YUKON LAND USE
PLANNING COUNCIL

PILOT STUDY OF SURFACE DISTURBANCE IN EAGLE PLAINS

Report and Recommendations

Abstract

This report describes the methods and results of a pilot study that mapped, evaluated and quantified anthropogenic disturbances in Land Management Unit 9 (Eagle Plains) of the North Yukon Planning Region. It makes recommendations for how these methods may be applied in other areas in implementing a cumulative effects management framework.

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Cover page image: Navigational map of a portion of Eagle Plains using base data from 1988 (Canadian Centre for Mapping, 1994). Note several annotations of "numerous cut lines".

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Summary

Purpose

This report describes the methods and results of a pilot study that mapped, evaluated, and quantified human-caused disturbances in Land Management Unit (LMU) 9 "Eagle Plains" of the North Yukon Planning Region. It also provides recommendations for how the piloted methods of that study may be applied in other areas of the North Yukon Region and beyond and provides some options and estimated costs to do so.

Abstract

In 2009, the North Yukon Regional Land Use Plan was the first regional plan to be completed and approved as per Chapter 11 of the Umbrella Final Agreement. Many of the recommendations in this Plan were designed to address oil and gas exploration and development within the winter range of the Porcupine Caribou herd. A key recommendation was to maintain effective caribou habitat over the long term by ensuring that the cumulative disturbances of human activities are kept below prescribed levels. More specifically, the Plan recommended that two cumulative effects indicators, *surface disturbance* and *linear disturbance*, be quantified and tracked. The Plan went on to say that "recovered" disturbances were to no longer "count" as disturbances.

The Parties to the Plan (Yukon and Vuntut Gwitchin governments) agreed that they should track disturbance levels and that the Yukon Land Use Planning Council ("YLUPC") check the conformity of project proposals to the plan. To check conformity, YLUPC would (among other things) see if a project would result in excessive disturbances by comparing the combined proposed and existing disturbances to the thresholds specified for that portion of the region (or Land Management Unit (LMU)) (Figure 1). Therefore, measuring existing disturbances are a key part of implementing this plan.

In 2016, YLUPC outlined a pilot study that would determine the amounts of existing disturbances in LMU 9, Eagle Plains, where most of the Region's human-caused disturbances are found. The piloted method needed to be practical, defensible, and accurate at a regional scale and needed to follow the North Yukon Regional Land Use Plan's spirit and intent with only minor refinements to the Plan's definitions of disturbance. The study had the following stages:

1. Determine specifications for imagery – specifically satellite imagery
2. Determine what information needs to be interpreted from the imagery
3. Evaluate field data to support mapping
4. Map and describe disturbances using satellite imagery
5. Analyze maps to calculate disturbance levels
6. Estimate costs for options of rolling out the method beyond the study area

This report describes the methods and results of that pilot study. It developed innovations to standard disturbance mapping procedures to meet the standards set by the Plan and better understand the recovery status of disturbed features. It successfully determined the status of both disturbance indicators in LMU 9. These values are 25% and 51% of the cautionary thresholds for that LMU. However, the cautionary threshold for Linear Density was exceeded before apparent recovery was considered. The methods developed in this pilot study can be used at a regional scale; however, they can be more cost-effective if focused on areas with relatively high disturbance levels.

Key Findings

- A skilled contractor was able to map human-caused (anthropogenic) disturbances using high-resolution satellite imagery.
- The contractor usually was able to: interpret what caused each disturbance, determine an approximate width of linear features, and assign the disturbance one of eight possible vegetation statuses.
- Oblique aerial photos and localized vegetation plot photos and data were used for ground-truthing vegetation interpretation. The oblique aerial photos were the most useful.
- Some vegetation statuses were assumed to meet the North Yukon Regional Plan's definition of "recovered". These were disturbances interpreted to have woody regenerating vegetation or where no soil or hydrological modification was evident.
- The mapped disturbances were analyzed to determine the amounts of the two disturbance indicators required in the Plan.
- For LMU 9 "Eagle Plains" the current amount of "Surface Disturbance" and "Linear Density" was determined to be 0.19% and 0.38 km/km^2, respectively. These values are 25% and 51% of the cautionary thresholds for that LMU. However, the cautionary threshold for Linear Density was exceeded before apparent recovery was considered.
- **The method used in this pilot study was able to determine the current status of both disturbance indicators as required by the Plan. Having been developed, it is the best option if it is urgent to determine the indicator amounts in the remaining LMUs of the Region.**
- Several options for determining the disturbance indicators, and their estimated costs, are presented. One that focuses high-resolution imagery and detailed interpretations on LMUs likely to have significant levels of disturbances is recommended. This option was estimated to cost $140k.
- A statistical analysis of vegetation plot data was unable to determine recovery rates or clear factors affecting recovery because of the difficulty in getting adequate number of plots to capture variations in vegetation communities, landscape position, and disturbances characteristics.
- A small number of tasks remain to make the most of this project. Of most importance is to communicate the results and to have them included into assessment processes.

Table of Contents

1. Purpose

This report describes the methods and results of a pilot study that mapped, evaluated and quantified anthropogenic disturbances in Land Management Unit (LMU) 9 "Eagle Plains" of the North Yukon Planning Region. The purpose of this study was to determine the baseline levels of disturbance indicators (surface disturbance and linear density) as required in implementing the cumulative effects management framework of the North Yukon Regional Land Use Plan (the Plan) (Vuntut Gwitchin & Yukon Governments, 2009). Based on the findings of this exercise, recommendations for how these methods may be applied in other areas are provided for consideration by the Yukon and Vuntut Gwitchin governments as they implement their regional plan. It may also help inform other regional planning processes and plan implementation in Yukon.

2. Background

The North Yukon Regional Land Use Plan was the first regional plan to be completed and approved as per Chapter 11 of the Umbrella Final Agreement. As such, it set a precedent for the process of regional planning in the Yukon, the content and approach of Yukon regional plans, and now, the implementation of plans in the Yukon.

The Plan, written by the North Yukon Planning Commission (North Yukon Planning Commission, 2009) provided a diverse set of recommendations; many were to address a key issue of oil and gas development in a large portion of the winter range of the Porcupine Caribou herd. Most relevant to this document, the Commission recommended that the cumulative effects of human activities are allowed below levels where excessive impact to caribou over the long term can be expected. More specifically, the Commission recommended that two cumulative effects indicators, *surface disturbance* and *linear disturbance*, be quantified and tracked. The Plan went on to define these indicators, as well as reasonably clear definitions for "disturbance" and "recovered". "Recovered" disturbances were to no longer "count" as disturbances.

The Commission recommended that these indicators be kept below levels[1] specified for each geographic sub-division of the region, or "Land Management Unit" (LMU). While these levels are not considered hard caps on development, they do represent thresholds in decision-making. For this reason, and to better differentiate these levels from levels of existing disturbance, they will be referred to here as "thresholds".

In approving the Plan and in planning its implementation, the Parties to the Plan (Yukon and Vuntut Gwitchin governments) agreed that they should track disturbance levels, that the Commission be dissolved, and that the Yukon Land Use Planning Council ("YLUPC") check the conformity of project proposals to the plan. To check conformity, the YLUPC would (among other things) compare the combined proposed and existing disturbances to the thresholds specified for the LMU in which the

[1] The Commission specified cautionary and critical levels. The first is an "early warning signal" that triggers "proactive management steps", while the second are the maximum acceptable levels.

disturbance (surface or linear) was located (Figure 1). Therefore, understanding and tracking existing disturbances are a key part of implementing this plan.

In 2015, after the first 3D seismic project occurred within the North Yukon region, the Yukon Government asked the YLUPC to pilot a project that would determine the amounts of existing disturbances in LMU 9, Eagle Plains. The method would need to be practical, defensible, and accurate at a regional scale.

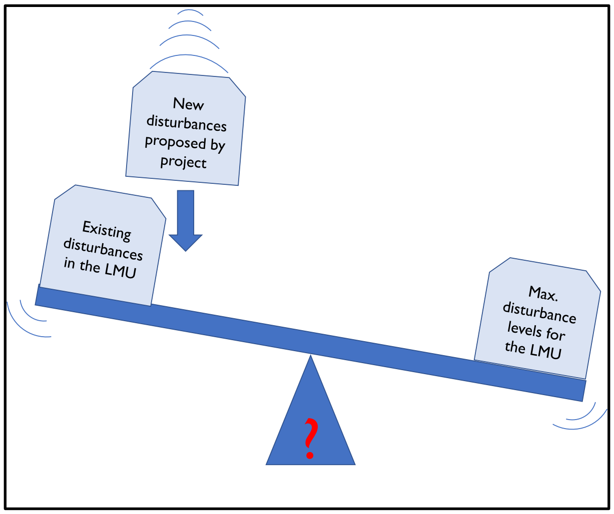


Figure 1: a schematic showing the evaluation of existing disturbances, proposed new disturbances and the thresholds.

3. Project Stages

The project's stages are discussed here in roughly the same order as they occurred. However, often two or more stages were progressing at the same time or stages progressed iteratively. Results of individual stages are presented in this section following their methods.

3.1. Scoping and options

In 2016, the YLUPC wrote a discussion paper (Skinner, 2016) that:

- outlined four options for tracking disturbance
- described its recommended course in greater detail
- discussed issues with the Plan's definitions of disturbance and recovery
- discussed end-uses of disturbance tracking and related products

The Parties agreed with the YLUPC's recommended course, which involved the interpretation of satellite imagery. However, at the Parties request, the YLUPC hired the Commission's former senior planner and author of the Plan to discuss the issues and options in the discussion paper, and suggest remedies that would still follow the Plan's spirit and intent (Francis, 2016).

3.2. Imagery evaluation

In 2016, YLUPC and YG staff and contractors assessed several potential sources of imagery to determine their suitability for this project:

- Medium-high resolution SPOT6 satellite images with 1.5m pixels
- High resolution Pleides (and others) satellite images with 0.5m pixels
- Very high-resolution elevation data from airborne LiDAR (Light Detection And Ranging)
- Air photos
- Stereo satellite images (SPOT6 or Pleides)

The first two of these options were used in small "pre-pilot" trials that tracked interpretation time and effort. Results of the interpretation trials were compared when possible. Airborne LiDAR was assessed for determining vegetation heights. Finally, specialists in acquiring and interpreting air photos of forests were consulted to estimate those costs. Cost estimates that considered image acquisition and interpretation for each option were then calculated.

Coarse LandSat imagery and disturbance mapping from it are available for the whole Yukon territory. Since LandSat's pixels are 30x30m, LandSat is not adequate for measuring and describing disturbances at the detail required by the Plan. However, the LandSat-derived disturbance mapping is useful for looking at general landscape patterns and cost estimates.

3.2.1. Results

None of these options alone were adequate for interpreting disturbance and recovery considering all aspects of the Plan's definitions for. However, it was felt that high-resolution satellite imagery would be adequate if the Plan's definitions of disturbance and recovery were modified slightly (see next section). Imagery options are compared in Table 1 below.

Table 1: Performance of 3 imagery sources. "~" denotes limited success.

	Medium-high res satellite	High resolution satellite	LiDAR
Can resolve width of narrow linear disturbances		✓	✓
Can resolve some soil/hydrological disturbances	~	✓	
Can resolve vegetation height		~	✓
Can resolve other vegetation characteristics	~	✓	
Burden of pre-processing & edge-matching	Low	High	High
Gaps in pre-purchased imagery	High	Low	Very high
Cost/km²	Low (7.2$/km²)	Medium (15.2$/km²)	Very high (60-84$/km²)
Cost for pilot*	Medium	Low	Very high

*cost for pilot was lower for high resolution imagery because of the extent already purchased.

Based on these findings, the Parties opted to use high-resolution imagery, and asked the YLUPC to purchase data to fill gaps in their 2010 imagery. YLUPC was able to acquire high-resolution imagery for nearly all identified imagery gaps. Some medium-high resolution imagery was also purchased where adequate high-resolution imagery was unavailable (<3% of LMU 9).

3.3. Honing definitions

The Plan's cumulative effects management framework is based on quantifying the amounts of two anthropogenic disturbance indicators. Anything that needs to be measured needs to be properly defined, and the Plan did a reasonable job of defining the indicators. However, the YLUPC's discussion paper (Skinner, 2016), the former senior planner's review (Francis, 2016) and the pre-pilot interpretations found that the Plan's definitions were inadequate or poorly linked in some cases, and difficult (and expensive) to implement in others.

The original definitions from the Plan:

Functional Disturbance is defined as: Physical land use disturbance that results in disruption of soil or hydrology, or that requires the cutting of trees. Activities considered exempt from functional disturbance creation are: 1) new linear features less than 1.5 m in width; 2) land use activities that occur on frozen water-bodies; 3) winter work with no required clearing of trees; 4) winter work that utilizes existing disturbances and linear features.
Surface disturbance is defined as: The amount of area physically disturbed by human activities. Such things as structures, roads, gravel quarries, seismic lines, access trails and similar features all create physical footprints on the land, resulting in direct habitat impacts. [measured in km^2, or if expressed as a density, the % of an LMU]
Linear Density is defined as: The total length of all human-created linear features (roads, seismic lines, access trails, etc.) in a given area. [measured in km within an LMU, or expressed as a density as km/km^2]
Recovery is defined as: As human-caused surface disturbances, including linear features, recover through natural re-vegetation or active reclamation, they are subtracted from the total amount of disturbed area. As a guide, human-caused surface disturbance is considered recovered when it no longer facilitates travel or access by wildlife and people. In forested areas, a feature can be considered recovered when it contains woody vegetation (trees and shrubs) approximately 1.5 metres in height.

3.3.1. Results

The former senior planner's report (Francis, 2016) recommended slightly revised, clarified and more consistent definitions that would still follow the Plan's spirit and intent. They clearly connect the concept of "functional disturbance" to "surface disturbance", "linear density" and "recovery". They also give more guidance for non-forested areas and connect these definitions to visibility in satellite imagery rather than on-the-ground measurements. These definitions guided much of the rest of this project. They are:

<u>Functional Disturbance</u> is defined as: Human-caused physical disturbance that results in the disruption of soil and/or hydrology, or that requires the cutting of trees (both live and standing dead). For practicality, functional disturbance is human-caused disturbance visible in imagery with at least 1.5 m resolution. Activities or human disturbances that do not contribute to functional disturbance creation are: 1) new linear features less than 1.5 m in width; 2) land use activities that occur on frozen water-bodies; 3) winter work with no required clearing of trees; and 4) winter work that utilizes existing disturbances and linear features.
<u>Surface disturbance</u> is defined as: The area of functional disturbance resulting from human activities. Human features such as settlements, gravel quarries, mine sites, seismic lines, access trails and similar create physical *footprints* on the land, resulting in direct habitat impacts. [measured in km^2, or if expressed as a density, the % of an LMU]
<u>Linear Density</u> is defined as: The total length of all functional disturbances resulting from linear features (roads, seismic lines, access trails, etc.) in a given area. [measured in km within an LMU, or expressed as a density as km/km^2]
<u>Functional disturbance recovery</u> is defined as: As a guide, human-caused functional disturbance (both surface and linear disturbance) is considered recovered when it no longer facilitates travel or access by wildlife and people. In forested areas, a feature can be considered recovered when it contains woody vegetation (trees and shrubs) approximately 1.5 metres in height. Similarly, in non-forested areas, a feature can be considered recovered when disruptions to soil and/or hydrology are no longer apparent. As human-caused functional disturbances recover through natural re-vegetation or active reclamation, they are subtracted from the total amount of disturbed area.

In the Plan, disturbances that are considered **recovered** are not meant to contribute to that LMU's total amount of functional disturbance. The pilot study found that only LiDAR imaging could determine whether-or-not a recovering disturbance in forested areas had woody vegetation over 1.5m in height.

Since LiDAR was prohibitively expensive and insufficient to be used alone for this project, the Parties agreed that the definition of **recovered** could be further modified to read:

> *… In forested areas, a feature can be considered recovered when it appears to contain woody vegetation (trees and shrubs) in high-resolution imagery. …*

Results of the pilot suggest that disturbances that appear to have woody vegetation in high-resolution imagery typically have woody vegetation over 1.5m in height.

3.4. Adapting the data model

Interpreting anthropogenic disturbances from satellite imagery is not new; it has been done by Yukon Government for years. Disturbance data from a number of separate mapping projects have been put into a consistent format, or *data model*, and placed into one central database. This database includes polygons that represent broad two-dimensional disturbances, lines that represent linear features, and rarely points that represent small features. Francis (2016) suggested that data from this project should be consistent with Yukon Government's Disturbance Mapping Standards and Guidelines. However, the standards before this project started did not include many attributes (also known as fields or types of information to be gathered for each mapped disturbance) that could be necessary to:

- "Filter out" disturbances that remain visible yet appear to be recovered
- Statistically explore spatial relationships between coarse vegetation status and type of disturbance, time since disturbance, and mapped biophysical features. This may allow recovery to be forecasted, or the development of best practices that reduce the duration of new disturbances.

To address these shortcomings, the Geographic Database Administrator at Energy Mines and Resources, YG, worked with YLUPC and other users of the disturbance database to expand the standards.

3.4.1. Results

The guidelines and standards document went through two iterations over the course of this project, resulting in version 3 (Yukon Government, 2017). Some of the changes include:

- The topology now allows overlapping lines if the same feature was used more than once. This was necessary to capture often different vegetation status that results from each use. For example, older, wider cutlines that were re-used in recent years for access often had woody vegetation revegetating the margins, with no vegetation in the middle.
- Minimum polygon size and width specifications were added
- Some attributes were modified and/or clarified, e.g., DISTURBANCE_TYPE, INDUSTRY_TYPE
  - Options for DISTURBANCE_TYPE were changed to reflect more the nature of the disturbance and less reason. The reason would often be evident by looking at INDUSTRY_TYPE. For example, disturbances with the TYPE of [cutline, survey cut lines, seismic] in the original model were assigned the DISTURBANCE_TYPE of [Cutline/Survey] in the new model.
- Several attributes were added, including:
  - CURRENT_ROAD_SURFACE: level of improvement done to the road. This has large implications to the recovery rate.
  - TRAIL_ROAD_USE: Refers to the intensity of use of trails from low, moderate to high use. Default: unknown.
  - DISTURBANCE_REUSED_IND: Indicates if an old linear disturbance is being reused.
  - DISTURB_VEGETATION_STATE: This vegetation state takes into account 3 variables that relate to the definition of recovery, 1) if there are Shrub/Trees regeneration, 2) If it is in Forested community or not, 3) if Soil or Hydro has been significantly modified. This was adjusted iteratively once interpretation began in earnest (see section 3.6, below). See Table 2, below.
  - ACTIVE_IND: indicates whether the features are active, inactive or decommissioned. In cases where this attribute is not interpretable, an area expert may need to assess.
  - DISTURBANCE_YEAR: Year of disturbance
  - DISTURBANCE_SEASON: Generally, summer or winter. This may be completed based on disturbance date and knowledge of typical disturbances in the area.

Table 2: Vegetation state, and the decision tree the interpreter used to reach them

Digitize vegetation status on feature								
Marginally visible	Distinctly visible							
(only visible b/c continuous with more visible disturbances) *NOTE: The interpreter of LMU 9 in 2017 did not digitize these features*	Surrounded by forest *(tree cover >10%, trees > ~1.5m height)*				Not surrounded by forest *(e.g.: alpine, tundra, burns with trees ~<1.5m height)*			
	Different from surrounding community			Similar to surrounding community	Similar to surrounding community	Different from surrounding community		
	No woody growth		Woody Growth of different species or density *POSSIBLE soil/ hydrological/ thermokarst modification*	Woody Growth of similar species *(May be less dense or tall, but should have a similar species composition to surroundings)*	No evident soil/ hydrological/ thermokarst modifications	No woody growth		Woody growth (height ~>1.5m implied) *(Vegetation response (or enhanced growth) may indicate water/drainage and/or nutrient change)*
	No evident soil/ hydrological/ thermokarst modifications *(e.g., recent woody vegetation clearing with little soil disturbance, or clearing in naturally unproductive site)*	Soil/ hydrological/ thermokarst modification evident *(e.g., gravel pit, ponding, different vegetation response)*				No soil/ hydrological/ thermokarst modification evident	Soil/ hydrological/ thermokarst modification evident *(indication of water/drainage and/or possible nutrient change)*	
X: Marginally visible	D: In forest + no woody regrowth	E: In forest + soil disturb *+no woody regrowth*	B: Different woody growth	A: Visible but similar to surrounding environment *No visible hydro/thermokarst difference*		G: Not in forest + no soil disturb evident *BUT different*	F: Not in forest + soil disturb *Including intermittent changes*	C: Not in forest + woody regrowth
NYLUP: Recovered/ Not Disturbed	**NYLUP: Not Recovered/ Disturbed**	**NYLUP: Not Recovered/ Disturbed**	**NYLUP: Recovered/ Not Disturbed**	**NYLUP: Recovered/Not Disturbed**		**NYLUP: Recovered/ Not Disturbed**	**NYLUP: Not Recovered/ Disturbed**	**NYLUP: Recovered/ Not Disturbed**

3.5. Evaluating field data

Two sources of "field" data were available to help test the methods explored in this project.

3.5.1. Oblique aerial photography

In 2006, the Canadian Wildlife Service flew cursory fix-wing aerial photographic surveys of interesting features around Eagle Plains and the Peel Plateau. These surveys focused on legacy disturbances from oil and gas exploration (1950's to early 2000's). The resulting geo-referenced oblique photos were provided to the North Yukon and Peel Watershed Planning Commissions. These were made available to the image interpreter to help ground truth interpretations.

3.5.2. Detailed ecological fieldwork

3.5.2.1. Fieldwork

In 2006 and 2007, Yukon Government and contractors did exploratory fieldwork and analysis of disturbance and recovery of legacy (>40 years old) oil and gas exploration. In 2014 and 2015 they focused detailed fieldwork in and around LMU 9 in order to better understand the relationships between mechanisms of disturbance, time since disturbance and local ecology and topology. Most of this fieldwork was on legacy disturbances (seismic lines, roads, well pads and airstrips).

In 2016-17, Yukon Government and the YLUPC partnered to wrap-up the 2014-15 work to produce:

- Final spreadsheets of field data
- Photos organized with plot data
- Interpretations of disturbance and recovery
- A project summary report that includes a summary of fieldwork and analytical methods and discussion of the ecological status of each plot and how it compares with the definitions of disturbance and recovery of the Plan (Simpson et al., 2017).

The total cost of the fieldwork (Yukon Government expense) was not provided. However, the cost of the contracts for the final work-up (YLUPC expense) was $22,165.00 + GST.

Results

The field project summary report (Simpson et al., 2017) reached a number of conclusions, typically based on qualitative assessments of their data and their field experience. Most of these won't be repeated here. Some of the more relevant conclusions include:

- Severe fire can reset the vegetative community and permafrost depth along seismic lines
- "It is difficult to identify any one factor as responsible for the impairment of growth on these disturbances."
- Seismic lines and airstrips can typically be expected to recover to normal site characteristics; this may not be expected of highly disturbed winter roads, well sites, camps and staging areas

- "The NYLUP suggests as a guide that in forested areas, a feature can be considered recovered when it contains woody vegetation (trees and shrubs) approximately 1.5 m in height. This may need to be re-considered as some Type 3 disturbed sites have recovered to this height or greater – but have done so in a modified manner presenting vegetated conditions anomalous to the region."

This report focused on ecological mechanisms of recovery, and industrial practices that may result in shorter-lived disturbances. It includes many valuable insights, and may be useful if the definitions of "disturbance" and "recovery" in the Plan are re-evaluated. However, it did not offer insight into the recovery rates of disturbances, nor a direct way of quantifying existing disturbance features – whether still disturbed or recovered.

The costs of this project were not provided to YLUPC, and were not considered in this report.

3.5.2.2. Statistical Analysis

In 2018, YLUPC and a contracted statistician attempted to statistically analyze the field data to help answer the following questions:

- Whether disturbance tracking should use recovery models, or simply re-interpret disturbances periodically?
- How necessary is a field program to better understand disturbance & recovery for tracking disturbance?
- How reliable is disturbance data interpreted from satellite imagery?

The statistician found that the data provided (spreadsheets) was "dirtier[2]" than anticipated and that the metadata (e.g., the report that describes what is in the data) were not clear. Therefore, the statistician developed and documented methods for cleaning and better documenting the data, which included suggestions for grouping similar values or classifications. YLUPC staff followed these instructions to get data in a form the statistician could better use. The statistician went on to "tidy" the data (e.g., drop data not useful to modeling, and adding derived variables that may).

Once the data were tidied up, additional information for each plot was added by intersecting the plot location with other spatial data in a GIS. In this way, remotely sensed elevation, slope, aspect, heatload, ecological land classification, surface shape, slope position and other descriptors were added.

[2] "Dirty" data are data that have one or more of: 1) inconsistent or incorrect coding, 2) ambiguous gaps (does a gap mean there is nothing there, or it wasn't noted?), 3) incorrect data, e.g., plot locations, 4) duplicate data.

There were 109 plots described by 76 fields or attributes. To try to make sense of all these attributes, the statistician used an unsupervised clustering technique called PAM clustering with a Gower distance matrix to find clusters of plots based on similar:

- Types of disturbance
- Underlying physical conditions of the landscape ("site class")
- Expected vegetation class

These clusters were visually compared by reducing attributes down to two dimensions using the algorithm "t-Distributed Stochastic Neighbor Embedding". This approach allows for a more intuitive assessment of the clusters. The statistician then looked at the *response trajectories* for each combination of the 3 ways of clustering the plots. *Response trajectory* is the difference between the observed and expected vegetation (disturbed vs control plots) compared with time since disturbance.

The statistician did some simple comparisons between field observations and available spatial data. Some spatial data are directly comparable with those observed in the field (e.g., elevation), while others are not (e.g., structural stage of vegetation observed in the field is not directly related to available ecological land classification spatial data).

Owing to the unexpected amount of data cleaning, the statistician was unable to deliver the expected deliverables, including a final report of her work. However, she was able to provide the results of a cursory analysis, some informal recommendations, and the detailed code used for these analyses. This code will help document what she did, and should be useful in further data exploration.

The statistician also recommended a spatial analysis that compares the disturbance interpretations (see Section 3.6) to other spatial data. This approach would establish thousands of virtual plots and could be a powerful way of linking vegetation status (see Table 2) to disturbance types and various landscape descriptors. She provided some code that she used to randomly locate these virtual plots.

The statistician budgeted and billed for 6.5 days ($7800) for this project but ended up putting in about 19 days work (3 times more than anticipated).

High-level Results

The results of the cursory analysis of field data were summed up by the statistician:

> *Moving forward, I believe these are too few data (because such high variability!) to produce confident management recommendations about disturbance design or location and recovery times.*

With high variability among plots, one would need many[3] paired plots for every combination disturbance type, site class, and vegetation class to see a distinct response trajectory. The statistician identified 24 or more potential combinations that could be tested. Therefore, if one assumes that 10 paired plots would be necessary per combination, two actual plots per pair, and 24 combinations of conditions to test[4],

[3] The statistician didn't provide an estimate of how many plots would be required.
[4] This number may be reduced since some combinations are likely rare on the landscape.

then about 480 plots would be necessary to get a response trajectory for all combinations of conditions. Ideally these plots would also reflect a range of times since disturbance – something lacking in Eagle Plains where most of the disturbance features were made over a 15-year span 40+ years ago.

Though further analysis could likely lead to a recommendation of a simpler survey that could be used to get more plots, access to all combinations of conditions would continue to be a problem. More importantly, finding solid response trajectories from field data could be impossible at this time without a broader range of disturbance ages.

Detailed Results

Clustering

Four clusters of disturbance characteristics were identified: polygonal features, compacted linear features, non-compacted linear features that run roughly north-south, and non-compacted linear features that run roughly east-west (Figure 2). It isn't surprising that the polygonal disturbances clustered separately from linear ones. Also, the fact that the compacted linear features clustered separately from non-compacted ones is supported by Simpson et al. (2017). Interestingly, the orientation of non-compacted linear features seemed to be significant. Further analysis should look for the drivers of this separation.

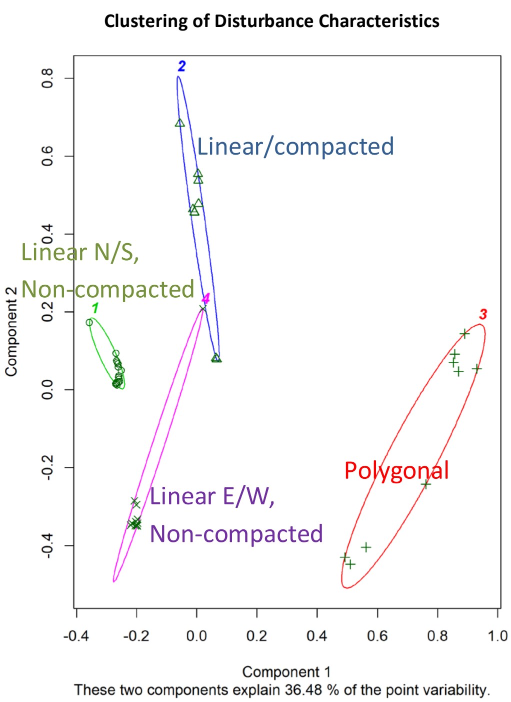


Figure 2: a two-dimensional visualization of the four clusters of disturbance characteristics

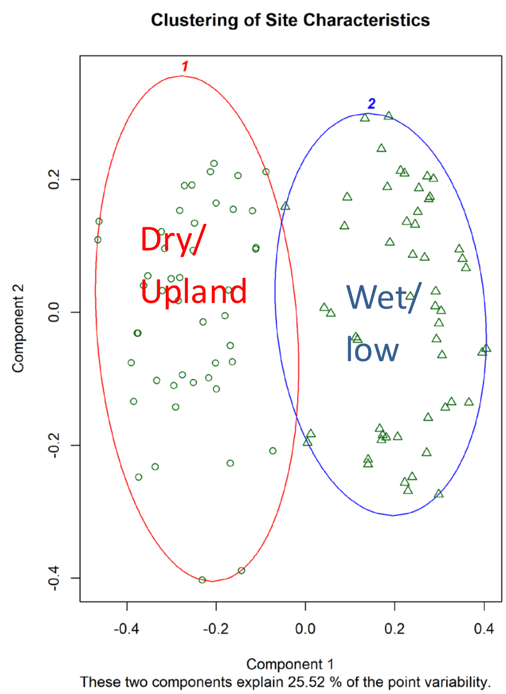


Figure 3: a two-dimensional visualization of the two clusters of site characteristics

Though there were many site characteristics noted in the field, they were best clustered into two distinct (and obvious) clusters (Figure 3).

The statistician attempted to cluster vegetation communities using general vegetation characteristics (Figure 4) and with more detailed characteristics (Figure 5).

There were ~ 8 combinations of site type and disturbance type with only on average ~7 plots per combination (Figure 6). The number of plots per combination was reduced because of the number of control plots and redundant/incomplete plots.

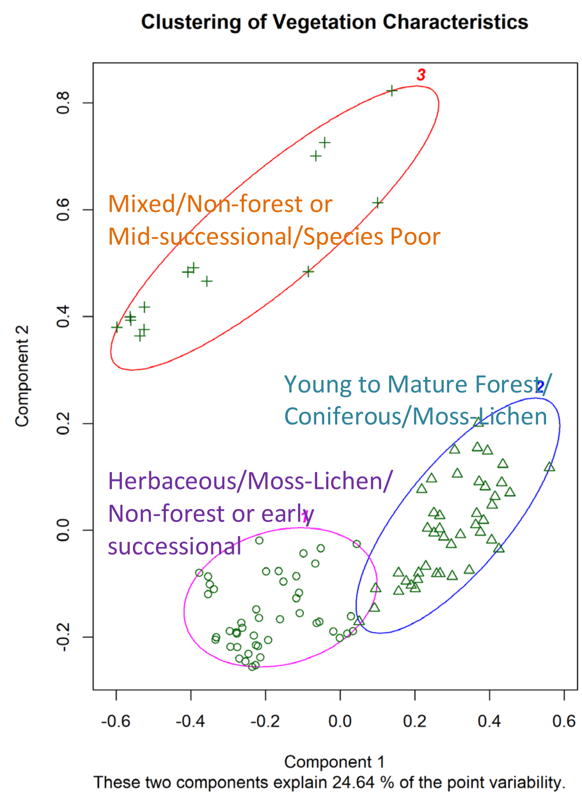


Figure 5: a two-dimensional visualization of the three clusters of general vegetation characteristics

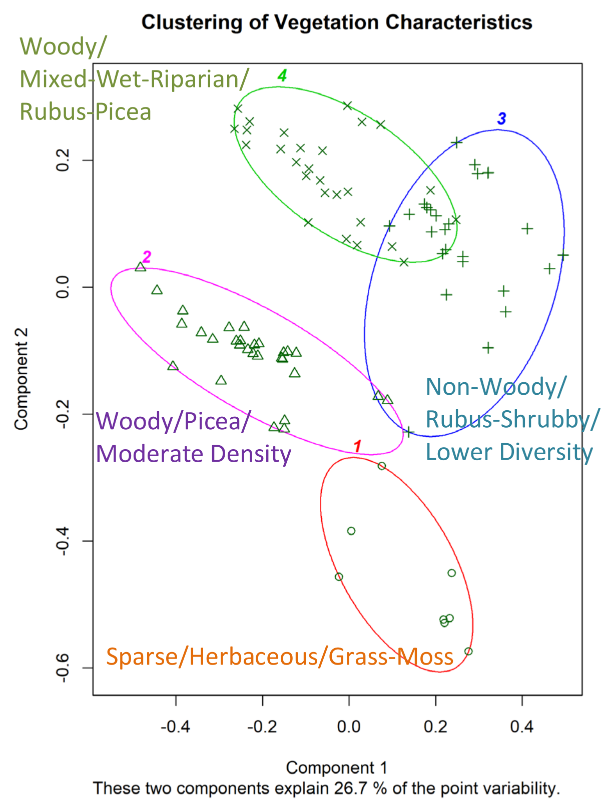


Figure 6: a two-dimensional visualization of the four clusters of more specific vegetation characteristics

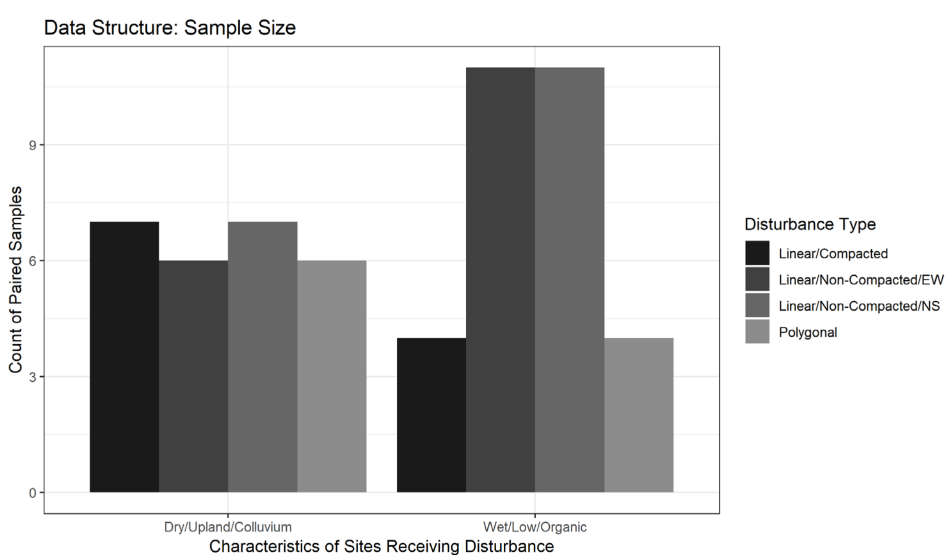


Figure 4: Sample size for each combination of disturbance and site types

Comparing Disturbances and Control:

For each combination of disturbance and site types, differences in vegetation between the control and disturbance plots were investigated. Over time, we would expect disturbed plots to gradually become more similar their control plot, with some site/disturbance combinations recovering faster than others. This pattern would show up in Figure 7 as a scattering of dots trending in the direction of the arrows. However, there are no strong patterns evident in that figure. This could be due to one or more of the following: 1) too few plots, especially from more recent disturbances or 2) high variability among plots.

The results suggest that there may be recovery in dry upland sites, for linear/compacted and linear/non-compacted/North-South disturbances. However, this pattern is very weak, and would disappear without one or two plots. In fact, similar analyses using different vegetation clustering (3 groups vs 4) yield conflicting conclusions.

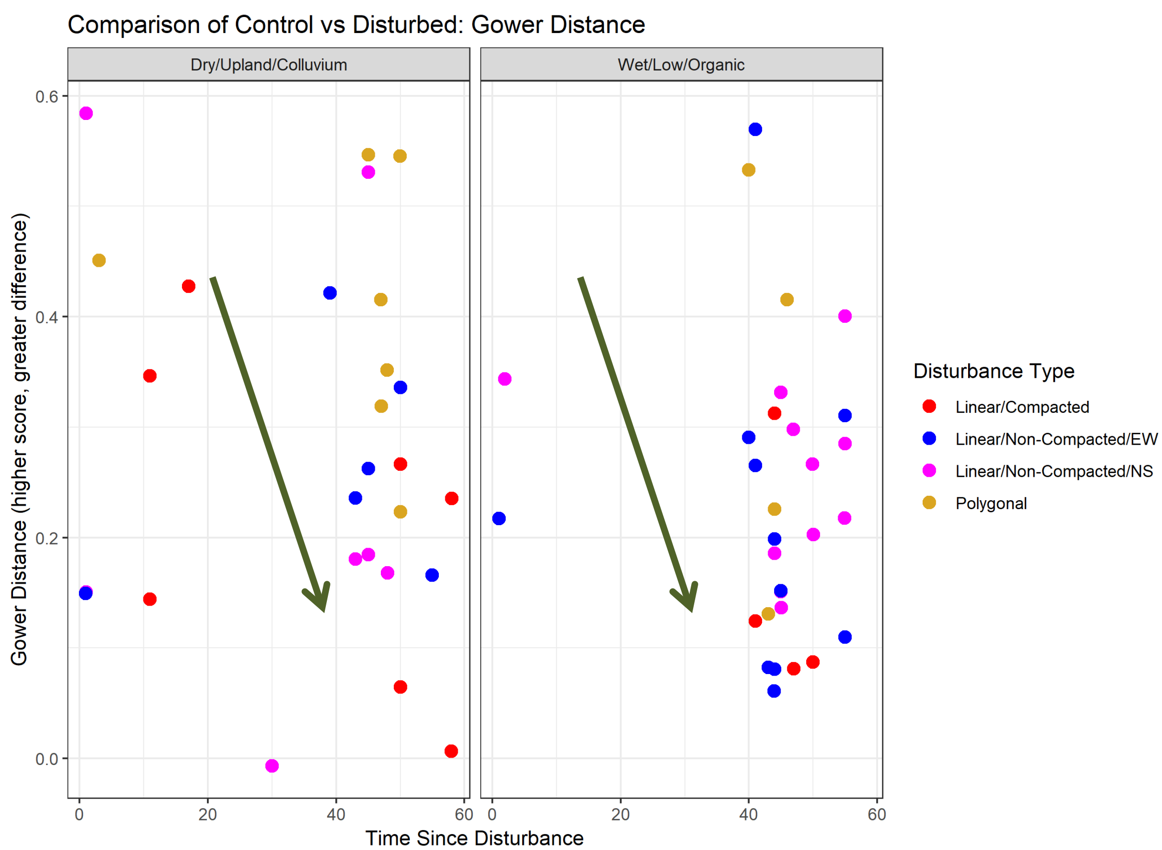


Figure 7: A greater Gower Distance indicates a greater difference between the disturbed site and the control site. The green arrows indicate the expected pattern.

Time Since Disturbance and Ranks:

The effect of recovery time on the "Recovery Rank" and "Disturbance Rank" of Simpson et al. (2017) was also investigated with disturbances grouped simply by either polygon or linear (Figure 8 for Recovery Rank). We would expect more recovery over time since disturbance. There is no indication of this in the figure, except possibly for linear disturbances on upland sites where lower ranked sites in yellow tend to be older (top of the figure). Again, more plots are needed on disturbances 10 to 30 years old to better support this trend.

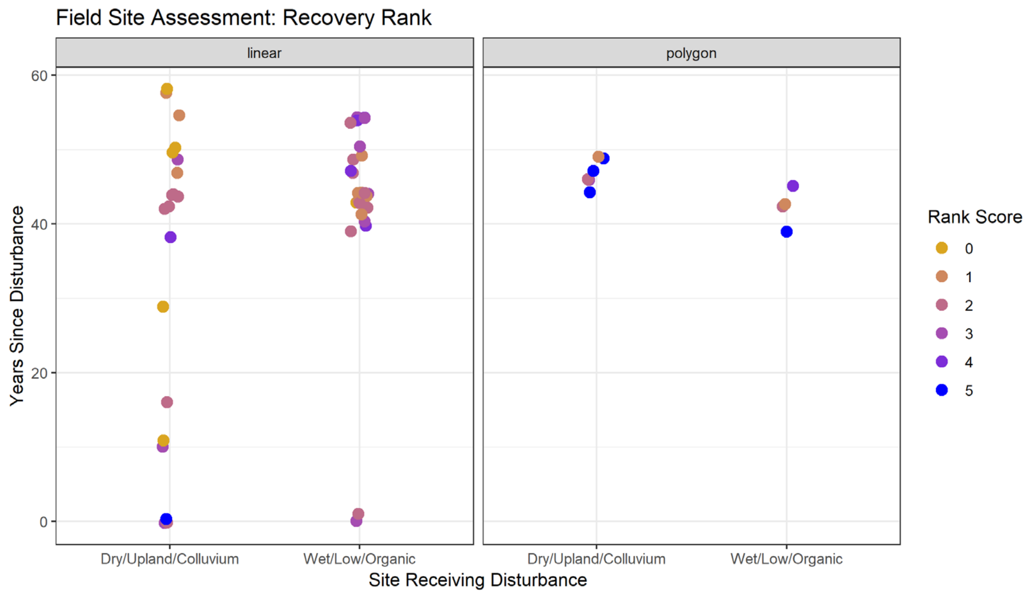
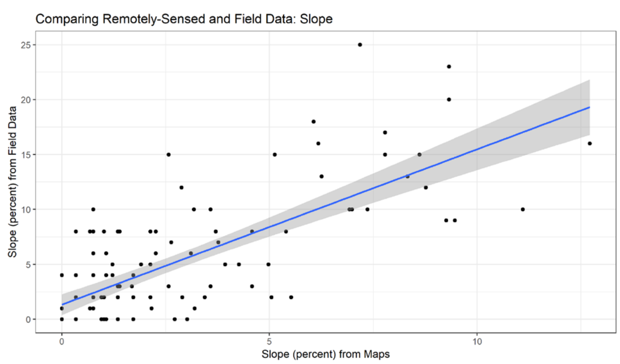


Figure 8: Influence of time and site on Recovery Rank. 0 indicates "no recovery required", 5 indicates "recovery not possible without significant intervention". We would expect higher ranks (bluer dots) near the bottom.

Compare Field data and Remote Sensed/mapped data:

In addition to the field plots, thousands of virtual plots on and off of mapped disturbances were randomly generated. Then for all three groups of plots (field, on disturbance, off disturbance), mapped data was given to each plot, including: elevation, slope, aspect, heatload (calculated from slope, aspect, latitude), and ecological land classification. To date, only the field data has been compared to mapped data. As expected, these data generally correspond closely (Figure 9).



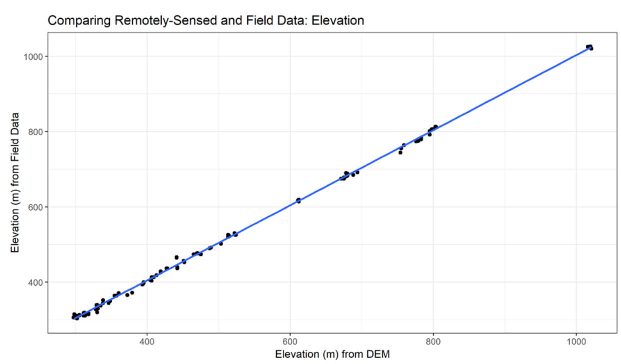


Figure 9: Some relationships between Field and Remotely-Sensed (Mapped) Data. Left: slope. Right: Elevation.

3.6. Imagery interpretation

After developing an RFP with colleagues in YG, the YLUPC contracted Aspect North in July of 2017 to interpret satellite imagery and maps, and to describe all human-caused disturbances in LMU 9 (Eagle Plains), following the established data model and guidelines (Yukon Government, 2017). A preliminary quality assurance (QA) analysis that involved EMR staff and contractors with on-the-ground experience in Eagle Plains indicated that Aspect North was performing adequately. However, the preliminary QA recommended that some of the vegetation status specifications be modified slightly.

Aspect North kept to their deadlines, despite the project being more time consuming than anticipated. The contractor delivered a draft final data and draft report.

The draft disturbance mapping was assessed a second time for quality by YG and YLUPC staff. The study area was divided into 6736 1x1km "cells" and 94 (or 1.4%) were randomly selected for quality assessment.

Using the feedback from the quality assessment, the contractor addressed many of the issues found, and produced a final report that detailed interpretation methods as well as issues encountered (Aspect North, 2018). To help determine the error rate of the width measurements, the contractor generated random points along linear features. YLUPC then measured the widths using the imagery at 103 of these points and compared them to the width of the entire line segment interpreted by the contractor, using a paired t-test.

3.6.1. Results

Of the eight received bids for the interpretation contract, only five met the minimum technical score. Of these, there was a very large range in bid prices: $15,000 to $98,585. Much of this variation could be due to the lack of familiarity potential contractors have with the new contract specification of interpreting vegetation status. The RFP placed half the evaluation's value on price, and the lowest priced proposal of the five qualified proposals won. The winning contractor, Aspect North, had great local references, and did a great job. However, the project was delayed because of several slight modifications to the project specifications. A contract extension valued at $5000 was granted by YLUPC to Aspect North to address these modifications. Further, Aspect North found the project more time-consuming that anticipated (largely due to interpreting the vegetation status), but did not charge the $9,750 shortfall. The total value of this project was ~$29,750.

At the draft stage, the contractor found that some of the descriptive information required in the contract could not be reasonably interpreted. Many of these descriptions are better suited for domain experts to fill in later, or are not necessary to determine current disturbance levels. These descriptors include:

- DISTURBANCE_SEASON: this would be useful to better understand how the season a disturbance occurs in relates to its recovery. However, it wasn't possible to interpret from the imagery. It is possible that an expert could suggest case rules for inferring the season.
- TRAIL_ROAD_USE: intensity of use of trails from low, moderate to high use
- ACTIVE_IND: Are the features active (Active (Y) / Inactive (N) / Decommissioned.

Errors noted during the second quality assessment were counted and categorized. Error rates over 5% are typically considered excessive. However, given the difficulty and subjectivity of vegetation interpretation, we were expecting higher error rates. Highlights include:

- ~3.7% of disturbance features were missed. This was due to a small gap in in imagery that was recent enough to capture the 3D seismic program of 2014. **Resolution:** The contractor filled this gap by using the GPS data provided by Northern Cross; however, the vegetation status remained missing in this area.
- <1% of the features digitized shouldn't have been
- <1% of the features were assigned either the wrong type or wrong industry of disturbance
- 9% of the linear features had noticeably wrong widths. This is likely because the widths reported for these features were averaged over their length, while the QA was done often for only a small segment. **Resolution:** The widths re-evaluated by YLUPC were only on average 20cm wider than the original width interpretation; however, the statistical analysis determined that this difference was insignificant (Figure 10).
- 15% of features had an incorrect vegetation status. It was not feasible or useful for the contractor to re-evaluate the vegetation status for all features; however, the contractor was asked to review certain cases. This error rate was expected given the methodology.
- 8% of the features referred incorrect satellite images. These errors will have no impact on the final analysis. **Resolution:** the contractor corrected most of these errors.

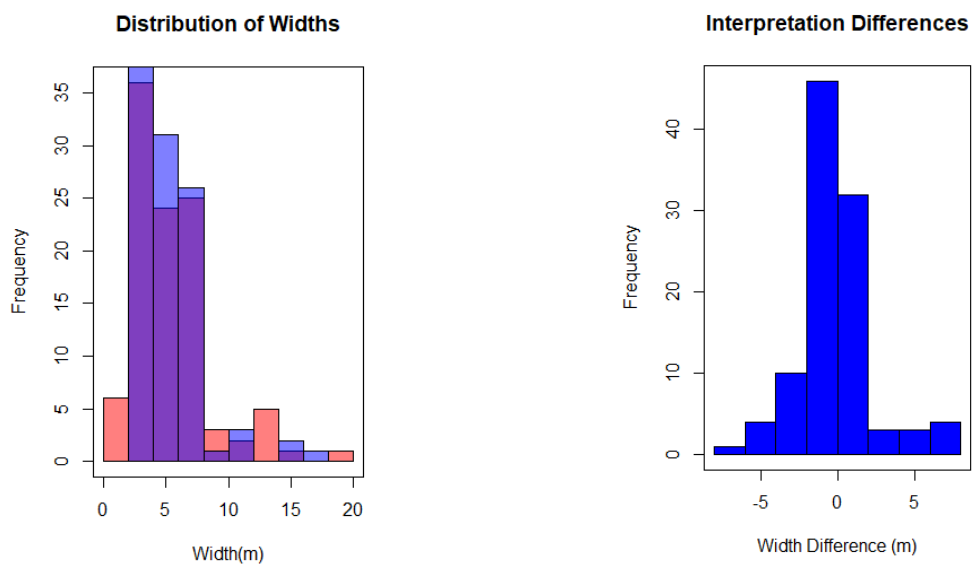


Figure 10: At left, blue bars represent the counts of random sampled interpreted (by the contractor) widths, while red represents the re-evaluated widths. Purple shows overlap. Note that the distribution of both samples is very similar. At right, the differences between the two samples at each random point is plotted. Note that the differences are clustered around 0 and are roughly balanced between positive and negative differences. This is as expected when there is no significant difference between the original interpreted widths and the re-evaluated widths.

- At least 6% of the features did not report recent fire history correctly. This isn't surprising given the incomplete fire database and the subjectivity of interpreting if a fire was recent.

The final report by the contractor is itself a resource for those preparing and executing interpretation contracts. For convenience, some of the more relevant conclusions include:

- "Oblique photos were the most efficient method in understanding the landscape and/or the disturbance." This was especially true for interpreting burned areas. See Section 3.5.1.
- "The YG field plot data were useful in the initial stages of this project. These point data contain substantial amounts of data which helped to gain a better understanding of the landscape as well as the vegetation condition of the disturbance."
- "SPOT 6 imagery was not useful for obtaining width measurements of features that were <4m."
- "The domain *X - Marginally Visible* under the *FEATURE_VEGETATION_STATE* field was not as useful as expected… Polylines were split and sections with no visibility were deleted." NOTE: This option was added to the scheme in Table 2, but not used in the end.
- "False-colour infrared (FCIR) was helpful in areas where there were light shadows or light cloud cover (haze) in the satellite imagery. FCIR was not helpful for determining *FEATURE_VEGETATION_STATE.*"
- "Satellite imagery with snow cover was useful for identifying disturbances; however, it was not advantageous in determining vegetation status. It would be easier to identify disturbances in snow covered areas if vegetation status was not a requirement."

The report also identified two issues:

- "As per the Standards and Guidelines, *DISTURBANCE_TYPE* domain *Recreational/Resource Road* is currently not permitted to have an *INDUSTRY_TYPE* domain of *Transportation*. For example, an access road to transportation related disturbances (e.g. gravel quarry) for road maintenance was prohibited under the current domain structure. This restricted combination; however, was applied to the final dataset. Consider revising as needed."
- "*FEATURE_VEGETATION_STATE* have not been completed for areas with SPOT 6 coverage, cloud cover, or in areas without imagery. These areas will have to be revisited when higher resolution imagery becomes available." NOTE: estimates of total disturbance levels in Section 3.7 compensated for this gap.

A total of 6195.7km of linear features and 38.7km^2 of polygonal features were digitized within the Eagle Plains study area (6414.6km^2). No point features were digitized.

3.7. Disturbance Analysis

The raw interpreted disturbance data described in the previous section gives a general indication of the amount of human-caused disturbances that are visible in the imagery. However, these numbers do not consider the definitions and exceptions described in the Plan, and have a few known gaps, and therefor cannot be used directly as the current level of disturbance in Eagle Plains. The following needs to be considered in the analysis:

- Area of linear features: the area of linear features needs to be included in the total surface disturbance tally. This is done by turning the linear features into polygons by "buffering" them by half their width, then merging these new polygons to the polygonal features. Area is calculated from this merged layer.

- Dempster Highway Corridor: disturbances within one kilometre of the highway are not to be counted.
- "Recovered" disturbances: not to be counted. The interpreted vegetation status can be used to eliminate features that appear to be recovered. See bottom row of Table 2.
- Overlapping linear features: sometimes the same linear disturbance is used again in a later exploration project. Typically, the more recent disturbance is narrower, but is less recovered. When this can be interpreted, the interpreted treated these as two separate features. Such features had to be "dissolved" together so that they were not double counted.
- Data gaps: amounts of disturbance within areas with missing or inadequate imagery were extrapolated. First, all disturbance features outside of the gaps were first categorized as being part of recent (i.e., 2013-2014) or older exploration activity. Next, the proportion of these features in each category interpreted as "unrecovered" is calculated. Lastly, this proportion is applied to features where vegetation status could not be determined to get an estimate of the amount (but not location) of these that have not yet recovered.

All these analyses were done using a spatial model developed by YLUPC in a GIS (ArcMap) that exported tables that were further analyzed in a spreadsheet. A similar analysis that couldn't address vegetation status was also done for coarse LandSat based disturbance data that is available for the entire Yukon Territory. Since the LandSat interpretation pre-dated the 2013-2014 exploration project, the interpretation results above were also analysed for just early disturbances to see if a simpler interpretation of LandSat yields comparable results.

3.7.1. Results

The attributes (or "fields") in the raw interpreted disturbance data that were necessary for this analysis were "vegetation state" and the "year of disturbance". Results of this analysis are presented the following table and figures. They are presented in steps to give an indication of the relative effect of each consideration in the analysis.

Table 3: Disturbance metrics from the disturbance interpretation project and a separate project that used coarser imagery (LandSat). These metrics are visualized in Figure 11 & Figure 12. They are shown in a map in Figure 13.

Description	Figure Number	Surface Disturbance (%)	Linear Disturbance (km/km²)	Surface Disturbance (% of cautionary threshold)	Linear Disturbance (% of cautionary threshold)
Raw interpreted	12a	0.6026	0.9659	80.6%	128.8%
Less Dempster corridor	12b	0.5692	0.9390	75.9%	125.8%
Less recovered	12c	0.1857	0.3685	24.8%	49.1%
Plus gap extrapolation	12d	0.1905	0.3804	25.4%	50.7%
As above, old features only	12e	0.1272	0.1595	17.0%	21.3%
LandSat	12f	0.2357	0.1821	31.4%	24.3%

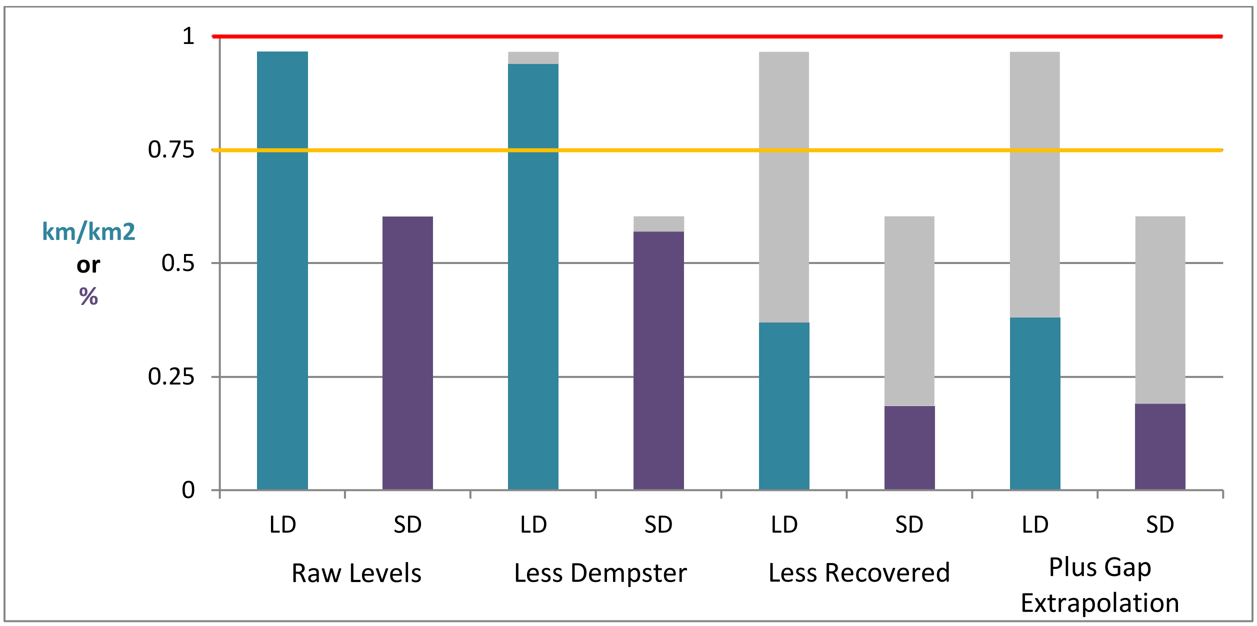


Figure 11: The results of each step of the analysis of the disturbance data, expressed relative to the size of LMU 9. The cautionary threshold is shown in amber, the critical in red.

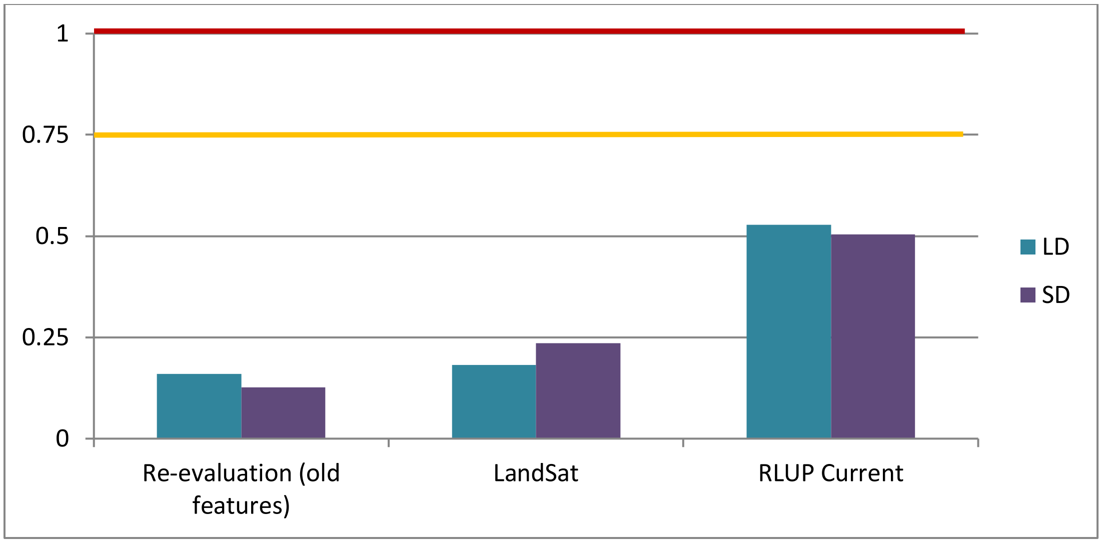


Figure 12: Amounts of legacy disturbance features from 3 sources: this project at left, interpreted coarse imagery at center, and the North Yukon Planning Commission's estimate provided in their Recommended Plan

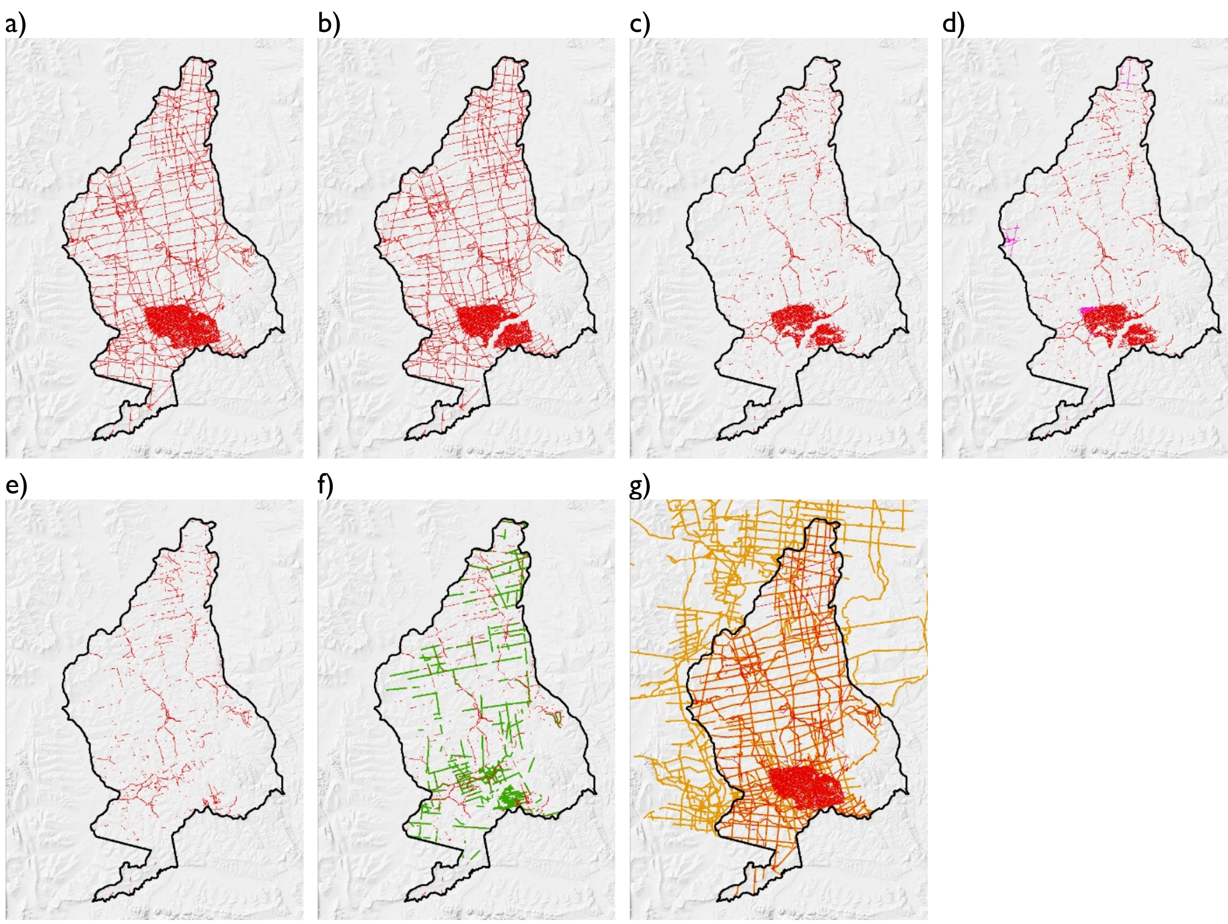


Figure 13: maps of LMU9 with different sources of disturbance data (orange= North Yukon Planning Commission; green= LandSat; pink= GPS or medium resolution imagery where vegetation status was extrapolated). Disturbance in red are from this project, but with different amounts of "filtering" or considerations: a & g) raw interpreted disturbances; b) without the Dempster Corridor; c, d, e, f) without "recovered" features; d) with gaps filled; e) with 3D-seismic features removed; f) comparison between LandSat-derived disturbance mapping with mapping from this project.

3.8. Costing analysis

The North Yukon Regional Plan recommended considering existing disturbances in land management decisions throughout the region. As this this project piloted methods only in LMU 9, there is a need to increase our understanding of existing disturbances in other areas of the Region. Based on the pilot study described above, the costs for options for filling this data gap were estimated.

3.8.1. Expenses

Some expenses were estimated based on the size of the project area; others were based on the amount of coarse disturbances (using LandSat-based disturbance mapping) relative to those in LMU 9.

The following components were considered:

- **Oblique aerial photos:** in 2006, CWS took thousands of oblique photos from an airplane flying over Eagle Plains and the Peel Plateau. These were very useful for the interpreter. Cost estimates were based on a recent hourly quote from a local charter company and on the flight-hours used by CWS, both in relocation of aircraft, and in actual photography flights. It does not include the costs of photographer. Ideally the photographer would be the interpreter.
- **Satellite imagery:** Cost estimates based on YG's current (January 2021) Standing Offer Agreement with their vendor. Other departments may be interested in cost-sharing this, especially for other regions to be planned. There are several factors when purchasing satellite imagery, including: resolution and satellite platform, size of study area, and whether to use archived imagery (cheaper, but would result in a patchwork of platforms and image dates) or "tasked" imagery (more expensive for high-resolution, but more uniform quality and image dates) and allows for the selection of specific (and more cost-effective) satellites, like the Pleides satellite. The cost of medium-high resolution imagery declines 40% when purchased for larger areas. In contrast, the cost of high resolution does not vary with project size.
- **Imagery processing:** Cost estimates based on those currently being paid by YG (January 2021). Processing costs vary from 4-21% of the imagery and depend on resolution and size of study area.
- **Imagery interpretation:** based on the contractor's fees for LMU 9, the contractor's comments on her under-estimation of costs and time, the larger size of the project area and the lower amount of disturbance expected (using available LandSat disturbance mapping as a guide).
- **Analysis and data loading:** assuming the methods remain similar, the only costs associated with this step would be some for internal staff time.

A field program could strengthen the results; however, the costs of helicopter-supported ground-truthing in remote LMUs would be prohibitive.

3.8.2. Costing Options

There are many ways to estimate costs for the North Yukon Region, based on varying the quality and extent of imagery and interpretation. Eight options were evaluated for the Region in addition to two very rough estimates for the entire Yukon. The options represent different trade-offs between cost, confidence in the results, needs to improve understanding of disturbance and recovery, and the need for full coverage of the Region. All estimates consider the unplanned overlap area in addition to the original Region and assume satellites will be "tasked" for this project. Descriptions of individual options are given in the next section.

3.8.3. Results

Options A, B, C and D only use high-resolution imagery but over different extents of the region.

Options E, F, G and H are hybrid approaches that focused the expenses of high-resolution imagery on LMUs considered to likely have higher disturbance levels, while medium-high imagery and standard disturbance mapping (i.e., no interpretation of vegetation status, and therefor recovery) is reserved for the rest in options E and F. Option G and H gets no new imagery or disturbance mapping LMUs likely with lower disturbance levels. LMUs considered to likely have higher disturbance levels were defined as those LMUs with LandSat-derived linear density over 20% of their cautionary level. LMUs zoned as Protected Areas were assigned the cautionary level for IMA I. Using this criterion, LMUs considered to likely have higher disturbance levels are: 2C, 8B, 8C, 9 and 10B (Figure 14). These LMUs total 11,195km^2 in area, or about 18% of the region.

"Option I" and "Option J" cover the entire Yukon Territory and use high and medium-high resolution imager, respectively. They are not an option for implementing the North Yukon Regional Plan but are included for exploratory purposes only.

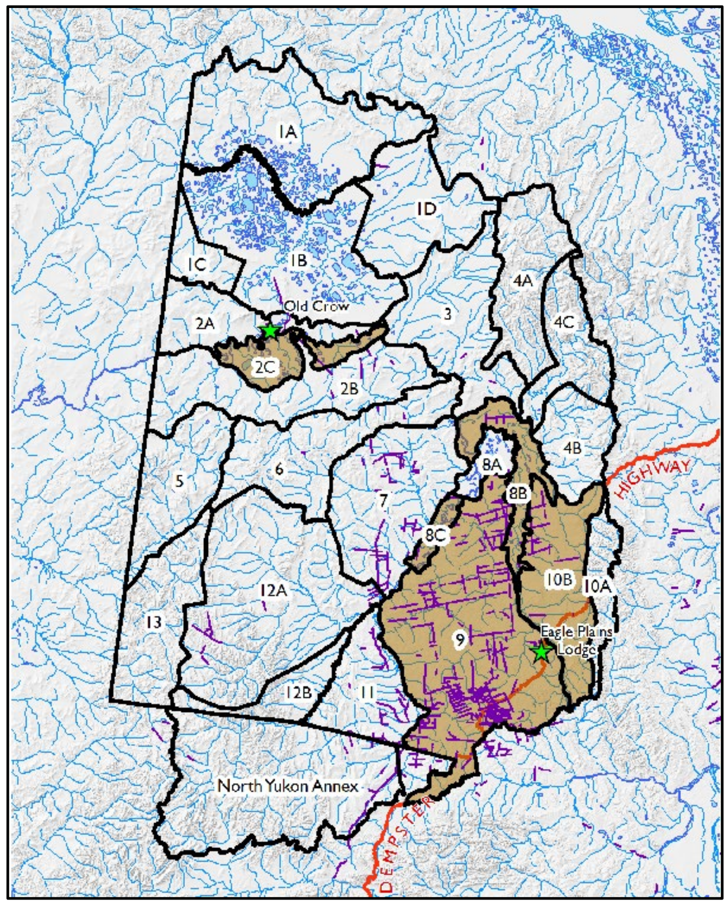


Figure 14: Map of the North Yukon Region. LMUs are labelled and outlined in black. Those selected in Option E to get high-res imagery and full interpretation are shown in orange. Linear disturbances mapped using LandSat are shown in purple.

Further comparisons of these options are found in Table 4, while cost breakdowns are shown in Figure 15 below.

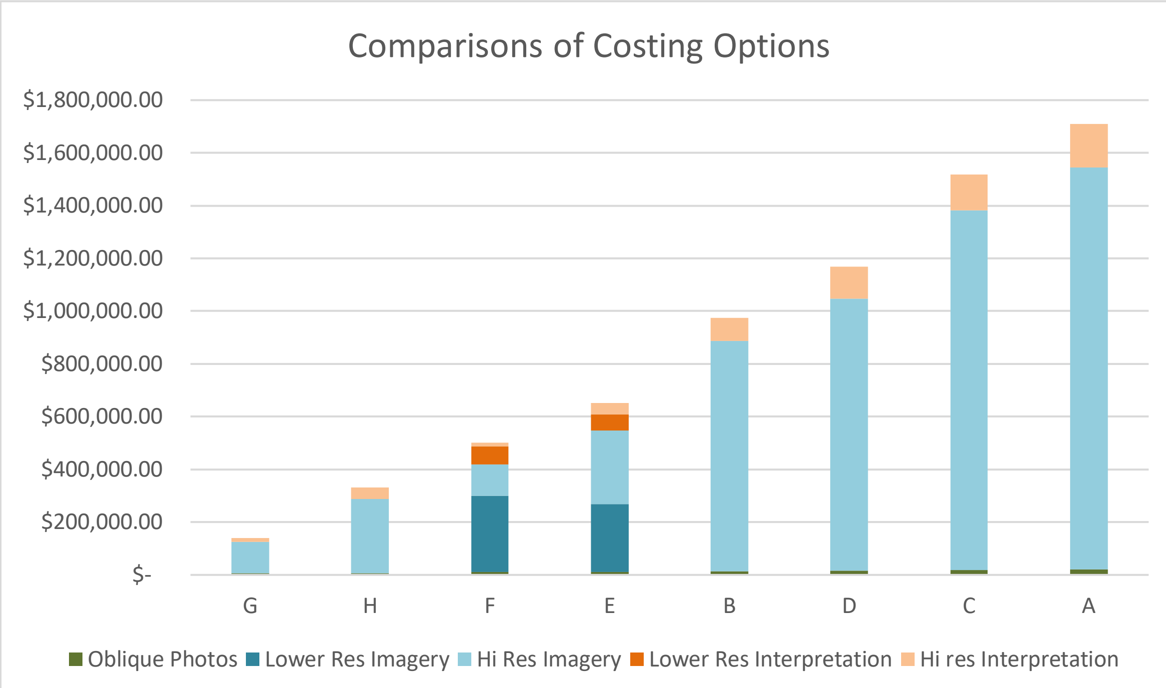


Figure 15: Cost breakdown of options for the North Yukon Region

Table 4: Costing options

	Option	Estimated Cost
A	**Entire North Yukon planning region at high resolution** ***Pros:*** • Re-evaluates of LMU9 which would test recovery of the 3D seismic program of 2014 • Provides quality data to develop methods of evaluating recovery over time • Covers the whole region with more uniform imagery and interpretation ***Cons:*** • Most expensive option	$1.7M
B	**Without LMU 9 and protected areas, at high resolution** ***Pros:*** • Provides high quality data for most of the region • Expenses drastically reduced by not including LMUs that have been done (LMU 9) or protected LMUs where establishing the current levels may not be useful in decision-making ***Cons:*** • Does not test recovery of the 3D seismic program of 2014 or legacy features • Disturbance data for LMU 9 based on a different date that other LMUs • Protected LMUs would be gaps in disturbance data	$1.0M

C	**Without LMU 9, at high resolution** ***Pros:*** • This would be the minimum extent to evaluate detailed disturbance for the whole region. ***Cons:*** • Does not test recovery of the 3D seismic program of 2014 or legacy features • Disturbance data for LMU 9 based on a different date that other LMUs • Only slight cost-savings	$1.5M
D	**Without protected areas, at high resolution** ***Pros:*** • Re-evaluates of LMU9 which would test recovery of the 3D seismic program of 2014 • Provides quality data to develop methods of evaluating recovery over time • Expenses reduced by not including protected LMUs where establishing the current levels may not be useful in decision-making ***Cons:*** • Protected LMUs would be gaps in disturbance data	$1.2M
E	**Entire North Yukon planning region at mixed resolutions** ***Pros:*** • Re-evaluates of LMU9 which would test recovery of the 3D seismic program of 2014 • Provides quality data to develop methods of evaluating recovery over time • Covers the whole region with fresh imagery and interpretation • Imagery and disturbance data quality is highest where disturbances are highest, thus saving expenses. ***Cons:*** • Inconsistent imagery quality and disturbance data could limit cost-sharing and later usefulness.	$650k
F	**Without LMU 9, at mixed resolutions** ***Pros:*** • Imagery and disturbance data quality is highest where disturbances are highest and where not redundant, thus further saving expenses ***Cons:*** • Inconsistent imagery quality and disturbance data could limit cost-sharing and later usefulness. • Does not test recovery of the 3D seismic program of 2014 or legacy features • Disturbance data for LMU 9 based on a different date that other LMUs	$500k
G	**Only LMUs likely have higher disturbance levels (except LMU 9), at high resolution** ***Pros:*** • Drastically lowest expenses • All expenses are focused where disturbances are highest and where not redundant ***Cons:*** • Does not test recovery of the 3D seismic program of 2014 or legacy features • Disturbance data for LMU 9 based on a different date than other LMUs • Most of the region would not have disturbance data or fresh imagery • Piece-meal approach would limit interest in cost-sharing.	**$140k**

H	**Only LMUs likely have higher disturbance levels (including LMU 9), at high resolutions** ***Pros:*** • Second lowest expenses • All expenses are focused where disturbances are highest • Re-evaluates of LMU9 which would test the recovery of the 3D seismic program of 2014 • Provides quality data to develop methods of evaluating recovery over time • Disturbance data for LMU 9 based the same date-range as other LMUs ***Cons:*** • Most of the region would not have disturbance data or fresh imagery • Piece-meal approach would limit interest in cost-sharing.	$330k
I	**Yukon Territory, at high resolution** ***Pros:*** • Proactive mapping of disturbances would facilitate regional planning exercises throughout the Yukon • Reasonably uniform disturbance mapping throughout the Yukon improves consistency of planning and land management decisions • High quality imagery and disturbance data could attract cost-sharing • High quality imagery and disturbance data would be compatible with the North Yukon Regional Plan ***Cons:*** • Project would have to be phased over a decade because of limitations in acquiring large amounts of imagery • Very high cost	$13.5M
J	**Yukon Territory, at medium-high resolution** ***Pros:*** • Proactive mapping of disturbances would facilitate regional planning exercises throughout the Yukon • Reasonably uniform disturbance mapping throughout the Yukon improves consistency of planning and land management decisions • Quality cost-effective imagery and disturbance data could attract cost-sharing • Lowest cost per area ***Cons:*** • Project would have to be phased over several years because of limitations in acquiring large amounts of imagery • Imagery and disturbance data would not be adequate for implementing the North Yukon Regional Plan	$2.8M

4. Discussion

4.1. Implications of disturbance levels

This project detected far more disturbance that anticipated, likely because it used high resolution imagery and previous mapping was incomplete. It found that linear density surpassed the cautionary threshold and approached the critical threshold, while surface disturbance approached the cautionary threshold. However, the use of high-resolution imagery also allowed the interpretation of the vegetation status of disturbance features, which made it possible to determine which features are recovered. When recovery was considered, both disturbance levels dropped abruptly. Therefor, the outcome of management decisions (i.e., conformity checks) would vary tremendously depending on if recovery is considered.

Similarly, the use of high-resolution imagery taken shortly after the 2014 3D seismic project allowed for most of those features to be detected and mapped, despite the seismic work being relatively low-impact. However, those features may have been noticeable because of a difference in reflectance due to ephemeral wood chips and broken vegetation rather than from persistent ecological differences or noticeable forest openings. If that is the case, a re-evaluation of the 3D seismic project area using the same methods would likely yield much less mapped disturbance. That would give oil & gas developers incentive to use lower-impact methods.

4.2. Evaluation of methods

The methods developed for this project (particularly those in Sections 3.4, 3.6, 3.7) worked as well as had been hoped and allowed for the mapping and quantification of both of the Plan's disturbance indicators. Though this project took much longer than anticipated, much time was lost to:

- YLUPC staff being busy on other projects
- Time and effort refining definitions and data model. This would not need to be done again.
- Time and effort analyzing field data. This would not need to be done again.

The method is scalable to the whole planning region, or indeed the whole Territory, particularly if the high-resolution and detailed interpretations are targeted to areas with higher levels of disturbance. In the North Yukon cases, work would have to be spread over 2 or more years. Work for the entire Yukon would have to be phased regionally over a decade or more.

The costly high-resolution imagery and full interpretation is necessary to understand likely recovery, and to get somewhat accurate widths of linear features. However, standard medium-high imagery (e.g., SPOT) and standard interpretation is sufficient for mapping the extent of most disturbance features. Calculating the area of linear features with this imagery is less accurate. Most significantly, because interpreting the vegetation state from standard medium-high imagery is not feasible, recovery of disturbances cannot be determined, and disturbance levels would appear much higher.

Not only is high-resolution imagery costly, but so is the interpretation of it to get the vegetation status of disturbances. As discussed in the previous section, it's use contributes to the detection of more disturbance, and later to the subtraction (due to recovery) of disturbance. A much simpler approach would be to use low-resolution imagery, like LandSat. Indeed, LandSat imagery yielded comparable disturbance levels (Figure 12). However, Figure 13 (e & f) shows little geographic correspondence between the two sources of imagery. In addition, LandSat would not capture small or narrow disturbances nor would be adequate for capturing recovery – two requirements of the Plan.

In recent years, imagery from a new LiDAR equipped satellite has been available for free. This imagery can be used to determine canopy height (Neuenschwander & Magruder, 2019). At the moment, this imagery may not have enough horizontal accuracy to pinpoint the vegetation height within narrow linear features. However, it is possible that these inaccuracies could be corrected using other available information. This imagery has not been evaluated in this project because it has only become available recently.

4.3. Costs

The cost-estimates provided in Section 3.8.3, especially those for the whole Territory, should be treated as being very approximate. They also do not include staffing within the Parties. Staffing requirement would include:

- Project management, including contract administration and QA
- Oblique aerial photography (flights are included in the estimate); however, this could also be contracted out to the interpreter
- Final analysis (could also be included in the contract)

Option G has by far the lowest estimated cost at about $140k yet would be sufficient for plan implementation. However, it would not contribute to our understanding of recovery and would unlikely attract cost-sharing from other projects.

Option H has the second-lowest estimated cost at about $330k. Like option G, it would be sufficient for plan implementation, but it would also contribute to our understanding of recovery. If disturbance from the 2014 3D seismic project has recovered as anticipated, the amount of disturbance mapped for LMU 9 would likely drastically decline.

4.4. Other benefits

The benefits of using this methodology for the rest of the region or for other planning processes, beyond determining the current disturbance levels, are discussed below.

4.4.1. Implementing the NYLUP

- Disturbance data for the as-yet unplanned "North Yukon Annex" (formerly in the Dawson Planning Region) will help inform the zoning there in any up-coming Plan review. These data will help select disturbance thresholds by giving an idea of the current level of disturbance, and the level relative to planned LMUs.

- Imagery used in developing disturbance data throughout the region (especially costing options A-F) could be useful in generating a new version of the Region's Ecological Land Classification, which could be useful in Plan Review.
- A solid baseline inventory of disturbance features could be used to better understand recovery trajectories, by either comparing to other spatial data, or to future re-evaluations. A near-term re-evaluation of LMU 9 (e.g., options A, D, E or H) would test idea that modern disturbances (i.e., the 2013/2014 seismic project) would recover quickly.
- Better characterized disturbance features may be useful in the analysis of cameral trap data in a caribou study in the area.
- Disturbance data could make any future surveys of access off the Dempster Highway more informative.

4.4.2. Other benefits

- Imagery would be made publicly available on YG's GeoYukon site, providing general benefits to oil & gas proponents and Dempster Highway maintenance.
- The Yukon Environmental and Socio-Economic Assessment Board (YESAB) has recently announced a change to their approach to considering cumulative effects. Assessors are now required to consider cumulative effects in their assessment of a project, rather than their previous practice, which was to conduct a separate and distinct determination of the significance of cumulative effects (YESAB, 2019). Assessors look to regional land-use plans to provide a regional view of levels of acceptable change. Understanding what disturbance is already on the landscape sets the context for additional disturbance and would allow for more accurate and fair assessments of potential project effects.
- In the case of costing Options E and F, or in the case where standard disturbance mapping is done throughout the region, SPOT imagery (or similar) would be used. This type of imagery is less expensive (roughly a fifth the cost of the high-resolution imagery used for most of this project), and easier to acquire, colour-correct and edge-match to make seamless coverage of a study area. For this reason, it:
    - Is becoming standard for other planning processes as base imagery
    - Is used for developing more detailed Ecological Land Classifications (ELCs), which in turn can be used with Traditional, local and/or expert Knowledge to create maps of habitat suitability.
    - Could be compared with future imagery using classification and change-detection algorithms. This could provide a less expensive and objective way to measure disturbance and recovery over time. However, this approach has drawbacks:
        - "disturbance" and "recovery" would need to be redefined and new thresholds developed if this method is to be used in the North Yukon Regional Plan's cumulative effects framework. This is one reason why this approach was not used for this project.
        - Thresholds for change based on this approach are not as intuitive or as easily communicated as the ones used in the Plan (and they are hard enough to communicate!)

- Is inadequate for determining widths of linear features, particularly those around the Plan's threshold width of 1.5 metres. It is also can't be used to determine vegetation status and therefor recovery. These are primary reasons this imagery wasn't used much in this project.

5. Recommendations

5.1. Suggested next steps

5.1.1. North Yukon Region

The methodology tested here was designed to determine the current levels of both the disturbance indicators of the Plan, and it proved successful. Though relatively expensive, it has been developed and tested, and is likely the most straight-forward path to implementing the Plan's cumulative effects framework for the region. This methodology is therefore recommended.

Any of the options described in Section 3.8.2 would be sufficient; however, **Option G is recommended** ("Only LMUs likely have higher disturbance levels (except LMU 9), at high resolutions") because it:

- focuses detail and effort in areas where tracking disturbance matters most
- achieves the minimum coverage of disturbance mapping at a cost well below other options.

This option should be able to be completed in 24 months, considering the time necessary to order and acquire imagery of the correct season, the time required to interpret it, and the time needed to analyse it.

Option H should also be considered. Though its estimated cost is almost 2.5 times higher than option G, it costs drastically less than the other options. It also would yield data that would help to develop methods of evaluating recovery over time as well as potentially "erase" much of the mapped disturbance from the 3D seismic program of 2014.

Other options may exist (see Sections 4.2 and 5.2); however, they may be speculative, may not adequately address linear features, and/or may require re-engineering the cumulative effects framework of the Plan. If it is not urgent to determine disturbance levels for the remaining LMUs, some of these other options should be explored. One promising option is to use satellite-based LiDAR data to supplement the process used in this study to make determination of recovery more accurate.

There are a few other tasks that would add value to this project. These include (in rough order of priority):

- Communicating the results of this and other disturbance mapping projects to the public, proponents, and project assessors/regulators.
    - At minimum, results should be posted on-line, with disturbance metrics (current levels and amount of acceptable additional disturbance) reported for each LMU. Proponents could use this information to help self-assess and modify projects prior to the YESAB process.

- This report and a summary should be posted on-line. A summary has already been posted at https://planyukon.ca/index.php/resources/planning-regions/north-yukon/521-surface-disturbance-in-eagle-plains-a-pilot-study.

- Another avenue of communication has already been demonstrated on YLUPC's interactive on-line GIS at https://planyukon.ca/index.php/resources/interactive-map. Users can click on an LMU and get up-to-date information on the disturbance indicators. This could also be done on YG's GeoYukon site, likely getting better audience reach, and having better support.

- YG's State of the Environment Report could be a logical place to provide updates.

- Disturbance data from this project gets loaded into YG's corporate disturbance database. A contractor could do this for about $7000.

- YLUPC provides a tidy package of technical reports, scripts, and data to the Parties to allow them to continue to build on this project.

- Developing internal processes that ensure that a disturbance database is updated annually with new disturbances. This is being done to some extent, but not spatially. This was outlined in Skinner (2016). It also is not adequately communicated more broadly (see first bullet).

- Developing a script (i.e., computer code) that analyses disturbance data to determine disturbance indicator levels in each LMU. The figures presented in this study came from an analysis that included some scripts, and much manual manipulation of data. One script would help make subsequent analyses faster, more transparent, and more reliable. This task would be inexpensive and may be possible as a side project at YLUPC or contracted out.

- The virtual plots developed in Section 3.5.2.2 could be analyzed to try to uncover patterns among disturbance type (what kind of disturbance), current vegetation status (and therefor recovery), and available ecologic and topographic spatial data. Such patterns could help forecast recovery and therefore amounts of human activity allowable in the Plan. A similar, but more data rich, analysis was done in northern Alberta, and found recovery rates were most influenced by soil moisture, width of linear disturbance and distance from the nearest road (van Rensen et al., 2015).

Beyond the mostly technical and near-term tasks described above, more work and decisions are needed to improve the overall cumulative effects framework described in the Plan. These include:

Long term maintenance of a disturbance database

Yukon Government maintains a spatial disturbance database. As disturbances are mapped in new study areas, they are added to the database. This ad hoc approach will not be sufficient to properly implement the Plan's cumulative effects management framework. As described in the third-to-last bullet above, new disturbances need to be added to this database (or a parallel one) annually. This approach would give reasonably accurate current levels of disturbance over the short-term, without great expense. For example, year-end reporting of projects in the region can (and typically do) submit spatial data on their activities. These can be collected in a database for disturbances since the most recent inventory.

However, this process would not be able to consider the recovery of any disturbance features. There are two way this could be done: modelling recovery and periodic re-evaluation of disturbances. As discussed in 3.5.2 above, it is difficult to understand all the factors affecting recovery, making accurate modelling difficult or impossible. Therefor, disturbances be should be remapped and evaluated periodically. These re-evaluations should be at the discretion of the Parties and their timing and detail would depend on current estimates of disturbance (see next section), the amount of expected disturbances or the amount of disturbance since the last evaluation, general understanding of recovery rates, and the timing of the next plan review. Criteria, triggers, specifications, and roles could be established ahead of time.

Cumulative Effects Indicator Levels and Management Responses

The Plan provide two indicator levels: cautionary and critical. These were intended to "*provide a clear statement regarding the level of human-caused environmental change that might be considered acceptable within a specific LMU*". The Plan suggests that when the cautionary level is reached, "*the respective governments should share information and review the health of the key ecological values, and if required, determine the management options to minimize and mitigate impacts.*". It then suggests that "*Critical indicator levels represent the point where the indicators may have reached or surpassed acceptable levels*".

The Plan's description of what is to happen when the cautionary level is reached is not very detailed. However, it could be used to trigger a high-resolution re-evaluation of disturbance in that LMU. Similarly, this report used a third indicator level in section 3.8.3 to develop some of the costing options. This third indicator level could be called the *precautionary level* and would be 20% of the cautionary level. If adopted, disturbance levels for all LMUs would be initially evaluated using available coarse disturbance mapping (based on LandSat imagery). Subsequent high-resolution disturbance mapping (as described in this report) would be triggered for those LMUs over the precautionary level.

5.1.2. The Peel Watershed Region

The recently approved Peel Watershed Region Plan includes a cumulative effects management framework for its IMAs (~20% of the region) that was copied from the North Yukon Plan. Therefore, the methods described in this report would apply to implementing that plan.

5.1.3. Dawson Region and beyond

Cumulative effects have been identified as an issue in the Dawson Region. Therefore, it is probable that the plan for that region will either include a cumulative effects management framework, or will give specific instructions to the implementors on how to develop one.

A cumulative effects report drafted for the previous Dawson Regional Planning Commission used best available disturbance data and expert opinions to quantify and forecast the same disturbance indicators as the North Yukon Plan. This report, now being updated, would be useful in developing a North Yukon style cumulative effects management framework. This template approach would accelerate plan development and implementation and would make project assessment more seamless. However, human activities and identified values of the Dawson region are different than in the North Yukon or in the IMAs of the Peel Watershed. For example, disturbance data could be combined with upcoming wetland mapping to create wetland disturbance indicators. In addition, Tr'ondëk Hwëch'in and the Wildlife Conservation Society – Canada have partnered to investigate the rate of past changes to forecast the future using a different method (change detection in LandSat imagery).

Considering these uncertainties, it is too early (or too late) to use the methods described above to collect detailed disturbance data for the Dawson Region.

5.2. Future considerations

The Yukon Government, in preparation for its involvement in future planning processes may wish to investigate alterative cumulative effects indicators that are measurable, socially or ecologically meaningful and cost-effective. Ideally, they should also be able to be communicated to lay audiences.

Software that automatically classifies satellite images or detects change (e.g. new disturbances or even recovery) between older and newer images is becoming more powerful and easy to use. Similarly, imagery is improving and is becoming more accessible. For example, there are a number of accessible tools that use the almost 40 years of LandSat imagery to look at landscape change. The Tr'ondëk Hwëch'in and the Wildlife Conservation Society – Canada partnership looking at past disturbances in the Dawson Region (see Section 5.1.3) could be a good local case study using these tools.

It remains to be seen if the coarseness of LandSat imagery and automated analyses of it could be translated into ecologically meaningful and measurable indicators. In any case, indicators using this approach would be difficult to communicate to a lay audience. For example, this approach may be able to provide an index of anthropogenic change from an agreed upon baseline image (which would have disturbances). Then this index could be compared to established thresholds.

Since the evaluation of imagery sources early in this project (Section 3.2), a new satellite ICESat-2 was launched and is now providing free world-wide LiDAR data that can be used to derive vegetation height (Neuenschwander & Magruder, 2019). Airborne LiDAR was evaluated in Section 3.2, but was deemed too expensive, and would not provide indications of soil or hydrology impacts. The availability of ICESat-2 data could now give image interpreters high-resolution vegetation height data from which recovery (as defined for forested areas in the North Yukon plan) could be determined. LiDAR data has already been demonstrated to be able to determine regenerating vegetation height in linear disturbances (Chen et al., 2017). However, this LiDAR was captured using unmanned aerial vehicles and provided high accuracy data, but for small study areas. Satellite-based LiDAR appears to be adequate in the broader Yukon context, though its lower horizontal accuracy may be a (surmountable) hurdle. LiDAR could possibly be used with change detection software or could be used by human interpreters. A small Yukon case-study using these data would help develop Yukon expertise in locating, preparing, and using these data, and would help determine their role in disturbance indicator monitoring.

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7. Appendix 1: Table of Recommendations

This table includes from the report for the North Yukon Region only.

#	Recommendation	Report section
	Broad Recommendations	
1	The Plan should be amended to include the recommended changes to the definitions of: • Functional disturbance • Surface disturbance • Linear density • Functional disturbance recovery	3.3.1
2	The methodology piloted in this project should be used to determine current levels of disturbance in other LMUs.	5.1.1
3	Option G, or alternatively option H, is recommended for how the methodology is applied to the Region to implement the Plan's cumulative effects framework.	5.1.1
4	Develop internal processes that ensure that a spatial disturbance database is updated annually with new disturbances.	5.1.1
5	Disturbances be should be remapped and evaluated periodically. Criteria, triggers, specifications, and roles could be established ahead of time. Establishing a precautionary threshold could clarify the triggers.	5.1.1
	Specific or Technical Recommendations	
6	Disturbance metrics (current levels, amount of acceptable additional disturbance, and certainty or mapping status) for each LMU should be reported on-line. This should be accompanied with explanations targeted to the public, proponents, and project assessors/regulators.	5.1.1
7	This report and a summary should be posted on-line.	5.1.1
8	Disturbance metrics, and their implications for the public, proponents, and project assessors/regulators should be available in an on-line GIS, including GeoYukon.	5.1.1
9	If more widely implemented, disturbance levels should be updated in YG's State of the Environment Report.	5.1.1
10	Disturbance data from this project should be loaded into YG's corporate disturbance database.	5.1.1
11	YLUPC should provide a tidy package of technical reports, scripts, and data to the Parties.	5.1.1
12	A script (i.e., computer code) should be developed that analyses disturbance data to determine disturbance indicator levels in each LMU.	5.1.1
13	The virtual plots developed in Section 3.5.2.2 could be analyzed to try to uncover patterns among disturbance type (what kind of disturbance), current vegetation status (and therefor recovery), and available ecologic and topographic spatial data.	5.1.1
14	A case-study evaluating remote-sensing techniques could be done to investigate alterative cumulative effects indicators that are measurable, socially or ecologically meaningful and cost-effective. Ideally, they should also be able to be communicated to lay audiences. Results could be useful for plan review or in other regions.	5.2