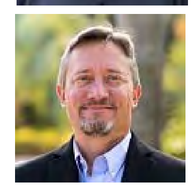
Future Conditions
100-Year Flood Elevation Map
Broward County, Florida

FSA Annual Conference
July 16, 2020

Mark Ellard, PE, CFM, DWRE, ENV SP, Senior Principal
Geosyntec Consultants

John Loper, PE, Associate Vice President
Taylor Engineering

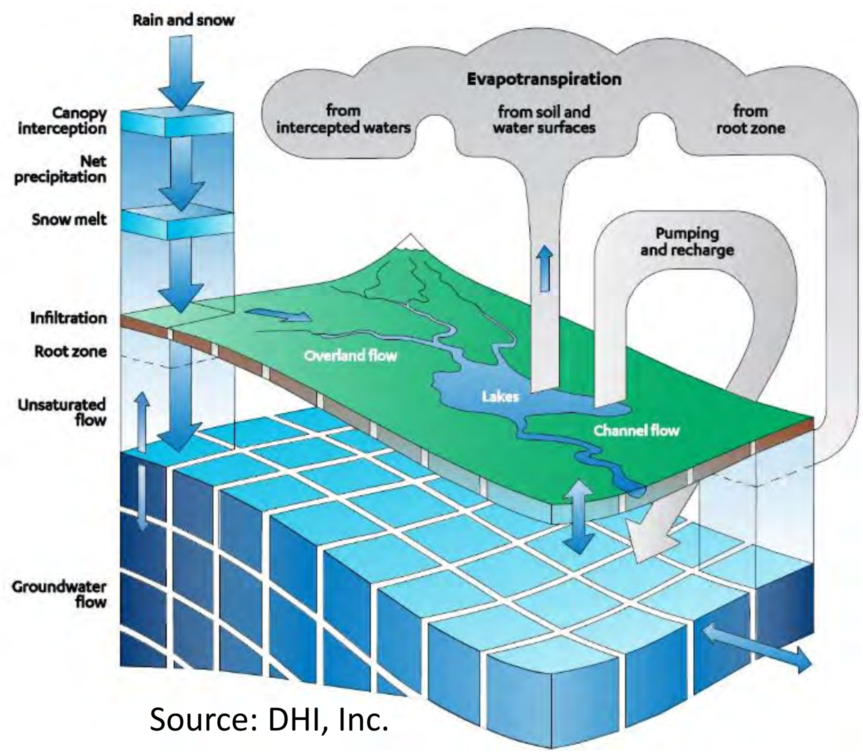


Project Team

- **Broward County** Leadership: Dr. Jennifer Jurado, PhD
- **Geosyntec**: Prime Consultant – Mark Ellard PM
  - Data Collection and Compilation
  - Stakeholder Outreach
  - Rainfall Analysis (current and future conditions)
  - Model QA/QC
  - Model Tool Development
  - CRS Evaluation and Recommendations
- **Taylor Engineering**: Hydrologic & Hydraulic Modeling - John Loper lead
  - Update Current Conditions Model
  - Future Conditions Model Development
  - Integration with Coastal Analysis
- **CLIMsystems** and **Jupiter Intelligence**: Future Rainfall Development
- **Stoner & Associates**: Surveying
- **Adept Strategy and Public Relations**
- Special Acknowledgement to Dr. Carolina Maran and Michael Zygnerski

Project Goals

- Mapping Future Flood Risk:
  - Increased rainfall due to warming climate
  - Year 2060-2069 sea level rise
  - Increased runoff due to higher water tables
  - Land use changes
  - Accomplished through integrated GW/SW modeling
- Will enhance infrastructure resilience:
  - Design standards
  - Finished floor elevations, streets, sanitary manholes, critical infrastructure, etc.
  - Support Infrastructure Vulnerability Assessment



Source: DHI, Inc.

Major Tasks

- Initial Stakeholder Outreach and Coordination
- Data Collection and Review
- Update Current Conditions Model – Existing MIKE SHE / MIKE 11 Model
  - Incorporate Stakeholder Data and Refine Model Computational Grid
  - Update Land Use and Parameters and Incorporate New Survey Data
  - Model Calibration/Validation and Current Conditions Design Storm Simulations
- Future Conditions Model Development & Execution
  - Evaluate Candidate Downscaled Climate Datasets
  - Develop Super-ensemble Rainfall Depth Projection
  - Run Future Conditions Model Simulations Design Storm Simulations
- Stakeholder Coordination
- Future 100-year Flood Map Development and Adoption

Stakeholder Coordination and Data Development

Stakeholder Data Coordination for Model

Initial Stakeholder Meetings

North Meeting

Central Meeting

South Meeting

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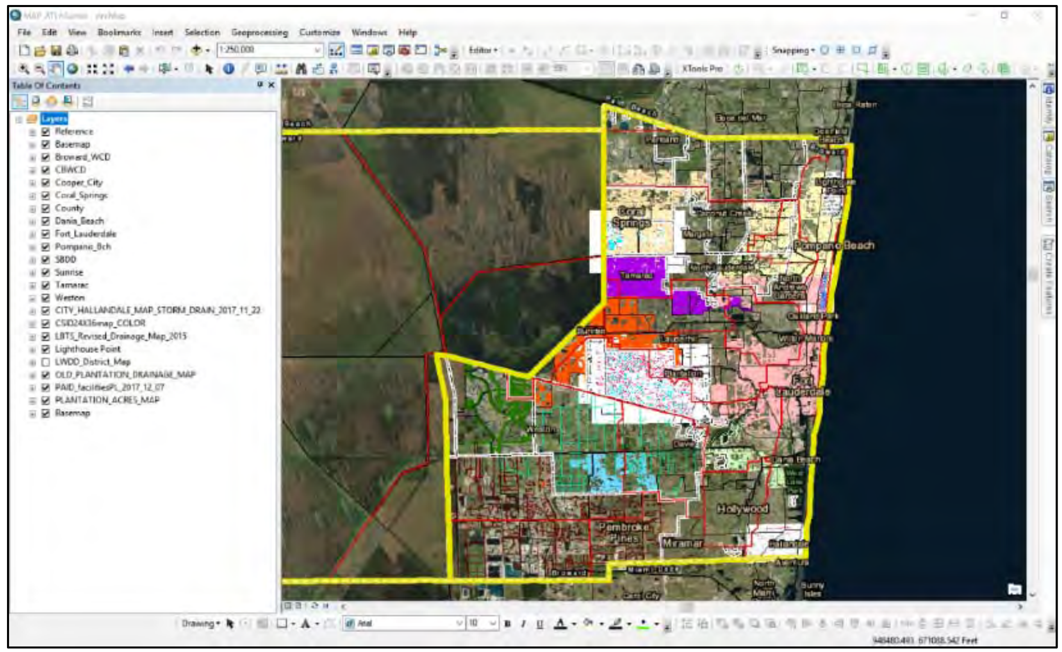
ADEPT Strategy & Public Relations

Stakeholder Data Coordination for Model

Stakeholder Data Contributors
Broward County Water Control District
Central Broward Water Control District
Coral Springs
Cooper City
Coral Springs Improvement District
Dania Beach
Fort Lauderdale
Hallandale Beach
Hollywood
Lauderdale-by-the-Sea
Lauderhill
Lighthouse Point
North Springs Water Improvement District
Oakland Park
Old Plantation Water Control District
Parkland
Pine Tree Water Control District
Plantation
Plantation Acres Improvement District
Pompano Beach
South Broward Drainage District
South Florida Water Management District
Sunrise
Tamarac
Weston

- Compiled Stakeholder GIS and Mapping data into a Project Map Atlas
- Provides reference for current and future conditions modeling
- Assists future Level-of-Service Efforts by SFWMD and County stakeholders



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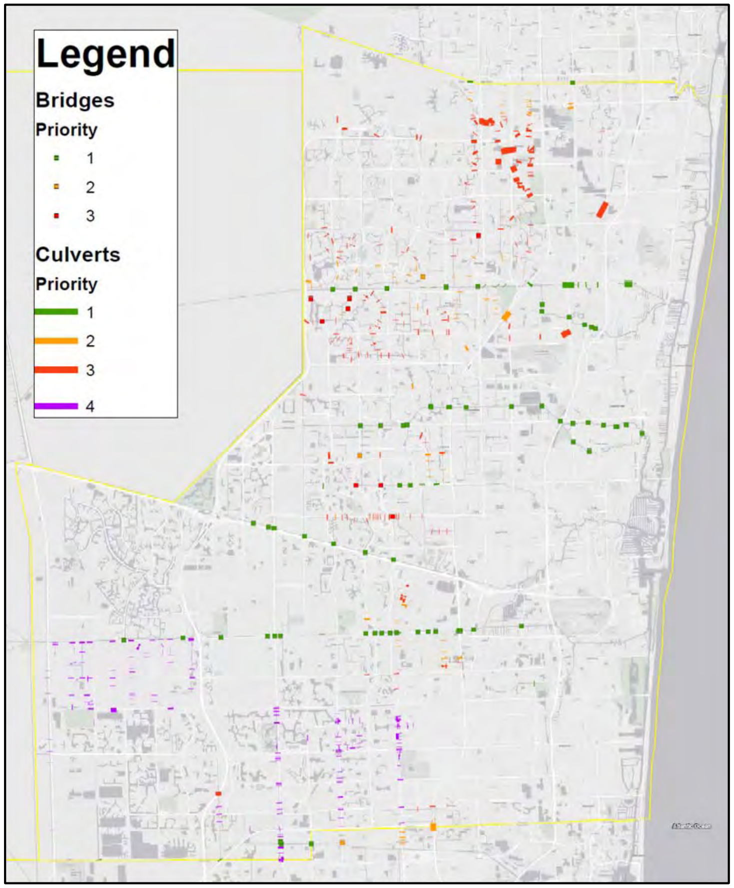
Future Conditions 100-Year Flood Elevation Map

Survey Scope

- Survey Needs
  - Confirm current structure data in existing model
  - Obtain new structure data for model
- Prioritized Features spread throughout County
  - Bridges
  - Culverts
  - Channel cross-sections
- Focus on areas with little or no available data
- Other Cross-section data obtained from available sources



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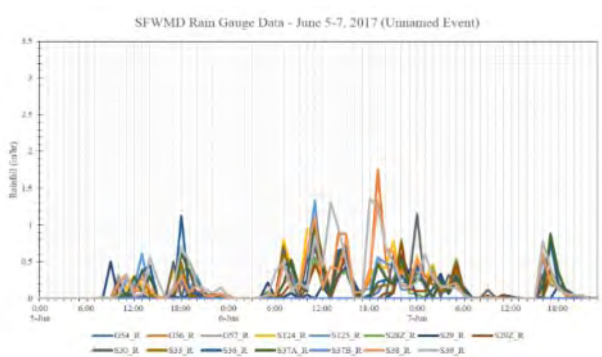
STONER & ASSOCIATES, Inc. SURVEYORS - MAPPERS

Rainfall Analysis for Calibration Event

- Reviewed gauge data from across urban area of County for stations with robust data sets
- Identified best candidate storms for model calibration
- Narrowed candidates to:
  - June 2017 (unnamed)
  - September 2017 (Irma)
- Selected June 2017 based on depth, antecedent conditions, and system response



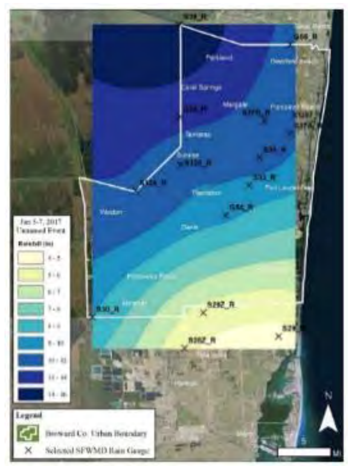


Figure 1: SFWMD Rain Gauge Stations Around Urban Broward County, FL.

Current Conditions Modeling Updates and Results

Model Updates

Compiled recent LiDAR from available sources, refined model topography

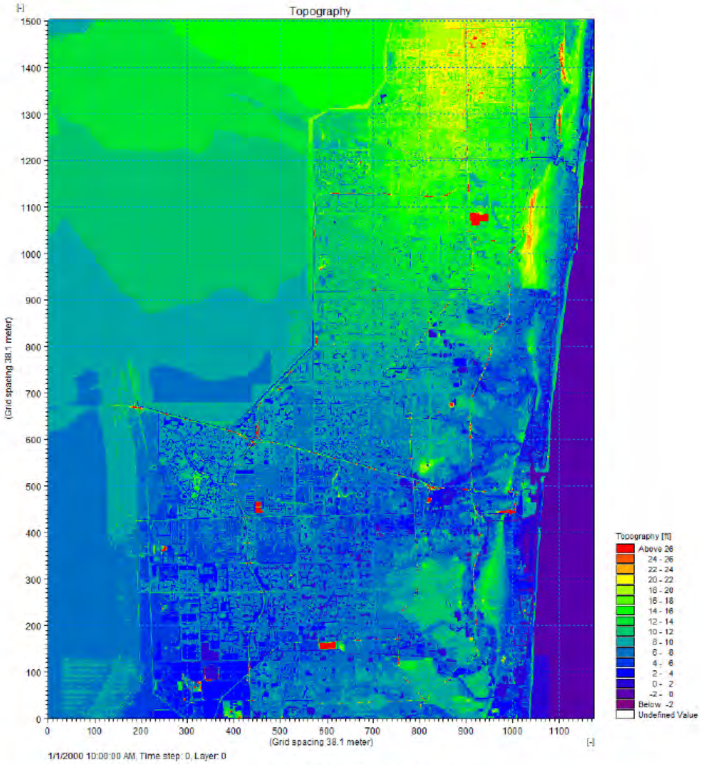


Figure 2: 125-ft Model Topography, NGVD29

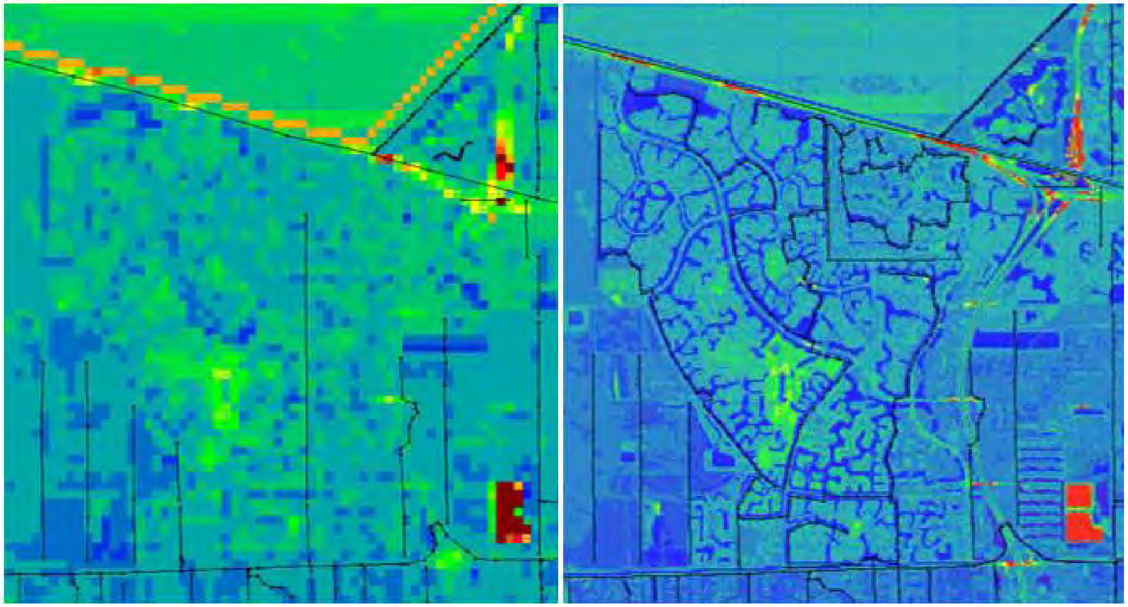


Figure 3: Before (left) and After (right) Topography in the Indian Trace/Weston Area.

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Future Conditions 100-Year Flood Elevation Map

Model Updates

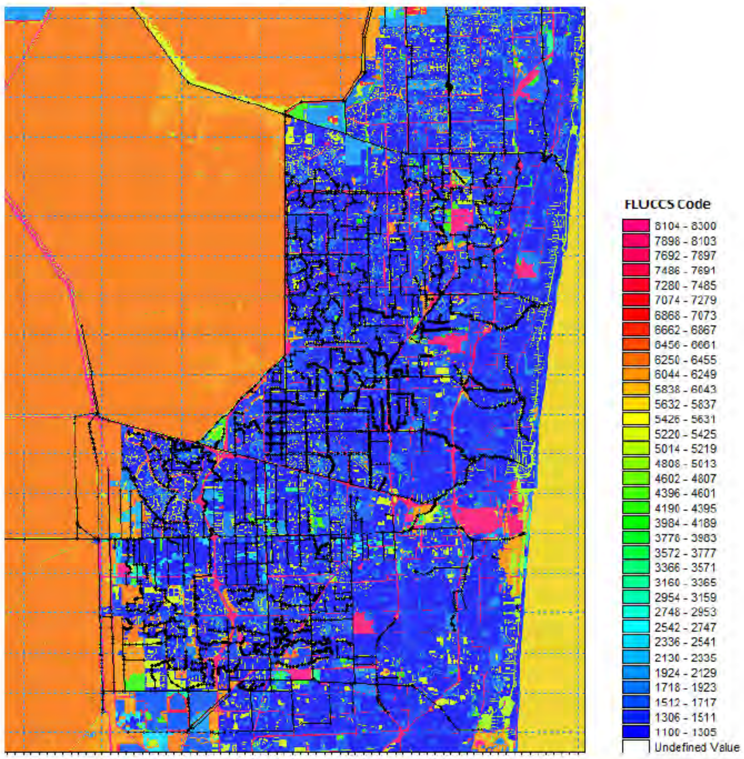

Figure 5: Map of Land Use

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Updated Land use

Refined model network

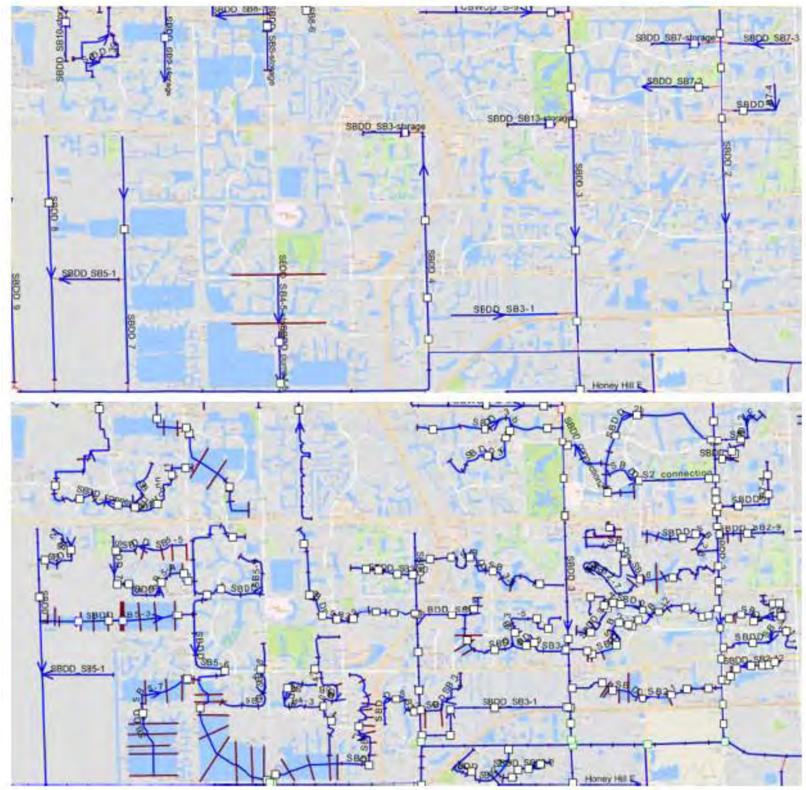
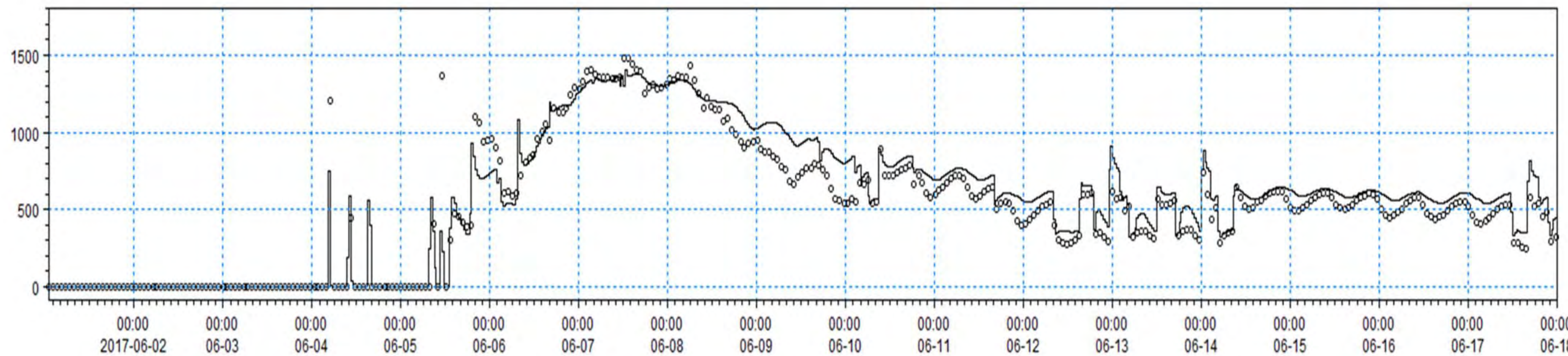
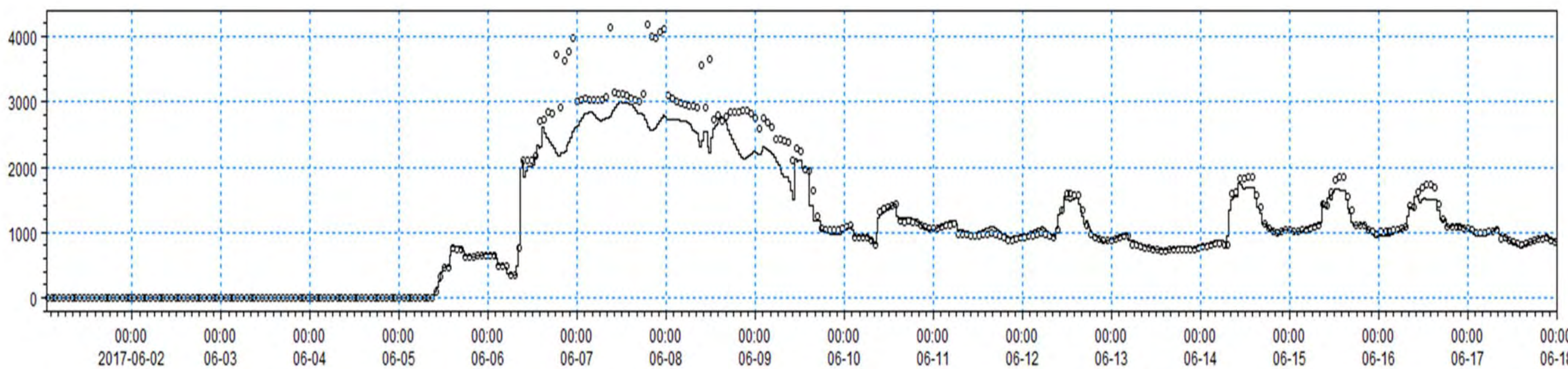


Figure 6: Before (top) and After (bottom) River Network

Future Conditions 100-Year Flood Elevation Map

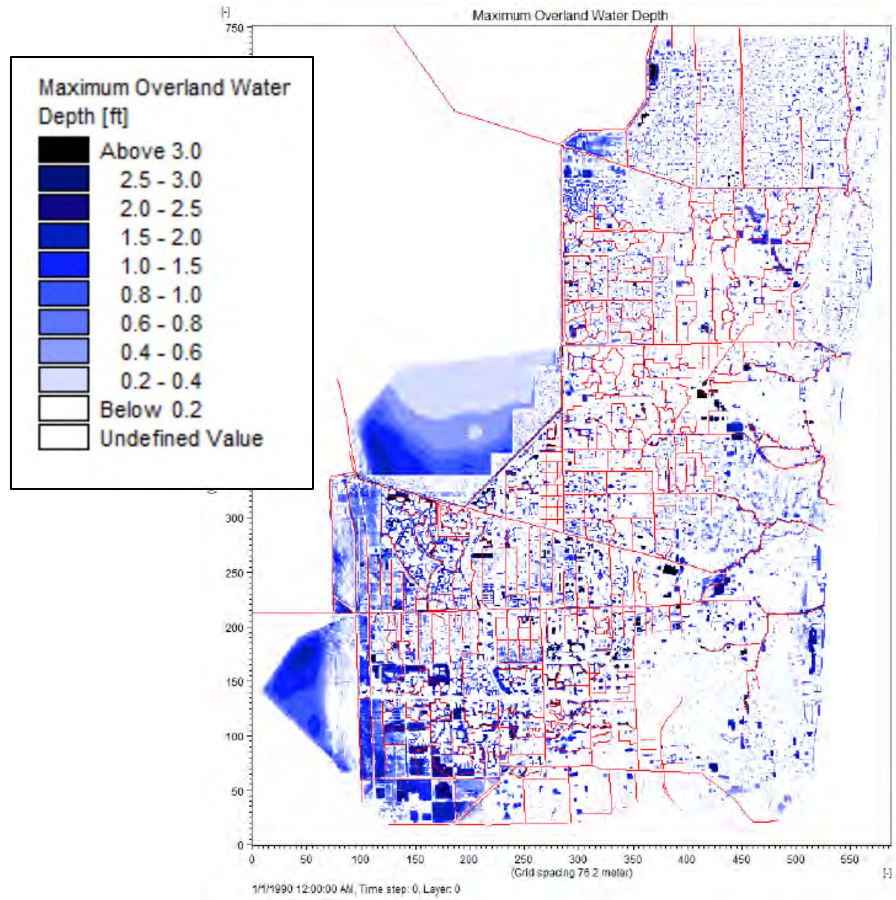
Calibration - G-54 and S-37A Discharge





Validation Storm Results

Maximum modeled overland flood depths - Validation storm



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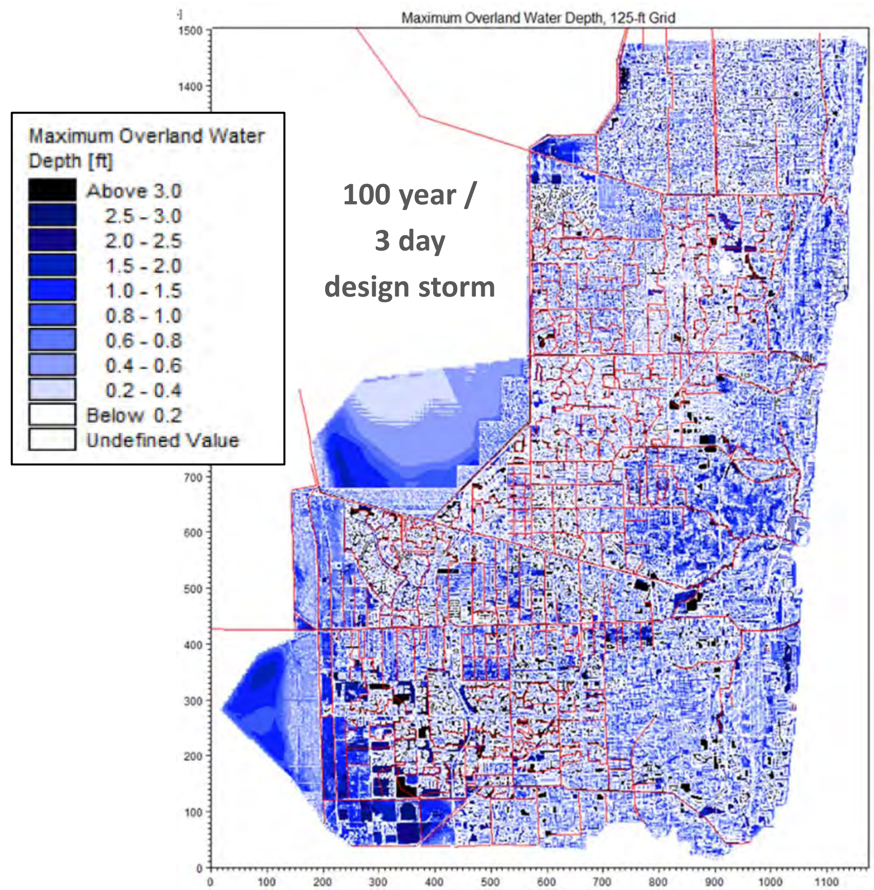
Design Storm Results

- 10, 25, 50, 100, and 500-year, 3-day rainfall events
- NOAA Atlas 14 for rainfall depths w/ SFWMD 3-day distribution
- Implemented rules-based operations for control structures and pumps
- Current conditions average wet season groundwater levels
- No storm surge



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Design Storm Results

- Example 100 Year / 3 Day Results Flood Profile - C-14

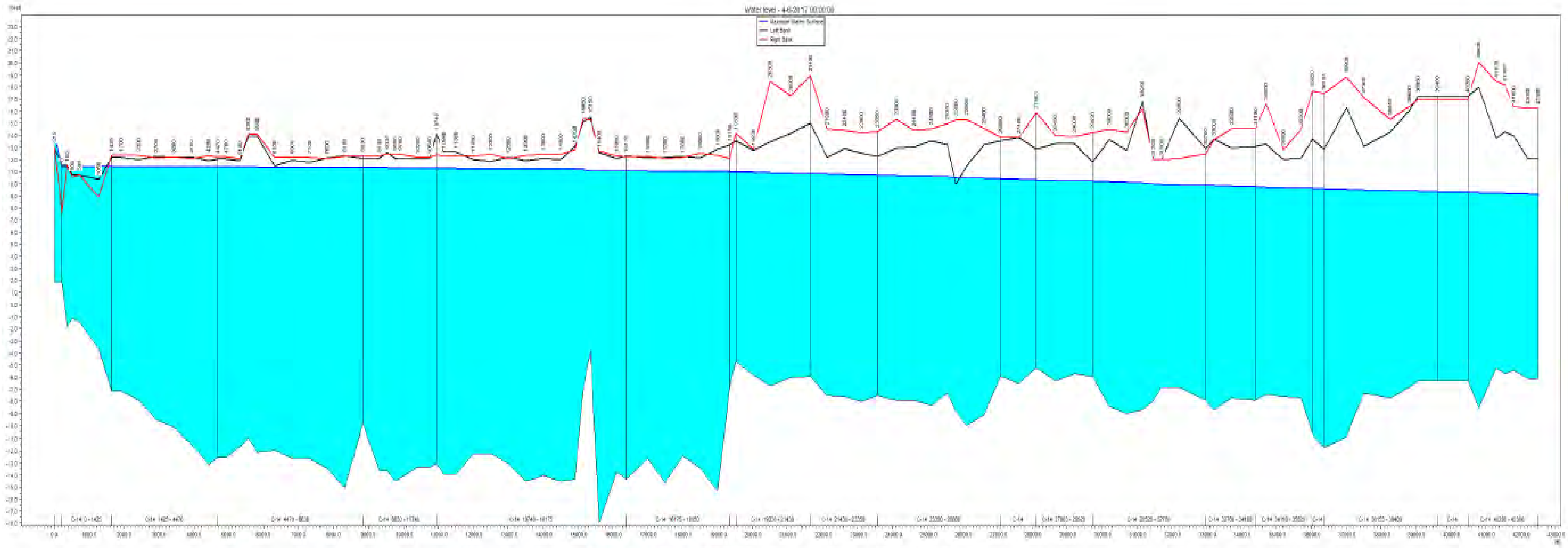
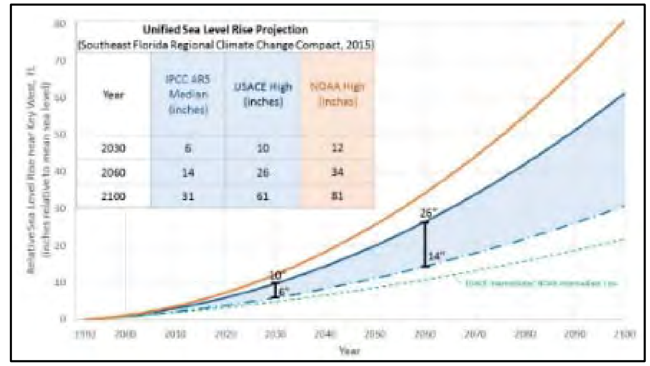


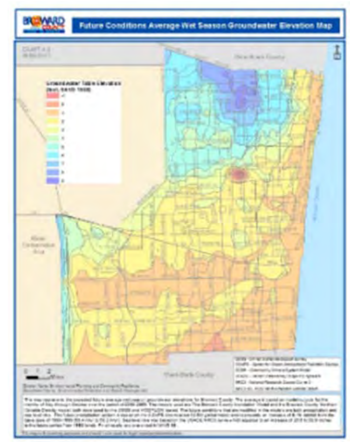
Figure 100: SFWMD C-14 Canal Maximum Water Surface Profile

Future Rainfall Projections

Future Conditions Model Updates

- 2ft Sea Level Rise (SE Climate Compact)
- Future Groundwater Conditions (Adopted Broward County GW Elev. Map)
- Future Land Use
- Future Major Infrastructure Projects
- Future Control Structure Operations
- ***Future Rainfall DDF/IDF***





Future Conditions 100-Year Flood Elevation Map

Team Partners

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JUPITER

BROWARD COUNTY FLORIDA

Future Rainfall Analysis

Obtain Rainfall Observations Dataset	Obtain Global Climate Models / Downscaled Datasets	Fitting Probab. Distribution Curve to both Observations and Downscaled Data	Compare Extreme Observations vs. Downscaled Data (historical period)	Calculate Change Factors (ratio future to historic)	Estimate and Distribute Future Rainfall Projections

Available Data / Approaches:

Obtain Rainfall Observations Dataset

- NOAA Atlas 14
- CPC Merged Analysis over CONUS
- SFWMD GARR (Baxter)
- NEXRAD
- SFWMD Regular Gauges

Obtain Global Climate Models / Downscaled Datasets

- BCCA – Statically (Reclamation)
- LOCA (UCSD) – Stat.
- CORDEX (WCRP) – Dynamically
- COAPS (FCI / FSU) – Dynamically
- VR-CESM (Hyperion) – Dynamically
- BCSA (UF)
- WRF – Jupiter
- Raw GCMs - SimClim

Fitting Probab. Distribution Curve to both Observations and Downscaled Data

- Annual Maxima
- Partial Duration Series
- GEV and other distribution types (Pearson III, Pareto, …)
- Shape/Location/Scale Parameters: L-Mom x MLE
- Regional Frequency vs. At site Frequency distributions

Compare Extreme Observations vs. Downscaled Data (historical period)

- Correlation metrics (RMSE, IVSS, Taylor Diagram)
- Bias calculations

Calculate Change Factors (ratio future to historic)

- Quantile Mapping x Quantile Delta Mapping
- Multiplicative x Additive Quantile Delta Mapping
- Best Model Results x ensemble approach
- Super ensemble vs. subset of best performing models
- Fit IDF Curves to selected durations and frequencies

Estimate and Distribute Future Rainfall Projections

- Add calculated deltas individually to each station x regional average
- Deterministic vs. perform stochastic simulation on ranges of calculated deltas
- Hourly distribution approaches (Santa Barbara, SFWMD, NOAA Atlas 14)

General Goals / Considerations:

Obtain Rainfall Observations Dataset

- Represent extreme rainfall precipitation
- Sub daily datasets preferable
- Appropriate Broward coverage
- Length of time series (min 25-30 years)

Obtain Global Climate Models / Downscaled Datasets

- Daily Rainfall Data (sub daily?)
- IPCC AR5 (CIMP 5)
- Regional Models
- RCP 8.5 and others?
- 2060 Horizon projection
- Min. 20 years of historical simulation
- Spatial Resolution (less than 30km)

Fitting Probab. Distribution Curve to both Observations and Downscaled Data

- Durations and Intensities of Interest (independently versus joint)
- Rolling window for annual maxima
- NOAA scaling factors (constrained x non-constrained)
- Bias Correction Steps applied previously?

Compare Extreme Observations vs. Downscaled Data (historical period)

- Evaluation parameters (RMSE, S, C…) – quality metrics
- Visualization of data – heat maps

Calculate Change Factors (ratio future to historic)

- Stationarity x non-stationarity bias calculation
- Average biases? Models? Spatially?
- Select best performing methods or combine them all together?

Estimate and Distribute Future Rainfall Projections

- Representing Uncertainties (stochastic approach)
- Spatial differences among changing factors

Large associated uncertainties

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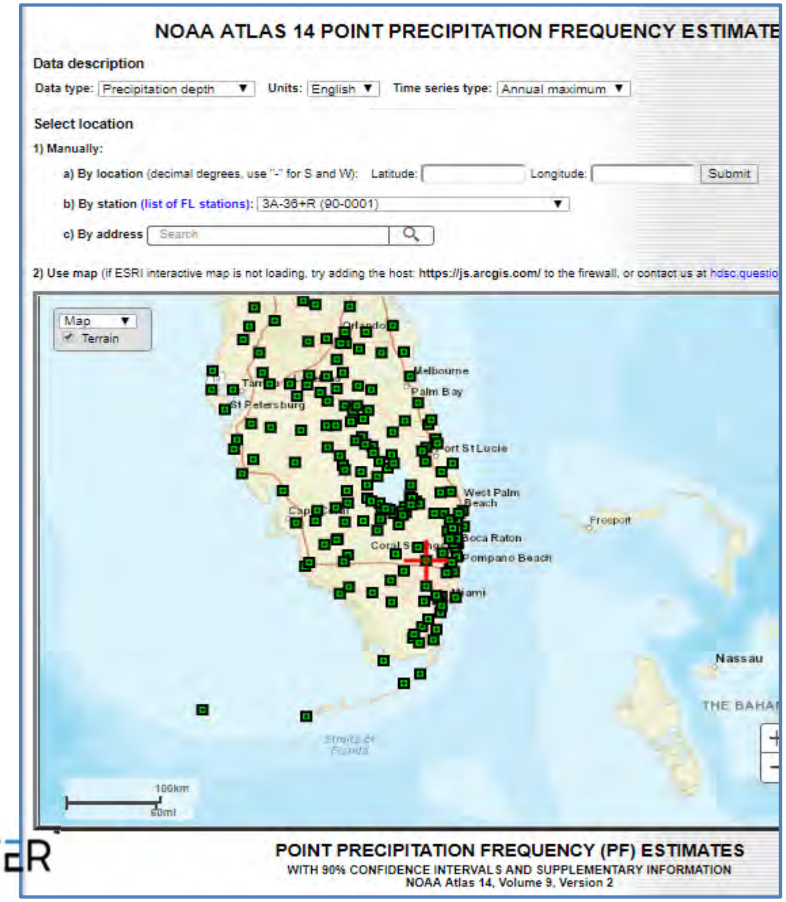
Future Rainfall Analysis Datasets

- Evaluated Datasets
  - CLIMsystems
    - BCCA
    - Hyperion
    - FSU COAPS
    - CORDEX
    - Raw GCMs
  - Jupiter Intelligence
    - LOCA
    - Jupiter WRF
- Leverage Atlas 14 Rainfall Stations
- Target Future Year 2060

All best currently available global model data



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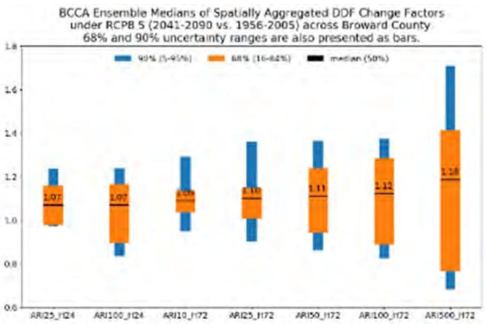
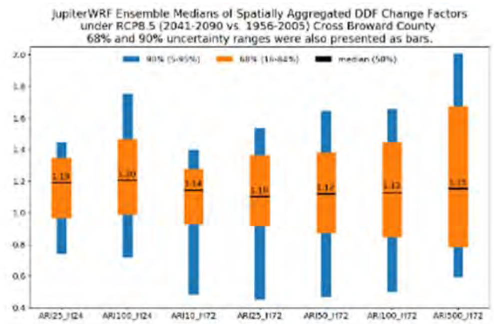
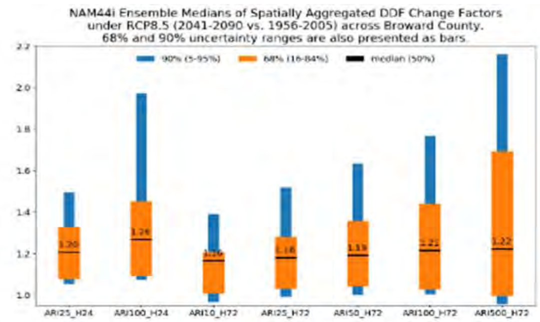
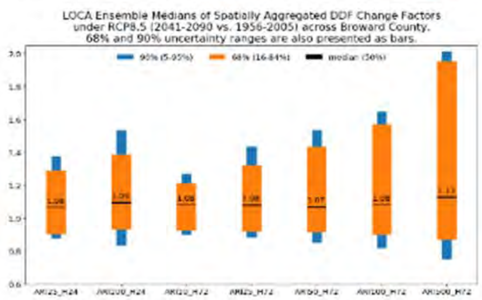
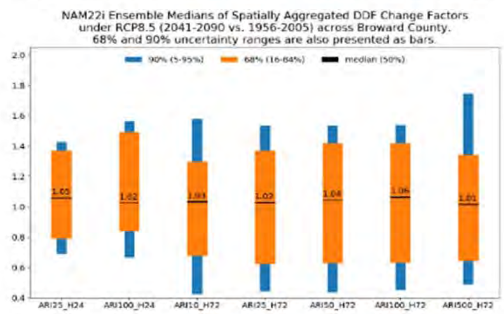
Rainfall Depth Change Factors

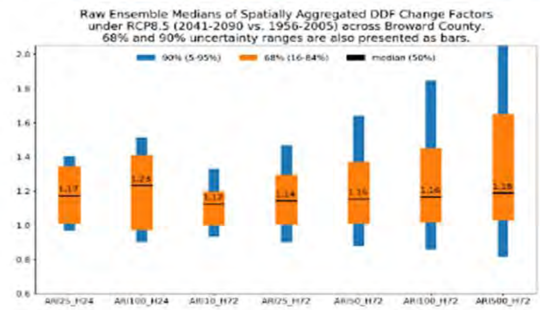












Despite large biases calculated between climate model data and observations…
All results and associated uncertainty ranges show increasing rainfall

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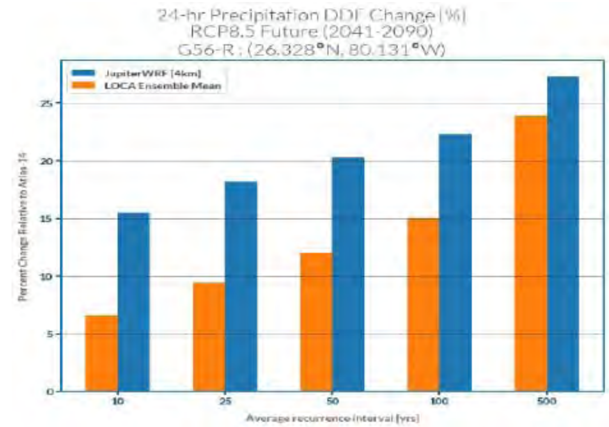
Future Rainfall – Experts Panel

- Workshop on September 17
  - Representatives from:
    - Broward County
    - SFMD
    - FIU
    - USGS
    - Consultant Team
    - Other interested parties
  - Consensus on strategy for moving forward:

Super-Ensemble approach



Future Conditions 100-Year Flood Elevation Map

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Combining Results for Broward

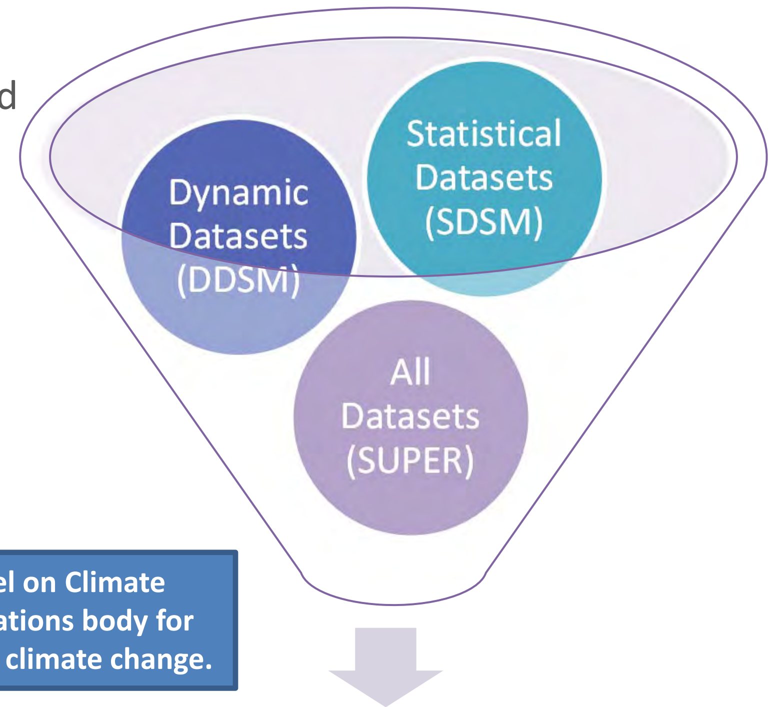
- Best available approach
- No significant difference for the calculated Change Factor among stations; small spatial variability:

ADOPT ONE FACTOR (%) FOR THE ENTIRE URBAN AREA

Super Ensemble Consensus

- Super-ensemble Approach:
  - Different subsets of all the individual model projections from the different datasets are chosen and fittings are calculated from each of these subsets (prob. analysis)
  - This approach more explicitly calculates the uncertainty in the median change factors, and reduce the generalization error of the predictions.
  - This approach converges on providing a single model domain-wide scaling value to use for storm events
- *Approach Aligned with IPCC Recommendations*

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.



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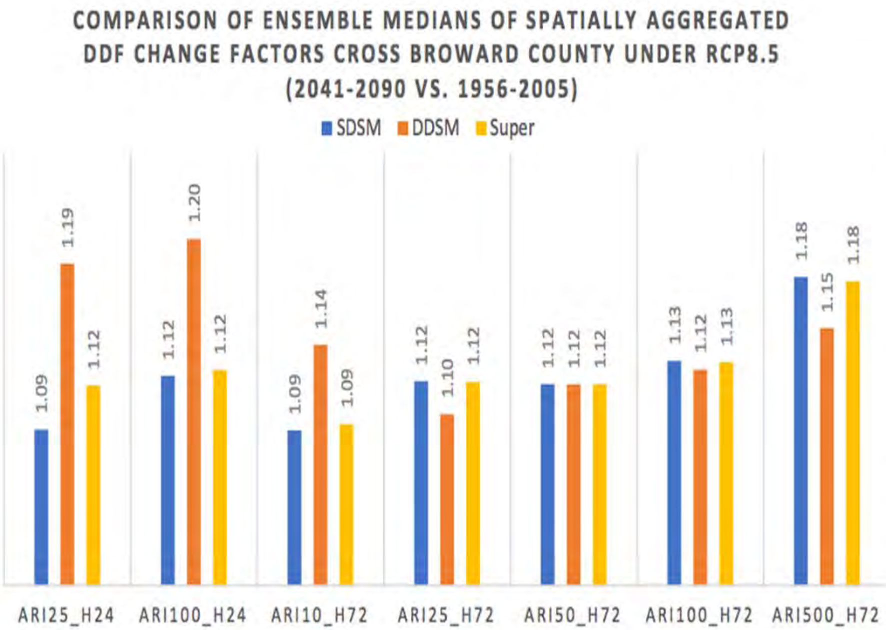
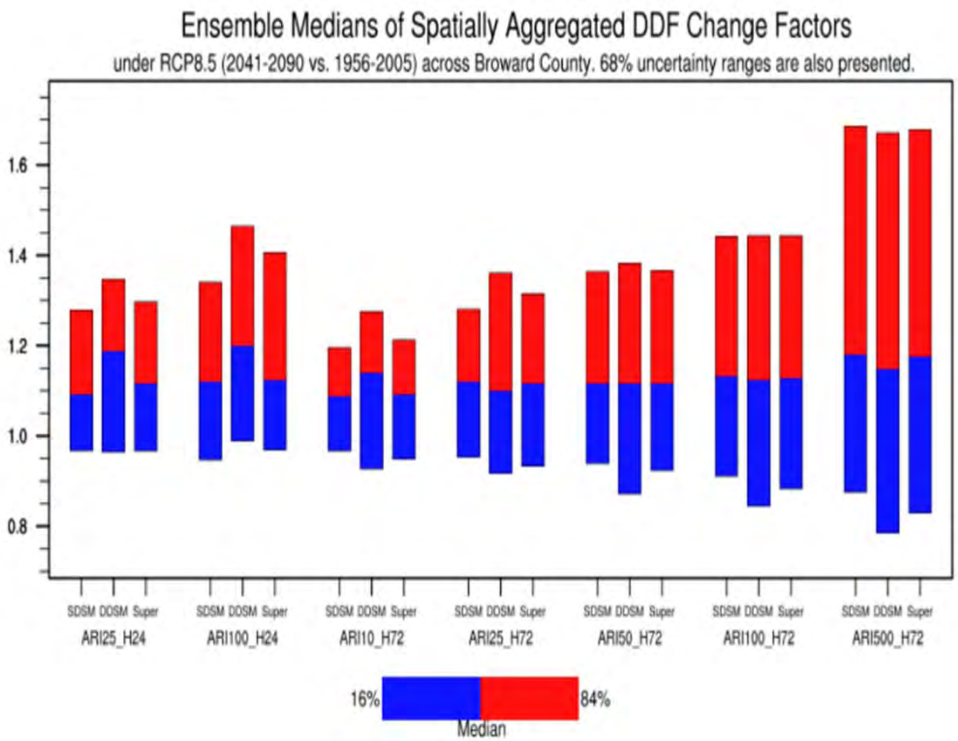
Ensemble Results for Different Return Periods



Note: (1) SDSM=Raw + BCCA + LOCA, DDSM=NAM22i + NAM44i + JupiterWRF, Super=SDSM + DDSM; (2) JupiterWRF only contributed to H24 in DDSM and Super.



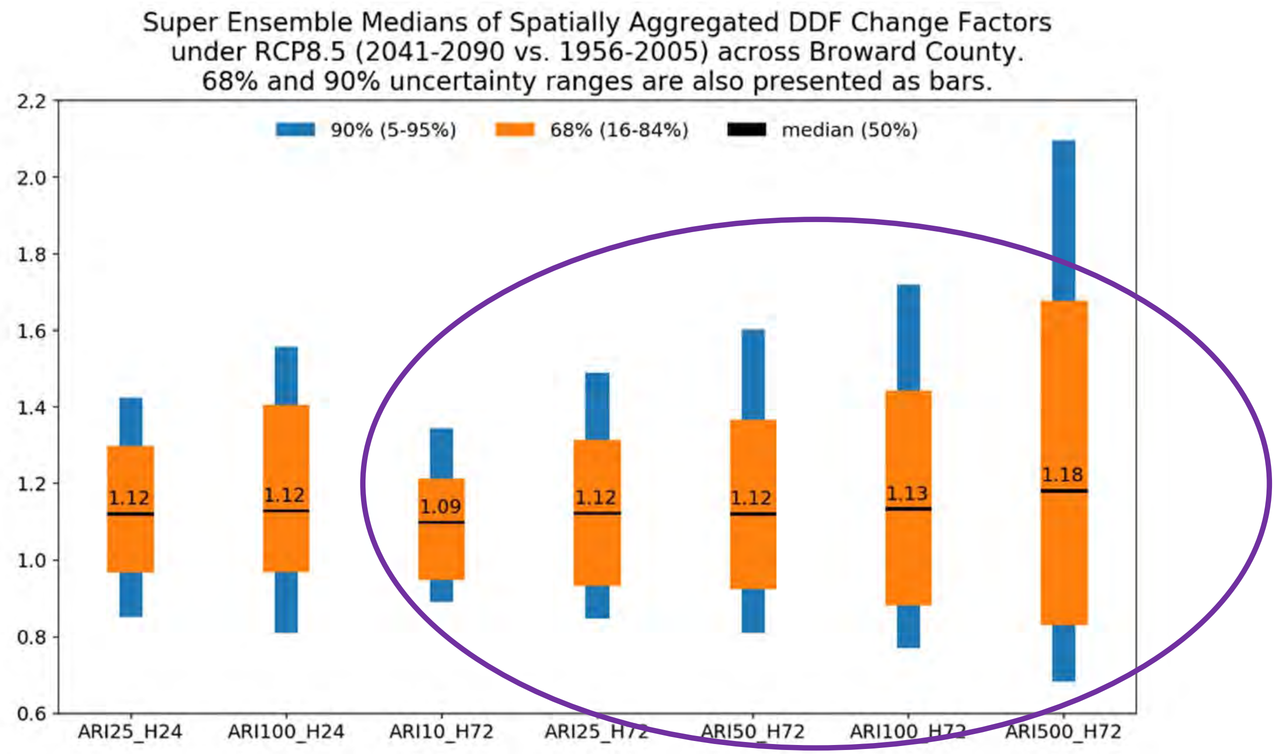
Future Conditions 100-Year Flood Elevation Map

Ensemble Results for Design Storms (Longer Durations - 3 days)

Single model domain-wide scaling values for design storm events

- 10 year/3 day = 9% increase
- 25 year/3 day = 12% increase
- 50 year/3 day = 12% increase
- **100 year/3 day = 13% increase**
- 500 year/3 day = 18% increase

All Datasets (SUPER)



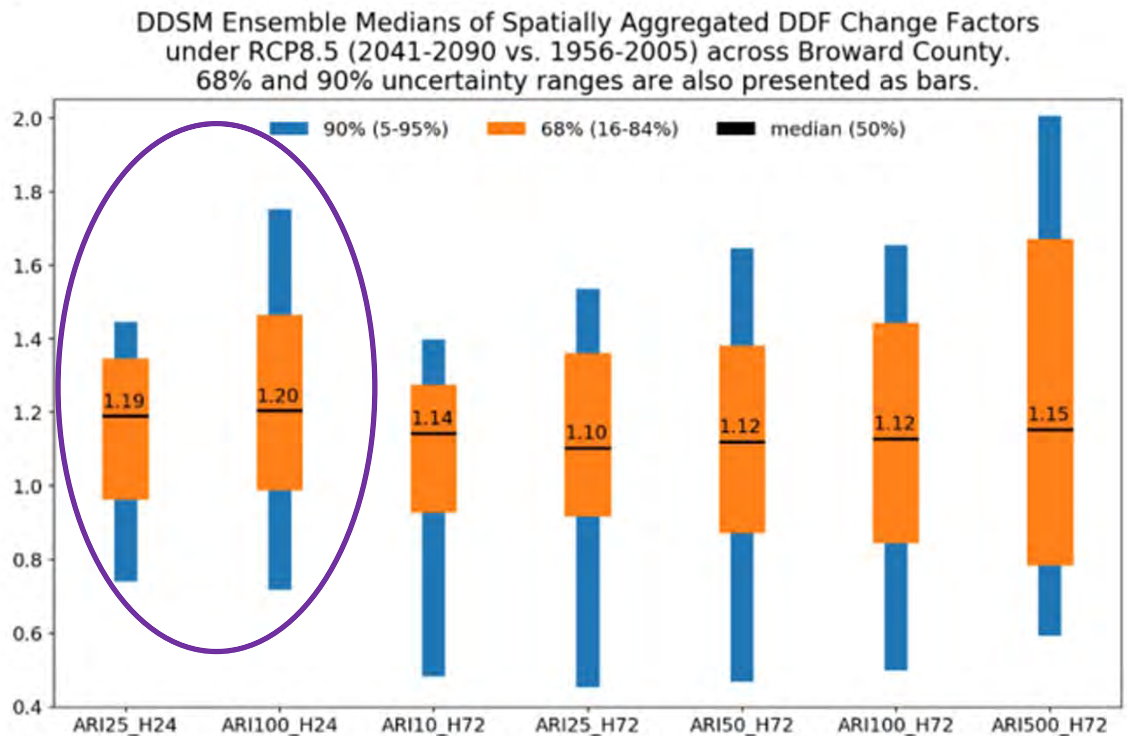
Whisker diagram of SUPER ensemble medians of spatially aggregated DDF change factors with uncertainty ranges.

Ensemble Results for Design Storms (Shorter Durations – 24 hours)

Single model domain-wide scaling values for design storm events

- 25 year/1 day = 19% increase
- 100 year/1 day = 20% increase

Dynamic Datasets (DDSM)



Whisker diagram of DDSM ensemble medians of spatially aggregated DDF change factors with uncertainty ranges.

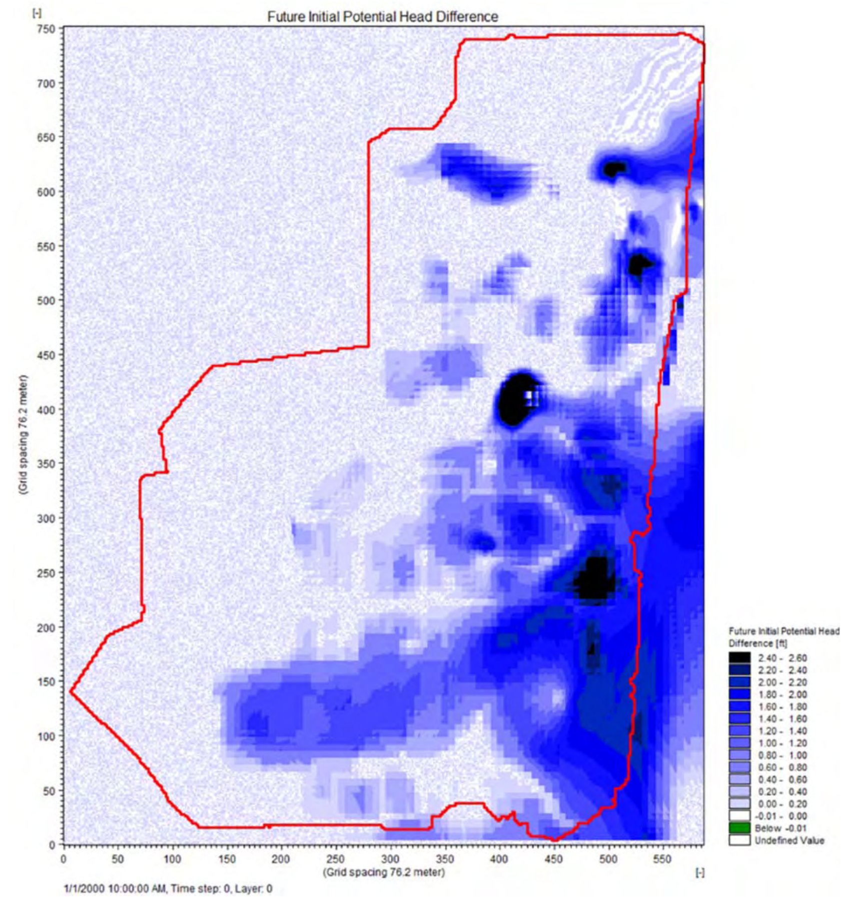
Future Conditions Modeling

Future Land Use

- Undeveloped and agricultural parcels were assumed to be developed by 2060.
- Exceptions:
  - Wetlands
  - Parks/preserves
- Several golf courses assumed redeveloped to residential, per input from County Planning Dept.

Future Groundwater

- Started with USGS MODFLOW Inundation Model results
- Subtracted Current Conditions map from Future Conditions to create difference map
- Zeroed out negative values and modeling artifacts



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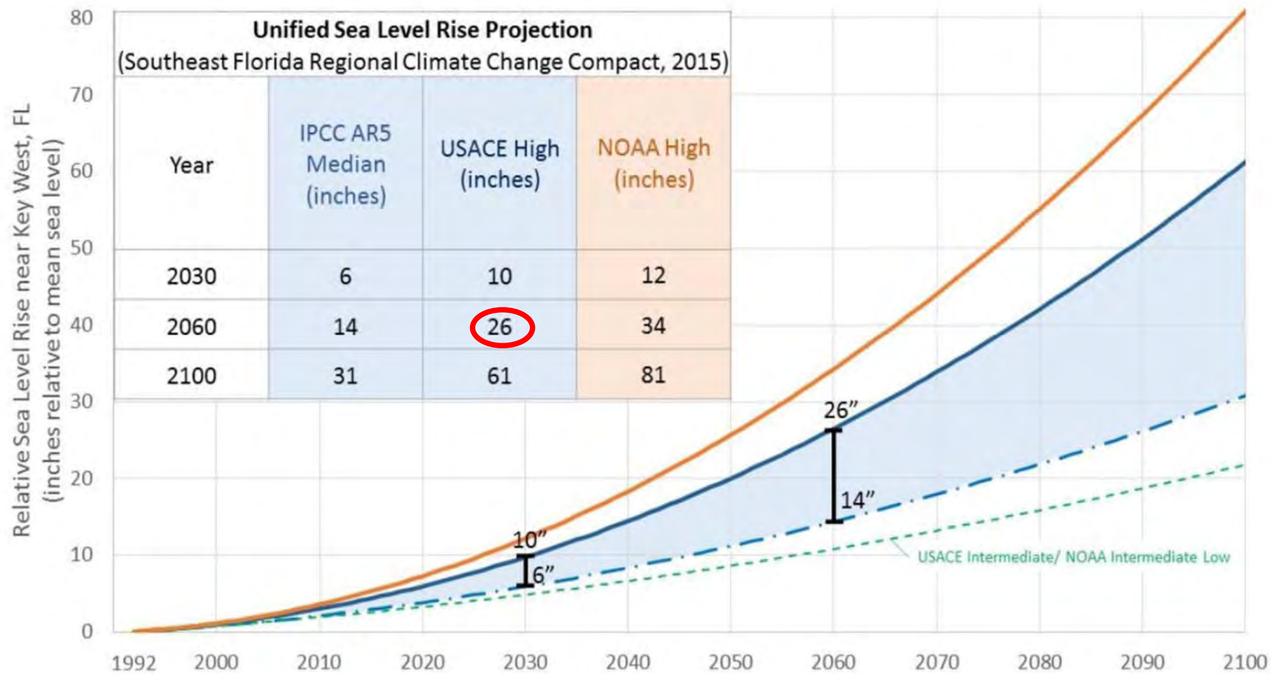
Future Tidal Outfalls and Boundaries

Tidal boundaries increased from current conditions by 26” for:

- 1-D channels
- 2-D Overland
- Groundwater



Unified Sea Level Rise Projection
(Southeast Florida Regional Climate Change Compact, 2015)

Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81

Future Rainfall

Increased Current Conditions 3-Day Depths by these multipliers:

- 10 Yr: 1.09
- 25 Yr: 1.12
- 50 Yr: 1.12
- 100 Yr: 1.13
- 500 Yr: 1.18

NOAA Station	Future 3-Day Storm Rainfall Depth (inches)				
	10-Year	*25-Year*	*50-Year*	*100-Year*	*500-Year*
PENNSUCO 5 WNW	10.53	13.55	15.79	18.42	26.31
MRF114	11.66	15.12	17.70	20.79	29.97
FT LAUDERDALE INTL AP	11.77	15.12	17.70	20.68	29.26
FT LAUDERDALE	11.77	15.23	17.92	21.02	30.21
S-36R	11.77	15.23	17.92	21.02	30.56
G57-R	11.99	15.57	18.37	21.58	31.27
CORAL SPRINGS	10.56	13.55	15.90	18.65	26.90
G56-R	11.66	15.12	17.81	20.91	30.21
MRF102	11.45	14.67	17.25	20.23	29.15
BOCA RATON	11.77	15.12	17.81	21.02	30.33
MRF213	10.54	13.44	15.79	18.42	26.43
MRF212	11.23	14.56	17.02	20.00	28.79
3A-36+R	9.16	11.76	13.78	16.16	23.36
NORTH NEW RVR CANAL 2	8.88	11.19	12.99	15.14	21.36

Future Conditions Results

Future 100-year / 3 day storm flood depth results

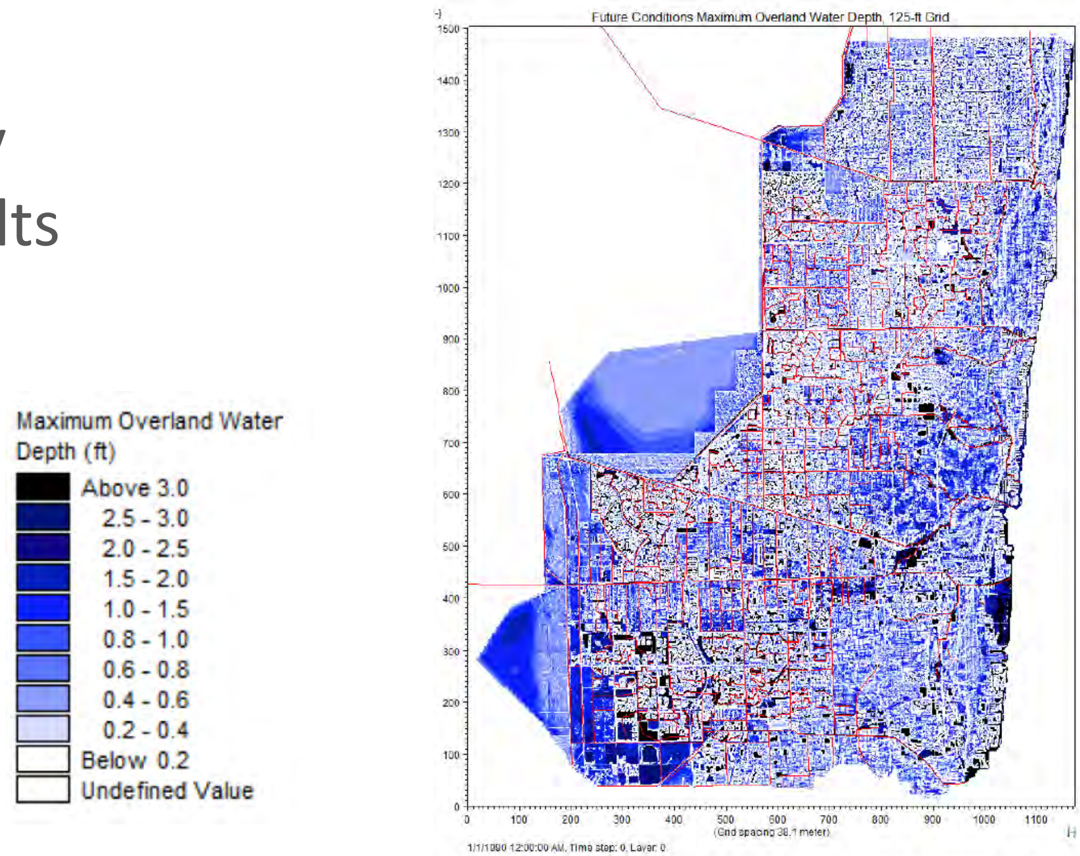


Figure 41: 100-Year Design Storm Maximum Overland Water Depth

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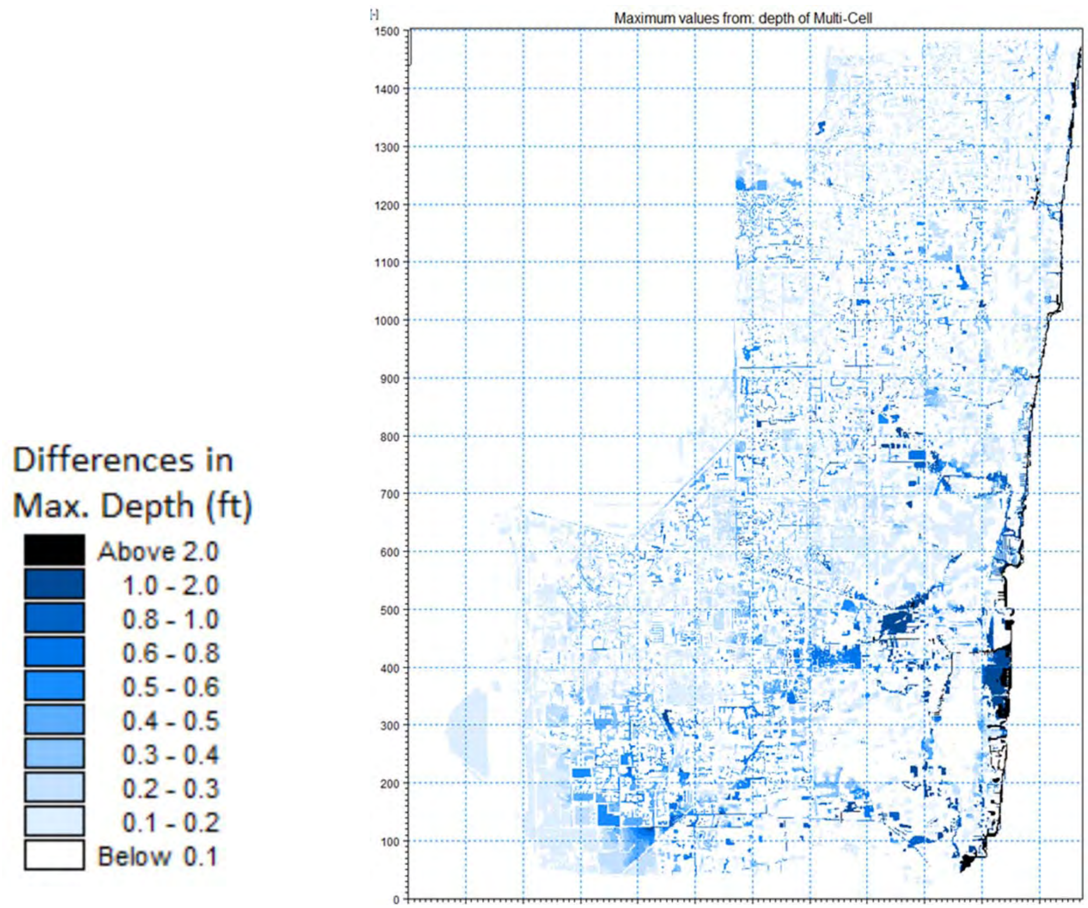
Future Conditions Results

Spatial difference comparison 100-year storm results

Future conditions maximum depths minus current conditions maximum depths



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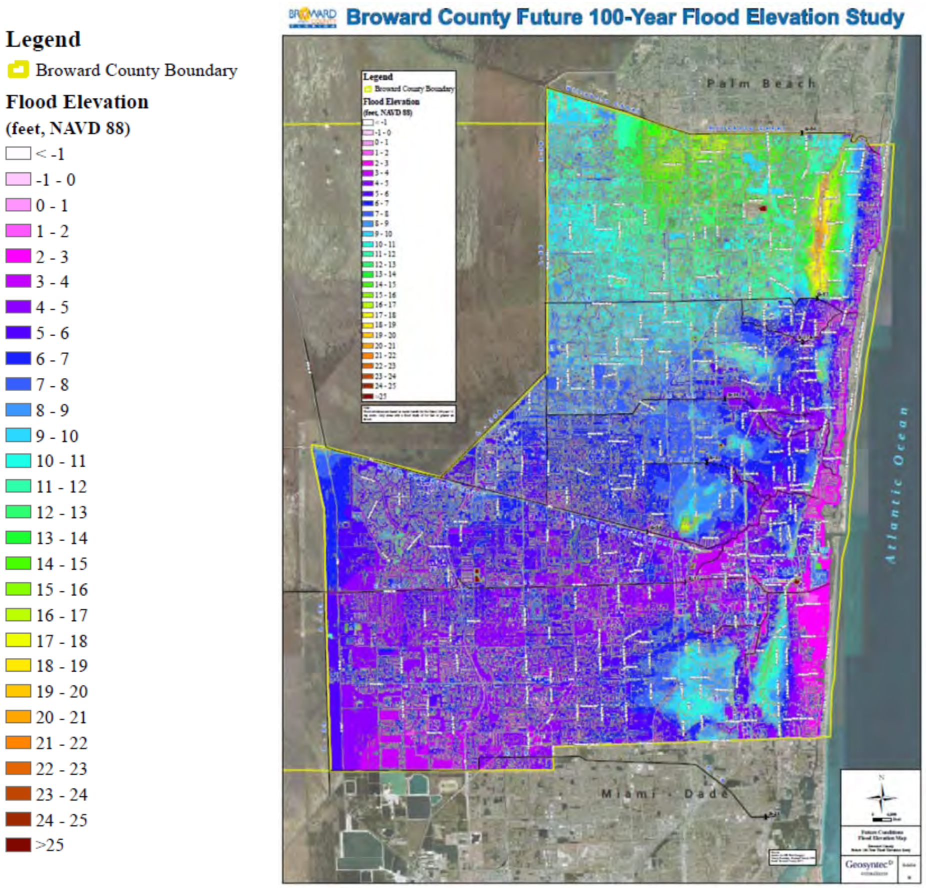
Future Conditions Results

- Preliminary Future 100-year / 3 day storm flood elevations (FT NAVD 1988)



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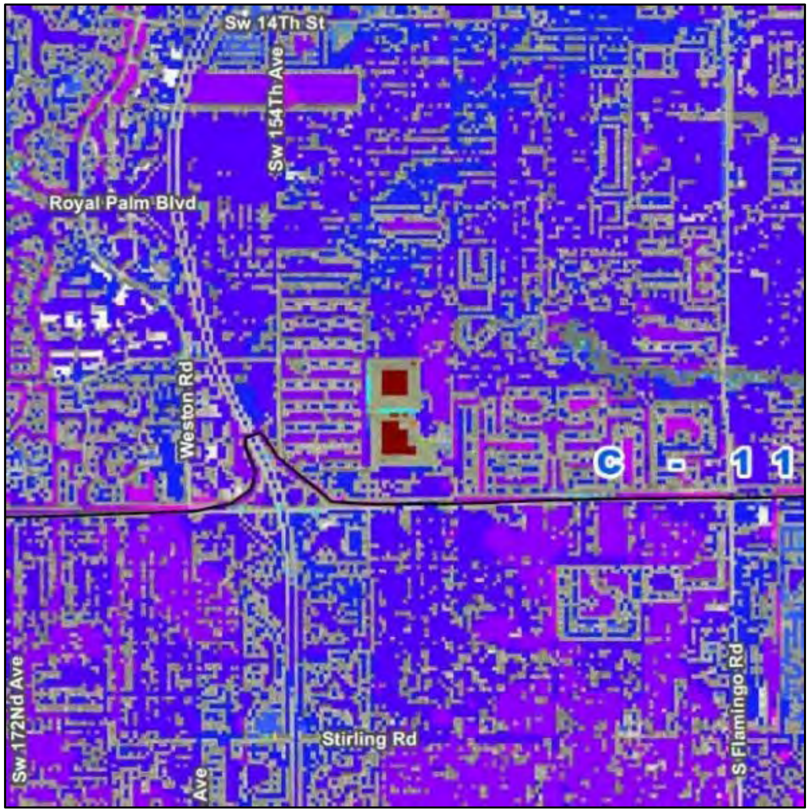
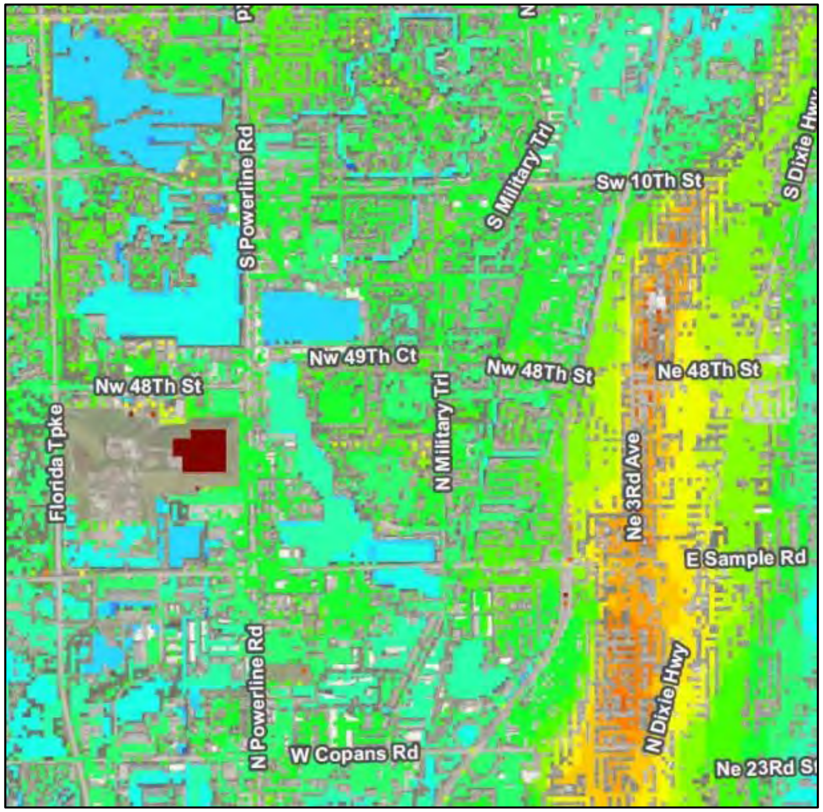
Future Conditions Results - Detail

Flood Elevation (feet, NAVD 88)

- < -1
- -1 - 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 16
- 16 - 17
- 17 - 18
- 18 - 19
- 19 - 20
- 20 - 21
- 21 - 22
- 22 - 23
- 23 - 24
- 24 - 25
- >25





Future Conditions 100-Year Flood Elevation Map

Next Steps

Current Progress and Next Steps

- Finalizing Future Conditions Model Runs
- Final Community Stakeholder Involvement
- Future 100 Year Community Flood Map Adoption

Thank you

Questions?

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