The Evolution of Bromate Contamination in the Hertfordshire Chalk Aquifer

C. M. Fitzpatrick[1], S.J. Cook[1], L. Lytton[2], P. Bishop[3], R. Sage[2], W.G. Burgess[1]

[1]UCL, Department of Earth Sciences, Gower Street, London, WC1E 6BT
[2]Three Valleys Water Ltd, Blackwell House, Three Valleys Way, Bushey, Herts, WD23 2LG
[3]Thames Water Utilities Ltd, Clearwater Court, Vastern Road, Reading, Berks, RG1 8DB

BACKGROUND

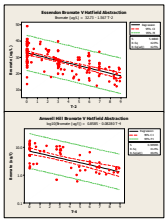
New Drinking Water Regulations came into force in December 2003, which introduced a new standard for bromate of 10 µg/l. In May 2000, during the course of preliminary sampling, Three Valleys Water detected bromate concentrations of 135-140 µg/l, well in excess of this standard, at the Hatfield Pumping Station. As a precaution the source was removed from public supply. A water quality monitoring programme was initiated in June 2000 and identified the source of the bromate as a former chemical works in Sandridge, now a residential development. This site has been determined as 'Contaminated Land' and designated a 'Special Site' as defined under Part IIA of the Environmental Protection Act 1990.

MONITORING PROGRAMME

The Environment Agency, Three Valleys Water and Thames Water continue to monitor water quality and water levels at a number of locations throughout the bromate impacted area. A total of approximately 370 locations have been monitored at some stage over the period 2000 to 2007 at various frequencies, although only approximately 50 locations continue to be monitored on a routine basis. Protection of the public water supply boreholes has been the main objective of the monitoring programme, which pays particular attention to key 'indicator' boreholes located at the edges of the main body of the 'plume' to assess plume boundary movement.

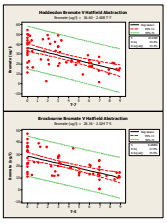
INFLUENCE OF ABSTRACTION AT HATFIELD

Since the cessation of pumping at Hatfield in 2000 there has been an increase in bromate concentrations recorded at public water supply sources down-gradient of Hatfield. A pumping trial has been underway at Hatfield since July 2005. Most noticeably at Essendon (143), but also at the Northern New River (NNR) sources (295-302), peak concentrations since the start of pumping at Hatfield have decreased compared to the trend before July 2005. It therefore appears that abstraction at Hatfield acts to intercept some of the bromate released into the aquifer from the source site that otherwise is transported down hydraulic gradient to these sources.



Evaluation of the data[4] has indicates statistically significant negative regression relationships for the response of bromate concentration to Hatfield abstraction rate.

Based on these relationships, an increase in Hatfield abstraction rate of 1 Ml/d is associated with a decrease in bromate concentration of 1.5-2.5 µg/l at the source well.



Source	Time lag*	R^2	Standard error	P-value**
For equation Bromate = A + B(Hat abst)				
Hatfield	0 days	52.0%	36.90	0.000
Essendon	2 days	42.9%	5.45	0.000
Hoddesdon	7 days	34.4%	10.65	0.000
Broxbourne	5 days	37.0%	8.29	0.000
For equation Log(Bromate) = A + B(Hat abst)				
Chadwell Spring	8 days	42.0%	0.200	0.000
Amwell Hill	4 days	41.4%	0.306	0.000
Amwell Marsh	6 days	55.6%	0.186	0.000
Rye Common	7 days	20.1%	0.460	0.000
Middlefield Pit	8 days	16.8%	0.202	0.000
Turnford	4 days	29.5%	0.220	0.000

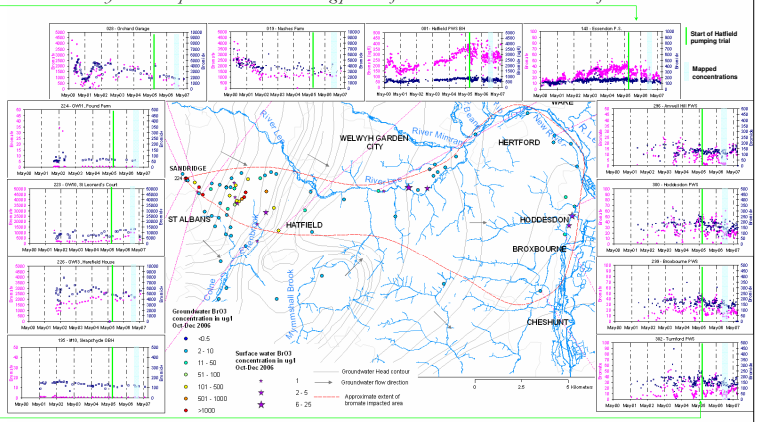
*time lag refers to the number of days between the Hatfield abstraction rate and the strongest response in source bromate concentration.
**The P-value refers to the hypothesis that the regression relationship is statistically significant, i.e. that the apparent relationship between y and x is not likely to arise due to chance alone.

Regression parameters for the 'best-fit' regressions for the response of bromate concentration to Hatfield abstraction rate.

Hatfield abstraction rate explains a significant amount of variation (ranging from 16.8% to 52.0%) in bromate concentration. The time lags for the 'best fit' regression line range from 0 days for Hatfield, 2 days for Essendon, and between 4 days and 8 days for the NNR wells.

The inferred travel time is therefore slightly slower than, but of the same order of magnitude as, the travel times observed in historical tracer tests between Water End and the NNR wells*. This relatively rapid flow rate between Hatfield and the source wells indicates that fracture flow is the dominant transport mechanism.

Bromate contamination is currently impacting more than 40 km² of the Hertfordshire Chalk aquifer. There are concerns for the long-term water quality of the aquifer, particularly with regard to public water supply abstractions where bromate concentrations have risen in recent years. This poster describes the evolving pattern of bromate movement across the Hertfordshire Chalk.



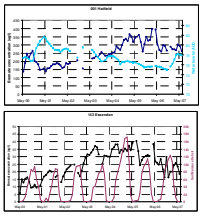
BROMATE EVOLUTION May 2000 – June 2007

The distribution of the bromate and bromide within the catchment has been described previously[1,2,3]. Recent data up to June 2007 is included in the time series above and the spatial distribution of bromate concentrations in groundwater for October-December 2006 when an extended monitoring was undertaken by the Environment Agency is illustrated.

Since June 2000, the spatial distribution of the bromate contamination has remained stable. In general, around the source site, concentrations of bromate have declined, although concentrations down-gradient of the source site have risen. The distribution of bromide concentrations generally mirrors that of bromate.

INFLUENCE OF RECHARGE

At Orchard garage (028), close to the source site, bromate concentrations appear to respond to seasonal variations in water level. Further down hydraulic gradient from the source zone at Hatfield, Essendon and the NNR wells, it has been noted[5] that seasonal fluctuations in bromate concentrations closely follow the seasonal cycle of soil moisture deficit (SMD). Seasonal peaks in bromate concentrations correspond to peaks in SMD, i.e. higher measured bromate concentrations correspond to dry conditions (high SMD). Higher water levels correspond to lower bromate concentrations.



Bromate Monitoring location	Sequential R^2			Total R^2	P-Value
	Hatfield abstraction rate	Water level at 028	Catchment SMD		
Hatfield (001)	4.2%	69.5%	0.0%	**73.8%**	0.000
Essendon (143)	17.0%	18.0%	10.0%	**45.0%**	0.000
Amwell Hill (296)	3.0%	6.0%	10.3%	**19.3%**	0.028
Amwell Marsh (297)	8.9%	4.7%	10.0%	**23.6%**	0.003
Broxbourne (299)	16.2%	12.2%	0.7%	**29.1%**	0.001
Hoddesdon (300)	18.9%	16.9%	1.0%	**36.8%**	0.000
Rye Common (301)	3.5%	0.4%	5.0%	**9.0%**	0.163
Turnford (302)	29.3%	22.8%	0.1%	**52.2%**	0.000

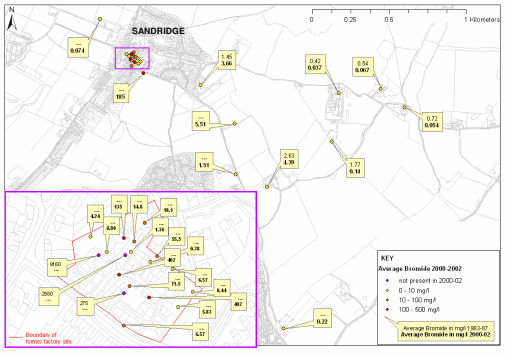
***M**ultiple regression parameters for the response of bromate concentration to Hatfield abstraction rate, water level at 028, and soil moisture deficit.*

Regression analysis is being used to quantify the relative contribution of Hatfield abstraction rate, SMD and water level at the source zone to bromate concentrations.

THE SOURCE ZONE

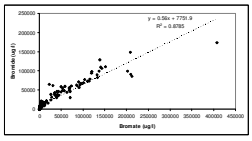
1955-1983	Chemical works operational
1983-1987	Buildings cleared and site left uncovered
	Site investigations and local monitoring (bromide only)
1987-present	Residential development
2000-2001	*Site investigations and regional monitoring (bromide and bromate)*

Chemical Works at Sandridge 1955-1983
Bromates and bromides produced as chemical intermediates.



Data available from site investigations before development (1983-1987) and after development (2000-2001)[6] indicate elevated concentrations of bromate and bromide in the soil and groundwater, with the highest concentrations coinciding with the former process and storage areas.

Prior to redevelopment, groundwater samples were not tested for bromate. Comparison of historical (1983-1987) and recent (post 2000) **bromide** concentrations in the vicinity of the source indicates a considerable decrease at the source site, but little change, or even moderate increases, at locations hydraulically down-gradient of the source site.



On the basis of bromate to bromide ratios for the source zone, it may be possible to estimate bromate concentrations in groundwater at the time of redevelopment.

Work is ongoing to develop a series of source terms for input to a groundwater flow model in order to encapsulate the range of inevitable uncertainty associated with incomplete knowledge of the history of contamination, and to infer the implications for model predictions of bromate transport.

PREDICTING FUTURE TRENDS

The observed spatial and temporal trends and statistical relationships between parameters will be used to calibrate regional groundwater flow and contaminant transport models. A program of borehole dilution testing and point-to-point tracer testing is scheduled to establish transport parameters and provide information on karstic behaviour. However, there is currently an absence of knowledge of bromate concentrations in porewater, which is critical for predicting future trends in the double-porosity Chalk.

References
Many Thanks to Jon Newton, of Environment Agency Thames Region for advice and provision of monitoring data.
*See poster By Simon Cook - Geological Controls on Hydrodynamics and Contaminant Transport in the Hertfordshire Chalk Aquifer.
1. Atkins (2004). Bromate Contamination in the Lee Valley. Phase 1: Data Collation and Conceptualisation. Undertaken on behalf of Thames Water Utilities Ltd. **2.** Vivendi Water Partnership, 2002. Bromate Groundwater Flow Study. Phase 1 (Conceptual Understanding) Report. Undertaken on behalf of the Environment Agency and Three Valleys Water. **3.** Atkins. 2006. Bromate Monitoring Data Review. Undertaken on behalf of the Environment Agency. **4.** Fitzpatrick, C.(2006). Hatfield Pump Trial Interim Report. . **5.** Lucy Lytton. **6.** Roberts, M. 2001. The Sandridge/Hatfield Bromate Pollution Investigation. Environment Agency Internal Report.

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