

Chapter 10: Conclusions

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10.0 Conclusions

A comprehensive study of trace metals in a catchment/lake system has been carried out with the objective of achieving a greater understanding of the relationship between atmospheric fluxes and their record in lake sediments. A small lake in the English Lake District, Blelham Tarn, was chosen for the study since it was known to be significantly affected by catchment erosion (Vanderpost *et al.*, 1997). The environmental tracer ^{210}Pb was used to both chronologically date and correct for disturbances in the records. The project included fieldwork, analytical laboratory work and mathematical modelling, in addition to data contributed by outside sources. Fieldwork consisted of the collection of three sediment and seven soil cores from the Blelham catchment along with a year long rainwater collection programme.

Trace metal concentration profiles for Blelham Tarn sediment cores A, D, and J taken in 1996 show variations in sediment core concentrations across the bed of the lake. Comparing the results for core 96/A with those for a core taken from a similar location one year later shows a broad similarity between the two sets of results, though there were differences in detail. Comparing the ^{210}Pb inventories of the 1996 cores with those from a more comprehensive suite of cores collected during the 1997 sampling programme (Appleby *et al.*, 1999) made it possible to quantify the extent to which the 1996 cores were from sites subject to significant catchment inputs or sediment focussing. Accumulation rates calculated from the radionuclide analysis of these cores show a significant acceleration in the 1980's at site J reflecting inputs of eroded soils to the southeast corner of the lake via Hole House Stream and Ford Wood Beck.

Trace metal concentrations and stable lead isotope signatures from four soil cores taken from the catchment suggest accumulation of atmospherically deposited lead. Lead isotope signatures from both the sediment and peat cores were used to yield information on the geochemical origin of lead and the relative contributions from different sources. The lead isotope signature of sediment core 96/A suggests a record for the introduction of petrol lead *c.* 1872 with a marker for the switch to unleaded petrol occurring in 1983. The peat core signature contains a record of petrol lead introduction in 1920 with a marker for the introduction of unleaded petrol in 1985. The true historical date for its introduction is somewhere between these years. Source determination calculations carried out on the data from core 96/A suggest that pollution from mining, smelting and other industries has been significant since at least the 1600's. Pollution from automobiles begins to increase from the beginning of the 20th century with peak emissions detected around the years 1969-1972.

The depositional flux history of the tracer ^{210}Pb was investigated using measurements from soil cores and precipitation. An experimental method was designed to extract ^{210}Pb and ^7Be from rainwater for analysis via gamma spectroscopy. The efficiency of this method was determined to be 92%. Measurements of fallout ^{210}Pb and ^7Be in precipitation collected at Esthwaite Water between April 1997 and July 1998 indicate a mean activity of $91 \pm 5 \text{ Bq kl}^{-1}$ and $2028 \pm 62 \text{ Bq kl}^{-1}$ respectively.

10.1 Comparison between Direct and Indirect Measurements

Direct measurements of ^{210}Pb deposition from precipitation in this area ($154 \pm 7 \text{ Bq m}^{-2} \text{ yr}^{-1}$) are remarkably close to indirect measurements from the seven soil cores collected in 1996 ($148 \pm 25 \text{ Bq m}^{-2} \text{ yr}^{-1}$), highlighting the value of soil cores as long-term monitors of ^{210}Pb deposition in this area.

Estimates were made of the atmospheric Pb, Zn and Cu fluxes at Blelham Tarn for the last 200 years. These were based on the average sediment fluxes from four cores (96/A, 96/D, 97/A, and 97/B), corrected for focussing using the ^{210}Pb data, and the Foulshaw Moss peat core. The mean fluxes of Pb, Zn and Cu for the period 1825-1995 were calculated to be 5.9, 4.5 and $0.7 \mu\text{g cm}^{-2} \text{ yr}^{-1}$ respectively. The mean fluxes of Pb, Zn and Cu for the period 1975-1995 were calculated to be 5.7, 7.4 and $1.1 \mu\text{g cm}^{-2} \text{ yr}^{-1}$ respectively. Comparing these fluxes to the direct deposition mean for 1975-96 it is clear that the lead fluxes calculated from the natural archives are higher by a factor of 5 whilst the zinc and copper fluxes are in good agreement.

10.2 Modelling

The model was used to show that approximately one quarter of the inputs of ^{210}Pb to the lake were due to transport from the catchment as opposed to direct deposition to the lake surface. The fraction of the annual fallout onto the catchment delivered to the lake is just 1.6%.

The atmospheric flux of lead over time was approximated by an exponential input function and used to model the transport rate from the catchment. The model suggests that 3% of the annual lead deposition onto the catchment is delivered to the lake and that catchment inputs to the lake may represent as much as 57% of the total atmospheric input. Modelling of zinc and copper transport in Blelham Tarn was hindered by their partition distribution in the lake being largely unknown.

Although significant, catchment inputs are concentrated in the southeast corner around the inlet streams. Away from the inlet streams, the flux to the sediments is dominated by direct fallout onto the lake. For lead, catchment inputs do not significantly affect the $\text{Pb}/^{210}\text{Pb}$ ratio and so it was used to normalise and reconstruct the atmospheric flux history of Pb, Zn, and Cu from the sedimentary record. Although these results leave many questions unanswered, they do at least establish a methodology for investigating catchment inputs.

10.3 Suggestions for Further Study

Because the data set collected by this project comes from various sources outside of the normal scope and control of a Ph.D. research collaboration, it necessarily contains many gaps. For example although the directly monitored trace metal fluxes in Cumbria are one of the longest records available for the UK they do not include all chemical fractions. Also, there was not enough time to set up any kind of water chemistry project for determining the distribution of chemical species within the water column.

Throughout I have tried to construct a coherent framework for interpreting data from Blelham Tarn within the boundaries and limitations of the data. The research contains the elements of a good data set, and the first-order model that is used to see how the atmospheric flux is related to the sediment record. Very few studies have managed to integrate so many factors to such a degree.

The following are recommendations for working towards a more coherent study of atmospheric flux measurements derived from sediment records:

- (i) A more concise record of the total depositional flux of trace metals in this area. Both filtered analysis and measurements of the particulate and dissolved components.
- (ii) Collection of sediment cores with 'stable' backgrounds. The three cores collected during this study did not have consistent sediment background values and had to be reinforced with cores from a later project.
- (iii) Determination of trace metal K_d values for Blelham Tarn suspended solids. No direct measurements of K_d have been made for this lake.
- (iv) Measurements of trace metal inputs from inlet streams, especially those in the southeast corner of the lake.
- (v) Soil core trace metal measurements around the southern side of the lake which has been subject to arable farming and sheep grazing.
- (vi) Determination of lead isotope ratios in airborne particulates for source determination.