Future 100 Year Flood Map for Coastal Resiliency in Broward County

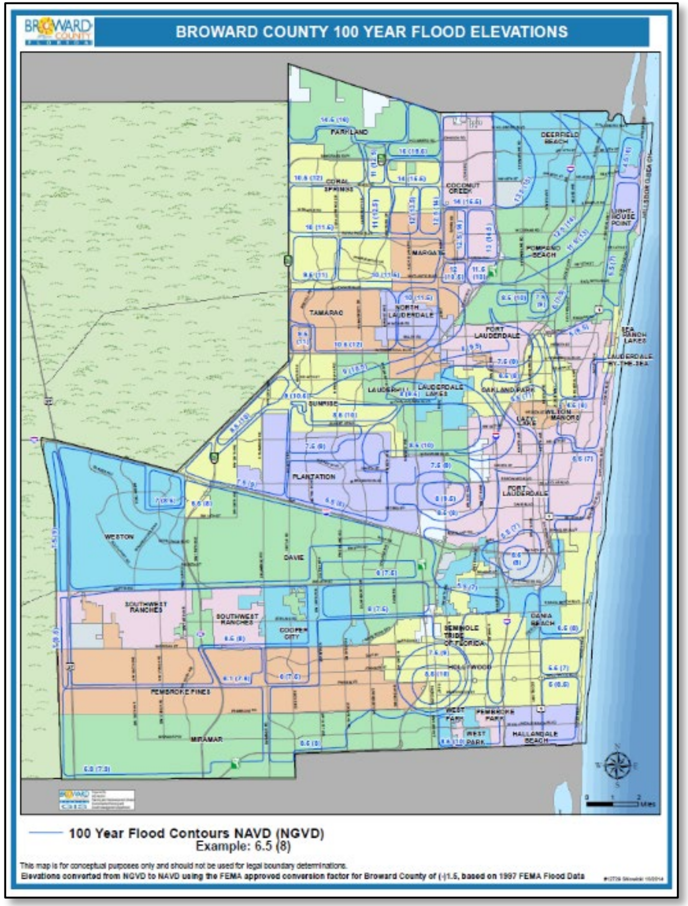
Mark Ellard, PE, CFM, D.WRE, ENV SP – Senior Principal
Geosyntec Consultants

Carolina Maran, PhD, PE – Chief of District Resiliency
SFWMD (formerly with Broward County)

2020 National Conference on Beach Preservation Technology
February 7, 2020
Sarasota, Florida

Project Goals

- Need to update current community 100 – year flood elevation map
- New Flood Map to Account for Future Flood Risk:
  - Year 2060 sea level rise
  - Increased runoff due to higher groundwater tables
  - Land use changes
  - Increased rainfall due to warming climate
- Will enhance infrastructure resilience:
  - Design standards
  - Finished floor elevations, streets, sanitary manholes, critical infrastructure, etc.



Geosyntec consultants

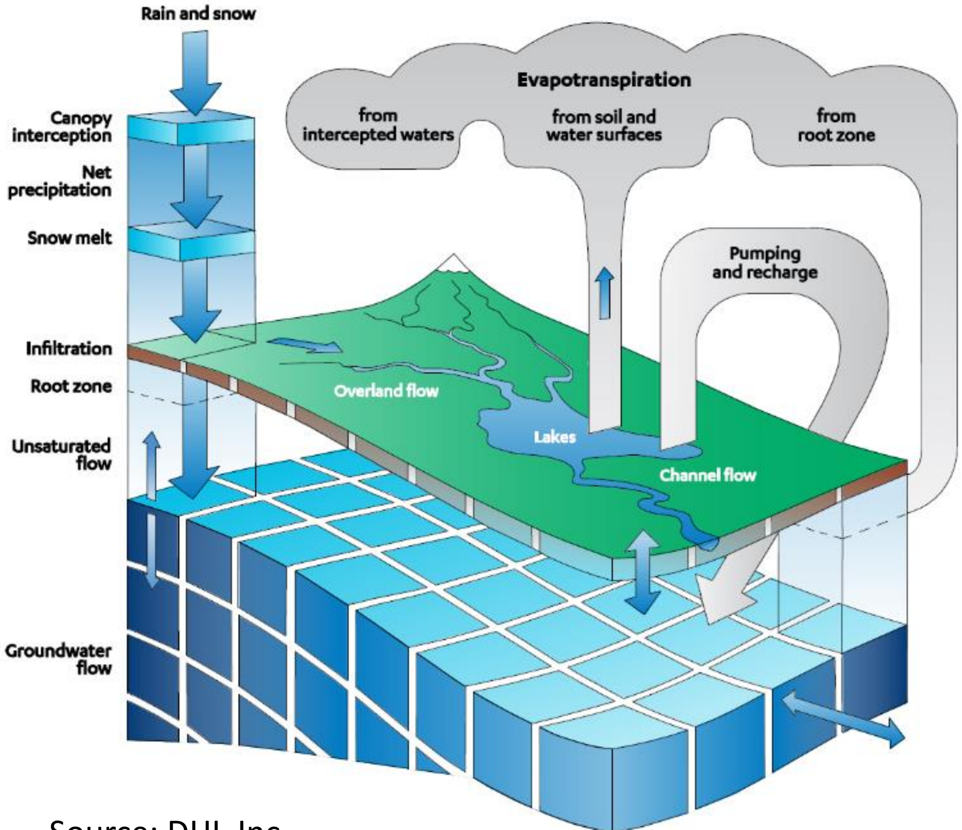
Major Tasks

- Initial Stakeholder Outreach and Coordination
- Data Collection and Review
- Update Current Conditions Model – Existing MIKE SHE / MIKE 11 Model
  - Incorporate Stakeholder Data, Refine Model Computational Grid, Update Land Use, Survey
  - Model Calibration/Validation
  - Current Conditions Design Storm Simulations (10, 25, 50, 100, and 500-year, 3-day)
- Future Conditions Model Development & Execution
  - Incorporate future climate projections (sea level rise, rainfall)
  - Incorporate future groundwater map, landuse, future projects, etc.
  - Run Future Conditions Model Design Storm Simulations (10, 25, 50, 100, and 500-year, 3-day)
- Future 100-year Flood Elevation Map Development
- CRS Evaluation

Current Conditions Modeling Updates and Results

Current Conditions Model Updates

- Existing DHI MIKE SHE / MIKE 11 (Hydro River) Integrated Hydrologic and Hydraulic Model
  - All Elements of Hydrological Cycle
  - 2D Surface Runoff
  - 1D Hydraulic Elements
  - 3D Groundwater Layers
- Used previously for water supply and FEMA flood mapping purposes
- Updated with current conditions data and refined to higher detail



Source: DHI, Inc.

Stakeholder Data Coordination for Model Development

Stakeholder Meetings

Stakeholders:

- **31 Municipalities**
- **23 Water Control Districts**
- **South Florida Water Management District**
- **USGS**
- **Other interested parties**

Current Conditions Model Updates

Updated model with current conditions data and refined to higher detail

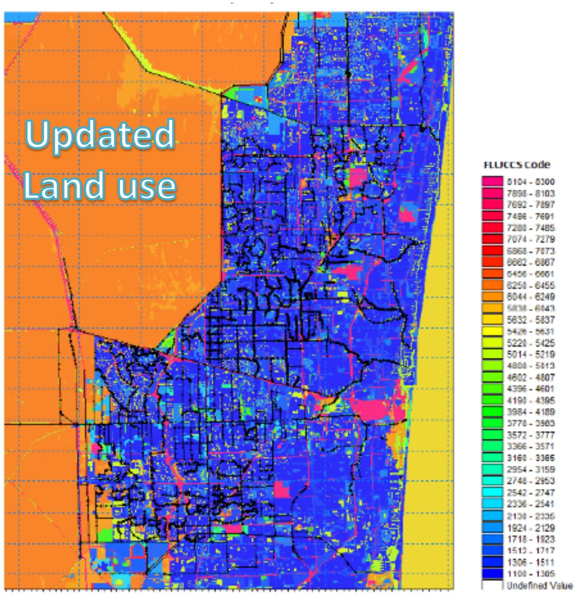


Figure 5: Map of Land Use

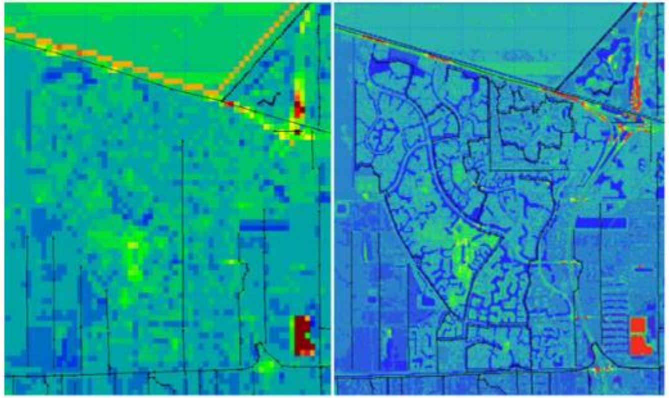


Figure 3: Before (left) and After (right) Topography in the Indian Trace/Weston Area.

Compiled recent LiDAR from available sources, refined model topography

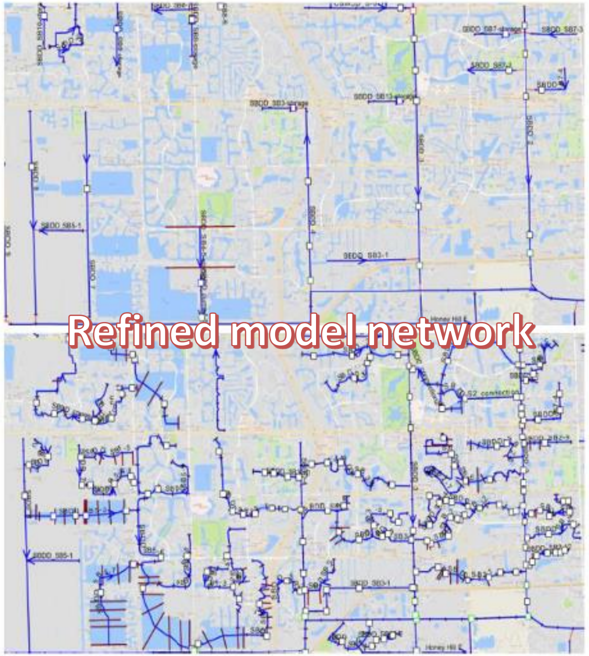


Figure 6: Before (top) and After (bottom) River Network

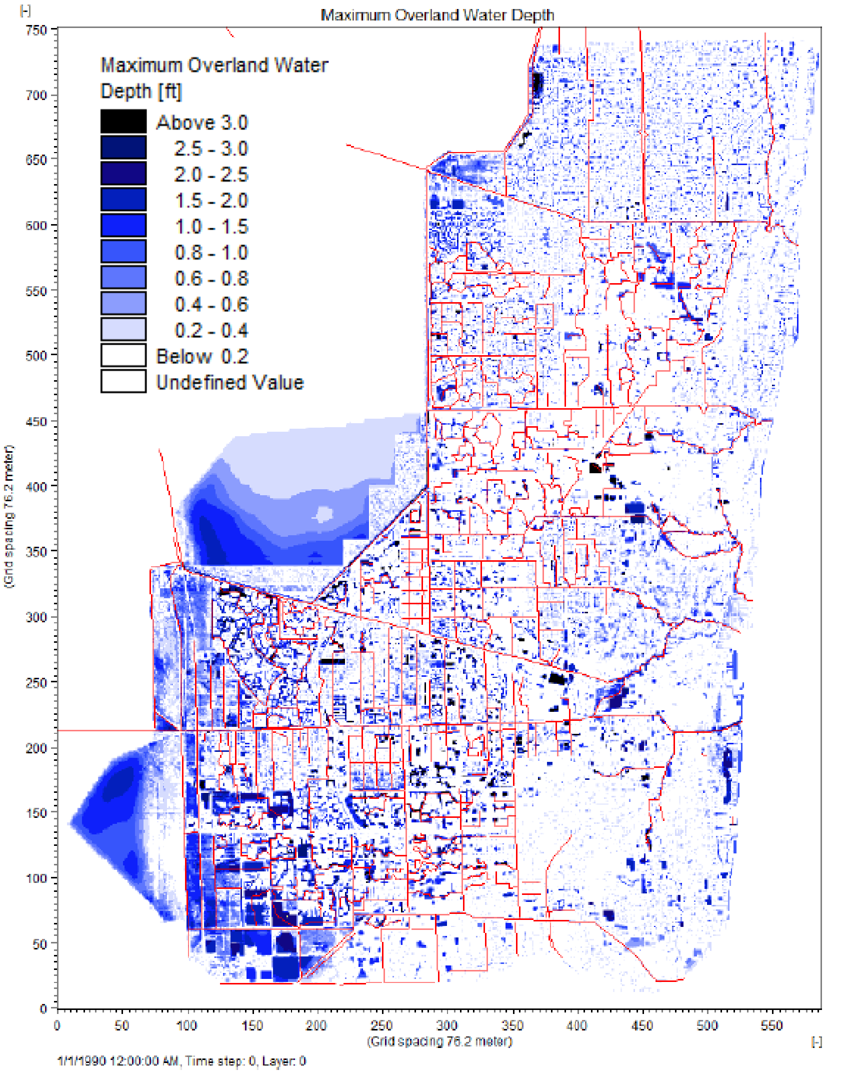
Future Conditions 100-Year Flood Elevation Map

Validation & Calibration

Maximum modeled overland flood depth results - Validation storm

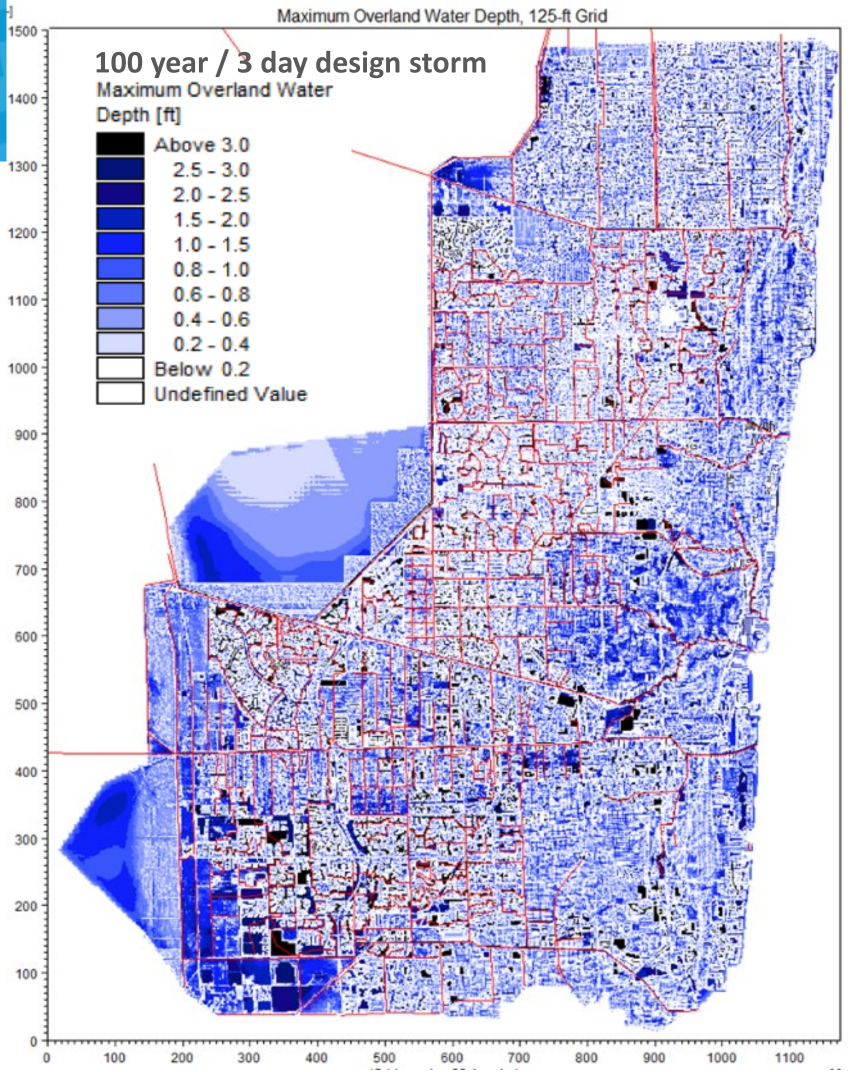
Verification Storm Selection for Model Calibration

- 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



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

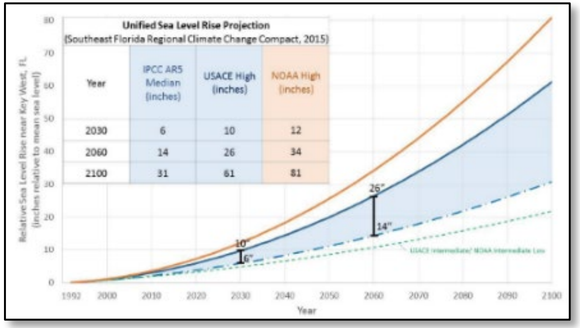


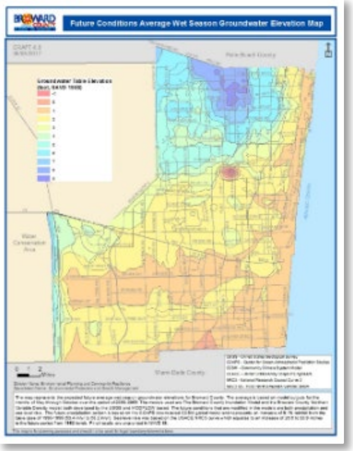
Geosyntec consultants

Future Rainfall Projections

Future Conditions Model Updates

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





Future Conditions 100-Year Flood Elevation Map

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

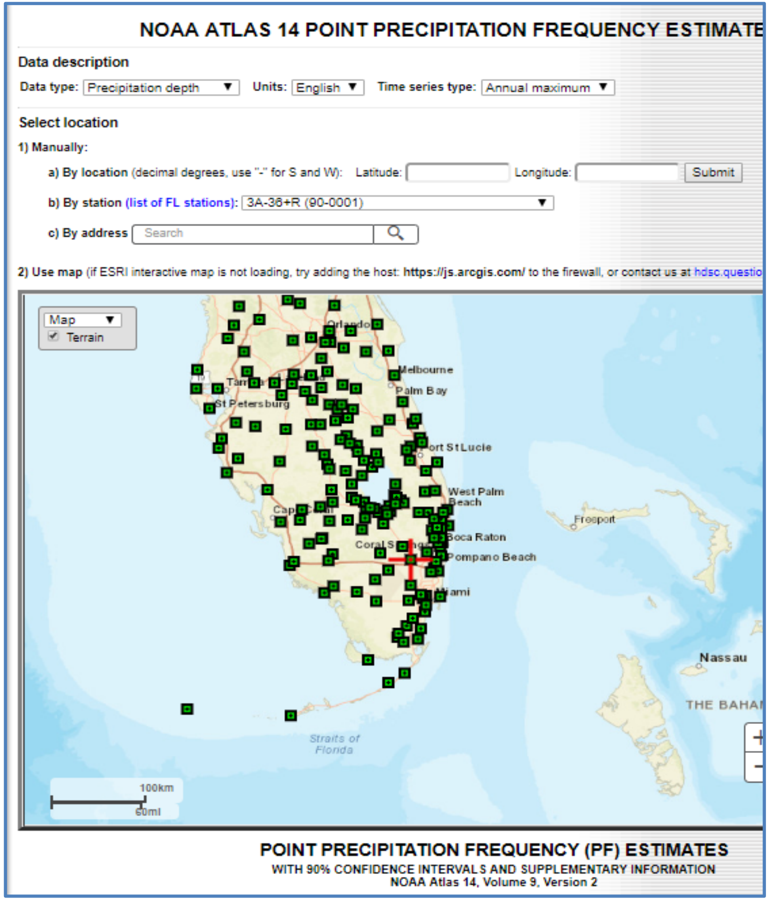
- Representing Uncertainties (stochastic approach)
- Spatial differences among changing factors

Large associated uncertainties

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



Geosyntec consultants

Bias Estimation for Different Datasets

Bias in 72-hour DDF precipitation depths in inches for downscaled models versus observations
Under RawGCM Hist (1956-2005). 5-95th percentiles across models shown
Station: 3A-36+R

Model / Average recurrence interval (years)	2	5	10	25	50	100	200	500	1000
ACCESS1-0	-2.4	-2.7	-3.3	-4.5	-5.7	-7.2	-8.8	-11.3	-13.4
ACCESS1-3	-2.2	-2.1	-2.3	-2.9	-3.5	-4.5	-5.4	-7.0	-8.4
BNU-ESM	-3.0	-3.7	-4.6	-6.1	-7.5	-9.1	-10.9	-13.5	-15.8
CCSM4	-2.5	-2.9	-3.6	-4.7	-5.7	-7.0	-8.4	-10.5	-12.3
CESM1-BGC	-2.6	-3.1	-3.7	-4.5	-5.2	-5.9	-6.5	-7.2	-7.5
CMCC-CM	-2.4	-2.9	-3.5	-4.5	-5.3	-6.2	-7.1	-8.3	-9.2
CMCC-CMS	-1.8	-2.1	-2.7	-3.7	-4.6	-5.7	-6.9	-8.7	-10.1
CNRM-CM5	-2.9	-3.2	-3.8	-4.9	-5.9	-7.2	-8.5	-10.7	-12.5
CSIRO-Mk3-6-0	-2.0	-2.5	-3.2	-4.4	-5.5	-6.8	-8.2	-10.3	-12.0
CanESM2	-3.4	-4.3	-5.2	-6.6	-7.8	-9.0	-10.2	-11.9	-13.0
EC-EARTH	-3.2	-4.2	-5.3	-7.0	-8.6	-10.4	-12.3	-15.3	-17.8
GFDL-ESM2G	-3.0	-3.9	-4.9	-6.6	-8.1	-9.9	-11.8	-14.7	-17.1
GFDL-ESM2M	-2.9	-3.8	-4.8	-6.4	-7.8	-9.5	-11.3	-14.0	-16.2
HadGEM2-ES	-2.1	-2.5	-3.1	-4.2	-5.2	-6.5	-7.8	-9.8	-11.4
IPSL-CM5A-LR	-3.8	-4.8	-5.9	-7.7	-9.2	-11.0	-12.9	-15.8	-18.2
IPSL-CM5A-MR	-3.5	-4.4	-5.3	-6.9	-8.3	-10.0	-11.8	-14.5	-16.8
IPSL-CM5B-LR	-2.8	-2.8	-3.0	-3.4	-3.7	-4.2	-4.4	-4.8	-4.8
MIROC-ESM	-3.0	-3.9	-5.0	-6.7	-8.2	-10.0	-11.9	-14.9	-17.3
MIROC-ESM-CHEM	-3.1	-4.0	-5.0	-6.7	-8.2	-10.0	-11.9	-14.8	-17.3
MIROC5	-2.4	-2.8	-3.4	-4.5	-5.5	-6.7	-8.0	-10.0	-11.6
MPI-ESM-LR	-0.8	-1.2	-1.9	-3.3	-4.6	-6.3	-8.1	-11.0	-13.4
MPI-ESM-MR	-1.7	-2.2	-2.9	-4.2	-5.4	-6.9	-8.5	-11.0	-13.1
MRI-CGCM3	-1.8	-2.2	-2.9	-4.2	-5.5	-7.1	-8.9	-11.7	-14.0
NorESM1-M	-3.1	-4.1	-5.2	-6.9	-8.4	-10.2	-12.1	-15.0	-17.4
bcc-csm1-1	-1.8	-1.8	-2.3	-3.4	-4.5	-5.9	-7.5	-10.0	-12.2
inmcm4	-3.2	-4.2	-5.2	-6.9	-8.4	-10.2	-12.0	-14.8	-17.1
0.05	-3.5	-4.4	-5.3	-7.0	-8.5	-10.3	-12.3	-15.2	-17.7
0.1	-3.3	-4.3	-5.3	-6.9	-8.4	-10.2	-12.0	-14.9	-17.4
0.5	-2.7	-3.0	-3.6	-4.6	-5.7	-7.2	-8.7	-11.2	-13.2
0.9	-1.8	-2.1	-2.5	-3.4	-4.6	-5.8	-6.7	-7.8	-8.8
0.95	-1.7	-1.9	-2.3	-3.3	-3.9	-4.8	-5.7	-7.1	-7.7

Average recurrence interval (years)

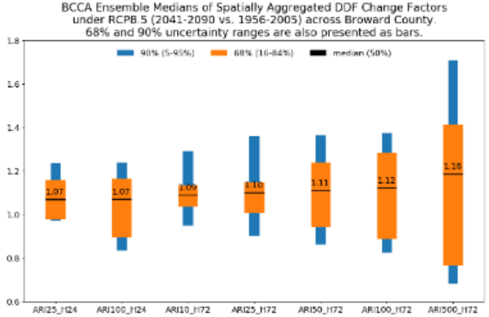
Bias in 72-hour DDF precipitation depths in % for downscaled models versus observations
Under RawGCM Hist (1956-2005). 5-95th percentiles across models shown
Station: 3A-36+R

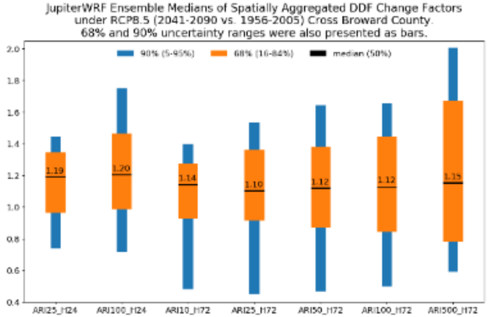
Model / Average recurrence interval (years)	2	5	10	25	50	100	200	500	1000
ACCESS1-0	-43.3	-38.9	-40.1	-43.7	-46.8	-50.2	-53.2	-57.0	-59.6
ACCESS1-3	-41.0	-30.0	-27.8	-27.9	-29.1	-31.1	-32.8	-35.4	-37.2
BNU-ESM	-54.4	-53.9	-55.9	-59.0	-61.4	-63.9	-65.9	-68.4	-70.0
CCSM4	-46.0	-42.5	-43.0	-45.1	-46.9	-49.0	-50.8	-53.0	-54.5
CESM1-BGC	-48.3	-45.4	-44.6	-43.7	-42.6	-41.5	-39.5	-36.4	-33.2
CMCC-CM	-44.7	-42.4	-42.5	-43.0	-43.2	-43.5	-43.1	-42.2	-40.9
CMCC-CMS	-32.1	-30.8	-32.6	-35.6	-37.8	-40.2	-41.8	-43.8	-44.8
CNRM-CM5	-52.4	-46.1	-45.5	-46.7	-48.1	-50.1	-51.7	-53.9	-55.4
CSIRO-Mk3-6-0	-36.3	-36.6	-39.0	-42.6	-45.0	-47.7	-49.6	-52.0	-53.5
CanESM2	-62.0	-62.5	-63.3	-63.7	-63.5	-63.1	-62.0	-59.9	-57.6
EC-EARTH	-59.2	-61.2	-63.9	-67.6	-70.2	-72.8	-74.8	-77.3	-78.9
GFDL-ESM2G	-54.3	-56.1	-59.1	-63.3	-66.2	-69.1	-71.4	-74.1	-75.9
GFDL-ESM2M	-52.6	-55.1	-58.0	-61.8	-64.3	-66.7	-68.5	-70.6	-71.8
HadGEM2-ES	-37.7	-36.1	-37.6	-40.5	-42.7	-45.2	-47.1	-49.4	-50.8
IPSL-CM5A-LR	-68.7	-69.6	-71.3	-73.6	-75.3	-76.9	-78.2	-79.8	-80.8
IPSL-CM5A-MR	-63.8	-63.0	-64.3	-66.6	-68.3	-70.2	-71.6	-73.5	-74.6
IPSL-CM5B-LR	-51.2	-40.5	-36.4	-32.9	-30.7	-29.1	-26.9	-24.1	-21.4
MIROC-ESM	-55.0	-56.9	-59.9	-64.1	-67.0	-69.9	-72.2	-75.1	-77.0
MIROC-ESM-CHEM	-56.2	-57.8	-60.6	-64.5	-67.2	-69.9	-72.2	-74.9	-76.7
MIROC5	-43.0	-40.2	-41.0	-43.2	-44.9	-46.9	-48.4	-50.3	-51.4
MPI-ESM-LR	-15.2	-17.1	-23.0	-31.7	-37.9	-44.1	-49.2	-55.4	-59.4
MPI-ESM-MR	-30.2	-31.2	-34.8	-40.2	-44.2	-48.2	-51.5	-55.7	-58.3
MRI-CGCM3	-32.2	-31.2	-34.7	-40.7	-45.3	-50.0	-54.0	-58.9	-62.2
NorESM1-M	-57.1	-59.2	-62.0	-65.9	-68.6	-71.2	-73.3	-75.8	-77.4
bcc-csm1-1	-33.0	-26.6	-28.1	-32.8	-36.9	-41.5	-45.5	-50.7	-54.1
inmcm4	-58.2	-60.6	-63.2	-66.6	-68.8	-71.0	-72.7	-74.7	-76.0
0.05	-63.3	-62.9	-64.2	-67.4	-69.9	-72.4	-74.4	-76.9	-78.5
0.1	-60.6	-61.8	-63.6	-66.6	-68.7	-71.1	-73.0	-75.5	-77.2
0.5	-49.7	-43.9	-43.8	-44.4	-46.8	-50.0	-52.4	-56.3	-58.9
0.9	-32.2	-30.4	-30.3	-32.8	-37.3	-40.9	-40.7	-39.3	-39.0
0.95	-30.7	-27.4	-27.8	-32.0	-32.2	-33.4	-34.5	-35.7	-34.2

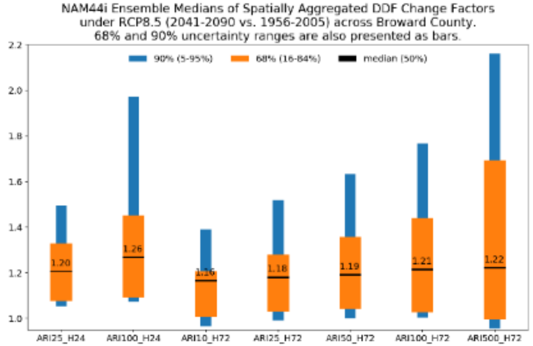
Average recurrence interval (years)

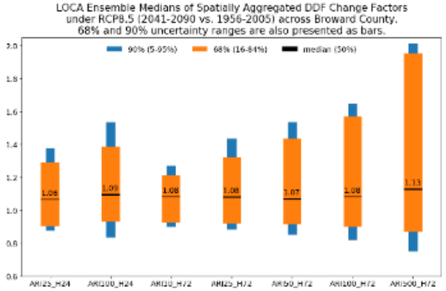
Despite large biases calculated between climate model data and observations…

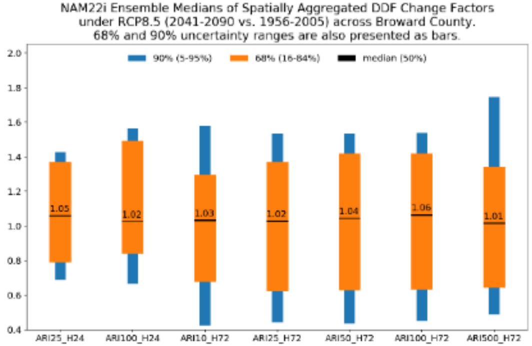
Rainfall Depth Change Factors

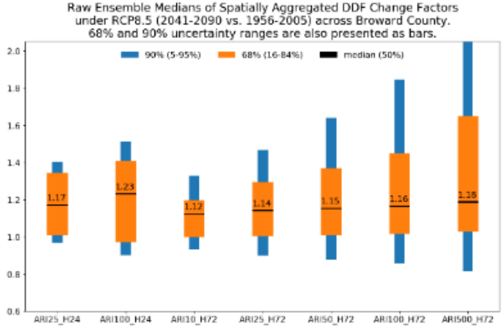












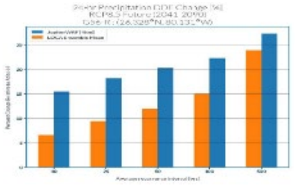
All results and associated uncertainty ranges show increasing rainfall

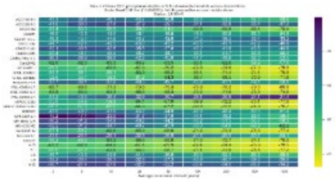
Geosyntec consultants

Future Rainfall – Experts Panel

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

Super-Ensemble approach recommended





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

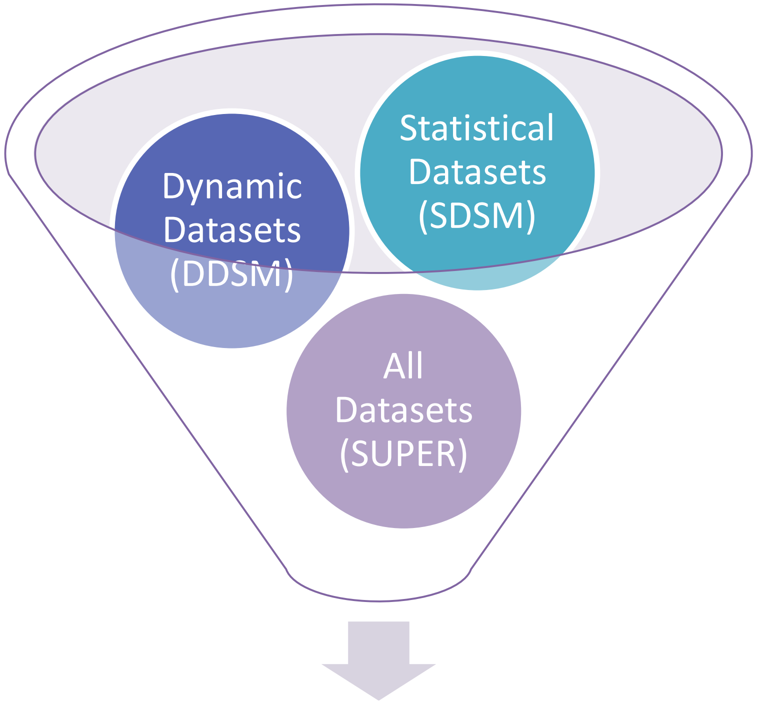
- Evaluating Results from Multiple Models
- Measure of Model Skills (model performance): yet to be identified
- Importance of characterizing uncertainty:
  - More than one dataset to represent observations
  - Multi-model calculations out-perform individual models
  - Multiple sources (Raw GCMs, Regional Models statistical & dynamical downscaled data)
  - Weighting or Subsets Approaches: need to determine statistical significance of the difference between models – given metric
  - ***Super Ensemble Approach,*** plus documentation of all individual results
  - Sample uncertainty space

Approach Aligned with all IPCC Recommendations

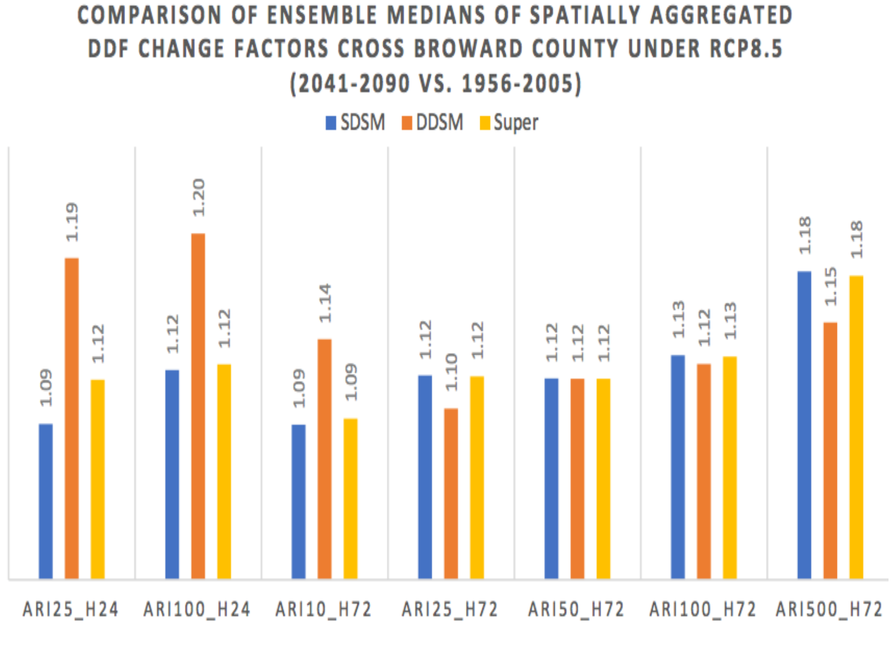
Geosyntec consultants

Super Ensemble Consensus

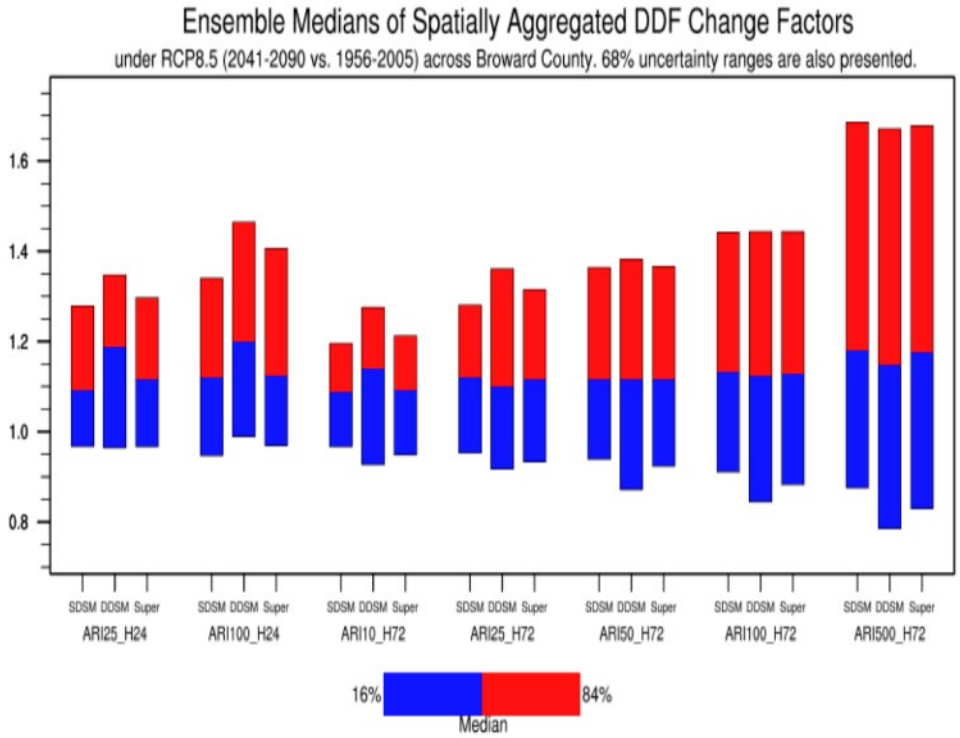
- Super-Ensemble Approach:
  - Different subsets of all the individual model projections from the different datasets are chosen and fittings are calculated from each of these subsets (prob. analysis)
  - This approach more explicitly calculates the uncertainty in the median change factors, and reduce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



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.

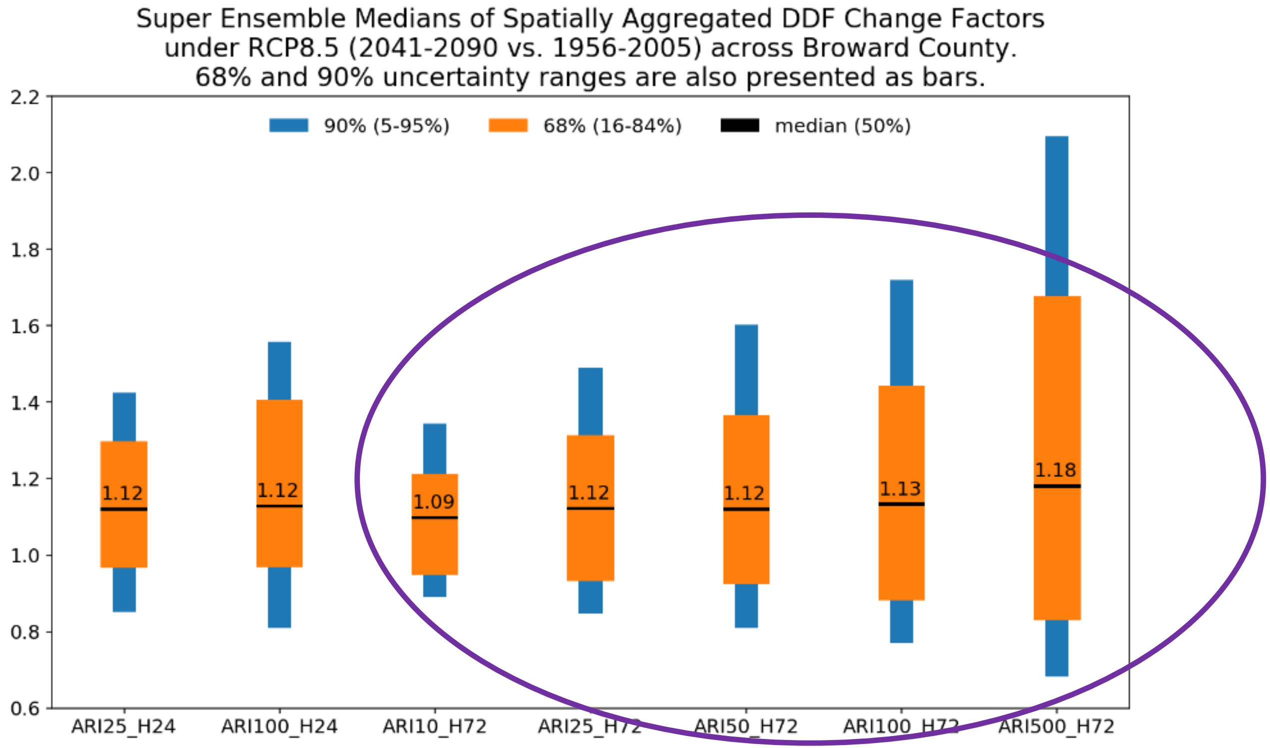


Super-ensemble Results for Design Storms (Longer Durations - 3 days)

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)



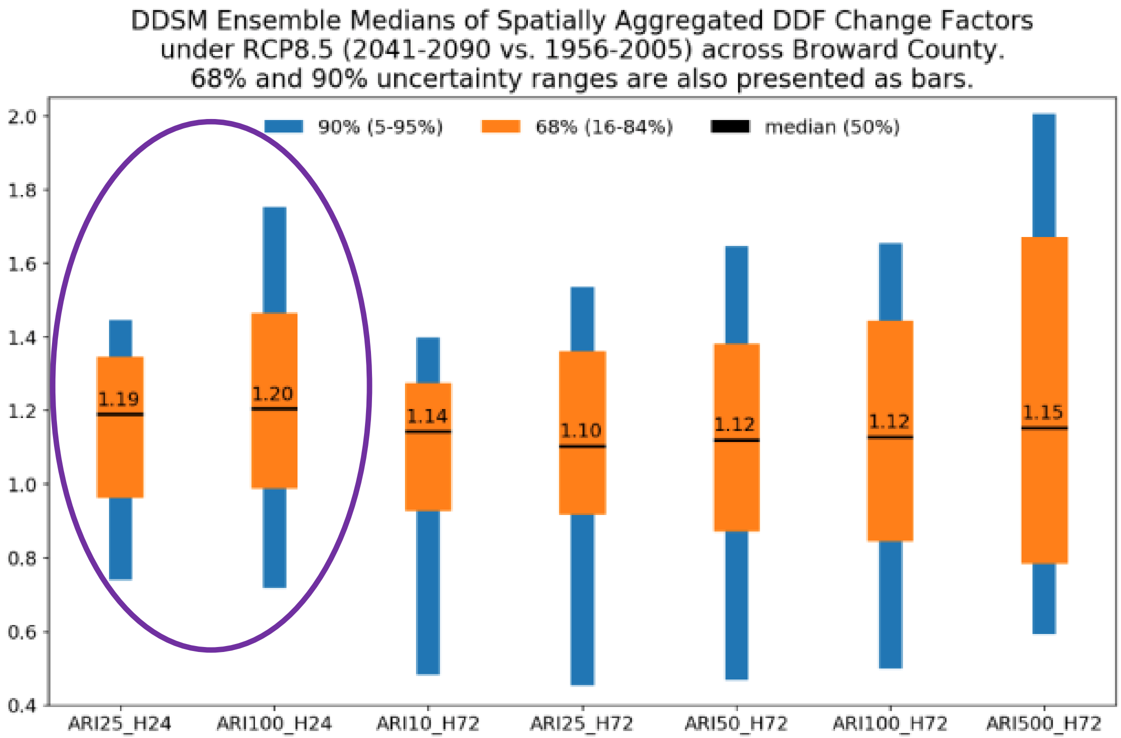
Whisker diagram of SUPER ensemble medians of spatially aggregated DDF change factors with uncertainty ranges.

Super-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.

Combining Results for Broward

- How to apply Change Factor spatially to design storm rainfall ?

- No significant difference for the calculated Change Factor among rainfall stations, small spatial variability

ADOPT ONE CHANGE FACTOR (%) FOR THE ENTIRE URBAN AREA

Future Conditions 100-Year Flood Elevation Map

Geosyntec consultants

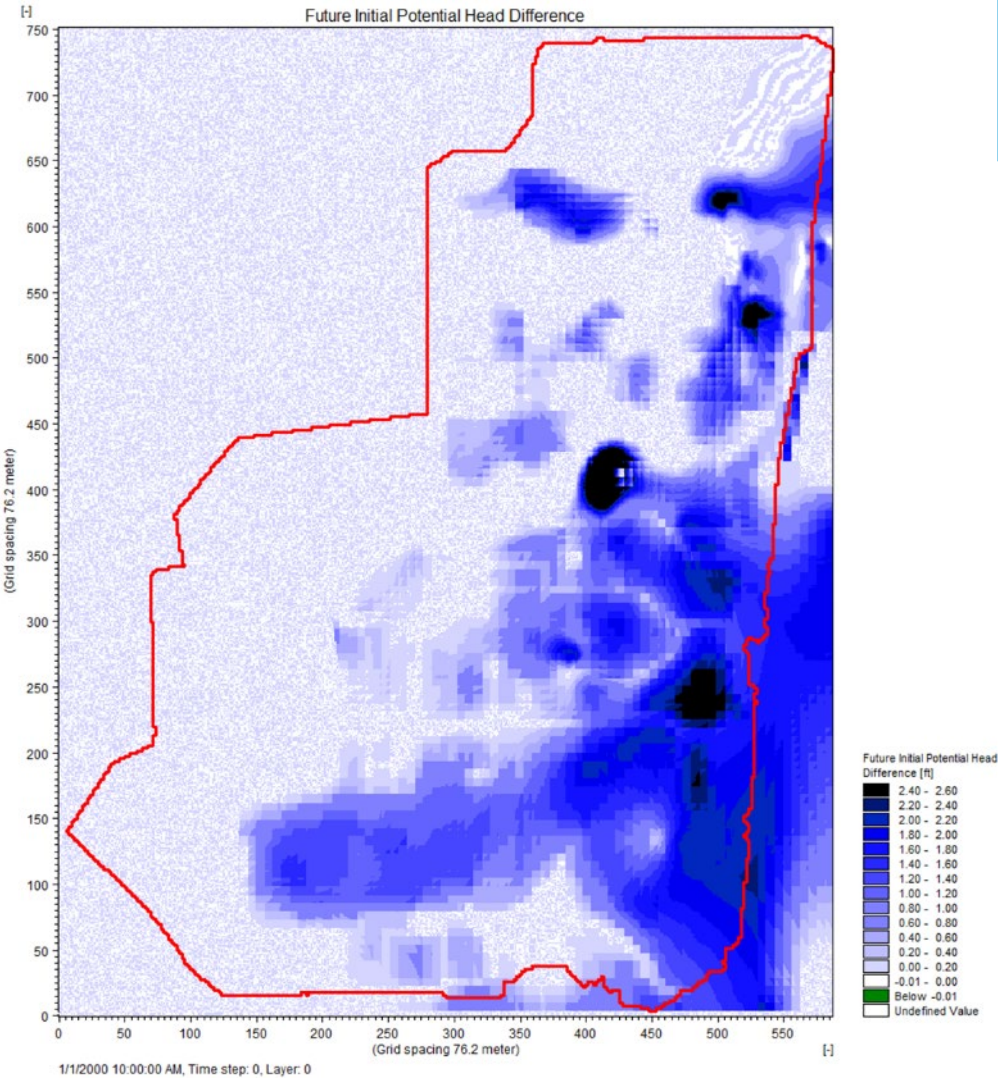
Future Conditions Modeling

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



Geosyntec consultants

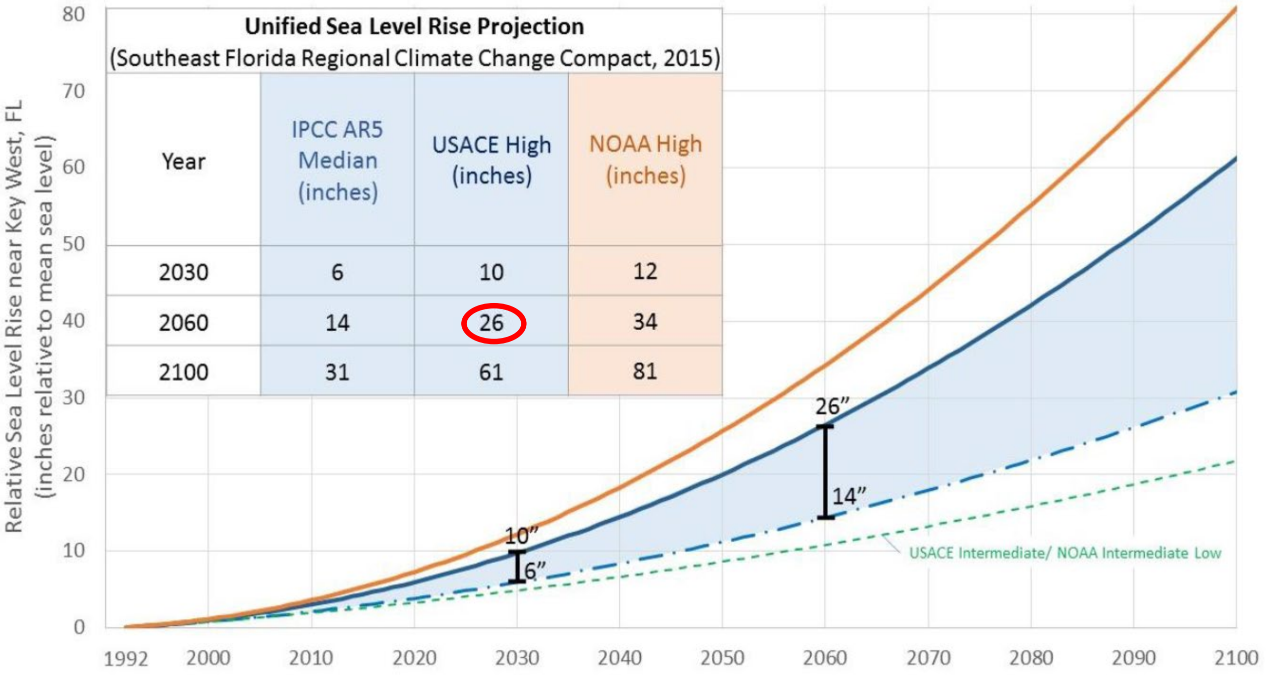
Future Tidal Outfalls and Boundaries

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

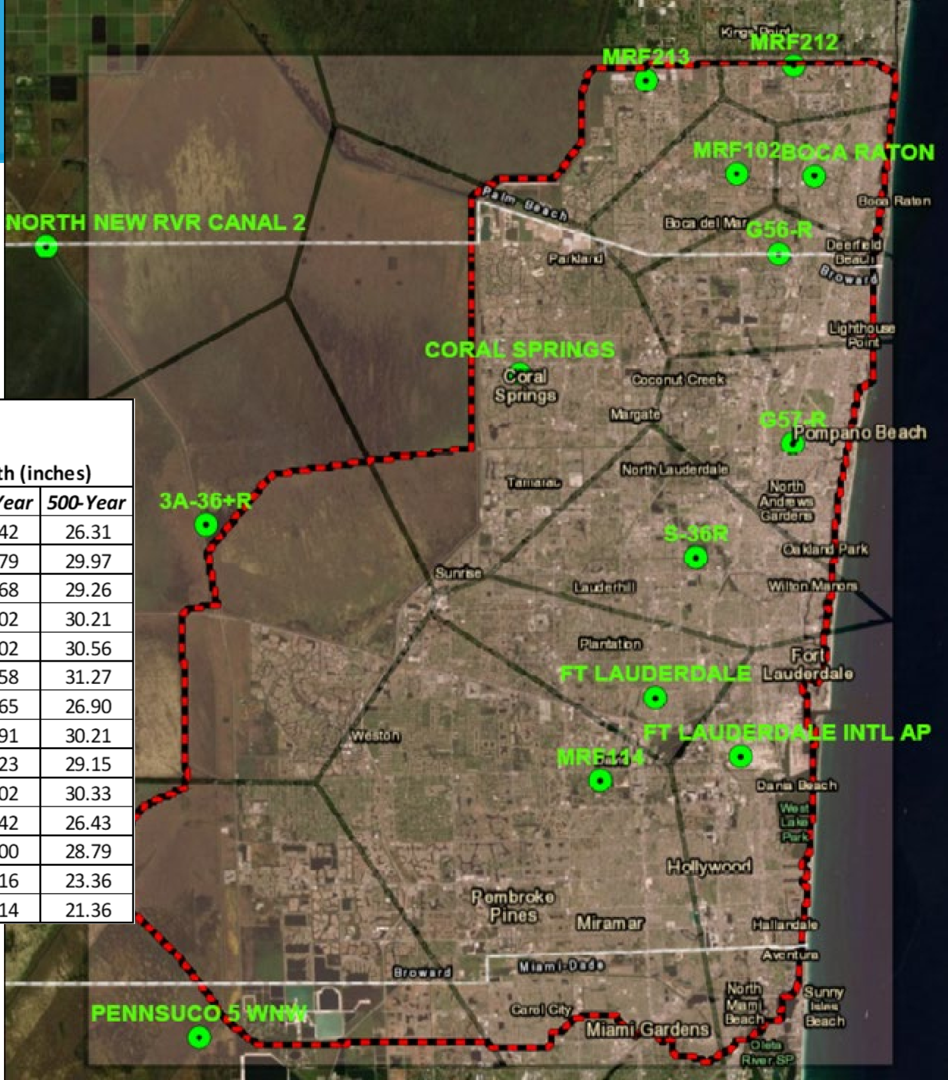


Future Rainfall

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

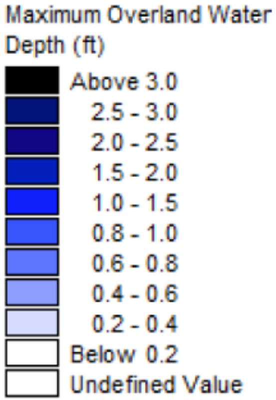
NOAA Station	Future 3-Day Storm Rainfall Depth (inches)				
	10-Year	*25-Year*	*50-Year*	*100-Year*	*500-Year*
PENNSUCO 5 WNW	10.53	13.55	15.79	18.42	26.31
MRF114	11.66	15.12	17.70	20.79	29.97
FT LAUDERDALE INTL AP	11.77	15.12	17.70	20.68	29.26
FT LAUDERDALE	11.77	15.23	17.92	21.02	30.21
S-36R	11.77	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



Geosyntec consultants

Future Conditions Results

Future 100-year / 3 day storm flood depth results



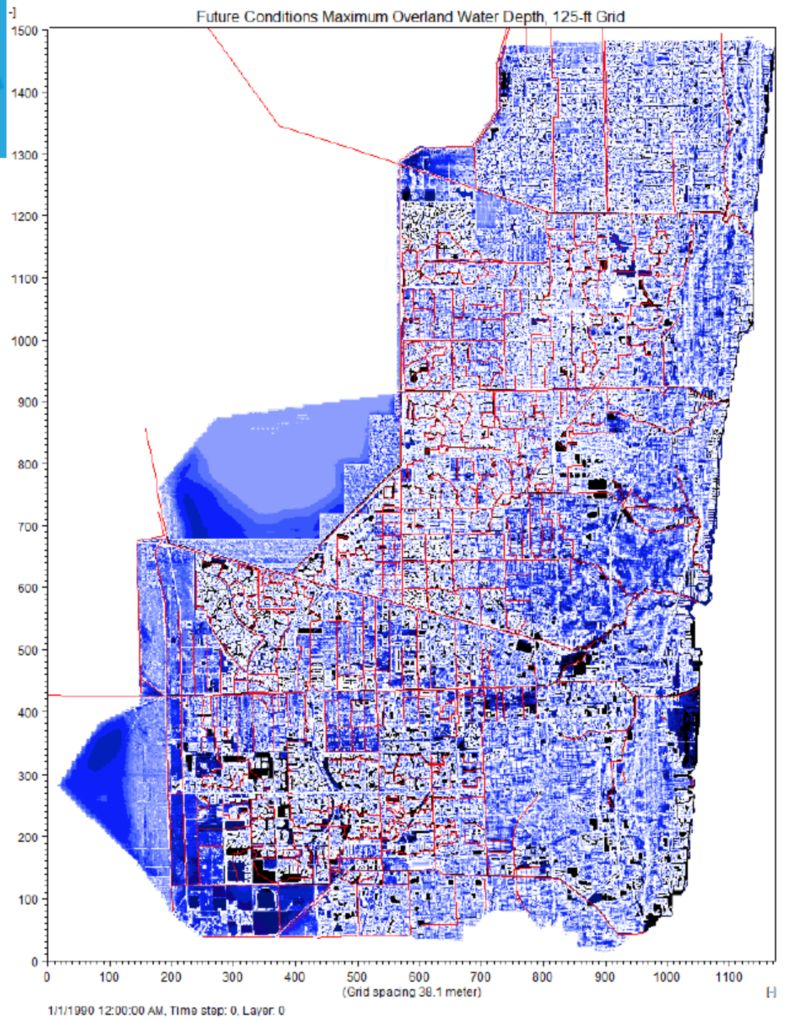
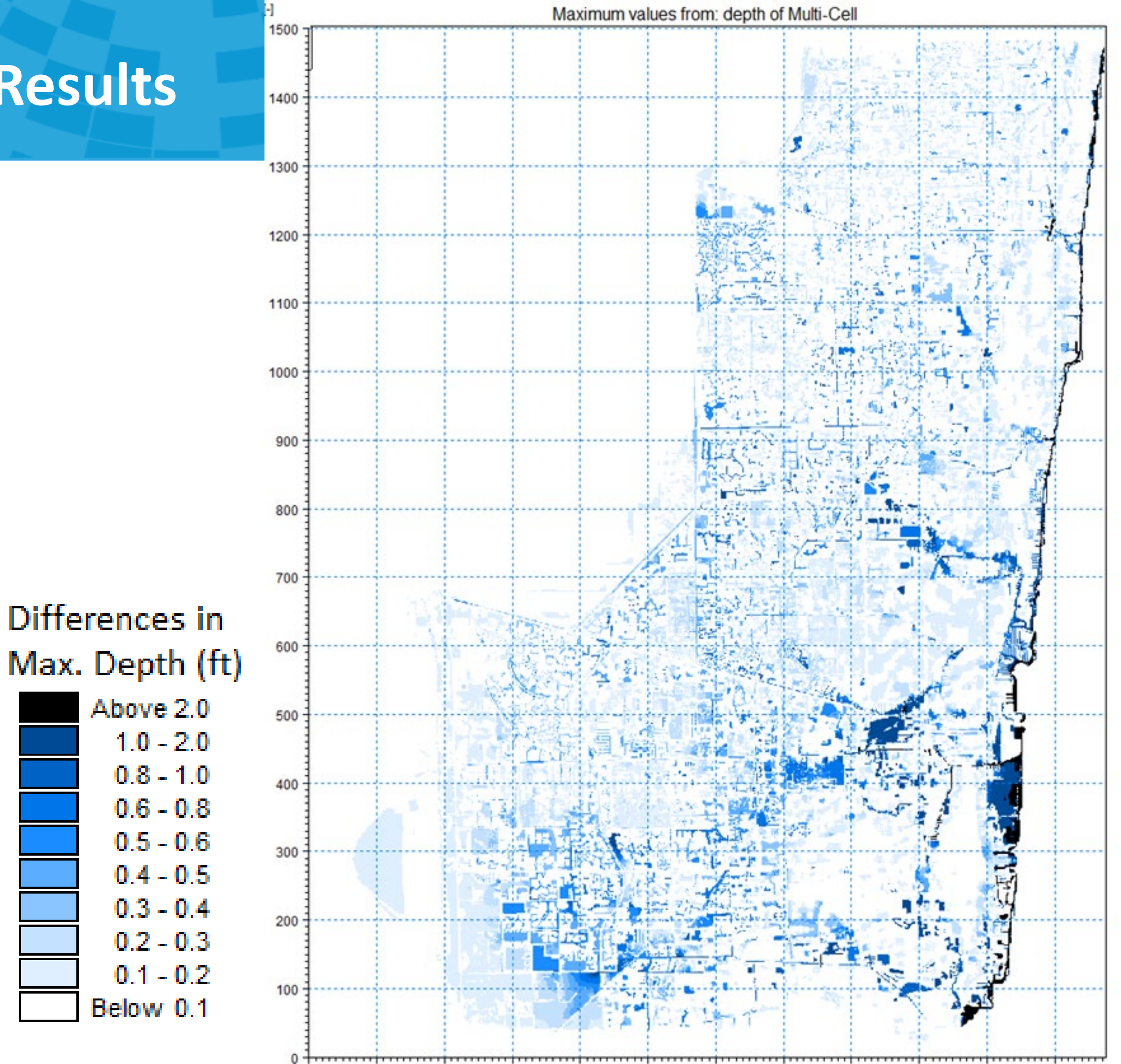


Figure 41: 100-Year Design Storm Maximum Overland Water Depth

Future Conditions Results

Spatial difference comparison 100-year storm results

Future conditions maximum depths minus current conditions maximum depths



Geosyntec consultants

Future Conditions Results

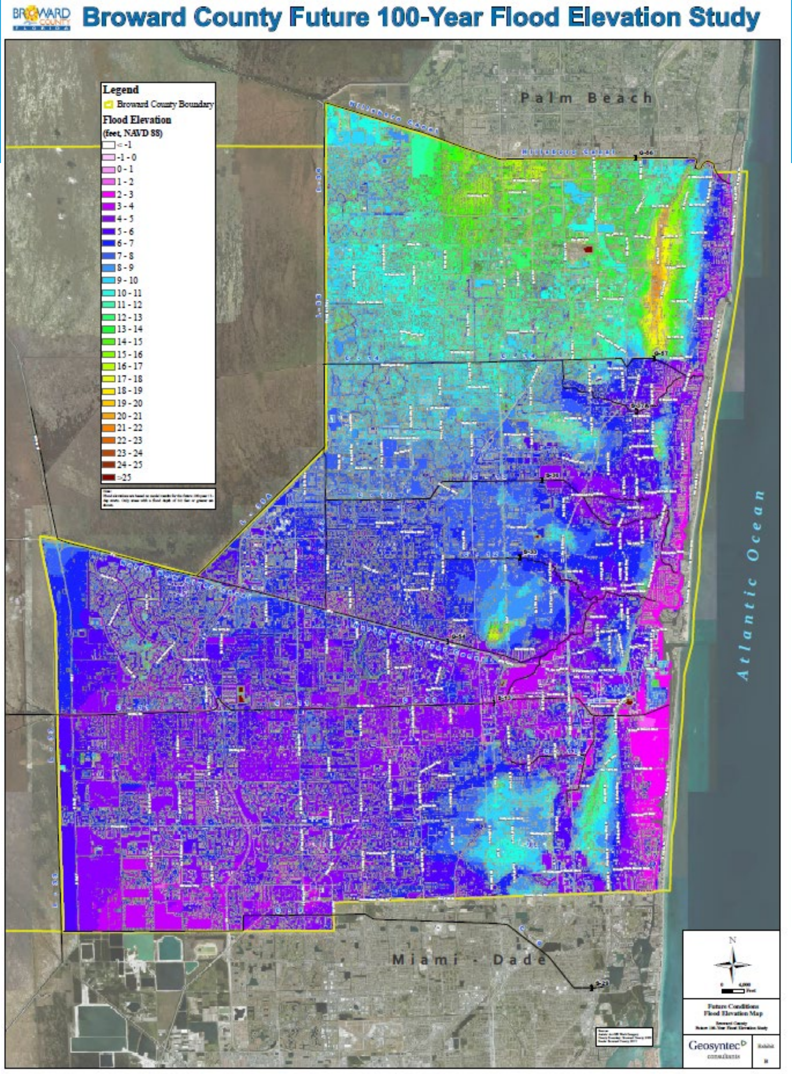
- Preliminary Future 100-year / 3 day storm flood elevations (FT NAVD 1988)

Legend

Broward County Boundary

Flood Elevation (feet, NAVD 88)

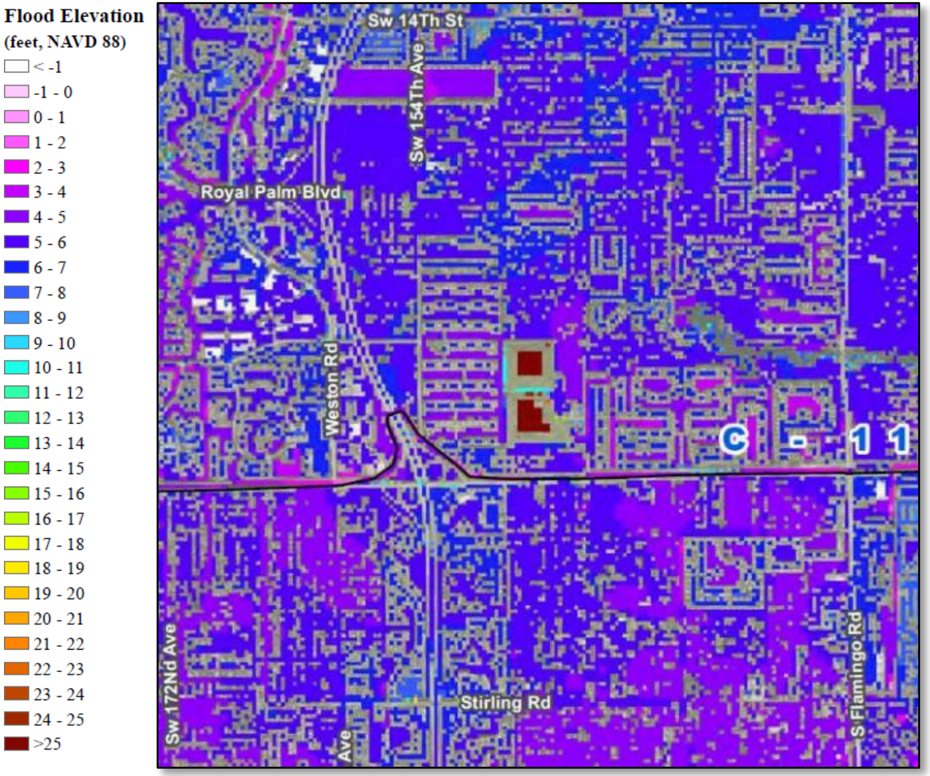
- < -1
- -1 - 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 16
- 16 - 17
- 17 - 18
- 18 - 19
- 19 - 20
- 20 - 21
- 21 - 22
- 22 - 23
- 23 - 24
- 24 - 25
- >25



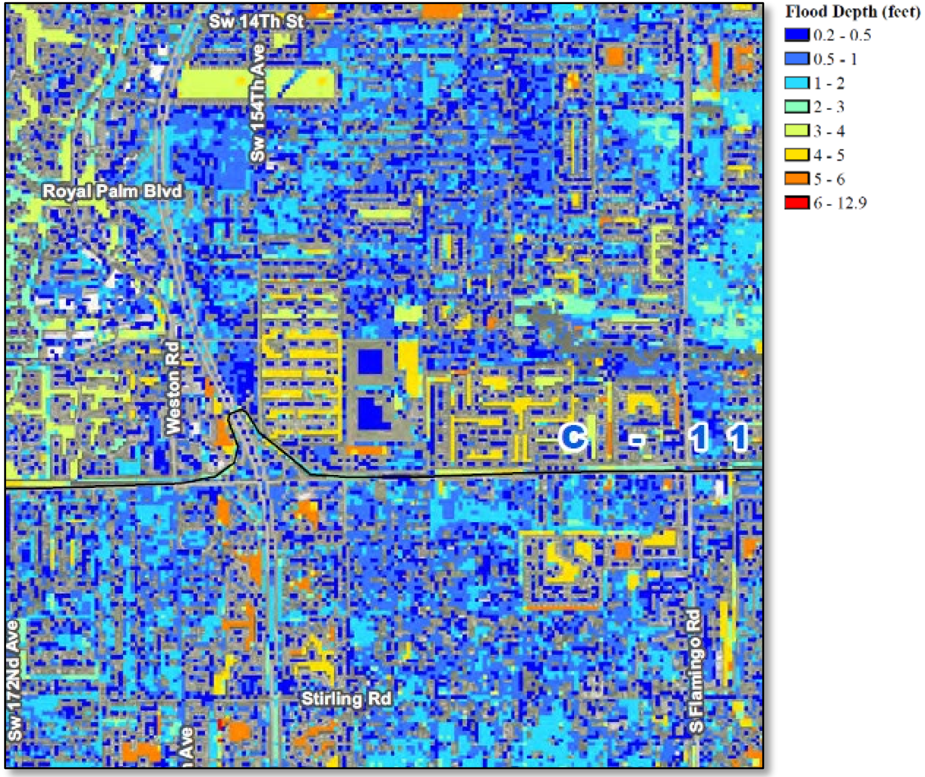
Geosyntec consultants

Future Conditions Results - Detail

Flood Elevation



Flood Depth

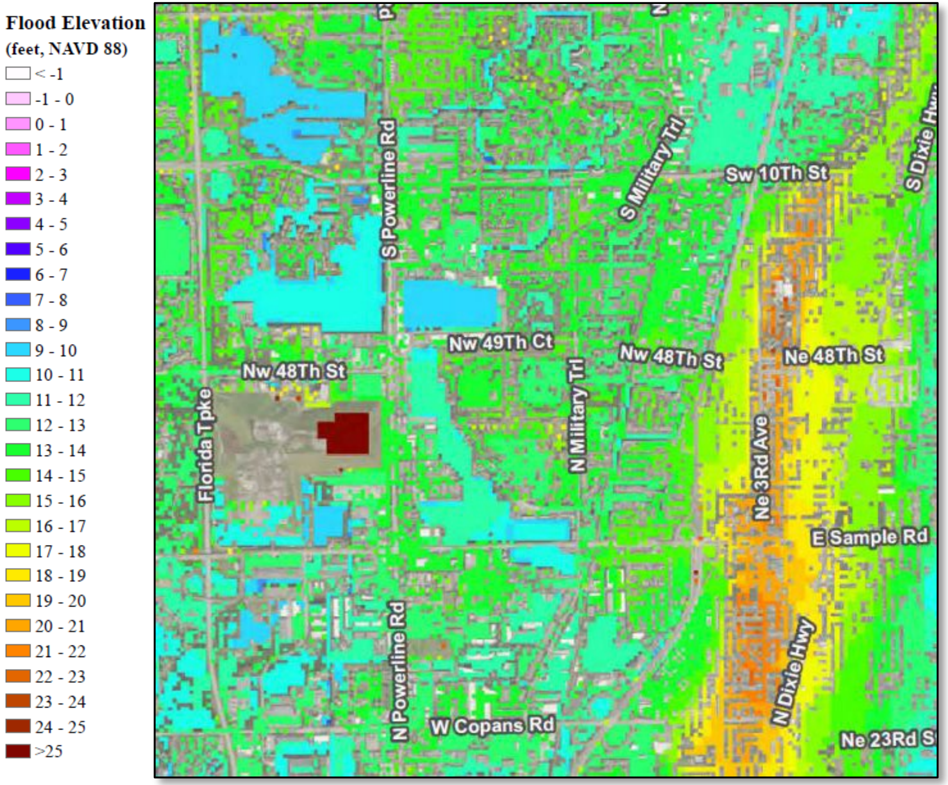


Geosyntec consultants

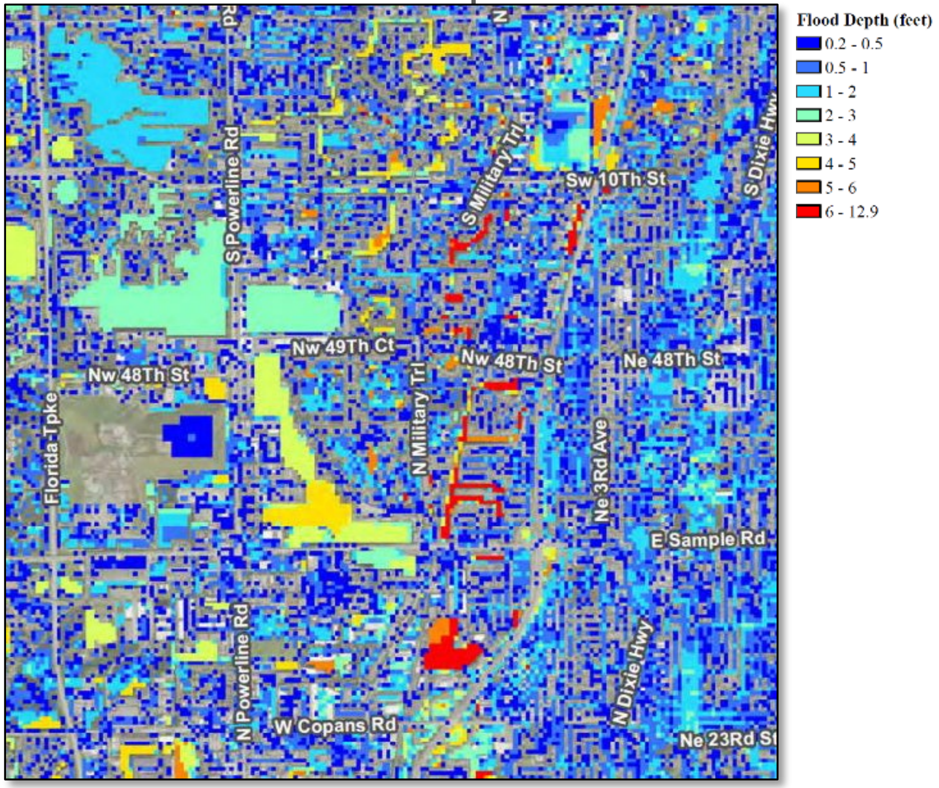
Future Conditions 100-Year Flood Elevation Map

Future Conditions Results - Detail

Flood Elevation



Flood Depth



Future Conditions 100-Year Flood Elevation Map

Next Steps

Next Steps

- Draft report and draft future conditions model results shared with stakeholders (January)
- 3 Stakeholder Workshops (North (2/4), Central (1/31), South (2/4))
  - Present Future Conditions Flood Elevation Map (results, technical assumptions)
  - Promote a technical discussion and opportunity for feedback
- Incorporate final comments from stakeholders and share updated flood map (February)
- 2 Informational Workshops to Community - March
  - Countywide – Agencies / Municipalities Workshop
  - Industry / Development / Business Community Workshop
- **Future Conditions 100 Year Flood Map Adoption Process – May thru August**

Project Team Acknowledgments

- Broward County Leadership: Dr. Jennifer Jurado, PhD
- Geosyntec: Prime Consultant
  - Data Collection and Compilation
  - Stakeholder Outreach
  - Rainfall Analysis (current and future conditions)
  - Model Tool Development
  - CRS Evaluation and Recommendations
- Taylor Engineering: Hydrologic & Hydraulic Modeling
  - 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 with Broward County for project and technical guidance

Thank you

Questions?

Mark Ellard, PE, CFM, D.WRE, ENV SP
mellard@Geosyntec.com
407-321-7030

Carolina Maran, PhD, PE
cmaran@sfwmd.gov
561-682-6868

Jennifer Jurado, PhD
jjurado@broward.org
954-519-1464