Mapping Temporal and Spatial Soil Hydrothermal and Mechanical Properties by way of the Soil Trafficability Prediction Model (STRAP)

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INTRODUCTION

The increased use of heavy machinery in forest operations has led to serious environmental problems such as decreased plant development (1-2), changing soil hydraulic properties (3) and soil degradation in the form of erosion, compaction, or rutting (4-5). Predicting soil trafficability has become crucial to help limit the impact of heavy forest operations on soils. The problem faced when trying to forecast soil trafficability is the ability to predict, not only where a machine will have issues, but also, what time of the year it will face them. The *Soil Trafficability Prediction* (STRAP) model was created to combine temporal and spatial soil-affecting attributes to forecast operations planning. This project will look at:

- creating a user-friendly model interface between ForHyM (temporal) and the ArcGIS model (spatial)
- calibrating STRAP for harvest areas in New Brunswick

STUDY AREA

This study focuses on three established harvesting areas (Fig. 1) in central and northern New Brunswick, **Black Brook** (near Saint-Quentin), **Deersdale** (in Juniper), and **Dorn Ridge** (northwest of Fredericton).

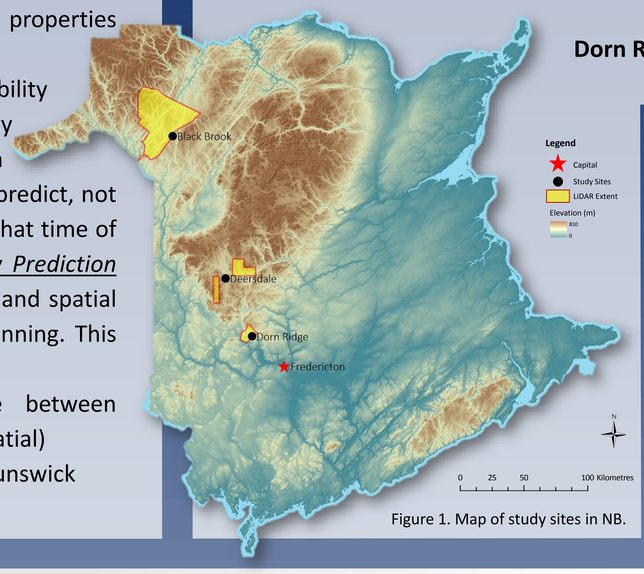


Figure 1. Map of study sites in NB.





MACHINES, SENSORS, AND FIELD WORK





Figure 3. Tigercat 635D grapple skidder (top), John Deere 1110E Forwarder (bottom)

Machines & Sensors:

Two John Deere forwarders, (1110E and 1510E) and a Tigercat 635D grapple skidder were equipped with distance sensors, inclinometers, GPS, and data loggers (Fig 3). The sensor data are being used to calibrate the STRAP model outputs to specific regions using rut depth, slope, and vehicle speed as calculating factors. Machine sensor data was collected from 2012-2014 with over **4.1 million** data points.

Field Work:

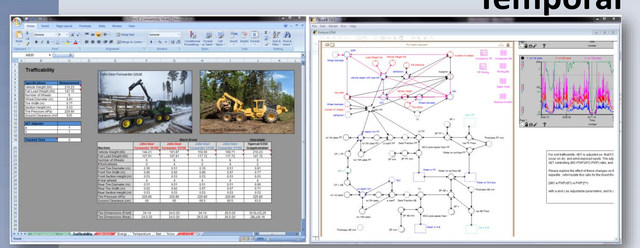
Ground truthing of machine trafficked areas are being used to verify sensory data, as well as calibrate model outputs to specific regions. The cone penetrometer was used to measure soil resistance to penetration (Fig. 4). Soil moisture, soil samples, rut measurements and delineation were also collected along tracks. Over **850** CI and moisture plots, and **350** soil sample plots were taken.



Figure 4. Field use of a cone penetrometer in a rut.

RESEARCH DESIGN

Temporal



Spatial

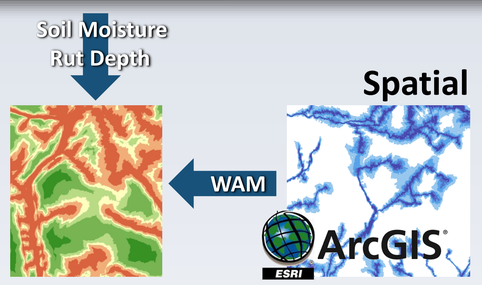


Figure 2. Overview of trafficability model design using temporal ForHyM and spatial WAM outputs to create trafficability maps over time.

The preliminary rut depth calculations integrated into STRAP (Eq. 1) is based on the relationship between soil rutting and soil moisture, integrating spatial wet-areas-mapping (WAM), which determine potential flow channels based on least slope-path by each cell on a map, to cone index (CI) and rut depth relationships within *ForHyM* (Fig. 2; 6). This project looks at utilizing and improving this method to model trafficability over time. The goal will be to reformulate Eq. 1 and calibrate it with actual field and machine generated inputs.

$$RD = RD_{low} - \left[RD_{low} - RD_{ridge}\right] * \left[\frac{1 - exp(-k_{RD} h_{wt})}{1 - exp(-k_{RD} h_{wt,ridge})}\right]^{p_{RD}} \quad \text{(Eq. 1)}$$

$h_{wt,ridge}$ = soil moisture index (DTW)
$MC_{ps,low}$, $MC_{ps,ridge}$ = moisture contents at the low terrain and ridge tops
k_{MC}, p_{MC} = coefficients to relate surface soil moisture to h_{wt}
RD_{low}, RD_{ridge} = rut depth values for low terrain and ridge tops



STRAP MODEL RESULTS

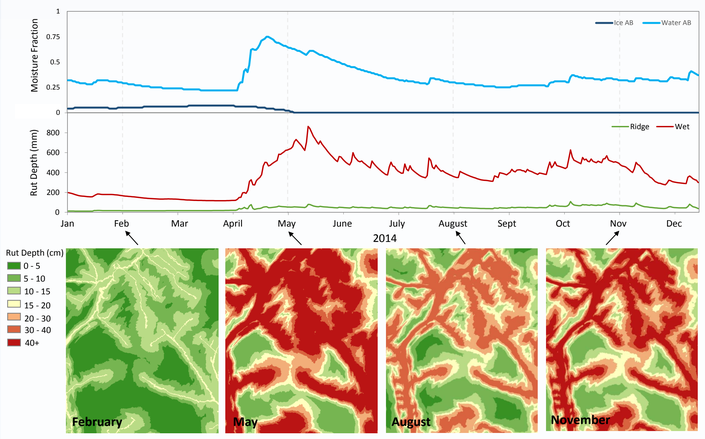


Figure 5. ForHyM moisture fraction and rut depth outputs (top) showing the potential rut depth for ridge tops vs wet depressions, with corresponding STRAP model outputs by month (bottom).

The preliminary STRAP model creates rut depth maps that can be generated at daily to yearly time intervals. For industry purposes, monthly maps are more suitable in terms ground operations planning. Figure 5 shows the importance of mapping potential rut depth over time (winter having minimal rutting due to frozen soil moisture, spring and fall having peaked soil moisture and rutting potential).

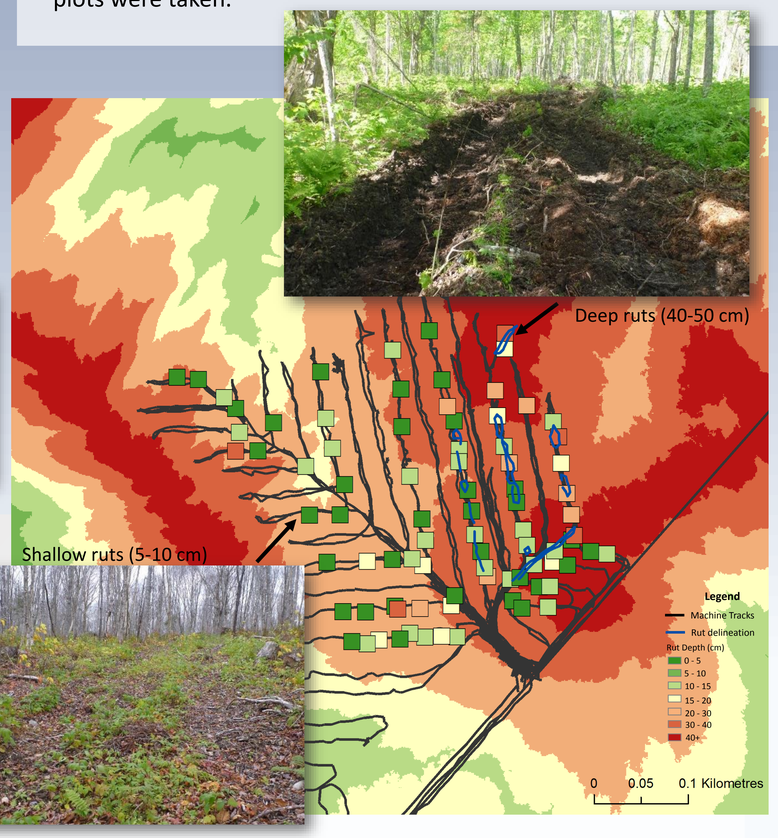


Figure 6. Shelterwood cut in Black Brook, NB showing field collected rut plots vs STRAP average rut depth calculated for June 2014.

Comparing preliminary STRAP results to field measured rut depth shows the necessity of calibrating regional outputs (Fig. 6). There is partial conformance in areas of deep and shallow rutting, but the model outputs could show better correlation once properly analyzed and calibrated. Rut delineation fell within STRAP areas of high potential rutting.

CONCLUSION

Producing trafficability maps over time is increasingly important as soil moisture properties change with changing seasons. The relationship between soil hydrothermal and mechanical properties plays a crucial role in soil trafficability. Knowing when a soil will be potentially saturated can reduce the geologically damaging and potentially irreversible risks associated with operating heavy machinery on forest soils.

This project will produce a model capable of predicting when and where potential hazards would occur, to help industry better manage their forest operations.

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