Temporal dynamics and projected future changes in the nitrate leaching in a small river catchment dominated by under-drained clay soil grasslands: analysis of high-frequency monitoring data

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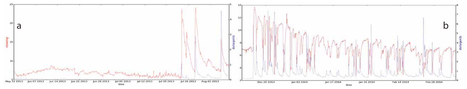
Introduction

Water pollution has long been an issue due to its adverse effect on human health and aquatic ecology. Eutrophication can lead to damage to natural ecosystems and the services they provide. Improvement of knowledge of pollutant behaviour and underlying catchment hydrology is still needed. Future projected climate change complicates the planning and implementation of mitigation measures as the different climate may impact the amount of nutrients leaving the river catchment in the future. The design of good mitigation measures will take into account the possible effects of climate change as well as current nutrient leaching patterns. New datasets of nitrate flux with high temporal resolution now provide the opportunity to consider the nitrate processes high level of detail, revealing the details of the processes. This poster presents an analysis of the nitrate dataset set from the River Eden Demonstration Test Catchment project and considers how these processes may be modified under projected climate change.

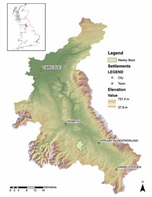


Stream flow and nitrate response for the Newby Beck Catchment in a, Summer and b, Winter

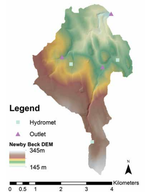
Newby Beck Catchment Location

Newby Beck is a sub-catchment of the River Eden, located in the north west of England and covers an area of 12.5 km^2. Newby Beck is an upland grassland catchment with a mix of dairy and sheep farming. The total annual rainfall ranges from 602 mm to 1264mm (for years 2011-2015, mean of 1042 mm). Average annual temperature ranges from 7.9°C to 8.9°C (for years 2011-2015, mean of 8.3°C). Soil is loamy and clayey with impeded drainage. The catchment hydrogeology is dominated by the superficial till deposits and hence a significant proportion of infiltration may result in relatively rapid shallow groundwater flow to the streams.

Newby Beck



The location of the Newby Beck sub-catchment within the River Eden catchment, Cumbria, England

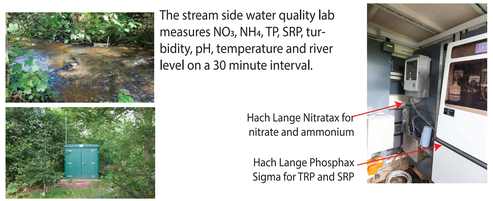


The Newby Beck sub-catchment , Cumbria, England

Aerial view of the Newby Beck catchment, Cumbria, England

Hydrological and Water Quality Monitoring

The nitrate concentration in the stream water is measured every 30 minutes using a Hach lange Nitratax stream side analyser. The results are cross verified with automatic water sampler and lab analysis. The catchment is equipped with an automated weather station (AWS). The catchment has three tipping bucket rain gauges. Water level is recorded using a combination of vented and non-vented pressure transducers. The stream has been gauged using both an ADCP or electromagnetic flow meter. Stage-discharge rating curves have been developed, which are used to convert water level into discharge. This dataset is from the River Eden Demonstration Test Catchment project (www.edendtc.org.uk).



The stream side water quality lab measures NO_3, NH_4, TP, SRP, turbidity, pH, temperature and river level on a 30 minute interval.

The data is then processed through the QA/QC process before being made available in the DTC data archive.

Statistical Methods

Understanding nitrate leaching patterns depends on transport (rainfall, soil hydrology) and source (supply) factors and can be investigated by observing hysteresis loops of storm events. Depending on the direction and shape of the loop, this approach gives information on the patterns of nitrate leaching: a straight line indicates a direct response of concentration to discharge, both peaking at the same time. Clockwise loops represent source limited processes and anti-clock wise loops represent transport limited processes.

The storm events were characterised by separation of hydrograph into base and storm flow and the calculation of a range of descriptors. Values for nitrate (mean, total flux, min, max, hysteresis direction & magnitude), discharge (average, total, start, peak, difference between start & peak discharge, time since last peak) & antecedent conditions (total rainfall, antecedent precipitation index, seasonality).

A correlation matrix was used to investigate how the antecedent variables are related to each other and to nitrate. To focus on the most relevant variables, stepwise multiple regression analysis was used.

Simulation Modelling Methods

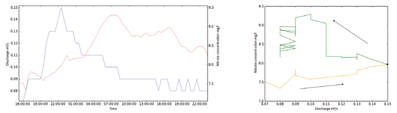
To predict the potential impacts of projected climate change on nitrate concentrations in stream water, the stepwise regression model was driven by simulation result from the HBV-Light catchment model and the UKCP09 weather generator. Predicting catchment discharge presents further uncertainties and hence the Generalised Likelihood Uncertainty Estimation (GLUE) method was used.

The predicted nitrate concentrations per storm event were calculated using the stepwise regression model. A sum of nitrate concentrations for each predicted series were calculated. The storm events within the projected future simulations were identified as described in the above statistical methods section.

Calculating the change between the nitrate for scenario and baseline resulted in a change factor (cf = (s-b) / b (where s is the scenario and b is the baseline) and plotting the change factors as a histogram shows the probability of change taking place, hence capturing the predictive uncertainty.

Statistical Results

Hysteresis analysis has shown the catchment to be dominated by storm events with clockwise loops (65% of total). There was also a clear seasonal distribution of clockwise to anti-clockwise hysteresis storm events. Summer and spring were dominated by anti-clockwise storm events while autumn and winter were dominated by clock-wise events. Hysteresis loop magnitude ranged from 0.28 to 12.84. Anti-clockwise hysteresis ranged from 0.32 to 12.84 while clock-wise hysteresis had magnitudes that were much smaller, ranging from 0.28 to 3.25. Clockwise events start with high amounts of nitrate being leached from the catchment; concentrations then decline either because the stream it is diluted by excess rainfall and runoff /drain-flow or because the nitrate source is depleted, or both. Anti-clockwise storm events, although not dominant, will result in large quantities of nitrate leached.

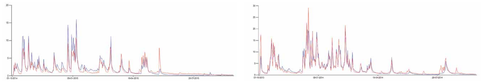


Storm event with clockwise hysteresis loop. Storm hydrograph (top) in blue with nitrate concentration superimposed in red. Concentration-discharge plot (bottom) of the same storm event, orange represents a rising limb, green represents a falling limb And the black circle marks the peak of the storm event.

Pearson's correlation matrix showS the average nitrate concentration to be correlated to seasonID and inversely to start discharge (both at P < 0.01), all the median temperatures prior to storm event and inversely to cosine curve (all at P < 0.001). Total nitrate flux is highly correlated to stormAPI (at P < 0.01), total rainfall, total discharge, peak discharge and [Qp-Qo] (all at P < 0.001).

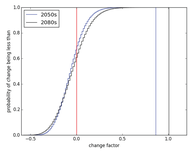
Simulation Modelling Results

The HBV-Light was calibrated for the hydrological years 2013-14 and 2014-15 on a daily basis. The validated model achieved a Nash Sutcliffe model performance statistics of 0.87. The model was then subjected to a blind performance assessment on the 2013-14 and 2014-15 hydrological years and achieved a Nash Sutcliffe model performance statistics of 0.83, indicating it was a good fit to the observed data. The measured and modelling discharge hydrographs from the model are shown in the figure below.



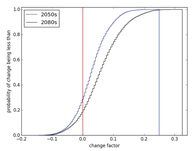
Measured and modelled discharge hydrographs showing the validation of the HBV-Light model

Annual River Discharge



Change factor graphs for river discharge in the 2050s and 2080s

Storm Nitrate Flux



Histogram of factor change for nitrate flux in the 2050s and 2080s

	AverageCons	EndOfFlux	StartWCons	DiffWCons	Hmean	HMagnitude
Time Since Last Peak	0.101	0.049	-0.286	-0.135	-0.127	-0.127
T-test RainBdf	0.168	0.127	0.157	-0.095	-0.147	0.129
antecAPI	-0.183	-0.184	-0.226	-0.101	-0.098	-0.101
Total Q	-0.206	-0.207	-0.070	-0.067	-0.088	-0.074
Total Q	-0.202	-0.203	-0.067	-0.064	-0.085	-0.071
Peak Q	-0.106	-0.107	-0.064	-0.071	-0.076	-0.092
Qp-Mean Qm	-0.205	-0.206	-0.014	-0.021	-0.035	-0.021
TMedian1	0.222	0.085	0.356	-0.084	-0.147	0.205
TMedian2	0.222	0.085	0.341	-0.070	-0.137	0.195
TMedian3	0.166	0.075	0.146	-0.029	-0.147	0.106
TMedian10	0.101	0.050	0.147	-0.036	-0.147	0.101
TMedian21	0.101	0.071	0.156	-0.142	-0.147	0.101
Season ID	-0.246	-0.021	-0.189	-0.142	-0.147	-0.101
Season Cos	-0.246	-0.098	-0.189	-0.142	-0.147	-0.101
	P < 0.1	P < 0.01	P < 0.05	P < 0.001		
100-200	0.255	0.325	0.189			

Stepwise regression has revealed the most important variables governing average nitrate concentrations being source related (temperature and time since last peak). Maximum nitrate concentration is governed by the same source-related variables (temperature and time since last peak) plus a slight influence by transport related variables (rainfall and discharge). Anticlockwise storm events, that produce the majority of the highest nitrate concentrations during storm events, are mostly observed when temperatures are higher and after prolonged droughts and are transport limited. Total nitrate flux is influenced by transport-related variables (total rainfall and the difference between peak and start discharge) with some influence from a source-related variable (time since last peak). The nitrate flux model (total rainfall, time since last peak and Qp-Qo) explains more total variability than models for any other dependent variable. The regression model explains 53.5% of the variance in total nitrate flux.

The HBV-Light model was used within the GLUE framework to predict changes in total discharge. The probability of there being no change in discharge by 2050s is 0.67. Hence, there is 33% probability of there being a positive change factor and thus a 33% probability of increase in discharge by the 2050s at the annual scale. Central estimate (probability of 0.5) for the 2050s shows the change factor being -0.06. There is 0.9 probability of change factor for discharge being less than 0.13. The probability of there being no change in discharge by 2080s is 0.61. Hence, there is a 39% probability of increase in discharge by the 2080s. Central estimate for the 2080s shows the change factor being -0.05. There is 0.9 probability of change factor for discharge being less than 0.18.

The probability of there being no change in nitrate flux by 2050s is 0.29. Hence, there is a 71% probability of increase in nitrate flux by the 2050s. Central estimate (probability of 0.5) for the 2050s shows the change factor being 0.03. There is 0.9 probability of change factor for total nitrate flux being less than 0.1. The probability of there being no change in nitrate flux by the 2080s is 0.18. Hence, there is a 82% probability of increase in nitrate flux by the 2080s. The central estimate (probability of 0.5) shows the change factor being 0.06. There is 0.9 probability of it being less than 0.15. The magnitude of nitrate flux increase will be larger by the 2080s than 2050s

Summary

This work informed the understanding of the hydrological dynamics of a drained clay soil grassland catchment and how nitrate leaching patterns depend on transport (rainfall, soil hydrology) and source (supply). The Newby Beck catchment is dominated by clockwise hysteresis events but anti-clockwise storm events still account for over one third of total storm events. Clockwise hysteresis storm events are source (or supply) limited. These events display initial increase in nitrate concentration due to readily available nitrate being mobilised through quick delivery pathways. It is then followed by a dilution of stream water. Nitrate concentrations are governed by preparatory processes of nitrate production at source in the soil. Projected climate change may act to alter these preparatory processes through increasing temperatures and more severe droughts in summer which would result in even more extreme nitrate leaching events. Combined with projected increase in winter temperatures, the increase in transport availability could act to increase the amount of nitrate leaving the catchment. It was estimated that there is a 71% probability of future nitrate flux increasing by the 2050s and an 82% probability of future nitrate flux increasing by the 2080s