

Resilience Assessment and Planning Study of Tide Gates in Coastal Connecticut

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Final Report

CIRCA
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More information on CIRCA can be found at: https://circa.uconn.edu/tidegates/

The Tide Gate Inventory Viewer website for the project is https://experience.arcgis.com/experience/410828f3e34e4889a0522ab872d9d2ee

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Executive Summary

Connecticut's tide gates were built to drain land and block tidal flooding, but they also restrict the tidal exchange that salt marshes need. About 1,290 of the state's 13,678 acres of salt marsh (9.4%) lie behind a tide gate, while the same structures often protect roads and homes. A gate that protects at storm levels may do little at routine levels, and a marsh can be degraded by a gate that looks hydraulically open. Decisions about repair, modification or removal therefore need both flood and ecological evidence.

All 68 tide gates identified along the Connecticut shoreline were inventoried and scored for priority using the Tide Gate System Rating (TGSR), which combines flood exposure of nearby structures, marsh condition and gate condition. Four systems were then assessed in detail: GF01 (Guilford), EH02 (East Haven, Farm River), NH01 (New Haven, West River) and WP01/WP02 (Westport). Each was modeled with a lumped hydraulic mass-balance model driven by 26.9 years of NOAA tide records, with and without the gate, for flood frequency and for 0 to 0.5 m of sea level rise (SLR). Field surveys of each structure and a MarshRAM assessment of each marsh were combined with the model results into site-specific recommendations.

The screening shows that 36 of the 68 gates (53%) have upstream salt marsh. Of the 55 gates that could be scored, 17 are High priority, 26 Medium and 12 Low. 13 gates could not be scored for access or status reasons, and 13 of the scored gates are provisional because they lie outside the mapped flood zone. Most High-priority gates rank High because of poor gate condition rather than flood risk: 15 of the 17 rate 3 or lower for condition on a 1 to 6 scale, 11 have no marsh behind them, and only seven have structures that would be exposed if the gate were opened. 15 of the 17 are in Fairfield. For many of these gates the question is repair versus decommissioning, not maintenance alone.

The four detailed sites behave very differently because they span the range of structure types: a renewed one-way gate, a removed gate, a mixed multi-gate structure and a two-way weir. At Guilford (GF01), the renewed gate has nearly eliminated flooding of the adjacent road and drains the marsh well, but as sea level rises the water inside the marsh will climb about twice as fast as the sea itself, so this protection will weaken over time. At East Haven (EH02), the gate is gone and the marsh is recovering, but the open channel lets water above 0.8 m onto the marsh on about 250 days a year, so nearby property is more exposed. At New Haven (NH01), the twelve-gate structure gives almost no

protection against everyday and moderately high tides because one gate is always open, but it does protect against the highest storm tides. At Westport (WP01/WP02), the gates hold water in the pond above a set level, which protects against moderate to severe flooding. Marsh condition did not follow gate restriction. The most restrictive gate (Guilford) has the healthiest of the four marshes, while New Haven has the most degraded, dominated by invasive Phragmites despite free water exchange at routine levels. Room for the marshes to migrate inland is low at all four sites, so they will need to build elevation in place.

The priority ratings are screening-level guidance, not an instruction to replace every High-priority gate. Our statewide recommendations are to: confirm with towns who owns, operates and maintains each gate, including the 20 whose status is unknown; inspect or repair first the High-priority gates that are in poor condition and have structures behind them, and confirm that gates rated High on condition alone are still needed before spending on repair; arrange access to the 11 gates that could not be inspected, starting with the four that have marsh behind them; use targeted monitoring where gate or marsh performance is uncertain; plan for sea level rise, since 51% of the state's gates are one-way flap gates that lose protection as the sea rises; and coordinate with towns and permitting agencies, since any structural or operational change is expected to need review. At the four sites, we recommend retaining the renewed Guilford gate with monitoring and a re-evaluation trigger at about 0.2 m of sea level rise; defining flood consequences before considering any structure at East Haven; confirming gate settings and measuring salinity at New Haven before changing the structure; and confirming gate operation at Westport, with no structural action.

Future work can include: deploy long-term loggers at all four sites to validate and calibrate the model; measure salinity, sediment supply and surface elevation on the marshes; calibrate the discharge coefficients; and apply the method to the remaining gates, including their sea level rise response, using two-dimensional modeling where flow paths can improve the understanding of the tide gate structures.

1. Introduction

1.1 Project Background

Coastal salt marshes in Connecticut, as elsewhere along the U.S. Atlantic shoreline, face compounding pressure from three interacting drivers: i) continued development in the coastal floodplain (Crossett et al. 2004; Dahl and Stedman 2013), ii) accelerating sea level rise (Sallenger et al. 2012; Sweet et al. 2022), and iii) increasing frequency and intensity of extreme precipitation and coastal storms under a changing climate (Kunkel et al. 2013; Easterling et al. 2017). For Connecticut specifically, the state's own sea level rise assessment (O'Donnell 2019), prepared for the Connecticut Institute for Resilience and Climate Adaptation (CIRCA) pursuant to Connecticut General Statutes §25-68o and Public Act 18-82, recommends that state and municipal planners anticipate up to 20 inches (0.51 m) of sea level rise above the National Tidal Datum Epoch in Long Island Sound by 2050. This value is the planning benchmark against which sea level rise sensitivity is evaluated

throughout this report; it corresponds to the 0.5 m upper limit of the sea level rise sweep (Section 2.4.6). Because the sweep adds each increment to the 1999–2026 observed water level record rather than to the epoch baseline, the increments represent a uniform offset applied to recent conditions.

Against this backdrop of increasing hydrological pressure, a legacy of nineteenth- and twentieth-century water control infrastructure continues to shape how Connecticut's remaining salt marshes experience tidal flooding. In the early to mid-twentieth century, many coastal salt marshes in Connecticut received flap- or sluice-gate-style tide gates, primarily to drain marshes for salt hay mowing, control mosquito populations, and protect coastal property from tidal flooding. Regular tidal inundation is critical to salt marsh habitat integrity, however, and the resulting drainage of saltwater from a salt marsh can have significant negative ecological consequences. These include expansion of the invasive and combustible common reed (Phragmites australis), loss of shallow-water shorebird habitat, and exposure of marsh peat to atmospheric oxygen. The latter drives marsh subsidence and the mobilization of previously sequestered carbon, nitrogen, phosphorus, and sulfur compounds as organic peat decomposes (Portnoy 1999). Additionally, partially respired organic material from mobilized peat can lead to reduced oxygen concentrations, nutrient enrichment, acidification, and trace metal release in adjacent tidal channels (Anisfeld and Benoit, 1997).

Across the Connecticut shoreline, 68 tide gates have been identified in varying conditions and states of operation. Of these, 30 (44%) have some quantity of upstream salt marsh, ranging from less than 1 to greater than 200 acres, theoretically affected by the tidal restriction each structure imposes. Not accounting for culverts or other tidal restrictions with comparable hydrological effects, tide gates specifically affect an estimated 1,085 acres of salt marshes in Connecticut, or 7.9% of the estimated 13,678 acres of salt marsh in the state.

The degree of ecological impact a given tide gate imposes depends on several interacting factors: the type and condition of the structure govern both the volume of tidal water able to flow upstream and the degree of restriction to migratory fish and macroinvertebrate passage, while the geomorphology of the water body over which the restriction sits determines the total upstream acreage affected. Assessing this impact and identifying appropriate, site-specific management responses requires understanding both dimensions together: the physical hydraulic behavior of each structure, and the ecological condition of the marsh it affects. This report addresses both dimensions through two complementary assessment methods conducted in parallel: quantitative hydraulic modeling (CIRCA) and marsh ecological assessment (Connecticut National Estuarine Research Reserve, CTNERR), synthesized here into joint, site-specific recommendations.

1.2 Project Goal

This report responds to a shared set of objectives spanning site selection, hydraulic and ecological assessment, and the development of actionable management recommendations. Building on the landscape-level tide gate inventory described in Section 2.1 and 3.1, four systems were selected for full quantitative and ecological assessment based on available budget and their capacity to represent

the range of physical conditions found among Connecticut's tide gates. This detailed assessment establishes a repeatable, quantitative methodology for characterizing how tide levels interact with a given structure and the properties and habitats around it, applying a simplified hydraulic exchange model to reveal each structure's actual operating behavior under real historical tidal and storm conditions.

Beyond characterizing each structure's hydraulic function, this work evaluates how each selected tide gate affects the surrounding ecosystem, marshes, adjacent waterbodies, and the broader landscape, including impacts on recreational use and on the marsh's capacity to migrate landward as sea levels continue to rise. These findings reflect both the technical evidence and the practical realities of managing these structures across the state.

The ultimate product of this effort is a set of concrete, site-specific management strategies for each selected tide gate, ranging from structural modification or removal to changes in operating regime, depending on what best balances effective flood mitigation against ecological cost at that particular site. Each tide gate is prioritized according to urgency, effectiveness, and the resources realistically available to carry it out.

Four tide-gated systems were selected for this detailed assessment: GF01 (Sluice Creek, Guilford), EH02 (Farm River, East Haven), NH01 (West River, New Haven), and WP01/WP02 (Sherwood Mill Pond, Westport). These sites were deliberately chosen to span a wide range of physical conditions, from a fully intact one-way flap gate (GF01), to a site with no gate (EH02), to a complex twelve-gate structure combining three distinct hydraulic mechanisms (NH01), to a two-way, retention-purpose structure unlike any other flood-control gate examined in this study (Westport), providing a broad enough basis to generalize findings toward the many other tide-gated systems identified across the Connecticut shoreline but not assessed at this level of detail.

1.3 Report Structure

Section 2 describes the methodology for creating the data inventory and qualitative assessment for all tide gate conditions, as well as both assessment approaches: the Marsh Rapid Assessment Method (MarshRAM) and Index of Marsh Integrity (IMI) field protocol used for the ecological assessment, and the hydraulic modeling workflow used for the quantitative assessment. Section 3 presents the results of each assessment independently. Section 4 synthesizes both assessments into joint, site-specific findings and recommendations, addressing prioritization considerations, identifying data gaps and recommending specific next steps.

2. Methodology

2.1. Data Inventory and Geodatabase

2.1.1 Initial Data Inventory

The initial tide gate inventory was provided by the CT DEEP as a shapefile containing 34 potential tide gate locations. These locations served as the starting point for developing a more comprehensive statewide inventory.

Each coastal town associated with an identified location was contacted to verify whether the tide gate was present, determine ownership status, obtain available structural and condition information, and identify any additional tide gates within the town that were not included in the original dataset. Towns with no known tide gate locations were also contacted to inquire if they had structures not identified in the initial inventory. Information received from the town was used to refine and expand the initial inventory before the field work assessment.

2.1.2 Field Protocols and Inspections

Each structure in the initial inventory (Section 2.1.1) was assigned a unique field ID, then carried through a structured field verification process covering both a statewide condition inspection (all inventoried tide gates) and a more detailed quantitative field survey (Figure 1). Statewide condition inspections were conducted across the full tide gate inventory. The field visits were completed on Sept 12, 26, Oct 15, Oct 22 of 2025 and May 27, June 25, Sept 4rd of 2026 dates. More detailed field surveys supporting the Task 2D quantitative hydraulic assessment were conducted at the four selected sites, including an RTK-GPS survey campaign on September 3, 2026 covering GF01, NH01, and WP01/WP02, in addition to site-specific visits at each location supporting gate geometry verification, discharge coefficient context, and model calibration (e.g. the GF01 2026 gate renewal survey, and field measurements supporting the EH02 open-channel C_d calibration against deployed Levelogger sensor data).

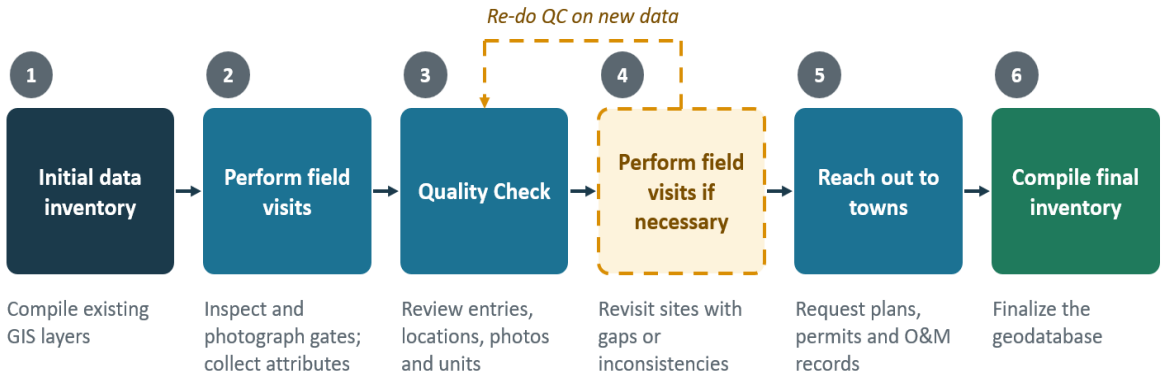


Figure 1: Field protocol and inspection workflow

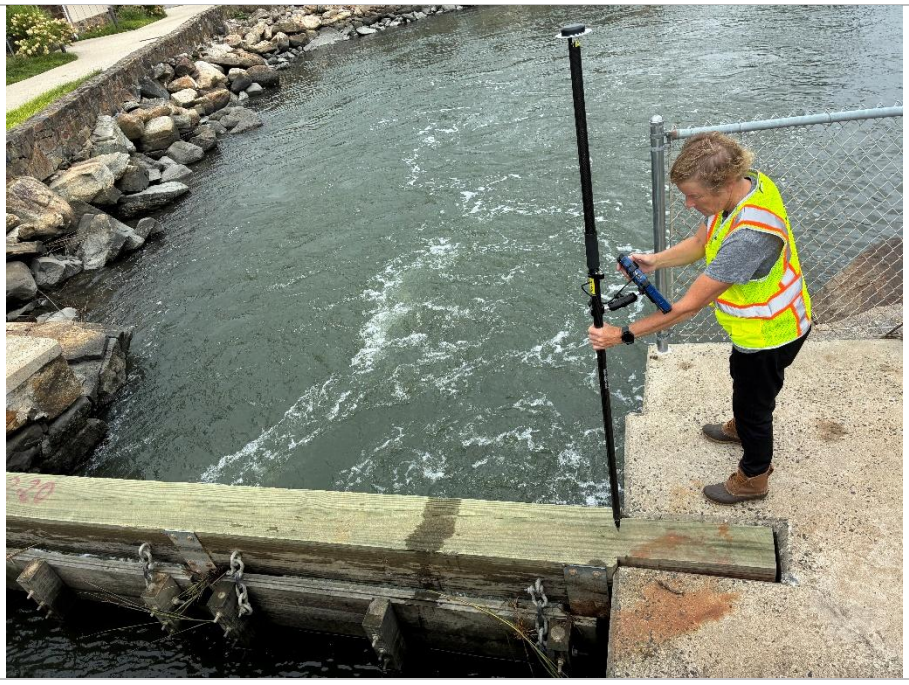
Two complementary field survey methods were used across the four sites, applied as site conditions and available equipment allowed (Figure 2):

- **RTK GPS survey:** direct, absolute-elevation measurement of key structural points (gate corners, channel cross-sections, deck/pier elevations), referenced directly to NAVD88 without requiring a separate datum conversion. Used at GF01, NH01, WP01/02 sites to varying degrees, and paired with LIDAR data to produce cross-section comparison figures (Section 3.3) at each site.

- **Leveling rod:** used for measurements requiring finer detail than a single RTK shot could practically capture (e.g. a specific structural dimension, or a water-surface reading at a documented instant), referenced to a local, arbitrary zero point and converted to NAVD88 by one of the two calibration methods described in Section 2.4.2.

Tide Gate Condition Assessment

In addition to the hydraulic geometry survey described above, each inspected tide gate's physical condition was evaluated using a Condition Assessment Rating (CAR), assigned to average of the gate and culvert elements following ASCE Manuals and Reports on Engineering Practice No. 130, Waterfront Facilities Inspection and Assessment. This is a standardized, widely-used framework for rating waterfront and coastal infrastructure condition, allowing this project's findings to be compared on a consistent basis with other tide gate condition assessments using the same standard (e.g. the Town of Fairfield's RACE Engineering 2023-2024 tide gate inspection report). A CAR was assigned to the tide gate system as a whole (Table 1).



a)



b)

Figure 2: a) Photo of RTK-GPS field survey equipment in use at a tide gate structure (e.g. the Sept 2026 GF01 campaign), and b) a leveling rod reading.

Table 1: Condition Assessment Rating (CAR) Scale

Rating	Category	Description
6	Good	No visible damage or only minor damage noted. Structural elements may show very minor deterioration, but no overstressing observed. No repairs are required.
5	Satisfactory	Limited minor to moderate defects or deterioration observed but no overstressing observed. No repairs are required.
4	Fair	All primary structural elements are sound but minor to moderate defects or deterioration observed. Localized areas of moderate to advanced deterioration may be present but do not significantly reduce the load-bearing capacity of the structure.
3	Poor	Advanced deterioration or overstressing observed on widespread portions of the structure but does not significantly reduce the

		load-bearing capacity of the structure. Repairs may need to be carried out with moderate urgency.
2	Serious	Advanced deterioration, overstressing, or breakage may have significantly affected the load-bearing capacity of primary structural components. Local failures are possible, and loading restrictions may be necessary. Repairs may need to be carried out on a high-priority basis with urgency.
1	Critical	Very advanced deterioration, overstressing, or breakage has resulted in localized failure(s) of primary structural components. More widespread failures are possible or likely to occur, and load restrictions should be implemented as necessary. Repairs may need to be carried out on a very high-priority basis with strong urgency.

Condition inspections consisted of a visual review of whole structure, documenting the condition of the culvert (where applicable), and tide gate. No underwater, subsurface, or pipe-penetration investigation was performed. The condition of hardware items was noted, culvert/gate dimensions were measured, and each structure was photographically documented.

2.1.3 Final Geodatabase

Following town outreach, field verification and survey, and subsequent data processing, the initial inventory was expanded and organized into a final geodatabase containing the primary spatial and tabular datasets used throughout the Tide Gate Assessment (Table 2). The geodatabase was structured to support mapping, analysis, scoring, and development of the Connecticut Tide Gate Inventory Viewer.

The final geodatabase includes tide gate locations, associated marsh units, infrastructure and flood-risk summaries, environmental indicators, and derived scoring tables. Common identifiers, including PlaceID, were used to relate tide gate records across datasets.

Table 2: Tide Gate Geodatabase Inventory

Dataset	Type	Description
Feature Classes		
Connecticut Tide Gate Field Survey and Photos	Point Feature Class	Verified tide gate locations with fields containing structure characteristics and

		attachments containing associated photos and documents.
Salt Marsh Ditch Lines	Polyline Feature Class	Drainage ditch features within associated marsh areas.
Critical Habitats	Polygon Feature Class	Depicts the location and distribution of selected Critical Habitats in the state of Connecticut.
Unvegetated to Vegetated Ratio_UVVR_	Polygon Feature Class	Displays the calculated ratio of unvegetated area to vegetated area in each marsh unit.
Salt Marsh upstream of tide gates _NWI 2024_	Polygon Feature Class	Displays the extent, approximate location and type of salt marshes in Connecticut upstream of tide gate locations. Derived from the National Wetlands Inventory.
Salt Marsh _NWI 2024_	Polygon Feature Class	Displays the extent, approximate location and type of salt marshes in Connecticut. Derived from the National Wetlands Inventory.
All Wetlands _NWI 2024_	Polygon Feature Class	Displays the extent, approximate location and type of wetlands and deepwater habitats in Connecticut. Derived from the National Wetlands Inventory.
Impervious Surface 2023	Polygon Feature Class	Contains statewide impervious surface and advanced transportation vector features for the State of Connecticut.
Connecticut Towns	Polygon Feature Class	Boundaries of towns in the State of Connecticut.
Tables		
Tide_Gate_Exposure_Scoring_NB_60m_Adjusted	Table	Combined marsh, flood exposure, structural condition, and system-level scores and classifications.

Tide_Gate_MHHW20in_Risk_Summary	Table	Summary of roads, bridges, and parcels potentially affected under the modeled flood scenario.
TG_Marsh_Unit_Features	Table	Marsh size, UVVR, impervious surface, ditching, migration, and related marsh characteristics.

2.2. Site Prioritization Framework

This section describes a GIS-based prioritization framework that combines three independent lines of evidence: flood-risk-if-opened, salt marsh ecological health, and physical condition into a single, ranking that CT DEEP and municipal partners can use to sequence tide gate maintenance, repair, or removal decisions across the study area. All four components' scales (Flood risk if opened, Marsh Health Index, CAR, Tide Gate System Impact) in this framework are oriented in the same direction to avoid sign errors. The higher the score (5 or 6 for CAR) represents the best condition, least concern, or negligible consequences, and the lower the score (1) represents the worst condition, greatest concern and critical consequences. The qualitative logic underlying the framework (Figure 3):

i) Restricting flow (i.e., keeping the gate as-is or making it more restrictive) protects upstream structures, but tends to degrade marsh condition,

ii) Removing or opening the gate raises flood risk to upstream structures, but tends to improve marsh condition and migration potential.

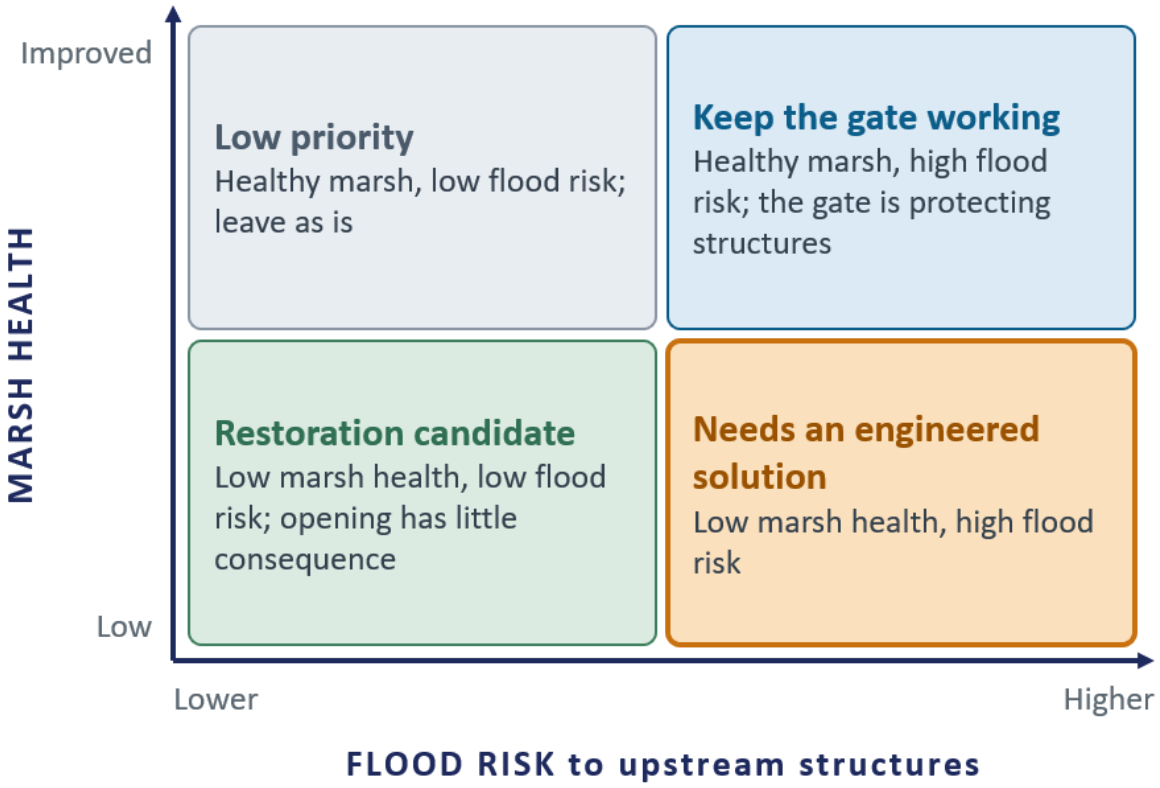


Figure 3: The qualitative logic for site prioritization

The prioritization is calculated through four indices:

2.2.1. Flood Risk (if the gate removed) Index

Two independent flood-extent data sources are combined to evaluate which structures are exposed if a gate were removed or left permanently open, consistent with a mean-higher-high-water (MHHW) plus 20-inch sea level rise planning scenario:

- CIRCA MHHW + 20 in polygon: The polygon using the interpolation between the tidal gauges of MHHW is added with 20 inches to delineate the inundation polygon. This file does not include the depth information.
- NOAA Sea Level Rise Depth Rasters: downloaded from NOAA's Digital Coast SLR data for Connecticut (https://coast.noaa.gov/slrdata/Depth_Rasters/CT/). These rasters are themselves the output of a flood-fill connectivity trace run across the DEM; i.e., NOAA's rasters already represent the fully-connected, unobstructed ("gate-removed") flood scenario, not a simple elevation threshold. The raster does not know a tide-gate structure exists; it traces where water would go if nothing blocked it, which is exactly the counterfactual this index needs. Because NOAA only publishes depth rasters at half-foot SLR increments, the 20 in (1.667 ft) target scenario is produced by linear interpolation between the 1.5 ft and 2.0 ft rasters:

$$NOAA_MHHW_20in = Depth(1.5\ ft) + 0.333 \times [\ Depth(2.0\ ft) - Depth(1.5\ ft)\ ]$$

Criterion 1: Structure Exposure Score

For each tide gate:

- Infrastructure/structure points are selected by location within a 60 m buffer of each gate, tagging each structure with a gate_id to have similar buffers with MarshRAM analysis.
- A structure is flagged exposed if either flood-extent source indicates inundation (a deliberately inclusive "union" rule, so a borderline structure is carried forward for review rather than dropped):

$$exposed = (CIRCA_MHHW20in_polygon = 1)\ OR\ (NOAA_MHHW_20in > 0)$$

- The count of exposed structures is tallied per gate and classified into 5 classes by Jenks natural breaks (relative breaks): the gate with the most exposed structures scores 1 (Critical); the gate with the fewest scores 5 (Negligible).

Criterion 2: Flood Depth Score

NOAA_MHHW_20in is sampled at each exposed structure point. NOAA_MHHW_20in do not consider restricting structures. For each gate, the maximum depth among that gate's exposed structures is carried forward. The rationale is that one severely-flooded critical structure should drive urgency more than several only marginally wet ones:

$$Gate\ depth\ value = \max(\ NOAA_MHHW_20in\ )\ \text{among that gate's exposed structures}$$

Per-gate maximum depths are classified into 5 classes by Jenks natural breaks: the deepest class scores 1 (Critical); the shallowest/no-depth class scores 5 (Negligible).

Criterion 3: Hydraulic Connectivity Modifier

Criteria 1 and 2 above rely on the CIRCA polygon as the primary reference layer and the NOAA raster as a check. Criterion 3 is a Boolean screen for the opposite failure mode: a structure that currently reads as "protected" under the CIRCA polygon but that NOAA's independent flood-fill connectivity trace reaches anyway; i.e., a hidden hydraulic connection (a narrow channel, ditch, or culvert) that the CIRCA polygon boundary missed. Two disagreement flags are defined at the structure level:

- flag_A (hidden-connection candidate): CIRCA says not exposed, but NOAA_MHHW_20in > 0. This means the gate protects less than the primary CIRCA layer implies, and is treated as a real finding.
- flag_B (calibration note only): CIRCA says exposed, but NOAA_MHHW_20in = 0. This is interpreted as the two products' underlying tidal datum assumptions disagreeing slightly at that point, rather than a genuine physical finding about the gate, and by itself does not change the score.

Any gate with at least one flag_A structure is treated as a connectivity candidate and receives a −1 tier modifier on the Flood Risk Index (minimum at 1; the index cannot go below Critical).

flag_B-only cases are documented as a CIRCA/NOAA calibration discrepancy in the gate's record but do not by themselves move the tier. Flagged gates are spot-checked visually against the DEM before the modifier is finalized, to distinguish a real hydraulic connection from a raster-alignment artifact; one diagnostic is a flagged structure that sits away from the gate's obvious main channel, which points to a secondary ridge/lobe connection path rather than an artifact.

Criterion 4: Critical Infrastructure Modifier

Independently of Criteria 1–3, each gate is checked for whether any of its exposed structures are critical infrastructure under FEMA's Community Lifelines framework (e.g., emergency services, power, water/wastewater, communications, transportation). If so, the gate receives an additional −1 tier modifier on the Flood Risk Index.

Flood Risk Index = average(Criterion 1 score, Criterion 2 score) − Modifiers (Criteria 3, 4)

with the result floored at 1 (Critical) and capped at 5 (Negligible).

2.2.2. Salt Marsh Health Index

The Marsh Health Index is scored on the same 5 (healthy/best) to 1 (severely degraded/worst) direction as the Flood Risk Index, drawing on the CTNERR ecological assessment (MarshRAM / Index of Marsh Integrity, IMI) developed in parallel for this project. We developed a qualitative marsh degradation index based on landscape-level analyses to use alongside infrastructure and property-at-risk information to support tide gate management and restoration decisions. The quality of salt marsh habitat was assigned to five ranks: high, moderately high, moderate, moderately low, and low. This index was designated based on the metrics described in Table 3. If the tide gate has multiple marshes upstream of it, the scores for each marsh unit are averaged against Table 3 to get that gate's Marsh Habitat Index.

Table 3: Salt Marsh Habitat Index

	Salt Marsh Habitat Index Categories				
Metric [%]	**High (5)**	**Moderately High**	**Moderate**	**Moderately Low**	**Low (1) More Critical**
Marsh Unit Size (acres)	≥ 100	50 – 99.9	25 – 49.9	5 – 24.9	< 5
UVVR	0 – 0.05	0.06 – 0.11	0.12 – 0.19	0.20 – 0.24	≥ 0.25
HUC-12 watershed % impervious cover	< 6	6 – 11.9	12 – 24.9	25 – 39.9	≥ 40
Phragmites australis proportion	< 5	5 – 24.9	25 – 49.9	50 – 74.9	≥ 75

2.2.3. System Impact Rating

The Flood Risk Index and Marsh Health Index are combined by simple averaging into a single System Impact Rating:

System Impact Rating = average(Flood Risk Index [with Criteria 3/4 modifiers], Marsh Health Index)

The system impact rating is reported on the same 1 (Critical) to 5 (Negligible) scale as its two inputs, and carries forward directly into the Tide Gate System Rating (Section 2.2.4).

Qualitative Priority Matrix

For communication purposes (site maps, summary tables), the same two inputs: Marsh Health (rows) and Flood Risk if Opened (columns) are also cross-tabulated directly into a 5×5 qualitative priority category, rather than reduced to the single averaged system impact rating number. This gives reviewers the two-axis context (why a site landed where it did) that a single averaged score would otherwise hide (Table 4 and 5):

Table 4: Qualitative Priority Matrix for System Impact Rating Scale direction: 5 = Negligible/best, 1 = Critical/worst

	FLOOD RISK IF OPENED				
Salt Marsh Health	**5 Negligible**	**4 Minor**	**3 Marginal**	**2 Severe**	**1 Critical**
1 — Critical	Strong removal candidate	Strong removal candidate	Restoration-leaning, review needed	Conflict site — engineer	Conflict site — engineer
2 — Severe	Strong removal candidate	Strong removal candidate	Restoration-leaning, review needed	Conflict site — engineer	Conflict site — engineer
3 — Marginal	Restoration potential — monitor	Restoration potential — monitor	Monitor, moderate priority	Protection-leaning — repair	Protection-leaning — repair
4 — Minor	Low priority	Low priority	Low-moderate — routine maint.	Repair / maintain as-is	Repair / maintain as-is
5 — Negligible	Low priority	Low priority	Low-moderate — routine maint.	Repair / maintain as-is	Repair / maintain as-is

Any site falling in the Marginal (3) row or column is flagged for a second look or field visit before a category is finalized, rather than accepted automatically from the GIS classification alone.

Table 5: Category definitions for Table 4.

LABEL	MEANING
Strong removal candidate	Severely degraded marsh, minimal flood consequence if opened.
Restoration-leaning, review needed	Marsh degraded, moderate flood risk — needs an engineering look first.
Conflict site — engineer	Marsh needs flushing, but opening risks structures — needs an engineered solution (self-regulating gate, muted regulator).
Restoration potential — monitor	Moderate degradation, low flood consequence — worth tracking, not urgent.
Monitor, moderate priority	Nothing extreme on either axis — periodic reassessment, no immediate action.
Protection-leaning — repair	Moderate degradation but possible flood consequence — favor keeping the gate functional.
Low priority	Healthy marsh, safe to open either way — nothing to do here.
Low-moderate — routine maint.	Healthy marsh, moderate flood consequence — standard upkeep, no special action.
Repair / maintain as-is	Healthy marsh, critical flood consequence if opened — the gate is doing real protective work.

2.2.4. The Tide Gate System Rating

The System Impact Rating captures flood and ecological consequence, but says nothing about whether the gate structure itself is physically capable of continuing to perform. That is supplied by the Condition Assessment Rating (CAR), scored 6 (Good) down to 1 (Critical) per the ASCE Manual of Practice No. 130 framework documented in Section 2.1.2 (Table 1). The two are combined into a single Tide Gate System Rating:

$$\textit{Tide Gate System Rating (TGSR)} = (\textit{CAR} \times \textit{System Impact Rating}) / 30$$

The divisor of 30 is the product of the two scales' maximum values (CAR max = 6, SIR max = 5), which normalizes TGSR to run from about 0.03 (worst: a critically-deteriorated gate at a site

where impact is also critical) to 1 (best: a good-condition gate at a negligible-impact site). This is the "0 to 1" rating, note that this is the TGSR, not the System Impact Rating itself, which stays on its native 1–5 scale; the two are easy to conflate because they both describe "impact" but they are different quantities feeding the same final formula.

TGSR is then classified into three maintenance-priority tiers (RACE 2024). Boundaries are computed as ≤ 1/3 High; > 1/3 and ≤ 2/3 Medium; > 2/3 Low, also similar to the RACE 2024 to complement the information between both studies in Table 6:

Table 6: Tide Gate System Rating Classification (RACE 2024)

Priority Tier	Recommended Action	TGSR Range
High	Maintain within 3 years	0.000 – 0.333
Medium	Maintain within 4 to 5 years	0.334 – 0.666
Low	Maintain within 6 to 10 years	0.667 – 1.000

A LOW TGSR number (near 0) corresponds to a HIGH maintenance priority (urgent), because TGSR is built from scales where small numbers mean worse condition/greater impact. A HIGH TGSR number (near 1) corresponds to a LOW priority (good condition, low consequence, can wait).

2.3. Marsh Ecological Assessment

2.3.1. Marsh Rapid Assessment Method (MarshRAM)

Environmental assessments of wetlands can be completed at varying spatial and temporal intensities. The EPA defines wetland monitoring and assessment at three levels, where level 1 is landscape scale (analysis of remote sensing data or aerial imagery), level 2 is rapid assessment (in-field analysis using simple indicators and focusing on environmental stressors), and level 3 is intensive assessment (quantitative analysis of biological integrity and hydrogeology) (EPA, 2006).

Here, we employed a level 2 assessment developed for New England/Rhode Island salt marshes called the Marsh Rapid Assessment Method (MarshRAM) (Ekberg et al., 2017, Kutcher, 2022). MarshRAM combines landscape-level geographic information system (GIS) analyses with rapid field assessments of obvious marsh stressors, dominant plant communities, and wildlife presence. There are five scored assessment categories: Ecosystem Functions and Services, Surrounding Land Use, Wetland Disturbances, Index of Marsh Integrity (IMI), and Migration Potential. Each category's "score" has little individual meaning, but it is useful to compare scores across study sites to understand the relative condition of salt marshes under varying environmental stressors. Relative determination of marsh conditions using a rapid assessment technique is appropriate for this study as we compare the impacts of varying degrees of tidal restriction imposed by tide gate structures across coastal Connecticut.

Desktop analyses

For each scored category of the MarshRAM technique (except for IMI, which requires plant community analysis), remote sensing data was utilized for a level 1 or landscape-scale analysis of the environmental conditions in and around each marsh unit. For some meso-scale features such as tidal restrictions, soil disturbances, and recreational access platforms, satellite imagery from Google Earth Pro was used to visually scan for the presence of stressors.

For the Surrounding Land Use and Wetland Disturbances categories, land cover characteristics were quantitatively analyzed in ArcGIS Pro. Land cover data at 1-meter resolution for the state of Connecticut was obtained from the University of Connecticut Center for Land Use Education and Research (CLEAR). CLEAR's Connecticut land cover dataset was adapted from the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) 2016 high-resolution aerial imagery land cover product (NOAA OCM, 2016).

The Surrounding Land Use, Wetland Disturbances, and Marsh Migration Potential categories required analysis of respectively 30, 60, and 150 meter "buffer zones" around the marsh assessment units. These zones were drawn with the Buffer tool in ArcGIS Pro, generating polygons that excluded the original marsh assessment unit. Figure 1 shows an example of a marsh assessment unit and the associated 30-, 60-, and 150-m buffer regions associated with the Wetland Disturbances, Migration Potential, and Surrounding Land Use analyses, respectively.

To assess the Surrounding Land Use, fractional land cover was determined for the area 150 meters surrounding a given marsh assessment unit. Land use intensity was scored according to the MarshRAM protocol, on a scale with classes of Very Low (natural areas), Low (recreational areas, recovering natural areas), moderately high (residential, mowed areas, marinas), and high (impervious land cover, row crops, mining and industrial operations). Similarly, a 30-meter buffer region around the marsh assessment unit was created to assess the %age of "cultural" land cover informing the Wetland Disturbances score. Finally, a 60-m buffer region surrounding the marsh assessment units was analyzed for marsh Migration Potential. Seaward water surfaces were excluded from this analysis, and all landward water surfaces were identified as having no marsh Migration Potential. The land within 60 meters of the marsh assessment unit was separated into elevation categories 20 inches above and below mean higher high water (MHHW), following legislation Public Act 18-82. For areas higher than 20 inches above MHHW, erosion resistance structures such as bedrock, hardened shorelines, and impervious surfaces were classified as having no Migration Potential, while erodible land surfaces had Low Migration Potential. Low-lying land surfaces lower than 20 inches above MHHW were classified on a scale of No, Low, Moderate, Moderately High, and High Migration Potential according to land use categories. The MarshRAM land use intensity and migration potential classes were associated with C-CAP land use classifications as described in Table 7.

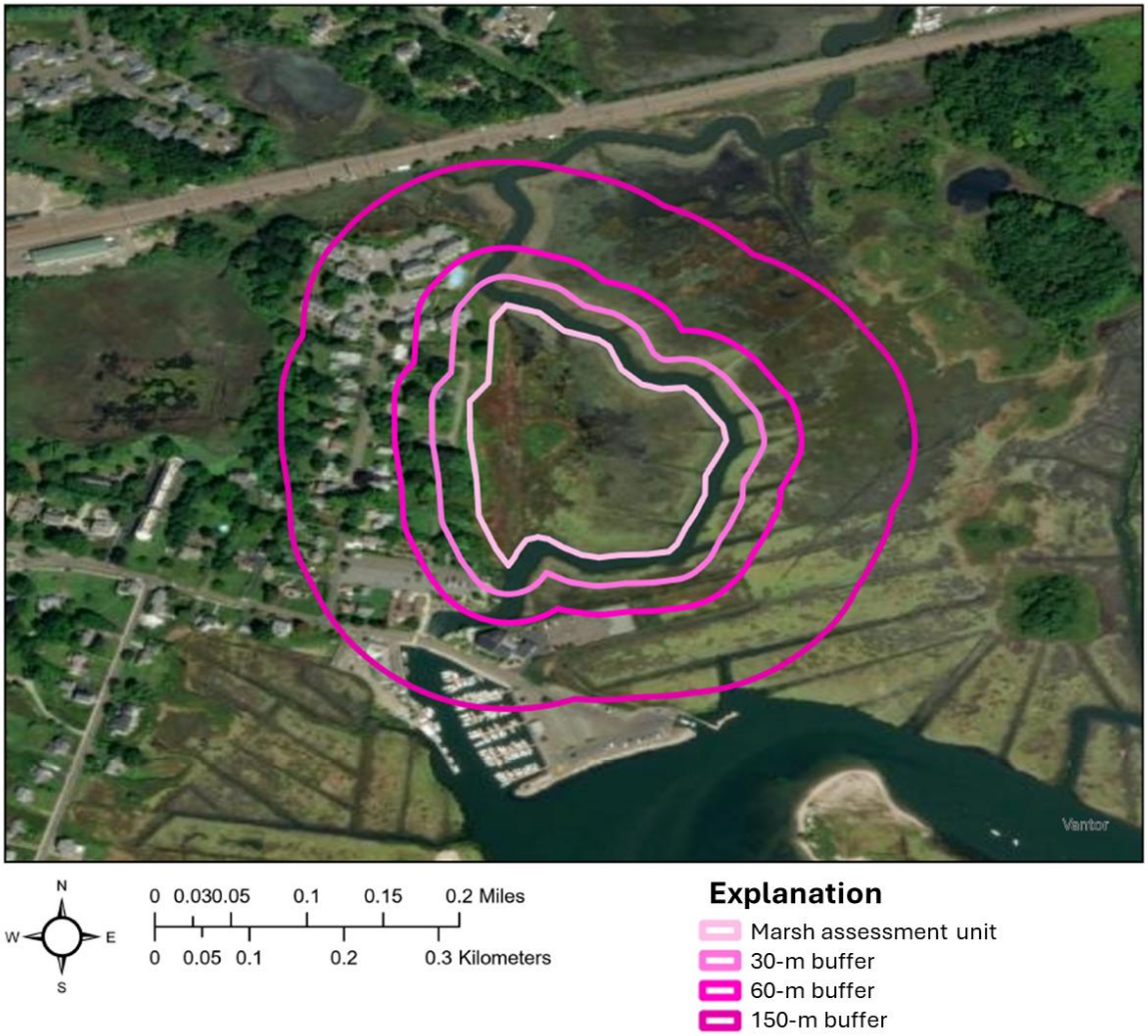


Figure 4. Example marsh assessment unit (Sluice Creek, Guilford) and buffer zones (excluding marsh polygon) drawn in ArcGIS Pro.

Table 7. Coastal Change Analysis Program (C-CAP) land use categories corresponding to MarshRAM land use intensity (for Surrounding Land Use scoring) and migration potential (for Migration Potential scoring) categories.

C-CAP land use category	MarshRAM land use intensity	MarshRAM migration potential
Developed, High Intensity	High	Low
Developed, Medium Intensity	High	Low
Developed, Low Intensity	Moderately High	Low
Developed, Open Space	Moderately High	Moderate
Cultivated Crops	High	Moderate
Pasture/Hay	Moderately High	Moderate
Grassland	Very Low	Moderately High

C-CAP land use category	MarshRAM land use intensity	MarshRAM migration potential
Scrub/Shrub	Very Low	Moderately High
Deciduous Forest	Very Low	Moderately High
Evergreen Forest	Very Low	Moderately High
Mixed Forest	Very Low	Moderately High
Palustrine Forested Wetlands	Very Low	Moderately High
Palustrine Scrub Shrub Wetlands	Very Low	Moderately High
Estuarine Forested Wetlands	Very Low	Moderately High
Estuarine Scrub Shrub Wetlands	Very Low	Moderately High
Palustrine Emergent Wetlands	Very Low	High
Estuarine Emergent Wetlands	Very Low	High
Open Water	Very Low	None
Palustrine Aquatic Bed	Very Low	None
Estuarine Aquatic Bed	Very Low	None
Unconsolidated Shore	Very Low	None
Barren Land	Very Low	Low
Tundra	Very Low	N/A
Perennial Ice/Snow	Very Low	N/A

Field assessments – Index of Marsh Integrity (IMI)

The desktop analyses included in the MarshRAM protocol are examples of Level 1 marsh assessment, at the landscape scale. The Index of Marsh Integrity (IMI) assessment is another scored component of MarshRAM and represents a Level 2 or rapid marsh assessment technique. For a given marsh unit, eight evenly distributed transects from the upland to the subtidal zone were chosen for field observations of dominant habitat types (Figure 5). The Avenza Maps app was used for geo-location on these transect lines in the field.



Figure 5. Sluice Creek marsh assessment unit (blue polygon) and transect lines (white lines) for Index of Marsh Integrity analysis

Field analyses of IMI were completed in September and October of 2025. At least two researchers walked the marsh transect lines within 1 – 2 hours of low tide. To start, one person stood at each end of a transect. One researcher walked a straight line on the transect towards the other, taking note of the dominant plant communities and counting the steps taken in each cover type, calling this data out to the other person. Both researchers recorded the data and compared after each transect. The vegetation cover types are described in Table 8 and are each assigned a coefficient of community integrity (CCI) that describes their habitat value and the degree to which it represents marsh degradation (Kutcher et al., 2022). For each transect, the total number of steps and number of steps taken in each habitat type were documented. The Index of Marsh Integrity was calculated as the sum of steps in a given habitat type multiplied by that habitat's CCI, divided by the total number of steps across the assessment unit. IMI is a relative index and ranges between 0-10 (Kutcher et al., 2022). A higher IMI value indicates a less degraded marsh environment.

Table 8. Marsh habitats and their corresponding coefficient of community integrity (CCI) identified during field IMI analysis. From Kutcher et al., 2022.

Marsh Habitat	CCI	Description
Salt Shrub	9	Infrequently flooded shrub community (>30% shrub cover) located at higher elevations on the marsh platform and at the upland interface; typically dominated by *Iva frutescens, Baccharis halimifolia*
Brackish Marsh Native	10	Emergent community where freshwater from the watershed dilutes infrequent flooding by seawater; typically dominated by non-halophytic, salt tolerant vegetation such as *Typha angustifolia, Schoenoplectus robustus, Spartina pectinata*
Phragmites	3	Areas where the invasive common reed *Phragmites australis* cover >30%
Meadow High Marsh	10	Irregularly flooded emergent high marsh community dominated by any combination of *S. patens, Juncus gerardii, Distichlis spicata; S. alterniflora* absent
Mixed High Marsh	7	Irregularly flooded emergent high marsh community comprised of any combination of *S. patens, Juncus gerardii, Distichlis spicata; S. alterniflora present*
Sa High Marsh	5	Irregularly flooded emergent high marsh; typically monoculture of *S. alterniflora*, although *Salicornia* sp. may be present
Die-off Bare Depression	1	Shallow gradual depression on marsh platform, irregularly flooded by tides but typically remaining flooded or saturated to the surface throughout the tide cycle; <30% vascular vegetation cover, or bare decomposing organic soil, typically with remnant roots of emergent vegetation; may have algal mat, filamentous algae, wrack, or flocculent matter present
Low Marsh	8	Regularly flooded, typically sloping emergent community located at the tidal edges of the marsh and dominated by tall-form *S. alterniflora*
Dieback Denuded Peat	0	Typically non-depressional marsh platform feature; marsh peat is exposed (vegetation <30%) and perforated from grazing, crab burrowing, and erosion; typically at or near tidal edge
Natural Panne	8	Shallow steep-sided depression on marsh platform with clearly defined edge; irregularly flooded, typically dry at low tide; species may include any cover of *Plantago maritima, Suaeda maritima, Salicornia* sp., *J. gerardii, Aster* sp.
Natural Pool	6	Shallow steep-sided depression on marsh platform with clearly defined edge; irregularly flooded by tides but typically remaining flooded throughout the tide cycle; organic or sandy substrate lacking emergent vegetation and roots but may support *Ruppia maritima*
Natural Creek	8	Narrow, natural, unvegetated, regularly-flooded or subtidal feature cutting into the marsh surface; typically sinuous
Ditch	2	Manmade ditches and associated spoils on the marsh surface; typically linear
Bare Sediments	4	Irregularly or infrequently flooded; sandy or gravelly sediments on the marsh surface with <30% vegetation cover; typically from recent wash-over event or elevation enhancement project

2.3.2. Landscape-level (tier 1) marsh analyses

The United States and the State of Connecticut have robust salt marsh datasets that include features such as vegetation mapping, unvegetated-to-vegetated ratios (UVVR), land cover (including areas of open water), ditching intensity, and more. These datasets were utilized to investigate the characteristics and integrity of marshes upstream of tide gate structures.

Salt marsh habitat classification

The extent of salt marsh habitat in coastal Connecticut was determined using the U.S. Fish and Wildlife Service's 2024 National Wetlands Inventory (USFWS, 2024). NWI wetland delineation is accomplished using a combination of digitized aerial imagery and topography, focusing on vegetation, visible hydrology, and geography. Notably, ephemeral waters are not considered wetlands in the NWI (Cowardin et al., 1979). On occasion, field reconnaissance is employed to clarify wetland extent and type. The NWI has a reported wetland feature identification accuracy of 98% and a precision of ± 0.2 ha (Dahl et al., 2020). Under the wetlands and deepwater habitats classification used in the NWI (FGDC, 2013 adapted from Cowardin et al., 1979), salt marsh habitat was selected in ArcGIS Pro by filtering the "ATTRIBUTE" field for estuarine intertidal (E2) codes and furthering filtering for emergent (EM), scrub-shrub (SS), and forested (FO) sub-categories.

Salt marsh habitats upstream of tide gates were manually determined in ArcGIS Pro. For tide gate locations that had been verified by a field visit, upstream salt marsh polygons were visually identified and selected. One exception was the Pine Creek salt marsh and tide gate complex in Fairfield, for which the flow regime was verified using the hydrodynamic diagrams in RACE (2024).

For several tide gates, the upstream marsh complexes are preceded by multiple tidal restrictions. One example is the Hammock River marsh complex in Clinton, upstream of tide gate CL01. There is a marsh platform immediately upstream of CL01, followed by a smaller marsh upstream of a culvert that runs underneath the Causeway. There is an additional salt marsh upstream of this that is preceded by a culvert underneath East Main Street. Finally, the furthest tidal marsh is upstream of a culvert that runs beneath Meadow Road. Each of these four salt marshes are upstream of CL01, but are potentially impacted by varying degrees of tidal restriction, such that analyzing all of these marsh units as a whole may not accurately reflect the impact of the tide gate structure alone on the upstream salt marsh habitat. Therefore, salt marshes upstream of tide gates but separated by additional tidal restrictions are segmented in our analysis. Importantly, this segmentation does not account for the degree of restriction imposed by a tide gate or culvert. It is possible that a culvert upstream of a tide gate imposes no additional flow restriction relative to the gate, but such analysis was outside of the scope of this work.

Marsh Integrity Indicators

The unvegetated to vegetated ratio (UVVR) of a wetland describes the proportion of a marsh surface that is either open water or otherwise unvegetated relative to the vegetated platform. A greater UVVR value indicates a greater proportion of unvegetated marsh area, which is associated with increased vulnerability to erosion. Here, we utilized the United States Geological Survey's 6-m resolution National Agriculture Imagery Program (NAIP)-derived UVVR dataset (Ackerman et al., 2023), in which UVVR was calculated for individual marsh units from the NWI. For a given marsh unit in our analysis, UVVR was area weighted.

The ditching intensity for each marsh unit was calculated in meters per hectare (m/ha). Salt marsh ditch polylines were obtained from Peck et al. (2025), in which ditches within NWI Estuarine

Emergent (E2EM) polygons were hand-digitized from the DigitalGlobe World Imagery Basemap at 0.3m resolution. Because ditches were visually selected at 0.3 m resolution, there may be buried or smaller ditches excluded from this layer that impact marsh hydrology and stability.

HUC-12 sub-watershed delineation polygons were obtained from the USGS Watershed Boundary Dataset (WBD) (USGS, 2025). HUC-12 is the smallest, most specific watershed category in the WBD. The % age of impervious surface coverage was analyzed at the HUC-12 watershed level for each marsh. An increased proportion of impervious cover in a wetland's watershed leads to more surface runoff of nutrients and other pollutants that can be introduced into the marsh ecosystem. Comprehensive impervious land cover data from 2023 were obtained from UConn's Center for Land Use Education and Research (UConn CLEAR, 2026).

Abutting Habitats and Natural Resources

Two qualitative layers are included in the Tide Gate Inventory Viewer: national diversity database (NDDB) and Connecticut Critical Habitats. NDDB areas are expressed as polygons that represent locations where Connecticut State and Federal endangered species have been observed (CT DEEP, 2026). The identification of species observed at a given location is intentionally withheld from the dataset for protection from disturbance. The Connecticut Critical Habitats layer (CT DEEP, 2024) describes specialized key habitats for species of Greatest Conservation Need identified in the state's Wildlife Action Plan (originally the Comprehensive Wildlife Conservation Strategy) (Terwilliger Consulting Inc., 2015). This dataset can be used to refine restoration decisions in areas where key habitats could be impacted by environmental change.

In this context, the NDDB and Critical Habitat layers provide coarse information about areas in which construction or restoration related to a tide gate or salt marsh may require endangered species protection measures or legal reviews, but this information should be analyzed in greater detail on a case-by-case basis prior to management decisions.

2.4. Quantitative Hydraulic Assessment

This section describes the complete methodology developed and applied under Task 2D to quantitatively assess the flood control function of each selected tide gate and its sensitivity to sea level rise. The methodology consists of six sequential steps, applied consistently across all four sites (GF01, EH02, NH01, WP01/WP02) with site-specific adaptations noted where they occur. The pipelinegiven below, each producing an intermediate artifact that feeds the next:

- Step 1: Hypsometric (elevation-volume) curve for the marsh basin, from LIDAR.
- Step 2: Tide forcing time series from the nearest long-record NOAA CO-OPS station.
- Step 3: Gate/culvert hydraulics (orifice, weir, and self-regulating-tide-gate flow physics).
- Step 4: Coupled mass-balance model solving for marsh water level over time.
- Step 5: Restricted (gate as-built) vs. unrestricted (gate removed) exceedance-frequency comparison.
- Step 6: Sea level rise sensitivity

2.4.1. Step 1: Marsh Geometry and Hypsometric Curve Development

The hypsometric curve defines how much water the marsh can hold at every elevation level. The cumulative marsh surface area, $A(z)$, and cumulative storage volume, $V(z)$, as functions of elevation, z , is the geometric foundation the mass-balance simulation (Step 4) depends on. It was developed from LIDAR-derived digital elevation model (DEM) tiles (2 ft horizontal resolution, referenced to NAVD88), mosaicked as needed to cover each site's full hydraulically-connected basin. The DEM was derived from CT ECO CT Ariel Imagery and LiDAR collection of 2023. The data meet the ASPRS 10 cm RMSEz vertical accuracy class (19.6 cm non-vegetated vertical accuracy at 95% confidence). Two known limitations apply at all four sites:

i) in dense Spartina marsh, LiDAR tends to read high by roughly 0.1–0.2 m because the laser does not reach the ground surface, which would overstate marsh surface elevations and understate storage below a given stage; and

ii) in channels, ponds and creeks, LiDAR records the water surface at the time of acquisition rather than the bed, which would understate channel and pond storage. Where site-specific RTK survey data were available (GF01, NH01, WP01/WP02), they were used to check the DEM.

Boundary Delineation: Two Methods

Two distinct methods were used to delineate the marsh area contributing to each gate, applied depending on data availability at each site:

- **Direct boundary clip:** where a directly applicable boundary already exists (the Connecticut National Wetlands Inventory (NWI) salt marsh dataset, filtered to the specific gate via its "Downstream" attribute), the DEM is clipped directly to that polygon. This is the preferred method where available, since it relies on an independently produced, authoritative wetland boundary rather than an assumption embedded in this project's own processing.
- **Flood-fill delineation:** where no directly applicable boundary exists, or where the available boundary is known to exclude part of the hydraulically-connected system, the marsh basin is instead delineated computationally. Starting from a seed point at the gate's own coordinates, the algorithm identifies every DEM cell that is both *i)* below a chosen elevation threshold and *ii)* reachable from the seed point without crossing a cell above that threshold. A simple elevation threshold ("include every cell below X meters, anywhere on the map") would incorrectly include any other low-lying area on the DEM tile that happens to sit below the same elevation, even if it is a physically separate water body with no hydraulic connection to the gate in question. Flood-fill avoids this by requiring connectivity, by including cells actually reachable from the gate's location.

Flood fill method is used at Westport (WP01/WP02) where and an NWI boundary exists but it excludes the tidal channel the gates physically sit on. A hypsometric curve built from NWI boundary clip would have been structurally unable to represent either gate's actual operating range. Flood-fill

delineation from each gate's coordinates was used instead to naturally capture the channel and the connected marsh platform together.

Once the basin is delineated by either method, cumulative area and volume are computed at 0.1 m elevation increments spanning the DEM's full valid range within the basin. At each increment z, $A(z)$ is the count of valid DEM cells at or below z (multiplied by cell area), and $V(z)$ is the summed product of (z minus each cell's elevation) across those same cells (multiplied by cell area). The total water volume the basin would hold if flooded to elevation z is represented by $V(z)$. Hypsometric curve is interpolated during the Step 4 simulation to obtain $A(\eta_{marsh})$ at each simulation timestep.

2.4.2. Step 2: Tide Data Acquisition and Datum Handling

The tidal forcing record was obtained from the nearest applicable NOAA CO-OPS tide gauge, covering the longest available historical period (1999-present at the time of this assessment, approximately 27 years) (Table 9). GF01, EH02, and NH01 share an identical underlying tide record, any similarity in their peak Sound-side water levels reflects this shared forcing.

Table *9*: NOAA Tidal Stations corresponding to the tidal gates.

NOAA Station	**Site(s)**	**Direct NAVD88 product?**
New Haven (8465705)	GF01, EH02, NH01	No - Mean Sea Level (MSL) datum retrieved, with a fixed offset applied to convert to NAVD88
Bridgeport (8467150)	Westport (WP01/WP02)	Yes - NAVD88 requested and returned directly, no manual offset required

The New Haven station does not publish a direct NAVD88 conversion (Table 9). Data were retrieved on the Mean Sea Level (MSL) datum and a fixed offset of –0.08 m was applied to convert to NAVD88, following the same site-specific conversion used in prior CIRCA work at a nearby reference station (Branford)(O'Donnell et al. 2017). The Bridgeport station's direct NAVD88 product was confirmed with the data provider before use and required no equivalent adjustment.

Several sites required field measurements (a graduated leveling rod referenced to a local, arbitrary zero point, or RTK GPS survey) to establish gate geometry, described fully in Section 2.3.4. Where a rod-based measurement was used, its zero point was converted to NAVD88 using one of two methods:

- **Static ground-elevation tie**: a single LIDAR-derived or RTK-surveyed elevation at a known point (e.g. the channel bottom at the gate) used to anchor the rod's zero point directly.
- **Instantaneous water-surface calibration:** the water surface itself read directly off the rod at a documented time, cross-referenced against the actual NOAA-observed water level (interpolated to that exact timestamp) at the corresponding station:

$$z_{offset} = \eta_{NOAA(t)} - r_{water(t)}, \qquad (1)$$

Where, z_{offset} is the corrected measurement, $\eta_{NOAA(t)}$, is the water level surface elevation read from NOAA station at the time *t*, and $r_{water(t)}$ is the rod elevation of the water at the same time *t*. This second method was used at GF01 (2026 gate renewal survey) and Westport, and in each case provided an additional real-world consistency check (e.g. cross-referencing a separately observed marsh-vs-Sound water level relationship against the modeled flow direction).

2.4.3. Step 3: Gate Configuration

Each gate's hydraulic behavior was characterized from a combination of field survey, and site observation, translated into a small set of parameters the Step 4 simulation requires: invert elevation, opening geometry (width and, for enclosed structures, height), a discharge coefficient, and a classification of the gate's directional behavior (Figure 6). Three sets of gate combinations and where it is used is given in Table *10*.

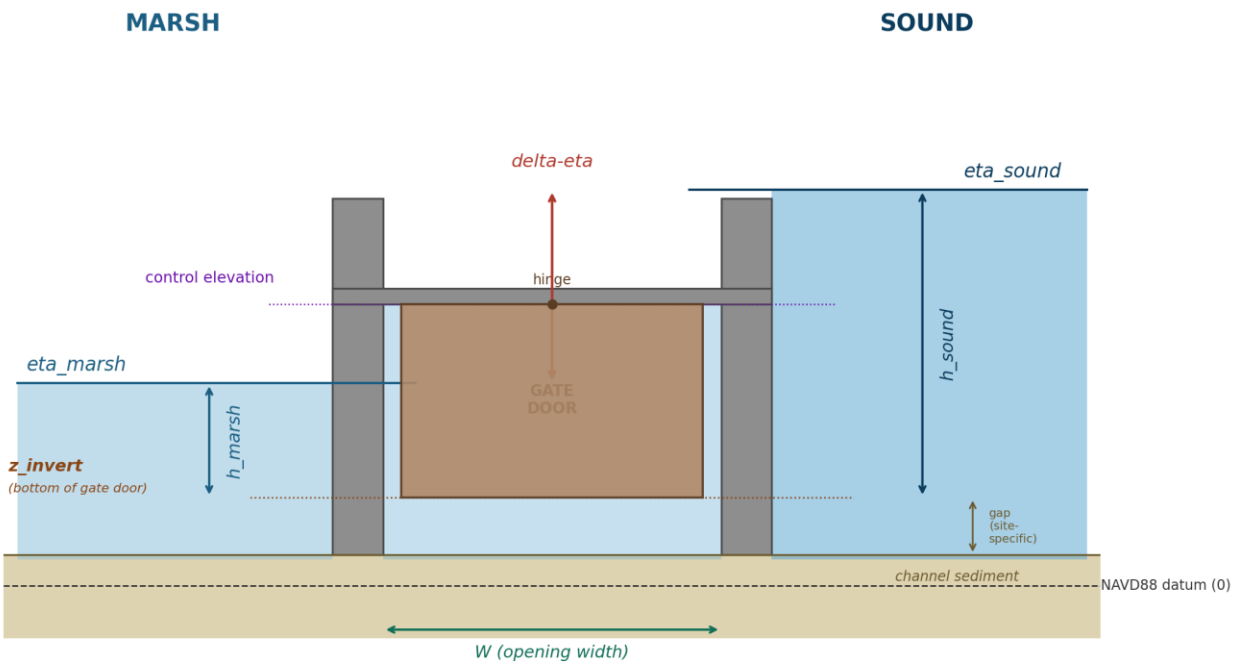


Figure 6: Gate representative sketch. Z_{invert} is the invert elevation (from the bottom of the sediment to the opening of the gate door), h_{marsh}, height of the water at marsh side, eta(η)$_{marsh}$ is the marsh side of the water surface absolute elevation above NAVD88, control elevation is the maximum level of water that the gate can allow, W is the opening width of the gate, h_{sound}, height of the water at the Sound side, eta(η_{sound} is the Sound side of the absolute elevation above NAVD88.

Table *10*: Gate type and flow behaviors

Gate type	Behavior	Sites where observed
Culvert (two-way)	Flow evaluated without restriction in either direction	NH01 (always-open path), Westport (both gate paths), EH02 (open channel and hypothetical culvert)
Flap (one-way)	Flow only when marsh level exceeds Sound level (drains marsh to Sound); zero flow otherwise, regardless of Sound level	GF01 (pre- and post-2026), NH01 (8 flap paths), Westport (individual gate leaves, aggregated to an equivalent two-way weir, see Section 3.3.4)
Self Regulated Tide gate (SRT) (threshold-locking)	Two-way flow while Sound-side depth above invert is at or below a threshold; locked fully shut in both directions once that threshold is exceeded	NH01 (3 SRT paths)

Where a discharge coefficient (C_d) could not be field-calibrated (Section 3.3 identifies which sites' C_d values are calibrated vs. generic starting estimates), values were selected based on standard hydraulic practice for the structure type, with an explicit rationale documented per gate rather than a single default applied uniformly. For example, at NH01, three co-located gate types (an always-open culvert, one-way flaps, and self-regulating float-operated gates) were assigned distinct discharge coefficients (0.70, 0.65, and 0.50 respectively) reflecting that a permanently obstruction-free opening, a cover that swings fully clear when open, and a mechanism whose buoyant float assembly remains continuously in the flow path even while open, represent genuinely different degrees of energy loss, consistent with standard culvert/gate hydraulics practice (e.g. .consistent with standard culvert and gate hydraulics practice (e.g., FHWA, 2012; Chow, V.T. (1959)), which treats an in-flow gate mechanism as a distinct, separately justified source of head loss), which treats an in-flow gate mechanism as a distinct, separately-justified source of head loss.

2.4.4. Step 4: Mass-Balance Model

The marsh's water level, η_{marsh}, is governed by a mass-balance equation. The rate of change of marsh water level equals the net volumetric flow through all gate flow paths, divided by the marsh's own surface area at the current water level (Section 2.3.2's hypsometric curve):

$$\frac{d\eta_{marsh}}{dt} = \frac{Q_{total}\,(\eta_{marsh}, \eta_{sound}(t))}{A(\eta_{marsh})}, \qquad (2)$$

Where η_{marsh} is the marsh side of the water surface level, $\eta_{sound}(t)$ is the Sound side of the water surface level (is the Step 2 tide forcing), $A(\eta_{marsh})$ is the marsh area at the marsh elevation level during time t and Q_{total} is the is the total discharge through every parallel gate path. In other words, this equation explains how fast the marsh water level changes right now equals how much water is flowing through the gate right now divided by how much surface area the marsh has to spread that water over right now. A bigger marsh (larger A) changes level more slowly for the same flow.

Gate Hydraulics

Flow through each individual gate path depends on the wetted condition on each side and the gate's structural type (orifice: an enclosed, fixed cross-section; or weir: an open crest with no fixed cross-section), independent of the directional gate-type classification in Section 2.3.3. The conditions considered are:

$$h_{marsh} = \eta_{marsh} - z_{invert}, \quad (3)$$

$$h_{sound} = \eta_{sound} - z_{invert}, \quad (4)$$

a) **Both sides dry:** Water hasn't even reached the gate's sediment bottom on each side, no flow

$$h_{marsh} \leq 0 \;\&\; h_{sound} \leq 0\,,\; Q = 0, \quad (5)$$

b) **Both sides wet:** Water covers the sediment on both sides and the gate has a fixed opening. Flow depends on the difference in elevation between the two sides (Δh). The water flows from the higher side to the lower side

$$h_{marsh} > 0 \;\&\; h_{sound} > 0\,, \quad (6)$$

$$Q = C_d\, A_{gate}\, sign(\Delta h) \text{ (submerged orifice)}, \quad (7)$$
$$sign = from\ high\ to\ low$$

$$\Delta h = \eta_{marsh} - \eta_{sound}, \quad (8)$$

c) **Open crest:** free weir discharge from higher side. Villemonte correction accounts for the fact that a downstream side that's already fairly full pushes back and reduces how much can spill over. This is why the same crest passes less flow once the lower side starts catching up.

$$Q = \pm C_d\, W \sqrt{g} h_1^{1.5} \left[1 - \left({}^{h_2}/_{h_1}\right)^{1.5}\right]^{0.385}, \quad (9)$$

$$h_1 = higher\ side\ depth$$

$$h_2 = lower\ \ side\ depth$$

d) **Only one side wet:** weir

$$Q = C_d W \sqrt{g} h^{1.5}, \quad (10)$$

Numerical Solution

The mass-balance equation was integrated with a custom fixed-step, fourth-order Runge-Kutta scheme implemented in MATLAB (time step 600 s). MATLAB's adaptive solvers (ode23, ode45, ode113) were tested and rejected, because they failed to complete in a practical time at gates. Since the flaps and SRTs assumed to have one-way flow the right-hand side of the governing equation genuinely non-smooth at every crossing, occurring many times per tidal cycle, and thousands of times across a multi-decade simulated record. An adaptive-step solver attempts to refine its step size near each such crossing to satisfy an error tolerance across a discontinuity that cannot actually be smoothly resolved; in the most severe case encountered during this project (NH01, with three simultaneously-active discontinuous gate paths). This produced a simulation that did not complete in a practical amount of time. A fixed step size (600 s / 10 minutes, matching the tide record's native resolution) avoids this failure mode entirely. The total number of steps, and therefore runtime, is known in advance regardless of how many discontinuities the simulated record contains, at the cost of not precisely resolving the exact instant of a crossing within a single step. This tradeoff is appropriate for a screening-level model in which the marsh's own response timescale (hours) is far longer than the fixed step.

2.4.5. Step 5: Restricted vs. Unrestricted Flood Frequency Comparison

To isolate each gate's protective contribution directly, the Step 4 simulation is run twice against the identical historical tide record: once with the gate's actual flow path (the "restricted" case), and once with the gate's restriction removed entirely, the marsh level driven directly by the Sound forcing. This is equivalent to a fully open connection (the "unrestricted" case). At sites with two named scenarios to compare directly rather than a single gate-vs-no-gate question (e.g. EH02's current open channel vs. a hypothetical culvert, or GF01's pre- vs. post-2026 gate), both scenarios are run through the identical Step 4 simulation and compared the same way, generalized beyond the strict restricted/unrestricted framing.

Flood Exceedance Metrics

For each chosen site, thresholds were chosen to span each gate's own reference elevations, (e.g. invert through the top of its opening, with margin on both sides), two metrics are computed for each case at each threshold:

- **Exceedance frequency:** the number of days per year the modeled marsh level exceeds the threshold.

- **Exceedance duration**: the average number of hours per day the threshold is exceeded, on days when it is exceeded at all.

The protection factor (PF) is the ratio of the average number of days per year on which a threshold elevation is exceeded in the unrestricted case (Sound level, i.e., gate removed) to that in the restricted case (marsh level behind the gate as modeled), where a day counts if the threshold is exceeded in at least one 10-minute step. A protection factor of 1 indicates no benefit from the gate at that threshold; a large protection factor indicates the gate provides strong protection; a protection factor below 1 indicates the restricted case actually floods more often than the unrestricted case would, a real and physically explainable outcome specific to gates that block drainage as well as inflow (Section 3.3.4).

2.4.6. Step 6: Sea Level Rise Sensitivity

This step evaluates how each site's flood control function responds to sea level rise, using a peak-over-record method distinct from a single-storm approach. At each of a series of SLR offsets (0 to 0.5 m in 0.05 m increments, spanning Connecticut's up to 0.5 m by 2050 planning benchmark, see Section 1.1), the entire Step 4 simulation is re-run with the Sound-side forcing uniformly raised by that offset. The single highest marsh water level reached anywhere in the full simulated historical record at each offset is recorded, the "peak-over-record" value at that SLR level (Figure 7).

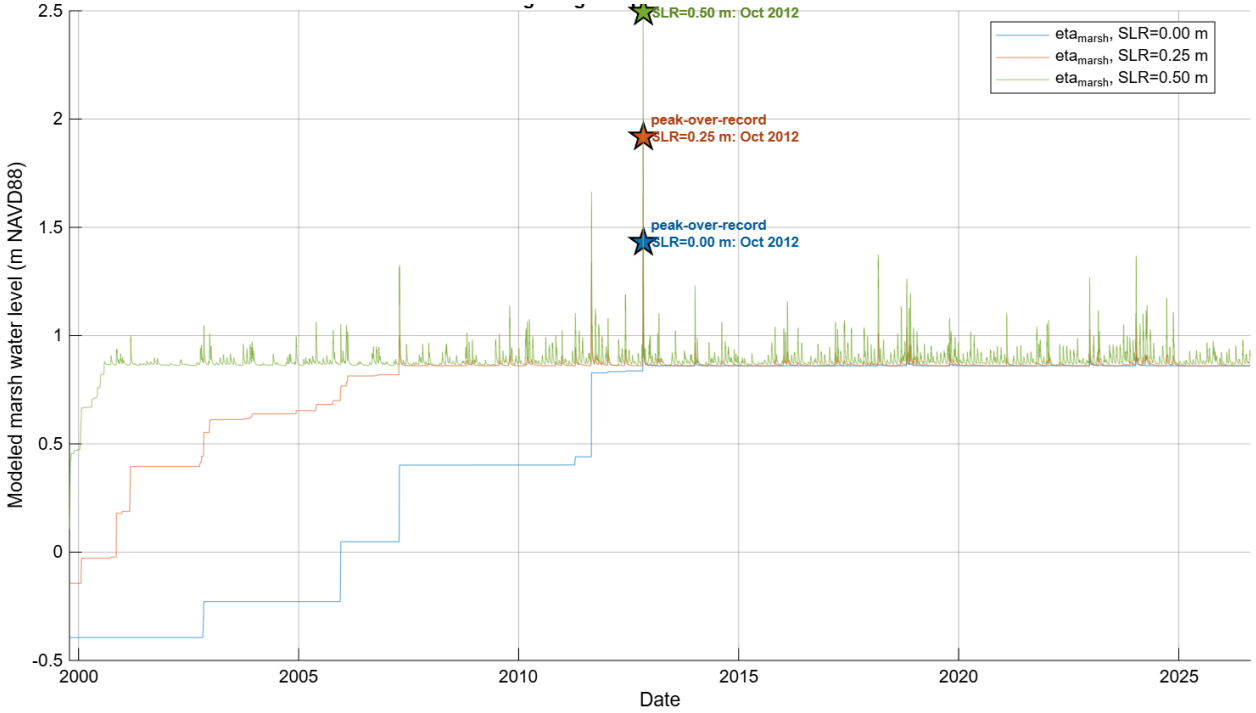


Figure 7: Peak-over-method: at each SLR level, scan the whole tidal record and take the single highest point (in this case Super Storm Sandy Oct 2012). X axis shows the years and y axis shows the modeled marsh water level by NAVD88 in GF01.

SLR sensitivity Metrics

Protection margin: (m): the SLR increment minus the increase in the modeled peak marsh level, equivalently (baseline peak + SLR) − modeled peak at that SLR. A margin of zero means the marsh peak rises one-for-one with sea level, a positive margin means it rises more slowly, and a negative margin means it rises faster than sea level itself. The margin is zero at the baseline by definition.

Peak Attenuation (m): the difference between the peak Sound level and the modeled peak marsh level at the same SLR, i.e., how far below the Sound the marsh peak stays. It describes the structure's effect at a given sea level, while the protection margin describes how that effect changes with SLR.

Local amplification factor: the point-to-point slope of modeled peak marsh level versus the SLR increment between consecutive tested points, i.e., the change in marsh peak per unit change in sea level. A factor of 1 means the marsh peak rises one-for-one with sea level, a factor below 1 means the structure is still attenuating the peak, and a factor above 1 means the marsh peak rises faster than sea level. A factor that climbs progressively across the swept range indicates that the structure's protection is eroding as sea level rises, rather than remaining a fixed reduction.

3. Results

3.1. Statewide Tide Gate Inventory

Once the statewide tide gate geodatabase and GIS-based prioritization analysis described in Section 2.1 and 2.2. were complete, an analysis of tide gate attributes, condition, and prioritization outcomes was performed across all tide gates identified in the Connecticut coastal inventory. **A total of 68 tide gates were identified in the statewide Connecticut inventory.**

- **Accessibility:** 57 of the 68 inventoried tide gates (84%) were accessible for assessment; the remaining 11 (16%) were located on private property or otherwise inaccessible, and could not be scored through the field-verified condition and structure-exposure workflow.

- **Type:** Flapper (flap) gates are the most common tide gate type statewide, accounting for 35 of the 68 inventoried gates (51%), consistent with the directional-type classification (flap / culvert / self-regulating) used throughout the four intensively-studied sites.
- **Associated Culvert:** 41 of the 68 gates (60%) have an associated culvert structure, meaning condition findings for these sites must account for both the gate itself and its culvert, consistent with the "TG_CONDITION" and "CUL_CONDITION" fields tracked separately in the prioritization geodatabase.
- **Gates per Site:** the number of individual tide gates sharing a single site/structure ranges from a minimum of 1 up to a maximum of 14, underscoring that “site” and “gate” are not interchangeable

units in the statewide inventory, a pattern already encountered directly in the intensive hydraulic assessment, where Westport's WP01 and WP02 are two physically distinct multi-gate gate structures sharing one marsh.

- **Geometry:** Rectangular openings (24) are somewhat more common than round/circular openings (19).
- **Material:** of the gates with steel (12) and aluminum (9) are the most common gate materials, followed by wood (7) and concrete (5).
- **Operational Status:** 35 of 68 gates (51%) are recorded as active. 7 are abandoned, 5 are under repair, 1 is proposed, and the operational status of 20 gates (29%) remains unknown.
- **Tide Gate Condition:** 10 tide gates statewide were recorded as being in Good condition (CAR = 6).

Among the subset of gates carried into the full prioritization workflow (Section 2.2), condition data is frequently incomplete at the individual-element level: several of the highest-priority gates (e.g., CL01, GF01, FF27) have a recorded tide gate condition but no recorded culvert condition, consistent with the partial field coverage already documented for the four intensively-studied sites in Section 3.3.

Following the Flood Risk Index / Marsh Health Index / Tide Gate System Rating (TGSR) framework developed in Section 2.2, a TGSR score and associated 3-tier maintenance priority were computed for 55 of the 68 inventoried tide gates (81%) in Figure 8. For 13 of these 55 gates, which lie outside the NOAA MHHW+20 in flood-zone layer, flood exposure was set to Negligible and the score is provisional (Table 13). The remaining 13 gates lack the access or condition data needed to compute a score (Table 12). Gates with a TGSR at or below 1/3 are placed in the High tier.

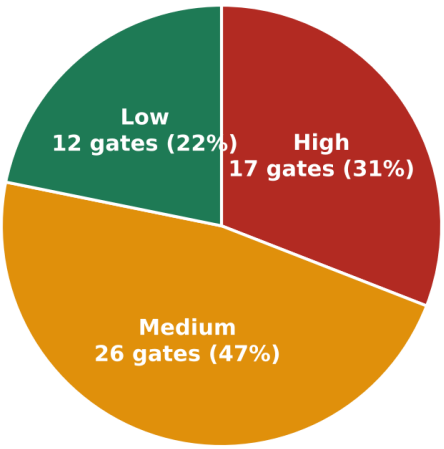


Figure 8: Statewide distribution of Tide Gate System Rating (TGSR) maintenance priority, n=55 scored gates.

The largest share of scored gates (47%) falls into the Medium priority tier (n=26), consistent with a statewide population that is neither broadly in crisis nor broadly low-concern, but roughly 31%, (17 gates) fall into the High priority tier, where condition and/or consequence is severe enough to

warrant maintenance action within 3 years. These 17 gates are listed in Table 11 with their driving Flood Exposure, Marsh Health, and condition inputs and their resulting qualitative Priority Matrix category. Ten of the 17 are provisional gates outside the flood-zone layer (Table 13), where the High tier reflects gate condition alone with no structures exposed if opened. The seven High-tier gates with exposed structures are CL01, FF12, FF27, FF29, FF31, FF32 and FF37. Notably, GF01, one of the four sites carried through the full quantitative hydraulic and field condition assessment, also surfaced in this GIS-driven screening: before the 2026 renewal it ranked High as a "Conflict site, need engineered solution" gate (elevated structure exposure if opened, Poor tide gate condition, CAR = 3). With the renewed gate recorded as Good (CAR = 6), its TGSR rises from 0.33 to 0.66 and it moves to the Medium tier with the matrix category "Repair / maintain as-is." This is discussed further in Section 3.3.

The distribution of the statewide tide gate priority after the GIS TGSR scoring is given in Figure 9. Provisional means the gate lies outside the NOAA MHHW+20 in layer, so its flood risk is considered Negligible. The provisional scores for these 13 gates are given in Table 13. There are also 13 gates that have no score, explained in Table 12. In Table 13, the tide gate itself is in poor condition at 11 of the 13 (average CAR of 3 or lower), which is what pulls TGSR down; ten of the 13 fall in the High tier and one in the Medium tier. None of them protects an exposed structure, and 11 of the 13 have no marsh behind them. By the matrix, those are "safe to open either way." That points to a different action than repair: confirm with the town engineer whether the gate is still functioning and still needed, and if not, consider decommissioning rather than spending repair money. FF25 (degraded marsh, no flood consequence) is the strongest removal candidate on this list.

Table 11: The 17 statewide tide gates in the High (0–3 year) maintenance priority tier, ranked by TGSR (lowest first). * = outside the NOAA MHHW+20 in layer; flood exposure set to Negligible (provisional).

Gate	Structures exposed	Flood exposure	Marsh health	System impact	Avg. CAR	TGSR	Priority matrix category
FF37	10	High	Negligible	Moderate	1	0.125	Repair / maintain as-is
BG01B*	—	Negligible	Negligible	Negligible	1	0.167	Low priority
FF04*	—	Negligible	Negligible	Negligible	1	0.167	Low priority
FF05*	—	Negligible	Negligible	Negligible	1	0.167	Low priority
FF25*	—	Negligible	High / Severe	Low	1.5	0.181	Strong removal candidate
FF12	11	Moderate	High / Severe	High / Severe	2	0.183	Monitor, moderate priority
FF16*	—	Negligible	Negligible	Negligible	1.5	0.250	Low priority
FF28*	—	Negligible	Negligible	Negligible	1.5	0.250	Low priority
CL01	9	High	Moderate	High / Severe	3	0.259	Conflict site — engineer
FF07*	—	Negligible	Moderate	Low	2	0.267	Restoration potential — monitor
FF27	5	High	High / Severe	High / Severe	4	0.300	Repair / maintain as-is
FF29	12	Low	Negligible	Low	2	0.300	Low priority
FF31	5	High	Negligible	Moderate	2.5	0.312	Repair / maintain as-is
FF32	7	Moderate	Critical	High / Severe	4	0.317	Low-moderate — routine maint.
FF24*	—	Negligible	Negligible	Negligible	2	0.333	Low priority

FF26*	—	Negligible	Negligible	Negligible	2	0.333	Low priority
FF34*	—	Negligible	Negligible	Negligible	2	0.333	Low priority

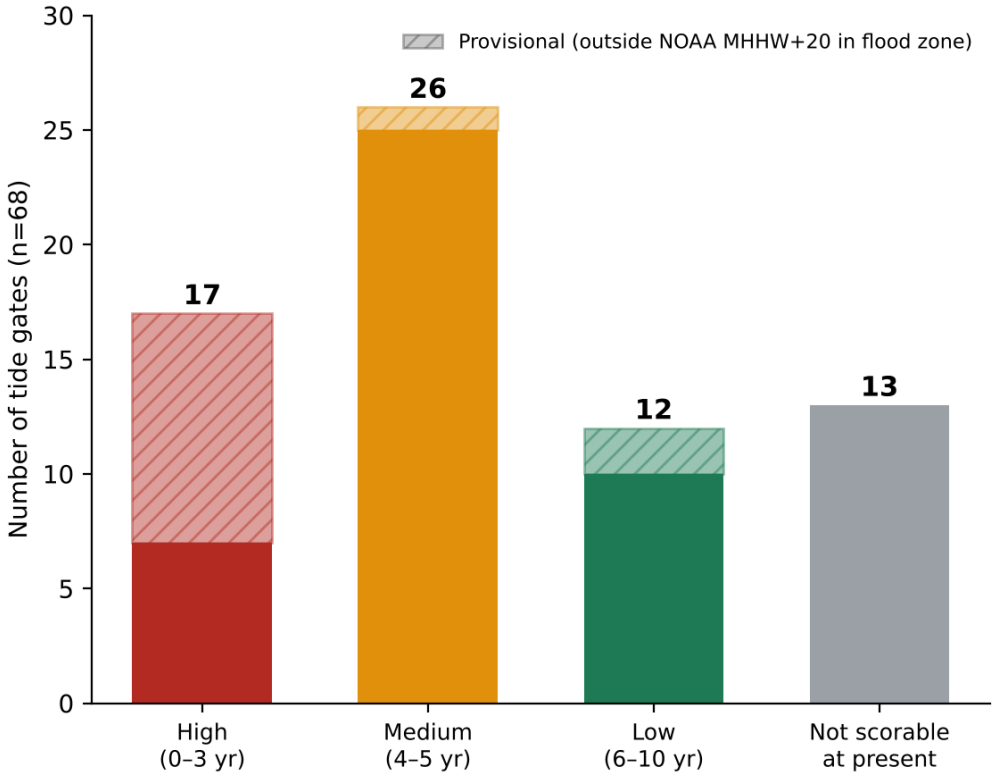


Figure 9: Statewide tide gate TGSR scoring (n=68). Hatched segments are provisional scores for gates outside the NOAA MHHW+20 in layer, where flood risk is considered Negligible.

Table 12: Reasons why the 13 gates that have no score

Reason (from GIS review)	Gates	Count	What it means
No access — private property	GW03, GW04, GW05, OS01, BF01, EH01, WF01, WF02	8	Need landowner or town permission.
No access — gate enclosed	OS02, SF01, ST03	3	Physical access or visibility problem, not just permission.
Removed tide gate	EH02	1	Not an active gate. Useful as a reference site for what happens after removal.
Accessible, operational status unknown	BG01A	1	The only gap closable with one field visit.

Table 13: Provisional TGSR for the 13 gates outside the flood zone.

Gate	Marsh	Avg. condition (CAR, 1–6)	Provisional TGSR	Tier	Matrix category
BG01B	No marsh	1	0.167	High	Low priority
FF04	No marsh	1	0.167	High	Low priority
FF05	No marsh	1	0.167	High	Low priority

FF25	Degraded (2.25)	1.5	0.181	High	Strong removal candidate
FF16	No marsh	1.5	0.250	High	Low priority
FF28	No marsh	1.5	0.250	High	Low priority
FF07	Marginal (3)	2	0.267	High	Restoration potential — monitor
FF24	No marsh	2	0.333	High	Low priority
FF26	No marsh	2	0.333	High	Low priority
FF34	No marsh	2	0.333	High	Low priority
FF02	No marsh	3	0.500	Medium	Low priority
DR03	No marsh	5	0.833	Low	Low priority
SF02	No marsh	5	0.833	Low	Low priority

Code "FF" (Fairfield) holds 37 of the 68 gates (54%) and 15 of the 17 High-tier gates (88%); the other two are CL01 and BG01B. Fairfield is the one place where a single coordinated inspection and repair-or-remove effort can address most of the state's near-term need. Greenwich (GW) has the largest access problem, with three private-property gates in Figure 10.

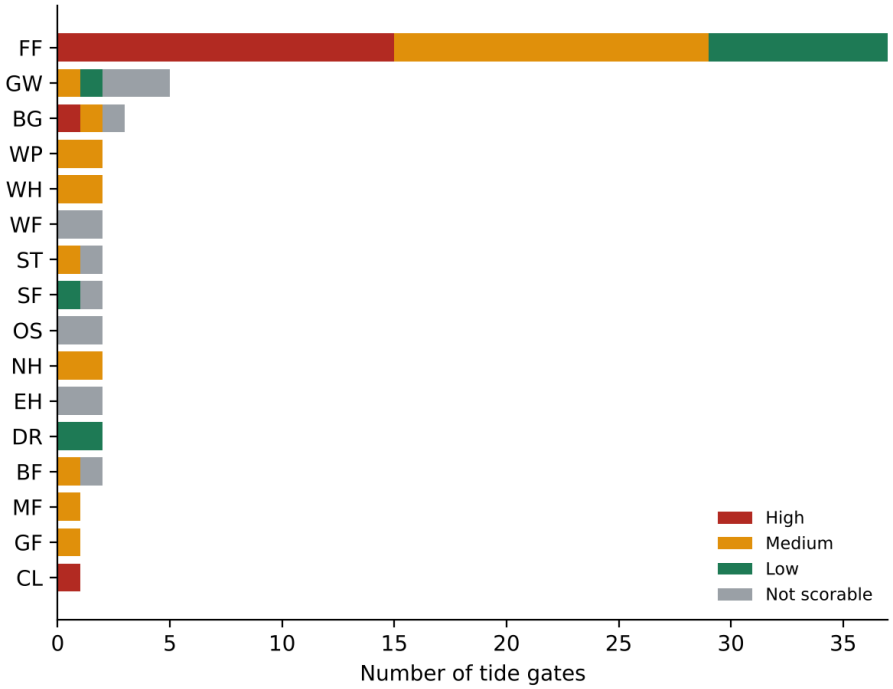


Figure 10: Tide Gates by Municipality code and priority

3.2. Marsh Ecological Assessment Results

3.2.1. MarshRAM results

Four sites were chosen for a full MarshRAM analysis incorporating field and desktop investigations. These sites are summarized in Table 14.

Figure 11 depicts the summarized salt marsh community composition % cover and index of marsh integrity for each marsh unit assessed. Sluice Creek, Farm River, and Sherwood Millpond had

similar IMI values (6.5, 6.1, and 6.0, respectively), while West River had a much lower IMI of 3.0 due to its 100% composition of the invasive *Phragmites australis,* which occupies and brackish to fresh conditions. Based on the IMI results, West River is in the "most degraded" category, while the remaining three marshes assessed are "intermediately degraded" (Kutcher, 2019).

Table 14. Description of the marsh assessment units chosen for a full MarshRAM investigation.

Marsh Site Name	Town	Downstream Tide Gate ID	Assessment Unit Area (m^2)
Sherwood Millpond	Westport	WP01 / WP02	48,172
West River	New Haven	NH01	30,485
Farm River	East Haven	EH02	76,558
Sluice Creek	Guilford	GF01	37,957

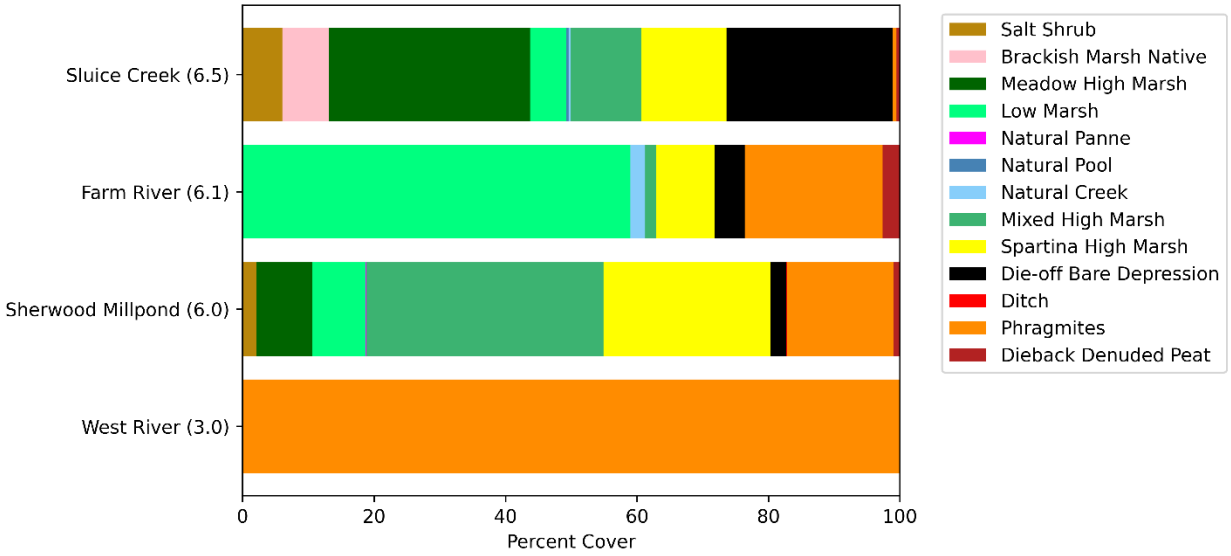


Figure 11. % cover of salt marsh community types summarized across eight walking transects in a given marsh assessment unit. From top to bottom, sites are ordered from highest to lowest Index of Marsh Integrity (parenthetical values following site names).

3.2.2. Landscape-level salt marsh analyses

Of the 68 tide gate structures identified along the Connecticut shoreline, 30 of them (44%) had some immediate presence of upstream salt marsh. This was identified based on the 2024 National Wetlands Inventory (US FWS, 2024) by filtering for Estuarine Intertidal Emergent and Scrub-Shrub habitats. Table 15 describes the acreage of upstream salt marsh associated with tide gate structures and associated information about the marsh and gates. Moving from top to bottom in the table, the towns are ordered from west to east.

Table 15. Tide gate structures with upstream salt marsh and associated metrics

Town	Watercourse	Tide Gate ID	Immediate Upstream Salt Marsh Area (acre)	Area-Weighted Marsh UVVR	Marsh Ditching Intensity (m/ha)	Cumulative Upstream Salt Marsh Area (acre)	Marsh HUC-12 Watershed Impervious Surface (%)
Westport	Sherwood Millpond	WP01	37.0	0.085	186	37.0	18.6
Fairfield	Pine Creek	FF05	0.5	0.061	0	0.5	42.5
		FF08	21.8	0.023	273	80.5	
		FF07	2.9	0.009	190	2.9	
		FF09	33.2	0.038	206	55.8	
		FF12	22.6	0.024	265	22.6	
		FF14	16.4	0.033	180	32.0	
		FF23	9.7	0.0004	119	9.7	
		FF25	5.8	0	244	5.8	
	Ash Creek	FF27	2.8	0.037	0	2.8	
		FF32	7.6	0.144	164.7	7.6	
		FF33	9.5	0.114	180.9	9.5	
Stratford	Lewis Gut	ST01	17.0	0.0004	124.8	17.0	39.6
	Ferry Creek	ST02	1.2	0	0	1.2	24.5
Milford	Great Creek	MF01	69.2	0.0634	83.0	69.2	21.0
West Haven	Cove River	WH02	48.0	0.042	68.6	48.0	36.9
	Old Field Creek	WH01	14.5	0.065	10.1	14.5	
New Haven	West River	NH01	39.0	0.0745	0	39.0	17.9
East Haven	Morris Creek	EH01	105.7	0.0301	59.2	105.7	33.7
	Farm River	EH02	163.9	0.0675	118.2	163.9	12.2
Branford	Mill Creek	BF02	24.8	0.178	86.0	24.8	29.8
	Branford Harbor	BF03	60.3	0.216	157.0	60.3	10.8
	Coastal Sound	BF01	58.6	0.132	148.7	58.6	
Guilford	Coastal Sound	GF02	35.1	5.70	232.5	35.1	
	Sluice Creek	GF01	107.8	0.0148	275.9	107.8	8.0
Clinton	Hammock River	CL01	200.9	0.038	209.5	200.9	14.0
Old Saybrook	Coastal Sound	OS01	14.2	0.237	286.9	14.2	13.9
	Oyster River	OS02	19.2	0.101	19.8	19.2	
Groton	Upper Lagoon	GR01	1.6	2.42	0	1.6	13.6

Fairfield

There is an extensive array of tide gate structures in Fairfield, mostly impacting Pine Creek and Ash Creek. In the Pine Creek complex, there are a total of 23 tide gates, 9 of which have upstream salt marsh habitat (Figure 12). The gates in the lower Pine Creek (FF16-22) directly protect nearshore properties, primarily along Fairfield Beach Road, and do not have substantial ecosystem impacts. The tide gates with direct impacts on upstream salt marshes include FF03, FF05, FF07-09, FF12, FF14, and FF23-25. In 2022, the Town of Fairfield contracted Race Engineering to perform a thorough review of all tide gates with recommendations for repair or replacement (RACE, 2024).

Tide gate FF03 is referred to by the Town of Fairfield as the McLevy Tide Gate. It is located near the mouth of Pine Creek. The structure is a 4-foot flap gate that was installed in 1997. In October 2024, Fairfield released a Request for Proposals (RFP) for the replacement of this tide gate. The Connecticut NWI does not classify the wetland upstream of this gate as a salt marsh, but rather a non-

tidal freshwater emergent or shrub/forested wetland that is seasonally saturated. The salinity profile and vegetation community should be evaluated at this site to verify its classification as a freshwater wetland. Regardless, the wetland is expected to be impacted by the downstream tide gate. Given the likelihood that the tide gate structure has restricted tidal exchange with the upstream wetland, this is a high-priority site for pre- and post-construction wetland monitoring to observe potential salinity, vegetation, and elevation changes associated with restored tidal flow.

Tide gate FF05 is upstream of a very small (0.5 acres) irregularly flooded high marsh platform. Downstream of this gate is a heavily ditched (348 m/ha), *Phragmites* dominated marsh 26.4 acres in size. Though this low marsh is not tidally restricted by a tide gate, it does abut a 900-foot flood control dike to its east which likely also impacts the marsh upstream of tide gate FF05. RACE 2024 noted that this flap tide gate was in very poor condition, as the outlet and the culvert were clogged with sediment. Therefore, this is not a functional tide gate and is likely restricting flow to the upstream marsh more than intended.

Tide gate FF08 is the first tidal restriction to the salt marsh complex on the west branch of Pine Creek, upstream of the flood-control dike. FF08 is a series of three self-regulating tide gates 5 feet in diameter each, first constructed in the early 1980's. It is currently undergoing construction to abandon the three gates, divert Pine Creek flow slightly northward, and construct three new SRTs with two additional sluice gates in between (RACE, May 2024). The outlet culverts for the tide gates are underneath a berm with a trail that is part of the Pine Creek Open Space Area. The 21.8-acre marsh directly upstream of FF08 is emergent high marsh with a moderate density of ditches (273 m/ha). This marsh unit is in between Kiwanis Field on Old Dam Road and residential units on Salt Meadow Road and South Pine Creek Road. Under 12 inches of sea level rise, open space in the western and southern boundaries of the marsh are expected to be inundated at MHHW and could develop new marsh platforms; however, under 20 inches of sea level rise, adjacent residential and recreational properties may be impacted.

Tide gate FF07 is upstream of the marsh that is upstream of gate FF08, so there are two tide gates restricting flow to the upstream 2.9-acre marsh. FF07 is a 3-foot diameter former flap gate missing both its flap and hinges. Prior to RACE inspection in 2023, sediment accumulation led to impounded water, but the Town of Fairfield then cleared the sediment to restore flow. The marsh upstream of FF07 is irregularly flooded emergent high marsh. This marsh unit is situated between residential properties on Field Point Drive, Salt Meadow Road, and South Pine Creek Road.

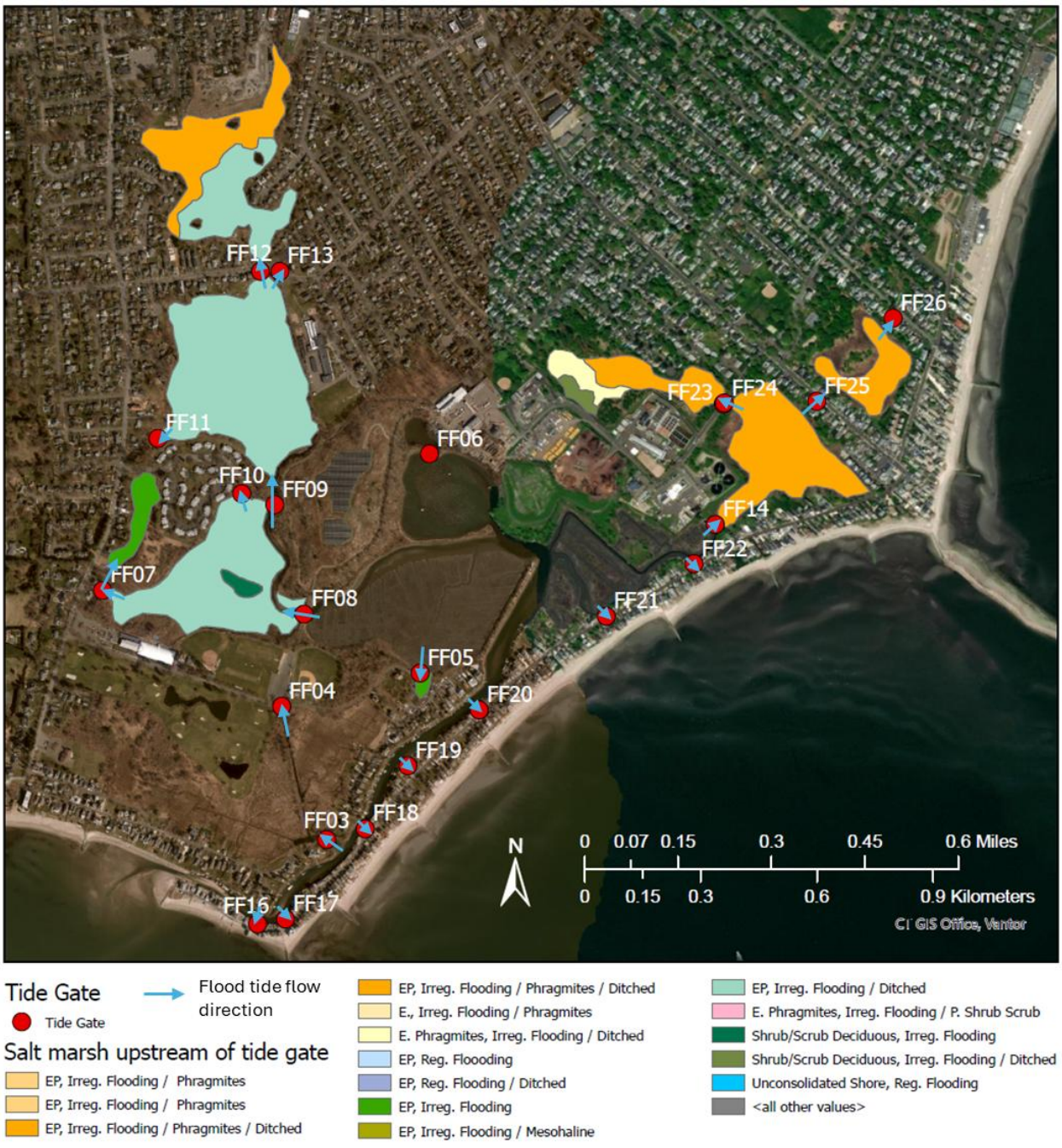


Figure 12. Tide gates and upstream salt marshes along Pine Creek and its tributaries in Fairfield, CT. Salt marsh habitats are classified based on the 2024 National Wetlands Inventory (US FWS, 2025), where E = emergent and P = persistent.

Tide gate FF09 is upstream of FF08 in the main channel of the west branch of Pine Creek. Site FF09 is composed of two adjacent self-regulating tide gates, one 4-feet in diameter (9A) and the other 5-feet (9B). There is a 33.2-acre continuous emergent high marsh unit directly upstream of FF09, situated between residential properties on Salt Meadow Road, South Pine Creek Road, and Oldfield

Road, as well as public services facilities on Mona Terrace. The outlet culverts for the tide gates are underneath a berm with a trail that is part of the Pine Creek Open Space Area. The floats for both gates are damaged or missing which hinders their ability to self-regulate flaps based on the tidal elevation. The inlet culvert for gate 9B additionally has severe corrosion and accumulated debris. This gate is recommended for repair/replacement (RACE, 2024). The upstream marsh has moderate ditching (206 m/ha) and some open water unvegetated areas leading to a slightly higher UVVR (area-weighted value of 0.04) than adjacent marshes. This marsh unit is also relatively lower-elevation than others in the Pine Creek complex, likely leading to the persistence of open water areas. Sediment supply to this marsh should be investigated to verify whether the tide control structures are leading to a lack of sediment accumulation and thus marsh subsidence.

Tide gate FF12 is in the main channel of the west branch of Pine Creek, upstream of FF08 and FF09 and underneath Oldfield Road. This 18-inch diameter duckbill gate is deteriorated such that it consistently remains open. However, there is also substantial slope erosion and sediment accumulation that block tidal flow (RACE, 2024). The upstream marsh is 22.6 acres in area and is moderately ditched (265 m/ha). The salt marsh also has a moderate proportion of unvegetated open water areas. The higher-elevation northwestward portion of this marsh unit is dominated by *Phragmites*, indicating infrequent saltwater delivery.

To the east of the flood-control dike, the eastern branch of Pine Creek connects another complex of marshes that are separated by tide gates (Figure 12). Tide gate FF14 is the furthest downstream of these structures. This site is composed of two 4-foot diameter SRTs that are in good condition (RACE, 2024) with two 5-foot diameter sluice gates in between (tide gate #15 in RACE, 2024). There is also a timber pile screen at the upstream outlet of the four culverts. There are a cumulative 32 acres of marsh upstream of the FF14 tide gates, 16.4 acres of which are immediately upstream. The adjacent upstream marsh unit is *Phragmites*-dominated and slightly subsided relative to the marsh on the downstream side of the tidal restriction. The marsh unit borders residential properties on Fairfield Beach Road and Reef Road as well as a wastewater treatment plant that has a newly-constructed earthen berm and stormwater pumps to protect against flooding and storm surge (Brone, 2025).

Tide gates FF23 and FF24 are located underneath Richard White Way, upstream of FF14 on the same tidal channel, leading to another marsh unit. FF23 is a 5.5-foot diameter flap gate that was submerged in sediment as of 2023 (RACE, 2024). FF24 is directly westward of FF23 and is a 2-foot diameter flap gate missing its flap and buried in sediment, entirely restricting flow (RACE, 2024). The upstream marsh (9.7 acres) is *Phragmites* dominated and has subsided with a minimum elevation of -0.24 feet (-0.07 m) NAVD88. This marsh unit is adjacent to residential properties on Longdean Road and Veres Street as well as a wastewater treatment plant, public works facilities, and a landscaping supplier.

Tide gate FF25 is underneath Reef Road and is also upstream of FF14, leading to another northward marsh unit. FF25 is a 4-foot diameter flap gate that is buried in sediment and missing its

flap and hinge assembly; this is a non-functioning tide gate that is impounding water. The upstream marsh unit of 5.8 acres is dominated by *Phragmites* and likely receiving little to no tidal exchange. This marsh is very closely bordered on all sides by residential properties on Reef Road, Fairfield Beach Road, and Rowland Road.

The western bank of Ash Creek in Fairfield also has a series of tide gates with upstream marsh units (Figure 13). FF27 is a 4-foot diameter SRT and an adjacent 4-foot diameter flap gate that runs under Turney Road by the South Benson Marina. The upstream 2.8-acre salt marsh is dominated by *Phragmites* and very closely borders residential properties on Milton Street and Oyster Road. This marsh unit is the Milton Street – Oyster Road Wetland Conservation Area (Ash Creek Assoc., 2023).

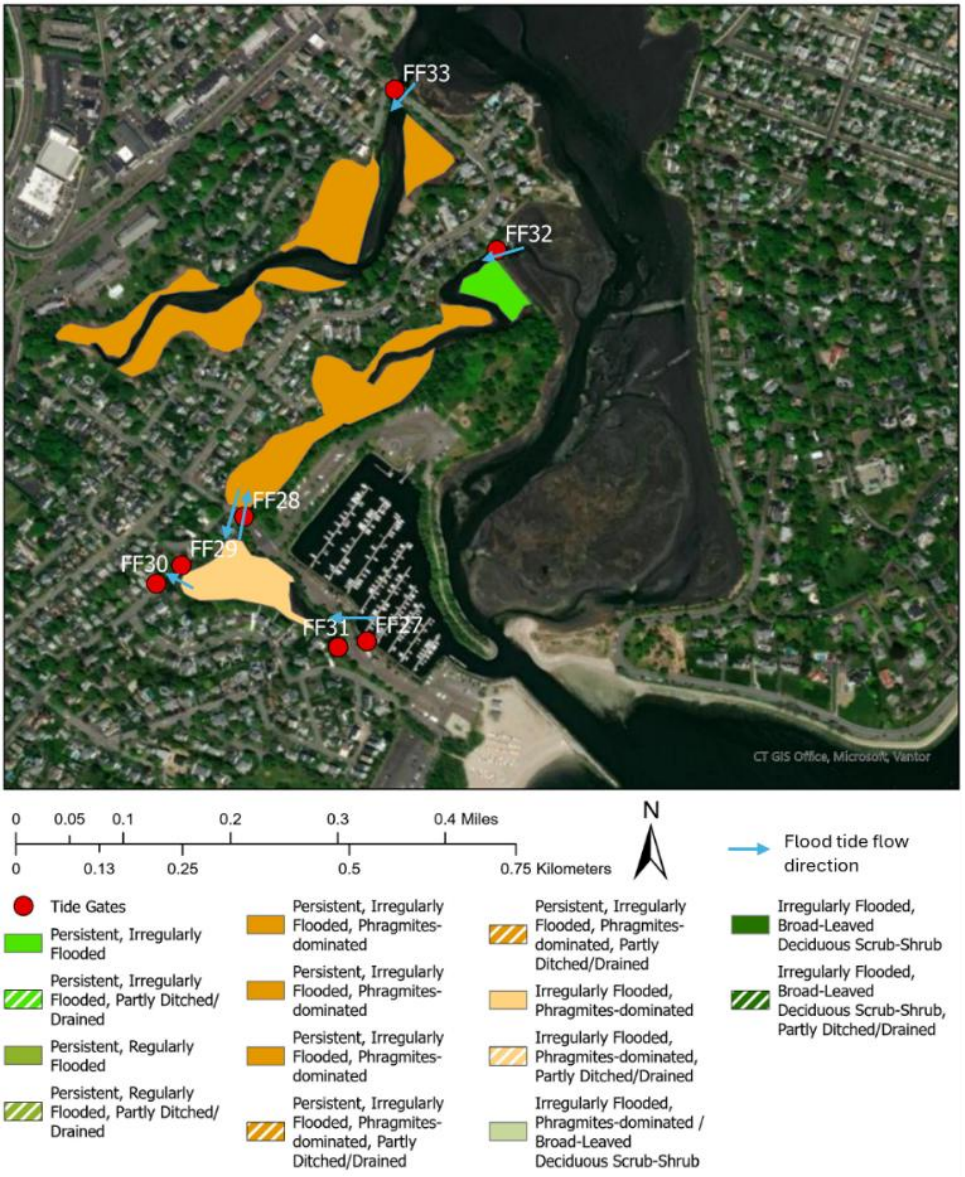


Figure 13. Tide gates and salt marshes along Ash Creek and its tributaries in Fairfield, CT. Salt marsh habitats are classified based on the 2024 National Wetlands Inventory (US FWS, 2025).

Tide gate FF28 is upstream of the previous marsh unit and should lead to another marsh unit that also receives flow at its opposite end from Riverside Creek, a tributary of Ash Creek. However, the flap gate to the 4-foot culvert at site FF28 is missing and the inlet was not located by RACE (2024), likely due to sediment burial. There is likely no flow or tidal exchange through this culvert; however, the upstream marsh does receive tidal exchange from Riverside Creek, as described in the following paragraph.

Tide gate FF32 is a 3-foot diameter SRT that restricts tidal flow into Riverside Creek, a tributary of Ash Creek. The gate is located at the northern end of a flood control dike (constructed in 1957) which also restricts tidal flow. The existing SRT was installed in 1975 to replace a conventional flap gate that had negatively impacted the upstream salt marsh. As of 2023, the gate is in satisfactory condition (RACE, 2024). There are 7.6 acres of salt marsh directly upstream of the tide gate, the majority of which is dominated by *Phragmites*. The marsh unit is bordered by residential property on Riverside Drive and by an open space and boat launch to the southeast.

Tide gate FF33 restricts flow in Turney Creek, a tributary of Ash Creek. In fall 2025, the Town of Fairfield completed replacement of the tide gates that were formerly replaced in 1994.

Stratford

There were three tide gates identified in Stratford, only one of which had a meaningful quantity of salt marsh. Gate ST01 on White Rock Creek / Lewis Gut had 17.0 acres of upstream marsh, while gate ST02 had 1.2 acres of Phragmites-dominated marsh surrounded by commercial and residential development.

Gate ST01, composed of culverts underneath Lordship Blvd, is upstream of the expansive Great Meadows salt marsh unit of the Stewart B. McKinney National Wildlife Refuge. This marsh is ecologically significant in part because it is the only known habitat for the endangered plant marsh pink (*Sabatia stellaris*) in the state of Connecticut (Bruce, 2021). According to GZA GeoEnvironmental (2016), the tide gate is not functional and full tidal exchange occurs, limited only by the culverts under Lordship Boulevard. The upstream salt marsh is dominated by Phragmites and has a UVVR of 0.0004 (essentially fully vegetated). This marsh unit is in a heavily developed watershed with 40% impervious surface coverage and is adjacent to the Sikorsky Airport.

Gate ST02 controls flow through Ferry Creek underneath Broad St. The current gate structure is a series of 6-foot concrete pipes with flap gates. These gates are to be replaced with combination sluice/flap gates in addition to raising the Broad Street bridge by 4’ to improve flood resilience (CT DEEP, 2025). The upstream salt marsh is 1.2 acres in size and fully vegetated with Phragmites. This marsh unit is not contiguous with other substantial habitats and likely provides limited ecosystem services.

Milford

One tide gate was identified in Milford. Gate MF01 is an SRT intersects the mouth of Great Creek at Silver Sands State Park. The gate was installed in 1989 to improve marsh drainage and protect

adjacent low-lying properties from flooding. The current structure is composed of two SRT's with box culverts that are 6' wide and 4.6' in height (Fuss & O'Neil, 2012). The vegetation of the upstream 69.2-acre salt marsh is dominated by Phragmites. The UVVR was 0.0634 and the ditching intensity was low at 88 m/ha.

West Haven

Two tide gates, both with upstream salt marshes, were identified in West Haven, gates WH01 and WH02. Each gate structure is maintained by the city of New Haven and they are set to maintain mean higher high water in the upstream marshes. WH01 is on Old Field Creek, restricting flow to 14.5 acres of upstream salt marsh. The WH01 gate structure, installed in 2008, is composed of two 54" self-regulating tide gates and one flap gate. WH02 is on the Cove River, restricting flow to 48 acres of upstream marsh. WH02, installed in 2022, is composed of four gates, two of which are 72" self-regulating tide gates, and the other two of which are 72" by 104" flap gates. The tide gated marshes in West Haven are primarily composed of Phragmites, indicating limited saltwater exchange.

East Haven

There is one tide gate structure that influences flow to salt marshes in East Haven. Site EH02 has the frame of a former tide gate, but no existing gate, and was included as a case study site – see the Farm River East Haven case study section. Gate EH01 controls flow on Morris Creek under S. End Rd adjacent to the Tweed New Haven Airport. The upstream 164 acres of salt marsh is fragmented and primarily composed of Phragmites. The marshes here are in a developed watershed with 34% impervious surface cover. These marshes are not contiguous with a broader wildlife complex but likely provide substantial ecosystem services as flood protection to adjacent properties.

Branford

Branford contains two tide gates with upstream salt marsh habitat. Gate BF01 restricts flow directly from the open Sound underneath the Branford Trail, near the Washburn Preserve. Gate BF03 intersects Sybil Creek underneath S. Montowese St. Site BF02, at the confluence of Mill Creek and Branford Harbor under Harbor St, formerly had a tide gate which was removed in 2017.

There are 22 acres of salt marsh habitat directly upstream of gate BF01, prior to an additional tidal restriction under the Amtrak bridge. In total, there are 149 acres of salt marsh upstream of gate BF01. According to the 2024 NWI, this marsh is regularly inundated with salt water and has a low proportion of Phragmites. It is moderately ditched at an intensity of 149 m/ha, and has a UVVR of 0.132, indicating a moderate amount of unvegetated area.

Gate BF03 restricts flow to 60 acres of upstream salt marsh, which have a moderate ditching intensity of 157 m/ha and a moderate UVVR of 0.216. These metrics indicate that the marsh is slightly degraded. It is a regularly inundated fringing marsh that is not part of a broader habitat complex, but likely provides flood protection to the bordering developed residential areas.

3.3. Quantitative Hydraulic Assessment Case Study Results

This section addresses the quantitative assessment described in Section 2.4 applied to GF01 (Guilford), EH02 (East Haven Farm River), NH01 (New Haven West River) and WP01 and WP02 (Westport Sheerwood Millpond) areas.

3.3.1. Guilford (GF01) Before and After 2026 Renewal

This section assesses the flood control function of GF01 and its impact on the surrounding marsh, and identifies potential impacts on ecosystems, accounting for sea level rise (SLR) projections and hydrological changes (Figure 14). This site was visited in August 2024 but then revisited September 2026 to incorporate how the tide gate system changed after the renovations (Figure 15, Table 16). The renewed gate's invert is roughly a meter lower than the original. Practically, this means the new flaps can open across a much wider range of tide conditions than the old sluice gate could (Table 16).

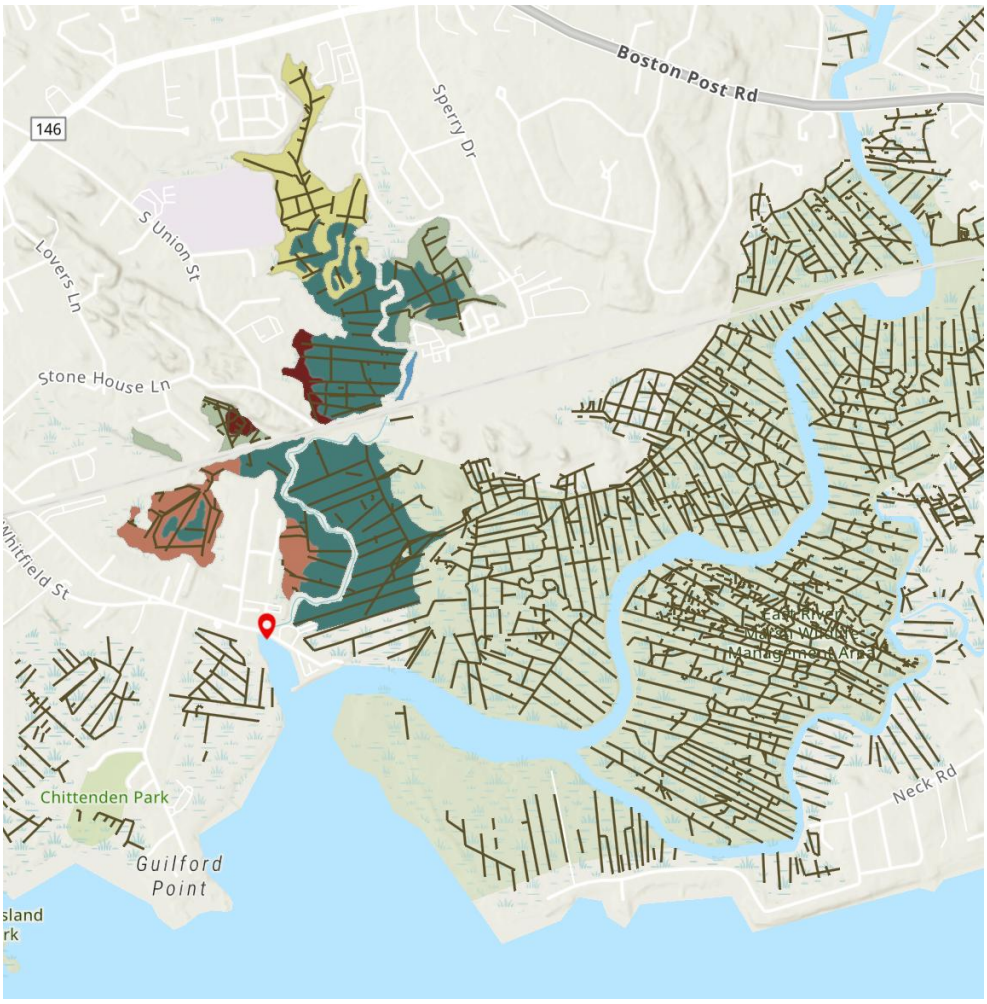
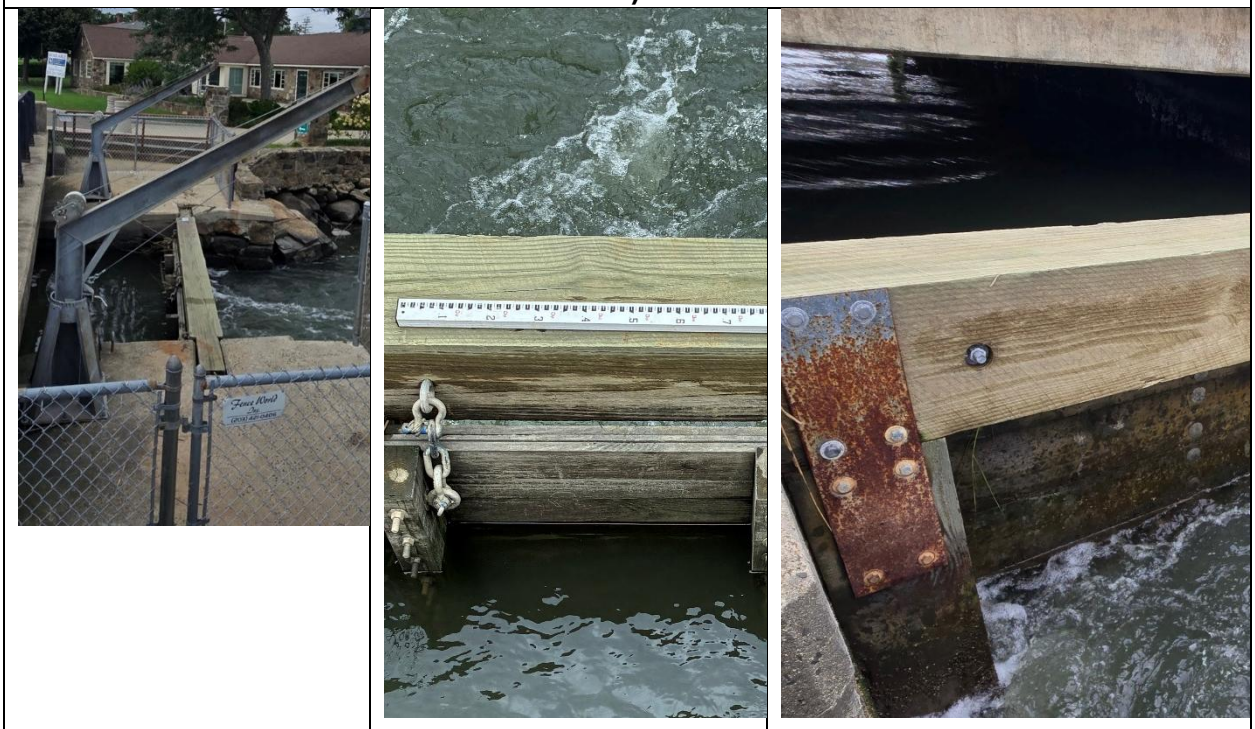


Figure 14: Location of GF01 marked with red pin shown screenshot from the Tide Gate Viewer. The immediate upstream colored area from NWI is considered for the marsh assessment.



a)



b)

Figure 15: a) Pre2026 renewal and b) Post-renewal in 2026 of GF01.

Table 16: Renewed and original gate dimensions of GF01

Parameter	**Pre-2026 (original)**	**Post-2026 (renewed)**
Structure	1 flap gate (middle beam ignored)	2 flap gates
Invert	0.8605 m NAVD88	-0.156 m NAVD88
Controlling elevation	1.8605 m NAVD88	1.144 m NAVD88
Opening width	1.85 m (single)	1.60 m x 2
Road overtopping path	1.7069 m crest, 13.11 m wide	unchanged

The renewal replaced the original sluice gate with flap gates set approximately 1 m lower. The invert of the original gate is 0.8605 m NAVD88 and the invert of the renewed gate is −0.156 m NAVD88, a difference of 1.02 m. Both structures pass flow in one direction only, from the marsh to the Sound. Because the renewed flaps can open at a much lower marsh stage and over a wider range of tide conditions, the marsh can now drain to a lower level than the original structure allowed (Table 16). The post renewal cross-section of the RTK GPS measurement on LIDAR is given in Figure 16.



a)

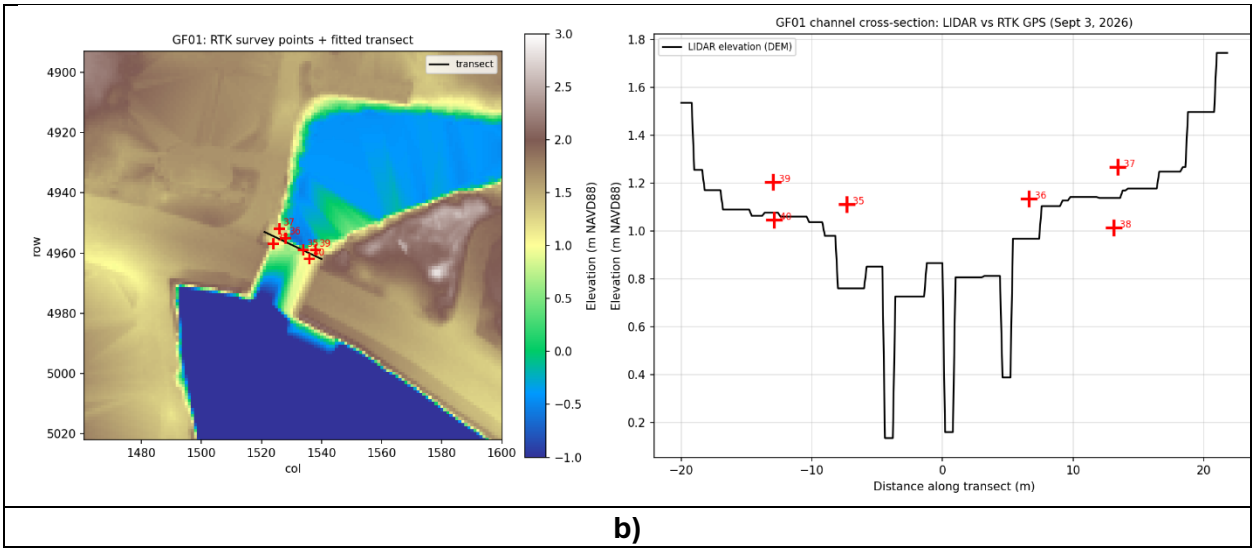


Figure 16: a) RTK measurement locations Guilford Marina Tide Gate, Sept 3, 2026 – coordinates and elevations in data file tidegates_sept2026.txt Points 35 and 36 = total width of the tide gate and b) the GF01 channel cross section over the LIDAR Measurements.

Marsh Storage Characteristics

The stage-storage relationship of the marsh, which supplies the A(η) term in the mass balance, was developed from the 2024 NWI marsh boundary and the project digital elevation model (DEM) (Figure 17, left). Cumulative area and cumulative volume as functions of elevation (NAVD88) are shown in Figure 17 (center and right), together with the original gate invert, the road crest, and the top of the gate opening.

The area curve shows a broad, flat marsh platform. Less than about 3×10^4 m² of the basin lies below roughly 0.3 m NAVD88, which corresponds to the tidal channels and creeks. Between roughly 0.3 m and 0.9 m the cumulative area increases to about 4.2×10^5 m², so that most of the marsh surface lies within a band of about 0.6 m in elevation. Above approximately 1.0 m the curve is nearly vertical at a total area of about 4.5×10^5 m² (45 ha), indicating that the marsh is bounded by steep upland and embankment slopes and that little additional area is wetted at higher stages.

The hypsometric curve follows from the area curve. Volume accumulates slowly below the marsh platform and increases linearly above about 1 m, at roughly 4.5×10^4 m³ for each 0.1 m of stage. The volume stored below the original gate invert is on the order of 1.4×10^5 m³, and the volume stored up to the road crest and the gate opening top is on the order of 5×10^5 to 6×10^5 m³. Because the model computes the rate of stage change as the net flow divided by the surface area at that stage, the large surface area at high stages limits how quickly the marsh level can rise for a given net inflow. This

storage effect is one reason the modeled marsh peak remains well below the Sound peak.

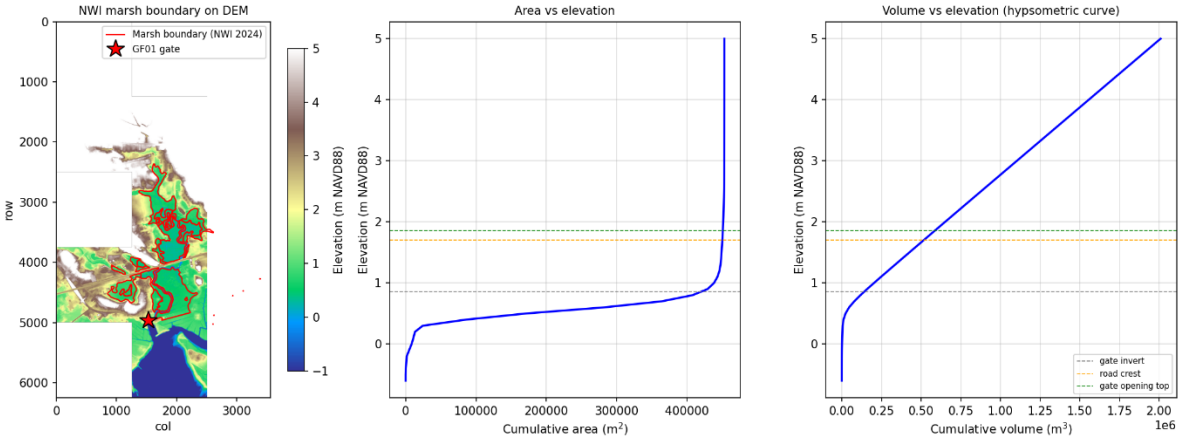


Figure 17: GF01 marsh boundary on the DEM (left), cumulative area versus elevation (center), and cumulative volume versus elevation, the hypsometric curve (right). Dashed lines mark the original gate invert (0.86 m), road crest (1.71 m), and gate opening top (1.86 m).

Simulated Marsh Water Levels

Marsh water level was simulated with the lumped mass balance described in Section 2.2, in which the rate of change of marsh stage equals the net flow through the structure divided by the marsh surface area at the current stage:

$$d\eta marsh / dt = Qtotal(\eta marsh, \eta sound) / A(\eta marsh), \qquad (11)$$

The Sound water level, $\eta sound$, is the NOAA water level record converted to NAVD88, and Qtotal is the sum of the flows through the gate, over the road crest, and through the fully submerged gate opening. The flap passes flow only when the marsh stage exceeds both the Sound stage and the gate invert. The equation was integrated over the 26.8-year record with a fixed-step, fourth-order Runge-Kutta scheme. Results for the original gate under the historical record are summarized in Table 17.

Table 17: Simulated marsh and Sound water levels, original gate, historical record

Metric	Pre 2026 (Original Gate)	**Post Renewal**
Maximum Sound (downstream) water level in record	2.642 m NAVD88 (consistent with Superstorm Sandy)	Same
Maximum simulated marsh (upstream) water level	1.431 m NAVD88	1.134 m NAVD88
Road/bridge crest (overtopping threshold)	1.71 m NAVD88; not reached	Same
Gate opening top (full submergence)	1.86 m NAVD88; not reached	1.144 m NAVD88; not reached (0.010 m below)
Correlation, marsh versus Sound water level	r = 0.055	r = 0.05
RMSE, marsh versus Sound water level	0.948 m	0.707 m

The simulated marsh level is effectively uncorrelated with the Sound level (r = 0.055), and the root-mean-square difference between the two series is 0.948 m. This is the response expected of a functioning one-way gate. In the model the flap gate passes flow in one direction only, from the marsh to the Sound. Water enters the marsh only by overtopping of the road crest (1.707 m NAVD88) when the Sound exceeds it, as it does during the largest surges in the record (maximum 2.642 m). Between such events the marsh can only drain, and drainage stops at the gate invert (0.861 m). No freshwater, groundwater or direct rainfall inflow is represented. Each run begins with the marsh at the first Sound level in the record with no spin-up period, so marsh levels in the early years of the record reflect that starting condition and not tidal exchange. Whenever the Sound is higher than the marsh, the flaps close and prevent backflow, so the marsh level is governed by storage and drainage conditions at the structure rather than by the Sound tide or storm surge. The maximum simulated marsh level of 1.431 m is 1.21 m below the maximum Sound level and is below both the road crest and the top of the gate opening. The model therefore indicates that neither road overtopping nor full submergence of the gate occurred at any time during the 26.8-year record Figure 18.

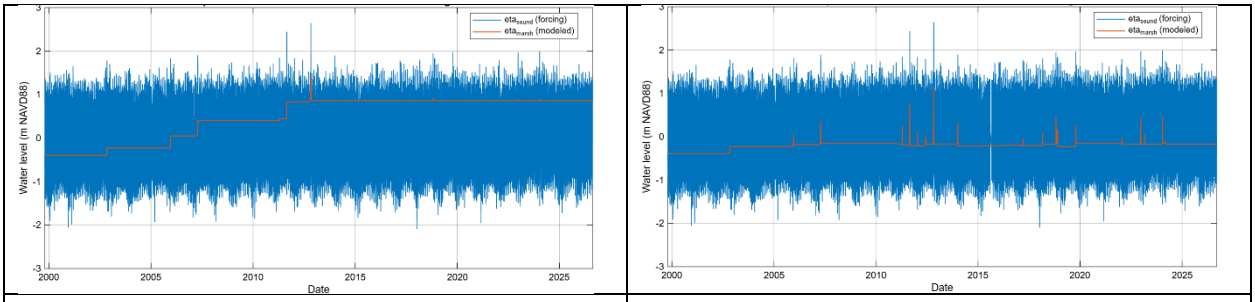


Figure 18: Simulated marsh water level and Sound water level, (a) original gate and (b) renewed gate during 1999-2026 of GF01.

After renewal, the lower invert allows the flaps to discharge at a much lower marsh stage and for a larger part of each tidal cycle. In the simulation the marsh level therefore draws down further on each falling tide, and individual rises in marsh level appear as distinct peaks, rather than remaining near the former invert elevation (Figure 18b). For the historical record, the maximum simulated marsh level under the renewed configuration is 1.134 m NAVD88, which is 0.297 m lower than for the original gate (Table 19, SLR = 0).

Flooding Frequency

The exceedance analysis uses the simulated marsh water level series to determine, for a range of threshold elevations, the average number of days per year on which the marsh level exceeds the threshold and the average number of hours per day above the threshold on those days. The same statistics were computed for the Sound record, which represents the unrestricted condition with no gate in place, so that the benefit of the structure can be separated from the natural tide range. Table 18 and Figure 19 compare the original and renewed gates. Marsh levels below the gate invert (0.86 m) in Table 18 reflect the model's starting condition: each run begins with the marsh at the first Sound level in the record, and the marsh then rises only when the Sound overtops the road crest (1.707 m).

These low-threshold values are therefore not interpreted as flood frequencies. Thresholds of 0.9 m and above reflect surge events and are unaffected.

For the original gate, the marsh level exceeded thresholds between 0.5 m and 0.8 m on approximately 204 days per year, and on those days the level remained above the threshold for the full 24 hours (Figure 19b). These elevations lie below the original invert of 0.8605 m. The gate cannot discharge below its invert, so water at these levels is retained in the marsh rather than flooded by the Sound; they are normal operating levels that the structure is not intended to block. Above the invert the exceedance frequency falls to essentially zero. By comparison, the unrestricted Sound level exceeds 1.0 m on roughly 200 days per year, 1.2 m on roughly 90 days per year, and 1.4 m on roughly 20 days per year (Figure 19a). The original gate therefore provided near-complete protection above its invert, with exceedances of 1.2 m or more of 0.07 days per year or less.

Table 18: Flood frequency above selected threshold elevations, original (pre-2026) and renewed (post-2026)

Threshold (m NAVD88)	Pre-2026 (days/yr)	Post-2026 (days/yr)	Reduction
0.0	281.6	0.71	99.7%
0.5	204.2	0.11	99.9%
0.8	204.2	0.04	99.98%
≥1.2	≤0.07	0	100%

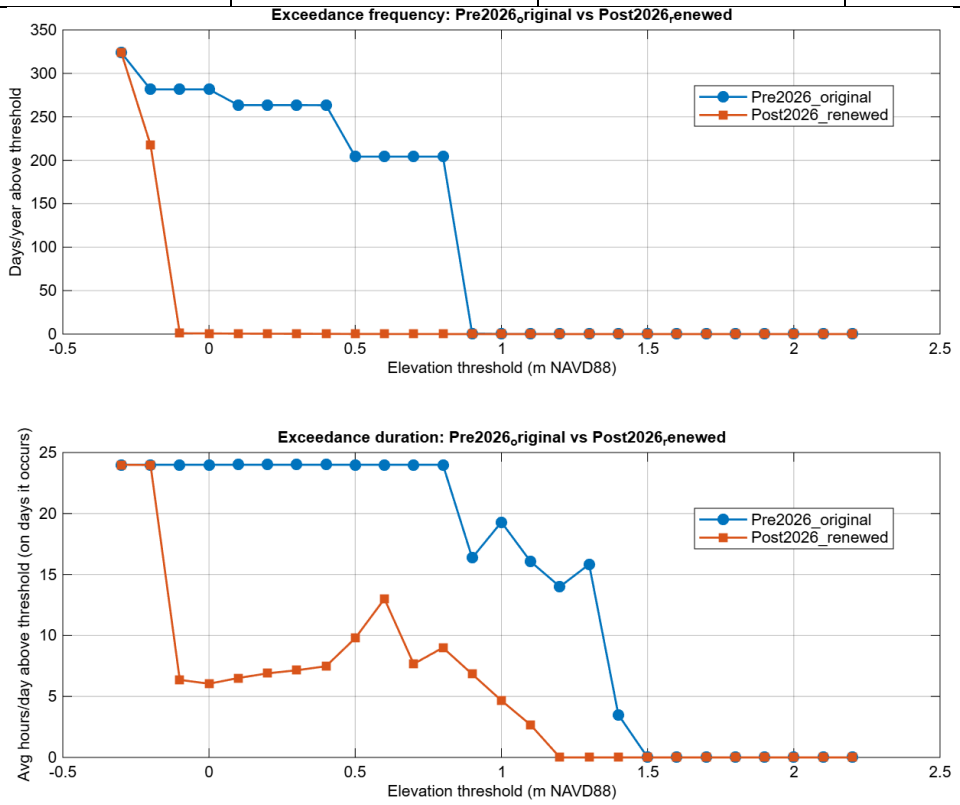


Figure 19: Exceedance of threshold elevations, gate removed (Sound record) versus original gate as built: (a) days per year above threshold; (b) average hours per day above threshold on days when the threshold is exceeded.

Sea Level Rise Sensitivity

The sensitivity of the marsh to SLR was evaluated by repeating the full 26.8-year simulation with a constant SLR offset added to the Sound record, in 0.05 m increments from 0 to 0.5 m, with the historical tide and storm signal otherwise unchanged. At each increment the highest simulated marsh level over the entire record was retained (the peak-over-record method). The upper end of the range corresponds to the 0.5 m by 2050 planning benchmark used for Connecticut. Results for both configurations are given in Table 19 and Figures 20 and 21.

Table 19: Peak simulated marsh level under SLR, original and renewed gate.

SLR (m)	Pre-2026 peak (m NAVD88)	Post-2026 peak (m NAVD88)	Reduction (m)
0.00	1.431	1.134	0.297
0.20	1.814	1.501	0.314
0.35	2.136	1.849	0.287
0.50	2.492	2.214	0.277

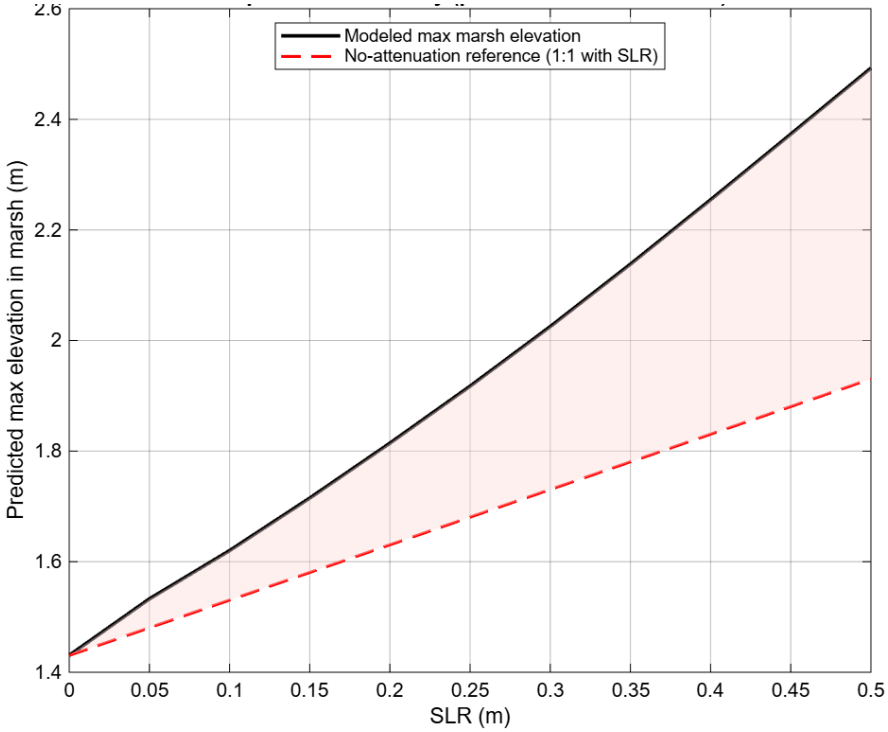


Figure 20: Peak simulated marsh elevation versus SLR, original gate (solid), compared with a reference line rising 1:1 with SLR (dashed).

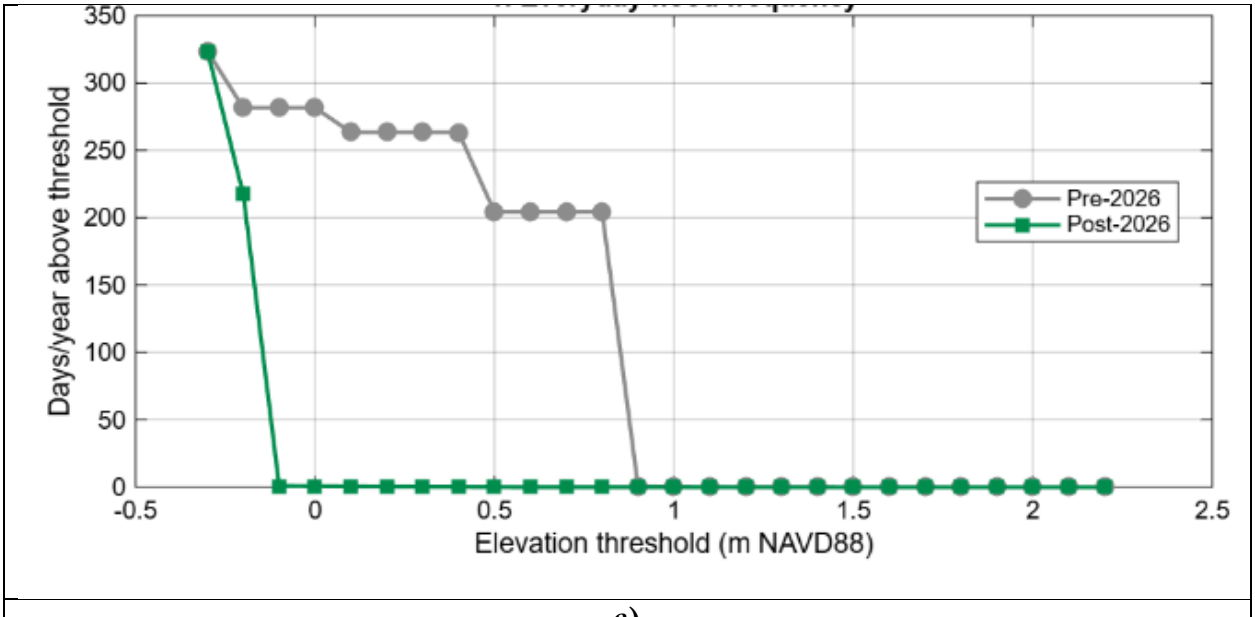
The protection afforded by the original gate decreases with SLR faster than the rise in the Sound. The simulated marsh peak rises from 1.431 m to 2.492 m over the 0.5 m SLR range, an increase of 1.06 m, or about 2.1 m of marsh peak for each meter of SLR, while the Sound peak rises one-for-one. The protection margin (Section 2.4.6) therefore falls from zero at present sea level to −0.56 m at 0.5 m of SLR: the marsh peak rises 0.56 m more than sea level itself. The peak attenuation, the

difference between the Sound peak and the marsh peak, decreases from 1.21 m at present sea level to about 0.65 m at 0.5 m of SLR. For the renewed gate the protection margin falls to −0.58 m at 0.5 m of SLR, and the peak attenuation decreases from 1.51 m to about 0.93 m.

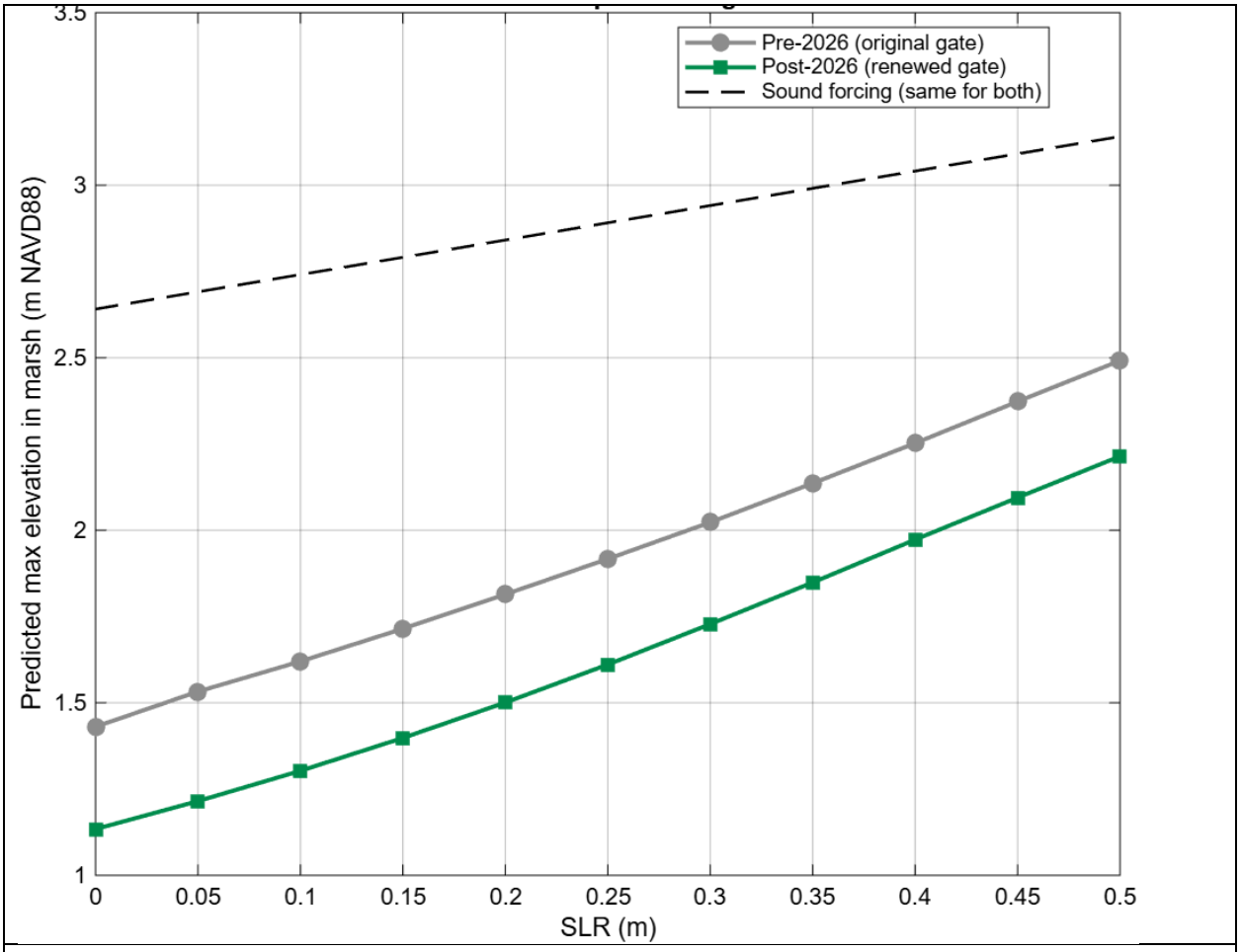
SLR raises not only the storm peaks in the Sound but also the daily low tide. A one-way flap gate can drain the marsh only when the marsh level is above the Sound level, so a higher low-tide level shortens and shallows the daily drainage window. Reduced drainage on each tidal cycle accumulates into a persistently higher marsh level, independent of any single storm.

For the original gate, the simulated marsh peak reaches the road crest (1.71 m) at an SLR of about 0.15 m and reaches the top of the gate opening (1.86 m) at about 0.22 m, both well within the 0.5 m benchmark for Sandy event. For the renewed gate, linear interpolation of Table 19 places these crossings at about 0.29 m and 0.35 m, respectively. The timing of these SLR values depends on the regional SLR curve adopted, but in either case they occur before the 0.5 m benchmark is reached.

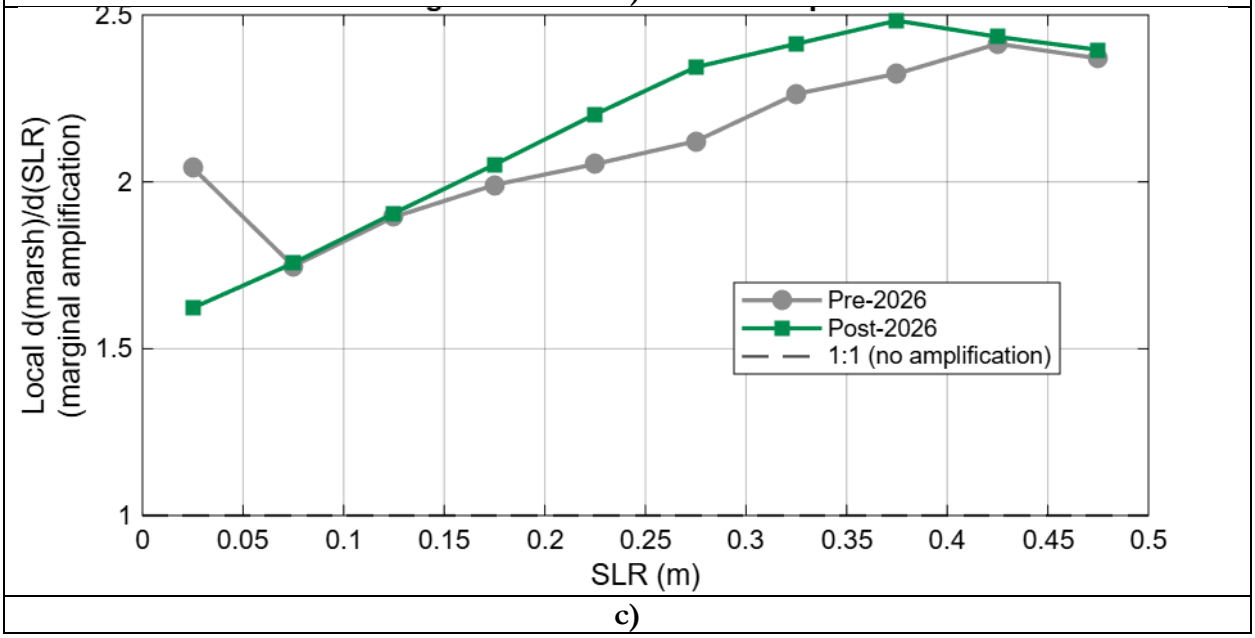
The local amplification factor, the additional marsh peak per additional unit of SLR, is shown for both configurations in Figure 21c. For the original gate it increases from roughly 1.9 near the road-crest crossing to roughly 2.4 at SLR of 0.4 m, and then levels off at about 2.4 between 0.4 m and 0.5 m. It is somewhat counterintuitive that the amplification factor does not decrease once the road crest and the gate opening top are exceeded, since both add flow capacity. The explanation is that the controlling constraint is not peak flow capacity but the length of time in each tidal cycle during which the flap can open at all. Additional capacity does not help while the drainage window is closing. This is the sense in which the term "choking" is used in this assessment: an increasing loss of protection with SLR, rather than a fixed reduction. These results support evaluating adaptation options for GF01 before overtopping is observed in the field.



a)



b)



c)

Figure 21: GF01 before and after the 2026 renewal: (a) flood frequency by threshold elevation; (b) peak marsh level versus SLR; (c) local amplification factor versus SLR

The renewed gate produces a lower peak marsh level than the original gate at every SLR increment, by a nearly constant 0.28 m to 0.32 m over the full 0 to 0.5 m range (Table 19). The benefit of renewal in marsh level therefore does not diminish under SLR within the range tested. The renewal does not, however, change the protection margin appreciably: the margins of the two gates differ by no more than 0.02 m at any increment (the renewed gate is slightly better up to about 0.25 m of SLR and slightly worse beyond about 0.3 m, reaching −0.58 m versus −0.56 m at 0.5 m of SLR), because the renewed gate's peak still rises about 2.2 m per meter of SLR. The renewal lowers the marsh peak by about 0.3 m at every SLR increment tested but does not slow its response to SLR.

The amplification factor results are less favorable and are reported as computed. At the lowest SLR increment (0 to 0.05 m) the renewed gate has the lower amplification factor (1.62 versus 2.04). From about 0.075 m to 0.4 m the renewed gate has a slightly higher factor, by 0.01 to 0.22, with the largest difference at 0.25 m to 0.375 m. At 0.45 m to 0.5 m the two are nearly identical. Averaged over the full range, the factor is 2.12 for the original gate and 2.16 for the renewed gate, which is essentially equal. The two findings are consistent: the renewed gate starts from a much lower marsh level and remains lower throughout, but its marsh level closes part of that difference slightly faster than the original gate's in the middle of the range. The cause has not been established. It may be related to the increased clearance between the renewed gate and the road crest, which delays the onset of the overtopping flow path, but this has not been confirmed.

The lower invert also means that the flaps can open over a considerably wider range of tide conditions than the original sluice gate could. Since the flap remains strictly one-way, the marsh can now drain more often and more completely whenever the marsh level exceeds the Sound level. More frequent drainage is generally favorable for marsh function, consistent with the tidal exchange considerations discussed for the original ecosystem analysis of GF01, but this has not been verified in the field. It is a hydrologic change introduced by the renewal in addition to the change in flood control, and it would be a reasonable starting hypothesis

Marsh and Ecosystem Assessment

Examined GF01 marsh area is given in Figure 22. GF01 received the highest Index of Marsh Integrity (IMI) score of the four case study sites (IMI =6.5, Figure 11). The marsh is primarily meadow high marsh with some large areas of open water. The remaining MarshRAM metrics are summarized in Table 20.

A formerly Phragmites-dominated area was mowed and has since transitioned to meadow high marsh (Figure 23). The treatment history beyond mowing has not been confirmed. With the new gate in place, monitoring should be continued to determine whether salt water continues to periodically inundate the high marsh. The low migration potential is relevant to the hydraulic results above. With little undeveloped upland available, the marsh has limited room to adjust landward as water levels rise, so the SLR response of the structure is a larger factor in the long-term condition of the marsh at GF01 than it would be at a site with greater migration potential.



Figure 22: Field area MarshRAM analysis done in GF01

Table 20: GF01 MarshRAM metrics

Metric	Score	Observations
Ecosystem Functions and Services	17 / 36	Part of a contiguous marsh platform supporting species such as saltmarsh sparrow.
Surrounding Land Use	8.0 / 10	Very low stress to the marsh; surrounded mostly by adjacent salt marsh or low-density residential land.
Wetland Disturbance	6.3 / 10	Upstream culvert under the railway bridge disconnects this marsh unit from those upstream; un-sewered surrounding development; moderate ditching intensity (188 m/ha).
Migration Potential	1.6 / 10	Minimal adjacent upland, and that upland is developed.

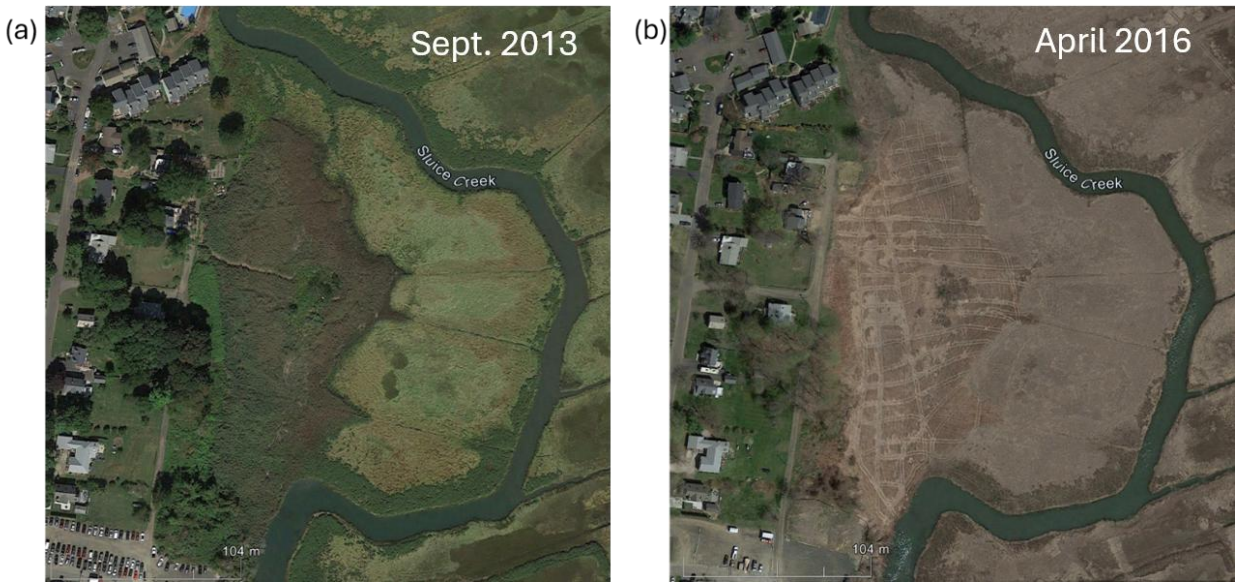


Figure 23: Marsh Area satellite image during a) Sept 2013 and b) April 2016 for GF01

3.3.2. East Haven (EH02), Farm River Open Channel and Hypothetical Culvert Scenario

EH02 is the former Meadow Street tide gate on the Farm River in East Haven. The gate was removed at a date that is not documented, and the site is now an open channel 8.84 m (29 ft) wide, although the remaining cobble abutments that once supported the gate still constrict the flow section. EH02 therefore differs from GF01 in that the assessment does not compare a gate against no gate (Figure 24, 25). Instead, two conditions are compared against each other: *i)* the existing open channel, which was calibrated against field water level data, and *ii)* a hypothetical reinstated two-way culvert 1.5 m wide at the same invert. The comparison is intended to show what the channel currently provides in terms of flood control and what a structure of this kind would change (Table 21). It is not a design proposal.

Table 21: EH02 channel and hypothetical culvert dimensions.

Parameter	Hypothetical Culvert	Open Channel
Hydraulic type	Orifice	Weir
Invert elevation	-1.2192 m NAVD88 (-4 ft)	
Width	1.5 m (placeholder)	8.84 m
Height	1.2 m (placeholder)	
Discharge coefficient (Cd)	0.65	0.2 (calibrated)

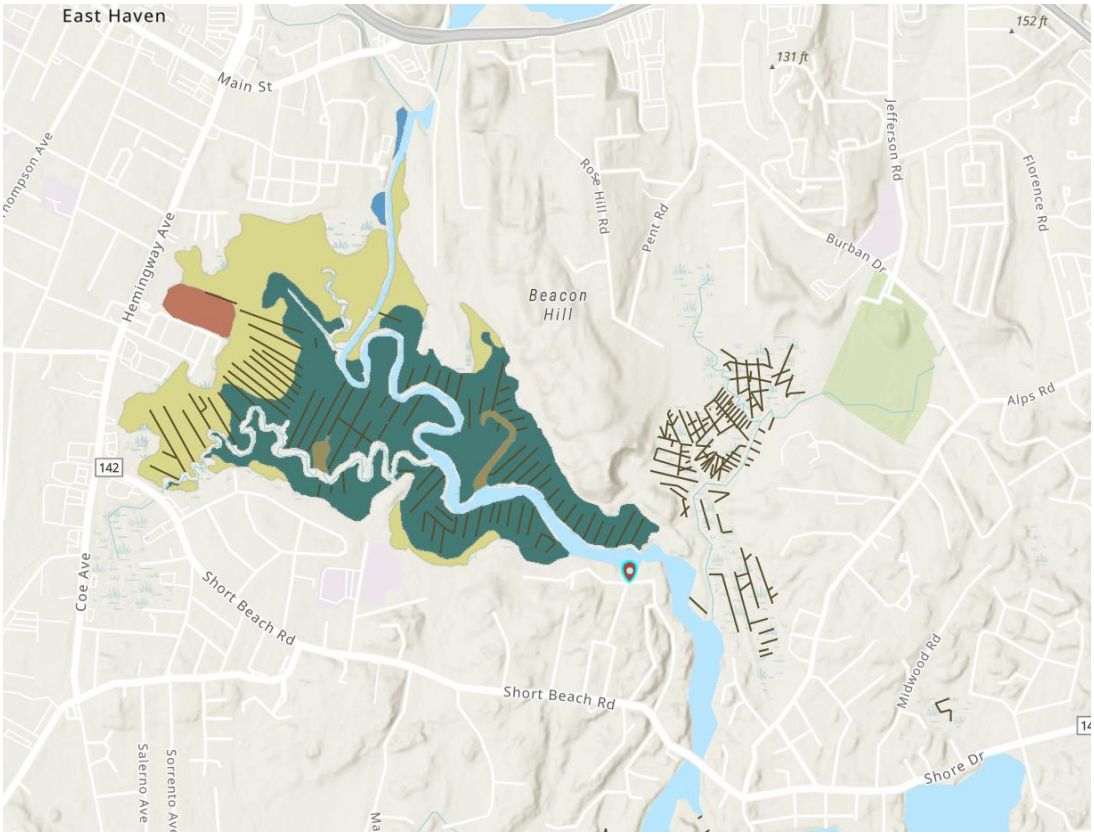


Figure 24: Location of EH02 marked with red pin shown screenshot from the Tide Gate Viewer. The immediate upstream colored area from NWI is considered for the marsh assessment.



Figure 25: EH02 existing condition

Marsh Storage Characteristics

The stage-storage relationship for the Farm River marsh was developed from the 2024 NWI marsh boundary and the project DEM (Figure 26). The marsh is considerably larger than at GF01 or NH01: the cumulative area curve flattens at approximately 6.6×10^5 m² (66 ha) above about 1.1 m NAVD88.

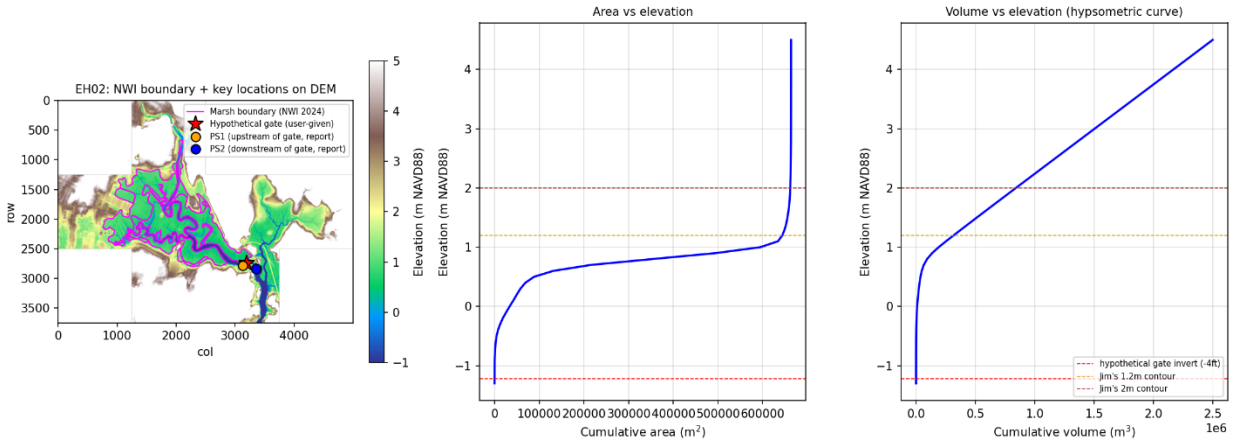


Figure 26: EH02 marsh boundary on the DEM, location of the hypothetical gate and sensors PS1 and PS2 (left), cumulative area versus elevation (center), and cumulative volume versus elevation (right).

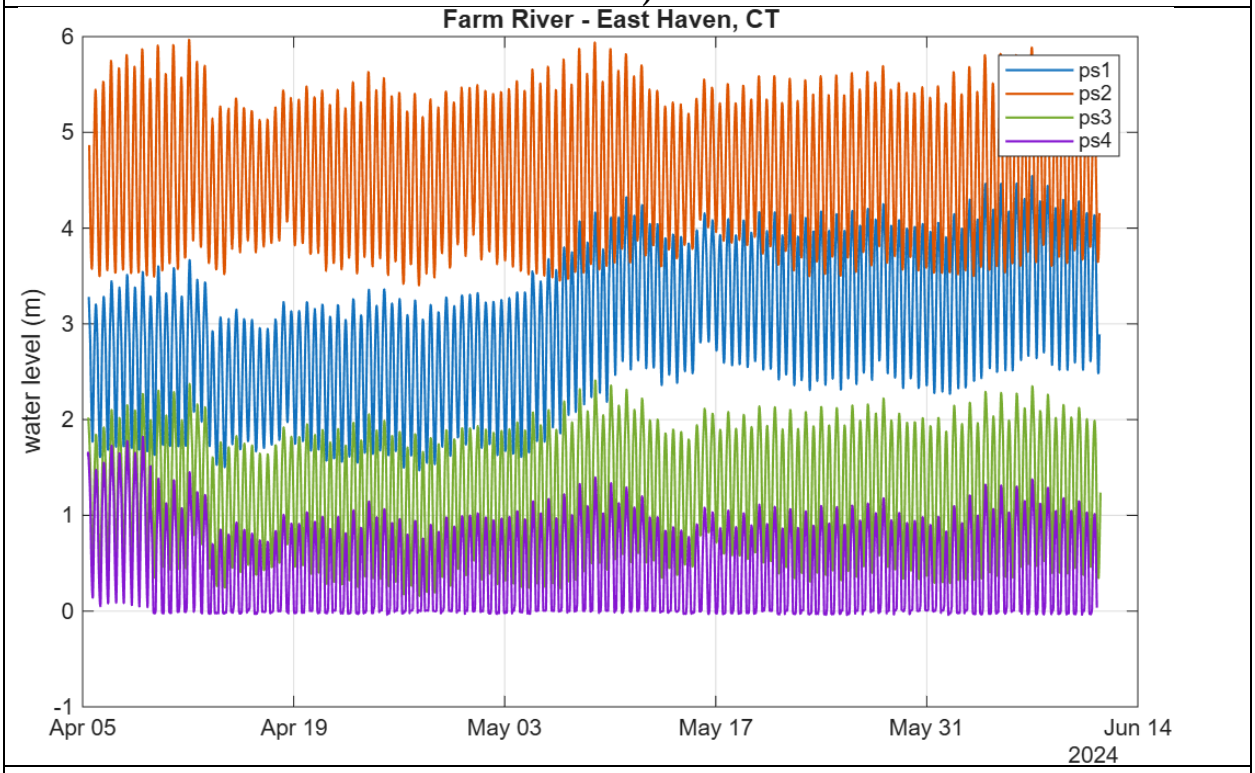
The area curve shows that the marsh surface is concentrated in a narrow elevation band. Below about −0.1 m the wetted area is less than 3×10^4 m² and corresponds to the main channel and its tributaries. Between 0.3 m and 1.1 m the cumulative area increases from about 5.8×10^4 m² to 6.3×10^5 m², so that roughly 90%of the marsh surface lies within 0.8 m of vertical range. Above 1.1 m the curve is nearly vertical. The cumulative volume at 1.1 m is about 2.5×10^5 m³, and above that elevation volume accumulates at about 6.6×10^4 m³ for each 0.1 m of stage. This shape governs the response of the marsh to a restriction at the gate. A tide that rises to 1.1 m must supply about 2.5×10^5 m³ to fill the basin to that level, whereas the tide range at the Sound is approximately 2 m. A narrow opening cannot pass this volume within a single flood tide, so the marsh will only partially fill. With an open 8.84 m channel the same volume can be passed in a few hours.

Model Calibration Against Field Data

EH02 is the only site for which the model could be calibrated against measured water levels. A Solinst Levelogger pressure sensor (PS1) was deployed by the Farm River observation program (O'Donnell et al. 2017) essentially at the former gate location, within about 40 m of the coordinates used in the model, from April 5 to June 11, 2024 (Figure 27). The recorded timestamps were in local time (EDT), while the NOAA New Haven record used for forcing is in GMT. The resulting four-hour offset initially produced an apparent lag between the marsh and the Sound that was not real, and the sensor series was corrected before calibration.



a)

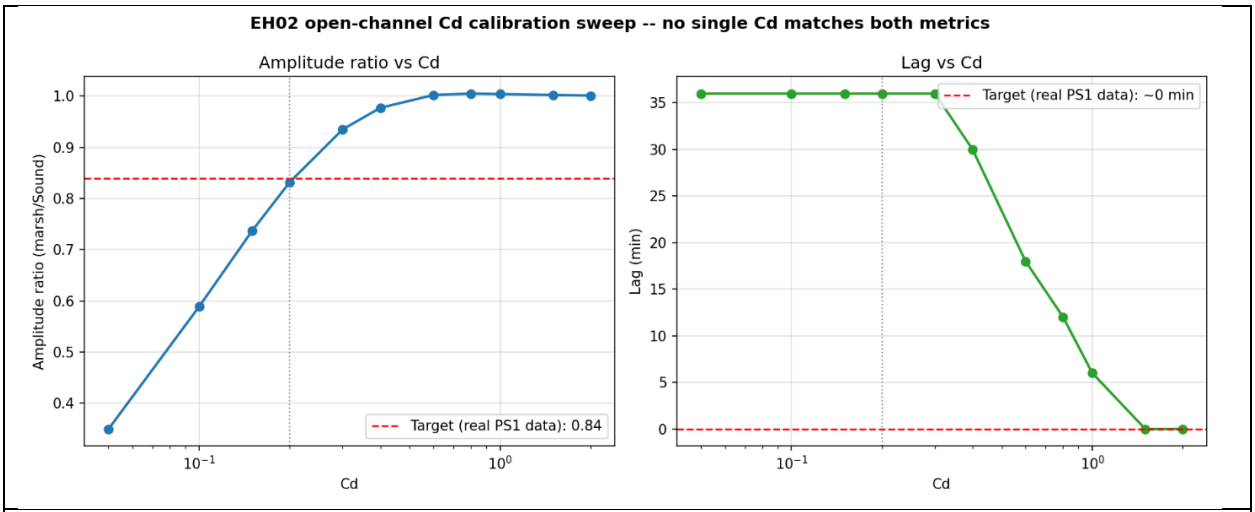


b)

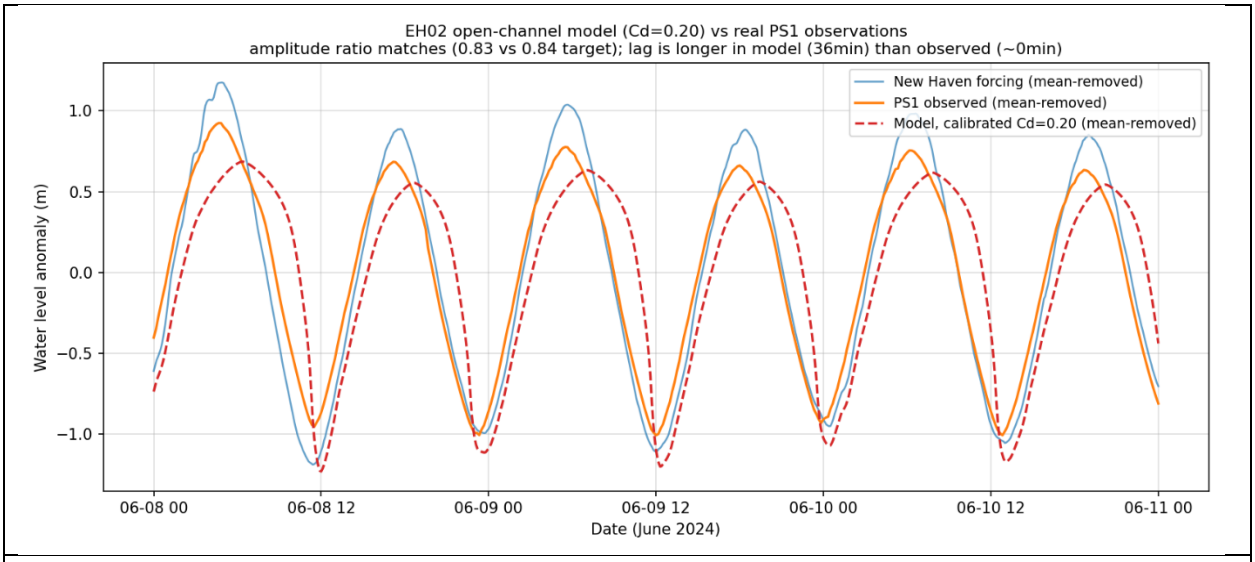
Figure 27: a) Water logger locations and b) Observed (PS1) versus modeled marsh water level, calibration window June 8-11, 2024

A clean window from June 8 to 11, 2024 was used as the calibration target (Figure 27b). the modeled marsh level reproduces the observed tidal amplitude (standard-deviation ratio 1.00) and attenuates the Sound signal to about 0.86 of its range, matching the logger. Using the fitted sensor elevation, the root-mean-square error is 0.36 m with correlation 0.81 when compared at the same time stamps. Most of that error is timing: the modeled high water lags the observed high water by about 60–90 minutes, and when the model is shifted by about 66 minutes the RMSE falls to 0.14 m and the correlation rises to 0.97. Bias is not reported separately because the sensor offset was fitted rather than independently surveyed [replace if elevation is available]. The open-channel coefficient (Cd = 0.20) is therefore an effective lumped coefficient that absorbs friction, contraction, the cobble-abutment constriction, unresolved storage and inertia, and errors in the DEM-derived width. It is tuned to reproduce amplitude, not to represent physical roughness. The calibration covers ordinary tides only (Sound peak about 1.36 m NAVD88 in the window). The surge analysis (Sound above about 2.6 m) is an extrapolation beyond the calibrated range.

The calibrated Cd = 0.20 is well below the 0.5–0.65 typically used for an open crest or gate opening (and used for the other sites in this report). It should be read as an effective, lumped coefficient: it absorbs friction and contraction in the channel, the constriction at the cobble abutments, and storage and inertia effects that the lumped model does not resolve, as well as any error in the surveyed width and the DEM-derived storage curve. The calibration covers four days of ordinary tides, with the Sound peaking at [x.x] m. The surge analysis, in which the Sound exceeds 2.6 m, applies the same Cd at stages well outside the calibrated range and is therefore an extrapolation. Results at high stage should be treated as indicative. Because the exceedance and SLR analyses depend on peak levels more than on timing, the slower modeled response is not expected to change multi-hour surge peaks, but it would, if anything, under-predict short-duration peaks.



a)

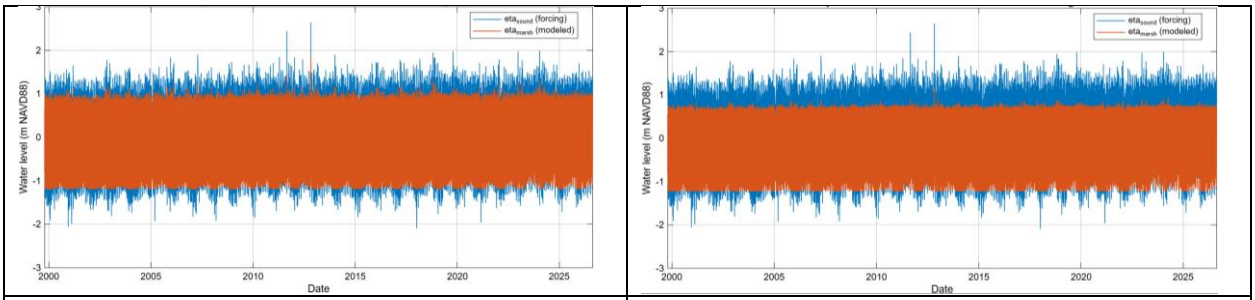


b)

Figure 28: a) EH02 amplitude vs Cd ration (left) and lag vs Cd (left), b)the calibrated Cd=0.2 compared to PS1 and New Haven Tidal Data

Simulated Marsh Water Levels

Marsh water levels were simulated for the 26.8-year record with the mass balance described in Section 2.2 for both the open channel and the hypothetical culvert (Figure 29). For the open channel, the simulated marsh level follows the Sound closely (r = 0.895) and fills nearly the full tidal range, with a maximum simulated level of 1.88 m NAVD88 at the baseline sea level. The marsh peak is lower than the Sound peak, which reached approximately 2.6 m during Superstorm Sandy, even though the channel is open. This is the effect of the finite channel section and the marsh storage described above: during a short-duration surge the channel does not pass enough volume to bring the marsh up to the Sound level.



a) **b)**

Figure 29: Simulated marsh water level (orange) and Sound water level (blue), 1999 to present, for (a) the existing open channel and (b) the hypothetical 1.5 m culvert.

For the hypothetical culvert, the simulated marsh range is clearly narrower. Marsh high water is truncated at about 0.8 m on most tides, the low water level is raised above the Sound's low water, and the maximum simulated level is 1.18 m NAVD88, which is 0.70 m below the maximum for the open channel. The correlation with the Sound decreases to 0.797. Because the culvert is two-way, the

marsh still follows the Sound on both the rising and falling limb, and the change relative to the open channel is one of degree. This differs from the GF01 flap gate, which decouples the marsh from the Sound (r = 0.055) on the rising limb.

Flooding Frequency

The exceedance statistics were computed in the same way as for GF01, for threshold elevations between −0.5 m and 2.0 m NAVD88 (Table 22 and Figures 30). At the lowest thresholds, the marsh is above the threshold on all 365 days of the year for both conditions, which reflects the marsh being tidal at all stages. The two conditions separate above about 0.5 m.

Table 22: Flood frequency above selected threshold elevations, EH02 open channel and hypothetical culvert.

Threshold (m NAVD88)	Open channel (days/yr)	Hypothetical culvert (days/yr)	Reduction
0.7	326.0	87.3	73%
0.8	252.6	3.0	99%
0.9	112.0	0.22	99.8%
1.0	17.4	0.07	99.6%
≥1.2	Nonzero to 1.8 m	0	100%

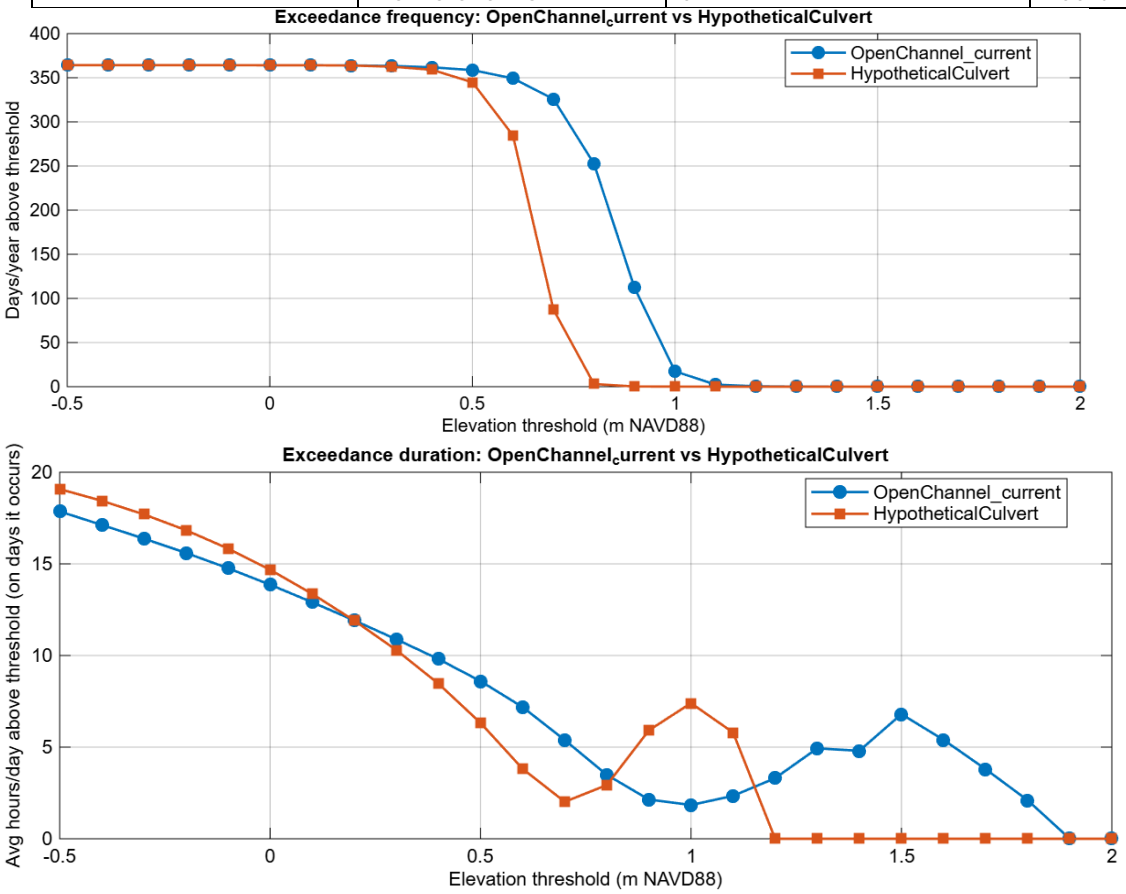


Figure 30: (above) EH02 exceedance frequency (days per year above threshold), open channel versus hypothetical culvert and (below) EH02 exceedance duration (average hours per day above threshold on days when exceeded), open channel versus hypothetical culvert.

For the open channel, the marsh exceeds 0.8 m on about 253 days per year and 0.9 m on about 112 days per year. The frequency decreases to 17 days per year at 1.0 m, and the channel does not fully eliminate exceedance until the threshold approaches 1.8 m. For a marsh that is directly open to the Sound, these values represent the normal spring high tide range (MHHW and MHW) rather than abnormal flooding. Their significance depends on the elevation of the adjacent structures, roads, and yards, which has not been included in this assessment.

The culvert reduces the frequency of exceedance for every threshold above about 0.6 m. Exceedance of 0.8 m is reduced from 253 to 3 days per year, and exceedance of 1.0 m from 17 to 0.07 days per year. No exceedance occurs at or above 1.2 m. The direction of this result does not depend on the uncalibrated culvert discharge coefficient or the placeholder opening height, because a narrower opening passes less flow for any head and will always reduce the volume delivered to the marsh in a given tide. The numerical values should be regarded as provisional until the culvert dimensions are defined. The duration statistics show a secondary effect that is relevant for planning. In the range of 0.9 m to 1.1 m, the average number of hours per day above the threshold, on days when it is exceeded, is longer for the culvert (up to 7.4 hours at 1.0 m) than for the open channel (1.8 to 2.3 hours). This is the expected behavior of a restricted opening, which drains more slowly after a high tide. Although these events are much rarer for the culvert, the stage that the marsh does reach persists longer.

Sea Level Rise Sensitivity

The SLR sensitivity was evaluated with the peak-over-record method described in Section 2.2, with SLR increments from 0 to 0.5 m for both conditions (Table 23 and Figures 31). For EH02 the protection margin is calculated as defined in Section 2.4.6. A positive margin indicates that the marsh peak rises more slowly than sea level, and a negative margin indicates that it rises faster.

For the open channel, the peak marsh level rises from 1.88 m to 2.44 m over the 0.5 m SLR range, an increase of 0.56 m. The marsh therefore rises slightly faster than sea level, and the margin is −0.06 m at 0.5 m of SLR. The local amplification factor (Figure 31 below) increases from 1.04 at the lowest increment to a maximum of about 1.16 at approximately 0.33 m of SLR and then eases slightly to about 1.15 at 0.5 m. The channel therefore passes sea-level rise at almost the same level, and the SLR response is dominated by the tidal signal itself and not by the structure.

For the culvert, the peak rises from 1.18 m to 1.42 m, an increase of 0.24 m for 0.5 m of SLR. The margin is positive at every increment and reaches 0.26 m at 0.5 m of SLR. The local amplification factor is well below 1.0 throughout, increasing from 0.37 at the lowest increment to 0.61 at 0.5 m (Figure 31). Unlike the open channel, the culvert curve does not level off over the range tested. The culvert continues to attenuate the peak but by progressively less per unit of SLR; extrapolation suggests the margin stops growing near 1.2 m. A linear extrapolation of the trend gives an SLR of approximately 1.2 m, which is well beyond the 0.5 m benchmark but is a long-term limitation of any fixed opening. The mechanism is similar to the one at GF01, but it operates much more slowly because the culvert is two-way and the drainage window does not close.

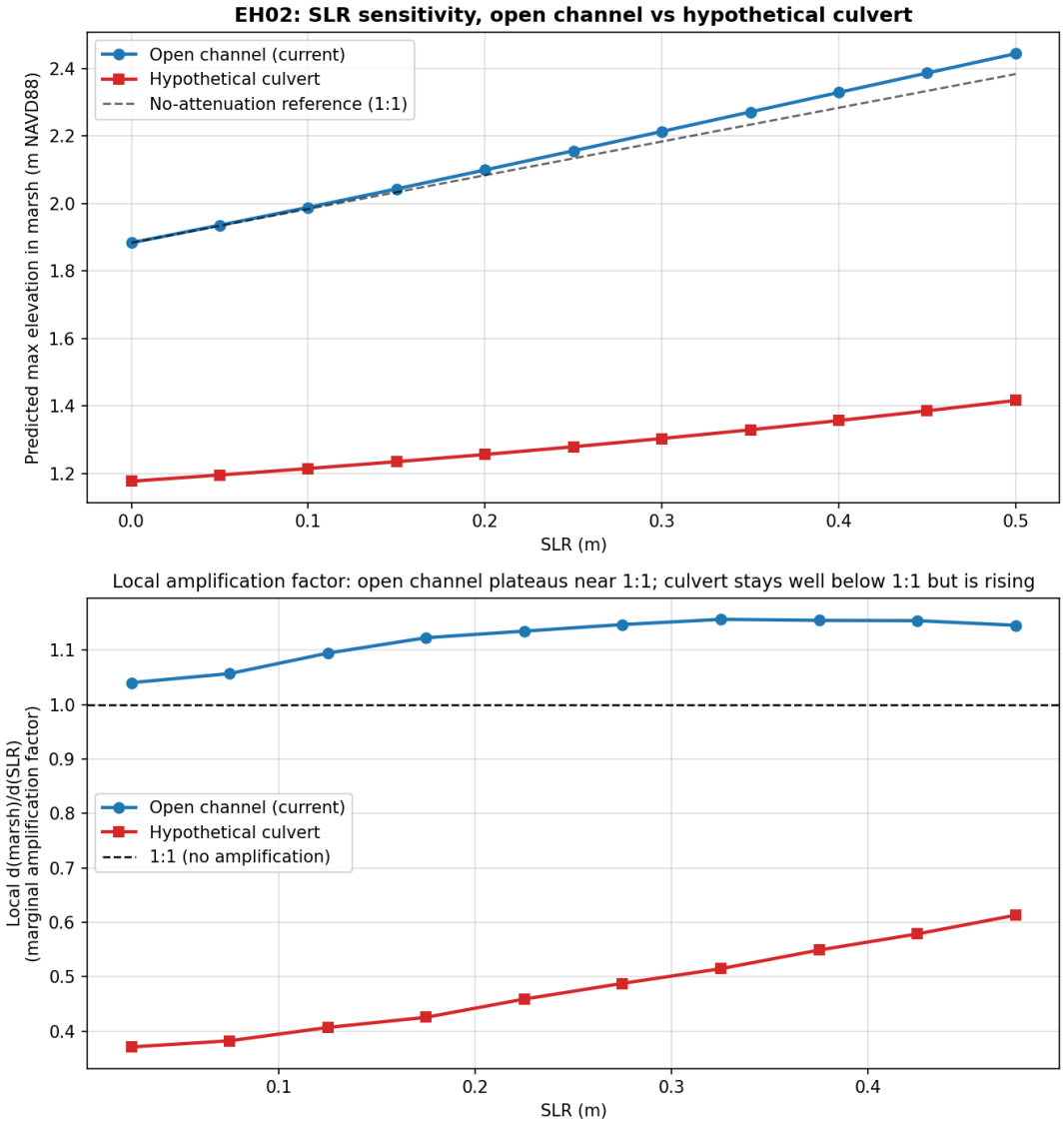


Figure 31: EH02 open channel (blue), and hypothetical culvert (red) peak marsh elevation versus SLR (dashed) compared with a reference rising 1:1 with SLR (dashed) (above) and local amplification (below).

Table 23: Peak simulated marsh level and protection margin under SLR, EH02.

SLR (m)	Open channel peak (m NAVD88)	Open channel margin (m)	Culvert peak (m NAVD88)	Culvert margin (m)
0.00	1.88	0.000	1.18	0.000
0.10	1.99	−0.005	1.21	0.062
0.20	2.10	−0.016	1.26	0.121
0.30	2.21	−0.030	1.30	0.173
0.40	2.33	−0.045	1.36	0.220
0.50	2.44	−0.060	1.42	0.261

Marsh and Ecosystem Assessment

EH02 received an intermediate Index of Marsh Integrity (IMI) score of 6.1, which is influenced by the dominance of low marsh vegetation. The marsh was tide-gated for approximately 150 years before the gate deteriorated. The present vegetation and elevation are most likely the result of subsidence during the period of restriction, followed by re-flooding after tidal flow was restored. Sediment studies are recommended to confirm this. The remaining MarshRAM metrics are summarized in Table 24.

The ecological and hydraulic results are consistent. The marsh currently has near-full tidal exchange (Section 3.2.2.2), which is the condition under which it is recovering from the long period of restriction, and the lowest MarshRAM score (Wetland Disturbance, 5.6) is attributed to the legacy of that restriction and not to a current stressor. A reinstated structure would again restrict flow to a marsh that is still adjusting to the earlier restriction, and the sizing sweep recommended in Section 3.2.2.7 should therefore be coordinated with the sediment studies.

Table 24: EH02 MarshRAM metrics

Metric	Score	Observations
Ecosystem Functions and Services	16 / 36	East Haven Marsh Wildlife Area, part of a habitat complex. Many waterfowl were observed directly using the marsh.
Surrounding Land Use	8.3 / 10	Very low stress to the marsh; surrounded mostly by adjacent salt marsh habitat or low-density residential land.
Wetland Disturbance	5.6 / 10	Evidence of vegetation and elevation change due to prior tidal restriction.
Migration Potential	2.5 / 10	Most of the surrounding upland is higher elevation than the +20" MHHW SLR projection

3.3.3. New Haven (NH01), West River Multi-Gate Structure

NH01 is a 12-gate structure about 25.6 m (84 ft) long in New Haven (Figure 32), discharging to the West River marsh. The gates are of three types operating in parallel: one always-open gate with no closing mechanism, three self-regulating tide gates (SRT; circular 1.0 m diameter, buoyant, float-operated), and eight one-way flap gates (1.5 m × 1.5 m) (Figure 33). All twelve gates are assumed to sit on a common sill at −0.719 m NAVD88 (Figure 34). The openings are therefore at different heights: the SRT crown is at 0.281 m, and the flap and always-open openings are topped at 0.781 m. For the model the 12 gates were aggregated into three flow paths (SRT ×3, flap ×8, always-open ×1). The LiDAR does not include the bridge deck and abutments, and a flood-fill of the bare-earth DEM would therefore treat the structure as open.

Marsh Storage Characteristics

The NH01 marsh is smaller than at EH02, with a total mapped area of about 1.7×10^5 m² (17 ha). As at the other sites, the area curve is nearly horizontal over a short elevation range: the cumulative

area increases from about 1.9×10^4 m² at 0.3 m to 1.3×10^5 m² at 0.7 m, and then to 1.7×10^5 m² by 1.1 m. Almost all of the marsh surface is therefore between the SRT crown (0.28 m) and 1.1 m NAVD88, which overlaps the range of the flap and always-open openings (top at 0.78 m). The stored volume to 1.1 m is about 9.6×10^4 m³ and increases by about 1.7×10^4 m³ for each 0.1 m above that elevation (Figure 35).

Because the marsh platform is so close to the elevation of the openings, small differences in how the gates operate at stages near 0.3 to 0.8 m will affect large areas of marsh. This is the range in which the always-open gate exerts its influence.

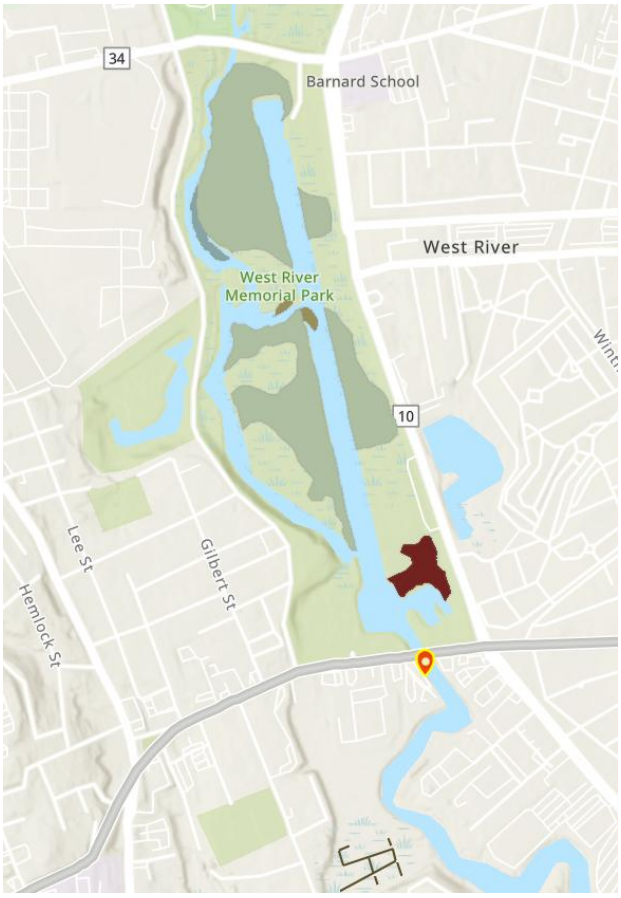


Figure 32: Location of NH01 marked with red pin shown screenshot from the Tide Gate Viewer. The immediate upstream colored area from NWI is considered for the marsh assessment.



Figure 33: NH01 tide gate structure with 3 SRT, 8 flaps and 1 always open gate

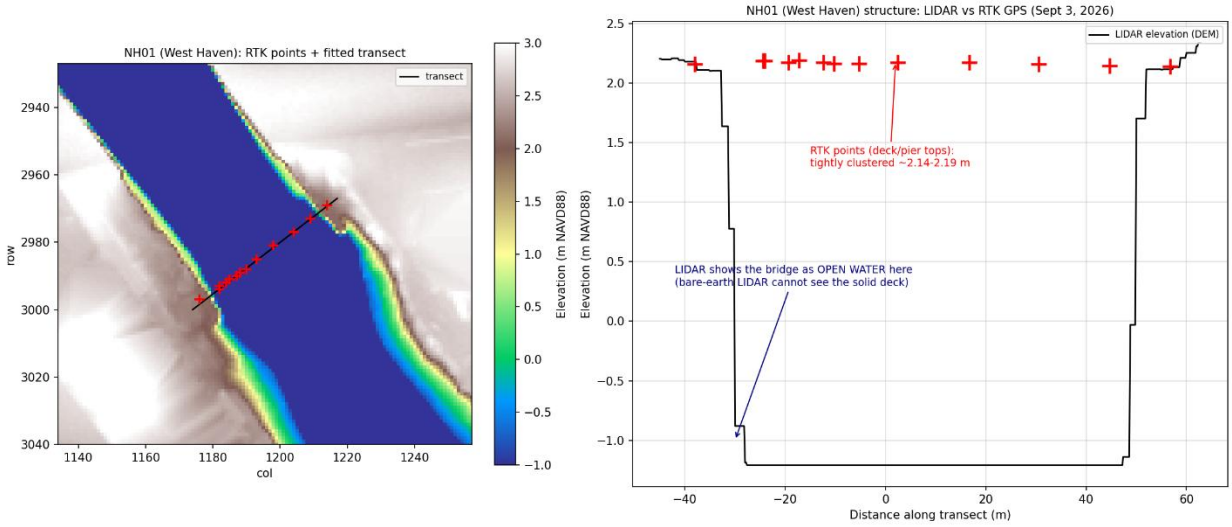


Figure 34: RTK measurement locations New Haven, Sept 3, 2026 – the NH01 channel cross section over the LIDAR Measurements.

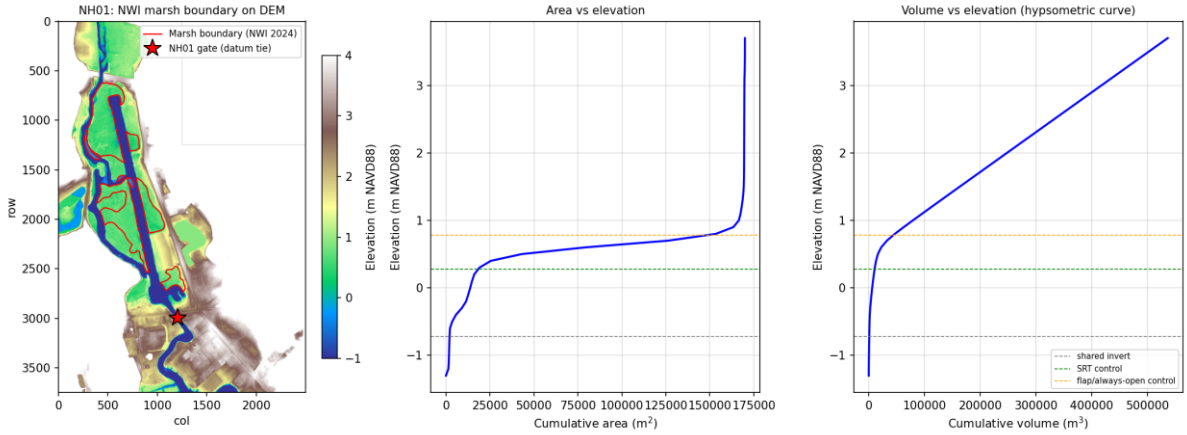


Figure 35: NH01 marsh boundary on the DEM (left), cumulative area versus elevation (center), and cumulative volume versus elevation (right). Dashed lines mark the shared sill (−0.72 m), the SRT crown (0.28 m), and the flap/always-open top (0.78 m).

Gate Operation and Field Checks

Two field observations were used to check the gate rules in the model. Photographs taken on June 25, 2026 at about 10:49 local time showed the SRT gates still open with the culvert fully submerged. The New Haven tide record at that time was 0.349 m NAVD88, which is 1.07 m above the sill. A second set of observations, during the RTK survey on September 3, 2026 at about 16:26 to 16:34 (Figure 36), again found the SRT gates open, at a tide of 1.232 m NAVD88 (1.95 m above the sill) that was an ordinary tide and not a storm. The SRT closure level could not be observed directly. The second visit gives a lower bound of about 1.95 m above the sill (1.23 m NAVD88), and the model uses 2.1 m above the sill (1.38 m NAVD88). This is consistent with the manufacturer's literature, which notes that some SRT installations are set to close only for extreme events and not on routine tides. In the June visit all eight flap gates were also observed to be closed, with the exception of the always-open gate, which is consistent with the flap rule in the model.

The discharge coefficient, Cd, for the tide gates are assumed to be 0.7 for always open gate, 0.65 for the flaps and 0.5 for the SRTs.



Figure 36: Sept 3rd, 2026 NH01 visit SRT positions.

Simulated Marsh Water Levels

Figure 37 shows the combination of the simulated marsh and sound levels for NH01. Over the 26.8-year record the simulated marsh closely follows the Sound at low and moderate stages, because the always-open gate passes flow in both directions at any stage up to its top (0.78 m NAVD88) regardless of the state of the other eleven gates. The additional gates only affect the marsh level when the Sound exceeds this elevation. Above that level the flap gates close on the flood tide and the SRTs remain open until the Sound reaches the closure level, and the marsh peak is increasingly limited relative to the Sound.

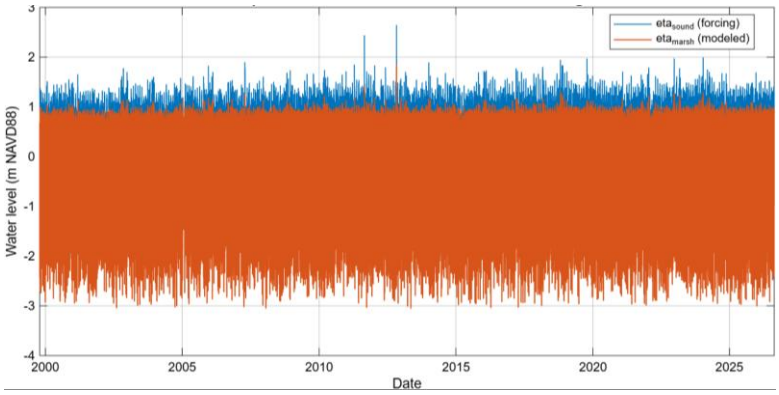


Figure 37: Simulated marsh and Sound water levels, NH01, 1999 to present

Flooding Frequency

The exceedance results show a protection profile that is different from the other sites. In the as-modeled structure, the marsh floods at essentially the same frequency as the unrestricted Sound for all thresholds up to about 0.6 m (Table 25, Figure 38). The protection factor (the ratio of unrestricted to restricted days per year) is between 0.997 and 1.00 for thresholds from −0.5 m to 0.5 m, indicating no protection, and rises only slowly above that: 1.00 at 0.6 m, 1.02 at 0.7 m, 1.10 at 0.8 m, 1.38 at 0.9 m, 2.2 at 1.0 m and 5.3 at 1.1 m. At 0.9 m, for example, the marsh is above the threshold on about 192 days per year, compared with 265 days per year for the unrestricted Sound. Strong protection appears only at about 1.2 m and above (protection factor 46 at 1.2 m), where the restricted marsh exceeds the threshold on fewer than two days per year. At 1.3 m and above the restricted case exceeds the threshold on eight days or fewer in the 26.9-year record, so the protection factors there (about 150 to 260 at 1.3 m to 1.5 m) indicate strong protection but are not well constrained numerically and are not interpreted further. The onset of protection at about 0.7 m to 0.8 m coincides with the top of the always-open gate (0.78 m NAVD88). The physical reasoning is that, below this elevation, water can always pass through this one gate in both directions, and the behavior of the SRTs and flaps does not control the marsh level. To test this directly, the model was re-run with the always-open gate removed, as a modeling exercise only and not as a proposed change (Figure 39). At thresholds below about 0.6 m, the marsh is above the threshold on essentially every day with and without the gate. From 0.7 m to 0.9 m the results diverge strongly: at 0.8 m the marsh exceeds the threshold on about 281 days per year with the gate in place and about 138 without it, and at 0.9 m on about 192 days per year with the gate and about 5 without it. At 1.0 m and above the 11-gate system almost never exceeds the threshold (0.19 days per year at 1.0 m). The gate also controls the extreme end of the range at present sea level: the maximum simulated marsh level is 1.86 m with all twelve gates and 1.14 m without the always-open gate. The always-open gate is therefore the dominant source of routine exchange at NH01 and also what allows the marsh to rise as high as it does during large events, while the other eleven gates limit the marsh only at the most extreme end of the range

Table 25: NH01 protection factor (unrestricted/restricted days per year above threshold)

Threshold (m)	Protection factor	Interpretation
0.0 to 0.7	~1.00-1.02	Essentially NO protection - restricted and unrestricted cases nearly identical
0.8	1.10	Slight protection
0.9	1.38	Protection strengthens
1.0	2.16	Strong protection
1.1	5.34	Near-complete protection

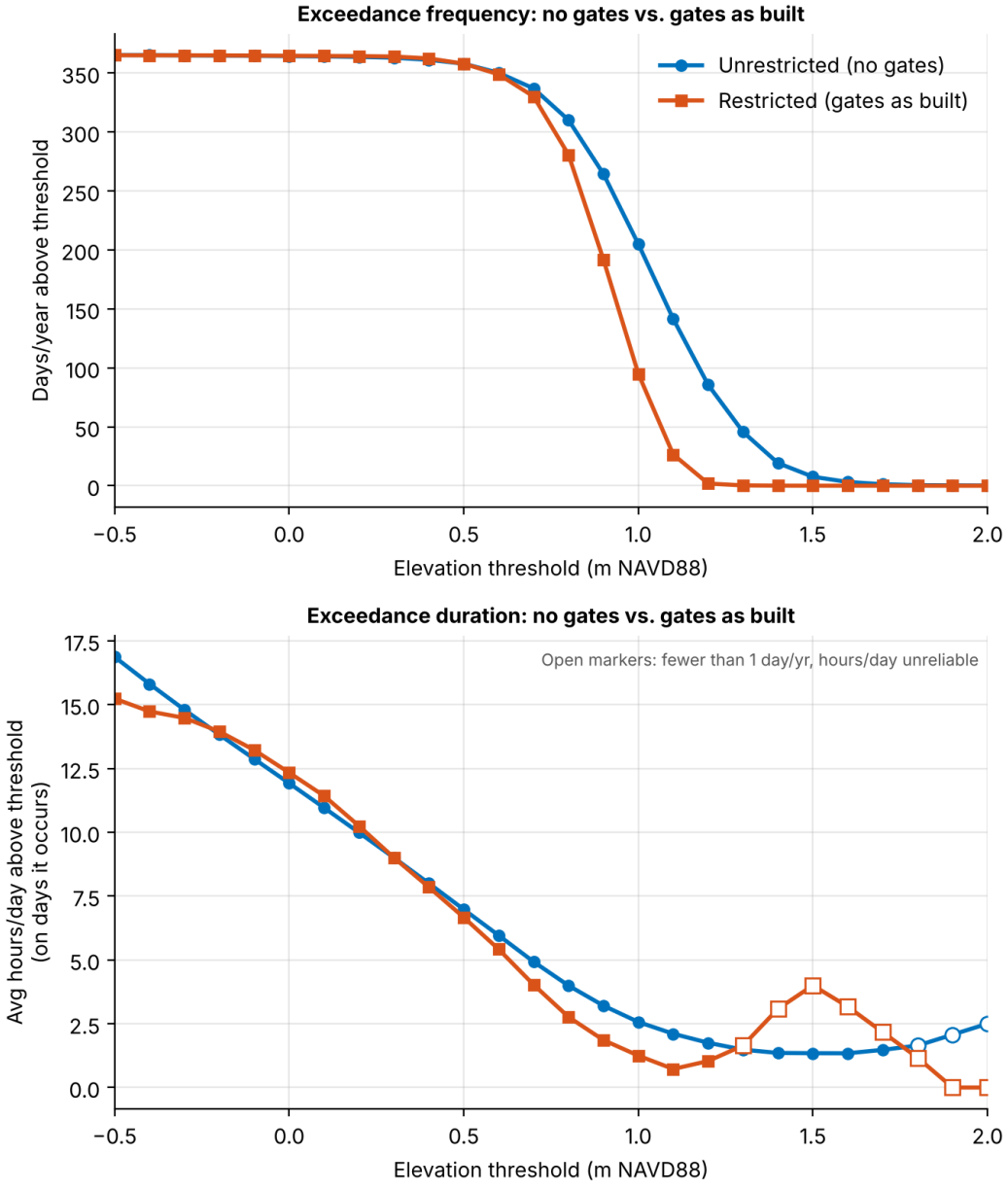


Figure 38: (above) NH01 exceedance frequency (days per year above threshold), restricted vs unrestricted (no gates) and (below) NH01 exceedance duration (average hours per day above threshold on days when exceeded)

Sea Level Rise Sensitivity

Figure 40 and Table 26 show the response of the peak marsh level to 0 to 0.5 m of sea level rise. For the full 12-gate system the simulated marsh peak rises from 1.864 m to 2.339 m, an increase of 0.47 m, or about 0.95 m of marsh peak for each meter of SLR. The local amplification factor (the slope of the marsh peak between consecutive SLR increments) is between 0.77 and 1.01 at every increment and does not exceed 1.0. The protection margin (Section 2.4.6), the SLR increment minus

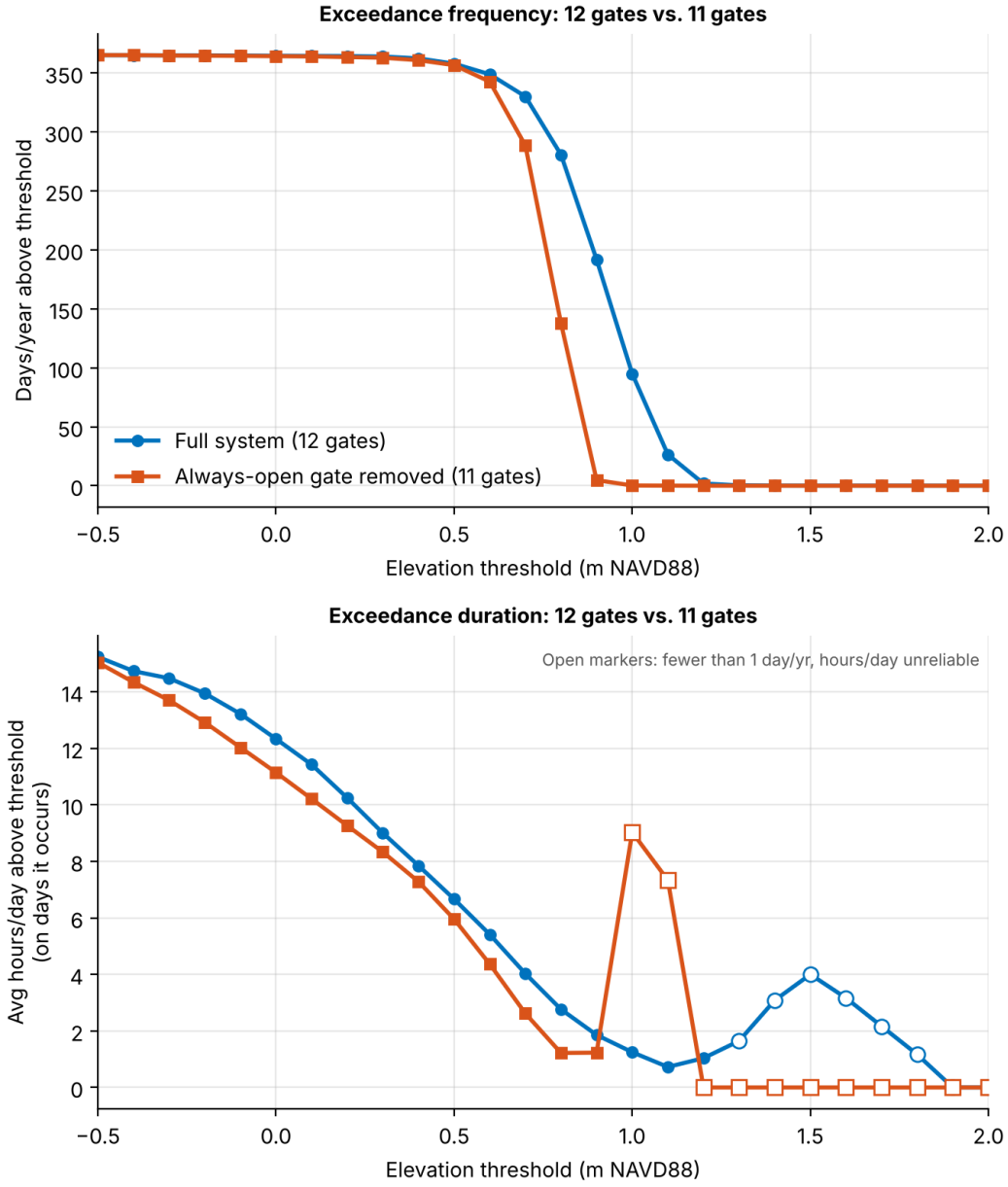


Figure 39: (above) NH01 exceedance frequency (days per year above threshold), full system and with the always-open gate eliminated (11 gates), and (below) NH01 exceedance duration (average hours per day above threshold on days when exceeded). Open markers indicate thresholds exceeded on fewer than one day per year, where the average duration is based on only a few events and is unreliable.

the increase in the modeled marsh peak, is small: +0.003 m at 0.05 m of SLR, rising to +0.025 m from 0.35 m of SLR onward. The structure therefore removes only a few centimeters of the sea level rise at the peak, and the marsh peak keeps a nearly fixed offset of about 0.8 m below the Sound peak (0.78 m at present sea level and 0.80 m at 0.5 m of SLR). At NH01, the marsh peak tracks the Sound under SLR, and the structure neither accelerates the response nor attenuates it appreciably. This is the behavior expected from the always-open gate, which passes flow in both directions regardless of the

other eleven gates. In the isolation test with the always-open gate removed (a modeling exercise only), the response is different. The marsh peak rises with SLR at about 0.95 m per meter up to 0.2 m of SLR, from 1.144 m to 1.332 m, and then stops rising: for 0.2 m of SLR and above it remains at about 1.33 m, and the protection margin grows to 0.31 m at 0.5 m of SLR. The plateau lies just below the SRT closure level assumed in the model (1.38 m NAVD88), above which the SRTs lock shut and, without the always-open gate, no path remains to the marsh. Its elevation therefore depends on that unconfirmed assumption. The always-open gate is thus also the reason NH01 offers little protection against SLR, and removing or narrowing it would trade routine tidal exchange for a large reduction in the SLR response.

Table 26: NH01 peak marsh level, protection margin and local amplification under SLR, full system and with the always-open gate removed (m NAVD88 for levels; m for margin)

SLR (m)	Sound peak	Full: marsh peak	Full: amplification	Full: margin	11 gates: marsh peak	11 gates: amplification	11 gates: margin
0.00	2.641	1.864	–	0.000	1.144	–	0.000
0.10	2.741	1.961	0.99	0.004	1.240	0.96	0.004
0.20	2.841	2.056	0.94	0.008	1.332	0.87	0.012
0.30	2.941	2.143	0.97	0.022	1.332	0.01	0.112
0.40	3.041	2.239	1.01	0.025	1.332	0.01	0.212
0.50	3.141	2.339	1.00	0.025	1.333	0.01	0.311

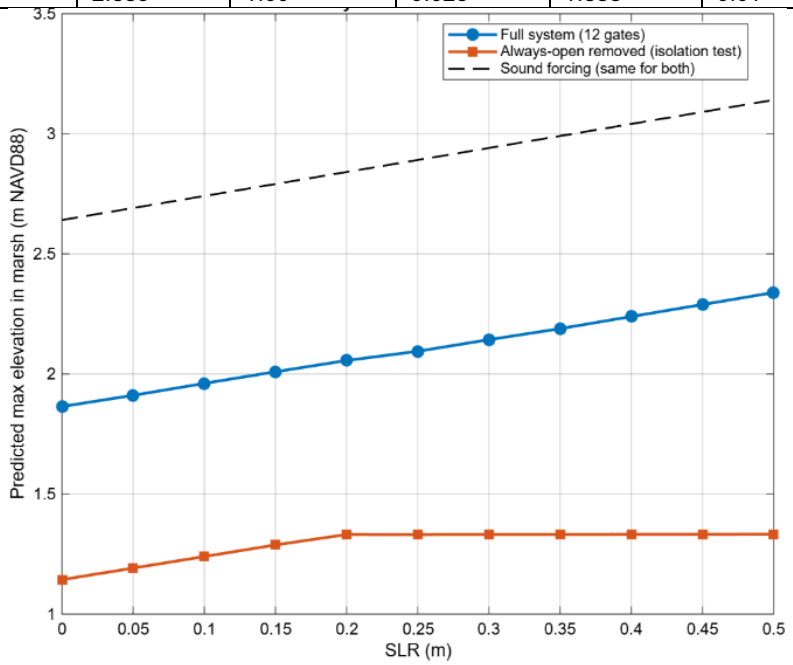


Figure 40: NH01 full system vs 11 gate system (red) SLR sensitivity comparison

Marsh and Ecosystem Assessment

NH01 received a very low IMI score of 3.0, which is attributed to dominance of the marsh by Phragmites (Figure 41). This most likely indicates little saltwater inundation, or a lack of a salt marsh plant source, or both. The remaining MarshRAM metrics are summarized in Table 27.

Table 27: NH01 MarshRAM metrics

Metric	Score	Observations
Ecosystem Functions and Services	11 / 36	Much lower than the other case study sites. Phragmites does not provide good habitat for many salt marsh organisms.
Surrounding Land Use	7.6 / 10	The immediate surroundings are low-density or open space development, but the broader landscape is highly developed.
Wetland Disturbance	6.9 / 10	Minimal stressors directly adjacent to the marsh, but Phragmites dominance suggests minimal tidal exchange.
Migration Potential	2.6 / 10	The marsh is small, so migration would not add a substantial area relative to the marshes of Connecticut.

The vegetation condition at NH01 indicates limited saltwater exchange with the marsh platform. This differs from the pattern suggested by the hydraulic results, in which the always-open gate passes tidal flow freely at stages up to its 0.78 m NAVD88 top, and the hydraulic model alone does not explain the difference, because it simulates water level but not salinity. For planning purposes, the hydraulic and ecological findings should be read together: the structure does not, by itself, appear to be the factor limiting tidal exchange at routine stages, and any proposed change to the structure should be evaluated against the vegetation condition.

3.3.4. Westport (WP01 and WP02) Gates, Sherwood Pond

WP01 and WP02 are two gate structures at Westport that discharge to a single shared marsh basin (Figure 41). This was confirmed by flood-fill delineation: starting from either site's coordinates yields the same basin at every threshold tested. WP01 has five parallel gate sets and WP02 has four, for nine gates in total. The two structures operate simultaneously and are modeled together as the combined Westport system (Figure 42), with each site kept as a separate flow path so that its contribution can be isolated. The model was driven with the Bridgeport (NOAA station 8467150) tide record for 1999 to present. The sites were surveyed by RTK on September 3, 2026 (Figure 43).



Figure 41: NH01 MarshRAM field analysis area

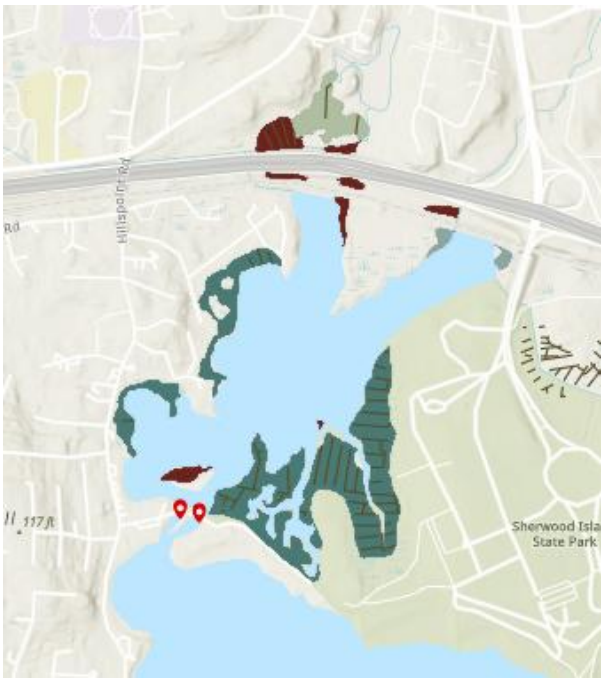


Figure 42: Location of WP01 and WP02 marked with red pin shown screenshot from the Tide Gate Viewer. The immediate upstream colored area from WP01 and WP02 is considered for the marsh assessment.



Figure 43: WP01 and WP02 gates

Each gate has two flap gates in series along the flow path (marsh, upper gate, lower gate, Sound) (Figure 43). Both gates sit on the same slab at −0.396 m NAVD88 (top of slab, −1.3 ft) and differ only in height. The lower gate is 0.43 m high, with a crest at 0.034 m NAVD88, and the upper gate is 0.85 m high, with a crest at 0.454 m NAVD88. Each gate set is 2.55 m wide, so the total widths are 12.75 m at WP01 and 10.2 m at WP02. Neither gate closes the channel: in the closed position, water spills over the crest as a weir. Every photograph from the site visit shows overtopping on every gate and none shows an open-channel condition (Figure 43).

In the observed position, the two gates in series behave as a single two-way weir at the higher crest, 0.454 m NAVD88. There is no flow in either direction until the water level on either side exceeds that elevation. The water that passes then flows according to the head difference, and Sound water

can enter the marsh over the crest as well as drain from it. The weir was modeled with a discharge coefficient of 0.6, a generic value for a broad-crested weir that has not been calibrated to this structure. This is different from the one-way flap at GF01 and from the gates at NH01.

The model holds the gates fixed in this observed position. There is no information on whether the gates are adjusted by an operator, seasonally or in advance of storms, and the results apply only to the observed condition. A field photograph on September 3, 2026 at about 11:10 showed 10 cm of water over the upper crest on the marsh side, implying a marsh level of 0.554 m NAVD88. The Bridgeport record gave −0.638 m at the same moment. The marsh was therefore higher than the Sound and flowing toward it, which is the direction observed and consistent with the model. This is a single consistency check and not a calibration.

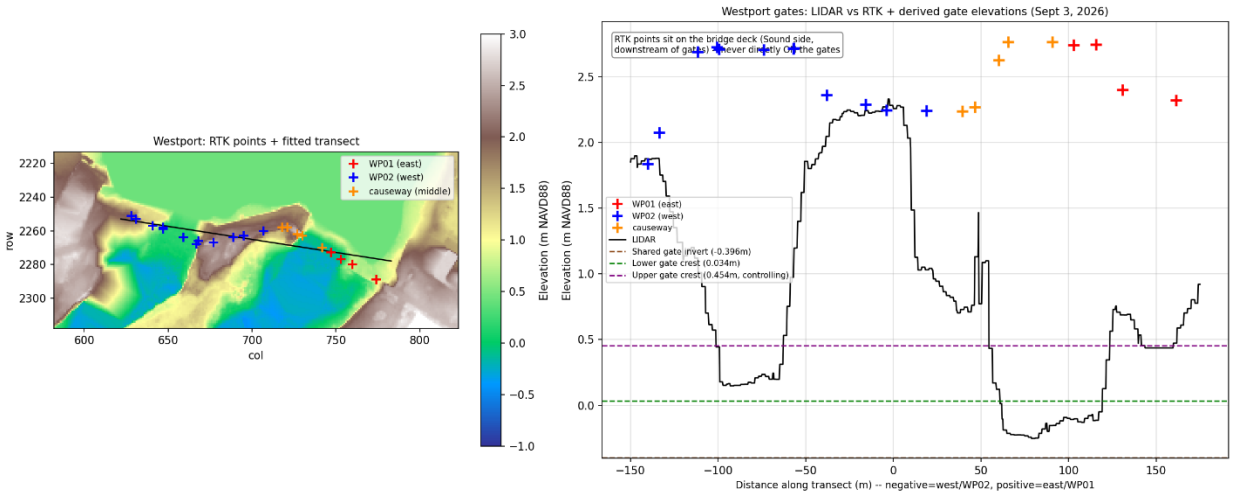


Figure 44: RTK measurement locations Westport Sept 3, 2026 – the WP01 and WP02 channel cross section over the LIDAR Measurements

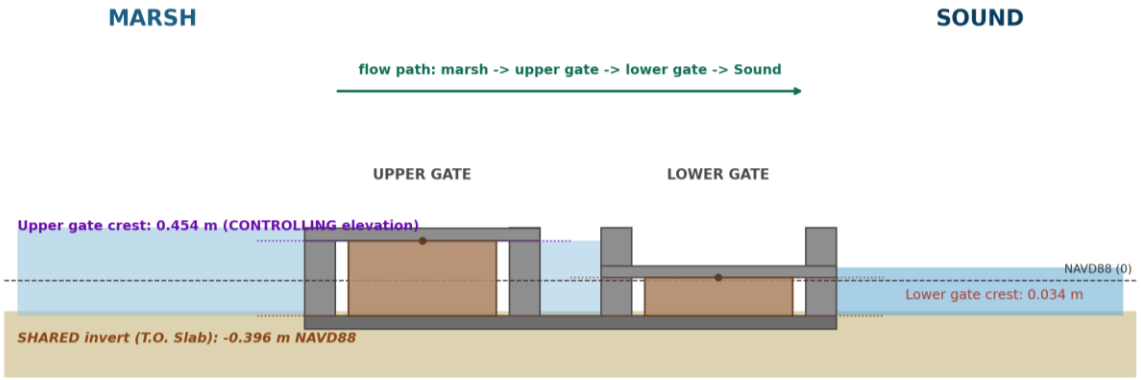


Figure 45: WP01/WP02 two gates series connected

Marsh Storage Characteristics

The hypsometric curve for the shared basin is used in the same way as at the other sites, as the A(η) term in the mass balance, but it could not be taken from the NWI marsh boundary as at GF01, EH02 and NH01. The National Wetlands Inventory maps vegetated marsh. At Westport it excludes the open water of the tidal pond behind the gates and the channel that the gates sit on, and the mapped polygons are scattered patches around the margin of the basin (Figure 46). At WP01/WP02, the basin was delineated by flood-filling the DEM outward from the gate coordinates up to an elevation threshold of 2.5 m NAVD88, which is above the highest stage in the 1999–2026 record (2.82 m at the Westport gate, Table 27) and above the crest of the structure (0.454 m), so that all cells hydraulically connected to the gates below that level were included in the hypsometric curve. A DEM clipped to those polygons had a minimum elevation of +0.44 m, which is above the surveyed slab (−0.396 m) and the lower gate crest (0.034 m) and just below the upper crest (0.454 m). A curve built from that clip would not have represented any stage below the crest, which is the range in which the gates operate, and would have omitted most of the water surface that actually stores and releases water through the gates.

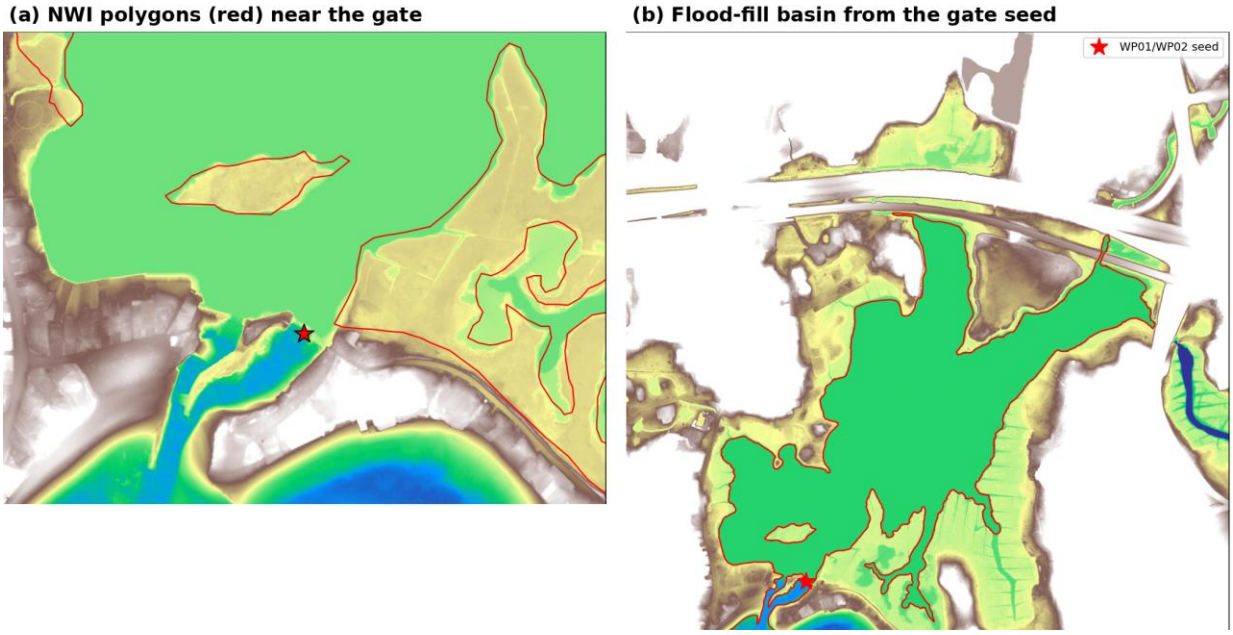


Figure 46: (a) NWI polygons (red) over the DEM near WP01/WP02, showing that the mapped marsh excludes the pond and channel; (b) basin delineated by flood-fill from the gate coordinates, with the DEM shaded by elevation

For that reason the basin was delineated by a flood-fill from the gate coordinates, as described in Section 2.4.1, in place of a mapped boundary. Starting at the gate, the algorithm includes every DEM cell that is below the selected elevation and can be reached from the gate through an 8-connected path of cells that are also below that elevation. A simple elevation mask would not be adequate here. It would include any other low ground on the DEM tile that happens to be at the same elevation, whether or not it is hydraulically connected to the gates, and it would count it as storage.

Figure 46b shows an example: the tidal channel along the eastern edge of the tile is as low as the basin but is separated from it by the road embankment and is correctly excluded by the flood-fill, while the embankment along the northern edge bounds the basin on that side. The flood-fill also confirms that WP01 and WP02 drain the same basin. Seeding the fill at either structure gives an identical basin at every elevation tested, which is the basis for modeling the two structures against one storage curve (Figure 47).

The cumulative area and volume were then computed at 0.1 m increments (Figure 47). Below 0.4 m the basin consists of the narrow channel at the gates, with a cumulative area of about 1.7 ha (1.7×10^4 m²) at 0.4 m. Between 0.4 m and 0.5 m the area increases by more than twenty times, to 38.6 ha (3.86×10^5 m²), and 96 % of the area at 0.5 m lies in that single 0.1 m interval. Above 0.5 m the curve is relatively flat: the basin grows only from 38.6 ha at 0.5 m to 43.8 ha at 1.1 m, and then increases steadily to 59.5 ha at 1.5 m, 66.9 ha at 2.0 m, and 75.2 ha at 2.5 m, as the surrounding marsh and low-lying upland are included. Cumulative volume is 3.4×10^4 m³ at 0.5 m, 2.4×10^5 m³ at 1.0 m, 4.9×10^5 m³ at 1.5 m, 8.1×10^5 m³ at 2.0 m, and 1.16×10^6 m³ at 2.5 m.

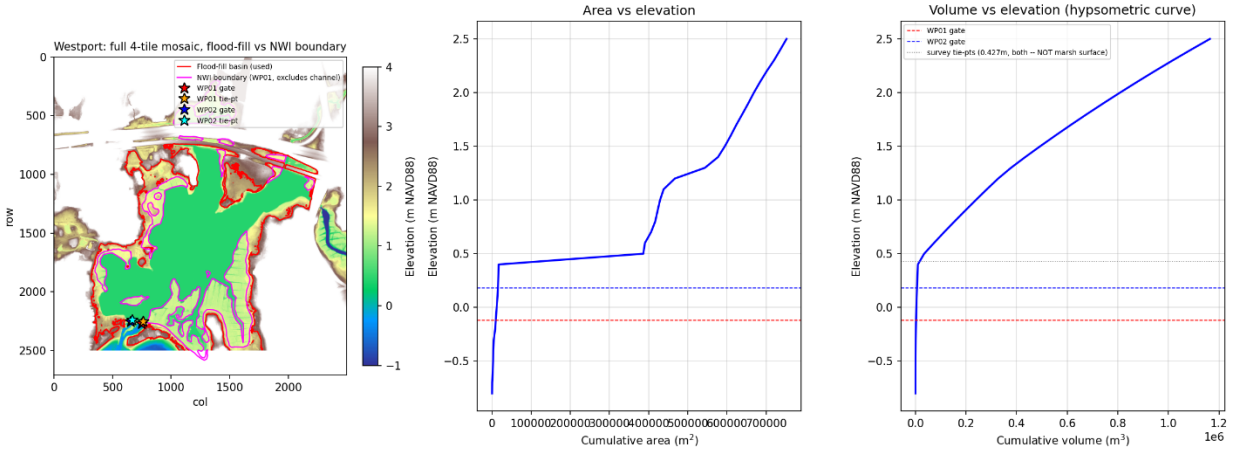


Figure 47: WP01 andWP02 marsh boundary on the DEM (left), cumulative area versus elevation (center), and cumulative volume versus elevation (right).

The step between 0.4 m and 0.5 m has a physical explanation. LiDAR does not penetrate water, so open water is represented in the DEM by the elevation of the water surface on the day of the flight. The nearly flat, roughly 37 ha surface between 0.4 m and 0.5 m is therefore the water surface of the pond, as it stood at the time of acquisition, and not the pond bed. It lies at almost exactly the elevation of the upper gate crest (0.454 m), which is where the pond would stand if it were held by the gates. This is consistent with the simulated behavior, in which the marsh does not fall below about 0.5 m. It also means that the curve contains no information on the bathymetry of the pond below that elevation. The storage volume below 0.45 m is not captured, and the stated volume at 0.5 m (3.4×10^4 m³) should be read as the volume above the pond surface. This does not affect the simulation, because the modeled marsh level never goes below the crest, but it does limit any statement about the water stored beneath it.

The shape of the curve governs how the marsh responds to the weir. Immediately above the crest, the surface area is already about 39 ha, and each 0.1 m of stage between 0.5 m and 1.0 m stores about 4×10^4 m³. At a head of 0.10 m over the combined crest length of 22.95 m (Cd = 0.6), the weir equation gives a discharge of about 1.3 m³/s, so that releasing 4×10^4 m³ takes on the order of eight hours even at that head, and longer as the head decreases, since discharge varies as the 3/2 power of head. The marsh can therefore release only a small volume from each tide when it is close to the crest. At a head of 1 m the same crest passes about 41 m³/s, and the structure moves large volumes quickly. The storage curve thus indicates a basin that is slow to drain when it is near the crest and much more responsive at higher stages, which is the pattern seen in the simulated water levels.

Simulated Marsh Water Levels

Marsh water level was simulated for the 26.8-year Bridgeport record (NOAA station 8467150, converted to NAVD88) with the mass balance described in Section 2.2, in which the rate of change of marsh stage equals the net flow through the structure divided by the basin area at the current stage, taken from the curve in Figure 48. For Westport the flow term is a single two-way weir at the upper gate crest (0.454 m), with a combined width of 22.95 m (12.75 m at WP01 and 10.2 m at WP02) and a discharge coefficient of 0.6. The direction of flow follows the head difference. No flow occurs in either direction when both the marsh and the Sound are below the crest, and in that case the marsh stage is unchanged. The equation was integrated with the same fixed-step, fourth-order Runge-Kutta scheme as at the other sites. The gates were modeled in the observed fixed position.

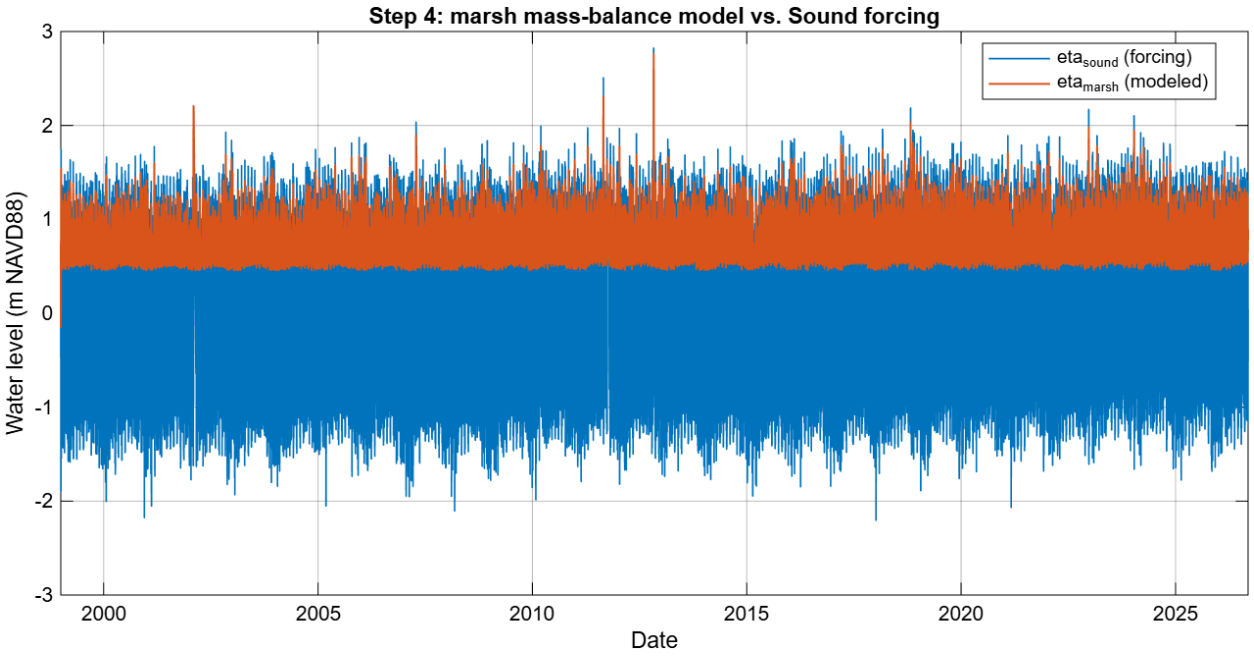


Figure 48: Simulated marsh water level (orange) and Sound water level (blue) at Westport, 1999 to present.

Figure 48 shows a response that is different from the other sites. The Sound level spans about −2.2 m to +2.8 m over the record, but the simulated marsh level does not fall below roughly 0.5 m at

any time. Because no flow can occur below the crest, the marsh cannot follow the Sound down on the ebb, and the lower boundary of the marsh trace sits just above the crest. It does not reach 0.454 m exactly, because weir discharge decreases as head decreases. With about 4×10^4 m³ stored in each 0.1 m of stage near the crest, the last few centimeters of head drain very slowly, and the next flood tide arrives before the marsh has reached the crest. This agrees with the one field observation available. At about 11:10 on September 3, 2026, 0.10 m of water was observed over the upper crest on the marsh side, which implies a marsh level of 0.554 m, while the Bridgeport record gave −0.638 m, so that the marsh was holding the stage that the model predicts.

Above the crest, the marsh rises on the flood tide, as Sound water spills over the weir. The typical high water in the marsh trace is somewhat lower than the typical high water in the Sound, since the crest limits the inflow on each tide, and the difference narrows as the Sound level increases. At the extreme event of the record (October 2012, Superstorm Sandy) the head over the crest is more than 2 m, the weir passes a very large flow, and the marsh peaks at 2.763 m, 0.061 m below the Sound peak. The structure therefore reduces the peak water level at Westport only slightly in the most severe event, and its attenuation is greatest at intermediate stages. This is examined in the exceedance analysis that follows.

At Westport the weir is two-way, so the marsh responds to the Sound whenever the Sound is above the crest, but it is cut off from the Sound below the crest, so the lower half of the tide range does not reach the marsh. The correlation with the Sound is therefore expected to be intermediate. The model does not include freshwater inflow, seepage, or evaporation, so the floor near 0.5 m is an upper bound on how high the marsh stays between tides.

Flooding Frequency

The Westport exceedance results are different from those at any other site (Table 28). Below the crest, the gates provide no benefit and are slightly worse than no gate. For thresholds from −0.7 m to 0.4 m the protection factor is 0.995 to 1.000. This is a consequence of the two-way weir mechanism. Since there is no flow in either direction below 0.454 m, the marsh cannot follow the Sound down on the ebb and its level is held at or above the crest. In the model the marsh is therefore above every threshold from −0.7 m to 0.4 m on essentially all 365 days of the year, whereas an unrestricted marsh would fall below these levels on each low tide (Figure 49).

Table 28: Westport protection factor (unrestricted/restricted days per year above threshold).

Threshold (m NAVD88)	Protection factor	Interpretation
−0.7 to 0.4	0.995 - 1.000	No protection; restricted marsh exceeds slightly more often than unrestricted
0.5	1.00	Break-even, at the upper gate crest
0.8	1.25	Protection becomes meaningful
1.0	1.80	Strong protection
1.2	2.89	Very strong protection
1.5	5.70	Near-complete protection

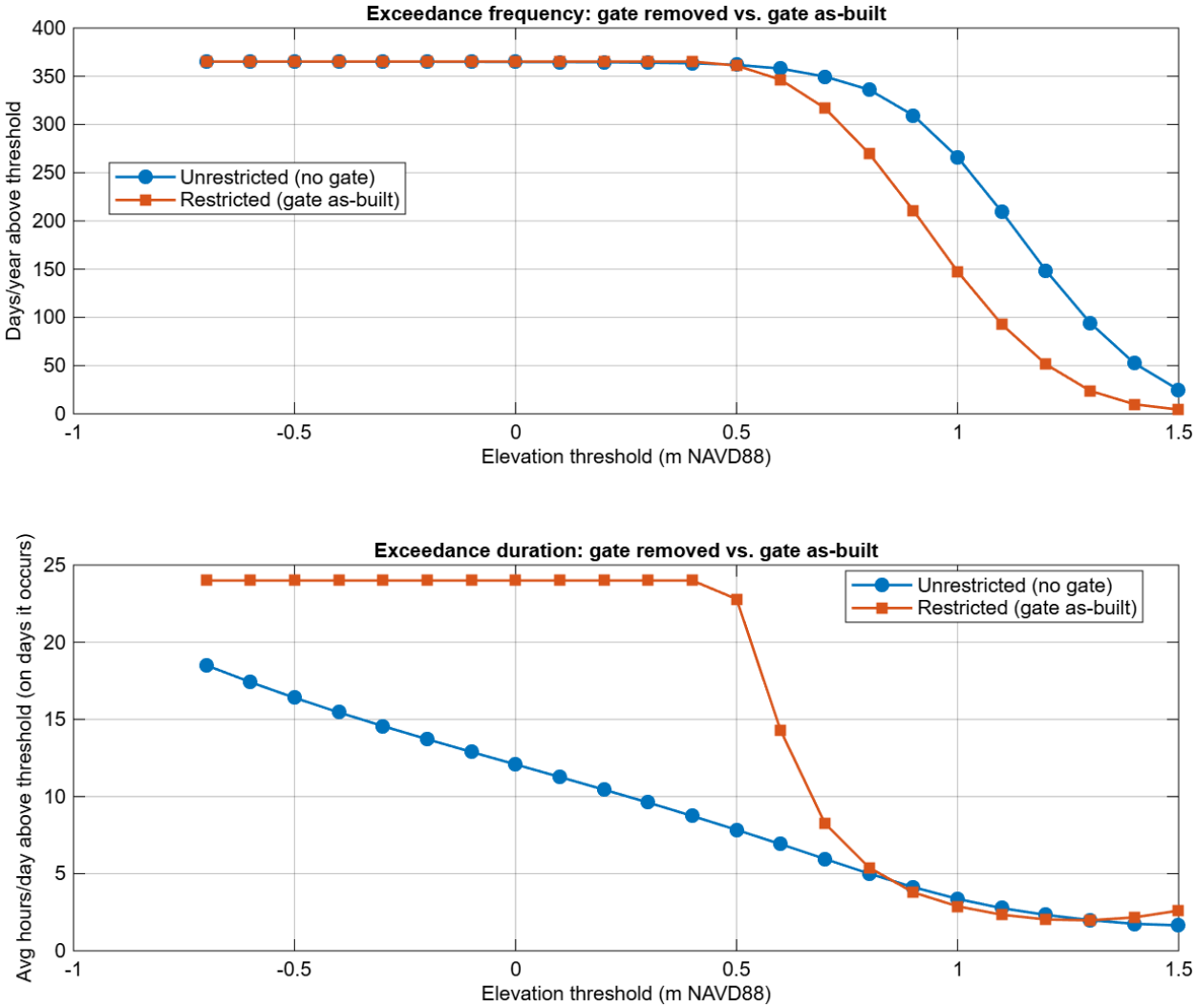


Figure 49: (above)WP01+02 exceedance frequency (days per year above threshold), restricted vs unrestricted (no gates) and (below) WP01+02 exceedance duration (average hours per day above threshold on days when exceeded)

Above the crest the protection factor increases quickly, to 1.25 at 0.8 m, 1.80 at 1.0 m, 2.89 at 1.2 m, and 5.7 at 1.5 m. The flood control provided by the Westport structure is therefore concentrated in the moderate to severe range, and not at everyday tide levels.

In the model, drainage below the crest depends only on flow over the weir. The marsh in the field also loses water by seepage and leakage around and under the gate leaves and at the abutments, which are not represented. The persistent high water level indicated by the model should therefore be regarded as an upper-bound representation of a marsh that does not drain below the crest. A short deployment of a water level logger in the marsh would confirm whether the marsh falls below 0.45 m NAVD88 on low tides.

Sea Level Rise Sensitivity

At the most extreme event in the 26-year record, the baseline peak marsh level is 2.763 m NAVD88 compared with a Sound peak of 2.824 m, a difference of only 0.061 m (Figure 50). At this stage both sides are far above the crest, and the structure has little effect on the peak. The Westport gates therefore show a middle-band protection profile: little or no effect at everyday levels, substantial effect in the moderate to severe range, and a reduced effect again for the most extreme event on record.

The response to SLR is mild. The local amplification factor remains close to 1.0 over the 0 to 0.5 m range (0.96 to 1.14, with no clear trend), and the protection margin remains small (−0.005 m to −0.036 m). The pre-2026 GF01 gate, for comparison, lost 0.56 m of margin over the same range. The two-way weir does not have the failure mode of a one-way gate, in which a higher Sound low tide shortens the daily drainage window, because a weir at 0.454 m is overtopped from either side whenever the stage exceeds the crest. The protection that the structure provides in the moderate to severe range is therefore durable under SLR in the range tested.

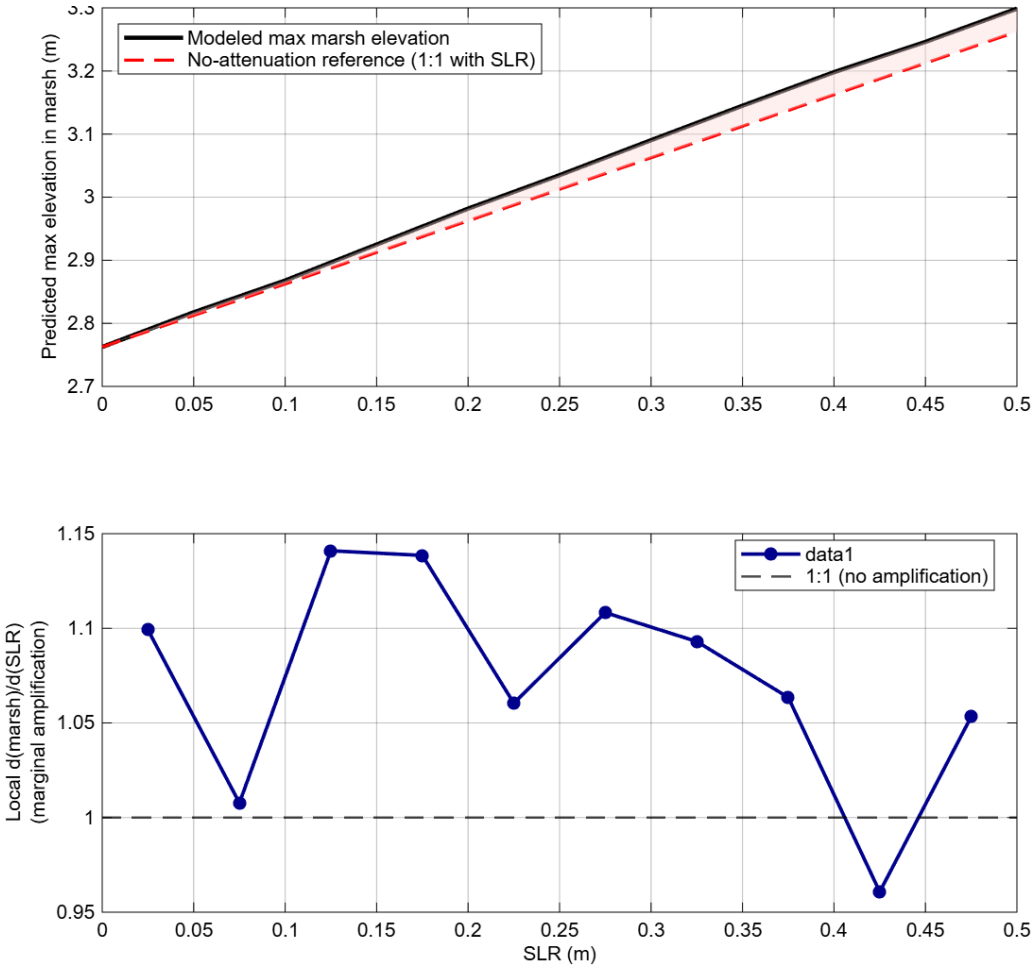


Figure 50: WP01+02 SLR sensitivity comparison

Marsh and Ecosystem Assessment

The Westport marsh received an intermediate IMI score of 6.0 and is dominated by mixed vegetation and Spartina alterniflora high marsh (Figure 51). The remaining MarshRAM metrics are summarized in Table 29.

Table 29: WP01+02 MarshRAM Metrics

Metric	Score	Observations
Ecosystem Functions and Services	15 / 36	Small marsh that is not part of a larger habitat complex; green space within a broader urbanized environment.
Surrounding Land Use	8.3 / 10	Low-intensity recreational development (Sherwood Island State Park).
Wetland Disturbance	7.0 / 10	Best score of the case study sites. Moderately high ditching intensity (292 m/ha). Deer trample tracks were observed.
Migration Potential	1.2 / 10	The adjacent upland is at a higher elevation than the MHHW + 20 in. SLR scenario.



Figure 51: WP01+02 MarshRAM field analysis area

The Wetland Disturbance score is the highest of the four sites, despite a ditching intensity (292 m/ha) that is higher than at GF01 (188 m/ha). This indicates that the vegetation does not show a strong response to the gate condition or to the ditching. The vegetation therefore does not provide evidence, in either direction, on the model finding that the marsh is held above the 0.454 m crest throughout the year. That finding remains to be verified by water level logging, and the two lines of evidence should be considered together when a recommendation for the structure is developed.

4. Discussion and Recommendations

4.1. Cross-Site Synthesis Qualitative Assessment

The qualitative assessment (Task 2C) scores every gate in the statewide inventory with the Tide Gate System Rating (TGSR), which combines the flood risk to upstream structures, the condition of the upstream marsh, and the condition of the gate and culvert.

Of the 68 tide gates in the inventory, 57 were accessed in the field and 11 could not be accessed because they are on private property or enclosed. Thirty-six gates (53%) have some salt marsh upstream. Flap gates are the most common type (35 gates, 51 %), and 41 gates have an associated culvert. Operational status is recorded as active for 35 gates (51 %), unknown for 20 (29 %), abandoned for 7 (10 %), under repair for 5 (7 %), and proposed for 1.

The GIS workflow scored 55 of the 68 gates, 13 of them provisionally because they lie outside the flood-zone layer (Table 30). 17 fall in the High tier and are to be maintained within 3 years, 26 in the Medium tier (4 to 5 years), and 12 in the Low tier (6 to 10 years). Many of the High-tier gates are High because of gate condition alone: 15 of the 17 have an average CAR of 3 or lower, and 11 have no marsh behind them. For these, the decision is repair versus decommissioning and not simply maintenance within 3 years. The remaining 13 gates could not be scored. Of the High-tier gates with structures exposed, CL01 is classed as a conflict site: opening it would put structures at risk, while the marsh needs flushing, so it needs an engineered solution such as a self-regulating gate and not a simple repair or removal. WP01 and WP02 are also conflict sites but fall in the Medium tier. GF01 ranked High before its 2026 renewal; with the renewed gate recorded as Good (CAR = 6) it is now Medium, "Repair / maintain as-is."

Table 30: High-tier gates with structures exposed if opened (see Table 11 for the full High tier).

Gate	Structures exposed	Avg. CAR	TGSR	Priority matrix category	Meaning
FF37	10	1	0.125	Repair / maintain as-is	Healthy marsh or none, critical flood consequence if opened: keep it running
FF12	11	2	0.183	Monitor, moderate priority	Nothing extreme on either axis: periodic reassessment
CL01	9	3	0.259	Conflict site — engineer	Marsh needs flushing, but opening puts structures at risk: engineered solution (self-regulating gate, muted regulator)
FF27	5	4	0.300	Repair / maintain as-is	Healthy marsh or none, critical flood consequence if opened: keep it running
FF29	12	2	0.300	Low priority	Safe to open either way: no immediate action
FF31	5	2.5	0.312	Repair / maintain as-is	Healthy marsh or none, critical flood consequence if opened: keep it running
FF32	7	4	0.317	Low-moderate — routine maint.	Moderate flood consequence: standard upkeep

With 31% of scored gates in the High priority tier and a further 47% in the Medium tier, the large majority of Connecticut's assessed tide gates (78%) will require maintenance attention within the next 5 years under this framework, where 32% of assessed tide gates and 48% of assessed culverts were rated fair or poor (Geosyntec, 2017).

Only 55 of 68 statewide gates (81%) carry a complete enough record to compute a TGSR (13 of them provisionally), and 11 gates (16%) could not be accessed at all. Flap gates are the single most common type statewide (51%). Section 3.3.1 documents a "choking" mechanism specific to one-way flap gates under sea level rise, where the daily drainage window shrinks as SLR raises the low-tide floor. Given how common flap gates are statewide, the SLR sensitivity findings from the four studied sites likely generalize to a meaningful share of the statewide inventory, though confirming that would require extending the Section 2.2 hydraulic modeling approach beyond the four detailed sites.

The municipality code FF (Fairfield) accounts for 37 of the 68 gates (54%) and 12 of the 15 Critical gates (80%), including the provisional scores, and all of its gates can now be scored. A single coordinated inspection and repair-or-remove effort in that municipality would therefore address most of the near-term need. Greenwich (GW) has the largest access problem, with three gates on private property.

4.2. Cross-Site Synthesis of Quantitative Assessment

The four detailed sites were chosen to represent the main structure types in the inventory: a one-way flap gate (GF01), a gate that has been removed (EH02), a multi-gate structure with mixed gate types (NH01), and a fixed two-way weir (WP01 and WP02). Each was assessed with the same hydraulic method (Section 2.4) and the same marsh assessment (MarshRAM). This section compares the basis of the four assessments, the hydraulic results, and the marsh results, and then draws the cross-site conclusions (Table 31).

Table 31: Summary of the quantitative assessment sites

	GF01 Guilford	EH02 East Haven	NH01 New Haven	WP01 + WP02 Westport
Structure and mechanism	Renewed 2026: two one-way flap gates, 1.60 m wide each. Original: single sluice gate, 1.85 m wide.	Gate removed. Open channel 8.84 m wide; hypothetical two-way culvert 1.5 m wide.	12 gates in parallel: 1 always-open, 3 SRT (1.0 m dia.), 8 flap (1.5 × 1.5 m).	9 gates (5 + 4), each two flap gates in series that act as one two-way weir, 22.95 m total width.
Controlling elevations (m NAVD88)	Invert −0.156 (original 0.861). Road crest 1.707.	Culvert invert −1.219.	Common sill −0.719. Flap/always-open top 0.781. SRT closure about 1.38 (assumed).	Slab −0.396. Lower crest 0.034. Upper crest 0.454 (controls).
Marsh basin	About 45 ha (112 ac), NWI polygon	About 66 ha, NWI polygon	About 17 ha, NWI polygon	About 39 ha at the crest, 75 ha at 2.5 m; flood-fill basin
Statewide Marsh Health Index	4.13	3.75	2.63	3.75
Tide forcing	NOAA New Haven, 1999 to present (26.8 yr)	NOAA New Haven	NOAA New Haven	NOAA Bridgeport (8467150)
Field basis	RTK survey of gate geometry, Aug 2024 and Sept 2026; no water level calibration	Levelogger calibration, Apr to Jun 2024 (r = 0.986, amplitude ratio 0.84)	RTK survey; two photo checks of SRT and flap state (Jun and Sept 2026)	RTK survey Sept 2026; one photo check of marsh level

Exchange with Sound	One-way. Correlation with the Sound r = 0.05, as before renewal (0.055).	Two-way. r = 0.895 (culvert 0.797).	Free at routine stages through the always-open gate. r = 0.903 with the Sound (RMS difference 0.40 m)	Two-way above the 0.454 m crest, none below it. Correlation not yet computed.
Flood Frequency profile	Days per year above 0 to 0.8 m reduced by more than 99% by renewal (e.g. 204 to 0.04 at 0.8 m).	Open channel: 253 days/yr above 0.8 m, 17 above 1.0 m. Culvert: 3 and 0.07 days/yr.	No protection below about 0.6 m. Protection factor 1.1 at 0.8 m, 1.4 at 0.9 m, 2.2 at 1.0 m, 5.3 at 1.1 m and 46 at 1.2 m.	No protection below the crest. Protection factor 1.8 at 1.0 m, 2.9 at 1.2 m, 5.7 at 1.5 m. Only 0.061 m below the Sound at the extreme event.
Response to SLR	Peak lowered by 0.28 to 0.31 m at every increment, but the marsh peak still rises about 2.2 m per metre of SLR (mean amplification 2.16; original gate 2.12).	Open: amplification 1.04 to 1.16, margin −0.06 m at 0.5 m. Culvert: 0.37 to 0.61, margin +0.26 m.	Amplification 0.77 to 1.01 (mean 0.95), margin +0.003 to +0.025 m. Without the always-open gate the marsh peak stops rising above about 1.33 m.	Amplification 0.96 to 1.14, margin −0.005 to −0.036 m.
Statewide TGSR (Task 2C)	0.662, Medium	No score (gate removed)	0.463, Medium (gate condition 6)	0.383, Medium (gate condition 4), both sites

The one-way flap at GF01 is the only structure at which the marsh peak rises about twice as fast as sea level. The two-way structures behave differently: Westport stays near 1.0, the EH02 open channel at 1.04 to 1.16, the EH02 culvert at 0.4 to 0.6, and NH01 near 0.95. This is consistent with the mechanism described in Section 2.2, in which a one-way gate can drain the marsh only when the marsh is higher than the Sound, so that a higher Sound low tide shortens the drainage window. Renewal at GF01 lowered the marsh peak by about 0.3 m but did not change the rate, because the mechanism is a property of the one-way gate and not of its invert.

Each site has a different protection profile when plotted against water level. The renewed GF01 provides protection at all levels. NH01 and Westport provide none at routine levels. NH01 provides little protection until above about 1.0 m, where it reduces flooding by about half, and strong protection only above about 1.2 m; its always-open gate (top at 0.78 m) sets this threshold. Westport provides protection above the 0.454 m crest, with protection factors of 1.8 at 1.0 m and 5.7 at 1.5 m.

The most restrictive structure (GF01) has the best marsh, and the structure with free exchange at routine stages (NH01) has the worst, which is dominated by Phragmites. At Westport, the model indicates that the marsh does not drain below the crest, and yet it has the best Wetland Disturbance score of the four sites. These results show that vegetation condition at a site depends on factors that the water level model does not represent: salinity, freshwater inflow, land management (mowing at GF01, ditching at Westport), and the history of the marsh (150 years of restriction at EH02). The hydraulic and marsh assessments are therefore complementary and neither is sufficient alone to select an action.

Migration potential is low at every site. The scores range from 1.2 to 2.6 out of 10. The marshes will have little room to move landward, and the adaptation of these marshes to SLR will depend mainly on their ability to build elevation in place. Sediment supply and the exchange allowed by the structures

are therefore the central issue for the long-term condition of the marsh, more so than the flood protection performance alone.

The statewide ranking and the hydraulic findings capture different information. The TGSR combines exposure, marsh condition and gate condition; it does not include the SLR response of the structure. After renewal, GF01 is in the Medium tier (TGSR 0.66, close to the Low boundary), as are NH01 (0.46, condition 6) and Westport (0.38, condition 4). The hydraulic results show what the score cannot: renewal removed the flooding problem, but at GF01 the marsh peak still rises about 2.2 m per meter of sea level rise, so a Medium score near the Low boundary may understate its long-term vulnerability. At Westport the SLR response stays near 1.0, so the Medium tier fits its stable protection.

4.3. Site-Specific Recommendations

The recommendations below combine the qualitative assessment and quantitative assessment results of the case studies. The limits apply to them are:

- The hydraulic model is a screening-level, lumped mass balance. It reports water level at the structure and in the marsh, but not salinity, sediment supply, or the elevations of the property that the structure protects.
- Elevation and value of adjacent structures, roads, and utilities were not part of the assessment. Wherever a recommendation depends on flood consequence, the first step is to obtain those data.
- Cost estimates and permitting pathways were not developed. Permit coordination with DEEP, the U.S. Army Corps of Engineers, and the Connecticut Coastal Management Act review is expected for any structural or operational change.

Site specific recommendations from the qualitative assessment shows:

- **Repair now:** FF37 and FF31 have Moderate marsh system impact (High flood exposreu, negligible marsh concern but poor gate condition, so a basic repair is the cheapest way out of the Critical tier. If FF37 went from CAR 1 to CAR 4, its TGSR would rise from 0.125 to about 0.50 (Medium). FF27, FF32 and FF12 have High/Severe flood or marsh status and deserve an inspection-scoped repair estimate.
- **Repair or decommission decision:** FF29 and the poor-condition gates among the 13 provisionally scored gates (BG01B, FF04, FF05, FF16, FF28, plus FF24, FF26, FF34 on the line) have no flood consequence. Confirm each is still in use before any repair spending; FF25 and FF07 additionally have marsh behind them and are restoration candidates.
- **Engineering review:** CL01 (TGSR 0.259), conflict site, engineer review
- **Unlock access where it matters most:** Four of the 11 no-access gates have marsh behind them (BF01, EH01, OS01, OS02), and OS02 also has 2 structures that intersect the flood zone. Start town and landowner outreach there. The other seven (GW03–05, SF01, ST03, WF01, WF02) have no marsh and are lower priority.
- **Quick field check:** BG01A: confirm whether the gate is operational.

Site specific recommendations for the selected four sites:

- **GF01**: The renewal removed routine high marsh levels and lowered the peak drainage, but it did not address the long-term condition of the marsh. With almost no migration space, the future of this marsh depends on whether it can build elevation in place. The renewed gate is still strictly one-way, which means that sediment delivery from the Sound is limited to whatever enters before the flaps close. The recommendations might include:
  - Retain the renewed structure and take no further structural action at this time. The hydraulic benefit is large and durable, and the marsh condition does not show a need for additional intervention.
  - Install water level loggers on the marsh side and the Sound side of the gate for at least one full spring-neap cycle, and repeat annually. This confirms the post-renewal drainage behavior of the marsh and provides the first field validation of the renewed-gate model. It is the lowest-cost action and should be done first.
  - Monitor vegetation along fixed transects in the high marsh, in particular the mowed former Phragmites area. The principal question is whether salt water continues to inundate the high marsh periodically after renewal, and whether Phragmites returns.
  - Adopt an SLR trigger for re-evaluation. The model places the road-crest crossing at about 0.29 m of SLR and the crossing of the top of the gate opening at about 0.35 m. The structure should be re-evaluated when observed relative sea level reaches approximately 0.2 m above the model baseline, so that any adaptation, such as a raised road crest or additional flow capacity, can be designed before overtopping occurs.

- **EH02:** The site has no gate. The culvert would offer clear flood benefits on paper, but the marsh is in a recovery process that depends on tidal exchange and sediment, and a new restriction would interrupt it. The recommendation therefore depends on a fact that the assessment does not have: what is flooded under the open-channel condition, and how often.
  - Define the flood consequence. Survey the elevations of homes, roads, driveways, and utilities adjacent to the Farm River marsh, and relate them to the exceedance table (Table 22). If the lowest damaging elevation is above about 1.0 m, the existing flood frequency is small and no structure is warranted on hydraulic grounds. If damage occurs at 0.7 to 0.9 m, the flooding is frequent enough to need a response.
  - If a structure is still needed, run a sizing analysis between the two bounding cases tested (8.84 m open channel and 1.5 m culvert), for example 2 to 6 m, and select the largest opening that meets the flood objective. The structure should be two-way and should have no one-way check valve. The remaining items to be defined are a real design height (1.2 m is a placeholder) and a calibrated discharge coefficient (0.65 is generic).
  - Carry out the sediment studies recommended in the marsh assessment, in parallel, with surface elevation measurements across the platform. They should establish whether the marsh has regained elevation since the gate failed, because this determines how much additional exchange the marsh needs and how much of a restriction it can tolerate.

- Install a second water level logger pair at the former gate location for at least a year. The 2024 calibration covers only two months (April to June), and a longer record would bracket the model against storm conditions.

- **NH01:** The marsh is in the poorest condition of the four sites. The structure already allows free exchange at routine stages through its always-open gate, which would normally favor salt marsh vegetation, yet the marsh is dominated by Phragmites. The model cannot explain the difference because it simulates water level and not salinity. Until the cause is known, a change to the structure cannot be said to offer an ecological benefit. The flood benefit is also modest at moderate levels: the structure reduces the number of days above 0.8 m by only about 10%, above 1.0 m by about half, and becomes strongly protective only above about 1.2 m. It does lower the largest event, with a modeled marsh peak of 1.86 m against a Sound peak of 2.64 m. Because this is a developed area, changes that reduce that storm protection are not justified without a better understanding of what the structure protects.
  - Retain the structure and its storm protection. Do not remove it or reduce its flood-event capacity at present, because the developed landscape and the reduction in the largest events indicate meaningful flood consequence..
  - Retain the always-open gate and do not narrow or close it. It is the one path that currently supplies routine exchange to a marsh that is already dominated by Phragmites, and any reduction would be expected to reduce exchange further. The isolation test shows what narrowing would trade: without this gate the marsh would exceed 0.8 m on about 138 days per year instead of about 281, and the peak would fall from 1.86 m to 1.14 m, giving more flood protection at the cost of routine exchange. The original purpose of the gate should be established before any change is proposed.
  - With the always-open gate in place the marsh peak rises essentially one-for-one with sea level, so the flood benefit of the structure at the peak does not erode under SLR but also does not grow. Re-evaluate when observed sea level has risen about 0.2 m, which is also the increment at which the controlled gates would begin to cap the marsh in the isolation test.
  - Measure the cause of the Phragmites condition. Install water level and conductivity loggers on the marsh platform and in the main channel for at least one year, and sample porewater salinity along transects.
  - Resolve the SRT closure elevation (currently a lower bound of 1.95 m above the sill plus margin), the flap opening height, and the always-open gate's contribution, and regenerate the exceedance and SLR tables.
  - If the measurements show that the marsh platform is not being inundated by salt water at routine stages, evaluate a modification to the controlled gates. The most direct option is to convert some or all of the eight flap gates to controlled two-way operation, for example SRT-type gates that stay open on routine tides and close for storm surge. This should be modeled before it is proposed.

- If salinity is restored, follow with Phragmites management (for example, mowing or herbicide), because a change in hydrology alone is unlikely to reduce the Phragmites cover in the short term.
- The marsh is small and migration potential is low, so the ecological gain is limited relative to larger sites, and the statewide ranking places NH01 in the Medium tier. The structure is, however, a good candidate for a demonstration of controlled two-way operation, because the three gate types already exist.

- **WP01 and WP02:** the principal hydraulic concern (a marsh that may not drain with the tide) is not matched by a clear ecological symptom. This suggests either that the modeled drainage restriction is more severe than the real one, because the model omits seepage and leakage through and around the gates, or that the marsh is adapted to the stable water level. Neither can be established without field data. No change to the structure is warranted until that question is answered, since the structure provides the moderate to severe flood protection for which it is relied on, and the marsh has a sound vegetation condition.
  - Confirm how the gates are operated. Establish whether an operator ever adjusts them, how, and under what conditions, and obtain any operating protocol. The model holds the gates fixed in the observed position, and every result for this site depends on that assumption.
  - Verify the marsh drainage behavior directly. Deploy water level loggers in the marsh and the Sound for at least one month that includes spring tides, and compare the marsh low water level with the 0.454 m crest. This is the single most useful measurement for this site, and is low-cost.
  - Take no structural action. The structure provides substantial, SLR-stable protection in the moderate to severe range, and the marsh condition is good.
  - If the loggers confirm that the marsh does not drain below the crest and a vegetation or habitat concern is identified, evaluate an operational change first. Candidate operations are to lower the controlling crest to that of the lower gate (0.034 m NAVD88), or to leave the gates open on routine tides and set them for storms. Neither requires new construction, and both can be modeled by changing the weir crest.

4.4. General Statewide Recommendations

The assessment reviewed 68 tide gates statewide and identified 17 as high priority. These ratings combine flood exposure to nearby structures, marsh health, and gate condition. They are screening-level priorities, not a uniform instruction to replace every high-priority gate immediately. Most high-priority gates rank high mainly because of poor condition, and 15 of the 17 are in Fairfield. Site-specific decisions should account for the gate's function, local flood consequences, marsh conditions, and work already underway.

1. Develop operation and maintenance plans with responsible towns. Confirm who owns and operates each gate, how it is opened and closed, and who is responsible for inspection and maintenance. For the 20 gates whose status is unknown, establish whether the gate remains operational and needed.

2. Prioritize follow-up by the action needed, not the rating alone.Inspect promptly the high-priority gates with structures exposed if opened (Table 30). For high-priority gates with no identified flood consequence, evaluate whether each should be retained, restored for marsh benefit, or decommissioned before spending on repair.

3. Resolve access and data gaps before making final site decisions. Arrange access to the 11 gates that could not be inspected, whether on private property or within enclosed structures, starting with the four that have marsh behind them. For provisionally scored sites, confirm local knowledge of flooding during high tides and storms rather than treating a negligible mapped flood layer as conclusive.

4. Use targeted monitoring to clarify gate and marsh performance. Deploy longer-term water-level loggers where tidal response or gate operation remains uncertain. At marshes where saltwater delivery is in question, measure conductivity, temperature, and salinity upstream before choosing an intervention. Interpret hydraulic results alongside observed marsh condition rather than in isolation.

5. Coordinate implementation with towns. Share site-specific findings with town, explain what a priority rating does, and does not mean, acknowledge projects already underway, and identify applicable technical or funding resources where available.

6. Plan for sea level rise. The current ranking does not include how a gate responds to rising seas (except for the quantitative assessed gates). One-way flap gates, 51% of the inventory, may lose protection as the sea rises. Adopt re-evaluation triggers for gates that protect roads or structures, and include sea level rise response in future screening.

4.5. Data Gaps and Caveats

The findings and recommendations in this report are limited by the data available. This section lists the gaps in the statewide inventory, the gaps at each of the four sites, and the caveats that apply to the recommendations in Section 4.3.

4.4.1 Statewide inventory

- Twenty-six of the 68 gates have no score from the GIS workflow. Thirteen of these are outside the NOAA MHHW + 20 in. flood zone and have been scored provisionally under an assumed flood score of 5 (Negligible). That treatment needs confirmation, as does the tier assigned to a TGSR of exactly 1/3 (FF24, FF26, FF34).

- Eleven gates could not be accessed: eight on private property (GW03, GW04, GW05, OS01, BF01, EH01, WF01, WF02), three enclosed (OS02, SF01, ST03). Four of these have marsh behind them (BF01, EH01, OS01, OS02).

- FF33 was replaced in fall 2025, FF08 is under construction, FF03 has an RFP, and ST02 is to be replaced. The TGSR rates for these gates are now out of date as October 2026.

- Operational status is unknown for 20 gates (29%). What a gate condition rating (CAR) of 1 means in practice (non-functional, abandoned, or still operating) needs to be established, because it determines whether the right action is repair, decommissioning, or paperwork.

- BG01A was accessible but its operational status is unknown. EH02 has been removed and is still in the inventory. GF01 has been renewed since it was rated.

- Gate condition ratings are a snapshot from the field visit. Condition changes after the visit, such as the GF01 renewal, are not reflected in the TGSR until the gate is re-rated.

- The municipality codes in the PlaceID field (for example FF) have been interpreted from the PlaceID pattern and need confirmation against the crosswalk.

- The statewide ranking does not yet include the SLR response of the structure. Only four gates have been modeled hydraulically.

4.4.2 The data gaps at four detailed sites

Table 32: Data gaps at the four detailed sites.

Site	Gap	Why it matters	Action
GF01	No field water level record after renewal. Discharge coefficient (0.65) not recalibrated for the new hardware. Mechanism for the mid-range amplification increase not confirmed. No parcel-level assessment of landward migration space or of the assets protected.	Needed to support the statement that GF01 has the highest IMI, to validate the renewed-gate model, and to decide whether any further modification is warranted.	Loggers on both sides of the gate; add IMI; re-rate the gate; parcel and asset survey.
EH02	Flood consequence unknown (what floods and at what elevation). Culvert height (1.2 m) and discharge coefficient (0.65) are placeholders. Calibration covers two months, and the modeled response is slower than observed (36 min against about 0). Effect of the remaining cobble abutments not assessed. Sediment and elevation data absent.	The recommendation depends on the flood consequence. The culvert results are provisional.	Asset elevation survey; sizing sweep with real dimensions; longer logger record; sediment elevation measurements.
NH01	SRT closure level is an assumed value (2.1 m above the sill, 1.38 m NAVD88), above the field-observed lower bound of about 1.95 m above the sill. Flap opening height unconfirmed (1.6 × 3.5 m given, 1.5 m assumed). Purpose and dimensions of the always-open gate unknown. Flap-state check not completed. No marsh water level record, so the model could not be calibrated. No salinity or porewater data to explain the Phragmites.	The onset of protection (from about 0.7 m, strong only above about 1.2 m), the peak reduction, and the SLR response all depend on these inputs, and the always-open gate largely controls the result. The ecological cause cannot be identified from water levels.	Obtain as-built drawings and operation records; confirm the SRT closure level, flap height and always-open gate size, then re-run the model; deploy water level and conductivity loggers on the marsh and in the channel for at least one year; sample porewater salinity.
WP01 + WP02	Gate operation unknown (whether an operator adjusts the gates). Discharge coefficient (0.6) generic. Interpretation of the 2.6 m "controlling elevation" as bridge clearance not confirmed. Pond bed below about 0.5 m not captured in the DEM. Seepage and leakage not represented. Basin delineation threshold and full SLR table not documented. Correlation and RMSE not computed.	Every result assumes fixed gates. The marsh drainage finding is an upper bound and has not been observed in the field.	Operating protocol; logger deployment in the marsh and Sound; bathymetry of the pond; complete the Step 4 and 6 outputs.

4.4.3 Caveats on the recommendations

- The recommendations are directional and are based on a screening-level hydraulic model. They are not designs, and they do not replace a site-specific engineering evaluation, a cost estimate, or a permit review.

- GF01, EH02 and NH01 share a single tide record from the [New Haven] NOAA gauge, which is a screening assumption. Because each gate is located some distance from the gauge (GF01 is about 15 mi east of New Haven), the tide at the gate will differ from the gauge record in phase, amplitude and surge height. These effects are visible at EH02, where the pressure-sensor record at the structure [lags / leads] the gauge. Because the model uses the gauge record unmodified, simulated exceedance frequencies and peak levels may be shifted by these differences, and phase lag in particular affects the timing of flap closure and the length of the drainage window.
- The model is a lumped mass balance driven by a historical tide record with a constant SLR offset. It represents water level at the structure and in the marsh, but not salinity, sediment supply, rainfall or freshwater inflow, groundwater, evaporation, wave action, or the change in marsh elevation over time. Results for peak levels are more reliable than results for timing.
- The flood-frequency results are given as the number of days per year above an elevation. They have not been related to the elevations of adjacent assets, so the severity of the consequence is not known. Where a recommendation depends on that consequence (GF01, EH02, NH01), the first action is the asset survey.
- Several inputs are placeholders or assumptions: the discharge coefficients, the EH02 culvert dimensions, the NH01 SRT closure level and flap height, and the Westport gate position. The quantities that depend on them are noted in Section 3.3 and should be treated as provisional.
- Some tables are from earlier model runs (NH01) and will change when regenerated. The recommendations for NH01 should be re-checked against the updated tables.
- The MarshRAM results are from a single field visit at each site. The relationship between the marsh condition and the structure is an association and not a demonstrated cause. The explanations offered for the marsh condition at NH01 and Westport have not been tested.
- The SLR triggers and the thresholds suggested in the recommendations (such as the 0.2 m trigger at GF01) are suggestions for discussion and do not come from a regulatory standard. The SLR range tested (0 to 0.5 m) corresponds to the Connecticut planning benchmark and does not cover the long-term behavior beyond it.
- The four sites are a small sample. The findings should not be extrapolated to other gates without the screening described in Section 4.1.
- Permitting pathways, costs, ownership, and maintenance responsibilities were not assessed. They will affect which of the options is feasible at each site.

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