The Horizontal Levee
Linking Wetland Hydrology and Biogeochemistry to Wastewater Contaminant Removal

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Abstract

In response to concerns about the effects of wastewater effluent discharges into San Francisco Bay, the Oro Loma Sanitary District built an experimental Horizontal Levee test facility in 2016 (which became operational in April 2017) to assess the effects of various design and operational parameters on the ability of this new type of system to improve water quality. Monitoring over the first two years of operations indicates that removal of wastewater-derived contaminants can be achieved in this type of system, though these benefits are highly dependent on hydrological conditions. Additionally, a combination of subsurface redox monitoring and nitrogen isotope signatures suggest that only a small portion (~7% of the wetland area) of the subsurface is responsible for the bulk of contaminant removal. Continuing research is focusing on how electron transfers between redox active elements in the subsurface could provide a long-term energy source for contaminant transformation and removal.

Motivation

The Horizontal Levee aims to address the following issues:

• Many wastewater treatment plants release potentially harmful levels of nutrients and trace organic contaminants into coastal and estuarine environments.
• Wastewater infrastructure in coastal area largely occupies low-lying land that is susceptible to storm surges and sea level rise.
• The majority of historical coastal wetland habitat has been lost in the San Francisco Bay area to urbanization.

Objectives & Hypotheses

Objectives

• Investigate how design and operation of a horizontal levee can be optimized for contaminant removal.
• Identify key transformation and removal pathways.

Hypotheses

A horizontal levee can achieve significant removal of wastewater-derived contaminants.

Hydrology is the most important variable controlling contaminant removal in a horizontal levee.

Nitrate-N is primarily removed by microbial denitrification in a horizontal levee.

Results

Nutrient Removal

• Variable over time, unclear role for seasonality.
Removal primarily occurs in the subsurface in the first ~5m

Impact of Different Variables on Contaminant Removal

• Impact of design and operational variables, as well as temperature, tested with regression analyses (see Table 1).
Hydrology is a controlling variable for removal of wide variety of contaminants (see Fig 6).

Site Description and Experimental Approach

Approach

1. The subsurface wetland is divided into 12 separate cells, allowing various treatments to be studied.
2. Influent and effluent water analyzed for nutrients and trace organic contaminants.
3. A water balance was constructed using anions (Cl- and NO3-) as tracers.
4. Pore water samples are collected at various positions and depths and analyzed for redox active species (e.g. NO3-, Fe(II), etc.).
5. Plant leaves, soils and wastewater were collected and analyzed for N isotope ratios.

Hypotheses

H2: Nitrate average overall fraction remaining: 0.36 (±0.19)
Unclear role of N load applied
Phosphate average overall fraction remaining: 0.79 (±0.44)

Mass Balance on Nitrogen

• Natural abundance N isotope ratios used to trace uptake by plants
• Up to ~47% of N removed taken up by plants in some cells
• Measurements from first year suggest >50% of applied N removed by microbial processes (e.g., denitrification)
• 15N tracer studies needed for confirmation

Fig 2, 3, and 4. Cross-section of the horizontal levee (above), a plan view delineating the experimental cells (bottom left) and a conceptual water balance (below). Experimental treatments vary based on: (i) hydrology, (ii) planting regimes, and (iii) topsoil types. The water balance shows the interplay between overland flow, subsurface flow and evapotranspiration in the levee.

Next Steps

• Investigation of clogging mechanisms and non-invasive control measures
• Continued monitoring of the site to investigate long-term contaminant removal

Design Implications

• Subsurface flow is key to contaminant removal - media layers appear to be effective with topsoil layers preventing significant diffusion of oxygen into subsurface that could inhibit denitrification, reuse of native sediments appears to work well
• Drainage layers must be coarse enough and have sufficient depth to pass flow
• Design should prevent fine particles from surface layers from plugging coarse bottom layers
• Variety of native plant communities appear to enhance contaminant removal, providing flexibility with respect to habitat restoration design
• Addition of woodchips useful in stimulating contaminant removal

Operational Issues

• Changes in hydraulic conductivity and residence time tracked over time (see Fig 9)
• Progressive decrease in hydraulic conductivity likely due to clogging
• Trade-off between increased residence time/performance and treatment capacity
• More thorough understanding of clogging mechanisms and non-invasive control measures required

Fig 9. Changes in median hydraulic conductivity (K, blue circles) and residence time (HRT, green circles) among experimental cells over the first 19 months of operation.

Results (cont.)

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Design Implications and Next Steps

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• Continued monitoring of the site to investigate long-term contaminant removal
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• Mechanistic contaminant removal studies to confirm observed results

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