

Village of Key Biscayne

Zone 1 Alternative Stormwater Plan

for:

TASK 1 – DATA COLLECTION AND REVIEW
TASK 2 – FLOOD AREA DELINEATION AND HYDRAULIC ANALYSIS

For Submission to:

Village of Key Biscayne

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Table of Contents

EXECUTIVE SUMMARY	1
1 INTRODUCTION	1
1.1 1993 Stormwater Management Master Plan – Williams, Hatfield & Stoner (WHS)	1
1.2 2011 Stormwater Master Plan Update – Tetra Tech.....	2
1.3 2015 Implementation of SWMP – EAC Consulting	3
1.4 AECOM 2024 Alternative Analysis Drainage Assessment.....	5
1.5 AECOM 2025 Tech Memo: Zone 1 Baseline Stormwater Modeling Results	10
2 TECHNICAL APPROACH.....	13
2.1 Regulatory and Design Criteria	15
2.2 Model Development	18
3 TASK 1 – DATA COLLECTION AND REVIEW.....	22
3.1 Model Boundary	23
3.2 Overview of Data Sources	26
3.3 Survey and Elevation Data.....	27
3.4 Rainfall and Hydrometeorological Data.....	28
3.5 Land Use Processing and Hydrologic Parameter Assignment.....	31
3.6 Soil and Unsaturated Zone Parameter Data	35
3.7 Surficial Aquifer	36
3.8 Summary of MIKE SHE Input Files and Their Function	37
3.9 Stormwater Infrastructure Data	38
3.10 Geotechnical Investigations	38
4 TASK 2 - AREA DELINEATION AND HYDRAULIC ANALYSIS	42
4.1 Model Domain and Grid Configuration	43

4.2	Boundary and Initial Conditions	44
4.3	Rainfall and PET Boundary Conditions	48
4.4	Overland Flow Representation	48
4.5	Unsaturated Zone (UZ) Configuration	49
4.6	Saturated Zone (SZ) Configuration	49
4.7	Aquifer Layering and Conductivity	50
4.8	MIKE+ and 2D Overland Flow Modeling	52
5	PRELIMINARY RESULTS:	56
5.1	Peak Flood Depth	56
5.2	Groundwater Levels	60
5.3	Water Budget	65
6	COST MANAGEMENT	74
6.1	Preliminary Layout	74
6.1	Preliminary Budget	76
7	TIMELINE – PROJECT PROGRESS	78
8	REFERENCES	79

List of Tables

Table 1 Summary of Design Parameters	15
Table 2 Summary of SWMP Progression.....	19
Table 3 Cumulative 24-hr Rainfall for 2017-2025	29
Table 4 Return Period and Rainfall Depth for 24-hr Rainfall for 2017-2025 (NOAA Atlas 14) .	29
Table 5 Cumulative 72-hr Rainfall for 2017-2025	30
Table 6 Return Period and Rainfall Depth for 24-hr Rainfall for 2017-2025 (NOAA Atlas 14) .	31
Table 7 Land Use Derived Surface and Subsurface Drainage Parameters.....	34
Table 8 Summary of ECSM Model Layers in the Key Biscayne Area.....	37
Table 9 Storage changes	70
Table 10 Atmospheric Inputs	71
Table 11 Overland Boundaries	71
Table 12 Groundwater (SZ) Boundaries and Drains	71
Table 13 Surface–Subsurface Exchanges.....	71
Table 14 Preliminary Budget Analysis of Drainage Well Installation with Pump	77

List of Figures

Figure 1 Outline of Analytical Zones	7
Figure 2 Model Domain and Zone 1 Coverage	24
Figure 3 Model Topography	28
Figure 4 Cumulative 24-hr Rainfall for 2017-2025.....	29
Figure 5 Cumulative 72-hr Rainfall for 2017-2025.....	30
Figure 6 Miami-Dade County Land Use Classification	32
Figure 7 Miami-Dade County Land Use Classification	35
Figure 8 Tidal Boundary Condition Derived From NOAA Observations (Virginia Key).....	45
Figure 9 Average Sea Level Virginia Key and Comparison with NOAA Projections	47
Figure 10 SW Infrastructure Data Implemented in the MIKE+ Model	54
Figure 11 Model Simulation of Peak Flood Depth and Extent for 6/6/2022	57
Figure 12 Zone 1 Model Simulation of Peak Flood Depth and Extent for 6/6/2022	59
Figure 13 AECOM Zone 1 Model Simulation of Peak Flood Depth and Extent for 6/27/2022...60	
Figure 14 Groundwater Levels at Woodcrest Rd and W Enid Dr During Irma, 2017	61
Figure 15 Groundwater Levels at Woodcrest Rd and W Enid Dr in June 2022	62
Figure 16 Tidal Groundwater Dynamics	64
Figure 17 Plan of Proposed Conversion of Gravity Well to Localized Pump Node.....	75
Figure 18 Detail of Proposed Conversion of Gravity Well to Localized Pump Node	76

EXECUTIVE SUMMARY

The Village of Key Biscayne has undertaken the Zone 1 Alternative Stormwater Modeling and Planning effort to reevaluate drainage performance using a modern, physics-based hydrologic and hydraulic modeling framework. This initiative responds to the Village's Request for Qualifications (RFQ #2025-13), which calls for a technically defensible evaluation of stormwater system performance under current and future conditions, including sea-level rise, shallow groundwater, evolving rainfall patterns, and the operational limitations of the existing stormwater network. This Executive Summary presents an overview of the model development, data integration, calibration events, preliminary simulation results, and the analytical basis for forthcoming alternative evaluations.

This effort aligns with contemporary regulatory expectations established by the South Florida Water Management District (SFWMD), Florida Department of Environmental Protection (FDEP), and U.S. Army Corps of Engineers (USACE) for coastal, low-lying municipalities experiencing compound flood risks. Modernized stormwater planning requires integration of groundwater-surface water interaction, tidal boundary conditions, and multi-scenario sea-level-rise (SLR) projections, which directly affect drainage capacity, design tailwater, and system operability. The application of a physics-based, fully integrated modeling system ensures compliance with SFWMD's requirements for hydrologic justification; supports USACE's resilience-based engineering principles, including dynamic boundary-condition evaluation; and provides a defensible technical foundation for project phasing, cost assessment, and permitting. By developing a model that reflects rainfall-runoff processes, overland flow routing, saturated and unsaturated zone interactions, and engineered conveyance features in a unified computational environment, the Village is implementing a best-practice framework consistent with current regional and federal stormwater guidance.

Modeling Framework and Objectives

Key Biscayne's stormwater challenges arise from a confluence of physical constraints: extremely low topographic relief, shallow and tidally responsive groundwater, limited infiltration capacity, minimal surface storage, and dependence on coastal boundaries that continue to rise over time. These conditions render traditional gravity-based conveyance increasingly ineffective. To address these complexities, the project employs an integrated MIKE SHE / MIKE+ modeling system that simulates unsaturated flow, saturated groundwater dynamics, overland routing, stormwater collection system hydraulics, pump behavior, drainage wells, and coastal boundary interactions within a unified computational environment.

These physical constraints require that barrier-island stormwater systems must be evaluated under combined tidal, rainfall, and groundwater forcing due to the diminished hydraulic head available for gravity discharge. The limited infiltration capacity and shallow water table also trigger ERP compliance considerations regarding water-quality treatment, exfiltration feasibility, and reliance on vertical conveyance strategies when horizontal gradients are insufficient. The MIKE SHE / MIKE+ integrated framework is consistent with SFWMD's requirements for demonstrating a defensible hydrologic basis (Applicant's Handbook Volume II) and meets USACE expectations for climate-informed engineering by incorporating tidal, rainfall, and groundwater dynamics into a coupled surface-subsurface system. This modeling structure provides the necessary fidelity to evaluate flooding mechanisms, test alternative drainage solutions, quantify performance metrics such as LOS depth and duration, and assess the

hydraulic benefits of distributed pumping and injection well strategies relative to more centralized designs.

To address these challenges, the project utilizes a coupled MIKE SHE / MIKE+ modeling system. MIKE SHE provides the distributed hydrologic engine for simulating infiltration, evapotranspiration, soil-moisture dynamics, groundwater flow, and overland hydrology. MIKE+ supplies the 1D representation of pipes, manholes, inlets, and drainage wells, along with a 2D overland mesh that resolves street-level flow paths, ponding, and circulation patterns. The coupled system enables the Village to quantify not only peak flood depths, but also flow directions, flood volumes, recovery times, and the interplay between groundwater and surface flooding - elements essential for evaluating localized mitigation strategies and comparing alternative drainage concepts.

This integrated modeling approach is consistent with USACE coastal system modeling guidance, which requires explicit representation of dynamic groundwater and tidal influences when evaluating drainage capacity and flood recession in coastal municipalities. The distributed hydrologic structure of MIKE SHE further supports SFWMD's requirement for demonstrating control of hydrologic inputs, including infiltration-excess vs. saturation-excess runoff, groundwater emergence, and the loss of unsaturated zone storage during storm events. The MIKE+ 2D module enables compliance with LOS evaluation criteria by producing spatially explicit flood-depth grids, extent mapping, and hydroperiod analysis, which are necessary for determining roadway accessibility, emergency vehicle thresholds, and structure exposure. The coupling of 1D, 2D, and groundwater domains ensures that the Village can evaluate not only magnitude-based flooding metrics but also process-level dynamics, such as flow reversals during high tide, local inflow/outflow connectivity, and sub-basin drainage patterns - information essential for designing distributed pump nodes, assessing drainage well performance, and developing cost-effective alternatives as required by the RFQ.

The combined system quantifies peak flood depths, flood volumes, time of inundation, flow paths, groundwater emergence, and the timing and magnitude of required discharge. These outputs are essential for screening decentralized drainage alternatives, comparing localized and system-level concepts, and supporting cost optimization.

The purpose of the modeling effort is to establish a reliable baseline understanding of Zone 1 hydrologic performance, identify flooding mechanisms and system bottlenecks, calibrate the model to observed events, and use these results to inform alternative drainage strategies aimed at reducing flood severity and improving resilience.

This project objective is consistent with the analytical requirements set forth in SFWMD's Environmental Resource Permit (ERP) Basis of Review, which mandates that stormwater system evaluations quantify watershed response, identify controlling hydraulic features, and demonstrate the adequacy of conveyance, storage, and discharge pathways under design conditions. The evaluation of flooding mechanisms - including groundwater emergence, tidal backpressure, and limited surface gradients - is also aligned with USACE EM 1110-2 hydrologic and hydraulic guidance, which emphasizes the need to analyze compound flooding effects and the interactions between rainfall and coastal water levels for low-lying barrier islands. Establishing a calibrated, physically based model ensures that alternative drainage concepts are tested under conditions that reflect both present-day and projected future hydraulic stressors, providing an analytically defensible foundation for selecting improvements that enhance long-term resilience, maintain roadway operability, and reduce structural flood exposure.

Model Domain, Grid Resolution, and Boundary Conditions

The model domain encompasses the entire island, distinguishing it from earlier drainage studies that restricted analysis to individual basins or right-of-way limits. The domain extends 10–20 ft offshore into Biscayne Bay and the Atlantic Ocean, incorporates northern wetlands, includes the full beach and dune system, and follows the southern hydrologic divide. This expanded boundary ensures complete representation of rainfall–runoff generation, groundwater gradients, inter-basin flows, tidal boundary controls, and storage processes throughout the island.

The use of a full-island domain reflects the modeling requirements associated with SFWMD regional-scale hydrologic evaluations and the USACE Coastal Storm Risk Management (CSRM) framework, both of which emphasize the necessity of capturing all relevant boundary conditions, inter-basin exchanges, and coastal interactions. By extending offshore, the model can apply dynamic tidal head boundaries, simulating how tide, mean sea level, and surge affect inland groundwater and surface-water conditions. Including wetlands and dune systems is critical for accurately representing natural storage, aquifer recharge, and hydraulic routing, which are required considerations under both ERP criteria and USACE environmental compliance processes. This domain configuration ensures that inland flooding predictions are not distorted by artificial boundary truncation, and it supports evaluation of alternatives that may modify discharge locations, drainage divides, or water table elevations across the island.

A 5-meter grid is used for the MIKE SHE groundwater domain, and a 5-foot resolution is applied to the MIKE+ 2D surface domain. Each surface cell is assigned its own land-use-specific hydraulic parameters, including Manning’s *n*, infiltration characteristics, depression storage, and overland leakage coefficients. Subsurface cells receive soil-type-based hydraulic conductivities, unsaturated-zone parameters, and drainage-level controls.

This dual-resolution configuration achieves the level of spatial fidelity expected in USACE coastal groundwater–surface water modeling and SFWMD integrated hydrologic evaluations, which require sufficient granularity to capture microtopographic depressions, street crowns, driveway sags, and shallow groundwater emergence. The 5-foot 2D mesh ensures that the model can resolve roadway-scale hydraulics governing localized ponding and overland conveyance, consistent with urban flood modeling best practices. The distributed assignment of hydrologic parameters complies with SFWMD’s expectation that land use, surface roughness, and soil characteristics be spatially explicit rather than generalized across broad drainage basins. The multi-layer subsurface parameterization reflects the structure of the Biscayne Aquifer and supports dynamic simulation of groundwater response, infiltration limits, and vertical/horizontal hydraulic gradients - critical elements for assessing drainage well performance, pump efficiency, and flood recession behavior.

Coastal boundaries are defined using observed NOAA tidal data, including the measured time series from the nearest NOAA station at Virginia Key. Tides are converted to NAVD88 and spatially interpolated along the full perimeter of the island, providing time-varying water levels for both MIKE SHE and MIKE+ boundary nodes. This approach allows tidal fluctuation, storm surge, sea-level rise scenarios, and groundwater-dependent backpressure to influence the inland model domain with full physical consistency. Future sea-level conditions are incorporated using NOAA Intermediate and Intermediate-High projections, reinforcing the resilience requirements of the RFQ.

This boundary-condition methodology satisfies key requirements established by USACE coastal engineering manuals, which stipulate that tidal and surge boundary conditions must be applied as time-

varying water surface elevations to evaluate accurate backwater effects, groundwater loading, and rainfall–tide compound flooding. The use of NAVD88 is consistent with SFWMD, Miami-Dade County, and USACE geodetic standards. Application of multiple SLR scenarios is consistent with both the USACE Sea-Level Change Curve Calculator and Miami-Dade Unified SLR Projection, ensuring the model captures mid-century operational stresses and reduced hydraulic gradients associated with higher mean water levels. Incorporating these dynamic coastal influences enables the model to simulate conditions that increasingly constrain Key Biscayne’s drainage performance, particularly the diminished role of gravity outfalls and the growing necessity for mechanical pumping and injection-based discharge strategies.

Data Sources and Integration

- Task 1 of the project - which has been fully completed - assembled all required datasets for the modeling framework, including:
- LiDAR-based topography (high-resolution DEM, contours, micro-depression mapping)
- Landscape and land-use data for parameterization of surface hydrology
- Soils, geotechnical borings, and infiltration parameters for defining the unsaturated and saturated zones
- Stormwater infrastructure inventory, including pipes, inlets, manholes, drainage wells, pump stations, and flow directions
- Finished floor elevations and right-of-way grades
- Rainfall records, including Hurricane Irma (2017), June 4–7, 2022, and local NOAA rainfall data
- Reference evapotranspiration time series, used to define the water balance under varying climatic conditions
- NOAA tidal and sea-level datasets, including annual mean sea-level observations and scenario projections
- SFWMD and USGS groundwater data, used for calibration and verification

The data assembly process completed under Task 1 satisfies foundational requirements articulated in SFWMD’s Applicant’s Handbook Volume II for hydrologic justification and in USACE EM 1110-2 series for hydraulic modeling. High-resolution LiDAR and elevation datasets allow precise delineation of flow paths and microtopographic depressions, which is essential in low-relief coastal municipalities where differences of a few inches govern inundation patterns. Incorporation of land-use data supports spatially explicit assignment of runoff coefficients, Manning’s roughness, and pervious/impervious distributions, ensuring compliance with SFWMD surface-water modeling standards.

Soils and geotechnical data improve representation of infiltration, groundwater recharge, and unsaturated-zone behavior, consistent with USACE groundwater modeling practices. Stormwater infrastructure data - pipes, inlets, manholes, drainage wells, and pump stations - meet the completeness criteria expected for municipal stormwater modeling and allow accurate replication of hydraulic controls, conveyance pathways, and system bottlenecks.

Rainfall records, including extreme events such as Hurricane Irma (2017) and the June 4–7, 2022 storm, provide essential calibration benchmarks that align with SFWMD recommendations for event-based model validation. NOAA tidal and SLR datasets supply the dynamic boundary conditions required for USACE coastal evaluations, capturing interactions between tidal forcing, groundwater rise, and reduced drainage gradients. SFWMD and USGS groundwater datasets support calibration of the groundwater table’s tidal and seasonal response, consistent with USACE expectations for coastal aquifer characterization.

By harmonizing all datasets to the NAVD88 datum and applying stringent quality control, the project establishes a regulatory-ready, internally consistent modeling database suitable for detailed hydrologic and hydraulic evaluations under Tasks 2 and 3.

These datasets have been processed, quality-checked, harmonized to NAVD88, and implemented into the MIKE SHE / MIKE+ coupled model. The modeling database is now fully operational and forms the analytical foundation for Tasks 2 and 3.

Calibration Simulations and Preliminary Results

Task 2 - Preliminary Simulations - is underway and foundational calibration and verification runs have been completed. Three events were selected to represent varying hydrologic conditions, rainfall intensities, and groundwater behaviors:

- Hurricane Irma (2017) – A high-intensity regional rainfall event coinciding with elevated tide and storm surge influences.
- June 4–7, 2022 Event – A severe rainfall event that produced widespread flooding across Key Biscayne and provides a strong observational benchmark for validating 2D overland routing and storage representation.
- SFWMD 5-yr, 24-hr Design Storm – Required by the RFQ for evaluating level-of-service performance and flood-duration thresholds.

For each event, the model successfully reproduced the basin wide hydrologic behavior observed during field inspections, historical records, high-water marks, drone imagery, and social-media documentation. The June 2022 simulation demonstrated excellent alignment with known flood-depth locations, including persistent depressions in Zone 1, tidal backpressure effects along the west boundary, and groundwater-driven loss of infiltration capacity in east-side dune zones. Hurricane Irma simulations captured the interaction of high rainfall intensity with storm-driven coastal water levels, confirming that tidal boundary conditions play a dominant role in Key Biscayne’s drainage response.

The selection of calibration events follows recognized best practices in SFWMD calibration guidance, which recommends validating hydrologic and hydraulic models using multiple storms representing different antecedent moisture conditions, rainfall intensities, and groundwater responses. Hurricane Irma allows calibration against conditions of combined storm surge, tidal loading, elevated groundwater, and intense rainfall - conditions consistent with USACE compound flood risk scenarios.

The June 4–7, 2022 event provides a high-fidelity benchmark for evaluating shallow overland flow, microtopography-controlled inundation, and groundwater emergence, all of which require accurate representation in MIKE SHE and MIKE+ to satisfy the RFQ’s requirement for localized flow analysis. The SFWMD 5-year, 24-hour design storm ensures compliance with RFQ-specified LOS criteria and is used to evaluate drainage system performance under regulatory design conditions.

The model's ability to reproduce basin-wide responses - including mapped flood extents, observed ponding depths, drainage system surcharging, and tidal backpressure effects - indicates successful calibration consistent with SFWMD and USACE expectations for model accuracy. The reproduction of tidal impacts during Irma further validates the integrated surface-groundwater modeling approach and confirms that future alternative evaluations will be hydrodynamically robust.

Flood maps have been generated for each calibration event, including peak depth, duration, flow direction, and recovery-time outputs. The maps reveal several recurring themes: surface flow paths follow micro-topography and are highly sensitive to small elevation differences; groundwater levels rise rapidly during storms, reducing effective storage and extending inundation; and interior roadways often become temporary conveyance channels, funneling runoff toward low points that lack positive drainage gradients.

These outputs - peak depth, duration, flow vectors, and recession times - are key performance indicators recognized in USACE urban flood modeling guidance and are required for demonstrating compliance with municipal LOS thresholds. The sensitivity of flow paths to microtopography reflects the necessity of using a 2D mesh of sufficient resolution, as mandated by modern hydrodynamic modeling standards for flat terrain. The rapid rise of groundwater during storm events aligns with Biscayne Aquifer behavior documented by USGS and SFWMD, confirming that infiltration-based drainage strategies have limited effectiveness when the unsaturated zone collapses during rainfall.

The identification of interior roadways acting as temporary conveyance channels is a critical engineering finding that supports the RFQ's requirement to evaluate alternative drainage solutions capable of intercepting runoff early and reducing hydraulic travel distances. These diagnostic products directly inform siting decisions for distributed pump nodes, localized drainage wells, and redesigned conveyance pathways.

Flooding Mechanisms Identified

Calibration and preliminary simulations reveal three principal drivers of flooding in Zone 1:

- Shallow groundwater and limited unsaturated storage, causing rapid transition from infiltration to saturation excess runoff.
- Tidal backpressure and reduced hydraulic head, limiting gravity discharge and causing inland retention even when rainfall subsides.
- Topographic micro-basins, where water accumulates and remains trapped unless actively pumped or intercepted by wells or distributed drainage features.

Flow-direction mapping shows that floodwaters often migrate counter to expected gravity paths under elevated tide conditions. This illustrates the need for drainage alternatives that minimize long overland or pipe conveyance distances before removal.

These identified flooding mechanisms directly correspond to hydrologic behaviors observed in coastal aquifers and low-relief environments documented in USACE coastal flood risk assessments and SFWMD regional groundwater studies. Shallow groundwater sharply reduces infiltration capacity, leading to saturation-excess runoff that must be accounted for when designing stormwater storage and conveyance elements. Tidal backpressure is recognized in USACE EM 1110-2-1417 as a dominant constraint on gravity drainage systems in coastal municipalities, mandating the need for mechanical conveyance where hydraulic head is insufficient. The presence of micro-basins underscores the need for localized interventions, such as distributed pump stations and drainage wells, which directly address sub-basin ponding characteristics and reduce reliance on long, flat conveyance pathways.

Implications for Alternative Drainage Analysis

- The modeling results support the RFQ requirement to evaluate a range of decentralized drainage strategies, including:
- Strategic placement of localized pump nodes at road confluences and micro-depressions
- Targeted installation or rehabilitation of deep injection wells (100–120 ft), with head-dependent injectivity evaluation
- Hybrid gravity–pump–well combinations to intercept runoff early
- Complementary green infrastructure where feasible
- Optimization of force main routing for overflow or fail-safe discharge

The RFQ requires consideration of alternative drainage strategies that explicitly respond to hydraulic, geometric, and regulatory constraints. Distributed pump-and-well systems are consistent with SFWMD ERP-based water-quality avoidance strategies, as injection wells minimize direct surface-water discharge while providing high-capacity vertical disposal. Evaluating head-dependent injectivity is aligned with FDEP Class V UIC permitting, which requires assessment of allowable injection head, groundwater mounding, and pretreatment requirements. Hybrid gravity-pump-well combinations allow interception of runoff at topographic depressions and provide redundancy under elevated tide conditions, consistent with USACE risk-informed design principles. Force main optimization ensures continuity of operations under exceedance conditions, preventing uncontrolled surface discharge and supporting compliance with water-quality protection standards, including Outstanding Florida Waters (OFW) criteria applicable to Biscayne Bay.

Summary and Path Forward

Completion of Tasks 1 and 2 satisfies the foundational steps outlined in the RFQ and provides a calibrated, defensible modeling environment consistent with County, SFWMD and USACE analytical expectations. The availability of flood maps, flow directions, and groundwater response outputs for multiple calibration events confirms that the model adequately replicates the hydrologic dynamics governing Zone 1.

Task 3 will rely on this validated platform to evaluate centralized pumping systems, hybrid configurations, and distributed pump-and-injection-well strategies. Performance will be assessed using LOS thresholds, regulatory design storms, and SLR boundary conditions. Cost implications will be analyzed consistent with capital improvement planning and risk-informed prioritization. The resulting phased strategy will align with Village objectives, permitting pathways, water-quality requirements, and long-term resilience planning.

1 INTRODUCTION

Since incorporation, the Village of Key Biscayne has undertaken a series of stormwater planning efforts - beginning with the 1993 Stormwater Master Plan, followed by successive updates in 2001, 2011, 2015, and 2024 - each progressively refining the community's understanding of flooding mechanisms, stormwater infrastructure performance, and the constraints imposed by the island's low topography and coastal boundary conditions. These planning documents form a historical continuum: each update builds upon earlier work, corrects or expands the technical foundation, and incorporates improved data, changes in hydrology, modeling tools, and regulatory expectations. Across all efforts, studies confirm that gravity drainage is unreliable on a barrier island with limited relief; vertical conveyance and groundwater interaction dominate recession behavior; gravity drainage alone cannot sustain long-term performance; tidal backflow and sea-level rise increasingly impair outfalls; and pump-assisted drainage is essential for maintaining roadway access and structural safety.

These reports document the water-quality implications of surface discharges. Under FDEP stormwater regulations, Miami-Dade County National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) requirements, and SFWMD Environmental Resource Permit (ERP) criteria, any stormwater directly discharged to surface waters must provide treatment of the "first flush" (first one inch or equivalent) to remove pollutants, sediments, and nutrients. These requirements substantially constrain the feasibility of new or expanded gravity outfalls to Biscayne Bay. The historical evolution of VKB's program shows that early use of drainage wells and deep injection wells was driven by both physical limitations of gravity drainage and the need to avoid water-quality discharge requirements associated with outfalls.

1.1 1993 Stormwater Management Master Plan – Williams, Hatfield & Stoner (WHS)

The 1993 Stormwater Master Plan was the Village of Key Biscayne's first island-wide assessment prepared after incorporation. At the time, the Village had limited documentation of existing drainage infrastructure and only a basic understanding of how rainfall, tides, and shallow groundwater interacted with the island's low elevations. The plan established the Village's initial stormwater framework, defined drainage basins, and outlined a capital improvement program that guided construction through the mid-1990s.

The plan documented existing conditions, identified areas of frequent flooding, and proposed a basin-based approach to improvements. The analysis relied on the survey and modeling tools available at the time, including centerline profiles and simplified hydrology and hydraulic methods. These inputs supported development of the Basin 1–8 improvements, which introduced new pipes, inlets, exfiltration systems, gravity wells, deep injection wells, and several pump stations. This infrastructure formed the foundation of the Village's present-day drainage network and initial GIS stormwater inventory.

The plan identified the island's limited hydraulic relief and tidal influence as key constraints. With most ground elevations between approximately 3.5 and 6 feet NAVD, gravity drainage opportunities were limited, and backflow from Biscayne Bay was common during high tide. Under these constraints, the plan concluded that vertical disposal through wells, supplemented where necessary by pumping, offered the most practical drainage strategy for a built-out barrier island with limited right-of-way and no feasible gravity outlets.

Subsequent evaluations in 2011, 2015, and 2024 confirmed both the strengths and limitations of the 1993 framework. While the basin structure and improvements provided an organized drainage system, later studies noted issues including shallow and maintenance-intensive wells, incomplete basin delineations, and design criteria that did not consider tidal variability or sea-level rise. These updates also documented reduced performance of older well systems under higher groundwater conditions.

Overall, the 1993 plan established the Village's first systematic drainage program and set the long-term direction toward distributed vertical disposal and pump-assisted systems. Later work has refined this approach, but the core finding remains consistent: gravity drainage alone is not adequate for the island's topography and tidal setting, and stormwater management must rely on strategically placed wells and mechanical conveyance to maintain performance under current and future coastal conditions.

1.2 2011 Stormwater Master Plan Update – Tetra Tech

The 2011 Stormwater Master Plan Update was the Village of Key Biscayne's first comprehensive reassessment of the 1993 plan using modern topography, GIS datasets, and dynamic modeling tools. The update consolidated available system information into a GIS-based stormwater atlas, standardizing elevations to NAVD88 and creating the Village's first complete inventory of pipes, inlets, wells, pump stations, and outfalls.

The study introduced a new InfoSWMM hydrologic-hydraulic model with refined LiDAR-based basin delineations and subcatchments. Design storms were based on SFWMD rainfall depths and NRCS distributions, and the analysis emphasized level-of-service assessment for the 10-year, 72-hour event. High-tide tailwater conditions were incorporated, reflecting observed constraints at gravity outfalls.

The model identified three principal problem areas - East Drive, Fernwood/West Heather, and Ridgewood/West Enid - where flooding exceeded LOS thresholds. Results showed that shallow exfiltration and older auger wells provided limited relief under high groundwater conditions. Updated drainage wells demonstrated substantially higher performance, consistent with redevelopment testing conducted around 2010.

Three classes of improvements were evaluated: enhanced exfiltration, tidal backflow prevention, and new drainage wells. Exfiltration enhancements were limited by right-of-way and groundwater conditions; flap gates reduced tidal inflow but did not materially improve rainfall-driven flooding. New drainage wells provided the most consistent LOS improvement across all modeled scenarios. The update therefore recommended targeted well installations supported by selective tidal control. These improvements were organized into a phased capital program with associated cost estimates.

The 2011 plan advanced the Village's technical capabilities by integrating LiDAR, dynamic modeling, and updated system inventory into a unified framework. Its primary limitations included a focus on three localized basins, limited calibration data, and the absence of explicit sea-level rise evaluation. Nonetheless, the update reinforced several key findings: gravity drainage is constrained by tides and low elevations; well-based disposal remains a necessary component of the system; and localized flooding patterns are driven by the combined effects of topography, groundwater, tidal conditions, and well performance.

The study provided the analytical basis for the subsequent 2015 and 2024 evaluations, supporting the continued transition toward a distributed drainage and well-supported conveyance system appropriate for future coastal conditions.

1.3 2015 Implementation of SWMP – EAC Consulting

The 2015 Stormwater Master Plan prepared by EAC Consulting represented a significant transition in the Village of Key Biscayne’s stormwater planning efforts. Compared to the 2011 Tetra Tech update, which focused on a refined system inventory and three localized drainage concerns, the 2015 plan - procured under RFQ 14-02 - was intended to evaluate stormwater conditions at a village-wide scale. The goal was to integrate improvements constructed after 2011, address updated regulatory requirements, incorporate sea-level-rise (SLR) considerations, and develop a comprehensive capital improvements plan (CIP) with conceptual designs, cost estimates, and a multi-year implementation schedule.

The 2015 study expanded analytical scope to include hydrologic and hydraulic evaluations across all basins within the island. Level-of-service (LOS) criteria were refined to align with Miami-Dade County Department of Transportation and Public Works (DTPW) and Regulatory and Economic Resources (RER) standards. Problem areas were ranked to support a two-tier improvement framework addressing both tidal flooding (Tier 1) and long-term drainage infrastructure needs (Tier 2). EAC incorporated SLR into boundary conditions for the first time in any Village study, advancing beyond the 1993 and 2011 plans. The analysis also applied updated regulatory requirements for water quantity and quality consistent with SFWMD, FDEP, DERM, and FDOT permitting pathways.

The LOS framework developed in 2015 refined earlier concepts by incorporating roadway passability criteria, ponding thresholds near residential structures, and protection of building pads to at least the 100-year flood elevation. EAC expanded the contributing drainage area from the former “ROW + 15 ft” assumption to ROW + 25 ft on each side, acknowledging that a broader area influences runoff characteristics under modern rainfall conditions. NAVD88 was adopted as the vertical datum to maintain consistency with Village, County, State, and federal datasets.

SFWMD rainfall depths and NRCS Type II distributions for the 5-, 10-, 25-, and 100-year, 72-hour design storms were applied consistently across 14 delineated basins, enabling systemwide comparison of LOS conditions. Regulatory criteria related to first-flush retention, water-quality treatment, structural thresholds, and a 25-year, 72-hour discharge standard were incorporated throughout the analysis. SLR projections to approximately 2040 were adopted from USACE and regional sources to adjust tidal tailwater elevations in the hydraulic model, recognizing that elevated sea levels reduce gravity drainage capacity and increase reliance on mechanical conveyance.

EAC collected data from SFWMD, USGS, NOAA, NRCS, USACE, Miami-Dade County, and Village as-builts, supplemented by photographic documentation. Field observations of tidal and rainfall-driven ponding along Sonesta Drive, West Heather Drive, and the K-8 School corridor were used to validate modeling assumptions and refine representations of drainage wells, pipe connectivity, and tidal influences.

For modeling, InfoSWMM was used beginning with the 2011 model but refined extensively to represent system changes. Basin boundaries were updated using LiDAR. Pipe and well characteristics were corrected to reflect lined pipes and revised hydraulic openings. Well performance curves were updated using redevelopment test data. Tailwater boundary conditions were revised to reflect elevated tide

stages under SLR projections. Three modeling scenarios were developed: the 2015 Control Model representing existing conditions; the Tier 1 Model evaluating high-tide mitigation at 20 outfalls; and the Tier 2 Model incorporating full infrastructure improvements including wells, pump stations, conveyance upgrades, and green infrastructure. Continuity errors remained within approximately ± 2 percent, indicating numerical stability appropriate for LOS assessment.

The modeling identified 14 problem corridors consistent with Miami-Dade RER procedures, where the 5- and 10-year storms produced ponding at or above roadway crowns or near private properties. Results from the 2015 Control Model indicated that tidal influence created recurrent nuisance flooding, increased pump cycling, and backpressure on gravity wells. These conditions were consistent with field observations and confirmed that tidal backflow and elevated groundwater levels were primary factors reducing system performance.

The study's two-tiered improvement strategy offered a structured progression of upgrades. Tier 1 proposed installation of backflow prevention devices - including flap gates, duckbill valves, and inline check valves - at 20 outfalls and Crandon Boulevard tie-ins to reduce tidal inflow, limit saltwater intrusion, and improve overall performance of wells and conveyance systems by decreasing tidal backpressure. These measures were considered cost-effective and suitable for short-term deployment.

Tier 2 provided long-term improvements including redevelopment and installation of gravity and injection wells with long-term capacities of approximately 850 gpm per foot of head, pump station retrofits converting two stations to submersible pump systems capable of approximately 22 cfs each, pipe upgrades and new conveyance routes to redistribute flows, and targeted use of green infrastructure for runoff attenuation and water-quality enhancement. Combined Tier 1 and Tier 2 measures demonstrated significant reductions in flood depth and extent across all problem areas under both existing and SLR conditions.

Capital costs in 2015 dollars totaled approximately \$24.86 million, with Tier 1 improvements estimated at approximately \$845,519 and Tier 2 improvements at approximately \$24 million. Costs included construction, mobilization, contingencies, incidental roadway restoration, engineering, construction administration, and CEI. EAC prepared a Ten-Year CIP phasing improvements over a decade to align with funding cycles, permitting schedules, and coordination with Miami-Dade County and other agencies. A parallel stormwater utility analysis identified the need for rate adjustments, acknowledging that major improvements would require external funding to avoid disproportionate impacts on residents.

The 2015 study provided several analytical strengths. It represented the first village-wide stormwater analysis incorporating SLR within tidal boundary conditions, evaluated LOS consistently across all basins, and aligned criteria with SFWMD, FDEP, FDOT, and Miami-Dade standards. It also advanced planning by integrating green infrastructure considerations. The study's limitations, noted in subsequent evaluations, included continued reliance on gravity and injection wells rather than comprehensive mechanical pumping systems, substantial capital costs relative to municipal scale, increased operational complexity, and an SLR planning horizon limited to 2040 rather than longer NOAA projections now commonly used.

Despite these limitations, the 2015 plan was a critical milestone in advancing the Village's stormwater program. It demonstrated that stormwater management cannot be addressed at isolated locations; it must be evaluated comprehensively considering tidal effects, groundwater dynamics, and system interconnectivity. The framework developed in 2015 significantly influenced subsequent planning efforts

and supported ongoing movement toward distributed pumping and injection well systems as the Village continues adapting to future coastal conditions.

1.4 AECOM 2024 Alternative Analysis Drainage Assessment

The most recent planning effort for the Village of Key Biscayne's stormwater system is the AECOM 2024 analysis, commissioned to reassess stormwater management strategies in light of updated sea-level-rise projections, revised level-of-service expectations, and the capital requirements associated with large-scale infrastructure improvements. Building on the Village's previous studies - including the 2011 and 2015 master plans and the detailed Zone 1 design effort - the 2024 scope focused on confirming the appropriate design storm and LOS criteria, developing system-scale alternatives consistent with a pumped, zone-based drainage framework, and evaluating these alternatives using updated hydrologic and hydraulic conditions.

AECOM's work included the development and testing of multiple drainage configurations intended to address the island's long-term operational needs under rising groundwater and tidal conditions. The study emphasized the assessment of phased, pump-assisted drainage districts, integration of redundant conveyance pathways, and identification of system elements required to support a fully pumped network. In addition, the study refined prior modeling components, incorporated updated regulatory considerations, and produced revised project cost estimates and phasing recommendations to assist with future budget planning and external funding pursuits.

1.4.1 Purpose, Scope, and LOS Framework

The study objectives consisted of four primary elements. AECOM was first tasked with confirming the appropriate design storm and level of service (LOS) criteria required to support long-term stormwater planning under projected 2060 climate conditions. The second objective involved evaluating multiple system-scale drainage configurations - identified as Alternatives 1 through 4 - to assess how varying pump capacities, outfall arrangements, and inter-zone conveyance connections would perform under future sea-level-rise scenarios. The third objective focused on optimizing a preferred alternative across eight major stormwater zones, including associated subzones and special facilities, to achieve target LOS while maintaining control of capital expenditures. The final objective translated the preferred system configuration into updated cost estimates and phasing recommendations suitable for long-range budgeting and funding coordination [ref 4].

AECOM adopted a 10-year, 24-hour design storm with a total rainfall depth of approximately 7 inches, consistent with SFWMD Basis of Review Volume IV rainfall depths. This represented a shift from the 72-hour storm events applied in the 2011 and 2015 studies and reflects a contemporary emphasis on evaluating shorter-duration, higher-intensity events that are increasingly represented in regional rainfall statistics and IDF analyses [ref 4]. The LOS framework was derived from Resolution 2024-19 and subsequent clarifications, which define roadway performance in terms of allowable depth and duration of flooding rather than requiring fully dry conditions at all times.

Within this framework, system performance is based on pump capacities ranging from 1 to 2 inches per hour, with the primary objective of maintaining roadway passability for emergency response. For the 10-year, 24-hour event, the LOS defines that at a pumping rate of 1 inch per hour, flooding may reach up to 12.5 inches above the lowest roadway crown for up to 3.5 hours. At 2 inches per hour, allowable

flooding is reduced to 9 inches above crown for a duration of up to 1.25 hours [ref 4]. This approach establishes LOS parameters that balance hydraulic performance with capital and operational feasibility and recognizes that limited-duration ponding may occur under design-level conditions.

1.4.2 Sea-Level Rise, Tailwater, and Roadway Elevation Criteria

A central element of the AECOM study is the explicit use of a 2060 planning horizon based on the NOAA Intermediate High sea-level-rise scenario. Relative to current mean high water (MHW), this scenario represents approximately 2.5 feet of projected sea-level rise. For modeling purposes, the effective tailwater elevation was set at 2.63 ft NAVD, corresponding to MHW plus the projected 2060 rise and an allowance for typical seasonal and meteorologic variability [ref 4]. This boundary condition governs the elevation at which outfalls and gravity conveyance features can operate and reinforces the requirement for pump-assisted discharge under future coastal conditions.

The study also reexamined roadway elevation criteria to ensure consistency between future roadway reconstruction and long-term flood protection objectives. The minimum design low-crown elevation was increased to 3.26 ft NAVD, compared to approximately 2.85 ft in prior planning documents. This update reflects the integration of NOAA sea-level projections with FDOT freeboard practices and is intended to preserve hydraulic margin under elevated tailwater conditions while maintaining roadway elevations within limits acceptable to Village policy and neighborhood context [ref 4]. AECOM noted that roadway raising can alter relative elevations between streets and adjacent building pads; therefore, LOS evaluations were tied to finished-floor elevation analyses to ensure that roadway modifications do not inadvertently increase structural flood risk.

1.4.3 Zones, System Concept, and Modeling Framework

To manage system complexity and support phased implementation, the Village is organized into eight primary stormwater zones, with additional subzones such as Zones 2A and 2B and specific facilities including the Yacht Club pump station. Each zone is planned to operate with its own pump station and discharge configuration. The zones are also interconnected to allow coordinated operation and optimization of outfall capacity at the system scale [ref 4]. This zoning structure is consistent with the Village's earlier basin delineations but links each service area to a defined pumped conveyance and controlled discharge point.

AECOM performed hydraulic simulations using an updated ICPR4 model, incorporating prior InfoSWMM modeling and the detailed Zone 1 design. ICPR4 was used to simulate storm-event conditions under the 2060 tailwater boundary and to evaluate the performance of multiple pumping configurations in response to the 7-inch, 10-year design event.



Figure 1 Outline of Analytical Zones

Data inputs for the model included the 2011 and 2015 hydrologic and hydraulic models, subsequent zone-level design models, updated LiDAR and survey information, record drawings of existing and recently improved stormwater infrastructure, NOAA sea-level-rise projections and associated curves, and SFWMD rainfall statistics and IDF analyses for Miami-area gauges [ref 4].

Using these inputs, AECOM conducted a statistical rainfall assessment to support pump rates in the range of 1 to 2 inches per hour and to evaluate how different pumping capacities affect ponding depth and duration during the design storm. For each of the eight stormwater zones, ICPR simulations were completed for multiple alternative configurations that varied pump capacity, the number and location of

outfalls, and the degree of hydraulic interconnection between zones. Alternatives were assessed in terms of LOS performance, constructability, phasing potential, and approximate cost, consistent with the study's combined technical and financial planning objectives.

1.4.4 Major Findings

The model results indicate that continued reliance on the existing combination of gravity drainage and injection wells, even with past improvements, does not meet the updated LOS under 2060 sea-level-rise conditions. Elevated tailwater reduces the hydraulic head available for gravity-driven systems, and the long-term effectiveness of wells becomes less certain as groundwater levels rise and regulatory constraints increase [ref 4]. AECOM's discharge-capacity assessment shows that the current system provides, on average, approximately half of the capacity needed to achieve LOS targets for the 10-year, 24-hour event. The deficiency varies by zone, but the overall system does not maintain adequate discharge capability under projected future conditions.

Zone-level evaluations demonstrate that each of the eight zones contains some combination of low ground elevations, restricted outfall conditions, and limited or absent pump capacity, resulting in ponding depths and durations that do not meet LOS criteria when SLR is included in the analysis. In Zone 1, encompassing the K-8 school and surrounding neighborhoods, simulated water levels exceed the target crown elevation during the 7-inch design event when evaluated with the existing infrastructure, indicating the need for additional discharge capacity and potentially targeted roadway elevation adjustments.

The study further evaluates the interaction between roadway elevation changes and adjacent structure elevations. Raising crown elevations to 3.26 ft NAVD improves roadway LOS performance but may alter localized ponding patterns if not coordinated with finished-floor elevation conditions. AECOM therefore incorporated structure-specific elevation information to ensure that roadway improvements do not create adverse impacts at nearby properties, emphasizing the need for integrated roadway and building-level protection under future sea-level conditions [ref 4].

1.4.5 Alternatives and Recommended System Configuration

AECOM evaluated four primary system alternatives, each reflecting a different level of pumping capacity, redundancy, and hydraulic interconnection. Alternative 1 established a baseline pumped configuration with distributed pump stations and outfalls assigned to each zone. Pump capacities were modest and inter-zone connectivity was limited, resulting in constrained LOS margins in several areas. Alternative 2 increased pump capacities and refined outfall arrangements, producing improved hydraulic performance with an estimated base contract cost of approximately \$290 million. Alternative 3 introduced additional redundancy through enhanced pumping and upgraded outfalls, increasing the estimated base contract cost to approximately \$319 million [ref 4].

The study identified Alternative 4 as the preferred configuration. This option is an optimized zone-based pumped system that builds on the baseline concept while refining pump capacities, outfall locations, and inter-zone connectivity to meet LOS requirements for the 7-inch, 10-year event. The configuration is structured to support phased implementation, allowing the Village to advance improvements on a zone or corridor basis subject to funding availability. Alternative 4 focuses on strategic placement of pump stations to maximize hydraulic benefit and avoid unnecessary duplication of infrastructure. The

configuration retains the capacity to adjust pumping rates between 1 and 2 inches per hour based on future budget considerations, risk tolerance, and evolving rainfall or sea-level projections [ref 4].

The selection of Alternative 4 is based on its balance of performance, cost, and implementation flexibility. It satisfies LOS criteria for the design storm, enhances system resilience under projected 2060 sea-level conditions, and offers a clear phasing structure relative to alternatives that incorporate higher levels of redundancy. The configuration is also compatible with prior design work for Zone 1 and conforms to Council direction regarding limitations on roadway elevation increases.

1.4.6 Costs, Phasing, and Implementation Considerations

AECOM prepared a Class 4 Opinion of Probable Construction Cost (AACE) for the optimized Alternative 4 configuration. The estimated base contract cost for all zones is approximately \$293.9 million, with a total project cost of roughly \$369.8 million in 2024 dollars when contingency, soft costs, and owner management are included [ref 4]. Costs were itemized by zone to provide detailed insight into investment requirements. Zone 1 has an estimated base cost of approximately \$49.0 million and a cost with contingency of \$63.7 million. Zones 2A and 2B have estimated base costs of approximately \$16.2 million and \$31.6 million, respectively. As a Class 4 estimate, AECOM notes that actual construction costs may vary from -30 percent to +50 percent due to the preliminary level of design development.

Phasing was recommended on a zone-by-zone basis, beginning with priority areas such as Zone 1 and other corridors previously identified as locations with recurrent flooding concerns. The phased structure is intended to align construction with available funding cycles, permitting and coordination needs, and construction sequencing considerations. This approach also allows the Village to implement improvements incrementally while pursuing grants and other external funding sources to support long-term program delivery [ref 4].

1.4.7 Interpretation and Next-Step Considerations

The 2024 AECOM analysis provides several substantive contributions to the Village's stormwater planning program. It establishes stormwater management within a long-term resilience framework by applying a 2060 planning horizon, the NOAA Intermediate High sea-level-rise scenario, and a modern 10-year, 24-hour design event. The LOS framework reflects a performance standard that is both technically supportable and financially achievable, allowing for limited-duration, shallow roadway flooding provided that emergency access is maintained and flooding durations remain within specified limits. The zone-based pumped system represents a structured progression from prior reliance on gravity drainage, wells, and small pumps, offering a coherent approach to increasing discharge capacity under elevated groundwater and tidal conditions. The alternatives analysis clarifies the cost-performance relationships among the options and identifies an optimized configuration that is technically defensible and internally consistent. In addition, the Class 4 AACE cost framework and detailed zone-level breakdowns provide a basis for budgeting, grant coordination, and long-range capital planning.

The scale of investment associated with the optimized alternative - approximately \$370 million - also underscores the need to evaluate cost management strategies and potential supplemental drainage measures. While not a critique of the pumped system concept, the magnitude of capital cost warrants examination of additional approaches that may reduce sole reliance on large pump stations. These measures may include distributed drainage wells paired with smaller pump facilities, expanded use of green infrastructure for runoff attenuation and water-quality benefit, targeted roadway elevation and

localized storage improvements, and non-structural practices such as source controls, private-lot retrofits, or updated redevelopment standards.

The evolving regulatory environment, including stormwater water-quality requirements, first-flush retention standards, and the protection of Biscayne Bay as an Outstanding Florida Water, indicates that future designs will need to incorporate water-quality treatment or avoidance strategies in parallel with capacity expansion. This may require integrating pumped zone systems with decentralized wells, treatment BMPs, or infiltration features that reduce pollutant loads and improve permitting feasibility.

Accordingly, the 2024 AECOM analysis should be viewed not only as a hydraulic system evaluation but also as a foundation for developing a combined approach in which a robust pumped backbone is supplemented by distributed drainage and water-quality enhancements. This combined framework supports a resilient, cost-effective, and regulatory-compliant stormwater system for Key Biscayne under future coastal conditions.

1.5 AECOM 2025 Tech Memo: Zone 1 Baseline Stormwater Modeling Results

The AECOM 2025 Technical Memorandum for Zone 1 has a deliberately limited scope. Its primary function is to present a single results table and a corresponding inundation-depth figure summarizing modeled water levels and recovery times within the Zone 1 drainage area for a defined baseline scenario [ref 5]. The memorandum is characterized as a planning-level baseline rather than a design or permitting document. Its purpose is to support comparison of assumptions and criteria between the Village's long-range 2060 design approach and a more constrained 2050 baseline, and to provide an order-of-magnitude indication of the pumping capacities that may be required under differing design and regulatory conditions [ref 5].

1.5.1 Purpose, Criteria Comparison, and Planning Context

The memorandum centers on a comparison between two distinct sets of criteria: the reference criteria, which correspond to the current Zone 1 project design and the planning posture documented in the 2024 Drainage Assessment, and the baseline criteria, which define the specific scenario modeled for planning purposes [ref 5].

The reference criteria reflect the Village's adopted stormwater planning framework. The planning horizon extends to 2060, consistent with the AECOM drainage assessment. Sea-level rise is represented using the NOAA Intermediate-High projection, and the design storm is the SFWMD 10-year, 24-hour event with a total rainfall depth of 7 inches [ref 5]. The residential contributing area is assumed to extend 100 feet beyond the right-of-way, capturing runoff from private parcels tributary to the Village's system. LOS is defined in two stages: an initial stage with 1 inch per hour of pumping capacity, permitting up to 12.5 inches of ponding above the lowest crown elevation for up to 3.5 hours; and an ultimate stage with 2 inches per hour of pumping, permitting up to 9 inches above crown for up to 1.25 hours [ref 5]. The minimum low crown elevation is set at 3.26 ft NAVD88, consistent with the 2024 report [ref 5].

The baseline criteria are intentionally less conservative. The planning horizon is 2050, and SLR is based on the NOAA Intermediate scenario. The design storm is the SFWMD 5-year, 24-hour event with a rainfall depth of 6 inches [ref 5]. The contributing area is limited to 25 feet beyond the right-of-way. LOS

is defined as a single threshold permitting up to 12 inches of ponding above the lowest crown elevation for up to 3.5 hours, without distinguishing between initial and ultimate pumping rates [ref 5]. Drainage pipe sizes remain fixed at the current/proposed Zone 1 design diameters, consistent with Village direction to hold conveyance sizing constant at this stage for cost control [ref 5].

AECOM identifies an important contextual distinction arising from these differences. Because the 2050/NOAA Intermediate scenario corresponds to a lower design groundwater elevation than the 2060/NOAA Intermediate-High posture, the modeled soil column exhibits greater available storage and percolation capacity during the design event. This reduces both the volume and rate of runoff entering the drainage system [ref 5]. The 2024 Drainage Assessment documents the Village's adopted policy to use NOAA Intermediate-High through 2060 for planning and design [ref 4]. Accordingly, the baseline scenario presented in the memorandum should be interpreted as a planning sensitivity relative to the more conservative design posture, rather than a replacement for it.

1.5.2 Methodology and Delivered Outputs

The memorandum is not intended to serve as a full modeling report and therefore does not restate the model setup, input datasets, or calibration procedures. It relies on the existing model framework and applies the baseline criteria adjustments described previously. The purpose is to present the resulting inundation stages, recovery times, and pump-capacity implications for Zone 1 while maintaining conveyance at the current design pipe sizes [ref 5].

AECOM's deliverables in the memorandum consist of Table 1, which summarizes maximum inundation stages and associated recovery times for each modeled Zone 1 basin (VKB-6, -12, -26, -31, -32, -33, and -34); Figure 1, which presents an inundation-depth map showing the spatial distribution of ponding under the baseline scenario; and several reference figures illustrating existing and proposed system layouts and inundation patterns for context [ref 5]. The presentation format is intended to convey baseline system behavior in a concise and accessible manner without the need for a complete technical report.

1.5.3 Major Modeling Results

The principal result of the memorandum concerns pumping-capacity requirements under the baseline assumptions. Using a 2050 planning horizon, the NOAA Intermediate sea-level-rise projection, the SFWMD 5-year/6-inch design storm, and existing Zone 1 pipe sizes, AECOM determined that the Village's LOS can be met with an estimated pumping capacity of approximately 57 cfs (about 25,600 gpm) [ref 5]. AECOM notes, however, that this value is not a design-level estimate because the conveyance system was not resized to achieve cleansing velocities or to reflect typical design storage characteristics. Retaining pipe diameters larger than design-true values increases internal storage and reduces flow velocities, which artificially lowers simulated ponding depths during a short-duration storm event [ref 5].

To address this limitation, AECOM provides a planning-level sensitivity estimate indicating that, if the pipe network were resized to typical design diameters and velocities, the pump capacity needed to meet LOS would likely fall in the range of 90 to 100 cfs (approximately 40,400 to 44,900 gpm) [ref 5]. This estimate is not based on a separate model run but represents a reasonable expectation informed by hydraulic principles and prior design analyses.

Table 1 summarizes inundation and recovery characteristics for the Zone 1 basins evaluated in the memorandum. The warning stage, corresponding to the lowest roadway crown elevation, is 2.03 ft NAVD88. The alert stage, defined as 12 inches above crown, is 3.03 ft NAVD88. Modeled maximum inundation stages range from approximately 2.79 to 2.99 ft NAVD88, and recovery times to below the warning stage are approximately 0.75 hours (45 minutes) [ref 5]. Under the baseline assumptions, peak water levels remain below the alert stage, and ponding durations remain within the 3.5-hour LOS limit established for the scenario [ref 5].

1.5.4 Constraints and Planning-Level Limitations

An important aspect of the Technical Memorandum is its clear identification of limitations associated with the baseline scenario. AECOM states that the scenario is not suitable for permitting or final design and provides the technical basis for this conclusion.

The first limitation concerns the reduced contributing area assumption (ROW + 25 ft). This approach excludes a portion of private-property runoff that is currently or historically routed to the Village's drainage system. Because adjacent property owners hold the right to discharge to the right-of-way, regulatory agencies would not accept a model that omits tributary flows from these parcels for permitting or design purposes [ref 5].

The second limitation relates to the retention of existing, larger-diameter pipes without application of standard cleansing-velocity design criteria. Maintaining these larger diameters increases pipe storage and reduces flow velocities relative to a system designed with optimized conveyance sizes. This condition reduces simulated peak water levels and lowers the apparent pump capacity required to meet LOS when compared to a design-true network configured for hydraulic efficiency and long-term maintenance needs [ref 5].

For these reasons, the memorandum specifies that the baseline scenario is appropriate only for comparative planning purposes, such as evaluating criteria trade-offs and estimating pump-capacity ranges, and should not be used directly for permitting or for development of detailed construction documents [ref 5].

1.5.5 Implied Next Steps and Use of Results

Although the Technical Memorandum does not advance a full set of alternatives, its discussion identifies the modifications required for the baseline scenario to advance toward a design-ready basis. AECOM indicates that future modeling intended to support permitting should expand the contributing-area assumptions so that private parcels discharging to the right-of-way are fully represented, resize the conveyance network to design-level diameters and velocities or explicitly account for the influence of pipe storage and cleansing-velocity criteria on pump sizing, and treat a pumping range of 90 to 100 cfs as the appropriate sensitivity band once conveyance is adjusted, as this capacity is expected to maintain LOS under design-constrained conditions [ref 5].

The memorandum also aligns conceptually with the Village's long-range design posture. The 2024 Drainage Assessment specifies the NOAA Intermediate-High projection through 2060 and identifies pumping infrastructure targeted to 1 to 2 inches per hour as the evolving LOS framework [ref 4]. Accordingly, while the 2025 baseline scenario uses a 2050 horizon and the NOAA Intermediate

projection, its primary value is in illustrating how pump capacity and LOS vary under less conservative assumptions relative to the formally adopted 2060 baseline.

The memorandum's primary actionable output is the order-of-magnitude pumping capacity - 57 cfs under the baseline conditions, with a planning sensitivity of 90 to 100 cfs when conveyance is resized - and the explicit statement that the baseline scenario is not suitable as a permit-ready basis [ref 5].

The document identifies limitations associated with the reduced contributing area and non-resized conveyance network, both of which decrease the apparent pumping requirement. The memorandum also highlights the expected increase in required pump capacity when design-level conveyance is implemented, providing useful sensitivity information for budgeting and risk management even in the absence of a fully recalibrated model.

The memorandum recognizes that the baseline assumptions are structurally more optimistic than the Village's adopted 2060 Intermediate-High planning standard. A less stringent design storm (5-year/6-inch) and a shorter horizon with a lower projected groundwater elevation naturally reduce modeled system loading compared to the design posture documented in the 2024 Drainage Assessment [ref 4, ref 5]. AECOM notes that the two modeling simplifications - the reduced contributing area and the use of larger pipes without cleansing-velocity constraints - further act to understate the required pumping capacity, although they are acceptable within the context of a planning-level exercise when properly disclosed [ref 5].

In summary, the AECOM 2025 Technical Memorandum provides a concise assessment of Zone 1 baseline performance under defined assumptions. It identifies pumping capacity ranges, documents how modeling simplifications influence the results, and distinguishes between planning-level and permit-ready analysis. When used as intended, it supports criteria comparison, risk framing, and early budgeting while leaving room for more detailed modeling consistent with the Village's adopted 2060 sea-level-rise and LOS framework.

- **References for this section**

1. [ref 4] AECOM. *Alternative Analysis Drainage Assessment – Village of Key Biscayne*. December 23, 2024.
2. [ref 5] AECOM (Erik M. Alcantara, PE). *Zone 1 Baseline Stormwater Modeling Results (Tech Memo / Baseline Stormwater Model Results Memo)*. October 8, 2025.

2 TECHNICAL APPROACH

The Village of Key Biscayne has initiated the Zone 1 Alternative Stormwater Modeling and Planning effort to evaluate existing flooding conditions, characterize hydrologic and hydraulic controls within the K-8 Basin, and develop a technical basis for future drainage improvements consistent with RFQ requirements for alternative analysis, cost reduction, and localized flood mitigation. The study area, designated as Zone 1 in RFQ #2025-13, includes the residential and institutional neighborhood surrounding the Key Biscayne K-8 Center. This basin has experienced recurring stormwater ponding during moderate and high rainfall events, influenced by shallow groundwater conditions, tidal boundary effects, and aging stormwater infrastructure.

The Village identified the need for updated, high-resolution modeling to quantify existing performance under present and future conditions and to systematically evaluate alternative drainage strategies capable of meeting LOS and resilience requirements while managing capital and operating costs. The RFQ specifies the need to document how groundwater conditions affect surface drainage, to determine flow directions during flooding, and to assess how these processes occur within Zone 1 and in areas previously identified as vulnerable in earlier planning studies [ref 4].

Earlier efforts—including the 2011 Tetra Tech Stormwater Master Plan, the 2015 EAC Stormwater Master Plan and Hydrologic and Hydraulic Analyses, and the 2024 AECOM Village-Wide Drainage Assessment—documented the hydrologic sensitivity of Zone 1 and the broader Village to intense rainfall and elevated groundwater. These studies established baseline information, identified problem corridors, and defined evolving LOS criteria. However, the models applied in those efforts had coarser spatial resolution and simplified representations of surface–subsurface interaction. They were suited to evaluating peak stages at drainage nodes, identifying basin-scale discharge deficiencies, and assessing the effects of sea-level rise and tidal tailwater conditions on system capacity. They were less suited to resolving detailed overland flow paths, localized hydraulic controls at the street and parcel scale, or dynamic coupling between groundwater elevations, unsaturated storage, and surface ponding.

The present effort builds on prior studies and extends their analytical capability in two principal ways. First, it directly responds to the RFQ requirement to evaluate alternative stormwater solutions for Zone 1 through a decision-support framework designed to compare system-scale and distributed drainage concepts, identify cost-effective combinations, and reduce localized flooding in targeted basins and streets. Second, it advances the analytical approach by applying a fully integrated MIKE SHE / MIKE+ modeling system capable of simulating unsaturated flow, saturated groundwater flow, evapotranspiration, infiltration, two-dimensional overland routing, and one-dimensional stormwater collection system behavior under tidal boundary conditions. This coupled modeling approach is explicitly designed to quantify the influence of groundwater elevation on surface drainage, establish accurate flow directions during flooding, and identify flood volumes and preferential pathways at a resolution appropriate for designing micro-drainage and distributed pumping strategies in Zone 1 and adjacent basins.

The scope of work in RFQ #2025-13 assigns the consultant team to conduct three primary tasks: (1) data collection and development of modeling criteria, (2) hydrologic and hydraulic modeling to evaluate Zone 1 discharge requirements and flooding mechanisms, and (3) identification and evaluation of system-level and location-specific drainage alternatives. This report addresses Tasks 1 and 2, which establish the analytical foundation for Task 3 by creating a baseline against which alternative strategies can be quantitatively evaluated. Tasks 1 and 2 include compilation of LiDAR data, topographic survey information, right-of-way and finished-floor elevation datasets, land-use mapping, soil and hydraulic property databases, rainfall and tide records, and stormwater infrastructure documentation. These datasets are used to define model geometry, boundary conditions, material properties, and parameter fields required to replicate existing hydraulic conditions, characterize groundwater–surface water interaction, compute realistic flood volumes and flow directions, and evaluate scenarios representing both existing conditions and potential improvements. Data provided by the Village—including LiDAR files, survey CAD files, right-of-way surveys, and finished-floor elevation datasets—are listed in the VKB File Deliverables Inventory and constitute the primary geometric inputs to the model [ref 1].

2.1 Regulatory and Design Criteria

Table 1 summarizes the design parameters, assumptions, and data sources used to develop the Zone 1 hydrologic and hydraulic modeling framework. These criteria reflect the requirements of the Village's RFQ, NOAA sea-level-rise projections, SFWMD rainfall guidance, NRCS hydrologic conditions, local groundwater behavior, and site-specific coastal boundary conditions. Each input contributes to the combined design scenario applied to evaluate system performance under the 2050 planning horizon.

The modeling year of 2050 is established in the RFQ and is consistent with the Village's near-term resilience planning window. Sea-level rise is represented using the NOAA Intermediate scenario, corresponding to approximately 1.5 feet of rise by 2050 relative to NAVD88. This scenario aligns with NOAA Technical Report NOS CO-OPS 083 (2022) and provides a mid-range trajectory suitable for evaluating cost-effective drainage improvements while maintaining system resilience. All elevations, boundary conditions, and hydraulic gradelines are expressed in NAVD88, which is the standard vertical datum used by Miami-Dade County and the Village's survey control network.

Table 1 Summary of Design Parameters

Parameter	Value / Methodology	Source or Basis
Design Year	2050	RFQ Criteria
Sea Level Rise Scenario	NOAA Intermediate (≈ 1.5 ft increase by 2050 relative to NAVD88)	NOAA Technical Report NOS CO-OPS 083 (2022)
Base Datum	NAVD88	Standard for Miami-Dade County
Design Storm	SFWMD 5-year, 24-hour	SFWMD Design Criteria
Rainfall Depth (5-yr, 24-hr)	6.56 inches	NOAA Atlas 14, Village of Key Biscayne
Rainfall Distribution	SFWMD Time Distribution Type II (centered peak)	SFWMD Basis of Design
Antecedent Conditions	AMC II – normal moisture condition	NRCS Hydrologic Conditions
Groundwater Level for Design	Seasonal High Groundwater = 2 ft below existing grade	Field review low-relief coastal setting, and additional analysis to be performed
Tailwater Condition	Tidal boundary set to +2.0 ft NAVD88 (based on the current MLW + SLR 2050 Intermediate)	Derived from NOAA Miami tide gauge and Intermediate SLR
Minimum Road Crown Elevation	Mean Sea Level + 1.0 ft ($\approx +1.35$ ft NAVD88)	RFQ Criteria / MDC standard
Level of Service (LOS)	14 in. maximum depth over road crown for ≤ 3.5 hours	RFQ Criteria
Residential Finished Floor Elevation (FFE)	Base Flood Elevation + 3.0 ft	RFQ Criteria
Residential Contributing Area	25 ft beyond ROW	RFQ Criteria
Soil Infiltration Rate	0.05 in/hr (urban fill / fine sand Miami-Dade County)	NRCS Soil Survey

Well Discharge Capacity, gravity and pumping	Ranging from 300-1200 gpm depending on aquifer, depth and well diameter	Reasonable Assurance Reports for this area
Impervious Area Coefficient	0.85 average within developed parcels	Based on existing GIS impervious coverage, will be additionally analyzed using USGS data
Pervious Area CN	74 (urban grassed areas, fair condition)	NRCS CN Table 2-2a, will be additionally analyzed based on soils, imperviousness, land use
Storm Drain Design Tailwater	Highest of local tidal stage or receiving Bay HGL (including SLR offset)	Hydrodynamic Boundary Definition
Model Grid or Node Reference	Based on existing topographic LiDAR (1-ft resolution, NAVD88)	Miami-Dade County LIDAR (2022), or VKB LIDAR
Optional Tidal Boundary Update for Future Horizons	Linear interpolation between NOAA Intermediate 2050 and Intermediate-Low 2080 curves (+1.5 ft to +2.2 ft NAVD88)	NOAA CO-OPS Data (2022)
Wind and Pressure Influence	Not applied (rainfall-driven design event)	Consistent with SFWMD 5-yr design
Evapotranspiration	Negligible during design event	Standard Design Practice

The design storm for the Zone 1 modeling is the SFWMD 5-year, 24-hour rainfall event, with a total depth of 6.56 inches derived from NOAA Atlas 14 for the Village of Key Biscayne. The temporal distribution is based on the SFWMD Time Distribution Type II, which represents a centered peak consistent with convective rainfall patterns in South Florida. Antecedent moisture conditions are represented as AMC II in accordance with NRCS hydrologic guidance.

Groundwater conditions are a primary control on drainage performance in low-relief coastal environments such as Key Biscayne. The design groundwater level is represented as a seasonal high water table located approximately 2 feet below existing grade, based on available field indicators, local well data, and the characteristics of the shallow surficial aquifer. Final groundwater design elevations will be confirmed using MIKE SHE groundwater simulations that incorporate tidal forcing and sea-level-rise adjustments.

Coastal tailwater conditions are represented by a tidal boundary elevation of +2.0 ft NAVD88, corresponding to projected mean low water (MLW + SLR 2050) under the NOAA Intermediate scenario. This boundary governs both gravity discharge potential and the groundwater gradient near the coastline and is applied consistently across MIKE SHE and MIKE+ coastal cells.

Roadway elevations are assessed relative to the projected sea-level baseline. The minimum design crown elevation is set at approximately +1.35 ft NAVD88, corresponding to Mean Sea Level +1.0 ft, and is consistent with the RFQ criteria and applicable Miami-Dade County roadway standards. The Level of Service (LOS) requirement is defined as no more than 14 inches of ponding above the road crown for a duration of 3.5 hours or less, following the Village's adopted performance criteria.

Finished Floor Elevation (FFE) protection follows the RFQ requirement that $FFE \geq BFE + 3.0$ ft to provide resilience to both coastal and rainfall-driven flooding under future conditions. The residential contributing area reflects runoff contributions from 25 feet beyond the right-of-way, consistent with RFQ specifications acknowledging that adjacent parcel drainage must be incorporated in roadway-level flood evaluations.

Soils and infiltration parameters are represented with an infiltration rate of 0.05 in/hr, typical of urban fill and fine sands in Miami-Dade County. Pervious-area curve numbers are based on $CN = 74$, representing urban grassed areas in fair condition, subject to refinement through field data, land-use mapping, and site-specific soil classification. Imperviousness within Zone 1 is approximated as 0.85, based on existing GIS datasets and USGS land-cover layers, with refinements to occur during parameter verification.

Drainage-well and injection-well discharges are represented using a general performance range of 300–1200 gpm, based on Reasonable Assurance Reports and documented performance of similar installations in nearby areas. These values inform head-dependent drainage representations in MIKE SHE and MIKE+, reflecting combined gravity and pumped outflow characteristics.

Storm drain tailwater is set as the greater of the local tidal stage or the receiving-water hydraulic grade line, incorporating sea-level-rise offsets and dynamic tidal behavior to ensure that backpressure conditions are accurately represented. All model grid references, elevations, and overland-flow domains rely on Miami-Dade County (2022) LiDAR, providing 1-ft contour resolution across Zone 1.

For future resilience assessments, optional tidal boundaries may be interpolated between NOAA Intermediate (2050) and Intermediate-Low (2080) projections, corresponding to water-level offsets between +1.5 ft and +2.2 ft NAVD88 depending on planning horizon. Meteorological wind and pressure effects are not applied because the 5-year, 24-hour design storm is defined as a rainfall-driven event under SFWMD guidance. Evapotranspiration is assumed negligible during the storm period, consistent with standard stormwater design practice.

These parameters collectively define a coherent modeling framework for evaluating the hydrologic and hydraulic performance of the Zone 1 drainage system under present and future conditions. They support MIKE SHE / MIKE+ simulations, flood mapping, evaluation of drainage alternatives, and the development of cost-effective improvements consistent with the Village's resilience objectives.

These criteria are especially challenging in a coastal island environment characterized by low relief, shallow groundwater, limited hydraulic gradients, and strong tidal influence. To meet LOS requirements cost-effectively, the modeling must represent more than nodal peak stages; it must quantify how groundwater rise reduces unsaturated storage, how overland flow redistributes water among depressions, and how flow directions and velocities during compound rainfall–tide conditions influence the placement of pumps, wells, and localized drainage measures to achieve the greatest reduction in flooding per unit investment.

The modeling framework consists of MIKE SHE for simulating rainfall-runoff generation, unsaturated-zone processes, groundwater flow, evapotranspiration, infiltration, and distributed overland hydrology, and MIKE+ for representing the 1D stormwater collection network and 2D overland routing on streets and open spaces. In coupled configuration, MIKE SHE provides a physics-based representation of

groundwater–surface water interaction, while MIKE+ provides dynamic hydraulic simulation of pipes, inlets, manholes, pump stations, outfalls, and surface routing. Together, these tools enable computation of flood magnitude, spatial distribution, flow direction, and recovery behavior across Zone 1.

During project scoping and at the October 22, 2025 kickoff meeting, the Village stated that the modeling must evaluate centralized and decentralized drainage strategies, including distributed pumping nodes, additional drainage wells, and green-infrastructure options. The Village also emphasized the need to understand approaches that could reduce capital and O&M costs, improve localized flooding conditions near the K-8 school and adjacent streets, and comply with evolving water-quality and first-flush requirements. Accordingly, Tasks 1 and 2 were structured to support the alternative analysis required by the RFQ. These tasks establish a baseline against which system-scale and distributed drainage concepts can be evaluated, quantify their hydraulic performance, and inform a cost-optimized combination of improvements in later phases. Although no drainage alternatives are selected in this report, the modeling results presented here directly support the screening, refinement, and economic evaluation of alternatives in Task 3.

The remainder of the report is organized to support this process. Section 2 describes data collection, datasets used in model development, and preprocessing required to convert datasets into MIKE SHE and MIKE+ inputs. It also summarizes how land-use categories were translated into spatially variable hydraulic parameters, including Manning’s roughness, surface detention storage, leakage coefficients, runoff coefficients, and drainage controls, with detailed derivations provided in Appendix A. Section 3 presents the hydrologic and hydraulic modeling of existing conditions, including model construction, boundary-condition development, soil and aquifer representation, and interpretation of MIKE SHE and MIKE+ output logs. Sections 4 and 5 describe the methodologies used in the MIKE+ 1D collection system model and the MIKE+ 2D overland-flow model, including the coupling approach with MIKE SHE.

2.2 Model Development

In historical context, the Village’s drainage approach has progressed through several distinct stages. The 1993 Master Plan was based on limited centerline survey data collected at approximately 100-foot intervals and defined drainage basins as roadway segments plus 15 feet on either side. This generated a coarse topographic representation and supported a drainage strategy focused on gravity conveyance, shallow wells, and minimal pumping capacity.

The 2011 update introduced the first high-resolution, Village-wide synthesis of topography and advanced toward computational basin routing, while documenting aging drainage wells and emerging clogging conditions. The 2015 hydrologic and hydraulic analysis applied LiDAR to refine basin delineations and identified tidal backflow and groundwater influence as primary controls on drainage recession. The 2024 Drainage Assessment confirmed, using updated GIS data and improved modeling techniques, that existing hydraulic gradients and reliance on drainage wells were insufficient to meet modern LOS under higher sea levels and elevated tailwater conditions.

In contrast, the distributed drainage concept envisioned for 2025 and beyond uses a high-resolution digital elevation model to support the siting and sequencing of pump nodes and discharge wells, incorporates multiple localized pump stations paired with deep injection wells, and employs a fully integrated MIKE SHE / MIKE+ modeling framework to represent groundwater interaction, overland flow routing, and stormwater infrastructure hydraulics within a unified system.

Table 2 Summary of SWMP Progression

Topic	1993 Master Plan	2011 Update	2015 H&H Analysis	2024 Drainage Assessment	Proposed Distributed System (2025+)
Topographic Data	Sparse centerline survey (~100 ft spacing), basin = road + 15 ft	First high-resolution Village-wide topography synthesis	LiDAR used for detailed basin delineation	LiDAR confirmed micro-depressions and roadway sags	High-resolution DEM drives pump node siting and staging
Drainage Philosophy	Gravity where possible; shallow wells; limited pumping	Recognition of aging wells and clogging	Documented tidal backflow and groundwater control limitations	Identified insufficient gradients and reliance on wells	Active management via pumps + injection wells at multiple nodes
Hydrologic Methods	NRCS/SCS static calculations; no dynamic model	First use of computational tools for basin routing	Early numerical modeling; improved recession analysis	Explicit evaluation of tidal interaction and groundwater	Full MIKE SHE / MIKE+ dynamic modeling with groundwater interaction
LOS Criteria	5-yr, 24-hr; crown-level ponding acceptable	Partial uplift, but still gravity-limited	Noted need for updated standards	Sea-level-rise and rainfall duration emphasized	LOS based on depth + duration + groundwater influence + SLR
Wells / Disposal	Shallow auger wells; early injection well concept	Evidence of declining well performance	Strong reliance highlighted as vulnerability	Regulatory/multiple maintenance constraints	Distributed deep injection wells paired with sump pumps
Pumping	Limited; conceptual only	Identified need for redundancy	Pump cycles sensitive to tidal tailwater	Centralized pumping vulnerable to single-point failure	Multiple localized pump stations reduce system-wide vulnerability
SLR & Tailwater	Not considered	Minimal recognition	First explicit tidal rise concerns	SLR central to modeling and design	SLR-constrained system requires mechanical and distributed redundancy
Network Geometry	Fragmented; few pipes	Better mapping begins	Basin connectivity improved	Updated GIS; systemwide deficiencies noted	Complete MIKE+ network built from storm atlas + validation
Best Outcome	Foundation for future planning	Recognized structural limitations	Identified persistent basin-level flooding	Consistent evaluation of centralized pumping system performance	Distributed system offers scalable, resilient, redundant drainage

Historically, hydrologic methods in the Village have progressed from NRCS/SCS static calculations without dynamic routing, to early computational basin-routing tools, to numerical modeling capable of improving recession analysis, and ultimately to explicit evaluation of tidal interaction and groundwater in the 2024 assessment. The proposed approach advances this progression by implementing fully dynamic MIKE SHE / MIKE+ modeling with groundwater interaction, enabling explicit analysis of flood volumes, time-dependent groundwater heads, surface–subsurface exchange, and directional overland flows. LOS criteria have evolved in parallel, shifting from standards permitting crown-level ponding under gravity drainage during 5-year, 24-hour events, to uplifted criteria that still depended on gravity

conveyance, to modern LOS definitions incorporating sea-level rise and rainfall duration, and finally to LOS based on depth, duration, groundwater influence, and SLR.

Drainage strategies in earlier periods focused on shallow auger wells and initial injection-well concepts. Subsequent updates documented declining well performance and noted the Village's reliance on wells as a vulnerability. The 2024 assessment identified additional regulatory and maintenance constraints. The proposed distributed system responds to these limitations by pairing distributed deep injection wells with sump-level pumps. This configuration reduces loading on individual wells, increases operational flexibility, and provides a pathway for meeting hydraulic LOS and water-quality requirements. Pumping strategies followed a similar trajectory. Early plans treated pumping as supplemental, later analyses recognized the need for redundancy, subsequent studies identified sensitivity to tidal tailwater, and the most recent assessment concluded that pumping is essential but that reliance on centralized stations alone introduces system vulnerability. The distributed system reduces this vulnerability by establishing multiple localized pump stations.

This historical perspective demonstrates why centralized pumping alone is not sufficient under projected sea-level-rise conditions and why the RFQ requires evaluation of distributed pumping in combination with vertical disposal. Centralized systems were more effective when mean sea level was lower and groundwater had greater vertical drainage capacity. Under present and projected SLR, centralized systems lose hydraulic head, experience increased conveyance distances, and concentrate operational risk. Flow directions and overland pathways become more complex as tidal backpressure and groundwater rise alter hydrodynamic behavior. A distributed system, evaluated using coupled MIKE SHE / MIKE+, provides a more flexible and cost-efficient means of routing stormwater from localized depressions, managing groundwater-surface-water interactions, and meeting water-quality requirements such as first-flush treatment and Outstanding Florida Water protections for Biscayne Bay.

From a permitting and funding standpoint, the evolution of prior studies supports a distributed drainage system incorporating strategically located pump stations and deep injection wells. Each past study—from 1993 through 2024—identified localized depressions and basin-scale disconnections as primary drivers of nuisance and roadway flooding. Distributed pump nodes target these same areas and directly remove stormwater where it accumulates, improving performance without requiring extensive roadway reconstruction. Centralized systems become increasingly sensitive to tailwater under SLR, while distributed systems maintain operational independence from coastal boundary fluctuations and provide redundancy across basins. The Village's built-out condition and narrow rights-of-way limit opportunities for surface storage, making compact distributed pump-and-well facilities operationally appropriate.

Regulatory frameworks—including SFWMD ERP first-flush rules (Ch. 62-330, F.A.C.), FDEP UIC Class V well regulations (Ch. 62-528, F.A.C.), FDEP NPDES MS4 permit requirements, and Miami-Dade County DERM protections for Biscayne Bay as an Outstanding Florida Water—favor approaches that reduce or avoid untreated surface discharge. The Village's shallow groundwater and limited land area limit the feasibility of traditional first-flush basins or large centralized treatment units. Injection wells avoid surface discharge and, when properly permitted and monitored, do not trigger surface-water treatment requirements. Distributed pump-and-well systems remove stormwater from the surface network, reduce pollutant loading to Biscayne Bay, and align with regulatory requirements for coastal resilience and water quality.

The technical approach section of this report explains why a coupled MIKE SHE / MIKE+ model is appropriate for supporting the RFQ's requirements for alternative analysis, cost management, and

localized flood mitigation. AECOM's 2024 alternative analysis demonstrates that Key Biscayne's stormwater challenges are driven by compound factors, including low-lying barrier-island topography, high-intensity rainfall, tidal influence and "sunny-day" flooding, shallow groundwater that limits infiltration and storage, high imperviousness, and very limited space for surface storage [ref 4]. In this context, the 2024 assessment concluded that reliance on purely gravity-dependent solutions is no longer viable and emphasized the need for mechanically pumped systems to meet LOS over decades of rising groundwater and higher tailwater conditions [ref 4].

AECOM's October 2025 Zone 1 Baseline Stormwater Modeling Results memorandum highlights the sensitivity of planning baselines to assumptions regarding time horizon, SLR scenario, design storm, contributing area, and conveyance sizing [ref 5]. Under the 2050 horizon, NOAA Intermediate SLR, the 5-year/24-hour event (6 inches), reduced contributing area (ROW + 25 ft), and pipe sizes held at existing/proposed diameters, LOS was met with approximately 57 cfs of pumping. AECOM notes that when conveyance is resized to design-level velocities, removing the artificial storage of oversized pipes, the pumping requirement to meet the same LOS increases to approximately 90–100 cfs [ref 5]. The memorandum emphasizes that reduced contributing area and non-resized conveyance make the baseline scenario suitable only for planning, not permitting, reinforcing the need for a comprehensive modeling framework that incorporates all contributing parcels and infrastructure constraints.

The existing ICPR4-based approach, documented in the 2024 assessment, relies on a 1D modeling structure in which LiDAR-derived DEMs are used to generate stage–area and stage–storage relationships for node-based storage. The Node Min/Max and Link Min/Max reporting indicate a framework well suited to assessing peak stages and identifying surcharge conditions at discrete nodes. However, this approach is less capable of addressing RFQ-relevant questions such as the spatial distribution of flood volumes, overland flow movement at the street and property scale, groundwater–surface-water interactions, and the effectiveness of micro-drainage, small pumps, or distributed wells in reducing localized flooding. In very flat terrain, where minor elevation differences can redirect flows, understanding the movement and redistribution of stormwater is often more critical than estimating peak ponding levels at a representative node [ref 3, ref 4, ref 10].

For these reasons, the analytical perspective must expand beyond peak stage to include flood volumes, flow directions, time-to-drain, and sensitivity to boundary conditions. A coupled MIKE SHE / MIKE+ model is well suited to this task. MIKE+ 2D Overland represents surface-water flow patterns on real topography and is commonly applied in urban drainage and flood-risk management [ref 6]. MIKE SHE adds the capacity to simulate spatially distributed rainfall–runoff, soil moisture, groundwater levels, and recharge, all of which are critical in a setting where groundwater depth strongly influences storage and infiltration [ref 4, ref 5, ref 7]. MIKE+ Collection Systems provides dynamic 1D simulation of the pipe and pump network across varied hydraulic regimes, including pressurized flow [ref 8]. MIKE SHE can be coupled with MIKE 1D/MIKE+ to create a unified model that represents unsaturated processes, groundwater, 2D overland flow, and 1D infrastructure in a physically consistent manner [ref 9].

In practice, this integrated framework allows the Village to delineate micro-catchments based on actual flow directions; route localized runoff using short laterals to nearby sumps and inlets; evaluate distributed pump nodes that transfer water from depressions to pretreatment and injection wells; and define overflow logic for conditions in which local well capacity is exceeded, routing excess water to secondary discharge pathways outside a specific flood cell. In a built-out environment with limited space for surface storage and a need for reliable pump-based conveyance, this distributed concept can reduce

reliance on large, system-wide conveyance upgrades and provide a more efficient means of sequencing capital improvements [ref 3, ref 4].

By representing groundwater, surface flow, and infrastructure hydraulics within one coupled system, the MIKE SHE / MIKE+ model becomes a tool for cost control and alternative optimization rather than only an LOS evaluation instrument. It enables quantification of where smaller, distributed interventions produce significant reductions in flood volume and duration, directly supporting the RFQ's requirements to evaluate alternatives, reduce overall costs, and mitigate localized flooding while meeting long-term regulatory and resilience objectives.

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13. University of South Florida – MIKE+ page describing coupled 1D–2D coastal urban flood modeling and MIKE SHE/MIKE+ coupling objectives.

3 TASK 1 – DATA COLLECTION AND REVIEW

Compile and evaluate LiDAR data, GIS-based drainage maps, historical rainfall records, and legacy hydrologic/hydraulic models. Review Village records and documented community input to identify existing and potential flood-prone areas. Develop preliminary design criteria that meet or exceed the minimum requirements and level of service specified in the RFQ, ensuring consistency with SFWMD, County, municipal, and state standards, as well as County sea level rise projections. Assess proposed discharge opportunities, including discharges to wells and the incorporation of green infrastructure practices, relative to existing discharge analyses to confirm feasibility and alignment with applicable permitting criteria. All findings, assumptions, and draft design criteria shall be submitted for Village review and approval prior to advancement into subsequent design phases.

The objective of Task 1 is to compile, evaluate, and prepare all datasets necessary for constructing the hydrologic and hydraulic model of Zone 1. These datasets include elevation data, rainfall time series, land use and surface characteristics, soil and unsaturated zone properties, stormwater infrastructure documentation, and reference design criteria. Each dataset plays a distinct role in defining the domain geometry, material properties, hydrologic processes, or boundary conditions within the MIKE SHE/MIKE+ modeling system. This section provides a comprehensive narrative describing the function

and importance of each dataset, the preprocessing steps applied, and the rationale by which the data are transformed into model-ready inputs. The resulting compilation forms a coherent geospatial and temporal foundation for Task 2 hydrologic and hydraulic analysis.

3.1 Model Boundary

The proposed MIKE SHE / MIKE+ model domain for the Village of Key Biscayne has been deliberately constructed to encompass the entire island and adjacent coastal waters, extending offshore, inland, and across all developed and natural areas that influence hydrologic and hydraulic behavior in Zone 1 and the surrounding basins. This expanded, island-wide modeling extent differentiates the present model from earlier efforts that focused primarily on roadway right-of-way basins or limited groupings of drainage subareas. By adopting a comprehensive spatial domain, the model ensures that all hydrologic components - rainfall, infiltration, groundwater levels, surface runoff, overland flow direction, infrastructure hydraulics, and coastal boundary interactions - are accounted for in an internally consistent, physically based framework.

3.1.1 Coastal Boundary Representation

The model boundary intentionally extends 10 to 20 feet offshore depth into Biscayne Bay and the Atlantic Ocean. This offshore extension establishes a physically meaningful coastal boundary condition for both surface water and groundwater processes. In MIKE SHE, the offshore zone provides a stable hydraulic boundary where tidal water levels, sea-level-rise projections, and storm surge conditions can be applied. Without extending the boundary offshore, any attempt to simulate coastal influence would require artificial boundary assumptions at the shoreline, which could distort gradients, misrepresent groundwater discharge pathways, and diminish the reliability of surface ponding predictions during storm events.

By including a buffer zone of open water, the model is able to:

- Represent future sea-level rise scenarios, as required by the RFQ, without modifying the land boundary geometry.
- Allow surface water to exit or enter the model domain under extreme tidal or storm surge forcing.
- Ensure that groundwater gradients reflect the true hydraulic continuity between the Biscayne aquifer and the coastal zone, rather than assuming a fixed or simplified water table boundary at the shoreline.

This is an essential improvement over prior models, which typically applied simplified fixed-stage or pseudo-tidal boundaries at the edge of land features.

3.1.1 Inclusion of Wetlands to the North and Mangrove Marshes

The model boundary extends northward to include adjacent wetlands and mangrove areas, recognizing that these natural landscapes exert measurable influence on groundwater levels, soil moisture dynamics, storage availability, and tidal attenuation. These areas also act as hydraulic buffers, influencing how water enters or leaves the island's aquifer system.



Figure 2 Model Domain and Zone 1 Coverage

The inclusion of the wetlands at the north is necessary for:

- Correctly simulating lateral groundwater fluxes between the Village and the natural areas to the north.
- Representing the hydraulic damping effects of wetlands during tide-driven groundwater rise.
- Avoiding the artificial “cutting off” of regional flow paths that would otherwise distort water levels within Zone 1 and other basins.

Earlier Village models - most notably those in 2011 and 2015 - did not incorporate these northern wetland units in a dynamically coupled groundwater domain, which limited their ability to capture the storage and release mechanisms that influence groundwater recovery in the northern part of the island.

3.1.2 Southern Boundary Delineation

To the south, the model boundary is set along the logical hydrologic divide of the island, capturing the region that contributes surface runoff and groundwater flow toward the Zone 1 basins and adjacent drainage zones. This southern terminus ensures that the model accurately reflects the regional slope, groundwater gradient, and drainage patterns without extending into areas that would not materially affect Zone 1 flooding dynamics.

3.1.3 Eastern Boundary Including the Atlantic Beach Zone

The eastern boundary includes the entire beachfront and dune system, recognizing that the Atlantic shoreline is a critical interface for:

- Sea-level rise and storm surge intrusion,
- Subsurface hydraulic gradients, and
- The loss or gain of storage during extreme events.

By incorporating the beach area rather than truncating the model at the urban development line, the model captures:

- Wave- and tide-driven aquifer responses,
- Potential inland migration of the water table during extreme events,
- The dynamic interaction between rainfall, infiltration, unsaturated flow, and coastal discharge, and
- Spatial variations in permeability and soil characteristics unique to beach and dune soils.

This boundary choice ensures that groundwater behavior is not artificially constrained and that the inland flooding response is correctly influenced by changing ocean conditions.

3.1.4 Groundwater Boundary Conditions and Conceptualization

Groundwater processes are essential to stormwater modeling in Key Biscayne due to the island's shallow water table and permeable limestone aquifer. The MIKE SHE model represents saturated groundwater flow using a distributed 5-meter grid that allows groundwater mounding, lateral flow, and discharge to coastal boundaries to be simulated in detail.

The expanded offshore and wetland boundaries serve as general head boundaries, allowing groundwater to rise or fall in response to:

- Tidal fluctuations,
- Seasonal variations,
- Long-term sea-level rise, and
- Pressure gradients produced by stormwater infiltration or pumping.

Because Zone 1 flooding is strongly controlled by groundwater emergence, representing the aquifer and its coastal connectivity across the entire island is essential. Earlier 1D-focused or basin-limited models were unable to simulate groundwater rise and recovery spatially, resulting in incomplete representation of flood duration and surface inundation behavior.

3.1.5 Differentiation From Previous Models

This model significantly improves upon earlier VKB modeling efforts in several fundamental ways:

- Full-Island Domain
 - Prior models often limited computation to basin boundaries or roadway rights-of-way.
 - The current model includes the entire island and surrounding coastal waters, ensuring complete representation of rainfall-runoff generation, groundwater movement, and inter-basin flow.
- Coastal Interaction and Sea-Level Rise
 - Earlier models approximated tide levels at the shoreline.
 - This model explicitly represents coastal boundaries, tidal forcing, and future sea-level rise within a physically based hydrologic framework.
- Groundwater–Surface Coupling
 - Prior models did not dynamically simulate groundwater rise and its influence on flooding.
 - The MIKE SHE domain allows groundwater to influence surface ponding, infiltration, and time-to-drain, which are critical in Key Biscayne’s conditions.
- Flow Direction and Volume Mapping
 - Previous models identified peak stages but not fine-scale flow patterns.
 - The 5-foot MIKE+ 2D overland mesh maps true surface-flow directions, enabling design of localized mitigation measures.
- Alternative Analysis Capability
 - This coupled model can test distributed drainage systems, combinations of pumping and wells, green infrastructure, road profile adjustments, and micro-drainage - as required by the RFQ.

In summary, the proposed MIKE SHE / MIKE+ model boundary - extending offshore, encompassing wetlands, including the Atlantic beachfront, and covering the entire island - provides the physical and regulatory fidelity needed to evaluate drainage alternatives, quantify groundwater–surface interactions, assess localized flood behavior, and identify cost-effective strategies for reducing flooding throughout Zone 1 and adjacent areas. The detailed grid structure and comprehensive assignment of land, soil, and hydraulic properties allow the model to meet the RFQ’s requirements for alternative analysis, cost minimization, water-quality compliance, and explicit representation of groundwater-influenced flooding pathways.

3.2 Overview of Data Sources

Multiple datasets were provided by the Village of Key Biscayne for use in this analysis, including LiDAR point clouds, digital orthophotography, right-of-way and topographic surveys, control point files, finished floor elevations, and stormwater-related maps [ref 1]. These datasets provide the geometric reference frame needed to define the model grid, surface elevations, depression storage patterns, and shallow topographic pathways within Zone 1. Additional hydrometeorological datasets were compiled

for rainfall event characterization, including high-resolution rainfall series and rolling 24-hr and 72-hr rainfall totals with associated return periods [ref 2]. Land use and property-scale hydrologic parameter datasets were supplied in the VKB-MDC Land Use shapefile, which contains an extensive attribute table that links each land use polygon to Manning's roughness, leakage coefficients, runoff coefficients, overland drainage parameters, and saturated-zone drainage parameters.

Soil and unsaturated-zone assumptions were derived from the NRCS SSURGO database, the MIKE SHE UZ library, and standard van Genuchten parameters supported by hydrologic literature [ref 3]. Regulatory and design constraints were taken from SFWMD design storm guidance, NOAA Intermediate sea-level rise projections, and explicit requirements stated in RFQ #2025-13 [ref 4]. These datasets collectively define the boundary conditions and physical processes governing overland runoff, infiltration, evapotranspiration, groundwater response, and flood storage dynamics within the model domain.

3.3 Survey and Elevation Data

Accurate representation of surface elevations is fundamental to hydrologic and hydraulic modeling because elevation governs the location of natural sags, runoff directions, stormwater flow paths, and areas susceptible to ponding. The Village provided the complete LiDAR dataset (three phases) and orthometric survey information as part of the "Aerial Survey SCS Folder" and associated deliverables. The *VKB Master Island Survey Report* and multiple right-of-way and topographic CAD files supplement the LiDAR with surveyed control points, localized spot elevations, utility structures, and finished floor elevations [ref 1].

The LiDAR dataset contains high-density point clouds in NAD83/NAVD88, providing an accurate ground surface suitable for generating a 5-ft digital elevation model (DEM), which is required for MIKE SHE overland flow, infiltration, and groundwater interaction. The role of the DEM in the model extends beyond surface routing: MIKE SHE also uses the topographic surface to define the upper boundary of the unsaturated zone and to resolve spatial differences in surface ponding thresholds and free-surface water levels.

To construct a MIKE SHE-ready DEM, the LiDAR data were filtered to remove building points and vegetation returns, retaining only ground-classified points. These points were interpolated using a combination of triangulated irregular network (TIN) gridding and spline-based smoothing to preserve microtopographic depressions while removing artifacts. The result is the *model-dem-5ft.dfs2* raster, referenced in the MIKE SHE preprocessing log. The preprocessing output confirms that the DEM grid differed from the MIKE SHE model grid resolution, triggering bilinear interpolation during import. Bilinear interpolation is appropriate for high-resolution LiDAR-based DEMs because it preserves gradients without introducing artificial steps.

Shallow topography is particularly important in Zone 1, where relief typically ranges from 3 to 6 ft NAVD88. Depressions of less than one foot strongly influence flood extent, especially near the K-8 school, Glenridge Road, and West Mashta Drive. The DEM also serves as the reference for the saturated zone drain level when expressed relative to ground elevation, ensuring that groundwater drainage activates at the appropriate surface elevation.



Figure 3 Model Topography

3.4 Rainfall and Hydrometeorological Data

Rainfall is the primary driver of flooding in Zone 1. To characterize storm events and calibrate future modeling stages, a detailed rainfall time series was compiled, including rolling 24-hour and 72-hour rainfall totals with associated return periods.

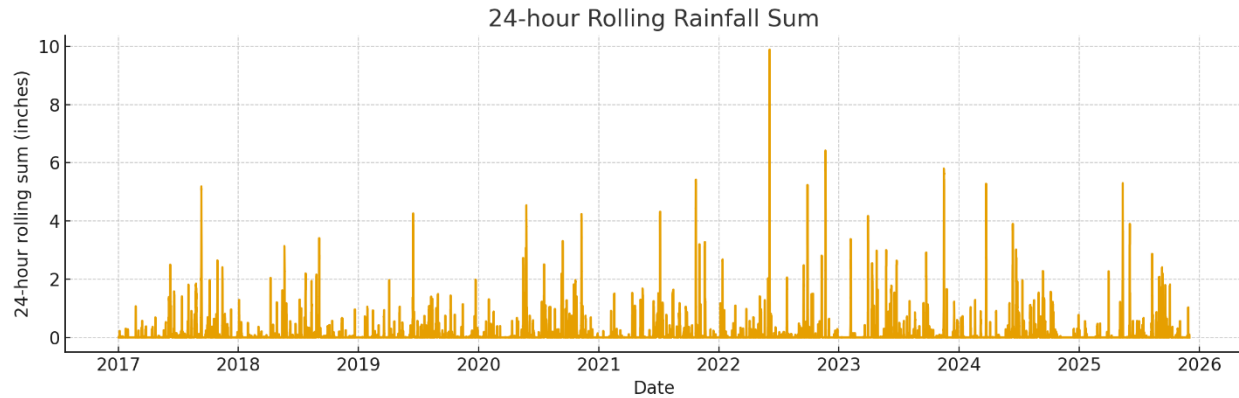


Figure 4 Cumulative 24-hr Rainfall for 2017-2025

The rolling sums were developed using 15-minute rainfall data, enabling precise quantification of cumulative stormwater load during significant periods. The resulting tables document storms producing 5–10 inches of rainfall over 24 hours and 7–11 inches over 72 hours, with corresponding return periods ranging from 2-year to 25-year events [ref 2].

Table 3 Cumulative 24-hr Rainfall for 2017-2025

Date	24-hr Rolling Sum (inches)	Return-Period Range (NOAA Atlas 14)
2022-06-04	11.15	10-yr – 25-yr
2022-06-05	11.15	10-yr – 25-yr
2022-06-06	11.02	10-yr – 25-yr
2020-05-26	7.36	2-yr – 5-yr
2020-05-27	7.06	2-yr – 5-yr
2022-06-07	6.98	2-yr – 5-yr
2020-05-25	6.94	2-yr – 5-yr
2022-09-28	6.73	2-yr – 5-yr
2022-09-29	6.73	2-yr – 5-yr
2022-11-21	6.68	2-yr – 5-yr

Table 4 presents the 24-hour rainfall depths associated with a range of return periods, as defined by the NOAA Atlas 14 Point Precipitation Frequency Estimates for southeast Florida. These values represent the expected total rainfall accumulation over a 24-hour period that corresponds statistically to different levels of rarity or frequency. Return periods are commonly used in hydrologic and hydraulic design to establish the level of storm protection required for stormwater systems and to evaluate flood risk.

In NOAA Atlas 14, the “return period” describes the average time interval between rainfall events of a given magnitude. For example, a 5-year, 24-hour storm has a rainfall depth that, on average, is exceeded once every 5 years, and more accurately, each year has a 10% chance (1/10) of experiencing rainfall of that magnitude or greater.

Table 4 Return Period and Rainfall Depth for 24-hr Rainfall for 2017-2025 (NOAA Atlas 14)

Return Period (years)	24-hr Threshold (inches)
1-yr	4.36
2-yr	5.13
5-yr	6.56
10-yr	7.93
25-yr	10.1
50-yr	11.9
100-yr	14.0
200-yr	16.2
500-yr	19.5
1000-yr	22.2

The rainfall analysis shows that several recent storms, including June 4–6, 2022, reached 10–25-year magnitudes, consistent with public observations of street flooding. These tables also illustrate the relative rarity of events exceeding 11 inches over 72 hours, which correspond to design magnitudes in the 10-25-year range.

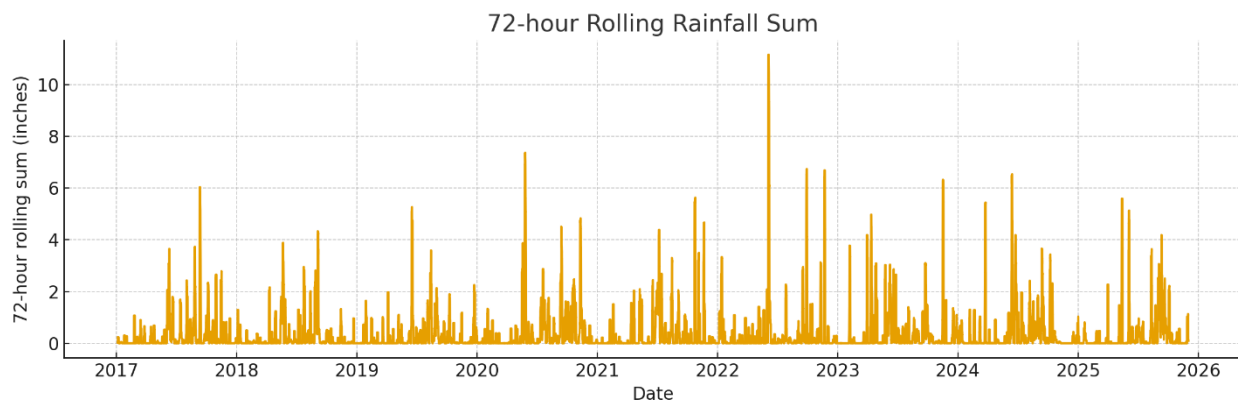


Figure 5 Cumulative 72-hr Rainfall for 2017-2025

For the purpose of modeling under Task 2, the SFWMD 5-year, 24-hour storm is applied as the design event, as required by the RFQ [ref 4]. Rolling precipitation values are also used to validate the intensity distributions and storm hyetograph shapes needed for MIKE SHE rainfall boundary conditions.

Table 5 Cumulative 72-hr Rainfall for 2017-2025

Date	72-hr Rolling Sum (inches)	Return-Period Range (NOAA Atlas 14)
2022-06-04	11.15	10-yr – 25-yr
2022-06-05	11.15	10-yr – 25-yr
2022-06-06	11.02	10-yr – 25-yr
2020-05-26	7.36	2-yr – 5-yr
2020-05-27	7.06	2-yr – 5-yr
2022-06-07	6.98	2-yr – 5-yr

2020-05-25	6.94	2-yr – 5-yr
2022-09-28	6.73	2-yr – 5-yr
2022-09-29	6.73	2-yr – 5-yr
2022-11-21	6.68	2-yr – 5-yr

Table 6 Return Period and Rainfall Depth for 24-hr Rainfall for 2017-2025 (NOAA Atlas 14)

Return Period (years)	72-hr Threshold (inches)
1-yr	5.76
2-yr	6.67
5-yr	8.36
10-yr	9.94
25-yr	12.4
50-yr	14.5
100-yr	16.8
200-yr	19.3
500-yr	22.9
1000-yr	25.8

Because overland flow and shallow groundwater respond to rainfall accumulation, not merely instantaneous intensity, these rolling totals provide insight into antecedent moisture conditions and the saturation behavior that contributes to multiple-day ponding after storms.

3.5 Land Use Processing and Hydrologic Parameter Assignment

Land use is a key determinant of runoff generation, infiltration capacity, surface roughness, drainage thresholds, and storage availability. The VKB-MDC Land Use shapefile contains detailed parcel-scale classifications along with a hydrologic parameter table. This table includes Manning’s roughness, runoff coefficients, detention storage, overland drainage parameters, and saturated zone drainage values for each land use polygon. These parameters were pre-assigned to reflect expected hydrologic behavior of each land use category and were incorporated directly into the MIKE SHE model as spatially distributed parameter maps.

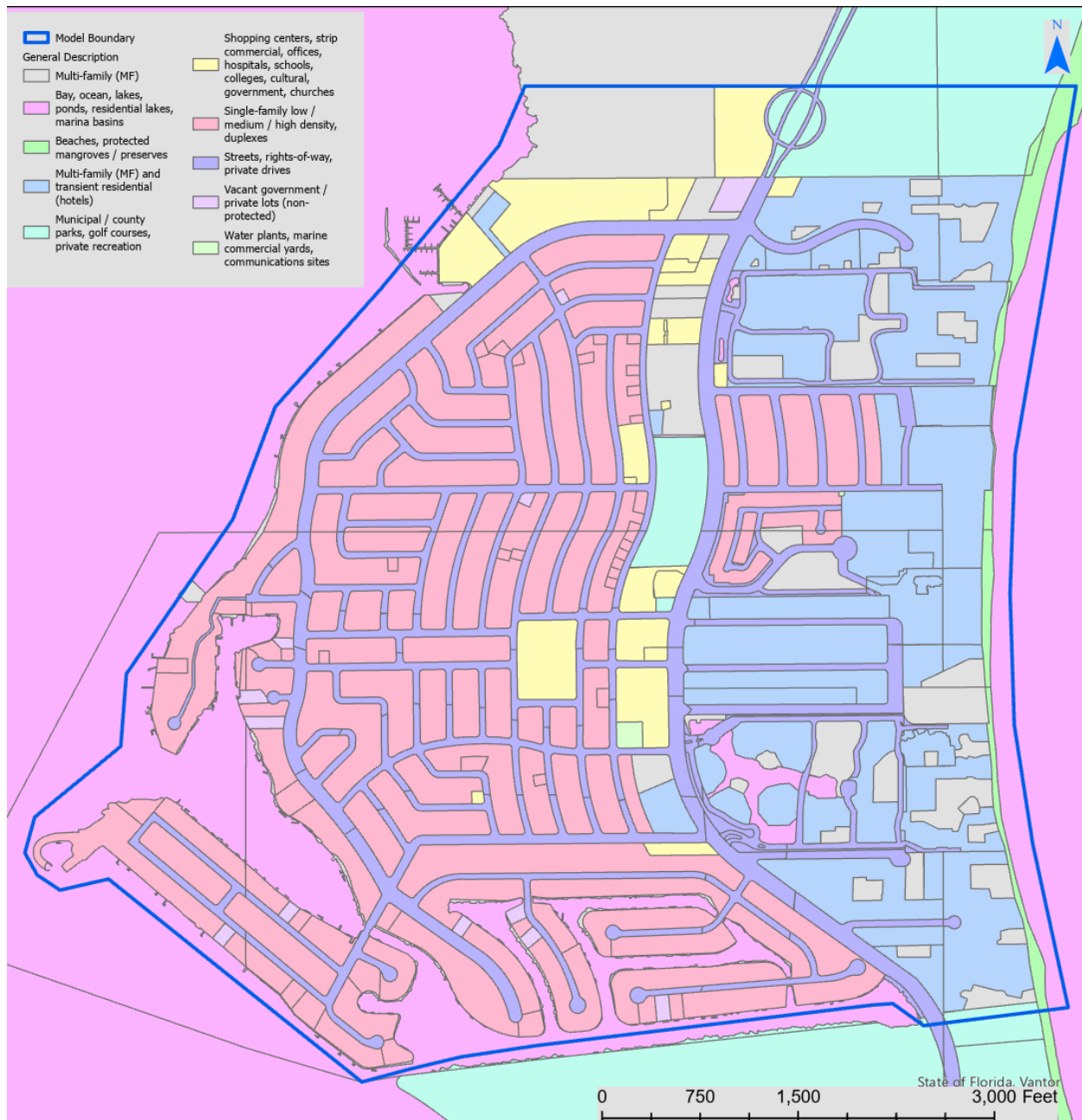


Figure 6 Miami-Dade County Land Use Classification

The derivation of these parameters follows established hydrologic literature, FDOT and SFWMD stormwater criteria, and MIKE SHE methodological guidance. A high-level summary is presented here, with the full derivation provided in Appendix A.

3.5.1 Manning's Roughness

Each land use polygon is assigned a Manning's n value reflecting its effective roughness. For residential areas, values incorporate the combined effect of lawns, pavement, driveways, fences, and building

obstruction. For commercial areas, roughness is lower due to large paved surfaces. These values control surface flow velocity, determining how quickly water translates across parcels during storms.

3.5.2 *Runoff Coefficient*

Runoff coefficients reflect the fraction of rainfall converted to immediate runoff and are derived from impervious percentage, lot coverage, and regional hydrologic datasets. In Zone 1, runoff coefficients range from moderate in medium-density residential areas to high in commercial and marine uses, reflecting the limited infiltration capacity under high groundwater.

3.5.3 *Detention Storage*

Detention values correspond to depression storage, representing shallow microtopographic storage and surface roughness. Residential parcels with landscaped areas can retain more initial rainfall, whereas commercial parcels generate runoff more readily.

3.5.4 *Overland Drainage Parameters*

Overland drainage depth and drainage inflow constants define how quickly ponded water on streets, yards, and commercial areas is captured by storm drains. Low thresholds in roadways reflect curb inlets and positive drainage infrastructure. Higher thresholds in grassy areas reflect natural depressions.

3.5.5 *Saturated Zone Drainage Parameters*

Drain level and time constants determine when and how the groundwater system releases water to overland flow or rivers. For a coastal island with shallow aquifers, drain levels are typically set near the ground surface. Time constants vary by land use to reflect subsurface connectivity.

These parameter assignments form the basis for distributed hydrologic behavior in MIKE SHE.

Table 7 Land Use Derived Surface and Subsurface Drainage Parameters

Base type	General description	Manning n	Detention storage (ft)	Impervio us runoff coef.	Overland– SZ exchange (s ⁻¹)	Overland drain depth (ft)	SZ drain level (ft below surface)	SZ leakage / response (s ⁻¹)	Notes
B1_OPEN_W ATER	Bay, ocean, lakes, ponds, marinas	0.03	0.00	1.00	1.0×10^{-4}	0.00	0.0	1.0×10^{-5}	Almost no detention, fast exchange with SZ
B2_NATURAL _PRESERVE_ BEACH	Beaches, dunes, protected mangroves	0.18	0.20	0.10	5.0×10^{-4}	1.00	2.0	1.0×10^{-4}	High infiltration, thick root zone, high water table
B3_PARK_GO LF_REC	Parks, golf courses, recreational open space	0.16	0.15	0.25	4.0×10^{-4}	0.80	1.8	8.0×10^{-5}	Well-maintained grass, moderate infiltration
B4_RES_LOW _MED	Single-family & duplexes (low– medium density)	0.13	0.08	0.50	2.5×10^{-4}	0.60	1.2	5.0×10^{-5}	Approx. 40–60% impervious, sandy lawns
B5_RES_MUL TI_TRANSIEN T	Apartments, condos, hotels	0.09	0.04	0.80	1.0×10^{-4}	0.40	0.8	3.0×10^{-5}	High imperviousness, rooftop drainage
B6_COMM_ OFFICE_INST	Commercial, institutional, schools, hospitals	0.07	0.03	0.90	8.0×10^{-5}	0.30	0.8	2.0×10^{-5}	Very high imperviousness
B7_ROADS_R OW	Roads, highways, rights-of-way	0.013	0.01	0.95	5.0×10^{-5}	0.20	0.5	1.0×10^{-5}	Asphalt / concrete, direct runoff
B8_VACANT_ URBAN	Vacant cleared lots (non-protected)	0.15	0.10	0.30	3.5×10^{-4}	0.80	1.5	7.0×10^{-5}	Weedy / sandy, moderate infiltration
B9_UTIL_IND USTRIAL	Utilities, wastewater plants, industrial, marine yards	0.06	0.03	0.85	8.0×10^{-5}	0.40	1.0	2.5×10^{-5}	Mostly impervious with some gravel areas

3.6 Soil and Unsaturated Zone Parameter Data

Soils influence infiltration, evapotranspiration, unsaturated storage, and timing of groundwater recharge. Unsaturated zone (UAZ) parameters were developed using NRCS SSURGO classifications and the standard van Genuchten–Mualem hydraulic functions [ref 3].

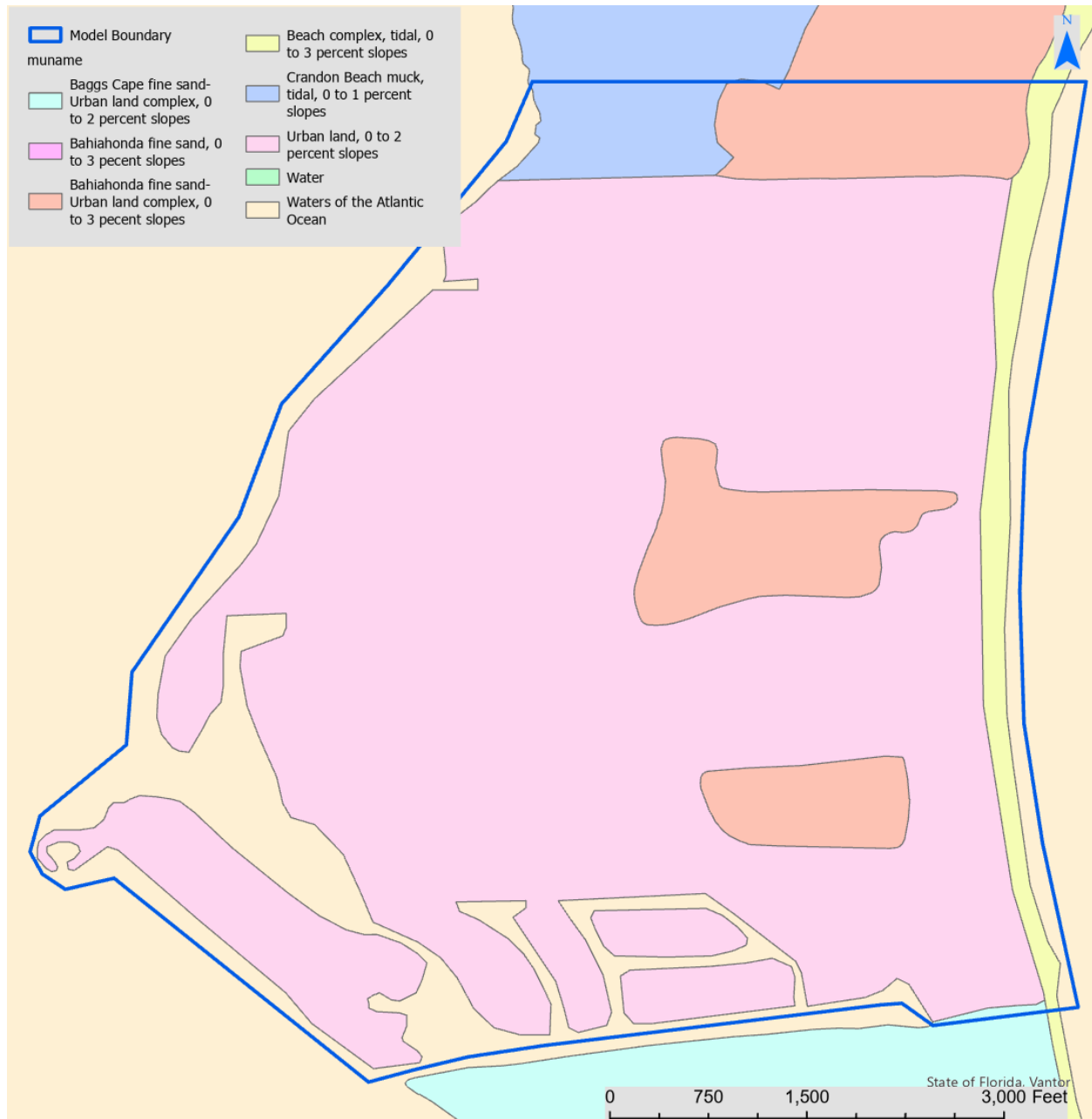


Figure 7 Miami-Dade County Land Use Classification

The VKB area is predominantly composed of fine sands, beach sands, and artificially compacted urban soils, with localized organic deposits in the Crandon Beach muck units. Soil hydraulic properties were assigned based on established parameter sets for these textures, with saturated hydraulic conductivity

values converted from SSURGO Ksat in micrometers per second. The UZ assumptions include residual and saturated water contents, pore-size distribution (n), air-entry pressure (α), and pore-connectivity parameters (l). These values define the nonlinear relationship between soil moisture, capillary pressure, and unsaturated hydraulic conductivity. Because the groundwater table in Zone 1 lies close to the surface, the unsaturated zone is often thin; however, dry-season and early-storm infiltration still depend on UZ behavior.

Richards / van Genuchten form model includes the following relationships:

- Water retention:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha |h|)^n]^{1-\frac{1}{n}}}$$

Relative saturation: $S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$

- Conductivity (Mualem):

$$K(S_e) = K_{sat} S_e^l \left[1 - \left(1 - S_e^{1/m} \right)^m \right]^2, m = 1 - \frac{1}{n}$$

The key parameters to set are θ_r , θ_s , α , n, l and Ksat are listed in the table below:

Soil group / map units	Texture	θ_r	θ_s	α (1/ft)	n	l	Ksat (ft/day)	Notes for MIKE SHE UZ material
Open water, Atlantic Ocean (99, 100)	Water	—	—	—	—	—	—	Exclude from UZ; SZ / BC only
Urban land over sand (15, "Urban land; Sand**")	Sand	0.045	0.40	4.42	2.50	0.5	2	Compacted urban sand
Beach complex (39, "Beach complex; Sand")	Sand	0.040	0.43	4.42	2.68	0.5	24–30	Loose beach sand
Bahiahonda fine sand (45) and Bahiahonda–Urban (50)	Fine sand	0.050	0.43	3.8	2.30	0.5	22	Fine coastal sand
Baggs Cape fine sand–Urban complex (47)	Fine sand	0.050	0.41	3.8	2.30	0.5	26	Slightly higher Ksat
Crandon Beach muck (48, tidal organic)	Organic	0.10	0.80	2.44	1.30	0.5	0.5	Tidal organic / mangrove muck

3.7 Surficial Aquifer

The entire Village of Key Biscayne is situated directly on the highly karstic Biscayne Aquifer, the primary drinking-water source for southeast Florida and one of the most transmissive aquifers in the world. The SFWMD East Coast Surficial Model (ECSM, 2022–2025) divides the surficial aquifer system into five

model layers that correlate with Quaternary and upper Pliocene units (Perkins, 1977). Table 1 and Figure 2 summarize the layering beneath Key Biscayne:

Table 8 Summary of ECSM Model Layers in the Key Biscayne Area

Model Layer	Geologic Units (Perkins, 1977)	Approx. Thickness (ft)	Horizontal K (ft/day)	Remarks
Layer 1	Miami Limestone, Fort Thompson Fm., Pamlico Sand, Key Largo Limestone	30 – 80	5,000 – 50,000	Highly karstic, solution pipes & cavities; primary injection target
Layer 2	Fort Thompson Fm., Anastasia Fm., upper Caloosahatchee	40 – 100	1,000 – 10,000	Still very transmissive; secondary injection zone
Layer 3	Lower Fort Thompson, Anastasia, Caloosahatchee	50 – 120	500 – 5,000	Base of Biscayne Aquifer in this area
Layer 4	Pinecrest Sand Member (Tamiami Fm.)	0 – 80	50 – 1,000	Transition zone
Layer 5	Ochopee Limestone Member (Tamiami Fm.) – Gray Limestone	50 – 150	50 – 500	Upper Floridan / lower confining unit

Key aquifer properties relevant to stormwater injection wells (ECSM peer-review documentation):

- Transmissivity commonly exceeds 50,000–75,000 ft²/day in the upper Biscayne Aquifer beneath Key Biscayne.
- Specific yield $\approx$ 0.20–0.22; storativity $\approx$ 0.001–0.005 (semi-confined deeper).
- Vertical anisotropy (Kh/Kv) $\approx$ 10:1 to 100:1 due to paleosol horizons.
- SFWMD has successfully applied MODFLOW-SEAWAT at 1,000 ft $\times$ 1,000 ft grid scale in this karst system, confirming that equivalent porous-media models are acceptable for regional tools.
- Saltwater interface is currently 1–3 miles west of Key Biscayne (2020 mapping), providing a large freshwater lens for injection without immediate upconing risk.

These characteristics make shallow Class V drainage wells (typically 80–120 ft deep, open-hole completion in Layer 1) the most effective and widely used stormwater disposal method in coastal Miami-Dade County.

3.8 Summary of MIKE SHE Input Files and Their Function

MIKE SHE requires several input files to define geometry, boundary conditions, and material properties. Based on preprocessing logs, the following key files were used:

- **model-dem-5ft.dfs2**: Defines ground surface elevation and overland flow routing, Obtained from KCI
- **imperviousness.dfs2**: Provides spatial variation in impervious cover, controlling runoff and infiltration (Obtained from USGS).
- **VKB-BOTTOM_EL.dfs2**: Defines bottoms of aquifer layers (Obtained from SFWMD)
- **VKB-KH.dfs2, VKB-KV.dfs2**: Provide horizontal and vertical hydraulic conductivities. (Obtained from SFWMD)

- **NRCS-UZ-DB.uzs**: Contains unsaturated zone soil hydraulic functions. (Obtained from NRCS)
- **Boundary time series (dfs0)**: Define rainfall and water-level forcing.

The preprocessing log confirms that several files required bilinear interpolation due to mismatched grids, a standard and appropriate method for LiDAR-based and survey-based datasets.

3.9 Stormwater Infrastructure Data

Stormwater infrastructure data collected under Task 1 informs the baseline hydrologic understanding needed for Task 2. The Village-wide ROW surveys contain culvert locations, inlets, catch basins, and pipe alignments. Finished floor elevations support assessment of vulnerability and potential flow paths. Existing discharge points and historical well locations inform the boundary conditions needed to interpret how rainfall and groundwater interact with the stormwater network.

These datasets ensure that the baseline hydrologic model can correctly characterize conditions in areas where overland drainage is influenced by engineered systems.

These inputs collectively establish the hydrologic framework for Task 2 baseline modeling.

3.10 Geotechnical Investigations

The Geotechnical Report prepared by Geosol in 2023 compiles subsurface investigations conducted to support stormwater infrastructure improvements in the Village of Key Biscayne, including work associated with the K-8 School Drainage Improvements and related outfall and pump station facilities [ref 1]. Although the report is primarily intended to characterize subsurface conditions for constructability and foundation design, its findings directly inform the feasibility and expected performance of stormwater injection wells, particularly in the context of the Village's RFQ requirements to evaluate cost-effective alternative drainage concepts that reduce localized flooding and consider groundwater and tidal controls [ref 2–4].

The report documents a substantial field exploration program using SPT borings across the project limits. Multiple boring groups were advanced to depths ranging from 50 feet in outfall areas to 80 feet in the pump station area, with laboratory testing used to classify soils and support engineering recommendations [ref 1]. Groundwater was encountered at shallow depths—typically between 1.3 and 2.8 feet below ground surface during dry-season drilling—and the report notes that groundwater elevations fluctuate with rainfall, tides, and seasonal cycles. This reinforces that groundwater conditions used for drainage design should be treated as dynamic and not static [ref 1].

Geologically, the report describes a surficial profile consisting of a thin veneer of sands (including Pamlico sands) and fill overlying Miami Limestone. It identifies solution features typical of South Florida karst environments—including small cavities, pinnacle rock, and sand infill below the water table—while indicating that large cavities or sinkhole-type instability are not expected [ref 1]. This geologic context is directly relevant to stormwater injection wells. It confirms the presence of a highly transmissive limestone framework capable of accepting injected flows, while also highlighting the need for well design and pretreatment systems that limit fines migration and manage long-term clogging risks.

The report includes a consolidated stratigraphy table identifying seven subsurface strata, including surficial fill, sands, organic/silty layers, and a deeper sandy limestone unit. The presence of shallow organic/silty strata explains why shallow infiltration practices alone have limited effectiveness and why vertical disposal is frequently needed when the unsaturated zone is thin and groundwater is persistently shallow [ref 1]. Construction observations, including difficulty dewatering limestone and episodes of total loss of drilling circulation, serve as strong indicators of high permeability within the limestone unit and corroborate its capacity to transmit significant flow volumes [ref 1]. The report also documents an “extremely aggressive” environmental exposure classification based on water-chemistry testing, which has implications not only for foundations but also for stormwater injection infrastructure, including well casing, screens, vault hardware, pumps, and electrical components in chloride-rich groundwater [ref 1].

3.10.1 Appropriateness of 100–120 ft injection wells as stormwater mitigation

The RFQ requires updated discharge assessments for Zone 1 that explicitly consider groundwater elevations under present and future conditions and evaluate how discharge capacity may change over the design life [ref 2]. In parallel, the distributed drainage concept being evaluated emphasizes localized pump stations paired with injection wells (historically 80–100 ft deep) to provide sub-basin-specific flood relief while avoiding the cost and disruption of large trunk conveyance and centralized facilities [ref 3]. Extending this concept to 100–120 ft well depths aligns with hydrogeologic logic: deeper wells increase the probability of intersecting transmissive limestone intervals and help stabilize performance when shallow groundwater rises and effective drainage head is reduced.

Several geotechnical findings support the use of injection wells in Zone 1. The shallow groundwater table observed in the borings confirms that the unsaturated zone provides limited storage and that major storm events will produce surface ponding strongly influenced by groundwater and tides [ref 1]. The surficial profile—thin sands over Miami Limestone—combined with drilling losses and dewatering difficulty confirms that the limestone is highly permeable and capable of receiving substantial injected flows when wells are properly constructed and maintained [ref 1]. The identification of small solution features suggests that well performance may vary spatially, reinforcing the value of a distributed well system that reduces the risk of localized underperformance and lowers hydraulic loading on any single well [ref 1, ref 3].

While the borings extend only to ~80 feet, the geotechnical findings strongly support the underlying premise of the distributed drainage alternative: Key Biscayne’s subsurface consists of a shallow sand cap over a highly transmissive limestone aquifer, and stormwater behavior is controlled by rapid groundwater interaction—a condition for which vertical disposal wells paired with localized pumping are an appropriate mitigation strategy [ref 1–3].

3.10.2 Suggested planning-level injection rates for 100–120 ft wells

For planning and alternative screening, injection-well performance should be treated as head-dependent and bracketed with conservative and optimistic assumptions. The 1993 Master Plan describes 24-inch drainage wells approximately 100 feet deep, with approximate capacities of 2,500 gpm under ~2 feet of head and a recommended planning value of ~1,500 gpm [ref 5]. These values provide a relevant performance envelope for modern distributed drainage. A reasonable planning range for a single 100–120 ft injection well is therefore 1,500 gpm as a conservative estimate and 2,500 gpm as an upper planning case, assuming comparable diameter and effective head.

This range should be expressed as a head–capacity curve, not a single value, because head varies with tides, antecedent wetness, and long-term sea-level rise [ref 1–2]. Pump stations serving distributed sub-basins should be sized to meet RFQ LOS requirements while remaining within allowable injection-head limits, with redundancy where sub-basin sensitivity or uncertainty warrants it [ref 3–4].

3.10.3 Permitting considerations: pretreatment, allowable head, and mounding

Injection wells reduce or eliminate routine surface discharge but do not remove regulatory obligations. Compliance shifts toward groundwater protection, pretreatment, allowable head/pressure, setbacks, and monitoring. The RFQ requires the consultant to apply federal, state, county, and local permitting frameworks, including FDEP and Miami-Dade DERM, as well as SFWMD requirements [ref 2]. SFWMD's Applicant's Handbook Volume II requires first-flush treatment sized for one inch of runoff detention or one-half inch of retention, with a minimum 80% TSS removal objective [ref 6]. This applies to any system with emergency surface discharge and informs pretreatment expectations for injection to manage sediments and floatables.

FDEP Class V UIC guidance emphasizes pretreatment and allowable injection head. The guidance describes the “well box” concept for pretreatment and notes that gravity disposal wells are generally limited to allowable heads (commonly ≤ 8 ft NGVD), with pumped systems potentially requiring passive bypass configurations to avoid exceeding allowable pressure. Pressurized operating modes may trigger additional monitoring and permit renewal cycles [ref 7]. These considerations align with the project's internal emphasis on verifying UIC spacing and allowable head limits during conceptual design [ref 4].

Groundwater mounding is a critical performance and permitting factor. High injection rates in a shallow, tidally influenced aquifer can elevate local groundwater heads, reducing effective well capacity and potentially increasing surface ponding in adjacent depressions. The geotechnical report confirms a high groundwater baseline and tidal sensitivity, and the RFQ requires discharge capacity evaluations that explicitly account for groundwater conditions [ref 1–2]. Any distributed pump-and-well alternative intended to be permittable and reliable must therefore quantify groundwater behavior during design storms, including head rise, mounding effects, and the influence of these changes on surface recession and flow paths.

3.10.4 Role of MIKE SHE / MIKE+ in well siting, mounding assessment, and RFQ compliance

The objective of the alternative analysis is not solely to size pumps but to identify drainage strategies that reduce localized flooding while meeting regulatory and cost constraints. The project workplan identifies MIKE+ as the platform for representing the 1D stormwater collection network and 2D overland flow, including placement of wells, pumps, and related elements to mitigate localized flooding [ref 4]. MIKE SHE adds the distributed groundwater and unsaturated-zone physics required to represent infiltration constraints, groundwater rise, recharge, and the influence of sea-level rise on available storage. This capability directly supports the RFQ requirement to consider current and future groundwater elevations and to evaluate how discharge capacity changes over the project's design life [ref 2].

Within a distributed pump-and-injection-well design, MIKE SHE can simulate groundwater head response around injection locations (including mounding), lateral dissipation of injected volumes, and localized impacts created by concentrated injection. Coupled MIKE+ 2D output provides street-scale

flow directions during flooding, allowing wells and sump locations to be placed where surface water actually accumulates, rather than relying on schematic flow assumptions.

By incorporating a domain that extends beyond Zone 1 and captures coastal boundaries controlling groundwater and tidal gradients, the MIKE SHE / MIKE+ framework reflects the full hydrologic system influencing Zone 1 flooding, including rainfall, overland flow, groundwater rise, tidal boundary effects, and inter-basin interactions [ref 4]. This avoids distortions associated with tightly bounded 1D models and supports robust evaluation of injection-well siting and performance.

3.10.5 Use of ECSM as the regional aquifer framework

The SFWMD East Coast Surficial Model (ECSM) provides a vetted regional representation of surficial aquifer structure, layering, and hydraulic-conductivity distributions [ref 8]. ECSM identifies Layer 1 as including Pamlico sand, Miami Limestone, and Fort Thompson Formation, consistent with the stratigraphy documented in the geotechnical report. ECSM hydraulic-conductivity fields are grounded in aquifer-test data and geostatistical methods, directly supporting predictions of injection-well mounding and lateral dissipation [ref 9].

The geotechnical findings at Key Biscayne confirm this conceptual framework: Pamlico sands and fill overlie Miami Limestone, with solution features indicative of a transmissive unconfined aquifer, and groundwater is shallow and responsive to tidal conditions [ref 1]. Drilling observations of high permeability, including difficulty dewatering limestone and complete loss of drilling circulation, further corroborate ECSM's representation of transmissive surficial units [ref 1, ref 9].

In the distributed drainage context, ECSM provides the regional constraint on aquifer layering, boundary conditions, and plausible hydraulic-conductivity ranges, while the geotechnical report and local groundwater observations provide the site-specific confirmation needed for design. This combination supports regulatory review by demonstrating that the modeling is grounded in both SFWMD regional characterization and project-specific subsurface investigations, consistent with the RFQ's groundwater-sensitive discharge evaluation requirement.

References for this section:

1. GEOSOL. *Geotechnical Report* (compiled PDF): includes (a) *Report of Subsurface Exploration and Geotechnical Engineering Evaluation – K-8 School Drainage Improvements Project* (Project No. 223160; dated Dec 28, 2023) and (b) *Supplement Geotechnical Engineering Report – Proposed Outfall Structures* (Project No. 224153; dated Oct 16, 2024).
2. Village of Key Biscayne. *RFQ #2025-13 Zone 1 Alternative Stormwater Modeling and Planning* (design criteria; groundwater requirement; permitting considerations).
3. GIT Consulting. *008-2025-10-22-GIT-Kickoff.docx* (MIKE+ 1D/2D framework; locating distributed infrastructure; UIC/head limits and permitting engagement).
4. WHS. *19930901_VKB Stormwater Master Plan_WHS.pdf* (historical injection-well capacity assumptions; first-flush capture/treatment concepts).
5. SFWMD. *Applicant's Handbook Volume II* (water quality sizing: 1 inch detention / 0.5 inch retention; 80% TSS objective).
6. FDEP. *UIC.pdf* (Class V guidance concepts for stormwater disposal wells: pretreatment/well box; head/pressure management; monitoring/permit expectations for pressurized operation).

7. SFWMD. *SFWMD_ECSM_PeerReviewMeeting1_09072022.pdf* (ECSM objectives; layering; lithology including Pamlico sand and Miami Limestone).
8. SFWMD. *SFWMD_ECSM_PeerReviewMeeting1_MeetingSummary.pdf* (ECSM hydraulic conductivity mapping grounded in aquifer test data).
9. FDEP. *Underground Injection Control – Well classifications (Class V)* (program context).

4 TASK 2 - AREA DELINEATION AND HYDRAULIC ANALYSIS

Define sub-catchments in Zone 1 based on natural sump points and topographic divides, differentiating these from the broader administrative boundary of Zone 1. Sub-catchments will represent the hydraulically distinct drainage units that control local runoff response, while the Zone 1 boundary provides the management and jurisdictional framework for implementation.

A baseline hydraulic and hydrologic model will be developed using MIKE+ (DHI Software), which integrates 1D drainage networks with 2D overland flow. Delineation of overland flow will be based on natural topography, with the model domain extending beyond the Zone 1 boundary to account for off-site influences and potential downstream or adjacent impacts. The baseline model will incorporate rainfall conditions, surface and subsurface storage, and sea level rise projections.

The conceptual system plan will be prepared at a level of detail sufficient to evaluate both existing conditions and candidate improvements. This will include representation of the detailed drainage system with pipes, check valves, control structures, and pumping operations to wells or regulated outfalls. The analysis will quantify runoff volumes, evaluate storage and conveyance, and identify priority sub-areas most susceptible to flooding.

The objective of this modeling effort is to identify potential locations where stormwater infrastructure elements - such as wells, distributed green infrastructure practices, pipelines, and localized pumping facilities - can be sited to address localized flooding. The evaluation will also consider available space for siting improvements to achieve a distributed stormwater management system capable of efficiently mitigating local flood-prone areas.

Flood extent and duration increase with sea-level rise due to reduced drainage capacity and elevated tailwater conditions. The 500-year event produces proportionally greater depths and areas of inundation under all horizons.

Task 2 consists of developing a physically based hydrologic and hydraulic model of Zone 1 using the MIKE SHE integrated modeling system. The purpose of this model is to quantify existing conditions under the required design criteria, evaluate hydrologic sensitivities specific to the K-8 Basin, and establish a baseline framework for evaluating stormwater improvement alternatives in subsequent project stages. This section documents the model domain, computational grid, groundwater and surface-water parameterization, boundary conditions, and interpretation of the preprocessing diagnostics. The modeling approach follows the requirements of RFQ #2025-13 [ref 4] and the data foundation established under Task 1.

4.1 Model Domain and Grid Configuration

The model domain encompasses the entirety of Zone 1 plus a surrounding buffer area to avoid numerical edge effects and ensure correct representation of off-site contributing flows. The grid is defined using a regular rectangular coordinate system aligned with the LiDAR-derived DEM. Although MIKE SHE allows flexible grid sizes, a fixed 5-ft resolution digital elevation model was used for topographic representation, which was interpolated to the model grid during preprocessing. The interpolation notice in the MIKE SHE log confirms that the DEM resolution differed from the model grid resolution, leading to bilinear interpolation. Bilinear interpolation is appropriate for high-resolution coastal topography, as it preserves slope continuity without creating artificial terraces.

The grid spacing was selected to achieve two objectives: (1) provide sufficient resolution to capture shallow depressions and street crowns essential to understanding overland flow in Zone 1, and (2) maintain computational efficiency. Because Zone 1 features very shallow relief - often less than 1 ft of elevation change across entire blocks - fine-scale representation is necessary to simulate ponding and localized flow barriers. This resolution also supports future coupling with MIKE+ 2D overland flow, which will rely on consistent elevation detail.

The model employs 5-meter grid resolution in the subsurface domain and 5-foot grid resolution for 2D overland flow. This dual-resolution structure is intentional:

- The 5-meter MIKE SHE groundwater grid provides enough spatial detail to capture local variations in soil type, water-table rise, and groundwater–surface-water interaction without overwhelming computational resources.
- The 5-foot MIKE+ 2D overland mesh supports highly detailed representation of streets, gutters, driveways, swales, micro-depressions, and local flow direction patterns essential for evaluating distributed drainage measures.

Each surface grid cell is assigned its own:

- Land use category,
- Manning’s roughness,
- Impervious/pervious ratio,
- Surface detention storage,
- Overland flow parameters, and
- Coupled subsurface and unsaturated zone properties.

Similarly, each subsurface cell receives:

- Soil type,
- Unsaturated-zone retention parameters,
- Hydraulic conductivity (KH/KV), and
- Drainage and recharge attributes.

This level of detail is essential for evaluating localized flooding, one of the primary mandates of the RFQ, and for designing small-scale drainage interventions like micro-drainage, distributed pump nodes, and drainage wells.

4.2 Boundary and Initial Conditions

Boundary conditions reflect the hydrologic isolation of Zone 1 while representing the tidal and groundwater interactions characteristic of Key Biscayne. For overland flow, the outer boundary of the domain acts as a no-flow boundary unless it coincides with a roadway that receives off-site drainage. Because Zone 1 is surrounded by other basins on the island, the boundary selection ensures that overland flow does not artificially exit the system where topography would not permit it.

Along the offshore perimeter of the model boundary, the tidal time series is applied as a time variable Constant-Head Boundary depending on local coastal geometry. Each groundwater boundary node receives a time-varying water level equal to the NOAA tidal elevation, allowing groundwater gradients to fluctuate synchronously with observed tides. This method:

- Captures the natural rise and fall of the water table in coastal limestone
- Allows the model to simulate tidal propagation inland through the Biscayne aquifer
- Establishes realistic baseflow gradients during rainfall–tide interactions
- Supports evaluation of future SLR scenarios by offsetting the observed tidal signal with NOAA projections

Groundwater levels measured in the Geotechnical Report - typically 1.3–2.8 feet below grade - match expected dry-season conditions and confirm that tidal forcing is a primary driver of groundwater variability, reinforcing the need for a correct coastal boundary representation.

The overland domain uses the same NOAA-derived tidal time series applied to all 2D edge-cells located along the ocean-facing boundary of the mesh. This establishes a dynamic boundary that:

- Allows overtopping or inflow during elevated tides or surge
- Allows outflow from inland areas toward the coast at low tide
- Enables the model to represent “sunny-day flooding”, an increasingly common issue in Key Biscayne
- Creates the necessary hydraulic gradient for evaluating free discharge, backwater effects, and flood recession rates

Because the 2D mesh has a **5-foot spatial resolution**, each boundary cell has its own precise elevation, enabling accurate prediction of when (and where) tidal waters enter or leave the island’s surface domain.

Although the NOAA tide gauge represents a single coastal location, the MIKE SHE / MIKE+ model requires assigning a water level to every boundary cell. This is achieved using spatial interpolation, a necessary step because:

- The west boundary faces Biscayne Bay
- The east boundary faces the Atlantic Ocean
- The north boundary interfaces with coastal wetlands
- Each portion of the island has a slightly different hydraulic response to tide

To resolve this:

1. The NOAA tidal curve is treated as the primary forcing signal.
2. The model linearly interpolates water level across the entire perimeter, applying minor spatial adjustments based on:
 - Coastal geometry
 - Wetland attenuation
 - Bathymetric depth
3. Each MIKE+ boundary node and MIKE SHE groundwater boundary cell receives a unique copy of the tidal time series, preserving spatial gradients.

This creates a continuous coastal boundary condition that reflects the physical connectivity between the island and surrounding waters.

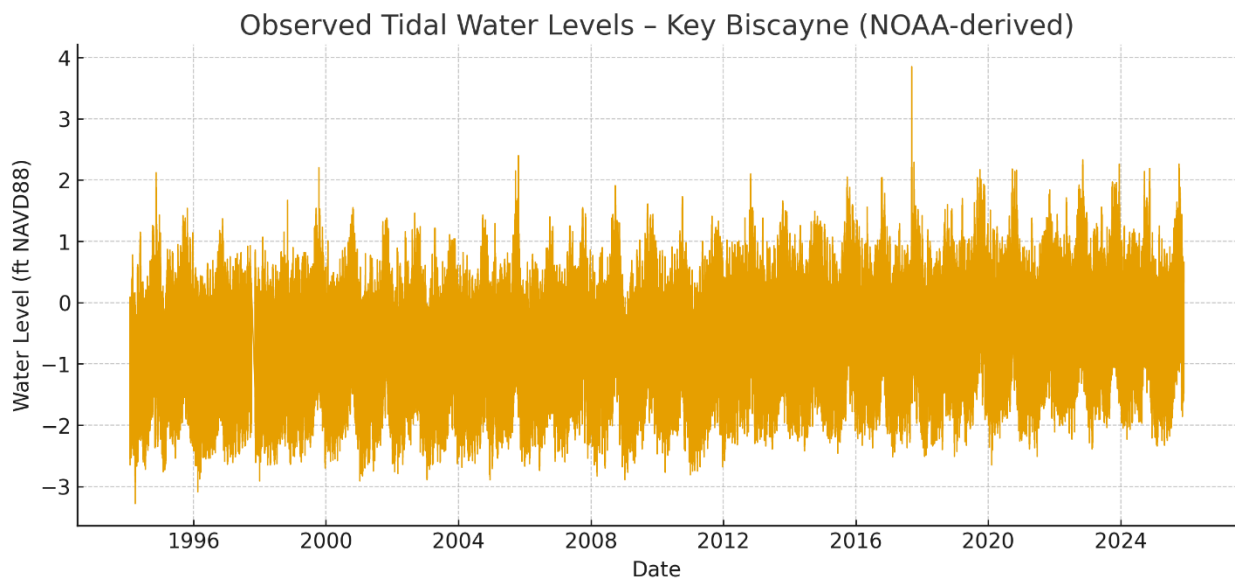


Figure 8 Tidal Boundary Condition Derived From NOAA Observations (Virginia Key)

The figure illustrates the temporal fluctuations applied along the entire domain boundary and demonstrates why a realistic tide signal is essential for modeling groundwater rise, coastal inundation, and flood recession.

Using an observed tidal boundary is essential for the Village's stormwater modeling because:

- Groundwater levels respond directly to tides, influencing infiltration, storage, and recovery
- Flood recession depends on the difference between inland water level and coastal tailwater elevation
- Stormwater discharge systems (gravity or pumped) experience hydraulic backpressure from elevated tides
- Sea-level rise is represented naturally by vertically shifting the tidal boundary
- Alternative drainage concepts - including distributed pumps and injection wells - must be tested under realistic tide-groundwater interactions

Earlier studies (2011, 2015) relied primarily on static or simplified tide stages, which cannot fully represent:

- Groundwater tidal propagation
- Backflow potential
- Flow direction reversal
- Local-scale surface flooding tied to high-tide blockage

The current MIKE SHE / MIKE+ model corrects this by using a fully dynamic tidal boundary applied to both domains.

The overland and groundwater boundary conditions in the MIKE SHE / MIKE+ model are constructed using observed NOAA tidal data, spatially interpolated along the model perimeter to create realistic, time-varying boundaries. Each boundary cell receives a unique, time-dependent coastal water level, enabling accurate simulation of:

- Groundwater rise and recession
- Overland flow direction and coastal inundation
- Tidal blockage of stormwater discharge
- Interactions between rainfall, tide, and groundwater
- Evaluation of distributed drainage alternatives under the RFQ

This approach represents a significant technical advancement over prior VKB drainage models and is essential for developing reliable, defensible stormwater improvements for Zone 1 and the Village as a whole.

The coastal perimeter of the larger Key Biscayne aquifer system is strongly influenced by Biscayne Bay, but Zone 1 lies in the interior of the island, where groundwater levels are controlled primarily by rainfall-driven recharge, aquifer transmissivity, and the shallow elevation of the water table. Initial groundwater heads were established using surveyed groundwater elevations from prior drainage studies and adjusted during warm-up to achieve dynamic equilibrium.

Figure 9 compares the observed annual mean sea levels at the Key Biscayne / Virginia Key NOAA tidal station with a suite of NOAA Local Sea Level Rise (SLR) projections, all expressed in absolute NAVD88 elevation. The black dots represent the measured annual mean sea level from approximately 1995 to 2024. These observations show a clear, persistent upward trend in water levels consistent with regional patterns of ocean warming, thermal expansion, and local land subsidence. This observed rise forms the empirical basis for understanding long-term coastal flooding exposure and for calibrating the hydrologic and hydraulic boundary conditions used in the MIKE SHE and MIKE+ modeling systems.

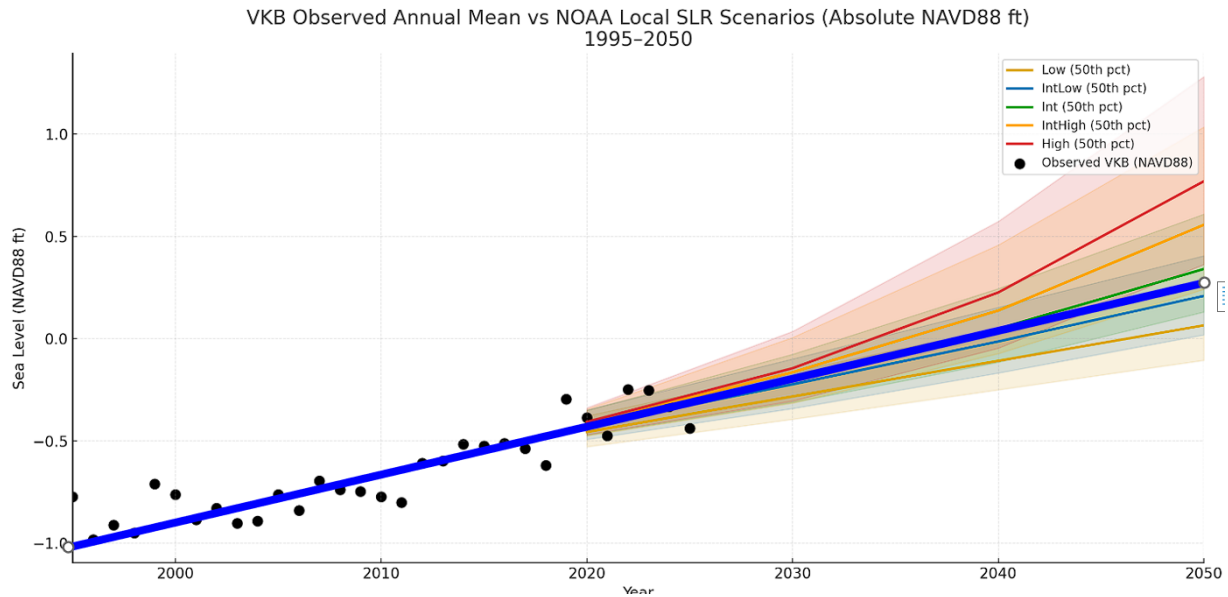


Figure 9 Average Sea Level Virginia Key and Comparison with NOAA Projections

Superimposed on these measured data is a blue line, which represents a linear regression of the observed annual mean sea levels. This regression was developed by the project team to quantify the local historical rate of sea level rise at Key Biscayne. The fitted trend falls between NOAA’s Intermediate-Low and Intermediate projections, suggesting that Key Biscayne’s recent sea-level trajectory aligns with moderate-rise scenarios rather than with the low or extreme upper-bound projections. This empirical trend is important because it anchors the analysis in real conditions experienced by the Village over the past three decades and supports the use of medium-range NOAA projections for stormwater planning and groundwater boundary condition development.

The colored lines and shaded bands on the chart represent NOAA’s Low, Intermediate-Low, Intermediate, Intermediate-High, and High SLR scenarios. These scenarios are based on different assumptions about climate forcing, global temperature rise, and ice-sheet melt behavior. The lower scenarios assume slower warming and minimal ice-sheet response, while the higher scenarios incorporate nonlinear acceleration in ice-sheet loss and more aggressive global-warming trajectories. The widening divergence of these curves after approximately 2030 illustrates the increasing uncertainty in long-term SLR behavior. For stormwater modeling and drainage planning, these differences have meaningful consequences because each increment of sea-level rise directly affects groundwater elevation, tailwater conditions at outfalls, the hydraulic head available to pumps and wells, and the duration of roadway and property flooding during major rainfall events.

The chart also demonstrates why SLR scenario selection is critical for the Zone 1 Alternative Stormwater Modeling effort. The black dots and blue regression line provide a measured record of local sea-level rise and confirm that NOAA’s Intermediate-Low and Intermediate scenarios are reasonable baselines for evaluating 2050 drainage performance, consistent with the RFQ. At the same time, NOAA’s Intermediate-High scenario becomes increasingly relevant after 2040, aligning with the Village’s resilience planning posture documented in the 2024 AECOM Drainage Assessment. This scenario captures accelerating SLR trends that may not yet be visible in the short observational window but

remain plausible based on global climate projections. Its inclusion ensures that alternative drainage strategies are evaluated not only for present conditions but also for mid-century resilience.

The magnitude of differences among the NOAA scenarios also underscores their operational significance. By 2050, the Low scenario indicates roughly half a foot of rise, while the Intermediate scenario approaches approximately 0.8 feet, and the Intermediate-High scenario approaches 1.2 feet. These differences are large enough to materially affect stormwater system performance. They influence groundwater elevation, reduce the effective storage in the unsaturated zone, increase the hydraulic load on injection wells, reduce gravity outfall capacity, and alter the timing and duration of roadway flooding. Integrating these differences into boundary-condition development is therefore essential for the MIKE SHE groundwater model and MIKE+ coastal tailwater representations.

Ultimately, this figure provides a consolidated, data-driven view of historical sea-level rise, modeled future trajectories, and their implications for stormwater system design. The observed measurements define the local empirical trend; the regression line quantifies the rate of rise; and the NOAA projections provide the standardized future scenarios required for regulatory compliance, alternative evaluation, and engineering justification. Together, they support the use of a dynamic, time-varying coastal boundary condition in the modeling framework and confirm the need to evaluate stormwater alternatives - especially distributed drainage and injection well strategies - under realistic sea-level rise scenarios through 2050 and beyond.

4.3 Rainfall and PET Boundary Conditions

The rainfall boundary condition uses the SFWMD 5-year, 24-hour storm, consistent with RFQ requirements [ref 4]. This rainfall event was distributed uniformly across the model domain without spatial variability, as Zone 1 is sufficiently small such that rainfall gradients are negligible for design purposes. Antecedent moisture was assigned through a multi-day warm-up simulation, allowing the unsaturated zone to equilibrate using MIKE SHE's Richards-equation soil water balance.

4.4 Overland Flow Representation

Overland flow in MIKE SHE is governed by the DEM, Manning's roughness values, and drainage structure parameters derived from the land use shapefile. The model simulates free-surface shallow flow using a diffusive wave approximation, which is appropriate for the low-gradient topography and shallow inundation depths observed in Zone 1.

4.4.1 Topography and Ponding

The DEM defines the microtopography that drives surface routing. Street crowns, gutters, driveways, and landscaped depressions influence localized ponding behavior. The model supports accumulation of water in depressions up to the drainage threshold defined by the overland drainage depth parameter. This allows MIKE SHE to represent both natural storage and street-level ponding.

4.4.2 Roughness

The Manning's roughness map derived from the land use dataset captures variation between roadways (lower roughness), residential blocks (higher effective roughness), commercial parcels, and green

spaces. This heterogeneity ensures that overland flow velocities are spatially realistic. For example, flow in roadways is fast and controls longitudinal drainage, while flow across residential parcels is slower due to fences, landscaping, and building obstructions.

4.4.3 Conceptual Overland Drainage

The land use attributes assign each polygon a threshold depth and inflow constant for conceptual overland drainage. When ponding exceeds the threshold (typically 3–10 mm in residential streets), water enters the conceptual storm drain system. In this baseline MIKE SHE-only configuration, this drained water is removed from the overland domain. In future phases, these flows will be passed to MIKE+ 1D collection elements.

4.5 Unsaturated Zone (UZ) Configuration

The unsaturated zone is modeled using the Richards equation, which simulates water movement under variably saturated conditions. Soil hydraulic functions were assigned to each grid cell according to the grouped soil units: fine sands, beach sands, urban complexes, and muck deposits. The van Genuchten–Mualem parameters assigned to each soil category (θ_r , θ_s , α , n , l) reflect the expected pore-size distributions and water retention characteristics [ref 3].

In Key Biscayne, where the water table often lies within 1–2 ft of the surface, the unsaturated zone is thin during storm events. Nonetheless, UZ modeling is important for replicating early rainfall infiltration, transitions between unsaturated and saturated flow regimes, and the timing of groundwater recharge. Because infiltration capacity diminishes rapidly once soils approach saturation, the Richards-equation representation is necessary to avoid overestimating infiltration during heavy rainfall.

4.6 Saturated Zone (SZ) Configuration

The saturated zone simulates groundwater flow and its interaction with surface water. Zone 1 lies atop the Biscayne aquifer, a highly transmissive limestone formation. The Village provided aquifer bottom elevation layers and horizontal and vertical hydraulic conductivity files, which were imported as distributed MIKE SHE maps. The preprocessing logs indicate that these rasters required bilinear interpolation to the model grid. Despite grid misalignment, the interpolation method is appropriate and preserves spatial conductivity patterns.

Groundwater drains to the overland domain when the water table exceeds the saturated-zone drain level assigned to each land use polygon. In urban and residential areas, this drain level is set near or slightly above ground surface to reflect rapid emergence of groundwater as surface ponding. The saturated-zone time constant controls the rate of groundwater release into the overland system; shorter time constants simulate efficient drainage pathways, while longer values reflect restricted subsurface connectivity.

This groundwater–surface water interaction is critical in Zone 1, where storms frequently raise the water table to or above ground elevation, contributing to prolonged ponding even after rainfall ceases.

4.7 Aquifer Layering and Conductivity

MIKE SHE supports multilayer aquifer representation. Five geological layers were imported from the VKB-BOTTOM_EL dataset. These layers represent the vertical stratigraphy of the upper Biscayne aquifer. The horizontal (KH) and vertical (KV) conductivity rasters define how easily groundwater moves through each layer. The preprocessing logs note that the bottom elevation and conductivity rasters were not grid-aligned, necessitating interpolation. This is expected when combining survey-derived surface rasters with geologically derived subsurface rasters and does not diminish model fidelity.

Aquifer transmissivity in Key Biscayne is high, but groundwater mounding can still occur under intense rainfall due to shallow depth to bedrock and limited lateral gradients. The conductivity fields were therefore retained without simplification to preserve heterogeneous lateral flow patterns.

The MIKE SHE baseline model incorporates high-resolution elevation, distributed land use parameters, Richards-equation unsaturated flow, multilayer aquifer properties, and RFQ-specified boundary conditions. The model reflects the hydrologic reality of Zone 1: limited relief, shallow groundwater, high imperviousness, and strong rainfall-driven responses. These conditions create a system highly sensitive to short-duration storms and prolonged multi-day accumulations.

This baseline characterization provides the technical foundation for evaluating Zone 1 discharge requirements and comparing stormwater improvement alternatives in later phases of the project. The integration of MIKE+ 1D and MIKE+ 2D components will be documented in subsequent sections once those analyses are completed.

- **SECTION 4. MIKE+ 1D COLLECTION SYSTEM MODELING**

The MIKE+ 1D stormwater collection system model will be developed following completion of the hydrologic and groundwater analysis documented in Sections 2 and 3. The purpose of the 1D model is to represent the engineered components of the Village's stormwater system - such as pipes, inlets, catch basins, manholes, discharge structures, and drainage wells - and to evaluate their hydraulic performance under both existing and proposed conditions. Although this section will be finalized upon completion of the MIKE+ 1D analysis, the following narrative describes the methodology, data requirements, and analytical framework that will guide model development.

- **4.1 Purpose of the MIKE+ 1D Collection System Model**

The 1D model will evaluate how runoff generated by the MIKE SHE hydrologic model enters, moves through, and discharges from the Village's stormwater collection system within Zone 1. The primary objectives include:

- Characterizing pipe conveyance limitations and inlet capture efficiency.
- Identifying surcharging, backflow, or hydraulic grade line exceedances under the RFQ-required design storm.
- Quantifying system-wide discharge requirements and the timing of peak flows at proposed pump stations or drainage wells.
- Supporting comparison of centralized and decentralized alternatives as directed during project scoping and the kickoff meeting [ref 4, 9].

The MIKE+ 1D model will allow direct coupling of hydrologic loads from MIKE SHE with system-level hydraulic behavior, enabling a fully integrated assessment of surface and subsurface flooding mechanisms.

- **4.2 Data Requirements and System Representation**

Stormwater infrastructure data collected under Task 1 will form the basis of the MIKE+ 1D network. These include:

- Right-of-way surveys and utility CAD files showing the location, size, and elevation of pipes, culverts, inlets, and manholes [ref 1].
- Village GIS stormwater asset layers.
- Historical pump locations and drainage well records from prior Village reports.
- Outfall configurations and any existing tidal control or backflow-prevention devices.

All inverts, pipe slopes, material types, and connectivity will be reviewed for consistency. Where data gaps exist - such as missing invert elevations or undocumented pipe segments - field verification or conservative assumptions will be applied.

The network will be encoded in MIKE+ using standard nodes and links:

- **Nodes:** inlets, catch basins, manholes, pump station wet wells, and drainage wells.
- **Links:** gravity pipes, culverts, force mains (if applicable).
- **Structures:** check valves, orifices, weirs, flow splitters, and tide-control devices.

Vertical constraints imposed by shallow groundwater tables will be explicitly considered, as infiltration into pipes or insufficient hydraulic grade differences can limit system performance.

- **4.3 Hydrologic Coupling with MIKE SHE**

The MIKE+ 1D model will be dynamically coupled to MIKE SHE using rainfall–runoff exchange links. After MIKE SHE simulates rainfall infiltration, unsaturated flow, groundwater rise, and overland ponding, runoff exceeding local storage thresholds is routed into MIKE+ through:

- **1D–2D exchange nodes** in streets (if MIKE+ 2D is active).
- **Direct surface inflow links** for inlets and basins.

This integration ensures that the drainage network receives realistic hydrologic loading reflective of Zone 1’s shallow groundwater and overland flow behavior.

- **4.4 Hydraulic Simulation Approach**

The MIKE+ 1D solver will compute hydraulic grade lines, flow rates, pressure conditions, and surcharging throughout the network under the SFWMD 5-year, 24-hour design storm and 2050 sea-level-rise boundary conditions [ref 4]. Simulated outputs will identify:

- Inlets unable to capture incoming runoff at peak intensities.

- Pipes operating under full or pressurized flow.
- Locations of potential overflow contributing back to surface flooding.
- Discharge capacity limitations affecting pump or drainage well performance.

Special attention will be given to the K-8 Basin, where frequent flooding suggests potential undersized conveyance or insufficient discharge capacity.

• **4.5 Role in Evaluating Drainage Alternatives**

The MIKE+ 1D model will be used to evaluate both existing conditions and conceptual improvement alternatives, including:

- Distributed pump-and-well nodes.
- Upsized pipes or added conveyance paths.
- Road-raising or harmonization concepts.
- Green infrastructure to reduce peak flows.
- Integration of gravity and pumped discharge systems.

Simulation results will support the derivation of construction costs, lifecycle costs, and risk evaluations in later phases, as defined in Task 3 and Task 5 deliverables [ref 9].

4.8 MIKE+ and 2D Overland Flow Modeling

The MIKE+ 2D overland flow component has been developed as a companion to the MIKE SHE hydrologic model, providing high-resolution street-level flood simulation across Zone 1. This layer has been essential for evaluating vehicular clearance thresholds, delineating flood extents and depths, and comparing baseline performance across the calibrated events. The completed MIKE+ 2D configuration now serves as the operational surface-water engine for understanding how rainfall, groundwater, and tidal conditions translate into observable flooding behavior within the basin.

4.8.1 Stormwater Infrastructure Data

Stormwater infrastructure data assembled under Task 1 have been incorporated into the MIKE+ model. The Village-wide right-of-way surveys provided culvert locations, inlets, catch basins, and pipe alignments, which were digitized and integrated into the 1D stormwater network. Existing discharge points, historical well locations, and documented drainage connections have been embedded into the model to reproduce system hydraulic controls, tailwater interactions, and bypass routes.

The figure presents a comprehensive spatial inventory of the Village of Key Biscayne's stormwater infrastructure, integrating both Village-owned assets and the Miami-Dade County (MDC) stormwater system, four principal infrastructure layers are annotated:

- Building footprints (orange) identify developed parcels and impervious structures relevant to runoff generation and flood-risk exposure.
- Miami-Dade County stormwater lines (blue) represent county-maintained conveyance systems that intersect or influence the Village's drainage network, particularly along the Crandon Boulevard corridor and adjacent developments.

- Village Class V injection wells (red circles) denote deep and shallow disposal points used for stormwater infiltration and subsurface discharge, which are critical to understanding system capacity, backflow sensitivity, and groundwater interactions.
- Outfalls (black with red labels) identify locations where stormwater discharges into Biscayne Bay or surrounding canals, with pipe diameters annotated to illustrate hydraulic constraints and outfall sizing.
- Village stormwater lines (yellow) represent the local conveyance system, including surface inlets, catch basins, culverts, and underground pipes.

Collectively, these layers demonstrate the extent, connectivity, and hydraulic dependencies of the Village-wide drainage system, including the interaction between local conveyance pathways and regional MDC infrastructure. The map also highlights the dispersed pattern of outfalls and injection wells, underscoring the importance of modeling localized drainage behavior rather than assuming uniform flow directions in the Village's flat topographic setting.



Figure 10 SW Infrastructure Data Implemented in the MIKE+ Model

Stormwater infrastructure data compiled under Task 1 have been fully incorporated into the MIKE+ stormwater model. Village-wide right-of-way surveys supplied detailed locations of culverts, inlets, catch basins, manholes, and pipe alignments, all of which were digitized and integrated into the 1D network representation. Miami-Dade County stormwater lines shown in blue were imported from county GIS datasets to ensure accurate representation of regional conveyance structures and inter-system hydraulic interactions.

Existing outfalls, documented drainage connections, and historical Class V injection wells were incorporated to characterize hydraulic controls, tidal tailwater conditions, and potential bypass routes during surcharge events.

These combined datasets allow the baseline hydrologic and hydraulic model to characterize both engineered conveyance elements and overland flow mechanisms that govern flood extent, flood depth, and recovery behavior throughout the Village, including Zone 1. The resulting model provides a spatially resolved foundation for evaluating improvements, assessing system performance, and developing mitigation strategies under current and future sea-level conditions.

These datasets ensure that the baseline hydrologic and hydraulic model accurately characterizes both engineered conveyance elements and the overland drainage features that govern flood extent and depth in Zone 1.

4.8.2 Purpose and Function of the MIKE+ 2D Model

The MIKE+ 2D model has been used to simulate shallow sheet flow, roadway flooding, and ponding within Zone 1 using a high-resolution 5-ft grid. Through this implementation, the model quantified flood depths, extents, and durations for the RFQ-specified design storm and for the calibration events (Hurricane Irma 2017 and June 4–7, 2022). The completed simulations demonstrate how roadway geometry and micro-topography control inter-basin routing, including preferential flow paths, local depressions, and hydraulic controls at street crowns.

The 2D results also allow direct assessment of emergency access criteria - such as 14-inch thresholds for emergency vehicles - under existing conditions. These outputs have been used to generate floodplain visualizations for communication with Village staff, Council representatives, and regulatory stakeholders.

4.8.3 Elevation Surface and Mesh Development

The MIKE+ 2D mesh has been fully developed using the processed 5-ft Miami-Dade County LiDAR DEM. Special attention was paid to capturing curb lines, driveway sags, street crowns, and gutter depressions that often vary by only a few tenths of a foot yet significantly influence ponding behavior in a low-relief coastal environment. The mesh extends slightly beyond Zone 1 to avoid artificial boundary truncations and ensure smooth hydraulic gradients near model edges. Areas outside the computational domain were assigned inactive or high-elevation boundary conditions to prevent non-physical routing out of the basin.

4.8.4 Coupling Between MIKE SHE, MIKE+ 1D, and MIKE+ 2D

The MIKE+ 2D model has been coupled with both MIKE SHE and the MIKE+ 1D stormwater collection system. Overland runoff generated by MIKE SHE enters the surface domain as spatially distributed hydrologic loading. The 1D network exchanges flow with the 2D surface grid through inlets, manholes, and overflow structures. Water can move bidirectionally - entering the network under normal drainage conditions or returning to the surface under surcharge or tailwater-driven backflow.

This coupled configuration has been critical for evaluating decentralized pumping concepts because it captures localized drawdown effects around proposed pump nodes, overland redistribution of

floodwaters, and the changes in system performance as flows are intercepted earlier and closer to their origin.

4.8.5 Hydraulic Process Representation

The MIKE+ 2D component solves the depth-averaged shallow-water equations using a diffusive-wave formulation, selected for stability and computational efficiency. Manning's *n* values were assigned from the land-use-based hydraulic parameter dataset developed in Task 1. Flow obstructions such as buildings were represented either through explicit polygons or by applying elevated roughness zones. Storm drain capture efficiencies and inlet operation were governed by the linked MIKE+ 1D nodes. Spatially varying infiltration was included where refinement was needed to reconcile runoff behavior under calibration events.

The model now produces flood-depth grids, inundation-duration maps, flow-direction rasters, and flood-recession curves for each simulated event and design storm. These outputs form the basis for the hydraulic performance evaluation required under Deliverable 1.

4.8.6 Application of MIKE+ 2D to Alternative Evaluation

With the completion of the baseline and calibration simulations, the MIKE+ 2D model is now being used to support the evaluation of decentralized pump-and-well configurations. The model quantifies reductions in flood depths and durations, identifies locations where LOS thresholds are met or exceeded, and compares decentralized strategies to centralized approaches tested in prior studies. Elevation inputs can be modified to test road-raising scenarios, utility conflicts, and harmonization strategies.

The 2D model has also been instrumental in identifying unintended hydraulic consequences such as potential shifting of floodwaters to adjacent blocks or acceleration of flow in sensitive areas. These diagnostics ensure that preferred alternatives not only reduce flooding in Zone 1 but also avoid transferring impacts elsewhere in the Village.

5 PRELIMINARY RESULTS:

The peak flood depth map for the June 6, 2022 rainfall event illustrates the spatial distribution and severity of overland flooding across the Village of Key Biscayne under a high-intensity storm that produced widespread ponding, documented drainage-system surcharge, and shallow groundwater emergence. This event is widely recognized as one of the most impactful rainfall-driven flooding events in recent Village history, characterized by intense short-duration rainfall coinciding with elevated antecedent groundwater conditions.

5.1 Peak Flood Depth

The depth map displays peak inundation depths across the island in a continuous 2D overland flow domain, with water levels mapped relative to local ground elevation. Depths range from shallow nuisance flooding (<0.25 ft) in higher-elevation or well-drained areas to extreme depths exceeding 3 ft in localized depressions, coastal edges, and low-lying residential sectors. The red-shaded perimeter areas, particularly along the western shoreline and near beach and dune systems, indicate where water levels

reached their highest magnitudes, reflecting a combination of low coastal elevation, limited conveyance, and backpressure from tide-influenced tailwater conditions.



Figure 11 Model Simulation of Peak Flood Depth and Extent for 6/6/2022

Interior neighborhoods exhibit moderate to severe flooding, with consistent areas of 1.0–2.5 ft depths, especially along roadways with limited positive drainage gradient. The K-8 School basin, Holiday Colony, and adjacent central-island neighborhoods show clusters of elevated flood depths, consistent with the known topographic depressions and drainage bottlenecks previously documented in the 2011, 2015, and 2024 studies. These inundation patterns closely follow the street grid, indicating that **roadway geometry strongly governs the conveyance of runoff.**

Southern neighborhoods, including the harbor and canal-lined residential peninsulas, demonstrate a mix of moderate street flooding and severe ponding at cul-de-sac termini and areas with restricted outfall pathways. In many cases, the shallow gradient and tidally constrained discharge capacity prevented effective drainage, resulting in prolonged inundation.

On the eastern Atlantic-facing side, the model depicts elevated flooding in the dune-adjacent zones where groundwater tables are shallow and stormwater infiltration is limited. The eastern boundary also reflects the influence of ocean-level conditions, where standing water accumulated broadly across low-lying beachfront parcels.

The map also highlights the importance of distributed topographic storage: many localized depressions across the island temporarily retained water to depths exceeding 1.5 ft, indicating that flooding was not solely driven by conveyance limitations but also by groundwater-related loss of infiltration capacity and limited vertical storage during the storm's peak intensity.

Overall, the June 6, 2022 peak depth map demonstrates that:

- Flooding was widespread island-wide, not confined to isolated problem areas.
- The western shoreline, central residential grid, and southern peninsula neighborhoods experienced the deepest inundation.
- Flood depths were controlled by a combination of limited conveyance capacity, shallow groundwater, tidal interaction, and low topographic relief.
- The flooding patterns are consistent with field observations, repetitive loss reports, and prior modeling studies.

This map therefore provides a spatially explicit representation of the magnitude and extent of flooding during a high-intensity rainfall event and clearly indicates areas where alternative drainage strategies - including distributed pump nodes, drainage wells, micro-drainage systems, or roadway profile adjustments - may be required to reduce localized flooding and enhance system resiliency under both current and future sea-level-rise conditions.

The detailed flood-depth and overland-flow map for Zone 1 reveals a highly structured flooding pattern driven by a combination of roadway geometry, shallow groundwater, tidal boundary conditions, and limited conveyance capacity within the existing stormwater network. Zone 1, which includes the residential neighborhoods surrounding the K-8 school and the central-western portion of the island, consistently demonstrates some of the most hydrologically sensitive areas in the Village. The 2D overland flow results illustrate how rainfall concentrates within this basin, how water is routed across local depressions, and how ponding persists where conveyance to neighboring basins or coastal discharge points is constrained.

Within Zone 1, the flooding pattern is dominated by a grid of interconnected shallow depressions aligned with the street network. Streets such as West McIntyre Street, Beechwood Drive, and West Enid Drive act as preferential pathways during the event, collecting runoff from surrounding parcels and conveying flow toward deeper low points. The blue-shaded inundation areas show depths commonly ranging from 0.5 to 1.5 ft, with several localized pockets exceeding 2 ft in micro-basins where surface elevations are lowest relative to surrounding terrain. These are locations where groundwater emergence, reduced infiltration capacity, and lack of positive drainage gradient combine to create persistent ponding.

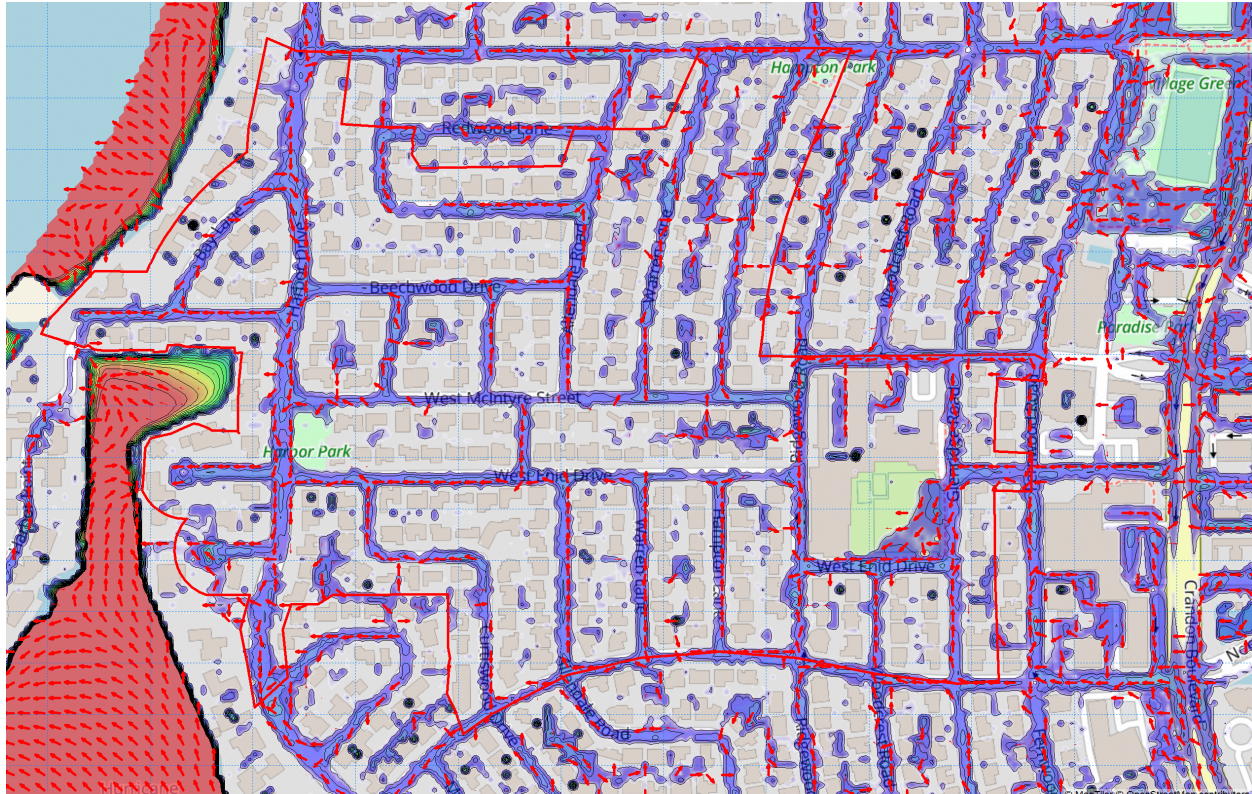


Figure 12 Zone 1 Model Simulation of Peak Flood Depth and Extent for 6/6/2022

The red overland-flow vectors emphasize the direction and magnitude of surface-water movement, highlighting how floodwaters traverse the basin under varying hydraulic conditions. In many segments of Zone 1, the vectors reveal bi-directional flow patterns, with water at times moving west toward the coastal boundary and at other times shifting east or north toward interior depressions. This hydraulic variability reflects the compound interaction between rainfall-driven runoff, shallow groundwater, and tailwater conditions at coastal edges. The model captures these reversals because the 2D domain uses true ground elevations at 5-ft resolution, making the direction of water movement responsive to even subtle changes in slope, road crown alignment, and tidal backpressure.

The figure also highlights a critical constraint that has been documented in earlier stormwater master plans and validated again here: Zone 1 contains several roadway corridors where gravity drainage is insufficient, especially when storms coincide with elevated tides. This is apparent where flow vectors converge at inland depressions and where water accumulates up-gradient from coastal edges rather than discharging freely toward Biscayne Bay. The western edge of Zone 1, adjacent to the harbor and waterfront areas, shows high flood depths along the red perimeter, indicating that even though these areas are geographically close to potential discharge points, tailwater induces backpressure, restricting outflow and causing water to pond inland.

Several sub-neighborhoods inside Zone 1 - particularly the blocks immediately west and south of the K-8 school - appear as consistent “collection bowls,” with runoff from surrounding higher streets draining inward rather than outward. These zones are critical candidates for alternative drainage improvements because localized pumping or injection wells could be positioned at these depressions to remove flood volume directly at the source rather than relying on long, hydraulically inefficient gravity pathways.



This spatially detailed understanding of Zone 1 reinforces the need for a drainage approach that goes beyond centralized conveyance. The patterns shown in the figure justify the RFQ-driven evaluation of distributed drainage options, including localized pump nodes and strategically placed injection wells, which target the precise areas where water accumulates, shorten the hydraulic travel distance, and bypass the gravitational and tidal constraints affecting this basin. The flood-depth and flow-path results produced by the MIKE SHE / MIKE+ integrated model therefore provide essential diagnostic insight for screening and refining alternative stormwater improvements tailored specifically to the hydrologic behavior of Zone 1.

Groundwater levels within the project area were evaluated to characterize the response of the Biscayne aquifer system to both extreme storm conditions and representative non-storm tidal periods. Figure 14 and Figure 15 present simulated groundwater elevations at monitoring points located near Woodcrest

Road and West Enid Drive under (1) Hurricane Irma conditions (September 2017) and (2) typical tidal conditions in June 2022. These results reflect the hydraulic behavior of a highly permeable coastal aquifer system and document the extent to which storm surge and tidal forcing influence near-surface groundwater levels across the island.

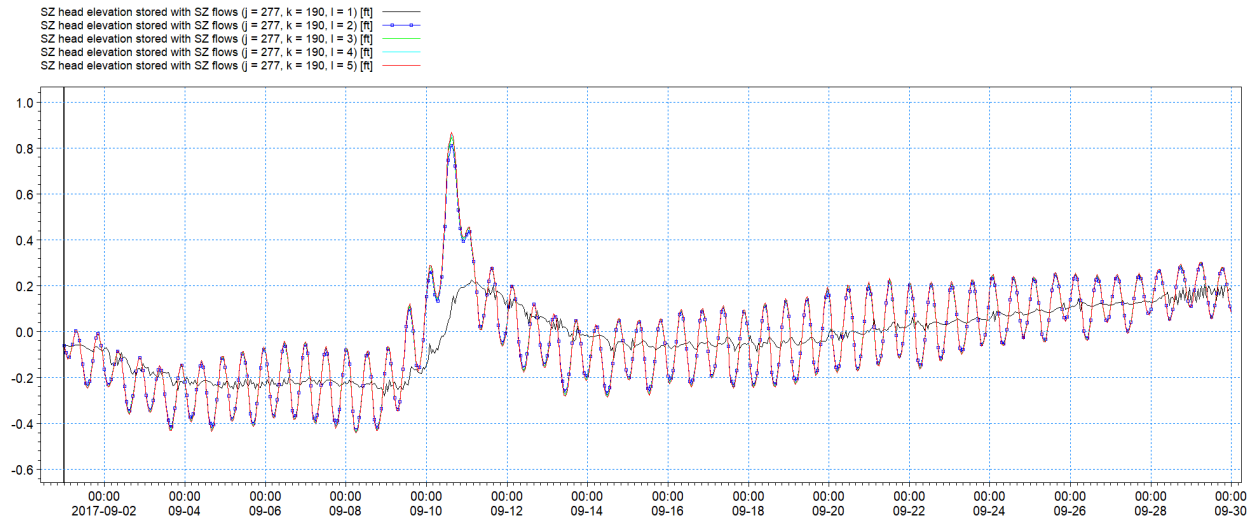


Figure 14 Groundwater Levels at Woodcrest Rd and W Enid Dr During Irma, 2017

During Hurricane Irma, the region experienced a peak storm surge of approximately 3.75 feet NAVD88, producing a substantial increase in coastal boundary water levels. Given the Biscayne aquifer's high transmissivity and minimal confinement, the elevated coastal head propagated inland with limited attenuation. The model results indicate:

- A rapid and uniform rise in groundwater elevations, consistent with storm surge transmission through a highly conductive limestone aquifer.
- Peak groundwater levels occurring concurrent with the external surge hydrograph, indicating direct hydraulic connectivity between coastal water levels and inland groundwater head.
- Tidal oscillations superimposed on the elevated groundwater condition, demonstrating that the aquifer remained responsive to short-period fluctuations despite the surge forcing.
- A gradual recession period following the storm peak, with groundwater levels returning to pre-event conditions over several days, reflecting aquifer drainage and dissipation of stored stormwater.

The elevated groundwater surface significantly reduced the available storage within the shallow saturated zone and limited the capacity of drainage wells, exfiltration systems, and soil infiltration processes. As noted in USACE EM 1110-2-1417 guidance, storm-induced groundwater mounding is a controlling factor that must be explicitly represented when evaluating flood risk, drainage system performance, and post-event recovery in low-lying coastal environments.

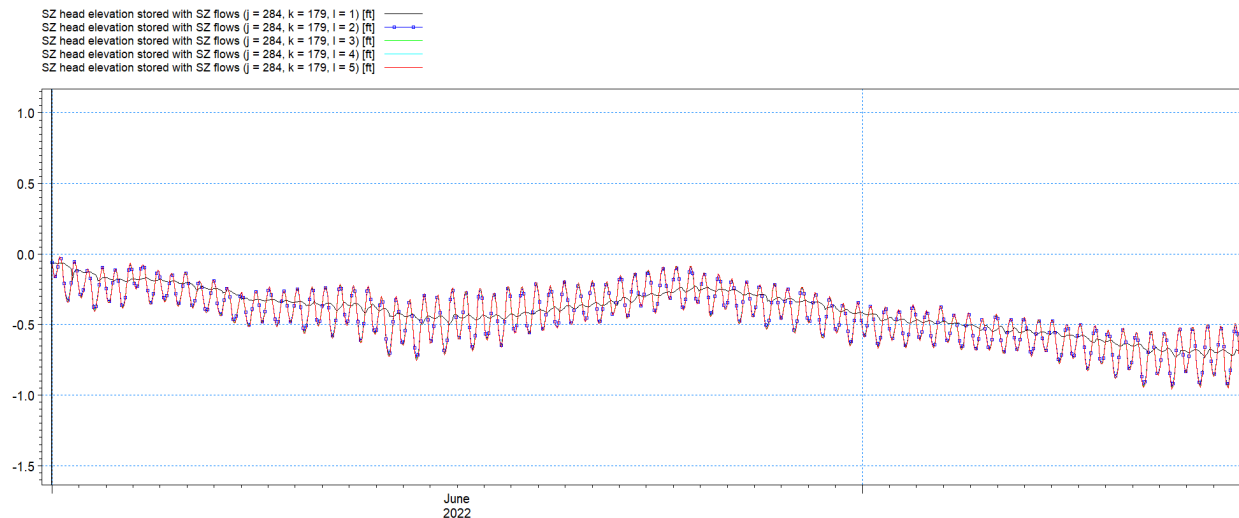


Figure 15 Groundwater Levels at Woodcrest Rd and W Enid Dr in June 2022

Groundwater levels during the June 2022 period reflect baseline hydrologic conditions absent major storm input. The simulations indicate:

- Semi-diurnal tidal oscillations of approximately 0.3 to 0.5 feet, which are consistent with normal variations in coastal water levels.
- A stable mean groundwater elevation controlled primarily by tidal boundary conditions, atmospheric pressure, and seasonal evapotranspiration patterns.
- Moderate diurnal variability associated with local recharge and aquifer-storage interactions.

These groundwater fluctuations confirm that, even under non-storm conditions, the aquifer system operates under continuous tidal influence, with groundwater levels frequently approaching near-surface conditions in portions of the Village. As noted in USACE coastal aquifer assessments, such hydrologic settings exhibit reduced infiltration capacity, rapid transition to surface ponding during rainfall, and limited buffering of stormwater inflows.

Comparison of the 2017 and 2022 groundwater hydrographs demonstrates the sensitivity of the Biscayne aquifer to both long-period (storm surge) and short-period (tidal) boundary conditions:

- Under storm surge conditions, groundwater elevations rise substantially due to direct hydraulic loading of the aquifer, reducing available storage and increasing the probability of system surcharge and overland flooding.
- Under typical tidal conditions, groundwater levels remain in a narrow oscillatory range, yet remain sufficiently elevated to limit infiltration and drainage system drawdown in advance of storm events.

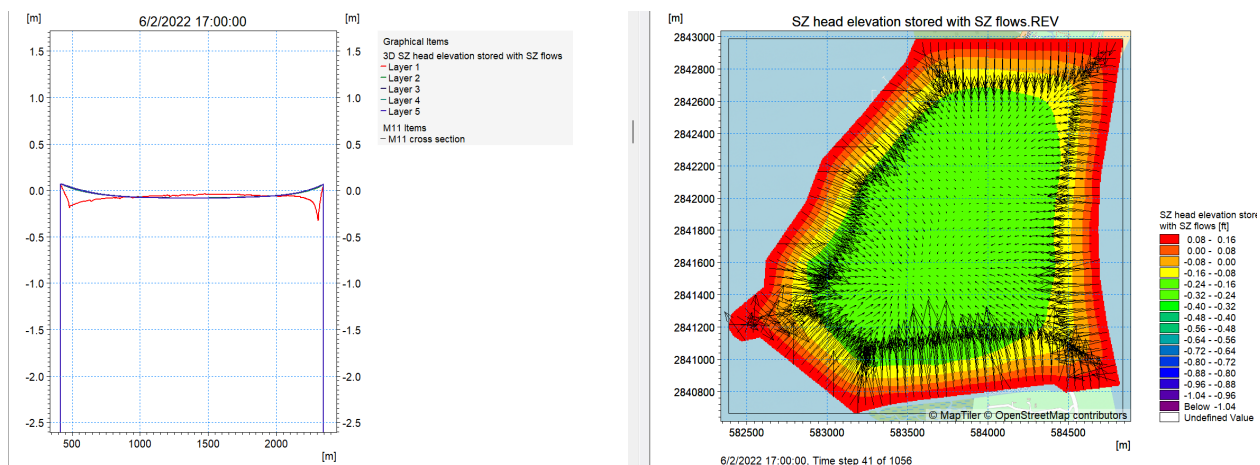
From a regulatory and engineering perspective, these findings indicate that:

- Stormwater infrastructure design must account for surge-driven groundwater mounding, consistent with USACE coastal flood risk management guidance, as elevated coastal stages directly reduce available subsurface storage and diminish system performance.

- Subsurface drainage features such as exfiltration trenches, gravity wells, and other pervious systems exhibit significant reductions in effectiveness under high groundwater conditions and must be evaluated under both surge and antecedent wet-season water table scenarios.
- Hydraulic modeling of stormwater systems must include dynamic groundwater and tidal boundary conditions to accurately represent the interaction between coastal forcing, inland drainage response, and system recovery.
- Reliance on infiltration-based stormwater controls is not appropriate in settings where groundwater levels routinely approach land surface, as the available unsaturated zone is insufficient to provide storage or percolation capacity, resulting in impaired performance during both moderate and extreme events.
- **Pumped discharge into regulated drainage wells is recommended where feasible, as mechanical conveyance provides a reliable method of removing stormwater when gravity drainage and infiltration pathways are compromised by elevated groundwater or storm surge conditions. Pumped systems reduce dependence on aquifer storage, mitigate the effects of tidal backwater, and allow controlled conveyance to permitted wells under a range of hydrologic conditions.**

Groundwater levels in the Village of Key Biscayne are strongly controlled by coastal water levels due to the high transmissivity of the Biscayne aquifer. During Hurricane Irma, surge-induced groundwater rise substantially reduced the functional capacity of infiltration-dependent drainage features, contributing to increased surface flooding and extended drawdown times. Under typical conditions, the aquifer remains tidally influenced, maintaining elevated groundwater levels that limit subsurface storage and constrain the performance of passive drainage systems. These conditions are consistent with USACE coastal hydrologic assessments and must be explicitly integrated into stormwater system design, modeling, and long-term resilience planning for the island.

The two sets of model outputs shown in Figure 16 represent tidal groundwater conditions within the Biscayne aquifer at two snapshots separated by approximately six hours. These snapshots document the characteristic tidal response of a permeable coastal aquifer system and provide a basis for evaluating stormwater drainage performance under variable hydraulic boundary conditions.



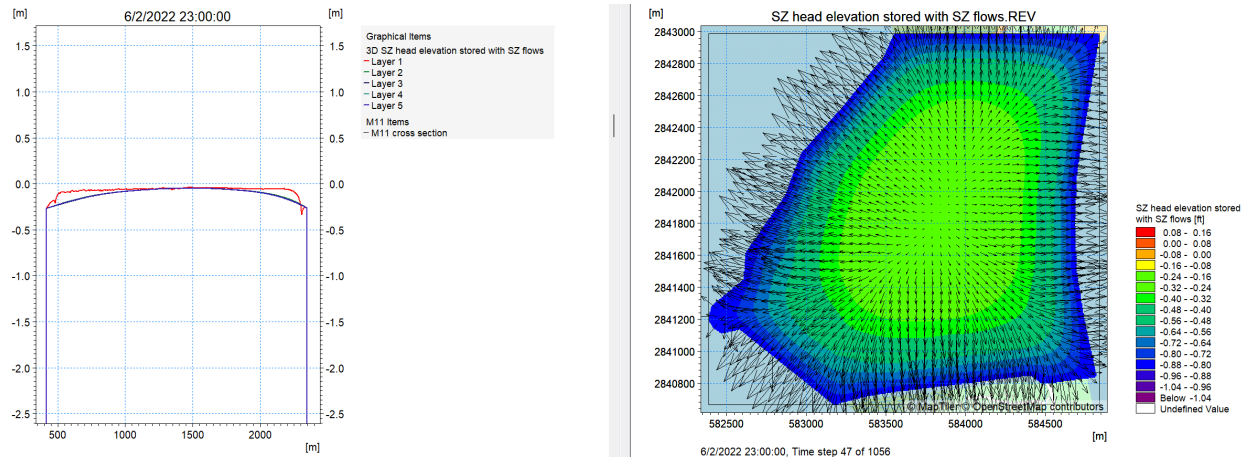


Figure 16 Tidal Groundwater Dynamics

East–West Transect Response

The east–west transect shown in the left panels depicts the groundwater surface across the island at two distinct points within the semi-diurnal tidal cycle. The following observations are noted:

- At the higher tidal stage, groundwater elevations along the island boundaries are elevated, creating a mild inward hydraulic gradient consistent with tidal loading of the aquifer.
- Approximately six hours later, the transect reflects tidal recession, with groundwater elevations along the perimeter lowering and the inland portion of the transect assuming a more convex configuration. This shape is indicative of seaward groundwater release during the ebb phase.

The alternating groundwater elevations demonstrate the dynamic nature of the aquifer system, which responds rapidly to coastal boundary conditions. This tidal modulation remains the controlling short-period influence on groundwater levels, even in the presence of long-term sea level rise. Accordingly, the representation of groundwater conditions should be based on mean tidal water levels rather than instantaneous maximum tides, consistent with USACE hydrologic evaluation practices for tidally influenced systems.

Plan-View Groundwater Flux Patterns

The plan-view flux vectors shown in the right panels describe the magnitude and direction of groundwater movement at the same two tidal stages. The model results indicate:

- During the incoming tide, flux vectors along the perimeter of the island show inland-directed flow, reflecting aquifer pressurization from elevated coastal water levels.
- During the outgoing tide, flux vectors reverse, demonstrating outward-directed flow and aquifer drainage toward the coast.

This alternating flux pattern is typical of unconsolidated or highly transmissive coastal aquifers and is consistent with USACE documentation of barrier island hydrogeologic behavior. The bidirectional exchange underscores that the ECSM system functions as a tidally driven hydraulic regime, with groundwater gradients reversing twice daily.

Implications for Stormwater System Performance

The modeled tidal response has several implications relevant to stormwater infrastructure planning and design:

1. Tidal forcing governs short-term groundwater behavior.
2. The semi-diurnal tide cycle, rather than isolated peak tide events, exerts the predominant influence on groundwater gradients and available subsurface storage.
3. Mean tidal water levels are the appropriate basis for steady-state and design analyses.
4. Maximum tidal elevations represent short-duration conditions and do not control the overall groundwater regime used for evaluating stormwater system function, consistent with USACE coastal groundwater evaluation procedures.
5. Subsurface drainage systems have variable performance across the tidal cycle.
6. Under elevated groundwater conditions associated with incoming tide, infiltration-based stormwater controls and gravity drainage features exhibit reduced effectiveness.
7. Dynamic groundwater representation is required for hydrologic and hydraulic modeling.
8. Accurate simulation of stormwater system behavior in coastal settings requires incorporation of time-varying groundwater boundaries that reflect tidal forcing.
9. Stormwater design must account for reduced storage and capacity during tidal loading.
10. During periods of high tide or storm surge, reduced hydraulic gradients may limit conveyance, extend drawdown times, and increase the probability of surface flooding.

The tidal groundwater dynamics shown in Figure 16 demonstrate that the ECSM aquifer responds predictably to semi-diurnal fluctuations in coastal water levels. Groundwater elevations and flux directions reverse within each tidal cycle, resulting in alternating periods of aquifer pressurization and drainage. These behaviors are consistent with USACE assessments of permeable barrier island systems and must be incorporated into stormwater modeling, design criteria, and resilience evaluations. The use of mean tidal water levels for analysis is therefore appropriate for representing long-term groundwater conditions that control stormwater system performance.

5.3 Water Budget

The water budget in the VKB model is calculated with MIKE SHE (and its coupling to MIKE+ for drainage), so the full hydrological cycle is represented as a set of fluxes between model domains. Below is a structured description of how the cycle is represented and how the DHI tools compute the water balance.

The VKB water budget is based on conservation of mass over the 3-D model domain:

$$\Delta S = P - ET - Q_{\text{surf}} - Q_{\text{gw}} - Q_{\text{drain}} + Q_{\text{boundary}} + Q_{\text{infrastructure}}$$

where:

- ΔS = change in total water storage (overland, unsaturated zone, saturated zone, drainage system)

- P = precipitation input
- ET = evapotranspiration losses
- Q_{surf} = net surface runoff leaving the domain
- Q_{gw} = net groundwater flow crossing the lateral/coastal boundaries
- Q_{drain} = discharge from drains, wells and stormwater network
- $Q_{boundary}$ = exchange with coastal water levels and any imposed head boundaries
- $Q_{infrastructure}$ = internal sources/sinks (e.g. abstraction wells, injection wells, leakage)

MIKE SHE computes each term in space and time, then the “Water Balance” tool aggregates volumes for the entire domain or user-defined subcatchments.

5.3.1 *Atmospheric inputs and losses*

Precipitation

- Time-series rainfall is applied to the land surface grid.
- In VKB, rainfall can be spatially uniform (single gauge) or distributed (radar/Thiessen polygons), but in all cases MIKE SHE converts it to a flux [L/T] on each grid cell.
- Rainfall is the main positive term in the water budget.

Interception and canopy processes

- A canopy/interception layer can be defined per land-use class.
- Rainfall first fills interception storage. Only excess throughfall reaches the overland or unsaturated zone.
- The intercepted portion is removed from the water budget through evaporation.

Reference ET and actual ET

- Reference evapotranspiration (e.g. Penman–Monteith) is provided as a time-series.
- MIKE SHE converts reference ET to **actual ET** by combining:
 - root depth and leaf area index,
 - soil moisture in the unsaturated zone,
 - water table depth (capillary rise),
 - wet surface evaporation in ponds or standing water.

ET is then split into:

- **Interception evaporation** (from canopy storages),
- **Surface evaporation** (from ponded water and bare soil),
- **Transpiration** (extraction from the unsaturated and saturated zones).

These are explicit loss terms in the water balance.

5.3.2 *Overland flow and surface water*

Overland flow domain

- The land surface is represented as a 2-D grid (same horizontal discretization as the UZ/SZ in MIKE SHE or a finer 2-D mesh in MIKE+ 2D if coupled).
- Surface roughness (Manning n), detention storage, and depression storage depth are defined per land-use class (as in the table you developed).

Surface routing and exchange

- Excess rainfall (after interception and infiltration) is added to overland storage.
- Overland flow is routed using diffusive wave or kinematic approximations.
- Exchange between overland and the unsaturated/saturated zones is handled through:
 - **Infiltration / exfiltration** at the soil surface (Richards' equation flux),
 - **Overland–SZ exchange coefficient** for direct leakage where the water table intersects the surface (e.g. in tidal wetlands).

Coastal and ocean boundaries

- Along the shoreline, overland cells and channels are connected to water level boundaries that represent tides and surge.
- Inundation from high coastal water level appears as an inflow into the overland domain, and drainage to the sea appears as an outflow.
- These boundary fluxes are reported separately in the water balance.

5.3.3 *Unsaturated zone (UZ) – Richards equation*

Vertical profile

- Each grid column has a vertical discretization of the unsaturated zone (above the phreatic surface).
- For each soil type (sand, fine sand, organic muck, etc.), van Genuchten–Mualem parameters (θ_r , θ_s , α , n , l , K_{sat}) describe:
 - the θ –pressure head relation, and
 - the unsaturated hydraulic conductivity function.

Fluxes in the UZ

Richards' equation is solved vertically:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[K(\theta) \left(\frac{\partial h}{\partial z} - 1 \right) \right] - S(z)$$

Key flux components:

- downward percolation from surface / overland layer,

- upward capillary rise from the saturated zone,
- plant root uptake (transpiration) represented as a sink term.

MIKE SHE computes:

- **Change in UZ storage** (integration of θ over depth),
- **Net recharge to groundwater** at the UZ–SZ interface, as a time-varying flux per cell.

5.3.4 *Saturated zone (SZ) – groundwater*

3-D groundwater flow

- The saturated zone is represented by one or more layers with horizontal and vertical hydraulic conductivities.
- Groundwater flow is governed by Darcy’s law and mass conservation (3-D Boussinesq approximation).
- The phreatic surface can rise into the lower unsaturated cells or drop below them; MIKE SHE updates the UZ/SZ interface dynamically.

Boundaries and interactions

Key SZ processes contributing to the water budget:

- **Recharge from UZ** (primary inflow to SZ).
- **Discharge to overland and channels** where the water table intersects the surface or river stages are lower (baseflow).
- **Lateral groundwater flow across model boundaries:**
 - Constant head boundaries along the coastal margin, with tidal forcing,
 - No-flow boundaries along groundwater divides, or specified flux boundaries if regional inflows are represented.
- **Pumping or injection wells** (if present), represented as internal sinks or sources.

MIKE SHE water balance outputs separate:

- net lateral groundwater boundary flux,
- net leakage to/from rivers and drains,
- total abstraction/injection.

5.3.5 *Stormwater network and drainage infrastructure (MIKE+ coupling)*

For VKB, the urban drainage system is important because a large fraction of runoff is captured by inlets and discharged to the ocean or surrounding bay.

- The 1-D drainage network (pipes, manholes, culverts, outfalls) is represented in **MIKE+ Collection Systems** or MIKE+ 1D.
- Inlets and manholes are coupled to the MIKE SHE or MIKE+ 2D overland domain through Q–H relations or weir/orifice equations.

Water-budget-relevant fluxes:

- inflow from overland to the pipe network (captured runoff),
- storage in pipes and manholes,
- outflows at outfalls or pump stations to the ocean or bay.

In the combined water balance, these appear as:

- **Internal redistribution** (overland → network → coastal boundary), and
 - **Net discharge to coastal boundary** through structure outflows.
-

5.3.6 *Wetland and tidal marsh representation*

For units such as Crandon Beach muck and mangrove areas:

- High θ s and low n values in the UZ represent high water content and slow drainage.
- Very shallow or zero SZ depth, combined with frequent coastal inundation, creates near-saturated profiles for most of the time.
- Overland–SZ exchange coefficients are large so that surface water and groundwater respond rapidly to tidal fluctuations.

These settings control:

- storage in the wetland soil column,
- short-term buffering of rainfall,
- long-term exchange with the surrounding bay.

5.3.7 *Water balance calculation with DHI tools*

Global and subcatchment balances

After each simulation, MIKE SHE produces:

- **Global water balance** for the full model area, and
- **Local balances** for user-defined catchments, polygons or model domains (e.g., VKB island, wetland zones, drainage basins).

The Water Balance tool aggregates:

- Volumes of precipitation, ET components, infiltration, recharge, groundwater inflow/outflow, overland outflow, channel discharge, and network discharge.
- Changes in storage in each domain (overland, UZ, SZ, channels / MIKE+).

All balances are reported as:

- time-series (e.g. daily or hourly fluxes), and
- cumulative volumes over the simulation period, with a closure error.

Closure and diagnostic use

- The difference between sum of inflows and outflows and total storage change is the **closure error**, which should remain small compared to total fluxes.
- Inspection of the water balance over wet years, dry years, and design storms allows:
 - verification that recharge, runoff, and ET are within expected ranges for VKB,
 - evaluation of the relative role of direct runoff vs infiltration vs groundwater discharge,
 - quantification of how much water leaves the island through pipes, through natural surface drainage, and through groundwater.

5.3.8 Interpretation for 5-yr 24-hr Design Event

Applied to VKB, the DHI water budget:

- converts local rainfall and ET into detailed surface, soil, and groundwater fluxes on a coastal barrier island,
- explicitly tracks the split between:
 - direct runoff to the bay/ocean (overland + pipes),
 - infiltration and recharge to the shallow coastal aquifer,
 - evaporative losses from urban areas, beaches, wetlands and open water,
- captures the interaction between sea-level/tidal forcing and groundwater heads, including periodic inflow of saline water at the coastal boundary and outflow during low tide.

This integrated accounting of the full hydrological cycle is what allows the VKB model to assess changes in flooding, groundwater levels, and discharge pathways under existing conditions and under future sea-level rise or infrastructure scenarios.

Table 9 Storage changes

Storage component	Depth (in)
Canopy storage	0.0017
Overland storage	0.85
Unsaturated-zone storage	0.11
Saturated-zone storage	0.26
Total storage increase	1.22

For a 6.56-inch event the model retains about 1.22 in of water inside the system:

- ≈0.85 in is held in surface detention and ponding.
- ≈0.11 in is stored as additional soil moisture.
- ≈0.26 in represents higher groundwater levels.

Therefore about **19% of rainfall** remains stored on the island after 7 days.

Table 10 Atmospheric Inputs

Flux	Depth (in)
Precipitation	6.56
Evapotranspiration	0.00

The design storm applies **6.56 in** of uniform rainfall over the catchment, with evapotranspiration relatively negligible during the short event and accumulation period.

Table 11 Overland Boundaries

Flux	Depth (in)
Overland boundary – West	232.56
Overland boundary – East	55.30

These values are the cumulative overland fluxes across the coastal boundaries, converted to depth over the whole subcatchment. Only a narrow coastal belt is exchanging water, so the normalization makes the equivalent depths very large. They represent strong tidal and storm-driven exchange with the ocean and bay, not additional rainfall.

Table 12 Groundwater (SZ) Boundaries and Drains

Flux	Depth (in)
SZ boundary – East	0.410
SZ boundary – West	0.259
Drain SZ / boundary – East	0.049
Drain SZ / boundary – West	0.000

Groundwater interacts with coastal boundaries at a more modest scale:

- ≈0.41 in equivalent depth through the eastern SZ boundary,
- ≈0.26 in through the western SZ boundary,
- ≈0.05 in routed through SZ drains connected to the eastern boundary.

These fluxes capture how the shallow aquifer exchanges with surrounding coastal waters during and after the event.

Table 13 Surface–Subsurface Exchanges

Process	Depth (in)
Infiltration to SZ	0.258
Exfiltration from SZ	0.041

Net recharge to groundwater is about 0.26 in (≈4% of rainfall). Exfiltration back to the surface is negligible over this period, confirming that most water either:

- stays in surface and soil storage, or
- is exported laterally to the coast.

During the 6.56-inch event:

1. Rainfall (6.56 in) reaches the land surface.
2. Water fills surface depressions (0.85 in) and infiltrates into the soil.
3. The unsaturated zone stores 0.11 in and transfers 0.26 in downward as recharge.
4. The saturated zone rises by 0.26 in and simultaneously exchanges water with coastal boundaries (0.41 in east, 0.26 in west).
5. Large volumes of water move laterally to the sea through overland boundary pathways and drainage.

Only 1.22 in remains stored; the rest is routed to the coastline.

The water-balance results summarized above should be considered **preliminary**.

Additional work is underway to refine the stormwater system representation, including:

- Updated overland-flow parameters based on final land-use and surface-material classifications.
- Revised drainage-network connectivity and inlet capture behavior.
- Evaluation of alternative conveyance options and elevations under varying tidal and sea-level conditions.
- Integration of proposed improvements into the MIKE+ network for system-wide hydraulic performance testing.
- Sensitivity analysis to confirm the robustness of infiltration and groundwater exchange assumptions.

These refinements will influence the final distribution of surface runoff, infiltration, groundwater recharge, and coastal discharge. Consequently, the present findings should be interpreted as early indicators rather than conclusive results.

The water-balance results presented in this section are preliminary. Further refinement of the stormwater system configuration, drainage network representation, groundwater parameters, and coastal boundary conditions is underway. These refinements will modify the distribution of runoff, infiltration, groundwater response, and discharge pathways. The following summary describes the hydrologic behavior indicated by the current integrated MIKE SHE/MIKE+ model of the island.

Coastal Boundary Exchange

The model boundary lies within open coastal waters. For this reason, the simulations produce large depth-equivalent fluxes across the overland boundary. These values primarily reflect diurnal tidal water movement across the model boundary rather than true stormwater-driven overland discharge from the island. As such, while an overland outflow component is present, it cannot be interpreted as the dominant stormwater mechanism at this stage. Boundary exchanges will be reassessed once the drainage system representation is finalized and the nearshore boundary conditions are refined.

Unsaturated and Saturated Zone Behavior

The island's sandy soils allow rapid infiltration, but the shallow water table limits the available storage in the unsaturated zone during larger events. The simulations show a modest recharge response and a noticeable rise in groundwater levels following rainfall. Groundwater boundary fluxes indicate dynamic exchange with the surrounding coastal aquifer, which is expected given the island's permeable soils and proximity to the coast. This exchange influences both the magnitude and duration of groundwater mounding following storm events.

Gravity Drainage Constraints

The model results indicate that gravity outfall performance is frequently limited by tidal water levels. High tides reduce the hydraulic gradient available for gravity conveyance and restrict flow capacity at certain times. These constraints are expected to persist and potentially increase under sea-level rise conditions. Under such circumstances, gravity drainage alone may not provide adequate stormwater drawdown during peak events.

Implications for Drainage Alternatives

Based on the preliminary simulations, drainage strategies that incorporate active conveyance, including pumped discharge or distributed dewatering wells, merit further evaluation. These approaches can maintain hydraulic gradients and remove surface water during periods when gravity discharge is reduced. The integrated model indicates that:

- Groundwater responds rapidly to rainfall, reducing infiltration capacity during storm peaks.
- Surface water storage increases in low-lying areas unless drawdown capacity is available.
- The tidal cycle affects outfall performance, limiting the reliability of gravity-based systems.

Under these conditions, pumped drainage and groundwater-based systems may improve operational flexibility and maintain system performance across a range of tidal and rainfall conditions.

Next Steps

These findings should be viewed as preliminary. Upcoming model refinements will:

- Improve representation of stormwater conveyance and outfalls,
- Incorporate proposed infrastructure alternatives,
- Reevaluate boundary exchanges with updated coastal hydrodynamics, and
- Compare passive and active drainage options under multiple scenarios.

A more definitive assessment of drainage alternatives will be completed once these refinements are incorporated and additional simulations are performed.

6 COST MANAGEMENT

The preliminary pump-node concept summarized in Table 7 represents an alternative, distributed pump configuration that can be placed at key junctions where multiple local drainage lines converge and where topography creates low depressions. The intent is to use these nodes as short-path gravity collection points: runoff from nearby streets and lots is allowed to drain by gravity into a compact structure located at the confluence, rather than being routed through long, flat trunk pipes toward a distant centralized station. Once collected in the local sump, flows are pumped into an existing or new deep drainage well and, where appropriate, into a small force main that can convey excess water toward another zone or secondary outfall. In this way, the pump node intercepts flows before they can spread across the basin into undesired locations, thereby reducing the extent and duration of surface flooding.

6.1 Preliminary Layout

The two attached drawings for West McIntyre Street show how this configuration would be physically implemented in Zone 1. The plan view depicts the pump station located in the roadway near the existing drainage well, with a proposed 6 ft × 4 ft precast drainage-well box, a pump vault, and short sections of 32–36 inch reinforced concrete pipe and 12 inch ductile-iron force main tying into the surrounding collection system.

The section view (A–A) shows the vertical arrangement: surface runoff enters the precast drainage box, drops to the pump sump, and is then lifted by submersible pumps through discharge piping into the deep well or force main, with an electrical control panel elevated above grade for flood protection.

Together, these drawings illustrate a compact, self-contained pump-and-well node that can be repeated at other confluences and low points identified by the MIKE SHE / MIKE+ flow-direction and depth results.



Conceptually, this configuration is well suited to the distributed drainage strategy described in the report. Rather than relying on long trunk sewers to carry stormwater across Zone 1 under very flat gradients, a node like the West McIntyre pump station can be sited directly at a low depression or junction where MIKE+ 2D results show recurrent ponding and converging overland flow. The surrounding network is then re-graded or re-connected so that runoff from nearby streets drains by gravity into this local sump. Because the gravity paths are short and aligned with actual modeled flow directions, the system is less sensitive to tidal backpressure and pipe friction losses. The pump node lifts the concentrated flow into a deep injection well or into a short force main segment, quickly removing water from the local flood cell and preventing it from migrating into adjacent blocks where it would otherwise increase flood depths and durations.

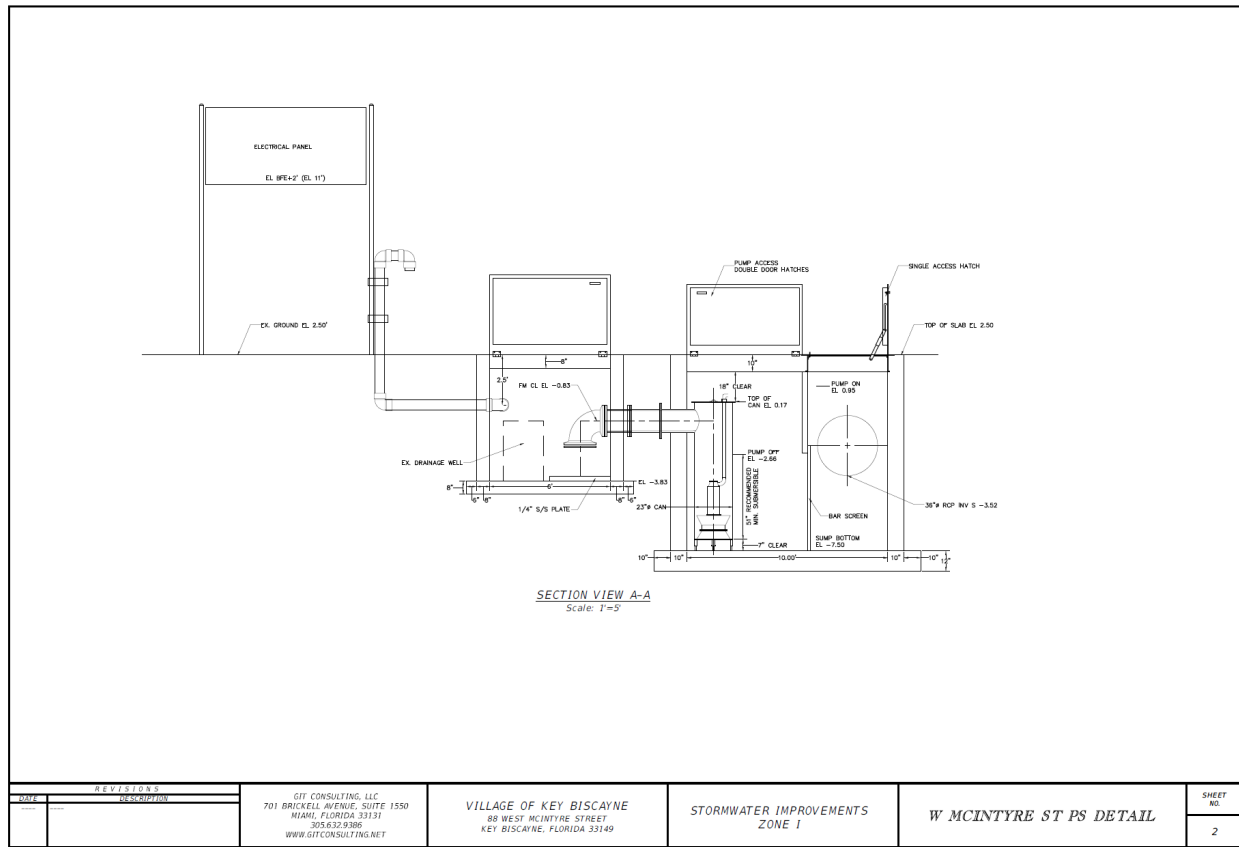


Figure 18 Detail of Proposed Conversion of Gravity Well to Localized Pump Node

6.1 Preliminary Budget

Table 14 provides a **preliminary budget analysis for one such installation**. The cost breakdown reflects all major components required for a complete, stand-alone station: mobilization, bonds, and insurance; maintenance of traffic along West McIntyre; dewatering and shoring for the deep excavation around the drainage well; a 6 ft × 4 ft precast drainage-well box with H-20 rated hatch; structural modifications to the existing drainage well (core drilling, stainless-steel plate, grouting, and connections); a precast valve vault or pump can with double-door hatches; short runs of large-diameter RCP in the roadway; a 12 inch ductile-iron force main; a 6 inch PVC gravity bypass; and adjustment or reconstruction of manholes and cleanouts.

The mechanical and electrical scope includes two submersible stormwater pumps in the 30–75 HP range (sized for roughly 10–20 cfs total capacity), discharge and check valves and fittings within the vault, a pump control panel with variable-frequency drives and RTU on an elevated slab, conduit and cabling, and an allowance for utility service, metering, SCADA integration, startup, and testing. Roadway and sidewalk restoration is included to return the street to pre-construction condition. The subtotal for these items is approximately \$651,100, and with a 25 percent contingency the total planning-level cost is on the order of \$814,000 for one distributed pump-and-well node.

From a cost-management perspective, the table demonstrates that localized pump nodes are financially tractable at the single-location scale and can be prioritized in a phased program. When combined with the MIKE SHE / MIKE+ modeling framework - which identifies the confluence points, local depressions, and groundwater-sensitive areas that most benefit from intervention - these nodes can be strategically replicated at a limited number of high-impact junctions. In aggregate, a distributed set of such pump-and-well stations offers a scalable way to intercept flows early, shorten drainage paths, and reduce localized flooding, while keeping overall capital investment and disruption lower than a purely centralized, large-station alternative.

Table 14 Preliminary Budget Analysis of Drainage Well Installation with Pump

Item	Description	Unit	Qty (assumed)	Unit cost	Amount
1.1	Mobilization, bonds, insurance	LS	1	\$ 57,000	\$ 57,000
2.1	Temporary traffic control and MOT on W. McIntyre	LS	1	\$ 15,000	\$ 15,000
2.2	Dewatering and shoring for pump station excavation (deep drainage well)	LS	1	\$ 50,000	\$ 50,000
3.1	6 ft x 4 ft precast drainage well box with H-20 rated hatch, complete	EA	1	\$ 30,000	\$ 30,000
3.2	Modifications to existing drainage well (core drilling, SS plate, grouting, connections)	EA	1	\$ 22,000	\$ 22,000
3.3	Precast valve vault / pump can with double door hatches	EA	1	\$ 45,000	\$ 45,000
3.4	32–36 in RCP, installed in roadway, incl. trench, bedding, backfill	LF	50	\$ 400	\$ 20,000
3.5	12 in ductile iron forcemain, installed, incl. trench, backfill, markers	LF	220	\$ 225	\$ 49,500
3.6	6 in PVC gravity bypass pipe, incl. fittings and connections	LF	60	\$ 110	\$ 6,600
3.7	Adjust / reconstruct manholes and cleanouts	EA	3	\$ 7,000	\$ 21,000
4.1	Submersible stormwater pumps with bases, rails, level controls, 30-75 HP, (10-20 cfs)	EA	2	\$ 60,000	\$ 120,000
4.2	Discharge valves, check valves, fittings, supports in vault	LS	1	\$ 35,000	\$ 35,000
5.1	Pump control panel with VFDs / RTU, enclosure on elevated slab	EA	1	\$ 90,000	\$ 90,000
5.2	Conduit, cabling, terminations, grounding and bonding	LS	1	\$ 30,000	\$ 30,000

5.3	Utility service, meter, SCADA integration, startup and testing allowance	LS	1	\$ 20,000	\$ 20,000
6.1	Roadway and sidewalk restoration, asphalt, base, striping	LS	1	\$ 40,000	\$ 40,000
Total					\$ 651,100
7.1	25% Contingency			\$ 162,775	\$ 162,775
Total Including Contingency					\$ 814,000
https://www.excelfluidgroup.com/blog/what-effects-your-pump-station-cost? https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/fpo/fpc/reports/historicalitemaveragecost/moving/market-area/pdf/historical-item-averages-market-area-03.pdf?sfvrsn=536d6672_2 https://www.ncp-inc.com/price1?					

7 TIMELINE – PROJECT PROGRESS

Task 1 has been fully completed. All required datasets - including LiDAR, survey, stormwater infrastructure inventory, land use and soil layers, groundwater and tidal boundary data, rainfall inputs, and NOAA-derived sea-level information - have been collected, quality controlled, and implemented within the coupled MIKE SHE / MIKE+ modeling framework. The model domain, grid structure, boundary conditions, and parameter fields are now fully established, providing a complete and defensible foundation for subsequent hydraulic and hydrologic evaluations.

Task 2 is underway, and the preliminary simulation phase has been successfully implemented. Calibration and verification runs have been completed for Hurricane Irma (2017), the June 4–7, 2022 rainfall event, and the SFWMD 5-year, 24-hour design storm. These simulations have been used to evaluate model behavior under observed rainfall, antecedent groundwater conditions, and tidal influences, and to refine both the MIKE SHE and MIKE+ components for accurate representation of overland flow, groundwater interaction, and drainage-system response. As part of this ongoing task, preliminary flood-depth maps and flow-direction products have been generated for each calibration and design event. These spatial outputs confirm that the model is capturing localized depressions, conveyance bottlenecks, and basin-scale interactions necessary for evaluating drainage alternatives in Task 3.

The overall four-month project schedule remains structured around staggered and overlapping tasks, allowing modeling, data refinement, and alternative development to progress efficiently in parallel. The decentralized drainage system concept - incorporating drainage wells, distributed pumping nodes, and green-infrastructure features - continues to guide the technical framework and the sequencing of analytical tasks.

Stakeholder coordination continues throughout the project. Engagement with Village staff, Council representatives, permitting agencies, and community stakeholders occurs not only at milestones but also as an integrated part of each task. This ensures that technical development, regulatory considerations, and conceptual design refinements remain aligned with the Village's objectives.

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5. Hydrogeology of the Surficial Aquifer System, Dade County, Florida URL: https://www.sfwmd.gov/sites/default/files/documents/cuptech_usgs_wrir_90_4108_dade.pdf Description: USGS report on Biscayne Aquifer structure and hydraulic conductivity (up to ~10,000 ft/day) in Miami-Dade.
6. Hydrogeology | Biscayne Aquifer | United States URL: <https://www.biscayne-aquifer.com/> Description: Information portal on Biscayne Aquifer hydrogeology and related assessment services, including stormwater well permitting.
7. MIKE SHE: Software for Integrated Surface Water/Groundwater Modeling URL: https://www.researchgate.net/publication/23266739_MIKE_SHE_Software_for_integrated_surface_waterground_water_modeling Description: ResearchGate paper summarizing MIKE SHE capabilities and calibration for urban runoff and groundwater interaction.
8. MIKE SHE: A Distributed, Physically Based Modeling System for Surface Water/Groundwater Interactions URL: https://www.researchgate.net/publication/288026531_MIKE_SHE_A_distributed_physically_based_modeling_system_for_surface_waterground_water_interactions Description: Detailed analysis of MIKE SHE's distributed structure for simulating recharge and surface–subsurface interactions in complex aquifers.
9. Carbonate Aquifer Characterization Laboratory | U.S. Geological Survey URL: <https://www.usgs.gov/centers/cfwsc/science/carbonate-aquifer-characterization-laboratory> Description: USGS laboratory for characterizing carbonate aquifers such as Biscayne, including porosity and 3D modeling studies.
10. Electrical Resistivity and Porosity Structure of the Upper Biscayne Aquifer in Miami-Dade County, Florida URL: <https://www.sciencedirect.com/science/article/abs/pii/S0022169415008203> Description: ScienceDirect article on Biscayne porosity (~40–50%), electrical resistivity, and saltwater intrusion implications.
11. East Coast Surficial Model (ECSM) Calibration Update Peer Review Meeting URL: <https://www.sfwmd.gov/event/east-coast-surficial-model-ecsm-calibration-update-peer-review-meeting-0> Description: SFWMD peer-review session for ECSM calibration, including boundary conditions and model performance discussion.
12. Web Board | South Florida Water Management District URL: <https://www.sfwmd.gov/science-data/web-boards> Description: SFWMD repository for ECSM and Floridan models, peer review documents, and modeling resources.

13. Movement of the Saltwater Interface in the Surficial Aquifer System URL: <https://pubs.usgs.gov/sir/2004/5256/pdf/sir20045256.pdf> Description: USGS study of Biscayne Aquifer anisotropy (horizontal/vertical 1:7 to 1:49) and saltwater intrusion modeling.
14. Hydrogeology, Aquifer Characteristics, and Ground-Water Flow of the Surficial Aquifer System (Broward County) URL: https://www.sfwmd.gov/sites/default/files/documents/cuptech_usgs_wrir_87_4034_broward.pdf Description: USGS Broward County report including transmissivity estimates (up to ~300,000 ft²/day) for Biscayne-equivalent units.
15. Environmental Monitoring | South Florida Water Management District URL: <https://www.sfwmd.gov/science-data/environmental-monitoring> Description: SFWMD water-quality and hydrologic monitoring portal for Biscayne Bay, canals, and stormwater impacts.
16. ECSM Peer Review Meeting (Initial) URL: <https://www.sfwmd.gov/event/east-coast-surficial-model-ecsm-peer-review-meeting> Description: SFWMD kickoff peer-review meeting and documentation hub for the East Coast Surficial Model.
17. RSM Training – HESM / ECSM Instructional Materials URL: https://www.sfwmd.gov/sites/default/files/documents/rsm_module_4.pdf Description: SFWMD training material on hydraulic conductivity, storage parameters, and ECSM input preparation.
18. Predicting Sea-Level Rise Impacts on Groundwater Quantity and Quality in Complex Hydrogeological Systems URL: <https://link.springer.com/article/10.1007/s41748-025-00583-5> Description: Springer article using ECSM/SEAWAT-type models to assess sea-level rise impacts on Biscayne groundwater.
19. Storm Water Management Model (SWMM) | US EPA URL: <https://www.epa.gov/water-research/storm-water-management-model-swmm> Description: EPA's SWMM platform for urban stormwater hydrology and hydraulics, including runoff coefficients and LID components.
20. Village of Key Biscayne Stormwater System Evolution Summary URL: https://files.keybiscayne.fl.gov/Documents/Elevating%20Our%20Island%20Paradise/Resources%20Hub/VKB%20Stormwater%20System%20History_10.08.24.pdf Description: Village summary of stormwater planning history, including WHS (1993), Tetra Tech (2011), EAC (2015), and AECOM (2024) studies.
21. Summary of Commonly Used Stormwater Models and Selecting a Model URL: https://stormwater.pca.state.mn.us/index.php/Available_stormwater_models_and_selecting_a_model Description: Overview of stormwater models (HEC-HMS, SWMM, MIKE, etc.) and guidance on selecting appropriate tools.
22. TOC Design Manual Chapter 2 – Stormwater URL: https://www.intrans.iastate.edu/wp-content/uploads/sites/15/2020/03/Chapter_02.pdf Description: Iowa stormwater design chapter covering TR-55, Rational Method, and Manning's n guidance.
23. Introduction to Stormwater Modeling | Minnesota Stormwater Manual URL: https://stormwater.pca.state.mn.us/introduction_to_stormwater_modeling Description: High-level discussion of rainfall-runoff modeling, TR-55, and selection of models for municipal drainage.
24. Storm Water Management Model: Performance Review and Gap Analysis URL: <https://pmc.ncbi.nlm.nih.gov/articles/PMC7326159/> Description: Peer-reviewed evaluation of SWMM performance and gaps for urban flooding prediction.
25. Storm Water Management Model – Wikipedia URL: https://en.wikipedia.org/wiki/Storm_Water_Management_Model Description: General overview of SWMM hydrology, hydraulics, and low impact development modules.
26. Effects of Stormwater Infrastructure Data Completeness and Model Resolution on Urban Flood Modeling URL: <https://www.sciencedirect.com/science/article/abs/pii/S0022169422000737>

- Description: Study on how network completeness and grid resolution affect SWMM-based 1D/2D urban coastal flood modeling.
27. Understanding Hydrologic and Hydraulic (H&H) Modeling – Streamline Tech URL: <https://streamline.tech/resources/understanding-hydrologic-and-hydraulic-modeling>
Description: Overview of H&H modeling roles in coastal stormwater and resiliency planning.
 28. Hydraulic Modeling Approaches in Drainage Design and Water Resources Engineering URL: <https://www.stormwater.com/stormwater-management/sewers-drainage-systems/article/53068986/hydraulic-modeling-approaches-in-drainage-design-and-water-resources-engineering>
Description: Stormwater Solutions article on hydraulic modeling approaches (including HEC-RAS) used in Florida drainage design.
 29. Guide for Selecting Manning's Roughness Coefficients URL: <https://pubs.usgs.gov/wsp/2339/report.pdf>
Description: USGS Water-Supply Paper 2339 with n-value guidance for natural channels and floodplains.
 30. Manning's n Values – Hydraulic Reference URL: https://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm
Description: Oregon State tables of Manning's n values for open channels and closed conduits.
 31. The Influence of Depression Storage on Runoff from Impervious Surfaces of Urban Catchments URL: https://www.researchgate.net/publication/271625456_The_influence_of_depression_storage_on_runoff_from_impervious_surface_of_urban_catchment
Description: Technical study of SWMM depression storage parameter sensitivity for urban runoff.
 32. Runoff Quality Prediction from Small Urban Catchments Using SWMM URL: <https://onlinelibrary.wiley.com/doi/10.1002/%28SICI%291099-1085%28199802%2912:2%253C311::AID-HYP579%253E3.0.CO%3B2-R>
Description: Wiley paper on SWMM calibration for runoff quantity and quality in Florida urban catchments.
 33. Guide for Selecting Manning's Roughness Coefficients (Wetland Studies) URL: <https://www.wetlandstudies.com/s/GuideForSelectingManningsRoughnessCoefficients.pdf>
Description: Applied manual with Manning's n guidance for streams, floodplains, and coastal wetlands.
 34. Manning's Roughness for Each Land Cover Definition of NLCD URL: https://www.researchgate.net/figure/Mannings-roughness-for-each-land-cover-definition-of-NLCD_tbl1_325476625
Description: ResearchGate table providing NLCD-based Manning's n values for use in distributed models.
 35. Drainage Criteria Manual – Determination of Stormwater Runoff (Bella Vista) URL: <https://cms7files.revize.com/bellavista/Document%20Center/City%20Departments/Street/Drainage%20and%20Stormwater%20Runoff/Drainage%20Manual/Chapter-3-Determination-of-Stormwater-Runoff.pdf>
Description: Municipal manual presenting runoff coefficients, depression storage, and design storm selection.
 36. Mile High Flood District – Urban Storm Drainage Criteria Manual, Volume 1 URL: https://www.mhfd.org/files/11d6efc42/06_Runoff%2BMarch%2B2024.pdf
Description: Guidance on runoff coefficients vs. imperviousness for urban catchments, applicable by analogy to coastal settings.
 37. Manning's Roughness Coefficient for HEC-RAS 2D Modeling (RASHMS) URL: <https://rashms.com/blog/mannings-n-roughness-coefficient-for-hec-ras-2d-modeling/>
Description: Discussion of 2D n-value selection and recommended reductions for coarse vs. fine meshes.
 38. NOAA C-CAP Land Cover Data URL: <https://coast.noaa.gov/digitalcoast/data/ccapregional.html>
Description: NOAA coastal land-use/land-cover data for imperviousness and Manning's n

mapping.

39. Harris County Flood Control District 2D Modeling Guidelines URL: <https://www.hcfcd.org/Media/1492/flood-control-district-2d-modeling-guidelines.pdf>
Description: Urban 2D modeling guidelines including recommended Manning's n ranges for streets and developed areas.
40. Montgomery County Drainage Criteria Manual (Draft 2024) URL: <https://www.mctx.org/DocumentCenter/View/12345/DCM-Draft-February-2024-PDF>
Description: Texas drainage manual with 2D modeling guidance and Manning's n tables.
41. College Creek Floodplain Study – Alfred Benesch & Company URL: <https://www.benesch.com/projects/college-creek-floodplain-study> Description: Example project including calibrated coastal/riverine n values used in 2D modeling.
42. USGS Biscayne Aquifer Saltwater Intrusion Project URL: https://fl.water.usgs.gov/projects/bay_aquifer_intrusion.html Description: USGS Biscayne intrusion modeling, including head and conductivity constraints.
43. SFWMD DBHYDRO Database URL: <https://www.sfwmd.gov/science-data/dbhydro> Description: SFWMD database providing rainfall, stage, and groundwater data for model calibration.
44. NOAA Atlas 14 Precipitation Frequency Data Server URL: <https://hdsc.nws.noaa.gov/pfds/> Description: NOAA rainfall frequency data and IDF curves for Florida coastal locations.
45. Miami-Dade County Unified Sea Level Rise Projection URL: <https://www.miamidade.gov/global/economy/unified-sea-level-rise-projection.page>
Description: County-level SLR curves and guidance for stormwater and resilience planning.
46. Tetra Tech – Village of Key Biscayne Stormwater Master Plan (2011) URL: <https://www.tetratech.com/projects/key-biscayne-stormwater-master-plan> Description: 2011 stormwater master plan, hydraulic analysis, and early basin prioritization.
47. EAC Consulting – Key Biscayne Hydrologic Analyses (2015) URL: <https://www.eacconsulting.com/projects/key-biscayne-hydraulics> Description: 2015 hydrologic and hydraulic analyses and capital improvements plan for Zone 1 and surrounding basins.
48. AECOM – Village-Wide Drainage Assessment (2024) URL: <https://aecom.com/projects/key-biscayne-drainage-assessment> Description: 2024 drainage assessment and resiliency plan using 2060 SLR scenarios.
49. DHI MIKE SHE User Guide URL: <https://www.dhigroup.com/technologies/mike-she> Description: Official MIKE SHE documentation for parameterization and calibration in integrated hydrologic models.
50. USGS Water-Resources Investigations Report 99-4213 – Gray Limestone Aquifer URL: <https://pubs.usgs.gov/wri/wri99-4213/pdf/wri99-4213.pdf> Description: USGS report on Gray Limestone Aquifer hydrogeology, relevant for deeper carbonate flow below Biscayne.
51. Perkins (1977) – Depositional Framework of Pleistocene Rocks in South Florida URL: <https://pubs.geoscienceworld.org/gsa/books/book/2107/Depositional-Framework-of-Pleistocene-Rocks> Description: GSA Memoir 147 describing Pleistocene formations including Miami Limestone and Fort Thompson strata.
52. TR-55 Urban Hydrology for Small Watersheds URL: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/?cid=nrcs144p2_071309
Description: NRCS guidance on curve numbers, runoff coefficients, and design storms for small urban watersheds.
53. HEC-HMS User's Manual URL: https://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_4.11_Users_Manual.pdf Description: USACE manual for rainfall-runoff modeling, used as a reference for hydrologic methods and parameter ranges.
54. Florida DEP Stormwater Manual URL:

- <https://floridadep.gov/water/stormwater/content/stormwater-manual> Description: State-level guidance on stormwater design, including urban runoff coefficients and treatment requirements.
55. IPCC AR6 Sea Level Rise Technical Report (WG1) URL: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf Description: Global SLR projections and technical background used to frame long-term coastal risk.
56. Streamline Technologies – StormWise Modeling Tips: 1D Node Storage and Boundary Stages URL: <https://streamline.tech/resources> Description: Practical modeling tips for ICPR/StormWise node storage and boundary-stage configuration.
57. University of South Florida – MIKE+ Coupled 1D–2D Urban Flood Modeling Framework URL: <https://www.usf.edu> Description: Example academic application of MIKE+ for urban flood modeling and education.
58. DHI – MIKE+ / MIKE SHE Product Pages and Urban Flood Resources URL: <https://www.dhigroup.com> Description: Official DHI product information for MIKE SHE, MIKE+ Collection Systems, MIKE+ 2D Overland, and urban flood packages.
59. Copenhagen Cloudburst Planning – Integrated Hydrological Model-Based Assessment URL: <https://www.mdpi.com> (search “Copenhagen cloudburst MIKE SHE MIKE URBAN”) Description: Case studies using integrated MIKE SHE / MIKE URBAN / MIKE+ modeling for climate-resilient stormwater systems.