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High-resolution flow-channel and wet-areas maps: a tool for better forest operations planning

Highlights

- High-resolution maps showing flow channels and wet-areas can be used to guide daily forest operations planning and related decision-making concerning timber access, machine-free-zones, and the design of silvicultural operations.
- Even at low resolution, the maps can help managers save time and money by identifying hydrological risks associated with road and trail construction and in-block field activities. The information can be used to avoid flow channels and wet-areas, thereby minimizing related soil and stream disturbances.
- In combination with other geospatial data layers, including digital elevation models, and the appropriate geospatial extension tools, the maps are also useful for:
  - delineating catchments,
  - evaluating alternate road and trail locations, and
  - making decisions concerning machine-specific soil trafficability conditions.

Accurate and comprehensive spatial hydrographic information is an important component in forest operations planning and contributes to better forest management practices and sustainable forest management. Such information can reduce environmental effects, and offer cost savings, by minimizing operational 'surprises' in road layout and construction, cut-block and harvest trail layout, site preparation and regeneration, and navigation. For example, a map depicting all ephemeral, permanent surface and near-surface water flow channels can be used to minimize road crossings over streams. This has the potential to decrease sediment and nutrient transport from soils to streams, reduce road construction and maintenance costs, and decrease the number of culvert placements. The same map can also help to reduce or avoid operation-induced disturbances in wet-areas next to flow channels and wetlands, whether they have been previously mapped or not.

This research note outlines a new process for identifying hydrographic surface features, including flow channels and wet-areas, by combining existing hydrology information with data about surface topography. The process used to generate these maps, at scales valuable to forest operations planners, is outlined and limitations are discussed. Applications for forestry and other land use planning arenas are described to show managers the potential of these hydrographic maps to minimize environmental impacts and realize cost savings in operations.

Flow channel and wet-area mapping

Conventional maps of surface drainage networks are largely derived from aerial photo-interpretation. Such maps are generally not complete for forested areas or are conducted at a resolution not useful for forest operations planning. They may omit low-order streams which – when not detected prior to field operations – present major difficulties in conducting the planned field activities within the allocated time and budget. Similarly, conventionally-derived wetland maps may capture only a small portion of the areas that would be too wet for forest operations, especially during the summer. This lack of information at the planning stage may translate into environmental impacts such as soil rutting or increased sediment transfer to water bodies and additional costs from major down-time losses during field operations. The surface drainage and wet-areas mapping products described here offer a systematic means to predict where flow channels and wet surfaces will occur.

The map is produced by combining the local Digital Elevation Model (DEM) with the existing hydrographic coverage for all currently-mapped lakes, streams, shorelines, and wetlands. Locating these features at high resolution improves the delineation of areas subject to hydrological risks, such as flooding, rutting, drought, soil erosion, and slumping. While the flow channels and areas depicted to be wet in the DEM-derived map may not always contain water, there is the risk for water to flow into and over these areas. Inappropriately located and timed operations and land-use practices would then translate these risks into unsightly and costly damage situations.

Digital elevation models (DEMs) are digitally-derived elevation maps. Depending on their source, DEMs either reflect bare-ground elevations or the elevations of the reflecting surface above the ground, including the forest canopy.

LiDAR (Light Detection and Ranging) is an air-borne laser-based technology used to systematically determine local differences in elevation, from bare ground to canopy level.

Wet-areas refer to portions of the landscape that are likely to be saturated at or near the surface for extended periods throughout each year. Examples are depressions, vernal pools (temporary pools of water), toe slopes, and areas next to ephemeral and permanent streams, lakes, and wetlands.

The cartographic Depth-to-Water (DTW) index shows the elevational rise above the nearest mapped surface-water features such as flow channels, streams, lakes, and shorelines. This index is sensitive to the assumed area needed for surface-flow accumulation.

Mapping process

The process begins with merging a digital elevation model (DEM) with the available hydrographic map for the area of interest. A hydrographically-corrected DEM is produced for which the derived flow of the DEM conforms to all previously mapped flow paths and shorelines. In essence, the surface-water features are "burnt" into the DEM so that the automated flow-accumulation algorithm leads to these features exactly (Figure 1).

The process then goes on to derive the cartographically registered depth-to-water (DTW) index for all areas next to the newly mapped flow-channel and surface water features. This index is determined by combining the elevational rise and distance away from each nearest hydrographic feature, where DTW=0 by definition (Figure 2). Typically, the DTW values generated tend to increase away from the DTW=0 reference locations: low values (e.g., DTW<1m) indicate wet or near saturated soil conditions, and higher values indicate moist (e.g., 1m<DTW<20m) to dry (e.g., DTW>20m) soil conditions. As expected, these values increase slowly in flat terrain and rapidly in steep terrain. The resulting maps therefore inform forest management and operations planners about local flow connections and ground moisture conditions at a high spatial resolution. Operationally-relevant map resolutions vary from about 1 m to 10 m depending on the source and resolution of the DEMs used.

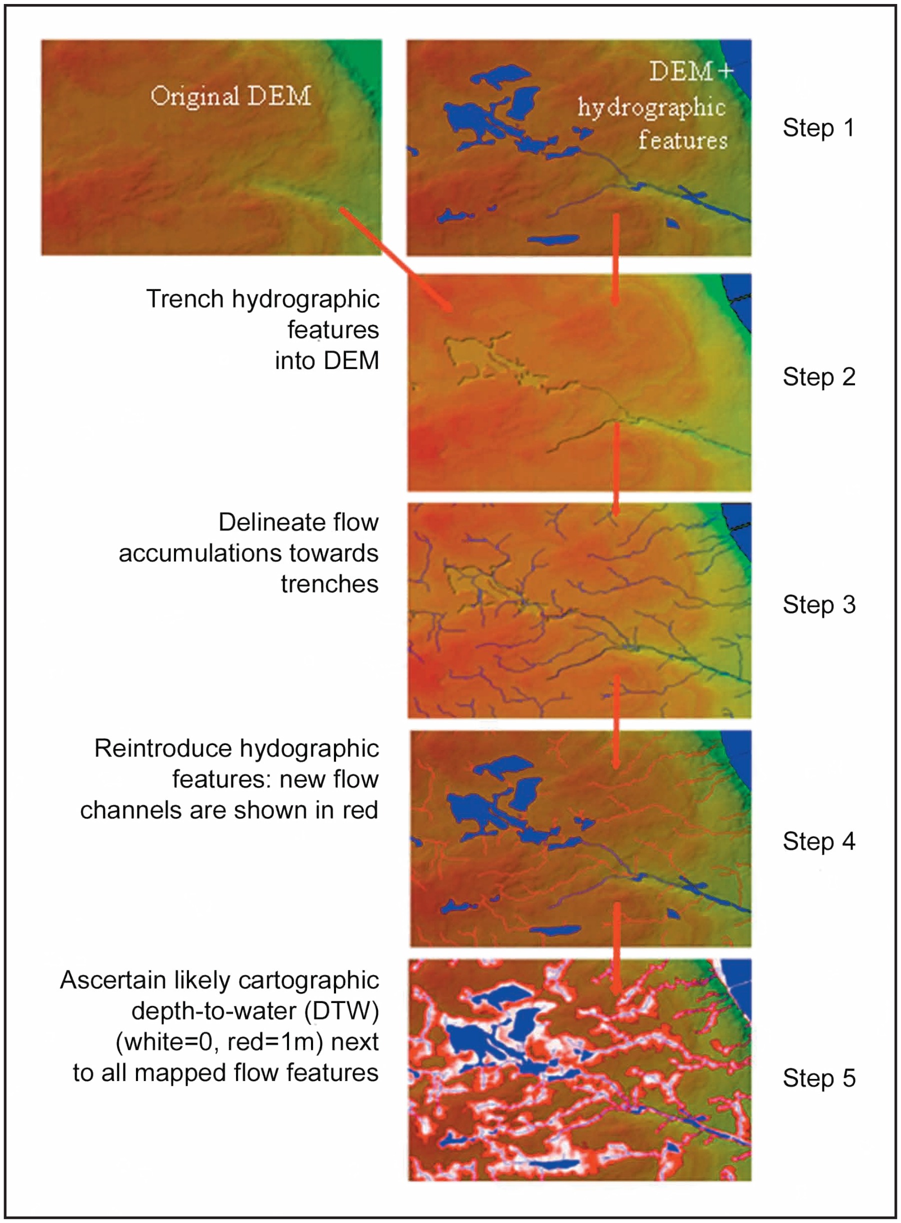

Figure 1. The wet-areas mapping process merges the existing hydrographic layer (blue) with the DEM, forming a "hydrographically-corrected" DEM-layer for the derivation of previously un-mapped flow channels and adjacent wet-areas as outlined by the cartographic depth-to-water index.

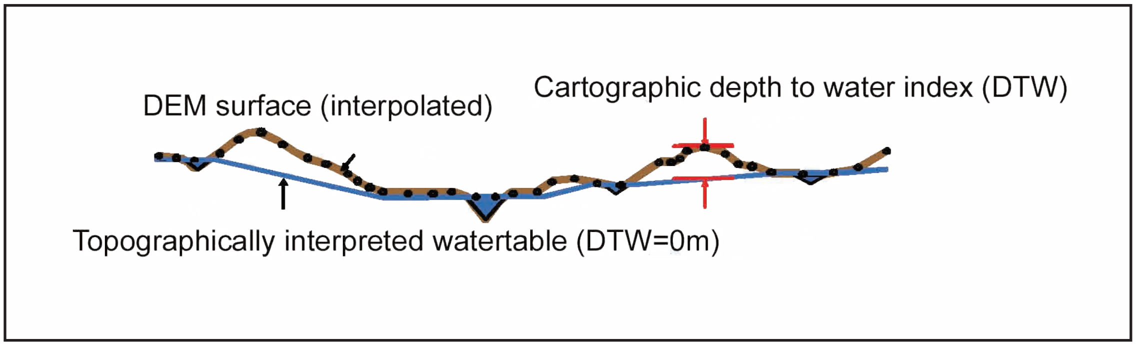

Figure 2. Wet-areas mapping principle and calculation of the depth-to-water index (DTW). All cartographically delineated streams and shorelines serve as the zero reference for the local depth-to-water index (DTW=0).

Mapping accuracy and limitations

Mapping process depends on accurate Digital Elevation Models

Wet-areas and flow channel maps in each area of application must be interpreted taking into account the limitations, resolution and accuracy of the available DEM and hydrographic data layers. Generally, high-resolution DEMs generate better flow-channel, wet-areas, and depth-to-water maps than low-resolution DEMs. Resolutions vary from bare-ground LiDAR-based grids on the order of 1 m or less, medium-coarse grids involving 10 to 30 m grid spacings derived from stereo-images (RADAR or optical reflectance images), to coarse grids at 100 to 300 m such as the national DEM coverage for Canada. As resolution decreases, DEM-guided flow-channel derivations for low-order streams become increasingly artificial, and very noticeably so in steep as well as flat terrains. Although flow-channel derivations become more exact with increasing resolution, they require special attention at locations where elevated roads would block topographically-controlled flows, therefore suggesting either a real flow blockage, or a bridge or culvert location.

GPS-guided field studies conducted in Alberta, Manitoba, Ontario, and the Maritimes revealed that the conformance between the DEM-derived flow-channel and wet-areas maps and actual ground conditions in terms of flow-channel paths, wetland borders, road stream crossings or culvert locations is generally within 50 m, 80% of the time, using provincial and DEM data sources with grid sizes of about 30 m. This precision generally increases to within 4 m, 90% of the time, when LiDAR-derived maps at 1-m resolution are used.

Cut-block distributions affect DEM accuracy

Since air photo and satellite-image derived DEMs may reflect elevations at canopy level, pre-image cut-block areas may appear as depressions. A data layer conveying the pre-imaging cut-block distribution within the forest management area of interest is needed to eliminate this artifact. In contrast, image-based canopy-level DEMs assist in deriving fairly accurate flow-channel and wet-areas delineations in as yet uncut forest areas, especially on flat terrain.

Mapping process is limited to surface and near-surface water flows

The mapping process deals only with surface or near-surface water flows that can be defined by topography. It does not address aquifer-based sub-surface flows or storage. It does, however, correctly predict short-range surface and sub-surface flow channels where deep percolation is restricted by subsoil compaction and/or low bedrock permeability, and is therefore still subject to direct topographic control.

Applications

Forestry related applications

The improved mapping of surface water flow channels afforded by this technique permits a wide range of forest management and planning applications. Most importantly, the maps are already used by a number of SFMN partners as base layers for designing field operations to optimize wood access, cut-block layouts, and within-block operations including site preparation, tree planting and stand-tending. Other applications include harvest scheduling, addressing wind exposure concerns along riparian zones, designating machine-free zones, re-addressing trail and route locations including ice roads, and assigning blocks for summer versus winter harvesting.

Using the flow-channel and wet-areas maps, planners can realize additional cost-savings through operations timing, and designing on-board navigation patterns for day and night operations. Patterns can be determined according to local soil trafficability conditions, as these conditions could change quickly from dry to wet, and from frozen to unfrozen, with and without snow cover.

For the daily soil trafficability estimation by location as well as machine type, or machine loads and trailing patterns, the DTW index map can be used to project likely variations in soil moisture (frozen or unfrozen), texture, bulk density, resistance to cone penetration, soil depth, and coarse fragment content and exposure that may occur between ridges and depressions. These derived soil properties, when combined with the expected tire loads and travel patterns, can then be used to map likely rutting depths and expected soil compaction levels across the operations area for current or projected weather conditions.

Broader applications of wet-areas mapping

The DEM-derived flow-channel, wet-areas and DTW index maps are currently used by a number of fish and wildlife and park managers for high-resolution habitat delineations of wet- and dry-land faunal and floral species, within the context of wetland management and wetland conservation. The maps can also be used to optimize and evaluate industrial and residential development locations such as housing developments, lagoons, gas stations, and oil and gas pads. The map products can assist in locating such developments where they would be least affected by water-related risk factors such as local flooding, soil slumping, and soil erosion, and would also limit contamination risks to downstream water supplies. Additional applications refer to discerning site, soil and water quality properties and processes as these vary across the landscape based on topographic influences.

The DEM-derived flow-channel and wet-areas maps may also prove valuable as:

- instruments for guiding discussions for environmentally-friendly land-use policies;
- a means to facilitate communications and integration among stakeholders holding multiple objectives for the same land base, including forestry; and
- a tool for more informed decision making about land use and allocation considering upstream and downstream impacts of related topographically-definable risks concerning the use of forest, soil and water resources.

Conclusion

Researchers have successfully applied the mapping process described here to create DEM-derived flow-channel and wet-areas maps in select areas across Canada and elsewhere. The procedures used to generate these maps are global, but the resultant maps must be interpreted by considering local climate, soil and vegetation conditions. They are best used in conjunction with local DEMs (hill-shaded), aerial photographs and existing forest and vegetation classification layers. The maps provide fairly reliable high-resolution delineations between uplands and wetlands, and provide the added benefit of revealing the topographic connectivity of flow channels and wetlands within and across watersheds. These maps can be used by resource managers to reduce operational, financial, and environmental uncertainties across a variety of applications, including daily forest operations planning.

Management Implications

- Hydrographic mapping, including flow channels, wet-areas, and depth-to-water indices, can be developed for specific forest management areas, across each province. This information can then be used in GIS systems to provide the needed information for forest management decision making.
- Managers should become aware of the benefits, limitations, and practices of using the flow-channel and wet-areas maps to reduce operational, financial, and environmental uncertainties in daily forest operations planning.
- Wet-area maps can be made publicly available through governmental web-based information services, as is the case in Nova Scotia and New Brunswick, in formats compatible with industrial, residential, governmental and municipal GIS applications.

Further reading

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