MODELLING DAILY SOIL MOISTURE CHANGES BY WAY OF TEMPORAL HYDROLOGY MODELING AND SPATIAL WET-AREAS-MAPPING

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OVERVIEW

- Introduction
- Forest Hydrology Model (ForHyM)
  - Temporal variations in soil moisture on a daily level
- Wet Areas Mapping
  - Soil moisture maps
  - Soil rutting maps
- Forest Operations in northern New Brunswick (JDI)
  - On the ground verification/calibration
- Conclusion
Real world problem:

How can we map changes in soil wetness across a watershed at a seasonal or daily interval to better manage against forest soil disturbance?

Integrating aspatial hydrology modelling (ForHyM) with spatial GIS-based wet-areas mapping (WAM).

- Daily soil moisture modelling with ForHyM using daily precipitation and air temperature records
- Wet-areas mapping using LiDAR derived DEM at 1m resolution
- Connecting the two to produce daily soil moisture maps
FOREST HYDROLOGY MODEL (FORHYM)

- Simple non-spatial trickle model
  - general applicability and simplicity
  - many studies on various catchments
    (Arp & Yin, 1992; Yin and Arp, 1994; Meng et al. 2005; etc…)

- Quantifies thermal and hydrological flows through soils and watersheds

Excel User Interface

STELLA Interface
FOREST HYDROLOGY MODEL (ForHyM)

- Addresses hydrothermal processes:
  - soil moisture by soil horizon
  - snowpack depth, frost depth, soil temperature
  - soil trafficability/rutting/compaction (sensitive to soil moisture and frost)

- All processes can be modelled over time (daily/weekly/monthly/yearly)
TOPOGRAPHIC LANDFORM (TLF)

- Based on topographic position index (TPI). Creates landform categories based on DEM range and slope thresholds.
  ✓ Compares elevation of each cell in DEM to mean elevation around that cell. (Weiss, 2001; Jenness, 2006)

- Use TLF to get ridge and valley inputs for ForHyM:
  ✓ Average Soil Type
  ✓ Average Vegetation Type
WET AREAS MAPPING

- Wet-areas-mapping (WAM) generates a cartographic depth-to-water (DTW).
  - DTW represents elevational rise from flow channels and surface water features
  - Mapped soil moisture content depends on log(DTW)
  - Mapped DTW and soil moisture content varies seasonally by flow channel reach (e.g. flow initiation requires 4 ha end of summer, < 0.5 ha during and after snow melt)
    (Murphy et al., 2007; Murphy et al., 2009; Vega-Nieva et al., 2009)

- Goal is to use LiDAR generated DEMs for daily forest operations planning to avoid soil compaction and rutting.
WET AREAS MAPPING

DTW
- <10 cm
- 10-25 cm
- 25-50 cm
- 50-100 cm
Vega-Nieva et al. 2009:

\[ MC_{ps} = MC_{ps,low} - \left[ MC_{ps,low} - MC_{ps,high}(h_{dtw,high}) \right] \\
\quad \times \left[ \frac{1 - \exp(-k_{mc} \cdot h_{dtw})}{1 - \exp(-k_{mc} \cdot h_{dtw,high})} \right]^{p_{mc}} \]
SOIL MOISTURE

- Geospatially DTW-interpolated soil moisture.

Black Brook, NB
Geospatially DTW-interpolated soil moisture.

August Moisture Content

- 0 - 10 %
- 10 - 20 %
- 20 - 30 %
- 30 - 40 %
- 40 - 50 %
- 50 - 60 %
- 60 - 70 %
- 70 - 80 %
- 80 - 90 %
- 90 - 100 %
SOIL MOISTURE

- Geospatially DTW-interpolated soil moisture.
SOIL MOISTURE

- Geospatially DTW-interpolated soil moisture.
SOIL RESISTANCE TO PENETRATION (CONE INDEX)

\[ C_{\text{field}} = 1.08 \times 10^{1.99-0.38} \ \text{Sand}-2.23\text{PS}-0.72 \ \text{MC}_{\text{PS}} \]

PS = pore space fraction
MCps = moisture content from DTW map
SOIL RUTTING DEPTH

Nominal Cone Index

\[ NCI = \frac{1000 \, CI \, bd}{W} \sqrt{\frac{\delta}{h}} \frac{1}{1 + 2d} \]

Rut Depth, single pass

\[ z_1 = \frac{r_1 (1 + t_1 \text{terrain}_1 + t_2 \text{terrain}_2 + \ldots)}{NCI} \]

Rut Depth, multi pass n

\[ z_n = z_1 \, n^{1/a} \]

NCI = cone index

W = machine load/wheel

d = tire diameter

b = tire width

h = tire section height

\( \delta \) = tire deflection

CI = cone index

z = rut depth

n = number of passes
SOIL RUTTING DEPTH

- Machine and load specific
- Using geospatially interpolated soil moisture, density, texture, and depth to compaction to infer soil penetrability, single to multiple pass
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FOREST OPERATIONS MONITORING

**Black Brook, NB**
John Deere 1110E & 1510E Forwarder

**Deersdale, NB**
Tigercat 635D Grapple Skidder
FOREST OPERATIONS MONITORING

- Ultrasonic machine clearance sensor
- Inclinometer (measuring machine tilt / operating angle)
- GPS Antenna (mounted on roof)
- Time stamp (10 second intervals)
- Data logger (collects all of the data)
WOOD SKIDDER TRACKING

Legend
- Mapped Water Bodies
- Skidder GPS Points

Hillshade Bare Earth
- High : 254
- Low : 0

Depth-to-water, m,
4 ha flow initiation

- <10 cm
- 10-25 cm
- 25-50 cm
- 50-100 cm

Grapple Skidder in Deersdale, NB
FOREST SKIDDER + HARVESTER TRACKING

Legend
- Mapped Water Bodies
- Harvester GPS Points
- Skidder GPS Points

Hillshade Bare Earth
- High: 254
- Low: 0

Depth-to-water, m, 4 ha flow initiation
- <10 cm
- 10-25 cm
- 25-50 cm
- 50-100 cm

Grapple Skidder in Deersdale, NB
SKIDDER TRAIL DENSITIES

Legend
- Mapped Water Bodies
- Harvester GPS Points

Skidder Trail Density
- 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 80

Depth-to-water, m, 4 ha flow initiation
- <10 cm
- 10 - 25 cm
- 25 - 50 cm
- 50 - 100 cm

Hillshade Bare Earth
- High : 254
- Low : 0

Grapple Skidder in Deersdale, NB
SKIDDER INCLINATION

Legend
Front to Back Inclination
-30 - -15
-15 - -10
-10 - -5
-5 - -2
-2 - 0
0 - 2
2 - 5
5 - 10
10 - 15
15 - 30
Mapped Water Bodies
Slope
High : 20
Low : 0

Depth-to-water, m,
4 ha flow initiation
<10 cm
10-25 cm
25-50 cm
50-100 cm

Grapple Skidder in Deersdale, NB
SKIDDER INCLINATION

Legend
Front to Back Inclination
-30 - -15
-15 - -10
-10 - -5
-5 - -2
-2 - 0
0 - 2
2 - 5
5 - 10
10 - 15
15 - 30

Mapped Water Bodies
Hillshade Bare Earth
High : 254
Low : 0

Grapple Skidder in Deersdale, NB

Depth-to-water, m,
4 ha flow initiation
- <10 cm
- 10-25 cm
- 25-50 cm
- 50-100 cm
Forwarder clearance (JD 1510E) on up slope areas only
Slight tendency towards increased rutting incidence for 1<DTW<2m

\[ y = -0.0587x + 60.298 \]
\[ R^2 = 1E-05 \]
High resolution images and LiDAR derived digital elevation data, bare ground, and full feature facilitate the assessment of soil trafficability.

Soil trafficability can be assessed by knowing sand content, soil density (pore space), and soil moisture content.

- Soil moisture content varies from ridge tops to depression by weather.
- Weather records can be used to assess daily to seasonal changes in soil moisture content and frost.

LiDAR derived soil trafficability maps are being tested and calibrated through using sensor equipped skidders, wood forwarders, and harvesters.

All of this should be useful for better forest operations planning.
QUESTIONS?

THANK YOU


