Investigating the catchment hydrology of the River Chess using groundwater and river discharge data

Keywords: catchment hydrology, runoff generation, groundwater, land use change, water extraction, discharge, chalk

Key skills associated with this activity:

Draw line and scatter plots in Excel
Carrying out and interpreting correlation analysis
Interpret catchment hydrology for a chalk catchment
Understanding the link between groundwater, river level and discharge in a chalk catchment
Discuss runoff generation mechanisms in the context of a chalk catchment
Discuss the impact of urbanization on catchment hydrology

Context:

The River Chess is located in a region of England which is underlain by chalk geology. This chalk geology has a major influence on the landscape, on the plants and animals in the area and on the flow of water through the landscape. Chalk is naturally porous and can hold water within its pore spaces and cracks in the rock. Rainfall in a chalk catchment will infiltrate through the soil and down into the chalk where it fills the pore spaces, creating an aquifer. In the context of a chalk catchment, the groundwater is the water held underground in the chalk rock and soils. This water feeds the rivers in the catchment through springs, and by upwelling into the river bed. In this activity you will be investigating the relationship between the groundwater in the catchment and the flows in the River Chess using data supplied by the Environment Agency. This relationship is important to understand because human activity, such as groundwater extraction to supply drinking water, can alter groundwater levels and hence the flow of water in the river (See 'Where does my tap water come from?' for further information).

> Download the dataset of groundwater levels and discharge for the River Chess and save the file on your computer. Open the file and examine the contents. Note the units of measurement for groundwater levels and discharge.

Groundwater levels from this dataset were measured from a location north of Chesham using an observation borehole which is maintained by the Environment Agency.

The river discharge was measured at the Environment Agency gauging station at Rickmansworth (Grid Reference TQ065948). The National River Flow Archive compiled by the Centre for Ecology and Hydrology contains useful information about the gauging station including photographs of the weir that is used to continuously monitor water levels (https://nrfa.ceh.ac.uk/data/station/info/39088).

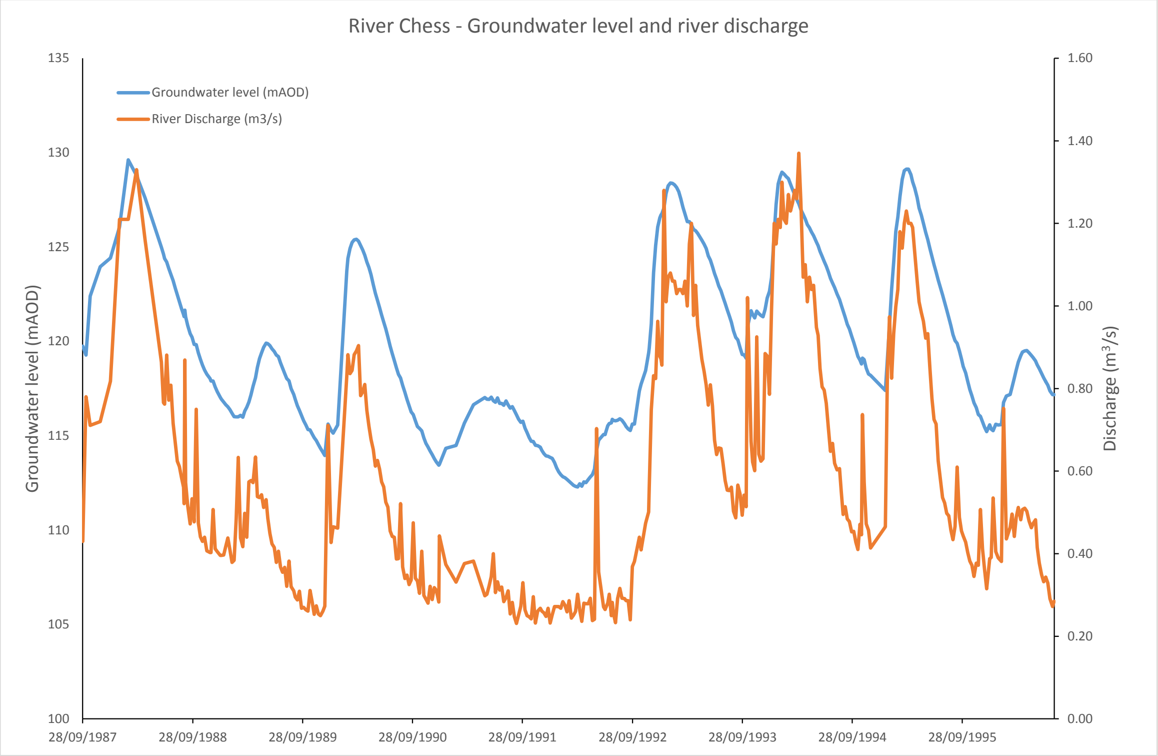
By this point you might be wondering what the units of measurement actually mean for discharge and for the groundwater levels. It is always important to state the units of measurement on any graph when reporting hydrological data.

mAOD stands for metres above ordnance datum. A datum is a reference surface which, in this case, is defined by the Ordnance Survey of Great Britain as the mean sea level at Newlyn in Cornwall between 1915 and 1921. So the groundwater level is measured relative to this mean sea level height. This allows hydrogeologists to assess the direction of flow of groundwater, and enables comparison of groundwater heights across the country.

m^3/s are the units of discharge which are commonly used in rivers, and can also be called 'cumecs' which is short-hand for cubic meters per second. This is a measure of the volume of water passing the point of measurement (in this case the gauging station) per unit of time (in this case every second). Sometimes discharge is referred to as river flow, however, flow can also be used to describe the velocity of water in a river so 'flow' can be a little ambiguous. We will stick to using the term discharge for the purposes of this exercise.

Activity 1: Use the interactive map on the ChessWatch site to locate Chesham and the gauging station at Rickmansworth.

Activity 2: Use EXCEL to plot a **line graph** of the data with time on the x (horizontal) axis, discharge (Units: m^3/s) on the primary y (vertical) axis and groundwater level (Units: mAOD) on the secondary y (vertical) axis. Try to replicate the type of plot below:



If you find this activity challenging then download our more detailed Activity 2 instructions designed to take you through the graph drawing step by step.

An important first part of analyzing any dataset is called exploratory analysis. Plotting this data as a line graph enables you to visualize and to explore patterns in the data.

Activity 3: Jot down bullet points of the key patterns that you see in the discharge and groundwater level.

Here are some points that you may have noticed:

- Discharge and groundwater levels seem to follow the same overall patterns over multiple years
- Both discharge and groundwater levels rise and fall on a yearly cycle and in some years this rise and fall seems more pronounced or exaggerated
- The curves in the groundwater levels look quite smooth but the discharge data looks more spikey

Let's take each of these bullet points in turn to see what our observations might tell us about the **catchment hydrology** in the River Chess. Each of the following exercises (corresponding to each observation above) can be tackled independently of one another:

(I) Explaining the patterns in groundwater and discharge data: Correlation analysis

(II) Explaining the patterns in groundwater and discharge data: The annual hydrograph

(III) Explaining the patterns in groundwater and discharge data: Runoff generation and examining the spikes in the discharge data

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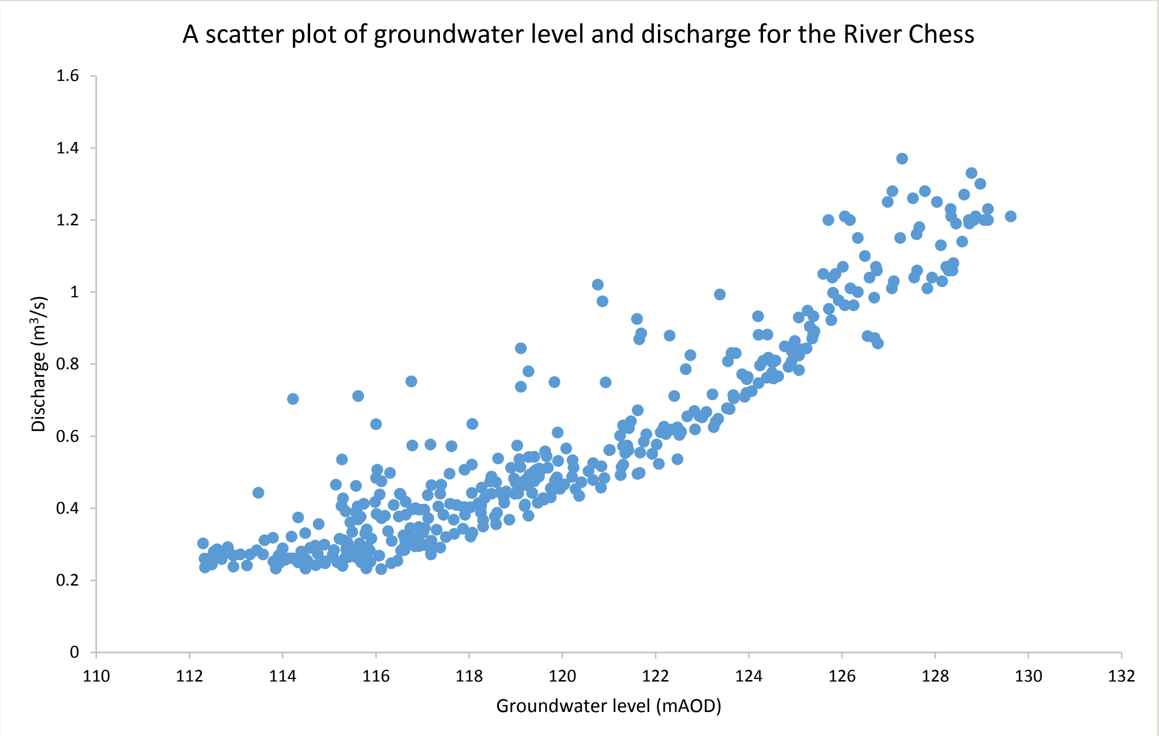
(I) Explaining the patterns in groundwater and discharge data: Correlation analysis

Our observation that discharge and groundwater levels follow the same overall pattern over multiple years might lead us to suspect that there is a relationship between the two variables. Furthermore the time series plot seems to suggest that the two variables are positively associated i.e. when groundwater levels rise, so does discharge (a negative relationship would mean that when groundwater levels rise then discharge falls). We can make a scatter plot in EXCEL to see if this is indeed the case.

Activity 1.1: Use EXCEL to plot a **scatter graph** of the data with Groundwater level on the x axis and Discharge on the y axis. Remember to give the graph a suitable title, and to label both the x and y axes with the variable name and units of measurement (in brackets). Try to replicate the plot below:



The human brain is very good at picking out visual patterns in datasets, but we also need a means of testing our observations and testing whether our hypotheses are statistically significant or whether they may have arisen from chance alone. We can mathematically test whether there is a relationship between groundwater level and discharge using correlation analysis.

Null hypothesis: There is no statistically significant relationship between groundwater level and discharge.

Alternative Hypothesis: There is a statistically significant positive relationship between groundwater level and discharge.

If you carry out a Pearson correlation analysis you will find that there is a significant positive relationship between groundwater level and discharge. The Pearson's correlation coefficient, r = 0.93 and is highly statistically significant (p<0.001). We can reject our null hypothesis and accept our alternative hypothesis.

Activity 1.2: Discuss why there is a statistically significant positive correlation between discharge and groundwater level.

Which is the dependent variable and which is the independent variable in this analysis? Remember that the independent variable is the cause whilst the dependent variable is the effect.

Does a rise in groundwater level cause a rise in discharge or does the rise in discharge cause the rise in groundwater level? See 'Where does the flow go?' and 'Where does my tap water come from?' for further information and help with your interpretation.

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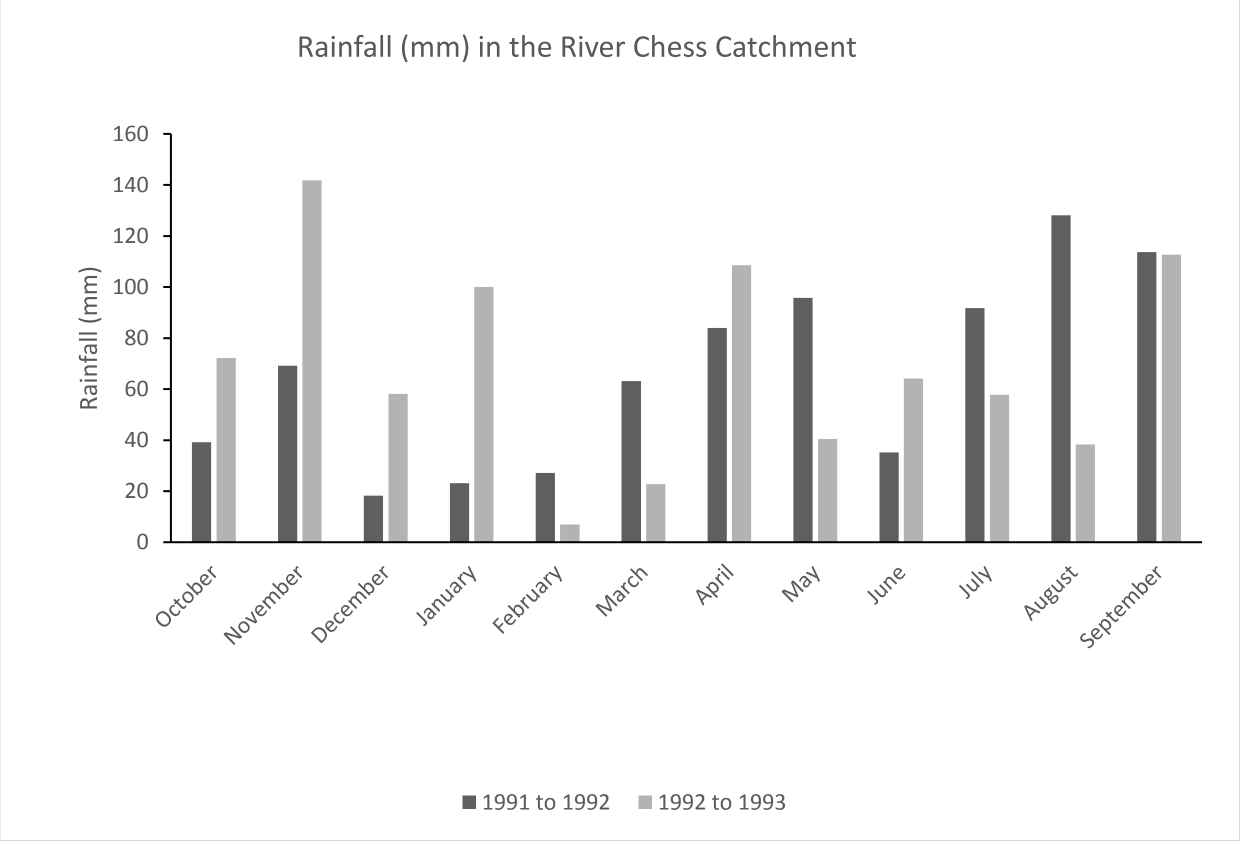
(II) Explaining the patterns in groundwater and discharge data: The annual hydrograph

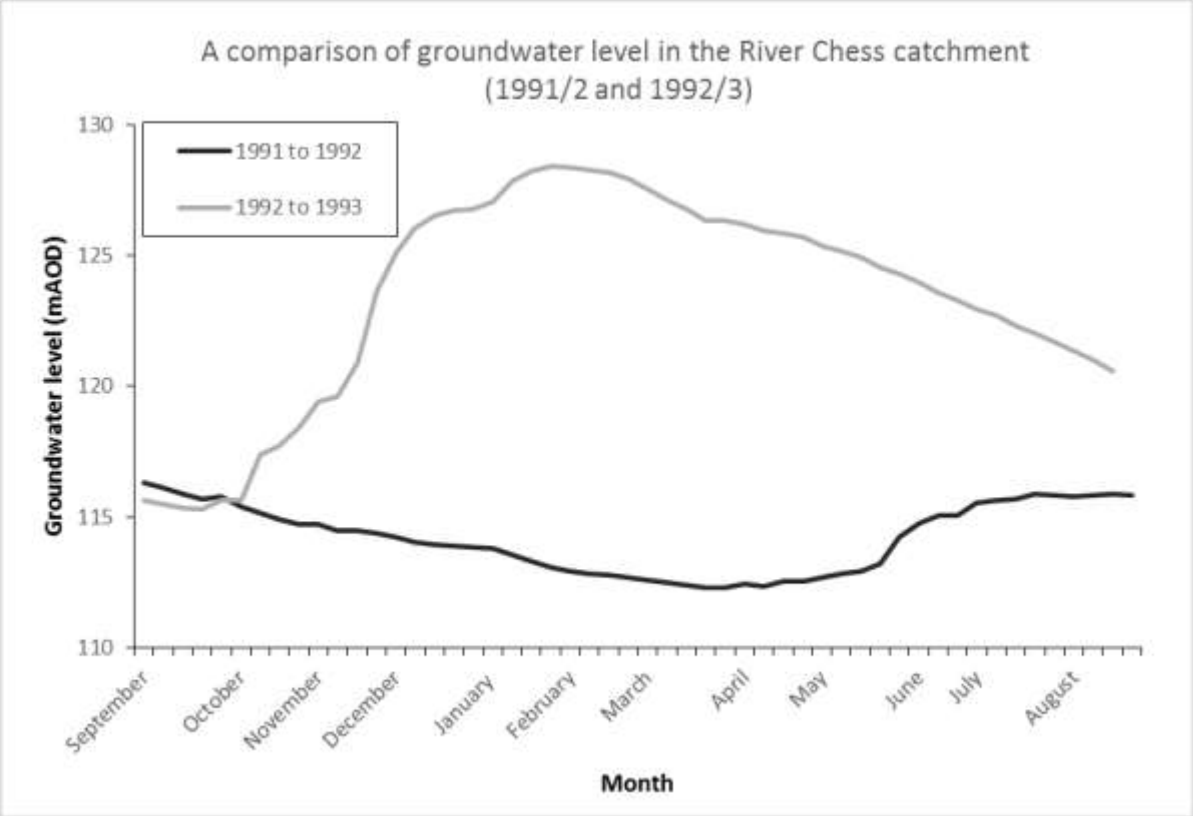
The figure below shows a column plot of rainfall data (created using EXCEL) for the River Chess catchment which compares October 1991 - 1992 to the rainfall in October 1992 – 1993. The hydrological year runs from October to October so that the impact of autumn and winter rain on rivers in the Spring can be properly assessed.

Rainfall is measured in units of millimetres i.e. depth of rainfall covering a unit area. One millimeter of measured rainfall is the equivalent of one litre of rain per metre squared of land area.



Activity 2.1: Note the difference in rainfall between the two years during the autumn and winter months. How much rain fell from October to February in 1991/2 compared to 1992/3? What effect might this have on groundwater levels?

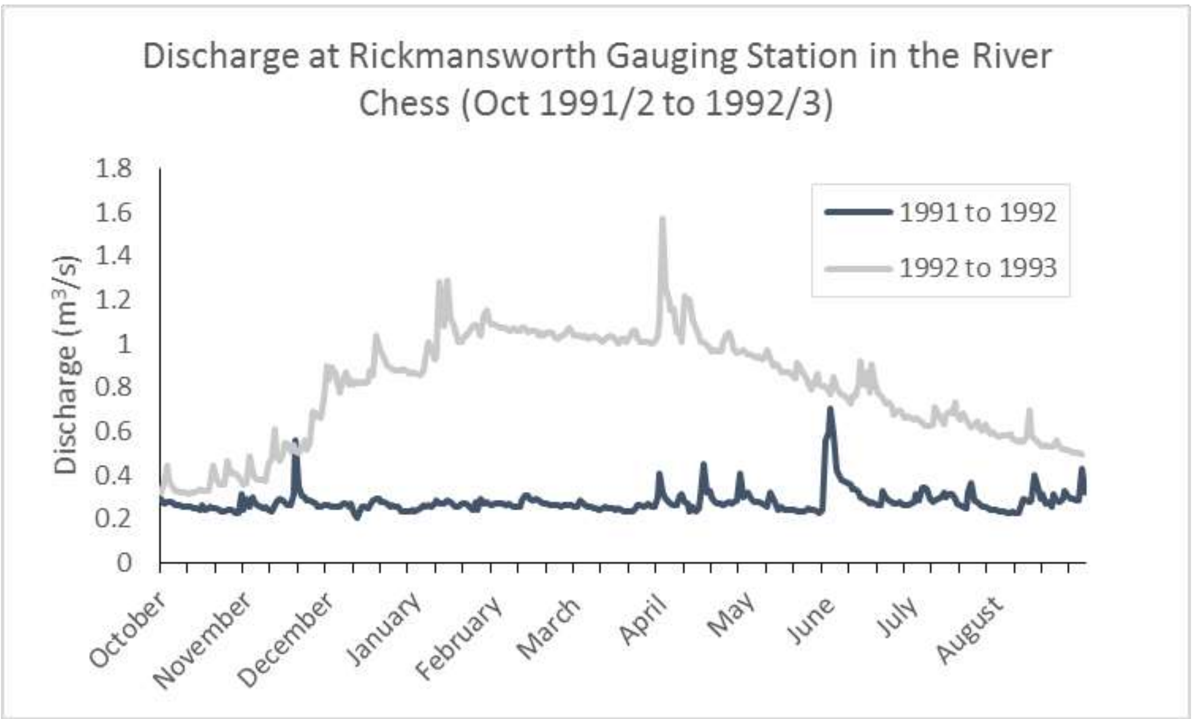
Now take a look at the groundwater levels in the River Chess catchment over this same time period. Does the data match your predictions?



Activity 2.2: What effect might these changes in groundwater level have on discharge in the River Chess? How might your scatter plot and correlation analysis of groundwater level and discharge lend support to your prediction?

Sketch out a graph of your predicted discharge by month for 1991/2 and 1992/3.

Now take a look at the annual hydrographs for the same period. A hydrograph is a graph of discharge versus time for a specific point in the river (in this case at the Rickmansworth gauging station).



From this data we can see that autumn and winter rainfall is important for both groundwater recharge and for river discharge. If autumn and winter rainfall is low then this results in lower river levels and discharge the following Spring. This can have consequences for the plants and fish in the river that rely on good flows in Spring to grow and develop.

Activity 2.3: Take a look at the groundwater levels and discharge from March to August. What happens over this time period? What other components of the hydrological cycle should we take into account when interpreting patterns in groundwater levels and hydrographs over an annual cycle?

The government publishes a monthly water report for England which you can access here: https://www.gov.uk/government/publications/water-situation-national-monthly-reports-for-england-2019. This is a useful resource for tracking changing river flows over the year, and to help understand the reasons for overall variations in discharge.

Activity 2.4: If you want to plot your own discharge data you could download data from the CEH Flow archive. Pick a year and plot an annual hydrograph using an EXCEL line plot. Explain the reasons for the pattern that you see in discharge over a one-year period. You can also download rainfall data for the River Chess catchment from this website to compare to the discharge.

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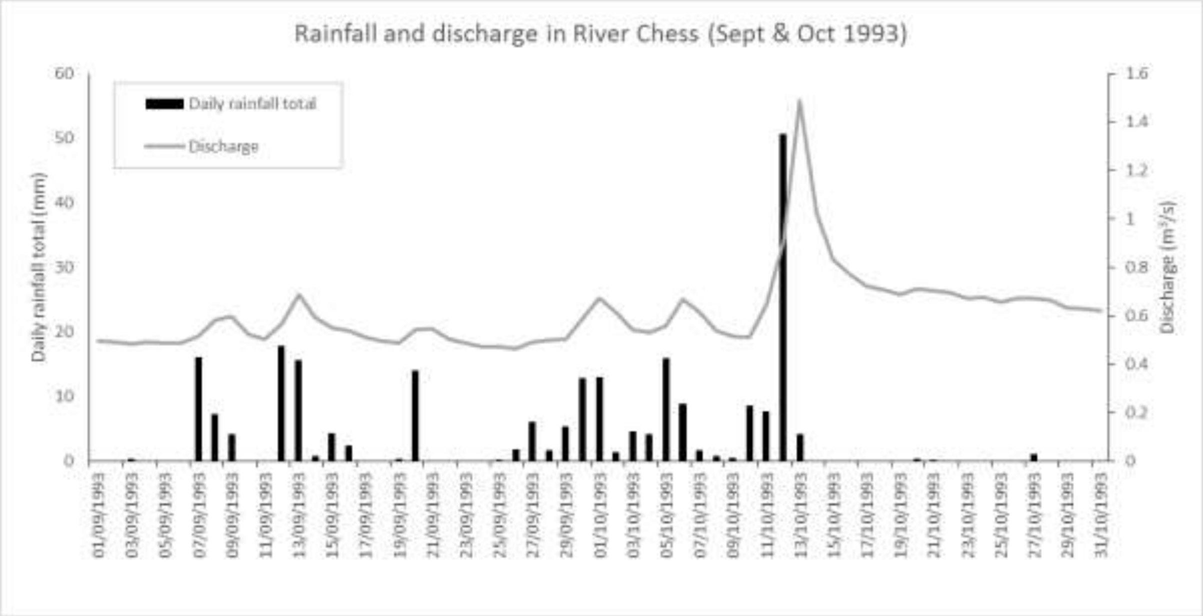
(III) Explaining the patterns in groundwater and discharge data: Runoff generation and examining the spikes in the discharge data

Chalk rivers are groundwater-fed, and the flow is dominated by contributions from groundwater (also termed ‘baseflow’). The River Chess has a ‘baseflow index’ of 0.95* which means that 95 % of the river water, calculated on an annual basis, is derived from groundwater. So where is the remaining 5 % of water coming from?

A clue to this additional source of water can be seen in the short-term spikes in the discharge whilst groundwater levels remain fairly constant. This is described as a ‘flashy’ hydrograph. A chalk stream would be expected to have a slow response to rainfall because it takes time for rainfall to travel down to the chalk aquifer and then into the river. So what might be causing these ‘spikes’ in discharge?



Activity 3.1: Use the interactive map on the ChessWatch site to note the different types of land use in the River Chess catchment. How does land use change as you move from the source of the river in the Chiltern Hills to its confluence with the River Colne at Rickmansworth?

Use the ChessWatch interactive map to identify three possible locations where rainfall might move rapidly from the catchment surface to the River Chess. Provide a justification for each location. How might runoff be generated in each example? How might you test whether these locations are indeed sites of rapid runoff (termed ‘quickflow’) to the river? Which river water quality challenges might these locations be associated with?

The catchment of the River Chess is in a location of the country that has been identified for future housing development. What might happen to the catchment hydrology as locations that are currently rural become more urbanized?

*This information is provided by CEH on the website for the gauging station at Rickmansworth