Agricultural adaptations to changing permafrost conditions in southern Yukon

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ABSTRACT
Yukon agriculture is adapting to the challenges caused by existing and changing permafrost conditions. An ongoing study identifies indicators of permafrost and changing permafrost conditions, documents adaptations farmers are making and uses baseline soil mapping, Agriculture and Agri-Food Canada's Land Suitability Rating System (LSRS) and climate scenario outputs for modelling future land suitability for agriculture in permafrost-affected areas. The presence of discontinuous permafrost near surface and at depth causes problems for agriculture so understanding where permafrost occurs and its condition is important for agricultural decision making. As LSRS does not currently take permafrost into account when rating land suitability for agriculture, we discuss the use of existing permafrost observational data, available detailed soil mapping and expert knowledge to incorporate known and observed permafrost conditions into the modelling.

RÉSUMÉ
L'agriculture du Yukon s'adapte aux défis engendrés par les conditions existantes et changeantes du pergélisol. Une étude en cours identifie les indicateurs du pergélisol et l'évolution des conditions du pergélisol, documente les adaptations que font les agriculteurs et utilise la cartographie des sols, le Système de classification des terres, selon leurs aptitudes pour les cultures (LSRS), et les modèles de scénarios climatiques, afin de modéliser les terrains propices à l'agriculture dans les secteurs affectés par le pergélisol. La présence de pergélisol discontinu près de la surface et en profondeur cause des problèmes à l'agriculture. Il est donc important, pour la prise de décision agricole, de comprendre où se trouve le pergélisol et son état. Puisque le LSRS ne prend actuellement pas en compte le pergélisol, nous discutons de l'utilisation des données du pergélisol, de la cartographie détaillée des sols et des connaissances des experts, afin d'intégrer dans la modélisation, les conditions du pergélisol.

1 INTRODUCTION

The Agriculture Branch of the Yukon Department of Energy, Mines and Resources is currently undertaking a four year project to identify challenges and barriers to agriculture caused by changing permafrost conditions. The objectives of the project are to document how Yukon farmers are adapting to changing permafrost conditions; to identify indicators of the permafrost conditions and to model future land suitability for various crops. To estimate land suitability for agriculture we are using a Land Suitability Rating System (LSRS) tool that integrates soil, climate and landscape properties to generate class ratings for land parcels for various agricultural crops. The tool has been used successfully in southern regions of Canada. However, one of the challenges to utilizing this approach in areas of the Yukon with sporadic and discontinuous permafrost is to better incorporate the presence of permafrost into the land suitability assessment process.

Observations of the response over time of permafrost degradation under cultivated landscapes will allow us to explore methods that allow LSRS to account for its impacts on growing conditions. In this paper we review how permafrost has been recognized in the historical soil mapping and how permafrost conditions are identified and documented in soil map data bases. Can permafrost affected areas ever expect to be suitable for agriculture development? How can one distinguish suitable areas from those which are not? Once identified, what limitations occur over time? Can farmers adapt to changing permafrost related challenges? How should permafrost be incorporated into LSRS? These are the questions addressed in this paper.

2 FARMERS AND PERMAFROST

Farming in Yukon began during the Klondike Gold Rush in the late 1800's. During the Gold Rush supplies were carried in over the Chilkoot Trail on people's backs or on paddlewheel river boats travelling more than 2000km up the Yukon River from its delta on the west coast of Alaska. The White Pass railway from Skagway, Alaska to

Whitehorse opened in 1900. Demand for fresh produce led to the development of farms in Dawson, Mayo and around Whitehorse. Much of that initial agriculture development did occur on land affected by permafrost, however long hours of daylight and warm summers allowed for production of large vegetables. Cattle grazing, hay and vegetable production all continued on a local scale, with some diminishment following the completion of the Alaska Highway in 1952 and further improvement to road infrastructure throughout the territory. The Yukon Government adopted an Agriculture Policy in 1982 to allow for development of land for agriculture to help promote a sustainable industry.

Some of this development has occurred on permafrost-affected soils resulting in numerous challenges for farmers. These challenges include delays up to 4 years or more before equipment can move onto cleared land, and delays up to 7 years before ground can be cultivated. Drainage of fields may be necessary; topsoil retention can be a challenge. Field operating conditions are dynamic. Typically soils are very wet after initial clearing but may dry out over time as the permafrost table lowers in the soil. However, if massive ice is present, subsidence and/or collapse can occur thereby limiting access for farm equipment (Figure 1). Building structures and fencing may settle or collapse as permafrost thaws or may be jacked up by frost action. Some areas never dry out sufficiently to be cultivated.

Figure 1. Subsidence and ponding in ice-rich glaciolacustrine materials after nearly 50 years of cultivation in the Takhini Valley west of Whitehorse, Yukon.

Adaptations to existing and changing permafrost conditions are necessary. Adaptations include planning for a delay in cultivation after land clearing. In 2006, the Yukon Agriculture policy was revised to allow for 7 instead of 5 years to develop land. Land is cleared in late fall or early spring when the ground is seasonally frozen. Ditching or other drainage may be required to help the soil to dry out. Often, more poorly drained areas underlain by permafrost are never cultivated and revert back to native sedges and willows. In areas of thermokarst, farmers may have to re-level fields as subsidence occurs. They may have to change crops, cultivation methods and intensity as soil conditions change. They may have to modify irrigation methods to adapt to drying out of the soil or to localized subsidence. Development of thermokarst may be delayed up to 15 years after initial clearing. In severe cases land use may shift from agriculture to grazing or land may be abandoned entirely.

These challenges illustrate the need to know in advance where permafrost occurs and what changes may be expected following clearing and cultivating. A secondary forcing function of permafrost melting will be on-going climate warming. In the following sections we describe how we might use field observations of the impacts of historic land clearing and forest fires along with soil maps and land rating tools to estimate these responses over the remainder of the 21st century in southern Yukon.

3 SOIL MAPPING APPROACHES TO DESCRIBING PERMAFROST

3.1 Legacy reconnaissance soil mapping

A reconnaissance level soil survey at 1:126,720 scale was undertaken in the Takhini and Dezadeash valleys in 1957 and 1958 (Day 1962). These valleys consist predominantly of fine textured glaciolacustrine sediments. No permafrost was identified by this mapping which was some of the first soil mapping in northern Canada. Cryosolic soils (permafrost-affected soils) were not recognized within the soil taxonomy used in Canada at that time.

Further Yukon reconnaissance soil mapping was undertaken in 1976 around numerous Yukon communities including Whitehorse, Dawson, Mayo, and Watson Lake (Rostad et al 1977). This mapping did recognize a few permafrost soils in the Dawson, Mayo, Ross River, Faro, Watson Lake, and Snag areas of Yukon but not in the Whitehorse, Carmacks or Pelly areas. This project adopted the original mapping for the Takhini and Dezadeash valleys.

3.2 More recent detailed soil mapping

Detailed soil mapping was undertaken in the later 1980's and 1990's in the valleys around Whitehorse (Mougeot and Smith 1992, Mougeot and Smith 1994, Mougeot Geoanalysis and AAFC 1997), and in the Klondike Valley and Sunnydale near Dawson City (Westland Resource Group 1987). Permafrost is identified in the mapping by the presence of Cryosolic soils as minor components within a polygon. Known permafrost was also identified with a polygon modifier as is commonly used in surficial mapping: thermokarst, solifluction, cryoturbation or permafrost within 1-2meters. The detailed Whitehorse mapping and associated standardized map database is available from the Canadian Soil Information website at: (http://sis.agr.gc.ca/cansis/nsdb/dss/v3/index.html). The Dawson soil map was used as the basis for a surficial map (McKenna and Lipovsky 2014) used for hazard assessment (Northern Climate Exchange draft-2015) and the cansis soil data base is in process (McKenna draft).

Site specific mapping has also been completed since 1985 in areas applied for by individuals for soil based, spot land agriculture. Additional mapping has also been completed for Agriculture Planned Land Releases This mapping describes the soils and the soil suitability for agriculture (Yukon Agriculture Branch unpub. 1985-2015).

4 LAND SUITABILITY RATING SYSTEM

4.1 Rating Historic Climate Suitability for Agriculture

The agriculture capability rating system used by the older mapping projects as well as by LSRS is a 7 class system based on climate, soil and landscape factors. This 7 class system has been used throughout Canada for many years since the original Canada Land Inventory in 1965. LSRS is a standardised system based on the original 7 classes whereby class 1 is fully suited and class 7 is unsuited for agriculture. These classes are clearly and crop-specifically defined such that they can be applied consistently across the country. Classes are defined numerically in a 100 point system. LSRS takes numerous climate, soil and landscape conditions including surface and subsurface soil texture, stoniness, moisture availability, excess moisture, salinity, slope, flooding, and contrasting landscapes into consideration. Several agro-climatic indices including effective growing degree days (EGDD), precipitation (P) and potential evapotranspiration (PE) are considered in the assessment of climatic suitability for individual crops. Each polygon and soil component is assessed; points are deducted for soil and landscape properties which will limit land suitability. Class rankings are then assigned based on these deductions to come up with a rating for land suitability for agriculture. A description of the agronomic concept behind LSRS is given in Agronomic Interpretations Working Group (1992). LSRS is currently designed as a web-based tool running on standardized soil map databases and gridded climate data as inputs to create regional assessments (Schut et al. 2012).

Climate has been the primary limiting factor throughout lower elevation valleys of the Yukon due to cool summer temperatures and the low number of growing degree days. Whitehorse, according to the original class rating was rated class 5 (Rostad 1977) due to climate (Eley and Findlay 1977). Dawson though at higher latitude is at a lower elevation with a more continental climate and is therefore characterized by warmer summer temperatures and higher summer rainfall and was rated as class 4 for climate.

Climate, soil and landscape factors are taken into consideration separately. For example if the climate changes, the soils which were not limiting at an agriculture suitability rating of 4 or 5 due to climate may become limiting if the climate improves to a class 3 or 2 or 1.

4.2 Rating Future Climatic Conditions with LSRS

The Land Suitability Rating System (LSRS) is composed of a set of algorithms that generate agro-climatic indices from gridded General Circulation models (GCM) scenario data and link these to an underlying soil map and databases. LSRS contains modules for rating land suitability for six common Canadian agricultural field crops. In this study, we utilized the spring seeded small grains (wheat, oats, barley) module of LSRS for the valley floor areas around Whitehorse where detailed soil mapping is available. The module integrates conditions to generate an overall land class rating for each polygon on the soil map.

For the climate input we used down-scaled Climate WNA projections from the Canadian global circulation model (CanESM_85) as input to LSRS. Land suitability for spring seeded small grains was generated for a series of 30 year normal time blocks 1951-1980; 1981-2010; 2011-2040; 2041-2070; and 2071-2099.

4.3 Results

Historical data from a few meteorological stations in southern Yukon reveal how marginal (class 5 in a 7 class system) conditions have been for grain production in the Whitehorse area. This correlates well with the LSRS ratings for the first time period modelled for the baseline 1951-1980 period as shown on Figure 2.

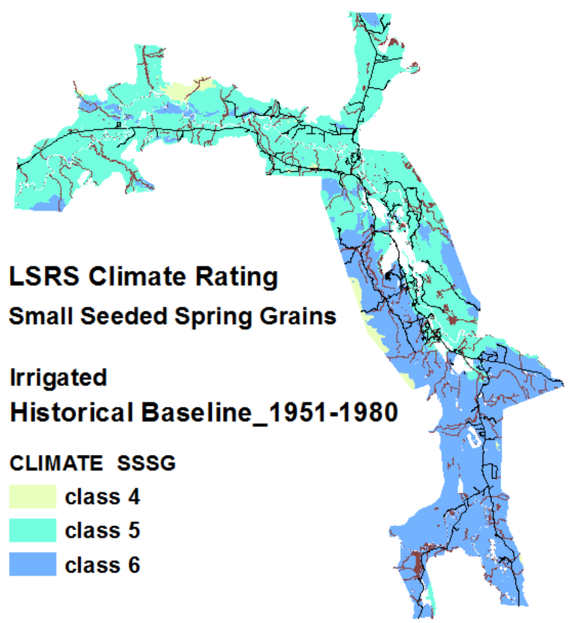

Figure 2 Soil Suitability for agriculture 1951-1980 with irrigation.

Recent climatic conditions in the Whitehorse area appear to have warmed based on the second time block 1981-2010, with agriculture suitability moving up a class to class 4, shown in Figure 3. This corresponds well to means of recorded temperatures and EGDD compiled by the Yukon Agriculture Branch (unpub.).

Based on future projections climatic conditions and therefore overall land suitability for agriculture improve with each future 30 year time block. By the 2011-2040 the climate rating for the Takhini valley is class 2, Whitehorse valley is class 3. However by 2041-2070 the overall land suitability begins to degrade due to increasing moisture

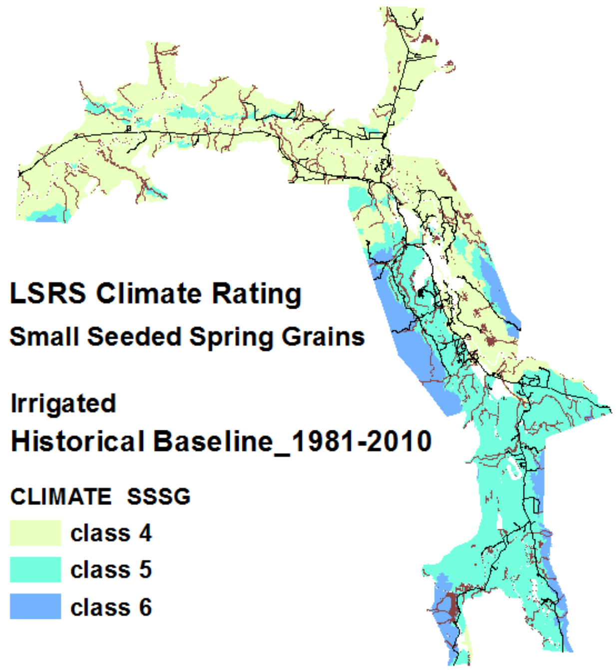

Figure 3 Soil Suitability for agriculture 1981-2010 with irrigation

deficiency which can be overcome to some extent with irrigation. By 2071-2100 that same land is predicted to be class 4 due to moisture deficiency (Figure 4) and even with irrigation could only be improved to class 2 (Figure 5). We anticipate undertaking similar modelling in the Dawson area once revised soil mapping is complete.

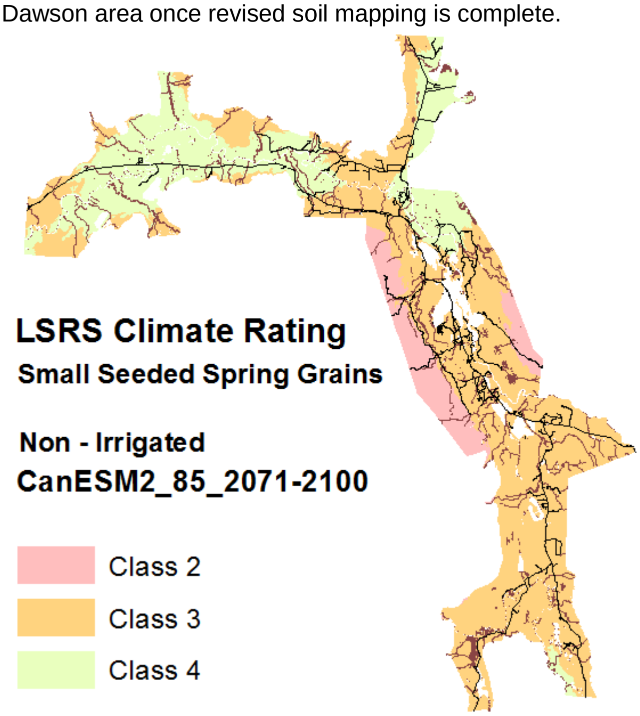

Figure 4 Climatic suitability classes for agriculture 2071-2100 without irrigation

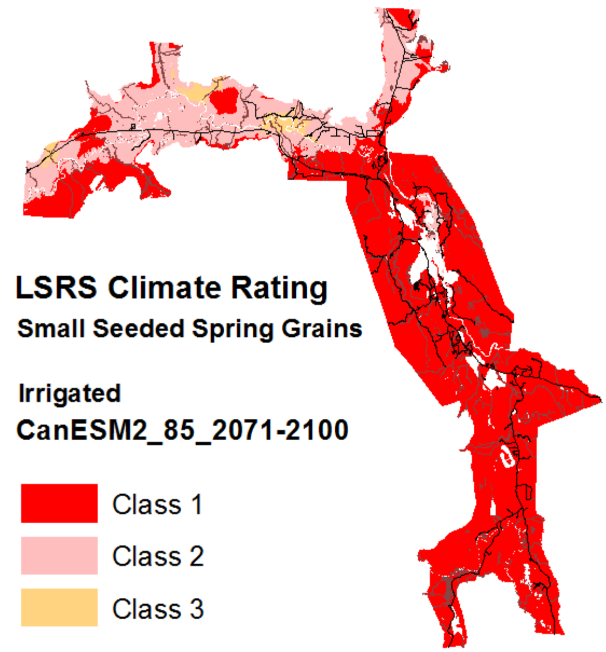

Figure 5 Climatic suitability classes for agriculture 2071-2100 with irrigation.

4.4 Incorporating Permafrost Conditions into LSRS

We know that there is permafrost in the Whitehorse and Dawson map areas. However permafrost is not considered in LSRS. '*Permafrost soils are not considered separately because once land is cleared of its vegetative cover the permafrost recedes to a depth greater than 1 meter*' (Agronomic Interpretations Working Group 1992). With increases in heat accumulation there will be increases in permafrost degradation. From observations and experience in mapping soils for agriculture in many parts of the Yukon, permafrost will likely recede when land is cleared, however the rate at which that occurs and how the land will react once cleared can vary dramatically. Identification of future changes is critical to planning in the region. As usual, limited subsurface data exists to map subsurface conditions in detail. Degradation of the ground surface will occur in areas of high ice permafrost. The rate of degradation will be related to the rate at which the soil warms.

In the Dawson area much of the land is underlain by permafrost. Agriculture has and is currently occurring on areas affected by permafrost. It is important to understand where this can be done sustainably without resulting in land or infrastructure abandonment because of thermokarst. This highlights the need for modelling future permafrost changes.

5 DISCUSSION

In the Whitehorse area soil profiles do not necessarily reflect the underlying permafrost. According to the

Canadian System of Soil Classification (Soil Classification Working Group 1998), Static Cryosols are characterized by having permafrost within 1 meter of the surface, Turbic Cryosols as having permafrost within 2 meters. In valleys around Whitehorse the top of the permafrost may occur from less than 1 meter to about 4 meters from the surface (Burn 1998, Yukon Geological Survey 2009, Lipovsky 2014). This permafrost is often not reflected by the surface vegetation. Even in unburned areas the presence of permafrost deeper than 1 meter from the surface is difficult to predict. In some areas active thermokarst identifies areas with massive ground ice. In other areas, pits or drier depressions can indicate former massive ice in permafrost or the presence of rafted ice bodies deposited in the original lake sediments. Mounded topography or cryoturbation at depth can indicate permafrost or maybe former permafrost. Burn (1998) indicated the active layer depth of the permafrost studied in the Takhini valley increased from 3m in 1978, to 3.5 in in 1990 and 3.8 in 1997 following a large forest fire in 1958. This warm permafrost with a mean annual temperature at the surface of about -0.2 and a depth of less than 20 meters, based on a simple analytic model, would take over 1000 years to degrade completely. A nearby field, also burned in 1958, and then cleared in the 1980's has suffered subsidence due to thermokarst over the past 30 years.

In Dawson, permafrost soils are common throughout the map area especially on northerly and shaded slopes and on many level areas. Depth of fine textured sediments is important. Thermokarst is common, in some cases triggered by, forest fires or other disturbance. This thermokarst often appears as intersecting linear depressions with some associated ground cracks indicating underlying ice wedges. In some valleys in the region, networks of ice wedge polygons can be seen in high resolution imagery. These appear most commonly where thick layers of fine textured silty loess and reworked loess (colluvial and fluvial fan deposits at the base of slopes) occur.

Understanding what can happen to permafrost-affected soils as they thaw is important. Different Cryosols will react differently and should not be treated the same way.

Depth of organic material overlying the soil surface affects the degree of insulation from air temperatures and regulates the rate of thaw or the preservation of underlying permafrost. Land clearing and cultivation can completely alter the surface thermal balance. A shallow depth to permafrost will likely substantially increase moisture in the surface soils. Orthic and Brunisolic Cryosol subgroups often occur in better drained sloping situations. Warming these soils will likely result in excess moisture for several years but water will likely drain away and the site dry out over time.

Ice-rich permafrost is a different situation. Depth to permafrost is important and the depth to where the high ice permafrost begins is important. At one location in the Klondike valley near Dawson, no evidence of subsidence appeared until about 15 years following clearing, at which time a tractor fell into a sink hole. Thermokarst has continued with trenches and cracks continuing to develop for the next 10 years. The long-term rate of soil warming may also need to be taken into account. The potential for long-term warming would further suggest that areas of high ice permafrost be avoided for agriculture development.

Permafrost is currently recorded in 2 ways on soil maps. Near-surface permafrost is fairly well identified in soil maps (designated as Cryosolic soils). High ice permafrost is identified where evidence of thermokarst already exists (identified by original soil maps and geomorphic process on surficial maps but is not currently in the data base). This information should be added to the map data so it can be included in LSRS modelling.

In areas where thermokarst is not evident yet and not identified in the mapping, one would need to complete an additional assessment of each soil polygon using image analysis, drill log data and any other permafrost data to For Cryosolic soils a point deduction is suggested based on several considerations (Table 1).

Table 1. Proposed considerations for LSRS ranking of permafrost-affected soils without massive ground ice

Soils (great group/ subgroup)	Considerations
All Turbic or Static Cryosols	Use point deductions for these very cold soils, greater when >10 cm organic surface cover. Greater point deductions should be used for these permafrost soils than for similar unfrozen soils in LSRS.
Gleysolic subgroups of Cryosols	Cryosolic soils with poor and very poor drainage have generally not been successfully developed for agriculture in Yukon. In one case it required 7 years from the time of initial clearing to systematically drain the wetland.
Organic Cryosols	Wetlands are currently not recommended for agriculture development in Yukon. Organic Cryosols could be rated using criteria as for non-permafrost Organic soils. Rating deductions could also take into account the EGDD values with higher values off-setting soil deductions.

What sort of deduction should be required for thermokarst or high ice permafrost conditions? Thermokarst is a landscape limitation where landscape pattern accounts for limitations due to contrasting soil areas. Proposed LSRS deductions (Table 2) for areas of thermokarst risk create a landscape with arable soils that can differ in time of seeding, harvesting or fertilizer application and/or present non-arable obstacles including sloughs and creeks. This would assist in modelling future changes in permafrost conditions.

Table 2. Proposed LSRS deductions for thermokarst

High ice permafrost	Probability occurrence	Degree of Limitation
Thermokarst present	100%	Unsuited
High Ice suspected	>75%	Extremely limited
High Ice suspected	51-75%	Very Severely limited
High Ice suspected	25-49%	Severely limited
High Ice suspected	<25%	Moderately limited

Finally, since LSRS uses a 30 year time frame and since 30 years is likely sufficient to trigger thermokarst development where high ice permafrost is present, it may not be necessary to incorporate a time lag for thawing permafrost.

6 CONCLUSIONS

Because the largest challenge caused by a warming climate in permafrost areas is related to thermokarst of soils where there is a large amount of ice rich permafrost, to reasonably predict the soil suitability for agriculture it is important to incorporate the potential occurrence of ice high-ice permafrost into the assessment. In most cases this is a variable not included in the initial soil map data base, and it is therefore recommended that each polygon be assessed for the probability of occurrence of high ice permafrost. The collection of borehole data and associated ERT data would help to confirm the presence of high ice permafrost. The presence of non-gleysolic Cryosolic soils can often be mitigated and can therefore be developed for agriculture. Permafrost conditions can be built into the LSRS model and used to model changes as a result of climate change.

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