Contaminant Mapping and Refugia: Hidden River Cave, Kentucky

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Hidden River Cave has a long history of exploitation as a power and water resource, as a tourist attraction and as the recipient of industrial waste and untreated municipal sewage, culminating in metal contamination, eutrophication and anaerobic conditions in the cave stream in the late 1970s. Upgraded treatment and construction of a trunk sewer in the early 1980s relieved the cave of the contamination, and water quality was restored along with the remarkable return of a variety of cave fauna, particularly the blind cave crayfish (*Orconectes pellucidus*). The geography of the contamination and recovery indicated that much of the recovery arose from a relatively pristine upstream tributary (Wheet River) that apparently acted as a refugium when much of the cave was contaminated.

The catchment area of the Hidden River Cave has been gradually industrialised in subsequent years, and the blind crayfish populations have reportedly declined or been eliminated in response to undocumented contamination events. In collaboration with the America Cave Museum and American Cave Conservation Association, the annual Kentucky field course from the University of Western Ontario has undertaken a longitudinal survey of cave contamination, with the objective of identifying contaminant source and pathways, and possible amelioration and protection. Narrative accounts of pollution episodes were used to loosely characterise the contaminant and its source tributary or inlet. The cave upstream of the entrance was surveyed for blind crayfish populations and evidence of contaminant residues. Water samples were collected from inlets and stream transects and analysed using spectrofluorometry (synchronous scans at delta lambda 20 and 90 nm). Fluorescence spectra were smoothed and normalised to the median fluorescence intensity ($I(med)_\lambda$ by wavelength ($I(norm)_\lambda = Log(I_\lambda / I(med)_\lambda)$) such that relatively high contamination was indicated by values > zero, and relatively clean water by values < zero. Specific fluorescence peaks also indicate particular fluorophores implying the contaminant source.

The narrative, observations and water quality revealed ongoing chronic and acute contamination associated with specific inlets and channels in the cave. These are summarised in table 1. Some contaminants were observed every year and are classified as chronic, others were delivered as on-off episodes and are characterised as acute likely a rising through accidental spills, although residues were often persistent. Other acute events were repeated suggesting more routine release. The annual survey method prevented accurate time demarcation of contamination episodes.

The nature of the contaminant was used to establish a putative land use, while the location and distribution was used to define a likely surface catchment area. Assuming a fairly direct link between the surface and underlying contaminant source allowed prospecting for the respective land use using Google Earth and Streetview. These sites were then investigated in the field to test the inferences arising from mapping.

A number of distinctive, but relatively low impact contaminants proved easy to track down. For example a trail of mulch debris running from the bin into an adjacent sinkhole draining into the headwaters of

Similarly, the plastic beads (#1, commonly called nurdles) are stock material used in plastic forming and injection molding. They were largely found downstream of "Main Corridor", the tributary that had carried the historical sewage effluent into the cave. A major plastic packaging plant lay immediately south of the inlet sinkhole, with a line of stock hoppers arrayed in the catchment area of the sinkhole. No runoff control or filtration protection was evident. An accidental spill of the plastic beads is inferred to have been washed or carried in runoff into the adjacent sinkhole and into the cave.

The organic waste events (#3, reported as foul smelling effluent with LNAPL blobs) are found in the Wheet River, but have an impact on all downstream reaches of the cave river. Various industrial plants occupy the upper Wheet River catchment, but the most likely source is a regional wastewater treatment plant established to handle waste from a bakery and condiments factory. The plant removes grease and solids (that are carried away by truck), digests the high BOD waters and passes the partically treated water to the regional sewage treatment plant. The Google Earth historical imagery reveals that this plant was created around 2008, but has expanded with the addition of runoff control and a waste lagoon in 2011. Informal narrative accounts indicate that excess load or mechanical failure lead to release of untreated or partially treated waste. Before construction of the lagoon, this waste would have entered a closed depression upstream of the Wheet River headwaters. Even after construction of the lagoon, field inspection has revealed collapses in the floor, and any waste entering the lagoon is left to discharge to the sinkhole, albeit at a reduced rate. Plans have been made to line the lagoon to reduce the risk of collapse.

The cave stream is lost under breakdown in the midsection of the cave, but a number of inlets convey contaminants that are seen in the downstream river. The most egregious source of contamination is a 6" drainage well that is inferred to open on the surface where it drains a pre-mix concrete operation. Streetview imagery reveals the forecourt of the plant being hosed down with runoff draining towards the well. Field inspection shows trucks being washed with contaminated runoff draining into the drainage well. The on-site settling pond is not functional.

The waterfall inlet has very distinctive contamination with steady flow (regardless of drought conditions), very low ambient fluorescence and odor of chlorine implying a drinking water source, but with the persistent presence of a distinctive fluorescein peak (512nm). The most likely source for this is a nearby carwash. Streetview and field inspection reveal runoff entering a drain that is inferred to soak away into groundwater. Various fluorescent dyes are used in Car wash soap solutions to increase the apparent brightness of the finish.

Oil and fuel contaminants in other inlets through the midsection of the cave may be from local garages, or a somewhat chaotic recycling yard that drains into a series of collapsing sinkholes.

Kneebuster contamination presents problems as this tributary has served as an important refugium and educational resource. A blob of DNAPL was observed in 2008, with dead crayfish on top. The most recent event occurred in summer 2015, when an oily black ooze entered from a side passage, eliminating all crayfish from the passage. These episodes are interpreted as "legacy" contamination sequestered in sediment deposited in the 1970s. Unfortunately, these materials retain their potency through many years

The final source of contamination is a small inlet that exhibits slimy overgrowths and a persistent peak at 410nm suggesting laundry brighteners in domestic sewage. The source of such contamination cannot be narrowed down, although the regional trunk sewer runs just overhead of this point in the cave.

The sinkhole plain topography means that surface runoff will inevitably drain into sink points in their respective closed drainage basin, with any ponding bypassed by construction of enhanced injection wells or bedrock soakaways that ensure recharge of unfiltered water. There is little prospect of taking surface runoff elsewhere. However, many of the sources of contamination could be ameliorated if not prevented by construction of runoff controls such as screens or oil-grit separation tanks. This does not appear to have been a priority, although many industries are keen to establish their environmental responsibility, and would likely support such protection.