Viridian Modelling: Explanatory Note 2
Standard HydroloGIS and additional modelling options

1.0 HydroloGIS Modelling

HydroloGIS is a unique method of identifying, ranking and prioritising nature-based solutions to water problems. It mathematically calculates the current and future ability of every ‘pixel’ across a landscape to mitigate problems such as flooding, erosion/siltation and diffuse pollution. It also looks to maximise the delivery of multiple benefits and its numerical basis aids the quantification of service delivery.

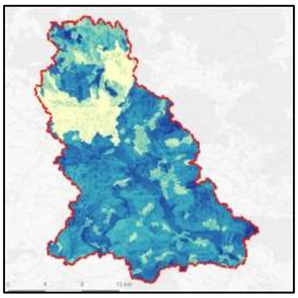
These results cannot be created using standard GIS or hydrological methods. These cannot identify what type of interventions to create; they cannot prioritise or rank solutions; and they often suggest spending resources in inefficient locations.

We use a raft of open-source or local data and a 5m resolution topographic layer, which is run through HydroloGIS to characterise the area of interest.

The outputs are data layers and maps showing current, relative landscape function and prioritised solutions that most improve the provision of water-flow service. The modelling also identifies flow accumulation networks and areas liable to rainfall ponding. These are all described in more detail below.

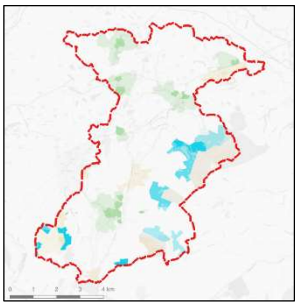
1.1.1 Relative Landscape function

This is the current, relative function of the landscape. Each 5m pixel is ranked for how well it is currently functioning to keep flood waters, diffuse pollution and erosion/siltation out of the watercourses.



This assesses entire flow paths and connectivity, as well as individual characteristics of each pixel across the catchment. An example of the mapped output for flooding is shown to the right; similar outputs can be created for soil-adsorbed pollutants (such as phosphates), soluble pollutants (such as nitrates) and erosion/siltation. The dark areas on the map show a high degree of current service provision, the pale areas a low provision.

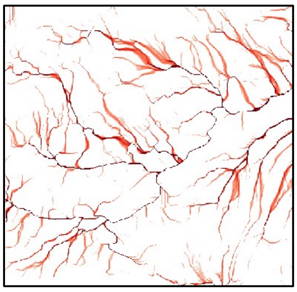
1.1.2 Identifying prioritised catchment solutions



This is the prioritised solutions for the whole area. The raw model outputs consider three broad categories: planting trees, reversion to semi-natural grassland and water retention features. Each 5m pixel is ranked for how much impact if will have on local problems, if the habitat on that pixel is optimised (the categories will be specified for each pixel). An example of the mapped output for a basket of water problems is presented on the right, showing the best 2%, 5%, 10% and 20% of solutions (dark to light colours; green is woodland planting, orange grassland reversion and blue water retention). These are the best compromise options to solve all problems simultaneously.

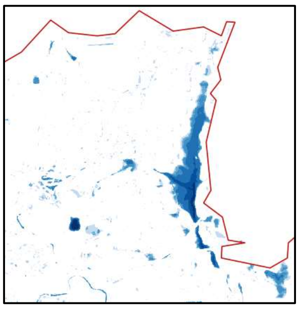
Similar data layers and maps can be created individually for river flooding, soil-adsorbed pollutants (e.g. phosphates), soluble pollutants (such as nitrates) and erosion/siltation.

1.1.3 Flow accumulation network



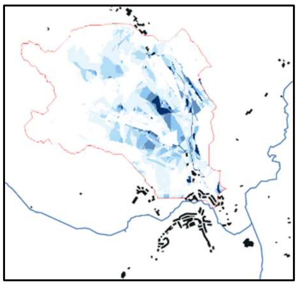
The hydrological aspect of HydroloGIS identifies where water flows over the surface of the landscape. The magnitude of water flowing across each pixel is calculated and concatenated to form the flow accumulation network. This is useful for identifying where most water naturally crosses the landscape and so where features such as ponds will intercept most water. The image to the right shows a flow accumulation extract, with the darker red denoting higher degrees of flow.

1.1.4 Identify natural depressions



The landscape contains depressions and areas of flat ground, which can confuse hydrological algorithms as they assume water always flows downhill. This can be overcome by ‘filling’ the DTM: the depressions and flat areas are altered so that they have a very shallow gradient in the direction of the neighbouring flows. The filling method captures the depth of each depression, so understands just how much water could accumulate there during heavy rains before being able to flow out again. This gives an idea of the depth of rainfall flooding that could be experienced in that location, or how much water could be captured in a pond. Depressions close to streams can be well deployed for leaky dam and flood plain works.

1.2 Pluvial Flooding



We can repurpose the fluvial flood prioritisation solutions from 1.1.2 to address pluvial (runoff) flooding at buildings or streets. We would first look at the areas known to suffer from pluvial flooding, then trace all parts of the landscape that drain down to those areas. This creates a ‘catchment’ area specific to the pluvial flood locations, which we use to ‘cookie cut’ the HydroloGIS prioritised solutions.

The way HydroloGIS works means that these solutions will re-rank themselves to stop flooding at the pluvial locations, rather than the river. The resultant outputs will therefore show what to do where to reduce rainfall flood impacts at the target infrastructure.

The image to the right shows an example of this output, with everywhere inside the red line draining down to the flooded streets and everywhere outside the red line draining away from the village. The darker the blue areas within the red line, the more effective those interventions will be (such as creating ponds or bunds).

This approach can also be applied to reduce storm water ingress into sewers, thereby lowering pumping costs and reducing combined sewer overflows (CSO).

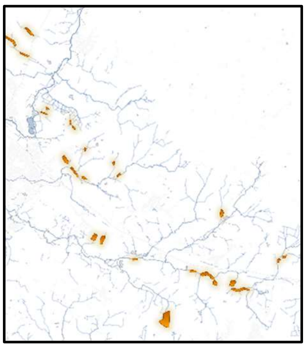
2.0 Specifying Outline Designs of Nature-based Solutions

HydroloGIS specifies three broad intervention types: water retention, reversion to semi-natural grassland and woodland creation. The latter two require little additional comment at this stage, with further specification such as species types begin possible only during the individual, site-based project phase. However, we can translate 'water retention' into more detailed measures at an early stage, which can include:

1. leaky dams and floodplain features (offline storage or reconnection);
2. mid-field Swales and bunds;
3. field-boundary actions (buffer strips, smart margins or ditch baffles);
4. wetland creation;
5. hedge planting;
6. soil infiltration (soil management); and
7. water resource enhancement.

2.1 Leaky dams and floodplain features

We can manually review where the flood solutions fall across or close to rivers and streams, as well as where high-priority locations drain into streams. This will be combined with land use/land cover data, topography, geology, general mapping (such as OS Explorer), aerial photography and ground-level images to select locations that are effective and practical for features. The review excludes locations where features may cause adverse impact to arable land, buildings and infrastructure.



2.2 Swales and bunds

These are only allowed on pasture, parks, recreational fields and similar grasslands. Swales and bunds can be grassed and used for their main function (such as grazing) until they fill with water during heavy rain. This would not be the case for arable land, which would have to revert to grassland or woodland.

Bunds and swales will be most effective in locations with fairly shallow slopes, where they will hold greater volumes of water, so only these areas will be selected from the relevant HydroloGIS water-retention solutions.

2.3 Field margins

Landowners may not be willing to sacrifice productive arable land for nature-based interventions. However, there will still be appreciable benefits from installing field-boundary features in the higher priority HydroloGIS locations. Buffer strips or smart margins (mixing natural vegetation with micro-storage features) will slow water and capture both diffuse pollution and sediment. Ditch baffles will hold water whilst still allowing the ditch to function.

We will therefore identify where the most effective 20% of HydroloGIS solutions intersect arable land.

2.4 Wetlands

Wetlands will function most effectively on the shallowest slopes with low permeability soils; or potentially on the shallowest slopes close to watercourses. We usually assume that landowners will not want to sacrifice arable land to create wetlands, in which case features are not allowed on arable fields (especially those of high agricultural grade).

Water-retention solutions from the relevant HydroloGIS output layers will be selected when they fall within these wetland restrictions.

2.5 Hedge planting

HydroloGIS can create a layer showing the areas where slowing the flow of water with undergrowth will be most effective. This will act as a good proxy for where planting hedges will be beneficial, as long as they are planted along major flow paths or cutting across swathes of lesser flows.

The most effective 20% of HydroloGIS flood outputs will be enhanced by a manual review of aerial images and flow paths to identify where creating hedges may be possible and effective.

2.6 Soil infiltration

Infiltration can conceptually be taken as simply another method of retaining water to reduce flows. HydroloGIS considers soil texture in calculating the placement of optimal natural flood mitigation measures. However, it does not consider changing the quality of the soil as relates to its permeability and water storage capacity, since detailed soil analyses across large swathes of land are generally not available at a reasonable spatial accuracy.

We would identify high opportunities for improving soil infiltration by limiting HydroloGIS to identify only water retention features across the catchments, then screening these for coincidence with well-drained soil types on fairly shallow slopes.

This usually assumes that all soils are currently being managed poorly and will benefit from actions such as sward lifting, cover crops or breaking plough pans. We can, however, add local data on soil quality if available and can exclude area that are in relevant stewardship schemes, as these should already have improved soil structure.

2.7 Water resource enhancement.

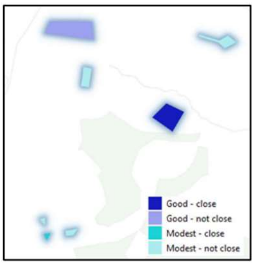
The HydroloGIS function for drought reduction is not well developed for areas other than arid zones, so we will use combinations of data to identify good opportunities to reduce drought.

Soil infiltration.

Improving soil infiltration will also help recharging groundwater. Areas identified in 2.5 should also be considered as good opportunities for recharging aquifers, when they overlay such aquifers. This will also improve soil moisture and help maintain baseflow to streams during droughts.

Reservoirs

Creating ponds or reservoirs to store water will help supply irrigation during droughts. These are best placed either where flows naturally accumulate, or where there are natural depressions in the ground. These will be combined with land use data to identify where ponding occurs outside of arable cultivation (or other high value uses).



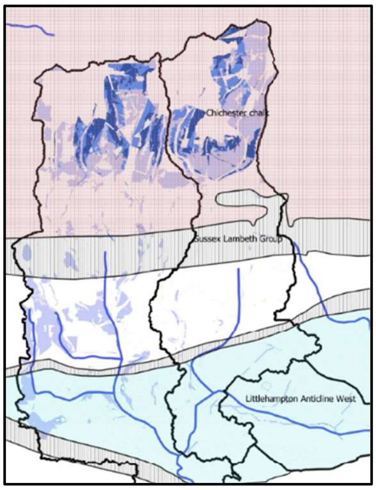
A manual review of these locations with various other data will highlight where there are good opportunities to create reservoirs to capture modest/high flows and offer low/high flood reduction co-benefits.

3.0 Groundwater Concerns

3.1 Groundwater flooding

We can use national and local data to identify where there has been local groundwater flooding and where there are higher risks of this in the future. The groundwater flood maps from GeoSmart are also very useful input data for this.

We can use this data with a range of topographic, geological and hydrogeological data, as well as borehole monitoring records, to identify both the flood mechanisms and contributing strata.



We apply all this data to create a source-pathway-receptor model, using indicator characteristics rather than deterministic flow modelling. This would not be appropriate for precise point-to-point analyses, but is suitable for the more generalised area-to-area calculations necessary for designing NbS to groundwater flooding.

We can then identify surficial NbS that will reduce flooding from either clearwater (major aquifer) or PSD (shallow aquifer) origins, whilst ensuring the interventions do not exacerbate problems elsewhere.

3.2 Aquifer recharge

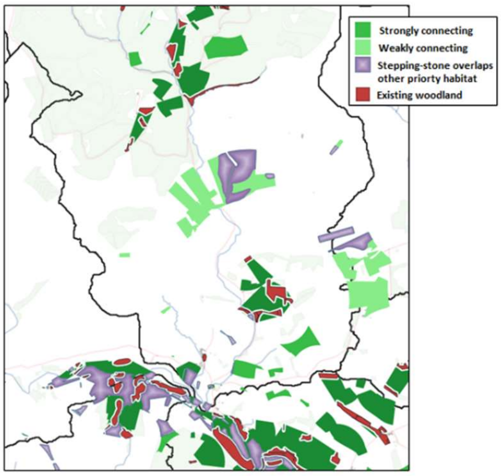
We apply a similar approach to 3.1, but looking to maximise percolation into the aquifer rather than avoid it. We add to this a whole raft of data on groundwater levels, abstractions, rainfall patterns, soil transmissivity, drainage to rivers and land use characteristics.

The HydroloGIS flood modelling blends with this to identify the most effective locations to place various NbS or aquifer recharge. We calcualte storage volumes and rates of precolation for each features, from which we can quantify the additional recharge volumes (and hence abstrction rates) from NbS.

We have also applied the method to maximise groundwater abstraction potential whilst delivering multiple co-benefits, with the results quantified in terms of additional cubic metres of abstraction water, carbon captured, biodiversity enhancement and fluvial flood damage costs avoided by the NbS.

4.0 Habitat Connectivity

We can identify where creating new habitats will fill gaps between existing areas of similar habitat. This creation of ‘stepping-stones’ will help species to flow across the landscape, extending their ranges and making populations more resilient.



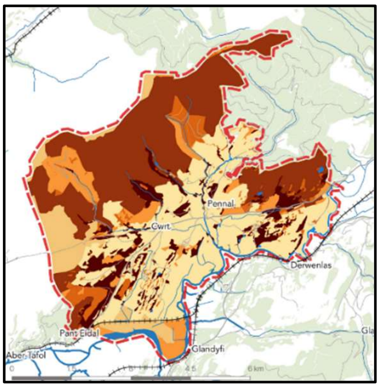
The Client would choose three habitats of most importance across the area, or those priority habitats that are most fragmented and in need of connecting. We can then assign the likely range of distances that species associated with these habitats can travel. This will allow us to model where placing stepping-stones will connect habitats for species with low, medium and high abilities to travel.

The output will be a map for each habitat type showing the extents of current habitats; stepping-stone opportunities for low, medium and high connectivity; and where such stepping-stones fall within other priority habitats. The latter is included as we considered it unlikely that one type of priority habitat would be replaced with another, although we leave this decision to users.

Finally, these stepping-stones can be compared with Natural England’s Priority Habitat Network layer to find overlaps. This layer is useful as it considers the potential for land to host various habitats. Stepping-stones are therefore more likely to be successful where they overlap with the Network, although this is not definitive and so stepping-stones away from the Network should not be entirely dismissed.

5.0 Carbon sequestration and stocks

We can use our natural capital baseline mapping and most locally-relevant literature values to understand the current carbon sequestration rates of existing land uses.



This can then be used to calculate the change in carbon that will result from the creation of NbS for other objectives, such as converting pasture to wetland features to reduce phosphate pollution. This can to used to ensure that the NbS for water problems also maximise the sequestration of carbon.

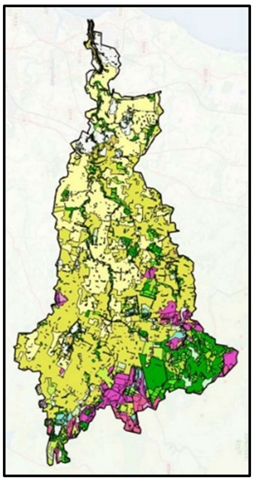
Alternatively, we can create a carbon potential map. This makes assumptions about likely land use changes (agreed with clients prior to modelling), so we can map the potential to enhance carbon capture through applying these changes.

The image to right shows a heat map for carbon stocks in soil and vegetation, with darkest brown being 273t/ha and lightest brown being 73t/ha.

6.0 Natural Capital Baseline

We would create a biotic natural capital extent map (physical extent account) using:

1. Corine 2018 as the foundation, as this has a very broad range of habitats and other land uses, but is not particularly accurate.
2. Corine would first be overwritten by the OS open woodland layer, as this has accurate, up-to-date mapping of trees. However, there are no descriptions of what type of trees are present, so is not as useful as subsequent layers.
3. Where there is coverage from Natural England's Priority Habitats layer, this would overwrite the two previous layers. It is not hugely recent or precise, but acceptably so and does have a good range of natural habitats. It is therefore more useful that those preceding it.
4. This combination layer would be overwritten by the National Forest Inventory, as it has the most useful combination of habitat boundaries (mainly but not exclusively trees) and descriptions.
5. Finally, local data can be added if available, assuming it is more recent and accurate than the above open sources.



We would determine natural capital condition in a similar hierarchical process:

1. We would first overlay the physical extent data with the SSSI quality data (favourable, unfavourable recovering, etc). This is a good base to use, as it offers direct habitat quality ratings for the areas it covers.
2. Where there is designated Ancient Woodland outside of SSSIs, this will be used to give some idea of woodland quality as ancient or replanted.
3. In all areas of peatland, we will overlay the preceding data with the Moorland Deep Peat Status layer from Natural England. This does not cover all peat, so where there is no coverage or the peat is described as 'no category', we will revert to SSSI data.
4. Outside of SSSIs, Ancient Woodland and Deep Peat coverage, we will use the Habitat Network data for 'habitat restoration-creation' and 'restorable habitat' to identify areas of poor-quality habitat. The logic here is that only degraded habitats would be identified as needing restoration.
5. We can add Stewardship agreement (point data) and Agricultural Land Classification data, as appropriate.
6. Finally, we can add local data as available.

Separately to the above, we would also use a climate change vulnerability layer to show which parts of the landscape are at high, medium or low risk from climate change.

Abiotic natural capital can be added as required.

We would use baseline and condition maps to create a table of areas, such as 'Deciduous woodland in favourable condition' or 'hagged peat bog'.

7.0 Quantifying benefits

7.1 Areas and Volumes

The simplest form of quantification will involve identifying the likely, potential number, type and area of NbS features to be installed. We would make assumptions about the characteristics of individual features that would be created within the modelled priority areas, under various scenarios. These numbers can then be extended into cost/benefit figures using rule-of-thumb values (quick and inexpensive) or more complex modelling (increasing cost with complexity).

7.2 Phoshates and nitrates

We can quantify the reductions in nutrient pollution that the highest priority NbS would deliver for rivers, for which we would use a variety of catchment calculators, literature values and case studies. We modify these outputs for the relative ability of the priority NbS at removing nutrients in runoff; sum this effect for the areas draining down to the NbS; then sum over a variety of scales.

We can also add Farmscoper modelling by forcing a spatial element into the system through the use of artifical 'mini-catchments' and 'mini-farms'.

We would partner with Royal Haskoning to model the effects that these reductions in nutrient loads reaching a river would have at specific locations downstream (such as a sewage works).

7.3 Flooding (damage costs avoided by NFM) Using VET-NFM

We can estimate of the damage costs avoided due to various extents of NbS, using our VET-NFM tool. This blends the extent and effectiveness of HydroloGIS's higher priority features, such as the most effective 5% of options, with various catchment characteristics and its response to flood events. This is combined with the average damage costs from the Multicoloured Manual to give the annual damage costs avoided by NFM due to a 1 in 100 year rainfall event. The results appear to be accurate to within an order of magnitude. This method is swift and a low cost option.

7.4 Flooding (hydrological flood modelling) with Ambiental

Flood benefits can also be quantified by combining our prioritised solutions with Ambiental's 2D flood modelling. This shows the flood depths at individual buildings and features during certain 'design' storms, such as a 1 in 100 year return-period event, both before and after the NbS have been installed. This modelling takes at least 5 weeks and is a higher cost option.

7.5 Flooding (volumes held by NbS features)

We blend the landscape characterists at each feature (such as slope angle or soil type) with likely attributes of the feature itself (such a bund height or pond depth) to estimate the unit storage volumes during storm events. We combine this with the number and area of NbS features, and estimated rate of uptake, to give likely, acheivable storage volumes from the project as a whole.

7.6 Cost:Benefit Calculations

The cost of creating the various NbS can be estimated from past experience and local examples (where available). These can be compared to multiple ecosystem services flowing from them to create cost:benefits for the suite of specified NbS interventions; likely options; or simple HydroloGIS ranking.

We can compare the quantified and qualified benefits of all potential ecosystem services though an iterative process visualised below. This can be powerful in ensuring that no services are overlooked, especially the 'softer' services that cannot be quantified financially and so are often omitted from accounts.