SITKA SEDGE NATURAL AREA HYDROLOGICAL ANALYSIS DRAFT ABRIDGED FINAL REPORT

This publication is an abbreviated summary of PGG/ESA's "Final Draft" (FD) Report. The FD is a technical document that presents the results of PGG/ESA's characterization, model development, model calibration, predictive model simulations and supplemental analyses. In this publication, PGG, ESA, and OPRD have excerpted the executive summary of the Final Draft Report, revised it for additional accessibility to lay readers, and included selected Final Draft figures to illustrate key concepts. Reviewers without a technical background in hydrology may benefit from beginning their review of the assessment work with this summary document, familiarizing themselves with PGG/ESA's findings and conclusions, and then (if desired) moving on to consult the Final Draft Report for more detailed technical information.

Contents

1.0 PROJECT OVERVIEW

The Oregon Parks and Recreation Department (OPRD) is interested in investigating the feasibility of responsible restoration of the Sand Lake Estuary (Figure 1-1). One component of the restoration scoping effort is deciding how to address a failing tide gate in the Beltz dike. Options range from replacement of the tide gate to removal of a portion of the dike. These modifications will alter the flushing processes in 12 acres of marsh area south of the dike, potentially improving habitat quality and benefitting federally listed salmonids in the marsh and upstream creek areas. The existing, failing tide gate is currently malfunctioning such that it allows limited tidal inundation of the marsh area.

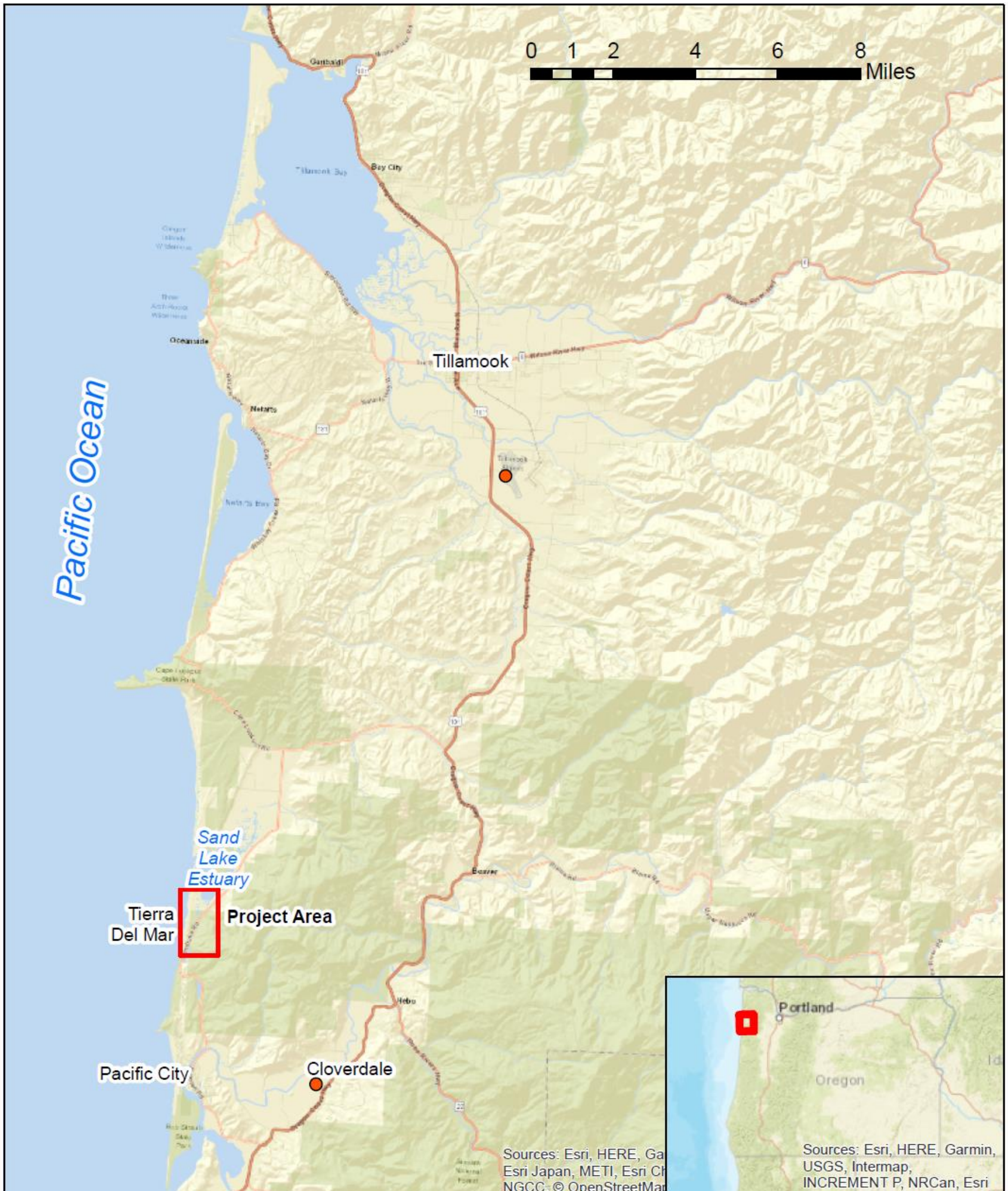
In Oregon, approximately 70% of estuarine wetlands have been lost to conversion. Sand Lake Estuary is perhaps one of the most intact for the entire coast. Native hydrology of the estuary has been altered by past human use, including construction of Beltz Dike that separates two estuarine communities: one open saltwater and saltmarsh, the other a combination of saltwater and saltmarsh, freshwater marsh, scrub-shrub wetland, and forested wetland. OPRD and various stakeholders have been investigating potential opportunities to restore fish passage and habitat in Beltz Marsh and tributary streams through dike modification and improved tidal exchange in the estuary south of the dike. This restoration would be targeted to benefit federally listed coho salmon and optimize native fish passage to Beltz and Reneke Creeks, while minimizing risks to the surrounding area. OPRD hopes to continue to collaborate with stakeholders from the local community and conservation organizations to identify potential restoration concepts, investigate and understand the risks and benefits of each potential restoration concept, and find a solution that enhances fish passage and habitat while not adversely impacting adjacent property.

The effects of increased tide water in the marsh on groundwater and stormwater drainage to the south in Tierra del Mar (TDM) have not previously been fully understood. The TDM community has raised concerns that marsh restoration could exacerbate historically problematic flooding which occurs regularly in the rainy season and causes standing water and potential septic-system impairment. OPRD retained Pacific Groundwater Group (PGG) and Environmental Science Associates (ESA) to evaluate how changes at the dike and tide gate may influence groundwater flooding issues at TDM and how a range of marsh restoration scenarios may alleviate or exacerbate those impacts now and in the future.

PGG and ESA's work built on a previous study that included preliminary characterization of topographic, surface-water and groundwater conditions along with development of a surface-water model. PGG and ESA's scope of work included:

- More detailed topographic, hydrologic and hydrogeologic characterization;
- Refinement and calibration of the prior surface-water model to predict tidal inundation under various potential future tide-gate and dike configurations;
- Development and calibration of a groundwater model of the water-bearing units (aquifers) and confining units (aquitards) underlying TDM, along with their hydraulic connection to surface-water features (Beltz Marsh, East Marsh, the Pacific Ocean, TDM ditches);
- Use of the groundwater model to predict how changes in Beltz Marsh inundation would affect groundwater conditions beneath TDM under scenarios of dike breach and replacement of the undersized existing tide gate with a modern muted tidal model that meets fish passage requirements;
- Surface-water and groundwater modeling to evaluate the effect of removing the beaver dam or using an alternate tide gate closure setting on the predictive scenario results; and
- Hydrologic and hydraulic analysis to evaluate the feasibility of a setback dike alternative, analyze the culvert that drains the east marsh across Sand Lake Rd, and characterize the protective value of the Beltz Dike if overtopped by flooding in Sand Lake.

- Assessment of the effect of elevated marsh water levels on drainage of TDM ditches and No-Name Creek/East Marsh.



This figure shows the location of the study site (red square) relative to regional geography. Precipitation data discussed in the report was collected from stations located in Tillamook and Cloverdale; weather stations are shown by red dots.

Figure 1-1

Project Location Map

Sitka Sedge Natural Area

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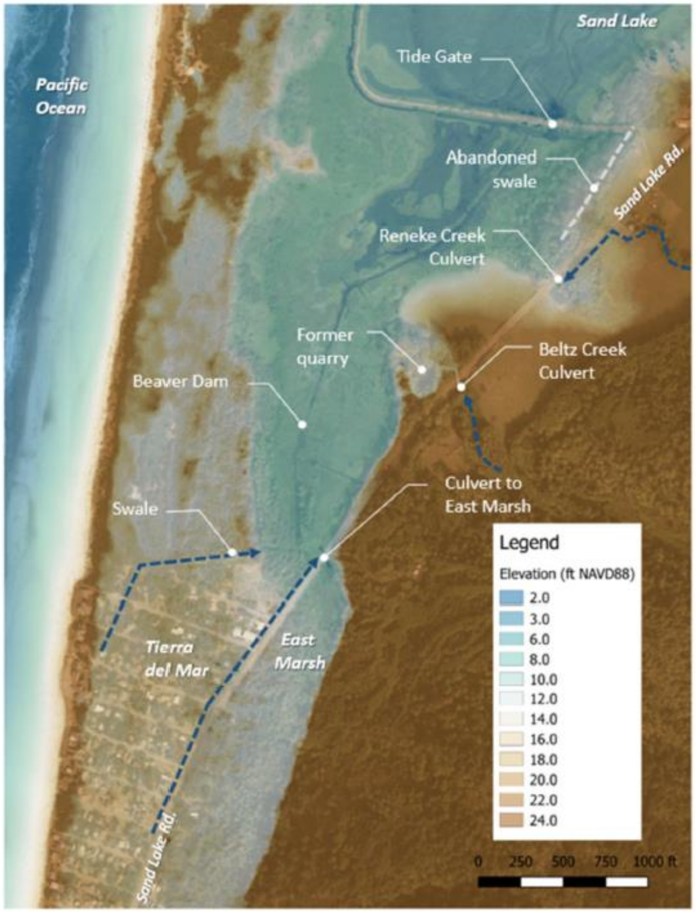
2.0 SURFACE-WATER HYDROLOGY

1. Surface water hydrology in Beltz Marsh and adjacent areas is influenced by tides in the Sand Lake Estuary, freshwater input from Reneke Creek and Beltz Creek, and local drainage features. Tides are the primary driver of regular surface-water level fluctuations in Beltz Marsh. Tidal fluctuations in the Pacific Ocean enter the marsh via the shallow Sand Lake Estuary and pass through Beltz dike via an existing culvert and tide gate.
2. Beltz Marsh is separated from Sand Lake by the Beltz dike. The dike has an approximate crest elevation of 12 feet. The FEMA base flood elevation in this area is 11.8 feet. FEMA floodplain mapping shows the Beltz dike but does not consider it a barrier that prevents flooding from Sand Lake.
3. High tides in Sand Lake are amplified (higher) compared to ocean conditions. Low tides in Sand Lake and Beltz Marsh are severely muted and never fall below 5.3 feet due to a controlling bed elevation in Sand Lake.
4. The existing tide gate is a leaky, wooden, top-hinged gate that allows significant water to enter the marsh during high tides. The tide gate has limited capacity to drain water out of the marsh. During heavy rainfall events, water accumulates behind the dike leading to elevated water surface elevations in Beltz Marsh that are not fully released during outgoing tide. It takes multiple low tide cycles after a significant rainstorm has ended for accumulated water to drain and for water levels in the marsh to equilibrate with Sand Lake. This water retention characteristic of the existing condition can impact adjacent groundwater levels beneath TDM.
5. Areas within the marsh below 5.0 feet remain inundated most of the time, while areas with elevations above 8.0 feet are rarely inundated. The low point in Sand Lake Road is approximately 11.6 feet. Residential areas within TDM have ground elevations generally ranging from 14.0 to 22.0 feet, or higher. TDM has installed a drainage ditch and culvert network that flows north and discharges into the marsh above the direct influence of the tide.
6. An existing beaver dam at the south end of Beltz Marsh impounds water and creates a backwater condition. The beaver dam elevation is approximately 7.0 to 7.5 feet, and water levels south/upstream of the beaver dam typically do not fall below 7.0 to 7.5 feet. The East Marsh is affected by the backwater from the beaver dam and is subject to tidal fluctuations during extreme high tides. Backwater from the beaver dam can lead to water surface elevations of 7.5 to 8.0 feet at the culvert connecting the East Marsh to Beltz Marsh across Sand Lake Road. There is a slope to surface water between TDM and the beaver dam.
7. The upland drainage network installed at TDM has limited capability to drain TDM following intense rainfall events due to a combination of local topographic depressions with a lack of positive surface-water drainage, absence of a drainage network along residential roads, and limited capacity of the culverts along Sand Lake Road to transmit flows. The two drainage ditches intercept shallow groundwater and convey it to Beltz Marsh.



FEMA Base Flood EL. +11.8 ft

Low top of Dike EL. +12.1 ft
Bottom of Tide Gate EL. +1.3 ft
Scour hole EL. -4.5 ft

Low tide in Sand Lake EL. +5.5 ft
MSL in Ocean EL. +3.8 ft

Reneke Ck. Culvert Invert. EL. +9.6 ft

Beltz Ck. Culvert Invert. EL. +20.7 ft

Top of Beaver Dam EL. ~8.0 ft

Culvert to East Marsh Invert EL. 5.15 ft
Low Point in Sand Lk. Rd EL. ~11.6 ft

Culvert Invert at Roma Ave = +11.7 ft
Land in Tierra del Mar EL. +14 to 22 ft

Note: *This figure summarizes the elevations of key features within the project area. All elevations are referenced to North American Vertical Datum 1988 (NAVD88).*

Figure 4-6
Elevations of Key Site Features and Water Levels (NAVD88)

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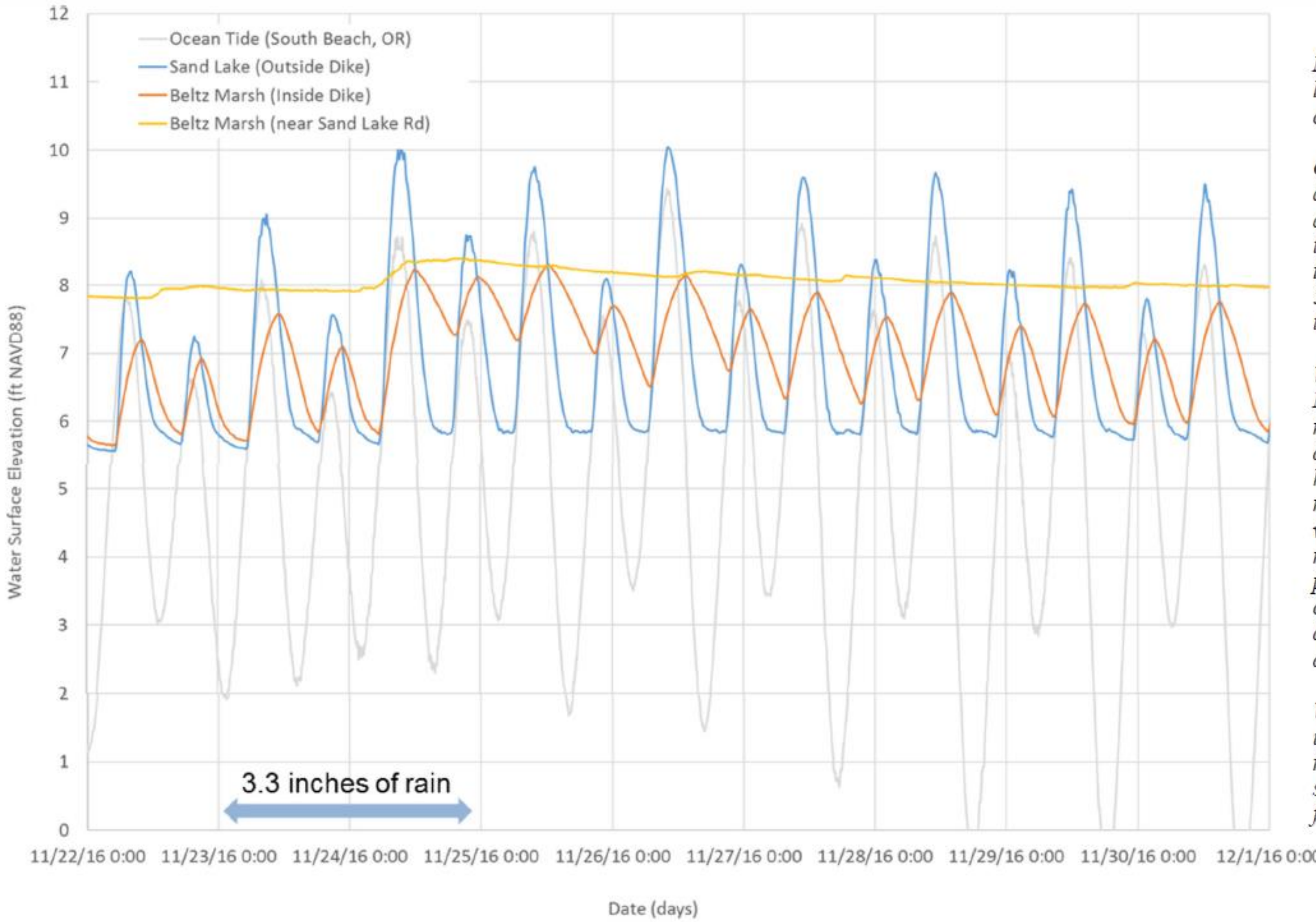
ESA



Note: *This figure shows water level data collected during a typical period during the wet season..*

Ocean tides fluctuate between 0' and 9.5'. Sand Lake water levels are typically slightly higher than the ocean at high tide. Low tides in Sand Lake never fall below 5.5' due to controlling bed elevations.

Water levels inside the dike/ Marsh show a muted tidal connection and low capacity for drainage. The tide gate prevents high tides from entering the marsh. After a rainfall event, water accumulates within the marsh, and the undersized culvert prevents efficient drainage. Accumulated water takes several days, and several low tides, to drain.

Water levels at Sand Lake Road upstream of the beaver dam are relatively constant at 8', with a slight increase following a rainfall event.

Figure 4-3
Typical Water Level Fluctuations in Beltz Marsh During the Wet Season

3.0 GROUNDWATER HYDROLOGY

8. PGG installed seven wells at four locations at TDM. There are two separated aquifers beneath TDM: a shallow unconfined aquifer with connectivity to the surface, and a deeper confined aquifer. PGG's wells were installed in both aquifers to track and compare their relative water level elevations (WLE's). Both aquifers are composed of sandy sediments and are separated by a clay layer that inhibits water flow between them (aquitard). The clay layer appears to be present throughout the study area and extends from bedrock on the east towards the beach areas west of the foredune. The layer appears to thin to the west and is inferred to pinch out and end under the foredune or beach. See Figures 5-1, 5-2a, and 5-2b.

9. PGG and OPRD measured water levels in monitoring wells installed above and below the clay layer over a 38-day monitoring period from February 16, 2018 to March 26, 2018. The timing of the monitoring was selected to capture the wet season – when the seasonally high water table coincides with relatively high rainfall. Additional water-level snapshots were taken in May and August 2018, with the former including water-level measurement at a temporary piezometer installed between existing monitoring wells to document the presence of a groundwater divide. Groundwater levels indicated:

   - There is a persistent downward vertical gradient between the Shallow and Deep Aquifers with a head differential of up to 4.25 feet across the clay layer. No upwelling from the deeper aquifer was observed beneath TDM, but likely occurs offsite where the deep aquifer discharges to surface-water features.
   - There is no tidal signature in the shallow aquifer and there is a muted tidal signature in the Deep Aquifer. This is consistent with unconfined conditions in the shallow aquifer and confined conditions in the Deep Aquifer unit, as suggested by geologic observations during drilling. See Figure 5-3.
   - The groundwater beneath TDM flows towards surrounding discharge points. A groundwater flow divide (a high point or "ridge-like" feature in the water-table) separates flow to the northwest (towards the beach) from flow to the north (towards Beltz Marsh) from flow to the northeast (towards the ditch along Sand Lake Road and the east marsh). See Figure 5-4c.
   - The water levels in the deeper aquifer unit suggest that the clay layer is absent, discontinuous or leaky near the bedrock contact east of TDM at the toe of the hillslope east of the east marsh, thus allowing groundwater discharge into the east marsh area via the shallow aquifer.

10. Groundwater flooding issues at TDM occur when the water table rises above the ground surface. This is most common during winter months and is qualitatively observed to occur with precipitation events greater than one inch in 24 hours. This flooding covers roads, driveways and yards, and can also impact septic system function with the water table near, but not above, the ground surface. After a groundwater flooding event, subsequent decline of the shallow water table is limited

by rates of groundwater flow towards discharge features (constructed drainage ditches and nearby surface-water features).

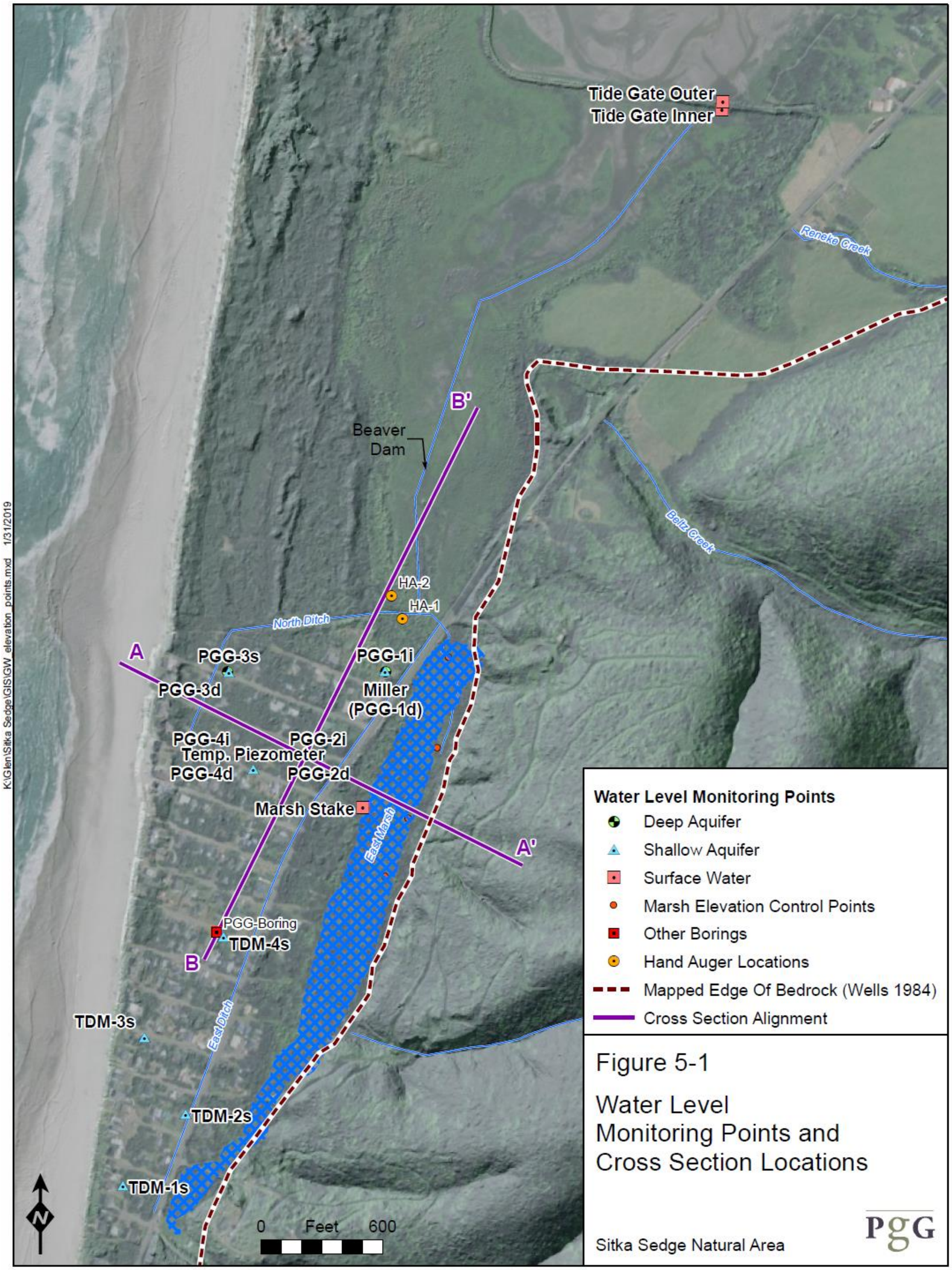


Figure 5-1

Water Level Monitoring Points and Cross Section Locations

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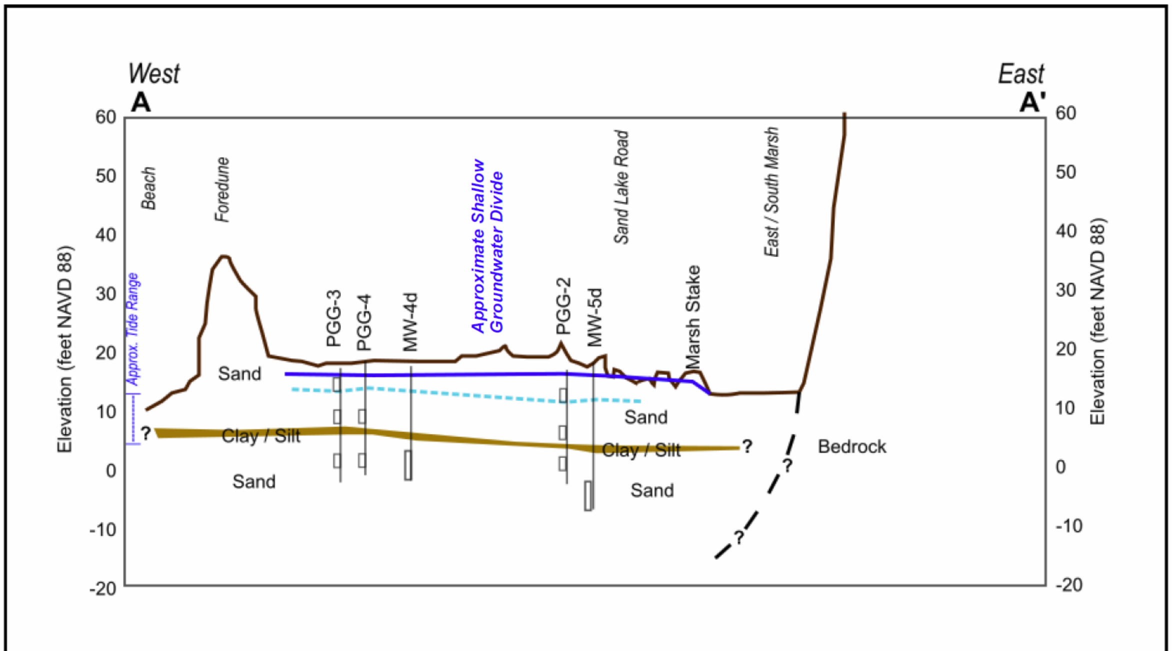

Notes:
— Shallow Potentiometric Surface
-- Deep Potentiometric Surface
15x Vertical Exaggeration

Well ID
Boring Axis
Screen Interval

This figure shows a cross section through the study area from the beach (west) to bedrock in the hills east of TDM. There are no borings at or west of the foredune, and the clay layer is expected to pinch out west of the foredune, though the location of that transition is uncertain. It is common for water levels (reflecting pressure head) in semi-confined or confined aquifers to rise above the elevation overlying confining layer, as observed for the deep potentiometric surface, above.

Figure 5-2a
Geologic Cross Section A-A'

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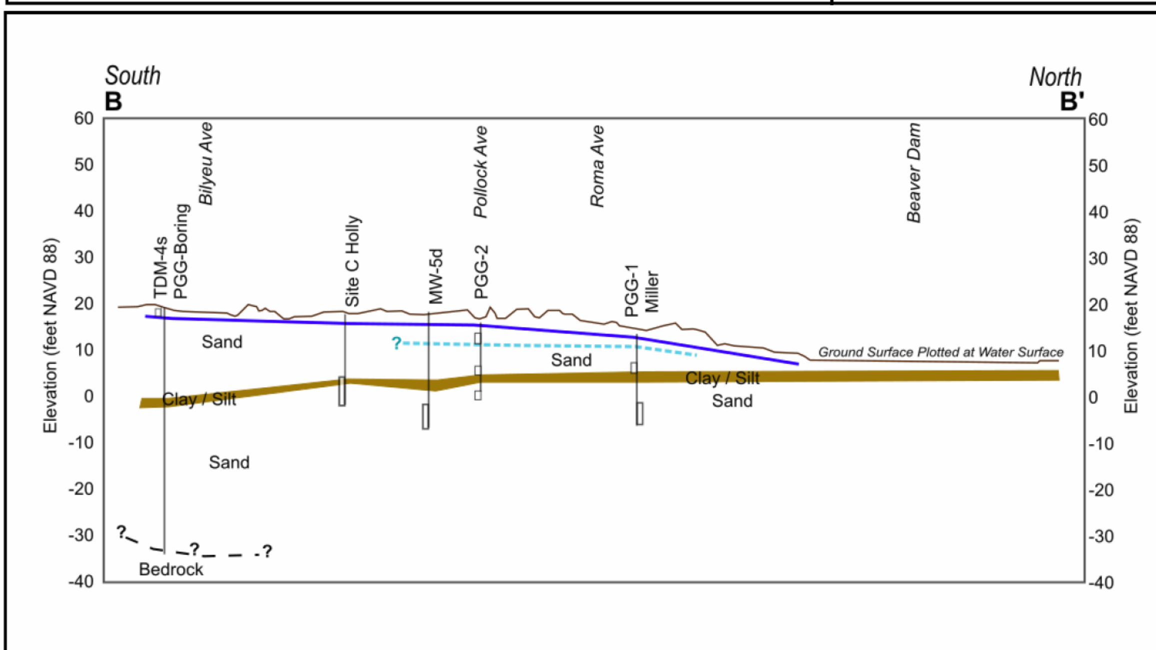

Notes:
— Shallow Potentiometric Surface
-- Deep Potentiometric Surface
15x Vertical Exaggeration

Well ID
Boring Axis
Screen Interval

This figure shows a south to north cross section through the study area from near the TDM Community Center into Beltz Marsh. The boring log from a well on Whalen Island on the north part of Sand Lake Estuary suggests that the clay layer is present throughout the estuary. The shallow potentiometric surface (water table) dips to the north reflecting groundwater discharge towards surface water features (some of which are out of the plane of the cross section). It is common for water levels in semi-confined or confined aquifers to rise above the overlying confining layer, as observed for the deep potentiometric surface, above.

Figure 5-2b
Geologic Cross Section B-B'

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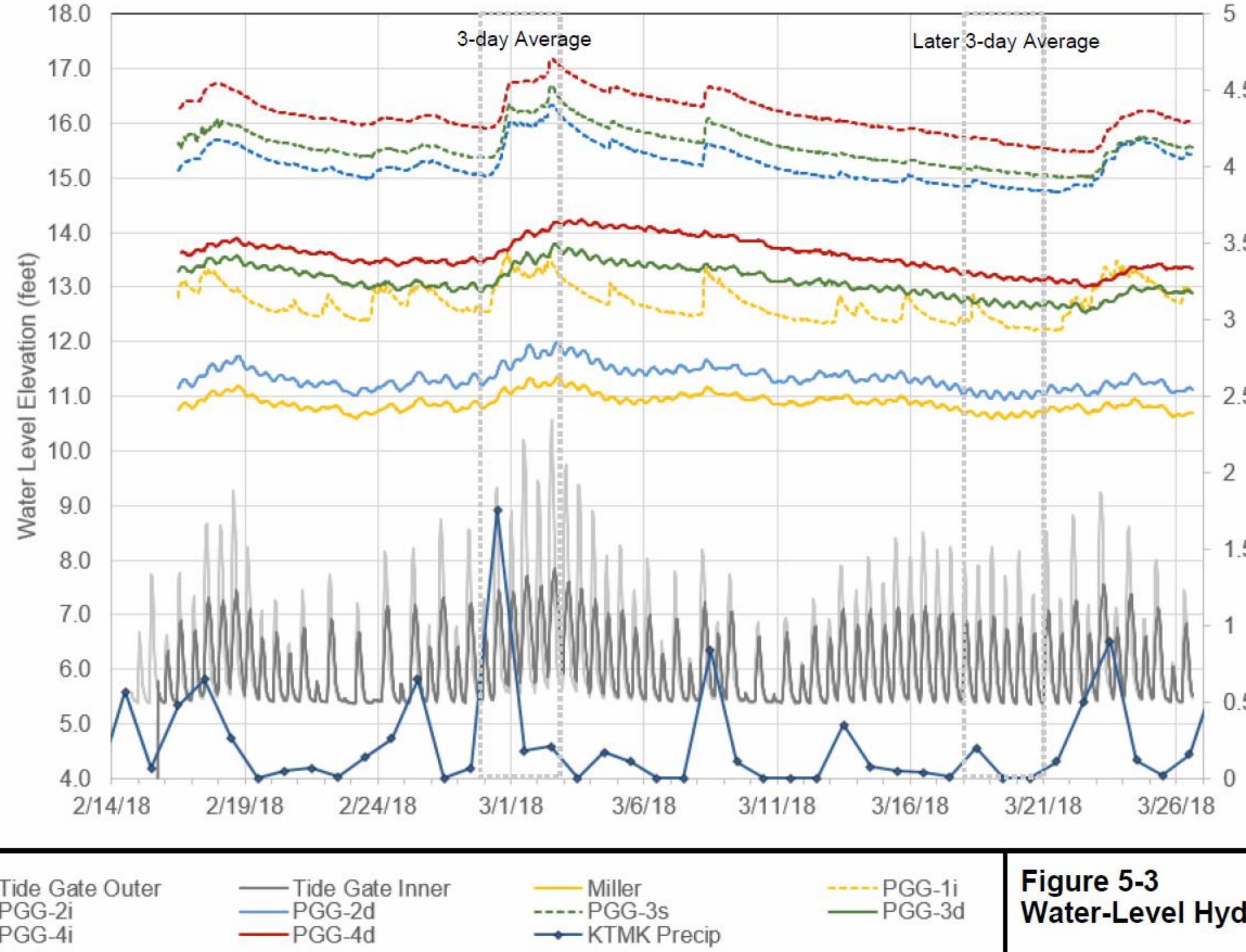

This figure shows the variation in water level elevations measured in each of the study wells and at the surface water monitoring points at the tide gate. This figure also shows the daily precipitation record from Tillamook, Oregon. Water levels measured in wells can be seen to rise following precipitation events as recharge reaches the water table. KTMK is the Tillamook weather station.

Figure 5-3
Water-Level Hydrographs

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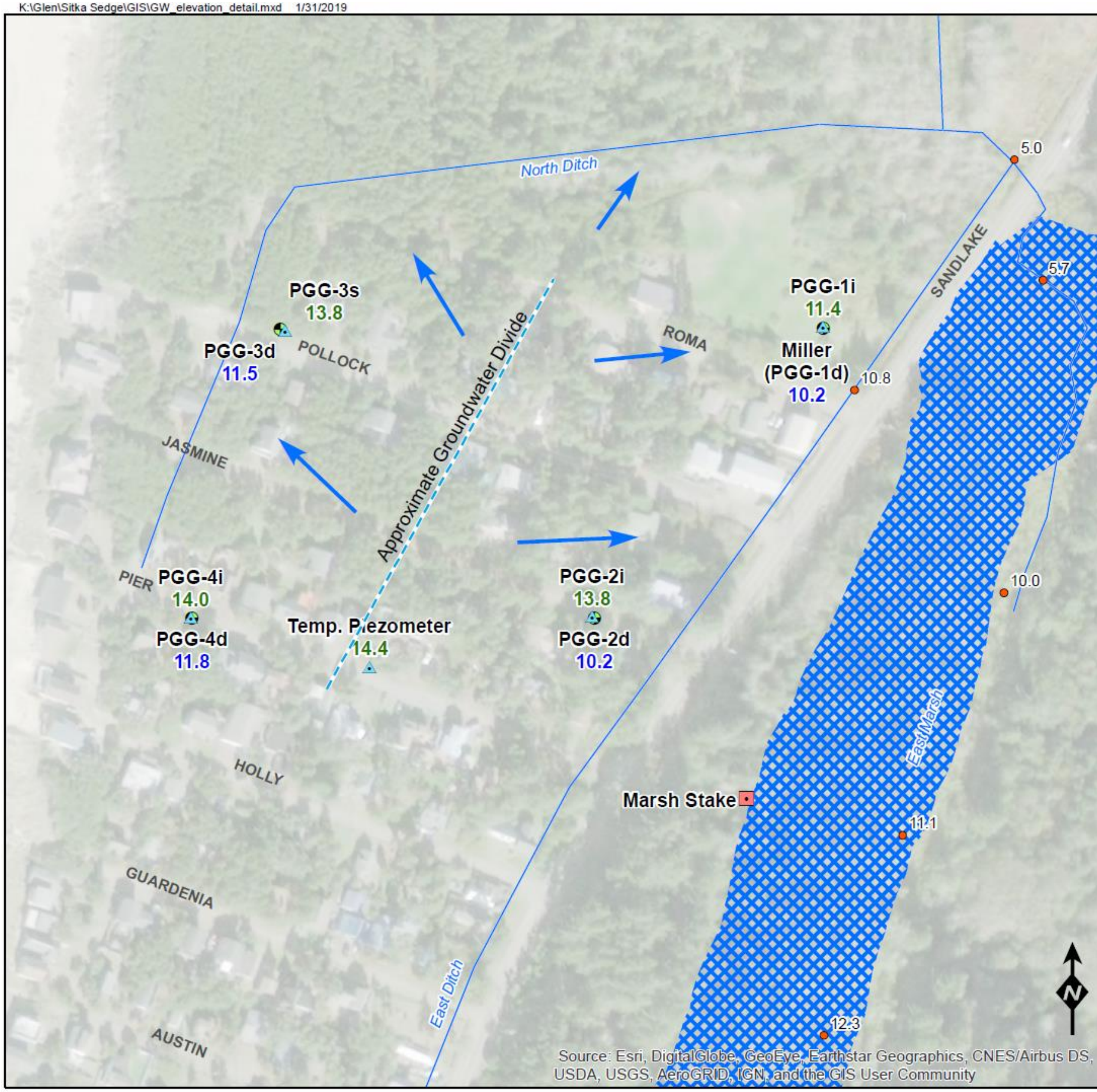

This figure shows the elecation of water levels at selected groundwater and surface water monitoring points. Groundwater will flow from areas of higher water levels to lower water levels. The water levels shown here were measured concurrent with the measurement of water levels at a termporary piezometer on Pier Avenue. This water level snapshot documented the presence of a groundwater divide in the shallow aquifer. The groundwater divide depicted represents the approximate location of a groundwater ridge which implies westward flow to the west of the line and eastward flow to the east of the line.

Water Level Elevation
5/21/2018

- Deep Aquifer
- Shallow Aquifer
- Surface Water
- Marsh Survey Elevations (4/2018)
- Expected Directions of Shallow Aquifer Groundwater Flow (Approximate)

0 Feet 200

Figure 5-4c

Water-Level Elevations 5/21/2018

Demonstrates Presence of Groundwater Divide

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Natural Area

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4.0 MODELING

Both surface-water and groundwater modeling were used to evaluate how changing the tide-gate configuration on the Beltz Dike would affect depth to groundwater in the shallow aquifer beneath TDM. The surface-water model was used to estimate how three different dike/tide-gate configurations (existing tide gate, modern fish-passage-regulation-compliant tide gate, and dike breach engineered for fish passage) affects the extent and duration of inundation in Beltz Marsh due to tides and stream inflows. The groundwater model was used to compare how shallow groundwater beneath TDM responds to inundation regimes predicted by the surface-water model.

4.1 SURFACE-WATER MODEL

11. An existing surface water balance ("bucket") model was updated for this study. The water balance model captures the essential hydrologic characteristics of the surface-water system and provides a time series of surface water levels (stages) as input to the groundwater model. The bucket model was modified to improve the stage-storage relationships in Beltz Marsh based on new topographic and bathymetric information provided by OPRD and to incorporate water inputs from TDM, the East Marsh, and direct precipitation on the marsh.
12. The bucket model was calibrated to a 7-month record of water level data collected inside and outside of the dike (November 2016 thru June 2017), which includes wet periods, dry periods and at least 5 intense rainfall events. Calibration was performed by adjusting the friction in the modeled tide-gate culvert opening and by assuming that the gate remained slightly open during rising tides (driving 'leaky tide gate' conditions). Calibration achieved a high level of agreement between modeled and observed water levels inside the marsh.
13. To understand how water levels in Beltz Marsh would be affected by alternatives to the existing tide gate, we developed an initial "worst case" hydrology scenario to use for predictive modeling scenarios. OPRD and the PGG/ESA team agreed on a 38-day hydrology scenario that incorporates: (1) a 28-day "wind-up period" with typical winter tide and runoff conditions from January 7th to February 4th, and (2) a 10-day 'storm' period from February 5th to February 14th based on precipitation and runoff scaled to approximate a 50-year storm that occurs during an extreme "king" tide event in Sand Lake Estuary.
14. The bucket model was configured to address three different tide-gate configurations in the Beltz dike. Besides the existing tide-gate configuration, two alternative configurations (both likely to meet fish passage criteria) included:
    - Breached Dike – excavating a portion of the dike to create an open "breach" or tidal channel inlet, sized based on Design Guidelines for Tidal Channels in Coastal Wetlands (Philip Williams & Associates, 1995). The modeled breach

extends to 0 feet elevation and ranges from 37 feet wide at the base to 53 feet wide at Mean Higher High Water.

- Modern Tide Gate System – replacing the existing culvert and tide gate with a modern tide gate system designed to meet fish passage criteria, while allowing the water level in the marsh to be controlled at a set elevation. Preliminary sizing is based on a Muted Tidal Regulator system that limits the surface water elevation to 7.0 feet; the tide gates shut when the interior water surface elevation reaches 7.0 feet and the tide gates re-open when the water level in Sand Lake falls below the interior water level allowing Beltz Marsh to drain. An alternative closure setting of 8.0 feet was also evaluated. The preliminary tide gate sizing includes two, side-by-side tide gates, each 8 feet tall and 10 feet wide.

15. Use of the model to simulate the 38-day hydrology scenario under all three tide-gate configurations was considered to provide a range of "book end scenarios" that span the range of predicted effects of various tide-gate configurations over a range of hydrologic conditions. The modeled scenarios are expected to reflect the greatest range in tidal stage in Beltz Marsh. Surface-water modeling results for the three scenarios include:

    - Existing Conditions (existing culvert and tide gate through dike):
        - During the 28-day wind up period, water levels inside marsh ranged from 5.5 to 8.3 feet.
        - During the 10-day storm period, water levels peaked at 12-12.5 feet.
        - Flood levels in the marsh remained above 9 feet for more than 3 days because the existing tide gate is inefficient at draining Beltz Marsh.
    - Breached Dike:
        - The breach is an efficient conveyance and water levels inside the marsh closely matched the water levels in Sand Lake at all times.
        - During the 28-day wind up period, water levels inside marsh ranged from 5.5 to 11.2 feet.
        - During the 10-day storm period, water levels briefly exceeded 12.0 feet.
        - The much larger opening allows water to freely drain out of the marsh, so elevated water levels quickly fell as the tide receded and were not impounded behind the dike.
    - Modern Tide Gate:
        - Peak daily water levels were lower than both the breached-dike and existing-tide-gate configurations because the tide gate closes when water levels inside the marsh reach 7.0 feet on a rising tide.
        - During the 28-day wind up period, water levels inside marsh ranged from 5.5 to 7.5 feet.

  - During storm conditions, water levels in the marsh were lower than both the breached-dike and existing-tide-gate configurations because of the limited tidal inflow and the efficient flow of water out of the marsh.
  - During the 10-day storm period, water levels briefly exceeded 10.0 feet, but quickly fell as the tide receded.
  - The alternate 8.0-foot closure setting yielded interior marsh water levels peaking approximately 1 foot higher during typical winter conditions and moderate storms. During the height of the storm scenario peak water levels were only 0.1’ to 0.2’ higher when using the 8.0’ closure setting compared to the 7.0’ closure setting.

16. Preliminary analysis was performed to evaluate the feasibility of constructing a setback dike located south of Reneke and Beltz Creeks that would allow for full tidal reconnection of the majority of Beltz Marsh while maintaining flood protection for TDM;
    - A setback dike constructed across the south end of Beltz Marsh, near the existing beaver dam, would have adequate storage volume capacity to contain rainfall and runoff from TDM and the East Marsh during a 100-year storm event.
    - An estimated 35 acre-feet of water could be stored upstream of the setback dike in this location before water levels would inundate the low point in Sand Lake Road (11.6’ NAVD88). Under a 100-year flood event, the combined inflows from the East Marsh and TDM would accumulate a maximum of 21 acre-feet in any 8-hour period (Figure 8-1). This is likely the maximum duration that elevated water levels in Sand Lake would prevent drainage out of the setback dike.
    - The setback dike configuration could result in lower peak and sustained water levels than the existing configuration, lower peak water levels than the breached dike configuration, and similar peak water levels to the modern tide gate configuration. A more-detailed analysis of a setback dike alternative could be pursued if later scoping indicates this alternative is desirable in the context of the current modeling results and wider environmental effects analysis.
17. The effect of surface water "backing up" upstream of the Sand Lake Road culvert in the East Marsh, or in the TDM east ditch along Sand Lake Road was characterized using hydraulic calculations for culvert capacity compared to stream flow estimates;
    - The estimated capacity of the culvert crossing sand lake road ranges from 7 cfs to a maximum of 18 cfs, depending on the water level difference on either side of the culvert. The estimated peak stream flows for the East Marsh during a 50-year event frequently reach 14 cfs, with a maximum peak of 23 cfs. The estimated peak stream flows for the East Marsh during a 100-year event frequently reach 16 cfs, with a maximum peak of 27 cfs. During both

the 50-year and 100-year event, stream flows from the East Marsh watershed would exceed the capacity of the culvert, resulting in stormwater backing up in the East Marsh.

- When water levels in Beltz Marsh are elevated (up to 12' NAVD88 under some modeled conditions), water levels in the East Marsh would rise to equilibrate. The capacity limitation would delay the time for water levels to equilibrate. These elevated water levels can also propagate upward into the TDM east ditch.
- In the TDM east ditch along Sand Lake Road, the lowest/northernmost culvert has an invert elevation of 11.72'. This 12-inch diameter culvert has a 3-percent slope and an estimated capacity of 8 cfs, but deposited sediment and debris blockages could significantly reduce the drainage capacity. Elevated water levels could infrequently inundate the pipe, influencing culvert hydraulics and reducing capacity of the pipe.
- Conservatively estimated 50-year and 100-year peak runoff rates draining to this culvert are 8 cfs and 10 cfs, respectively. Actual flows are likely less and infrequently exceed the capacity of culverts along Sand Lake Rd. A more detailed assessment of capacity and condition of all of the east ditch culverts could be undertaken to identify potential blockages or bottlenecks and sources of water backing up.

18. The protective value of an overtopped dike for its ability to reduce peak water levels or delay rising water levels upstream of Beltz Dike was characterized using hydraulic calculations, based on assumed water levels exceeding the crest elevation of the dike;
    - The modeled water levels in Sand Lake nearly overtop Beltz Dike. More extreme high tide conditions resulting from a storm surge or sea level rise would overtop Beltz Dike, and water levels within Beltz marsh would eventually equilibrate to the water levels in Sand Lake. During overtopping events, the dike may still offer some flood protection, or have a buffering effect by slowing water down as it fills Beltz Marsh.
    - Under a full dike breach scenario, water levels in Beltz Marsh would rise and fall along with water levels in Sand Lake, and the remaining dike would not offer any provide any protection or delay rising water levels.
    - Under the existing configuration, or with a Modern Tide Gate in place, the dike would delay rising water levels, depending on the height of water over the crest of Beltz Dike (12.1' NAVD88). Using weir overflow calculations, we estimated:
        - When the dike is overtopped by 0.5 feet (approximately 12.6' water level), water would overflow into Beltz Marsh at a rate of approximately 1,000 cfs, and it would take about 3.5 hours to fill in/equilibrate.
        - When the dike is overtopped by 1.0 feet (approximately 13.1' water level), water would flow into Beltz Marsh at a rate of

approximately 6,500 cfs. At this rate, it would take only 30 minutes to completely fill in/equilibrate.

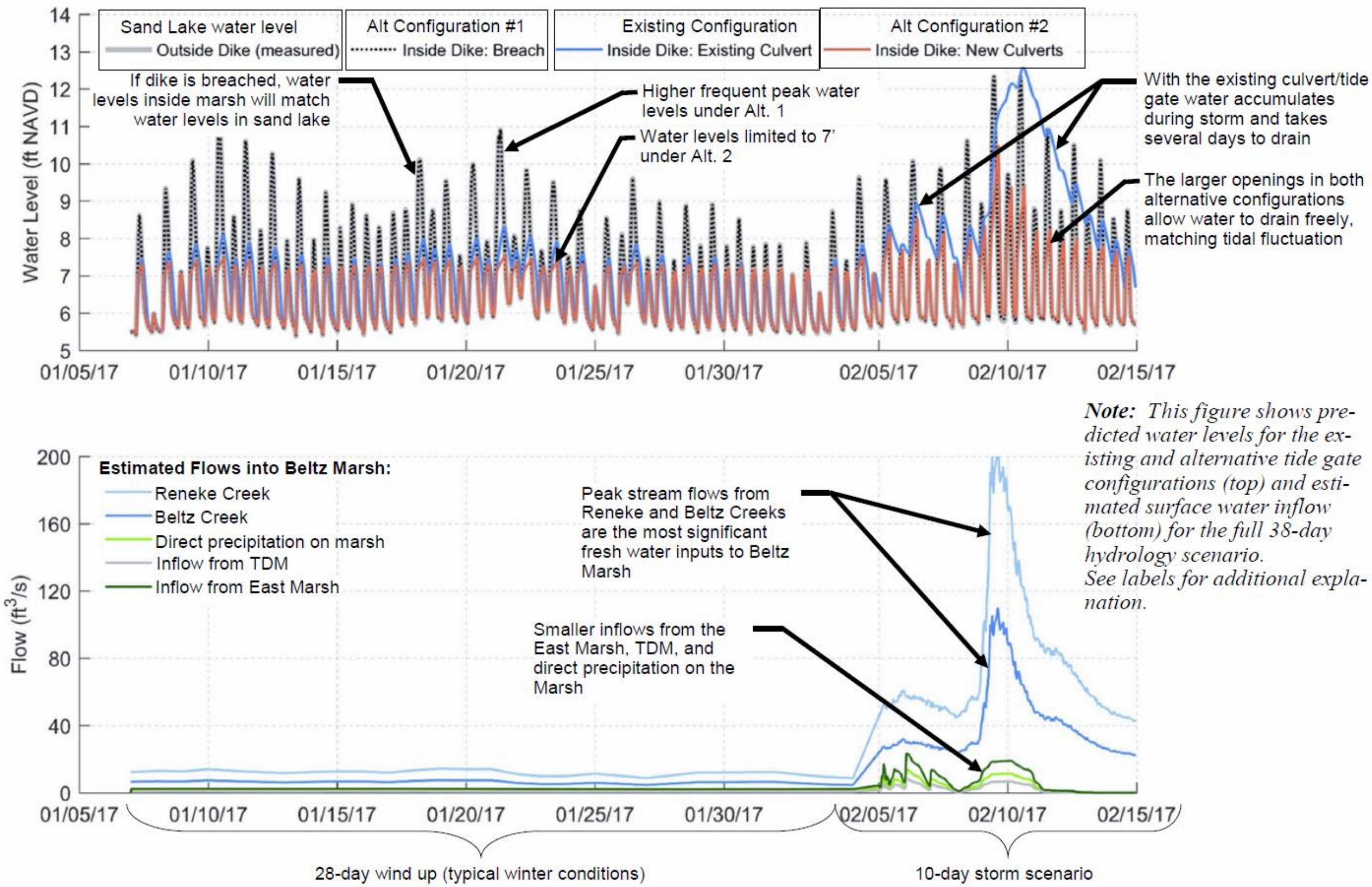
- Depending on the depth of water overtopping the dike, the overtopped dike can provide some flood protection value by delaying rising water levels. However, overflowing water could cause erosion along the embankment which could lead to dike failure or an un-planned dike breach. To counteract this potential failure, low spots in the dike could be identified and rock armoring could be installed to protect the embankment from erosion during overflows.

19. The surface-water model's stage-storage relationship was modified to assess how the inclusion (or exclusion) of inundation accumulated behind the beaver dam affects surface-water model results (i.e., if substantial additional storage volume could be achieved by removing the beaver dam);

    - Based on field observations and review of the LiDAR/PhoDAR surface, we lowered the inundated area by an average of 2 feet. This adjustment resulted in 2.1 acre-feet of additional storage volume below the elevation of 8'. A new stage-storage relationship was developed from the modified surface, and the surface-water model predictive scenarios were re-run to determine if the additional storage would affect modeled water levels.
    - With the beaver dam removed, the additional storage lowered modeled water levels by a maximum of 0.1 feet. When plotted together, the water levels are not visibly different (Figure 8-2). Removing the beaver dam would not have a noticeable effect on water levels during storm conditions.

20. The surface-water model was adjusted to simulate the modern tide gate configuration with an 8-foot closure setting (rather than a 7-foot closure setting) during the same time 38-day prediction period as used in the previous model. Appendix H refers to modeling both 7.5 and 8-foot closure settings; however, in completing the 8-foot setting and finding insignificant storm-scenario differences from the 7.0 closure setting (in terms of both surface water and groundwater effects), it was decided that additional modeling effort and expense to complete the intermediate 7.5-foot closure setting was not necessary.

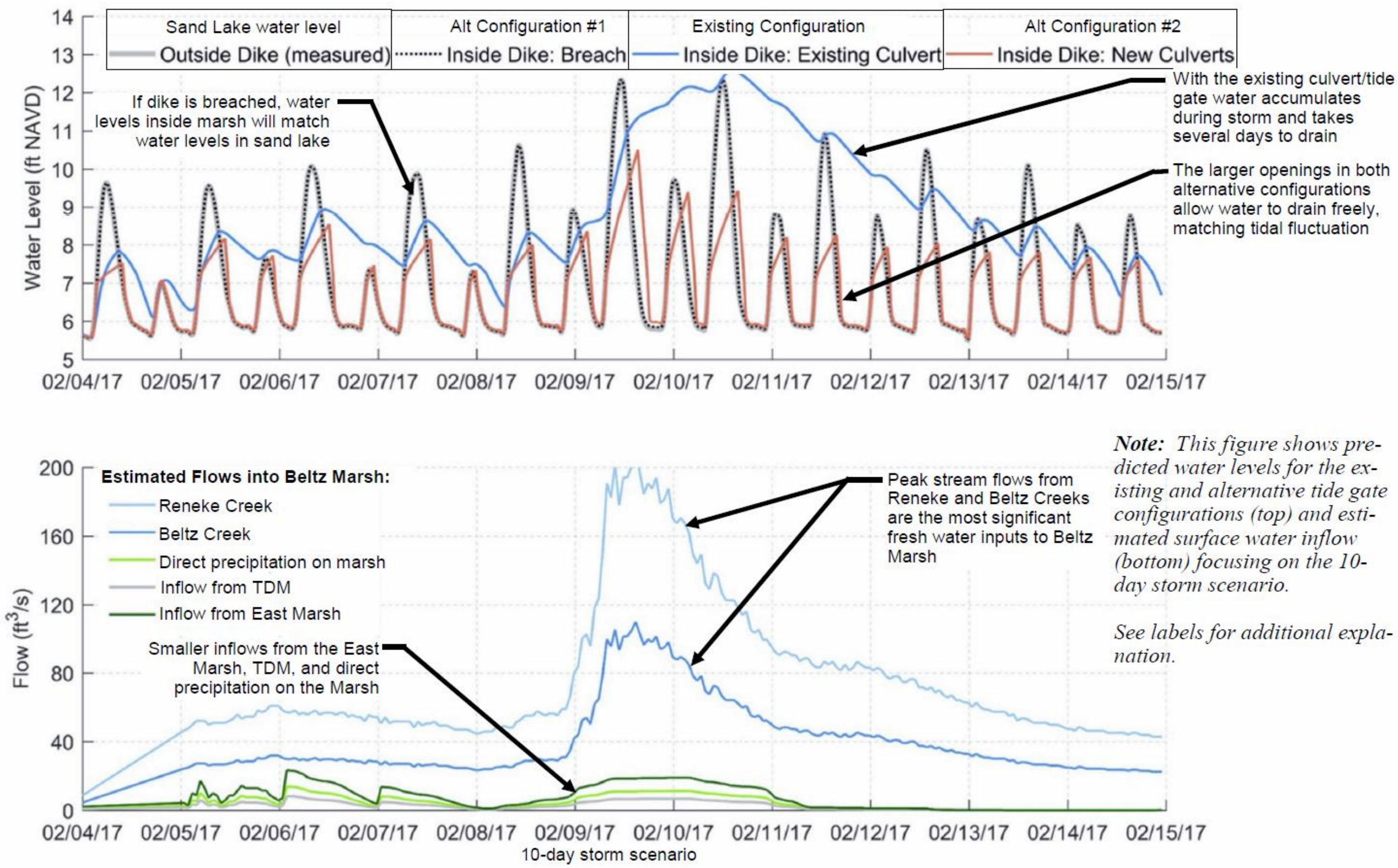
    - In the surface-water model, the alternate 8.0-foot closure setting yielded interior marsh water levels peaking approximately 1 foot higher during typical winter conditions and moderate storms. During the height of the storm scenario peak water levels were only 0.1' to 0.2' higher when using the 8.0' closure setting compared to the 7.0' closure setting (Figure 8-3). if the additional storage would affect modeled water levels.



SOURCE: ESA surface water model. Runoff values were scaled to 50-year values based on precipitation measured at Tillamook and runoff measured at the USGS Tucca gauge

Figure 7-1
Predicted Water Levels in Beltz Marsh for the Existing and Alternative Tide Gate Configurations for the Full 38-day Hydrology Scenario

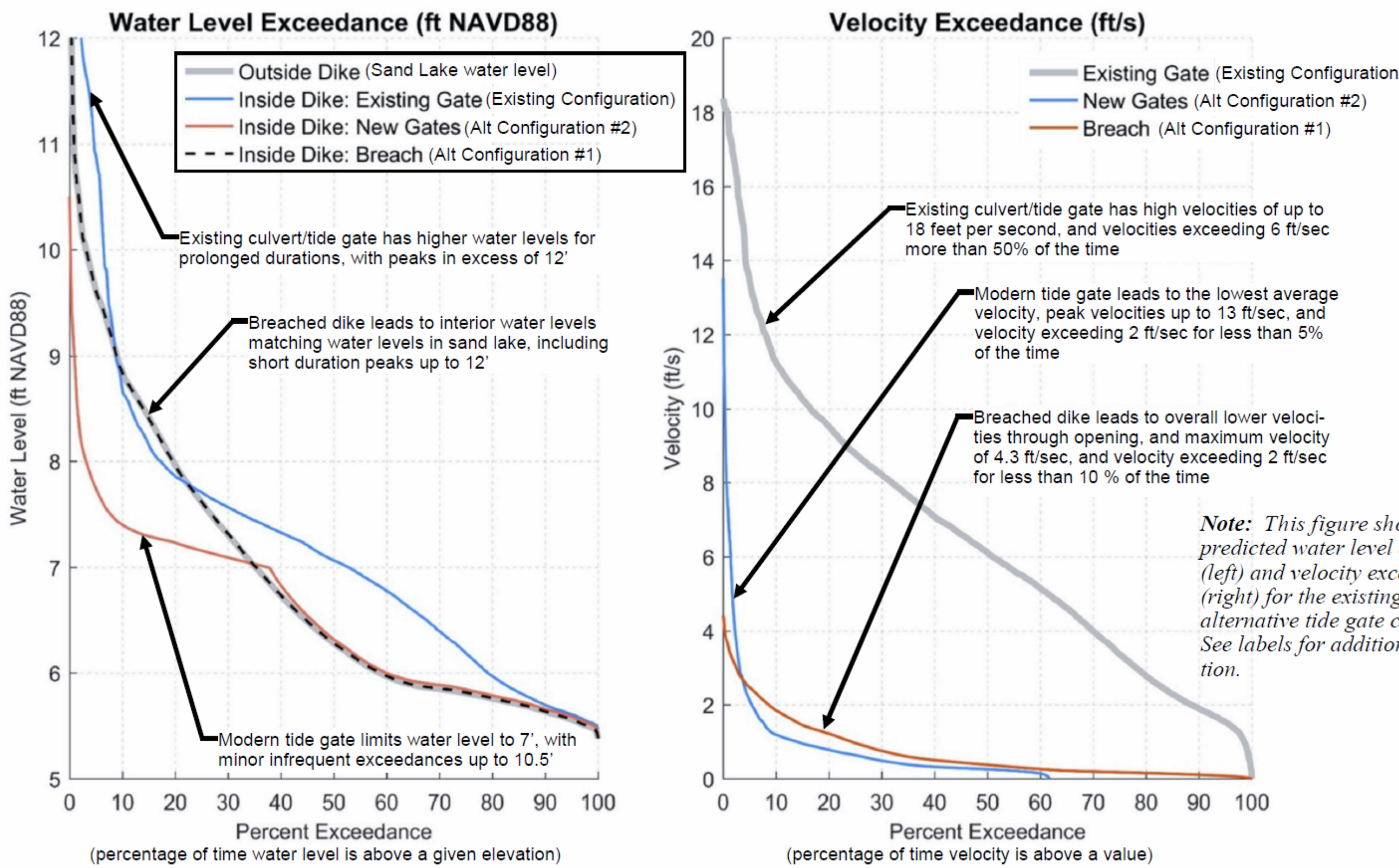
Sitka Sedge Natural Area



SOURCE: ESA surface water model. Runoff values were scaled to 50-year values based on precipitation measured at Tillamook and runoff measured at the USGS Tucca gauge

Figure 7-2
Predicted Water Levels in Beltz Marsh for the Existing and Alternative Tide Gate Configurations for the 10-day Storm Scenario

Sitka Sedge Natural Area

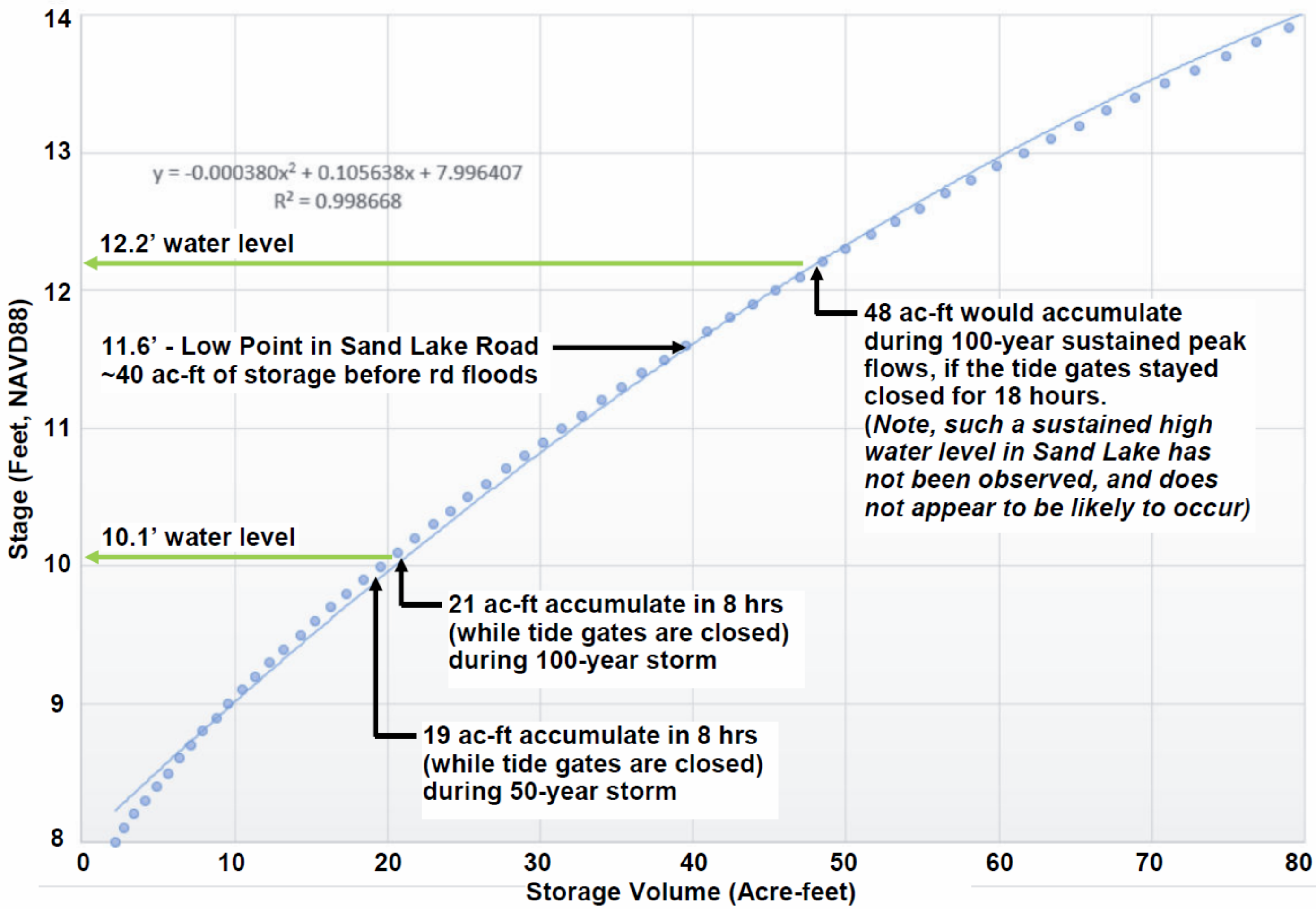


Note: This figure shows predicted water level exceedances (left) and velocity exceedances (right) for the existing and alternative tide gate configurations. See labels for additional explanation.

SOURCE: ESA surface water model. gauge

Figure 7-3
Comparison of Water Level Exceedances and Velocity Exceedances for Existing and Alternative Tide Gate Configurations

Sitka Sedge Natural Area



Note: This figure shows the stage-storage volume relationship for a theoretical setback dike constructed near the existing beaver dam, oriented east-to-west, across the south end of Beltz Marsh. The blue dots correspond to storage volume measurements at each 0.1-foot elevation increment. The solid blue line is the best-fit trend line for these data points.

The setback dike would be intended to allow the Beltz Dike to be fully breached while preventing tidal flooding from occurring at the south end of the marsh and at Tierra del Mar.

Based on preliminary conceptual analysis, it appears that a setback dike in this location would have adequate flood storage capacity to contain the combined 100-year storm surface-water inputs from TDM, the East Marsh, and direct precipitation.

See labels for additional explanation

SOURCE: ESA derived stage-storage relationship based on PhoDAR terrain surface provided by OPRD.

Figure 8-1
Annotated Stage-Storage Relationship for the Area Behind a Proposed Setback Dike

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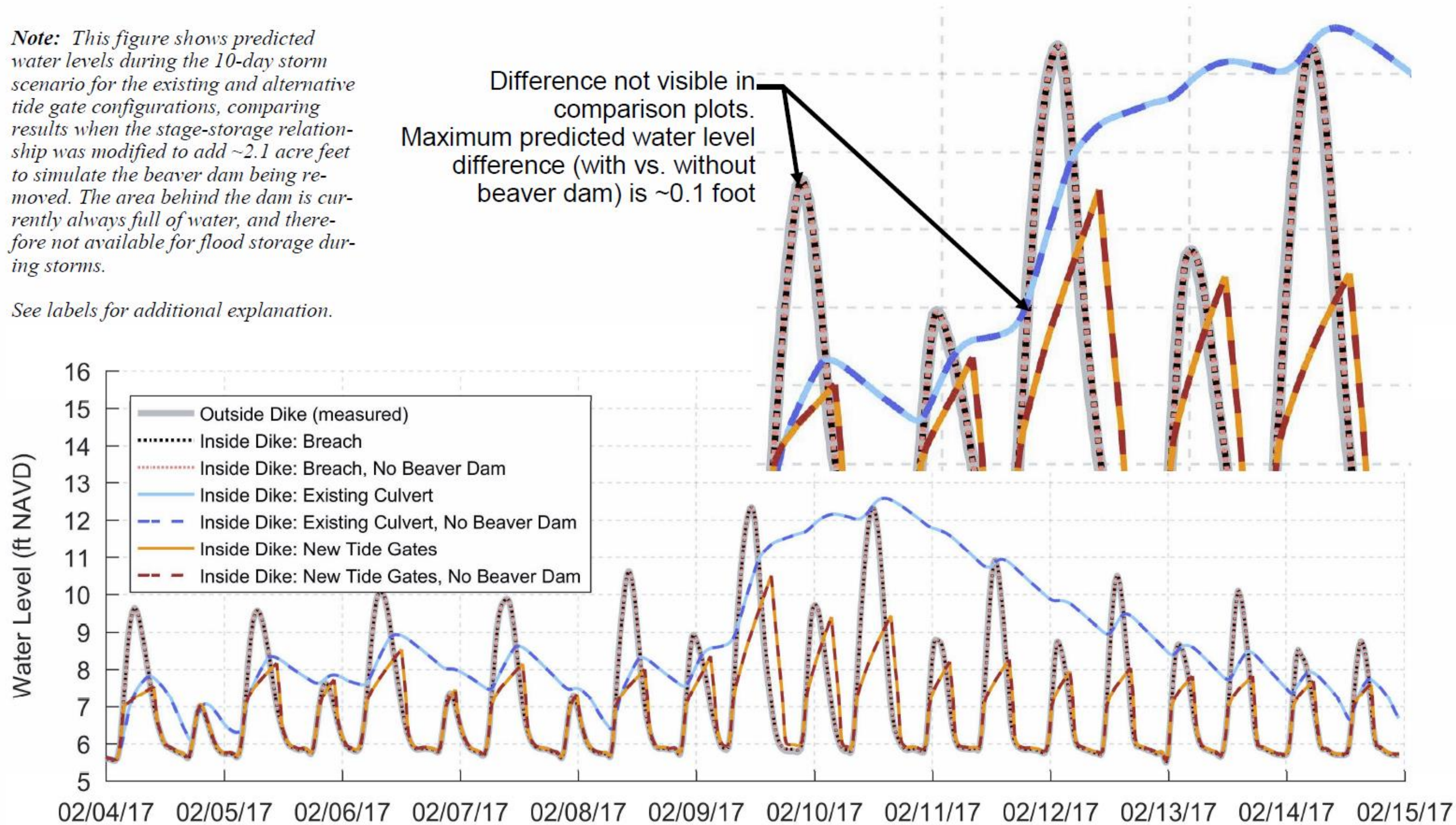
Note: This figure shows predicted water levels during the 10-day storm scenario for the existing and alternative tide gate configurations, comparing results when the stage-storage relationship was modified to add ~2.1 acre feet to simulate the beaver dam being removed. The area behind the dam is currently always full of water, and therefore not available for flood storage during storms.

See labels for additional explanation.



SOURCE: ESA surface water model. gauge

Figure 8-2
Comparison of Predicted Water Levels for the Alternative Configurations, with and without the Beaver Dam

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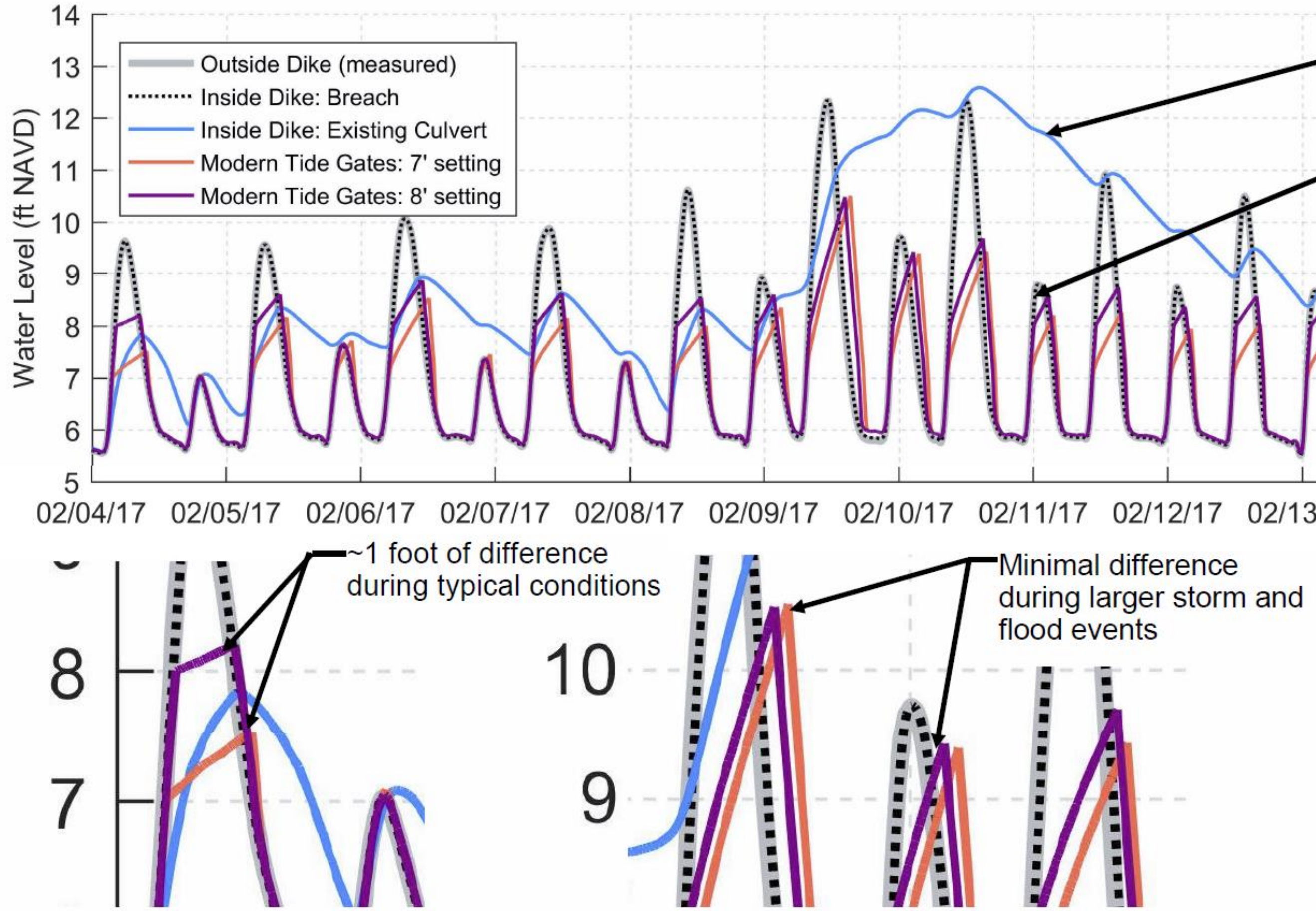


Note: This figure shows predicted water levels during the 10-day storm scenario for the existing and alternative tide gate configurations, focusing on the comparison between the 7-ft and 8-ft tide gate settings for the Modern Tide Gate configuration.

See labels for additional explanation.

SOURCE: ESA surface water model. Runoff values were scaled to 50-year values based on precipitation measured at Tillamook and runoff measured at the USGS Tucca gauge

Figure 8-3
Comparison of Predicted Water Levels for Modern Tide Gate Using 7-foot Vs. 8-foot Closure Settings

ESA

Sitka Sedge Natural Area

4.2 GROUNDWATER MODEL

21. The groundwater model covers a 442-acre area that extends west-to-east from the beach to the bedrock uplands and north-to-south from Beltz Marsh to Sears Lake. The model divides up the subsurface into interconnected cube-like “cells”, which are further grouped into three “layers”. The top layer represents the shallow aquifer, the middle layer represents the clay aquitard, and the bottom layer represents the Deep Aquifer. The top of the model is the land surface, and the bottom is the estimated bedrock surface that underlies the sedimentary aquifers.

22. The groundwater model represents key elements of the groundwater and surface-water flow systems, including:

    - The hydraulic properties of the shallow aquifer, the clay aquitard and the Deep Aquifer;
    - The role of exposed and buried bedrock in constraining groundwater flow;
    - Groundwater levels within aquifer units and the hydraulic gradients between aquifer units;
    - Hydrologic interactions between aquifers and key surface-water features including Beltz Marsh, the East Marsh, the Pacific Ocean, and drainage ditches excavated at TDM;
    - Tidal influence and inundation along the coastline and within Beltz Marsh; and
    - Groundwater recharge from precipitation and septic-system effluent.

23. The groundwater model was calibrated in steady-state (time-averaged) and transient (time-varying) modes. Steady-state calibration focused on matching average groundwater elevations observed during the 38-day wet season monitoring period (2/16/18-3/26/18), and transient calibration focused on matching the groundwater level variations observed during the monitoring period. Calibration also considered water-level differences between the Shallow and Deep Aquifers, predicted areas of groundwater flooding, and discharge to TDM drainage ditches. Two versions (“realizations”) of the model were developed during calibration which reflect different magnitudes and timing of groundwater recharge based on precipitation records from the two nearest weather stations with published data (Tillamook and Cloverdale). These stations are assumed to represent the potential range of precipitation in TDM, as they provide different precipitation values (Tillamook is wetter on average, and Cloverdale is drier on average). The dual realization approach was chosen to bracket a range of precipitation uncertainty, and (via model calibration) yield a range of aquifer properties that provides a range of model predictions of groundwater-level response to changes in Beltz Marsh inundation. Additional model configurations can be considered to further explore predictive uncertainties associated with hydrogeologic uncertainty.

24. Model calibration provided good matches to both average groundwater elevations and groundwater-level responses to precipitation and tidal variation. Calibration also included a “sensitivity analysis”, which quantified the sensitivity of steady-state model calibration to ranges of key model parameters. The parameters that had the most effect on calibration matches between observed and predicted groundwater elevations included: rates of groundwater recharge, horizontal hydraulic conductivity of the sandy sediments that comprise both the Shallow and Deep Aquifers, and vertical hydraulic conductivity of the clay aquitard. Model calibration was not very sensitive to the hydraulic conductivity of the finer-grained sediments that have accumulated on the bottom of Beltz Marsh. Supplemental calibration with both the steady-state and the transient models showed that experimentally enhancing the hydraulic connectivity between the marsh and the Shallow Aquifer beneath TDM to create an “enhanced marsh connectivity” (EMC) model did not significantly affect calibration success. Lastly, groundwater levels beneath TDM were not sensitive to whether channels behind the beaver dam were represented as permanently inundated (dam functioning) or open to tidal variation (dam removed). For this reason, the beaver dam was not represented in final versions of the groundwater model.

4.3 MODEL PREDICTIONS OF GROUNDWATER LEVEL CHANGES

25. Both realizations of the groundwater model were used to predict how the three Beltz Dike configurations would affect groundwater levels in the Shallow Aquifer beneath TDM. The predictive simulations included 28 days of average wet-season precipitation and winter tidal variation followed by a ten-day long “storm event” that included extreme (King) tides, high onshore winds, and high precipitation recharge.

26. Relative to current tide gate configuration, the model predicted that a modern tide gate would reduce wet-season shallow groundwater elevations beneath TDM by very small amounts (<0.01 feet = <1/8 inch) during average conditions. During flood conditions, the model predicted water-level reduction of up to 0.17 feet (about 2 inches) in monitoring well PGG-1i (located in the Shallow Aquifer adjacent to Beltz Marsh). This effect rapidly diminishes with distance from the marsh, and is not predicted for any other Shallow-Aquifer monitoring wells referenced in this report. Predicted reductions in groundwater elevations occur due to propagation of reduced surface-water elevations in Beltz Marsh that result from both: 1) more efficient drainage achieved by the modern tide gate, and 2) the tide gate design’s prevention of incoming tide after water surface elevation outside the dike exceeds 7.5 feet. Model simulations originally assumed a tide-gate shutoff of 7 feet NAVD88; however, supplemental simulations with an 8-foot shutoff did not significantly change predictions of Shallow Aquifer responses beneath TDM. During the king tide/50-year storm event, surface water levels were predicted to be higher than the 7.0 foot closure setting scenario by 0.1 to 0.2ft (1.2 to 2.4 inches). This increase in surface-water level translated to a maximum groundwater level increase of 0.01 ft (less than 1/8 inch) adjacent to Beltz Marsh in TDM Well PGG-1i.

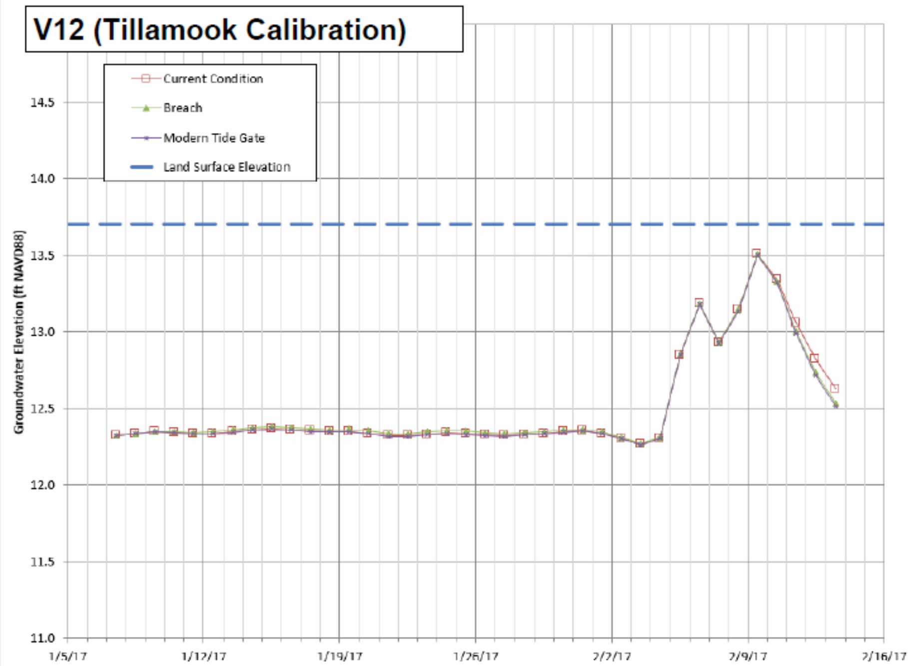
27. Relative to existing conditions, the dike-breach simulations predicted insignificant change in shallow groundwater elevations beneath TDM during average conditions

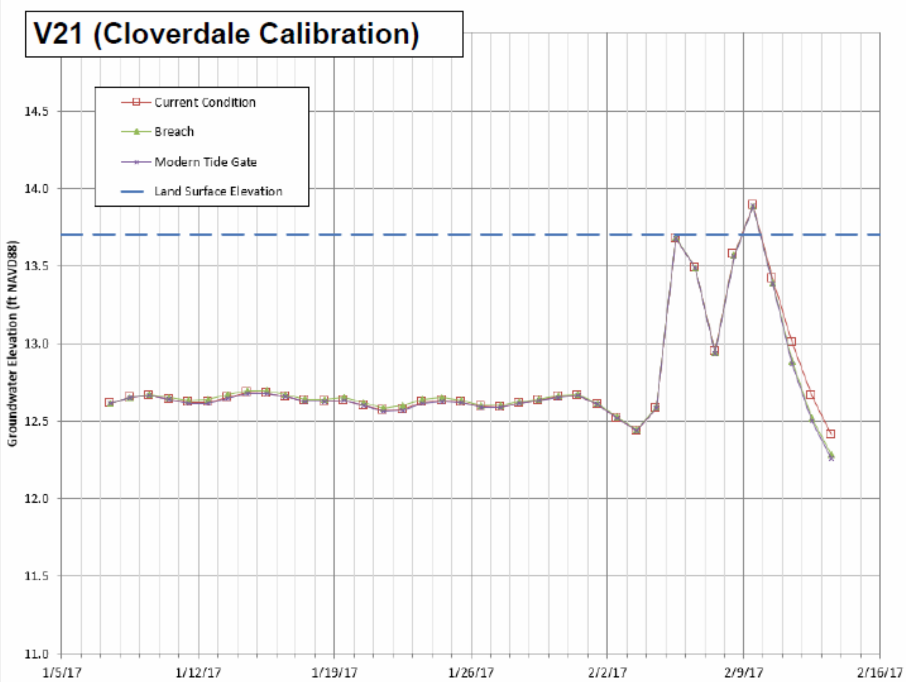
and reduced groundwater elevations during the storm event. During average conditions, water levels in Shallow-Aquifer monitoring well PGG-1i (located adjacent to Beltz Marsh) were predicted to exhibit increases up to 0.02 feet (or, ¼ inch). This minor increase occurs because the breached dike allows more tidal exchange and supports higher peak surface-water elevations in Beltz Marsh. The increase is predicted to decay rapidly with distance from Beltz Marsh, and is not predicted for any other Shallow-Aquifer monitoring wells referenced in this report. During storm conditions, Shallow-Aquifer groundwater level reductions are predicted to range from a maximum of 0.14 feet (1.7 inches) in Well PGG-1i (near Beltz Marsh), diminishing rapidly in monitoring wells located farther south. Reduced groundwater elevations during storm conditions arise because better drainage through the dike breach reduces the accumulation of stream inflows behind the dike causing less prolonged inundation.

28. Model predictions for the Deep Aquifer exhibit the same trends as noted above for the Shallow Aquifer, but water-level changes are predicted to be larger than for the Shallow Aquifer. This difference occurs due to the confined nature of the Deep Aquifer, which results in enhanced propagation of water-surface elevation changes in Beltz Marsh back into the adjacent groundwater system. The clay confining layer between the Shallow and Deep Aquifers constrains the influence of predicted changes in the Deep Aquifer on water levels in the Shallow Aquifer. The model therefore predicts that water-level changes in the Deep Aquifer will have minimal impact on the Shallow Aquifer.

29. Supplemental predictive analysis with the EMC model showed that experimentally increasing the hydraulic connectivity between the marsh and the Shallow Aquifer beneath TDM increased the groundwater response to flood rise in the marsh during the king tide/50-year storm *equally* for all three dike configurations; however, groundwater beneath TDM drained more quickly with the alternative dike configurations during recession of the flood event. This effect is most pronounced adjacent to Beltz Marsh, where groundwater levels in Well PGG-1i predicted with the EMC model showed 0.25 feet (3 inches) more rise during flood buildup for all three dike configurations (which plot atop one another, similar to Figure 7-5 below); however, the EMC model predicted that groundwater levels for the alternative dike configurations would to fall 0.1 feet (1.2 inches) lower than predicted with the current model at four days after the flood peak. Faster water-level declines are predicted because enhanced connectivity allows the Shallow Aquifer to drain faster.

30. Examples of WLE hydrographs over the 38-day predictive simulation period are provided in Figures 7-5 through 7-8. The figures allow comparison of predicted WLE's for each dike configuration over 28 days of average wet-season conditions and 10 days of storm conditions for each realization of the model.





Note:
This figure compares groundwater model predictions of water-level hydrographs in Monitoring Well PGG-1i for a hypothetical 28 days of average winter conditions (1/7—2/3) followed by 10 days of "flood" conditions (2/4—2/13).

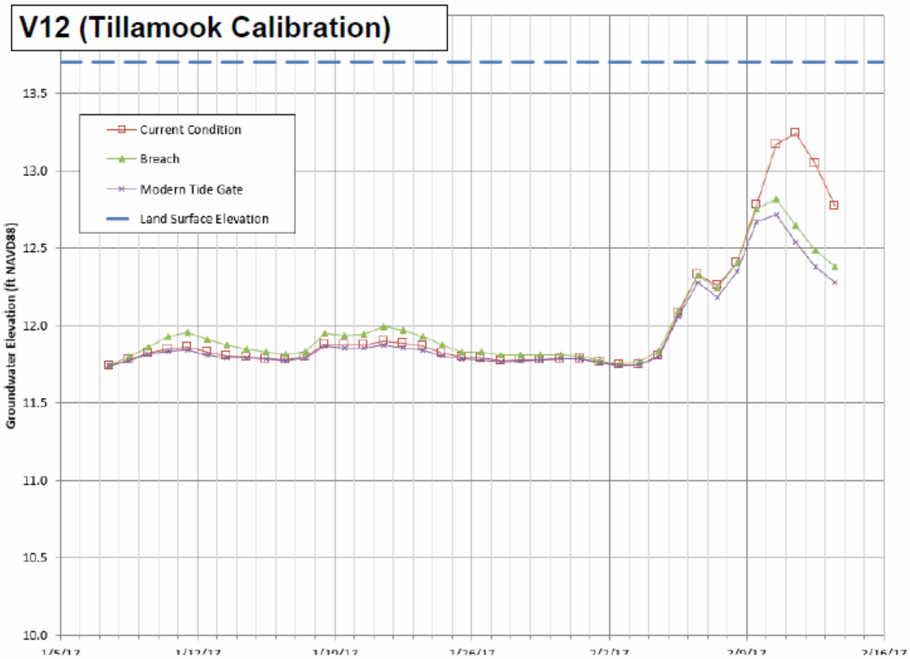
Predicted differences between the 3 dike configurations are negligible with the exception of slightly higher water levels during the "flood" condition with the current tide gate. This occurs because Beltz Marsh remains inundated for longer periods under the current condition due to limited drainage through the existing tide gate.

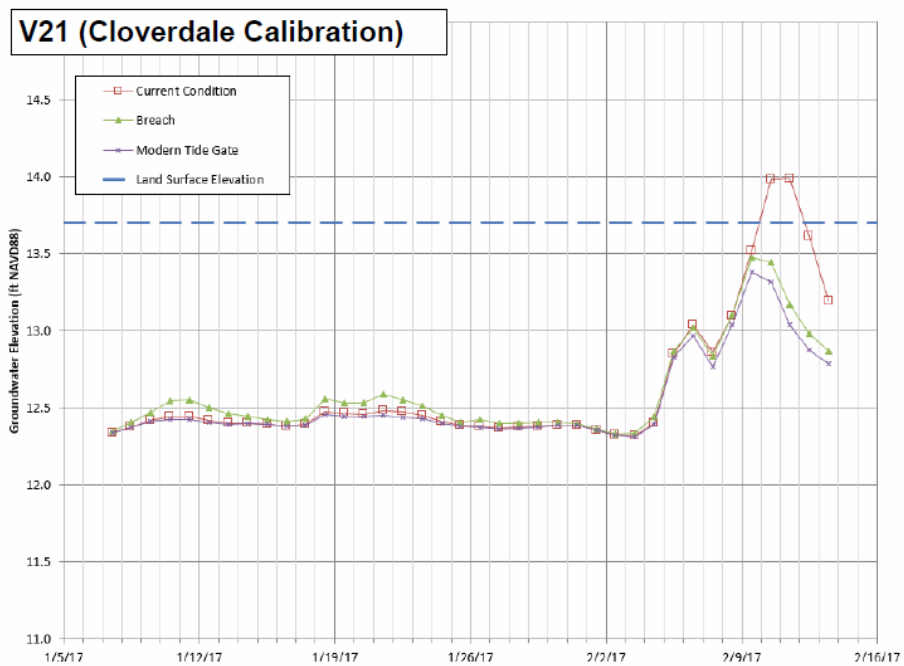
Well locations are mapped on Figure 5-1.

Figure 7-5
Predicted Effect of Dike Configuration on Groundwater Levels in PGG-1i (Shallow Aquifer)

Sitka Sedge Natural Area

PGG





Note:
This figure compares groundwater model predictions of water-level hydrographs in Monitoring Well PGG-1d for a hypothetical 28 days of average winter conditions (1/7—2/3) followed by 10 days of "flood" conditions (2/4—2/13).

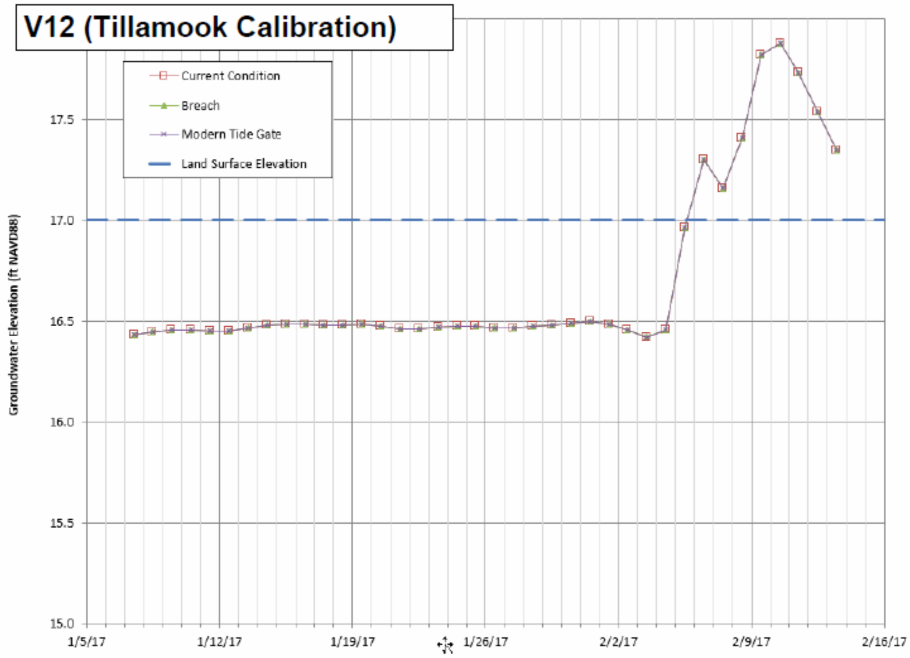
Predicted differences between the 3 dike configurations are negligible with the exception of higher water levels during the "flood" condition with the current tide gate. This occurs because Beltz Marsh remains inundated for longer periods under the current condition due to limited drainage through the existing tide gate.

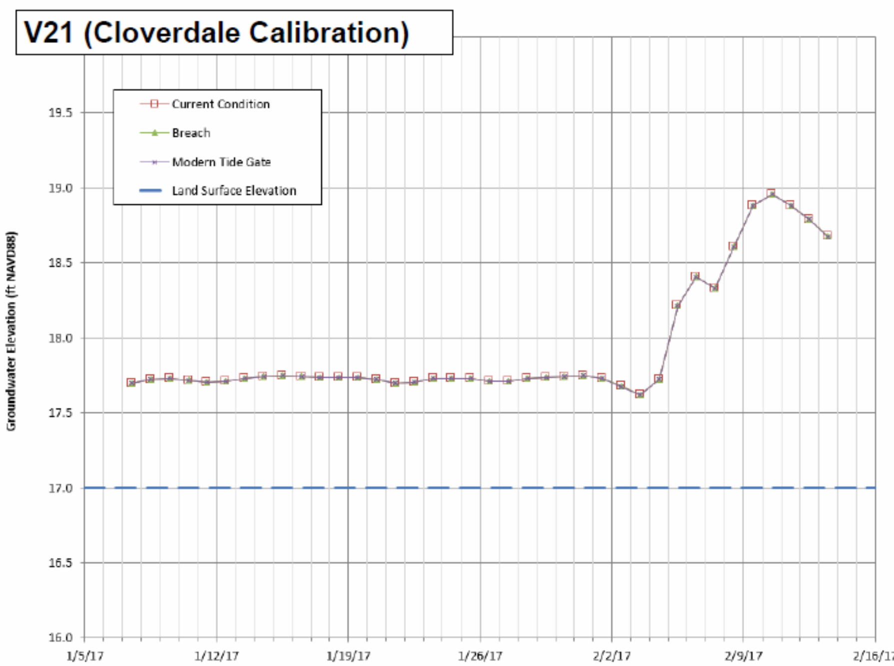
Well locations are mapped on Figure 5-1.

Figure 7-6
Predicted Effect of Dike Configuration on Groundwater Levels in PGG-1d (Deep Aquifer)

Sitka Sedge Natural Area

PGG





Note:
This figure compares groundwater model predictions of water-level hydrographs in Monitoring Well PGG-2i for a hypothetical 28 days of average winter conditions (1/7—2/3) followed by 10 days of "flood" conditions (2/4—2/13).

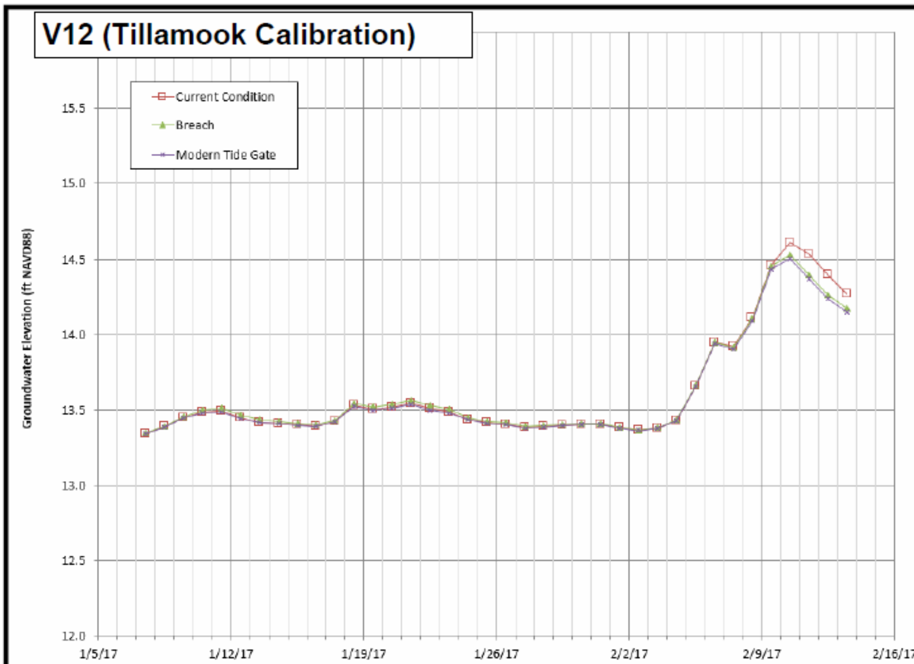
Predicted differences between the 3 dike configurations are negligible.

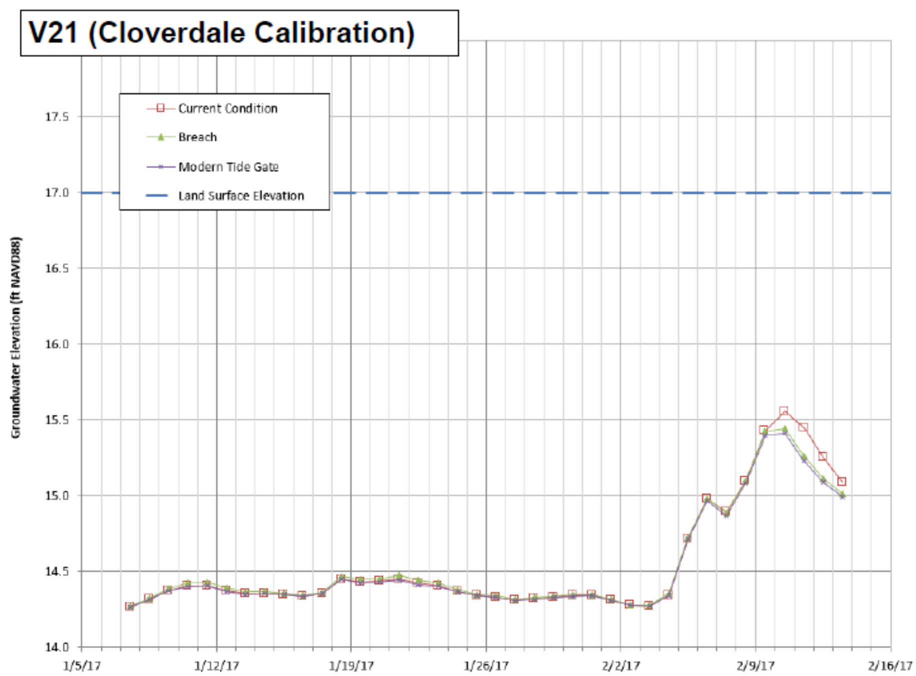
Well locations are mapped on Figure 5-1.

Figure 7-7
Predicted Effect of Dike Configuration on Groundwater Levels in PGG-2i (Shallow Aquifer)

Sitka Sedge Natural Area

PgG





Note:
This figure compares groundwater model predictions of water-level hydrographs in Monitoring Well PGG-2d for a hypothetical 28 days of average winter conditions (1/7—2/3) followed by 10 days of "flood" conditions (2/4—2/13).

Predicted differences between the 3 dike configurations are negligible with the exception of slightly higher water levels during the "flood" condition with the current tide gate. This occurs because Beltz Marsh remains inundated for longer periods under the current condition due to limited drainage through the existing tide gate.

Well locations are mapped on Figure 5-1.

Figure 7-8
Predicted Effect of Dike Configuration on Groundwater Levels in PGG-2d (Deep Aquifer)

Sitka Sedge Natural Area

PGG

5.0 DISCLAIMER

This work presented in this abridged report is being completed under Contract 7952 with the State of Oregon Parks and Recreation Department. PGG and ESA’s work was performed, and this report prepared, using generally accepted hydrogeologic and hydrologic practices used at this time and in this vicinity, for exclusive application to the Sitka Sedge Natural Area, and for the exclusive use by Oregon Parks and Recreation Department. This is in lieu of other warranties, express or implied.