Land use change and the water environment of the West Weald over a 30-year period 1971–2001

R. Howorth and C. Manning

Introduction

This study was initiated by the West Weald Landscape Project (WWLP), working with the Environment Agency to establish the links and potential benefits of a more natural landscape through the provision of 'ecosystem services' to the water environment. The WWLP is a partnership initiative working towards an enhanced and more naturally functioning landscape in the West Weald, for the benefit of both wildlife and people. This landscape-scale focus covers an area of 240 km^2 in West Sussex and Surrey at the western end of the clay-based Low Weald. The West Weald is one of the most wooded landscapes in the UK, 21% of the area being ancient woodland, including the internationally important nature conservation sites of Ebernoe Common and The Mens Special Areas of Conservation (SACs), both Sussex Wildlife Trust (SWT) nature reserves. The project aims to stabilise and enhance the biodiversity of core forest areas, whilst working across the wider countryside to encourage more sympathetic and integrated land management. SWT is actively pursuing landscape 're-naturalisation' around its reserves, including at an area of ex-arable land adjacent to Ebernoe Common, Butcherland fields, which is undergoing natural reversion towards a future forest mosaic and where the former agricultural drainage ditches have been filled in to hold up water.

Landscape-scale management that fosters a more natural environment offers the potential for enhanced ecosystem functioning and operation of natural processes, potentially building greater resilience to predicted climate change impacts and providing expanded 'ecosystem services' to human society. Such an approach fits well with the EC Water Framework Directive being implemented by the Environment Agency, with its focus on integrated river basin management to safeguard and restore aquatic ecosystems. The potential hydrological benefits of more natural landscapes include: extended lag times between rainfall events and corresponding river flow, due to water being held for longer on the land by vegetation; greater attenuation of high flow regimes in watercourses, diminishing extreme flood peaks downstream; and improved water infiltration to the better-structured soils found under woodland, reducing surface runoff production, rill/gully erosion and sedimentation of water courses (Cook *et al.*, 2005). Possible water quality benefits include reduced nitrate pollution levels and potential reduction of some toxins entering watercourses (Cook *et al.*, 2005). There has been a lack of comprehensive supporting evidence in the UK on the significance of land use (particularly arable agriculture) in influencing hydrology and flood risk at the catchment scale, whereas a clear link has been found at the local (field) scale between agricultural intensification and increasing flood impacts from rapid surface runoff (O'Connell *et al.*, 2004).

Methods

Two principal adjacent catchments of similar size and characteristics were selected for study in the West Weald Landscape Project area. The River Kird catchment covers an area of 67 km^2 based on the Low Weald clay and is dominated by arable agriculture but contains much woodland. The River Lod catchment to the west covers an area of 52 km^2, is dominated by woodland rather than arable land, and rises on the Lower Greensand ridge before flowing over the Weald clay. A third smaller (sub-) catchment, Petworth Brook, covering an area of 15 km^2 was included for land use and water quality trend analysis.

Land use

West Sussex County Council (WSCC) provided land use data from their series of Phase 1 equivalent habitat surveys for the period 1971–1981–1991–2001, the area statistics of which were analysed using ArcView GIS for each decade for the whole project area and in each of the three catchments. WSCC Map Plot habitat data comprising hectare grid centroids (based on the most abundant habitat, except in 1971) was used rather than actual polygon data, which exist for 1991 and 2001 only. Differences in classification systems existed between the years 1971, 1981 and 1991/2001, thus habitat codes were compared as far as possible following the system of Middleton (2005). Individual habitats were aggregated into six broad habitat types: woody vegetation (woodland and scrub); non-woody permanent vegetation (grasslands mainly); arable and bare ground/rock; surface water**;** built-up land; and other/miscellaneous.

Hydrology

The Environment Agency provided rainfall gauge data and river flow telemetry station data covering a 30-year time period (*c.* 1970 onwards) for the two main catchments of the Rivers Kird and Lod. Flow duration curves (FDCs) based on daily mean flow data were generated to assess changes in the distribution of flow over the study period and each individual decade. The decadal FDCs for each river were subjected to a paired T-test to determine any significant difference between time periods. Average daily rainfall for each decade was calculated using one shared gauge station, and average daily potential evaporation was also calculated. Principal Components Analysis (PCA) was performed to investigate any structure in the relationships between the hydrological, climate (average daily rainfall and potential evaporation) and land use (area coverage of the six broad habitat types) variables over the study time period. A separate PCA was conducted for the fifth (Q_5), fiftieth (Q_{50}) and ninety-fifth (Q_{95}) flow percentiles to identify whether any relationships were consistent over the range of high, medium and low flows respectively.

Water quality

Water chemistry data including the general quality assessment (GQA) variables of biological oxygen demand (BOD), ammonia and dissolved oxygen (DO), as well as pH, nitrate and orthophosphate, were supplied by the Environment Agency for the three catchments covering the majority of the study period (from 1976/77 generally). A regression line was fitted against the values for each sampling station in each of the three GQA variables to assess any trends over time. The chemical GQA classes were provided for each station for 1990–2004 and the equivalent pre-1990 classes were calculated, and a regression line was fitted against the time series values. A PCA was performed to assess the relationships over the study period between chemical water quality (nitrate and orthophosphate only, as the GQA variables yielded no meaningful results), climate and land use, to identify any potential influence of changing land use on altering the chemical signature of the rivers. Biological data existed for a shorter time period of *c*. 13–15 years (1989–2005 maximum) in the project area, consisting of aquatic macro-invertebrate family abundances and the calculated measures of average score per taxon (ASPT), number of taxa, and family lotic invertebrate index for flow evaluation (LIFE); a regression line was fitted against the time series data of each variable to assess trends. Predicted ASPT scores for unpolluted conditions enabled calculation of an ecological quality index (EQI) against actual scores, with a regression line again fitted. No analysis of the biological water quality data against land use was possible due to the short duration.

Results

Land use

Significant changes in land use have taken place over the study period across the whole West Sussex project area (Figure 1), principally between the 'non-woody permanent vegetation' (mostly agriculturally 'improved' grassland) and 'arable and bare ground/rock' (mostly arable agriculture) classes. Although arable land use initially declined in area during the 1970s, it subsequently increased dramatically (by about 250%) through the 1980s at the expense of improved grassland before then declining more gradually through the 1990s. This recent decline has been compensated for by woody vegetation (mostly broadleaved woodland), which until the 1990s had been steadily decreasing in extent but had expanded significantly to cover a third of the whole project area by 2001. Other broad habitat types cover a lesser area of the whole landscape. These general land use trends were repeated in each of the three catchments.

Hydrology

The FDC figures for each decade in the Kird and Lod catchments showed a statistically significant difference over the study period between the hydrological regimes of the 1970s and 2000s according to the paired T-tests. This is also supported by statistically significant differences between each decade in both catchments, apart from the 1980s–1990s for the Kird, and the 1980s–1990s and 1990s–2000s for the Lod. The FDCs for both catchments were found to become steeper over time, implying that they are becoming increasingly 'flashy' i.e. the lag time between the onset of rainfall and the peak flow in both rivers is becoming shorter. Table 1 displays the PCA correlation eigenvalue analysis over three flow regimes in the Rivers Kird and Lod for the first two principal components (accounting for >82% of the cumulative variance). A consistent pattern is evident across the range of flows in the River Kird, with a good relationship between flow and arable land use for Principal Component 1 (PC1), accounting for most variance in the dataset, shown through the higher correlations (of the same sign) of these variables. Rainfall has a comparatively weaker (negative) correlation with PC1, implying that land use (arable agriculture) is influencing the magnitude of flow generation in the Kird catchment. The positive correlations between flow and the land uses of 'woody vegetation' and 'built-up' land in Principal Component 2 (PC2) indicate that these also affect the magnitude of flow generation in the Kird catchment. The River Lod did not have the same consistent patterns between flow and land use as the Kird. The main relationship was found for the Q_5 (high) flow percentile, for which the strongest correlations occurred between flow and arable land for PC1 again, suggesting that land use is important in affecting the size of flow generation in the Lod catchment at high flows at least.

Water quality

The chemical GQA scores showed clear declines over time for each of the four sampling stations on the three water courses of the study (R^2 values >0.68 of the regression trend lines). Trends in the three individual GQA elements were far less marked and were variable, however.
Nitrate and orthophosphate displayed differing trends. Nitrate increased in the River Lod but was relatively stable in the Kird until 2000, with both rivers experiencing more recent declines; Petworth Brook had an increasing trend throughout the whole study period. Orthophosphate declined reasonably in both the Kird and Petworth Brook, but was relatively static in the Lod. The PCA for the three catchments is displayed in Table 2 (showing the first two principal components, accounting for >83% of the cumulative variance). A strong correlation was found in PC1 between arable land use and nitrate concentrations in Petworth Brook and the River Lod, whereas for the River Kird this correlation was only evident in PC2, implying a weaker relationship between surface runoff production from arable land use and in-stream nitrates. Orthophosphate concentrations showed no correlation with arable land use in any of the catchments studied.

The short biological EQI data series revealed differing

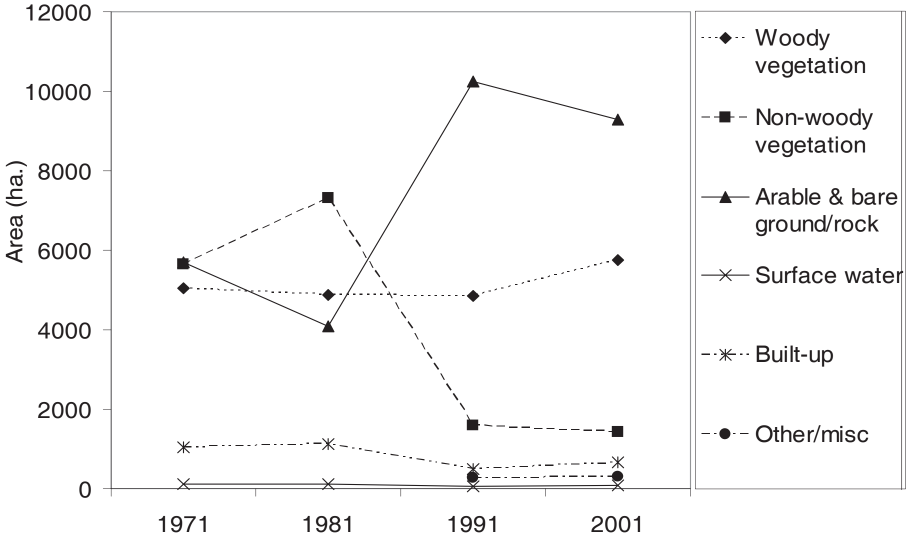

Figure 1 *Broad habitat changes in the whole project area of W. Sussex*

Table 1 Rivers Kird and Lod hydrological eigenvalue analysis

Flow percentile	*Q_5 (high)*		*Q_{50} (median)*		*Q_{95} (low)*	
Principal Component axis	*PC1*	*PC2*	*PC1*	*PC2*	*PC1*	*PC2*
RIVER KIRD						
Flow	0.308	0.445	0.25	0.544	0.216	0.579
Woody vegetation	0.331	0.394	0.338	0.365	0.34	0.36
Non-woody vegetation	-0.378	0.185	-0.385	0.176	-0.388	0.167
Arable	0.363	-0.278	0.369	-0.263	0.373	-0.252
Surface water	-0.261	0.156	-0.267	0.163	-0.272	0.141
Built-up	-0.345	0.354	-0.35	0.332	-0.353	0.321
Rainfall	-0.31	-0.465	0.389	0.103	-0.318	-0.424
Potential evaporation	0.302	-0.398	0.306	-0.367	0.308	-0.361
RIVER LOD						
Flow	-0.349	-0.345	-0.174	0.465	-0.181	-0.509
Woody vegetation	-0.299	-0.418	-0.23	-0.525	-0.3	-0.386
Non-woody vegetation	0.404	-0.214	0.442	0.011	0.43	-0.184
Arable	-0.383	0.287	-0.433	0.057	-0.41	0.252
Surface water	-0.049	-0.107	-0.056	0.256	-0.05	-0.168
Built-up	0.409	-0.218	0.452	-0.054	0.43	-0.176
Rainfall	0.355	0.364	0.304	0.383	0.359	0.361
Potential evaporation	-0.06	0.607	-0.164	0.537	-0.082	0.544

Table 2 *Eigenvalue analysis for chemical water quality in the three study catchments.*

	River Kird		*River Lod*		*Petworth Brook*	
Principal Component axis	*PC1*	*PC2*	*PC1*	*PC2*	*PC1*	*PC2*
Woody vegetation	0.294	0.384	-0.170	0.569	0.115	-0.687
Non-woody vegetation	-0.351	0.137	0.389	-0.045	0.412	0.075
Arable	0.337	-0.229	-0.383	-0.030	-0.411	0.047
Surface water	-0.350	0.145	-0.098	-0.129	-0.188	-0.684
Built-up	-0.317	0.312	0.407	-0.001	0.444	-0.005
Rainfall	-0.263	-0.458	0.254	-0.469	0.366	-0.198
Potential evaporation	0.277	-0.428	-0.179	-0.544	N/A	N/A
Nitrate	-0.246	-0.491	-0.319	-0.370	-0.445	-0.082
Orthophosphate	-0.357	0.049	0.361	0.043	0.289	-0.081

trends for the three water courses, with a substantial improvement ($R^2 = 0.40$) in water quality in the Kird, mixed trends in the Lod (although actual ASPT scores were all significantly greater than predicted, hence water quality was good) and a deteriorating trend ($R^2 = 0.28$) in Petworth Brook (although actual ASPT scores were again greater than predicted). Trends in ASPT followed those of EQI. Macro-invertebrate taxa diversity was stable in the Kird and Lod upstream over time, but showed a weak declining trend in the Lod downstream and Petworth Brook (R^2 values = 0.14 and 0.11 respectively). Family LIFE trends on flow showed increasing values in the Kird and Lod downstream but no real change in the Lod upstream or in Petworth Brook.

Discussion

The land use trends identified in the West Weald and its constituent catchments differ somewhat from the general trends found for the whole of West Sussex during the 30-year study period (Middleton, 2005). In the whole county, arable agriculture has been gradually decreasing since the 1980s to 53% cover in 2001 (a little less than the Kird, but significantly more than the Lod catchment). Much of the arable decline in West Sussex has resulted from increases in developed areas (Middleton, 2005), rather than being related to changing improved grassland and woodland cover as in the West Weald. Developed areas have increased in area during each decade in West Sussex, from 9.3% of land area in 1971 to 13.7% in 2001 (excluding transport infrastructure), greater than the rural West Weald with just *c.* 3–4% in the 1990s–2000s. Woodland cover (excluding scrub and plantation) in West Sussex declined from 12.9% to 10.7% of land cover from 1971 to 1991 and then increased to 12.2% by 2001, in common with the general trend of ‘woody vegetation’ in the West Weald, although a much greater proportion is present here at *c.* 30% cover. The differences in habitat classification methodology employed by WSCC over the study period reduce the accuracy of exact comparisons between decades (especially the 1970s) but do not negate the general trends.

Changing land use practices, principally arable agriculture, have been shown to be apparently contributing to an increasingly flashy flow regime in both the Kird and Lod subcatchments. Such increased responsiveness of flow regimes can be attributed to changes in land use conditions inducing increased surface runoff production (e.g. Boardman, 1990), apparently through the conversion of permanent improved grassland to arable cultivation. This is more apparent in the Kird catchment, which has a greater proportion of arable cover than the Lod, perhaps explaining the stronger PCA results. The influence of land use on hydrological regimes in the River Lod may only be observable at higher flows due to its greater baseflow component, with only greater rainfall events inducing surface runoff. Arable land use acts to induce more flashy catchments primarily due to a reduced vegetation cover density (Mitchell, 1990), reducing rainfall interception by vegetation and allowing saturation-excess surface runoff to be readily induced on UK soils (Morgan, 1996). Surface runoff can act as a significant soil erosion agent (Burt *et al.*, 1998), inducing field rill and gully formation and increasing sediment loads in rivers which can result in downstream flooding. The built environment also acts to increase surface runoff through the creation of impervious paved areas (Nelson and Booth, 2002), transmitting water to rivers within a shorter time interval and increasing the discharge for a particular storm recurrence interval, potentially inducing river bed and bank erosion. Built-up land use is relatively low (< 5%) in the West Weald, although it has likely increased over the study period, despite the contrary results obtained (due to changing classification), and may have increased the responsiveness of watercourses. Woody vegetation, in contrast, serves as a buffer against excessive rainfall runoff and reduces peak flows (Cook *et al.*, 2005). In natural well-forested areas, erosion and surface runoff is extremely limited, although groundwater recharge may be reduced in comparison to more open vegetation. According to the PCA analyses, the influence of woodland cover on flow regimes appears to be of secondary importance, however, featuring in the second PCA axis in the Kird catchment only. These results are based on just four observations of decadal land use, however; thus only limited confidence can be attributed to the influence of land use change, although it does provide a likely explanation for the hydrological changes observed.

The clear declining water quality trend in chemical GQA class in each of the three water courses is somewhat surprising, given the lesser trends of the three component GQA variables, although the West Weald does match the overall pattern across Sussex (S. Ashworth, *pers. comm.*). The causes of GQA declines may be a result of organic pollution or could be a consequence of declining DO concentrations, perhaps related to stimulation of algal biomass by nitrate. The nitrate increases evident in all rivers up to the year 2000 generally are the result of increasing agricultural fertiliser applications in farming which are now declining in some areas. The reduction in phosphate in the Kird probably indicates higher quality sewage effluents. The weaker PCA relationship between arable land use and nitrate concentrations in the River Kird (along with runoff production from rainfall) might be explained by its lower average nitrate concentrations, despite the greater proportion of arable agriculture, than the Lod. This arable–nitrate relationship is consistent with the hydrology PCA, with increased arable land use being linked to increased runoff, changing hydrological regimes and detrimental increases in nitrate concentrations. Confidence in these inferences could be increased through more observations, although they do support the extensive qualitative evidence. The biological water quality data partly contradicted the water chemistry trends furthermore, and thus the overall water quality evidence is not conclusive.

Conclusions

Land use changed markedly over 30 years in the study area, especially through increased arable land use in the 1980s and more recent increases in woody vegetation cover, suggesting that a more natural landscape is now developing in the West Weald. River flow became more responsive or flashy over the study period, and this was principally related to the increase in arable land use, especially in the River Kird. The shorter time series of water quality data revealed contrary trends between chemical (declining GQA) and biological (improving EQI) measures, although a relationship was found between arable agriculture and nitrate. Sensitive catchments may require changes in land use rather than simply altered land management practices to address water problems. A future landscape with more permanent (woody) vegetation has the potential to benefit the water environment through greater attenuation of high flow regimes, reduction of downstream flooding, reduced land runoff and enhanced soil percolation. Further research could usefully focus on assessing trends in changing lag times between rainfall events and river flows and prediction of the implications of changes in land use and climate using hydrological catchment models.

Acknowledgements

Funding came from the Environment Agency Sussex Area's Fisheries, Recreation & Biodiversity section to the West Weald Landscape Project to undertake this study; the support of the Hydrometry, Water Resources, Chemistry and Biology sampling sections, and the Environment Agency Southern Region's Hydrology section was also invaluable. West Sussex County Council (WSCC) kindly allowed use of its Phase 1 habitat data.

References

Boardman, J., 1990. Soil erosion on the South Downs: a review. In: *Soil Erosion on Agricultural Land,* J. Boardman, I.D.L. FosterJ.A. and Dearing (Eds.), Wiley, Chichester, UK. 88–105.

Burt, T.P., Matchett, L.S. and Haycock, N.E., 1998. Floodplains as buffer zones. In: *United Kingdom Floodplains,* R.G. Bailey, P.V. Jose and B.R. Sherwood (Eds.), Westbury Publishing.

Cook, D., Greenaway, T., Southgate, F. and Brocklebank, H., 2005. *Floodplain Forest Concept Study*. Sussex Otters & Rivers Project, Sussex Wildlife Trust.

Middleton, J., 2005 *Land use and habitat change in West Sussex: 1971-1981-1991-2001.* Records Centre Survey Unit, Sussex Wildlife Trust.

Mitchell, D.J., 1990. The use of vegetation and land use parameters in modelling catchment sediment yields. In: *Vegetation and Erosion,* J.B. Thornes (Ed.), Wiley, Chichester, UK. 289–310.

Morgan, R.P.C., 1996. *Soil Erosion and Conservation* . 2nd Edition*.* Longman, UK.

Nelson, E.J. and Booth, D.B., 2002. Sediment sources in an urbanizing, mixed land use watershed. *J. Hydrol.*, **264***,* 51–68.

O'Connell, P.E., Beven, K.J., Carney, J.N., Clements, R.O., Ewen, J., Fowler, H., Harris, G.L., Hollis, J., Morris, J., O'Donnell, G.M., Packman, J.C., Parkin, A., Quinn, P.F., Rose, S.C., Shepherd, M. and Tellier, S., 2004. *Review of impacts of rural land use and management on flood generation. Part A: Impact study report.* Technical report for DEFRA Flood & Coastal Defence R & D project FD2114.