Coastal Watershed Planning – Analyzing Bacterial Loads in a Rural Watershed for BMP Implementation

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Overview

- Watershed Protection Plans
- How sampling results translate into SELECT and Load Reduction Goals (LDCs and Tidal Mixing)
- Implementation Phase: How Load Reduction Goals translate into real-world management measures

End Goal: Decreased Levels of Bacteria = Improved Water Quality
Watershed Protection Plans

Load Duration Curve (EFU 8042546; n=43)

- High Flows
- Mid-Range Conditions
- Low Flows
- Load Regression Curve
- E. Coli TMDL with 10% MOS

Percent of Days Load Exceeded

Stakeholder approved and EPA accepted
Galveston Bay

- Double Bayou
- Cedar Bayou
- Bastrop Bayou
- Armand Bayou
- Dickinson Bayou
- Westfield Estates
Sampling Stations

- Two on each Fork, one at Anahuac WWTP
- Two Year sampling period
- **routine** events (sampling @ twice a month)
- **targeted** rain events @ 3/year
Double Bayou Bacteria Geometric Mean

*Geometric means includes routine samples only

- **E. coli Geometric Mean Criterion (126 MPN/100 mL)**
- **Enterococci Geometric Mean Criterion (35 MPN/100 mL)**

<table>
<thead>
<tr>
<th>Location</th>
<th>E. coli (w/ most probable number)</th>
<th>Enterococci (geometric mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Fork Upper @ FM 1663</td>
<td>94</td>
<td>123</td>
</tr>
<tr>
<td>Anahuac Waste Water Treat.</td>
<td>5</td>
<td>72</td>
</tr>
<tr>
<td>East Fork Lower @ Carrington Rd</td>
<td>72</td>
<td>123</td>
</tr>
<tr>
<td>East Fork Upper @ Sykes Rd</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>West Fork Lower @ Eagle Ferry Rd</td>
<td>78</td>
<td></td>
</tr>
</tbody>
</table>
Spatially Explicit Load Enrichment Calculation Tool (SELECT)

- Developed at the Dept. of Biological and Agricultural Engineering and the Spatial Science Laboratory at Texas A&M University
- Spatially characterizes potential bacteria loads
- Uses layers in a GIS to calculate potential loads
  - Land Use, Delineated watersheds, Soils, Hydrography

Photos courtesy of Linda Sheed
Estimating Populations

- Estimate populations in the watershed that might be contributing to bacterial loads – people, livestock, wildlife, etc.

- Example – Dogs in Anywhere Watershed
  - 1 dog per household in Anywhere
  - Estimated Anywhere Population: 10,775 (from Census block data)
  - *E. coli* load per dog
    - (fecal excretion rates for animals/humans are calculated and published by the EPA)
    - $5.0 \times 10^9$ Fecal Coliform = $2.5 \times 10^9$ *E. coli*
  - SELECT will calculate different potential loads from these inputs for Anywhere
Functions of Stakeholder Workgroups with SELECT

Workgroups

- Review population estimates
- Review results & give feedback to adjust model
- Use results in determining type/number/placement of BMPs

SELECT Model

- Apply populations to appropriate land uses
- Calculate bacteria loading
- Create map showing areas of highest to lowest potential loading
SELECT Results

- Ran Spatially Explicit Load Enrichment Calculation Tool (SELECT) model to determine potential source output and location
- Met with workgroups to discuss and fine tune results

Watershed @ 62,000 acres
Double Bayou Upper East Fork Load Duration Curve (LDC – Estimate of Pollutant Loads)

- High Flow Conditions = 84% reduction needed
- Mid-Range Flow Conditions = 30% reduction needed
- Low Flow Conditions = 0% reduction needed

Note the blue line has crossed and is under the red line (in compliance) at this point.
Trinity Bay

- Part of Galveston Bay Estuary System
- Relatively Shallow
  - 2 to 3 meters (6.6 to 9.8 feet)
- Largely enclosed
- Not heavily influenced by tides
- Winds significantly influence fluctuations and water levels
Flow Example: 3 Day Variance in Water Flow Patterns at West Fork Lower

- 24-hour data – irregularity of tidal, wind and other influences

Diurnal Pattern

Semidiurnal Pattern

Irregular Pattern
Bacteria Loadings

• Loadings for the West Fork Lower station were analyzed based on volumetric calculations.

• Daily loads on bacteria sampling days were calculated by integrating the 15-minute volume increments into a day’s worth of volume (units of cubic meters, or m³).
  – So, every 15 minutes the flow meter sampled: Flow in cubic feet per second, or cfs.
  – Integrating the day’s worth of 15 minute measurements resulted in final volume for the day.
  – If you think of that cross section of the bayou as bowl, we are interested in all flow into that bowl during one day: This is total volume ($V_t$).
Bacteria Loadings

- Blue dots on or below the yellow line are meeting
- Blue dots above the line are exceeding

West Fork Lower: $V_t$ and Daily Load

![Graph showing the relationship between daily load and $V_t$.]
BMPs and Measured Load Reductions

• Deposition distance of ~7 ft from stream (opposed to instream) leads to 95% reduction of bacteria that reaches stream (Larsen, Buckhouse et al. 1988)

• Riparian Herbaceous Buffers
  – Used with alt. water source
  – 27 m (~90 ft) wide riparian buffer = 69% instream bacteria reduction
  – Also, can reduce bacteria inputs from wildlife and feral hogs

• Dynamic multi use BMPs such as this combination are preferred and will be given priority
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Questions?

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Double Bayou WPP Current State

- Double Bayou 2012 Integrated Report (impaired waters in the State of Texas)
  - West Fork
    - low levels of dissolved oxygen
    - elevated levels of bacteria
  - East Fork
    - concern for elevated levels of bacteria
    - concern for low dissolved oxygen

- Low dissolved oxygen is a concern for aquatic life because they require a certain amount of dissolved oxygen to live and reproduce

- Elevated levels of bacteria can be a concern for people using a waterway for recreational use, because elevated concentrations can indicate the presence of human disease causing pathogens
Load Duration Curves

- Incorporate the concentration of constituent (in Double Bayou’s case, bacteria) to produce the Load Duration Curve (LDC)
- The “load” is expressed as amount of pollutant per unit time – i.e., bacteria in cfu/day.
- Resulting curve reflects the maximum load a stream can carry across the regime of flow conditions (low flow, medium flow, high flow) without exceeding the water quality standard.
Load Duration Curves

• Flow regime pollutant concentrations can be useful for evaluating potential point or nonpoint sources

• Primarily high flows exceedances $\rightarrow$ nonpoint sources
  – High flows usually linked to higher rainfall events; surface runoff which can carry pollutants to the stream

• Primarily low flows exceedances $\rightarrow$ point sources
  – Low flows usually linked to no runoff entering the stream and primarily direct discharges contributing
LDC – Estimate of Pollutant Loads

Load Duration Curve (EFU 8042546; n=43)

- High Flows: 84% reduction needed
- Mid-Range Flow Conditions: 30% reduction needed
- Low Flow Conditions: 0% reduction needed

Note the blue line has crossed and is under the red line (in compliance) at this point.
Trinity Bay

• Winds are the dominating factor in circulation patterns
  – tides and freshwater inflows also influencing factors
• Trinity and San Jacinto rivers = majority of freshwater inflows
• Inflow seasonality
  – Spring rains = largest volume of freshwater inflows (April & May)
  – During this time, salinity in Trinity Bay can drop to 0 psu (practical salinity unit)
  – Normal conditions = @10 psu
  – Typical low-flow season @ July-October
Double Bayou

- Trinity Bay’s circulation patterns contribute to Double Bayou’s flow patterns
- The tidal influence is relatively weak in this shallow estuary system, but there are tidal effects
  - As the tide comes in (whether due to direct tidal flow or wind patterns), water flows up the bayous
  - Strongest observed response at the lower West Fork sampling station (closest station to Trinity Bay)
Bacteria Loadings

- Enterococci sample concentration measured for the day multiplied by total Volume for the day results in the calculated daily load for each sample (units of cfu/day, total sample size for West Fork Lower was 46)

- Maximum allowable load was calculated in the same manner, using the maximum allowable Enterococci standard of 35 cfu/100 mL

\[
\text{Daily Load} \left( \frac{\text{cfu}}{\text{day}} \right) = V_t \left( \frac{m^3}{\text{day}} \right) \times C \left( \frac{\text{cfu}}{100 \text{ mL}} \right) \times 1,000,000 \left( \frac{\text{mL}}{m^3} \right)
\]

Total amount of water accumulated in our “bowl” during the day

The bacteria grab sample concentration

Conversion factor for units
Load Reduction Goal

- As with the percent reduction goal determined by LDC analysis, the percent exceedance categories were evaluated.
- As opposed to categorizing by flow, such as with the LDC analysis, the focus was on the categories themselves and distribution within each category.
- Categories based on distribution frequency.

<table>
<thead>
<tr>
<th>Percent Exceedance Category</th>
<th>Number of % exceedances in each category</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>75-100%</td>
<td>17</td>
<td>90%</td>
</tr>
<tr>
<td>40-74%</td>
<td>15</td>
<td>59%</td>
</tr>
<tr>
<td>Under 0 (meeting criteria) - 39%</td>
<td>14</td>
<td>-1044%</td>
</tr>
</tbody>
</table>

**How can we achieve load reduction goals?**
Negative Discharge – Tidal Mixing dilutes Bacteria

- Statistical analysis conducted on the bacteria samples in the categories of positive discharge and negative discharge
- Showed that the Enterococci levels of negative and positive flows at WFL are statistically different
- Negative flow samples’ percent exceedance was **18%** and the positive flow samples’ percent exceedance was **94%**
- Conclusion: tidal mixing dilutes the bacteria concentration and the resulting bacteria loads would not exceed the regulatory load, during negative flow sample periods.
Bacteria Loadings

• Irregular flow pattern at West Fork Lower → LDC approach basing pollutant loadings on flow regimes would not work

• Little correlation between positive flow and bacteria concentration for West Fork Lower
  – Likely due to the wind-driven nature of the system – periods of intense rainfall will often be accompanied by high winds, causing erratic flow patterns.

• One note here – strong connection between bacteria results for targeted rain events compared to non-rain event samples.
  – Targeted rainfall event samples: Enterococci had a 100% exceedance rate
• Conclusion from previous slide is based on the assumption that the Bay is not a source of bacteria – which is true

• Analyzed bacteria data from the four stations in the figure, data from 2001-2014

• Geomean of the Enterococci from these years (46 samples) is 7.6; of these, the most recent samples (20 of the 46) have a geomean of 6.6
- Designated Use: Aquatic Life
- Low Dissolved Oxygen levels can indicate an excessive demand on the oxygen in the system.

< 0.5 mg/L *Anoxic* – Oxygen dependent animals die
< 3 mg/L *Hypoxic* - Most aquatic organisms cannot survive
  4-5 mg/L *Aquatic organisms become stressed*
> 6 mg/L *Optimal for many aquatic organisms*
Dissolved Oxygen

- **Time dependent**
  - Plants don’t produce oxygen during the night - but oxygen is still being used then for respiration, so dissolved oxygen (DO) concentrations will be the lowest in a water body in the morning.

- **Temperature dependent**
  - The colder the water, the greater capacity it has to hold oxygen.
Dissolved Oxygen

- **Salinity dependent**
  - As salinity in water increases, its ability to hold DO decreases.
  - But DO decreases more as temperature goes up regardless of salinity.

- **Event dependent**
  - DO can go up right after a rainfall because fresh rain water, which is high in DO, is flushed into the system.
  - After a lag period, the DO may go down because of increased bacteria in the runoff leading to increased decomposition.
Variation in Dissolved Oxygen and Water Temperature: 
Double Bayou (not including WWTP)

- R² = 0.4954
- R² = 0.681
<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>Animal Units</th>
<th>Number of Farms per Subwatershed</th>
<th>Recommended Number of WQMPs*</th>
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<td><strong>Total</strong></td>
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<td><strong>122</strong></td>
<td><strong>52</strong></td>
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