Ecosystem service: landscape contribution to flood risk and mitigation

Purpose

The objective of the mapping is to apportion a relative value across mainland Cornwall corresponding to landscape's contribution to downstream flood risk. The spatial mapping of flood risk, in turn informs estimates of the current and potential flood mitigation service value of habitat cover.

Background

Estimates of the landscape's contribution to flood risk derive from:

1. Identifying potentially vulnerable areas (PVAs) which are defined as buildings at risk of downstream flooding.

2. Estimating quantified scores of each grid cell's contribution to downstream flood risk via (i) direct surface water overland flow, (ii) peak river flow (iii) identifying floodplain and riparian zones in flood-prone catchments.

3. Estimating a combined flood risk contribution of grid cells across the landscape.

4. Estimating relative and potential mitigation values of habitats across the landscape.

There is growing evidence supporting the potential role of land cover on the mitigation of downstream flood risk. Key mechanisms by which land cover can influence flood risk include the interception of rainfall and evapotranspiration, improved soil infiltration, reduced surface water runoff, and the slowing and interception of overland surface flow. Each of these mechanisms can slow and reduce the magnitude of downstream peak flows. Soil erosion is also highly influenced by land cover and can magnify the risk and/or cost of surface water flooding by reducing the effectiveness of flood mitigation measures such as drainage ditches.

The effect of landcover can be significant. Within upland river catchments, infiltration rates of forest soils have been estimated as 60 times higher within native woodland shelterbelts compared with grazed pasture (Nisbet et al 2011, p 19). The importance of the riparian and floodplain environments has also been demonstrated with the increased roughness associated with planting native floodplain woodland along a grassland reach of the River Cary in Somerset predicted to reduce flow velocity by 50% (above p 20), delaying downstream flood peak by 140mins. Thomas & Nesbit (2006) suggested that floodplain and riparian woodland have potential for attenuating large floods within downstream towns and cities. Nisbet et al (2011) conclude that there is sufficient evidence to promote floodplain and riparian woodland planting to reduce flood risk in appropriate locations, especially when other benefits are factored into the calculation.

Methodology

1. Identifying potential vulnerable areas

Potentially vulnerable areas (PVAs) were determined from where existing built-up areas, or areas assigned to a future building allocation zone, fell within Environment Agency flood risk zones for surface water or rivers/seas flooding. A 'PVA' value was assigned to each of these cells proportional to the 'at-risk' built-up area.

2. Estimating risk contribution of the landscape

To assist calculation, key mechanisms by which landcover can contribute to the flood risk of potentially vulnerable areas are considered:

i. Contribution to surface water runoff draining directly to a PVA.

ii. Contribution across the wider upstream catchment area to peak river flows affecting PVAs.

iii. Contribution of the floodplain to river flood risk to catchment PVAs.

iv. Contribution of the riparian zone on river flood risk to downstream PVAs.

i. Contribution to flood risk from direct surface water runoff

Only areas directly upslope of PVAs were considered to have a mitigating value on surface water flooding. Areas draining to a PVA along a permanent watercourse were *not* included (these are captured by ii below). The surface water risk contribution of each cell *x* is calculated as the sum of the PVA value of all cells along the flow path from cell *x* that are vulnerable to surface water flooding (>0.1% probability per annum). The flow path only extends as far as the first permanent watercourse downhill from cell (*ie* excludes river/stream flow). The risk contribution may be understood as the sum of all downstream buildings at risk of surface water flooding (see figure 1).

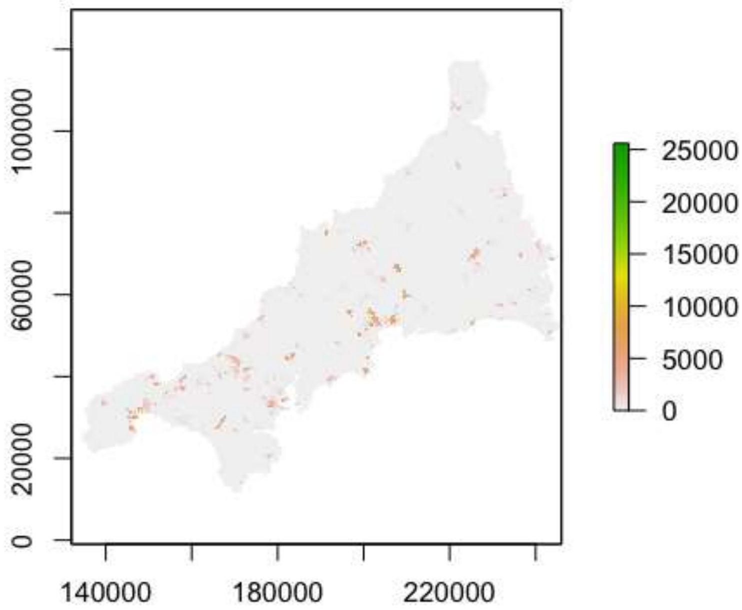


Figure 1: Contributions to surface water flood risk expressed as the area of downstream buildings (m2) at risk of surface water flooding,

ii. Contribution of upstream catchment to downstream flood risk from river and sea.

The flood risk contribution of a cell to downstream river flooding was calculated by estimating its contribution to peak flow at downstream river nodes prone to flooding.

The contribution of each cell *x* ($Rrisk_x$) may be defined as:

$$Rrisk_x = \sum_{i=1}^{i=n} (CP_{xi} * PV_i)$$

n = the number of vulnerable downstream river nodes.

CP = contribution of cell *x* to the peak flow at node *i* (value 0 to 1.0)

PV = risk value at node *i*.

In terms of calculation, the following analytical steps were followed:

- All PVA cells were assigned to their nearest river/stream node (defined as a branch in the watercourse network) with the risk value of each node equal to the sum of the PVA of assigned cells.

- The upstream catchment area for each PVA node was calculated from a hydrologically corrected DEM (see technical notes).

- The flow times from each cell to each downstream PVA node was calculated from the flow path and by applying the modified Manning's equation to estimate relative flow velocity for each cell. The Mannings coefficients for different landcover types are described in the technical notes.

- The contribution of each cell (*CPi*) to peak flow at each PVA node is calculated by fitting a log-normal distribution to flow times, estimating the probability density function of this distribution, weighted by the maximum value of the function.

The rick value of a single cell will equal the sum of its contribution to the peak flow of all downstream river nodes multiplied by the PVA value of each node.

Figure 2 (a) shows the resulting estimates of contributions to downstream risk and (b) shows the same risk but weighted by the size of the upstream catchment, normalised to a scale of 0 to 100 (curtailing upper values to the 0.99 quantile to reduce the effect of extremes). The logic of dividing by catchment area is that the relative contribution to downstream risk of a single cell will be less when it forms part of a large compared with a small catchment.

The two maps highlight different catchment types. In the unweighted map (a), larger catchments, with greater downstream areas at risk, are emphasised. In contrast, the weighted map (b) highlights smaller, typically 'flashy' catchments. Figure 3 overlays Environment Agency rapid reaction catchments, showing how these rapid reaction catchments are sell represented in the weighted flood rick contribution map.

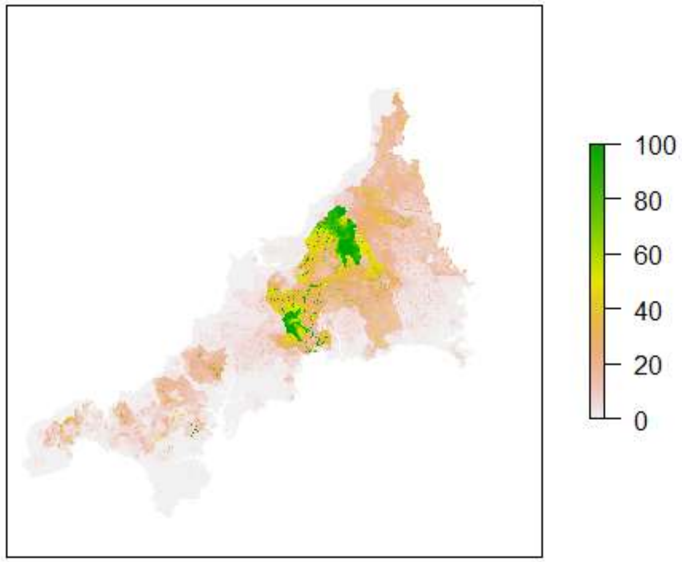
In terms of using these flood contribution maps to inform our prioritization and opportunity maps we adopted the map weighted by catchment area as it assigns a value to individual cells while accounting for the size of the wider catchment. Ideally, the choice of map should be informed by the type and scale of any intervention the mapping is to inform. Smaller flood-prone catchments are likely to give the greater potential benefits per 'grid cell', but if catchment-wide interventions are being looked at, a non-weighted map of landscape flood-risk contributions may be more appropriate.

iii. Floodplain risk contribution

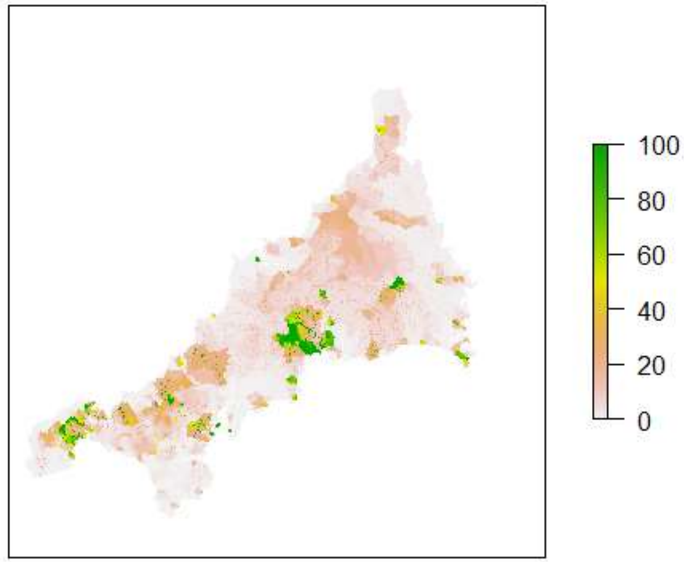
The floodplain zone is defined as all areas that are within a river or sea flood zone. All cells within these zones were given a floodplain risk 'contribution value' equal to the sum of the PVA risk value of every downstream river node (normalised as above).

iii. Riparian zone risk contribution

The riparian zone is defined by applying a buffer (30m or 50m depending on the resolution of the analysis) to all open watercourses. All cells within these riparian zones were given a riparian flood risk 'contribution value' equal to the sum of the PVA risk value of every downstream river node (normalised as above).



a)



b)

Figure 2: Contributions to downstream river/sea flood risk expressed as (a) unweighted by catchment size and (b) weighted by catchment area. In (b) the river catchment areas, such as the Camel and Tamar, are given less emphasis due the large catchment area compared to downstream area of flood risk.

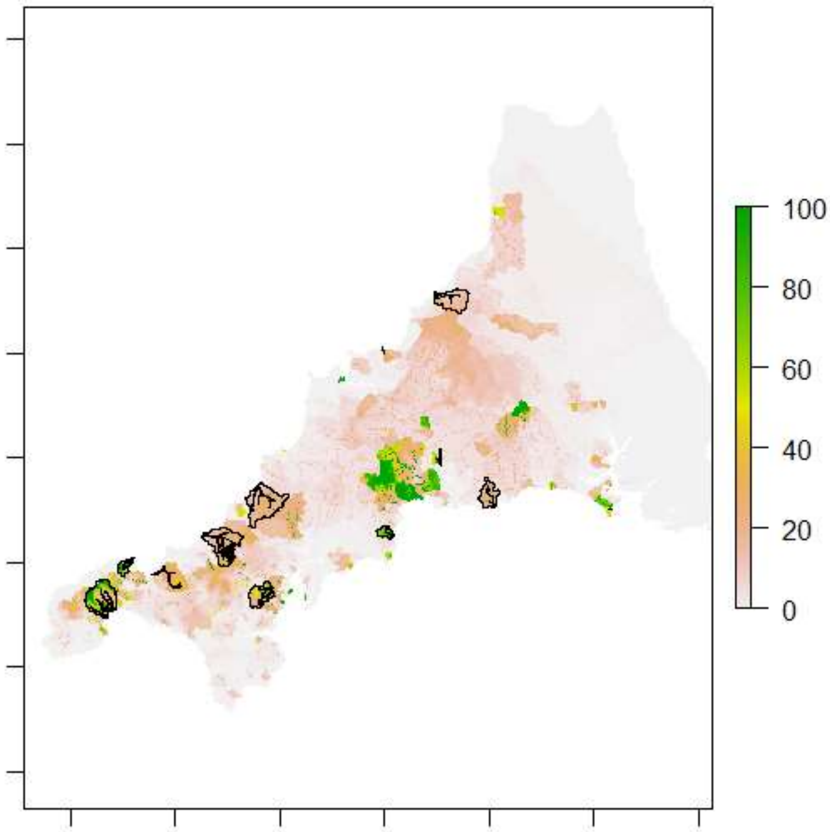


Figure 3: Contributions to downstream river/sea flood risk weighted by catchment area overlaid with EA rapid reaction catchment polygons (black)

Estimating a combined flood risk contribution of the landscape

A combined flood risk contribution is firstly estimated from summing each cell's risk contributions to surface water flooding (i) and river/sea flooding (i). This value is then weighted by rainfall intensity and the percentage of surface water runoff for the soil type attributed to each cell (see technical notes for the sources of this information).

The total contribution of each cell to surface water and river/sea flood risk, *SWRrisk*, can therefore be expressed as:

SWRrisk = (*SWrisk* + *Rrisk*) x SR

Where SR is a value from 0 to 1.0 relating to the soil runoff and rainfall.

The final floodrisk value attributed to a cell is the **maximum** of *SWRrisk*, the floodplain risk and riparian zone risk. The method emphasises the importance of the riparian and floodplain areas in contributing to, and mitigating, flood risk. The final flood risk values are normalised and scaled from 0 to 100.

Estimating landcover flood mitigation values

Each of the paths by which the landscape may contribute to flood risk is also associated with potential mechanisms by which landcover can mitigate flooding, namely:

(i) Slowing or interception/infiltration of direct surface water overland flow,

(ii) Slowing or reduction of downstream peak river flow,

(iii) Floodplain habitats augmenting water infiltration and slowing flow,

(iv) Riparian habitats slowing water course flow,

For each habitat type we have attributed a simple value from 0 to 1.0 (see table 3.1) reflecting a judgement of the relative mitigation value of the habitat when considering these potential effects.

The **existing** flood mitigation value (*FMV*) of each cell *x* can therefore be expressed as:

$$FMV_x = (Frisk_x * LC_x)$$

Where $Frisk_x$ = flood risk value of cell *x* and LC_x = sum of all habitat mitigation values (0 to 1.0) weighted by the percentage cover of that habitat within each cell. The landcover value of built-up environments was related to the estimate of vegetation derived from NDVI.

Types of map

Mapping the **total landscape risk contribution** $(Frisk_x)$ can be used as an indicator of the potential contribution of the landscape to downstream flood risk. The risk contribution provides an indicator of the potential *flood* mitigation benefits that could be generated for example by woodland and/or wetland creation.

Mapping the **flood mitigation value** (*FMV*) of each cell is used to provide a relative flood mitigation service ecosystem value across Cornwall.

For mapping purposes both risk contribution and mitigation values were normalised to a range between 0 and 100.

Uses and Applications

Assigning relative flood risk contribution and mitigation values to a whole landscape can at best be only indicative, as there are numerous methodological limitations to the approach adopted.

Some of the key factors that need to be considered when making use of the resulting maps are outlined below.

- **Maps are indicative of where land cover change (habitat removal or creation) is most likely to have an effect on flood risk.**
- **The risk contribution map indicates catchment areas where habitat creation might form a key part of natural flood mitigation interventions.**
- **The flood mitigation value indicates habitats where habitat removal is most likely to augment downstream flood risk.**
- **Maps give no indication of flood mitigation value, or risk contribution, of landcover where there is no downstream at-risk area.** The value of an ecosystem service derives from the 'demand' for that service. Where there is no demand, a service will have no 'value'. The highest existing and potential flood mitigation values are therefore found in catchments with the highest downstream flood risk (defined by built-up areas at risk of flooding).
- **The maps are not suitable for capturing the effect of large-scale modification of the land cover of a catchment.** Large-scale alteration of the landcover of a catchment can significantly alter the overall contribution of the landscape to factors such

as downstream peak flow, which would require more dynamic modelling to estimate impacts.

- **The highest risk contribution and mitigation values are found in catchments with the highest built-up areas at risk of flooding per upstream catchment area.** These tend to be small, 'flashy' catchments with buildings at risk of flooding.
- **No account is taken of sub-surface drainage patterns** or of areas benefitting from flood protection' or food storage areas.
- **No account is taken of watercourse characteristics** affecting flow velocity for the calculation of contributions to peak.
- **Flow from lakes and reservoirs is enforced by the hydrological DEM used in the methodology.** This may over-estimate the contribution of reservoir catchments on downstream flooding
- **The presence of transport infrastructure at risk of flooding is not accounted for**, such as main road and railways within flood zones.
- **The effect of land management practices are not included.**
- **Effect of soil transport on flood risk has not been included**

References

Broadmeadow S, Thomas H, Nisbet T. 2014. *Opportunity mapping for woodland creation to reduce diffuse water pollution and flood risk in England and Wales*. Forest Research March 2014. Forest Research, Surrey, 41pp.

Forbes H, Ball K & McLay F 2015 SEPA Natural Flood Management Handbook. Scottish Environment Protection Agency. ISBN number: 978-0-85759-024-4

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Nisbet T, Silgram M, Shah N, Morrow, Broadmeadow S. 2011 *Woodland for Water: Woodland measures for meeting Water Framework Directive objectives*. Forest Research Monograph, 4, Forest Research, Surrey, 156ppP

Thomas H, Nisbet TR 2006 *An assessment of the impact of floodplain woodland on flood flows.* Water and Environment Journal 21:2, 114-126.

Data sources – use and copyright

Data used in the creation of this and the other ecosystem service maps on Lagas are listed here.