Nutrient Discharges from Mayaguez Bay Watershed (Rio Grande de Anasco)

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• Water Resources Research Institute (UPR-Mayaguez)
• Duration: 3 years
• Funds: $120,000
• Collaborators
  • Prof. Myrna Alameda
  • Ronald Corvera Gomringer
  • Undergraduate and graduate students
Presentation Outline

1. Land-use evaluation and GIS assemblage
2. Bacterial-indicator dynamics during base-flow and elevated base-flow
3. Nutrient dynamics during base-flow and elevated base-flow
4. Storm event nutrient and sediment analysis
5. Hydrologic modeling
6. Summary
Water quality

- Nutrients and sediments - runoff
- Nutrients and sediments - low and intermediate flow
- Hydrology
- Indicator bacteria
- GIS and hydrologic models

Nutrient and sediment yields and loads
Project objectives

- Quantify seasonal and annual nutrient, sediment, and bacterial concentrations and loads to sub-basin outlets during base-flow and storm events

- Characterize land-use factors influencing nutrient loads

- Assess the relative non-point source nutrient contribution to surface waters
Background

- The lack of an adequate numerical standard for N and P does not permit adequate assessment of the water-quality status.

- This may result in continued degradation of surface-water quality and discrepancy between PR and other ecoregions.

- A "watershed approach" is the best alternative towards assessment of point and non-point sources and load allocation among sources for nutrient contribution.
The Rio Grande de Añasco (RGA) watershed

- Approx. area of 52,278 ha
- Estimated population of > 175,000
- Most without sewer system
- Few large-scale animal feeding operations
1. Land-use evaluation and GIS assemblage

- 1977 Digital land-use map
- Coverages: soils, hydrologic soil grouping, geology, topography
- Digital orthoquad photographs 1997
- IKONOS™ image (2000)
- Farms, crops, related activities with USDA-NRCS collaboration
- Software Arc View ver 3.2; Watershed Modeling System (WMS ver. 6.1)
Coverages

Geology Map of Rio Cercada Sub - Watershed

Soil Series Map Rio Cercada Sub - Watershed

Farms of the Rio Cercada - Sub Watershed

Crops Map Rio Cercada Sub - Watershed
Land use maps
## Land use distribution

<table>
<thead>
<tr>
<th>Uso</th>
<th>Miraflores</th>
<th>Cerro Gordo</th>
<th>Cerrote</th>
<th>Chamorro</th>
<th>Guaba</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ha)</td>
<td>(%)</td>
<td>Area (ha)</td>
<td>(%)</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>Sub-urban</td>
<td>25.8</td>
<td>11.5</td>
<td>8.0</td>
<td>1.1</td>
<td>8.6</td>
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<tr>
<td>Agriculture</td>
<td>8.6</td>
<td>3.9</td>
<td>144.6</td>
<td>20.2</td>
<td>25.9</td>
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<tr>
<td>Rangeland</td>
<td>51.7</td>
<td>23.1</td>
<td>96.3</td>
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<td>34.5</td>
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<tr>
<td>Forest</td>
<td>137.8</td>
<td>61.5</td>
<td>393.5</td>
<td>55.1</td>
<td>224.3</td>
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<tr>
<td>Pasture</td>
<td>0.0</td>
<td>0.0</td>
<td>72.3</td>
<td>10.1</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>224.0</strong></td>
<td><strong>714.7</strong></td>
<td><strong>293.3</strong></td>
<td></td>
<td><strong>397.3</strong></td>
</tr>
<tr>
<td>Housing/</td>
<td>560</td>
<td></td>
<td>776</td>
<td></td>
<td>435</td>
</tr>
<tr>
<td>Structures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Bacterial indicator dynamics during base-flow and elevated base-flow
Objectives

- Quantify trends and concentrations of indicator bacteria
- Isolate and identify coliforms and enterococcus
- Identify probable sources of bacteria contamination
Introduction

Hypothesis: Surface water in rural sub watersheds have high concentrations of indicator bacteria

• What are the concentrations and temporal and spatial variation?

• What type of organisms are present?

• What is the source?
Sampling stations

1. Miraflores
2. Cerro Gordo
3. Chamorro
4. Cerrote
5. Guaba
Sampling (A) and hydrologic characterization (B)
Water-quality indicators

- Hydrologic flow (in situ, velocity meter)
- Suspended solids (sediments) (EPA 160.2)
- pH (EPA 150.1)
- EC (EPA 120.1)
- Total P and dissolved P (EPA 365.2)
- Total N (TKN) (EPA 351.2)
- Chlorophyll-a (EPA 445.0)
- Total coliforms (Coliscan® Easygel®)
- Escherichia coli (Coliscan® Easygel®)
- Enterococci spp. (m-Enterococcus agar)
Quantitative and qualitative analysis of coliforms and enterococcus

- **Pour plate technique:** water sample mixed with selective media “Coliscan Easy Gel ®”
- **Enterococcus:** Membrane filtration w/ selective media for enterococcus “m-Enterococcus Agar”
- **Confirmation test:** (i) gram stain and (ii) growth in selective media
- **Biolog® MicroLog™** for species identification
Frequency distribution of bacteria

- **E. Coli**: Miraflores (10^5 CFU/100 mL), Cerro Gordo (10^4), Cerrote (10^3), Chamorro (10^2), Guaba (10^1)

- **Enterococcus spp.**: Miraflores (10^5 CFU/100 mL), Cerro Gordo (10^4), Cerrote (10^3), Chamorro (10^2), Guaba (10^1)

**Total coliforms**

- Miraflores (10^5 CFU/100 mL), Cerro Gordo (10^4), Cerrote (10^3), Chamorro (10^2), Guaba (10^1)
Suggests that sources, and factors that affects its survival are similar among groups.
Bacterial transport is associated with suspended sediments.

Correlation (r) among sediments and:
- Total coliforms = 0.631
- *E. coli* = 0.537
- *Enterococcus* = 0.558
• *Enterococcus* transport is associated with nutrients

• Pearson correlation among *Enterococcus* and:
  - DP = 0.292
  - TP = 0.191
  - TKN = 0.332

• Total coliforms and *E. coli* also were correlated with DP, only

![Graph showing correlation between Log10 Enterococcus (cfu/100 mL) and Dissolved P (mg/L)]
Relationship between bacterial density and distance from the point of interest at Miraflores
Coliformes totales (cfu/100 mL)

- 5 marzo 2003
- 15 junio 2003
- 20 abril 2004 (1)
- 20 abril 2004 (2)
Six genera and eleven species of coliforms were isolated

- *Escherichia* 26%
- *Enterobacter* 26%
- *Klebsiella* 22%
- *Raoutella* 11%
- *Citrobacter* 7%
- *Pectobacterium* 7%

Two genera and eight species of enterococcus were isolated

- *Enterococcus* 90%
- *Lactococcus* 10%
### Identification and origin

<table>
<thead>
<tr>
<th>Genera</th>
<th>%</th>
<th>% / genera</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterococcus faecalis</td>
<td>41</td>
<td></td>
<td>humano, poultry</td>
</tr>
<tr>
<td>Enterococcus gallinarum</td>
<td>13</td>
<td></td>
<td>poultry</td>
</tr>
<tr>
<td>Enterococcus casseliflavus</td>
<td>9</td>
<td></td>
<td>humano, herbívores</td>
</tr>
<tr>
<td>Enterococcus flavescens</td>
<td>9</td>
<td></td>
<td>unknown</td>
</tr>
<tr>
<td>Enterococcus mundtii</td>
<td>9</td>
<td></td>
<td>herbívores</td>
</tr>
<tr>
<td>Enterococcus faecium</td>
<td>3</td>
<td></td>
<td>humano, herbívores, poultry</td>
</tr>
<tr>
<td>E. sulfureus</td>
<td>3</td>
<td></td>
<td>unknown</td>
</tr>
<tr>
<td>Enterococcus sp.</td>
<td>3</td>
<td></td>
<td>unknown</td>
</tr>
<tr>
<td>Lactococcus gaeviae (=Enterococcus)</td>
<td>6</td>
<td>90</td>
<td>unknown</td>
</tr>
<tr>
<td>L. lactis ss. lactis (=Enterococcus)</td>
<td>3</td>
<td>10</td>
<td>unknown</td>
</tr>
<tr>
<td>Coliforms / %</td>
<td>%</td>
<td>% / genera</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td><em>Citrobacter freundii</em></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. koseri</em></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Enterobacter cloacae</em></td>
<td>11</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td><em>E. aerogenes</em></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. amnigenus</em></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. cancerogenes</em></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Enterobacter sp</em></td>
<td>3.7</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>18.5</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td><em>Escherichia vulnevis</em></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Klebsiella pneumoniae ss pneumoniae</em></td>
<td>18.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>K. pneumoniae</em></td>
<td>3.7</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td><em>Raoutella terrigena (=Klebsiella</em>)*</td>
<td>11</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><em>Pectobacterium caratovorum (=Enterobacter</em>)*</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
¿Why are bacteria persistent in the water column?
1. Sedimento Columna del agua

2. log CFU / 100 mL agua

3. Coliformes totales

4. Enterococcus
Relationship between bacterial density and distance from the point of interest at Miraflores
1. Coliformes totales (cfu/100 mL)

2. Distancia a partir del punto de cierre (m)

3. 5 marzo 2003
4. 15 junio 2003
5. 20 abril 2004 (1)
6. 20 abril 2004 (2)
2. Summary

- Rural sub watersheds have high concentrations of indicator contaminant bacteria

- There is variation among watersheds, cannot quantitatively link to land use

- Bacteria were positively related to sediments and nutrients (en especially DP) but not with hydrologic flow

- Indicator bacteria increased with increasing distance from the point of interest with highest values near the zone with highest population density
2. Summary (cont.)

- Enterococcus spp. Indicate that probable sources of contamination are: humans, herbivores, poultry

- The absence of formal animal feeding operations suggests that bacteria originate from:
  - Poultry and domestic animals near residences
  - Gray water discharges
  - Septic-tank malfunctioning

- The presence of bacteria affect the water quality of tributaries feeding the RGA river
3. Nutrient dynamics during base- and elevated base-flow
Objetives

• Quantify changes in causal factors (nutrients) and response factors (Chlorophyll-a)

• Caracterize the influence of land use on nutrient dynamics in streamwaters

• Quantify annual yields and loads from sub watersheds
## Water-quality dynamics\(^1\) - mean values

<table>
<thead>
<tr>
<th>Location</th>
<th>TP ((\mu g/L))</th>
<th>DP ((\mu g/L))</th>
<th>TKN (mg/L)</th>
<th>DIN (mg/L)</th>
<th>SS (mg/L)</th>
<th>Flow (m(^3/s))</th>
<th>Chlor(_{a}) ((\mu g/L))</th>
<th>N:P(diss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miraflores</td>
<td>55.9 a</td>
<td>48.7 ab</td>
<td>0.085 a</td>
<td>0.575 b</td>
<td>3.57 b</td>
<td>0.052 e</td>
<td>0.188 b</td>
<td>12.4 c</td>
</tr>
<tr>
<td>Cerro Gordo</td>
<td>54.8 a</td>
<td>40.3 bc</td>
<td>0.121 a</td>
<td>0.617 b</td>
<td>20.5 a</td>
<td>0.208 b</td>
<td>0.285 ab</td>
<td>16.5 bc</td>
</tr>
<tr>
<td>Cerrote</td>
<td>52.1 a</td>
<td>36.9 c</td>
<td>0.077 a</td>
<td>0.624 b</td>
<td>1.94 b</td>
<td>0.131 c</td>
<td>0.390 a</td>
<td>23.3 b</td>
</tr>
<tr>
<td>Chamorro</td>
<td>62.8 a</td>
<td>53.6 a</td>
<td>0.123 a</td>
<td>0.954 a</td>
<td>1.45 b</td>
<td>0.088 d</td>
<td>0.190 b</td>
<td>20.7 bc</td>
</tr>
<tr>
<td>Guaba</td>
<td>23.4 b</td>
<td>25.2 d</td>
<td>0.065 a</td>
<td>0.805 a</td>
<td>2.52 b</td>
<td>0.336 a</td>
<td>0.439 a</td>
<td>42.7 a</td>
</tr>
</tbody>
</table>

\(^1\) TP = total P; DP = dissolved P; TKN = Total Kjeldahl N; DIN = inorganic N; SS = suspended sediments; Chlor\(_{a}\) = chlorophyll-a; N:P(diss) = DIN/DP ratio.
## Correlation matrix pearson (coefficients)

<table>
<thead>
<tr>
<th>Parametro</th>
<th>DP</th>
<th>TP</th>
<th>TKN</th>
<th>Clor$_a$</th>
<th>SS</th>
<th>DIN</th>
<th>N:P$_{(diss)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TP</td>
<td>0.201</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TKN</td>
<td>NS</td>
<td>0.192</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chla</td>
<td>-0.351</td>
<td>NS</td>
<td>0.180</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SS</td>
<td>NS</td>
<td>NS</td>
<td>0.303</td>
<td>NS</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DIN</td>
<td>0.267</td>
<td>NS</td>
<td>NS</td>
<td>-0.377</td>
<td>NS</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N:P$_{(diss)}$</td>
<td>-0.604</td>
<td>-0.431</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Flow</td>
<td>-0.185</td>
<td>-0.356</td>
<td>NS</td>
<td>NS</td>
<td>0.296</td>
<td>0.270</td>
<td>0.458</td>
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<td>Temp</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>-0.313</td>
</tr>
<tr>
<td>pH</td>
<td>-0.207</td>
<td>-0.246</td>
<td>-0.296</td>
<td>NS</td>
<td>-0.293</td>
<td>NS</td>
<td>0.394</td>
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<tr>
<td>EC</td>
<td>-0.241</td>
<td>NS</td>
<td>-0.188</td>
<td>NS</td>
<td>-0.380</td>
<td>NS</td>
<td>0.224</td>
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</table>
Multiple regression models among water-quality parameters

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Equation</th>
<th>Intercept</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>-0.00307*(temp) – 0.02781*(flow) + 0.00569*(ecoli)</td>
<td>0.126</td>
<td>0.220</td>
</tr>
<tr>
<td>DP</td>
<td>-0.00858*(DIN) – 0.00453*(temp) + 0.00854*(ecoli) – 0.02728*(flow) – 0.0000842*(ec)</td>
<td>0.181</td>
<td>0.428</td>
</tr>
<tr>
<td>TKN</td>
<td>Non-significant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIN</td>
<td>-0.003*(temp) + 0.0053*(ecoli) + 0.157*(DP) – 0.0252*(flow)</td>
<td>0.120</td>
<td>0.223</td>
</tr>
<tr>
<td>Chla</td>
<td>0.00119*(EC) – 0.30417*(DIN) + 0.2552*(flow) + 5.718*(TP) – 0.545 *(DP)</td>
<td>0.027</td>
<td>0.616</td>
</tr>
</tbody>
</table>

1 Temp = temperature; flow = log₁₀(hydrologic flow); ecoli = log₁₀(E. coli); DIN = inorganic N; TP = Total P; DP = Dissolved P; EC = Electrical conductivity
Water-quality dynamics (cont.)

- Organisms are utilizing dissolved nutrient forms (DP $\gamma$ DIN)
  - Positive (weak) correlation between DP and TP
  - Negative correlation between DP and Chl$_a$
- Nutrient concentrations are diluted with hydrologic flow
- Subwatershed areas influenced hydrologic flow
- There are differences among watersheds for various water-quality parameters
  - Possible nutrient limitations
  - Changes in land use
What are the nutrient sources and land use factors that influence nutrient concentrations?

- Include data from five sub watersheds in northern Puerto Rico (10 total)
- Multiple regression models of TP, DP, TKN, DIN concentrations with land use proportions of each sub watershed
- \[ Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots + \beta_n X_n \]
  - where \( X_i \) is the relative land use proportions of agriculture, forest, suburban, rangeland, pasture
  - \( \beta_n \) are the estimated regression coefficients
  - \( Y \) is the predicted nutrient concentration

- For example:

\[
\log_{10} TP = -0.775 \cdot (Ag) -1.373 \cdot (For) + 2.496 \cdot (Urb) -2.607 \cdot (Ran) - 1.080 \cdot (pas); \; r^2 = 0.96
\]
What happens if land use changes by at most 10%?

![Graphs showing changes in Total P, Dissolved P, TKN, and DIN under different land-use changes.](image-url)
Empirical approach to estimate annual yields (export coefficients)

\[ \text{Load}_{\text{nutrient, sediment}} = \int_{\text{Time}} Q_i C_i \, dt \]

\[ \text{EC (kg P/ha/yr)} = \text{Load} / \text{sub watershed area} \]

where \( Q_i \) is the hydrologic flow, \( y \) \( C_i \) is the nutrient concentration, and \( dt \) is the time interval (approx. 15 days)
Area-load relationships for subwatersheds

\[ y = 0.8121x + 0.5426 \]
\[ R^2 = 0.9537 \]

\[ y = 1.0757x - 0.501 \]
\[ R^2 = 0.9055 \]
# TP loads and yields for five sub watersheds

<table>
<thead>
<tr>
<th>Sub watershed</th>
<th>Empirical loads kg P/ws/yr</th>
<th>Empirical yields kg P/ha/yr</th>
<th>Theoretical yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miraflores</td>
<td>93</td>
<td>0.414</td>
<td>1.18</td>
</tr>
<tr>
<td>Cerro Gordo</td>
<td>367</td>
<td>0.514</td>
<td>0.834</td>
</tr>
<tr>
<td>Cerrote</td>
<td>209</td>
<td>0.713</td>
<td>0.665</td>
</tr>
<tr>
<td>Chamorro</td>
<td>149</td>
<td>0.374</td>
<td>0.523</td>
</tr>
<tr>
<td>Guaba</td>
<td>745</td>
<td>0.564</td>
<td>0.590</td>
</tr>
</tbody>
</table>
## TP loads and yields for ten sub watersheds

<table>
<thead>
<tr>
<th>Sub watershed</th>
<th>Empirical loads kg P/ws/yr</th>
<th>Empirical yields kg P/ha/yr</th>
<th>Theoretical yields kg P/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miraflores</td>
<td>93</td>
<td>0.414</td>
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</tr>
<tr>
<td>Guaba</td>
<td>745</td>
<td>0.564</td>
<td>0.590</td>
</tr>
<tr>
<td>S. Grande</td>
<td>254</td>
<td>1.32</td>
<td>1.59</td>
</tr>
<tr>
<td>Jua</td>
<td>418</td>
<td>1.48</td>
<td>0.57</td>
</tr>
<tr>
<td>Caonilla</td>
<td>4256</td>
<td>0.81</td>
<td>0.82</td>
</tr>
<tr>
<td>Jauca</td>
<td>497</td>
<td>0.34</td>
<td>0.50</td>
</tr>
<tr>
<td>Saliente</td>
<td>1658</td>
<td>0.22</td>
<td>0.50</td>
</tr>
</tbody>
</table>
3. Summary

- Described the water quality status of rural subwatersheds in the tropical Caribbean
- Estimates of annual TP yields from subwatersheds
- Evaluate possible land-use scenarios on stream water quality
- Agric to suburban conversion presents largest change in TP and DP concentrations
4. Storm event nutrient and sediment analysis (R. Corvera-Gomringer)
Objectives

• Quantify TP, TKN, and SS concentrations during storm (runoff) events in two sub waterhseds
Methods

- Points of interest equipped with ISCO 3700 automated samplers
- Equipment connected to pressure transducer to record continuous water height during storm event
- Equipment programmed to sample composite water samples (15 subsamples of 600 mL each)
- Stage and storm duration was adjusted accordingly during the year to sample various types of events
• Storm event flow was determined from rating curves developed from channel cross-sections

• Event hydrologic discharge was determined as determined by LPA (Section 5)

• Water samples transported on ice within 24 h after the event and analyzed for sediments and nutrients as described previously
Mean values during storm events

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>PT</th>
<th>PD</th>
<th>NTK</th>
</tr>
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<tbody>
<tr>
<td>Miraflores</td>
<td>1551.92</td>
<td>0.34</td>
<td>0.06</td>
<td>1.70</td>
</tr>
<tr>
<td>Cerro Gordo</td>
<td>2737.81</td>
<td>0.48</td>
<td>0.02</td>
<td>3.15</td>
</tr>
</tbody>
</table>
TP load vs discharge

Miraflores

Total storm event discharge (m³)

TP Load (kg)

\[ y = 1.291x - 4.911; R^2 = 0.56 \]

Cerro Gordo

Total storm event discharge (m³)

Total storm event

Rising limb of hydrograph

\[ y = 0.873x - 2.961; R^2 = 0.538 \]
5. Hydrologic modeling (L. Perez-Alegria)
This is the help window.
Base Flow Determination
Low Flow Analysis - San Sebastian Station USGS 50144000

Recurrence (years)

Flow (cfs)

$7Q_{25}$
Base Flow Analysis (cont.)

**Base flow for the un-gauged watershed:**

\[ Q_b = \frac{Q_x}{A_x} A_b \]

Where \( Q_b \) is the extrapolated base flow for the un-gauged watershed with drainage area \( A_b \) and \( Q_x \) is the baseflow at watershed of drainage area \( A_x \)

**Base flow and areas in subwatersheds**

<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>Area (Ha)</th>
<th>Base Flow (cfs)</th>
</tr>
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<tbody>
<tr>
<td>San Sebastián</td>
<td>24291.92</td>
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<tr>
<td>Cercada</td>
<td>224</td>
<td>0.63</td>
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<tr>
<td>Cerro Gordo</td>
<td>714.7</td>
<td>2.00</td>
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<tr>
<td>Cerrote</td>
<td>293.3</td>
<td>0.82</td>
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<tr>
<td>Chamorro</td>
<td>397.3</td>
<td>1.11</td>
</tr>
<tr>
<td>Guaba</td>
<td>1320</td>
<td>3.70</td>
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</table>
Base Flow and Runoff Separation

Hydrograph

Runoff Flow

\[ Q_{base} = 0.7 \, Q \]

Base Flow

\[ Q_{base} = 0.7 \, Q \]
Precipitation Data
## Input Parameters

<table>
<thead>
<tr>
<th></th>
<th>Curve Number</th>
<th>SCS Lag (h)</th>
<th>Base Flow (cfs)</th>
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<td>Cercada</td>
<td>81.40</td>
<td>0.27</td>
<td>0.63</td>
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<tr>
<td>Cerro Gordo</td>
<td>83.1</td>
<td>0.49</td>
<td>2.00</td>
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<tr>
<td>Cerrote</td>
<td>70.30</td>
<td>0.40</td>
<td>0.82</td>
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<tr>
<td>Chamorro</td>
<td>78.00</td>
<td>0.36</td>
<td>1.11</td>
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<tr>
<td>Guaba</td>
<td>71.20</td>
<td>1.54</td>
<td>3.70</td>
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Hydrograph
Estimated Mean Daily Flow Cerro Gordo Watershed - 2003
Estimated Mean Daily Flow Chamorro Watershed - 2003

<table>
<thead>
<tr>
<th>Date</th>
<th>Flow (cfs)</th>
<th>Estimated Flow (cfs)</th>
<th>Grab Samples (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-Dec-02</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>19-Feb-03</td>
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<td></td>
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<tr>
<td>10-Apr-03</td>
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<td>30-May-03</td>
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<td></td>
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<tr>
<td>19-Jul-03</td>
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<td>7-Sep-03</td>
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<td>27-Oct-03</td>
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<tr>
<td>16-Dec-03</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Estimated Mean Daily Flow Guaba Watershed - 2003

Date
31-Dec-02 19-Feb-03 10-Apr-03 30-May-03 19-Jul-03 7-Sep-03 27-Oct-03 16-Dec-03

Flow (cfs)

Estimated Flow (cfs)
Grab Samples (cfs)
Flow for Storm Event at Ungaged Sites
Rating Curves

Rating Curve - Cercada Watershed

\[ y = 57.555x^{1.9852} \]
\[ R^2 = 0.9976 \]

\[ y = 4.8522x^4 - 32.299x^3 + 116.7x^2 - 29.092x \]
\[ R^2 = 1 \]

Rating Curve - Cerro Gordo Watershed

\[ y = 38.221x^{2.5505} \]
\[ R^2 = 0.9944 \]

\[ y = -0.3555x^4 - 3.8652x^3 + 113.49x^2 - 78.132x \]
\[ R^2 = 0.9999 \]
Estimated Flow Comparison - Cercada Watershed

Q HEC-HMS (cfs)

Q Rating Curve (cfs)
Estimated Flow Comparison - Cerro Gordo Watershed
Load Models
Cercada Watershed – Grab Samples

**DP Load Grab Samples - Cercada Watershed**

- Equation: $y = 8E-07x^{0.0041}
- R^2 = 0.8545$
- Equation: $y = 1E-06x$
- R^2 = 0.8746

**TP Load Grab Samples - Cercada Watershed**

- Equation: $y = 3E-06x$
- R^2 = 0.7100

**N Load Grab Samples - Cercada Watershed**

- Equation: $y = 1E-05x^{0.9999}$
- R^2 = 0.3856
- Equation: $y = 2E-06x$
- R^2 = 0.2625
Cercada Watershed – Grab Samples and Storm Events

DP Load Grab Samples and Storm Events - Cercada Watershed

$$y = 0.000000066x^{0.96485148}$$
$$R^2 = 0.85446143$$

$$y = 2E-13x^2 + 1E-06x$$
$$R^2 = 0.876$$

TP Load Grab Samples and Storm Events - Cercada Watershed

$$y = 0.0000026x^{0.6223366}$$
$$R^2 = 0.7186840$$

$$y = 5E-13x^2 + 1E-06x$$
$$R^2 = 0.8009$$

N Load Grab Samples and Storm Events - Cercada Watershed

$$y = 0.0000000000172x^{0.86395204}$$
$$R^2 = 0.63198201775$$

$$y = -6E-12x^2 + 3E-05x$$
$$R^2 = 0.2389$$
Cerro Gordo Watershed - Grab Samples

DP Load Grab Samples - Cerro Gordo Watershed

\[ y = 6 \times 10^{-5}x^{0.517} \]
\[ R^2 = 0.9593 \]

\[ y = 1.6 \times 10^{-6}x \]
\[ R^2 = 0.9593 \]

TP Load Grab Samples - Cerro Gordo Watershed

\[ y = 0.000000388x^{1.1048} \]
\[ R^2 = 0.9556 \]

\[ y = 2 \times 10^{-5}x \]
\[ R^2 = 0.9594 \]

N Load Grab Samples - Cerro Gordo Watershed

\[ y = 2 \times 10^{-6}x^{0.573} \]
\[ R^2 = 0.5502 \]

\[ y = 3 \times 10^{-6}x \]
\[ R^2 = 0.4298 \]
Cerro Gordo Watershed - Grab Samples and Storm Events

DP Load Grab Samples and Storm Events - Cerro Gordo Watershed

\[ y = 0.0000057b^{0.8096577} \]
\[ R^2 = 0.8096577 \]

\[ y = 8E-67x \]
\[ R^2 = 0.5362 \]

TP Load Grab Samples and Storm Events - Cerro Gordo Watershed

\[ y = 0.000008851x^{0.935764787} \]
\[ R^2 = 0.935764787 \]

\[ y = 8E-08x \]
\[ R^2 = 0.8279 \]

N Load Grab Samples and Storm Events - Cerro Gordo Watershed

\[ y = 0.000000011b^{0.79712158} \]
\[ R^2 = 0.79712158 \]

\[ y = 1E-05x \]
\[ R^2 = 0.8187 \]
Cerrote Watershed - Grab Samples

DP Load Grab Samples - Cerrote Gordo Watershed

TP Load Grab Samples - Cerrote Gordo Watershed

N Load Grab Samples - Cerrote Gordo Watershed
Chamorro Watershed Grab Samples

**DP Load Grab Samples - Chamorro Gordo Watershed**

- \( y = 1E-06x^{0.0444} \)
- \( R^2 = 0.8234 \)
- \( y = 1E-08x \)
- \( R^2 = 0.2705 \)

**TP Load Grab Samples - Chamorro Gordo Watershed**

- \( y = 9E-06x^{0.8584} \)
- \( R^2 = 0.9373 \)
- \( y = 1E-08x \)
- \( R^2 = 0.7459 \)

**N Load Grab Samples - Chamorro Gordo Watershed**

- \( y = 0.0086x^{0.5258} \)
- \( R^2 = 0.1074 \)
- \( y = 2E-08x \)
- \( R^2 = 0.3447 \)
Guaba Watershed Grab Samples

**DP Load Grab Samples - Guaba Gordo Watershed**

\[ y = 1E+02x^{0.894} \]
\[ R^2 = 0.9303 \]

**TP Load Grab Samples - Guaba Gordo Watershed**

\[ y = 3E+07x^{1.0234} \]
\[ R^2 = 0.792 \]

**N Load Grab Samples - Guaba Gordo Watershed**

\[ y = 1E+07x^{1.1776} \]
\[ R^2 = 0.4266 \]

\[ y = 3E+08x \]
\[ R^2 = 0.694 \]
Annual Loads
## Total Annual Load - 2003

<table>
<thead>
<tr>
<th></th>
<th>DP (kg)</th>
<th>TP (kg)</th>
<th>N (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cercada</strong></td>
<td>134.472</td>
<td>145.91</td>
<td>1577.37</td>
</tr>
<tr>
<td><strong>Cerro Gordo</strong></td>
<td>232.235</td>
<td>1079.3</td>
<td>2925.826</td>
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<tr>
<td><strong>Cerrote</strong></td>
<td>111.528</td>
<td>173.13</td>
<td>185.126</td>
</tr>
<tr>
<td><strong>Chamorro</strong></td>
<td>213.853</td>
<td>235.46</td>
<td>142.3803</td>
</tr>
<tr>
<td><strong>Guaba</strong></td>
<td>225.116</td>
<td>258.92</td>
<td>951.859</td>
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</table>
## Annual Load - 2003

### Base flow

<table>
<thead>
<tr>
<th></th>
<th>DP (kg)</th>
<th>TP (kg)</th>
<th>N (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cercada</td>
<td>8.82</td>
<td>12.14</td>
<td>19.93</td>
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<tr>
<td>Cerro Gordo</td>
<td>22.50</td>
<td>39.37</td>
<td>70.23</td>
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<td>Cerrote</td>
<td>7.75</td>
<td>16.24</td>
<td>25.06</td>
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<tr>
<td>Chamorro</td>
<td>17.00</td>
<td>24.46</td>
<td>26.74</td>
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<tr>
<td>Guaba</td>
<td>23.94</td>
<td>23.47</td>
<td>63.91</td>
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</table>

### Runoff

<table>
<thead>
<tr>
<th></th>
<th>DP (kg)</th>
<th>TP (kg)</th>
<th>N (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cercada</td>
<td>125.65</td>
<td>133.77</td>
<td>1557.44</td>
</tr>
<tr>
<td>Cerro Gordo</td>
<td>209.74</td>
<td>1034.74</td>
<td>2855.60</td>
</tr>
<tr>
<td>Cerrote</td>
<td>103.78</td>
<td>156.90</td>
<td>160.07</td>
</tr>
<tr>
<td>Chamorro</td>
<td>196.86</td>
<td>211.00</td>
<td>115.64</td>
</tr>
<tr>
<td>Guaba</td>
<td>201.18</td>
<td>235.44</td>
<td>887.95</td>
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Annual Yields
## Total Nutrient Annual Yield - 2003

<table>
<thead>
<tr>
<th></th>
<th>Annual Yield (kg/ Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DP</td>
</tr>
<tr>
<td>Cercada</td>
<td>0.61</td>
</tr>
<tr>
<td>Cerro Gordo</td>
<td>0.33</td>
</tr>
<tr>
<td>Cerrote</td>
<td>0.39</td>
</tr>
<tr>
<td>Chamorro</td>
<td>0.56</td>
</tr>
<tr>
<td>Guaba</td>
<td>0.18</td>
</tr>
</tbody>
</table>
# Nutrient Annual Yield - 2003

## Base Flow nutrient Annual Yield

<table>
<thead>
<tr>
<th></th>
<th>DP</th>
<th>TP</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cercada</strong></td>
<td>0.04</td>
<td>0.05</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Cerro Gordo</strong></td>
<td>0.03</td>
<td>0.06</td>
<td>0.10</td>
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<tr>
<td><strong>Cerrote</strong></td>
<td>0.03</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Chamorro</strong></td>
<td>0.04</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Guaba</strong></td>
<td>0.02</td>
<td>0.02</td>
<td>0.05</td>
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</tbody>
</table>

## Runoff Nutrient Annual Yield

<table>
<thead>
<tr>
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<th>DP</th>
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<tbody>
<tr>
<td><strong>Cercada</strong></td>
<td>0.57</td>
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<td>0.37</td>
<td>0.55</td>
<td>0.56</td>
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<tr>
<td><strong>Chamorro</strong></td>
<td>0.51</td>
<td>0.55</td>
<td>0.30</td>
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<tr>
<td><strong>Guaba</strong></td>
<td>0.16</td>
<td>0.18</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Project summary

- Described the water quality status (bacteria and nutrients) of rural sub watersheds in the tropical caribbean

- Estimates of annual TP, DP, TKN loads and yields from sub watersheds during both low flow and high flow events

- Evaluate the effects of possible land-use scenarios on stream water quality

- Importance of an integrated focus (at the watershed level) to find solutions for water-quality improvement
Acknowledgements

- Prof. Myrna Alameda

- Agricultural Experimental Station support staff: J.L Guzman, O. Santana, V. Santiago, J. Aponte

- Graduate students: R. Corvera-Gomringer, J. Diaz, G. Suarez, Idarnis Gaztambide

- Numerous undergraduate students

- USDA-NRCS

- UPRM- WRRI