Dissertation

Improved Methodologies for Modeling Storage and Water Level Behavior in Wetlands

by

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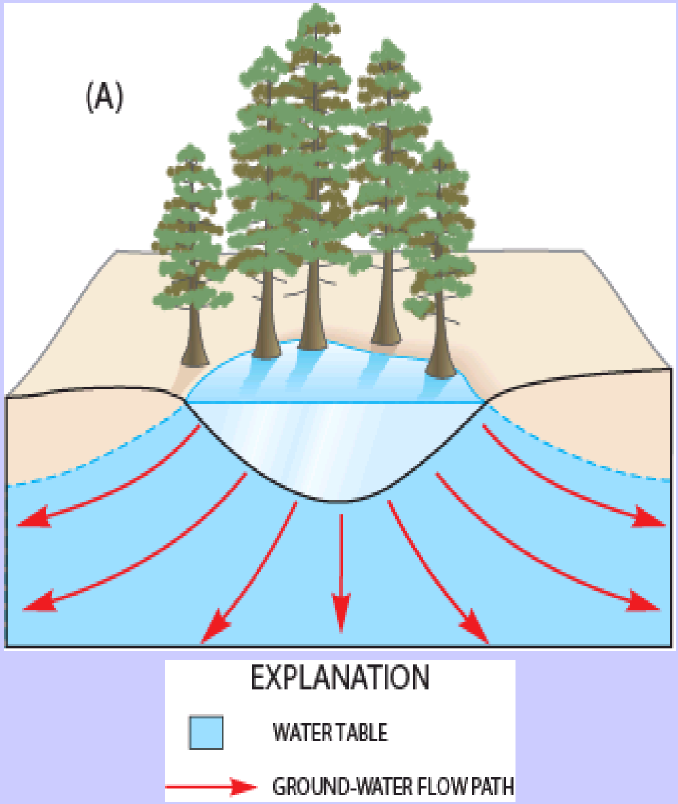
Wetlands

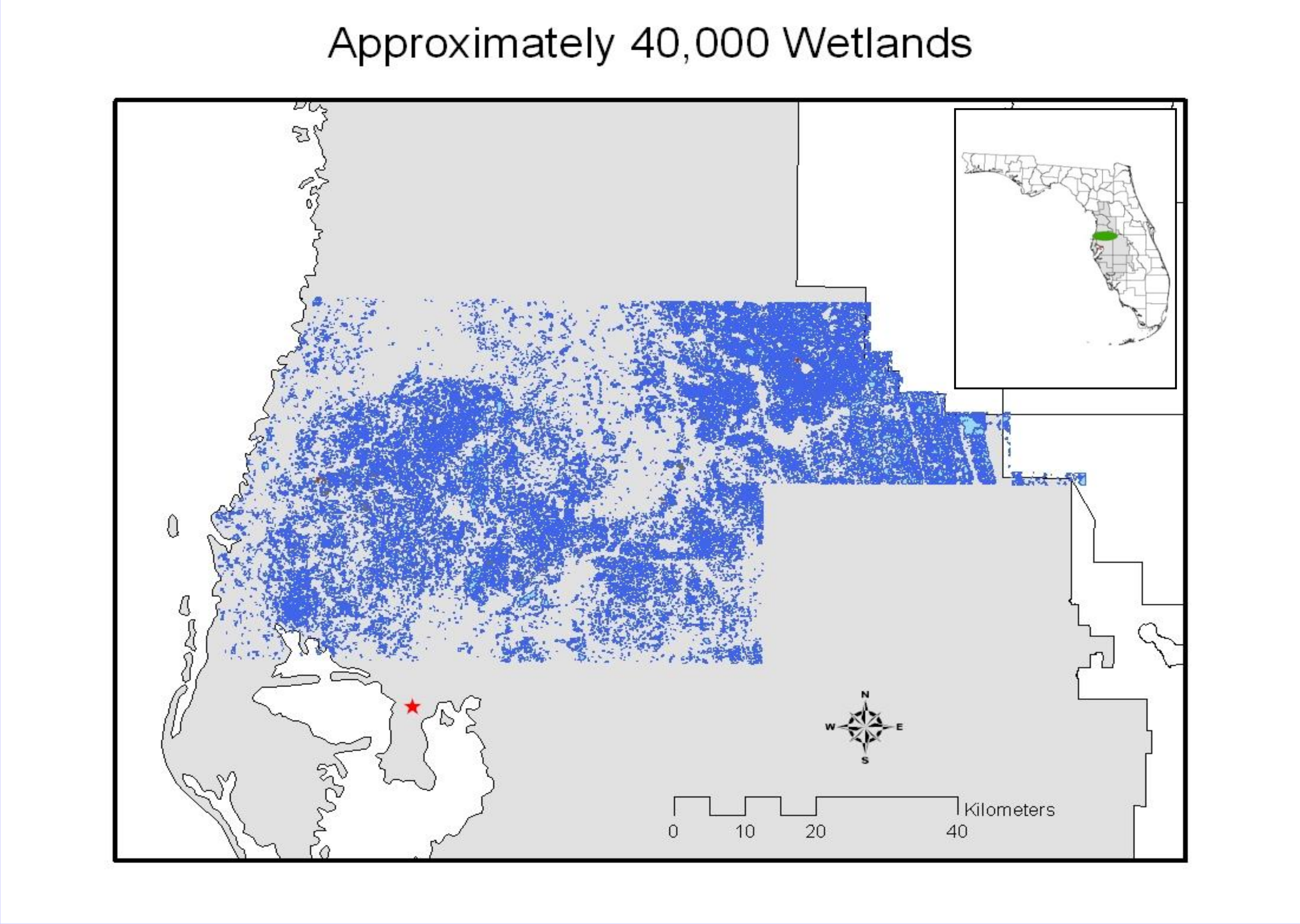
- Important role in the hydrology watersheds
- Influence
  - Water storage
  - Surface water runoff
  - Groundwater recharge



From Lee et al. (2009)

Wetlands – Regional Scale

- Hundreds or thousands of wetlands in a region or study area
  - 20% Land surface in SWFWMD
  - 29% Florida (Lee et al. 2009)



Hydrologic Modeling Implications

- Without reasonable wetland
  - Hydraulic information
  - Storage information

- Hydrologic models may produce inaccurate estimates
  - Stream flows
  - Groundwater recharge
  - Flood plain delineation
  - Wetland sustainability

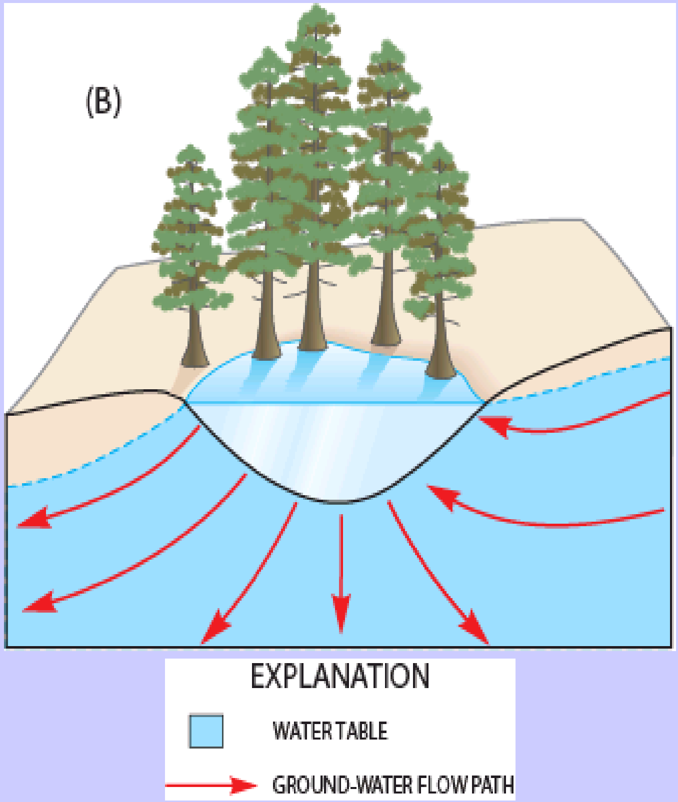
- May not accurately represent or predict the system water balance

Accurate Hydrologic Models

- Water resource engineers and hydrologists

- Better define:
  - Surface and subsurface water level fluctuations associated with wetlands
  - Movement of water into and out of wetlands
  - Surface and subsurface water storage of wetlands

- All wetlands in a hydrologic study area



Problem – Limited or No Hydrologic Data

- Wetland surface water storage data
  - Detailed bathymetry maps
  - Developed from extensive surveys
- Wetland surface water and groundwater elevation data
  - Collected using monitoring wells
    - Within the wetland extents
    - Surrounding uplands
- Largely determined
  - With a guess
  - Through model calibration

Question

- How can we REASONABLY quantify the cumulative effect wetlands have on a:
  - Watershed
  - Hydrologic region (e.g. west-central Florida)
- Use in large hydrologic models
  - Tampa Bay Water
  - Integrated Hydrologic Model

Dissertation Contributions

1) New Wetland and Lake Storage Model

- Describe above bed storage characteristics

2) New Insight into Wetland Water-Level Behavior

- Probabilistic Analysis (Frequency Analysis)
- Characterize wetland water-level fluctuations

3) New Insight on Wetland Groundwater Recharge Characteristics

- Probabilistic Analysis (Frequency Analysis)

Wetland and Lake Stage-Storage Model

Wetland Stage-Storage Characteristics

General Model Development and Evaluation

Wetland Bathymetry Data Sets

- Development data set
  - West-central Florida
    - 5 Cypress
    - 5 Marsh
    - 17 Lakes
  - North Dakota
    - 10 pothole
  - Saskatchewan, Canada
    - 10 pothole

Statistic	Wetland Characteristics A_o (x10^3 m^2)	h_o (m)	V_o (x10^3 m^3)
Mean	60	1.5	99
StD	80	1.0	190
Min	1.21	0.3	0.41
Max	352	4.3	850
	Lake Characteristics		
Mean	2,383	8.4	13,665
StD	4,500	3.7	30,130
Min	57	3.6	142
Max	14,700	18.0	106,000

- Validation data set
  - 21 Lakes in west-central Florida
  - Independent

Method - Wetland Stage-Storage Model

- Stage-storage Model*
  - Power-function
  - Used to predict wetland storage
  - Absence of survey data
  - **Assumption:** Circular Paraboloids
- New fitting “shape” parameter (*m*)
  - Describing stage-storage behavior
  - Developed using a iterative process
- Shape parameters
  - Developed for specific wetlands
  - General parameters
    - Multiple wetlands
    - Various wetland groups

$$V(h) = \left(\frac{A_o h_o}{m}\right)\left(\frac{h}{h_o}\right)^m$$

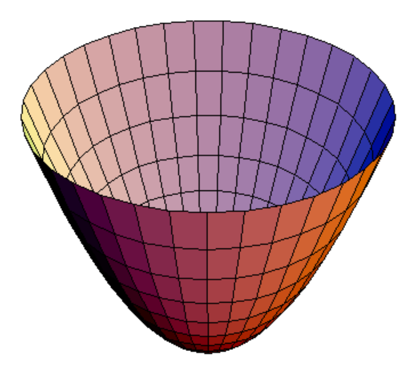
$V(h)$ = pool volume @ stage h

A_o = Maximum pool area

h_o = Maximum pool depth

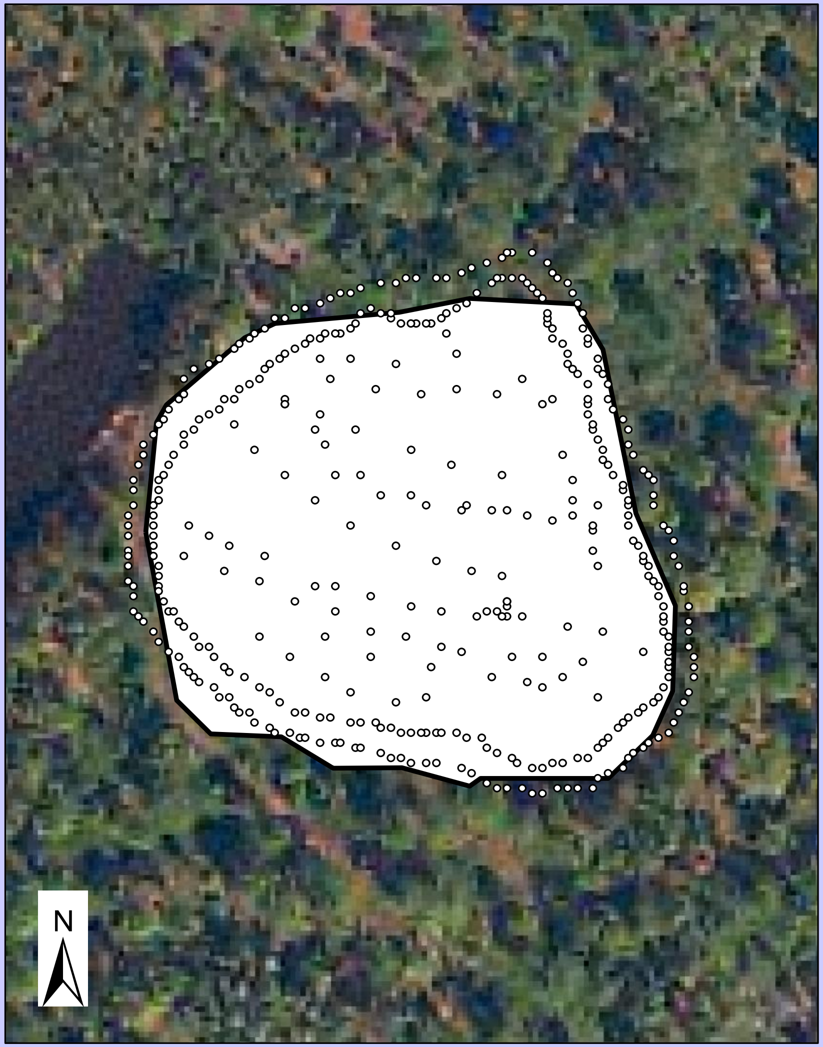
*(Nilsson et al. 2008)

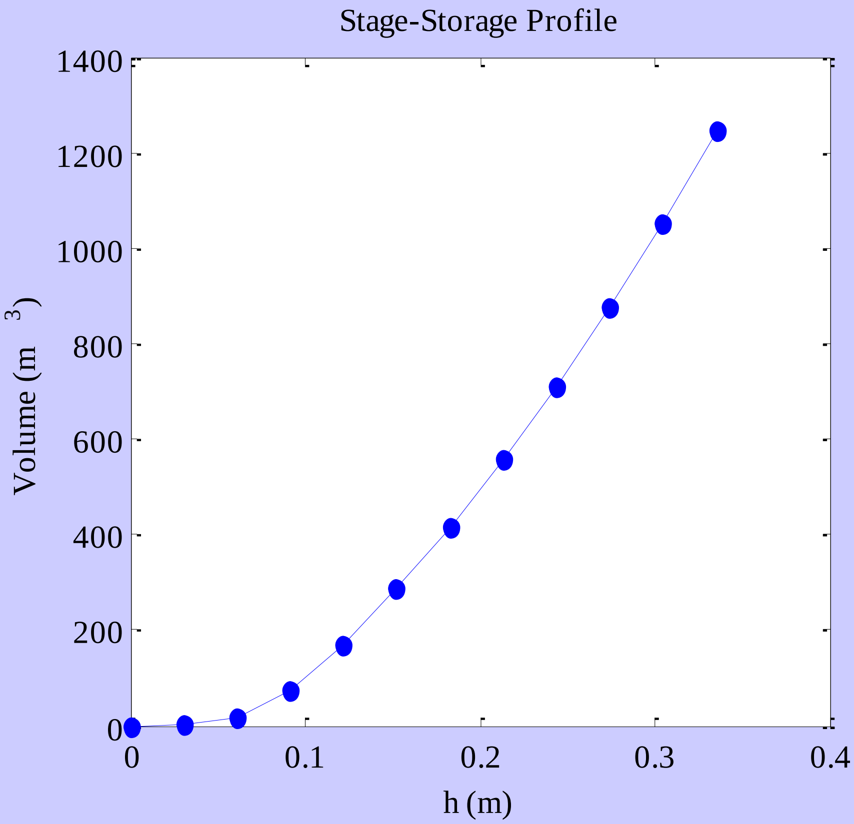
*(Nilsson et al. In Press)

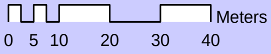


$$V = \frac{1}{2}\pi r_o^2 h$$

Wetland GIS Extents and Bathymetry Survey Locations

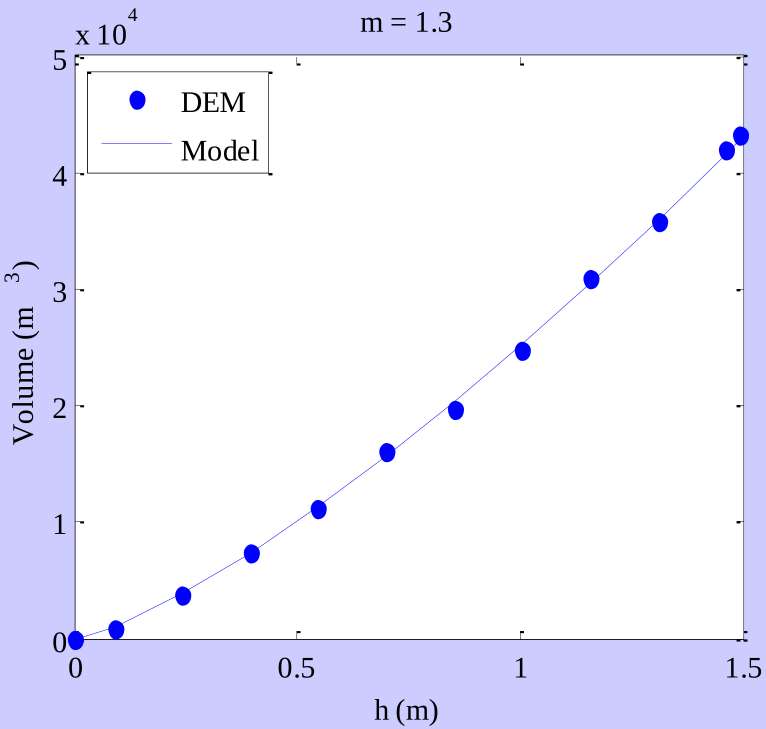


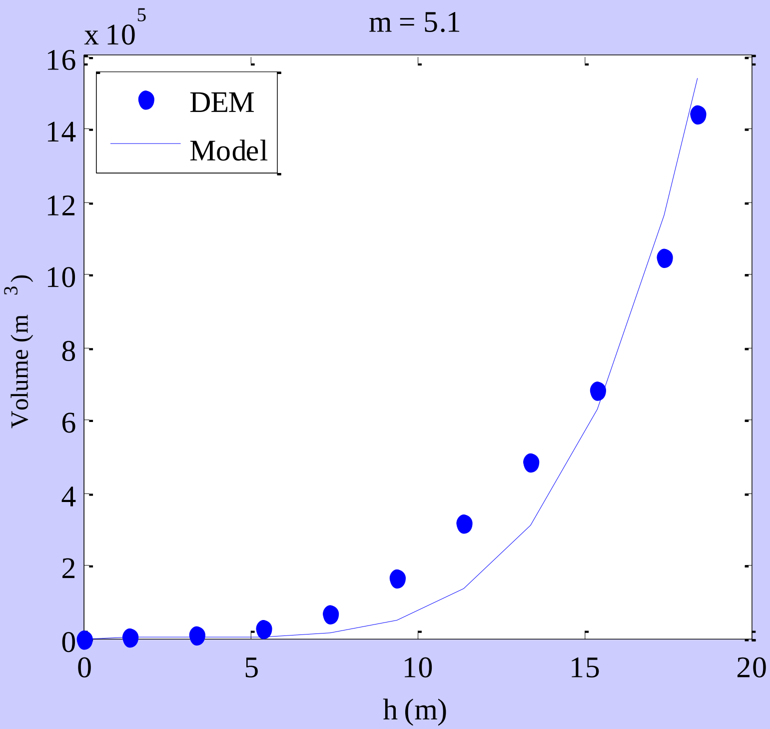




Results – Specific Model Shape Parameters (*m*)

- Individual wetland parameters
  - 1.3 – Pothole
  - 5.1 – Lake





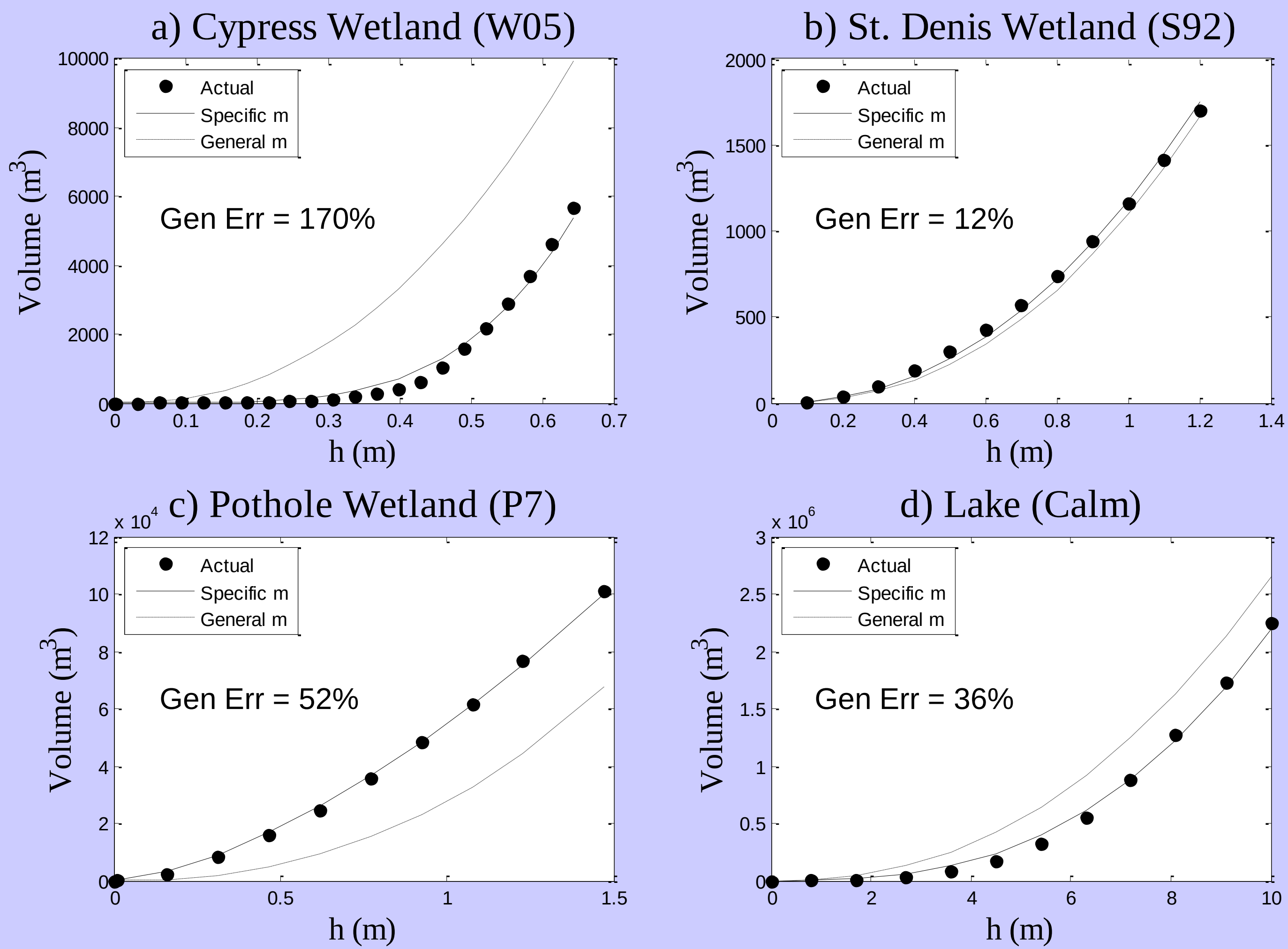
Results – Optimal General Model Storage Parameters / Errors

- Category parameters
  - 2.7 – Cypress
  - 2.5 – Marsh
  - 2.0 – Pothole (Canada)
  - 1.5 – Pothole (N.D.)
  - 2.5 – Lake
  - **2.3 – All Wetlands and Lakes**

- Category volumetric errors
  - 46% - Cypress
  - 32% - Marsh
  - 12% - Pothole (Canada)
  - 15% – Pothole (N.D.)
  - 42% - Lakes
  - **46.4% - All wetlands and lakes**

$$V_{ARE} = \frac{1}{k}\sum_{i=1}^{k}\left[ABS\left(\frac{(V_{Vh})_i - (V_{GIS})_i}{(V_{GIS})_i}\right)\right]*100\%$$

Results – Model Representations



$$V_{ARE} = \frac{1}{k}\sum_{i=1}^{k}\left[ABS\left(\frac{(V_{Vh})_i - (V_{GIS})_i}{(V_{GIS})_i}\right)\right]*100\%$$

Results – Validation Data Set Storage Errors

- Validation data set
  - Independent data set
  - 21 Lakes in west-central Florida

Statistic	Lake Characteristics A_o x10^3 m^2	h_o m	V_o x10^3 m^3
Mean	107	5.5	222
StD	91.6	2.2	181
Min	9.41	1.8	13.5
Max	332	9.8	571

$$V(h) = \left(\frac{A_o h_o}{m}\right)\left(\frac{h}{h_o}\right)^m$$

$$h(V) = (h_o)\left[\frac{V}{\left(\frac{A_o h_o}{m}\right)}\right]^{\left(1/m\right)}$$

- Storage errors
  - $m = 2.3$ Mean Error = 47.2%
  - $m = 2.5$ Mean Error = 38.0%
- Stage errors
  - $m = 2.3$ Mean Error = 14.6%
  - $m = 2.5$ Mean Error = 13.2%

Wetland Water Level Frequency Analysis

Empirical and Analytical Distribution Functions

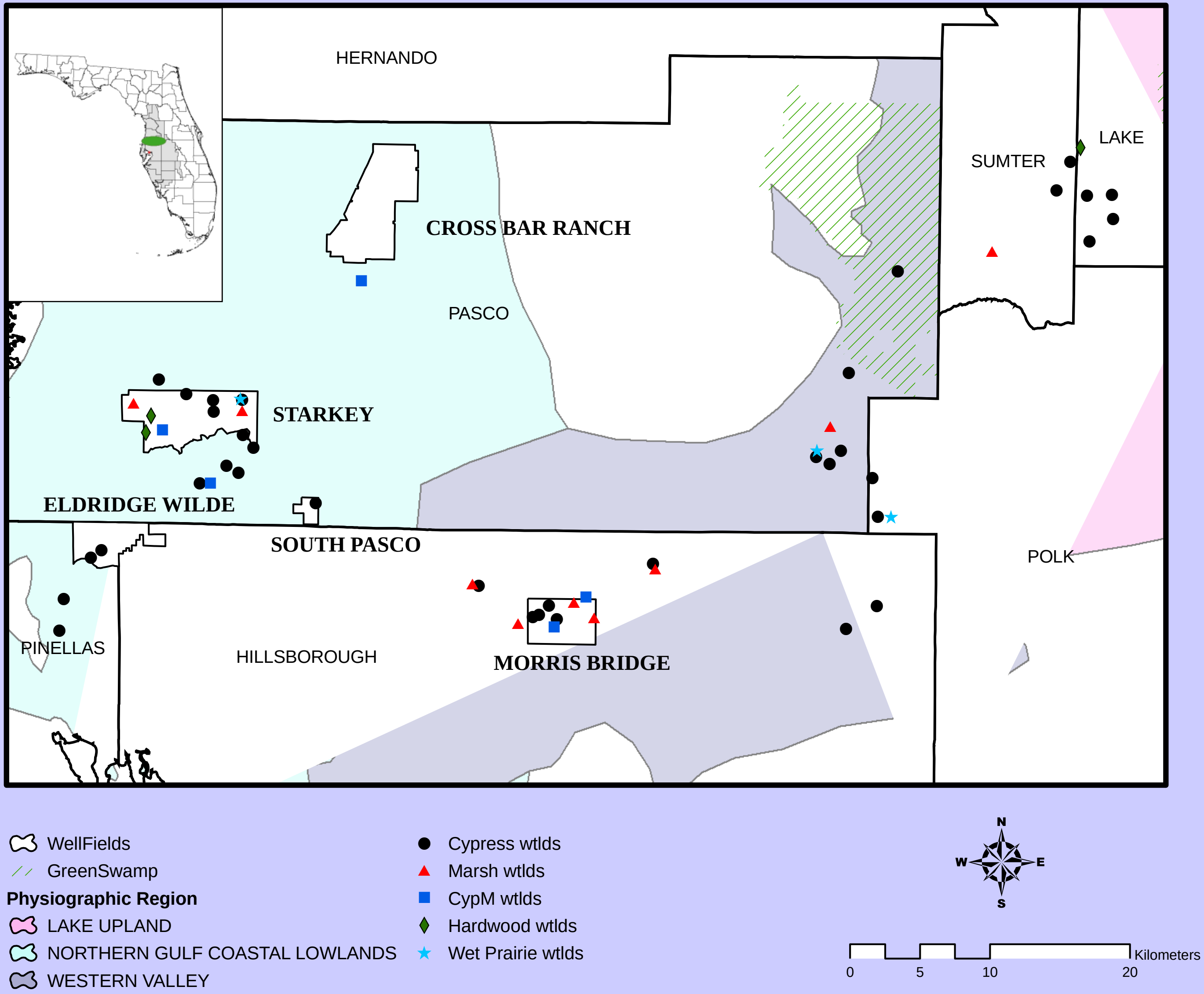
Wetland Water Level (hydroperiod) Characterization

Groundwater Recharge Characteristics

Wetland Water Elevation Data Sets

- Southwest Florida Water Management District (SWFWMD)
- Long-term water elevation data
  - Collected over seven years
  - Paired wetland monitoring wells
    - Wetland well – surface and subsurface water levels
    - Upland well – groundwater levels
- 56 Isolated wetlands in the northern Tampa Bay Region
  - 36 Cypress
  - 9 Marsh
  - 5 Cypress-marsh
  - 3 Hardwood
  - 3 Wet prairie

Wetland Locations



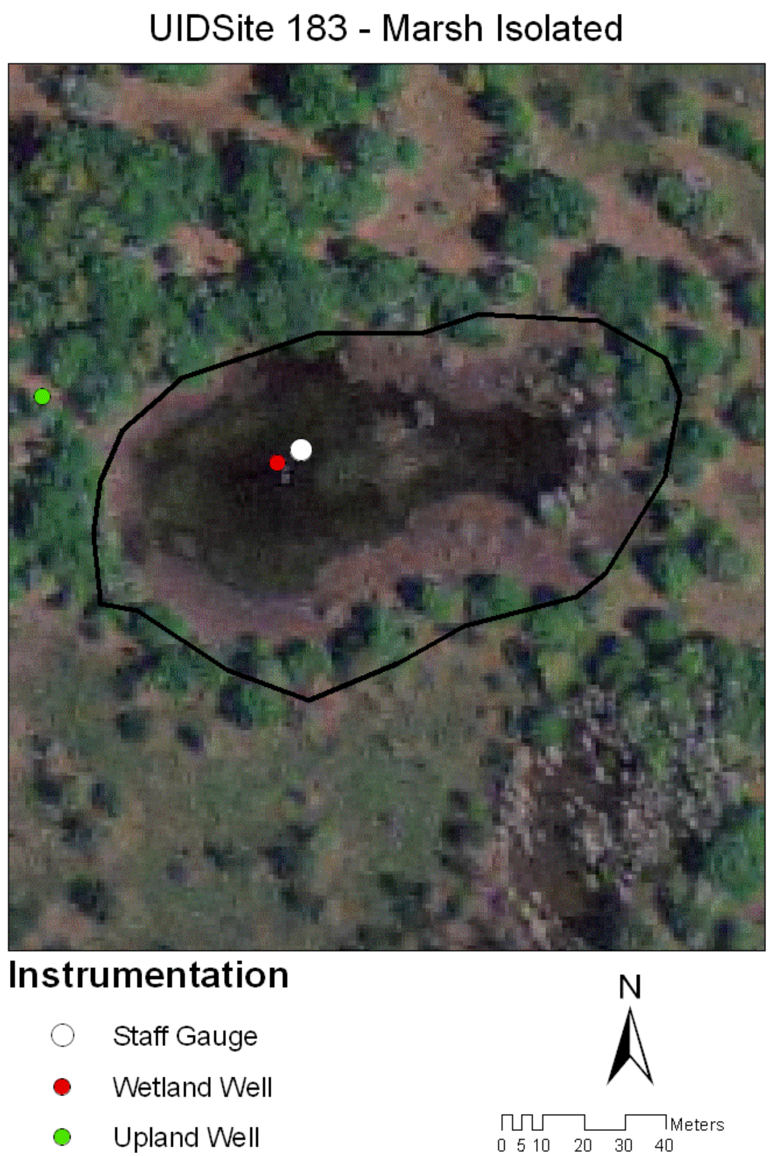
Physiographic regions are broad-scale subdivisions based on terrain texture, rock type, and geologic structure and history

Wetland Characteristics

Statistic	Regional Wetlands A ($x10^3$ m^2)	Regional Wetlands P ($x10^2$m)	Regional Wetlands h_o (cm)	Cypress A ($x10^3$ m^2)	Cypress P ($x10^2$m)	Cypress h_o (cm)	Marsh A ($x10^3$ m^2)	Marsh P ($x10^2$m)	Marsh h_o (cm)
Mean	**51.7**	**9.3**	**76.1**	**40.2**	**8.9**	**61.8**	**52.7**	**6.8**	**101.1**
Min	1.1	1.5	36.0	3.0	2.0	36.0	1.1	1.5	46.9
Max	392.9	50.4	250.2	354.0	50.4	148.7	392.9	31.2	235.0

Statistic	Cypress-Marsh A ($x10^3$ m^2)	Cypress-Marsh P ($x10^2$m)	Cypress-Marsh h_o (cm)	Hardwood A ($x10^3$ m^2)	Hardwood P ($x10^2$m)	Hardwood h_o (cm)	Wet Prairie A ($x10^3$ m^2)	Wet Prairie P ($x10^2$m)	Wet Prairie h_o (cm)
Mean	**40.0**	**8.6**	**138.8**	**223.3**	**24.7**	**87.4**	**34.7**	**8.4**	**56.1**
Min	15.5	4.6	74.7	159.3	22.9	64.6	2.9	2.7	37.2
Max	59.7	14.8	250.2	272.6	27.7	104.5	89.0	17.4	85.3

SWFWMD well and staff gauge locations



Empirical Distribution Functions (EDFs)

- Developed
  - Wetland surface and subsurface water elevation data
  - Upland groundwater elevation data

- Identify respective wetland hydrologic behavior
  - Periods of inundation and dry conditions
  - Periods of groundwater recharge

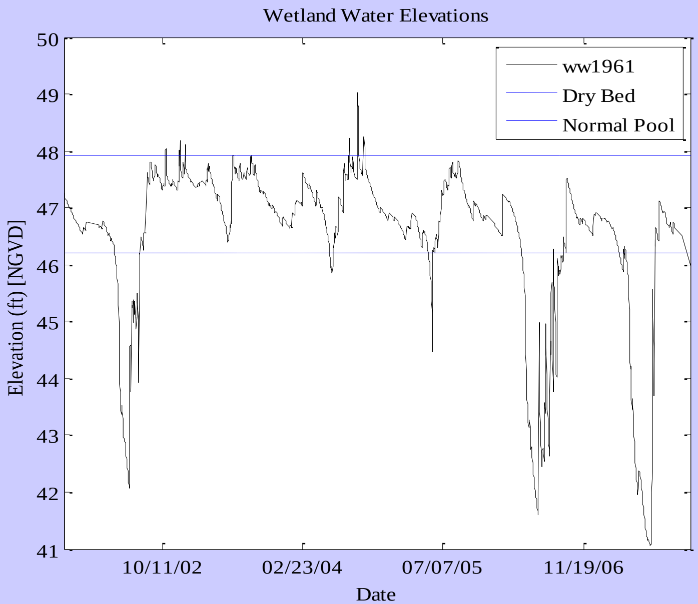
Empirical Distribution Functions (EDFs)

- Discrete step function
  - $f_s(p_m)$ is the relative frequency
  - x is an observation

$$F_s(p_x) = \sum_{m=1}^{x} f_s(p_m)$$

- Relative frequency (p_m)
  - Point estimate of exceedance probability
  - m is the rank
  - N is the sample size

$$p_m = \frac{m}{(N+1)}$$



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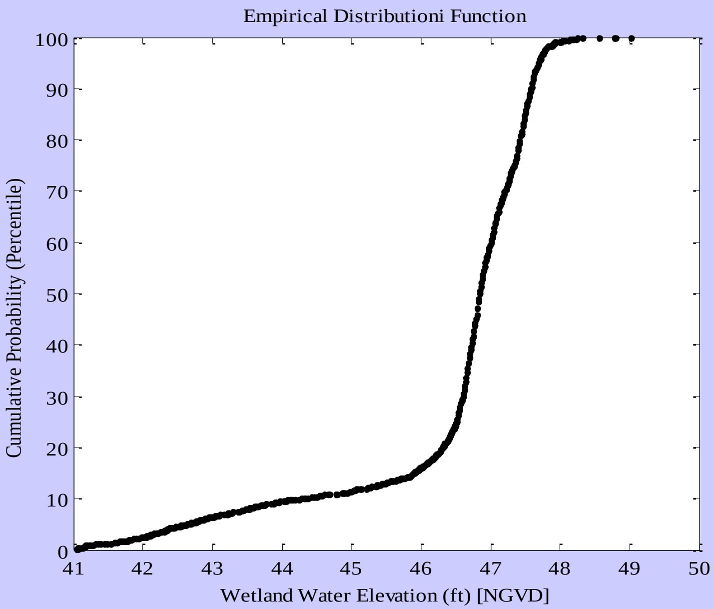
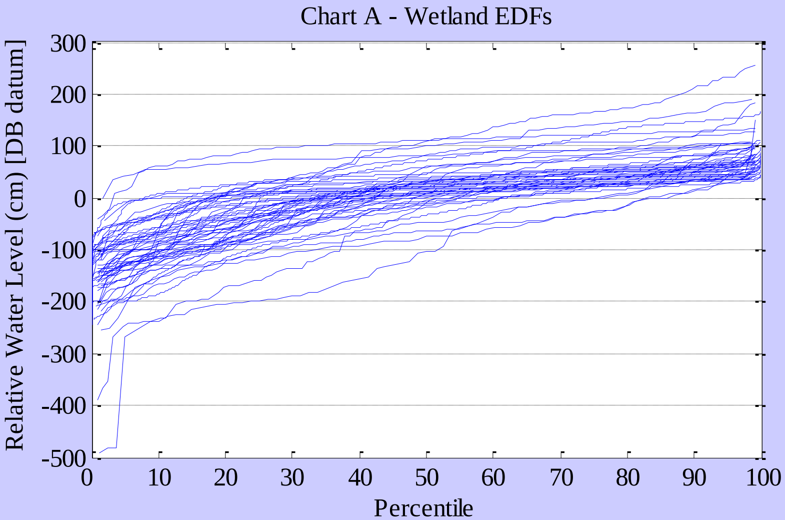
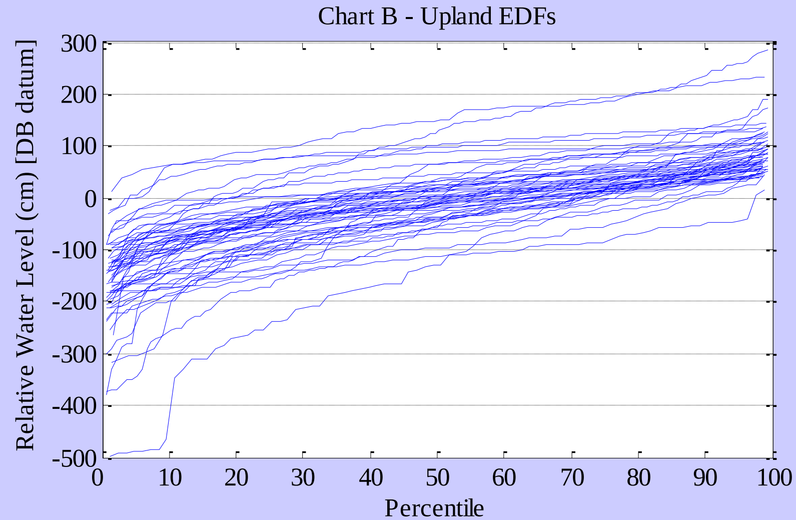
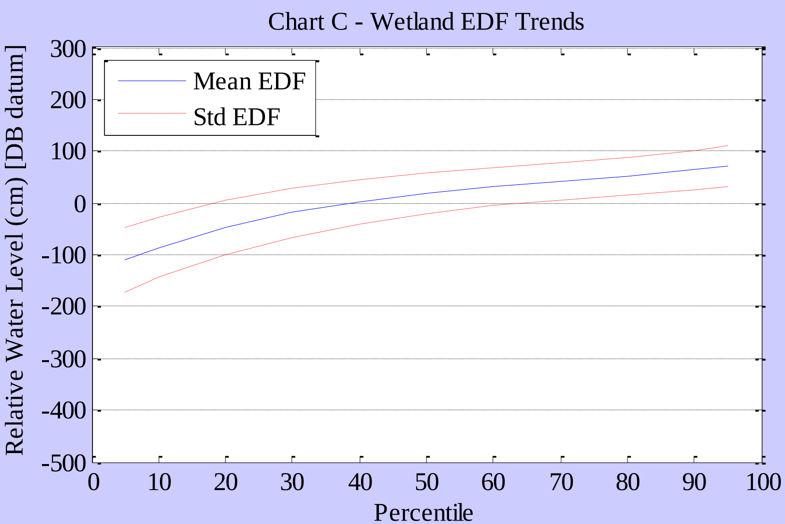
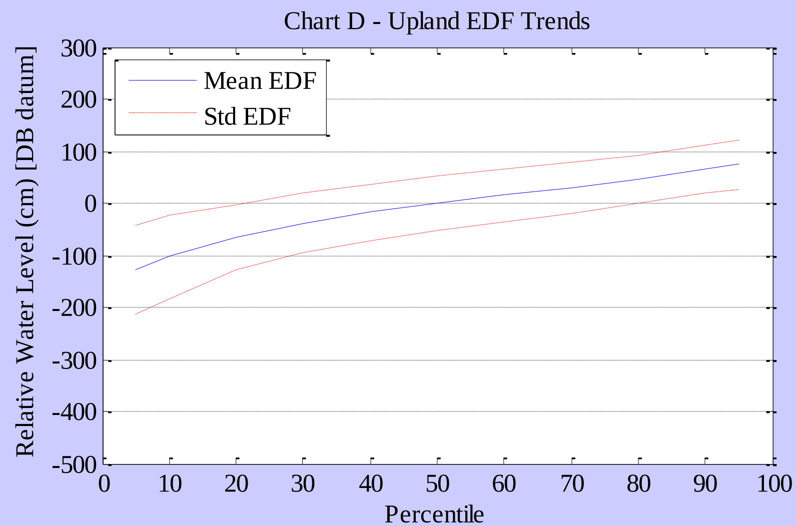


Results – Empirical Distribution Functions

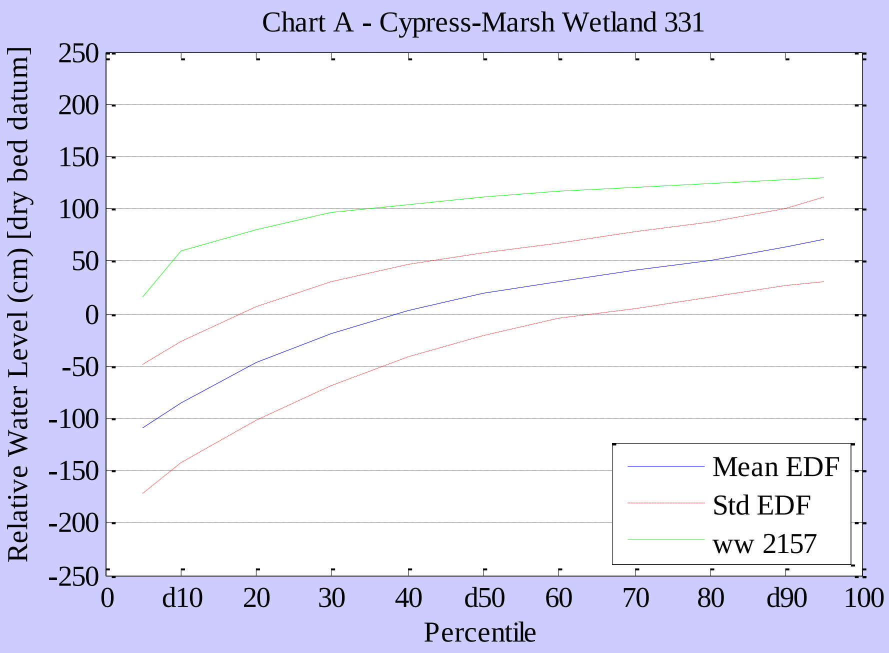




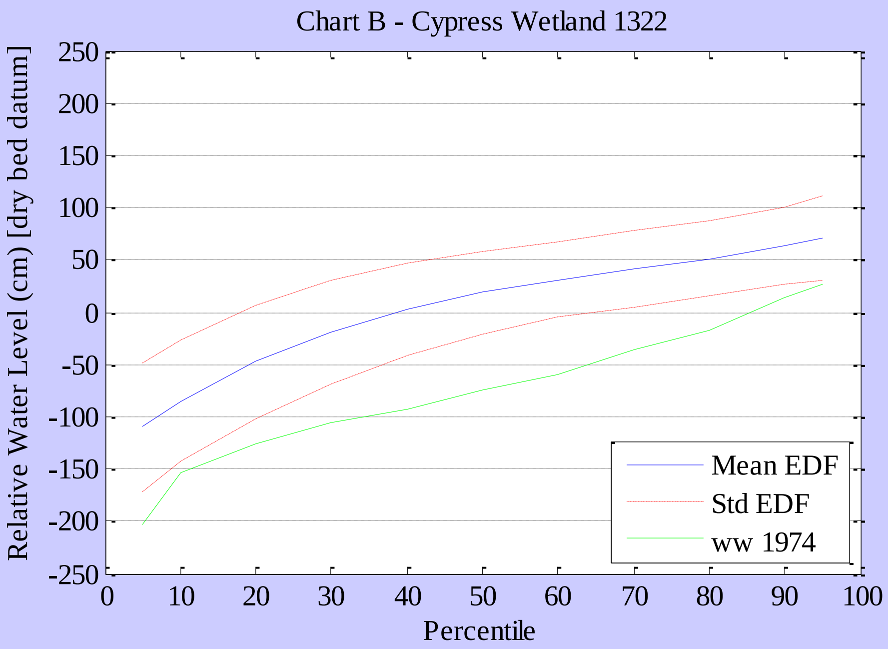




Application – Impacted Wetland Identification

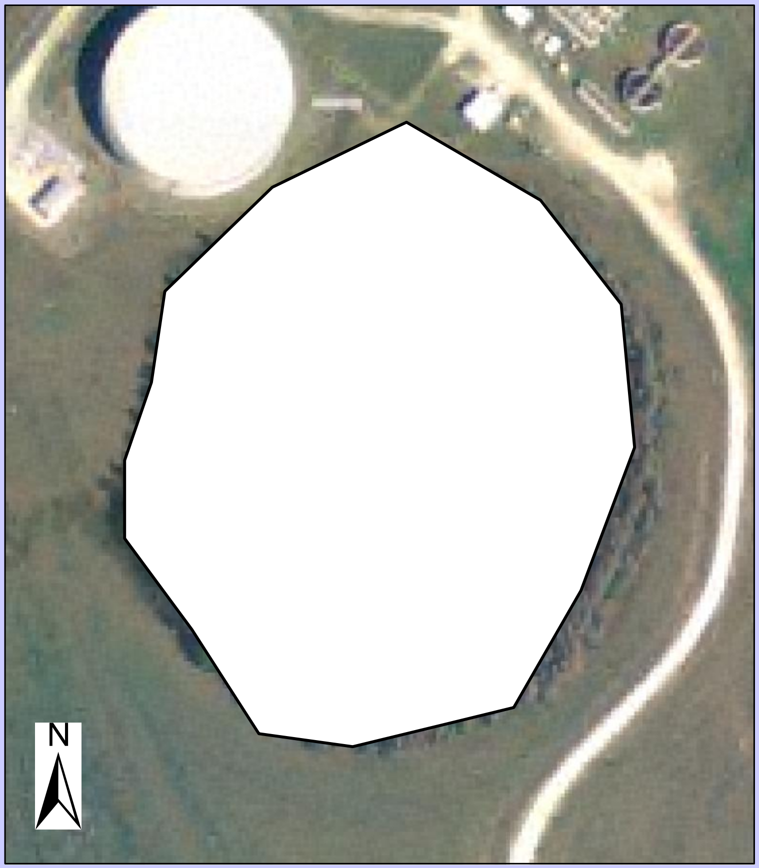


- Waste water treatment plant
- Spray field
- Artificially raise the water-table



- Greatly depressed water levels
- Falling cypress tress

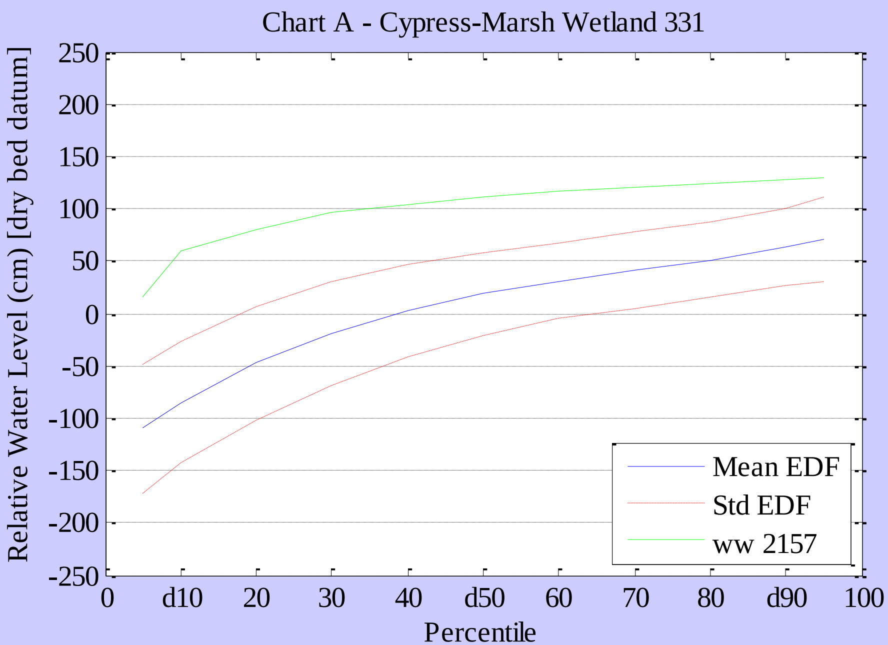
Application – Cypress-Marsh Wetland



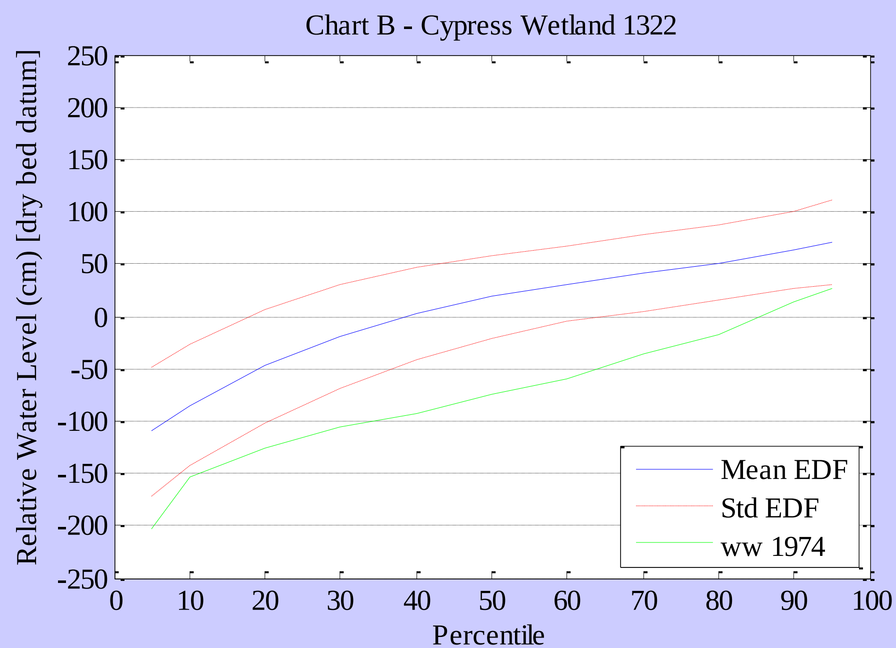
GIS Wetland Extents

0 5 10 20 30 40 Meters

Application – Impacted Wetland Identification



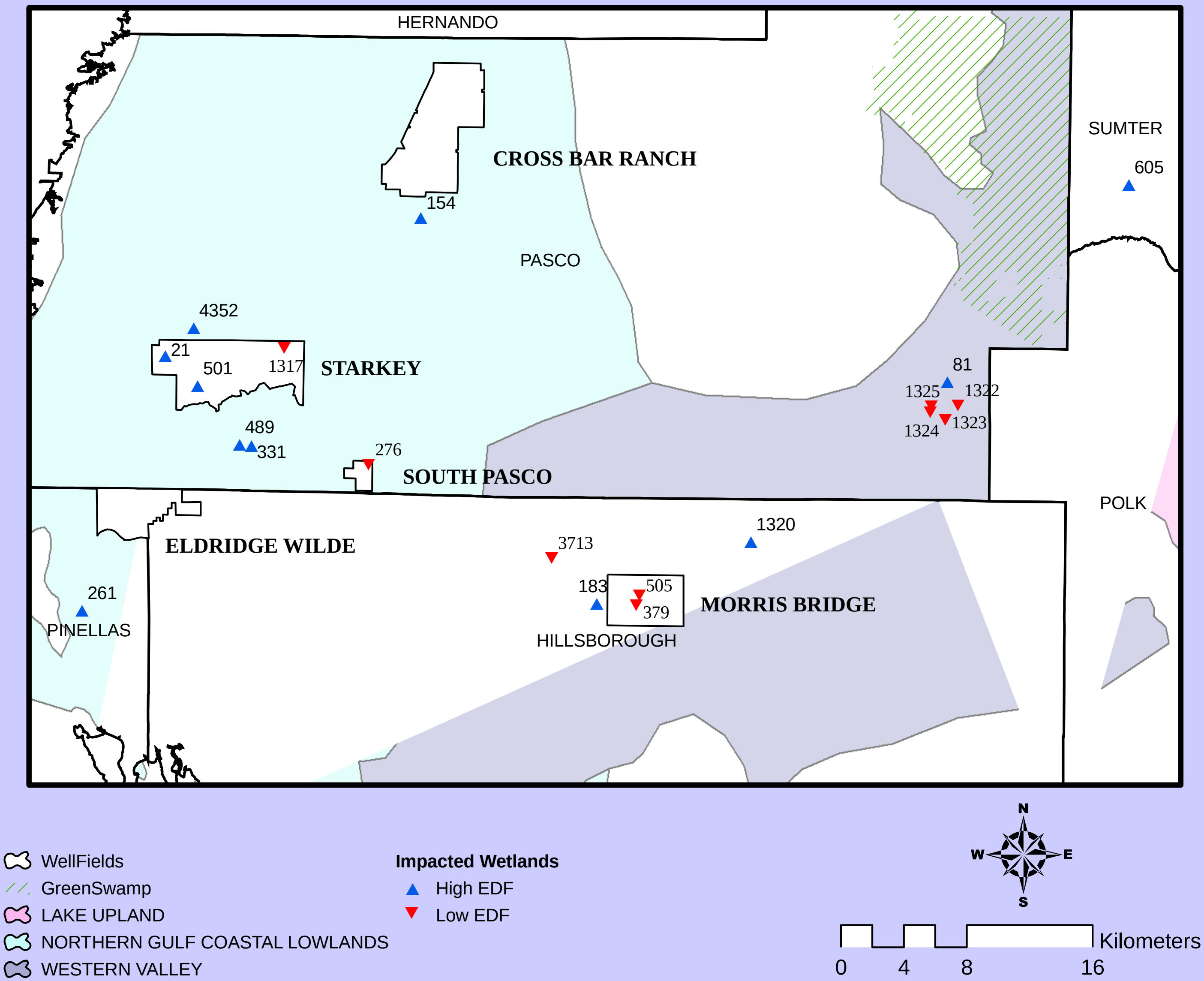
- Waste water treatment plant
- Spray field
- Artificially raise the water-table



- Greatly depressed water levels
- Falling cypress tress

Application – Cypress Wetland

Application – Impacted Wetland Locations



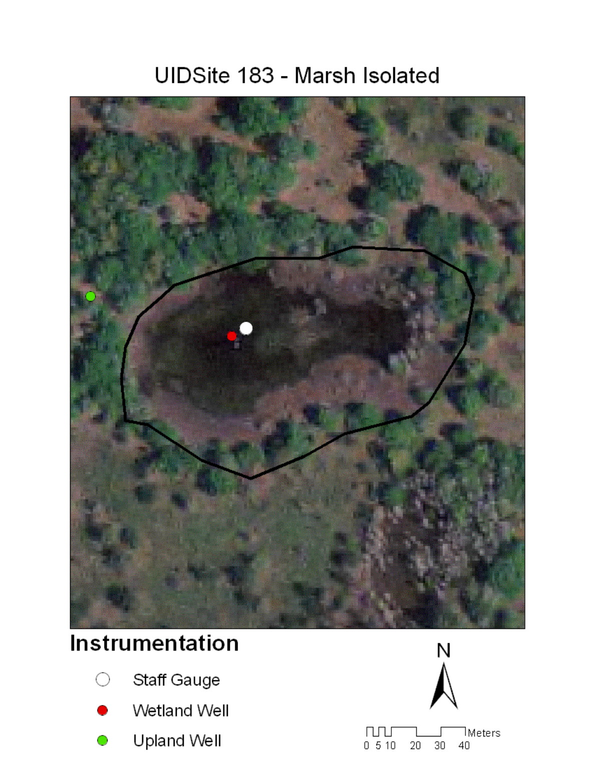
EDF Outliers

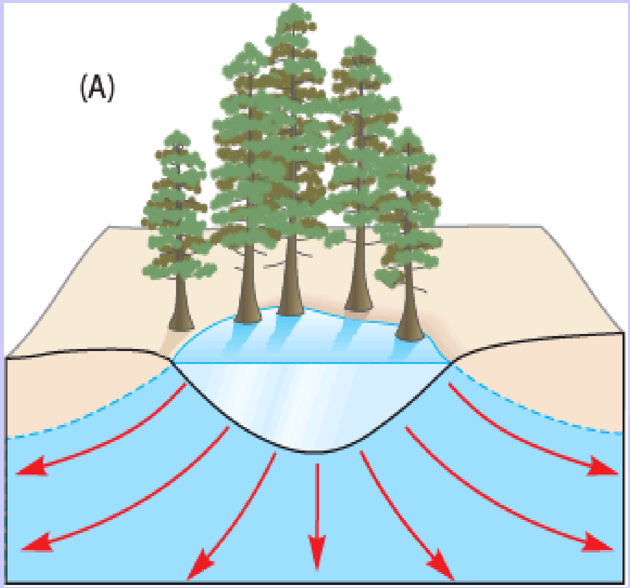
11 High

9 Low

Results – Dry Bed and Normal Pool Index (Relative Frequency)

Statistic	Regional Wetlands			Cypress			Marsh		
	F(DB)	F(NP)	h_o (cm)	F(DB)	F(NP)	h_o (cm)	F(DB)	F(NP)	h_o (cm)
Mean	**0.39**	**0.96**	**74.4**	**0.38**	**0.96**	**61.8**	**0.38**	**0.96**	**94.6**
Min	0.02	0.76	36.0	0.02	0.76	36.0	0.13	0.86	46.9
Max	0.86	0.99	250.2	0.86	0.99	148.7	0.65	0.99	235.0
	Cypress-Marsh			Hardwood			Wet Prairie		
	F(DB)	F(NP)	h_o (cm)	F(DB)	F(NP)	h_o (cm)	F(DB)	F(NP)	h_o (cm)
Mean	**0.35**	**0.99**	**131.4**	**0.36**	**0.95**	**87.4**	**0.70**	**0.97**	**56.1**
Min	0.05	0.98	62.2	0.23	0.89	64.6	0.49	0.95	37.2
Max	0.64	0.99	250.2	0.45	0.99	104.5	0.85	0.99	85.3





Recharge Characteristics

Groundwater Recharge Characteristics

- Head difference (*dH*)
  - Wetland water elevations, *W(h)*
  - Upland groundwater elevations, *U(h)*

$$\left(dH\right)_t = W(h)_t - U(h)_t$$

- Matched water elevation records
  - Based on collection date, *t*
  - Entire data record (7 years)
  - Seasonal records
    - Peak wet season (March – May)
    - Peak dry season (July – September)
    - Extreme water-table elevations

Results – Groundwater Recharge Characteristics

- Temporal Data

Statistic Data Count	Separation Distance (m)	Head Difference (cm) All 5178	 Dry season 1237	 Wet season 1255
Mean	**56**	**9.2**	**12.8**	**0.3**
StD	25	37.1	39.3	34.7
Median	57	3.7	5.5	-1.5
Min	8	-177.7	-139.6	-177.7
Max	149	227.7	215.2	189.6
Range	142	405.4	354.8	367.3

- Frequency Analysis
  - Recharge Conditions, F(dH = 0)

	Mean	Median
All Records	59%	62%
Dry Season	61%	66%
Wet Season	47%	47%

Summary and Conclusions

Conclusions – New Wetland and Lake Storage Model

- Describe above bed storage characteristics of wetlands
- Analytical method
  - 2 physical parameters (A_o and h_o)
  - A single wetland shape parameter
  - Describe the storage characteristics of wetlands and lakes
  - Acceptable and quantifiable errors
- Storage model has good predictive capability
  - Wetland categories
  - Various groups of wetlands
- Shape parameters
  - Used as a calibration factor in hydrologic models
- Reduced cost in surveying wetlands by obtaining
  - A_o from GIS databases
  - h_o from minimal wetland surveys

Conclusions – New Insight into Wetland Water Level Behavior

- Probabilistic Analysis (Frequency Analysis)
- Characterize wetland water-level fluctuations
  - Provide insights into interactions between wetland
    - Surface water levels
    - Groundwater levels
- Identify the specific water level indices and general behavior
  - West-central Florida wetlands
  - Wetland types
  - Regional groups
  - 61% - Standing water present in wetlands
  - 4% - Normal pool markers exceeded

Conclusions – New Insight into Wetland Water Level Behavior

- Probabilistic Analysis (Frequency Analysis)
- Recharge features
  - 59% - Overall
  - 61% - Dry season
  - 47% - Wet season
- Check the calibration of hydrologic models
- Empirical distribution functions were used to
  - Identify potentially impacted wetlands
    - High water levels
    - Low water levels

References

- Lee, T. M., Haag, K. H., Metz, P. A., and Sacks, L. A. (2009). "Comparative Hydrology, Water Quality, and Ecology of Selected Natural and Augmented Freshwater Wetlands in West-Central Florida." U.S. Geological Survey Professional Paper 1758, 152.

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Questions