# Wet Detention Systems

By: Harvey H. Harper

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# Definitions

- Retention - A group of stormwater practices where the treatment volume is evacuated by either percolation into groundwater or evaporation
  - No surface discharge for treatment volume
  - Substantial reduction in runoff volume
  - Retention practices include:
    - Dry retention
    - Harvesting (Reuse irrigation)
    - Underground storage systems

- Detention - A group of stormwater practices where the treatment volume is detained for a period of time before release
  - Discharge of treatment volume over a period of days
  - No significant reduction in runoff volume
  - Detention practices include:
    - Wet detention
    - Dry detention

# Wet Detention Ponds

Wet detention ponds are essentially man-made lakes

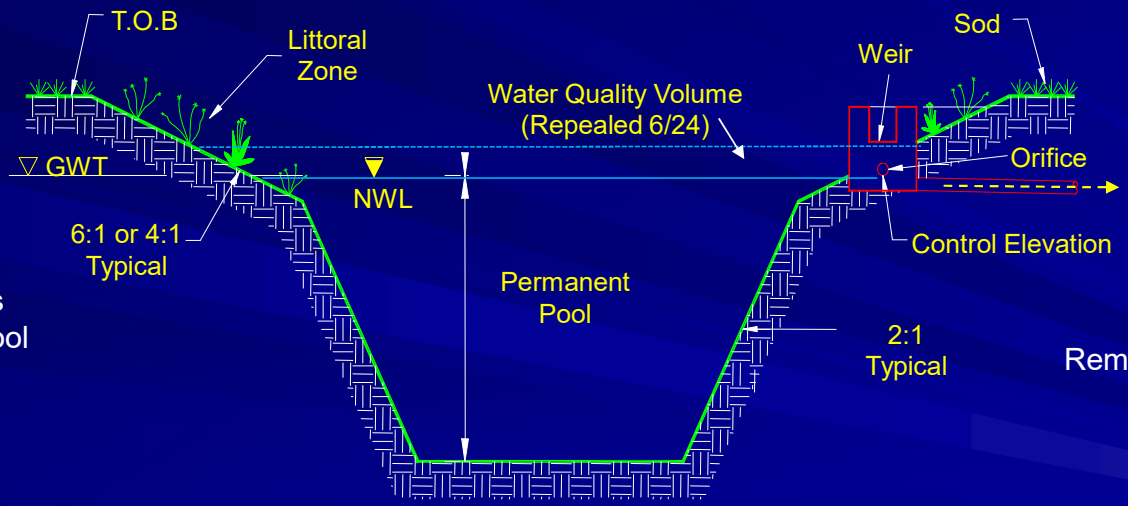
Wet Detention Ponds Can Be Constructed as Amenities

Wet Detention Lakes Can Be Integral to the Overall Development Plan

Wet detention ponds are governed by the same physical, biological, and chemical processes as natural lakes

# Wet Detention Ponds

- Essentially man-made lakes
- Subject to all physical, biological, and chemical processes in surface waters
- Highly predictable performance




Pollutant removal processes occur within the permanent pool volume

Removal efficiency is a function of residence time

- Physical Processes
  - Gravity settling – primary physical process
    - Efficiency dependent on pond geometry, volume, residence time, particle size
  - Adsorption onto solid surfaces
- Biological processes
  - Uptake by algae and aquatic plants
  - Metabolized by microorganisms
- Chemical processes
  - Co-precipitation by metal oxides

# Wet Detention Pollutant Removal Processes

- Physical Processes
  - Gravity settling – primary physical process
    - Efficiency dependent on pond geometry, volume, residence time, particle size
  - Adsorption onto solid surfaces
- Biological processes
  - Uptake by algae and aquatic plants
  - Metabolized by microorganisms
- Occur during quiescent period between storms
- Permanent pool crucial
  - Reduces energy and promotes settling
  - Provides habitat for plants and microorganisms

# Detention Time

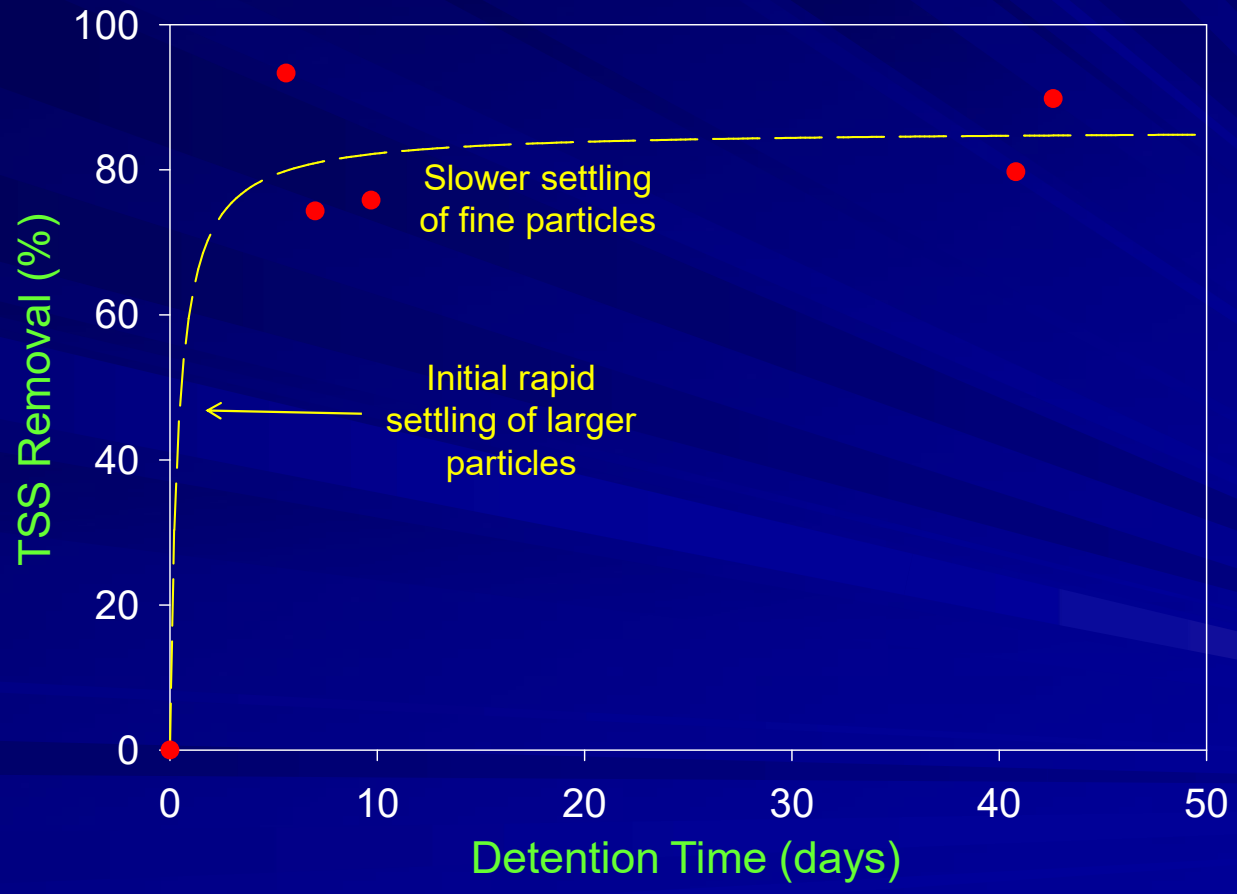
Performance efficiency of wet detention is a function of detention time:

$$\text{Detention Time, } t_d \text{ (days)} = \frac{\text{PPV}}{\text{RO}} \times \frac{365 \text{ days}}{\text{year}}$$

where:

PPV = permanent pool volume below control elevation (ac-ft)
RO = annual runoff inputs (ac-ft/yr)

# TSS Removal as a Function of Detention Time

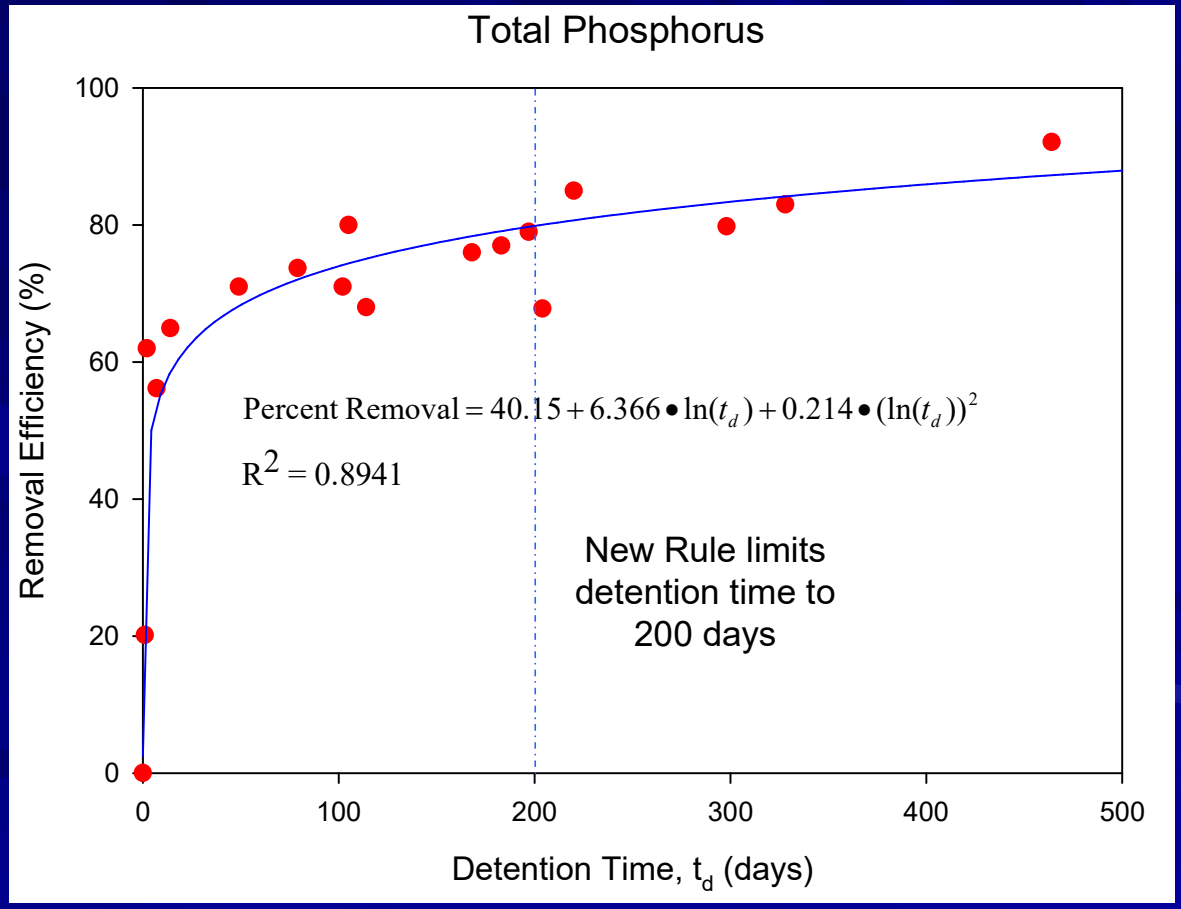


# Phosphorus Removal for Untreated Runoff in Wet Ponds

- Phosphorus removal is highly predictable

- Studies are available with detention times as long as 450 days

- All studies had littoral zones, so littoral zone impacts are included in calculated removal efficiencies



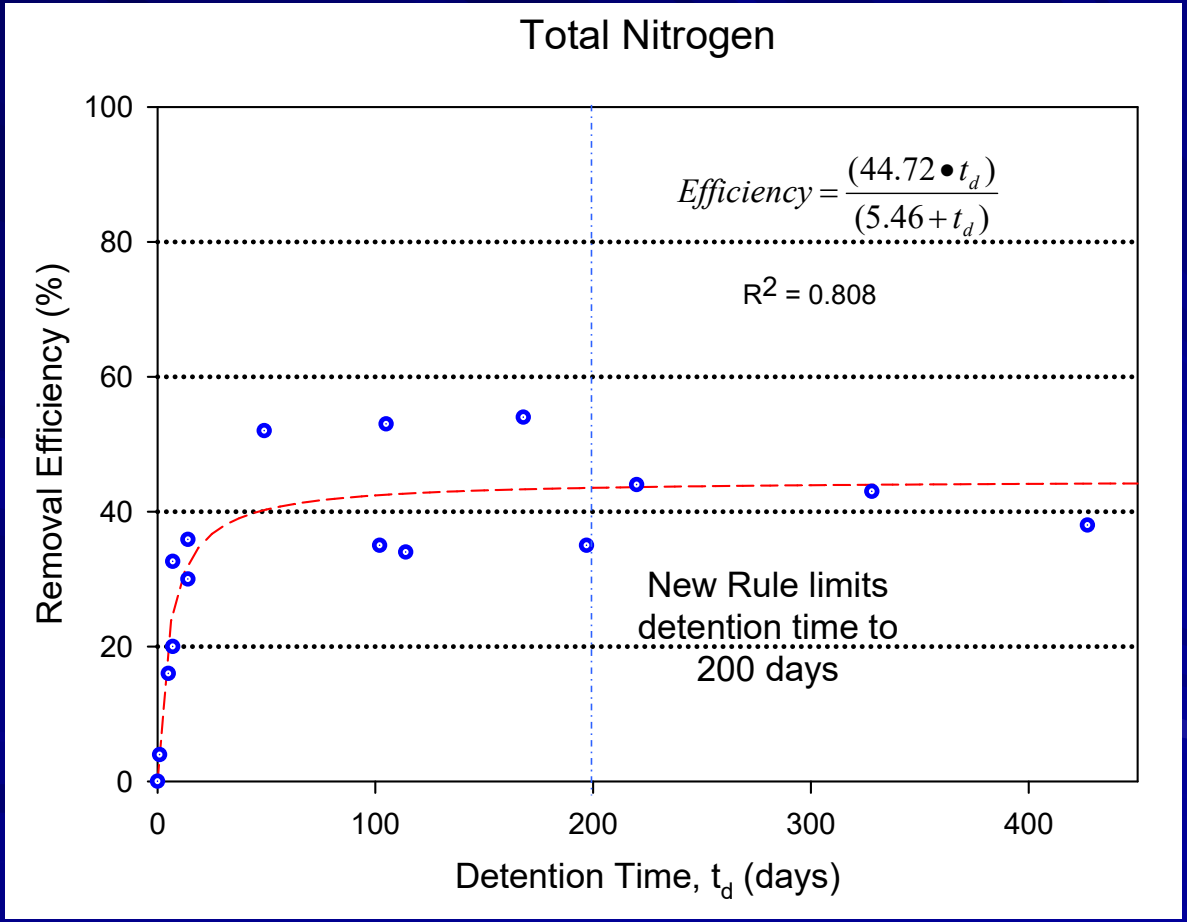
# Nitrogen Removal for Untreated Runoff in Wet Ponds

- Nitrogen removal depends on the forms of nitrogen present

- Inorganic N is removed by biological uptake

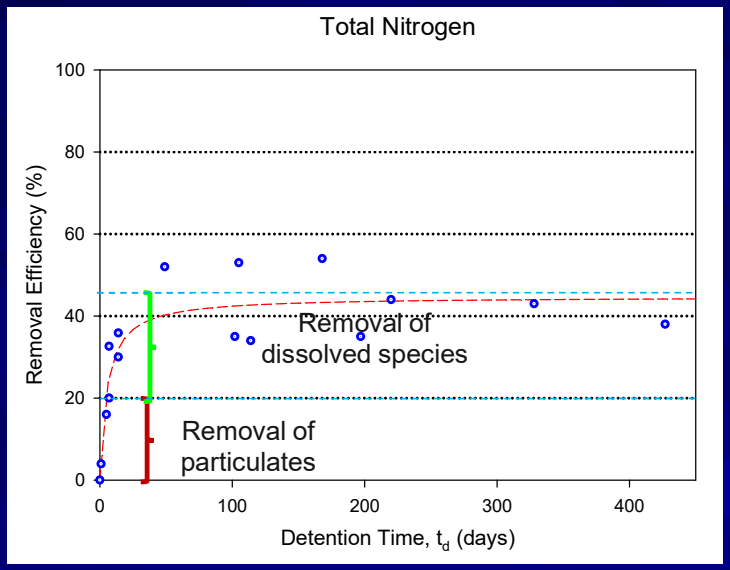
- Particulate N is easily removed

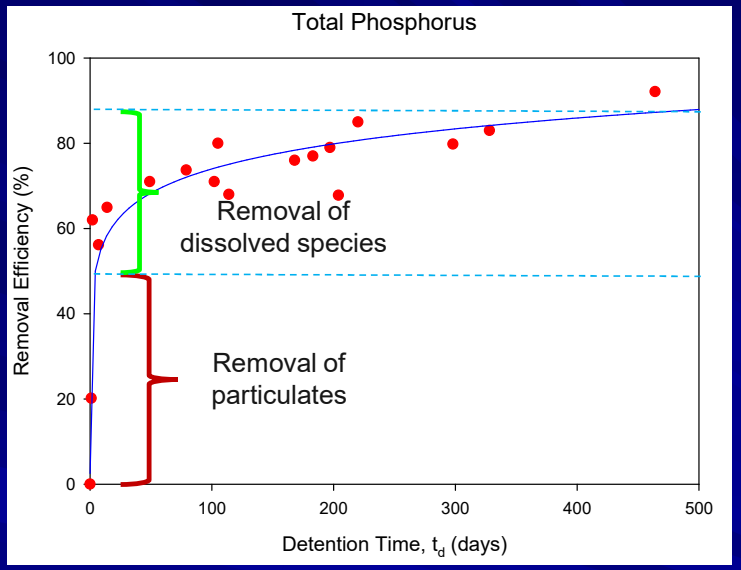
- Organic N is not removed easily



# Nutrient Removal Relationships for Wet Ponds

## Nutrient Removal is Primarily a Function of Detention Time




- These relationships were developed for <u>untreated</u> runoff only
- The relationships do not apply when the runoff gets pre-treatment
- Removal of dissolved pollutants is a function of concentration
  - Removal rates decrease as the water column concentration decreases
  - Removal stops when Irreducible concentration is reached

# Factors Negatively Impacting Efficiencies of Wet Ponds

Cattails

Waterfowl Loadings

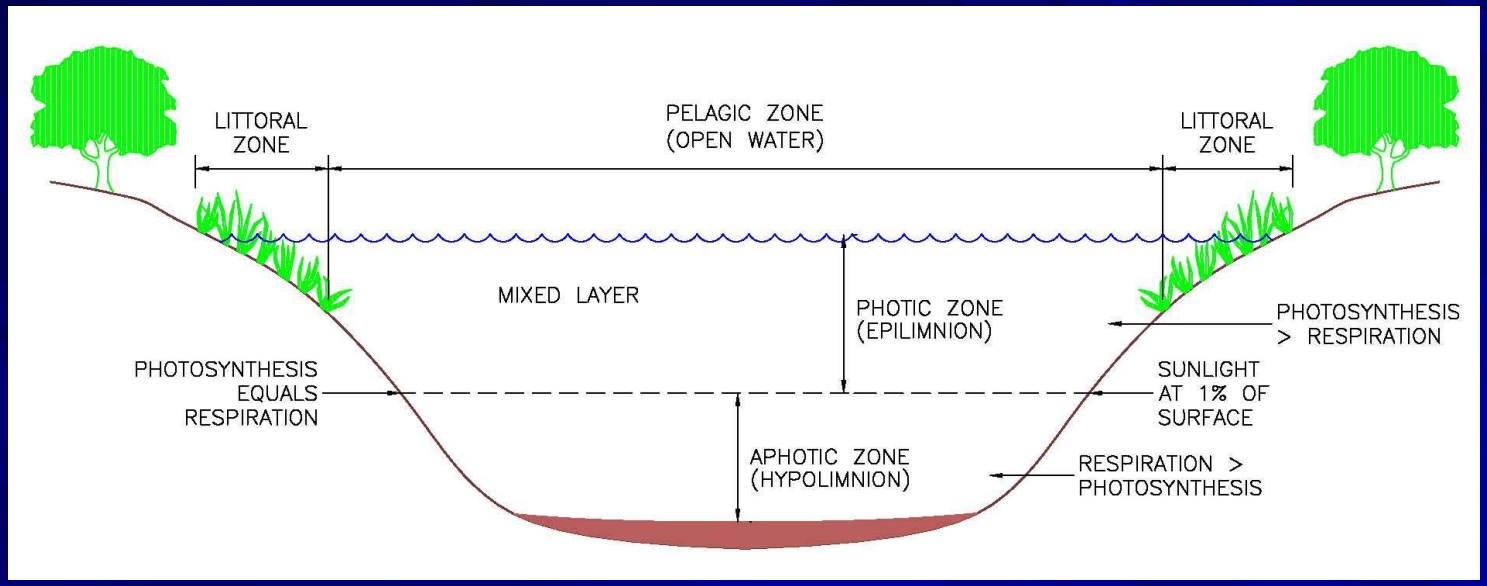
Managing Ponds as Amenities

Use of Copper Sulfate and Herbicides for Algae Control

# Comparison of Wet Detention Design Criteria for Florida WMDs

| Design Parameter | SJRWMD | SRWMD | SWFWMD | SFWMD |
|---|---|---|---|---|
| Water Quality Treatment Volume | First 1" runoff or 1.25 times imp.% | Same as dry retention | First 1" of runoff | First 1" runoff or 1.25 times imp.% |
| Detention Time | 14-day average wet season | 14-day average wet season | 14-day average wet season | None specified |
| Depth Requirements | Max: 12 ft. Mean Depth: 2-8 ft | Max: 12 ft. Min: 2 ft | None | None |
| Littoral Zone Requirements | 30% of pond surface: 80% survival after 2 yrs | Not addressed | 35% concentrated at the outfall | 20% of pond area or 2.5% of basin |
| Volume Recovery | < 50 % in 24 hours | < 72 hours by perc, evap. or ET | 50% in 72 hours; 100% in 5 days | < 50 % in 24 hours |

# Zonation in a Typical Lake



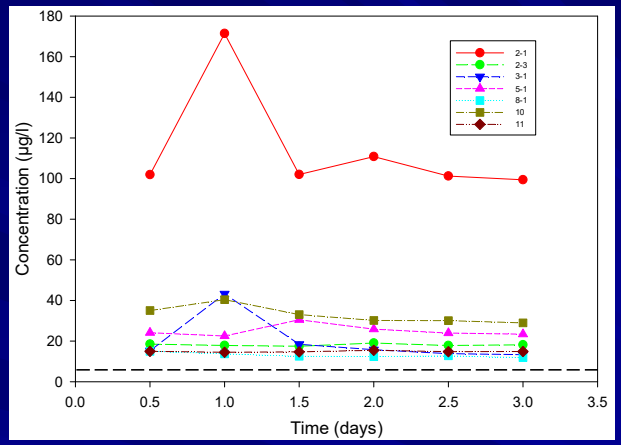

- Deep areas of lakes that become anoxic can release ammonia, phosphorus, and gases from organic rich sediments which have accumulated over centuries

- Although wet detention ponds have the same physical, chemical, and biological processes as natural lakes, wet detention ponds do not have muck accumulations or other conditions responsible for internal nutrient release

# Mean Water Quality Characteristics of Wet Detention Ponds in the Stoneybrook Development from 8/01 – 12/07
(n=27 events)

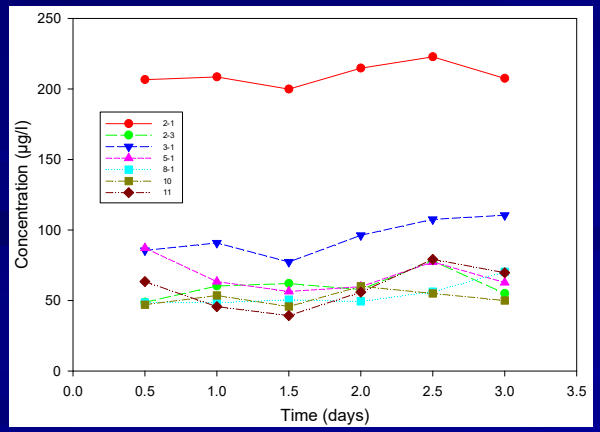
- During 2001-2007, ERD monitored water quality in a series of deep wet detention ponds for a new development
- Pond depths ranged from 20-25 ft
- Water quality monitoring conducted at pond outfalls for 72 hours following rain events of 0.5 inch or more
- No significant change in concentration over time

Total Copper

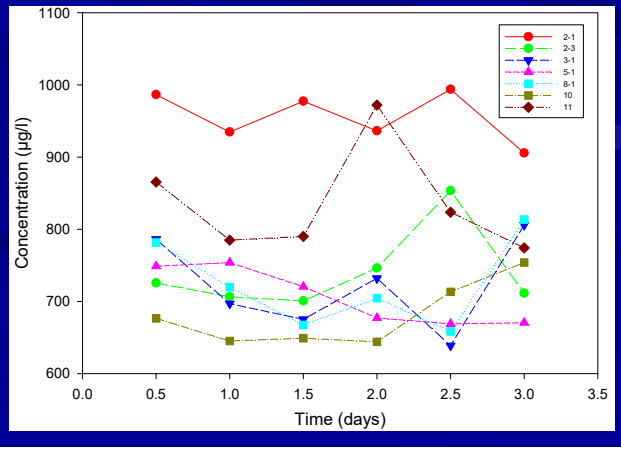



Class III Criterion

Ammonia



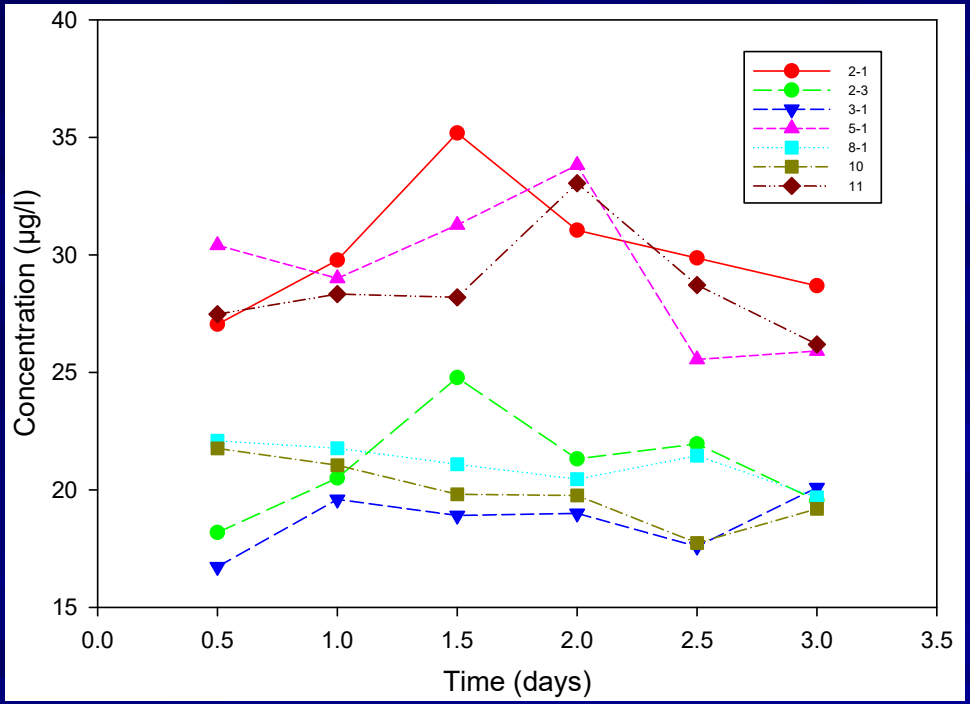

Total N



# Mean Water Quality Characteristics of Wet Detention Ponds in the Stoneybrook Development from 8/07 – 12/07

(n=27 events)

## Total P




- No significant change in outfall concentration over time

- Monitoring conducted by ERD has never detected evidence of significant release of nutrients from bottom sediments in a wet detention pond

- However, the WMDs, in an abundance of caution, have decided to limit the areas of a wet detention pond used to calculate the annual detention time and corresponding effectiveness to the volume above the hypothetical anoxic zone

- ERD developed a methodology for estimating the anoxic zone depth based on algal productivity

# Relationships Between Lake Parameters

- P regulates the growth of algae in most freshwater lakes
- Data collected Lake Watch data from more than 1,000 lakes in Florida and developed relationships between trophic state parameters – mean annual values

1. Relationship between TP and chlorophyll-a:

$$\ln(\text{chyl-a}) = 1.058 \ln(\text{TP}) - 0.934$$

where: chyl-a = chlorophyll-a concentration ($mg/m^3$)
TP = total P concentration ($\mu g/l$)

2. Relationship between chlorophyll-a and Secchi disk depth:

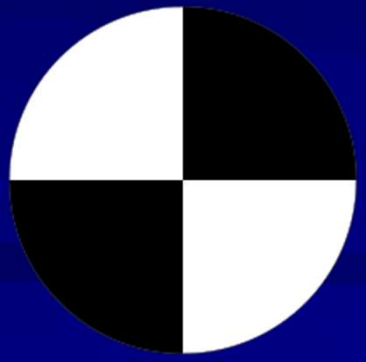
$$SD = \frac{24.2386 + [(0.3041)(\text{chyl-a})]}{(6.0632 + \text{chyl-a})}$$

where: SD = Secchi disk depth (m)

chyl-a = chlorophyll-a concentration ($mg/m^3$)

# Secchi Disk Depth

- Measure of water transparency
- Measurement is conducted by lowering a 20 cm diameter disk into water
- Disk is lowered until it is no longer visible. Disk is then raised until it is visible again. The Secchi disk depth is the average of the two depths



Standard 20 cm Disk

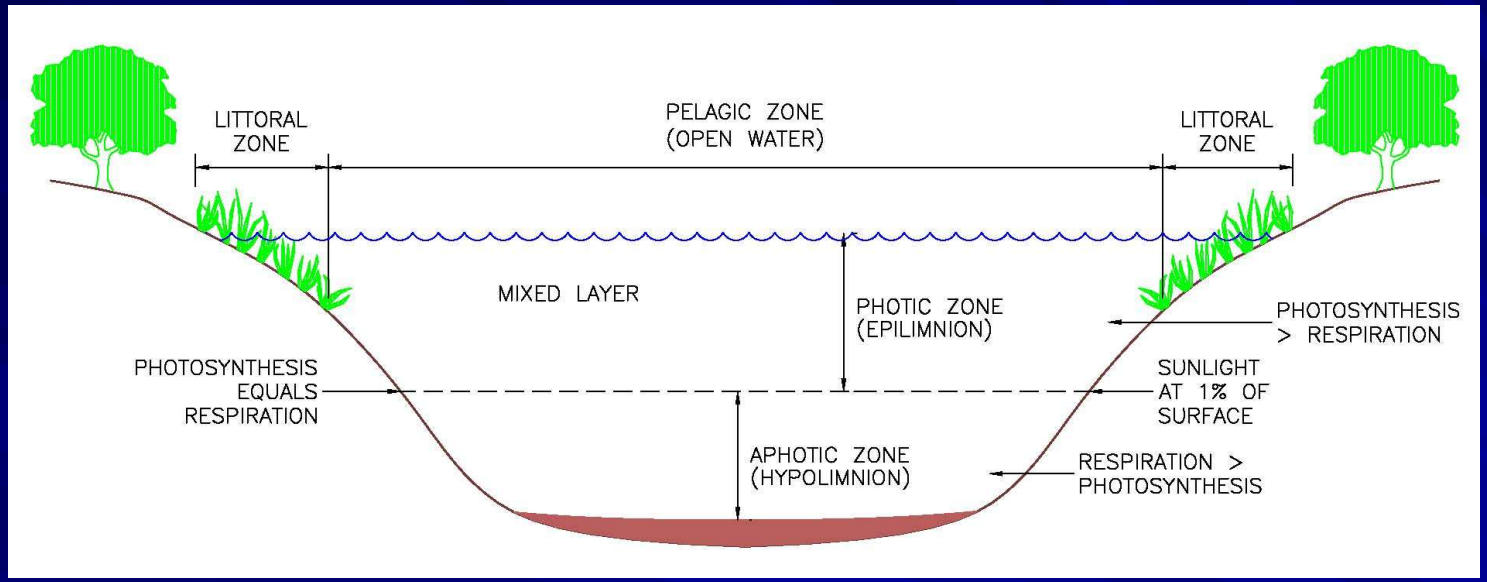
Father Pietro Secchi
Scientific advisor to the Pope
(1818-1878)

Measured water clarity in Mediterranean Sea from Papal yacht

# Estimation of Anoxic Depth

- The depth at which anoxic conditions (DO < 1 mg/L) occurs in a lake or pond is a function of the water quality characteristics
- Since anoxia is related to the penetration of sunlight, factors which impact light penetration should have a predictable relationship with anoxic depth
- A data set was developed to evaluate relationships between anoxic depths and related water quality parameters
  - Collected data included
    - Chlorophyll-a – measure of algal biomass which can shade light
    - Secchi disk depth - measure of light penetration
    - Total P – most stormwater ponds and lakes are phosphorus limited, and algal productivity is regulated by the amount of P available
    - Anoxic depth – the depth at which dissolved oxygen concentrations reduce to < 1 mg/L
  - ERD obtained geomean water quality data from more than 100 lakes in Florida
- A regression analysis was conducted to evaluate relationships between these variables

# Calculation of Anoxic Depth




*Anoxic Depth (m) = 3.035 x Secchi (m) – 0.004979 x Total P (mg/l) + 0.02164 x chyl-a (mg/m$^3$)*

*($R^2$ = 0.951)*

The above equation is valid for: 0.25 m < anoxic depth < 9.0 m
0.09 m < Secchi disk depth < 3.49 m
0.001 mg/l < Total P < 0.498 mg/l
1 mg/m$^3$ < chly-a < 332 mg/m$^3$

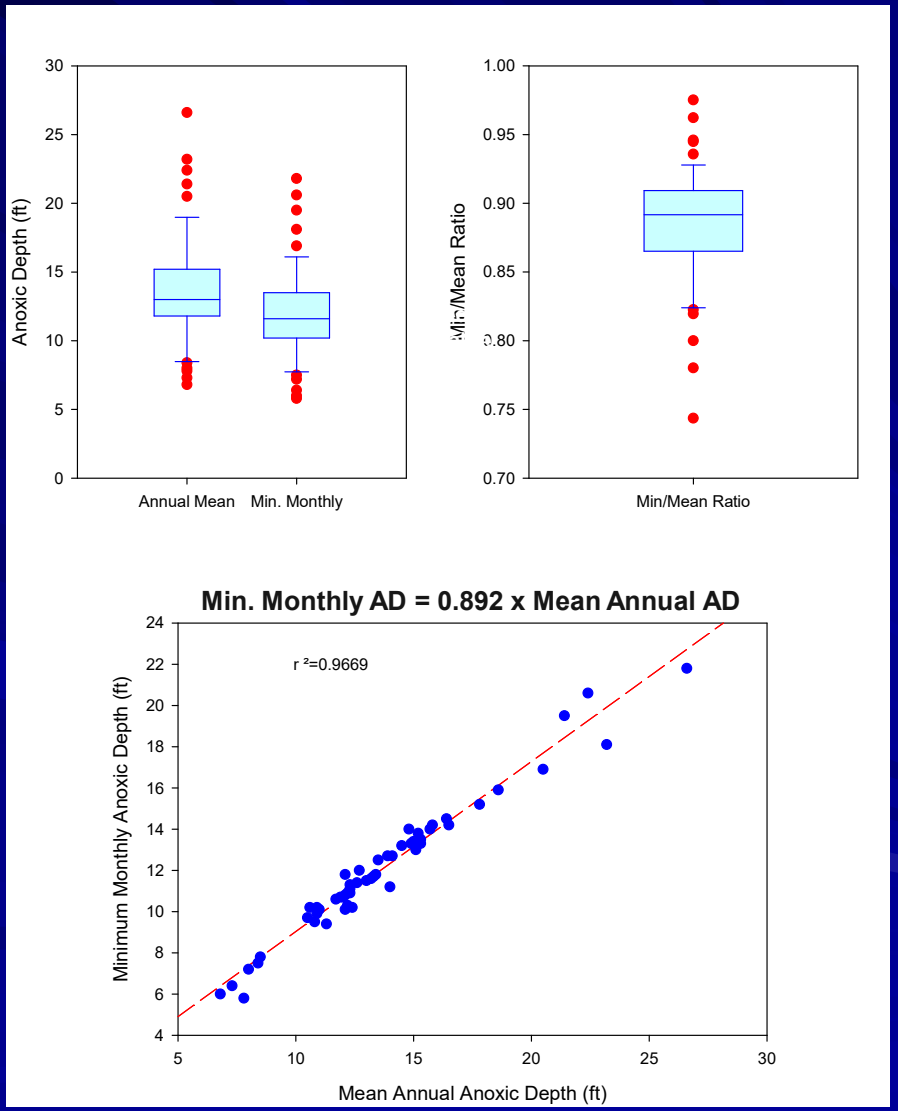
## Relationships Between Mean Annual Anoxic Depth (AD) and Minimum Monthly Anoxic Depth

- Model was developed to calculate anoxic depth for a wet pond on a monthly time step

-The AD calculation provides an estimate of the mean annual AD

- To impart a conservative bias to the analysis, some of the WMDs require that anoxic conditions not occur during any given month

- A conversion is used to convert the calculated mean annual AD to a minimum monthly value



# Calculation of Design Anoxic Depth

- If mean annual water column characteristics are used to calculate the anoxic depth, then the calculated depth represents a mean annual anoxic depth
- However, anoxic depth will vary throughout the year
- The pond design should be based on the minimum anticipated monthly anoxic depth:

Min. Monthly Anoxic Depth = 0.892 x Mean Annual Anoxic Depth

# Wet Detention Example

Evaluate wet detention for similar developments in Pensacola, Orlando, and Key West

1. Project Hydrologic and Mass Loading Characteristics:

| Location | Annual C Value | Runoff (ac-ft/yr) | TN Loading (kg/yr) | TP Loading (kg/yr) |
|---|---|---|---|---|
| Pensacola | 0.304 | 149.3 | 344 | 55.4 |
| Orlando | 0.253 | 94.8 | 219 | 35.2 |
| Key West | 0.266 | 79.8 | 184 | 29.6 |

# Wet Detention Example – cont.

## 2. Calculate required pond detention time ($T_d$):

Detention time required to achieve 80% TP removal =

$$Eff = 40.13 + 6.372 \ln (t_d) + 0.213 (\ln t_d)^2$$

By iteration, Td = ~ 200 days (79.9%)

Anticipated TN removal for a 200 day detention time =

$$Eff = \frac{(43.75 \times t_d)}{(4.38 + t_d)} = \frac{44.72 \times 200}{5.46 + 200} = 42.6\%$$

# Wet Detention Example – cont.

## 3. Calculate Permanent Pool Volume (PPV):

For the Pensacola site, the PPV requirement is:

$$\frac{149.3 \text{ ac-ft}}{\text{yr}} \times 200 \text{ days} \times \frac{1 \text{ year}}{365 \text{ days}} = 81.8 \text{ ac-ft}$$

For the Orlando site, the PPV requirement is:

$$\frac{94.8 \text{ ac-ft}}{\text{yr}} \times 200 \text{ days} \times \frac{1 \text{ year}}{365 \text{ days}} = 51.9 \text{ ac-ft}$$

For the Key West site, the PPV requirement is:

$$\frac{79.8 \text{ ac-ft}}{\text{yr}} \times 200 \text{ days} \times \frac{1 \text{ year}}{365 \text{ days}} = 43.7 \text{ ac-ft}$$

# Wet Detention Example – cont.

## 4. Calculate mean annual pond TP concentration (Pensacola):

Annual mass of TP discharged from pond (79.9 % removal)=

$$\frac{55.4\ \text{kg}}{\text{yr}} \times (1 - 0.799) = 11.1\ \text{kg}$$

This mass will be released in discharges from the pond outfall. Assuming that inflow and outflow are equal, outflow volume is 149.3 ac-ft.

Mean pond discharge concentration =

$$\frac{11.1\ \text{kg TP}}{\text{yr}} \times \frac{1\ \text{yr}}{149.3\ \text{ac-ft}} \times \frac{1\ \text{ac}}{43{,}560\ \text{ft}^2} \times \frac{1\ \text{ft}^3}{7.48\ \text{gal}}$$

$$\times \frac{1\ \text{gal}}{3.785\ \text{liter}} \times \frac{10^6\ \text{mg}}{\text{kg}} = 0.060\ \text{mg TP/L} = 60\ \mu\text{g TP/L}$$

# Wet Detention Example – cont.

5. Calculate pond annual chloropyhll-a concentration:

The relationship between TP and chlorophyll-a in a Florida waterbody can be expressed by the following relationship:

$$\ln(\text{chyl-a}) = 1.058 \ln(\text{TP}) - 0.934$$

where: chyl-a = chlorophyll-a concentration ($mg/m^3$)

TP = total P concentration ($\mu g/l$)

$$\ln(\text{chyl-a}) = 1.058 \ln(60) - 0.934$$

$$\text{chyl-a} = e^{2.94} = 40.4 \ mg/m^3$$

# Wet Detention Example – cont.

6. Calculate mean annual pond Secchi disk depth:

The relationship between chlorophyll-a and Secchi disk depth in a Florida waterbody can be expressed by the following relationship:

$$SD = \frac{24.2386 + [(0.3041)\,(\text{chyl-a})]}{(6.0632 + \text{chyl-a})}$$

where: SD = Secchi disk depth (m)

chyl-a = chlorophyll-a concentration ($mg/m^3$)

$$SD = \frac{24.2386 + [(0.3041)\,(40.4)]}{(6.0632 + 40.4)} = 0.79 \text{ m} = 2.6 \text{ ft}$$

# Wet Detention Example – cont.

## 7. Calculate mean annual depth of anoxic conditions:

The depth of anoxic conditions (AD) in a wet detention pond can be expressed by the following regression relationship:

$$AD = 3.035 \times Secchi + 0.02164 \times (chly\text{-}a) - 0.004979 \times Total\ P$$

where:

| | | |
|---|---|---|
| AD | = | anoxic depth (m) |
| Secchi | = | Secchi disk depth (m) |
| chly-a | = | chlorophyll-a concentration ($mg/m^3$) |
| Total P | = | total phosphorus concentration ($\mu g/l$) |

# Wet Detention Example – cont.

## 8. Calculate mean annual depth of anoxic conditions – cont.

AD = 3.035 (0.79) + 0.02164 (40.4) - 0.004979 (60) = 2.97 m = 9.8 ft

The anoxic depth calculated using this method reflects a mean annual anoxic depth.

The minimum monthly anoxic depth is calculated as:

Min. Monthly AD = 0.892 x mean annual AD

Min. monthly AD = 0.892 x 2.97 m = 2.65 m = 8.7 ft

# Modeled Impacts of Additional PPV

| Detention Time (days)[1] | TP Mass Removal (%) | Pond TP Conc. (mg/l) | TP Discharge (kg/yr) |
|---|---|---|---|
| 8 | 68.6 | 0.094 | 56.4 |
| 11 | 69.9 | 0.089 | 53.9 |
| 17 | 71.3 | 0.085 | 51.2 |
| 26 | 72.7 | 0.080 | 48.4 |
| 39 | 74.3 | 0.075 | 45.4 |
| 58 | 75.9 | 0.069 | 42.1 |
| 87 | 77.7 | 0.063 | 38.7 |
| 130 | 79.6 | 0.057 | 35.0 |
| 195 | 81.6 | 0.050 | 31.1 |
| 293 | 83.8 | 0.042 | 26.9 |
| 440 | 86.1 | 0.035 | 22.3 |

1. Each detention time increased by 50%

## Impacts

1. Increased mass removal
2. Reduced discharge concentrations and mass loadings
3. Increased dilution for slug inputs

# Concept of Irreducible Concentration

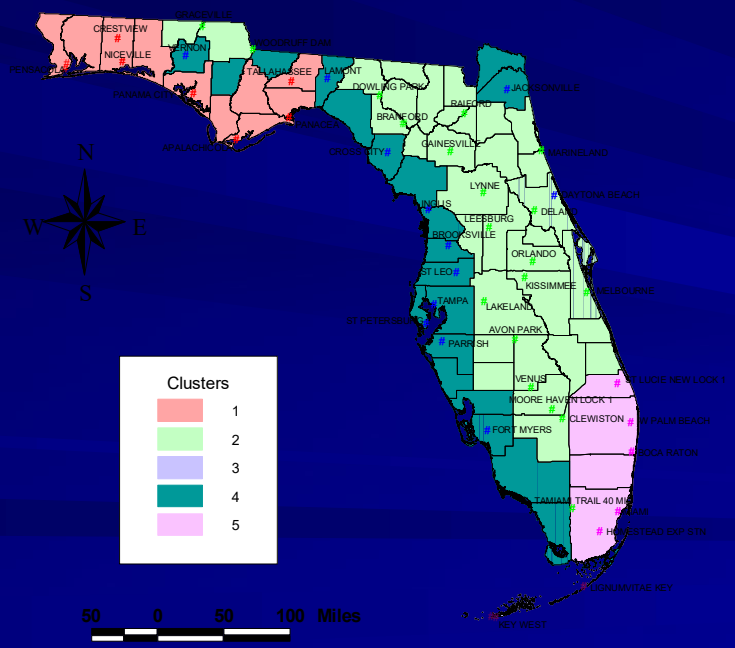
- Irreducible concentrations reflect the limitations of removal pathways for a particular pollutant in a treatment system
  - In wet ponds, the most significant processes are:
    - Sedimentation
    - Biological uptake
- When the irreducible concentration is reached, no significant additional removal is possible regardless of additional treatment volume or time

| Parameter | Units | Total N | Total P |
|---|---|---|---|
| Assumed Minimum Irreducible Concentration | µg/l | 400 | 10 |

- Concept is widely used in modeling wastewater treatment wetlands

# Comparison of 14 Day Wet Season with Mean Annual Detention Time

- Some of the Water Management Districts base their pond detention time designs on a 14-day wet season detention time
- This Methodology is based on a mean annual detention time




| Meteorological Zone | Equivalent Annual Detention Time (days) |
|---|---|
| 1- Panhandle | 17.1 |
| 2- Central | 19.9 |
| 3- Keys | 21.8 |
| 4- West Coastal | 20.2 |
| 5- Southeast | 21.0 |

# Impacts of Color on Wet Pond Effectiveness

- Color
  - Caused by dissolved organic molecules
  - Common organics in Florida are tannins and lignins
    - Caused by organic matter from decomposition of leaves, roots, and plant litter
  - Wetlands commonly discharge colored water
- Impacts of color
  - Reduces light penetration into water
    - Reduces depth of photic zone
  - Often reduces pH to values < 5
    - Limits algal species and aquatic plants
  - Some color compounds act as natural algaecides
  - Nutrients more likely to be bound into organic molecules
    - Unavailable for algal uptake and removal
  - Substantially reduces effectiveness of wet ponds
    - Limited primarily to removal of particulate matter
    - No significant biological removal

Color caused by dissolved matter: tannins

# Wet Detention Systems

By: Harvey H. Harper

January 2026