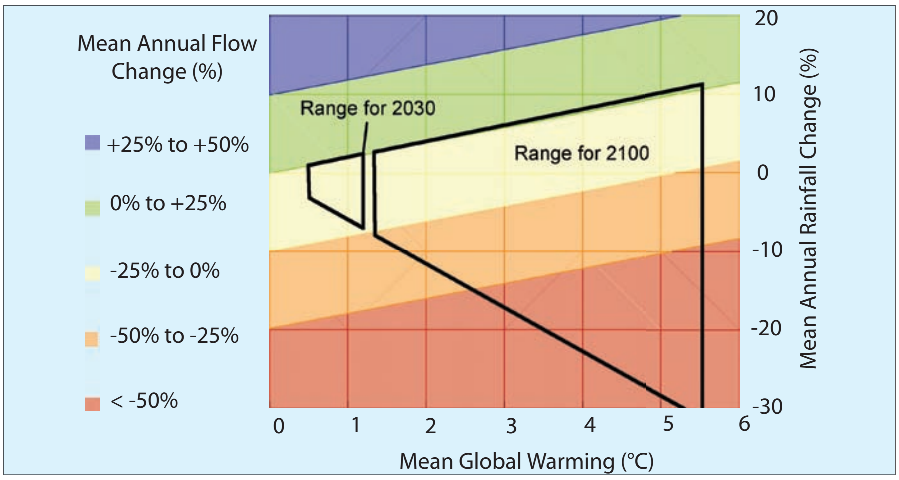

Figure 3: Murray Darling Basin runoff response to warming and rainfall change.

bulk allocations of surface water are unsustainable. Abstraction and climate change, along with catchment modification leading to high water tables and degraded water quality, represent serious threats to the capacity to rehabilitate floodplain wetlands to a healthy, functioning state. Measures to adapt to climate change must be sensitively implemented. Environmental allocations need not relate solely to volume, but also to variability and timing, so that various uses are favored differently from one year to the next. The widespread and timely adoption of water use efficiencies is essential to avoid both long-term deleterious effects to aquatic ecosystems and to maintain an irrigation industry that is a significant provider of food to Australia and elsewhere. Without increased efficiencies, the trade-off of continued water use and land practices under a drying climate is to risk placing all lowland MDB wetlands beyond the reach of restoration to any natural condition defined by its past experience.

References

Jones, R.N., Bowler, J.M. and McMahon, T.A., 1998: A high resolution Holocene record of P/E ratio from closed lakes in Western Victoria, *Palaeoclimates*, **3**: 51–82.

Gell, P., Bulpin, S., Wallbrink, P., Bickford, S. and Hancock, G., 2005: Tareena Billabong – A palaeolimnological history of an everchanging wetland, Chowilla Floodplain, lower Murray-Darling Basin, *Marine and Freshwater Research*, **5**: 441-456.

MacGregor, A.J., Gell, P.A., Wallbrink, P.J. and Hancock, G., 2005: Natural and post-disturbance variability in water quality of the lower Snowy River floodplain, Eastern Victoria, Australia, *River Research and Applications*, **2**: 201-213.

Jones, R. N., McMahon, T. A. and Bowler, J. M., 2001: Modelling historical lake levels and recent climate change at three closed lakes, Western Victoria, Australia (c.1840-1990), *Journal of Hydrology*, **246**: 159-180.

Jones, R.N., Whetton, P.H., Walsh, K.J.E. and Page, C.M., 2002: *Future impacts of climate variability, climate change and land use change on water resources in the Murray Darling Basin: overview and draft program of research*, Murray Darling Basin Commission, Canberra, ACT, 27 pp.

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The rise and fall of atmospheric pollution: The paleolimnological perspective

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The catchments of remote mountain lakes often comprise sensitive geologies and sparse soils and these factors, in combination with severe meteorology, conspire to produce fragile ecosystems. Anthropogenic impacts in these areas are limited to long-range transported pollutants and large-scale effects such as climate change, but despite their isolation from direct contamination, the additional stress of atmospheric pollutant deposition often results in detectable chemical and/or biological change. Remote lakes can, therefore, act as 'early warning' indicators for less sensitive sites and as a result they have become a useful tool in monitoring the impacts of atmospherically deposited pollutants. Recent studies in Europe have shown that long-range transported pollutants have been impacting remote lakes for hundreds of years and that this deposition can result in the accumulation of both trace metals and persistent organic pollutants in biota sometimes to significant levels. The lake sediment record of remote lakes provides the temporal dimension to such observations. In remote regions long-term monitoring is often absent and so paleolimnology provides a means to determine directions of change (i.e. deterioration or improvement) as well as, via reliable chronologies, rates of these changes. Such information thus provides a historical context for contemporary measurements as well as a base-line against which to measure future impacts.

Paleolimnological records of pollutants from remote lakes have been produced from many areas of the world and consistently show significant increases in pollutant deposition in agreement with historical trends in industrial activities on regional and international scales. However, if we assume that the sediment record can faithfully record the past trends in anthropogenic emissions to the atmosphere then it must also be the case that these lake sediments will record the decline in pollutant emissions observed in many industrialized countries since the 1970's. In some cases such reductions have been dramatic, for example, declines of over 80% and 75% for mercury (Hg) and lead (Pb) in the UK respectively. However, our studies at Lochnagar in Scotland have shown that while there have been considerable reductions observed in the emissions of metals to the UK atmosphere, and similar reductions recorded in the metal content of deposition across the country, the total amount of metal entering the loch and recorded in the sediments remains almost unchanged since the 1950's (e.g., Pb: Fig. 1). As atmospheric deposition is known to have declined, this 'additional' metal can only be derived from previously deposited contamination being released from storage within the sparse catchment soils.

A number of hypotheses have been proposed to explain this observation (Rose et al., 2004). First, that this is due to a simple time-lag effect, i.e. metals deposited onto the catchment take a number of years to work through to the water body and thus the enhanced catchment inputs now observed are the result of high metal deposition decades ago. Second, increased erosion of the contaminated levels of catchment soils (possibly resulting from the effects of increased drought or episodes of high rainfall) are bringing the catchment-stored metals into the lake.

At Lochnagar, as in many areas of Scotland, there is significant catchment peat

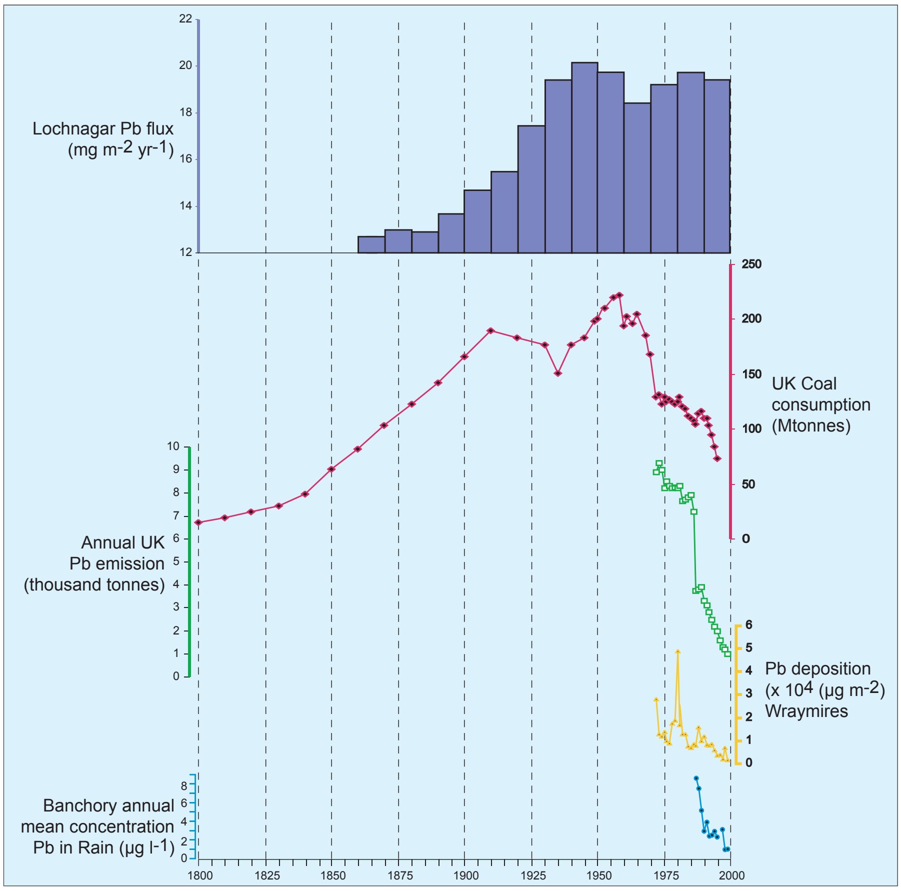

*Figure 1: The Lochnagar full basin sediment flux for Pb (**histogram** columns are decadal) (Yang et al., 2002); UK coal consumption since 1800 (**red line**) (data from Farmer et al., 1999); annual UK Pb emission data (**green line**); measured Pb deposition data (1972–1999) from the UK rural network site at Wraymires (**yellow line**) (data from Baker, 2001); annual mean volume weighted Pb in rain from the North Sea Network Banchory site (**blue line**) (data from Playford and Baker, 2000). Figure was first published in Journal of Limnology, 2004: 63(1). Reproduced with permission.*

erosion, but the faces of the main eroding peats are over a meter high and probably cover hundreds, if not thousands, of years. Therefore, erosion of these faces would be expected to result in a substantial amount of uncontaminated material entering the loch resulting in lower, sediment metal concentrations, but greater input fluxes. Third, a gradual increase in average air temperatures and a reduction in sulfate deposition have led to enhanced decomposition and solubility of soil organic matter, which is then increasingly leached as dissolved organic carbon (DOC) in wet periods. Metals are known to have a strong affinity for DOC and hence elevated DOC input may result in enhanced metal input from the catchment. Certainly, the DOC levels in Lochnagar waters, as at many sites, have increased in recent years. Persistent organic pollutants are also known to have a strong affinity for DOC and this mechanism would, therefore, also be applicable for catchment stored organic contaminants. Fourth, warmer winters resulting in longer ice-free periods would provide more time for algae to scavenge metals from the lake water. These would then take the incorporated metal into the sediment with them when they become part of the record. At Lochnagar, frequent ice observations have only been made over the last decade and it is now established that ice cover is reduced and that break-up can occur at any time through the winter following high temperature periods or storms. Modeling studies also indicate that the period of winter ice cover at Lochnagar has reduced by about two months over the period 1960 to 2000.

The EU funded project Euro-limpacs has resolved to test these hypotheses in order to ascertain the roles that the various mechanisms play in pollutant re-mobilization from catchment soils. The project is due to report in 2009, but early data suggest that catchment soil erosion is an important factor. It may be that the cause is a combination of these processes, but certainly the second, third and fourth hypotheses all imply a climate-driven response. Climate predictions for Lochnagar indicate that by the 2080's July mean air temperature could increase by 2–4°C, while winter mean monthly temperatures will rarely fall below 0°C. Further, winter precipitation may increase by 11-21% and decrease in summer by 17-33%. Such predictions would exacerbate soil erosion, leaching of DOC and potential algal growth periods (i.e. the effects of the second to fourth hypotheses would be enhanced by predicted climate changes). Yang et al. (2002) estimate that at levels observed for 2000 there is about 400 years worth of deposition stored in the Lochnagar catchment soils, and that already catchment sources dominate inputs from direct atmospheric deposition. With such a potential store in the soils, future inputs to the loch may remain constant or even increase despite successful emissions-reductions policies.

Climate-driven release of catchment-stored pollutants is not restricted to enhanced inputs from soils. The retreat of glaciers is also thought to be releasing the pollutants that they have stored from atmospheric deposition, and this could also affect a large number of high mountain lakes around the world. Furthermore, climate change may also impact pollutants in remote lakes indirectly by affecting usage and transport mechanisms. A warmer atmosphere may increase the atmospheric lifetimes of volatile compounds and enable less volatile compounds to become more mobile, while climatic systems themselves could also be altered increasing transport to remote regions. Furthermore, persistent organic pollutant and trace metal availability may also increase through the elevated usage of pesticides and fertilizers as a result of new invasive species and reduced agricultural productivity. Previous lake sediment evidence suggests that even if this usage is at a considerable distance from the lake of interest, long-range transport of pollutants from remote source regions could result in enhanced inputs.

Acknowledgements

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References

Baker, S.J., 2001: Trace and major elements in the atmosphere at rural locations in the UK: Summary data for 1999, *National Environmental Technology Centre Report*, AEAT/R/ENV/0264: 80pp.

Farmer, J.G., Eades, L.J. and Graham, M.C., 1999: The lead content and isotopic composition of British coals and their implications for past and present releases of lead to the UK environment, *Environmental Geochemistry and Health*, **21**: 257–272.

Playford, K. and Baker, S.J., 2000: Atmospheric inputs of heavy metals to the North Sea: Results for 1999, *National Environment Technology Centre Report*, AEAT/ENV/336/47044102.

Rose, N.L., Monteith, D.T., Kettle, H., Thompson, R., Yang, H. and Muir, D.C.G., 2004: A consideration of potential confounding factors limiting chemical and biological recovery at Lochnagar, a remote mountain loch in Scotland, *Journal of Limnology*, **63**: 63-76.

Yang, H., Rose, N.L., Battarbee, R.W. and Boyle, J.F., 2002: Mercury and lead budgets for Lochnagar, a Scottish mountain lake and its catchment, *Environmental Science and Technology*, **36**: 1383-1388.