

DigiBog_Hydro User Manual

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Version 1: 30th November 2020

The development of the user-friendly GUI for DigiBog and the training in its use as a peatland restoration design tool was funded as part of the iCASP project (NERC Grant NE/P011160/1)



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1. Background and basic principles

DigiBog_Hydro simulates subsurface water flow and water-table behaviour in soils and shallow aquifers, including peatlands such as raised bogs and blanket bogs. It can be used as a stand-alone model but also forms part of what is called the 'full' DigiBog, a model that simulates peatland development over time (peat accumulation and peat degradation – see the iCASP *Short Guide to Peatland Development Models*). DigiBog_Hydro is written in Fortran 95 and was originally only available in a form without a user interface, meaning those using the model had to develop their own tools for setting up input files and processing output data. As part of the iCASP Optimal Peatland Restoration (OPR) project the model has been updated to have a user-friendly front end or GUI (graphical user interface), that simplifies model set up, making it easier for users to undertake useful model simulations.

1.1 In simple terms

In essence, DigiBog_Hydro simulates water movement through a soil or aquifer – peat in our case. Water moves from where the water table is higher to where it is lower. This situation is visualised in Figure 1. The rate at which water flows through the soil will depend on the steepness of the water-table gradient (steeper gradients give higher rates of flow) and the permeability or hydraulic conductivity of the peat (the higher the hydraulic conductivity, the higher the rate of flow).

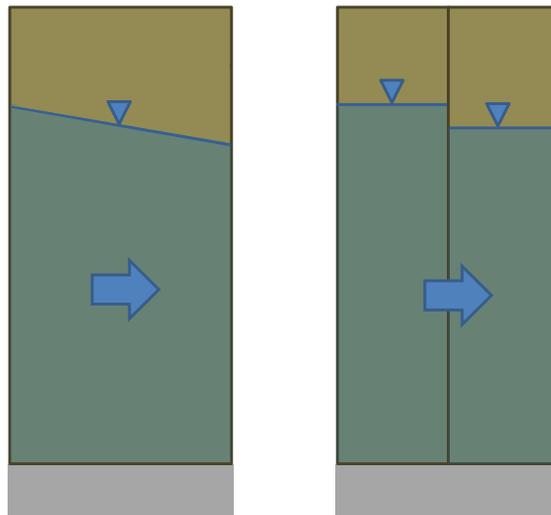


Figure 1. *Subsurface water flow through a peat soil.* Left: cross section through a peat soil on a flat clay substratum. The water table is sloping downwards from the left and water flow in the peat below the water table is from left to right. Right: In a model we can conceptualise the peat as consisting of multiple columns. Here, two are shown. Each column has its own water table value and the sloping water table in the left-hand diagram is represented as a step down in water-table levels between the two columns. The inverted triangles represent the position of the water table.

Water tables will rise in response to rainfall additions and will fall due to seepage to the peatland margin and evapotranspiration. ('Seepage' is a term used to describe water flow below a water table; seepage is synonymous with 'groundwater flow'.) A simple example is the water balance of a hagg (or hag) (Figure 2). Water flows to the margin of the hagg to a gully where it is rapidly conveyed downstream. Because water levels in the gully at the edge of the hagg always remain low, water flows out of the hagg. Rapid downstream flow of water in gullies ensures water levels in them remain at or close to the ground surface except during and immediately after rain storms. The hagg is topped up with rainwater, but can also lose water via evapotranspiration. If a gully is dammed, so

that water levels in it rise to the level of the dam, water flow from the hagg will be reduced. The level of water outside the hagg may be termed the 'drainage base' and this is the level to which water will drain; the level to which the water table will fall in response to seepage. If the drainage base is raised, water levels in the peat at the edge of the hagg will be higher and water-table gradients within the hagg will be lower. Overall, the hagg will be wetter. This situation is shown diagrammatically in Figure 3.

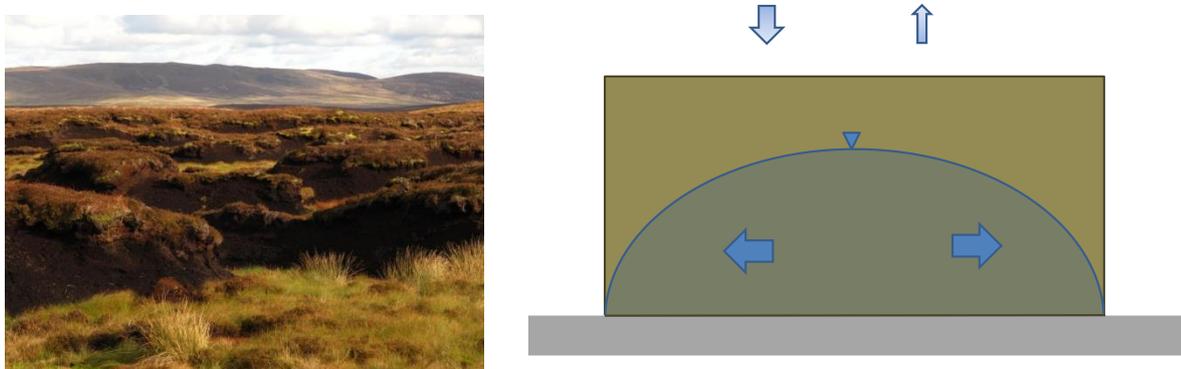


Figure 2. *The water balance of a peat soil.* Left: Peatland hagg at the Migneint in north Wales. Right: Cross section through an idealised hagg. Water drains to the margin of the hagg, causing a doming of the water table. Water is also lost from the hagg via evapotranspiration. The hagg's source of water is rainfall. Rainfall additions exceed evapotranspiration losses over annual timescales.

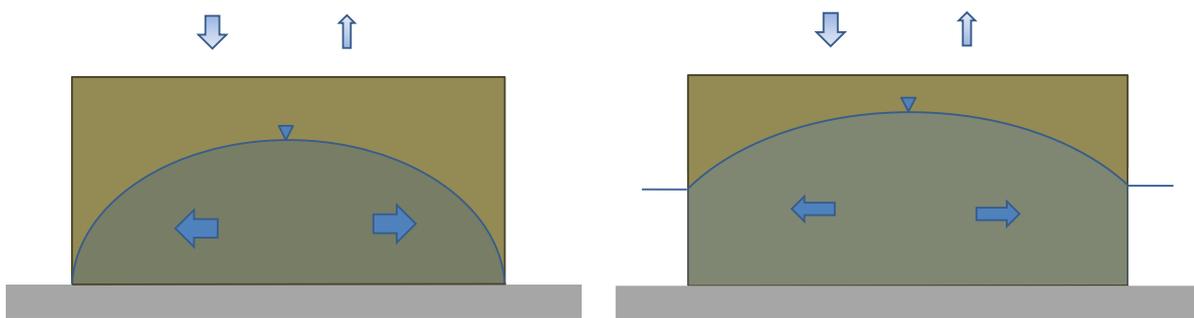


Figure 3. *The effect of raising water levels (the drainage base) in the gully surrounding a hagg on within-hagg water tables.* Left: Water mostly at the ground surface outside the hagg. Right: Water levels raised outside the hagg by gully blocking, causing a slowing of water loss from the hagg and higher water tables within the hagg.

DigiBog_Hydro is able to represent the situation shown in Figure 3 and also hydrological conditions in blanket peatlands where the peatland has been artificially drained with grips or restored through grip blocking. DigiBog can represent other types of peatland too, including raised bogs (whether in a natural or heavily-modified state).

1.2 DigiBog_Hydro's representation of peatlands

The situation depicted in Figures 2 and 3 can readily be simulated in DigiBog_Hydro. A hagg, or indeed any wider area of peatland stretching over distances of 100s m, is represented in DigiBog_Hydro as a set of contiguous columns of peat. These sit on top of underlying, non-peat material such as clay or rock, the surface of which may be flat or sloping in the model. The height of each column may vary to represent differences in peat thickness and variations in the height of the peat surface. Figure 4 shows how the model is set up for a single hagg.

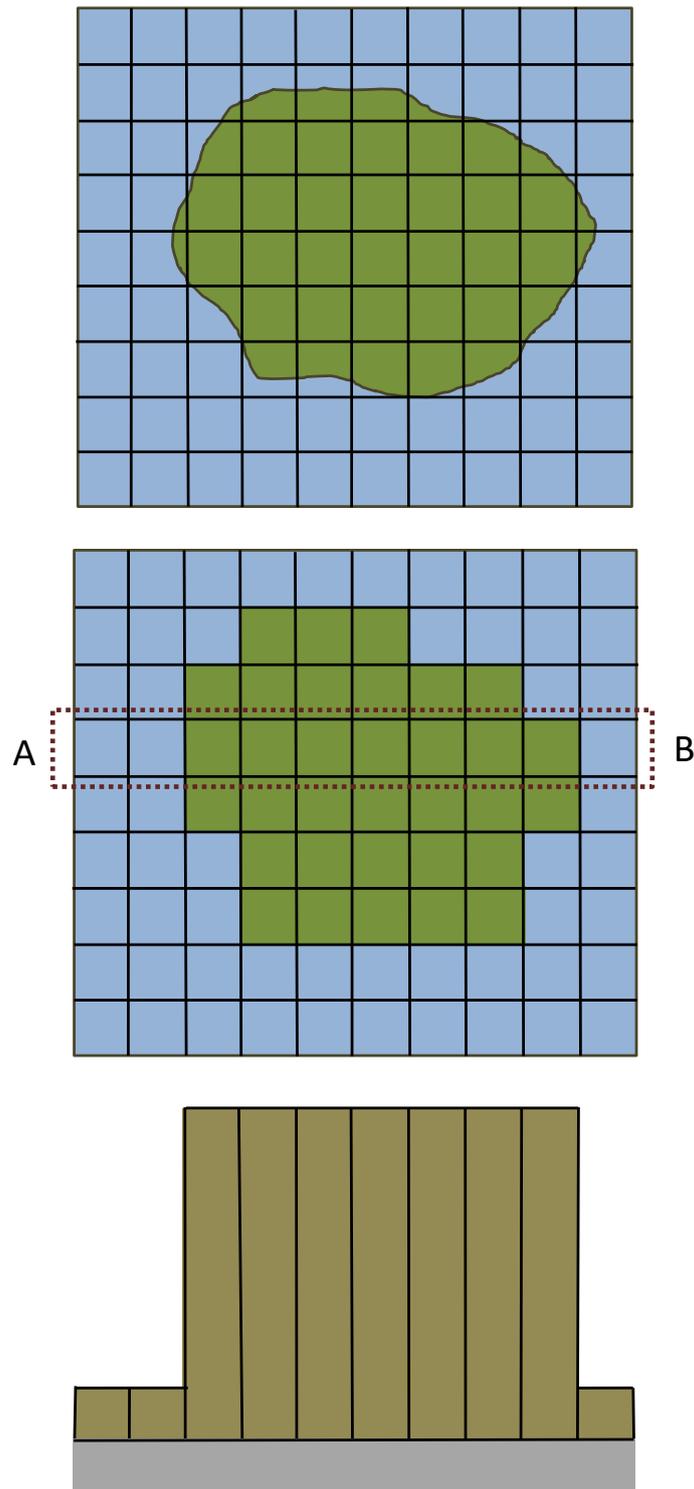


Figure 4. *Setting up DigiBog_Hydro for a single hagg.* Upper: Plan view of the area to be modelled. The top of the hagg is shown as green, while gully areas are shown as blue. The grid represents the surface of the columns of peat in DigiBog. In DigiBog, a column cannot represent more than one thing. Therefore, columns have to be 'declared' in the model as either hagg or gully bottom in this case. Middle: the digitised representation of the hagg and gully. Lower: cross section along line A-B (middle panel) showing height of the peat columns representing the hagg and gully. The surface of the hagg is shown as flat, but hagg surfaces are often sloping and such slopes can be represented in DigiBog_Hydro.

In the lower panel in Figure 4, the peat columns are shown as one colour, perhaps implying uniform peat properties with depth. However, in DigiBog_Hydro it is possible to represent changes in peat properties – hydraulic conductivity (K) and the drainable porosity (s) (see below) – with depth. For example, K and s may be higher near the peat surface. In DigiBog_Hydro such variation is accounted for by dividing a column into layers, each with its own properties. In fact, column heights are not separately prescribed in DigiBog_Hydro. The layers making up a column are specified by the model user, and the overall height of the column is the sum of the layer thicknesses. Of course, a column may comprise just a single layer, but it is common to specify three or more layers. Each layer has three properties: its thickness, its K and its s . This facility in DigiBog_Hydro means peat properties can vary with depth but also between columns; in other words, peat properties can vary in three dimensions across a peatland.

Those working in peatlands who do not have a background in groundwater hydrology mostly have a reasonable appreciation of what is meant by K . Loosely, when we talk of the hydraulic conductivity or permeability of a peat we know we are referring to the ease with which water can flow through it. K can vary greatly between different peat types and range from values typical of clay soils right up to values typical of gravelly soils. This variability is sometimes not appreciated; 'peat' is not a single soil type, it is a multitude of soil types.

The water table is a less well understood phenomenon. It is often referred to as the top of the saturated zone in an aquifer or soil. Strictly, however, the water table is an energy or pressure surface. It is the plane within an aquifer or soil where the water is at atmospheric pressure. This surface is sometimes called the free surface and it is the equivalent of the water surface of above-ground water bodies such as lakes and rivers. Above the water table many soil pores retain water; the soil is not completely dry. Only some of the pore space is empty or air-filled, and this part of the porosity is called the drainable porosity or specific yield. The pores making up the drainable porosity are those that need to be drained to cause the water table to fall, or filled to cause the water table to rise. Further complications include the situation where air or decay gases are trapped as bubbles in soil pores below the water table, and where there is a capillary fringe above the water table where the soil is saturated or close to saturated. However, these complications are not considered in DigiBog_Hydro, at least not in publicly-available versions of the model.

The drainable porosity is expressed as a proportion of the total volume of the soil. Therefore, a drainable porosity of 0.1 means that 10% of the total soil volume needs to be drained for the water table to fall, or filled for it to rise. A simple example can help clarify. Imagine a column of peat in which the water table resides at a depth of 30 cm, and in which the peat above the water table has a drainable porosity of 0.10. During a period of rain, 11 mm of water is added to the soil. If this depth of rainfall was added to a tank of water, the water level in the tank would rise by exactly the amount of rainfall: 11 mm. In the peat, only a small amount of the space above the water table – the pores that comprise the drainable porosity – needs to be filled for the water table to rise. Therefore, the water table will rise by more than 11 mm. In fact, because only 10 percent of the pore space needs to be filled, the water table will rise 10 times more than the depth of the rainfall: 110 mm or 11.0 cm, giving a new water-table depth of 19.0 cm. In peat soils, s can be quite variable, ranging from values of ~0.05 for well-decomposed or highly-humified peat up to 0.6 or even 0.7 for 'fresh' *Sphagnum* peat.

1.3 DigiBog_Hydro's key equation

To use DigiBog_Hydro to explore how water tables in a peatland respond to different meteorological conditions and to management interventions like the digging or blocking of a ditch, it is enough to understand that water flows in the model from where it is higher to where it is lower, and to have a basic sense of what is meant by K and s (as described above in section 1.2). However, those wishing to become expert users are encouraged to read up on the groundwater theory underpinning the model and to make the effort to understand the model's equations. Model users interested in knowing more about the theory behind the model are recommended Freeze and Cherry (1979) (particularly Chapters 2 and 5) for information on Darcy's Law, drainable porosity (specific yield), and the Dupuit-Forchheimer approximation for shallow groundwater flow.

DigiBog_Hydro is based on a simple finite-difference representation of a variant of the 2-D groundwater Boussinesq equation (see McWhorter and Sunada, 1977). The version of the Boussinesq equation used by DigiBog_Hydro is:

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x} \left(\frac{\kappa(d)}{s(d)} d \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\kappa(d)}{s(d)} d \frac{\partial h}{\partial y} \right) + \frac{P(t) - E(h, t)}{s(d)} \quad (1)$$

where h is water-table elevation (L – length (units such as metres)) above a datum, t is time (T – time (units such as seconds)), x and y are the distances in the (Cartesian) horizontal plane (L), d is the thickness of flow (that is, the local height of the water table above underlying (assumed impermeable) mineral soil, sediment or rock) (L), κ is depth-averaged hydraulic conductivity (K) below the water table (L T⁻¹), s is drainable porosity (proportion – dimensionless), P is the rate of rainfall addition to the water table (L T⁻¹), and E is the rate of evaporative (or transpirative) loss of water from the water table (L T⁻¹). Further details of the model and how it has been tested may be found in Baird *et al.* (2012).

Baird, A.J., Morris, P.J., and Belyea, L.R. 2012 The DigiBog peatland development model 1: rationale, conceptual model, and hydrological basis. *Ecohydrology* 5, 242–255, doi: 10.1002/eco.2. A pdf copy can be provided on request.

Freeze, R.A., and Cherry, J.A. 1979. *Groundwater*. Prentice Hall, Englewood Cliffs, New Jersey. A pdf is free to download at: <http://hydrogeologistswithoutborders.org/wordpress/original-groundwater-by-freeze-and-cherry-1979-now-available-online/>

McWhorter, D.B., and Sunada, D.K. 1977. *Ground-water Hydrology and Hydraulics*. Water Resources Publications: Fort Collins.

1.4 Working within boundaries

When using DigiBog_Hydro to represent hydrological conditions in an area, it is necessary to specify the area of interest, as in Figure 4 for example. All models like DigiBog_Hydro require information on what happens at the boundary of the modelled area. For example, if DigiBog_Hydro was used to represent the flow of water through a blanket peatland on a hillslope, it would be necessary to know what happened at the upslope boundary (often the hillslope divide) and what happened at the downslope boundary (often a river or gully). The model can predict or simulate what happens within its boundaries, but it requires the model user to specify what happens at the boundaries for it to work. In practice, two possibilities exist: (i) the user specifies a rate of water flow across the boundary, or (ii) the user specifies a water level just outside the boundary that the model then uses to calculate flow across the boundary.

The following example helps explain both types of 'boundary condition'. Figure 5 shows a representation within DigiBog_Hydro of a blanket peatland on a hillslope. The model extends from the hillslope divide (the catchment boundary) to the base of the slope in which there is a river. By definition, water does not flow across the hillslope divide. Therefore, the boundary condition here is a flow boundary condition where 'flow' is specified as zero. Boundary conditions in which flow is specified (including zero flows) are known as a type of Neumann boundary condition, named after a German mathematician. At the base of the slope, water flows from the peatland into the river. This could also be represented as a Neumann condition by the model user, but they would have to 'guestimate' a sensible value of flow between the peatland and the river. A better option is for the user to specify the river level, and to let the model calculate the rate of flow between the peatland and the river (this rate will depend on the difference in height between the water table in the model column next to the river – which can change – and the river water level). When the user specifies a water level on the model boundary rather than a flow across a boundary it is known as a Dirichlet boundary condition (after a French mathematician). In all models like DigiBog, boundary conditions are specified for, or 'attached' to, 'imaginary' boundary cells. These are shown in Figure 6 for the hillslope represented in Figure 5.

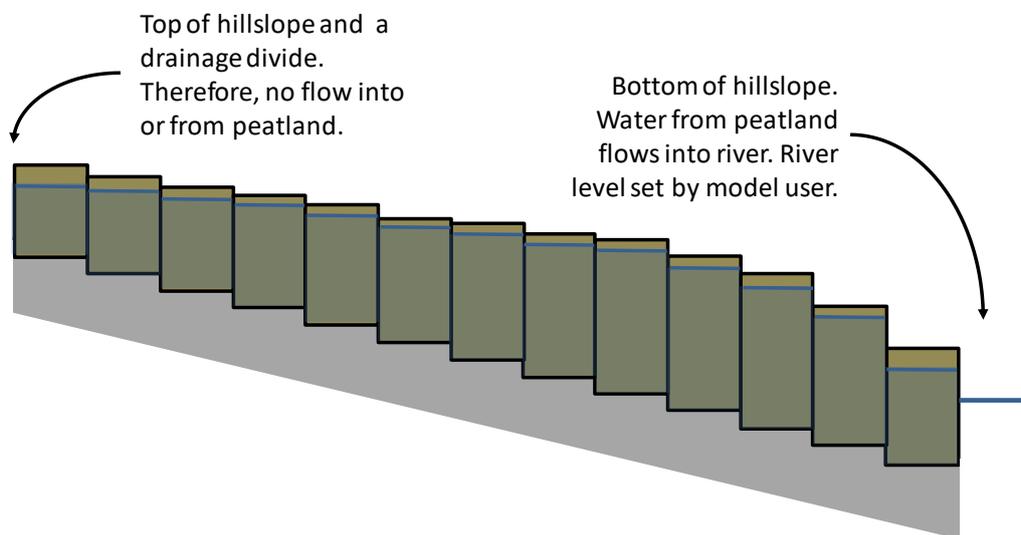


Figure 5. The domain of a DigiBog_Hydro representation of a blanket peatland on a hillslope.

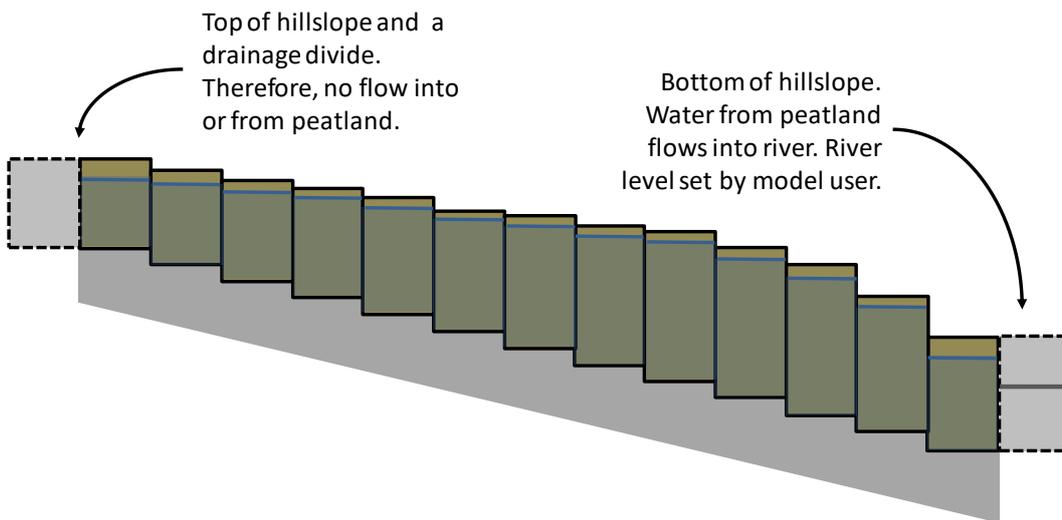


Figure 6. The domain of a DigiBog_Hydro representation of a blanket peatland on a hillslope, showing the boundary condition columns or cells.

1.5 Representing restoration measures in the model

Simulating the restoration of ditch drains or gullies is done in two ways in DigiBog_Hydro. These two ways are identical in how they simulate the various types of dam; the difference between them arises in how the user wishes to simulate the build-up of water behind the dam. The user should decide where they would like to place their dams and what type of dam they wish to simulate. It is possible to simulate impermeable dams or permeable dams made from materials such as stone. The type of dam is chosen from the layer properties file – the user can use pre-specified dams or create one of their own (as explained in section 2). Dams are placed in the landscape by changing the type of column (its class) in one of DigiBog_Hydro's input files (see section 2).

How the peat columns behind a dam are treated depends on the type of dam being simulated and how the user wishes water to pond around the dam. In DigiBog_Hydro all columns are topped by a 'ponding layer' that is specified by the user and is the same for all columns in a simulation. The ponding layer sets the depth to which water can pond on the peatland surface before it is lost to the model boundary via assumed overland flow (which is not explicitly modelled). The first and simplest option for representing a dam is to leave the prior ponding depth unaltered – that is, to leave the ponding depth the same as that used in the unrestored simulation before the dams were added. Details of how to specify the ponding layer are provided in section 3. The user should, however, consider how this default setting will apply to their restoration simulations. For example, if the top of a modelled dam is 100 cm above the height of the cells immediately upstream of it and the ponding depth is set at 25 cm, water will not be able to pond to the level of the top of the dam in these upstream cells (Figure 7). Sometimes this is what a user intends – indeed it is often what is observed in the field where dams are relatively low in height or permeable (leaky). The obvious limitation to this approach is that it cannot be used to simulate the creation of deep ponds behind dams and their effect on the water tables in adjacent peat columns representing hagsgs, for example (see Figure 3 for how this might work).

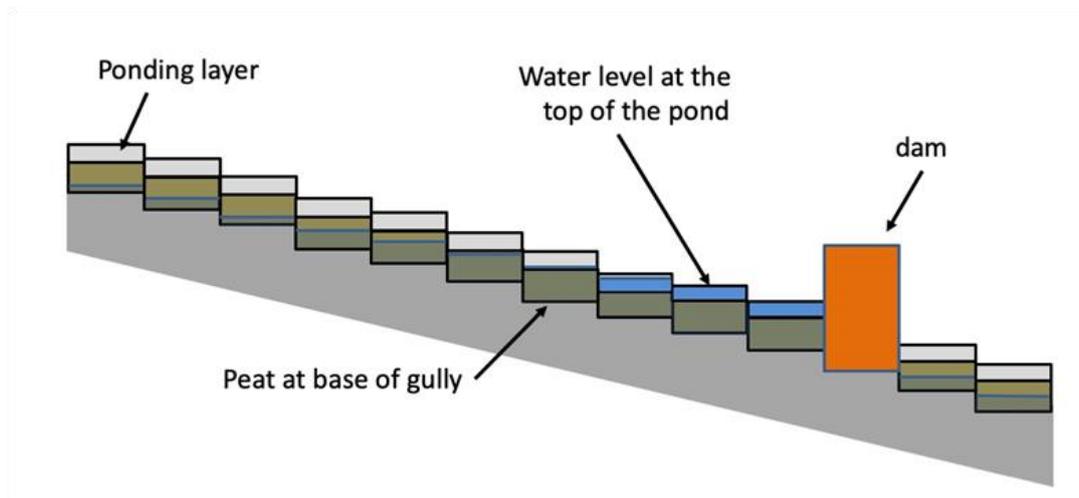


Figure 7. *Simulating a dam in a gully (in long section).* In the cells upstream of the dam, the above-ground water level is limited to the top of the ponding layer, forming a somewhat unrealistic strongly-sloping water surface. Any water above the top of the ponding layer is lost from the model domain.

It is possible to alter the ponding depth so that it is thicker, but this still doesn't address fully the problem shown in Figure 7. For example, the ponding layer could be set to 100 cm to allow a deeper pond (or pool) to be created upstream of a dam. However, as noted above, this would mean that a 100 cm layer would be applied to all columns in the simulation, potentially causing rainfall to be stored in excess across the peatland's surface (and not just behind dams), rather than being lost to the model boundary via overland flow.

A better alternative is to modify the columns upstream of the dam so that they have a 'peat' layer that mimics a flexible or variable ponding layer. Figure 8 shows how this works. Upstream of the dam the cells are altered to have this new layer that mimics above-ground conditions; it has a high permeability and a drainable porosity close to 1 (see Table 2 in section 3). The effect is that water can pond to different *depths* in the cells upstream of the dam, to give a single ponding *height* that is the same between cells. In all other cells away from the dam, the ponding depth can be maintained (25 cm in the above example). Using this 'mimicking' approach, it is possible to simulate deep ponding behind dams and, for example, the situation shown in the right-hand side of Figure 3.

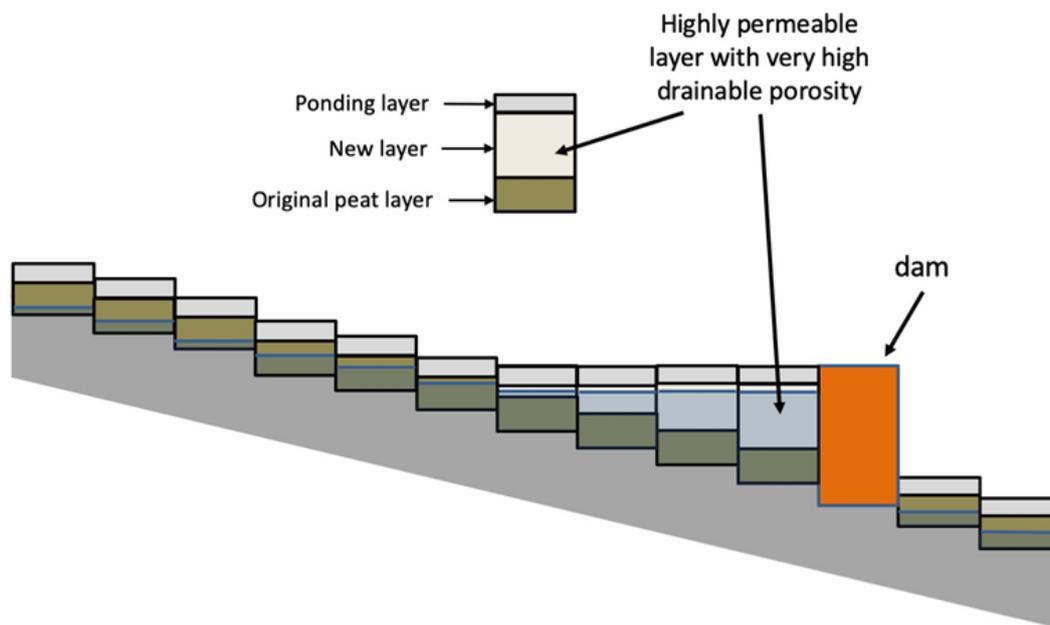


Figure 8. Alternative method for simulating a dam in a gully using an upper layer that mimics the peatland surface. Adding a highly permeable layer with a high drainable porosity simulates the creation of a deeper pond behind the dam while allowing all other columns to maintain the ponding depth used in any pre-restoration simulations.

1.6 What values of K and s should be used to represent blanket peatlands?

Any simulation using DigiBog_Hydro will be of a 'toy' version of a landscape. Unless detailed measurements of K and s are made across the area being simulated, the model will only ever provide a relatively simple approximation of the hydrological functioning of the area. This can still be very useful, however, when comparing management interventions, and when investigating how particular management scenarios might 'play out' under a changing climate. For example, provided a model setup is used that produces water-table depths within reasonable ranges for a site, it will be possible to use the model to compare the hydrological efficiency of different restoration scenarios. In this situation, it may be found that ditch blocking at 5-m intervals is barely more effective at raising water tables in the peatland than dams every 10 m, in which case a management decision may be made to opt for the considerably cheaper 10-m interval.

It can be difficult to know what K and s values to use in a simulation. K can vary enormously between different peat types (see section 1.2), but little work has been done on the K of blanket peat, and there is a dearth of published data that can be used as a guide. Therefore, as part of the Optimal Peatland Restoration project on iCASP, we commissioned the University of Manchester (UoM) to undertake a K survey of blanket peat near to (proximal, within 0.5 m), and far away from (distal, 10 m), gully walls in a hagged peatland in the Peak District (Upper North Grain). The UoM team measured K at six sites (three proximal and three distal) and at six depths at each site. At each measurement point, replicate tests were done. A large data set of K values was generated, which has been distilled into some advisory ranges in Table 1. Table 1 also includes some suggested values of s , based on expert judgement from the authors.

Table 1. Ranges of suggested K and s values to use in simulations of blanket peatlands. The higher proximal values in the upper peat may reflect cracking of peat at this location on the upper part of the gully wall.

Part of peat profile	Hydraulic conductivity, K (cm s^{-1})	Drainable porosity (s)
Upper 5 cm	0.0005 – 0.2 (proximal) 0.0002 – 0.0015 (distal)	0.3 – 0.5
5 – 10 cm	0.000015 – 0.0018	0.2 – 0.3
20 – 30 cm	0.000015 – 0.0007	0.1 – 0.3
50 – 140 cm (and deeper)	0.000001 – 0.00016	0.05 – 0.1

It is recommended that the upper end of each range is used in a 'first pass' simulation of any area. If this appears to give a peatland that is too dry (very deep water tables) then start to move down through the suggested range.

2. Using DigiBog_Hydro: creating the setup files

There are five files that are required to use DigiBog's graphical user interface (GUI) to set up a simulation:

- the surface DEM file (*.asc)
- the basal DEM file (*.asc)
- the layer classification file (*.asc)
- the layer properties file (*.csv)
- a time series of net rainfall (*.txt)

These files should be placed in the current simulation directory (folder) (all other files needed to run the simulation and the outputs will be placed in this directory when the model runs). Note that * is a wildcard for the filename.

The first three files describe the configuration of the landscape to be simulated. The surface DEM describes the surface topography of the peatland and the basal DEM describes the 'topography' of the base of the peat, which in DigiBog_Hydro is assumed to be an impermeable rock or sediment such as clay. While it is relatively common to have a detailed surface DEM (for example, from a LiDAR or drone survey), information on the position of the base of the peat is often patchy. The classification file contains information on the properties of each column in the peatland, in particular the hydraulic conductivity and drainable porosity (K , s) (see sections 1.2 and 1.4 and below). These three files must be identically formatted matrices that refer to the surface, base, and type of peat for each column in a simulation. Irregularly shaped peatlands can be simulated in DigiBog_Hydro, but, in this case, these three input files must still contain matching matrices (see discussion of 'off' cells at the end of this section).

Each of these three files is created or exported from GIS software as an ascii file, via 'Save Layer As' -> '*.asc', or similar method, depending on the GIS software package being used. Each file is made up of space-separated values, where each value represents one $1 \text{ m} \times 1 \text{ m}$ cell from a DEM raster. There should be no spaces at the start of each line, and any metadata should be removed from the top lines of this file. Note that it is possible to use other spatial resolutions if a $1 \text{ m} \times 1 \text{ m}$ grid cannot be obtained as discussed in section 4.

All three of the files must 'line up' exactly (see Figure 9) and refer to precisely the same area of a landscape. It is recommended that they are all exported from the GIS at the same time, where a copy of each is made by clipping the 'master' copy of the GIS data by the same square shape, for each file. If the files do not line up, it is likely that the simulation will give erroneous outputs or fail to run altogether.

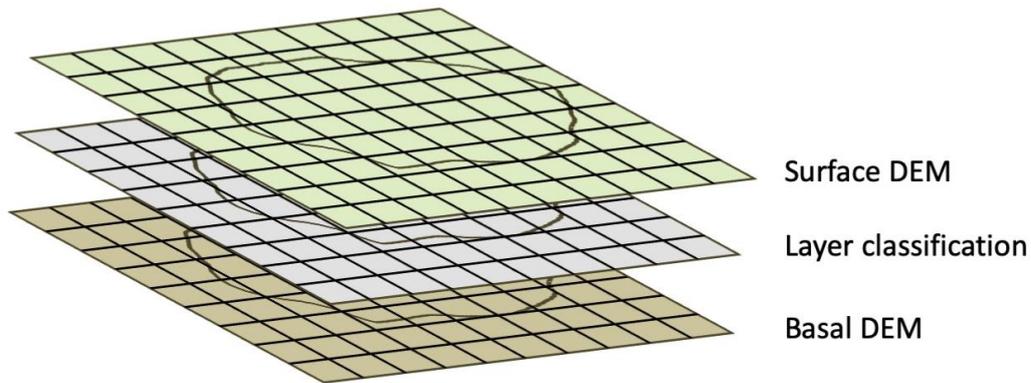


Figure 9. The three files that specify the top, bottom, and properties of each peat column in a simulation. As shown here, the three files line up exactly.

Units for the surface and basal files should be in metres. For example, the contents of the following file would represent a 5 m × 5 m grid area, with altitudes between 560 m and 600 m.

```
562 591 589 580 598
566 588 594 562 584
561 572 571 581 574
562 588 563 582 576
577 596 593 598 582
```

The classification file contains one 'class' integer per cell, where each class represents the soil conditions to be applied to that cell in the simulation. Different classes may represent different peat types, or a class could be used to represent a particular restoration method such as a dam. The class file also includes boundary conditions for the model. Classes are broken up into group numbers of a 100, as described in the table below.

Table 2. Classes used in DigiBog_Hydro to represent different peat types and model boundary conditions.

Class number(s)	Example	Description	Use
0	0	Represents an 'off' cell. See explanation below this table.	A cell which will not be used in the model simulation.
100s	101, 102, ..., 199	Represents a boundary condition in the model.	Used as a boundary condition usually at the edges of the simulation area.

200s and 300s	201, 202, ..., 399	Represents a class of peat soil conditions.	Used to describe a certain condition of peat soils: less decomposed and more permeable peat; more decomposed and less permeable peat; etc.
400s	401, 402, ... 499	Represents a restoration method on top of some peat.	Used to represent some method of restoration in the simulation; for example, a section of dam.

The exact values that each of these classes represent are covered in more detail above in section 1.6 and below in section 3.1. However, it is worth noting briefly here what is meant by an 'off' cell (class 0). Figure 10 shows a very simple domain for the model. From left to right, it shows in plan eight columns, denoted 'on'. These represent a strip of hillslope from the hillslope divide (left) to a river at its base (right). The hillslope divide is represented by a Neumann zero-flow condition, denoted 'neu'. At the base of the slope, a user-defined water level is set; as noted in section 1.4, this is a type of Dirichlet condition and is denoted 'diri'. The strip of 'on' columns follows the gradient, so it is also assumed there is no lateral hillslope flow, and this is ensured by having neu cells either side of the 'on' cells. Altogether, there are 26 cells needed for the simulation (eight 'on' cells, and 18 boundary cells). However, DigiBog_Hydro requires that all model domains are square or rectangular in shape – that they are matrices (see above, this section) – which leaves four corner cells as shown in Figure 10. These must be included in model input and output files, but, because these are unused, they are denoted as 'off'. This designation means that the part of the model that calculates water flows between cells ignores them.

In practice, most model domains used in DigiBog_Hydro have an irregular shape, that has to be set within a rectangle or square, so more complicated patterns of boundary and off cells are the norm.

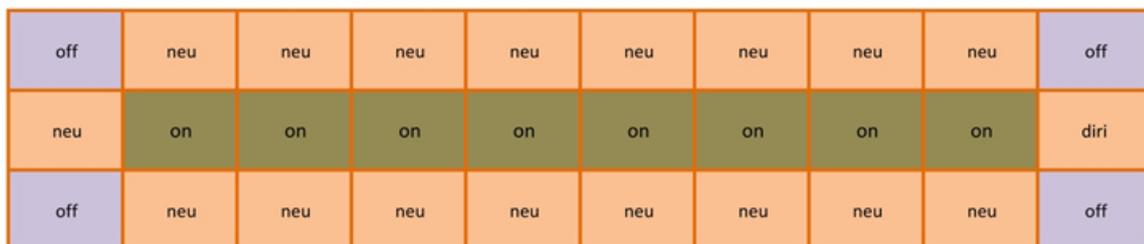


Figure 10. A simple DigiBog_Hydro setup showing 'off' or unused cells. The figure shows a peatland in plan view (looking down).

A tutorial about how to create the three GIS-generated input files (surface, base and layer classification) can be found at the end of this manual in the Appendix.

3. Using DigiBog_Hydro: using the graphical user interface (GUI)

When first opening the DigiBog_Hydro GUI, the user is presented with a window (Figure 11) containing two options: **GIS Setup** for model setup, or **Model Outputs** for creating some water table outputs from simulations that have already been run.

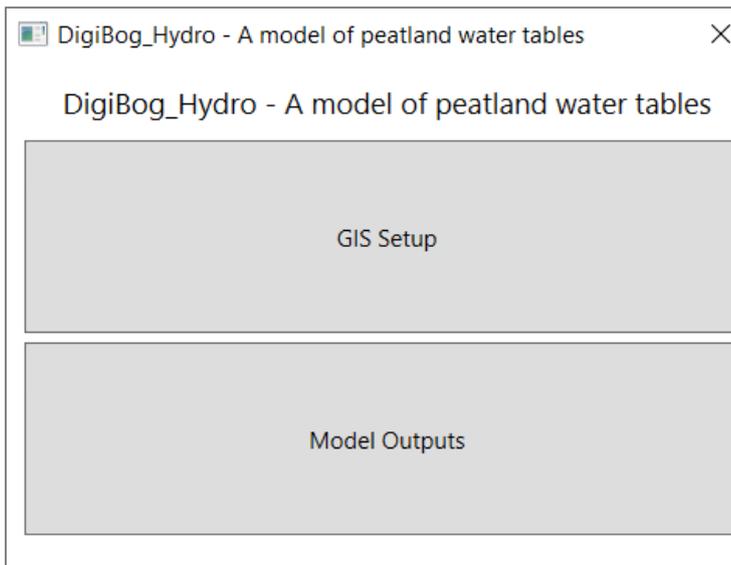


Figure 11. The opening window in the DigiBog_Hydro GUI.

3.1 Setting up and running a simulation in the GUI

If the **GIS Setup** option is selected, a simulation setup window will appear as shown in Figure 12. In this window there are two buttons to the right, and a central panel through which the user sets up their simulation. **Clear All Fields** will reset the options in the central panel, while **Close** will close the setup window and return to the main menu (Figure 11).

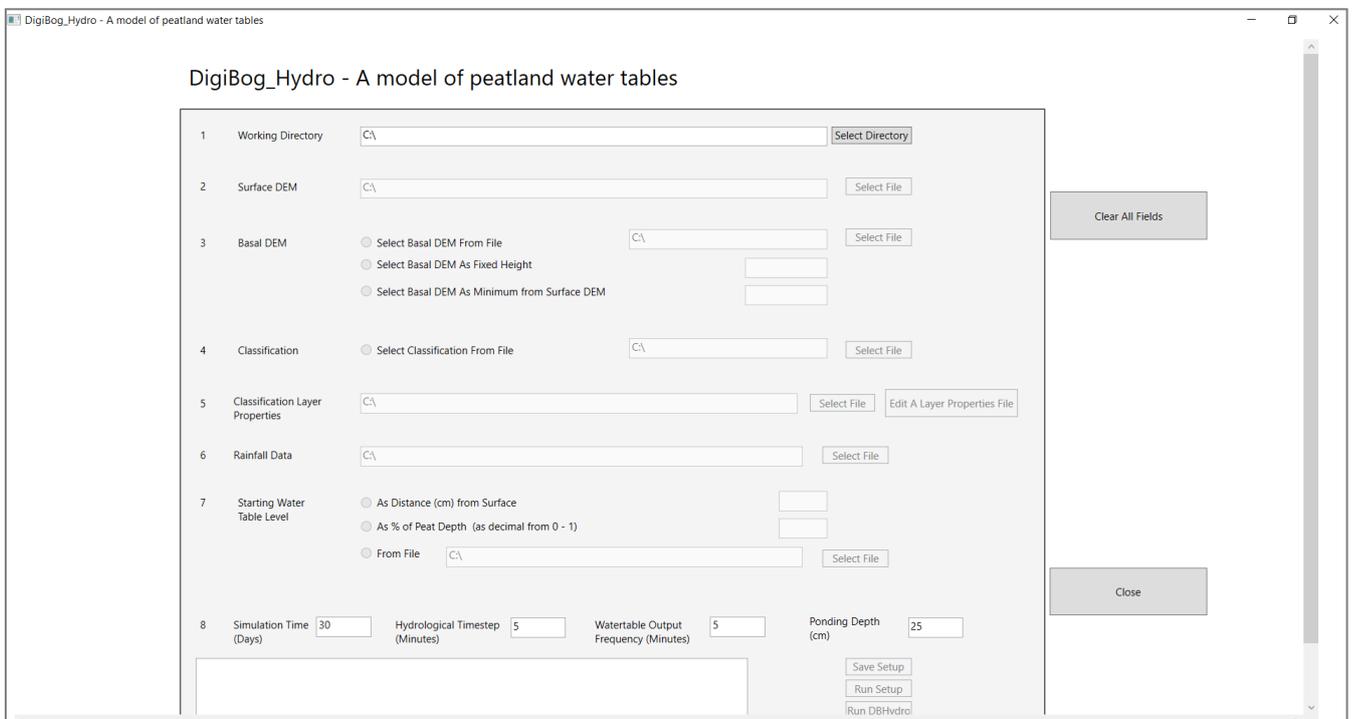


Figure 12. The model setup window in the DigiBog_Hydro GUI.

In the central panel of the setup window, each of the steps 1-8 must be completed in turn. For example, it is not possible to choose options on step 2 before step 1 is completed; this requirement prevents key steps from being missed. Instructions for each step are given below.

Step 1: Working Directory

Click the **Select Directory** button and then choose the directory (folder) in which the simulation will be saved (this is the current simulation directory). It is a good idea to have a separate directory for each individual simulation. For example, a 'master' folder called 'DigiBog_Hydro_Simulations' may contain within it the folders for a number of simulations called 'My_First_Simulation' and 'My_Second_Simulation' and so on.

Step 2: Surface DEM

Click **Select File** and choose the surface DEM file to be used for the simulation; this is the *.asc file exported from the GIS (see section 2).

Step 3: Basal DEM

For most uses, choose **Select Basal DEM From File**, and choose the basal DEM *.asc file to be used. Options are also given for using a basal DEM of fixed altitude (for example, 550 m across the whole area to be simulated) (**Select Basal DEM As Fixed Height**) or using the **Minimum from Surface DEM**, which produces a basal DEM of fixed height using the minimum value of the surface DEM (Step 2). These two options may be infrequently used, but are useful to have when simulating idealised shapes and scenarios or comparing different peat types, where a variable basal topography is not required.

Step 4: Classification

Click **Select Classification From File**, and then select the classification *.asc file in to be used for the simulation.

Step 5: Classification Layer Properties

The classification layer properties file assigns specific properties to each of the classes being used in the simulation; the classes are specified in the classification *.asc file (Step 4). For example, a class denoted as 201 in the classification file (see Table 2) may comprise two layers of peat of 20 and 80 cm thickness, with the K and s values in each layer, respectively, as follows: 0.001 cm s⁻¹ 0.3, and 0.00001 cm s⁻¹ 0.2.

It is strongly recommended that the five input files are placed in the current simulation directory, and that any editing of the classification layer properties file is done before running the DigiBog_Hydro GUI. The classification layer properties file can then be selected from the current simulation directory when required during the simulation's set up.

However, it is also possible to select the classification layer properties file from a previous setup or to edit a file within the GUI. To select a properties file from a previous setup, click **Select File** and choose the 'layer_props.csv' file from the desired location (the directory from a previous simulation). Alternatively, to make changes to a layer properties file, select **Edit a Layer Properties File**. This will open a new window (Figure 13), showing either the current properties (if a layer_props.csv is present in the selected working directory), or some properties from a base template. From here, the **Select** option can also be used to load a previously-used layer_props.csv file, amend its values, and save the file. If additional classes are needed, it is best to amend the *.csv file directly, either in a spreadsheet package such as Excel or a text editor. In this fashion, it's possible

to add additional classes as well as increase the number of Layer_n columns (Figure 13), but, in doing this, it is important any required fields are not removed, and that the correct names are used in the 'Property' column (Figure 13). Any fields without a set value must contain 'NA' as shown in Figure 13.

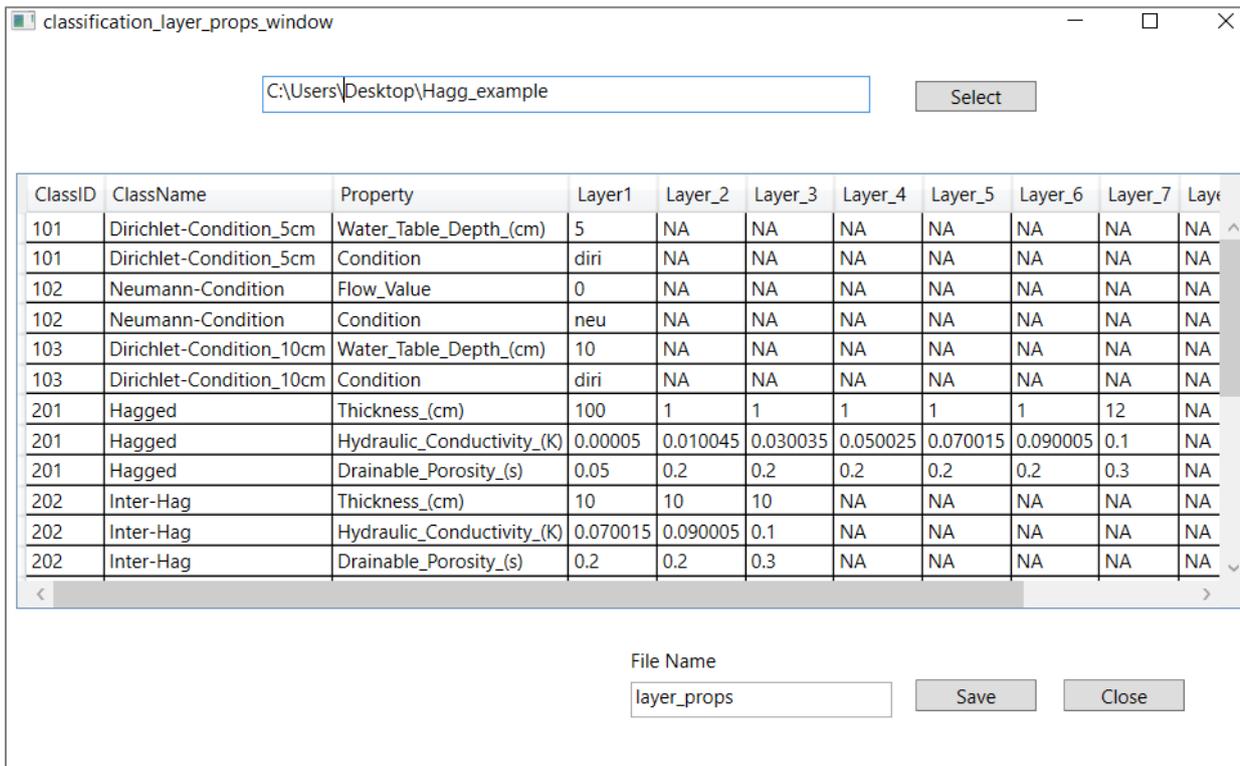


Figure 13. Updating the classification layer properties.

In the file, 'ClassID' (Figure 13) refers to the class used in the classification file (see section 2). It links the properties found in this table to the classes for each cell that will be used in the simulation. Each class has two or more rows assigned to it. The two types of boundary condition ('100' fields) state whether the class represents a flow (Neumann-Condition) condition or a water level (Dirichlet-Condition) as described in section 1.4. They also show that the flow is zero for the Neumann condition used in DigiBog_Hydro and give a water-table depth (below the surface) for the Dirichlet condition. All other classes represent peat columns and include three rows of data: 'Thickness_(cm)' (the thickness of a layer making up part of a column of peat), 'Hydraulic_Conductivity_(K)' (the hydraulic conductivity (K) of a layer), and the drainable porosity (s) of a layer ('Drainable_Porosity_(s)'). The ClassIDs must match across all the rows that relate to a class to correctly assign the properties. 'ClassName' (Figure 13) is simply a descriptive field to keep track of what particular classes are for, and should be named according to their associated properties.

The 'Property' field contains one of six values as shown in Table 3.

Table 3. Explanation of Property field values used in the layer properties file.

Property	For class:	Units	Use
Water_Table_Depth_(cm)	Dirichlet-Condition	cm	Prescribes a water table to a boundary condition. Only Layer_1 is required (all else should be 'NA')
Condition	*-Condition	diri / neu	Sets this class as either a Dirichlet or Neumann boundary condition
Flow_Value	Neumann-Condition	cm ³ s ⁻¹	Prescribes flow across the boundary as zero (in the current version of the model)
Thickness_(cm)	Peat Properties	cm	Thickness of each layer in the class
Hydraulic_Conductivity_(K)	Peat Properties	cm s ⁻¹	Hydraulic conductivity of each layer in the class
Drainable_Porosity_(s)	Peat Properties	Pore space as a proportion of the total volume of the peat in the layer (0 – 1)	Drainable porosity of each layer in the class

As noted above, the '100' field classes (Figure 13) are used for boundary conditions, and properties for boundary conditions are entered into the Layer_1 column.

The '200' and '300' field classes (Figure 13) represent peat columns and contain the three layer properties required by the model. Any of these classes should have at least one layer, and the changes in values from layers 1 to n should represent the changing properties going up from the bottom to the surface of the peat column, where Layer_1 is at the base of the profile and Layer_n at the top. When the setup script runs, it attempts to assign thicknesses as close as possible to the thickness properties specified in the layer properties file. However, if the overall peat thickness specified by the DEM (that is, the difference between the surface and basal DEM files for a specific cell/column) is less than or greater than the sum of all layers for the assigned class, the layers' thicknesses will be adjusted. If less than, all the layers will be reduced proportionally so that they fit the DEM-specified thickness. If greater, then Layer_1 (the basal layer) will be expanded to fill the difference in thickness between the sum of the layers and the DEM.

Restoration classes are identified with a '400' field. These work similarly to peat classes, except they usually contain only two layers, so that a dam 'sits' on the original material specified for that area of the landscape in the classification file. For example, if creating class '401' as an entirely impermeable dam that is 200 cm in height, Layer_2 (the upper layer) is set to a thickness of 200 cm, with K and s both given a value of 0. Layer_1 is then assigned, by the user, the same properties used for that location in the pre restoration simulation. Layer_2 will be the majority of this class, while Layer_1 is used to 'fill' spaces (if any), so that the thickness of the dam plus the peat corresponds exactly to the difference between the surface and basal DEM files.

Step 6: Rainfall Data

DigiBog_Hydro is 'driven' by rainfall and evapotranspiration (see the last term in equation (1) in section 1.3). Rainfall is treated as an addition to the model, and evapotranspiration as a loss (see also Figures 2 and 3). Therefore, rainfall additions will cause water tables to rise (move nearer the ground surface, or even to rise above it) and evapotranspiration will cause them to fall. DigiBog_Hydro does not require separate values of rainfall and evapotranspiration. Instead, it uses *net rainfall* which is the difference between rainfall and evapotranspiration ($P - E$ using the notation in equation (1) in section 1.3). Net rainfall is expressed in the model as a rate in cm s^{-1} , which applies for one day at a time. So, for example, if there was 1 cm of rain on a particular day and 0.3 cm of evapotranspiration, net rainfall for the day would be 0.7 cm. This is then expressed as a rate that applies for the duration of the day: $0.7 \text{ cm} / 86400 \text{ s (in a day)} = 0.000008101 \text{ cm s}^{-1}$. Click **Select File** and choose the required rainfall data file. This is a simple text file, where each line contains a daily rainfall rate, in cm s^{-1} . If your simulation is 30 days in length, you should have at least 30 lines of data in this file. Note that net rainfall will be negative if precipitation is less than evapotranspiration.

Step 7: Starting Water Table Level

For the model to run, it needs an initial condition – a starting condition – and this is the position of the water table relative to the ground surface. There are three options in the GUI for the starting water table level in the simulation:

As Distance (cm) from Surface

This option sets the water-table depth everywhere at a set distance below the surface. For example, if a '0' is entered, the peat is initially fully saturated.

As % of Peat Depth

This option requires the user to specify a value between 0 and 1 that sets the starting water-table position at this proportion of the peat's thickness, for each cell. For example, a value of 0.25 for a cell of thickness 100 cm would mean a starting water-table depth of 75cm.

From File

For this option, use **Select File** to choose a file containing the starting water-table level for each cell. It is important to note that the values in the file should be expressed as water-table heights above the base of the peat profile, and not as water-table depths.

Step 8: setting the model parameters

Some additional information is required from the user for the model to run, as follows:

Simulation Time (Days)

This is the number of days to be simulated in a model run (it is not how long the model takes to complete a run, which is much less).

Hydrological Timestep (Minutes)

This is the interval used by the model in its hydrological flow calculations. To solve equation (1) in section 1.3, the model divides time into a series of discrete chunks or timesteps, and for each of these it works out flow between the model cells. If too large a timestep is used, the model may become unstable and its solution may fail. Five minutes is a sensible maximum timestep to use, while 1 minute should provide a stable solution even for quite extreme model setups. Please refer also to Section 4.

Watertable Output Frequency (Minutes)

This is the interval at which the water-table levels (for all cells in the model) are written to file. It is recommended that this is longer than, and not the same as, the hydrological timestep; otherwise, especially if large areas are simulated, an enormous amount of data will be produced by the model. A typical, and useful, output interval is one day (1440 minutes).

Ponding Depth (cm)

This is the height above the peat surface (from the surface DEM) that water is allowed to 'pond' to, before it is considered to be lost as surface runoff (see section 1.5).

Once Steps 1-8 have been completed, click **Save Setup**, **Run Setup** and **Run DBHydro**, each in turn. At each step, the model notes, via a popup window, that the process is running, and the user will know it has completed the task when the popup disappears, and when notified in the text box to the left-hand side of the buttons. Any error messages will also appear here. **Save Setup** saves all the parameters and files from Steps 1-8 to the working directory (chosen in Step 1). **Run Setup** runs the setup script, creating all of the necessary model files, from the parameters and files saved during Steps 1-8. **Run DBHydro** will run DigiBog_Hydro.exe, also using the parameters and files saved during Steps 1-8.

3.2 Looking at the results from a simulation in the GUI

After completion of a model run, a user should go to the main window and select **Model Outputs** (Figure 11). In the model's output window there are two panes (Figure 14): the top pane for generating water-table depth graphs and statistics for a single simulation, and the bottom pane for generating water-table depth comparison graphs between two contrasting scenarios (of the same site, pre- and post restoration for example, or for two different restoration scenarios).

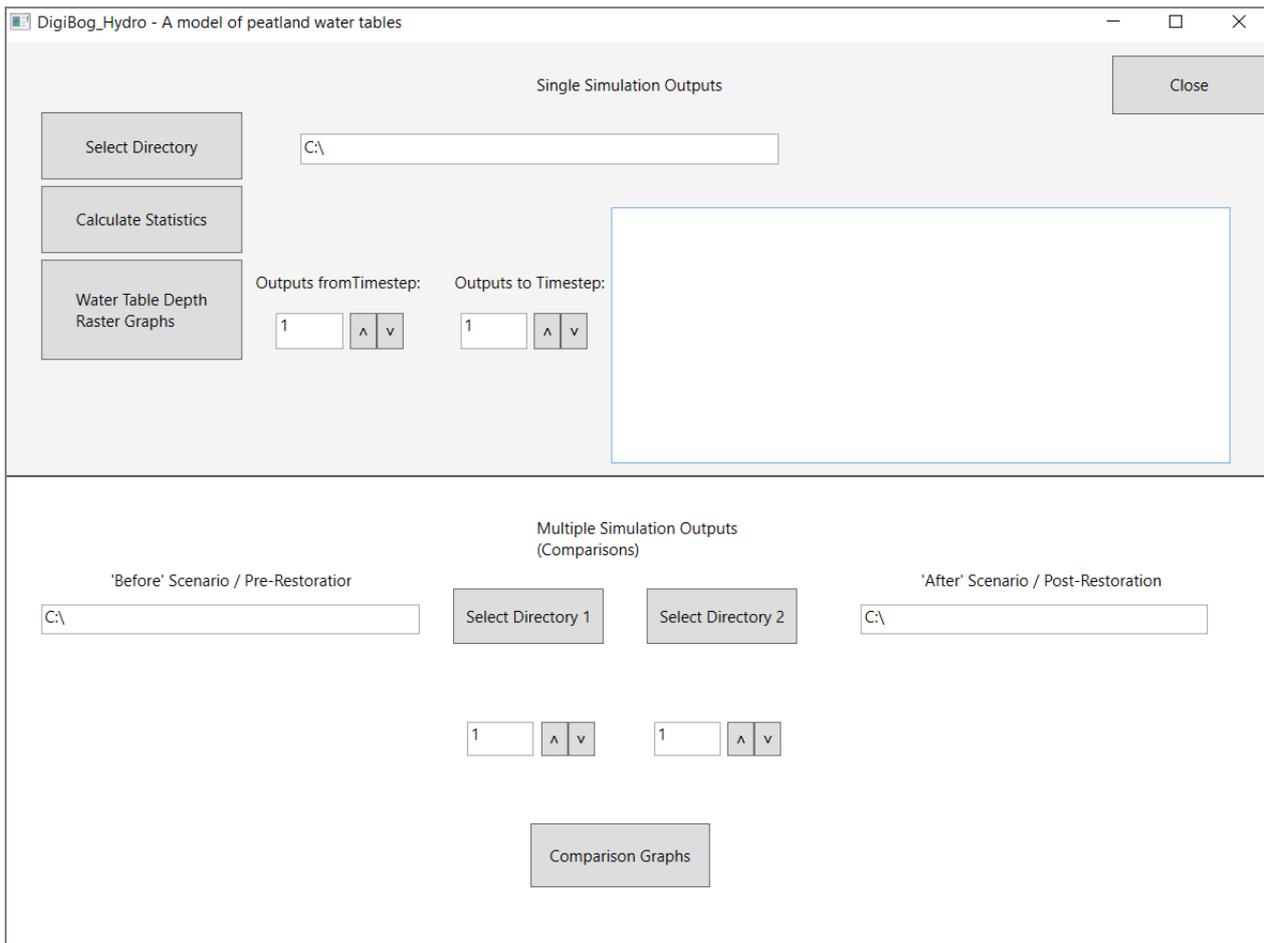


Figure 14. *DigiBog_Hydro's output window.* Note that 'Timestep' in the above window refers to day number of the simulation.

For the single simulation outputs, click **Select Directory**, and choose the directory in which the simulation is stored. This is the same directory as selected in Step 1 of the simulation setup (see beginning of section 3.1). Clicking the **Calculate Statistics** button generates a small *.csv file in 'Directory/Outputs', with some statistics including water-table depths for each class type (Tables 2 and 3) averaged over the simulation. The **Water Table Depth Raster Graphs** button generates a graph for each output interval in the simulation. Using the **from/to Timesteps** boxes control the number of graphs produced.

The lower panel works in much the same way as the upper panel, except that the user identifies two simulations to be compared.

The GUI has been designed to produce both spatial and temporal plots of peatland water tables. The temporal plots will automatically adjust to show the water tables for additional peat classes. Outside of the GUI, the model produces detailed outputs containing water-table depths for every model cell for every output interval. The file – hydro_wt_output.txt – is saved in the current simulation directory and is formatted as a single column of data. Using the x and y coordinates of each column for each time step, the user can reconstruct the spatial plots so that they can be imported into a GIS program and displayed on a map. To ensure that the water table outputs from a simulation correspond to the correct location in the landscape, it is important to follow the format shown and described below.

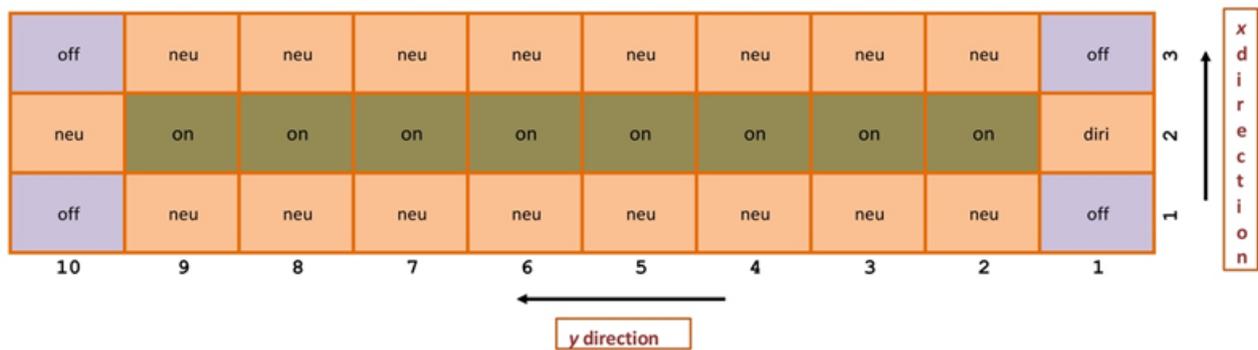


Figure 15. *x and y indexing for the simple model set up shown in Figure 10.*

Figure 15 shows the example discussed at the end of section 2. It represents a down-slope transect of peatland. In the version of the figure shown immediately above, the *x* and *y* indexing is also shown. DigiBog_Hydro writes out water-table depths as a single-column text file in the format: *x1,y1, x1,y2, ..., x1,yn; x2,y1, x2,y2, ... x2,yn* etc. Note that 'off', 'diri', and 'neu' columns are written out as -999.0. Hence, the output file for the above set up would start with 10 values of -999.0 for the row *x1,y1* to *x1,y10*. The column of water-table depths would then continue with row *x2,y1* to *x2,y10* which would start with -999.0 for the 'diri' cell at *x2,y1*, followed by eight values for the water tables in cells *x2,y2* to *x2,y9* and a single -999.0 for the 'neu' column at *x2,y10*. Row *x3,y1* to *x3,y10* repeats the first row. Therefore, if the above landscape was run for a year and the water tables were written out every day, there would be 365 days × 30 cells equalling 10,950 items of data written to the file *hydro_wt_output.txt*, each occupying a separate row in the single-column file.

4. Troubleshooting: hints and tips

There are few error messages produced in the current version of the DigiBog_Hydro GUI. If the model fails to run, appears to hang, or produces outputs that are not 'right', the following should be tried.

- Are there spaces in the file path? Filenames and directories should not contain spaces. For example, use 'My_simulation' and not 'My simulation'.
- Are the boundary condition water levels higher than the adjacent peat columns? This configuration will cause water to flow *into* the model domain rather than drain *out* from it and may cause model instabilities.
- Do the input file matrices align correctly? Check the surface, base and layer classification files are aligned. Use a text editor (for example, Notepad++ or similar) to check these files, not a word processor because the latter may leave (hidden) formatting information in the file.
- Are the three input files generated from GIS specified as matrices (that is, ensure they are not irregularly shaped)?
- Are the three input files generated from GIS identically formatted (for example, does one contain more spaces between the values than the others)?
- Does the spatial resolution of the input files equal 100 cm × 100 cm? DigiBog_Hydro does not detect the spatial resolution of the input files but sets it to 100 cm. If using a different resolution (for example, 200 cm × 200 cm), the *hydro_parameters.txt* file must be edited. During the setup of the model, clicking **Run Setup** will generate the files DigiBog_Hydro requires to run. These files are placed in the current simulation directory: here you will find

the hydro_parameters.txt file. The parameters file is a single column of ten rows of data. The eighth row will read 100.0 (the spatial resolution is in cm). Using a text editor change this value to the spatial resolution (in cm) of your DEM (in the above example, 200.0). The model can now be run through the GUI as usual.

- Do the spatial outputs look like a 'chequerboard'? This may be because the model timestep is too big, especially if you are trying to simulate a steep slope. Try specifying a smaller value. See section 3.1, Step 8.
- If a smaller time step does not improve the 'chequerboard' effect, try increasing the spatial resolution from 100 cm to 200 cm (this will require the surface and base input files to be recreated at 200 cm resolution). It is helpful to calculate the steepest gradient to see if this is the likely cause of the problem.

5. Example model outputs

The files for two example model simulations are available from the DigiBog website (<https://water.leeds.ac.uk/our-missions/mission-1/digibog/>). The first is based on the example of a hagg shown in Figure 4, and the second is a more complicated example of a gullied landscape and the use of a series of impermeable dams. Users may wish to run DigiBog_Hydro using these files to check that they are using the model correctly, getting the same results as shown here. In the examples below, two types of plot of water-table depth are shown: spatial plots (at the start and end of the simulation) and a temporal plot. The outputs also include a plot of net rainfall. These outputs can be found in the 'Outputs' sub-directory of the current simulation's directory that this version of DigiBog_Hydro generates when it runs.

5.1 Outputs from a simulation of a simple hagg

In this example, a 20-m diameter hagg is set in a 100 m × 100 m 'inter-hagg' landscape (Figure 16). The setup is similar to that shown in Figures 3 and 4 and shows how a single block (hagg) of peat drains into the surrounding landscape. At the start of the simulation, the water table was set to the top of all of the peat columns representing the hagg. No rainfall was added during the simulation which was run for 30 days. By the end of the simulation (Figure 16), water has drained deep into the hagg and ponded on the surface of the surrounding peat. Figure 17 shows how the water tables in the hagg and surrounding peat changed over time.

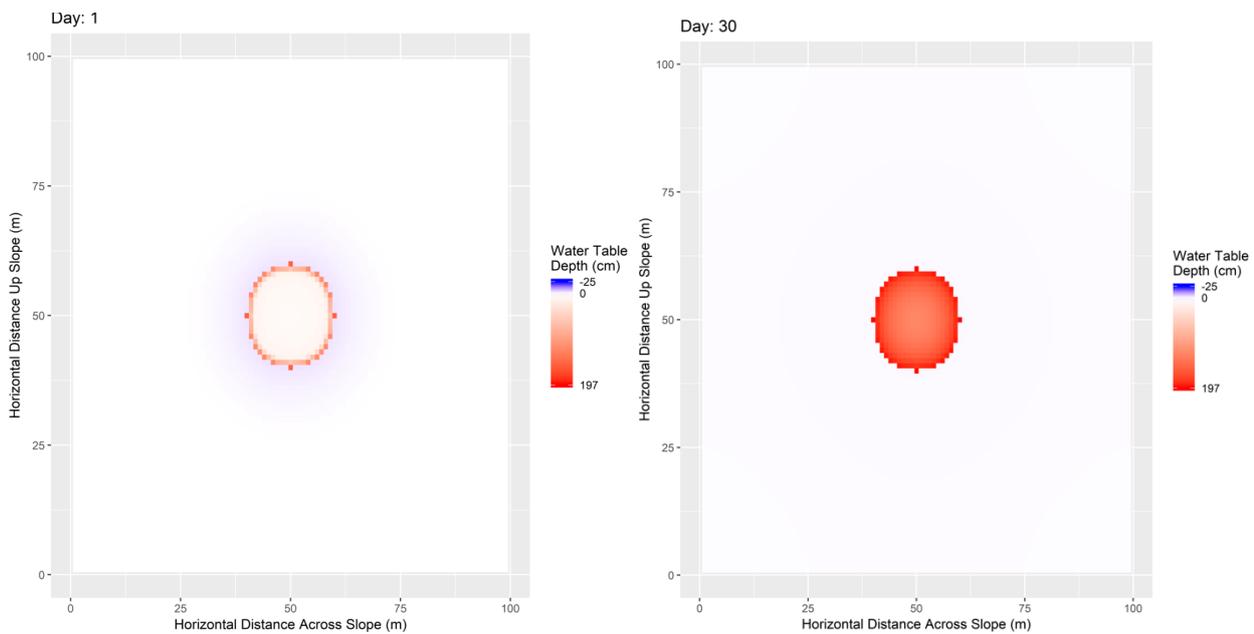


Figure 16. *DigiBog_Hydro's spatial plot showing water tables in the hagg at the end of one day and 30 days.*

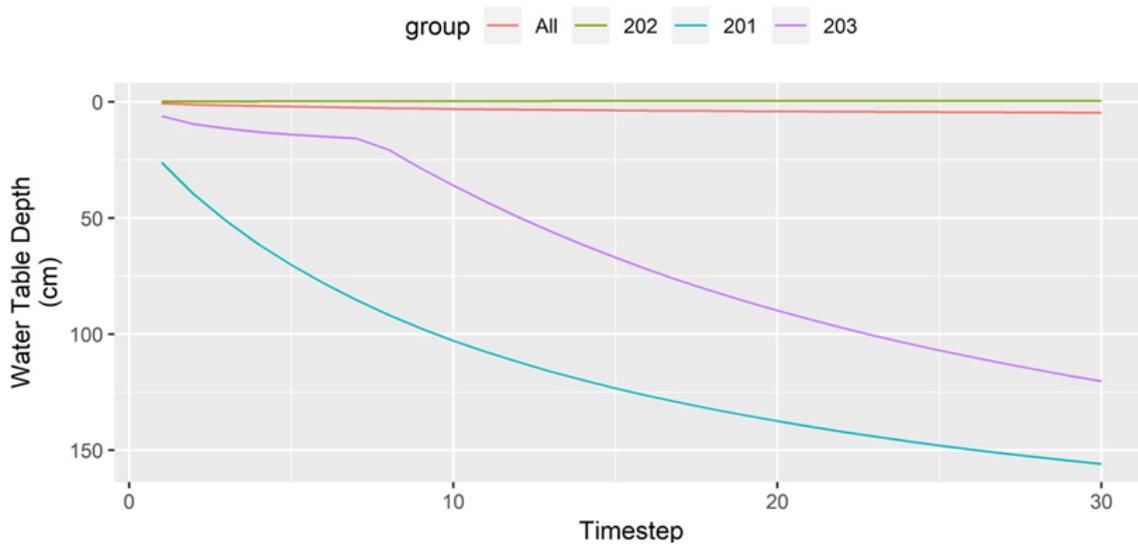


Figure 17. *DigiBog_Hydro's temporal plot showing the water tables in the hagg at the end of 30 days. Water-table depth is the depth below the peatland surface for the given classes, not the height of the water table above a datum. The green line (Class 202) shows the average water-table depth for the inter-hagg or non-hagg area, the red line (All) shows the average water-table depth for the whole area that is modelled (hagg and inter-hagg), the purple line (Class 203) denotes conditions in the centre of the hagg, and the cyan line (Class 201) conditions at the edge of the hagg.*

Figure 17 shows how peatland classes can also be used to explore what happens in different parts of the modelled area. The hagg that was simulated had the same profile of peat properties throughout; it was laterally-uniform. However, the columns representing the centre and edge of the hagg were placed in different classes from each other so that they could be plotted separately in the figure. It's then easy to compare how water-table dynamics in the centre of the hagg differ from those at the margin. This principle also applies to investigating the effect of restoration measures.

A model user, for example, may classify areas of peatland next to a dam differently from those far away from the dam so that the distance of influence of the dam can be assessed (see below).

5.2 Outputs from a simulation of a complex gullied landscape

Figures 18-21 show outputs from a larger and more complex example: a gullied landscape pre- and post- restoration. Both simulations were run over 30 days and included net rainfall inputs shown in Figure 18. To allow the user to see changes to water-table depths due to restoration, some peat columns near to dams were given different peat classes (301 and 302 – Figures 20 and 21). In the restoration simulation, a series of impermeable dams (class 401) was added. The net rainfall time series (Figure 18) is saved with the output plots of water-table depth in the outputs sub-directory within the current simulation directory.

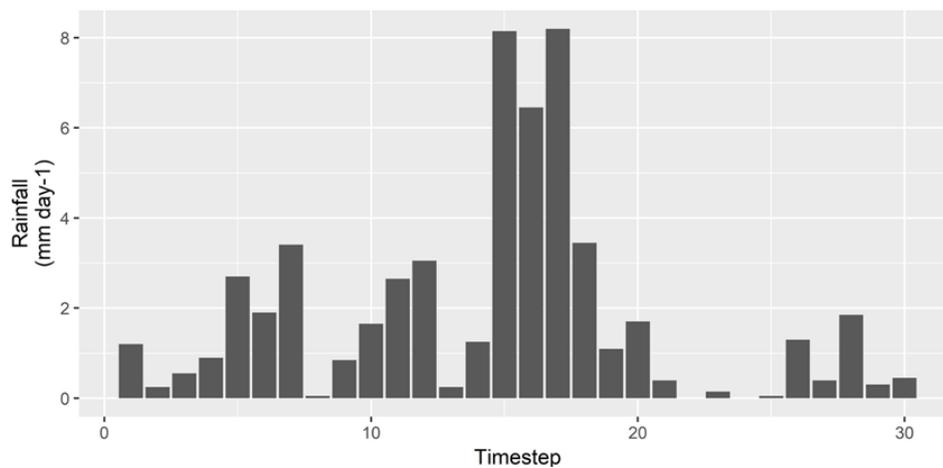


Figure 18. The net rainfall time series used in the simulations of the gullied landscape. Note that ‘Timestep’ in the graph refers to day number of the simulation.

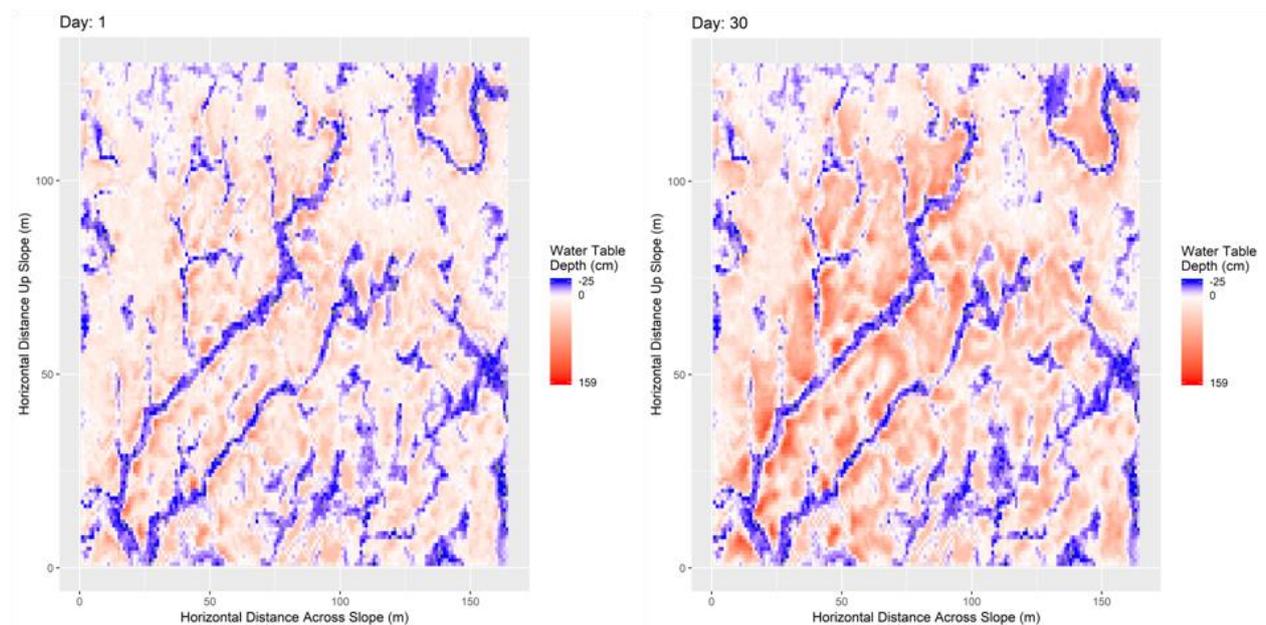


Figure 19. The gullied area in its pre-restoration state at end of the 1st and 30th days of the simulation.

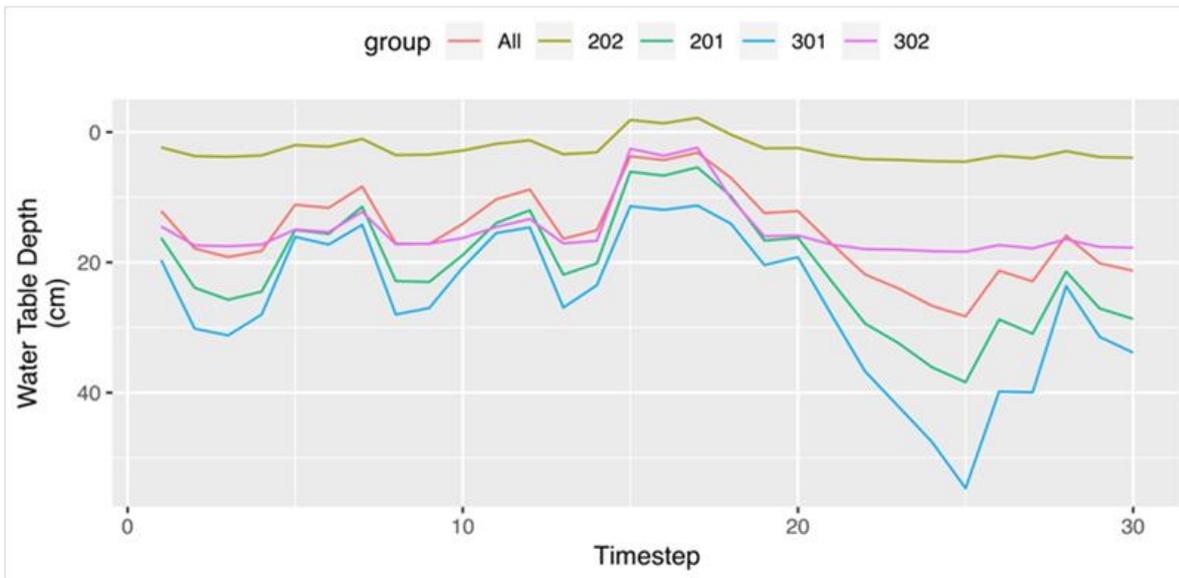


Figure 20. Water table dynamics in different parts of the pre-restoration gullied landscape. The red line (All) shows the average water-table depth for the whole area that is modelled (hagg and inter-hagg (gullies)). The bright green line (class 201) shows the average water-table depth in hagged peat and the green line (class 202) shows the average water-table depth for the columns around the hags (inter-hagg). The blue line (class 301) denotes conditions within hagg peat in an area near to where dams were placed in the restoration simulation (Figure 21) and the purple line (class 302) denotes conditions in the inter-hags (gullies) near to the dams.

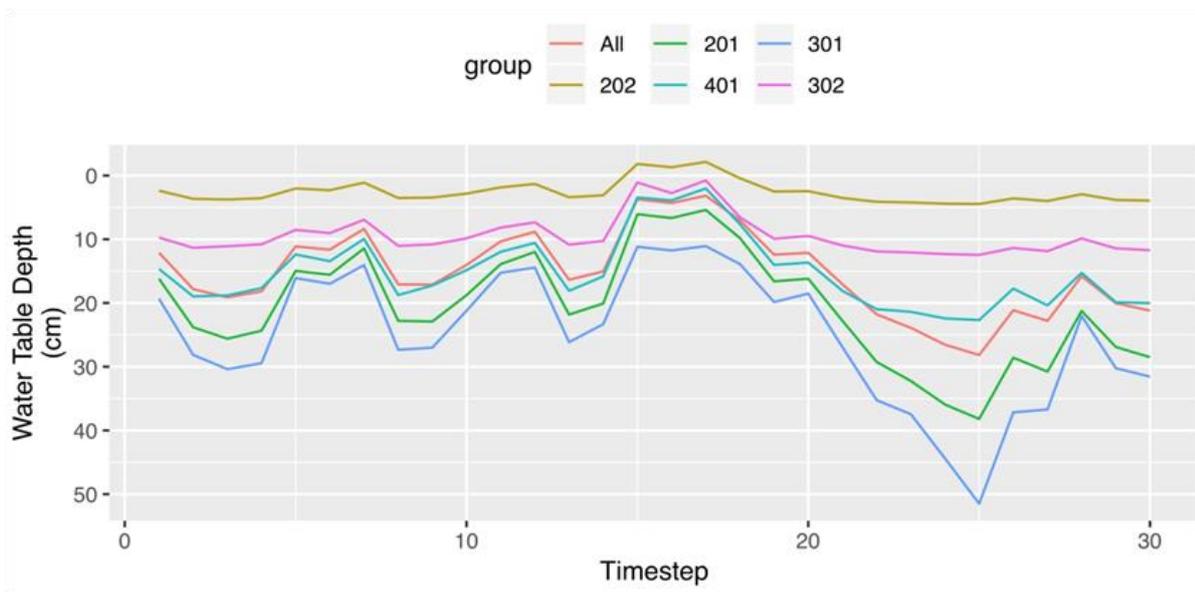


Figure 21. Water table dynamics in different parts of the post-restoration gullied landscape. Note that there is an additional class shown in this plot (401 – the impermeable dam class). The model auto-allocates line colours to classes and auto-adjusts the water-table depth axis. However, it can be seen clearly that Class 302 (same colour in both plots) has substantially shallower water tables (that is, nearer the peat surface) by ~5 cm post-restoration.

Appendix: Preparing input data files using ArcGIS

A contribution from Yorkshire Peat Partnership



Input data files for DigiBog_Hydro can be prepared using any GIS software. Here we provide a guide prepared by Chris Osborne of Yorkshire Peat Partnership for those using ArcGIS. It is prepared in the form of a tutorial. Those having any questions about its content should contact Chris directly at YPP's Skipton offices (<https://www.yppartnership.org.uk/about-us>). The appendix contains edits by Rhoswen Leonard (Natural Resources Wales) and Sam Dixon (Moors For the Future Partnership).

Area of Interest and 1-m grid

To begin, find an area of interest (AOI) on the site of interest that includes the features or location you wish to model (such as a series of gullies or hags). Draw a rectangular shapefile encompassing the area and aim to have a width/height no larger than 200 m – this will help to focus the simulation and reduce processing times. An example is provided below.



Next, create a grid within the AOI using the ‘Create Fishnet’ tool in ArcGIS. Set the ‘Template Extent’ to the AOI, set the cell size to 1 m and the geometry type to polygon. The grid output will likely cross over the boundary of the AOI – this is expected because, in most cases, the drawn AOI will not fully contain 1 m cells (unless its width and height are an integer value).

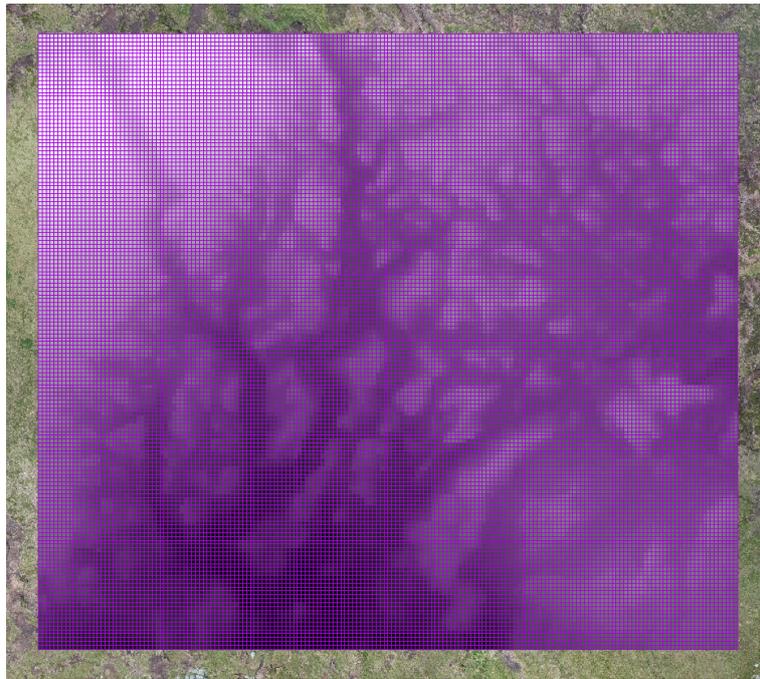
The grid output will be used to clip the surface and base rasters (see section 2 in the main part of the manual) as well as create the classification file (see sections 2 and 3.1). Using the grid instead of the AOI for the clip process will ensure that the 1m spacing is enforced.

Surface DEM

As we are using a 1-m grid, convert the DEM to a 1-m resolution. This can be done with either the export function or resample tool available in ArcGIS. The resample tool allows the user to choose the most appropriate re-sampling method. Next, clip (data management toolbox) the DEM to the grid output and make sure that the following parameters match:

- Use input features for clipping extent (ensures raster is clipped to the boundary and not to individual features)
- Maintain clipping extent

An example of a clipped raster to grid is shown below:



An example of raster fitting to a grid with 1 m spacing is shown below:



Base DEM

To create the base raster, first create a peat depth dataset by interpolating peat depth points (if peat depth data is not available, consider using the fixed value option in the DigiBog interface and skip the rest of this section – see section 3.1, Step 3). Use the Kriging tool in ArcGIS, and select a suitable number (ArcGIS defaults to 12) of peat depth points that surround the subset area (make sure the cell size is set to the same resolution as the surface file) – see the figure below. A small number of points will increase the error associated with the peat depth predictions.



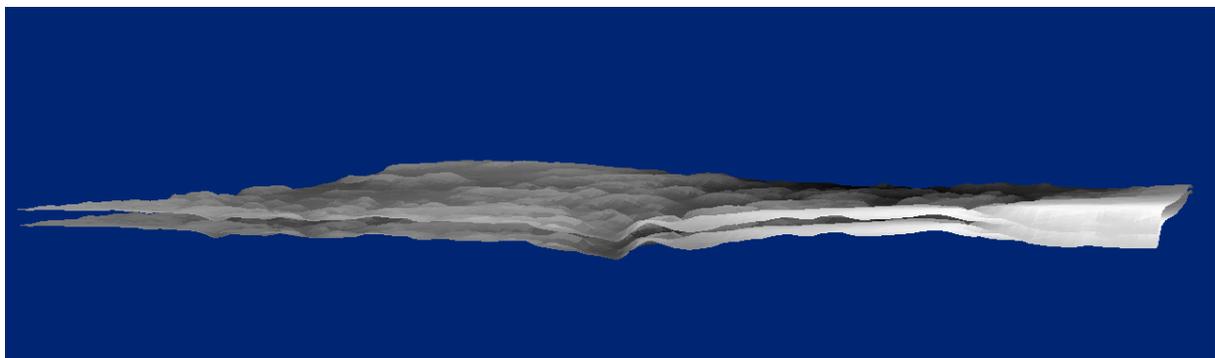
Next, clip the kriging output to the grid using the same parameters used for the surface raster. The clipped peat depth raster and clipped surface raster will be perfectly aligned (this is required for the next raster calculator step).

Use 'Raster calculator' in ArcGIS to subtract the peat depth dataset from the surface dataset; this will create the base dataset required for DigiBog_Hydro:

$$\text{Surface} - \text{peat depth} = \text{Base}$$

Note: make sure that the peat depth dataset is the same unit scale (that is, metres) as the surface dataset. For example, a 130 cm peat depth should be converted to 1.3 m before or during the raster calculation.

There should be a positive difference in elevation between the surface and base raster files – evidenced by the example below:



Layer properties

Before creating the final classification raster, the layer properties file needs to be created. Consider the different class types across the subset area. In this example, the two main classes are gullies and non-gullies. DigiBog_Hydro classification files require boundary classes around the perimeter. The boundary classes are:

- Dirichlet (101) – water level
- Neumann (102) – zero flow

Assign the rest of the classes for the subset to the layer properties csv file (the numbers need to be alternate to the boundary class numbers). Also, make sure that the *.csv has the correct format, such as the breakdown of the thickness, hydraulic conductivity, and drainable porosity properties.

Below is an example of a simple layer properties csv (Figure 13 from the main part of the manual).

ClassID	ClassName	Property	Layer1	Layer_2	Layer_3	Layer_4	Layer_5	Layer_6	Layer_7	Laye
101	Dirichlet-Condition_5cm	Water_Table_Depth_(cm)	5	NA	NA	NA	NA	NA	NA	NA
101	Dirichlet-Condition_5cm	Condition	diri	NA	NA	NA	NA	NA	NA	NA
102	Neumann-Condition	Flow_Value	0	NA	NA	NA	NA	NA	NA	NA
102	Neumann-Condition	Condition	neu	NA	NA	NA	NA	NA	NA	NA
103	Dirichlet-Condition_10cm	Water_Table_Depth_(cm)	10	NA	NA	NA	NA	NA	NA	NA
103	Dirichlet-Condition_10cm	Condition	diri	NA	NA	NA	NA	NA	NA	NA
201	Hagged	Thickness_(cm)	100	1	1	1	1	1	12	NA
201	Hagged	Hydraulic_Conductivity_(K)	0.00005	0.010045	0.030035	0.050025	0.070015	0.090005	0.1	NA
201	Hagged	Drainable_Porosity_(s)	0.05	0.2	0.2	0.2	0.2	0.2	0.3	NA
202	Inter-Hag	Thickness_(cm)	10	10	10	NA	NA	NA	NA	NA
202	Inter-Hag	Hydraulic_Conductivity_(K)	0.070015	0.090005	0.1	NA	NA	NA	NA	NA
202	Inter-Hag	Drainable_Porosity_(s)	0.2	0.2	0.3	NA	NA	NA	NA	NA

File Name: layer_props

Buttons: Save, Close

Classification of peat properties

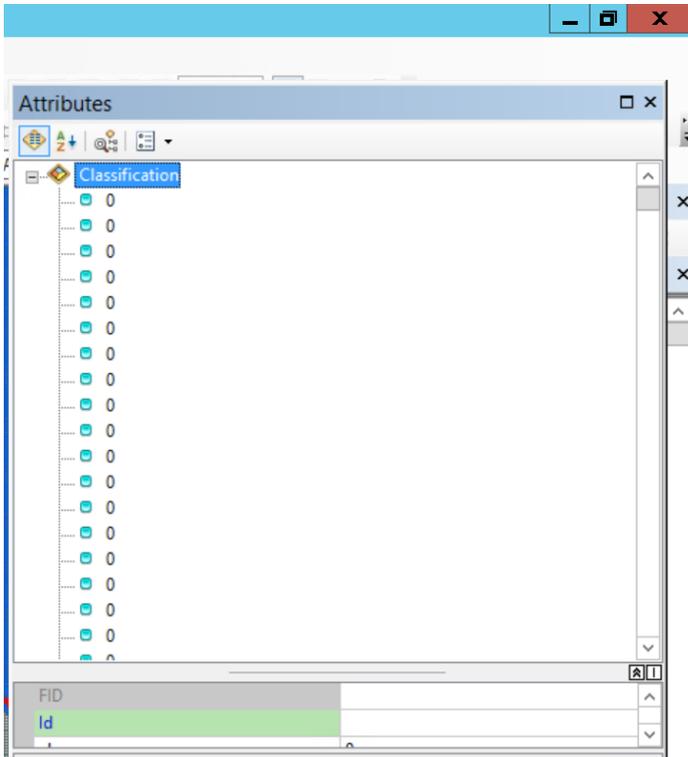
Now that the layer properties file has been created with the appropriate class names, the classification raster can be generated. The classification raster needs to contain the Class_ID number for each model cell, as specified in the layer properties file (for example, 101 for a Dirichlet boundary). Create a copy of the grid shapefile and call it 'classification'. Next, manually select the cells in the copy and assign the class number values to them using the DEM as a reference.

For example, one way to classify multiple cells at once is as follows;

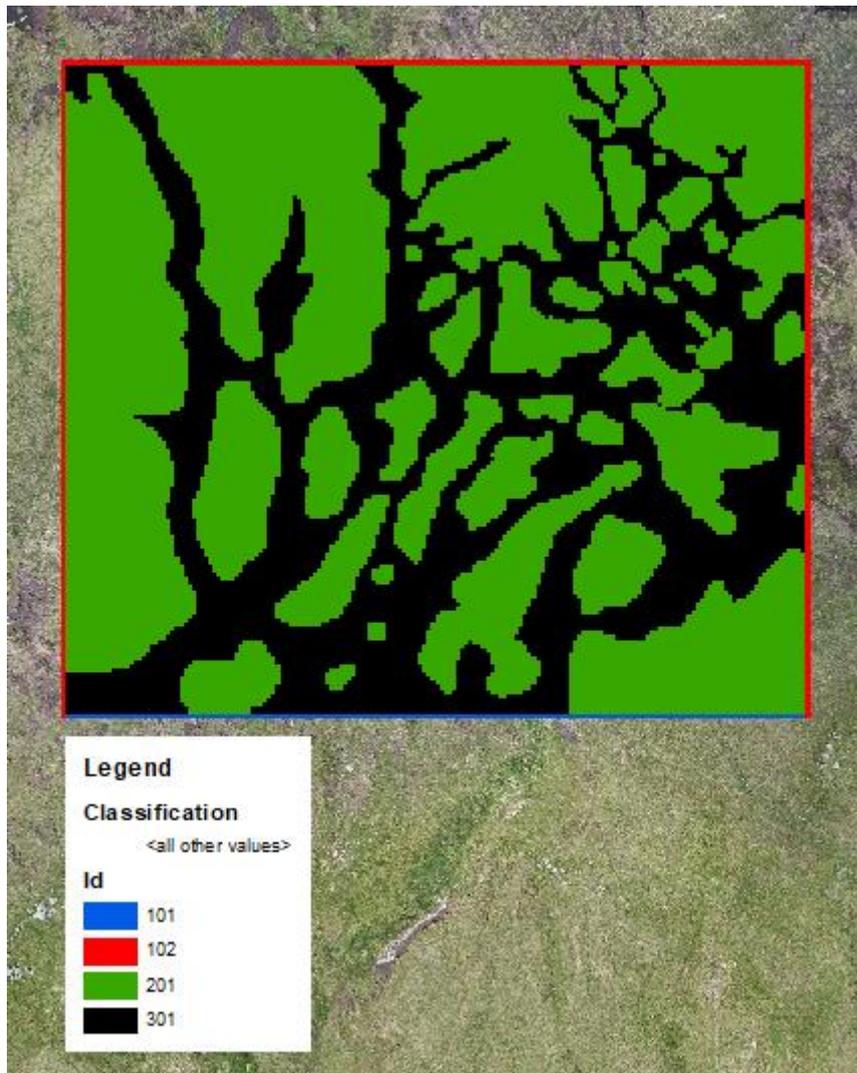
1. select multiple cells using the select tool (polygon, polyline, etc),

2. open 'attributes' in the editor toolbar,
3. highlight the 'classification' .shp file.
4. Enter the class value in the relevant attribute column, e.g. id.

All selected cells will update with the specified classification value.



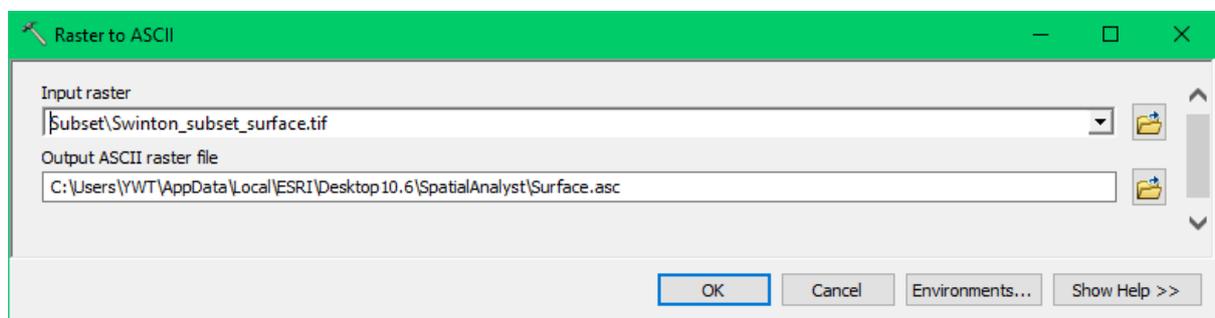
Below is an example of a finished classification.



The classification is currently in shapefile format and will need to be converted to a raster. Convert the shapefile to a .tif ensuring the 'Id' field is selected for the value parameter and the cell size is set to 1 m.

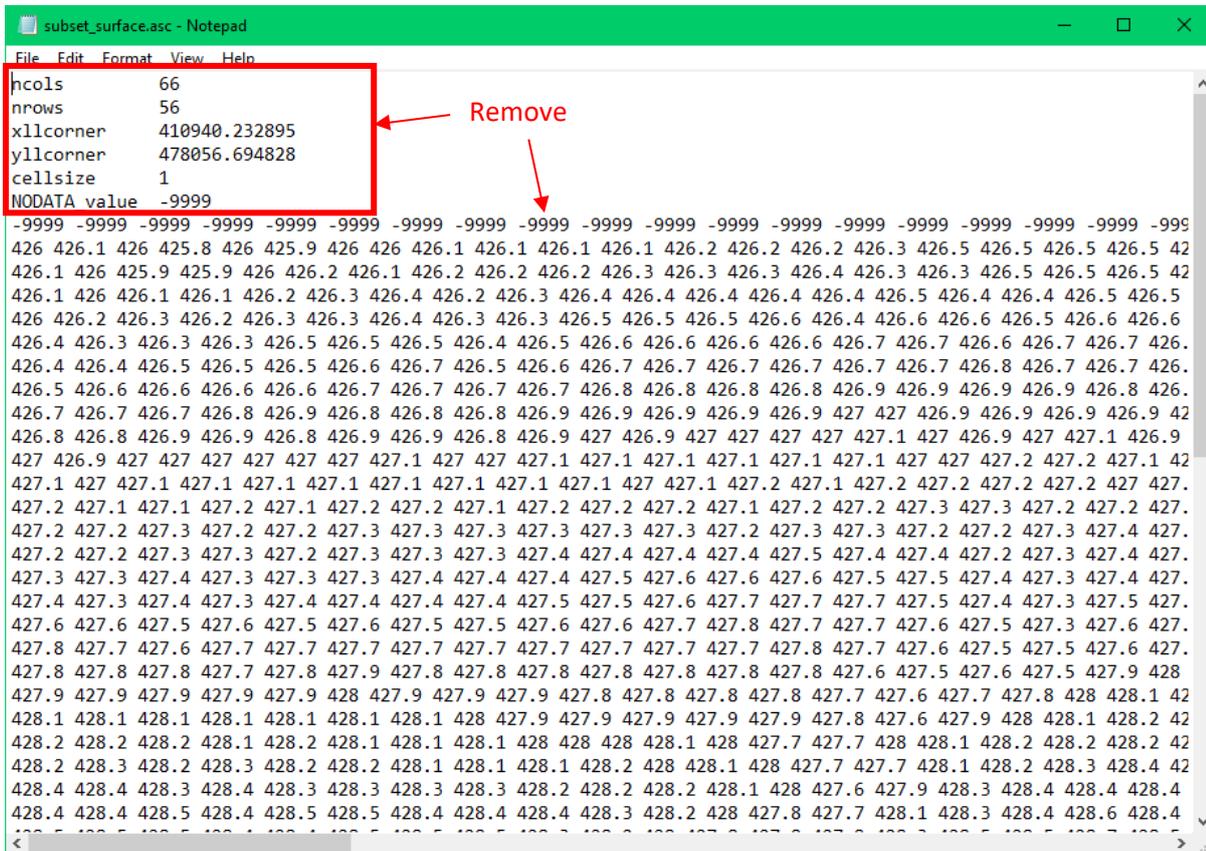
ASCII Conversion

As DigiBog_Hydro requires an *.asc file, run the 'Raster to ASCII' tool to convert the rasters:



Note that the tool does not allow users to save an ASCII to a file path that contains spaces. If the output location contains spaces, save the *.asc files to the desktop and then copy them to the appropriate folder.

Once the output has been saved, edit the *.asc file (using Note Pad) and remove the metadata rows alongside any NoData values:



In addition, make sure there are no spaces at the end of each row – they have to be manually deleted.

Considerations

The list below details a few rules that need to be followed for DigiBog_Hydro simulations to work:

1. ASC files must not have a space at the end of each line
2. Surface and base ASCs **CAN** have variable precision
3. Class 'thickness' in the layer properties file cannot exceed the minimum difference between the surface and base elevation