – 36 are location specific scatterplots of wetland area by volume

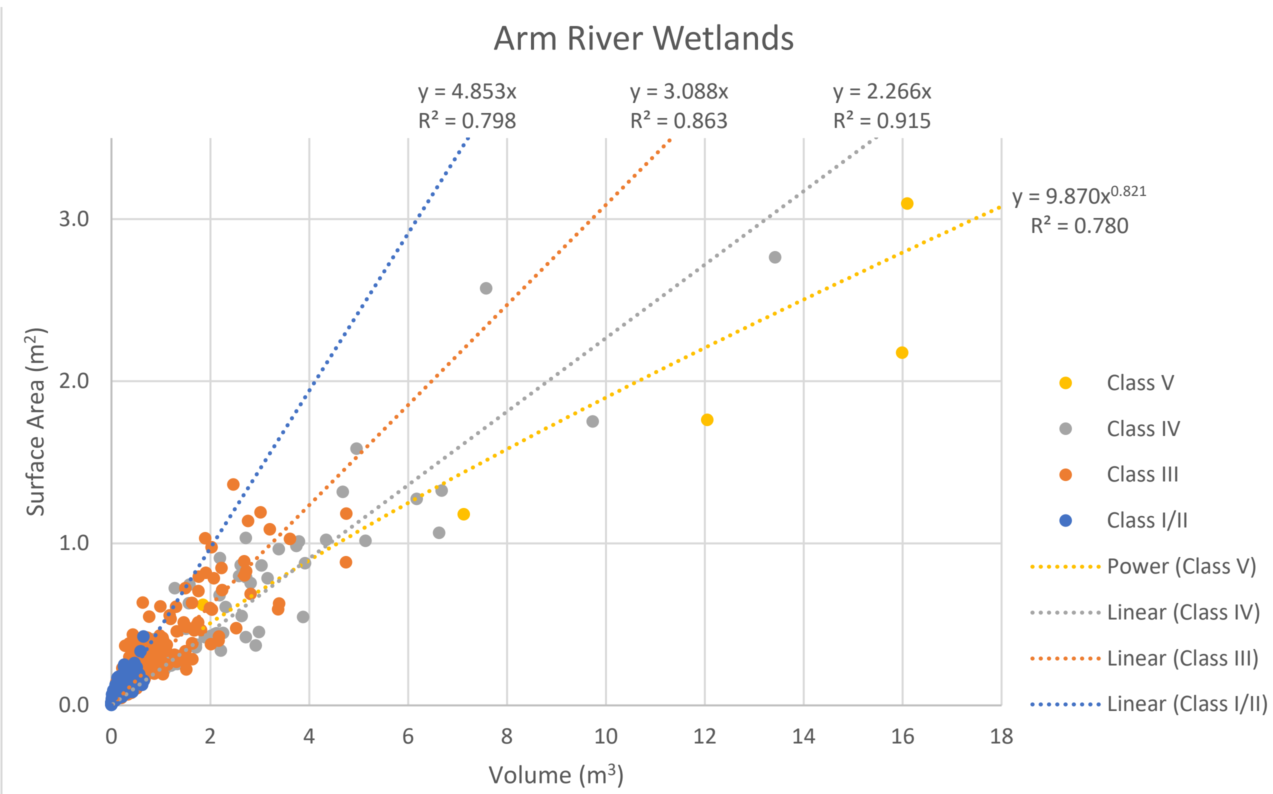


Figure 33

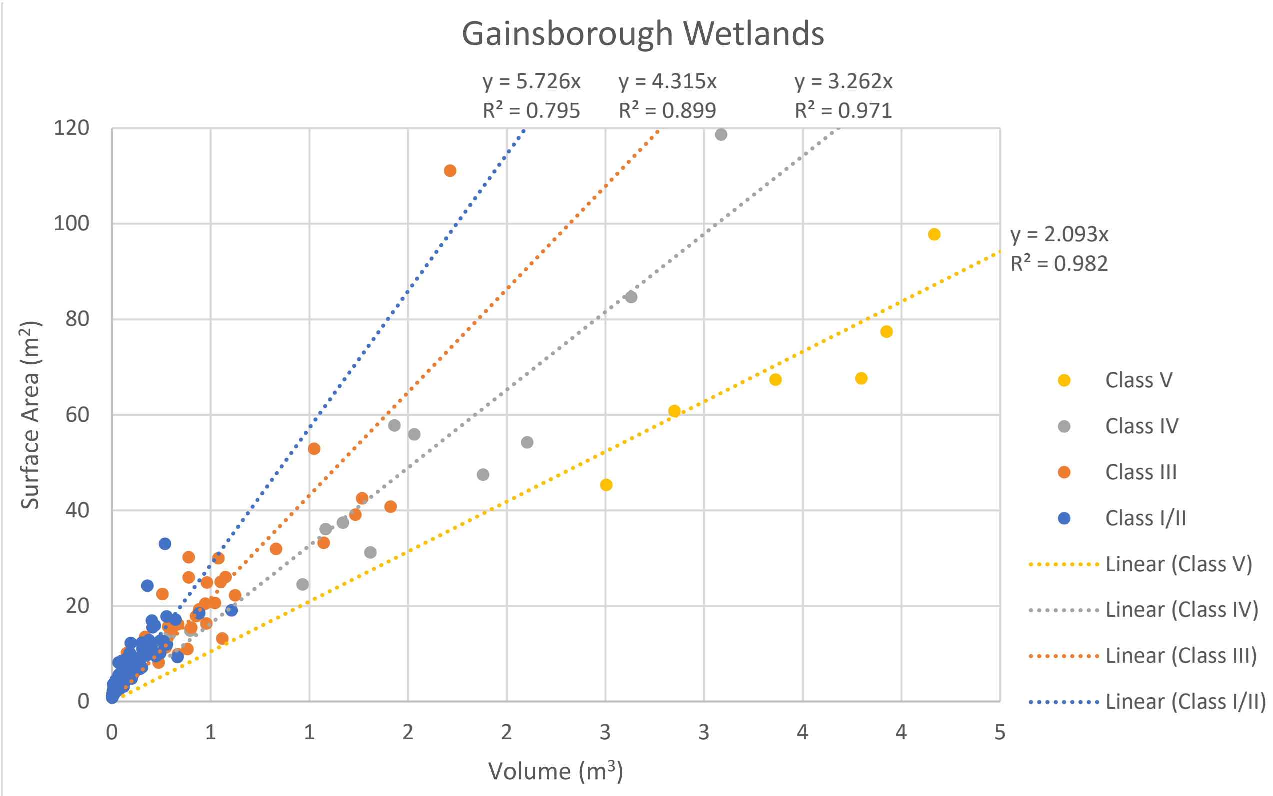


Figure 34

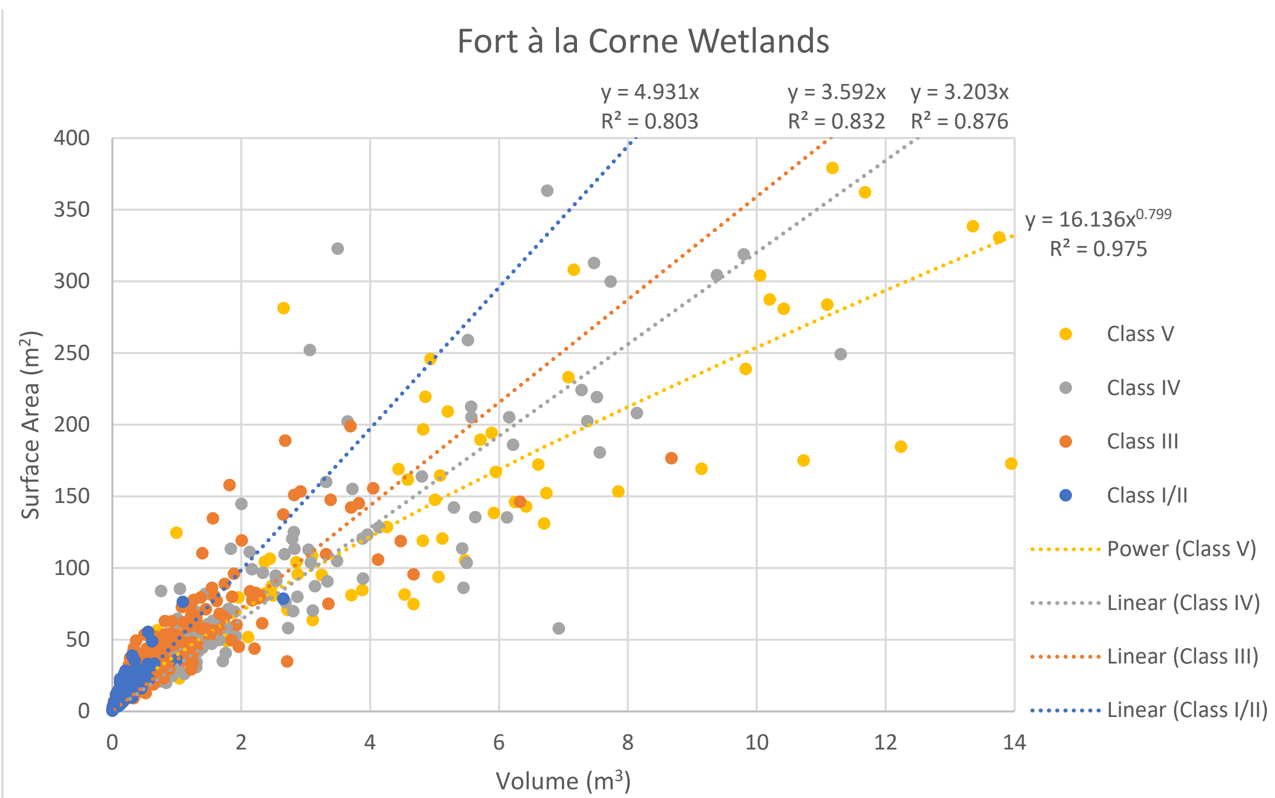
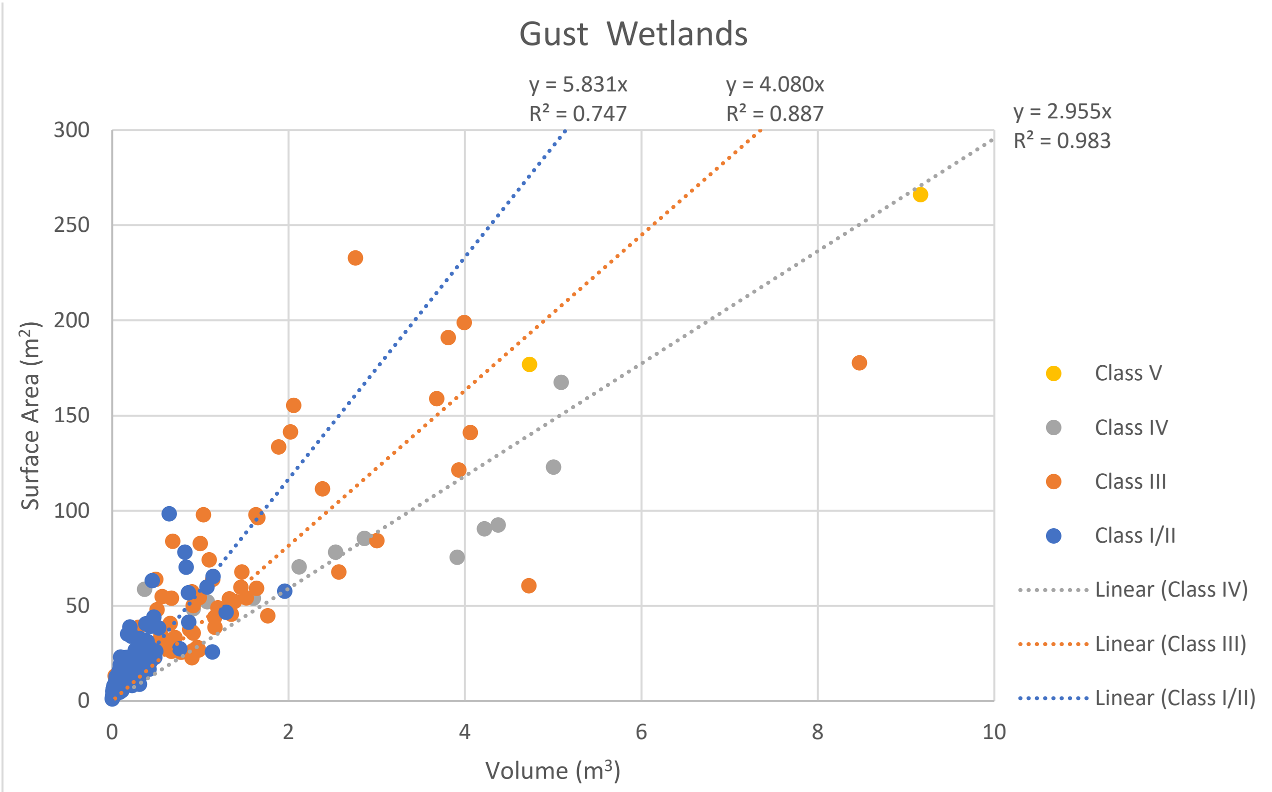


Figure 35



Gust Wetlands
y = 5.831x
R² = 0.747
y = 4.080x
R² = 0.887
y = 2.955x
R² = 0.983
300
250
200
150
100
50
0
Surface Area (m²)
0
2
4
6
8
10
Volume (m³)
Class V
Class IV
Class III
Class I/II
Linear (Class IV)
Linear (Class III)
Linear (Class I/II)

Figure 36