

Detection of Sewage Indicators in Hanalei Bay

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I. Routes of Introduction

The most likely routes of introduction of human sewage into Hanalei Bay include [i] direct discharge via designed outfalls (treated sewage) or holding tanks aboard boats (untreated sewage), [ii] indirect surface discharge from sewage entering rivers or streams that empty into the Bay, and [iii] indirect subsurface discharge from sewage entering groundwater that discharges into the Bay. Ongoing studies designed to monitor bacterial levels in Hanalei Bay suggest that while the first two routes may contribute seasonally and/or sporadically to sewage contamination, it is likely that the third route (groundwater discharge) may be the most substantial and potentially the most problematic.

Lacking sanitary sewers and a centralized wastewater treatment facility, the community of Hanalei relies on individual septic systems to treat wastewater that is produced by residential households. The concrete septic tanks should be installed in soils that are not water saturated (i.e., so-called vadose zone soils); however, the combination of hydrogeologic and climatic conditions in Hanalei renders this task virtually impossible. The relatively porous surface soils, a high annual rainfall (both along the coast and on the slopes of the surrounding mountains), and a relatively flat (low-elevation) topography contribute to the presence of a shallow groundwater table underlying the most densely populated areas of the community. During much of the year, at least a portion of the individual septic tanks is located below the depth of the groundwater table, substantially increasing the probability of a hydraulic connection between the two. Components of the raw sewage may then migrate toward the Bay, representing the direction of regional groundwater flow. While small-scale sources or sinks along the coast may locally alter groundwater flow directions, the net water movement is from major recharge zones in the mountains to submarine discharge zones in the coastal waters (e.g., Hanalei Bay).

The most easily transported sewage components are highly water-soluble compounds such as nitrate, phosphate, sulfate, and other inorganic substances, which are often referred to as “nutrients” because they stimulate the proliferation of aquatic and marine plants/algae. This is why frequent plankton blooms and overgrown aquatic “weeds” are commonly associated with sewage contamination of marine or freshwater environments. Only slightly less mobile than the inorganic ions are low-molecular weight organic substances that can actually be dissolved in groundwater. These substances include highly decomposed plant and animal matter such as simple sugars and volatile fatty acids, as well as certain solvents and other commercial products that are routinely washed down the drain. Still less mobile in groundwater are heavy metals (e.g., lead, arsenic, cadmium) that tend to adsorb, or “stick,” to the soil grains because of their positive

electric charge and large organic molecules (e.g., non-decomposed plant and animal matter, oils, large biomolecules) that are not very soluble in groundwater. Even less mobile are the various microorganisms (e.g., viruses, bacteria, protozoa) that tend to be either filtered out or adsorbed by soil particles; however, these organisms have been shown to be surprisingly mobile in groundwater flowing through coarse-grained sands or gravels.

II. Sewage Indicators

Over the last several decades, there has been considerable amount of research directed toward identifying both organic and inorganic indicators of sewage that may be analyzed in freshwater or seawater. The obvious applications are to identify whether, where, and at what levels human sewage is being introduced to natural aquatic environments. In this section, I will review five of the most widely used indicators of human wastewater and comment on their applicability to detecting sewage components that may be transported by groundwater flow.

- Fecal sterols are the most widely used indicators of human sewage in the sediments of both marine and freshwater environments. A human metabolite of cholesterol known as *coprostanol* has been used worldwide to definitively identify the discharge of both raw and treated sewage into the environment (Writer et al. 1995; Chan et al. 1998). Unfortunately, coprostanol is a relatively insoluble organic compound in water, which is why it is primarily associated with the sediment fraction. It is unlikely that this indicator would move very far in groundwater. Similarly, both natural and synthetic estrogens have been used as markers of sewage impacts on surface water, groundwater, and marine environments (Atkinson et al. 2003). Steroidal estrogens are apparently more water-soluble than are fecal sterols, making them a better candidate for groundwater analyses.
- Surfactants used in the manufacturing of common detergents is another proven indicator of sewage contamination in marine environments. Specifically, a class of surfactants known as *linear alkylbenzenes* (LABs) has been utilized because they are slightly water soluble, resistant to wastewater treatment, relatively easy to detect, and only moderately degradable in the environment (Zeng et al. 1998). While LABs have a better chance of being transported in groundwater than does coprostanol, they are generally present at considerably higher concentrations in sediments than in the water column, suggesting that they may be adsorbed by soil particles in all but very coarse-grained aquifers. Nevertheless, if Hanalei groundwater contains a relatively high dissolved organic content, the LABs could be transported in association with these natural organic substances.
- Caffeine (*dihydrotrimethyl-purinedione*) has the distinct advantage of being water-soluble and has been detected in wastewaters at concentrations approaching 1 ppm (mg/L). While caffeine does biodegrade in aquatic ecosystems, it may be a

good candidate for analysis in groundwater because of its high solubility and moderately low detection limits. Considering the extensive area over which groundwater is introduced to the coastal marine environment in Hanalei Bay, caffeine concentrations may be too low to be detected in the Bay.

- EDTA (*ethylene diaminetetraacetic acid*) is a so-called chelating agent that is an ingredient in many kitchen and bathroom cleaning products. EDTA is highly water-soluble and its biodegradability is limited, particularly if it occurs in water as a metal complex. As a result, this compound has been used as an indicator of sewage in both groundwater aquifers and rivers (Ding et al. 1999). This compound also has the advantage of being detected with the use of conventional analytical techniques, as opposed to the biomolecular indicators that must be detected using specially developed and expensive technologies.
- A so-called *coliphage* group of viruses have received considerable attention in recent years as an indicator of sewage (specifically coliform bacteria) in both freshwater and marine systems. Coliphage viruses are apparently found in both human and avian feces; therefore, they would serve as a more definitive indicator of sewage in groundwater than in seawater. There are limited data on the fate and transport of these viruses in groundwater; however, the coliform bacteria must be lysed (i.e., the cell wall broken) to release the coliphage, which should be more mobile than its much larger bacterial host.

In addition to these five specific markers of sewage, three common inorganic anions (i.e., minerals possessing a negative electrical charge) are routinely included in evaluating the sewage impacts on aquatic ecosystems. The first two are the aforementioned nutrients, nitrate and sulfate, which tend to be highly elevated in wastewaters compared to natural fresh waters. The third is fluoride, a common ingredient of toothpastes and mouthwashes, which is a rare component of natural fresh waters. Obviously, these three indicators are appropriate only for groundwater analyses because seawater is characterized by relatively high background concentrations.

III. Demonstrating Submarine Groundwater Discharge

Another approach that researchers have adopted to assess the effects of groundwater contaminants on marine ecosystems is to measure or to mathematically model the mass flux of water from coastal aquifers to nearshore marine systems. Thus far, modeling has proven to be the least reliable of the assessment techniques because so many of the pertinent physical processes affecting mass flux are unknown (e.g., tidal pumping, wave action). Moreover, most onshore-to-offshore groundwater models assume that hydraulic gradients and the resulting discharges are relatively uniform (both temporally and spatially) along the coastline. A recent study conducted along the Atlantic Coast suggests that these assumptions are probably not valid and that both the magnitude and location of groundwater discharges are variable (Holly et al. 2003).

Measurement techniques routinely employed to estimate submarine groundwater discharge include direct physical methods such as seepage flux meters and indirect chemical methods such as groundwater tracer tests (Burnett et al. 2002). A simple seepage flux meter consists of a chamber placed open-end down in the marine sediments that collects seepage water in a removable plastic bag that is secured to a small opening in the top. Flux meters are generally emplaced at high tide because the transition from high to low tide (serving to reduce the hydraulic pressure) usually corresponds to the greatest groundwater discharge. The tracer tests may be performed with natural constituents of the groundwater or with water-soluble markers (e.g., dyes, salts, trace organics). An effective and inexpensively analyzed natural tracer is radon-222, which a radioactive gas that is present at low levels in groundwater but virtually absent in surface waters (both marine and freshwater) as a result of its high volatility. Exotic tracers are particularly effective for assessing whether groundwater contributed from a specific source (e.g., septic systems underlying public beach restrooms) is impacting the downgradient seawater. In some respects, the aforementioned sewage indicators could be considered “unintentional” exotic tracers.

IV. An Approach for Hanalei Bay and Adjacent Groundwater

One could approach demonstrating the potential transport of sewage components to Hanalei Bay in one of several ways. I will briefly outline one approach here; however, other approaches may prove to be as effective or even more effective.

- Perform a limited submarine groundwater discharge study to assess which areas of the Bay are likely receiving the greatest flux. The radon-222 analysis would probably be the cheapest and the least subject to sampling difficulties.
- Results of the submarine discharge study could be used to determine where seawater sampling (if any) are performed and where temporary groundwater monitor wells are located (e.g., upgradient from the marine discharge zones).
- Sample groundwater monitor wells for a suite of indicators including inorganic anions, EDTA, LABs, and perhaps caffeine. On the basis of these data, select analytes for seawater sampling.
- If suspected sources of sewage are identified, place a groundwater sample probe downgradient or the source. When the probe can be placed close to the source or in coarse-grained soils, groundwater could be sampled for microorganisms.

V. References

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