Runoff and Pollutant Load Generation

Stormwater BMP Selection, Design, and Monitoring

Florida Stormwater Association
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Rainfall
Precipitation drives the hydrologic cycle.

The runoff component must be conveyed and treated.

Understanding precipitation is essential to understanding and quantifying runoff.
Rainfall Data

- An evaluation of Florida rainfall data was conducted by Harper and Baker (2007) for FDEP which is summarized in the document titled “Evaluation of Current Stormwater Design Criteria within the State of Florida”

- Study included an evaluation of rainfall characteristics throughout the State, including
  - Rainfall depths
  - Rainfall variability
  - Inter-event dry periods
Meteorological Monitoring Sites Used to Generate Rainfall Isopleths

- Data obtained for 1971-2000
  - 160 sites total
    - 111 sites in Florida
    - 49 sites in perimeter areas
- Rainfall isopleths were developed for 1971 – 2000 based on the historical data.

- Florida rainfall is highly variable ranging from ~38 – 66 in/yr, depending on location.
Expanded View of Rainfall Isopleths

- Expanded view plots are available in the 2007 Harper and Baker report
Meteorological Evaluation

- Obtained historical 1 hour rainfall data from the National Climatic Data Center (NCDC) for each available meteorological station – 45 of 111 Florida stations
  - Data availability ranged from 25 – 59 years per site

- Grouped data into individual rain events
  - Used 3 hour separation to define individual events

- Created historical data set of daily rain events over period of record for each site

- Developed annual frequency distribution of individual rain events for each monitoring site
Typical Rainfall Frequency Distribution

- A large number of annual rain events are small depths
- A relatively small number of annual events are large depth
- Similar, but variable, patterns for stations throughout Florida
Characteristics of Rainfall Events at Selected Meteorological Sites

- Rainfall is highly variable in the number of “small” and “large” events at sites around the state
- This impacts both runoff generation as well as treatment system performance efficiency

Percent of Annual Rainfall Events Less Than 1 inch (%):
- Branford: 80
- Cross City: 82
- Ft. Myers: 84
- Jacksonville: 86
- Key West: 88
- Melbourne: 90
- Miami: 92
- Orlando: 94
- Pensacola: 93.5%
- Tallahassee: 84.0%
- Tampa: 84.0%

Highest: 158 events in Miami
Lowest: 104 events in Cross City
Variability in rainfall frequency impacts:

- Runoff C values
- Recovery and performance efficiency of stormwater management systems, especially dry retention
Runoff Generation

- Runoff generation is a function of:
  - Precipitation
  - Soil types
  - Land cover
- Understanding precipitation is essential to understanding and quantifying runoff
Typical Hydrologic Changes Resulting From Development

- **Natural Ground Cover**
  - 40% Evapo-Transpiration
  - 10% Runoff
  - 50% Infiltration

- **35-50% Paved Surfaces**
  - 35% Evapo-Transpiration
  - 30% Runoff
  - 35% Infiltration

- **30% Paved Surfaces**
  - 38% Evapo-Transpiration
  - 20% Runoff
  - 42% Infiltration

- **75-100% Paved Surfaces**
  - 30% Evapo-Transpiration
  - 55% Runoff
  - 15% Infiltration
Runoff Volume Estimation

- Runoff generation is a function of a variety of factors, including:
  - Land use
  - Impervious surfaces
  - Soil types
  - Topography –
    - Basin slope
    - Depressional areas
  - Precipitation amount and event characteristics
- Model must be capable of incorporating each of these factors
Runoff Estimation Model

- A standardized method for estimation of runoff generation was developed by Harper and Baker (2007) for FDEP summarized in the document titled “Evaluation of Current Stormwater Design Criteria within the State of Florida”

- Modeling was conducted using the SCS Curve Number (CN) methodology
  - Common method used by most civil engineers
  - Model used to calculate annual runoff coefficients (C values) for meteorological sites throughout Florida
Runoff Coefficients

Runoff coefficients (C values)

- Runoff coefficients reflect the proportion of rainfall that becomes runoff under specified conditions.
- Tabular C values are used to size pipes using the Rational Formula:

\[ Q = C \times i \times A \]

Where: \( C \) = estimate of runoff proportion for a design storm event (typically 10 yr)

- Runoff coefficients are often improperly used for estimation of runoff volumes for non-design storm conditions.
- Tabular runoff coefficients were never intended to reflect estimates of annual rainfall/runoff relationships.
### Common Rational Formula Runoff Coefficients

<table>
<thead>
<tr>
<th>Area</th>
<th>Runoff Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business (Downtown)</td>
<td>0.70 to 0.95</td>
</tr>
<tr>
<td>Business (Neighborhood)</td>
<td>0.50 to 0.70</td>
</tr>
<tr>
<td>Residential (Single-Family)</td>
<td>0.30 to 0.50</td>
</tr>
<tr>
<td>Residential (Multi-Units, Detached)</td>
<td>0.40 to 0.60</td>
</tr>
<tr>
<td>Residential (Suburban)</td>
<td>0.25 to 0.40</td>
</tr>
<tr>
<td>Apartment</td>
<td>0.50 to 0.70</td>
</tr>
<tr>
<td>Industrial (Light)</td>
<td>0.50 to 0.80</td>
</tr>
<tr>
<td>Industrial (Heavy)</td>
<td>0.60 to 0.90</td>
</tr>
<tr>
<td>Parks, Cemeteries</td>
<td>0.10 to 0.25</td>
</tr>
<tr>
<td>Playgrounds</td>
<td>0.20 to 0.35</td>
</tr>
<tr>
<td>Unimproved, Natural Areas</td>
<td>0.10 to 0.30</td>
</tr>
</tbody>
</table>

- Common C values reflect runoff potential under design storm event conditions
- Rational runoff coefficients **do not** reflect the proportion of annual rainfall which becomes runoff
SCS Curve Number Methodology

- **SCS Curve Number (CN) methodology**
  - Outlined in NRCS document TR-55 titled “Urban Hydrology for Small Watersheds”
  - Common methodology used in many public and proprietary models
  - Curve numbers are empirically derived values which predict runoff as a function of soil type and land cover
  - Can be used to predict event specific runoff depths and volumes
  - Runoff generation based on impervious area, soil types and land cover
  - Model incorporates two basic parameters:
    - Directly connected impervious area (DCIA)
      - Percentage of impervious area which has a direct hydraulic connection to the drainage system (0 – 100%)
    - Curve Number (CN)
      - Measure of the runoff generating potential of the pervious areas (grass, landscaping, etc.) and impervious areas which are not DCIA (0 – 100)
## Typical Curve Numbers (TR-55)

<table>
<thead>
<tr>
<th>Cover Type and Hydrologic Condition</th>
<th>Curve Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Open space (lawns, parks, golf courses, cemeteries, etc.):</td>
<td></td>
</tr>
<tr>
<td>Poor condition (grass cover &lt; 50%)</td>
<td>68</td>
</tr>
<tr>
<td>Fair condition (grass cover 50% to 75%)</td>
<td>49</td>
</tr>
<tr>
<td>Good condition (grass cover &gt; 75%)</td>
<td>39</td>
</tr>
<tr>
<td>Impervious areas:</td>
<td></td>
</tr>
<tr>
<td>Paved parking lots, roofs, driveways, etc. (excl. ROW)</td>
<td>98</td>
</tr>
<tr>
<td>Streets and roads:</td>
<td></td>
</tr>
<tr>
<td>Paved; curbs and storm (excl. ROW)</td>
<td>98</td>
</tr>
<tr>
<td>Paved; open ditches (including right-of-way)</td>
<td>83</td>
</tr>
<tr>
<td>Gravel (including right-of-way)</td>
<td>76</td>
</tr>
<tr>
<td>Dirt (including right-of-way)</td>
<td>72</td>
</tr>
<tr>
<td>Pasture, grassland, or range:</td>
<td></td>
</tr>
<tr>
<td>Poor condition</td>
<td>68</td>
</tr>
<tr>
<td>Fair condition</td>
<td>49</td>
</tr>
<tr>
<td>Good condition</td>
<td>39</td>
</tr>
<tr>
<td>Brush—brush-weed-grass mixture:</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>48</td>
</tr>
<tr>
<td>Fair</td>
<td>35</td>
</tr>
<tr>
<td>Good</td>
<td>30</td>
</tr>
<tr>
<td>Woods:</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>45</td>
</tr>
<tr>
<td>Fair</td>
<td>36</td>
</tr>
<tr>
<td>Good</td>
<td>30</td>
</tr>
</tbody>
</table>
# Typical Curve Numbers (TR-55)

<table>
<thead>
<tr>
<th>Cover Type and Hydrologic Condition</th>
<th>Imp. (%)</th>
<th>Curve Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lot size: 1/8 acre or less</td>
<td>65</td>
<td>77</td>
</tr>
<tr>
<td>Lot size: 1/4 acre</td>
<td>38</td>
<td>61</td>
</tr>
<tr>
<td>Lot size: 1/3 acre</td>
<td>30</td>
<td>57</td>
</tr>
<tr>
<td>Lot size: 1/2 acre</td>
<td>25</td>
<td>54</td>
</tr>
<tr>
<td>Lot size: 1 acre</td>
<td>20</td>
<td>51</td>
</tr>
<tr>
<td>Lot size: 2 acre</td>
<td>12</td>
<td>46</td>
</tr>
<tr>
<td>Water/wetlands</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **General curve numbers for available for residential areas**
  - General CN values reflect the combined runoff potential for the combined pervious and impervious areas
    - Do not directly address DCIA
    - Should not be used in BMPTRAINS model

- **Water/wetland areas are assigned a CN and C-value of zero since precipitation and evaporation are approximately equal over an annual cycle**
Directly Connected Impervious Areas (DCIA)

- **Definition varies depending on the type of analysis**
  - **Flood routing – Major events**
    - DCIA includes all impervious areas from which runoff discharges directly into the drainage system
    - Also considered to be DCIA if runoff discharges as a concentrated shallow flow over pervious areas and then into the drainage system
      - Ex. – Shallow roadside swales
    - Often generously estimated to provide safety factor for design
  - **Annual runoff estimation – Common daily events**
    - DCIA includes all impervious areas from which runoff discharges directly into the drainage system during small events
    - Does not include swales
    - Generally results in a lower DCIA value than used for flood routing
SCS Curve Number Parameters

- **Non-Directly Connected Impervious Areas (non-DCIA):**
  - Includes pervious areas + impervious areas which are not considered to be DCIA
- **Non-DCIA Curve Number (non-DCIA CN Value):**
  \[
  \text{Non-DCIA CN Value} = \frac{(\text{Area}_{\text{perv.}}) \times (\text{CN}_{\text{perv.}}) + (\text{Area}_{\text{non-DCIA}}) \times 98}{(\text{Area}_{\text{perv.}}) + (\text{Area}_{\text{non-DCIA}})}
  \]

- The Non-DCIA CN Value is then used to calculate the soil storage:
  \[
  \text{Soil Storage, } S = \left( \frac{1000}{\text{nDCIA CN}} - 10 \right)
  \]
Separate calculations were conducted for the DCIA and non-DCIA areas.
- Using an overall CN value for the area would lead to significant errors in estimating runoff.

1. **Runoff from non-DCIA areas is calculated by:**

   \[ Q_{nDCIAi} = \frac{(P_i - 0.2S)^2}{(P_i + 0.8S)} \]

   - \( CN \) = curve number for pervious area
   - \( Imp. \) = percent impervious area
   - \( DCIA \) = percent directly connected impervious area
   - \( non-DCIA \) = curve number for non-DCIA area
   - \( P_i \) = rainfall depth for event (i)
   - \( R_{nDCIAi} \) = rainfall excess for non-DCIA for event (i)

2. **Runoff from DCIA is calculated as:**

   \[ Q_{DCIAi} = (P_i - 0.1) \]

   When \( P_i \) is less than 0.1, \( Q_{DCIAi} \) is equal to zero.
Impacts of Rainfall Variability on Annual Runoff Coefficients

- Continuous simulation of runoff from a hypothetical 1 acre site using SCS curve number methodology and historical rainfall data set for 45 rainfall sites with hourly data
  - Data ranged from 13 – 64 years per site, but most contained 30+ years of data per site (mean of 4,685 events/site)
  - Data separated into individual events using 3 hour separation
- Runoff modeled for each event at each site for (mean of 4,685 events/site) :
  - DCIA percentages from 0-100 in 5 unit intervals
  - Non-DCIA curve numbers from 25-95 in 5 unit intervals
  - 350 combinations per rainfall site
- Total generated runoff depth compared with rainfall depth to calculate runoff coefficient:
  \[
  C \text{ Value} = \frac{\text{Total Runoff Depth}}{\text{Total Rainfall Depth}}
  \]
Meteorological Sites Included in Runoff Modeling

- 45 sites total
- Runoff modeling conducted for each rain event at each site over available period of record
## Modeled C Values for Various Combinations of CN and DCIA

### Modeled C values for Miami – 64 years from 1942 - 2005

<table>
<thead>
<tr>
<th>NDCIA CN</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
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<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>85</th>
<th>90</th>
<th>95</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.008</td>
<td>0.048</td>
<td>0.088</td>
<td>0.128</td>
<td>0.168</td>
<td>0.208</td>
<td>0.248</td>
<td>0.288</td>
<td>0.328</td>
<td>0.368</td>
<td>0.408</td>
<td>0.448</td>
<td>0.488</td>
<td>0.528</td>
<td>0.568</td>
<td>0.608</td>
<td>0.648</td>
<td>0.688</td>
<td>0.728</td>
<td>0.768</td>
<td>0.808</td>
</tr>
<tr>
<td>35</td>
<td>0.012</td>
<td>0.052</td>
<td>0.092</td>
<td>0.132</td>
<td>0.171</td>
<td>0.211</td>
<td>0.251</td>
<td>0.291</td>
<td>0.331</td>
<td>0.370</td>
<td>0.410</td>
<td>0.450</td>
<td>0.490</td>
<td>0.529</td>
<td>0.569</td>
<td>0.609</td>
<td>0.649</td>
<td>0.689</td>
<td>0.729</td>
<td>0.768</td>
<td>0.808</td>
</tr>
<tr>
<td>40</td>
<td>0.018</td>
<td>0.057</td>
<td>0.097</td>
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<td>0.255</td>
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<td>0.334</td>
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<td>0.413</td>
<td>0.452</td>
<td>0.492</td>
<td>0.531</td>
<td>0.571</td>
<td>0.611</td>
<td>0.650</td>
<td>0.690</td>
<td>0.729</td>
<td>0.769</td>
<td>0.808</td>
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<tr>
<td>45</td>
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<td>0.064</td>
<td>0.103</td>
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<td>0.495</td>
<td>0.534</td>
<td>0.573</td>
<td>0.612</td>
<td>0.651</td>
<td>0.691</td>
<td>0.730</td>
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</tr>
<tr>
<td>50</td>
<td>0.034</td>
<td>0.072</td>
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<td>0.343</td>
<td>0.382</td>
<td>0.421</td>
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<td>0.537</td>
<td>0.576</td>
<td>0.614</td>
<td>0.653</td>
<td>0.693</td>
<td>0.732</td>
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<tr>
<td>55</td>
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<td>0.732</td>
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<td>0.808</td>
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<tr>
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<td>0.095</td>
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<td>0.695</td>
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<td>0.220</td>
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<td>0.588</td>
<td>0.624</td>
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<td>0.698</td>
<td>0.735</td>
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<td>0.629</td>
<td>0.665</td>
<td>0.701</td>
<td>0.737</td>
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<td>0.808</td>
</tr>
<tr>
<td>75</td>
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<td>0.155</td>
<td>0.189</td>
<td>0.223</td>
<td>0.258</td>
<td>0.292</td>
<td>0.327</td>
<td>0.361</td>
<td>0.395</td>
<td>0.430</td>
<td>0.464</td>
<td>0.498</td>
<td>0.533</td>
<td>0.567</td>
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<td>0.636</td>
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<td>0.450</td>
<td>0.482</td>
<td>0.515</td>
<td>0.547</td>
<td>0.580</td>
<td>0.613</td>
<td>0.645</td>
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<td>90</td>
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<td>0.550</td>
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<td>0.602</td>
<td>0.627</td>
<td>0.653</td>
<td>0.679</td>
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<tr>
<td>95</td>
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<td>0.464</td>
<td>0.482</td>
<td>0.500</td>
<td>0.518</td>
<td>0.536</td>
<td>0.554</td>
<td>0.572</td>
<td>0.590</td>
<td>0.609</td>
<td>0.627</td>
<td>0.645</td>
<td>0.663</td>
<td>0.681</td>
<td>0.699</td>
<td>0.717</td>
<td>0.736</td>
<td>0.754</td>
<td>0.772</td>
<td>0.790</td>
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</tr>
<tr>
<td>98</td>
<td>0.614</td>
<td>0.624</td>
<td>0.633</td>
<td>0.643</td>
<td>0.653</td>
<td>0.662</td>
<td>0.672</td>
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Annual C Values as a Function of DCIA and non-DCIA Curve Number

Pensacola/Tallahassee

Runoff Coefficient

Key West

Runoff Coefficient
### Impacts of Rainfall Characteristics on Runoff Generation

<table>
<thead>
<tr>
<th>City</th>
<th>Percent of Annual Rainfall Volume &lt; 0.1 Inch (%)</th>
<th>Percent of Annual Rainfall Volume &gt; 1.0 Inch (%)</th>
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<tr>
<td>Branford</td>
<td><img src="chart1.png" alt="Bar Chart" /></td>
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<td>Cross City</td>
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<td><img src="chart1.png" alt="Bar Chart" /></td>
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</table>

- Key West and Melbourne have a higher percentage of small rain events and a lower percentage of large rain events
  - Results in less annual runoff volume
- Pensacola and Tallahassee have a lower percentage of small events and a higher percentage of large events
  - Results in more annual runoff volume
- Cluster analysis used to identify areas with similar annual rainfall/runoff relationships (C values)

- Analysis identified 5 significantly different areas

- Differences due to rainfall distribution rather than annual rainfall depth
Relationship Between Curve Number, Percent DCIA, and C Value

- Linear relationship between C Value and DCIA

- Exponential relationship between C Value and CN value

- Implies that averaging CN values is statistically invalid and leads to overestimation of runoff volume
Runoff Characteristics

- Runoff concentrations are characterized by a high degree of variability:
  - From event to event
  - During storm events

- Variability is caused by variations in:
  - Rainfall Intensity
  - Rainfall Frequency
  - Soil Types
  - Land Use
  - Intensity of Land Use
  - Weather Patterns

- Variability should be included in the monitoring protocol for runoff collection

- NPDES data should not be used since these data reflect runoff characteristics for specific rain event conditions
  - NPDES data are useful for comparing different sites because the data are collected in a similar manner
Highway Runoff
(I-4 and Maitland Ave from 1980-82)

Zinc

More than a 10 fold difference between min. and max. values
Runoff Characteristics and Loadings

- Runoff characteristics are used in many engineering analyses, including:
  - Pollutant loading analyses
  - TMDL calculations
  - Pre/post loading evaluations

- Runoff concentrations are commonly expressed in terms of an event mean concentration (emc):
  \[ \text{emc} = \frac{\text{pollutant loading}}{\text{runoff volume}} \]

- An annual emc value is generally determined by evaluating event emc values over a range of rainfall depths and seasons
  - Generally estimated based on field monitoring
  - Usually requires a minimum of 7-10 events collected over a range of conditions

- Annual mass loadings are calculated by:
  \[ \text{Annual mass loading} = \text{annual runoff volume} \times \text{annual emc} \]
Based on the literature survey, common land use categories were developed based on similarities in anticipated runoff characteristics:

- **Pre-Development**
  - Agriculture (pasture, citrus, row crops)
  - Open Space / Forests
  - Mining
  - Wetlands
  - Open Water / Lake

- **Post-Development**
  - Low-Density Residential
  - Single-Family Residential
  - Multi-Family Residential
  - Low-Intensity Commercial
  - High-Intensity Commercial
  - Industrial
  - Highway

**FLUCCS (Florida Land Use Cover Classification System) codes contain too much detail and often misclassifies land use activities**

- Insufficient characterization data exist to provide emc values for all FLUCCS codes
- FLUCCS codes can be converted to the general categories based on anticipated runoff characteristics
  - Ex. Mobile home parks, recreational areas (golf courses)
Land Use Categories

- **Low Density Residential (LDR)** – rural residential with lot sizes >1 acre or less than one unit per acre
- **Single Family Residential (SFR)** – typical detached family home with lot <1 acre, includes duplexes in 1/3 to 1/2 acre lots, golf courses
- **Multi-Family Residential (MFR)** – residential units consisting of apartments, condominiums, and cluster-homes
- **Low Intensity Commercial (LIC)** – commercial areas with low traffic levels, cars parked for extended periods, includes schools, offices, and small shopping centers
- **High Intensity Commercial (HIC)** – commercial areas with high traffic volumes, includes downtown areas, malls, commercial offices
- **Industrial (Ind.)** – manufacturing, shipping and transportation services, municipal treatment plants
- **Highway (HW)** – major road systems and associated ROW, including interstate highways, major arteries
- **Agriculture (Ag)** – includes cattle, grazing, row crops, citrus, general ag.
- **Recreation/Open Space** – includes parks, ball fields, open space, barren land, does not include golf courses
- **Mining (M)** – general mining activities such as sand, lime rock, gravel, etc.
## Single Family Residential Runoff Characterization Data (n = 17)

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<th>Reference</th>
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<td>Mattraw, et al. (1981)</td>
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<td>German (1983)</td>
<td>TN 2.20</td>
<td>TP 0.340</td>
<td>BOD 7.1</td>
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<td>Lopez, et al. (1984)</td>
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<td>Orlando-Duplex</td>
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<td>Palm Beach-Springhill</td>
<td>Greg, et al. (1989)</td>
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<td>Holtkamp (1998)</td>
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<td>ERD (2000)</td>
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<td>TP 0.280</td>
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<td>TSS 57.1</td>
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<td>Fl. Keys-Key Colony</td>
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<td>Tallahassee-Woodgate</td>
<td>COT &amp; ERD (2002)</td>
<td>TN 1.29</td>
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<td>Windemere</td>
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<td>Pb 0.062</td>
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### Mean Value
- TN: 2.07, TP: 0.327, BOD: 7.9, TSS: 37.5, Cd: 0.003, Cr: 0.012, Cu: 0.016, Fe: 0.320, Pb: 0.019, Zn: 0.004
- Median Value: TN: 1.85, TP: 0.309, BOD: 6.5, TSS: 34.9, Cd: 0.002, Cr: 0.015, Cu: 0.014, Fe: 0.350, Pb: 0.020
- Log-Normal Mean: TN: 1.87, TP: 0.301, BOD: 6.6, TSS: 29.3, Cd: 0.002, Cr: 0.009, Cu: 0.014, Fe: 0.267, Pb: 0.017

*Note: Pb values not included in mean or median value due to dramatic reductions in lead from removal of lead in gasoline.*
<table>
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<tr>
<th>Location</th>
<th>Reference</th>
<th>Reported EMC (mg/l)</th>
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<th>TP</th>
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<tr>
<td>Broward Co. (6 lane)</td>
<td>Mattraw et al. (1981)</td>
<td>0.96 0.080 9.0</td>
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<td>Miami I-95</td>
<td>McKenzie et al. (1983)</td>
<td>3.20 0.160 42.0</td>
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<td>Flamingo Dr. Collier, County</td>
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<td>0.94 0.060 18.5</td>
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</tbody>
</table>

not included in mean value due to reductions from removal of lead in gasoline
Comparison of Typical Nitrogen Concentrations in Stormwater

1-2 fold increase for most land uses

Typical natural area conc.
Comparison of Typical Phosphorus Concentrations in Stormwater

3-10 fold increase for most land uses

Total Phosphorus Conc. (mg/L)


Typical natural area conc.
Impacts of Reuse Irrigation on Runoff Characteristics

- The chemical characteristics of reuse water are highly variable, depending on location and level of treatment

- Characteristics of secondary effluent – minimum level of treatment
  - Nitrogen ~ 4-20 mg/l, mostly as NO$_3^-$ and organic N (2-15 times higher than urban runoff)
  - Phosphorus ~ 2-15 mg/l (8-60 times higher than runoff)
  - On average, secondary reuse water is similar in characteristics to septic tank leachate
  - No requirement to measure nutrient levels, except NO$_x$
  - Approximately 2/3 of WWT plants in Florida provide secondary treatment

- Characteristics of tertiary effluent – adds nutrient removal
  - Nitrogen - < 3 mg/l
  - Phosphorus - <1 mg/l
  - Tertiary reuse is similar in characteristics to HDR stormwater runoff
  - Approximately 1/3 of WWT plants in Florida provide tertiary treatment

- Impact assessments for reuse only give a cursory look at nutrient impacts
  - Most simply state that the presence of nutrients will increase the value of the water
Comparison of Mean Stormwater Characteristics of Basin Areas with and without Reuse Irrigation (ERD, 1994)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Without Reuse&lt;sup&gt;1&lt;/sup&gt;</th>
<th>With Reuse&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Enrichment By Reuse (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>mg/L</td>
<td>40.5</td>
<td>58.1</td>
<td>44</td>
</tr>
<tr>
<td>Ammonia</td>
<td>µg/L</td>
<td>87</td>
<td>537</td>
<td>520</td>
</tr>
<tr>
<td>NOx</td>
<td>µg/L</td>
<td>218</td>
<td>456</td>
<td>109</td>
</tr>
<tr>
<td>Total N</td>
<td>µg/L</td>
<td>1,526</td>
<td>2,355</td>
<td>54</td>
</tr>
<tr>
<td>SRP</td>
<td>µg/L</td>
<td>192</td>
<td>241</td>
<td>25</td>
</tr>
<tr>
<td>Total P</td>
<td>µg/L</td>
<td>376</td>
<td>569</td>
<td>51</td>
</tr>
<tr>
<td>BOD</td>
<td>mg/L</td>
<td>4.8</td>
<td>7.7</td>
<td>59</td>
</tr>
</tbody>
</table>

1. Geometric mean values

Conclusion: Secondary reuse irrigation increases concentrations of nutrients by approximately 50%
Natural Area Monitoring Project

Objectives

- FDEP funded project to characterize runoff quality from common natural undeveloped upland vegetative communities in Florida

- Data to be used to support pre-development runoff quality for Statewide Stormwater Rule

Work Efforts

- Total of 33 automated monitoring sites established in 10 State parks throughout Florida

- Monitoring conducted over 14 month period from July 2007 – August 2008 to include variety of seasonal conditions

- Total of 318 samples collected and analyzed for general parameters, nutrients, demand parameters, fecal coliform and heavy metals
Monitored State Parks

- Alfred B. Maclay Gardens
- San Felasco Hammock
- Silver River
- Lake Louisa
- Paynes Creek
- Myakka River
- Fakahatchee Strand Preserve
- Faver-Dyker
- Wekiva Springs
- Jonathan Dickinson
<table>
<thead>
<tr>
<th>Classification</th>
<th>Area (acres)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Strand</td>
<td>15,008</td>
<td>0.1</td>
</tr>
<tr>
<td>Dry Prairie</td>
<td>1,227,697</td>
<td>11.4</td>
</tr>
<tr>
<td>Hardwood Hammock/Forest</td>
<td>980,612</td>
<td>9.1</td>
</tr>
<tr>
<td>Mixed Pine/Hardwood Forest</td>
<td>889,010</td>
<td>8.3</td>
</tr>
<tr>
<td>Pinelands</td>
<td>6,528,121</td>
<td>60.7</td>
</tr>
<tr>
<td>Sand Pine Scrub</td>
<td>194,135</td>
<td>1.8</td>
</tr>
<tr>
<td>Sandhill</td>
<td>761,359</td>
<td>7.1</td>
</tr>
<tr>
<td>Tropical Hardwood Hammock</td>
<td>15,390</td>
<td>0.1</td>
</tr>
<tr>
<td>Xeric Oak Scrub</td>
<td>146,823</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>10,758,155</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Monitored natural areas include more than 92% of upland land covers in Florida.
Alfred B. Maclay Gardens State Park
Monitoring Site Natural Communities

**Community Characteristics**

- Well-developed, closed canopy forests of upland hardwoods on rolling hills
- Most common in northern panhandle Florida
- Generally lack shortleaf pine, American beech and other more northern species
- Occur on rolling hills that often have limestone or phosphatic rock near the surface

**Mixed Hardwood Forest**
Mesic Flatwoods/Pinelands

Community Characteristics

- Synonyms: pine flatwoods, pine savannahs, pine barrens

- Characterized as an open canopy forest of widely spaced pine trees with dense ground cover of herbs and shrubs

- Occur on relatively flat, moderately to poorly drained

- Soils typically consist of 1-3 feet of acidic sands generally overlying an organic hardpan or clayey subsoil

- Most widespread biological community in Florida

- 30 to 50% of the State's uplands
Community Characteristics

- Synonyms: low flatwoods, moist pine barren, hydric flatwoods, pond pine flatwoods, cabbage palm/pine savannah or flatwoods

- Relatively open-canopy forests of scattered pine trees or cabbage palms

- Relatively flat, poorly drained terrain

- Soils consist of 1 to 3 feet of acidic sands overlying an organic hardpan or clay layer
Silver River State Park
Natural Communities

**Community Characteristics**

- Synonyms: mesic hammock, climax hardwoods, upland hardwoods, beech-magnolia climax, oak-magnolia climax, pine-oak-hickory association, southern mixed hardwoods, clay hills hammocks, Piedmont forest

- Well-developed, closed canopy forests of upland hardwoods on rolling hills

- Most common in northern and central peninsula Florida

**Upland Hardwood Forest**
Lake Louisa State Park
Monitoring Site Natural Communities

**Community Characteristics**

- Synonyms: longleaf pine upland forest, loblolly-shortleaf upland forest, clay hills, high pineland

- Rolling forest of widely spaced pines with few understory shrubs and a dense ground cover of grasses and herbs

- Occurs on the rolling hills of extreme northern Florida

- Soils are composed of sand with variable amounts of Miocene clays

**Ruderal/Upland Pine Forest**
Fakahatchee Strand State Park
Monitoring Site Natural Communities

Strand Swamp

Community Characteristics

- Synonyms: cypress strand, stringer
- Shallow, forested, usually elongated depressions or channels dominated by bald cypress
- Situated in troughs in a flat limestone plain
- Soils are peat and sand over limestone
- Occur mainly in Collier County
San Felasco Hammock Preserve State Park
Monitoring Site Communities

**Community Characteristics**

- Synonyms: mesic hammock, climax hardwoods, upland hardwoods, beech-magnolia climax, oak-magnolia climax, pine-oak-hickory association, southern mixed hardwoods, clay hills hammocks, Piedmont forest
- Well-developed, closed canopy forests of upland hardwoods on rolling hills
- Most common in northern and central peninsula Florida north of Ocala
- Generally lack shortleaf pine, American beech and other more northern species

**Upland Mixed Forest**
Myakka River State Park
Monitoring Sites Natural Communities

Dry Prairie

Community Characteristics

- Synonyms: palm savannah, palmetto prairie, pineland-threawn range

- Nearly treeless plain with a dense ground cover of wiregrass, saw palmetto, and other grasses, herbs, and low shrubs

- Relatively flat, moderately to poorly drained terrain

- 1 to 3 feet of acidic sands generally overlying an organic hardpan or clayey subsoil
Community Characteristics

- Synonyms: sand pine scrub, Florida scrub, sand scrub, rosemary scrub, oak scrub

- Closed to open canopy forest of sand pines with dense clumps or vast thickets of scrub oaks and other shrubs dominating the understory

- Occurs on sand ridges along former shorelines

- Well washed deep sands

Wekiva River State Park
Monitoring Site Communities

Xeric Scrub
# Natural Land Use Runoff Characteristics

<table>
<thead>
<tr>
<th>Land Type</th>
<th>No.</th>
<th>Total N (µg/l)</th>
<th>Total P (µg/l)</th>
<th>Iron (mg/l)</th>
<th>Fecal Coliform (cfu/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Prairie</td>
<td>12</td>
<td>1,950</td>
<td>107</td>
<td>1.259¹</td>
<td>72</td>
</tr>
<tr>
<td>Hydric Hammock</td>
<td>17</td>
<td>1,072</td>
<td>26</td>
<td>0.537</td>
<td>43</td>
</tr>
<tr>
<td>Marl Prairie</td>
<td>3</td>
<td>603</td>
<td>10</td>
<td>0.162</td>
<td>83</td>
</tr>
<tr>
<td>Mesic Flatwoods</td>
<td>26</td>
<td>1,000</td>
<td>34</td>
<td>0.598</td>
<td>363¹</td>
</tr>
<tr>
<td>Mixed Hardwood Forest</td>
<td>39</td>
<td>288</td>
<td>501</td>
<td>1.479¹</td>
<td>166</td>
</tr>
<tr>
<td>Ruderal/Upland Pine</td>
<td>2</td>
<td>1,318</td>
<td>347</td>
<td>3.311¹</td>
<td>17</td>
</tr>
<tr>
<td>Scrubby Flatwoods</td>
<td>17</td>
<td>1,023</td>
<td>27</td>
<td>0.741</td>
<td>295¹</td>
</tr>
<tr>
<td>Upland Hardwood</td>
<td>79</td>
<td>891</td>
<td>269</td>
<td>0.776</td>
<td>155</td>
</tr>
<tr>
<td>Upland Mixed Forest</td>
<td>16</td>
<td>676</td>
<td>2,291</td>
<td>0.437</td>
<td>372¹</td>
</tr>
<tr>
<td>Wet Flatwoods</td>
<td>77</td>
<td>1,175</td>
<td>15</td>
<td>0.347</td>
<td>117</td>
</tr>
<tr>
<td>Wet Prairie</td>
<td>9</td>
<td>776</td>
<td>9</td>
<td>0.069</td>
<td>68</td>
</tr>
<tr>
<td>Xeric Hammock</td>
<td>1</td>
<td>1,318</td>
<td>2,816</td>
<td>0.814</td>
<td>108</td>
</tr>
<tr>
<td>Xeric Scrub</td>
<td>3</td>
<td>1,158</td>
<td>96</td>
<td>0.060</td>
<td>1533¹</td>
</tr>
</tbody>
</table>

¹ Values which exceed Class III criterion
A wide variability was observed in nutrient concentrations from natural areas

- Natural areas with deciduous vegetation were characterized by higher runoff concentrations

- Natural areas with deciduous vegetation were characterized by higher runoff concentrations

- Natural areas had exceedances of Class III criteria for iron and fecal coliform

- After the community is identified, the annual mass loading is calculated:

\[
\text{Annual Loading} = \text{emc conc. for community type} \times \text{annual runoff volume}
\]
1. Florida Vegetation and Land Cover (FFWCC)

- Reflects existing land cover based on aerial photography – both developed and natural areas
- Original survey conducted in 1990s included:
  - 17 natural and semi-natural cover types
  - 4 land cover types reflecting disturbed land
  - 1 water class
- Survey updated in 2003 and included:
  - 26 natural and semi-natural cover types
  - 16 land cover types reflecting disturbed land
  - 1 water class
- Coverage maps are available for all of Florida
2. **Florida Natural Areas Inventory (FNAI) - 2010**

- Developed by Florida Department of Natural Resources (DNR)
- Reflects original, natural vegetation associations in Florida
- Natural communities are characterized and defined by a combination of physiognomy, vegetation structure and composition, topography, landform, substrate, soil moisture condition, climate, and fire
- Named for their most characteristic biological or physical feature
- Grouped into 6 Natural Community Categories with 13 Natural Community Groups and 66 sub-groups based on hydrology and vegetation
- FNAI is system used by State Park system
- Coverage maps are not available for all of Florida
- This coverage index selected for natural area characterization study

Runoff Loading Calculations
Example Calculations

1. **Land Use:**
   - 90 acres of single-family residential
   - 5 acres of stormwater management systems
   - 5 acres of preserved wetlands

2. **Ground Cover/Soil Types**
   - A. Residential areas will be covered with lawns in good condition
   - B. Soil types in HSG D

3. **Impervious/DCIA Areas**
   - A. Residential areas will be 25% impervious, 75% of which will be DCIA
     - Impervious Area = 25% of developed site = 90 ac x 0.25 = 22.50 acres
     - DCIA Area = 22.50 acres x 0.75 = 16.88 acres
     - DCIA Percentage = (16.88 ac/90.0 ac) x 100 = 18.7% of developed area

4. **Post Development Annual Runoff Generation**

<table>
<thead>
<tr>
<th>Project Location</th>
<th>Area (acres)</th>
<th>Impervious Areas</th>
<th>DCIA</th>
<th>Non-DCIA CN Value</th>
<th>Annual Rainfall (in)</th>
<th>Annual C Value</th>
<th>Runoff (ac-ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pensacola</td>
<td>90</td>
<td>25</td>
<td>22.5</td>
<td>16.68</td>
<td>18.75</td>
<td>81.4</td>
<td>65.5</td>
</tr>
<tr>
<td>Orlando</td>
<td>90</td>
<td>25</td>
<td>22.5</td>
<td>16.68</td>
<td>18.75</td>
<td>81.4</td>
<td>50.0</td>
</tr>
<tr>
<td>Key West</td>
<td>90</td>
<td>25</td>
<td>22.5</td>
<td>16.68</td>
<td>18.75</td>
<td>81.4</td>
<td>40.0</td>
</tr>
</tbody>
</table>
5. **Generated Loading to Stormwater Pond:**

Under post-development conditions, nutrient loadings will be generated from the 90-acre developed single-family area.

Stormwater management systems are not included in estimates of post-development loadings since incidental mass inputs of pollutants to these systems are included in the estimation of removal effectiveness.

Mean emc values for total nitrogen and total phosphorus in single-family residential runoff

\[
\text{TN} = 1.87 \text{ mg/l} \quad \text{TP} = 0.301 \text{ mg/l}
\]

**a. Pensacola (Zone 1) Project**

TN load from single-family area:

\[
\frac{149.3 \text{ ac-ft}}{\text{yr}} \times \frac{43,560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{1.87 \text{ mg}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 344 \text{ kg TN/yr}
\]

TP load from single-family area:

\[
\frac{149.3 \text{ ac-ft}}{\text{yr}} \times \frac{43,560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{0.301 \text{ mg}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 55.4 \text{ kg TP/yr}
\]

<table>
<thead>
<tr>
<th>Location</th>
<th>TN Loading (kg/yr)</th>
<th>TP Loading (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pensacola</td>
<td>344</td>
<td>55.4</td>
</tr>
<tr>
<td>Orlando</td>
<td>219</td>
<td>35.2</td>
</tr>
<tr>
<td>Key West</td>
<td>184</td>
<td>29.6</td>
</tr>
</tbody>
</table>
6. **Pre-Development Runoff and Mass Loadings:**

The natural vegetation on the area to be developed (90 acres) consists of 60% mesic flatwoods and 40% wet flatwoods in fair condition on HSG D soils.

From TR-55, the CN value for wooded areas in fair condition on HSG D soils = 79

<table>
<thead>
<tr>
<th>Project Location</th>
<th>Area (acres)</th>
<th>Impervious Areas</th>
<th>DCIA</th>
<th>Non-DCIA CN Value</th>
<th>Annual Rainfall (in)</th>
<th>Annual C Value</th>
<th>Runoff (ac-ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pensacola</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>79</td>
<td>65.5</td>
<td>0.154</td>
</tr>
<tr>
<td>Orlando</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>79</td>
<td>50.0</td>
<td>0.105</td>
</tr>
<tr>
<td>Key West</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>79</td>
<td>40.0</td>
<td>0.125</td>
</tr>
</tbody>
</table>

Mean emc values for total nitrogen and total phosphorus under pre-development conditions:

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Percent Cover (%)</th>
<th>Runoff emc Values (mg/L)</th>
<th>Combined emc Values (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total N</td>
<td>Total P</td>
</tr>
<tr>
<td>Mesic flatwoods</td>
<td>60</td>
<td>1.000</td>
<td>0.034</td>
</tr>
<tr>
<td>Wet flatwoods</td>
<td>40</td>
<td>1.175</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Example Calculations – cont.

6. Pre-Development Runoff and Mass Loadings – cont.:

   a. Pensacola (Zone 1) Project

   TN load from pre-developed areas:

   \[
   \text{75.6 ac-ft/yr} \times \frac{43,560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{1.07 \text{ mg}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 99.8 \text{ kg TN/yr}
   \]

   TP load from pre-developed areas:

   \[
   \text{75.6 ac-ft/yr} \times \frac{43,560 \text{ ft}^2}{\text{ac}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{0.026 \text{ mg}}{\text{liter}} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 2.42 \text{ kg TP/yr}
   \]

<table>
<thead>
<tr>
<th>Location</th>
<th>TN Loading (kg/yr)</th>
<th>TP Loading (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pensacola</td>
<td>99.8</td>
<td>2.42</td>
</tr>
<tr>
<td>Orlando</td>
<td>52.0</td>
<td>1.26</td>
</tr>
<tr>
<td>Key West</td>
<td>49.5</td>
<td>1.20</td>
</tr>
</tbody>
</table>
Example Calculations - cont.

7. Calculate required removal efficiencies to achieve post- less than or equal to pre-loadings:

Summary of pre- and post-loadings and required removal efficiencies

<table>
<thead>
<tr>
<th>Project Location</th>
<th>Total Nitrogen</th>
<th>Total Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Load (kg/yr)</td>
<td>Post-Load (kg/yr)</td>
</tr>
<tr>
<td>Pensacola (Zone 1)</td>
<td>99.8</td>
<td>344</td>
</tr>
<tr>
<td>Orlando (Zone 2)</td>
<td>52.0</td>
<td>219</td>
</tr>
<tr>
<td>Key West (Zone 3)</td>
<td>49.5</td>
<td>184</td>
</tr>
</tbody>
</table>