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Dissolved Metal Contamination from Mine Wastes – Risk Assessment and Quantification in the Tamar Catchment

Project summary SC060095

Mine wastes left at abandoned mine sites risk polluting streams and rivers, particularly with zinc, cadmium and nickel, according to a new study by the University of Plymouth and the Environment Agency. Field and laboratory tests and mapping with a Geographical Information System (GIS) have been used to prioritise the pollution risk from mine waste sites in Devon and Cornwall. These mine wastes are likely to continue to release pollutants for many decades.

Contaminants from abandoned metal mines are transported from mine waste tips via surface run-off and shallow groundwater into streams and rivers. In South West England, a long history of metal mining has left a legacy of abandoned mines, most of which are currently not remediated (cleaned up), or do not have an accountable owner. The risk of surface water pollution from these sites must be assessed in the River Basin Management Plans required under the EU Water Framework Directive. The Environment Agency has created a database of abandoned metal mines in South West England, including mine waste tips. Prioritising these sites based on their potential to generate acid mine drainage, particularly from diffuse sources, has been addressed through a PhD project at the University of Plymouth.

The aim of this study was to investigate the magnitude and geochemistry of mine waste leachate migration via surface and shallow sub-surface pathways to watercourses – that is, the amount of contaminants leaching into streams and rivers. The knowledge gained from this study, carried out in the Tamar River catchment, will help us to better understand and shape our management strategies for abandoned mine sites throughout South West England.

Two study sites, Devon Great Consols, an abandoned copper-arsenic mine near Gunnislake and Wheal Betsy, a former lead-silver mine near Mary Tavy, were chosen for their contrasting mineralogy and hydrology. Field studies were carried out during 2007-2009 to capture and analyse mine waste drainage waters under a range of hydrological conditions.

In addition, laboratory experiments were conducted on mine waste material removed from both sites. Column experiments based on European standard up-flow percolation tests were carried out in order to mimic water percolating through mine spoil and study the movement and levels of contaminants released into the water from the waste material. Batch experiments were carried out on the same material at fixed solid:liquid ratios of 2:1, 5:1 and 10:1. Concentrations of metals (such as zinc, lead, copper, manganese and aluminium), metalloids (arsenic and antimony) and major ions were analysed.

Contaminant concentrations in the column discharge were largely similar to those obtained in batch extractions and for most elements, laboratory experiments provided a good proxy for observations made in the field. Batch experiments at low liquid:solid ratios and the initial leaching phase of column experiments may be used to simulate conditions when previously unsaturated waste material produces leachate following rain, sometimes referred to as the “first flush”. On the other hand, the steady-state condition reached at the end of a column leach experiment, or in high liquid:solid ratio batch experiments, may be used to establish the mobility of contaminants from spoil material under continuously saturated field conditions, that is, below the water table.

Discrepancies in pH between laboratory and field results highlighted the strong pH control on metal release from mine waste. The geochemical interpretation of the column leach studies was supported by mineralogical assessment of the mine waste material by scanning electron microscopy (SEM) coupled to energy dispersive x-ray spectroscopy (SEM-EDX) and powder x-ray diffraction (XRD). The results indicate that secondary phase minerals (usually iron hydroxyl-sulphate precipitates) are ubiquitous in the waste material and exert a strong control on leachate geochemistry, largely by absorbing or releasing contaminants.

Primary sulphide minerals were also present in the mine waste, including arsenopyrite, chalcopyrite, galena and sphalerite. SEM examination of mineral texture showed that arsenopyrite was more resilient to weathering than other sulphides, which appeared to be highly altered.

Although Wheal Betsy was abandoned in 1877 and Devon Great Consols in the 1960s, the abundance of primary metal sulphide grains in samples suggests that mine wastes will continue to cause water pollution for many years to come.

Field studies also indicated element-specific attenuation of contaminants during transport from the mine spoil to the watercourse. In particular, arsenic and copper at Devon Great Consols and lead at Wheal Betsy showed a strong affinity for mineral surfaces, while zinc, cadmium and nickel tended to be highly mobile.

The results of field work, batch and column experiments were compared to assess the validity of each approach for obtaining information to predict the levels and movements of contaminants from mine spoil. In addition, a GIS-based risk prioritisation computer model for mine waste in the Tamar Catchment was constructed from ten parameters, including: area of mine waste, proximity to streams, rainfall, vegetation cover and underlying geology.

Waste tips at Wheal Betsy and Devon Great Consols mines ranked highly in this model. Tin-streamed workings also carried high risk, but these are less likely to contain mobile contaminants in the residual waste after prolonged leaching.

Within the model, drainage and catchment areas were defined for each waste tip. These were used in conjunction with rainfall data to estimate the annual water discharge from waste tips and combined with metal concentrations determined from field and laboratory studies, the annual flux of contaminants was estimated. At Devon Great Consols, the combined fluxes from three large areas of mining waste were high for aluminium (8,420 kg/year), copper (3,630 kg/year), arsenic (2,410 kg/year), manganese (1,030 kg/year) and zinc (305 kg/year). At Wheal Betsy, zinc (2,260 kg/year) contributed the highest metal flux with leachate from the waste tips located around the engine house, followed by aluminium (294 kg/year), manganese (338 kg/year), lead (401 kg/year) and cadmium (23 kg/year). The contrasting composition of leachate reflects differences in mineralogy and hydrology between the sites.

A modified version of the model has since been used to prioritise sites in Devon and Cornwall. This should help the Environment Agency create an inventory of abandoned mine waste sites that are causing serious environmental damage for the EU Mining Waste Directive.

Variations in the mineralogy of waste tips, weathering rates of sulphide minerals and absorption rates of different elements all lead to complex leachate composition. Nevertheless, the column and batch experiments offer a means of determining leaching potential and with automation could provide a rapid screening method.

Combining these with hydrological data and computer modelling can generate useful annual flux predictions. However, field studies are still required to ensure lab tests are valid and to investigate the natural attenuation potential of the migration pathway.

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