PREDICTING THE SPATIAL DISTRIBUTION OF COLOURED WATER IN NORTH YORKSHIRE

G.N. Mitchell and A.T. Mc Donald

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G.N. Mitchell and A.T. McDonald

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School of Geography, University of Leeds

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G.N.Mitchell[1] and A.T. McDonald[2]

ABSTRACT - A model to predict the spatial distribution of discoloured water is tested against colour observations from the Upper Nidd valley, North Yorkshire, UK. The model is weighted to account for moorland burning and artificial drainage. The weighted model is able to accurately predict the intensity and distribution of coloured water draining 15 sub-catchments. The applications of the model are seen in colour hazard mapping and in providing data necessary to the operation of an effective colour reducing catchwater management strategy.

Keywords: Colour prediction; Hazard mapping; Catchwater management; moorland ditching; moorland burning.

INTRODUCTION

Runoff discoloured by naturally occurring organic material is a problem for water resource managers. Discoloured water causes consumer complaint, increases mobilisation of some metal ions, is associated with acid flushes, and can produce mutagens on chlorination. These problems can be addressed by improved water treatment, and by reducing the colour of water arriving at treatment works. Reductions in raw water colour can be achieved

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1.Research Assistant,

2.Chairman,

School of Geography, University of Leeds, Leeds, LS2 9JT.

by a combination of catchment and catchwater management strategies.[1]

The relationship between the spatial distribution of discoloured water and catchment characteristics has been determined for an upland catchwater system in the Upper Burn valley, North Yorkshire, UK.[2] Primary non-point sources of colour were identified as areas of Winter Hill peat with slopes $\leq 5°$, particularly those with high drainage densities. Heather burning and moorland gripping were identified as land management practices likely to increase water discoloration. These findings are in broad agreement with those derived from earlier studies in the Upper Nidd and Elan valleys.[3,4] A stepwise regression procedure allowed the development of a model to predict the spatial distribution of water discoloration. Coloured water was also found to be closely associated with aluminium, iron and manganese in runoff. This indicated that strategies adopted to reduce the colour of raw water arriving at treatment works were likely to have the added advantage of reducing the level of these metals.

The utility of such a model is twofold. Catchwaters can be managed to systematically exclude catchments from water gathering, so reducing the average reservoir colour whilst minimising loss of yield. The operation of such a strategy is dependent on a knowledge of the spatial distribution of coloured water in the catchwater. A predictive model thus enables the likely spatial distribution of colour within a catchwater to be determined without recourse to an intensive colour survey.

Catchwater manipulation is a strategy not always available to catchment managers. Under these circumstances it is particularly important that managers are aware of which catchments will give the severest colour response to land management operations. The model therefore aims to identify those sub-catchments in a catchment system that are most sensitive to these operations. For the uplands the land management practises identified as important in water discoloration are artificial drainage and heather burning, important to maintain and improve the quality of grouse moor. The model can thus also be applied to produce simple colour hazard maps, aiding catchment managers in land use decisions.

MODEL TESTING

The model, built from data collected from the upper Burn valley, predicts the Colour of water draining upland catchments. The model M_u has the form:-

$$\text{Log}_{10}\text{Colour} = 0.00512(\%\text{TCLA}_{5°}) - 0.609(\text{MSS}) + 0.00368(\%1011\text{b}) + 0.21435 \qquad (1)$$

Where for each sub-catchment:

$\%TCLA_{5°}$ Per cent of Total Channel Length in area with slope ≤5°.

MSS Main stream slope[5]. Slope between 10 and 85 percentiles of main stream length.

%1011b Per cent catchment coverage by the Winter Hill Soil association

The performance of this predictive model was tested using data collected from the Upper Nidd valley. An accurate picture of the spatial distribution of colour in the How Stean catchwater of the Upper Nidd was determined from 32 separate snapshot exercises conducted between February 1986 and March 1987. The catchwater has a total area of 17 km^2. The mean observed colour at each intake along the catchwater, and the colour predicted by the model M_u are presented in Table I.

The difference between observed and predicted Colour was analysed using a t-test (Table II) and a Wilcoxon matched pairs signed rank test (Table III). The t-test compares population means and is a measure of the degree to which the mean colour of the entire catchwater is predicted. The Wilcoxon rank test takes into account the relative magnitude of the individual cases that make up the catchwater mean and so measures the degree to which the spatial distribution of observed and predicted colours match.

Both tests show that there is a significant difference between the observed and predicted colours using model M_u, although they are significantly correlated ($R= 0.61$, $P<0.01$, $N=15$). The performance of model M_u is relatively poor, tending to underestimate the colour levels. This is attributed to the particularly high incidence of artificial ditching and moorland burning, previously identified as colour producing operations, practised on the How Stean catchments. However, the colour of water from four sub-catchments with low artificial drainage intensities and no evidence of moorland burning was predicted to within 1 au/m. This, and the significant correlation, indicates that the model M_u is likely to perform well in less intensively managed moorland catchwaters. However, intensively managed moorland catchments are likely to contribute the highest colour waters to reservoirs, and so these colour yields need to be accurately identified by the model.

In an earlier paper the initial model was developed. At the site of this development no measures of drainage intensity were investigated. However, in the application of the model to the present test site we note that significant areas of ditching exist in these catchments that have marked deviation in colour yield from that predicted. Thus, the initial model, Mu in (1) above, was weighted to represent the influence of moorland drainage. A spreadsheet was used to optimise model performance with the addition of a factor to represent drainage intensity. This was calculated as

$$f_{di} = 0.1\ (\log_{10} Di + 0.854)$$

When Di = drainage intensity in km/km^2

which when incorporated into the regression model produces a new model M_d with the equation:-

$$\log_{10} \text{colour} = 0.00512\ (\%\ \text{TCLA}\ 5^{o}) - 0.609\ (\text{MSS}) + 0.00368\ (\%\ 1.11\ b) + 0.1 \log_{10} Di + 0.29975 \qquad (2)$$

Such a development could not formally be incorporated into the multivariate framework because of its absence from the generative dataset.

Whereas definitive data on the areal extent of ditching could be determined at the application site, the influence of burning is much more difficult to quantify in terms of burn temperature, age and areal extent. The prediction power of the model can be significantly improved by the adoption of a multiplier (M_{d+b}) as below:

$$Log_{10}Colour = (0.00512(\%TCLA_{50}) - 0.609(MSS) + 0.00368(\%1011b) + 0.1((Log_{10}DI) + 0.29975) \times b \quad (3)$$

Where b = 1 if no burning evident, 2 if burning is evident.

Because of the crude nature of the data available optimisation procedures that depend on internal data are not available and thus the weighting is retained as a simple multiplier. Note, however, that it does not result in the doubling of colour but acting through the log transformation does yield an R value of 0.8.

The Colour of water predicted by these weighted models for each intake is shown in Table I. Table II shows that both weighted models are able to predict the mean catchwater colour. Table III shows that both weighted models are also able to predict the spatial distribution of colour within the catchwater. This demonstrates that the weighted models are successful in predicting water colour at each intake.

Model M_{d+b} in (3) produces the best prediction. The greatest errors are for Armathwaite and Dunlin intakes. Armathwaite intake is over estimated as the burning weighting is crude, simply presence or absence. Whereas the majority of the catchments reported here are small, Armathwaite is much larger. Thus, the presence of burning will, for most catchments, be a catchment wide influence but in the case of Armathwaite is likely to influence only part of the calculation. Including detail on the areal extent of burning should improve this prediction. Dunlin intake is under-estimated, possibly due to the high variance in the observed data.

DISCUSSION

The model is effective in predicting the magnitude, and the spatial distribution of coloured waters in an upland catchwater. It is therefore able to provide the colour data necessary to the operation of an effective catchwater management strategy.

The model can also be used for hazard mapping. In catchments where no water sampling has taken place, the model is useful in identifying catchment areas that have the highest potential for discolouring water. These areas should be avoided when grouse moor improvements are planned. If these areas cannot be avoided, the weighted model should enable catchment managers to predict the equilibrium colour level following burning or ditching. It should be noted that for several months following these practices colour levels will be much higher than the equilibrium level, and depend on the time of year the ditching or burning took place.[1]

Wherever possible such models should be simple to use. Catchment main stream slopes are readily derived from OS maps and Digital Terrain Models, while the areal extent of Winter Hill peat can be derived from soil maps. Where soil maps are not published at the required scale they may be obtained from the Soil Survey and Land

Use centre. The variable $\%TCLA_{50}$ is potentially time consuming to calculate, particularly where many catchments are involved, and could be dropped from the model, which then gives greater weight to the Winter Hill coverage. However, this reduces the ability of the original model to account for the spatial variation of colour in the Upper Burn catchwater from 81.6 to 57.0 per cent. There is therefore a trade off between ease of use and model performance. Nevertheless, even the full model should be a more cost effective means of accurately determining mean annual colours than an intensive water sampling programme.

The weighted models await testing on a further independent catchwater. It is therefore recommended that before model implementation limited sampling, perhaps one 'snapshot', be conducted to confirm the distribution of colour predicted by the weighted model(s).

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Table I. Observed and predicted Colour (au/m at 400 nm) at How Stean intakes.

Intake	Observed Mean	σ	M_u	M_d	M_{d+b}
Armathwaite	10.37	(4.39)	5.37	4.59	21.00
Butts	2.67	(1.84)	1.40	1.20	1.43
Blackwell	4.92	(2.14)	1.42	2.15	4.64
Buskap	5.72	(5.52)	2.94	2.51	6.30
Crake	3.77	(3.30)	4.51	3.85	3.85
Aygill	6.46	(2.97)	4.58	4.34	4.34
Dunlin	6.99	(6.98)	1.59	3.61	3.61
Egret	7.64	(6.15)	2.80	8.64	8.64
Fieldeare	6.79	(3.18)	3.11	6.86	6.86
Staining	7.15	(3.14)	4.54	8.04	8.04
Blowing	4.45	(2.02)	3.54	5.89	5.89
Straightsteen	3.72	(1.87)	4.61	4.97	4.97
Grouse	11.59	(5.69)	9.44	11.58	11.58
Backstean	4.75	(2.78)	4.65	4.69	4.69
Little Backstean	4.17	(2.47)	3.38	4.16	4.16
	N = 32				

Table II. Comparison of Observed with predicted Colour (au/m) levels along the How Stean catchwater.

	Mean	δ	Association with obs colour R	t	2-tail prob
observed colour	6.0773	2.477	-	-	-
M_u	3.8587	2.001	<u>0.6146</u>	4.27	0.001
M_d	5.1387	2.715	<u>0.6765</u>	1.73	0.105
M_{d+b}	6.6667	4.655	<u>**0.8000**</u>	-0.75	0.468

<u>sig at 0.01</u> <u>**sig at 0.001**</u>

Table III. Wilcoxon matched pair signed rank test of observed and predicted colour for How Stean catchwater.

Model	Z	2-tailed prob
M_u	-3.0670	0.0022
M_d	-1.1927	0.2330
M_{d+b}	-0.6248	0.5321