BIPOLE III TRANSMISSION PROJECT
Soil Productivity Monitoring for Agricultural Lands - 2018
FINAL

Prepared for :

Manitoba Hydro

Submitted by:

Stantec

Bipole III Transmission Soil Productivity Monitoring for Agricultural Lands – 2018

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Sign-off Sheet

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1.0 INTRODUCTION

Manitoba Hydro retained Stantec Consulting Ltd. (Stantec) to conduct monitoring of soil productivity along the portion of the Bipole III Transmission Project (the "Project") under agricultural crop production. This report represents the third annual report[1] on this monitoring component and includes monitoring information on the final stages of the construction phase and the first year of the operations phase of the Project.

In agro-Manitoba, primarily in the southern portion of the Project, the productivity of soils for arable agriculture is valued by agricultural producers as a primary source of income. Agricultural production is also of general benefit to society. Soil productivity can be affected by the use of heavy equipment and vehicles, disturbance of surface materials during grading, excavation of foundations, and removal of vegetation. The mechanisms of effects of construction activities on soil productivity are primarily physical, but secondary or indirect effects to productivity may occur through chemical and biological changes as a result of physical disturbances. Soil productivity is a result of numerous soil environmental factors and conditions and is difficult to measure or assess. However, these direct effects on soil properties are typically manifested in, and can be assessed using, vegetation productivity. Therefore, a vegetation productivity indicator can be used as an effective proxy for soil productivity. As such, vegetation productivity was used as an effective screening tool in areas of agricultural production to assess the effectiveness of prescribed mitigation in the maintenance and reclamation of soil productivity following construction activities.

The soil productivity monitoring program relies primarily on the use of the Normalized Difference Vegetation Index (NDVI). NDVI is calculated from remotely-sensed data collected through satellite imagery and evaluates the difference between NDVI values on the right of way (RoW) and adjacent, comparable off RoW areas. This program may be supplemented by field assessments to confirm effects. These assessments would be conducted where deemed necessary by Manitoba Hydro to better understand the nature, degree and extent of effects in situations where recovery does not appear to be taking place, for example.

1.1 OBJECTIVE

The objective of the monitoring program is to monitor crop performance in agricultural portions of the Project RoW as a key indicator of Project effects on soil productivity. The soil productivity monitoring program includes monitoring conducted for one year prior to construction, an assumed two-year construction period and for two years following construction. Applicable Project components include N4,

[1] The first annual report was submitted in 2016 and included monitoring information on the preconstruction (baseline) phase and preliminary construction phase. The second annual report was submitted in 2017 and included monitoring information on the construction phase.

C1, C2, S1, and S2 (**Map 1-1**), with portions of these components under crop production included in the monitoring program.

A three-tiered approach to monitor and assess soil productivity is being applied. This approach relies primarily on desktop-based activities, namely remote sensing of vegetative productivity using the Normalized Difference Vegetation Index (NDVI). The Tier 1 approach for initial crop productivity screening was implemented. Tiers 2 and 3 were not warranted for 2018 (**Figure 1-1**).

The monitoring activities being undertaken are outlined in **Table 1-1**.

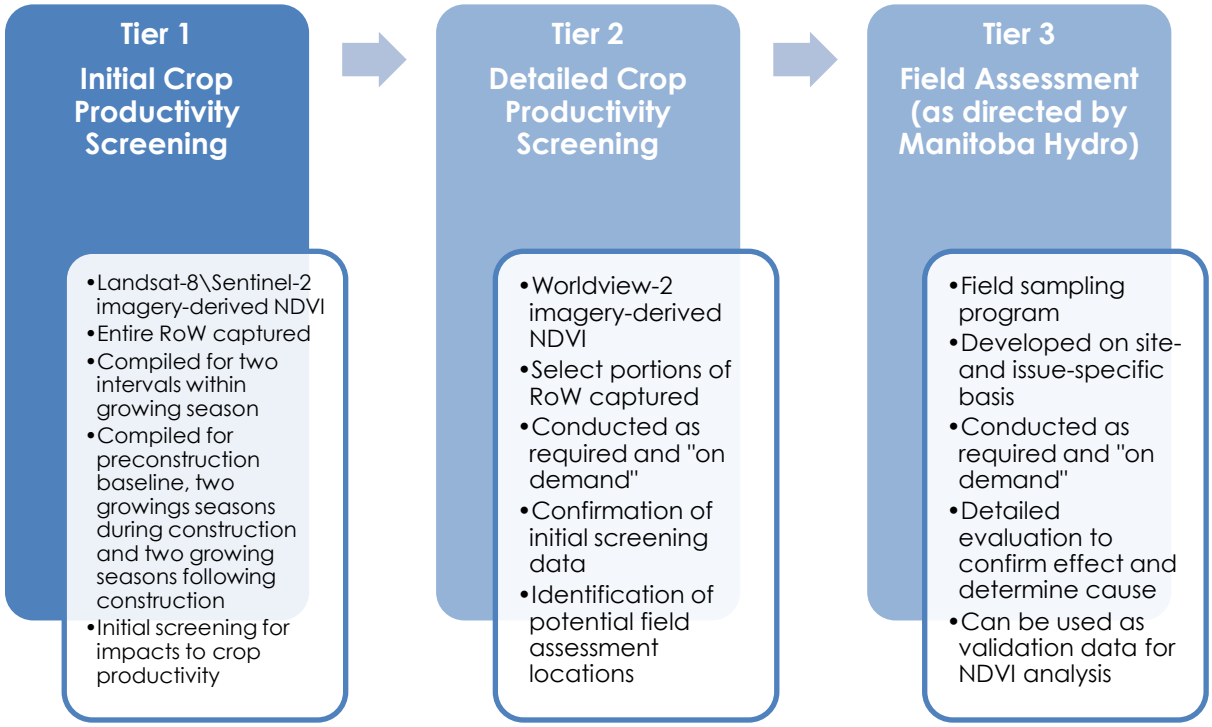


Figure 1-1 Key Aspects of the Proposed Three-Tiered Soil Productivity Monitoring and Assessment Approach for Bipole III Transmission Project

MAP 1-1 - Project Area

Table 1-1 Summary of Monitoring Activities

Phase	Task Description	Parameters	Duration	Frequency	Timing	Measurable Indicator(s)
Tier 1 Preconstruction phase (baseline)	Map crop productivity and crop type along RoW, access roads, and other temporary project footprints, plus a non-disturbed buffer area	Crop performance	One year prior to construction (pre-construction baseline) for all segments (N4, C1, C2, S1 and S2).	1-2 times per growing season	Summer	NDVI
Tier 1 Construction phase	Map crop productivity and crop type along RoW, access roads, and other temporary project footprints, plus a non-disturbed buffer area, using Landsat-8 or Sentinel-2 imagery	Crop performance	Year 1 and Year 2 of construction phase.	1-2 times per growing season	Summer	NDVI
Tier 2 and Tier 3 Post-construction phase (if required)	Map crop productivity at targeted locations and crop type along RoW, access roads, and other temporary project footprints, plus a non-disturbed buffer area, using Worldview-2 imagery. Areas for Tier 2 assessments should be selected based on review of the Sentinel-2 imagery and consideration of areas of notably reduced On RoW NDVI values that do not appear to be recovering following completion of construction activities. Field assessments at targeted locations to determine soil and crop productivity On RoW and Off RoW where differences were determined using NDVI analysis (Tier 1).	Crop performance; Soil conditions	Year 3 and Year 4 (two years following construction).	As required	Summer	NDVI and/or specific field assessment measurements for soil and crop conditions

2.0 METHODOLOGY

The methods used to conduct the soil productivity monitoring program are summarized below.

2.1 IMAGE ACQUISITION

For the 2018 monitoring season, imagery was collected from the Sentinel-2 satellite to support the Tier 1 Initial Productivity Screening[2]. The Sentinel-2 sensors provide sufficient radiometric and spatial resolution to capture crop conditions across a landscape in a cost-effective manner.

The Sentinel-2 satellite collects multispectral data, including Blue (465-520 µm), Green (540-575 µm), Red (650-685 µm) and Near Infrared (NIR) (800-915 µm) wavelengths. It collects this information at 10 meter by 10 meter resolution on a five-day revisit period. The sensor is affected by atmospheric interference such as clouds, fog, rain or smoke and requires cloud free conditions to collect surface spectral reflectance information.

Satellite image acquisition for the Bipole III RoW required multiple orbital paths due to the sheer extent of the area of interest. Due to cloud cover, a long repeat coverage period and a high level of orbital overlap, multiple orbital tracks were required over varying dates to compile a single, cloud-free imagery mosaic for the RoW sections N4 to S2 in 2018. Acquisition dates for 2018 were July 6, 15 and 18.

Tier 2 Detailed Crop Productivity Screening using WorldView-2 or comparable imagery was planned for post-construction years. However, it was not collected during 2018 as some construction was still underway in 2018. Acquisition of this higher-resolution imagery is planned for 2019.

2.2 IMAGE PROCESSING

All satellite imagery was atmospherically corrected using PCI Geomatica 2017 – ATCOR software. Top of atmosphere (TOA) reflectance values were used to convert raw pixel values to spectral reflectance signatures using the radiometric calibration coefficients from the Sentinel-2 sensors. Haze removal was performed as part of the atmospheric correction allowing for precise vegetation measurements. ATCOR successfully normalized solar illumination conditions at different time periods allowing for accurate change detection analysis. Individual images were clipped and mosaiced together creating continuous coverages of agricultural land use areas in N4 to S2.

2.3 NORMALIZED DIFFERENCE VEGETATION INDEX

Imagery was processed to quantify agricultural crop health by implementing the NDVI formula. NDVI is a measure of vegetative vigor or plant health using the Red and Near-Infrared (NIR) channels of the electromagnetic spectrum. NIR energy is highly reflected by healthy vegetation while Red wavelengths

[2] In previous years data was used from a combination of Landsat-8 (2015 and 2016) and Sentinel-2 (2016, 2017) satellites.

are highly absorbed by vibrant vegetation (**Figure 2-1**). This relationship is not as strong in stressed vegetation and is non-existent in dead vegetation. This unique vegetative property, provides detail on vegetation health and is exemplified in the NDVI formula;

(NIR – RED) / (NIR + RED) = NDVI

NDVI values range from 1 (healthy vegetation) to -1 (non-vegetation). Results of the NDVI formula can vary from one landscape to another but typically areas of water, sand, or infrastructure show very low NDVI values (for example, -0.5 or less). Bare soil usually scores near 0.0 on the NDVI scale range. Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.1 to 0.4). High NDVI values (approximately 0.5 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage.

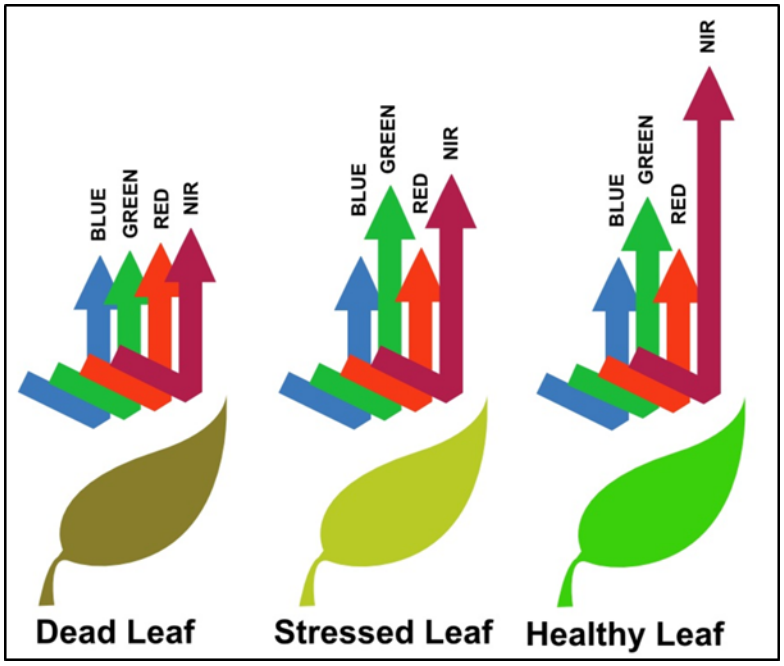


Figure 2-1 Spectral Reflectance Amount Variations for Blue, Green, Red and NIR Energy of Dead, Stressed and Healthy Crop Leaves

2.4 DATA ANALYSIS

2.4.1 Study Area Definition

2.4.1.1 On RoW and Off RoW Study Areas

In order to analyze data and evaluate for potential effects to crop productivity on the RoW from construction activities, "On RoW" and "Off RoW" study areas were established. For the 2018 monitoring program: the 20-m Corridor centered on the Bipole III route centerline was used for evaluation of On RoW productivity[3]. Off RoW study areas were defined using 66-m wide buffer areas on each side of the RoW (**Figure 2-2**). The definition of these areas for sections N4-S2 (752 km in length) allows for the comparison of NDVI values in areas likely to be disturbed by construction (i.e., On RoW) to adjacent, comparable areas not disturbed by construction (i.e., Off RoW).

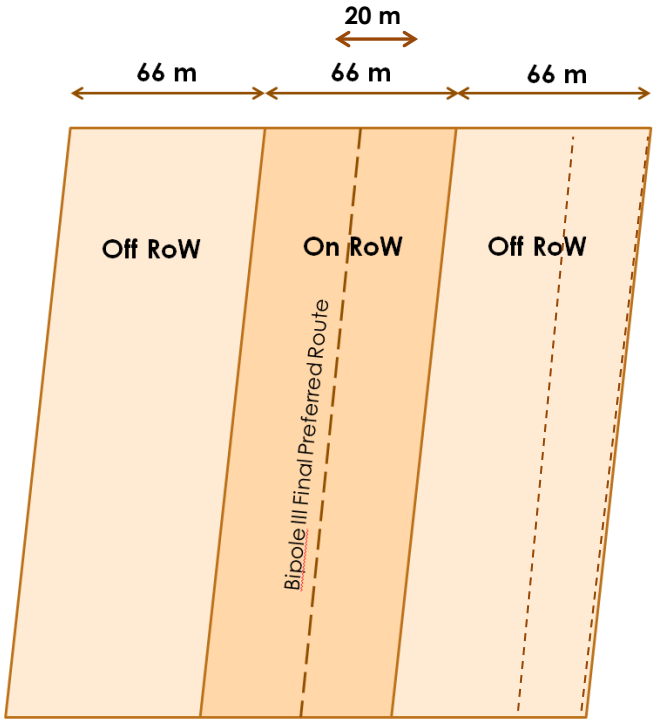


Figure 2-2 Conceptual Drawing of On RoW and Off RoW Study Area Corridors

[3] For the evaluation of 2015 and 2016 cropping seasons only a 66-m-wide On RoW corridor was used. However, a learning and recommendation from the outcomes of this evaluation was to include a second, narrower (i.e., 20-m) corridor in recognition that much of the disturbance along the transmission line in agricultural fields is generally confined to a narrower portion of the entire RoW typically centered on the centreline. A two corridor (i.e., 66-m and 20-m) On RoW evaluation approach was used in 2017 to better identify differences between On RoW and Off RoW areas. Based on the comparison of data within the two corridors, it was determined that using the 20-m corridor was more effective. Therefore, only the 20-m corridor was evaluated in 2018.

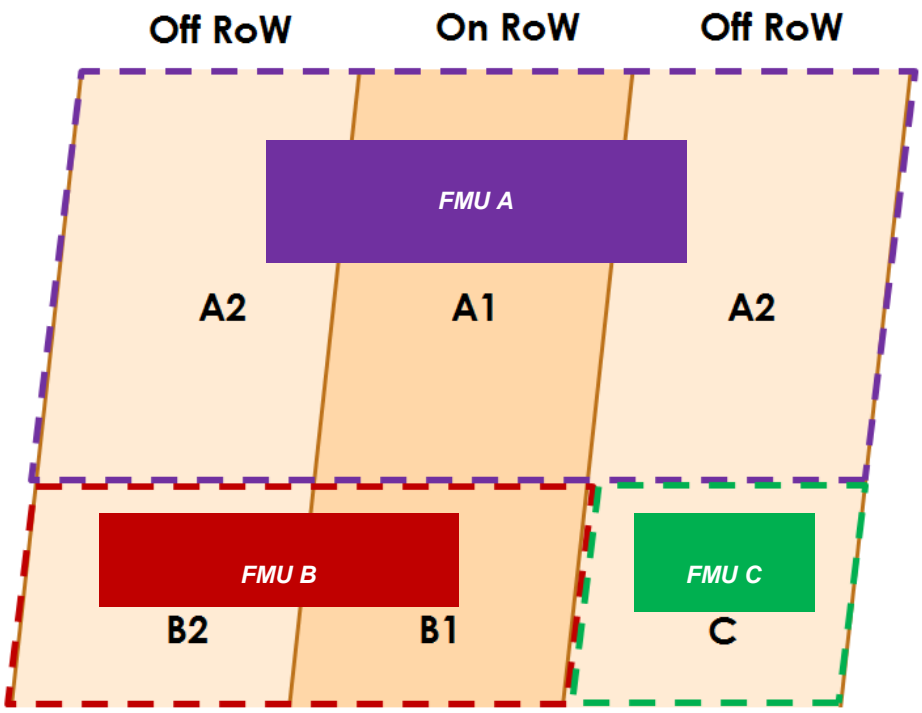
2.4.1.2 Agricultural Field Management Units

The 20-m corridor On RoW study area and the Off RoW study areas were "clipped" by quarter section boundaries and further delineated into Field Management Units (FMUs), or areas within a given quarter-section that were under agricultural crop production and associated with a management unit for the purposes of crop production[4]. The location and orientation of the RoW in some cases was such that Off RoW areas on either side of the RoW could be in different FMUs with different crops being grown in a given monitoring year. Through the delineation of FMUs, non-agricultural land uses (e.g., infrastructure such as road, rail and other transmission lines, tree/forest cover, wetlands, abandoned land, etc.) were removed from the evaluation, and the resulting On RoW and Off RoW polygon pairs allowed for a better "apples-to-apples" comparison (**Figure 2-3**).

In cases where multiple FMUs were delineated within a given quarter section, these FMUs were labelled successively with "A", "B", and "C" to yield unique identifiers for data management and comparative evaluation purposes.

A total of 778 FMUs were defined within the agricultural study area in 2018.

[4] The delineation of FMUs was recommended following the evaluation of 2015 and 2016 cropping seasons in order to improve comparative evaluation between On RoW and Off RoW areas. It was determined that comparisons would be improved with the identification and delineation of areas within a field that are managed as the same unit (i.e., there are often multiple field management units within a given quarter section, or non-agricultural land uses). The use of FMUs replaced the use of Agriculture and Agri-Food Canada crop type inventory data that was used for evaluation of 2015 and 2016 data.



Within FMU A (purple), the On RoW area "A1" is compared against the Off RoW "A2" areas to determine the NDVI difference. Within FMU B (red), the On RoW area "B1" is compared against area "B2" to determine the NDVI difference. FMU C (green) is eliminated from the evaluation as it does not have a comparable area On RoW.

Figure 2-3 Conceptual Drawing of Use of Field Management Units (FMU) to Determine On RoW and Off RoW Areas for Comparison

2.4.2 Statistical Analysis

Basic statistical analyses were conducted on NDVI values for On RoW areas, comparable Off RoW areas, and differences between On RoW and Off RoW. The objective of these analyses was to better understand the differences and to evaluate differences against established threshold values. The threshold values were used to determine with statistical confidence when negative difference values were indicative of practically-meaningful reductions in NDVI values On RoW relative to Off RoW.

Statistical analyses included frequency histograms and quartile analyses to understand the character and distribution of mean On RoW and Off RoW values. For difference values, values were plotted against the expected normal distribution, quartiles were determined, and percentiles and residuals (difference between actual difference values and expected values [i.e., no difference between On RoW and Off RoW]) were examined to characterize the data distributions and identify "outliers".

2.4.3 Visual Assessment

A manual visual review of select portions of the RoW was conducted for 2018 NDVI data in order to identify visual evidence of construction effects along the agricultural RoW. This was conducted due to an absence of reliable spatial data on construction activities that could be used to direct targeted data reviews and to confirm the sensitivity of the statistical approach in determining “real” differences relative to what the NDVI data showed. The visual review was used to identify NDVI value patterns indicative of construction disturbances around tower footprints, and linear disturbances along centreline for select FMUs identified as “negative outliers” and “positive outliers”, as well as a selection of other FMUs.

Video footage was collected and provided by Manitoba Hydro along Project sections S1 & S2. Footage was collected using a helicopter-mounted camera on August 3, 2017. Video footage was reviewed against NDVI data from 2017 and 2018 and was used to assist in interpreting NDVI results and validate NDVI data findings, where sufficient detail was discernible in the footage possible and where the disturbance occurred before the footage was taken.

2.4.4 Tower Structure Work Areas

Following review of 2015 and 2016 NDVI data, a recommendation was made to include evaluation of NDVI values in close proximity to tower locations. This recommendation was made in recognition that, generally, more intensive construction activity is associated with tower erection than other activities throughout the RoW. In order to complete this evaluation, a 33-m buffer was applied to tower locations (66-m diameter area around each tower) that fell within delineated FMUs. The NDVI values within these buffered areas were evaluated against a comparable 66-m diameter area within the Off RoW portion of the given FMU, in closest proximity to the tower as possible. In some cases, particularly where the RoW straddles a quarter section or half-mile line, a tower construction work area could be split between two FMUs. Therefore, the number of tower construction areas evaluated did not match the number of tower structures within delineated FMUs.

3.0 RESULTS

NDVI evaluation results summaries are presented in the following subsections for the entire agricultural RoW, by Project section and segment, and by FMU.

Tabular based results are complemented with map books of the change detection or differences between On RoW and Off RoW values along the entire length of the agricultural RoW for the 2018 Sentinel-2 NDVI data. These maps are presented in **Appendix D** as follows: **Map Series 4-100** (N4), **Map Series 4-200** (C1), **4-300** (C2), **4-400** (S1), and **4-500** (S2).

3.1 NDVI FOR THE ENTIRE AGRICULTURAL ROW

While the NDVI comparative analysis for the entire agricultural study area in N4 to S2 for 2015 and 2016 coverages revealed minimal NDVI differences when On RoW was compared to Off RoW, the difference was notably higher in 2017 and 2018 data relative to 2015 and 2016 (**Table 3-1**). As a reminder, NDVI output values have an absolute range from +1 to -1. NDVI differences within the entire agricultural study area of -0.010, 0.001 and -0.010 for 2015 (Landsat-8), 2016 (Landsat-8) and 2016 (Sentinel-2), respectively, were considered negligible. This was not unexpected due to the minimal amount of construction that had occurred in agricultural areas by the end of 2016, and the small proportion of the RoW that was disturbed in agricultural fields where construction has occurred.

However, it was apparent in 2017 data for both the 66-m Off Row Corridors and 20-m On Row Corridor that a greater negative difference in NDVI values had emerged. Differences between mean values of On RoW and Off RoW for the entire agricultural study area were -0.024 (-3.71% of Off RoW values) and -0.038 (-5.80% of Off RoW values) for the 66-m and 20-m corridors, respectively. These higher negative values appeared to be evidence that Project construction disturbance had resulted in lower NDVI values for On RoW areas compared with similar Off RoW areas. The greater difference value found for the 20-m RoW suggested that using the smaller corridor width provides a more sensitive approach to screening for potential construction disturbances along the RoW.

In 2018, the differences between mean values of On RoW and Off RoW for the entire agricultural study area were -0.032 (-4.20% of Off RoW values) for the 20-m corridor. This suggests that Project construction activities have again resulted in lower NDVI values On RoW compared with similar Off RoW areas. However, the difference in 2018 (-4.20% of Off RoW values) is lower when compared to 2017. This suggests there were less effects within the RoW in 2018, presumably due to fewer construction disturbances, when compared with 2017.

Table 3-1 Comparison of NDVI for Entire Agricultural Study Area for 2015 to 2017

Entire Agricultural RoW (N4 to S2)	NDVI Values					
	On RoW Mean	Off RoW Mean	Difference (On RoW – Off RoW)	Difference (% Off RoW)	Difference (% NDVI Range)	Source
2015	0.667	0.677	-0.010	-1.48%	-0.50%	Landsat 8
2016	0.673	0.672	0.001	0.15%	0.05%	Landsat-8
2016	0.511	0.521	-0.010	-1.92%	-0.50%	Sentinel-2
2017 (66-m On RoW corridor)	0.633	0.657	-0.024	-3.71%	-1.22%	Sentinel-2
2017 (20-m On RoW corridor)	0.617	0.655	-0.038	-5.80%	-1.90%	Sentinel-2
2018 (20-m On RoW corridor)	0.731	0.763	-0.032	-4.20%	-1.60%	Sentinel-2

Note:

Absolute values are not comparable between years and data sources as these data were collected during different time periods (with different crop type distribution and at crop stages) within a given year and between years. However, it is valid to compare differences expressed as percentages between years.

Data comparison was limited to the 20-m corridor in 2018 as this approach was found to be most effective in detecting construction disturbances within the RoW.

3.2 NDVI BY PROJECT SECTION AND SEGMENT

When analyzing the NDVI coverages by Project section, similar change detection results were found for the entire agricultural study area (**Table 3-2**). All Sections within the agricultural study area displayed negative differences between On RoW and Off RoW NDVI values. Compared with results from 2015 and 2016 (not presented here), when differences were generally considered negligible and in some cases were positive, the 2018 results (and 2017 results; not presented here) at the Project section level appear to provide confirmation that construction disturbances have occurred within each Section, and have resulted in lower NDVI values On RoW compared with similar Off RoW areas. When the differences were compared to Off RoW areas, % differences were found to range from -3.08% to -5.86% within the 20-m Corridor.

A couple of interesting patterns in the data include:

- There was no obvious geographic trend in differences in 2018, unlike in 2017 when negative % differences were found to be greater in a “north to south” direction (N4 < C1 & C2 < S1 & S2);
- Differences across sections comprised a smaller range relative to 2017.

These patterns suggest conditions across Project sections are becoming more similar or uniform.

Table 3-2 Comparison of NDVI by Project Section for 2018 for 20-m Corridor

Agricultural RoW Section	NDVI Values				
	On RoW Mean	Off RoW Mean	Difference (On RoW – Off RoW)	Difference (% of NDVI Range)	Difference (% of Off RoW Mean)
N4	0.792	0.817	-0.025	-1.26%	-3.08%
C1	0.655	0.696	-0.041	-2.04%	-5.86%
C2	0.588	0.609	-0.021	-1.06%	-3.47%
S1	0.723	0.761	-0.037	-1.86%	-4.90%
S2	0.799	0.827	-0.027	-1.37%	-3.31%

3.3 NDVI VALUES FOR INDIVIDUAL FIELD MANAGEMENT UNITS

A summary of basic statistics for On RoW, Off RoW and differences between On Row and Off RoW is found in **Table 3-3**. The median and mean values (already presented above for the entire agricultural study area) were found to be lower for On RoW FMUs than Off RoW FMUs resulting in negative values for the median and mean difference between On RoW and Off RoW. Of the 778 FMUs, differences were found to be negative in 599 (77%) and positive in 179 (23%). Similar to results in 2017, these data have a negative "skew" relative to the expected "0" difference if crop productivity was the same on and off the RoW (i.e., assuming no construction disturbances). However, there were a higher count and proportion of negative values in 2018 compared to 2017 (548 negatives or 72% of FMUs), suggesting the potential for a higher number of FMUs impacted by construction disturbances.

Table 3-3 Basic Statistics for 2018 NDVI Results for FMUs – 20-m Corridor

Parameter	On RoW	Off RoW	Difference (On RoW - Off RoW)
Count	778	778	778
Mean	0.731	0.763	-0.032
Minimum	0.306	0.291	-0.366
Median	0.756	0.801	-0.024
Maximum	0.941	0.965	0.322
Range	0.636	0.674	0.689
Count of Negatives	N/A	N/A	599
% Negatives	N/A	N/A	77%
Count of Positives	N/A	N/A	179
% Positives	N/A	N/A	23%

In 2017, a threshold level was determined that could be used to support the use of the Tier 1 remotely-sensed NDVI approach in determining FMUs where differences between On RoW and Off RoW were such that Project disturbances were likely the reason for the difference. In other words, the threshold was established as a level at which values that do not exceed it are within the normal variation of differences between On RoW and Off RoW in the absence of a major disturbance. The values that exceed the threshold in a positive direction are considered "positive outliers" and are likely due to incorrect FMU delineation or some other anomaly, while those that exceed the threshold in the negative direction are likely the result of disturbance within the RoW reducing crop productivity. A combination of approaches was used to establish the threshold, including reviewing quartile ranges, standard deviations and prediction intervals, visually examining the shape of percentiles curve, and the distribution of residual values. This same approach was used in 2018 to evaluate the applicability of the previously-established threshold value to the 2018 dataset. These data characterizations and statistical analyses are presented in **Appendix B**.

The threshold value was established at +/-0.11 NDVI units in 2017. Based on a review of the 2018 data and consideration of statistical parameters and visual examination of data (as described above) this threshold still appears valid and is therefore used as the threshold for 2018 data evaluation purposes.

Using a threshold value of +/-0.11 yielded 69 negative values (9% of FMUs) and 12 positive values (2% of FMUs). Of the 69 negative values that exceeded the threshold, the majority were in sections S1 and S2, with counts by section as follows: N4 – 2 (2% of FMUs in N4), C1 – 16 (14% of FMUs in C1), C2 – 4 (5% of FMUs in C2), S1 – 29 (11% of FMUs in S1), and S2 – 18 (7% of FMUs in S2). This is indicative of current or remaining effects from construction activities during or prior to 2018 across the various sections. The variability in counts below the threshold across the sections is indicative of variable amounts of construction across the sections, the annual or seasonal timing of construction activities, or the nature and intensity of construction activities. Notably, there was a reduction in FMUs with NDVI differences below the threshold from 2017 to 2018 from 109 to 69. This consisted of a large reduction of FMUs in S1 & S2 (reduced by approximately 50%) and slight increase in FMUs in N4, C1 & C2. This is indicative that recovery from the main construction activities generally appears to be occurring (reduction of FMUs below threshold from 14% in 2017 to 9% in 2018), particularly in the prime agricultural lands predominantly in sections S1 & S2 (reduction of FMUs below threshold from 18% in 2017 to 9% in 2018).

3.3.1 Trend Analysis 2017 to 2018

NDVI values that have differences below the threshold value in 2017 and/or 2018 were evaluated for trends in direction and magnitude of NDVI difference values from 2017 to 2018. A total of 147 individual or unique FMUs had NDVI difference values that were below the threshold in 2017 and/or 2018. As reported above, this was composed of 109 FMUs in 2017 and 69 FMUs in 2018, when overlapping FMUs year-over-year are counted (i.e., those that were below threshold in 2017 AND 2018). A summary of counts and proportions of these data are presented in **Table 3-4**.

Of the 147 FMUs, 93 (63%) have NDVI difference values that trended in the positive direction in 2018, with 80 (54%) considered recovered to a level above the threshold, and the remaining 13 (9%) recovering while still having values below the threshold.

The other 54 FMUs (37%) that were below the threshold in 2017 and/or 2018 trended in a negative direction in 2018. Of these, 14 (10%) were below threshold in 2017 and remained as such in 2018 – this indicates situations where a disturbance that occurred during the 2017 season (prior to July-August 2017 when NDVI data was captured) persisted through the 2018 season. The other 40 FMUs (27%) were above threshold in 2017 but fell below the threshold when 2018 NDVI values were evaluated – this indicates a disturbance that occurred after July-August 2017 and persisted through the 2018 season.

Table 3-4 Trends in NDVI Difference Values for FMUs below the Threshold in 2017 and/or 2018

Parameter	Description	Count	Proportion
Positive trend ("+ve")	**Recovered or recovering**	**93**	**63%**
Below threshold 2017 Above threshold 2018	Recovered	80	54%
Below threshold 2017 Below threshold 2018	Recovering	13	9%
Negative trend ("-ve")	**Disturbance persists**	**54**	**37%**
Above threshold 2017 Below threshold 2018	Disturbance persists – disturbance occurred after August 2017	40	27%
Below threshold 2017 Below threshold 2018	Disturbance persists – disturbance occurred prior to July 2017	14	10%
Total		**147**	**100%**

3.4 VISUAL ASSESSMENT

A visual assessment of NDVI values On RoW and Off RoW was completed to identify visual evidence in NDVI data of construction effects along the agricultural RoW and to validate the statistical approach discussed above. A select number of FMUs were reviewed as it was not practical to visually review all 778 FMUs. This review focused on FMUs that had NDVI values below the threshold value.

Video footage collected on August 3, 2017 was provided for Project sections S1 & S2. The video footage was reviewed and compared against NDVI differences from 2017 and 2018. Observations of NDVI data and visual evidence of disturbances in the video footage were made. A total of 178 FMUs were reviewed as part of this process, representing approximately 23% of total FMUs. However, most of the 147 FMUs that had NDVI difference values that were below the threshold in 2017 and/or 2018 were evaluated as part of this process.

In some cases, visual evidence supported NDVI results from 2017. However, as the video was taken after the 2017 NDVI was collected (July to August 2017) and before the 2018 NDVI was collected (July 2018), the video footage did not support NDVI interpretation in many cases.

Notes from the video review are found in Table A-2 (**Appendix A**).

A series of examples of the types of disturbances found through NDVI difference evaluation are presented in Figures C-1 to C-7 (**Appendix C**).

3.5 NDVI VALUES AT TOWER STRUCTURE WORK AREAS

A total of 910 tower structure construction work areas were evaluated within the agricultural study area in 2018[5]. The comparison between 30 m buffered tower areas and comparable Off RoW areas within the same FMU yielded the following results:

- In 2018, 722 of 910 tower locations (79% of all tower locations evaluated) had a negative difference in NDVI values On RoW vs. Off RoW, while 188 tower locations (21% of all tower locations evaluated) had a positive difference in NDVI values.
- In 2018, 139 tower locations (15% of all tower locations evaluated) had negative difference values that were below the threshold value of -0.11.
- When compared with 2017 this represents a 15% reduction in tower locations that were below the threshold. This data suggests a trend towards recovery of crop productivity at tower work areas.

As noted, the NDVI difference values appear to be trending towards recovery. However, it is unlikely that the NDVI difference values will return to pre-construction levels (i.e., normal distribution around a zero difference with equal numbers of positive and negative differences). It is expected that the tower footprint and areas immediately surrounding the tower footprint will have different crop productivity (and different NDVI values) than comparable off RoW areas due to these areas not being returned to crop production.

A summary of the number of tower structures falling within various NDVI difference value classes is provided in **Table 3-5** and illustrated in **Figure 3-1**.

[5] In 2017, a total of 893 work areas were evaluated. These data were re-evaluated and updated 2017 results are presented here. The reason for the difference in work areas being evaluated was due to changes in FMU delineations.

Table 3-5 Summary of NDVI Differences for Tower Structure Work Areas

NDVI Difference (On RoW – Off RoW)	2017		2018		Change (2018-2017)	
	Count	%	Count	%	Count	%
<-0.5	6	1%	0	0%	-6	-0.7%
<-0.4 to -0.5	9	1%	2	0%	-7	-0.8%
<-0.3 to -0.4	41	5%	7	1%	-34	-3.7%
<-0.2 to -0.3	68	7%	35	4%	-33	-3.6%
<-0.11 to -0.2	149	16%	95	10%	-54	-5.9%
<0 to -0.11	404	44%	583	64%	179	19.7%
>0 to 0.11	205	23%	163	18%	-42	-4.6%
>0.11 to 0.2	19	2%	18	2%	-1	-0.1%
>0.2	9	1%	7	1%	-2	-0.2%
Total	**910**	**100%**	**910**	**100%**	**0**	**0.0%**

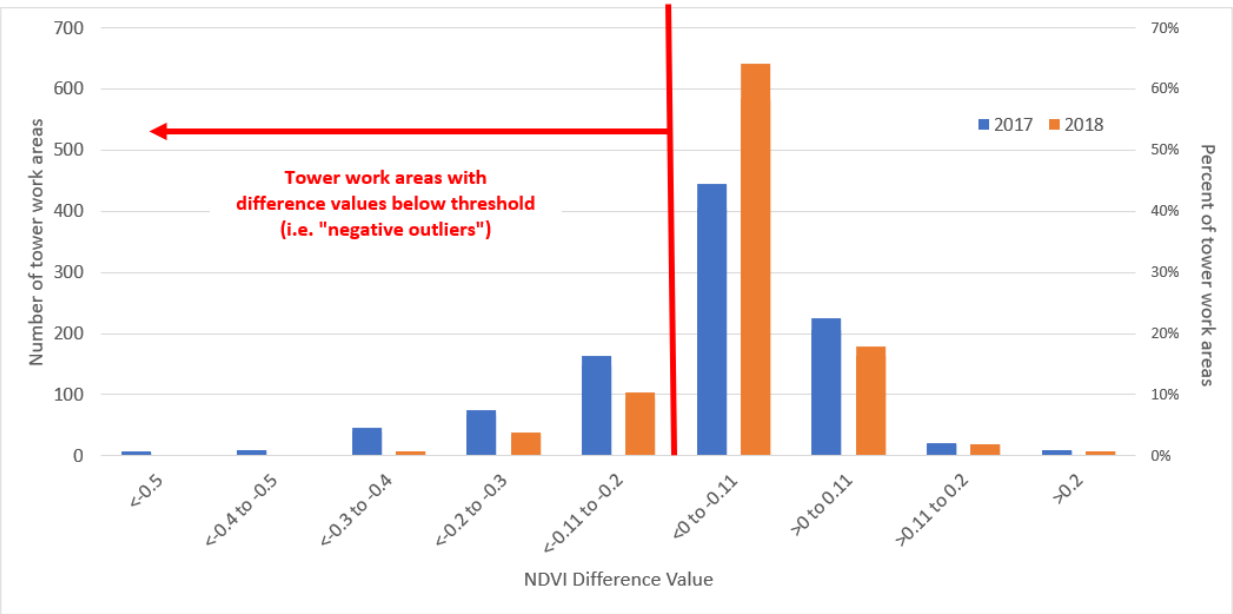


Figure 3-1 Tower work areas in NDVI Difference Classes – 2017 and 2018

4.0 SUMMARY AND CONCLUSIONS

The NDVI On RoW and Off RoW analysis of FMUs demonstrated that there have been measurable reductions in On RoW NDVI relative to 2017 when the entire agricultural study area was evaluated, as well as within each Project section when they were evaluated individually. These results suggest the Project construction activities have resulted in disturbance to crop and soil productivity along the Project RoW within the area of agricultural crop production. However, when compared with 2017, the NDVI difference values in 2018 were smaller. This suggests a general trend towards a return to pre-construction productivity.

The evaluation of FMUs in 2018 was limited to the 20-m Corridor around the centreline, as it was determined in 2017 that evaluating this narrower corridor along the centerline produced more reliable change detection results. This approach recognizes that construction activities (e.g., vehicle traffic between tower locations) tend to be more intensive or concentrated in close proximity to the centreline (as opposed to the same level of intensity and disturbance across the entire RoW width).

A threshold value of an NDVI difference of +/-0.11 (approximately 10-15% of the Off RoW NDVI values) was established based on a statistical and qualitative review of the 2017 NDVI values On RoW and Off RoW. The validity of this threshold value was confirmed for the 2018 evaluation. Therefore, the threshold value of +/-0.11 (or 10-15% of the Off RoW NDVI value) appears to provide a reasonable approximation of natural variation in the data, outside of which negative differences in NDVI values (On RoW – Off RoW) can be indicative of potential Project effects to crop (and soil) productivity within the agricultural RoW.

An evaluation of buffered tower structure work areas indicated that approximately 15% of these areas had substantively-reduced NDVI values (i.e., below the threshold) relative to comparable Off RoW areas. This is indicative that Project disturbances persist in these areas; an expected result due to the intensive nature of construction activities related to tower erection. However, the data in 2018 indicates an approximate 15% reduction in tower areas that were below the threshold compared to 2017 when 30% of tower work areas were below the threshold. Therefore, it appears that the level of disturbance is less in 2018 compared with 2017. In other words, it appears that the crop productivity in work areas appears to be recovering or trending towards pre-construction levels.

The Tier 1 Initial Crop Productivity Screening Approach appears to be providing an effective approach to detecting changes in crop (and soil) productivity along the agricultural RoW and at tower locations. The continued use of this approach should provide an effective means of monitoring crop (and soil) productivity during the post-construction phase of the Project. The incorporation of Tier 2 Detailed Crop Productivity Screening during the post-construction phase will provide a more detailed desktop-based, remotely-sensed NDVI approach to evaluating select areas of the agricultural portion of the Project RoW. These areas would be selected primarily based on situations where effects do not appear to be recovering following the completion of construction activities. This more detailed analysis using higher resolution NDVI data would allow for better delineation of effects and improved reliability on degree, extent and, potentially, magnitude of effects.

Additionally, Tier 3 Field Assessments may be conducted during the post-construction phase, if and as required, to confirm the nature and degree of effects to crop and soil productivity in areas that do not appear to be recovering post-construction. These field assessments would be developed on a site- and issue-specific case and will be conducted as directed by Manitoba Hydro.

5.0 RECOMMENDATIONS

The following recommendations are made to continue to improve the soil productivity monitoring program in subsequent years:

- Continued review and revision of FMUs, particularly those identified as FMUs requiring improvement following review of 2018 monitoring data. Improved FMU delineation will result in more reliable Tier 1 Crop Productivity Screening results.
- Evaluate NDVI values in 2019 relative to 2017 and 2018 data to confirm crop productivity in On RoW FMUs and tower work areas is trending to pre-construction levels.
- Tier 2 Detailed Crop Productivity Screening should be completed along select portions of the RoW starting in 2019, per the proposed monitoring plan. This more detailed screening will be completed using higher-resolution Worldview-2 (or similar) imagery. Areas for Tier 2 assessments should be selected based on review of the Sentinel-2 imagery and consideration of areas of notably reduced On RoW NDVI values from 2017 and 2018 monitoring seasons.
- Tier 3 Field Assessments should be completed if, and as, required. Areas requiring field assessment would be those that had notably-reduced On RoW NDVI values (as confirmed by Tier 1 and/or Tier 2 assessments) that do not appear to be recovering post-construction. Field assessment may also be considered in response to landowner-identified post-construction concerns with crop or soil productivity. Field assessments should be developed on a site- and issue-specific case and will be conducted as directed by Manitoba Hydro.

5.1 DATA NEEDS

There are currently no additional data needs.

6.0 REFERENCES

AAFC, 2013. Overview of Classification Methodology for Determining Land Capability For Agriculture, Agriculture and Agri-Food Canada. May 31, 2013. http://sis.agr.gc.ca/cansis/nsdb/cli/classdesc.html.

Appendix A TABLES

Table A-1 Bipole III On/Off RoW Agricultural Extent NDVI Comparative Analysis by Section Segment for 2018

Section-Segment	NDVI Values - 20-m Corridor			
	On RoW Mean	Off Row Mean	Difference (On RoW - Off RoW)	Difference (% of Off RoW)
N4-S9	0.759	0.734	0.025	3.40%
N4-S16	0.702	0.728	-0.026	-3.54%
N4-S17	0.501	0.485	0.016	3.28%
N4-S19	0.389	0.384	0.005	1.31%
N4-S20	0.568	0.566	0.002	0.44%
N4-S21	0.413	0.410	0.003	0.78%
N4-S23	0.683	0.717	-0.034	-4.78%
N4-S24	0.753	0.764	-0.011	-1.45%
N4-S25	0.714	0.733	-0.019	-2.58%
C1-S1	0.706	0.749	-0.043	-5.77%
C1-S2	0.708	0.749	-0.041	-5.52%
C1-S3	0.553	0.599	-0.045	-7.53%
C1-S4	0.585	0.573	0.012	2.14%
C1-S6	0.763	0.797	-0.034	-4.27%
C1-S7	0.613	0.618	-0.004	-0.71%
C1-S8	0.575	0.640	-0.065	-10.12%
C1-S9	0.659	0.648	0.011	1.76%
C1-S10	0.650	0.651	-0.002	-0.26%
C1-S11	0.610	0.663	-0.053	-7.98%
C1-S12	0.594	0.615	-0.021	-3.38%
C2-S2	0.595	0.611	-0.016	-2.69%
C2-S3	0.643	0.668	-0.025	-3.70%
C2-S4	0.697	0.696	0.001	0.14%
C2-S5	0.643	0.643	-0.001	-0.10%
C2-S6	0.520	0.525	-0.005	-0.97%
C2-S7	0.609	0.620	-0.011	-1.75%
C2-S8	0.529	0.550	-0.020	-3.70%
C2-S9	0.569	0.585	-0.017	-2.84%
S1-01	0.670	0.671	-0.001	-0.12%
S1-02	0.718	0.756	-0.038	-4.97%
S1-03	0.450	0.457	-0.008	-1.69%
S1-04	0.352	0.345	0.007	2.06%

Table A-1 Bipole III On/Off RoW Agricultural Extent NDVI Comparative Analysis by Section Segment for 2018

Section-Segment	NDVI Values - 20-m Corridor			
	On RoW Mean	Off Row Mean	Difference (On RoW - Off RoW)	Difference (% of Off RoW)
N4-S9	N4	S9	0.863	0.883
N4-S16	N4	S16	0.800	0.820
N4-S17	N4	S17	0.742	0.736
N4-S19	N4	S19	0.770	0.795
N4-S20	N4	S20	0.784	0.814
N4-S21	N4	S21	0.816	0.854
N4-S23	N4	S23	0.823	0.833
N4-S24	N4	S24	0.774	0.818
N4-S25	N4	S25	0.798	0.829
C1-S1	C1	S1	0.799	0.827
C1-S2	C1	S2	0.703	0.734
C1-S3	C1	S3	0.678	0.710
C1-S4	C1	S4	0.674	0.676
C1-S6	C1	S6	0.786	0.849
C1-S7	C1	S7	0.673	0.722
C1-S8	C1	S8	0.769	0.796
C1-S9	C1	S9	0.719	0.795
C1-S10	C1	S10	0.713	0.763
C1-S11	C1	S11	0.571	0.683
C1-S12	C1	S12	0.538	0.561
C2-S2	C2	S2	0.554	0.582
C2-S3	C2	S3	0.624	0.646
C2-S4	C2	S4	0.575	0.587
C2-S5	C2	S5	0.414	0.368
C2-S6	C2	S6	0.572	0.582
C2-S7	C2	S7	0.626	0.639
C2-S8	C2	S8	0.548	0.606
C2-S9	C2	S9	0.588	0.616
S1-S1	S1	S1	0.704	0.736
S1-S2	S1	S2	0.625	0.650
S1-S3	S1	S3	0.561	0.612
S1-S4	S1	S4	0.693	0.723

Table A-1 Bipole III On/Off RoW Agricultural Extent NDVI Comparative Analysis by Section Segment for 2018

Section-Segment	NDVI Values - 20-m Corridor			
	On RoW Mean	Off Row Mean	Difference (On RoW - Off RoW)	Difference (% of Off RoW)
S1-S5	S1	S5	0.787	0.805
S1-S6	S1	S6	0.652	0.737
S1-S7	S1	S7	0.803	0.810
S1-S8	S1	S8	0.772	0.803
S1-S9	S1	S9	0.761	0.795
S1-S10	S1	S10	0.703	0.756
S1-S12	S1	S12	0.717	0.753
S1-S13	S1	S13	0.784	0.819
S1-S14	S1	S14	0.677	0.681
S1-S15	S1	S15	0.566	0.609
S1-S18	S1	S18	0.744	0.766
S1-S19	S1	S19	0.750	0.760
S1-S20	S1	S20	0.653	0.635
S1-S21	S1	S21	0.660	0.737
S1-S22	S1	S22	0.829	0.856
S1-S23	S1	S23	0.653	0.697
S1-S24	S1	S24	0.733	0.820
S2-S1	S2	S1	0.733	0.772
S2-S2	S2	S2	0.832	0.847
S2-S3	S2	S3	0.834	0.909
S2-S4	S2	S4	0.847	0.870
S2-S5	S2	S5	0.735	0.827
S2-S6	S2	S6	0.878	0.888
S2-S7	S2	S7	0.886	0.900
S2-S8	S2	S8	0.873	0.877
S2-S9	S2	S9	0.748	0.863
S2-S10	S2	S10	0.820	0.828
S2-S12	S2	S12	0.846	0.852
S2-S13	S2	S13	0.855	0.870
S2-S14	S2	S14	0.842	0.838
S2-S15	S2	S15	0.852	0.883
S2-S16	S2	S16	0.870	0.899

Table A-1 Bipole III On/Off RoW Agricultural Extent NDVI Comparative Analysis by Section Segment for 2018

Section-Segment	NDVI Values - 20-m Corridor			
	On RoW Mean	Off Row Mean	Difference (On RoW - Off RoW)	Difference (% of Off RoW)
S2-S17	S2	S17	0.894	0.907
S2-S18	S2	S18	0.904	0.921
S2-S19	S2	S19	0.849	0.921
S2-S21	S2	S21	0.892	0.895
S2-S22	S2	S22	0.883	0.879
S2-S24	S2	S24	0.671	0.713
S2-S25	S2	S25	0.752	0.750
S2-S26	S2	S26	0.884	0.892
S2-S28	S2	S28	0.823	0.854
S2-S29	S2	S29	0.856	0.860
S2-S30	S2	S30	0.912	0.932
S2-S31	S2	S31	0.805	0.819
S2-S32	S2	S32	0.719	0.801
S2-S33	S2	S33	0.760	0.811
S2-S34	S2	S34	0.835	0.866
S2-S35	S2	S35	0.746	0.762
S2-S36	S2	S36	0.705	0.791
S2-S37	S2	S37	0.677	0.726
S2-S38	S2	S38	0.645	0.711
S2-S40	S2	S40	0.692	0.729
S2-S43	S2	S43	0.791	0.811

Table A-2 Comparison between NDVI Difference Values (2017 & 2018) and Video Footage (2017)

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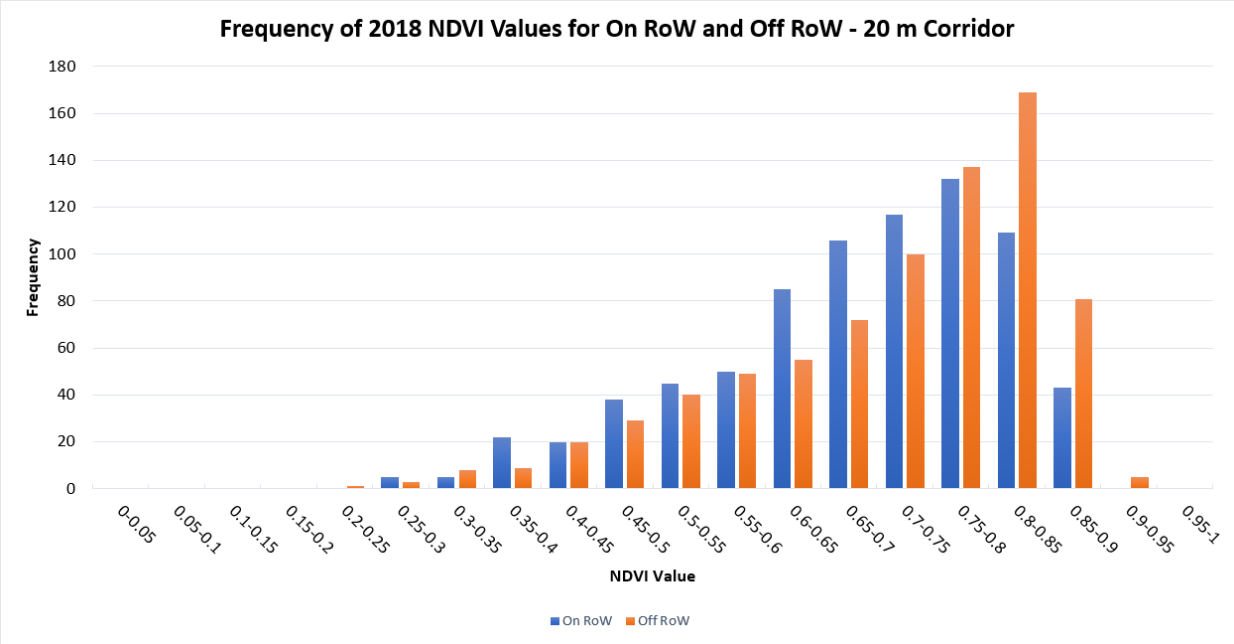
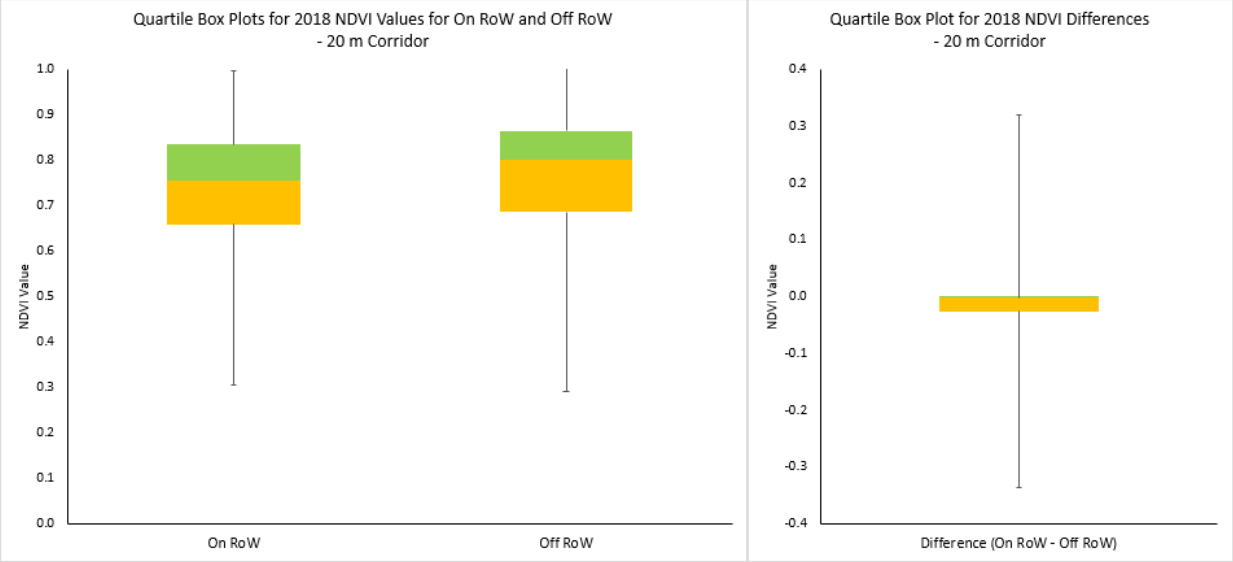
Appendix B STATISTICAL ANALYSIS



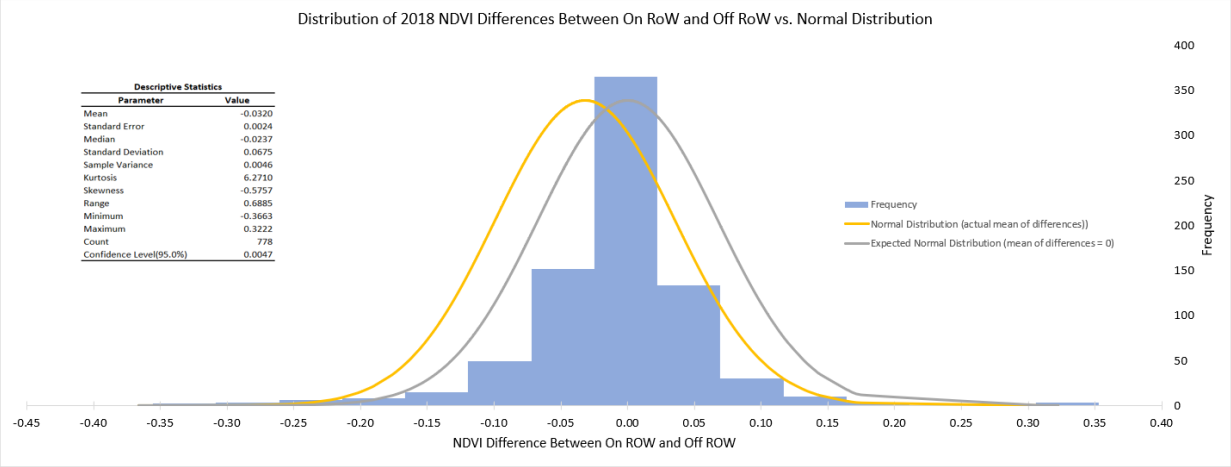
The frequency histogram above shows that there is a higher frequency of high NDVI values Off RoW and a higher frequency of low NDVI values On RoW. This demonstrates a skewness to the On RoW data.

Figure B-1 Frequency of 2018 NDVI Values for On RoW and Off RoW – 20-m Corridor



The quartile box plots for On RoW and Off RoW display the ranges (between minimum and maximum values shown by the "whiskers") are fairly similar between On RoW and Off RoW, the median value (centre of box) as well as the first quartile (25th percentile) and third quartile (75th percentile) are lower for On RoW values than Off RoW. When the box plot for NDVI differences is examined, it shows the median is negative and most of the data (between 25th and 75th percentile) are in a fairly tight range (narrow distribution) and mostly negative in value, while the maximum and minimum values are much wider ranging (suggests "extreme" values).

Figure B-2 Quartile Box Plots for 2018 NDVI Values for On RoW and Off RoW and for Differences – 20-m Corridor

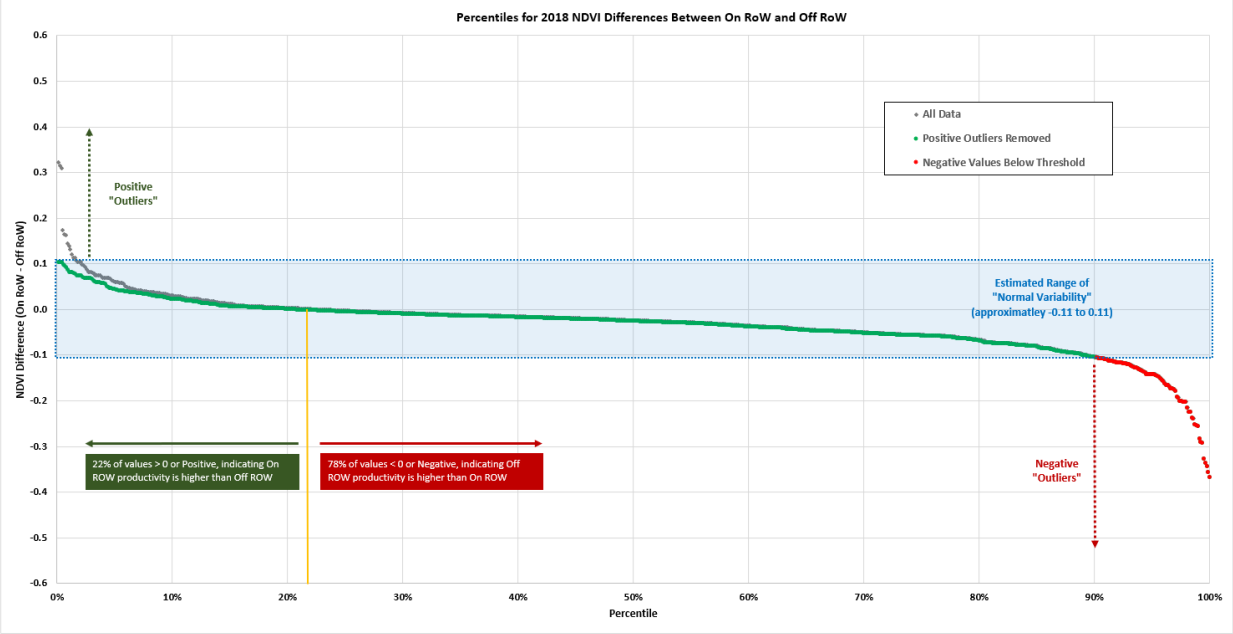


The frequency of difference values is displayed in columns (blue bars) relative to the:

- *normal distribution curve (orange line; based on actual data around the actual mean value of -0.032), and,*
- *"expected" normal distribution curve (grey line; assumed mean difference of 0 and same shape of curve as the actual normal distribution).*

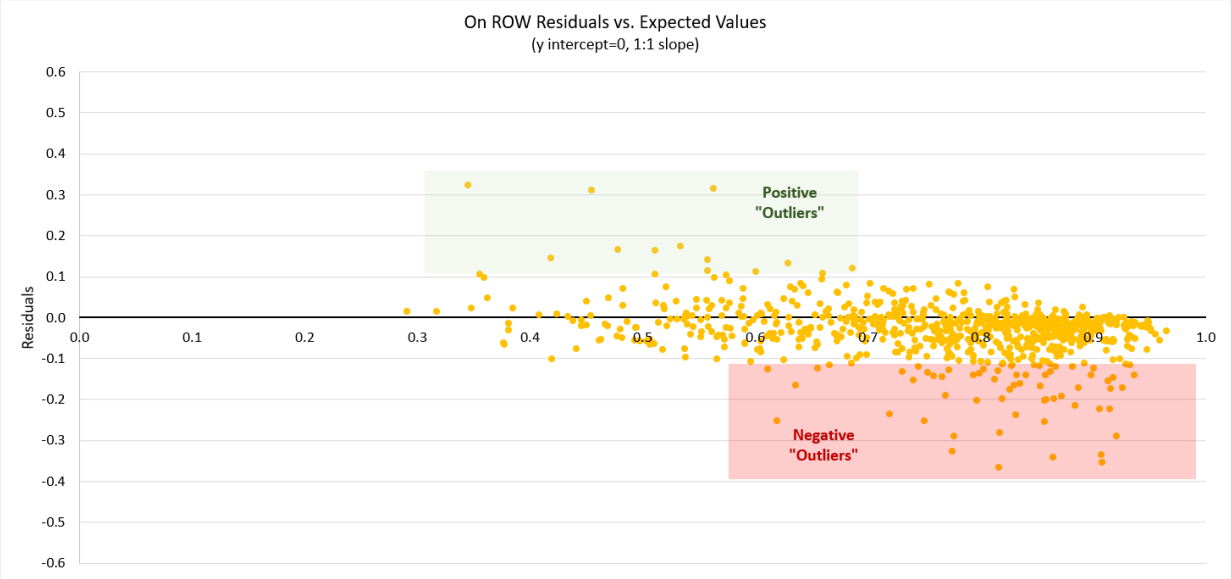
These data demonstrate that the actual difference values are "skewed" in a negative direction.

Figure B-3 Distribution of 2018 NDVI Differences Between On RoW and Off RoW – 20-m Corridor



The percentiles chart provides a visual display of the difference values from individual FMUs. Approximately 22% of differences were found to be positive (On RoW – Off RoW = >0), while 78% were found to be negative (On RoW – Off RoW = <0). This is further evidence of the "skewness" of the data. The estimated range of "normal variability" around an expected difference of 0 is estimated to be approximately -0.11 to 0.11. Therefore, values above 0.11 can be considered "positive outliers" while values below -0.11 can be considered "negative outliers". Based on this analysis there are many more "negative outliers" than "positive outliers". Approximately 9% of FMUs are considered in the "negative outlier" range, while only 2% of FMUs are considered in the "positive outlier" range.

Figure B-4 Percentiles for 2018 NDVI Differences Between On RoW and Off RoW – 20-m Corridor



The residuals chart above was created by plotting residual values (difference between actual and expected values) for On RoW against expected values for On RoW (assuming On RoW and Off RoW are expected to be the same). This provides another means to visually assess the distribution of differences for each FMU against expected values. The plotted distribution indicates "positive outliers" (those differences >0.11) are fewer and tended to be found in the lower range of NDVI values (<0.7) while the "negative outliers" are much more numerous and occur in the higher range of NDVI values (>0.6). The pattern of the residuals (1. more negative than positive residuals; 2. more "positive outliers" in the lower range; and, 3. more "negative outliers" in the higher range of expected values) is further evidence the difference values are being affected systematically. In the case of "positive outliers", the likely explanation for this systematic variability is either incorrect FMU delineations or headland effects. In the case of "negative outliers", disturbances to crop productivity by construction activities is the likely cause.

Figure B-5 Residuals for 2018 NDVI Values for On RoW vs. Expected Values – 20-m Corridor

Appendix C NVDI DIFFERENCE EXAMPLES

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Available in accessible formats upon request