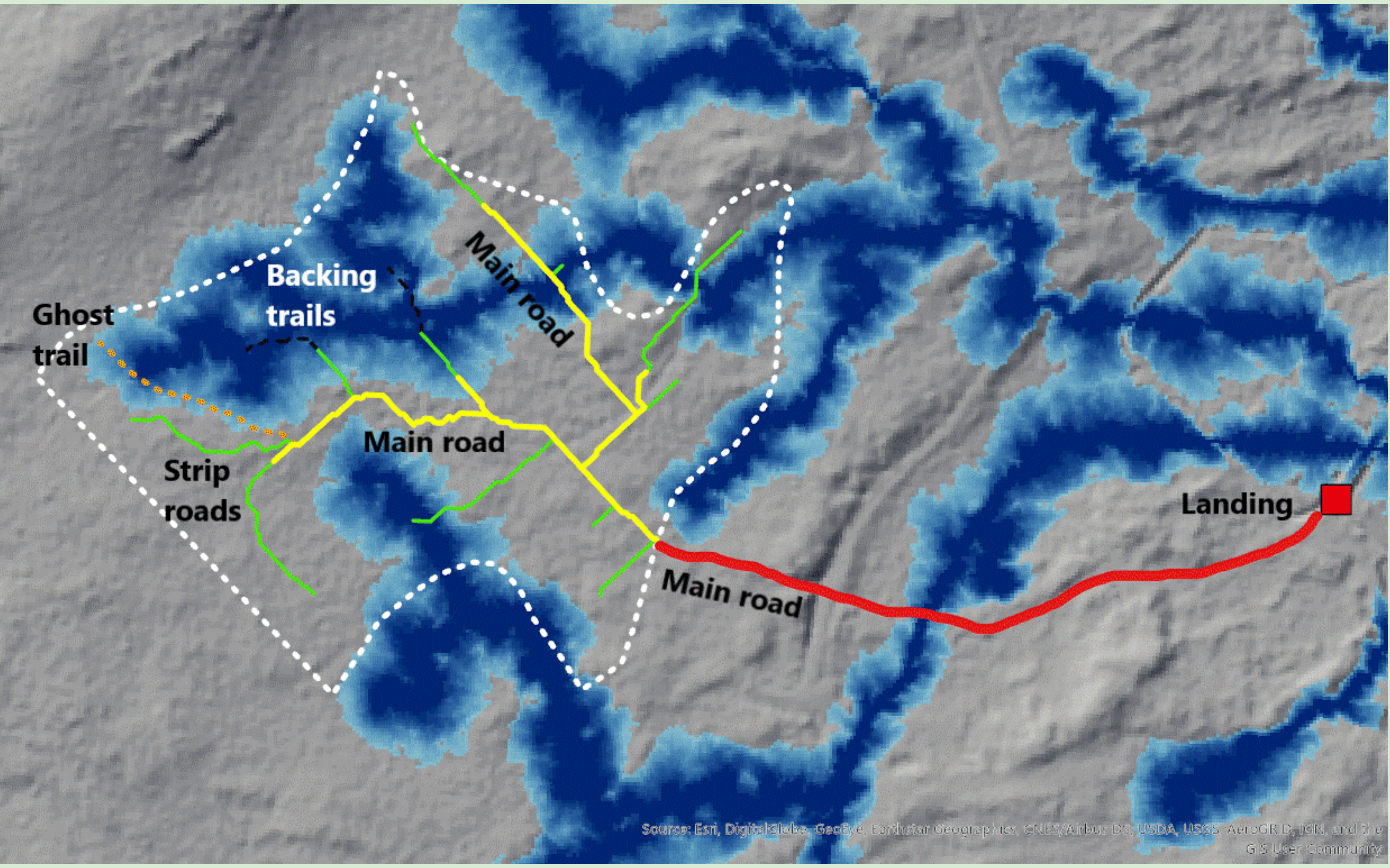
ARBETSRAPPORT 1051-2020

# A guide to using wet area maps in forestry

En guide för hur man kan använda markfuktighetskartor i skogsbruket




Using wet area maps can help plan the logging road system, location of landings, stream crossings and the need for ground protection at final felling. This wet area map is a depth-to-water map provided by the Swedish Forest Agency, superimposed on the hillshade of a 3D model of the land surface. DTW © Swedish Forest Agency, Elevation data, grid 2+ © The Swedish mapping, cadastral and land registration authority.

skogforsk

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Leena Finér, Fredrik Johansson & Lars Högbom

# Sammanfattning

Markfuktighetskartor är kartor som visar var det finns fuktiga och blöta områden i anslutning till vattendrag och sjöar. Markfuktigheten modelleras främst utifrån topografiska data. Modellerna som används varierar något och resulterar i kartor med olika precision, men gemensamt för alla markfuktighetskartor är att de omfattar en betydligt större andel av alla vattendrag än konventionella kartor, särskilt små vattendrag med omgivande blöta områden. Denna handbok ger exempel på hur markfuktighetskartor kan användas vid skogsbruk i Östersjöregionen för att förbättra skogsbrukets miljöhänsyn. Handboken är avsedd för planerare, entreprenörer, maskinförare, privata skogsägare och tjänstemän i skogsbruket och vid olika myndigheter.

# Summary

Wet area maps indicate the location of wet areas adjacent to streams and lakes. Soil wetness is modelled primarily using topographic data. Different models result in maps that differ in accuracy, but they all include a much larger proportion of the watercourses than conventional maps, in particular smaller streams with adjacent wet areas. This guide illustrates how wet area maps can be used for practical forestry in the Baltic Sea region to improve environmental planning. This guide is intended for forestry planners, contractors, machine operators, private forest owners, and forestry and authority employees.

Interreg Baltic Sea Region

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WAMBAF Tool Box

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# Preface

This guide illustrates how wet area maps can be used for practical forestry in the Baltic Sea region to improve environmental consideration. It is intended for forestry planners, contractors, machine operators, private forest owners, and forestry and authority employees. Practical experience of using this type of map in Sweden and Finland, scientific studies and reports and expert judgements form its basis. Recommendations for further reading are also provided.

**Before implementing any of the measures or procedures proposed, it is essential that practitioners ensure that they comply with national legislation, other regulations and forest certification standards.**

This guide has been produced as part of the EU Interreg project WAMBAF Tool Box (https://www.skogsstyrelsen.se/en/wambaf/), running from 1 August, 2019 to 31 January, 2021.

The authors wish to express their sincere thanks to Marjo Ahola, Jonas Amrén, Joakim Gustafsson, Antti Leinonen, Jonny Lundgren, Per Norbäck, Magnus Olofsson and Tobias Wegebro for sharing their knowledge and experience, and to our colleagues in the WAMBAF Tool Box project for providing valuable comments on a previous version of this report.

Map data were obtained from:

Elevation data, grid 2+ © The Swedish mapping, cadastral and land registration authority (Figs. 3C, 3D, 8, 10, 15, 20C-F, 22, 26 and 30)

GSD-Property Map, Vector © The Swedish mapping, cadastral and land registration authority (Figs. 20D and 21)

GSD-Property Map, Combined raster © The Swedish mapping, cadastral and land registration authority (Figs. 3A, 20B, 29A and 29C)

DTW © Swedish Forest Agency (Figs. 2, 4, 7, 8, 15 and 29B)

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MLWAM © Department of Forest Ecology and Management, Swedish University of Agricultural Sciences (Figs. 20F, 28 and 29C)

Orthophoto © Department of Forest Ecology and Management, Swedish University of Agricultural Sciences (Figs. 3B, 3D, 20A, 21, 23, 25 and 28)

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Flow accumulation © Department of Forest Ecology and Management, Swedish University of Agricultural Sciences (Figs. 10 and 30C)

Stream networks © Department of Forest Ecology and Management, Swedish University of Agricultural Sciences (Fig. 23)

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# Contents

# A useful tool for practical forestry

Forest land covers between 30 and 70 percent of the land area in Baltic Sea countries, and includes many lakes and watercourses. Forestry is important in the region, but it is also important to protect forest waters from the negative impacts of forestry. These negative impacts can be avoided or mitigated by careful planning of forestry operations (Fig. 1).

Fig. 1. Protecting springs and smaller streams and rivers on forest land is important because they are usually more severely affected by forestry operations than larger rivers and lakes. For example, a wheel rut near a stream may significantly increase the influx of eroded soil, which is harmful to aquatic organisms. Photo E. Ring

Wet area maps are a relatively new type of map that indicate the location of wet areas adjacent to streams and lakes. They include the location of the smallest streams, which are often missing on conventional maps. Wet areas are important for water quality, and this type of map has been shown to be useful for forestry planning to protect water, soil and biodiversity, as well as during onsite operations.

There are different types of wet area maps, one being the Depth-To-Water (DTW) map, which has been used in Swedish forestry for about six years, and is generated by modelling the groundwater level across the landscape. Wet area maps generated by machine learning (MLWAM) are currently being developed in Sweden, Finland, Latvia and Poland. Both these types of maps show the wet areas adjacent to streams and lakes but can differ in accuracy for a given site. Currently, in the Baltic Sea region, DTW maps are in operational use in Sweden and Finland.

In DTW maps, soils of different wetness are highlighted in different shades of blue. Dark blue areas show where the modelled groundwater level is within a few decimetres of the soil surface, and indicate wet soils (Fig. 2). Light blue areas show where the groundwater level is close to a depth of one meter, and indicate moist soils. In the DTW maps for Sweden, the dark blue areas include streams and lakes, which can be identified by adding relevant map layers. Many of the smaller streams are missing on conventional topographic maps.

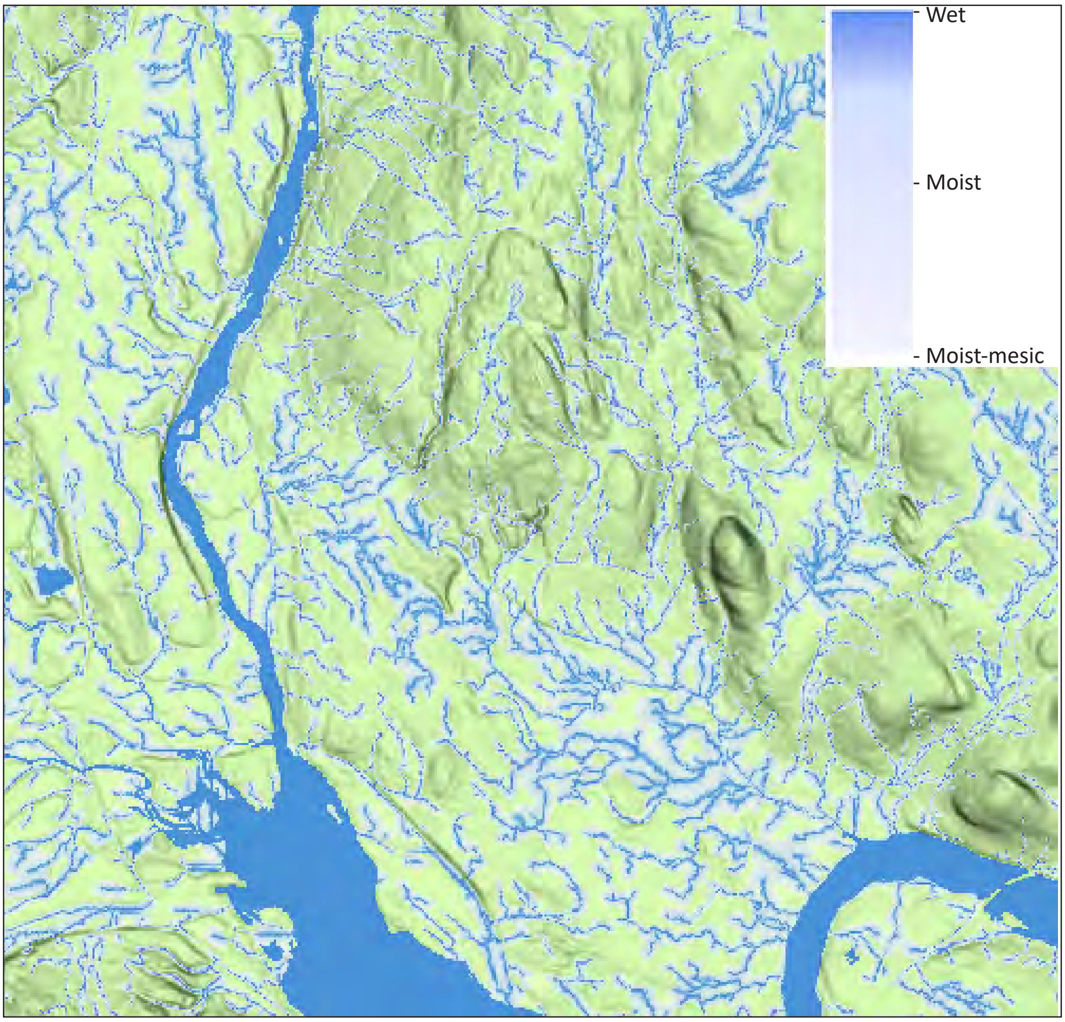
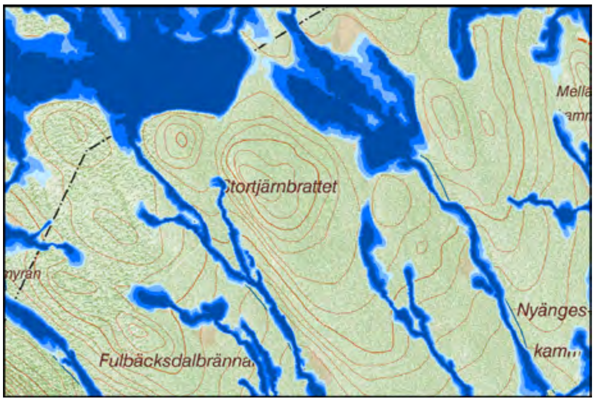


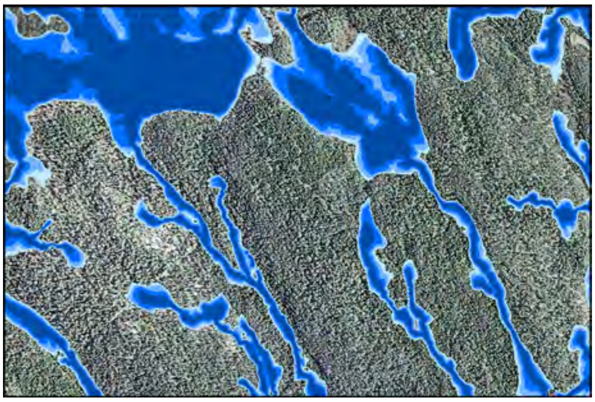
Fig. 2. A DTW map for a site in Sweden, showing wet areas adjacent to streams and lakes. Increasing wetness is indicated on a scale from light blue to dark blue. This map was obtained from the website of the Swedish Forest Agency (https://www.skogsstyrelsen.se/sjalvservice/karttjanster/skogliga-grunddata/) on 23 March 2020, and the legend has been translated to English.

Information from several digital maps can easily be combined, for example by changing the transparency of the maps (Fig. 3). Different map layers can also be toggled on and off.

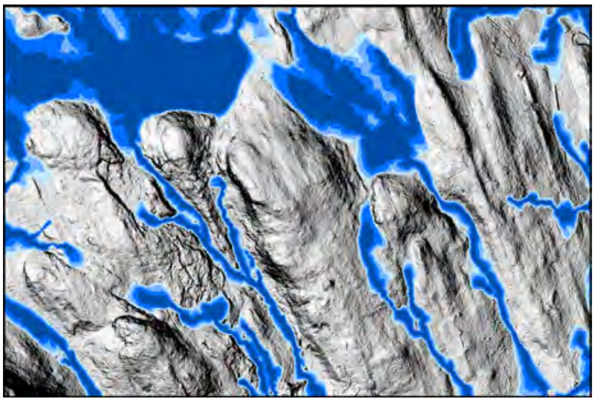
3A. The wet area map superimposed on a topographic map.




3B. The wet area map superimposed on an orthophoto showing the forest.



3C. The wet area map superimposed on the hillshade of a digital elevation model (a 3D model of the land surface).



3D. The wet area map and an orthophoto rendered transparent and superimposed on the hillshade of a digital elevation model.

Fig. 3A-D. A wet area map displayed in different ways. Map layers can be combined or viewed one at the time, as a matter of personal taste.

# Ten examples on how to use wet area maps in forestry

Wet area maps can be used as a tool when planning or carrying out forestry operations near streams and lakes, to avoid long-lasting damage to soil and water ecosystems, and costly interruptions during operations. For example, wet area maps can be used to:

1) provide an overview of the stream network
2) identify smaller streams
3) plan the extraction road network
4) find suitable locations for stream crossings
5) judge whether logging residue is needed for ground protection
6) delineate forest buffers along streams and lakes
7) identify wet areas with rich flora near streams
8) protect the riparian zone from fertilization and site preparation
9) avoid accidental stream crossings
10) identify sites suitable for mounding.

Examples 1-10 are illustrated in Figs. 4-13.

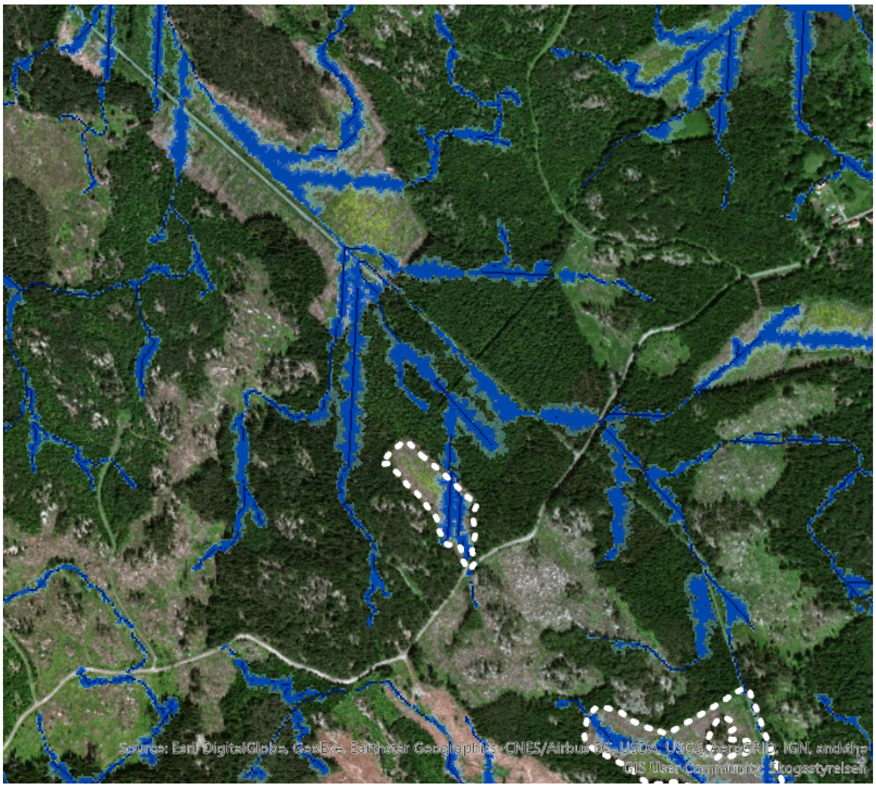



**Fig. 4. Overview of a stream network—Example 1.** The wet area map provides an overview of the stream network not only within the site of operation but also upstream and downstream (here in an area in south-central Sweden). This information is useful when planning water protection, for example in connection with ditch-cleaning operations, which increase the transportation of eroded soil downstream.

**Fig. 5. Identification of smaller streams—Example 2** Wet area maps indicate the location of smaller streams that are often missing on conventional maps. Knowing the location of the streams is necessary in order to protect them, for example from being traversed by forest machinery, but also for maintaining or forming riparian forests with high ecological functionality. Photo E. Ring

**Fig. 6. Planning the extraction road network—Example 3** An initial plan for an extraction road network can be made in the office using a wet area map. Transportation should preferably be located outside the blue areas on the map to reduce the risk of rutting. A field visit is then required to confirm or change the proposed road network. In this photo, driving in the wet area with mosses may result in wheel ruts that transport soil into the stream at high water flow. Photo E. Ring

**Fig. 7. Finding suitable locations for stream crossings—Example 4** When a stream crossing is unavoidable, potentially suitable locations for placing a bridge can be identified on a wet area map in the office. Such locations are indicated where the blue zone adjacent to a stream is narrow. The suitability of the identified location can then be confirmed or revised by making a field inspection before the start of the operation.

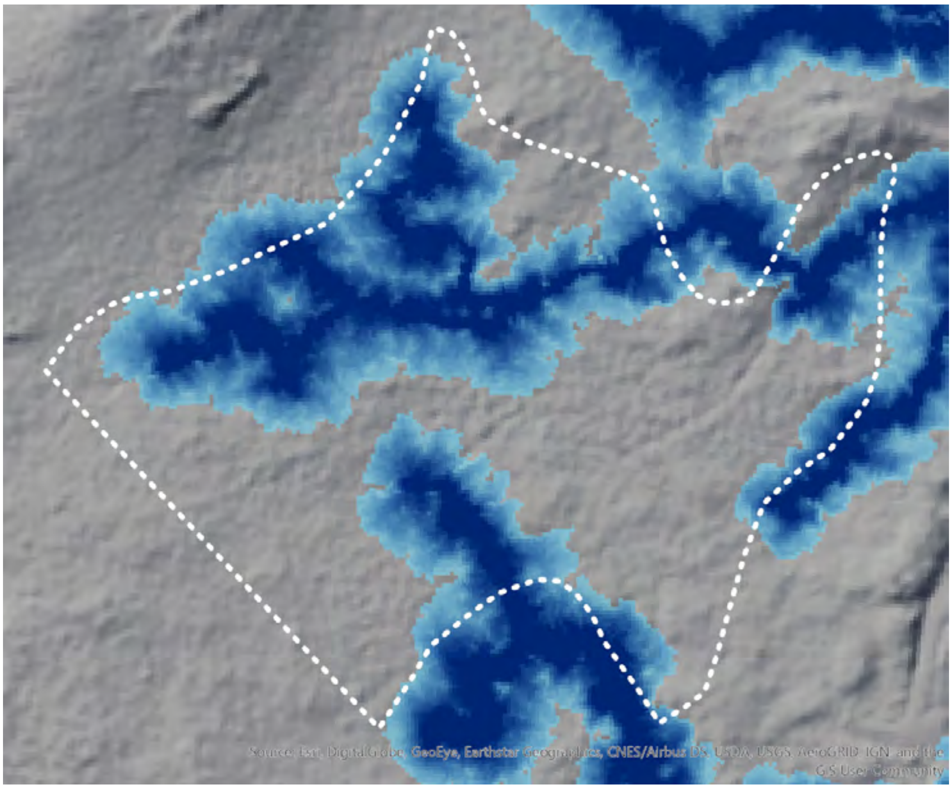



**Fig. 8. Judging where logging residue is needed for ground protection—Example 5** A wet area map can be used to judge where logging residue is needed for ground protection. Conversely, areas where logging residue can be harvested can be identified, generally within the grey areas. However, because wet areas shrink and expand depending on the weather, so does the potential area for logging residue harvest. The need for extra ground protection must also be considered.

**Fig. 9. Delineating forest buffers along streams and lakes—Example 6** Wet area maps can be useful for delineating forest buffers with variable widths to include sensitive wet areas, but other factors must also be considered to achieve sufficient shading, leaf litter input, supply of deadwood and other desirable buffer functions. Note that forest buffers with defined fixed widths are prescribed by law in some Baltic Sea countries. Photo E. Ring

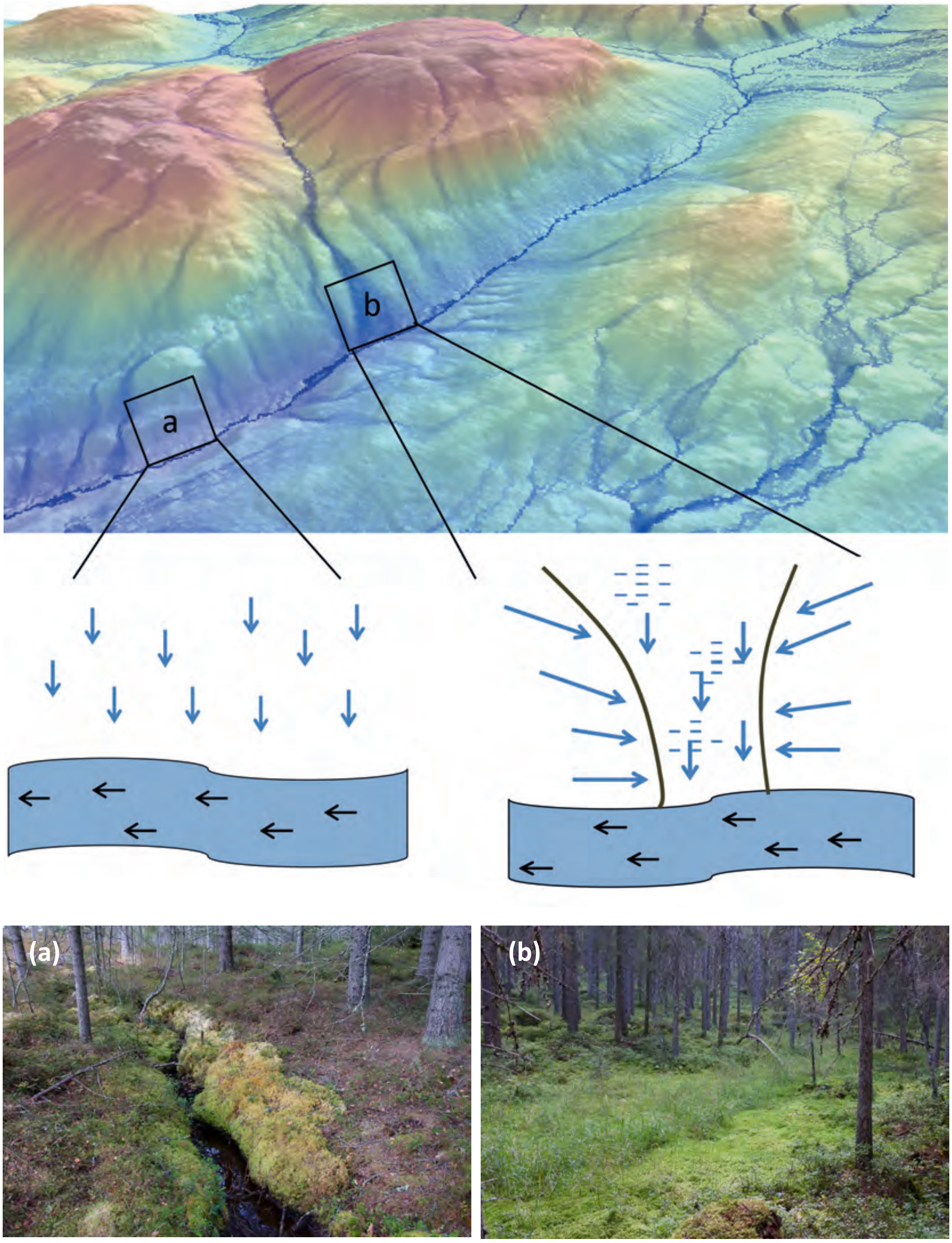



**Fig. 10. Identifying wet areas near streams with richer flora—Example 7** Groundwater typically discharges into a stream as exemplified in (a). However, sometimes groundwater discharge concentrates in certain areas before entering the stream, as exemplified in (b). In boreal forest, areas with concentrated groundwater discharge host a different and more species-rich flora than stream banks with more uniform groundwater discharge (a). They also have more productive soils and a disproportionally large effect on stream water quality. A wet area map can be useful for identifying those wet areas with richer flora that should be part of the forest buffer and protected from traversing forest machinery. Illustration adapted from Laudon et al. (2016) and photos by E. Ring.

**Fig. 11. Protecting the riparian zone from fertilization and site preparation—Example 8** Wet area maps can be useful for identifying critical zones along streams and lakes that must not be fertilized or site prepared. It is important to bear in mind that the extension of the stream network varies with the water flow. Thus, wet area maps with different stream initiation thresholds can be generated to indicate dry and wet conditions (see Figs. 23, 25 and 26). Photo E. Ring

**Fig. 12. Avoiding accidental stream crossings—Example 9** Accidental crossing of smaller streams can be avoided if their locations are known. Smaller streams can be difficult to see when the ground is covered by snow or when the logging is carried out in the dark. Photo S. Tegelmo

**Fig. 13. Identifying sites suitable for mounding—Example 10** If a wet area map indicates that a large part of the regeneration site is wet, site preparation by mounding may be considered. Photo E. Ring

# Wet area maps for planning and executing forestry operations

Wet area maps can be used for indoor and outdoor planning and during forestry operations. They are useful during field inspections and during the execution of forestry operations, especially if the location of the forest machinery is displayed in real-time (Fig. 14). With real-time locations the machine operator knows the location of the machinery continuously in relation to the wet areas shown on the map. Wet area maps also make it easier to plan operations when the ground is covered with snow.

**A field visit should be made after initial desk planning using a wet area map, to check and adjust the borders and positions of planned roads, stream crossings, protection zones, etc.**

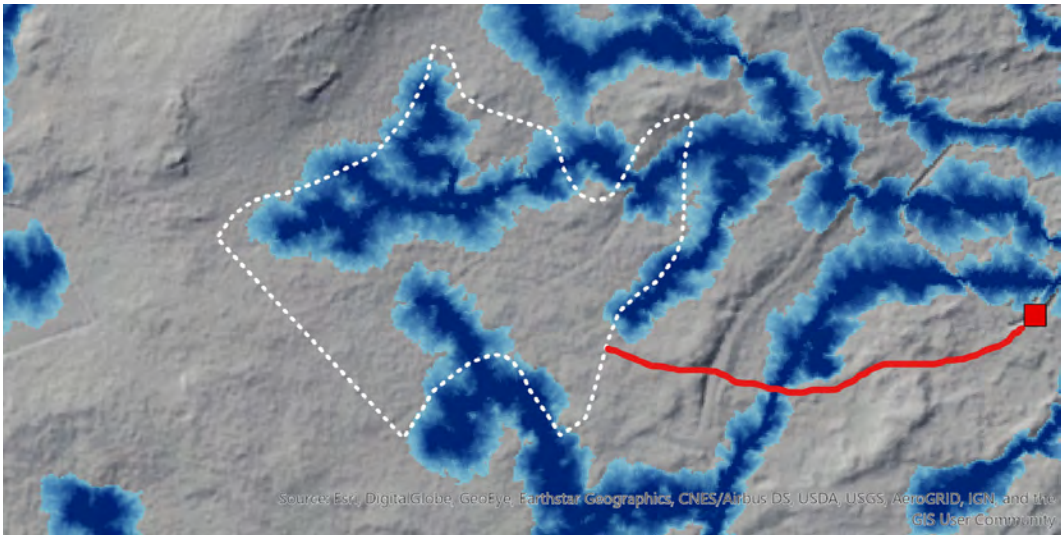
Fig. 14. Seeing the location of the forest machinery on a wet area map in real time helps the machine operator avoid driving in sensitive wet areas. Photo E. Viklund

## Harvesting—thinning and final felling

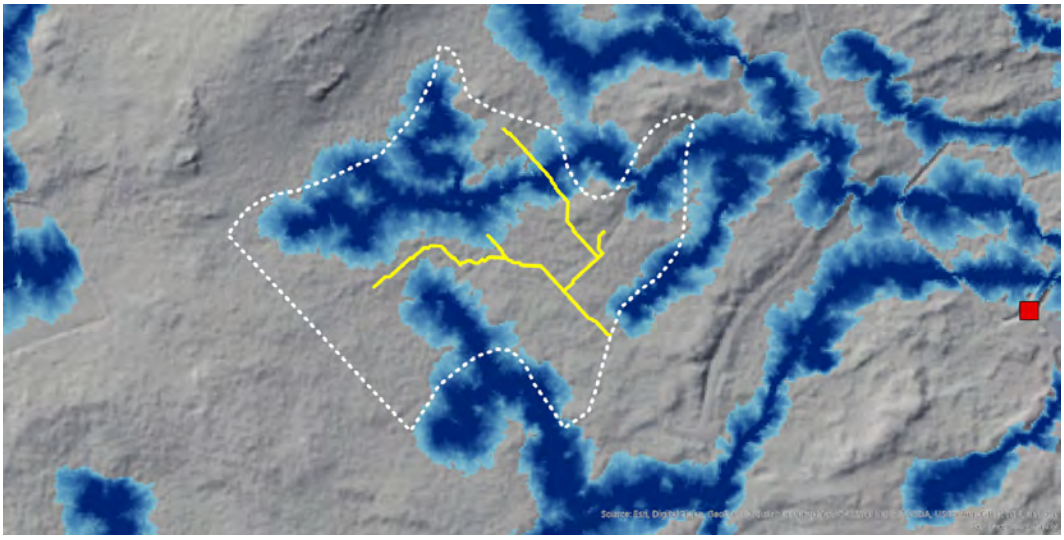
Using wet area maps can help plan the road system, location of landings, stream crossings and the need for ground protection at final felling (Fig. 15). A wet area map can also be useful when planning biodiversity conservation measures, for example the delineation of forest buffers.

Thinning operations are potentially more difficult to plan than final felling because of the fixed distance between strip roads. When planning thinning operations, wet area maps can be useful for identifying potential problems and acknowledging those problems from the start.

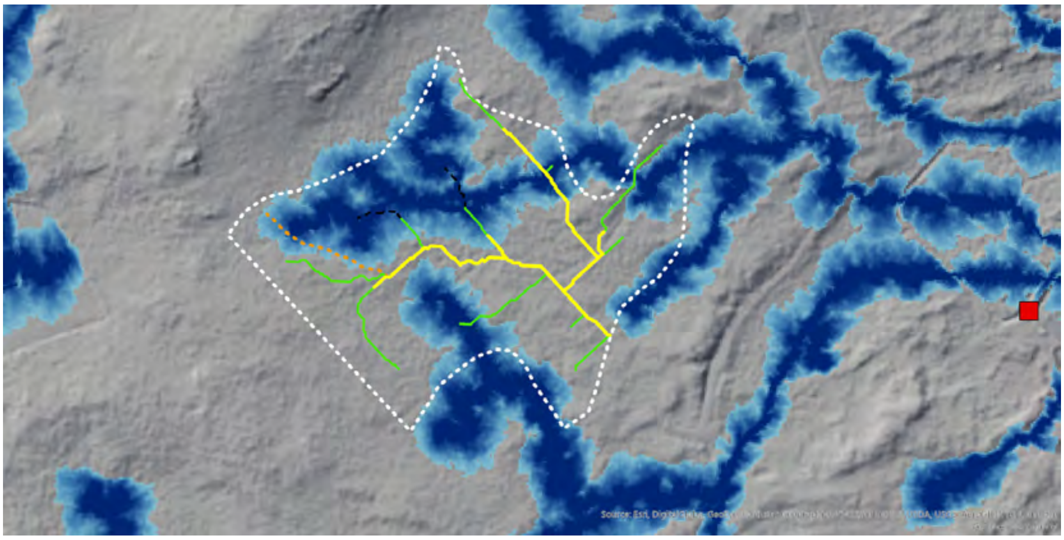
## Planning the road network at final felling —an example of how to use a wet area map



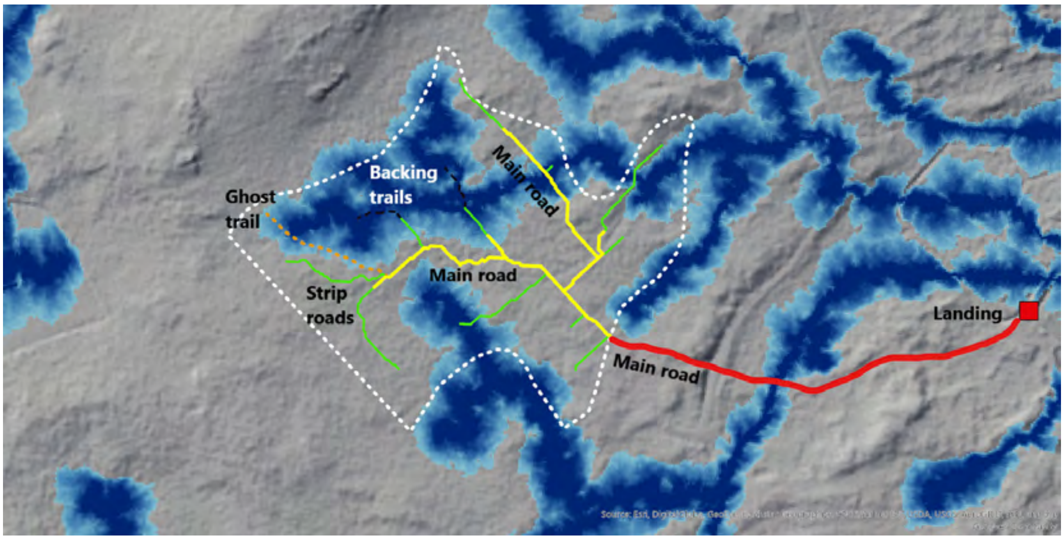

**15A. The main road from the logging site to the landing** Timber must be transported from the logging site to the landing (red box), and crossing a wet area may be unavoidable. Thus, a suitable location for the crossing must be found, i.e. where the wet zone is narrow and the slope inclination is not too steep. The transportation distance and topography must also be considered—to find the shortest route with suitable ground conditions. The conditions are checked in the field and the road alignment adjusted if necessary.



**15B. The main road system on the logging site** The system of main roads on a site is designed with respect to the size and distribution of the timber volume. Each road segment must be able to bear the required number of passes without breaking. The main roads are located outside the wet areas as much as possible and reinforced with logging residue. The conditions are checked in the field, the road alignment adjusted if necessary, and the need for additional ground protection such as logging mats determined.



**15C. Logging roads, ghost trails and backing trails** Strip roads (green lines) and ghost trails (orange dashed line) are mostly planned onsite (in operational forestry) based on the main road system and markings made in the field during prior field inspections. Logging residue is used for ground enforcement in all dark blue areas and wherever else it is needed. A "ghost trail" across a wet area is only used by the harvester, and the harvester uses its boom to place the harvested trees in nearby drier areas. The forwarder can then collect the timber without entering the wettest areas. To reduce ground impact, the forwarder can also back empty into sensitive areas (black dashed lines) and start loading from the end of the road and refrain from filling up the entire log bunk. The load should be topped up later before reaching the landing.




**15D. The entire extraction road network** Ground conditions can worsen rapidly depending on the weather, so the operation must continuously adapt to the current situation.

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Fig. 15A-D. The wet area map used in this example is a DTW map provided by the Swedish Forest Agency, superimposed on the hillshade of a 3D model of the land surface.

## Regeneration

If a forest buffer is not retained during clearcutting (Fig. 16), there are still measures that can be taken to protect or improve the water quality. A wet area map can be used to identify areas that should be excluded from site preparation and planting of conifers, for example wet areas and zones adjacent to streams and lakes (Fig. 16). Promoting natural regeneration of broadleaved trees in these areas will increase the proportion of broadleaved trees on site and provide a good starting point for future forest buffers.

Fig. 16. Avoiding site preparation and driving in wet areas adjoining surface water, as indicated by a wet area map, will help protect the surface water from increased inputs of eroded soil. Furthermore, refraining from planting conifers in wet areas will favour broadleaved trees along the stream or ditch, which is beneficial for aquatic life. Photo E. Ring

## Pre-commercial thinning

In wet areas broadleaved trees regenerate easily. Retaining a high proportion of broadleaved trees may be warranted in these areas, for example along surface water (Fig. 17). A wet area map can be used to find such areas where more broadleaved trees could be left during pre-commercial thinning. Leaf litter from broadleaved trees provides a higher quality food source for aquatic organisms than conifer needles.

Fig. 17. A wet area map can be used to find wet areas alongside streams and lakes where a higher proportion of broadleaved trees is beneficial. Photo E. Ring

## Forest roads

Wet area maps can be used to find suitable road alignments when planning forest roads, for example to avoid areas with low soil-bearing capacity and unnecessary crossing of streams (Fig. 18). Road construction and maintenance of road ditches expose mineral soil that can erode and increase the transport of soil particles to nearby water. Road ditches should not be directly connected to streams, which needs to be considered when determining the alignment of a road, and an overview from a wet area map of the streams and lakes in an area can be helpful. A wet area map can also help determine where road culverts need to be installed.

Fig. 18. Building a forest road is an option for transportation, for example if adjacent compartments are to be harvested soon. An initial plan for the road alignment can be made from a wet area map. Photo E. Ring

## Fertilization

Forest fertilizer must not be spread across streams or areas with high connectivity to nearby streams and lakes (Fig. 19). To secure streams and lakes from direct fertilization, a wet area map can be used to identify critical areas where no fertilizer must be spread (note that fertilization is often regulated by law, guidelines and forest certification standards). Real-time location of the tractor on the map will help the machine operator spread the fertilizer in designated areas.

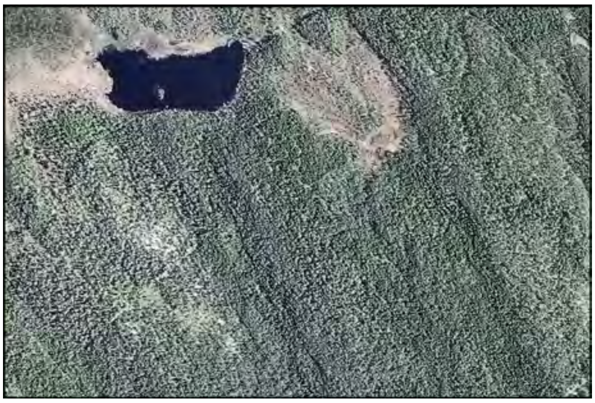
Fig. 19. A tractor spreading fertilizer in a conifer stand growing on mineral soil. Photo D. Malm

# From conventional maps to wet area maps

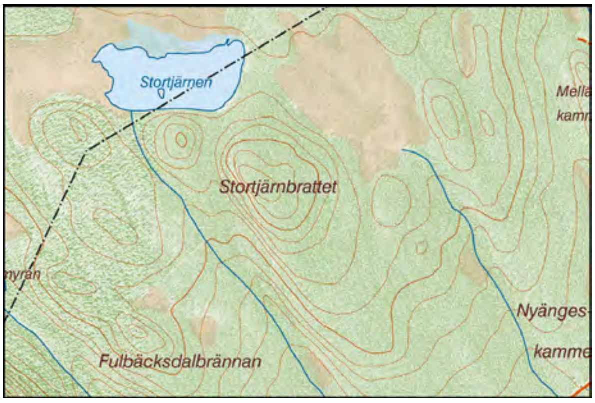
Technical developments over the last few decades mean it is now possible to collect and process large data sets. As a result, new methods of generating maps have evolved. In this section, the development and features of Depth-To-Water (DTW) and wet area maps generated by machine learning (MLWAM) are briefly described, to help interpretation of the information they present (Fig. 20).

## From aerial photos to machine learning – a quick tour

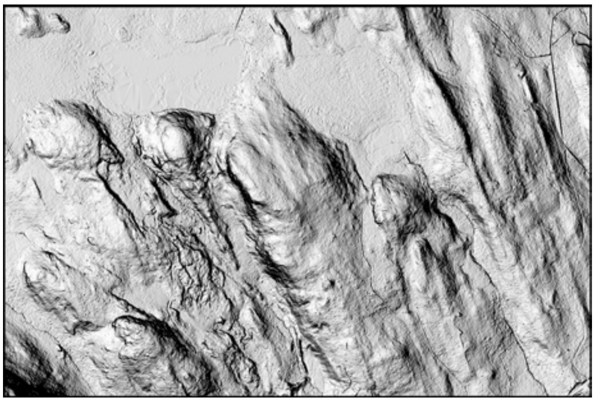
20A. An aerial photo



20B. A conventional map

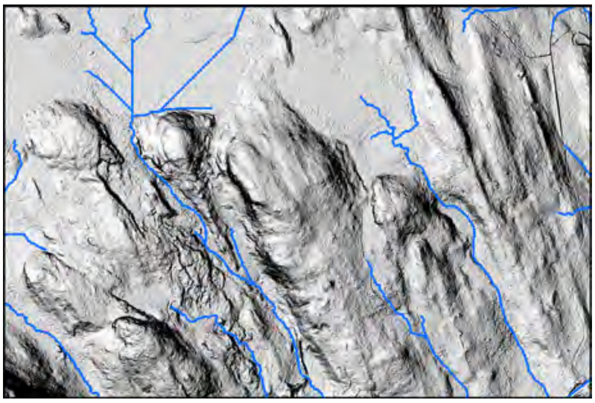



20C. A 3D model of the land surface from Lidar measurements

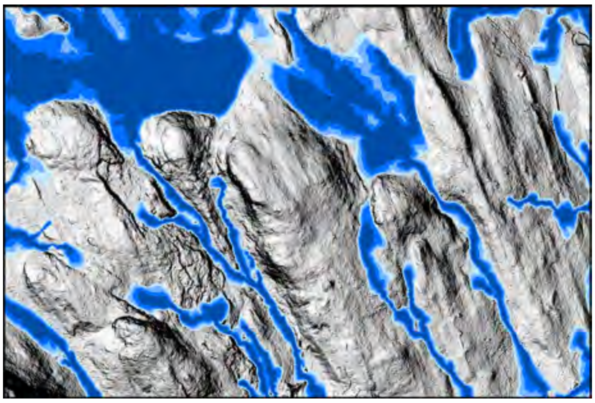


20D. A stream network generated from a 3D model

This map includes all streams, including the smallest. The streams form a network, so streams at the inlets of a lake are schematically connected to the lake outlet.



20E. DTW map
DTW maps are generated by modelling the groundwater level across the landscape using the stream networks and a map layer showing the lakes.



20F. MLWAM
This wet area map was generated by combining information from several maps and field data into one map, indicating soil moisture, using machine learning.

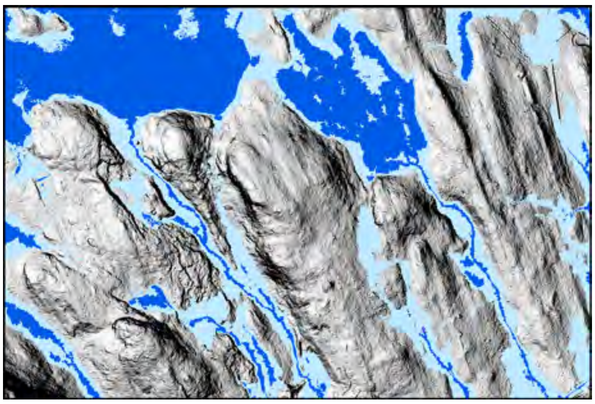


Fig. 20A-F. A summary of the development of maps showing wet areas, streams and lakes. These maps are of the Krycklan Catchment in northern Sweden.

## Conventional maps lack many of the smallest streams and wet areas

On conventional maps, the smallest streams and wet areas are often missing from forest areas, partly because they are difficult to detect below the forest canopy, both in aerial photos and in the field (Fig. 21).


Fig. 21. An aerial photo of forest land in Sweden, with lakes and streams from conventional maps superimposed on the photo.

## Lidar measurements can be used to picture the land surface

Many landscapes have been scanned using Lidar (light detection and ranging), based on laser technology, from aeroplanes. From the data point clouds generated, high-resolution 3D models of the landscape can be created that reveal small-scale features such as stream channels, ditches and roads, even from below the forest canopy (Fig. 22).

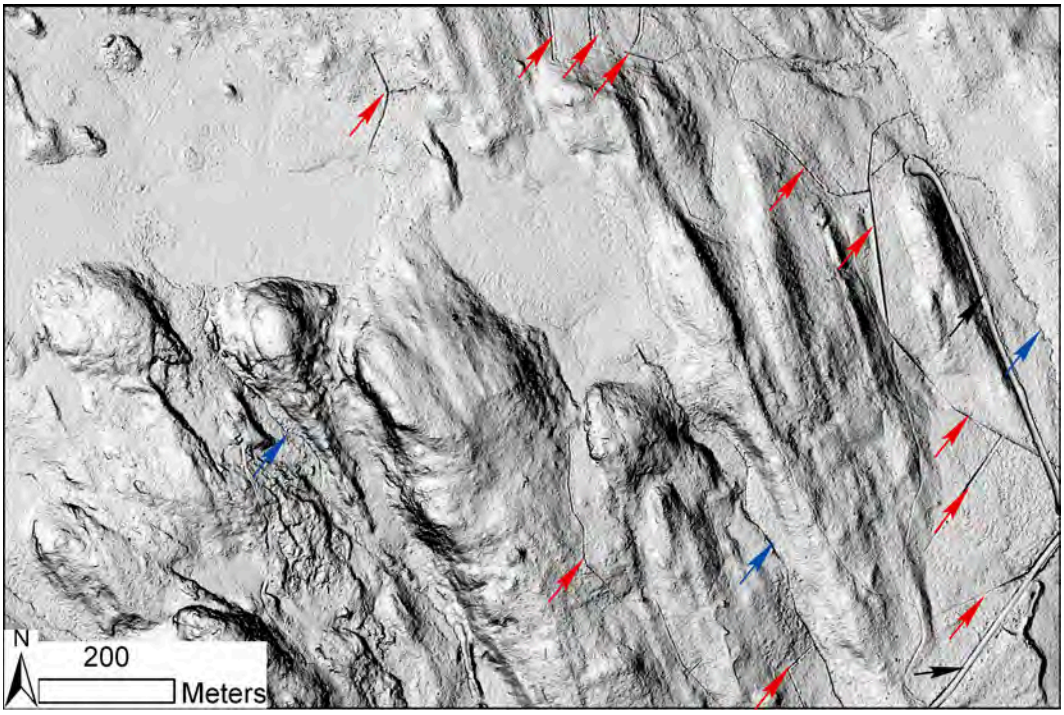



Fig. 22. A high-resolution 3D model of the land surface derived from Lidar data of the same area shown in the aerial photo in Fig. 21. It reveals roads (black arrows), smaller streams (blue arrows) and ditches (red arrows), which in the photo were hidden under the canopy.

## Stream networks are more accurate when derived from a 3D model of the land surface

Conventional maps show the larger stream networks that can be identified from aerial photos, but in fact the majority of stream networks consist of smaller streams. These smaller streams are usually missing on conventional maps because they are covered by the forest canopy. However, using 3D models of the land surface obtained from Lidar measurements, water flows can be modelled and stream networks generated that include those smaller streams (Fig. 23). The extension of the stream network is controlled by the stream initiation threshold. This threshold determines where the streams start in the landscape, i.e. when enough groundwater has accumulated to become surface water and form a stream. The modelled stream network with a stream initiation threshold of 10 ha shown in Fig. 23 (Left) is similar to the stream network seen on more conventional maps, while the modelled stream network with a 2-ha stream initiation threshold (Fig. 23 Right) shows smaller, previously unmapped, streams.

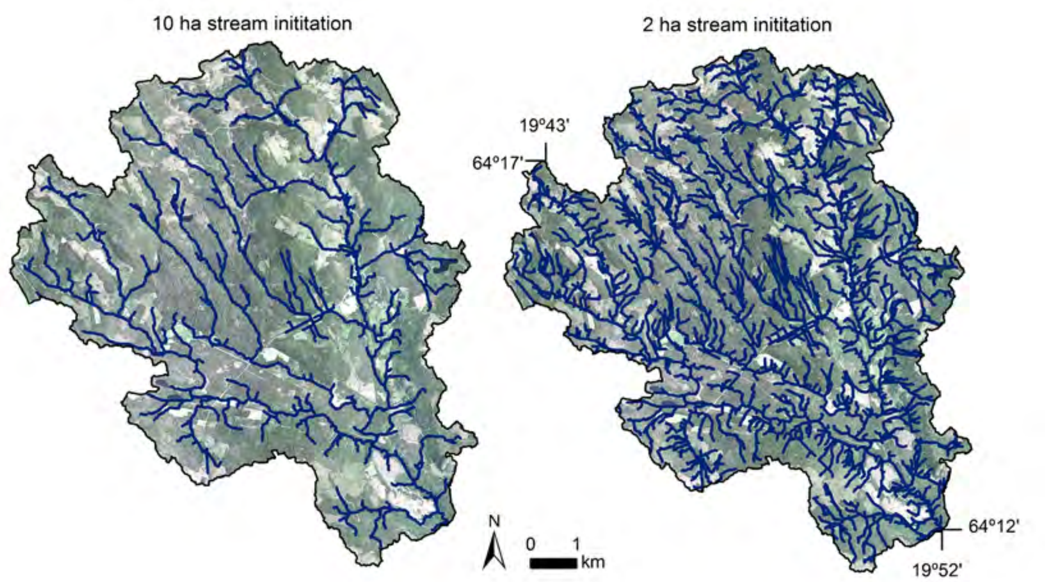



Fig. 23. Two maps of the stream network in the Krycklan Catchment, northern Sweden. Left: stream network generated by setting the stream initiation threshold to 10 ha. Right: stream network generated by setting the stream initiation threshold to 2 ha.

## DEPTH-TO-WATER MAPS

### DTW maps show the depth of the modelled groundwater level

Once a more complete stream network has been generated (Fig. 23), the groundwater level can be modelled throughout the landscape (Fig. 24). The depth from the soil surface to the modelled groundwater level can then be calculated. This is called the Depth-To-Water (DTW) index. If the groundwater level is close to the surface, the soil is wet, and if the level is deep below the surface, the soil is dry. In addition to the large open wetlands that can be seen on conventional maps, DTW maps show the riparian wet and moist areas near streams and lakes.

A DTW map is generated by setting two thresholds, the stream initiation threshold for the stream network and the DTW index. The first threshold determines where the streams start in the landscape (Fig. 23). This threshold value differs between regions, soils, topography and climate. To use a fixed value for an entire country would generate maps that are too wet in some regions and too dry in others. The second threshold determines the width of the mapped wet soils along stream networks; commonly, soils with an index less than 1 are marked as wet. In DTW maps, soils with a low DTW index (<1) are marked in blue (Fig. 25). Dark blue areas show where the modelled groundwater level is close to the surface, indicating wet soils. Light blue areas show where the groundwater level is about one meter deep, indicating moist soils.

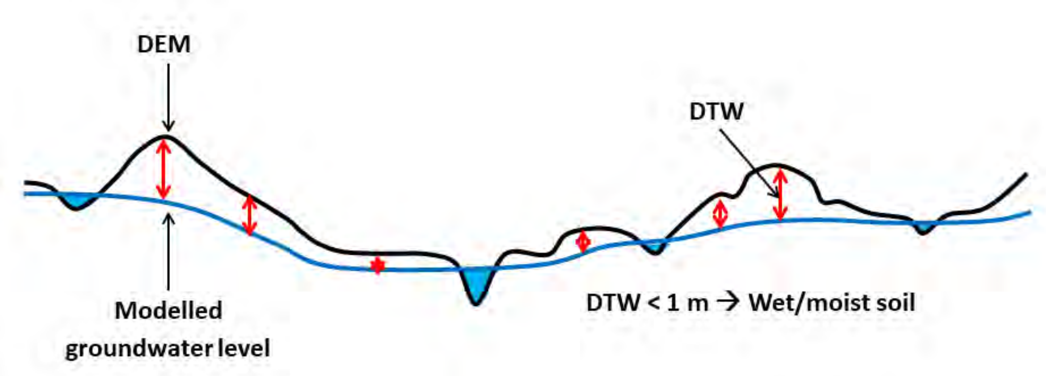



Fig. 24. The groundwater level is modelled throughout the landscape based on the stream network, including the smaller streams. The depth from the soil surface (DEM) to the modelled groundwater level is then calculated: this is the DTW index.

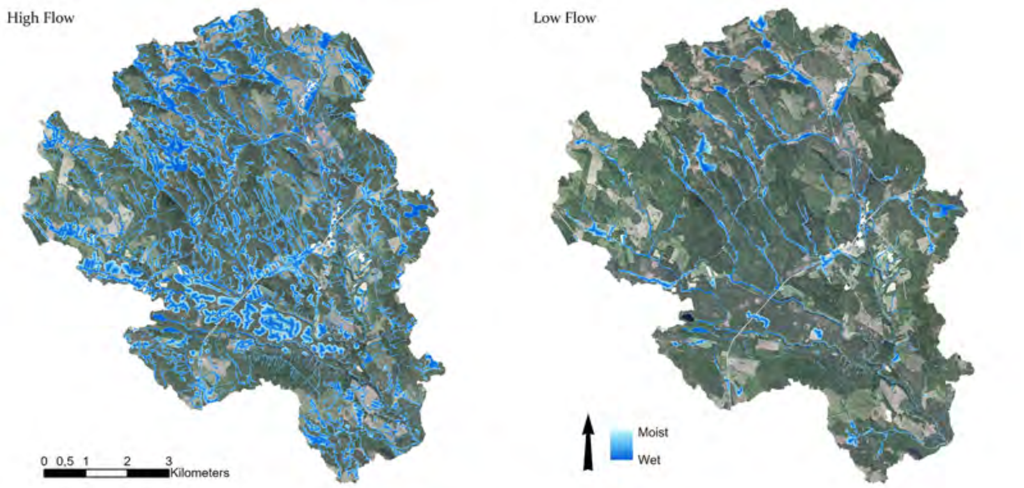



Fig. 25. DTW maps for the stream network in the Krycklan Catchment, northern Sweden, during high water flow (left) and low water flow (right). Illustration by William Lidberg.

## DTW maps can show both low and high stream flow conditions

The size of stream networks shrinks and expands depending on current weather conditions (Fig. 25), and DTW maps can be used to illustrate this seasonal variability (Fig. 26). Green areas show soils that are wet during low flow conditions and blue areas indicate soils that wet up during high flow conditions. Green and blue areas on the maps indicate where soil disturbance should be avoided, to protect nearby streams and lakes from increased inputs of eroded soil, hazardous elements and nutrients. However, depending on local conditions, for example soil type, an even larger area may be required. Although the maps can provide valuable information, field visits are strongly recommended.

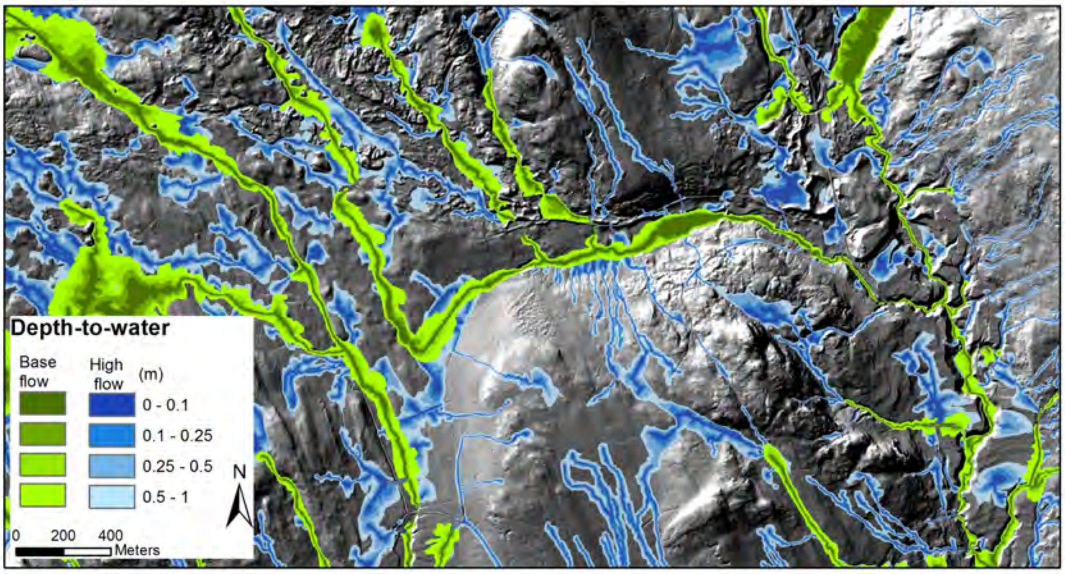



Fig. 26. During periods with low water flow (baseflow), the stream network will shrink to the areas marked in green, while during high flow the stream network and the area with wet soils will expand to the areas marked in blue.

## WET AREA MAPS GENERATED BY MACHINE LEARNING

Recently, wet area maps have been developed further using machine learning. To adapt the wet area maps to different regions, with different soils, topography and climate, many maps with different thresholds can be generated and used together with field data to train a computer to automatically combine the information into one map. So far, such a map has only been produced for Sweden. The Swedish MLWAM was generated by combining information from 28 maps and using soil data from the Swedish Forest Inventory from 20 000 plots distributed across Sweden (Fig. 27). Before training the model, the five soil moisture classes used for field classification were condensed into three classes because of the low number of observations of the most extreme soil moisture classes (dry and wet). The model was then trained to classify each pixel into one of those three classes: dry-mesic, mesic-moist and moist-wet (Fig. 28).

MLWAMs model the average moisture conditions and take into account local climate, soils, topography, etc. This generates more accurate maps of wet areas compared with DTW maps, which can indicate values that are too wet or too dry for some regions.


Fig. 27. A MLWAM has been generated for Sweden by combining the information from 28 maps and using soil data from the Swedish Forest Inventory from 20 000 plots distributed across Sweden. The map shows the location of the field plots. Illustration from Lidberg et al. (2020).

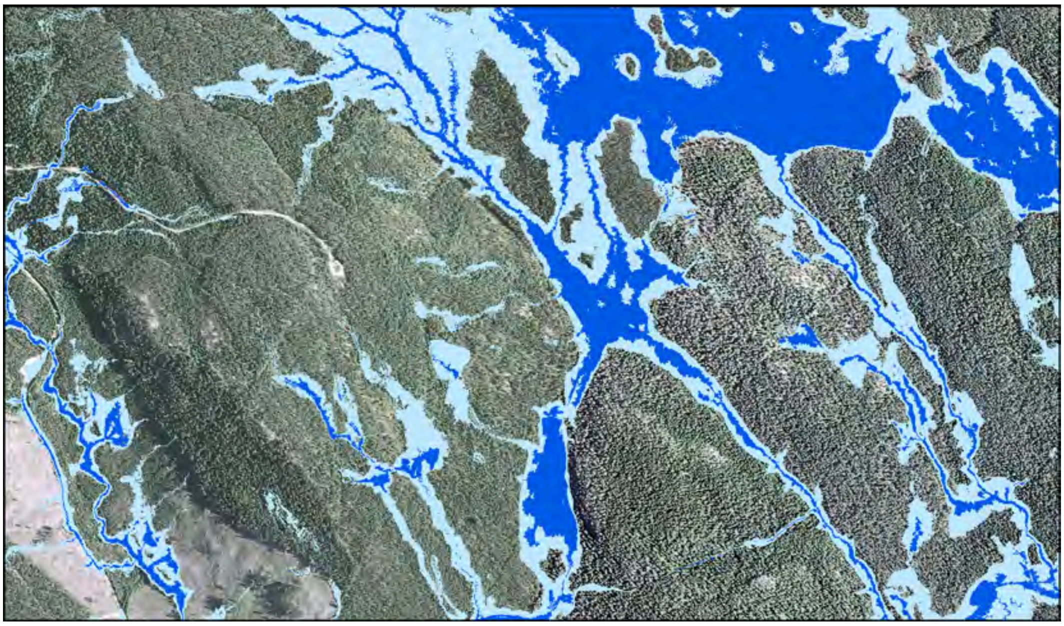
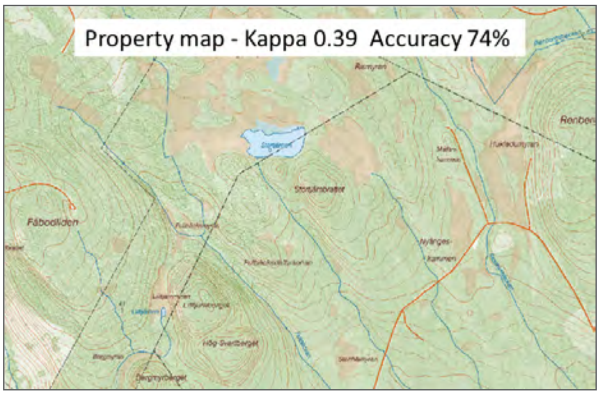


Fig. 28. This MLWAM shows three classes of soil moisture: dry-mesic (transparent, i.e. where the orthophoto is visible), mesic-moist (light blue) and moist-wet (dark blue).

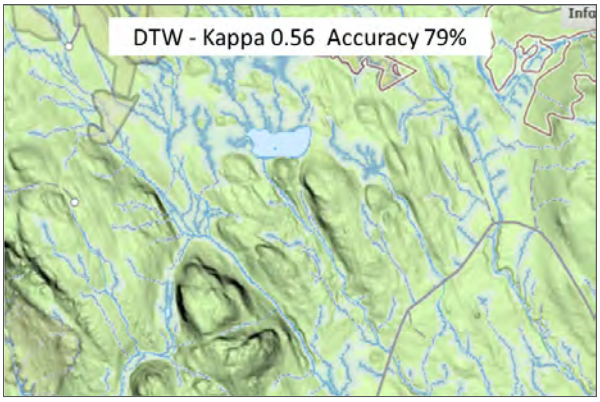
## IMPROVED ACCURACY

Wet area maps display the hydrological network better than previous topographic maps. By comparing different types of maps with field data, a measure of how well individual maps perform can be calculated. We used overall accuracy, or accuracy and kappa values (Cohen´s kappa index), as a measure of performance (Fig. 29): a kappa value of 1 and an accuracy of 100 % would indicate a perfect agreement between the map and the field.

29A. Topographic maps, as exemplified by the Swedish Property map (1: 12 500), are drawn from aerial photos and show large mires and wetlands. Many smaller wetlands and riparian soils hidden below the canopy are missing.




29B. Compared with topographic maps, the performance of a DTW map is obviously better, with higher kappa and accuracy values. Smaller streams and wetter soils near streams and lakes are indicated, although some larger mires remain undetected. A DTW map can also misrepresent the soil as too wet or too dry for some regions.




29C. Machine learning can improve the performance of wet area maps, with higher kappa and accuracy values. So far, only Sweden has produced a MLWAM. This map captures both the larger wetlands and the riparian soils and can be adjusted for regions with different topography, soils and climate. This is the most accurate map to date and will soon be freely available for use.

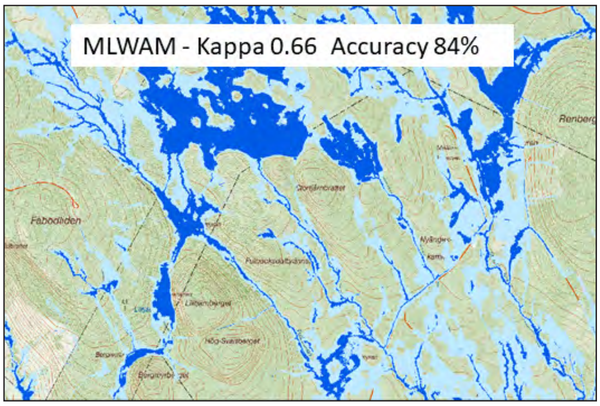
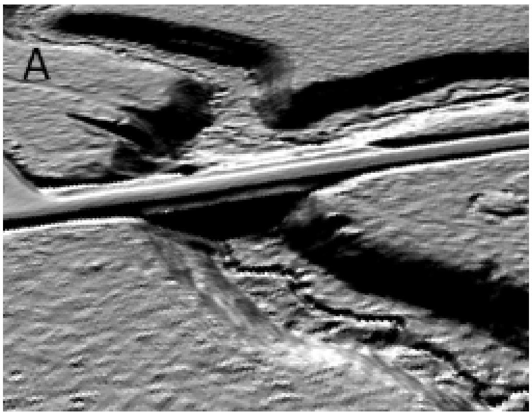


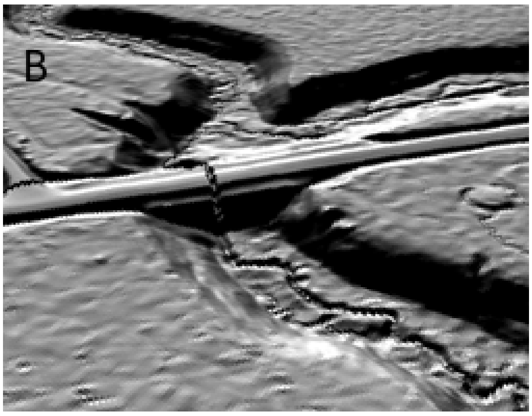

Fig. 29A-C. A short overview of how the accuracy of wet area maps has improved since their first development. To calculate the kappa and accuracy value, the maps were divided into two classes for wetness, but the original maps are shown here.

## KNOWN LIMITATIONS OF WET AREA MAPS

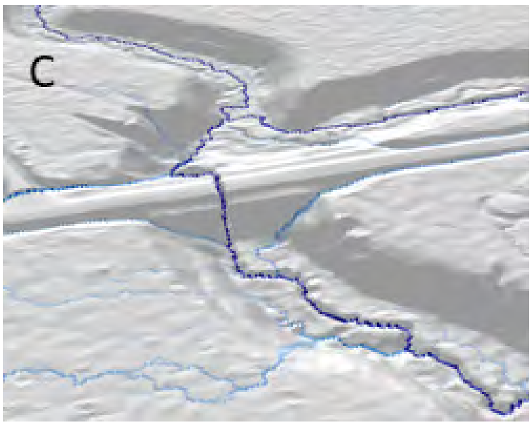
While digital wet area maps are more accurate than conventional maps, they are not perfect. An accuracy of 80 percent means that the maps are incorrect in 20 percent of cases. These errors are mostly found near roads. In a 3D model of the land surface, roads act as artificial dams, while in reality streams flow under roads through a culvert or under a bridge. This mapping problem can be solved by processing the 3D model of the land surface automatically using GIS programs (Fig. 30). While this works well in most cases, as in Fig. 30, it can remain inaccurate for some locations because the location of all bridges and culverts is not known. Therefore, wet area maps can still contain errors alongside roads. Another source of errors is related to the choice of stream initiation threshold (Fig. 23). By choosing an incorrect stream initiation threshold, areas surrounding the headwaters, i.e. the smallest streams, may become too dry or too wet on the DTW map. Therefore, a field visit should be made after initial desk planning using a wet area map.




30A. In a 3D model of the land surface a road acts as an artificial dam.




30B. By processing the 3D model of the land surface automatically using a function called breaching, the modelled water can be routed across the road.




30C. After breaching, water is no longer stopped by the road and the stream continues along its course.

Fig. 30A-C. By pre-processing a 3D model of the land surface, water is allowed to move freely across a digitial landscape. Roads are generally elevated above the surrounding ground surface and can act incorrectly as dams. In this example, “breaching” was used to allow the stream to continue across the road.

# Wet area maps in the Baltic Sea region – some highlights

- DTW maps were first developed in Canada at the University of New Brunswick (https://blogs.unb.ca/afrc-research-highlights/2019/05/wet-areas-mapping.php).
- In the Baltic Sea region, the introduction of DTW maps in practical forestry started in Sweden in 2014.
- In 2016, the Swedish Forest Agency provided DTW maps for the whole of Sweden.
- As part of the EU Interreg project WAMBAF Tool Box, ending in January of 2021, DTW maps for the whole of Finland have been generated (2020) and are ongoing for Latvia and Poland.
- During 2015-2019, the wet area map was developed further at SLU, Sweden, by introducing machine learning (resulting in MLWAMs). (http://www.slu.se/mfk/)
- MLWAMs will be produced for Sweden during 2020-2021.
- Preparations to produce MLWAMs for Finland, Latvia and Poland during 2019-2021 are being made as part of the WAMBAF Tool Box project.

# Practical experience of forestry professionals in Sweden and Finland

DTW maps have now been used in operational forestry in Sweden and Finland for some time. To benefit from the practical experience of using these maps, eight forestry professionals were interviewed using a pre-set questionnaire during 2019 and 2020. The professionals worked as contractors, planners, machine operators and planning experts in Sweden and Finland, and had used DTW maps (which were available in different versions) on forest land for some years. In most cases, the professionals responded to the questions with thinning and final felling operations in mind. They all found that DTW maps generally perform well and are useful for their work. However, on some sites the maps were found to be inaccurate. Such sites included peatlands and flat areas.

The forestry professionals used the DTW maps to plan before an operation, and also during the operation of forest machinery. For example, the map could be used by the machine operator to determine whether logging residues should be harvested or used for ground protection. The maps were used for planning road systems, the location of stream crossings, the location of landings, conservation measures and identifying easy and difficult harvesting sites.

The introduction of DTW maps was found to have simplified the planning of main roads and allowed planning to start earlier, ahead of the logging operation. Field planning was more efficient when areas with low soil-bearing capacity could be identified initially from the DTW map. The planning of the road system could then focus on those areas outside the wet areas.

In order to improve the wet area map, the forestry professionals suggested that information on hydrology, soil type, tree stand, stand age, stand borders, tree root biomass and possibly contour lines could be added. Adding a function to include information on local weather or precipitation was also suggested.

More feedback from the professionals is presented below. The quotes have been interpreted and edited by the authors.

## COMMENTS BY FORESTRY PROFESSIONALS

### Examples of how DTW maps are used

“When I arrive at the site, I turn on the DTW map and look at the slopes. I frequently shift between the orthophoto and the DTW map.”

“When I get the instructions for the logging site, I turn on the DTW map and look at the contour lines. This gives quite a good overview.”

“I turn on the DTW map before I go out to plan in the field. I visit the site and check if the DTW map is correct. Sometimes I bring a paper version of the map, but often I keep the map in my head. Back at the office, I update the map to make sure that this information is available on the maps in the forest machines.”

“I try to avoid moist areas on the map as far as possible. I try to place main roads as elevated as possible and crossings where the wet areas around the stream are as narrow as possible.”

“I do not plan operations in blue areas or areas surrounded by blue areas.”

“When I am planning, I turn on the DTW map and determine where main roads, crossings, etc., should be located. The machine operators use the DTW maps and are calibrated against it. I visit the site to put up marking strips and use a soil probe to confirm the location when needed. I do not think that the planning can yet be carried out only from the office. A field visit is necessary to get a good result.”

“I make a preliminary plan at the office. Then I make a field visit where I compare the information on the DTW map with what I see in the field. I pay attention to soil type, ground vegetation and topography of the site. Landings are not planned on areas that are dark blue on the DTW map. Main roads are not planned in blue areas, and if other trails must be located in blue areas they are used only once.”

## If there are blue areas on the wet area map – what kind of action do you take?

“As little driving as possible in the blue areas. Use logging residue for ground protection if driving cannot be avoided.”

“No driving along the blue areas. If a crossing is necessary, try to find a suitable location.”

“All blue areas are not necessarily exempted from traffic, but then “ghost trails” or other measures may be needed.”

“If the forwarder needs to collect timber, the forwarder should only have to pass once.”

## Your best advice to someone who is going to start using wet area maps

“Learn how to use the map by going out in the field and compare the map with what you see in the field.”

“Just start to use them, with confidence. They are useful for focusing the field work to potential “hot spots”.”

“Check green and grey areas in order to find the best road alignment. If you need to cross blue areas, make sure that the traversed distance is as short as possible.”

“Take some time to understand and place the main roads to which short extensions trails can be added if the area is wet.”

“Look at the map before starting to harvest because there are often flaws in the planning.”

“The same indication on the DTW map can mean different things on different type of soils. It is important to calibrate your interpretation of the map on different types of soils by making many field visits.”

“Do not rely entirely on the map. But also, avoid visiting areas on the site that are easy to interpret from the map.”

“Try to drive only in elevated areas and away from the blue areas.”

# More information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More information on how to protect forest waters from negative impacts during forestry operations is available on YouTube. The instruction film “Traceless” provides examples of how wet area maps can be used in practical forestry: https://www.youtube.com/watch?v=xauLNORS4m0. The film “Forest and water” explains how forestry may affect water and what forestry can do to avoid negative impacts: https://www.youtube.com/watch?v=GuhLnBJAGlg. Photo L. Högbom