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March 20, 2019

Ms. Stephanie Freed
WRA, Inc.
2169 G East Francisco Blvd.
San Rafael, CA 94901

Re: **Applicability of NCI (2016) Hydrology Report to Corte Madera 4-Acre Tidal Marsh Restoration Project**

Dear Ms. Freed,

Noble Consultants, Inc. (NCI) has reviewed the 35% design plans, dated December 13, 2018, and the corresponding project description that were prepared by WRA, Inc. for the Corte Madera 4-Acre Tidal Marsh Restoration Project. Based on these documents provided by WRA, the proposed project will create 4 acres of tidal marsh within Corte Madera Ecological Reserve (CMER). This marsh will be connected to the existing tidal channel, the northern drainage channel, in order to restore tidal connectivity to the project site.

NCI (2016) performed a hydrological analysis[1] for four project alternatives that were proposed at that time. The area of the proposed tidal marsh ranges from 4.9 acres to 32.9 acres for those four alternatives. The following conclusions were made in NCI (2016) analysis: (1) The northern drainage channel has enough capacity to provide full tidal exchange for the restored marsh using the recommended design parameters for the breach and internal tidal channels for all alternatives evaluated; (2) The increased tidal prism that will result from any of the alternatives should not cause significant scour within the northern drainage channel if the recommended design parameters for the breach and internal tidal channels are used.

The area of the tidal marsh proposed by WRA in 2018 is 4 acres, which is smaller than the marsh area (4.9 to 32.9 acres) that was included in NCI's (2016) analysis. The increased tidal prism caused by the tidal marsh proposed by WRA in 2018 is also expected to be less than that included in NCI's (2016) analysis. Therefore, the above two conclusions drawn in NCI's (2016) analysis shall also apply to WRA's (2018) 35% design provided the levee breach (to the northern drainage channel) and internal tidal channels are sufficiently large that won't restrict tidal flow in these channels. These two conclusions are re-stated in the following:

(1) The northern drainage channel has enough capacity to provide full tidal exchange for the marsh proposed in WRA's (2018) 35% design provided the levee breach and internal tidal channels are sufficiently large that won't restrict tidal flow in these channels.

(2) The proposed Corte Madera 4-Acre Tidal Marsh Restoration Project should not cause significant scour within the northern drainage channel.

[1] Noble Consultants, Inc., 2016. Hydrology Report, Wetland Restoration Design and Permitting Support Services at Corte Madera Ecological Reserve, Corte Madera, Marin County, California. Prepared for Golden Gate Bridge Highway and Transportation District. Prepared on August 14, 2015, and revised on January 11, 2016.

We appreciate the opportunity to submit our re-statement of NCI's (2016) hydrological analysis for the Corte Madera 4-Acre Tidal Marsh Restoration Project. Please let us know if you have any questions.

Sincerely,

NOBLE CONSULTANTS, INC.



Wenkai Qin, Ph.D., P.E., D.CE
Principal Engineer

Hydrology Report

WETLAND RESTORATION DESIGN AND PERMITTING SUPPORT SERVICES AT CORTE MADERA ECOLOGICAL RESERVE

CORTE MADERA, MARIN COUNTY, CALIFORNIA

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Date: August 14, 2015
Rev: January 11, 2016

NCI Project No: J882-19

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EXECUTIVE SUMMARY

Noble Consultants, Inc. (NCI) performed a hydrological analysis of the project alternatives for wetland restoration at the Golden Gate Bridge, Highway and Transportation District's 72-acre parcel adjacent to the Corte Madera Ecological Reserve in Corte Madera, Marin County. The purpose of the analysis was to address the following questions:

- Determine if the northern drainage channel has the capacity to provide full tidal exchange for the restored tidal marsh;
- Determine the preliminary design parameters for the size of the breach and the size of the internal tidal channels;
- Determine if the additional tidal exchange would have a significant adverse effect on the northern drainage channel;
- Assess the feasibility of including a tidal connection along the eastern or southern levee to existing adjacent tidal channels including the impacts and benefits of that connection;
- Estimate the required height of improved levees to provide protection from wave run up now and in the future with sea level rise.

The hydraulic analysis was performed using the unsteady flow HEC-RAS model. The physical features of the model included the northern drainage channel, Shorebird Marsh, the small tidal marsh that is located to the northwest of the restoration area, and the selected alternative designs for the restoration project. The analysis included seasonal fluctuations in the operation of the water control structures that are located between the Shorebird Marsh and the northern drainage channel. These control structures are used by the Town of Corte Madera to manage water for flood control and water fowl. The model results included estimates of the water elevation in the drainage channel and restored marsh alternatives. Model results also included estimates of flow rates, flow velocities, and shear stress with the northern drainage channel, the proposed breach, and the proposed tidal channels within the restored marsh.

NCI analyzed three (1, 2B & 3B) of the five (1, 2A, 2B, 3A and 3B) alternative restoration plans provided by WRA, Inc. (WRA). Alternatives 1, 2B, and 3B were developed by WRA and represented the range in project size (acres of tidal marsh) and variation in hydrologic conditions. NCI also analyzed a fourth alternative modified by NCI which is Revised Alternative 2B. Alternative 1 is the smallest restoration alternative and provides approximately 4.9 acres of restored tidal marsh. Alternative 2B represents the largest feasible restoration alternative and includes approximately 32.9 acres of restored tidal marsh. Alternative 3B represents an alternative that is likely to be more resilient to sea level rise. This alternative provides fewer acres (22.5 acres) of restored tidal marsh, and preserves low lying uplands that would likely convert to tidal marsh as sea levels rise over the next 50 years.

WRA also provided a preliminary design for the size of the proposed breach in the northern drainage channel and the tidal channels within the restoration area. When NCI analyzed these three alternatives they determined that the breach and internal channels were too small and would likely result in significant scour within the breach, internal channels, and segments of the northern drainage channel for all 3 alternatives. In response to these findings, NCI revised alternative 2B to include an optimized design for the breach and internal tidal channel and repeated the hydraulic analysis to confirm that the revised design would result in no significant scour in the breach, internal tidal channels, or northern drainage channel.

NCI also evaluated the feasibility of including an additional breach through the eastern or southern levee, which would connect to the existing adjacent tidal sloughs. This included surveying portions of these tidal channels from the Bay edge to near the potential levee breach connection points. These channels have adjacent documented endangered species habitat. However any low elevation breach that would induce scour in these channels would negatively impact this known habitat. Therefore no low elevation breaches were feasible in these areas. Given these conditions NCI determined that a high level breach would be feasible if the bottom elevation of the breach was limited to +6' NAVD88 in order to minimize potential scour in the existing tidal sloughs. When water elevations are above +6' NAVD88 water at the breach location would disperse across the marsh plan. This increased cross sectional area will reduce potential scour within the existing tidal sloughs. When water elevations are below +6' NAVD88 the breach crest will block flows in either direction. This design will protect the existing sloughs from increased flow and potential scour.

The results of the analysis provided the following general conclusions:

- The northern drainage channel has enough capacity to provide full tidal exchange for the restored marsh using the recommended design parameters for the breach and internal tidal channels for all alternatives evaluated.
- The cross section of the proposed breach in the northern drainage channel and internal tidal channels should be redesigned based on the following recommended design parameters and these should be incorporated into all of the design alternatives:
    - The bottom width should be 6' at elevation of 0' NAVD88;
    - Side slopes should be 5(H):1(V) for elevations between 0' and +3' NAVD88;
    - Include a 6' wide bench at elevation +3' NAVD88 on both sides;
    - Side slopes should be 8(H):1(V) at elevation above +3' NAVD88;
    - The top width of the breach section is approximately 130' at +8' NAVD88.
    - The cross section of the internal channels should become smaller as the distance from the breach location increases.

- The increased tidal prism that will result from any of the alternatives should not cause significant scour within the northern drainage channel if the recommended design parameters for the breach and internal tidal channels are used.
- An additional breach along the eastern or southern levee would be feasible if the crest of the breach is designed to be wide (greater than 400 feet) and limited to elevation +6' NAVD88. This design will prevent significant adverse impacts to the existing tidal sloughs in the adjacent marsh.
- Based on a review of published data, the 100-yr flood elevation on levees was estimated to be +10' NAVD88. This included compensation for wave run up. In addition, the 100-year flood elevation in 2050 was estimated based on predicted rates of sea level rise to range between 10.3' and 12.0' NAVD88. The existing unimproved levees do not contain the estimated 100-year flood. Existing levees that surround the project site are unimproved and vary in height according to the following review and summary of the project topographic survey data (Table 1). In addition, the western levee is not located within lands that are owned by the District.

Table 1. Summary of the Heights of Existing Levees Based on the Project Topographic Survey Data

Location of Existing Unimproved Levees	Typical Height of Levees (feet, NAVD88)	Lowest Elevation (feet NAVD88)
Northern levee	9-13	9
Western levee	9-12	9
Eastern levee	9-10	9
Southern levee	9.5-10	9.5

1 INTRODUCTION

This hydraulic analysis was conducted by Noble Consultants, Inc. (NCI) to assist in the wetland restoration design and permitting services at Corte Madera Ecological Reserve, Marin County, CA. The vicinity map of the project site is shown in Figure 1. WRA developed a series of preliminary wetland restoration alternatives for this project. The proposed restored Corte Madera Marsh will be connected to the northern drainage channel by breaching a segment of the levee on the north side of the property. The descriptions of these alternatives are presented in WRA's design documentation. Our analysis is to investigate the feasibility of these alternatives from the hydrological aspect and to assess the project impacts to the existing waterways. Among WRA's five alternatives, three alternatives were selected to be included in our hydraulic analysis. These alternatives are Alternatives 1, 2B, and 3B. The existing condition, under which the proposed restored Corte Madera Marsh is not hydraulically connected to the local waterways, was also included in our analysis for comparison with WRA's alternatives. Additionally alternatives for having a tidal connection on the eastern or southern levees were investigated. It was determined that only high elevation breaches were acceptable since any low level breaches would cause unacceptable impacts to existing endangered species habitat.

Our hydraulic analysis was conducted particularly to address the following questions:

- Determine if the northern drainage channel has the capacity to provide full tidal exchange for the restored tidal marsh;
- Determine the preliminary design parameters for the size of the breach and the size of the internal tidal channels;
- Determine if the additional tidal exchange would have a significant adverse effect on the northern drainage channel;
- Assess the feasibility of including a tidal connection along the south facing levee;
- Estimate the required height of improved levees to provide protection from wave run up now and in the future with sea level rise.

Based on the model results for WRA's preliminary alternatives, it was determined that the breach and internal channels were too small and would likely result in significant scour within the breach, internal channels and segments of the northern drainage channel. Therefore, revisions were made to the breach and internal channels and further hydraulic analysis was conducted for these revised configurations in order to determine the optimal channel size that would result in a stable channel condition in these channels. For simplicity, Alternative 2B was selected for this channel size optimization analysis. The results are also documented in this report.

2 HYDRAULIC MODEL SETUP

Our hydraulic analysis was conducted using the unsteady flow HEC-RAS model, which was developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center. The physical features of the model included the northern drainage channel, Shorebird Marsh, the small tidal marsh that is located to the northwest of the restoration area, and the selected project alternatives. The geometry schematic of the hydraulic system included in the model and the river stations of the northern drainage channel are shown in Figure 2.

2.1 Channel Cross Sections

Four cross sections were surveyed by NCI to characterize the channel geometry of the northern drainage channel. These sections are located approximately at Stations 0+00 (channel mouth), 3+60 (PG&E foot bridge), 9+56, and 17+36, respectively. The entire length of the channel is approximately 1,900 feet. These four sections, as shown in Figure 3 through Figure 6, respectively, were used in the HEC-RAS model to develop the geometry for the northern drainage channel, with additional cross sections being interpolated with a maximum interval of 100 ft. In order to apply the water levels in San Francisco Bay at the downstream boundary of the model, and to minimize the unduly influence of the downstream boundary condition on the reach of interest, the modeled reach was artificially extended into the Bay by approximately 2,000 feet.

2.2 Storage Volume of the Small Marsh Northwest of the Project Site

As shown in Figure 2, a small marsh is located on the northwest to the project site and is connected to the existing northern drainage channel with a small channel. This marsh was modeled as a storage basin in the HEC-RAS model. The storage curve (storage volumes versus elevations) was developed based on the topographic survey that was conducted by Hogan Land Services in September 2014. The derived storage curve for this small marsh is shown in Figure 7.

2.3 Shorebird Marsh

Shorebird Marsh is located on the west to the project site. The Shorebird pump station pumps water from Shorebird Marsh to the northern drainage channel during winter flood season. Two 5’ wide by 5’ high box culverts with two gates are installed under the pump station cutoff wall to connect Shorebird Marsh and the drainage channel.

Based on the Town of Corte Madera document[1] and our personal communication[2] with the Town, the gate on the channel end of the south culvert is a flap gate that opens towards the

[1]Town of Corte Madera, Storm Water and Water Quality Management Policy, Originally approved on April 2, 1991, Amendment approved on November 21, 2000, and October 16, 2001, respectively.

drainage channel, allowing water to flow out of the marsh to the channel only; and the gate on the north culvert is a slide gate controlled by the water level in Shorebird Marsh. The gate operation rules are listed in Table 2-1 of the Town's policy document[1], and are summarized in Table 2 of this memorandum. The gate on the north culvert will automatically close when the water level in Shorebird Marsh exceeds the "Close-Gate Elevation". For example, during the summer breeding season, this gate will automatically close when the water level in Shorebird Marsh reaches -0.5 feet, NGVD 29. During ebb tides, water will flow out of the lagoon through the flap gate on the south culvert when the channel water level is lower than Shorebird Marsh. The gate on the north culvert will open when the water level in Shorebird Marsh drops below -0.5 feet, and will remain open until the water level exceeds -0.5 feet NGVD 29 again during next flood tide cycle.

Table 2. Recommended Operations for North Gate of Shorebird Marsh

Operation Mode	Dates of operation	Close-Gate Elevation
Summer Mode		
Breeding Season	Apr 1 – Aug 15	-0.5' NGVD
Post-Fledging Season	Aug 15 – Beginning of the fall maintenance period	+1.0' NGVD
Winter Mode		
Low Winter	48 hrs. before precipitation until a clear 48-hr forecast	Pump down to -2.0' NGVD and allow discharge only
High Water	No precipitation forecasted	+0.75' NGVD

Note: 0' NGVD29 = +2.64', NAVD88

As shown in Table 2, Shorebird Marsh is hydraulically connected to the northern drainage channel with gravity flow through the culverts for majority of the time except for the winter season with precipitation. Due to the large size of Shorebird Marsh, the typical flow condition in the northern drainage channel is controlled by the water exchange between Shorebird Marsh and the channel. Our analysis focuses on the three periods with normal operational condition, which includes the two summer modes and the winter mode with high water (no precipitation forecasted). The winter mode with low water (days with precipitation) was not included in our hydraulic analysis. Among the three modes included in the analysis, the close-gate elevation has the highest value (+1.0' NGVD29) in the post-fledging summer season. Therefore, the maximum water exchange between Shorebird Marsh and the northern drainage channel occurs in this season that is between August and the beginning of the fall marsh maintenance, resulting in the strongest flow in the northern drainage channel.

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[2] Personal communication, Eric Polson of NCI with Town staff.

It is possible that the pumping flow rate in the low-winter days may be even higher than the flow rates during the three normal operation periods. But the duration of these low-winter days is much shorter than the duration of the three normal operation periods. The channel morphology is typically controlled by the (dominant) flow condition that occurs for most of the time. In other words, the overall morphologic condition of the northern drainage channel is controlled by the flow condition associated with these three normal operational periods.

No comprehensive topographic survey was found for Shorebird Marsh. The September 2014 topographic survey by Hogan Land Services covered the channel located along the east side within Shorebird Marsh. The storage curve of Shorebird Marsh was estimated based on this limit survey data and google images (estimating water edges/contours, and elevations of high grounds). The estimated storage curve is shown in Figure 8. It is noted that the maximum water level in Shorebird Marsh is controlled at +3.64' NAVD88 (or 1.0' NGVD29) in the summer post-fledging season. Thus the storage capacity above this elevation does not impact water exchange between the marsh and the channel.

2.4 Storage Volume of Proposed Restored Corte Madera Marsh

The preliminary grading plans were developed by WRA for five wetland restoration alternatives/concepts, namely Alternatives 1, 2A, 2B, 3A and 3B. The descriptions of these alternatives are presented in WRA's design documentation. Three alternatives (Alternatives 1, 2B, and 3B) were included in our hydraulic analysis. The area of the proposed new tidal marsh is 4.9 acres, 32.9 acres, and 22.5 acres, respectively, for these three alternatives. The proposed restored Corte Madera Marsh was modeled as a storage basin in the HEC-RAS model. The storage curves were developed based on the corresponding grading plans, as shown in Figure 9. At the elevation of +7.0' NAVD88, the storage volume of the marsh is approximately 11 ac-ft, 60 ac-ft, and 42 ac-ft for Alternative 1, 2B, and 3B, respectively.

2.5 HEC-RAS Downstream Boundary Condition

In order to minimize the unduly influence of the downstream boundary condition on the reach of interest, the modeled reach was artificially extended from the channel mouth into the Bay by approximately 2,000 feet. The water surface elevations measured at Richmond (NOAA Station ID: 9414863) were assigned at this downstream boundary. One month of data measured for January 2015, as shown in Figure 10, was used as the representative downstream water surface elevations in our model analysis.

2.6 HEC-RAS Model Calibration

Water surface elevations were measured by NCI in the northern drainage channel underneath the PG&E foot bridge (at Station 3+60) for approximately a one month period between December 24, 2014 and January 25, 2015. This data set was compared to the water surface

elevations computed with the HEC-RAS model, as shown in Figure 11 for January 2015. The model results show reasonable agreement with the data.

Based on the channel condition and model calibration, the Manning's n-value was set to 0.025 for the main drainage channel, and 0.04 for the floodplain beyond this main channel. It is noted that the model results are insensitive to the Manning's n-value for this analysis due to the short length of the channel and the relatively slow flow velocity in the channel.

Due to the large size of Shorebird Marsh, the flow condition in the drainage channel is controlled by the water exchange between Shorebird Marsh and the channel. Therefore, a good agreement between the model results and the measured data also indicates that the configuration of Shorebird Marsh, including the storage capacity of the marsh and the connection (culverts with gates) between the marsh and the channel, was reasonably represented in the HEC-RAS model.

3 SIZE OPTIMIZATION FOR THE BREACH AND INTERNAL TIDAL CHANNELS

As discussed later in this memorandum, scour is expected in the breach channel and in the internal tidal channel near the breach for WRA's preliminary alternatives. Therefore, a channel size optimization analysis was conducted to determine the optimal channel size that would result in a stable channel condition in these channels. For simplicity, only Alternative 2B was included in this size optimization analysis. A series of revisions were made to the breach and internal tidal channels, followed by additional hydraulic analyses for these revised configurations until an optimal channel size, which will result in a stable channel condition, was determined.

The optimized breach channel section is shown in Figure 12. This breach channel has a bottom width of 6' at the elevation of 0' NAVD88, a side slope of 5(H):1(V) below the elevation of +3' NAVD88, 6' wide benches at this elevation on both sides, and then a side slope of 8(H):1(V) for the elevation above +3' NAVD88. The internal tidal channel near the breach will have the same configuration as the breach section. The cross section of the internal channels should become smaller as the distance from the breach location increases to be consistent with the reduction of tidal prism and the resulting water exchange volume. This can be done by reducing the channel width or elevating the channel bottom.

The revision to the internal tidal channel also changes the storage capacity of the proposed restored Corte Madera Marsh. The revised storage curve compared to the original Alternative 2B is shown in Figure 13. Because of the enlarged and lowered internal tidal channel, the storage capacity of the marsh is increased. The increase is relatively greater for lower elevations.

4 MODEL RESULTS

The model results for the existing condition (without Corte Madera Marsh), WRA's three preliminary alternatives (Alternatives 1, 2B, and 3B), and Alternative 2B with the optimized size for the breach and internal tidal channels are analyzed and presented in this section. Since the boundary conditions of the HEC-RAS model are the same among these scenarios, the difference in the model results is caused by the geometry configurations associated with each scenario.

4.1 Tidal Fluctuation Range in the Proposed Restored Corte Madera Marsh

The predicted water levels at the proposed restored Corte Madera Marsh for WRA's three preliminary project alternatives are shown in Figure 14 for the three seasons (or three Shorebird Marsh operations), respectively. While the model simulations were conducted for one month period (using January 2015 tides), these figures only show the results for 16 days in order to have a better resolution. As discussed before, these three seasons cover most time of each year except for the winter days with precipitation. Therefore, the results for these three seasons shall represent the typical condition at the project site. The results for Alternative 2B with the optimized size for the breach and internal tidal channels are shown in Figure 15.

The (annual) lowest and highest water levels at the marsh were determined from the model results for the three seasons, and are listed in Table 3. As a comparison, the highest and lowest water levels at Station 3+60 (PG & E foot bridge) in the northern drainage channel under the existing condition are also listed in this table.

As shown in these figures and in Table 3, the water levels in the proposed restored Corte Madera Marsh will show negligible difference for high tides among various alternatives, but will be somewhat different for low tides. The water levels in the marsh will vary between approximately the bottom elevation of the breach channel and the highest water level in the existing northern drainage channel (+7.2' NAVD88). It noted that the breach channel bottom elevation is at +3.0' NAVD88 for WRA's three preliminary alternatives, and is at +0.0' NAVD88 for Alternative 2B with optimized size for the breach and internal tidal channels, This indicates that the northern drainage channel has enough capacity to provide non-muted tidal fluctuation range between the bottom elevation of the breach channel and the highest water level in the drainage channel. Further enlarging of the breach and internal tidal channels will not significantly improve the tidal exchange for the marsh.

The flow discharges for the water exchange between the marsh and the northern drainage channel are shown in Figure 16 for WRA's three preliminary alternatives, and in Figure 17 for Alternative 2B with optimized size for the breach and internal tidal channels. The maximum flow discharges passing through the breach channel compared to the peak flow discharges in the exiting northern drainage channel (at Station 3+60) are summarized in Table 3.

Table 3. Variation Ranges of Water Levels and Tidal Exchange Flow Discharges in the Proposed Restored Corte Madera Marsh

Alternatives	Water level (feet, NAVD88)		Flow discharge (cubic feet per second)	
	Minimum	Maximum	Minimum[4]	Maximum[5]
Existing[1]	1.0	7.2	-259	379
Alt 1	3.0	7.2	-79	91
Alt 2B[2]	3.1	7.2	-312	404
Alt 3B	3.0	7.2	-247	260
Alt 2B, Rev[3]	**1.1**	**7.2**	**-372**	**385**

Note: 1. Existing condition in the northern drainage channel at Station 3+60 (PG&E foot bridge).
2. WRA's preliminary Alternative 2B.
3. WRA's Alternative 2B with optimized channel size for breach and internal tidal channels.
4. Maximum discharges for water flowing out of the marsh.
5. Maximum discharges for water flowing into the marsh.

4.2 Stability of the Proposed Breach and Internal Tidal Channels

The flow velocities and the channel bottom shear stresses were computed for the breach channel. The time series of the computed flow velocities are shown in Figure 18 for WRA's three preliminary alternatives, and in Figure 19 for Alternative 2B with the optimized channel size for the breach and internal tidal channels. The time series of the channel bottom shear stresses are shown in Figure 20 for WRA's three preliminary alternatives, and in Figure 21 for Alternative 2B with optimized channel size.

The (annual) variation ranges of the flow velocities and the bottom shear stresses in the breach channel were determined from the model results for the three seasons, and are listed in Table 4. As a comparison, the variation ranges in the existing northern drainage channel (at Station 3+60, or under PG & E foot bridge) are also listed in this table.

As shown in Figure 16 and in Table 4, the peak flow velocities at the breach channel for WRA's three preliminary alternatives will be much higher than the existing condition in the northern drainage channel. Particularly, the maximum flow velocity at the breach channel can be as high as 5.6 feet per second (fps) for preliminary Alternative 2B, compared to the maximum flow velocity of 1.7 fps in the existing northern drainage channel.

As shown in Figure 18 and in Table 4, the bottom shear stress in the breach channel for WRA's three preliminary alternatives will be much higher than that in the northern drainage channel. The maximum shear stress will be approximately 7.5 Pascal (Pa) for Alternative 1, 24.2 Pa for

Alternative 2B, and 14 Pa for Alternative 3B, compared to 2.2 Pa for the existing northern drainage channel. The existing northern drainage channel seems to be in a dynamical equilibrium condition in long term. If using the existing bottom shear stress in the northern drainage channel as a baseline measure, channel scour is expected in the breach channel and in part of the internal tidal channel that is close to the breach location.

Table 4. Variation Ranges of Flow Velocities (fps) and Bottom Shear Stresses (Pascal) in Proposed Breach Channel

Alternatives	Flow velocities (feet per second)		Channel bottom shear stresses (Pascal)	
	Minimum[4]	Maximum[5]	Minimum	Maximum
Existing[1]	-1.2	1.7	0.0	2.2
Alt 1	-1.9	2.9	0.0	7.5
Alt 2B[2]	-2.9	5.6	0.0	24.2
Alt 3B	-2.7	4.3	0.0	14.0
Alt 2B, Rev[3]	**-2.1**	**1.8**	**0.0**	**2.4**

Note: 1. Existing condition in the northern drainage channel at Station 3+60 (PG&E foot bridge).

2. WRA's preliminary Alternative 2B.

3. WRA's Alternative 2B with optimized channel size for breach and internal tidal channels.

4. Maximum flow velocities for water flowing out of the marsh.

5. Maximum flow velocities for water flowing into the marsh.

It is note that the flow discharges, the flow velocities and the channel bottom shear stresses will decay as the distance from the breach location increases. As a result, the maximum channel scour is expected to occur in the breach channel, and the channel scour will decrease as the distance from the breach location increases.

As shown in Figure 19, Figure 21, and Table 4, the peak flow velocities and the peak bottom shear stresses in the breach channel will significantly drop after optimizing (increasing) the size of the breach and internal tidal channels. The optimized channel section is shown in Figure 12. The maximum flow velocity in the breach channel will drop to 2.1 fps and the maximum bottom shear stress will drop to 2.4 Pa, which are similar to the condition in the existing northern drainage channel. The existing northern drainage channel seems to be in a dynamical equilibrium condition in long term. If using the existing bottom shear stress in the northern

drainage channel as a baseline measure, the breach channel and the internal drainage channel with the optimized cross section are expected be in a stable condition, without significant scour or sedimentation.

4.3 Impact to the Northern Drainage Channel

The results for the existing condition and for the project alternatives were compared for various seasons (or Shorebird Marsh operations) at three representative locations along the northern drainage channel. The three locations are located at Stations 19+00, 9+56, and 3+60. As shown in Figure 2, these stations are located in the upper, middle, and lower reaches of the channel, respectively. It is noted that Stations 19+00 and 9+56 are located upstream of the proposed breach location, while Station 3+60 is downstream of the breach.

Existing Condition

The water levels computed for the three representative locations are shown in Figure 22 through Figure 24 for three seasons, respectively. Figure 25 though Figure 27 show the flow discharges, Figure 28 through Figure 30 show the flow velocities, and Figure 31 through Figure 33 show the derived channel bottom shear stresses. The annual variation ranges of these hydraulic parameters are listed in Table 5 through Table 8, respectively.

The water levels in the existing northern drainage channel vary between +1.0' NAVD88 and +7.2' NAVD88 based on the model results for the one-month simulation period. The tidal flow discharges depend on the seasons (or the Shorebird Marsh operation modes). The maximum tidal flow discharge can be slightly less than 400 cubic feet per second (cfs). The peak tidal current velocity is less than 2 fps, with the peak channel bottom shear stress of approximately 2.2 Pa.

It is noted that the strongest tidal currents (flow discharges, flow velocities, and channel bottom shear stresses) occur in the summer post-fledging season between August 15 and the beginning of the fall maintenance, when the Shorebird Marsh (north) gate closes at the highest control marsh water level of 3.64' MAVD88 (1.0' NGVD29). Compared to the other seasons, the close-gate elevation for this season is the highest, resulting in the maximum water exchange between Shorebird Marsh and the northern drainage channel.

Project Impact to Water Levels in Northern Drainage Channel

The water levels computed for WRA's three preliminary alternatives and Alternative 2B with the optimized channel size are shown in Figure 34 through Figure 45 for the three representative locations in the northern drainage channel for various seasons, respectively. The water levels for the existing condition are also included in each of these figures for comparison. The annual variation ranges of the water levels, compared to the existing condition, are summarized in Table 5. As shown in these figures and in Table 5, the water levels along the drainage channel

associated with each project alternative show negligible difference from the existing condition. In other words, these four project alternatives will have negligible impact (0.1 feet or less) to the water levels in the northern drainage channel.

Table 5. Variation Ranges of Water Levels (ft, NAVD88) in Northern Drainage Channel

Alternatives	Sta 19+00		Sta 9+56		Sta 3+60	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Existing	1.3	7.2	1.1	7.2	1.0	7.2
Alt 1	1.3	7.2	1.1	7.2	1.0	7.2
Alt 2B[1]	1.3	7.2	1.2	7.2	1.1	7.2
Alt 3B	1.3	7.2	1.1	7.2	1.1	7.2
Alt 2B, Rev[2]	**1.3**	**7.2**	**1.2**	**7.2**	**1.1**	**7.2**

Note: 1. WRA's preliminary Alternative 2B.

2. WRA's Alternative 2B with optimized channel size for breach and internal tidal channels.

Project Impact to Flow Discharges in Northern Drainage Channel

The flow discharges computed for WRA's three preliminary alternatives and Alternative 2B with the optimized channel size, compared to the existing condition, are shown in Figure 46 through Figure 57 for various seasons, respectively. The annual variation ranges of the flow discharges, compared to the existing condition, are summarized in Table 6. As shown in these figures and in Table 6, the flow discharges in the lower reach of the drainage channel that is downstream of the proposed breach location will be increased due to the added water exchange between Corte Madera Marsh and the channel. On the other hand, these project alternatives will have limited impact to the flow discharges in the middle and upper reaches of the northern drainage channel that is upstream of the breach location.

Project Impact to Flow Velocities in Northern Drainage Channel

The flow velocities computed for WRA's three preliminary alternatives and Alternative 2B with the optimized channel size, compared to the existing condition, are shown in Figure 58 through Figure 69 for various seasons, respectively. The variation ranges of the flow velocities, compared to the existing condition, are summarized in Table 7. As shown in these figures and in Table 7, the flow velocities in the lower reach of the drainage channel that is downstream of the proposed breach will be increased due to the added water exchange between Corte Madera Marsh and the channel. The change is more significant for flood currents that flow from the Bay

into the marshes. On the other hand, these project alternatives will have insignificant impact to the flow velocities in middle and upper reaches of the northern drainage channel that is upstream of the breach location.

Table 6. Variation Ranges of Flow Discharges (cfs) in Northern Drainage Channel

Alternatives	Sta 19+00		Sta 9+56		Sta 3+60	
	Minimum[3]	Maximum[4]	Minimum	Maximum	Minimum	Maximum
Existing	-254	143	-342	233	-379	259
Alt 1	-254	143	-344	232	-408	313
Alt 2B[1]	-251	143	-338	198	-645	512
Alt 3B	-253	144	-341	208	-580	439
Alt 2B, Rev[2]	**-251**	**144**	**-340**	**155**	**-646**	**553**

Note: 1. WRA's preliminary Alternative 2B.

2. WRA's Alternative 2B with optimized channel size for breach and internal tidal channels.

3. Maximum discharges for water flowing towards Shorebird Marsh (flood tides).

4. Maximum discharges for water flowing towards the Bay (ebb tides).

Project Impact to Channel Morphology in Northern Drainage Channel

The channel bottom shear stresses computed for WRA's three preliminary alternatives and Alternative 2B with the optimized channel size, compared to the existing condition, are shown in Figure 70 through Figure 81 for various seasons, respectively. The maximum shear stresses, compared to the existing condition, are summarized in Table 8. As shown in these figures and in Table 8, the bottom shear stresses in the lower reach of the drainage channel that is downstream of the proposed breach location will be slightly increased due to the added water exchange between Corte Madera Marsh and the channel. For example, the maximum bottom shear stress at Station 3+60 is approximately 2.2 Pa for the existing condition and for Alternative 1, but it will increase to 2.8 Pa for Alternative 2B, 2.4 Pa for Alternatives 3B, and 2.3 Pa for Alternatives 2B with optimized channel size. The existing northern drainage channel seems to be in a dynamical equilibrium condition in long term. If using the existing bottom shear stress in the northern drainage channel as a baseline measure, Alternatives 2B and 3B may induce insignificant scour in the lower reach of the northern drainage channel that is downstream of the breach location. On the other hand, Alternative 1 and Alternative 2B with optimized size for the breach and internal tidal channels will not induce any noticeable morphologic change to the northern drainage channel.

Table 7. Variation Ranges of Flow Velocities (fps) in Northern Drainage Channel

Alternatives	Sta 19+00		Sta 9+56		Sta 3+60	
	Minimum[3]	Maximum[4]	Minimum	Maximum	Minimum	Maximum
Existing	-0.6	1.4	-1.2	1.7	-1.2	1.7
Alt 1	-0.6	1.4	-1.2	1.7	-1.3	1.7
Alt 2B[1]	-0.6	1.4	-1.2	1.6	-1.9	1.9
Alt 3B	-0.6	1.5	-1.2	1.6	-1.9	1.8
Alt 2B, Rev[2]	**-0.6**	**1.5**	**-1.3**	**1.8**	**-2.1**	**2.0**

Note: 1. WRA's preliminary Alternative 2B.

2. WRA's Alternative 2B with optimized channel size for breach and internal tidal channels.

3. Maximum flow velocities for water flowing towards Shorebird Marsh (flood tides).

4. Maximum flow velocities for water flowing towards the Bay (ebb tides).

Table 8. Variation Ranges of Bottom Shear Stresses (Pascal) in Northern Drainage Channel

Alternatives	Sta 19+00		Sta 9+56		Sta 3+60	
	Minimum[3]	Maximum[4]	Minimum	Maximum	Minimum	Maximum
Existing	0.0	1.6	0.0	2.0	0.0	2.2
Alt 1	0.0	1.6	0.0	2.0	0.0	2.2
Alt 2B[1]	0.0	1.5	0.0	1.8	0.0	2.8
Alt 3B	0.0	1.6	0.0	2.0	0.0	2.4
Alt 2B, Rev[2]	**0.0**	**1.7**	**0.0**	**2.3**	**0.0**	**2.3**

Note: 1. WRA's preliminary Alternative 2B.

2. WRA's Alternative 2B with optimized channel size for breach and internal tidal channels.

5 FEASIBILITY OF THE SOUTHERN AND EASTERN TIDAL CONNECTION

In addition to breaching the levee on the north side of Corte Madera Marsh to provide tidal action to the marsh, it is also possible to breach the southern and eastern levees to introduce additional tidal action to the marsh. Breaching these levees will provide additional waterway for water exchange between the marsh and the Bay, and lower the water exchange volume through the northern breach channel. This will reduce potential scour in the northern breach channel and in the internal tidal channel, and thus alleviate the project impact to the northern drainage channel. We recommend breach these levees at elevation of approximately +6.0' NAVD88.

When the Bay water level is higher than +6' NAVD88, the marshes/mudflats outside of Corte Madera Marsh will be flooded. The Bay water will flow into Corte Madera marsh through these marshes/mudflats, not just through the small tidal sloughs cut through these marshes/mudflats. When the Bay water subsides, the water will flow out of Corte Madera Marsh back to the Bay through these marshes/mudflats as well. By doing that, the impact to these small tidal sloughs will be minimized.

6 100-YEAR FLOOD ELEVATION ON LEVEES

6.1 FEMA 100-Year Flood Elevation

The FEMA Flood Insurance Rate Map (FIRM)[3] was reviewed. As shown in Figure 82, the 100-year flood elevation, or the base flood elevation (BFE), is +9' NAVD88 for the project site. However, this BFE of +9' NAVD88 not only applies for the areas fronting the Bay, but also applies for inland areas. We suspect the wave contribution, or the wave runup on the levees, was not included in the determined BFE. We then reviewed the FEMA Flood Insurance Study (FIS) for Marin County[4]. One shoreline section (Transect B88), which transverses the Corte Madera Marsh, was included in FEMA's coastal flooding analysis. The 100-year (1% annual chance) stillwater elevation determined for this transect is +9.7' NAVD88, and the BFE is +10' NAVD88. To be conservative, the 100-year flood elevation on the levees surrounding Corte Madera Marsh, including both the stillwater level and the wave contribution (runup), is estimated to be +10' NAVD88 under the existing condition.

6.2 Sea Level Rise

Sea level has been rising since the end of the last ice age. The sea level rise (SLR) predictions from different agencies were reviewed and are summarized as follows.

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[3] FEMA Flood Insurance Rate Map (FIRM), Marin County, California and Incorporated Areas, Panel 0467E. Revised March 17, 2014.

[4] Flood Insurance Study, Marin County, California and Incorporated Areas. Revised March 24, 2014.

National Research Council (NRC) and CO-CAT Guidance

The National Research Council (NRC) issued a report in June 2012[5]on sea level rise for the coasts of California, Oregon, and Washington. Based on the predictions of future SLR from this NRC (2012) report, the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) developed a SLR guidance[6] to advise California on planning efforts. Using the range of SLR presented in the NRC (2012) report, CO-CAT selected SLR values based on agency and context-specific considerations of risk tolerance and adaptive capacity. The SLR predictions recommended by CO-CAT are listed in Table 9.

Table 9. CO-CAT Sea Level Rise Projection Using 2000 as the Baseline

Time period	South of Cape Mendocino
2000-2030	0.13 to 0.98 ft
2000-2050	0.39 to 2.00 ft
2000-2100	1.38 to 5.49 ft

USACE Sea Level Rise Guidance

Three SLR scenarios are presented in the Corps' guidance EC 1165-2-212[7] (USACE, 2013). The three SLR scenarios include: (1) the "low" SLR rate using the historic rate of sea level change, (2) the “intermediate” SLR rate using the modified NRC Curve I, and (3) the “high” rate using the modified NRC Curve III. Based on this guidance, SLR values between year 2000 and years 2050 and 2100 are listed in Table 10.

Based on the CO-CAT and USACE guidance, sea level will increase by approximately 0.3 feet to 2 feet between 2000 and 2050. Assuming the wave contribution remains the same in the future, the future wave runup elevation or the flood elevation will increase with the sea level rise. The 100-year flood elevation on the levees surrounding Corte Madera Marsh in 2050 is expected to be range from +10.3’ NAVD88 to +12.0’ NAVD88.

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[5] National Research Council (NRC), 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future (2012). http://www.nap.edu/catalog.php?record_id=13389.

[6] CO-CAT, 2013.”State of California Sea-Level Rise Guidance Document”, March 2013 update.

[7] USACE, EC 1165-2-212, Sea-Level Change Considerations for Civil Works Programs. October 2011.

Table 10. Sea Level Rises Estimated with USACE Guidance

Scenarios	2000-2050	2000-2100
Low Scenarios: Historic Rate	0.3 ft	0.7 ft
Intermediate Scenarios: Modified NRC-I	0.6 ft	1.6 ft
High Scenario: Modified NRC-III	1.5 ft	4.9 ft

In conclusion, the 100-year flood elevation, including both the extreme stillwater level and the wave action (runup) on these levees, is approximately +10' NAVD88 under the existing condition, and will be +10.3' to 12.0' NAVD88 in 2050. Based on the topographic survey that was conducted by Hogan Land Services in September 2014, the crest elevations of the existing eastern and southern levees vary between +9' to +11' NAVD88. Portions of these levees will be overtopped under the existing condition. If the worst scenario of sea level rise is considered, these levees will be completely overtopped in 2050.

7 SUMMARY AND RECOMMENDATIONS

This hydraulic analysis was conducted by Noble Consultants, Inc. (NCI) to assist in the wetland restoration design and permitting services at Corte Madera Ecological Reserve, Marin County, CA. The proposed restored Corte Madera Marsh will be connected to the northern drainage control channel by breaching a segment of the levee on the north side of the marsh. Among the five alternatives that were developed by WRA, three preliminary alternatives (Alternatives 1, 2B, and 3B) were selected to be included in our hydraulic analysis.

Based on the model results for these three preliminary alternatives, it was determined that the breach and internal channels were too small and would likely result in significant scour within the breach, internal channels and segments of the northern drainage channel. Therefore, a series of revisions were made to the breach and internal channel sections and further hydraulic analyses were conducted for these revised configurations until the optimized channel section was determined. For simplicity, Alternative 2B was selected for the channel size optimization analysis.

The hydraulic analysis was conducted using the unsteady flow HEC-RAS model. The physical features of the model included the northern drainage channel, Shorebird Marsh, the small tidal marsh that is located to the northwest of the restoration area, and the selected project

alternatives. The analysis included seasonal fluctuations in the operation of the water control structures that are located between the Shorebird Marsh and the northern drainage channel. These control structures are used by the Town of Corte Madera to manage water for flood control and water fowl. The model results included estimates of the water elevation in the drainage channel and restored marsh alternatives. Model results also included estimates of flow rates, flow velocities, and shear stress with the northern drainage channel, the proposed breach, and the proposed tidal channels within the restored marsh.

Our findings and recommendations are summarized in the following:

- For WRA's three preliminary alternatives, the water levels in the proposed restored Corte Madera Marsh will vary between approximately the bottom elevation of the breach channel (+3.0' NAVD88) and the highest water level in the existing northern drainage channel (+7.2' NAVD88). This indicates that the northern drainage channel has enough capacity to provide approximately non-muted tidal fluctuation range between the bottom elevation of the breach channel and the highest water level in the drainage channel. Further enlarging of the breach and internal tidal channels will not significantly improve the tidal exchange for the marsh.

- For WRA's three preliminary alternatives, the peak flow velocities and the peak bottom shear stresses in the breach channel will be much higher than the existing condition in the northern drainage channel. This is particularly true for Alternatives 2B and 3B. The existing northern drainage channel seems to be in a dynamical equilibrium condition in long term. If using the existing bottom shear stress in the northern drainage channel as a baseline measure, channel scour is expected to occur in the breach channel and in part of the internal tidal channel that is close to the breach location. A "stable" or "equilibrium" channel is typically recommended for channel design.

- Based on the channel size optimization analysis, the size of the breach channel and the internal tidal channel for Alternative 2B need to be increased in order to maintain a relatively equilibrium condition in these channel. As shown in Figure 12, the optimized breach channel has a bottom width of 6' at the elevation of 0' NAVD88, a side slope of 5(H):1(V) below the elevation of +3' NAVD88, 6 feet wide benches at this elevation on both sides, and then a side slope of 8(H):1(V) for the elevation above +3' NAVD 88. The internal tidal channel near the breach will have the same configuration as the breach section. The cross section of the internal channels should become smaller as the distance from the breach location increases in order to be consistent with the reduction of tidal prism and the resulting water exchange volume. This can be done by reducing the channel width or elevating the channel bottom.

- Alternative 2B with optimized (increased) size for the breach and internal tidal channels will provide a water level fluctuation between +1.1' and +7.2' NAVD88 in the proposed

restored Corte Madera Marsh. The northern drainage channel has enough capacity to provide approximately non-muted tidal fluctuation range in the marsh between the bottom of the breach channel and the highest water level in the drainage channel. The peak bottom shear stress in the breach channel will be similar to the condition in the existing northern drainage channel, which will result in a relatively stable condition in the breach channel and in the internal tidal channel, without significant scour or sedimentation.

- WRA's three preliminary alternatives and Alternative 2B with optimizing breach and internal channel size will have negligible impact (0.1 feet or less) to the water levels in the northern drainage channel, but will increase the flow discharges and flow velocities in the lower reach of this drainage channel that is downstream of the breach. On the other hand, these project alternatives will have insignificant impact to middle and upper reaches that are upstream of the breach location.

- If the existing northern drainage channel is relatively stable, Alternatives 2B and 3B may induce insignificant scour in the lower reach of the northern drainage channel that is downstream of the breach location. On the other hand, Alternative 1 and Alternative 2B with optimized channel size will not induce any noticeable morphologic change to the northern drainage channel.

- In addition to breaching the levee on the north side of Corte Madera Marsh to provide tidal action to the marsh, it is feasible to breach the southern and eastern levees to introduce additional tidal action to the marsh. It will reduce potential scour in the northern breach channel and in the internal tidal channel close to this breach, and alleviate the project impact to the northern drainage channel. We recommend breach these levees at elevation of approximately +6.0' NAVD88 to minimize the project impact to the small tidal sloughs outside of Corte Madera Marsh.

- The FEMA Flood Insurance Rate Map (FIRM) and Flood Insurance Study (FIS) for the project site were reviewed. The 100-year flood elevation, including both the extreme stillwater level and the wave action (runup) on these levees, is approximately +10' NAVD88 under the existing condition, and will be +10.3' to +12.0' NAVD88 in 2050. The crest elevations of the existing eastern and southern levees vary between +9' to +11' NAVD88. Portions of these levees will be overtopped under the existing condition. If the worst scenario of sea level rise is considered, these levees will be completely overtopped in 2050.



Note: Revised based on Figure 2 of RFQ/RFP

Figure 1. Location of Project Site Vicinity Map

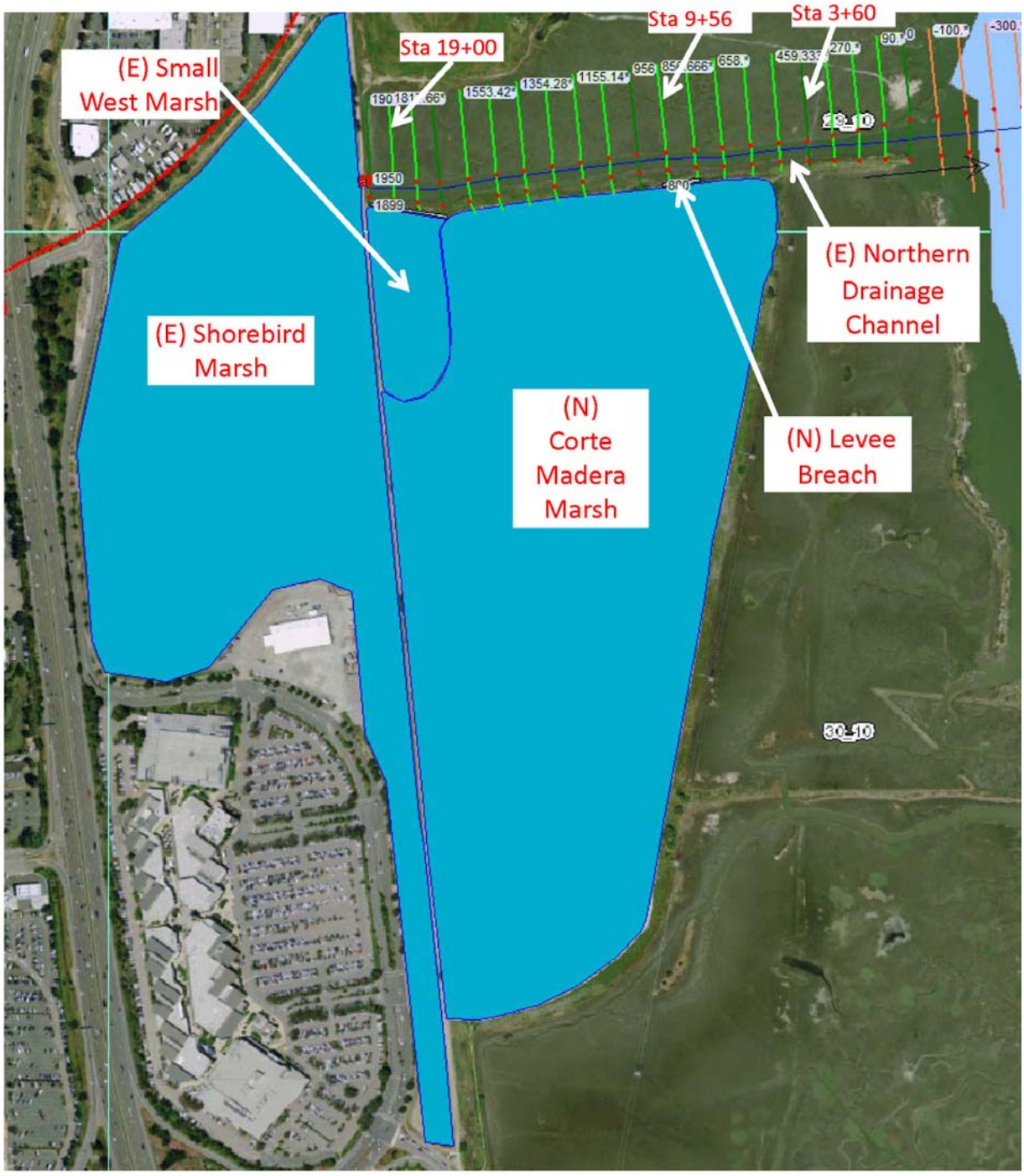
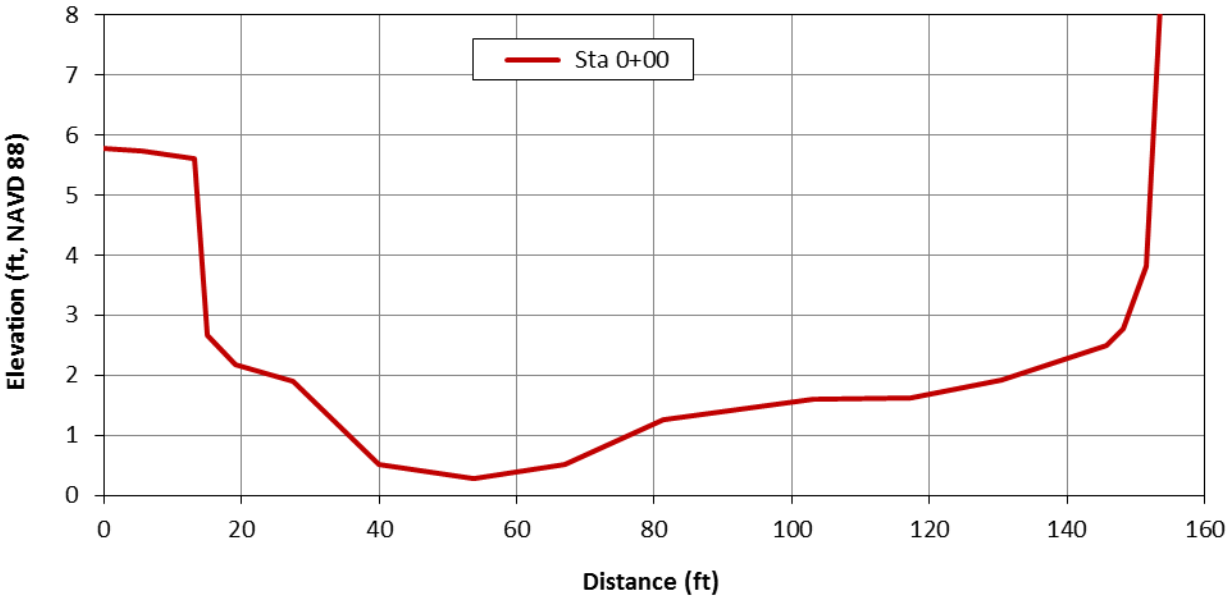
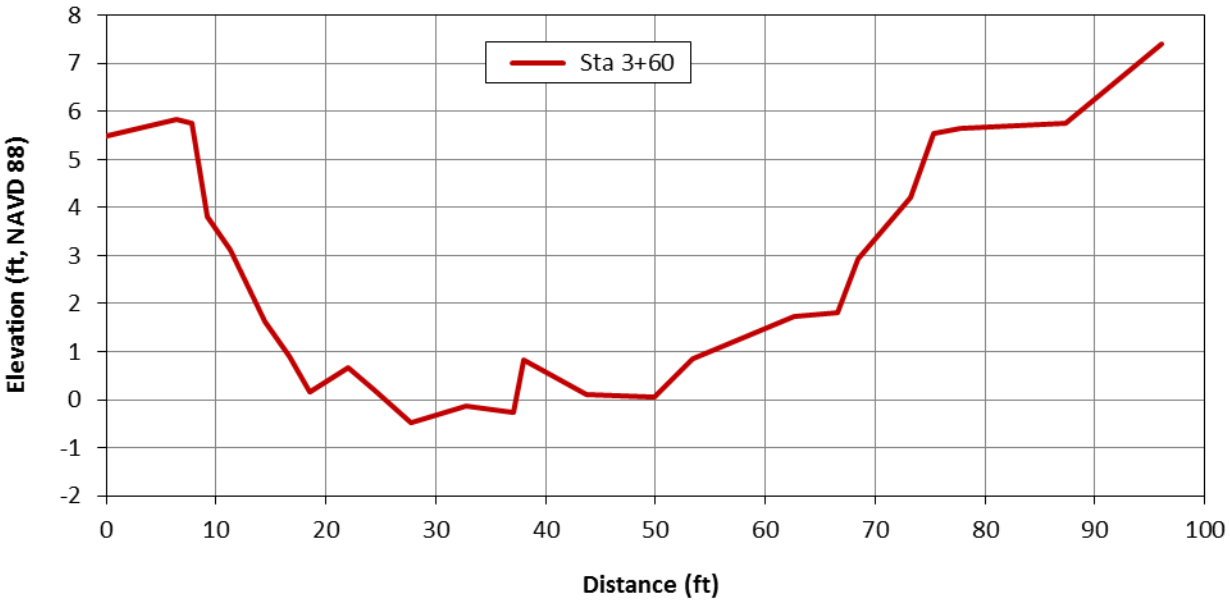


Figure 2. Geometry Schematic and Stations of the Existing Northern Drainage Channel



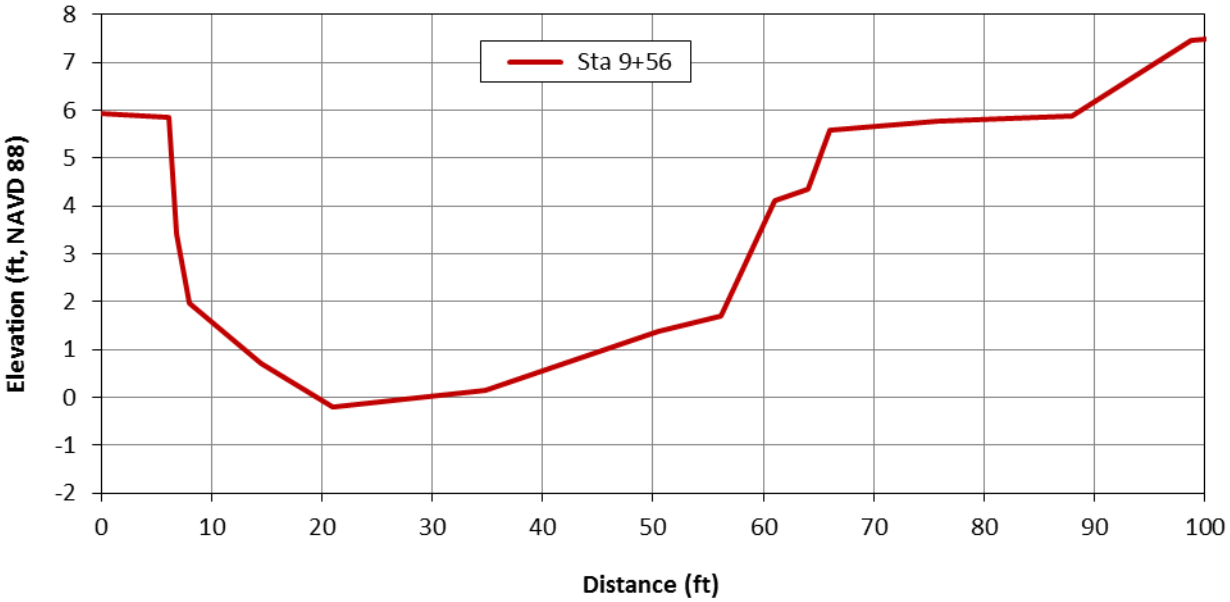
Note: north bank on the left and south bank on the right.

Figure 3. Surveyed Northern Drainage Channel Cross Section at Station 0+00



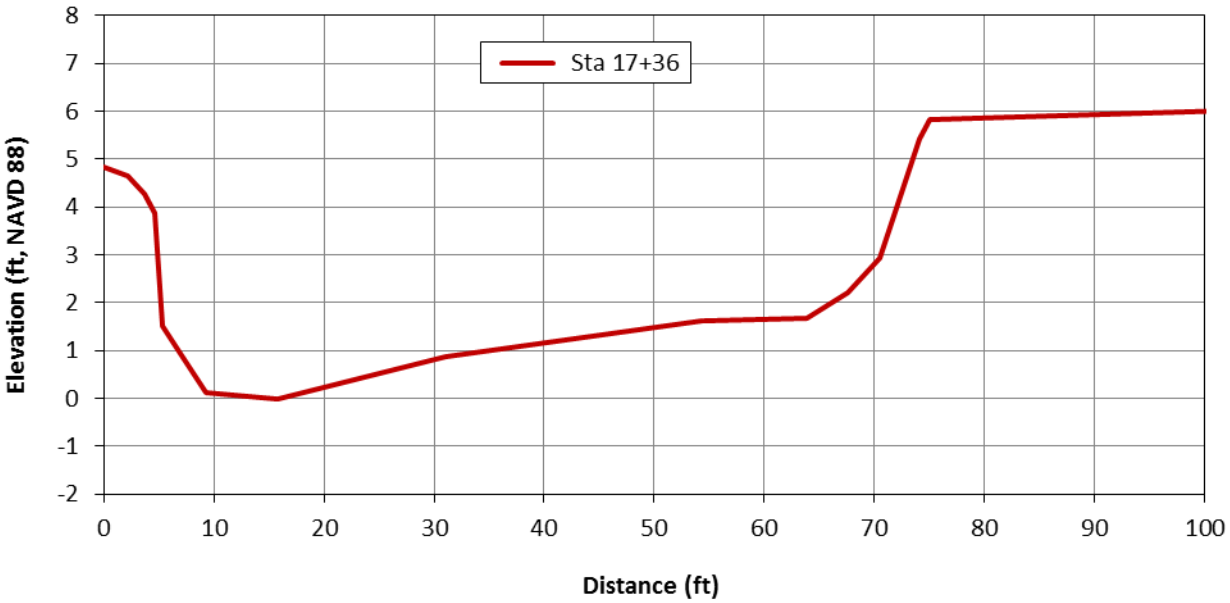
Note: north bank on the left and south bank on the right.

Figure 4. Surveyed Northern Drainage Channel Cross Section at Station 3+60



Note: north bank on the left and south bank on the right.

Figure 5. Surveyed Northern Drainage Channel Cross Section at Station 9+56



Note: north bank on the left and south bank on the right.

Figure 6. Surveyed Northern Drainage Channel Cross Section at Station 17+36

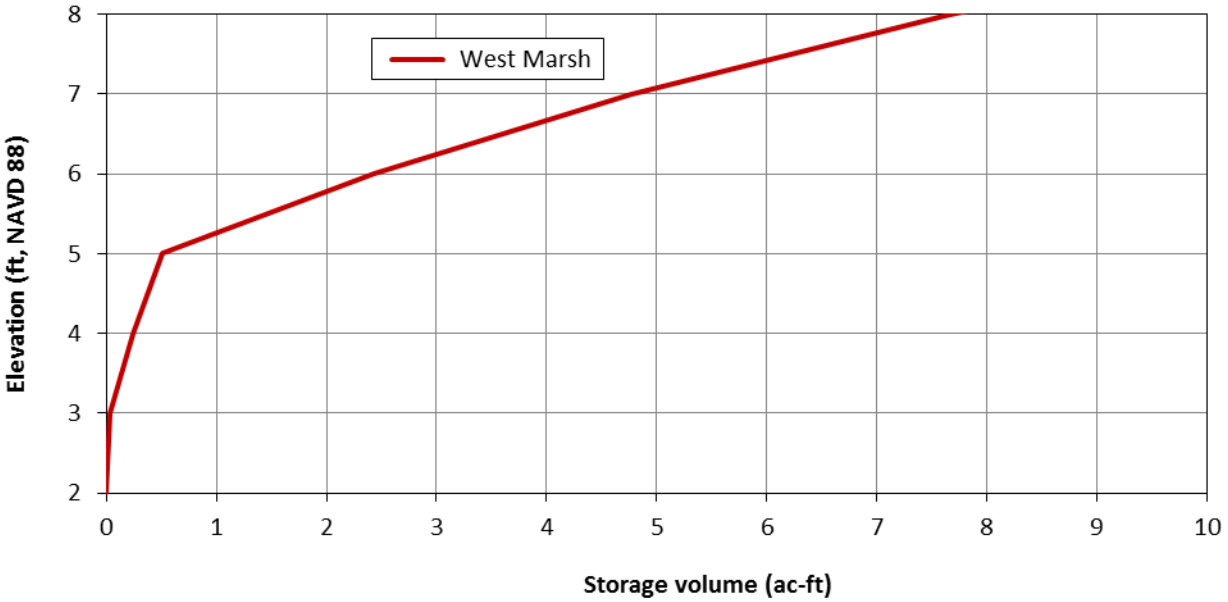


Figure 7. Elevation versus Storage Volume Curve for the Small Marsh Northwest of the Project Site

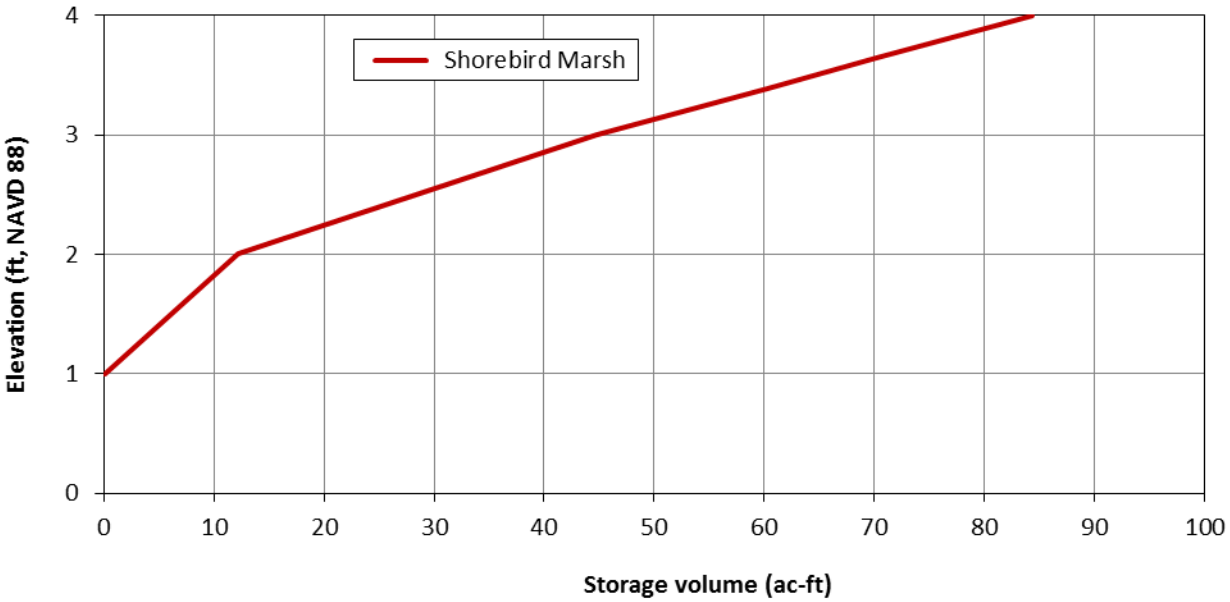


Figure 8. Elevation versus Estimated Storage Volume Curve for Shorebird Marsh

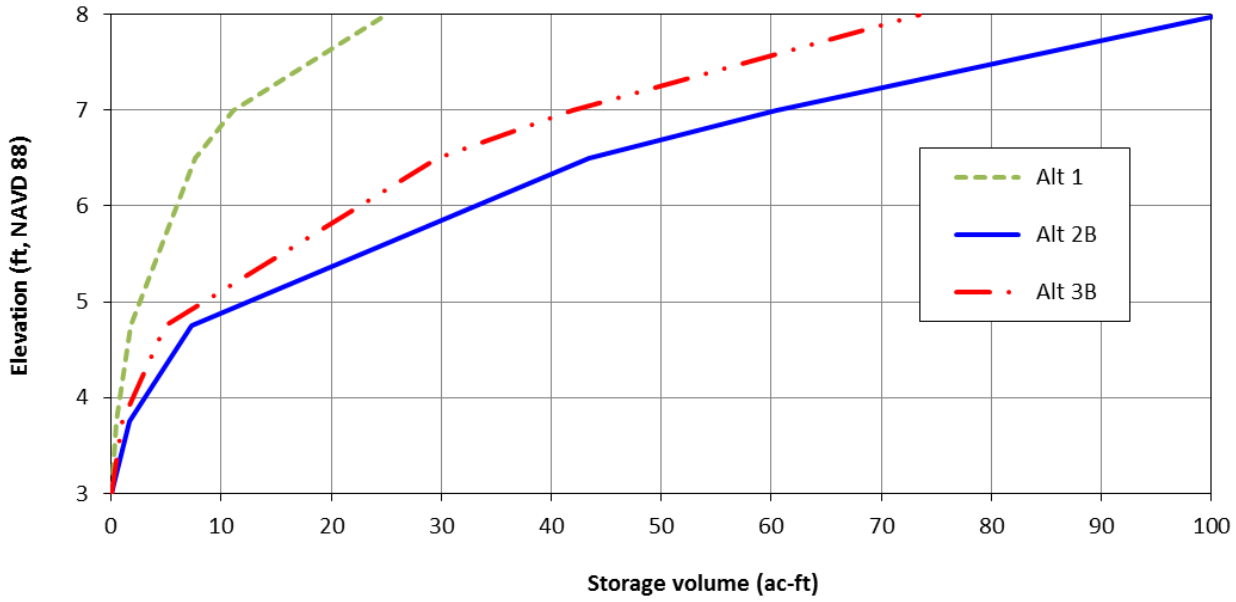


Figure 9. Elevation versus Storage Volume Curves for the Proposed Restored Corte Madera Marsh

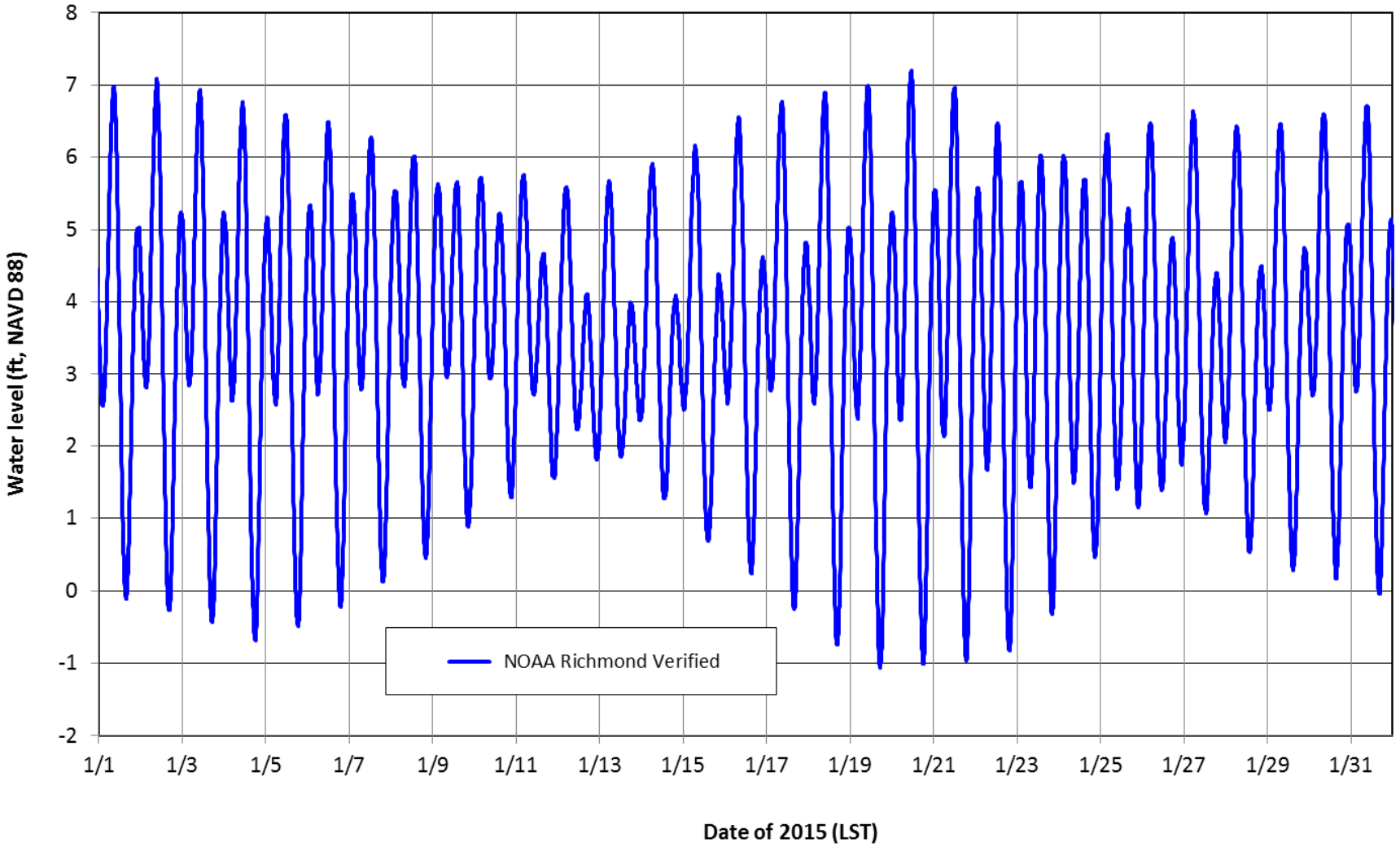


Figure 10. Measured Water Surface Elevation Data at NOAA Station at Richmond

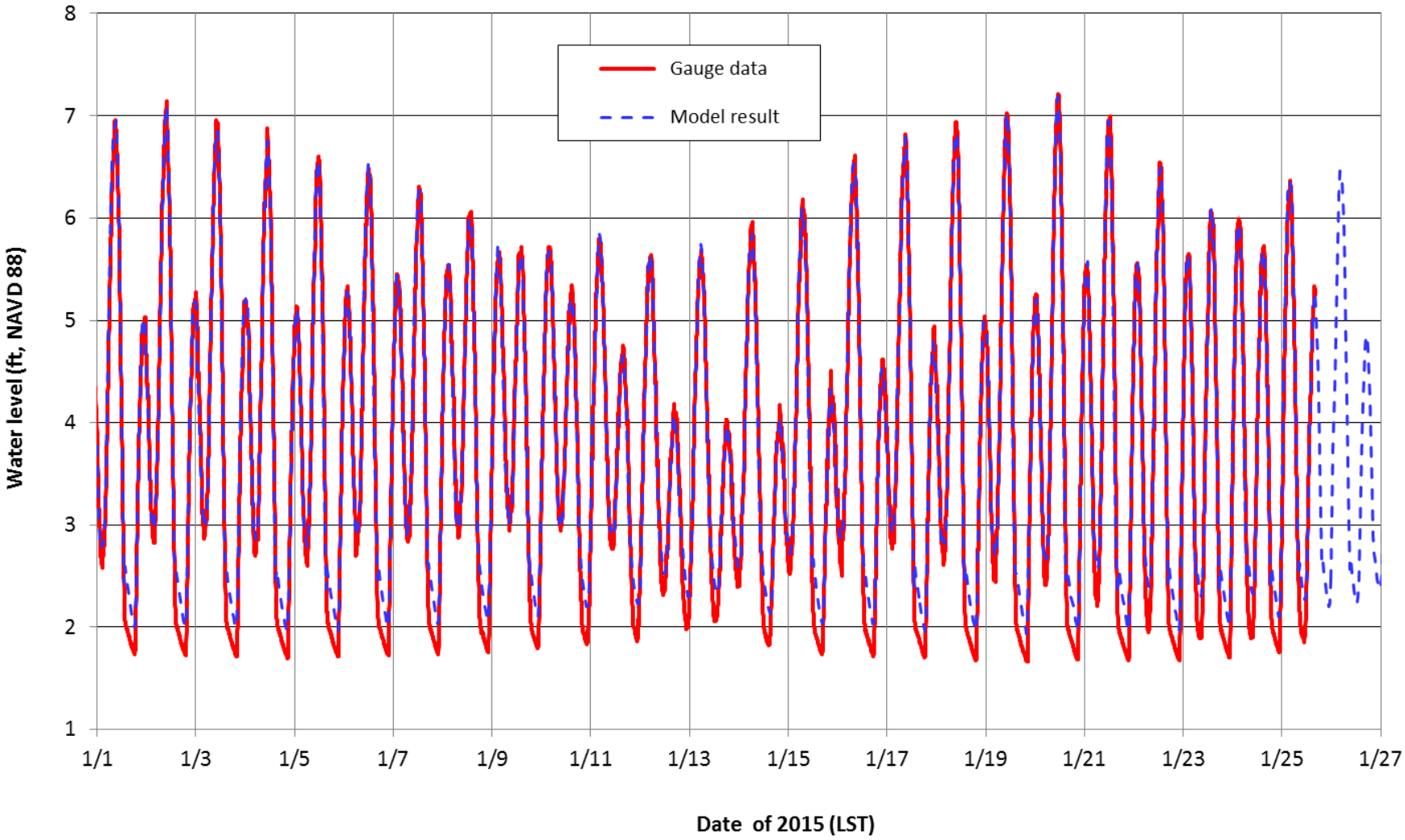


Figure 11. Comparison of Water Levels between Model Results and Data at Sta 3+30

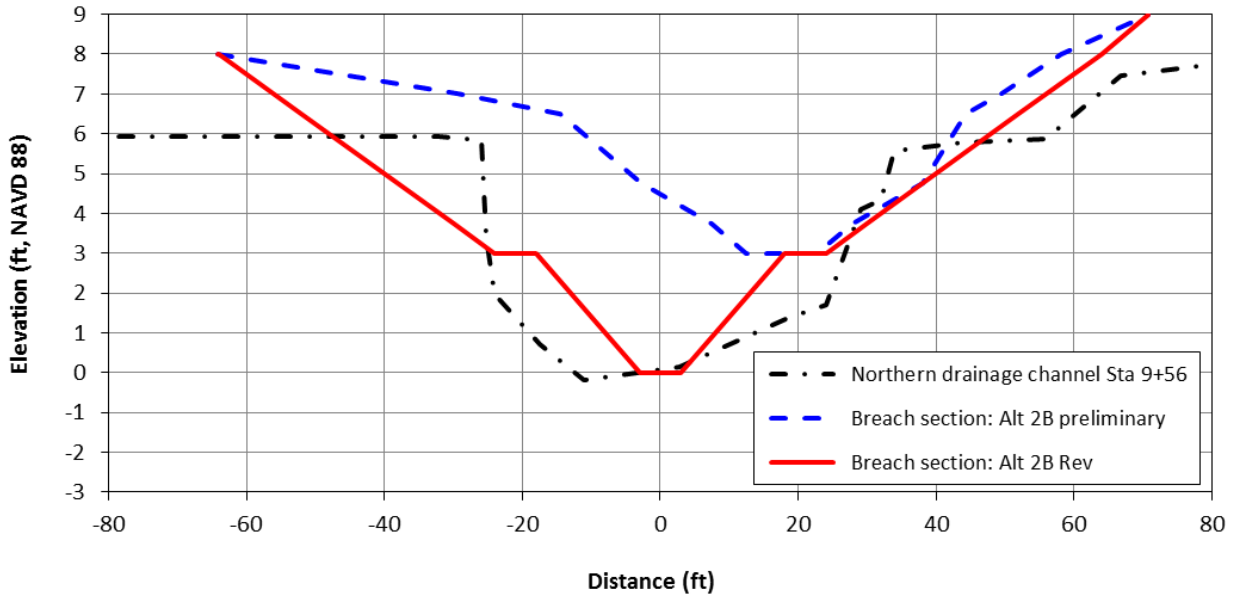


Figure 12. Optimized Breach Channel Section for Alternative 2B

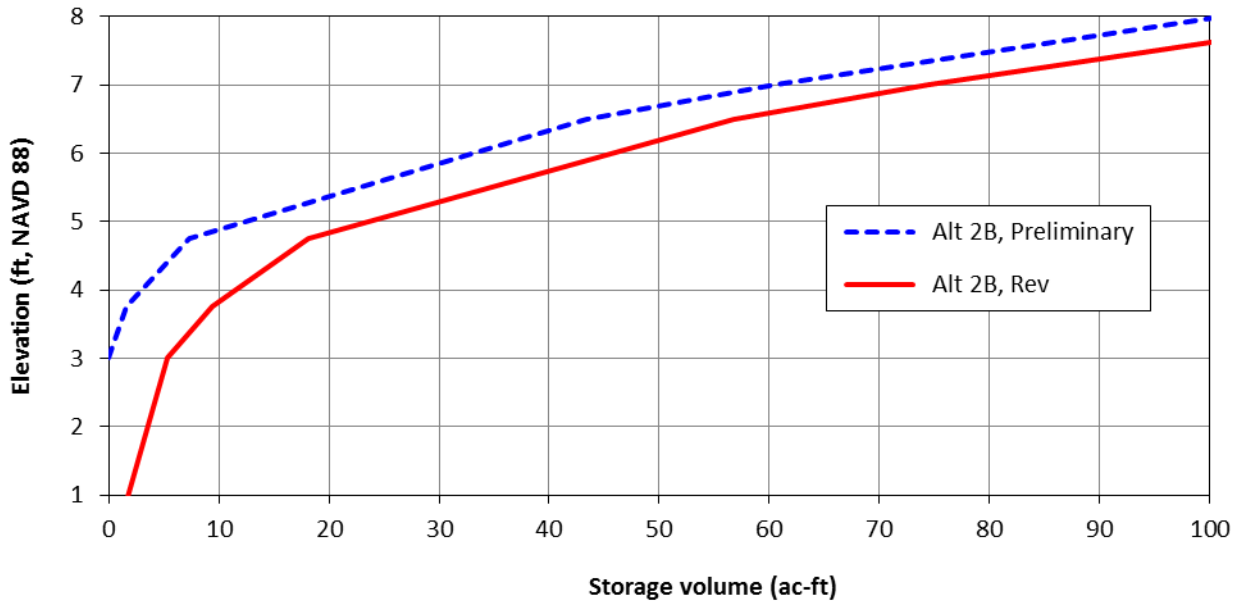


Figure 13. Revised Corte Madera Marsh Storage Volume Curves for Alternative 2B

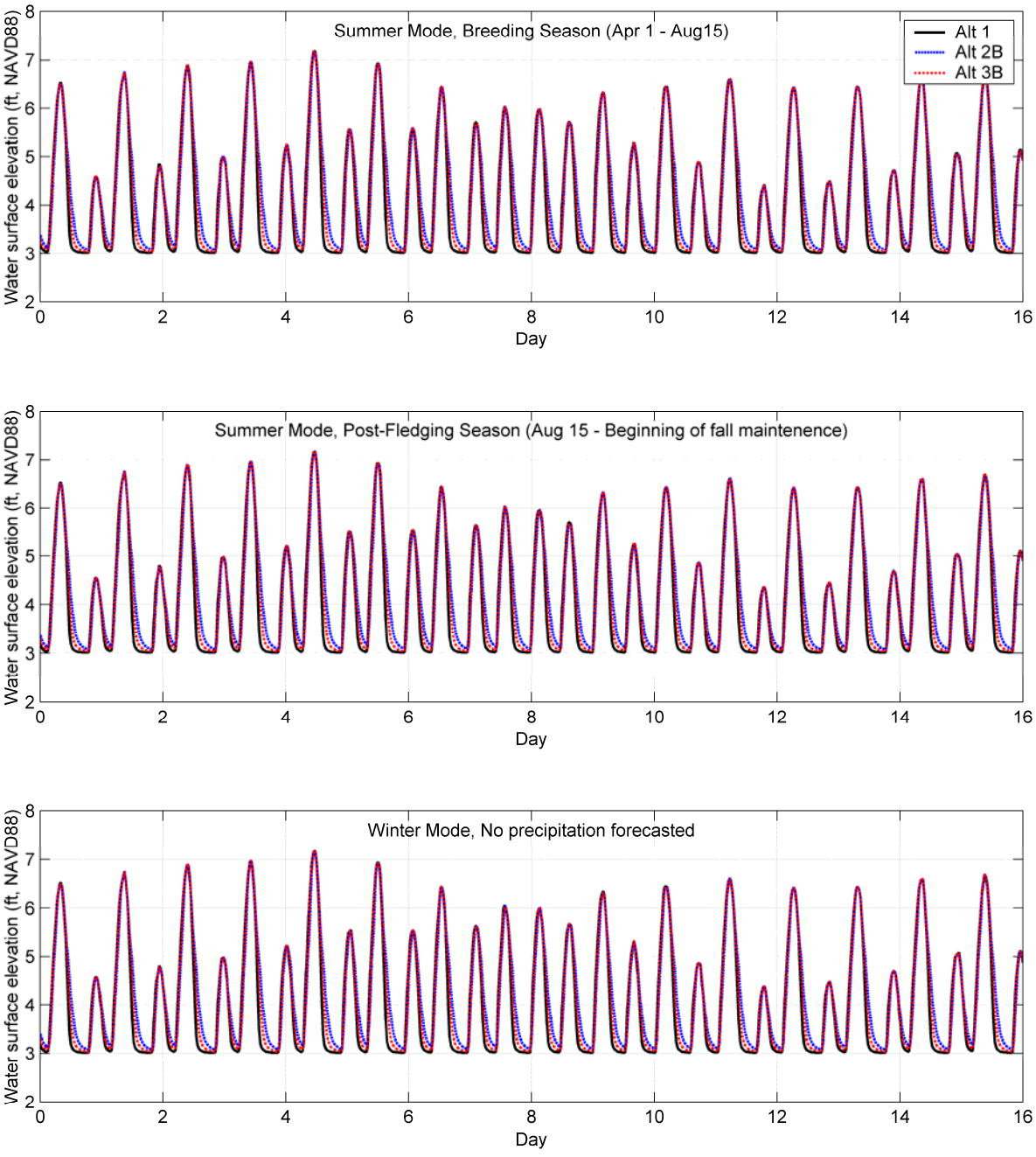


Figure 14. Water Levels in Proposed Restored Corte Madera Marsh for WRA's Preliminary Alternatives 1, 2B, and 3B

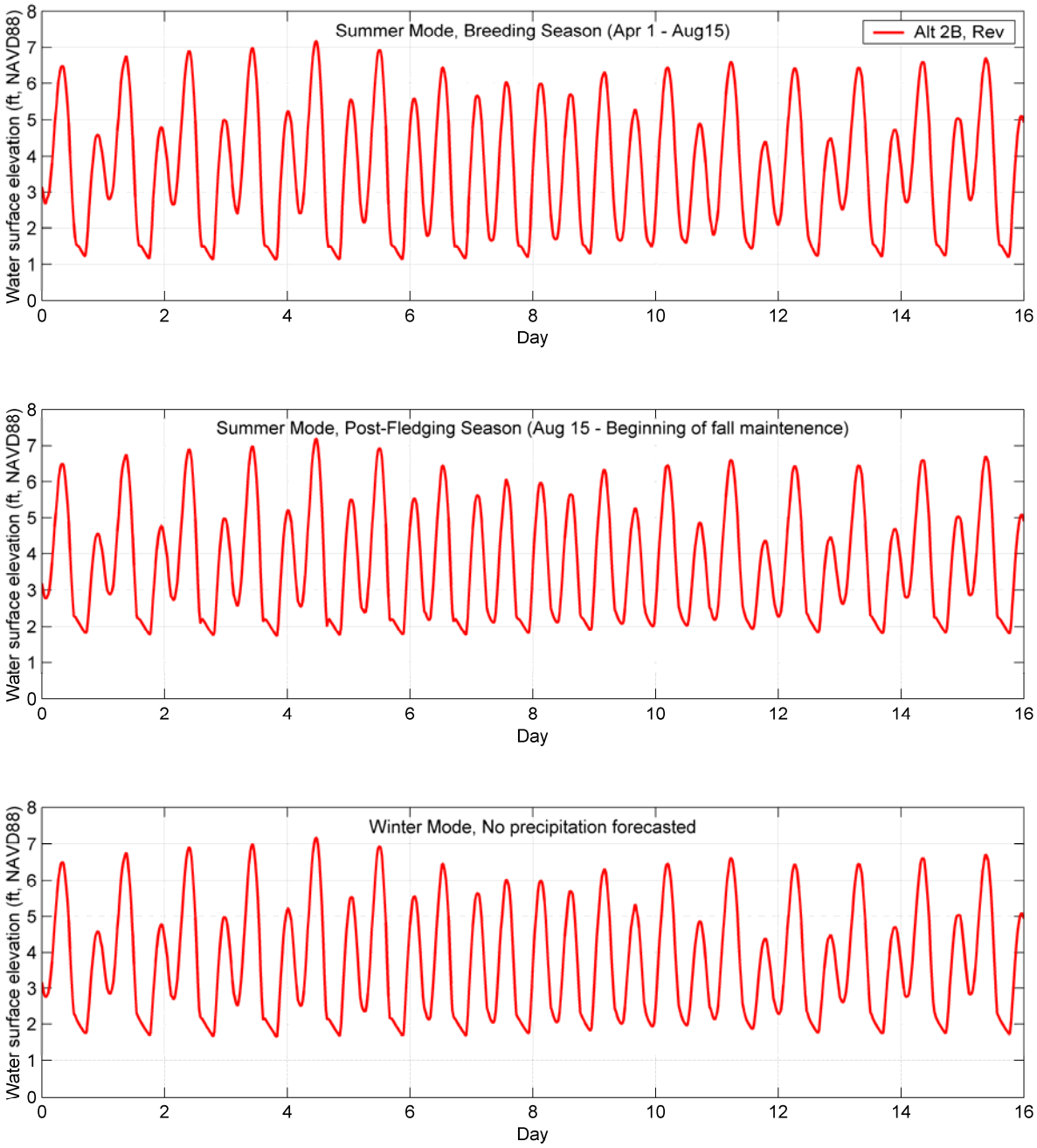


Figure 15. Water Levels in Proposed Restored Corte Madera Marsh for WRA's Alternative 2B with Optimized Size for Breach and Internal Tidal Channels

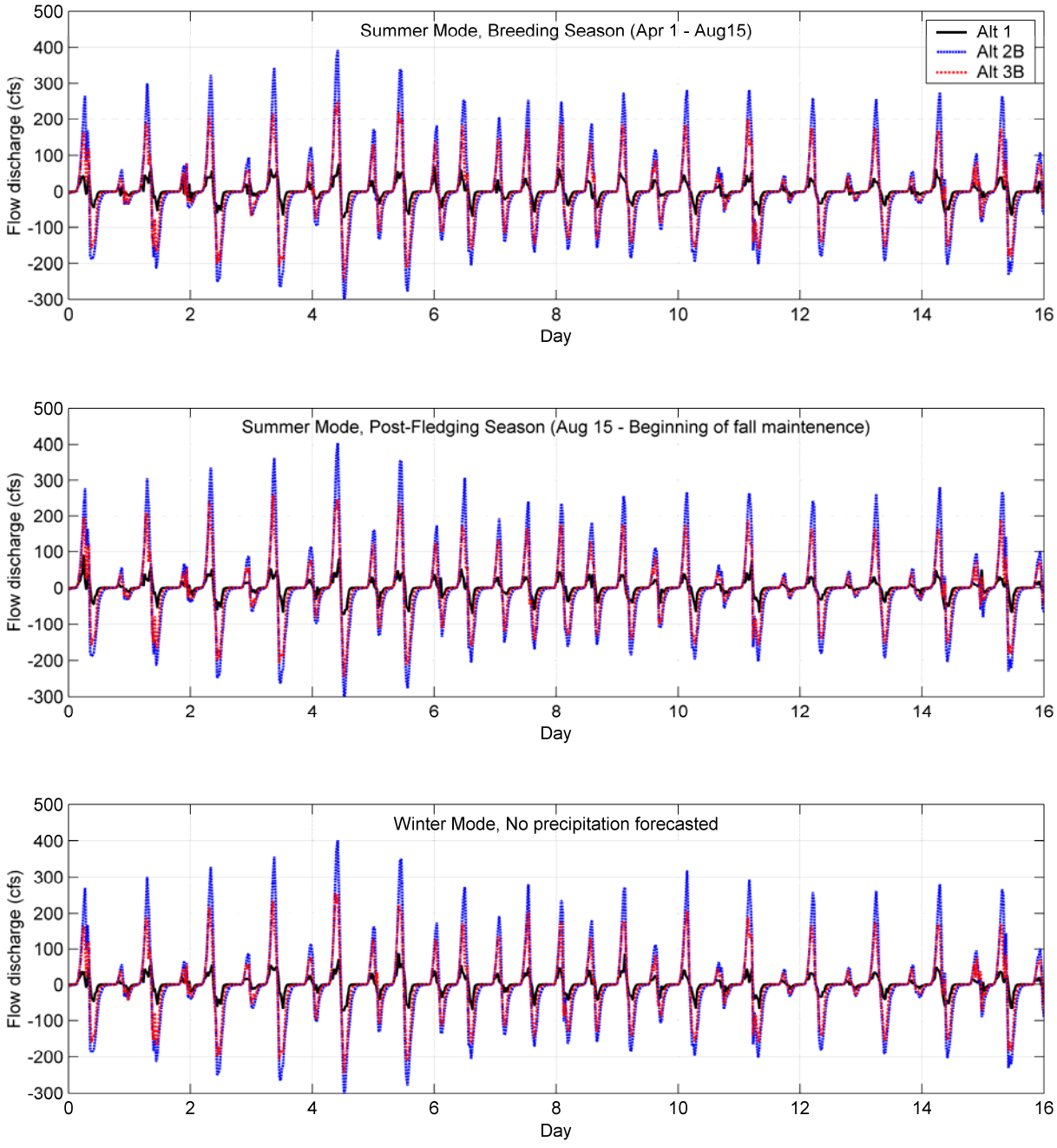


Figure 16. Flow Discharges in the Proposed Breach Channel for WRA's Preliminary Alternatives 1, 2B, and 3B

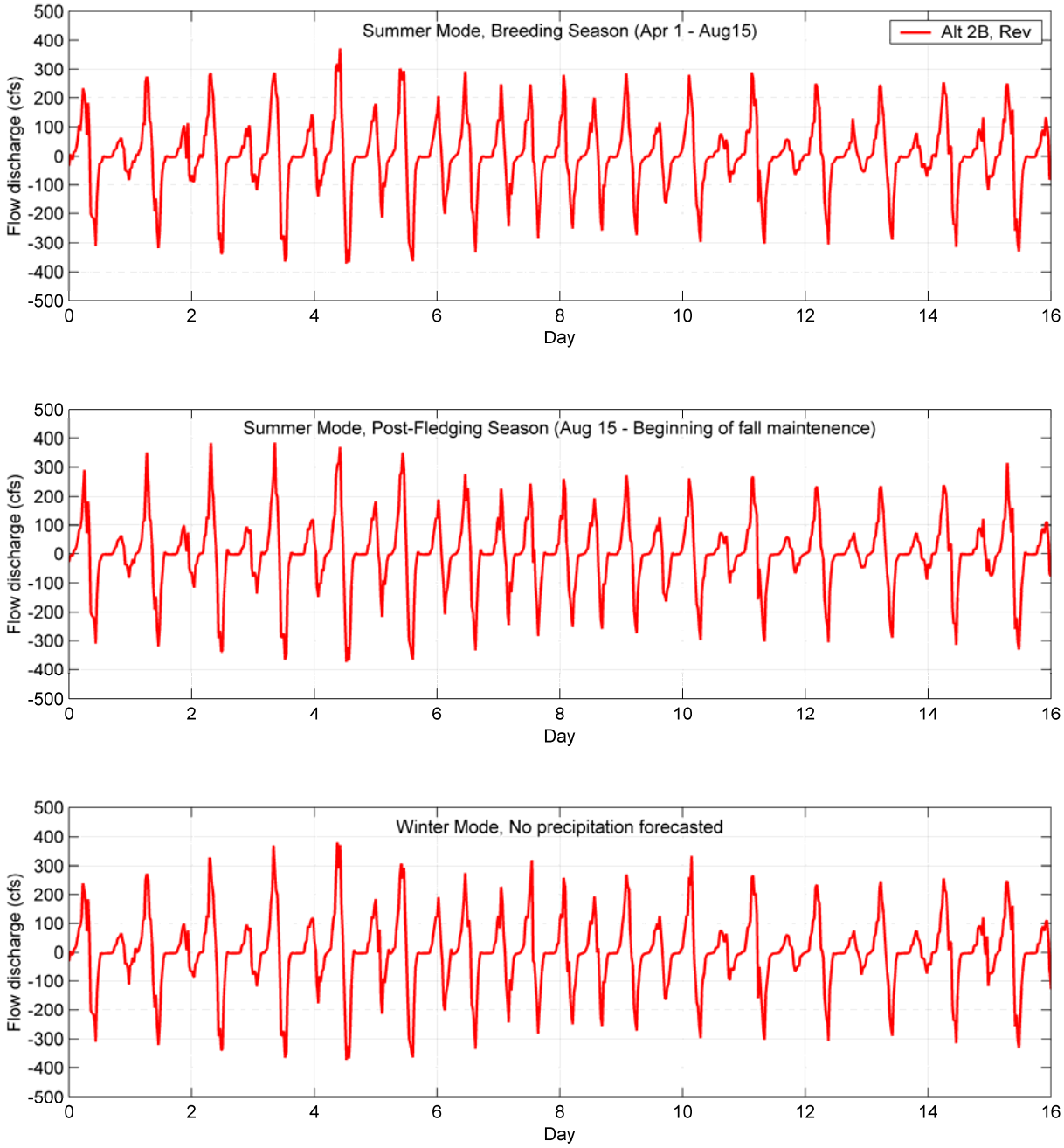


Figure 17. Flow Discharges in the Proposed Breach Channel for WRA's Alternative 2B with Optimized Size for Breach and Internal Tidal Channels

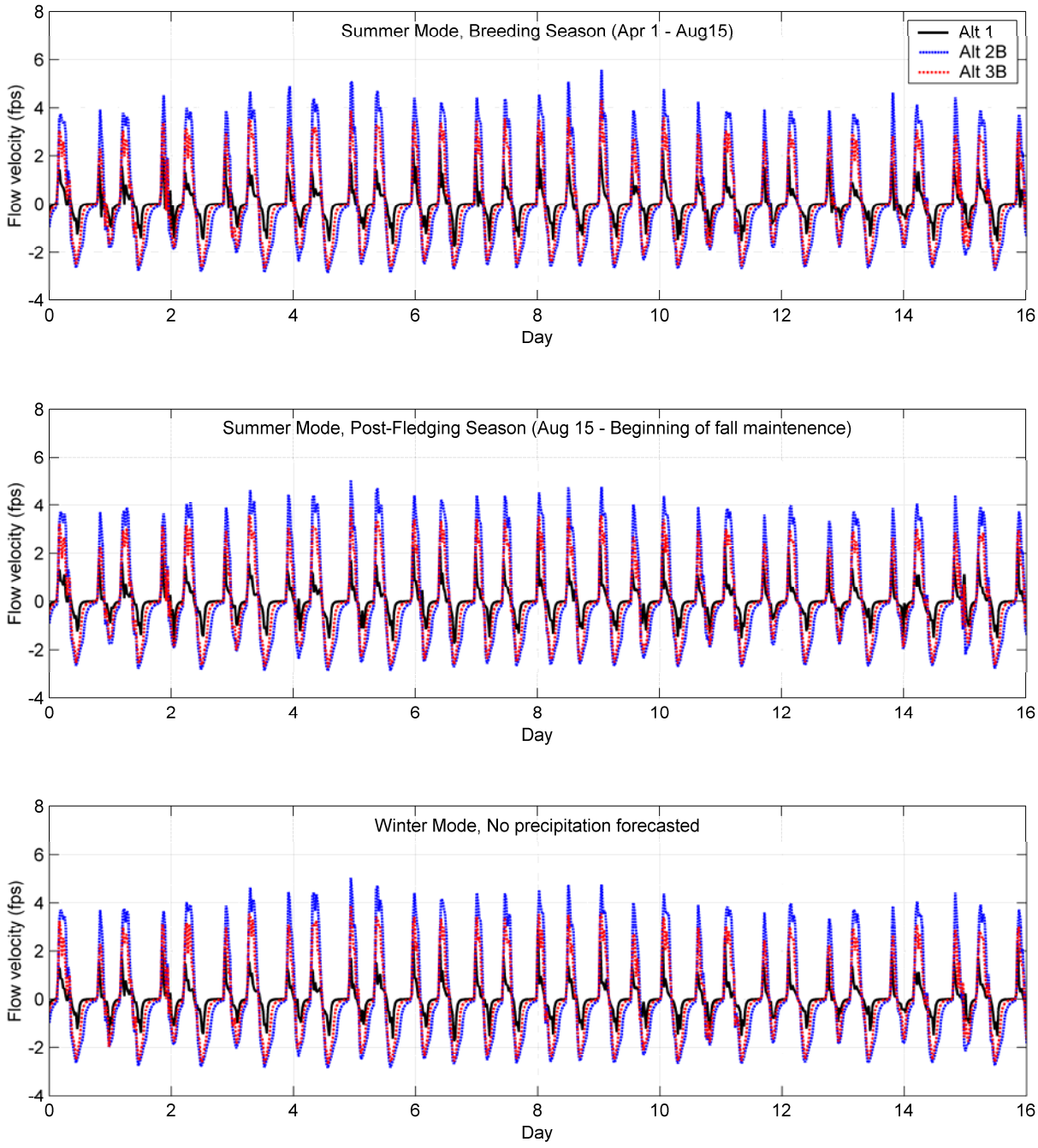


Figure 18. Channel Flow Velocities in the Proposed Breach Channel for WRA's Preliminary Alternatives 1, 2B, and 3B

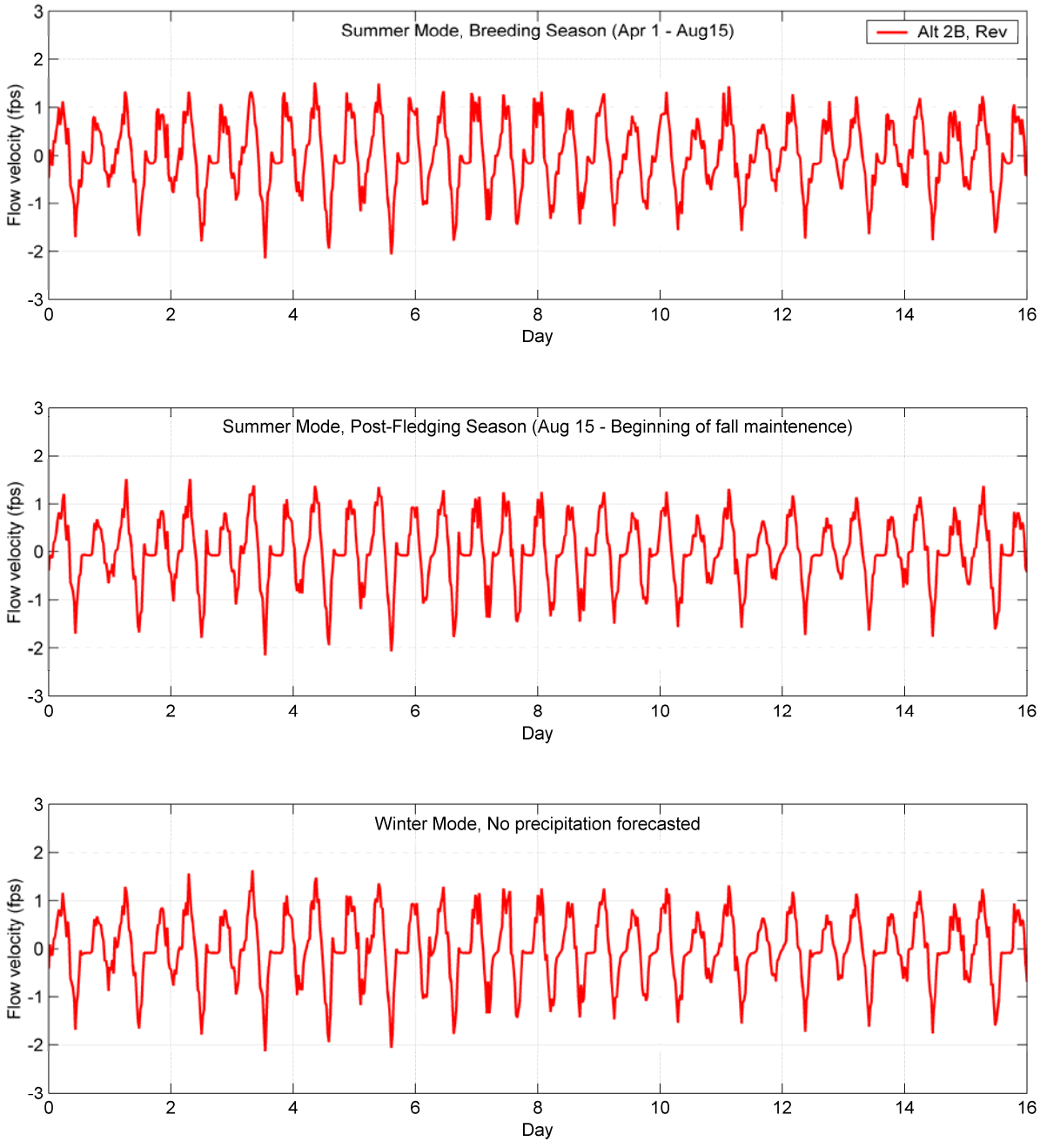


Figure 19. Channel Flow Velocities in the Proposed Breach Channel for WRA's Alternative 2B with Optimized Size for Breach and Internal Tidal Channels

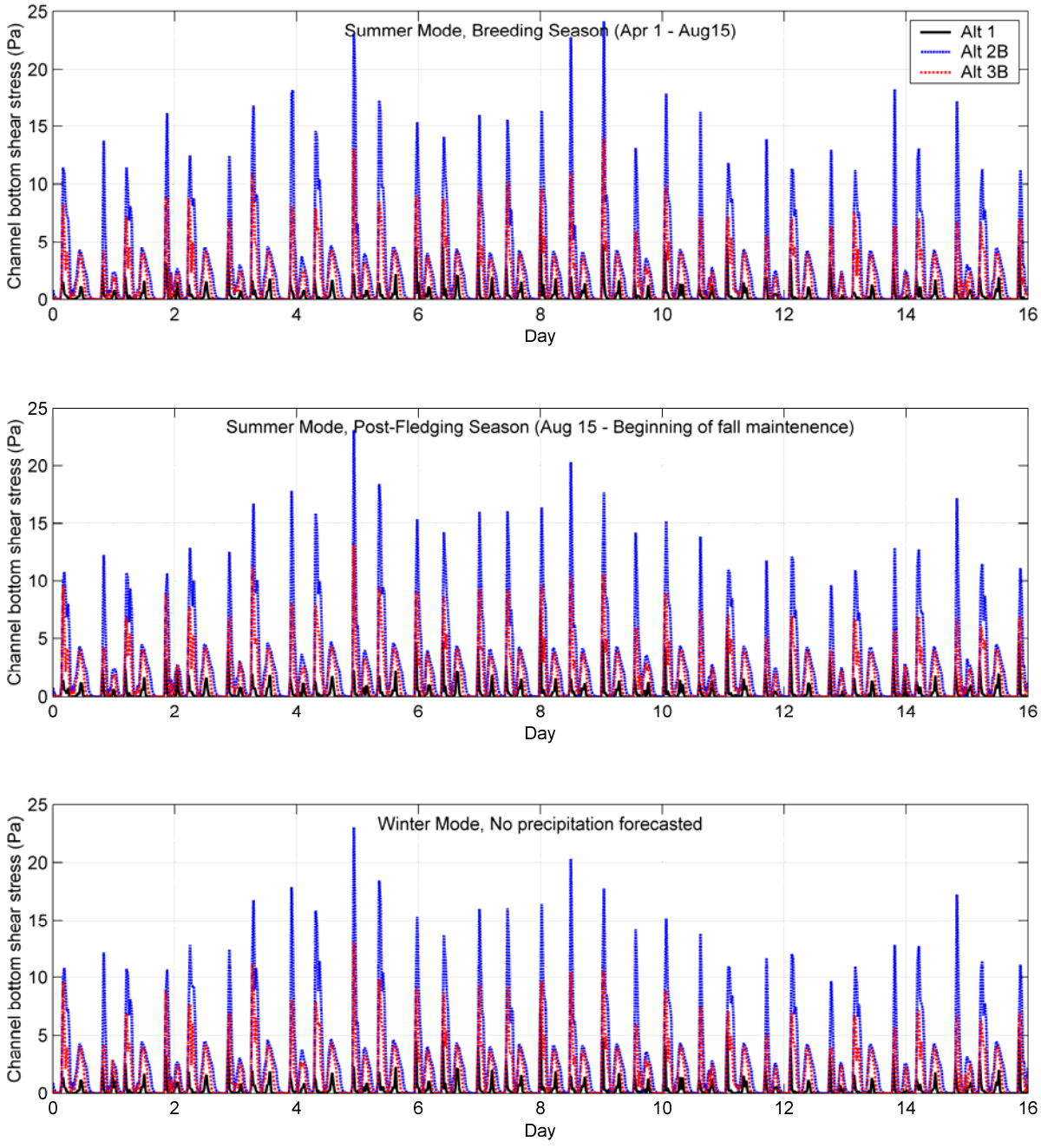


Figure 20. Channel Bottom Shear Stresses in the Proposed Breach Channel for WRA's Preliminary Alternatives 1, 2B, and 3B

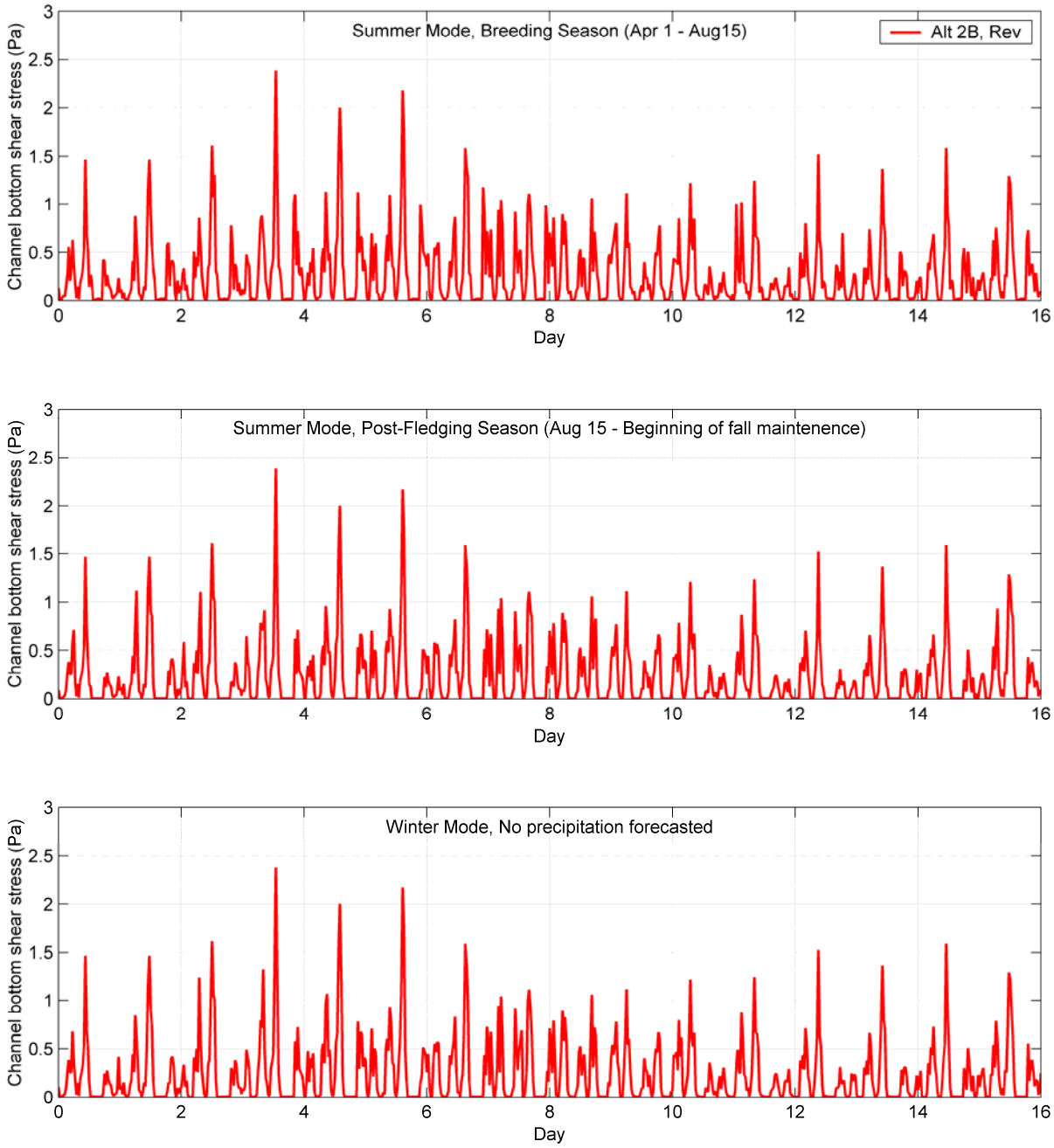


Figure 21. Channel Bottom Shear Stresses in the Proposed Breach Channel for WRA's Alternative 2B with Optimized Size for Breach and Internal Tidal Channels

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Existing Conditions in Existing Northern Drainage Channel

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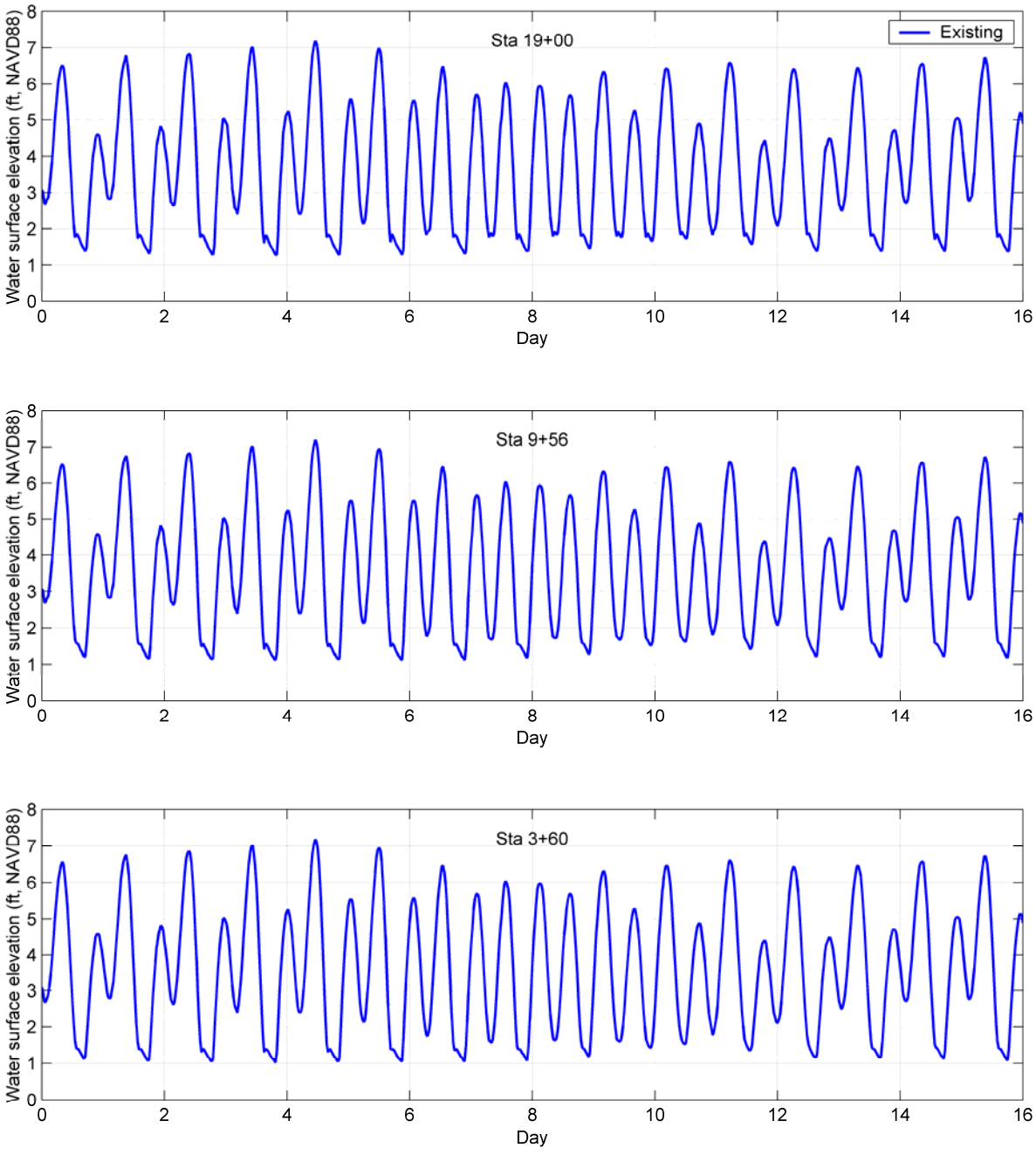


Figure 22. Water Levels in Existing Northern Drainage Channel (Apr 1 – Aug 15)

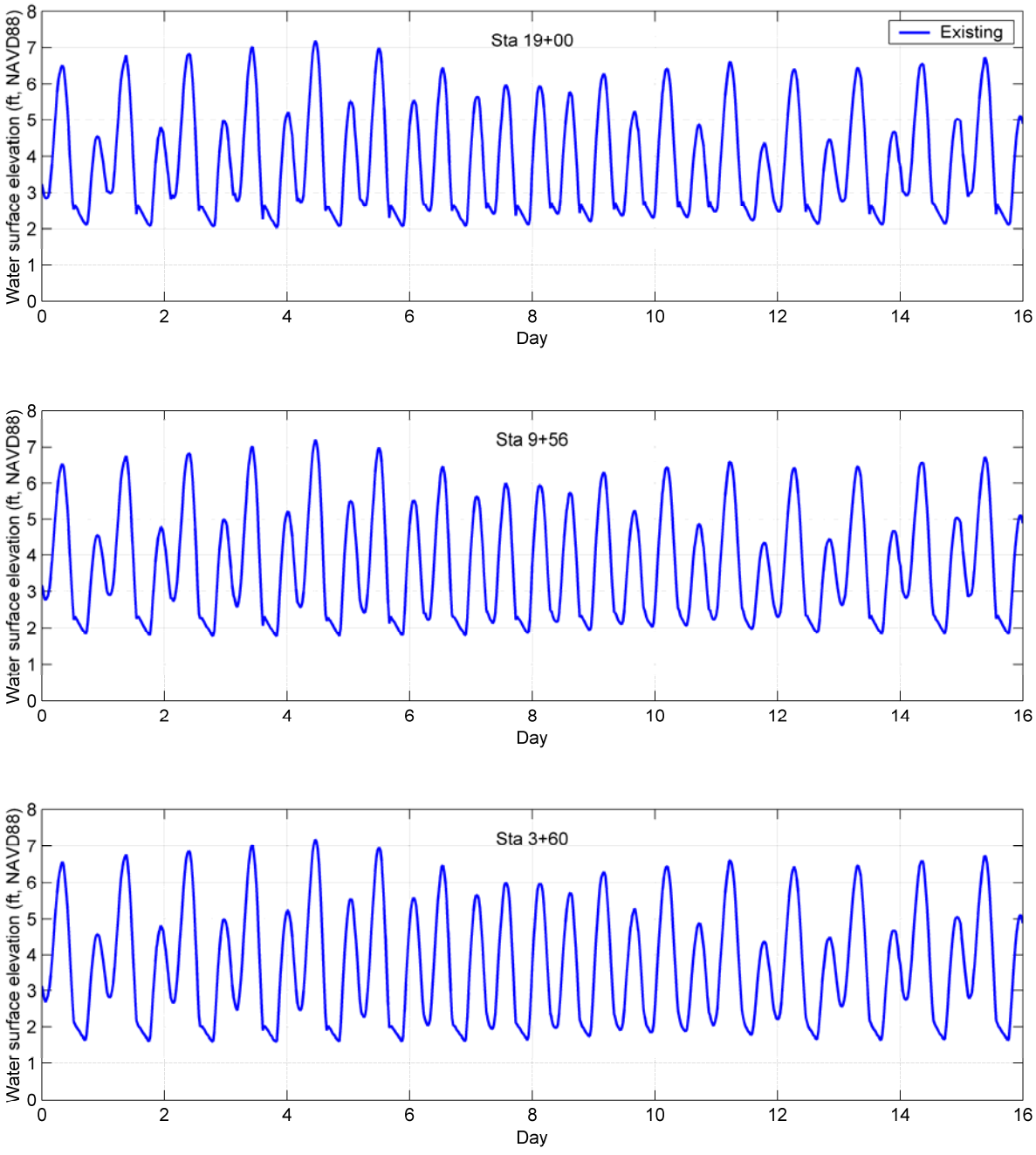


Figure 23. Water Levels in Existing Northern Drainage Channel (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

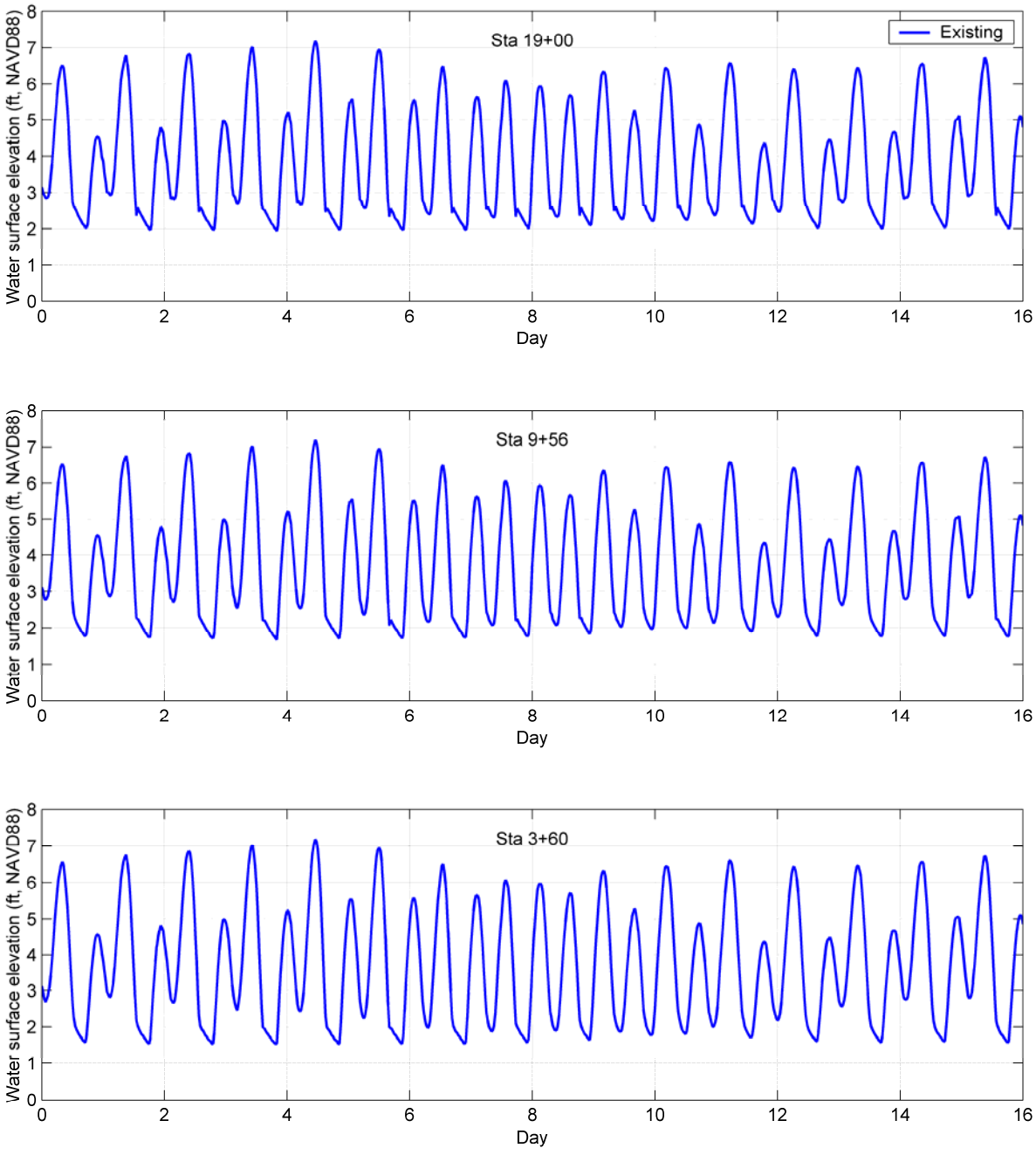


Figure 24. Water Levels in Existing Northern Drainage Channel (Winter with No Precipitation Forecasted)

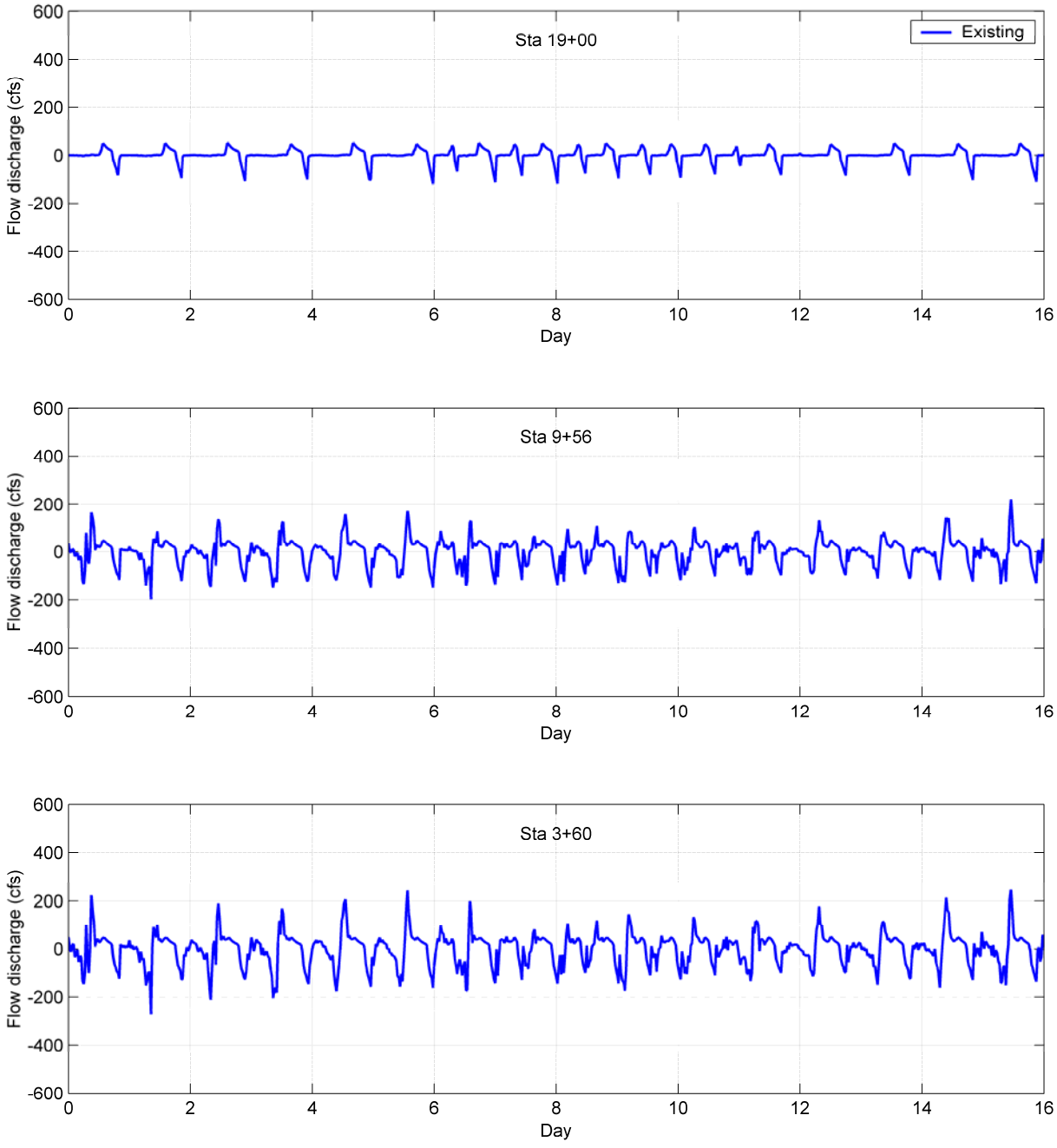


Figure 25. Flow Discharges in Existing Northern Drainage Channel (Apr 1 – Aug 15)

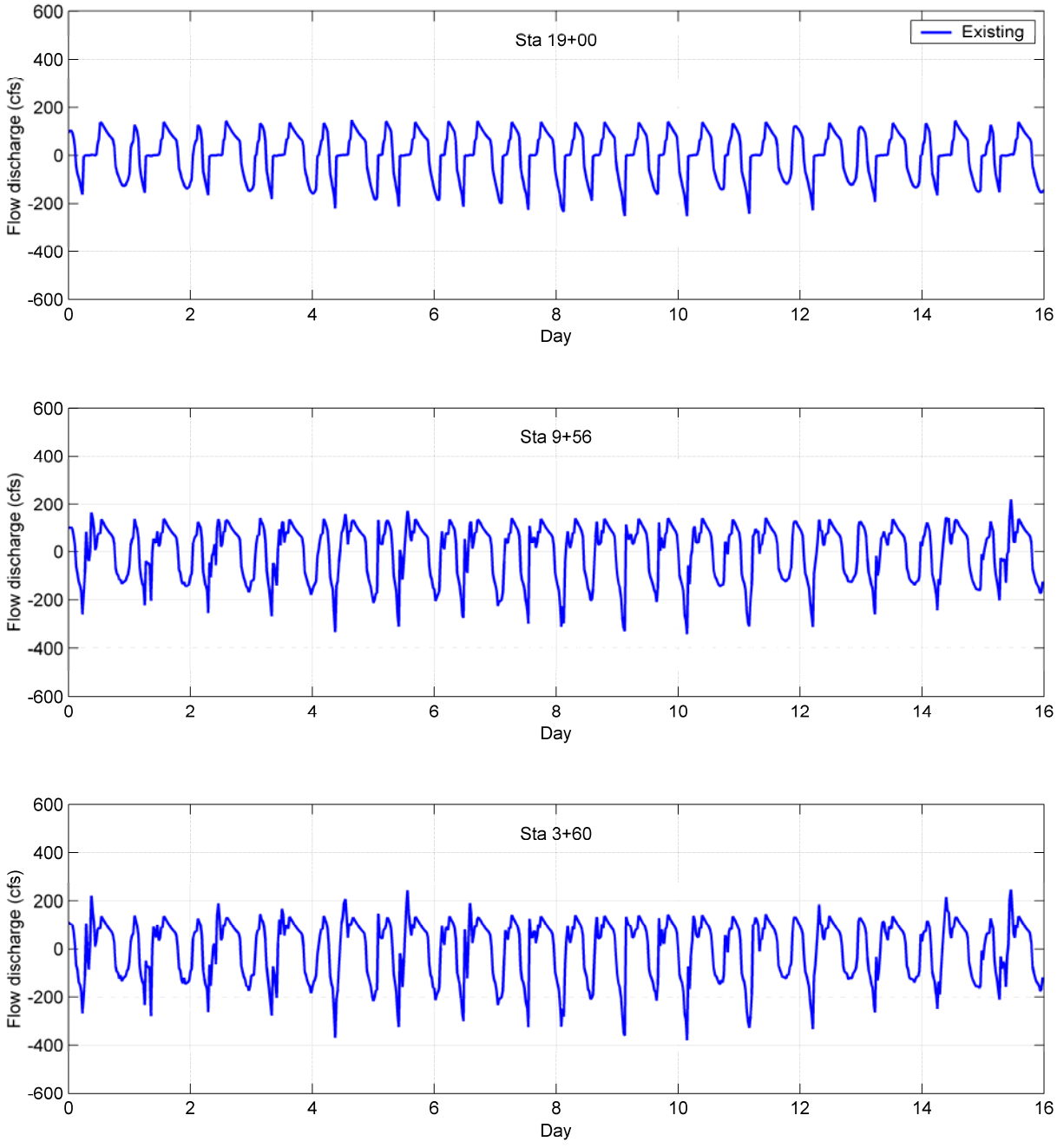


Figure 26. Flow Discharges in Existing Northern Drainage Channel (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

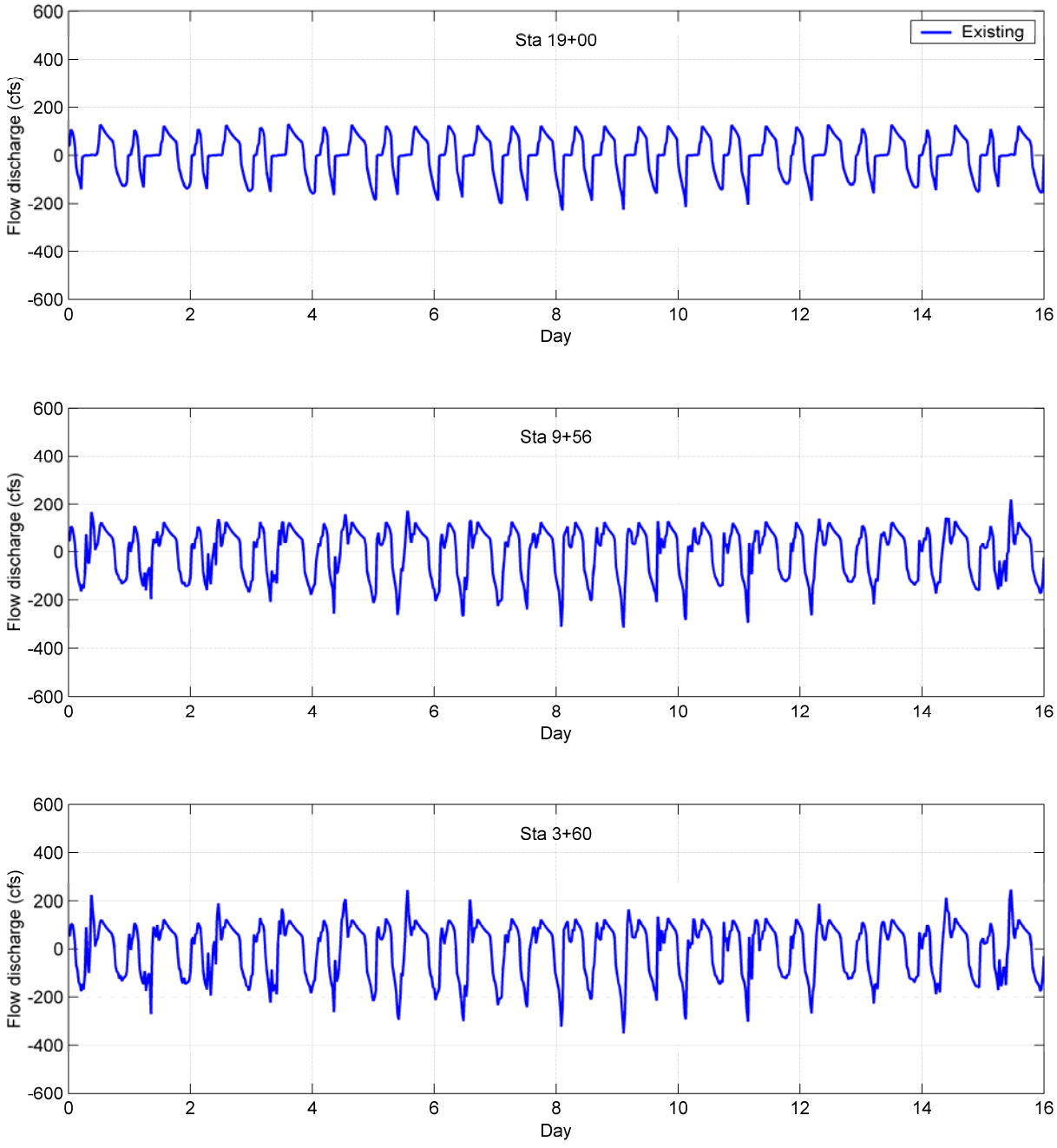


Figure 27. Flow Discharges in Existing Northern Drainage Channel (Winter with No Precipitation Forecasted)

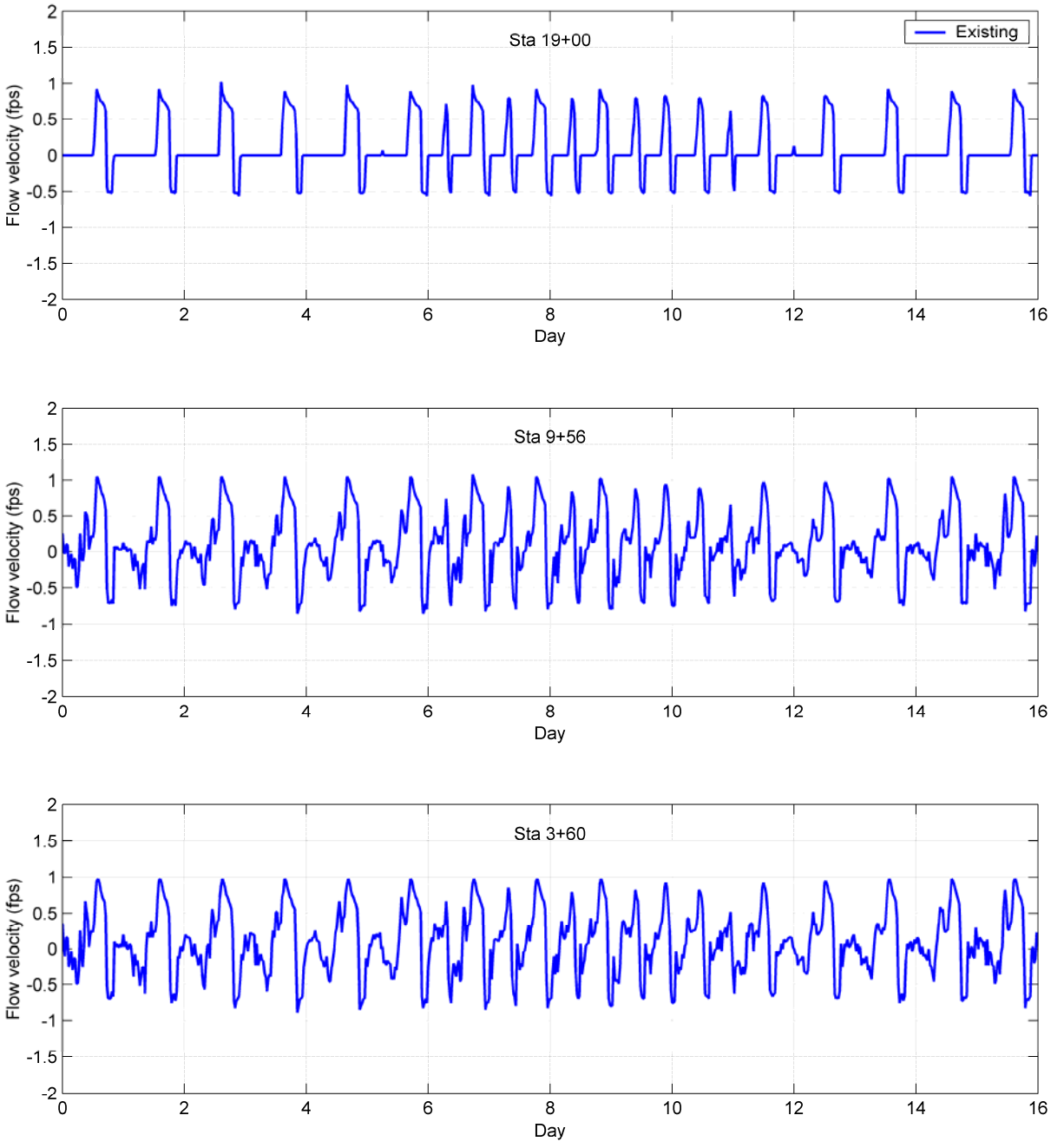


Figure 28. Flow Velocities in Existing Northern Drainage Channel (Apr 1 – Aug 15)

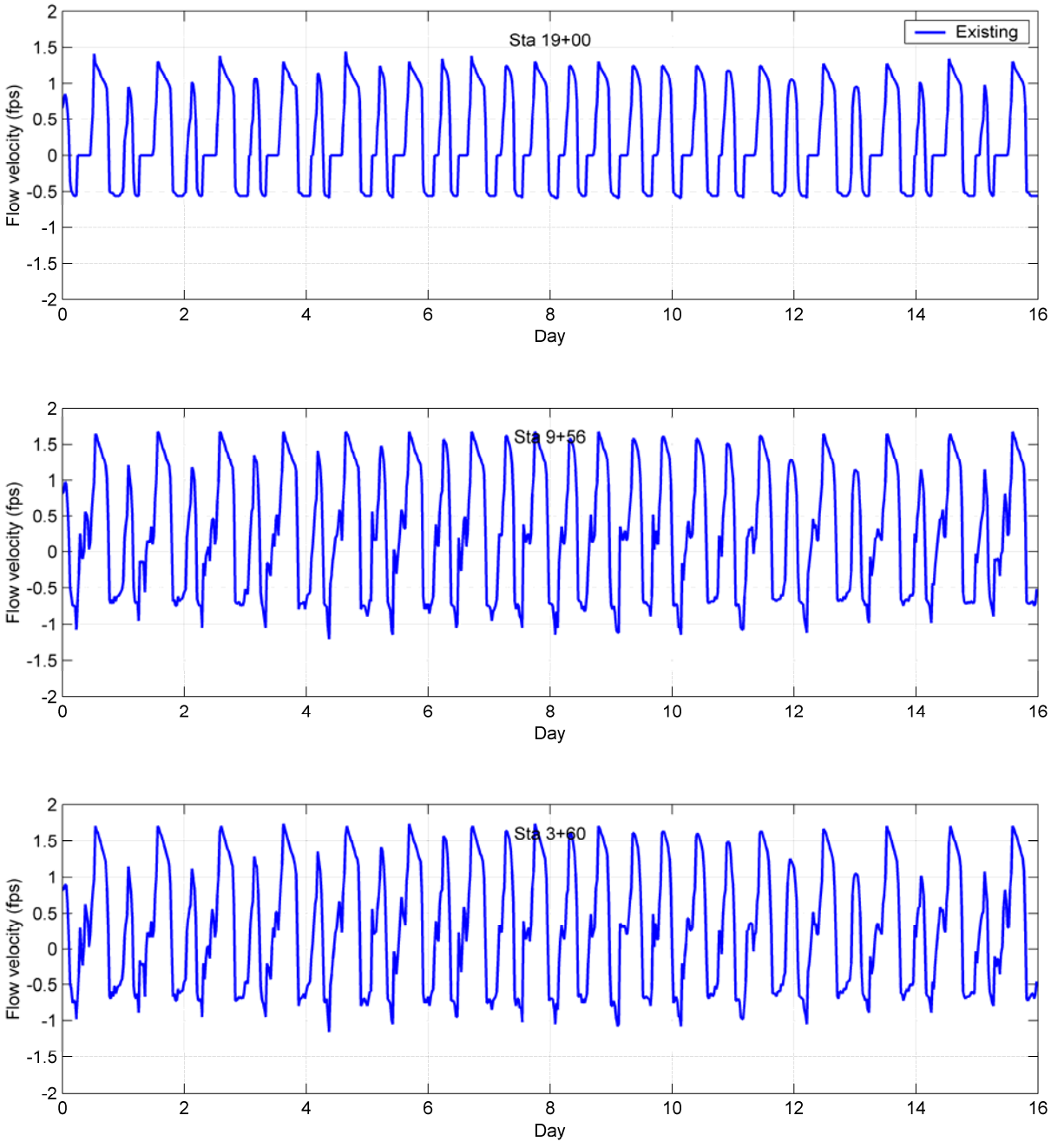


Figure 29. Flow Velocities in Existing Northern Drainage Channel (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

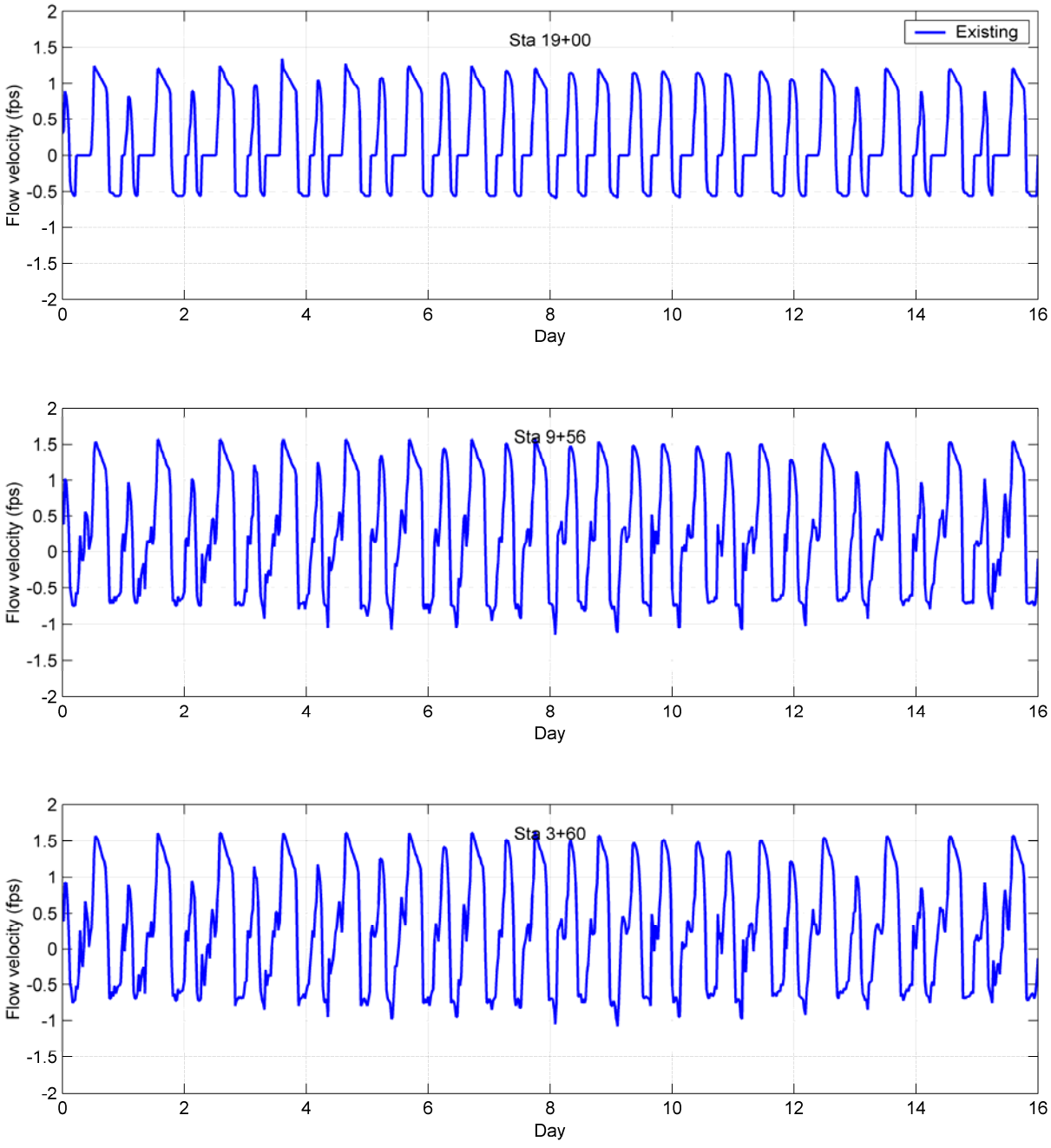


Figure 30. Flow Velocities in Existing Northern Drainage Channel (Winter with No Precipitation Forecasted)

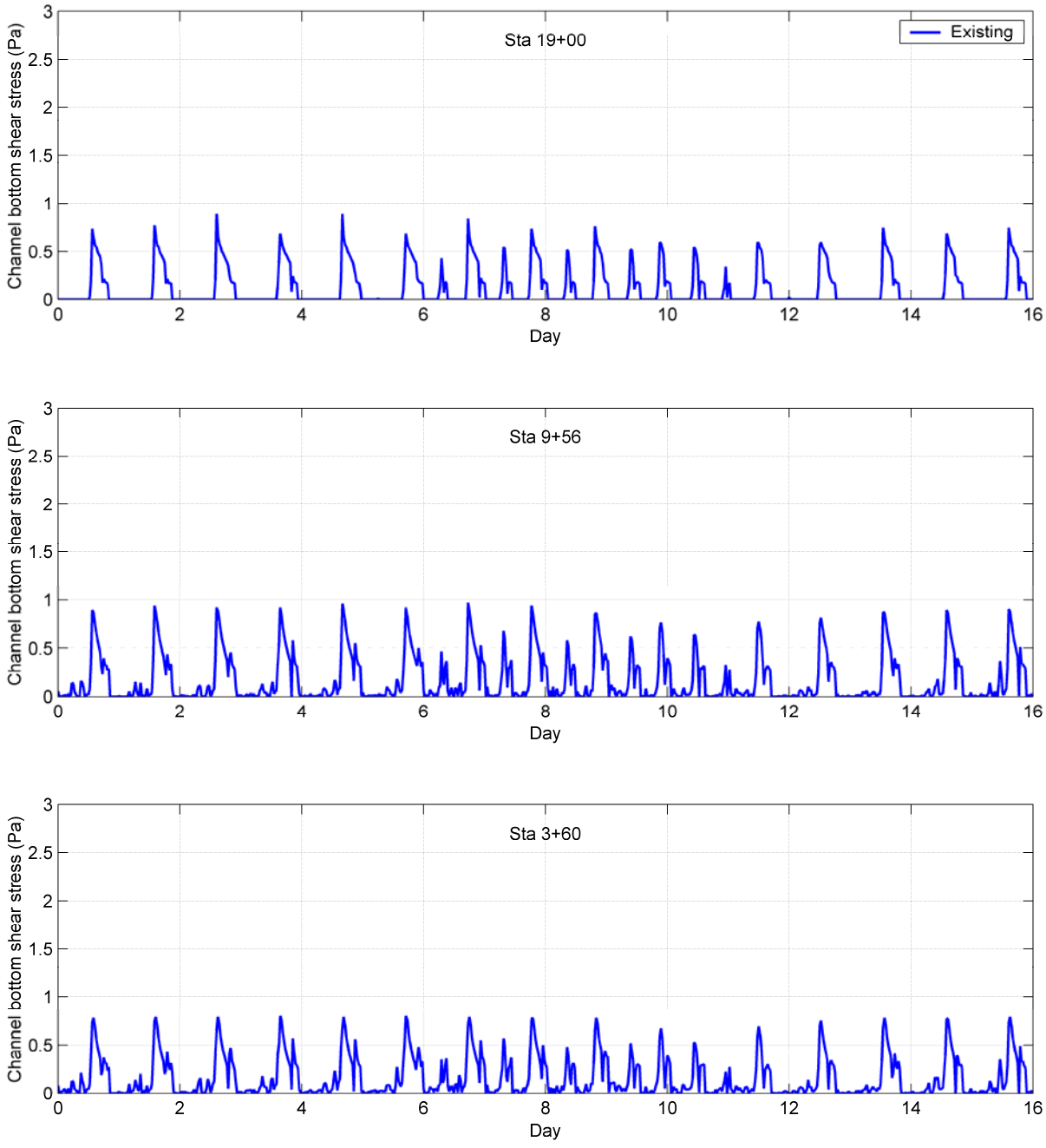


Figure 31. Channel Bottom Shear Stresses in Existing Northern Drainage Channel (Apr 1 – Aug 15)

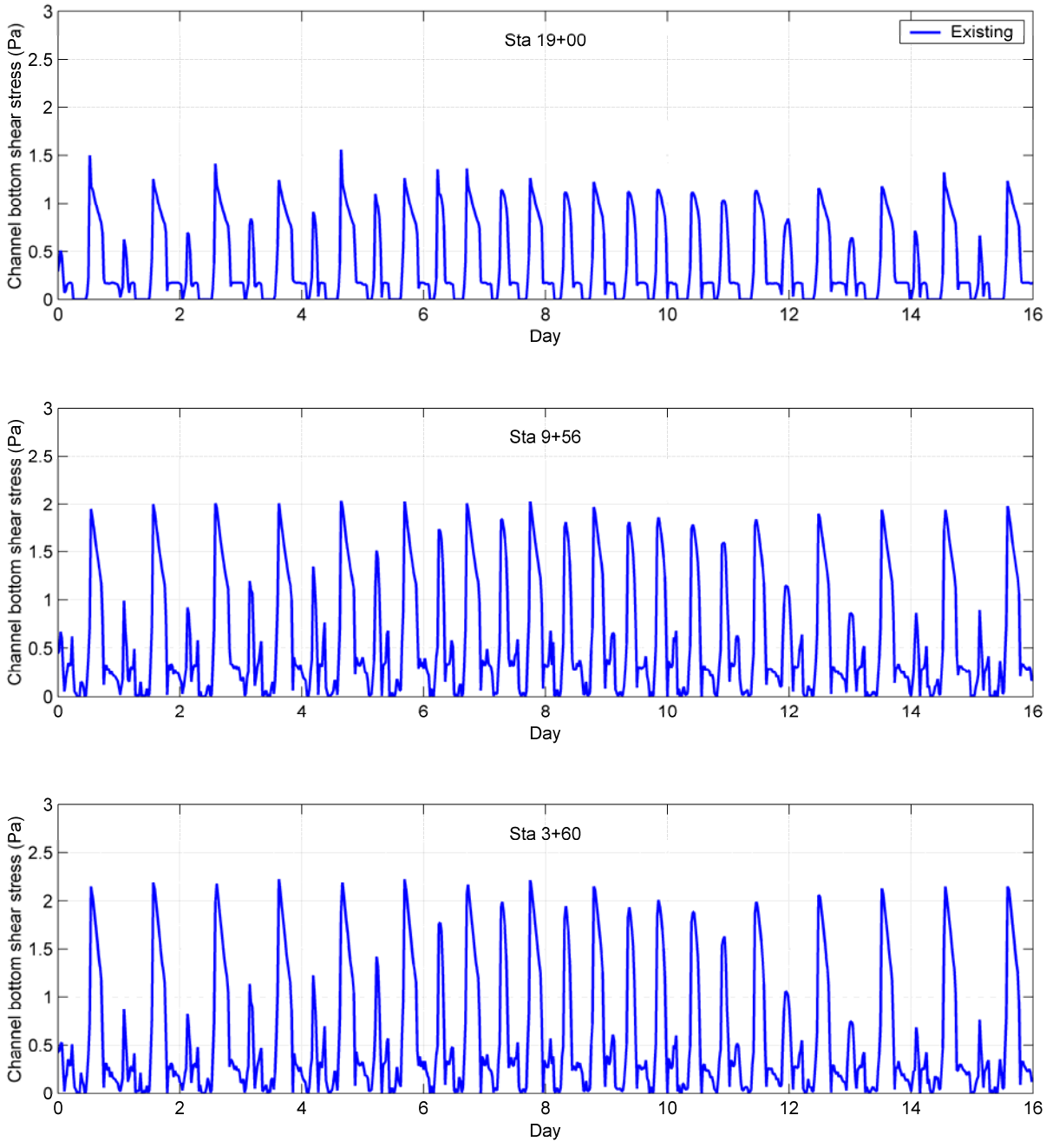


Figure 32. Channel Bottom Shear Stresses in Existing Northern Drainage Channel (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

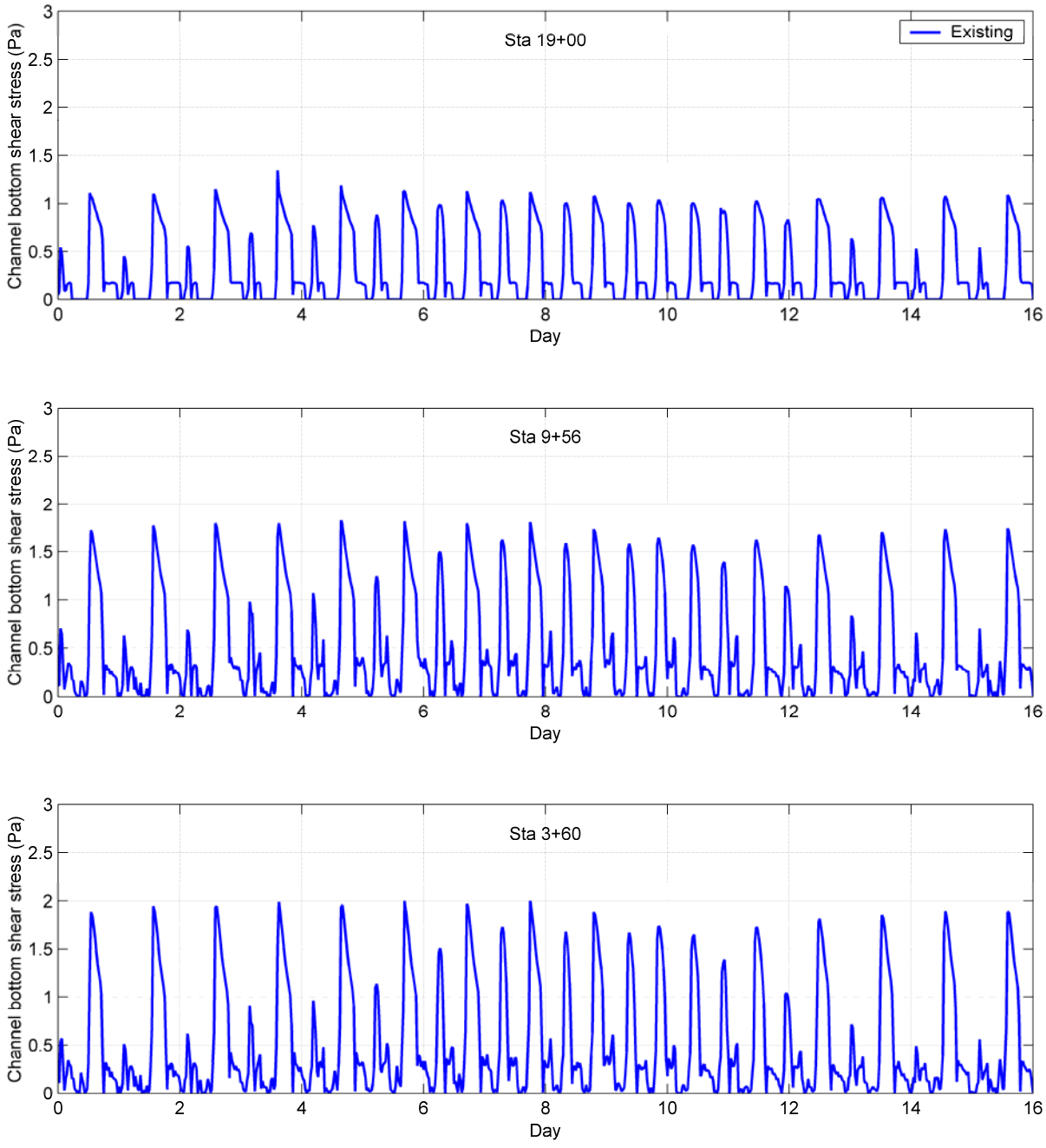


Figure 33. Channel Bottom Shear Stresses in Existing Northern Drainage Channel (Winter with No Precipitation Forecasted)

Water Levels in Northern Drainage Channel for WRA's Alternatives

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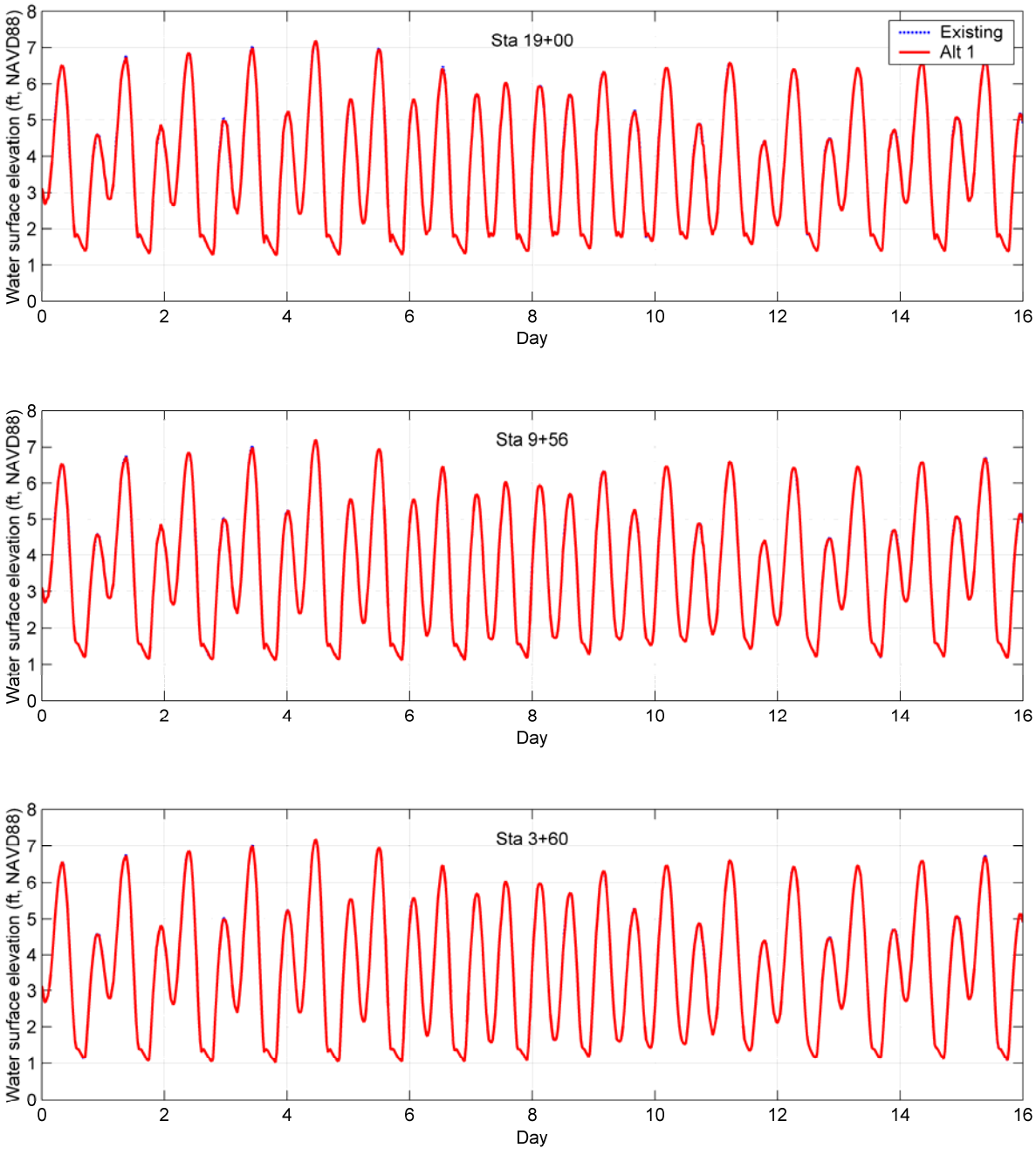


Figure 34. Water Levels in Northern Drainage Channel for WRA's Alternative 1 (Apr 1 – Aug 15)

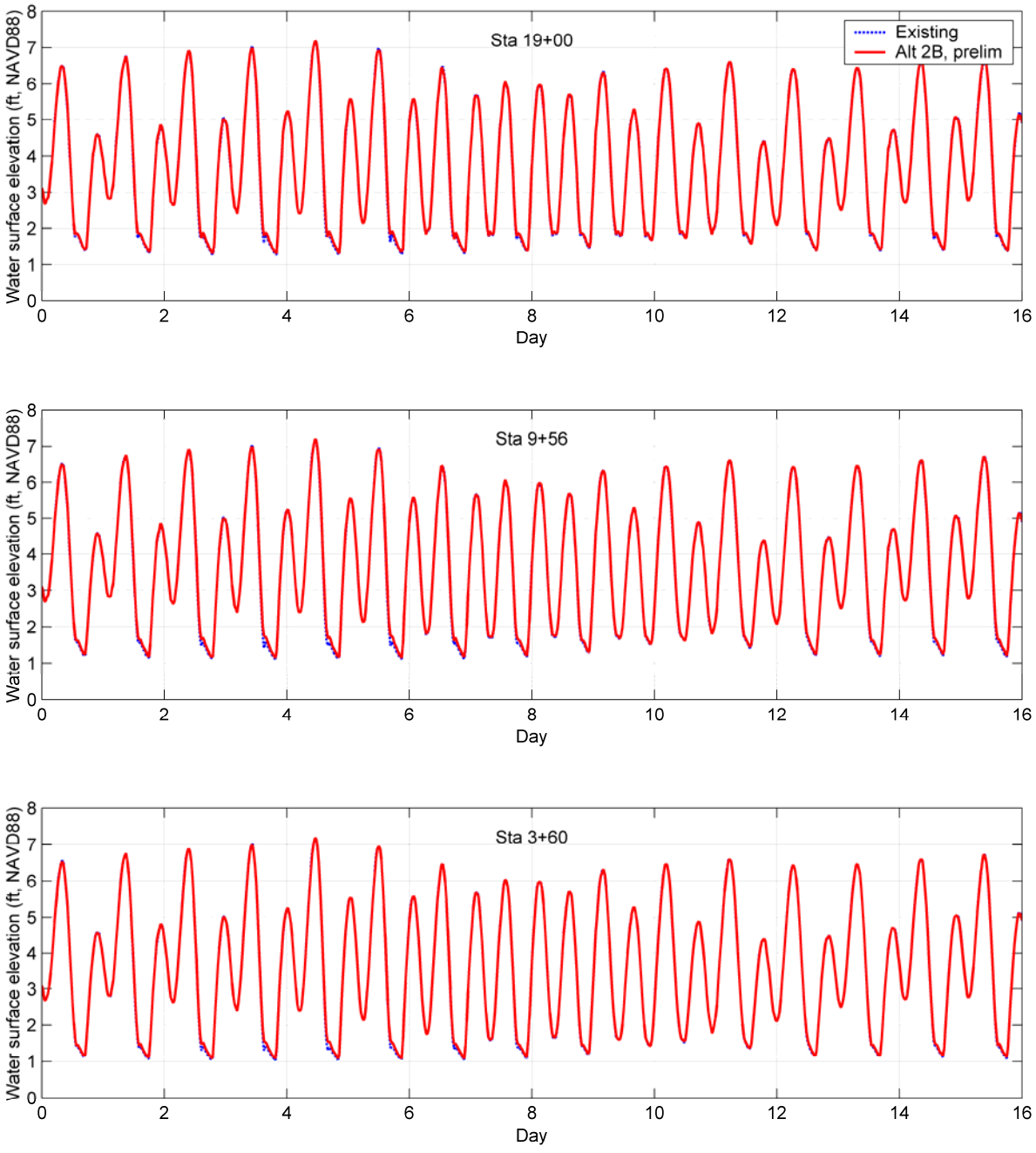


Figure 35. Water Levels in Northern Drainage Channel for WRA's Alternative 2B (Apr 1 – Aug 15)

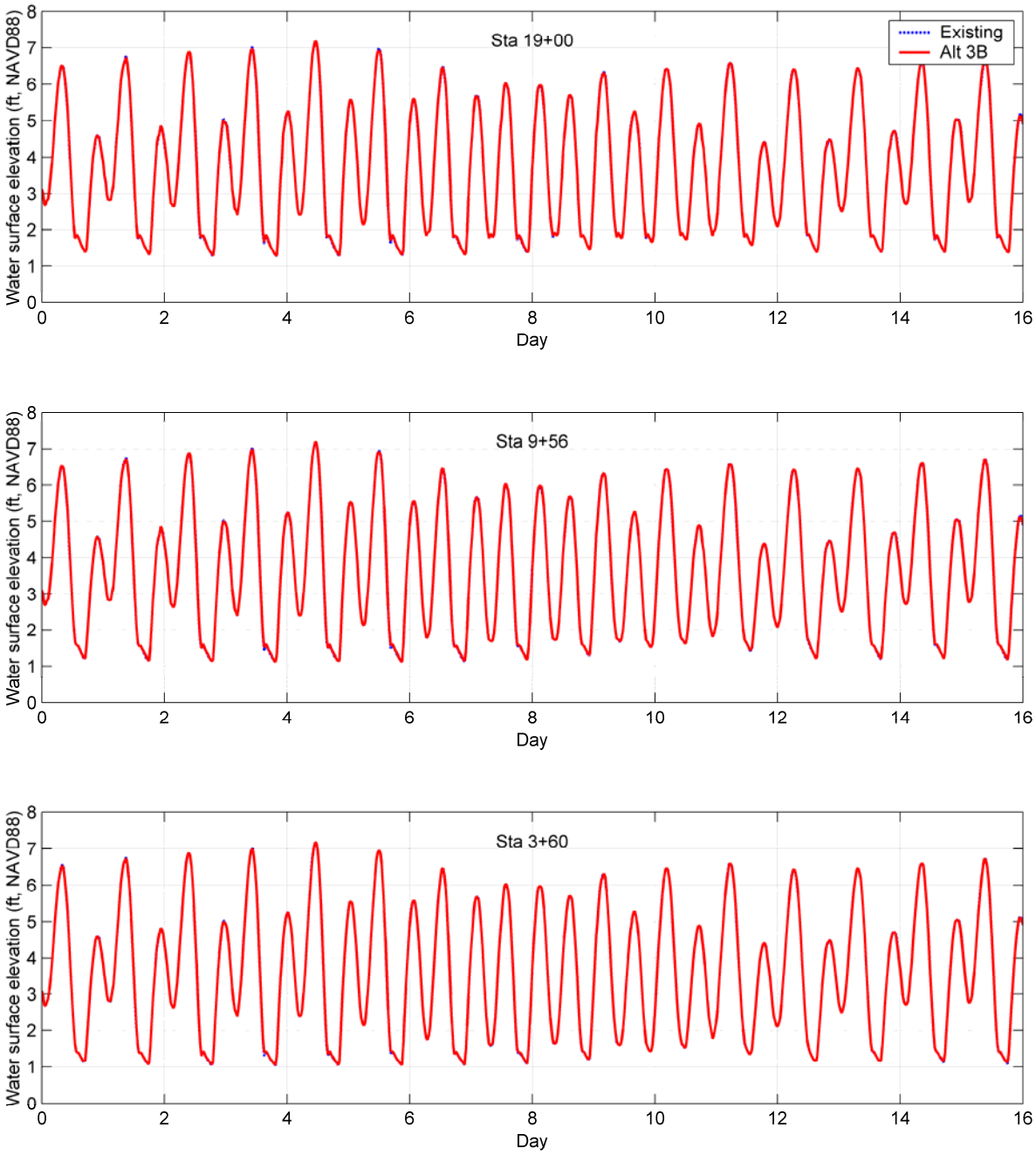


Figure 36. Water Levels in Northern Drainage Channel for WRA's Alternative 3B (Apr 1 – Aug 15)

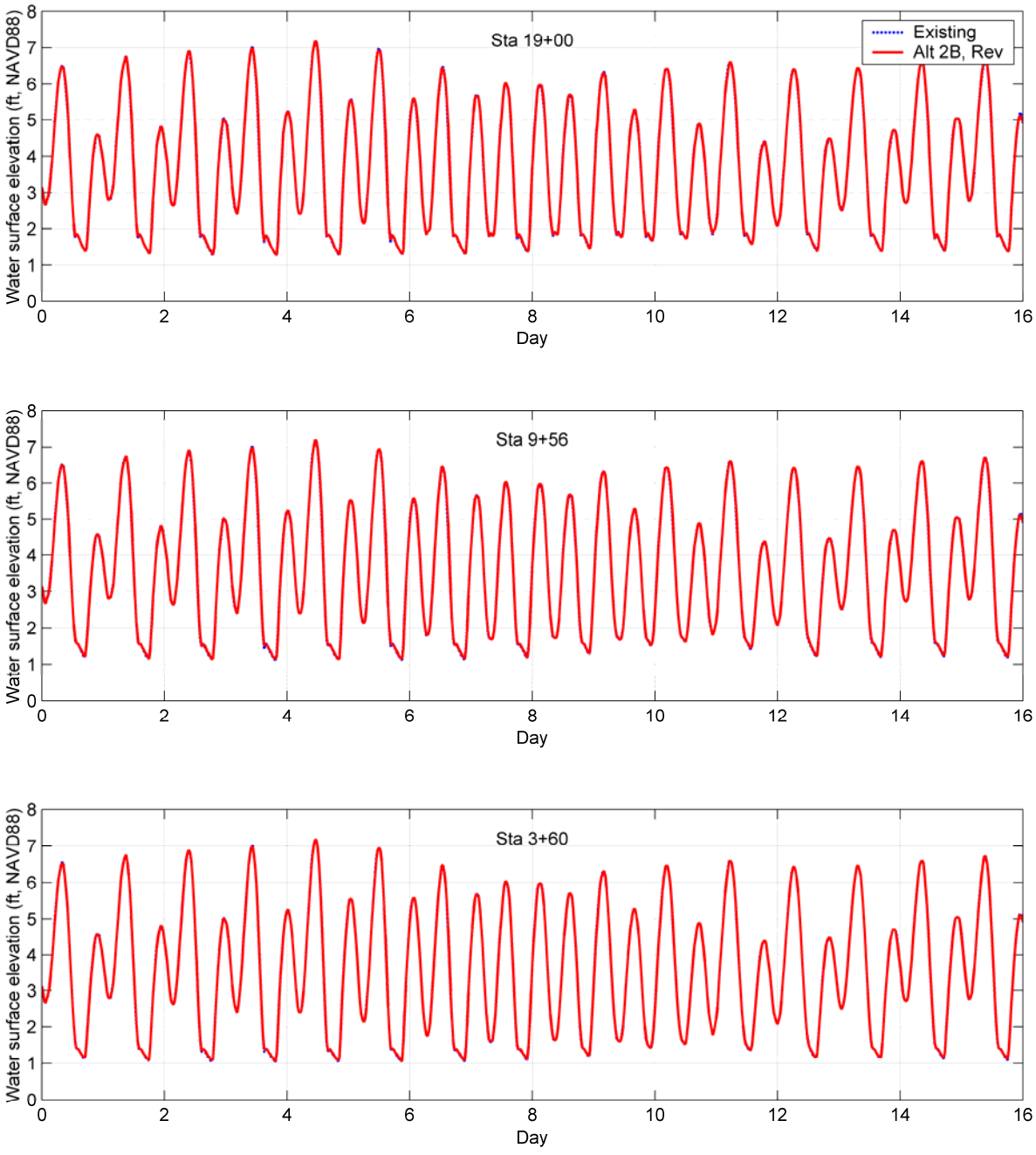


Figure 37. Water Levels in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Apr 1 – Aug 15)

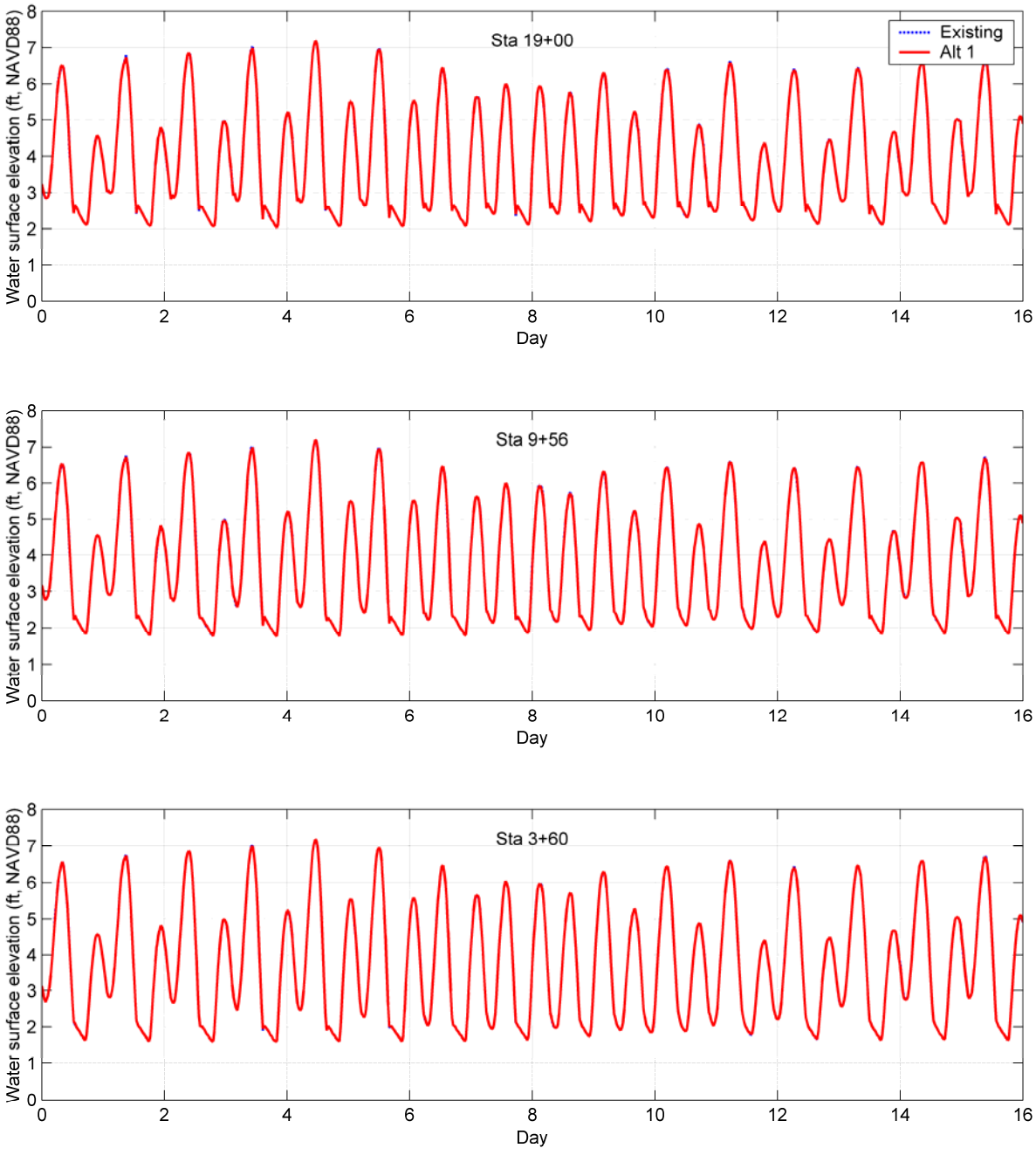


Figure 38. Water Levels in Northern Drainage Channel for WRA's Alternative 1 (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

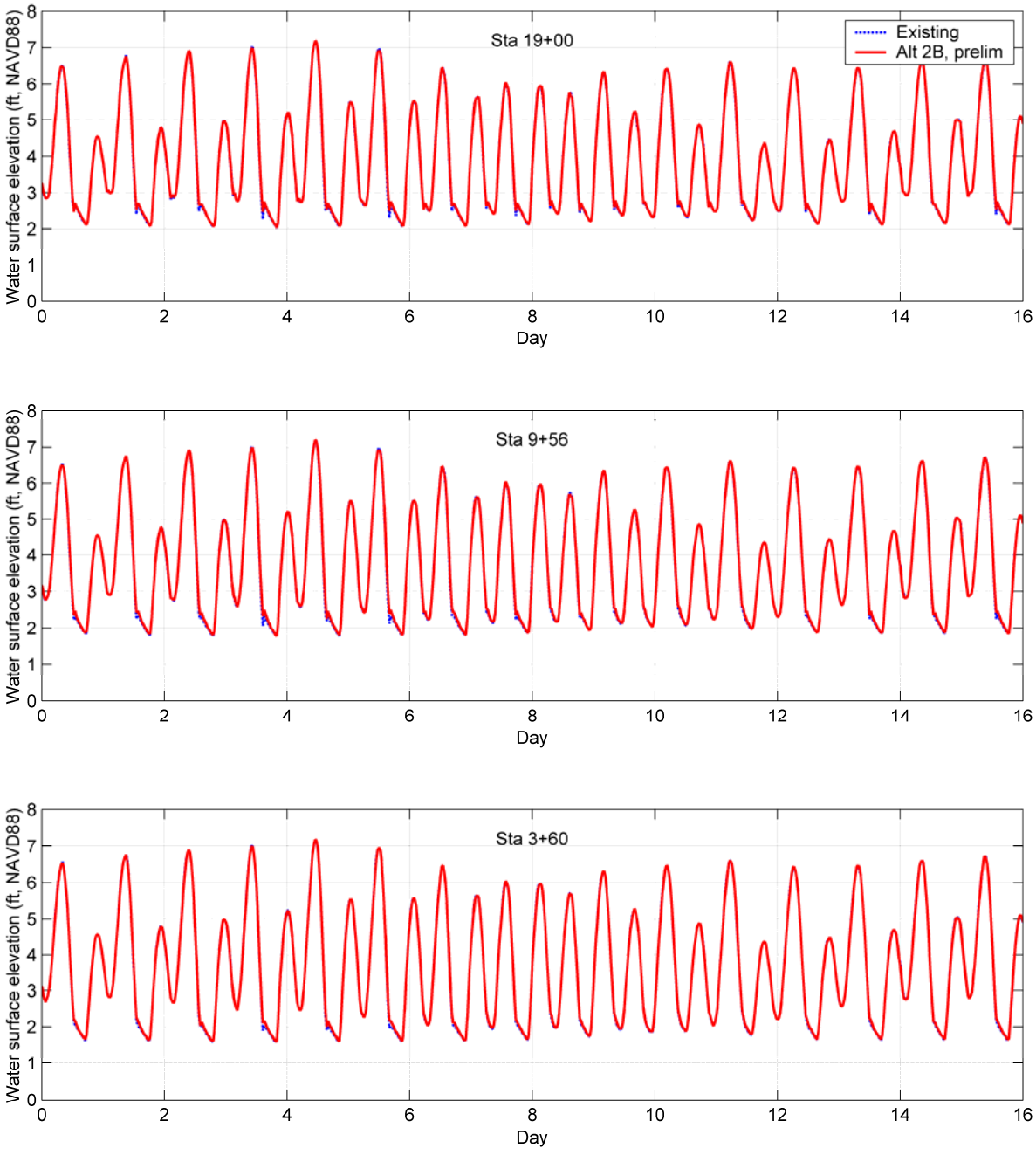


Figure 39. Water Levels in Northern Drainage Channel for WRA's Alternative 2B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

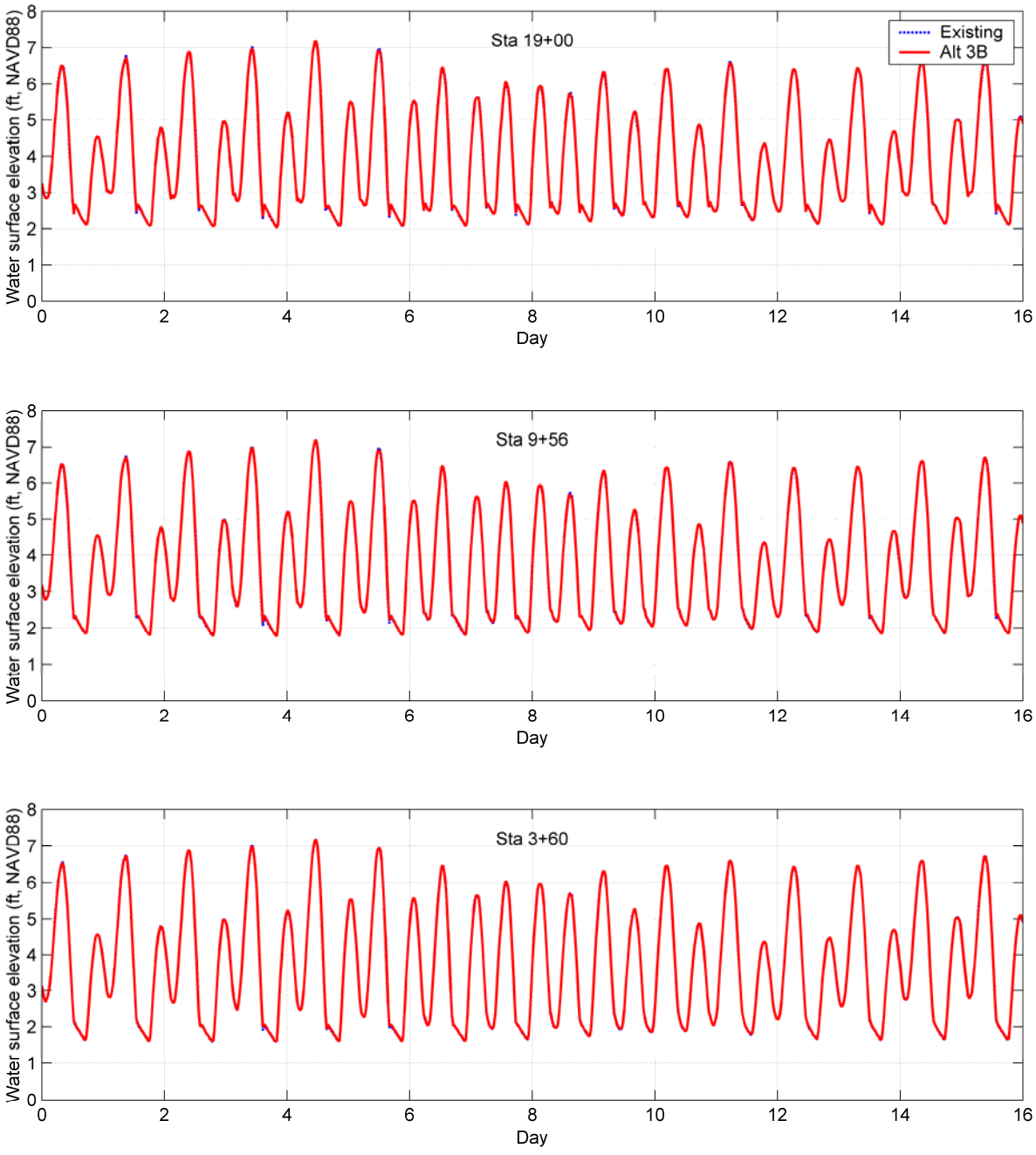


Figure 40. Water Levels in Northern Drainage Channel for WRA's Alternative 3B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

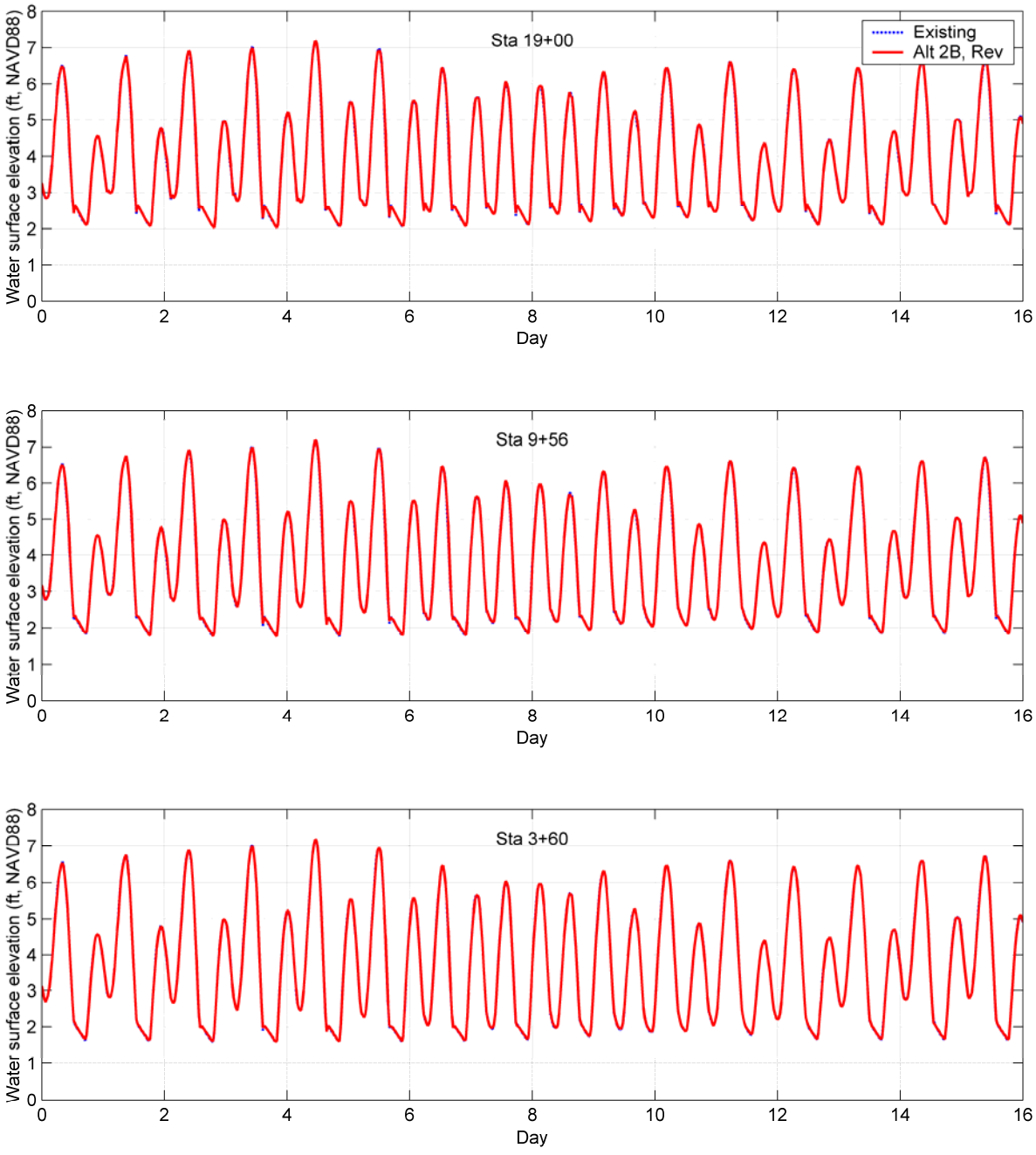


Figure 41. Water Levels in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

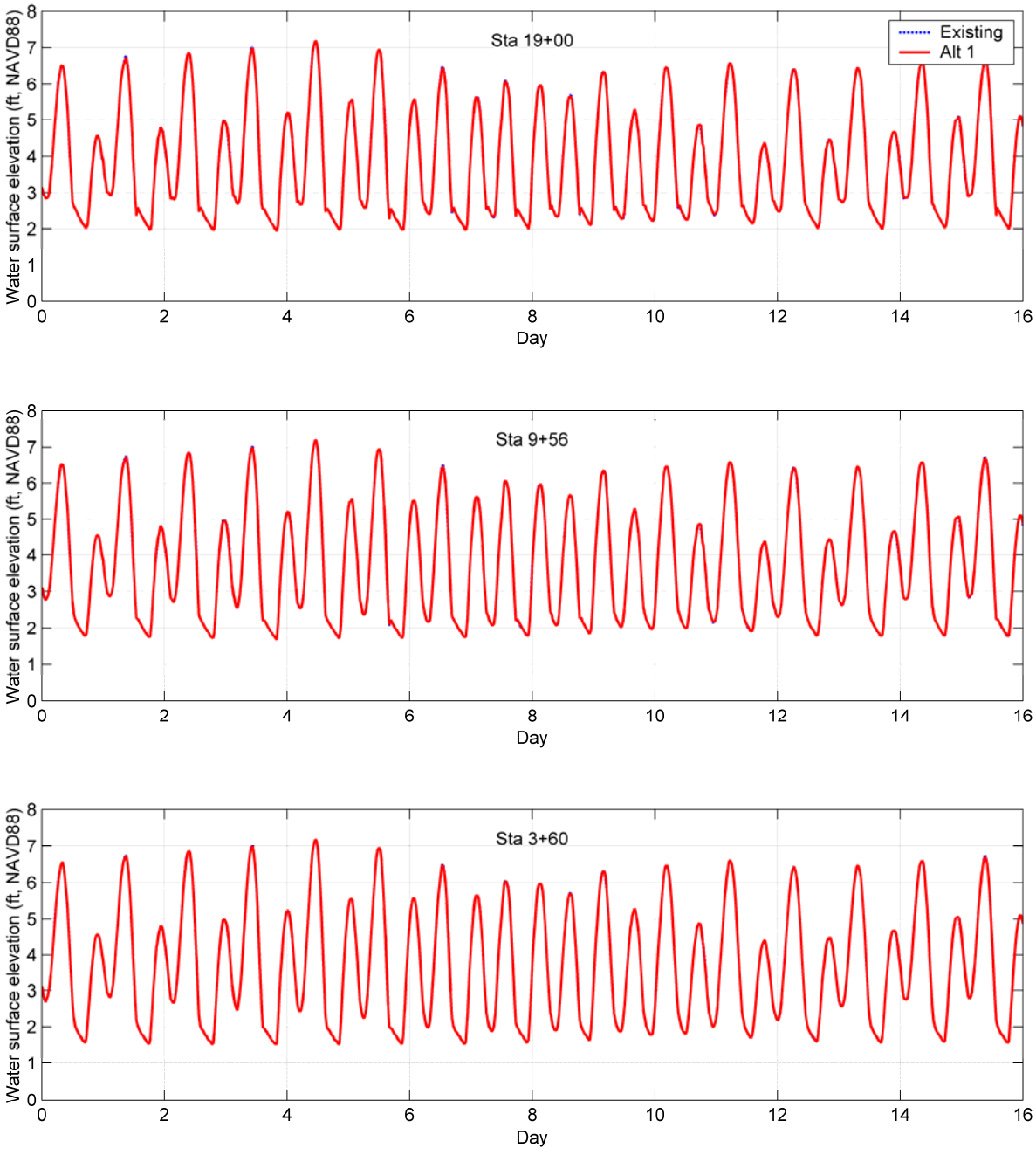


Figure 42. Water Levels in Northern Drainage Channel for WRA's Alternative 1 (Winter with No Precipitation Forecasted)

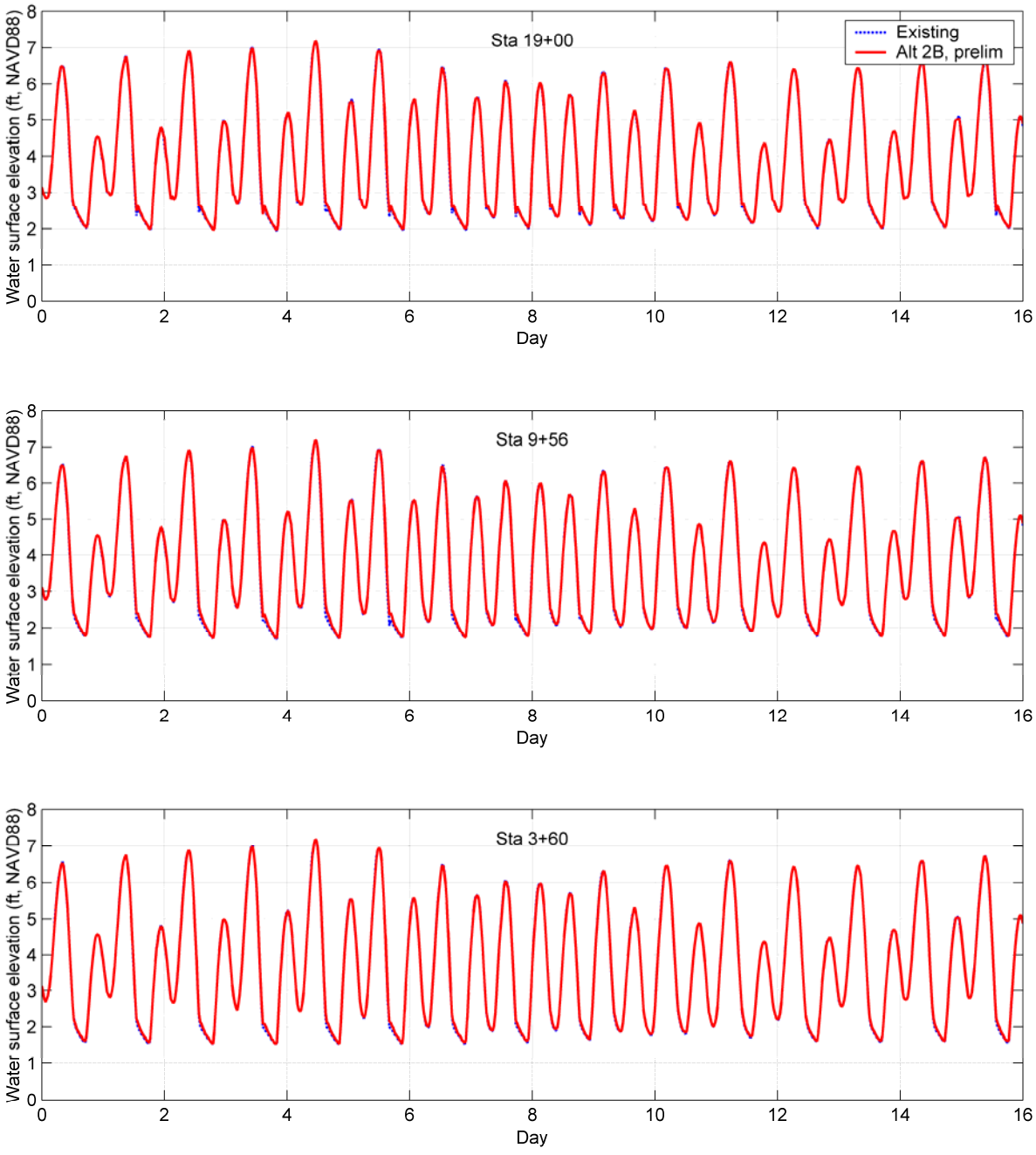


Figure 43. Water Levels in Northern Drainage Channel for WRA's Alternative 2B (Winter with No Precipitation Forecasted)

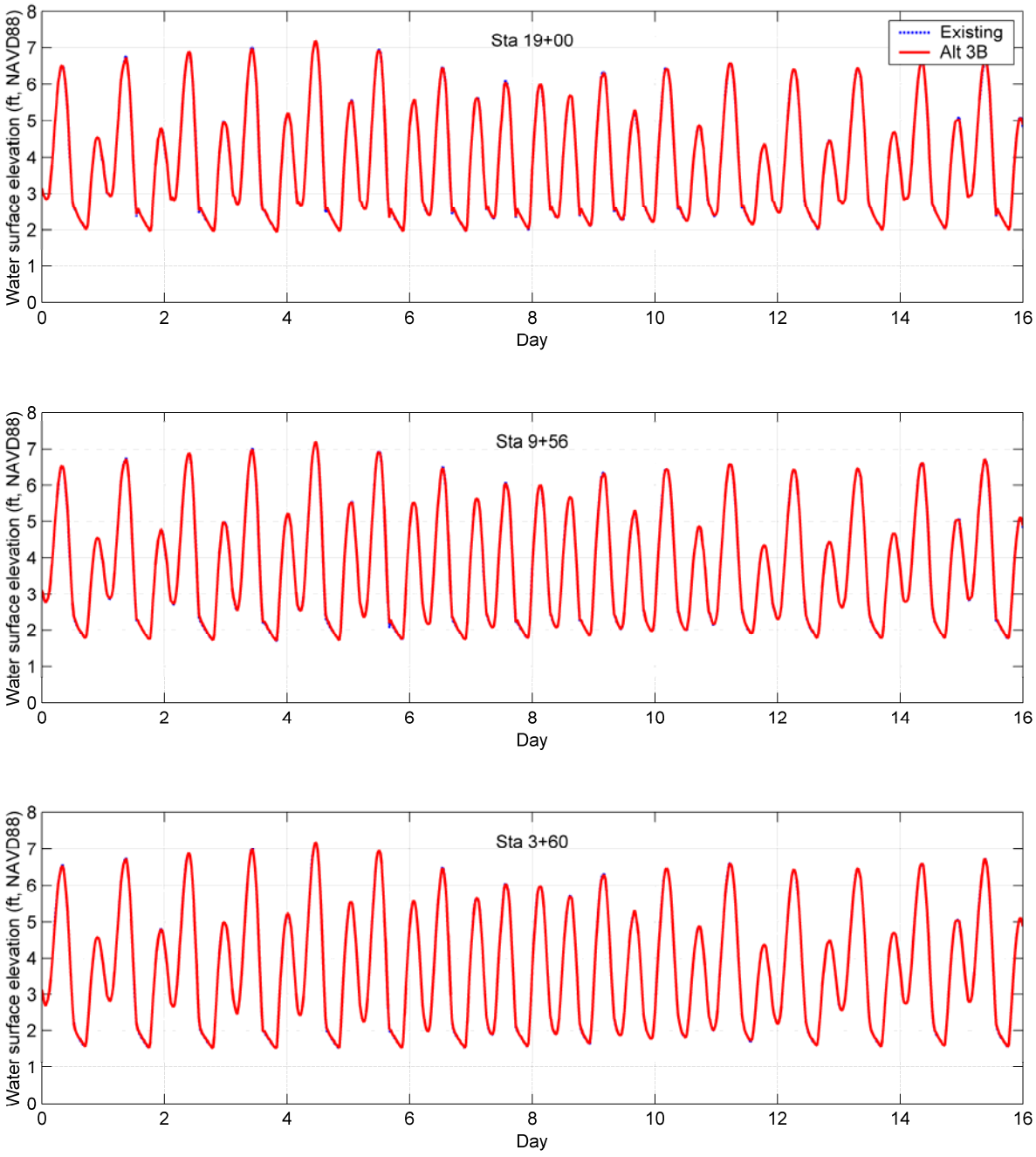


Figure 44. Water Levels in Northern Drainage Channel for WRA's Alternative 3B (Winter with No Precipitation Forecasted)

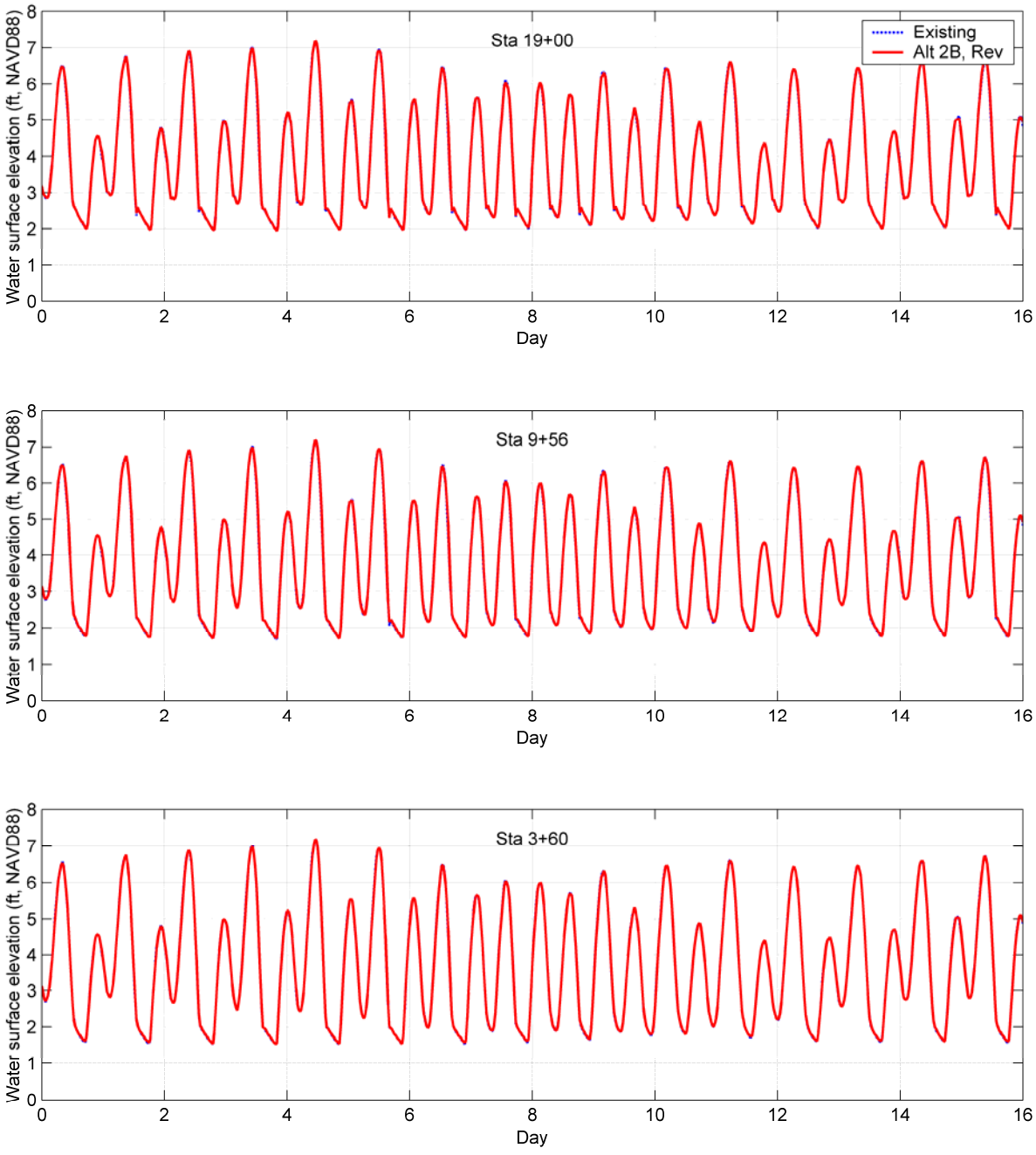


Figure 45. Water Levels in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Winter with No Precipitation Forecasted)

Flow Discharges in Existing Northern Drainage Channel

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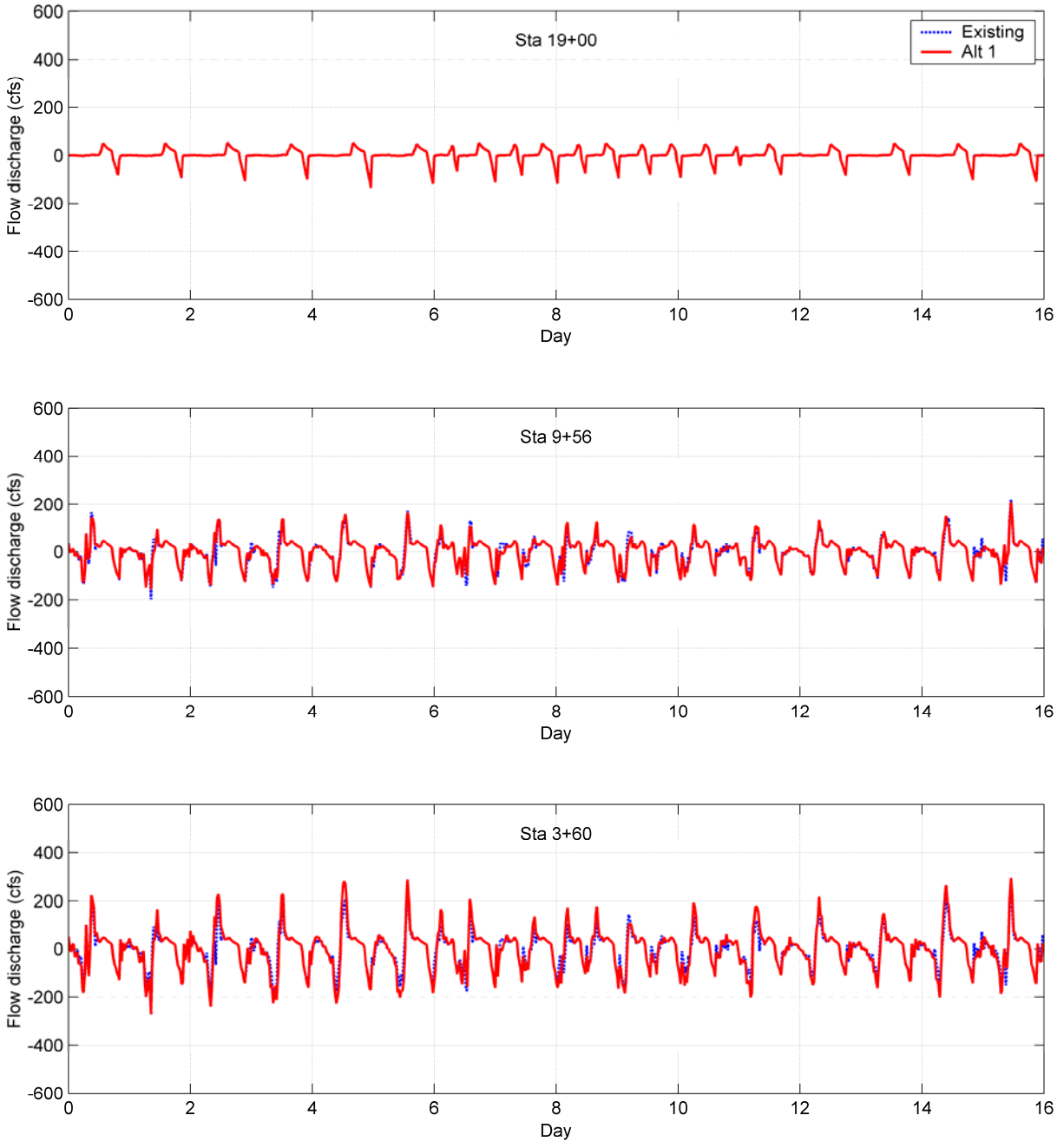


Figure 46. Flow Discharges in Northern Drainage Channel for WRA's Alternative 1 (Apr 1 – Aug 15)

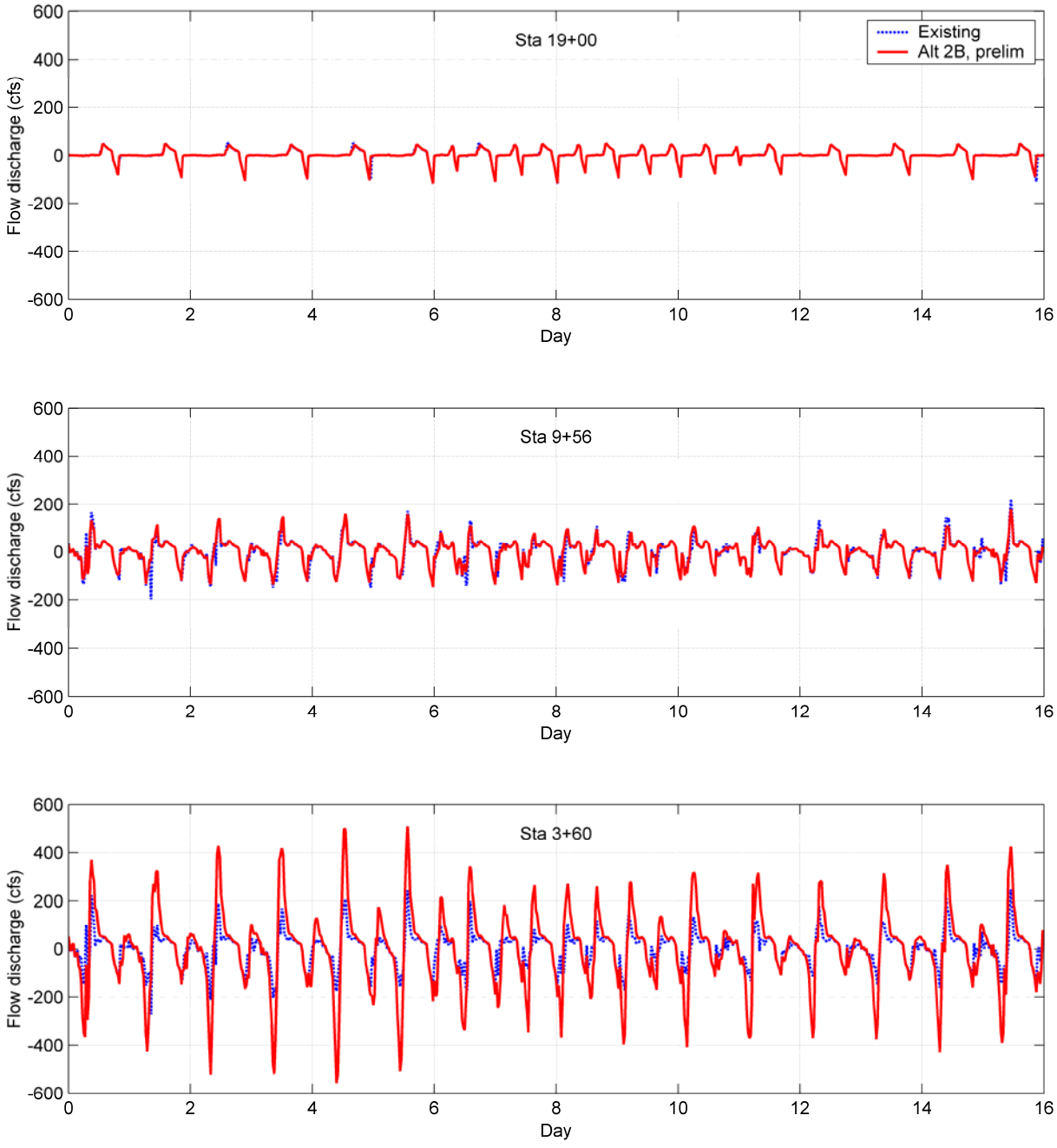


Figure 47. Flow Discharges in Northern Drainage Channel for WRA's Alternative 2B (Apr 1 – Aug 15)

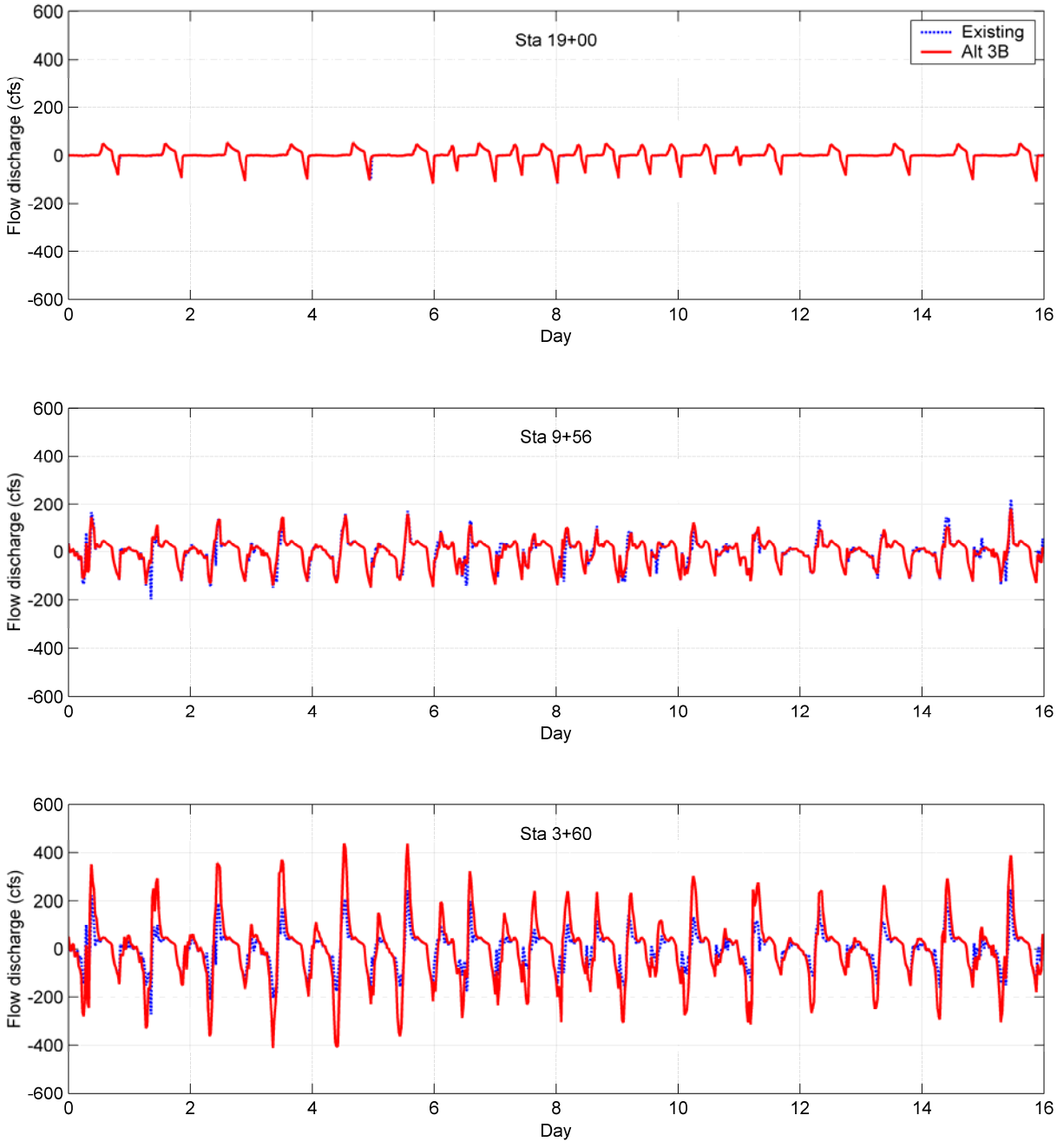


Figure 48. Flow Discharges in Northern Drainage Channel for WRA's Alternative 3B (Apr 1 – Aug 15)

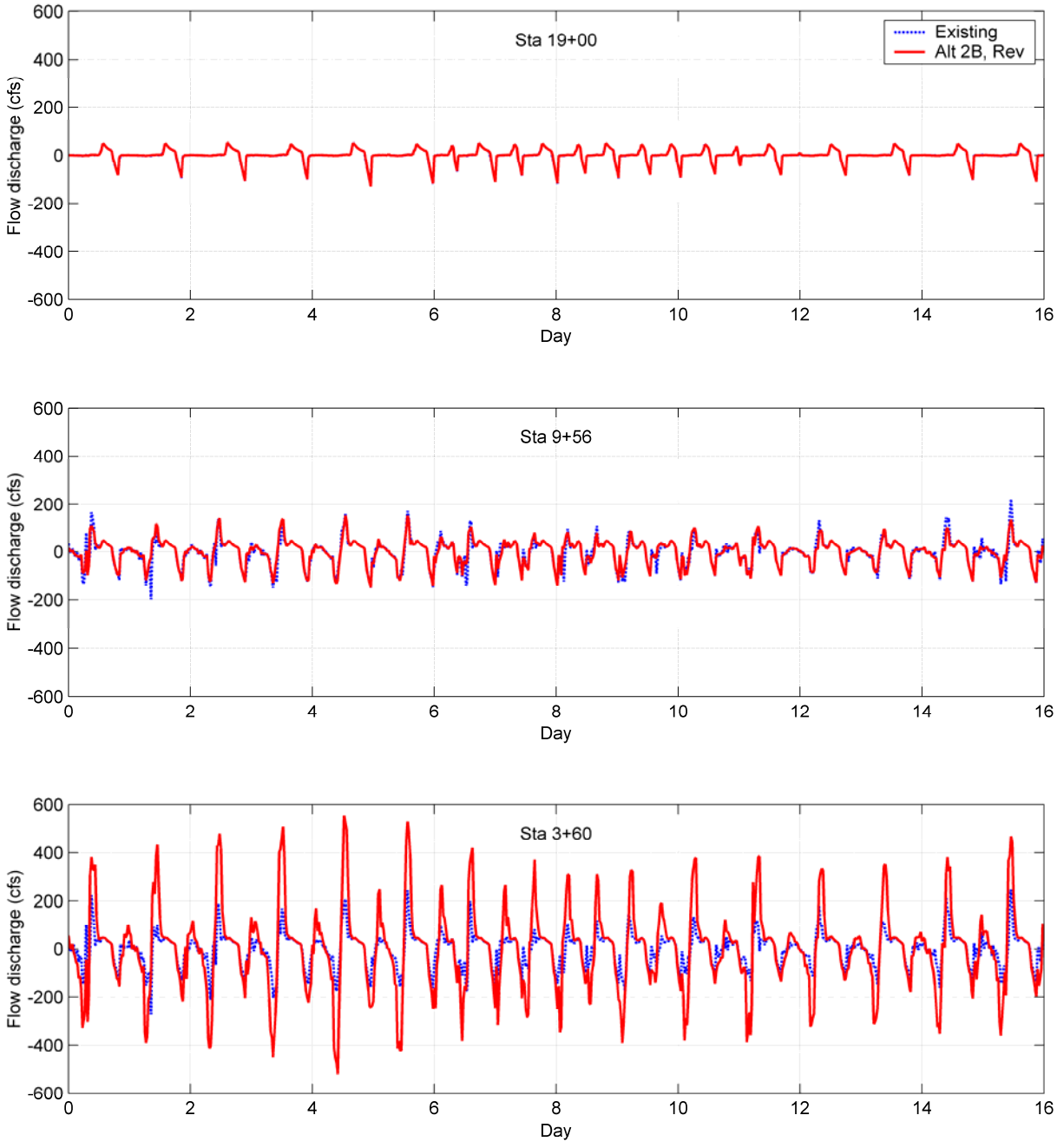


Figure 49. Flow Discharges in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Apr 1 – Aug 15)

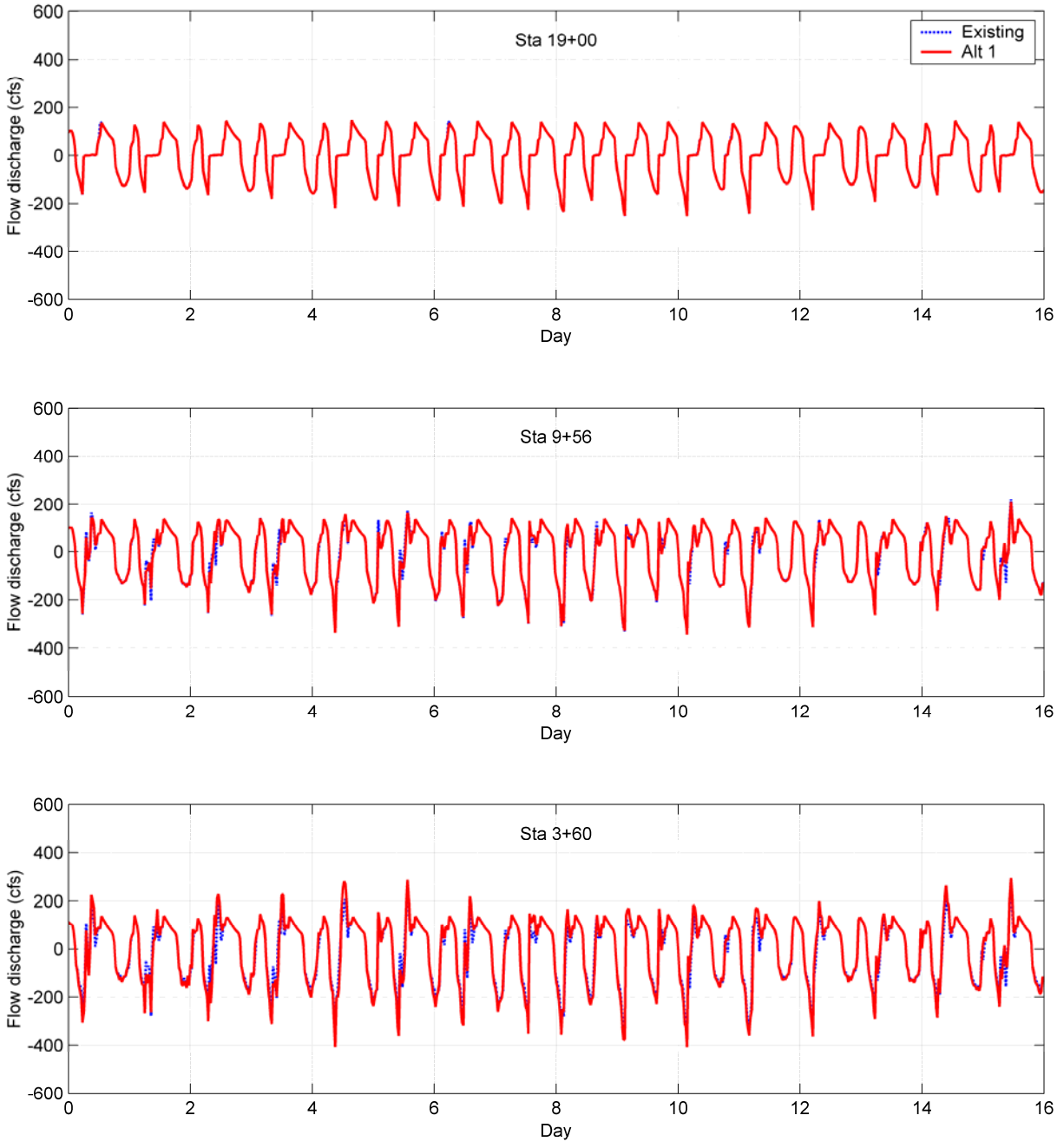


Figure 50. Flow Discharges in Northern Drainage Channel for WRA's Alternative 1 (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

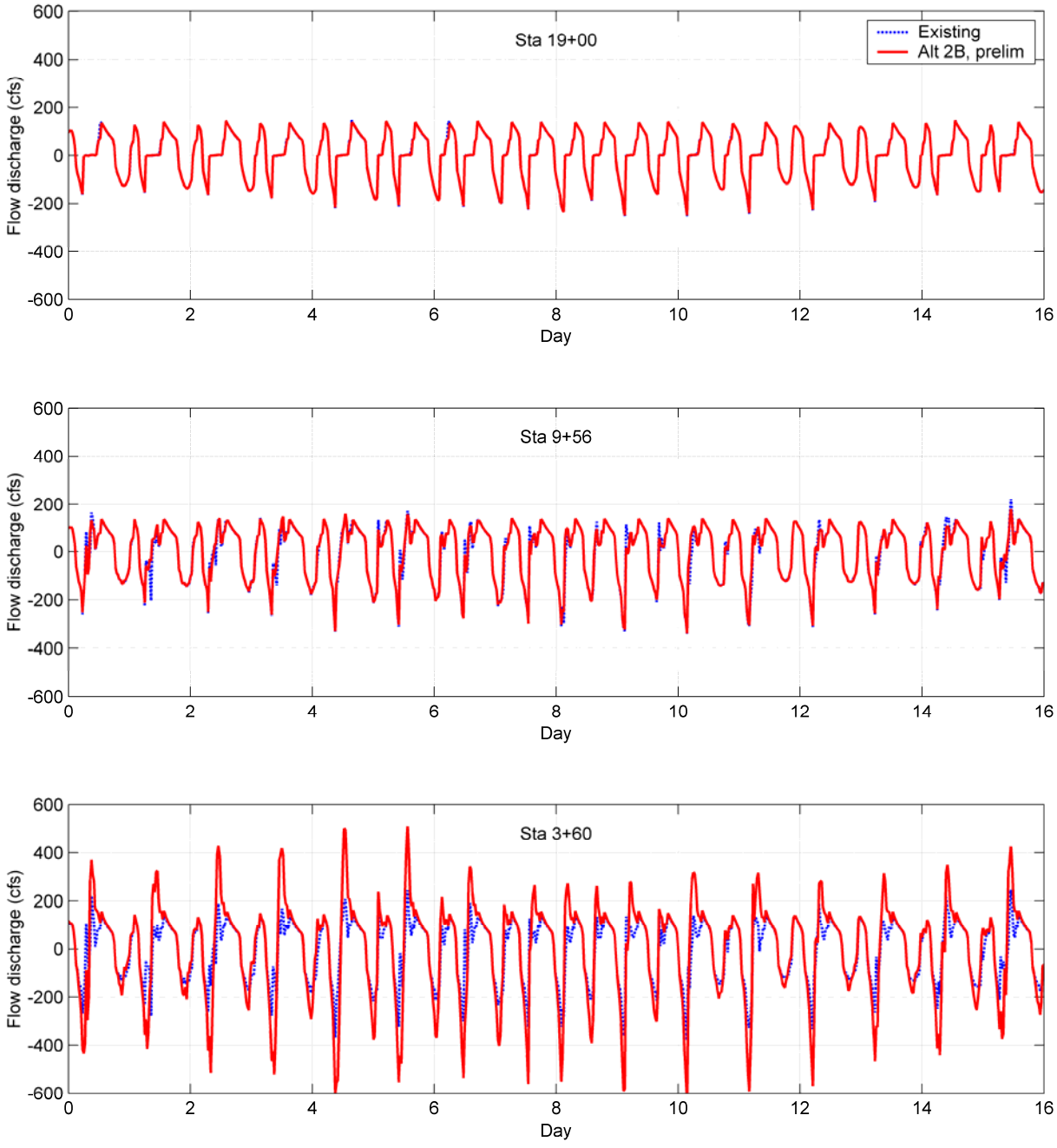


Figure 51. Flow Discharges in Northern Drainage Channel for WRA's Alternative 2B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

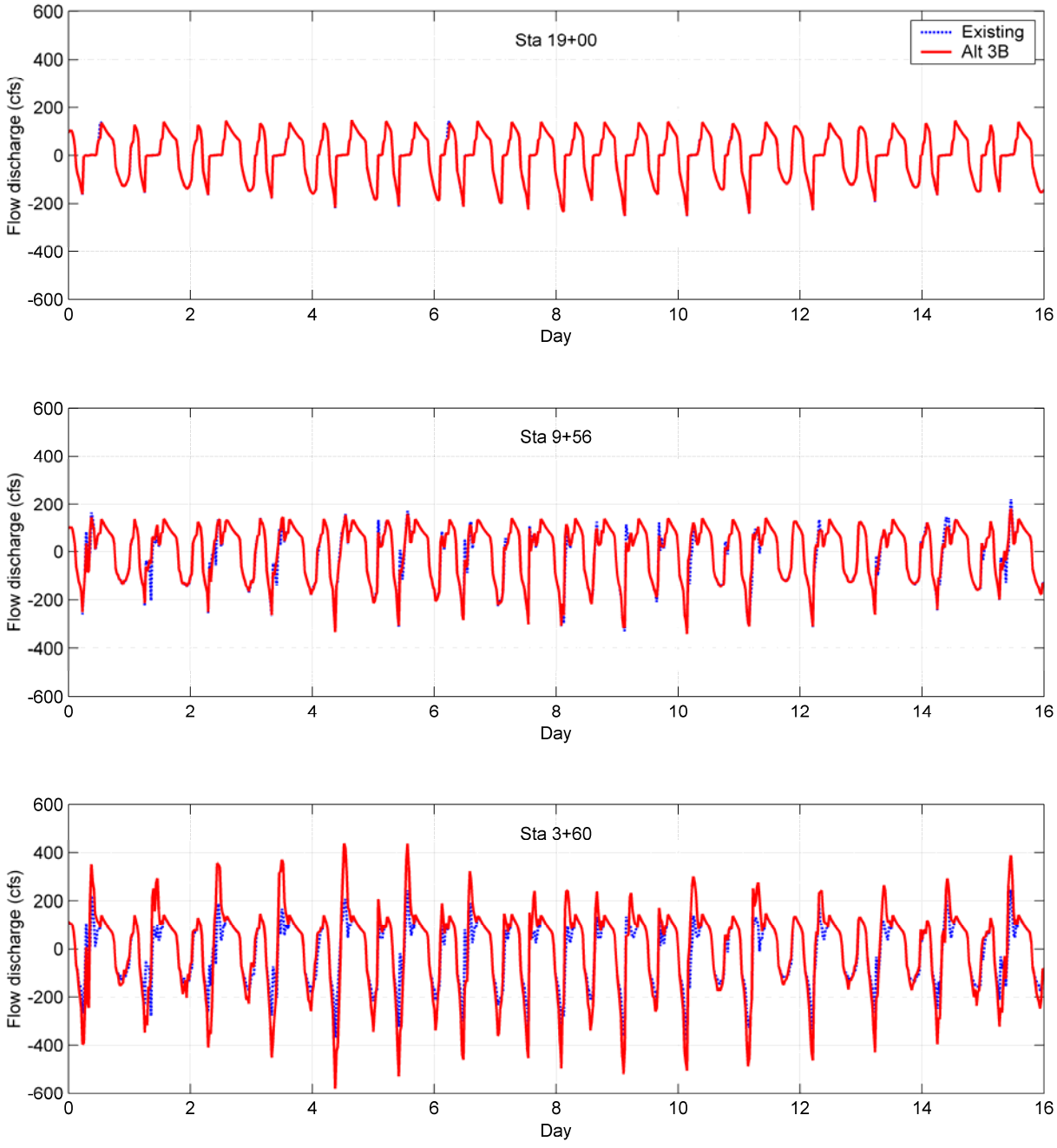


Figure 52. Flow Discharges in Northern Drainage Channel for WRA's Alternative 3B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

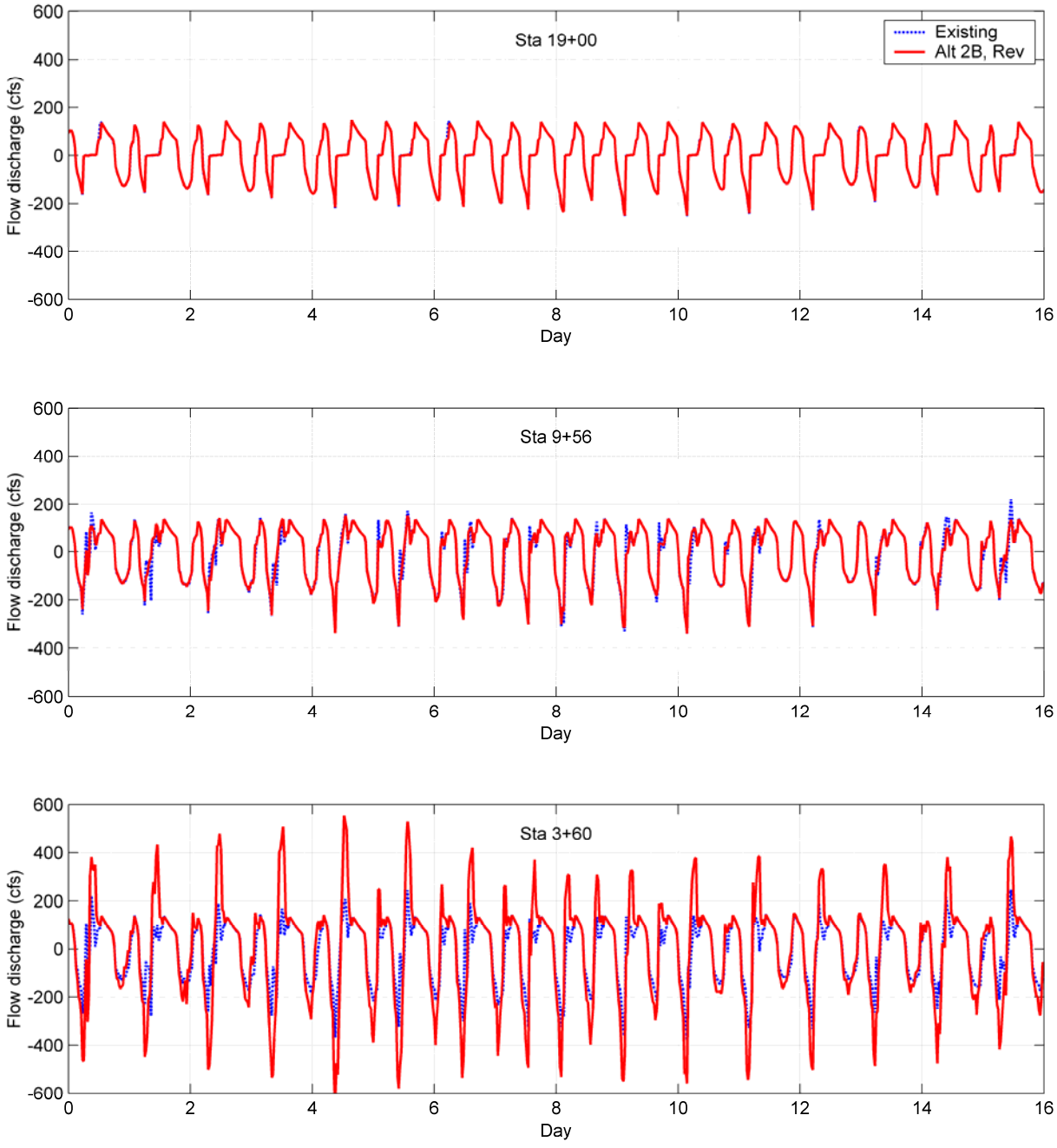


Figure 53. Flow Discharges in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

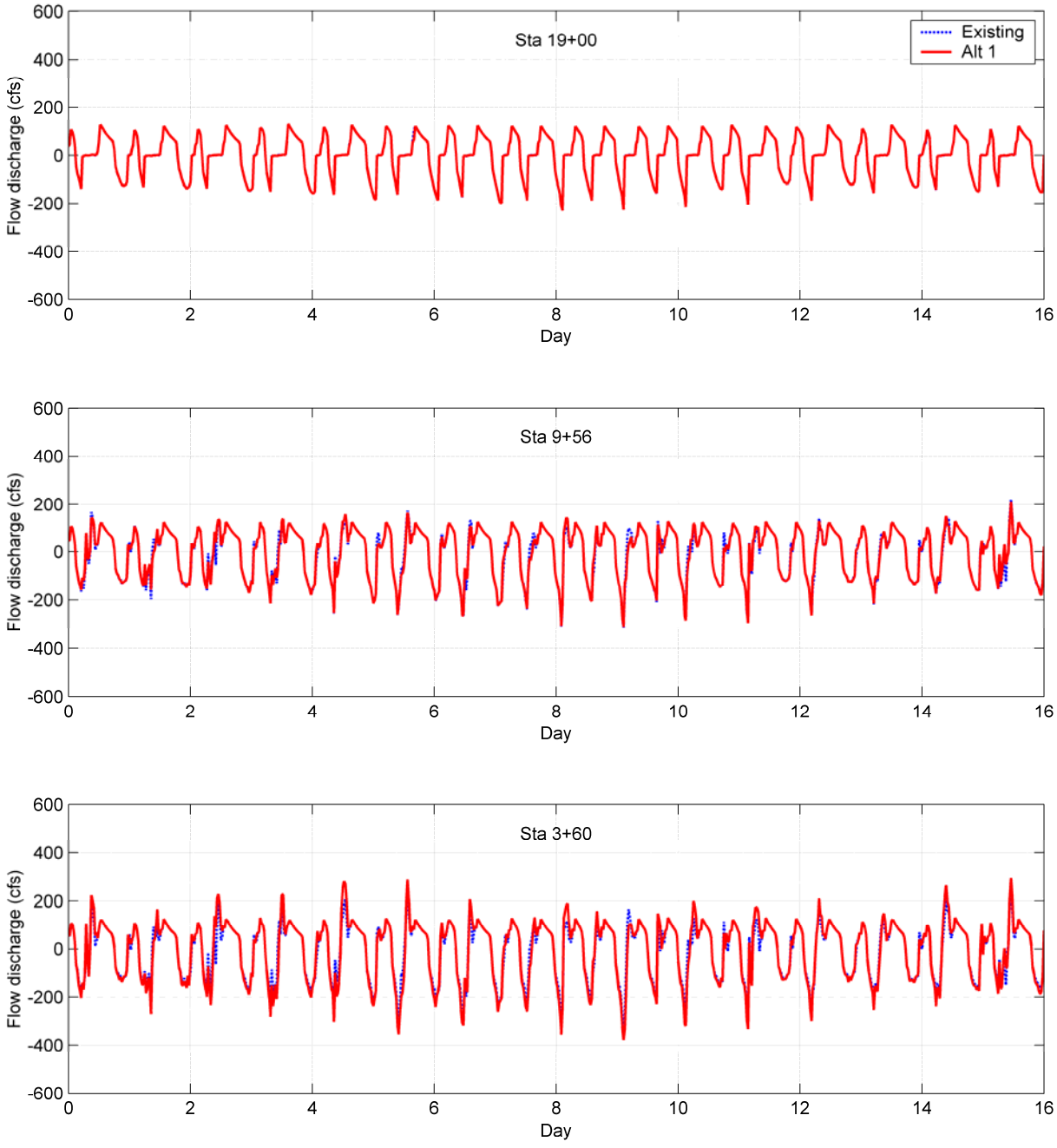


Figure 54. Flow Discharges in Northern Drainage Channel for WRA's Alternative 1 (Winter with No Precipitation Forecasted)

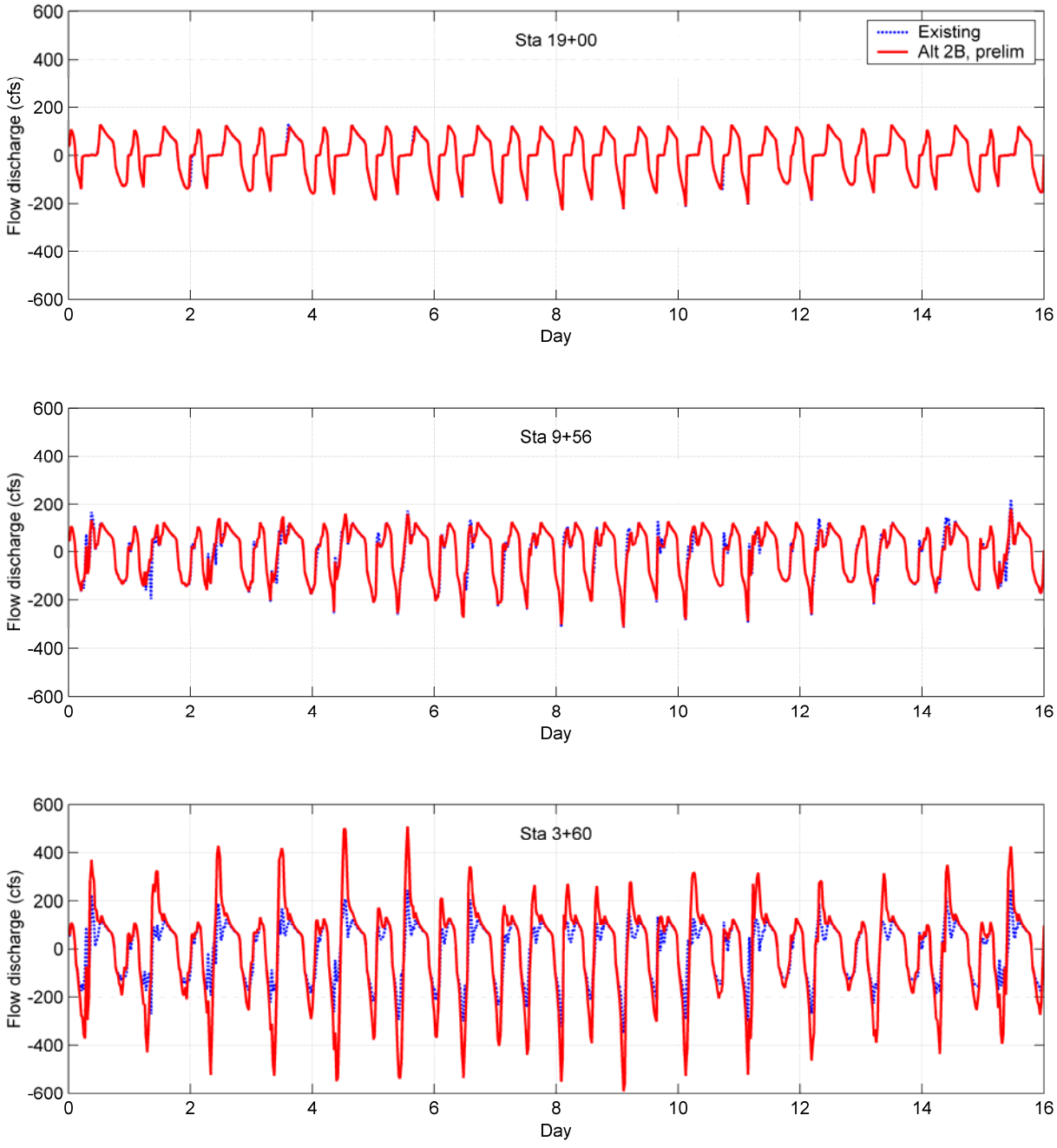


Figure 55. Flow Discharges in Northern Drainage Channel for WRA's Alternative 2B (Winter with No Precipitation Forecasted)

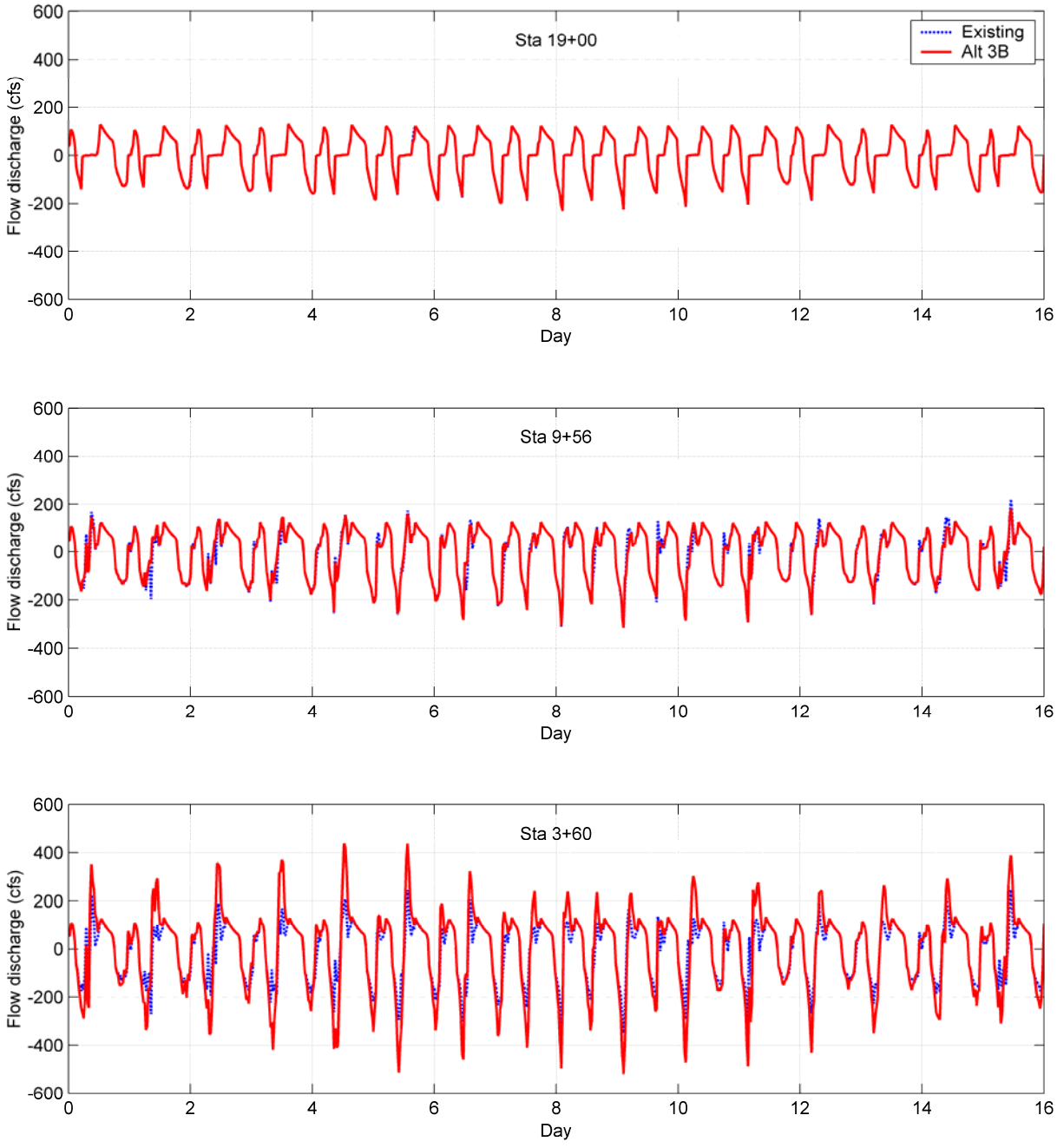


Figure 56. Flow Discharges in Northern Drainage Channel for WRA's Alternative 3B (Winter with No Precipitation Forecasted)

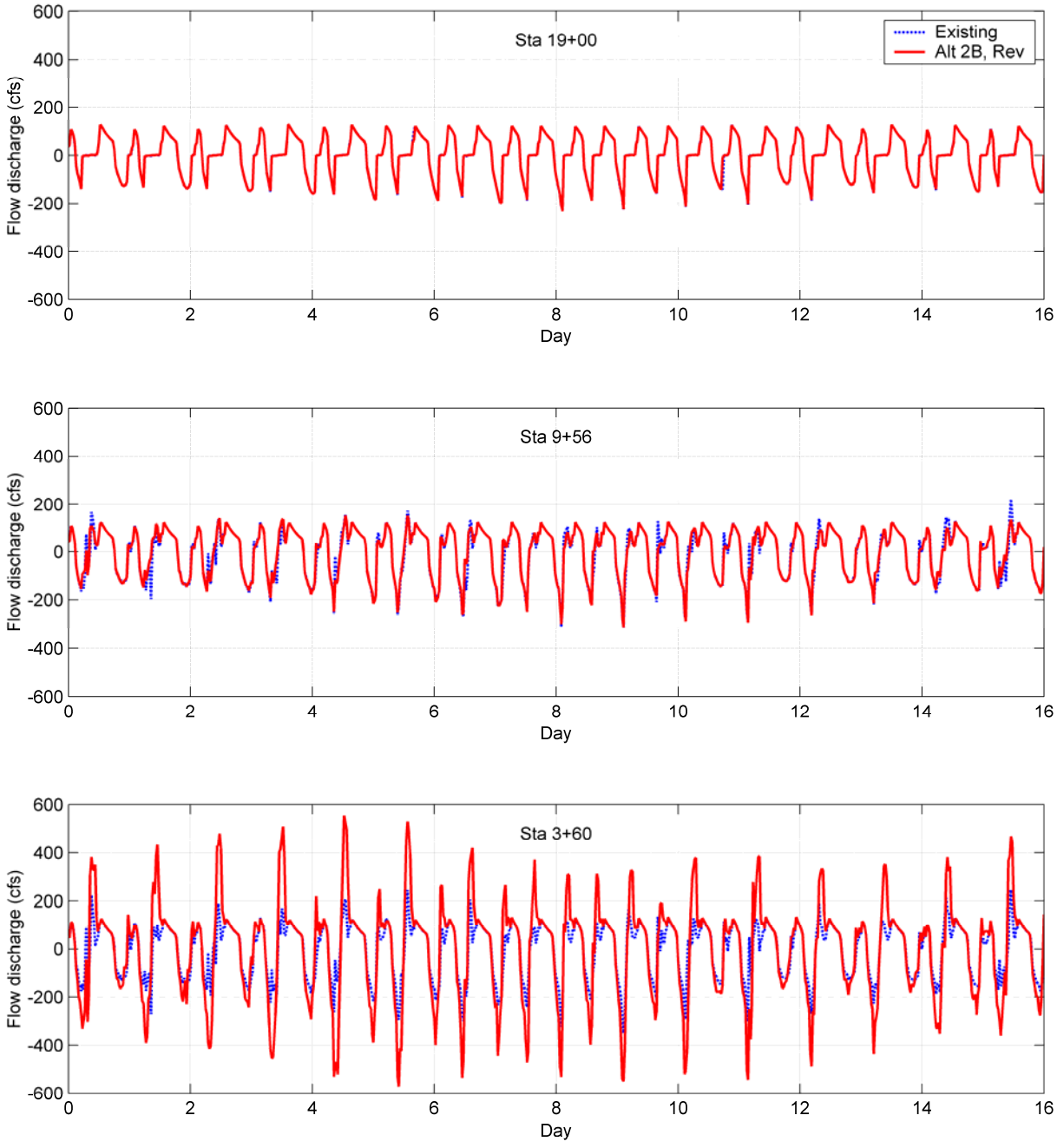


Figure 57. Flow Discharges in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Winter with No Precipitation Forecasted)

Flow Velocities in Existing Northern Drainage Channel

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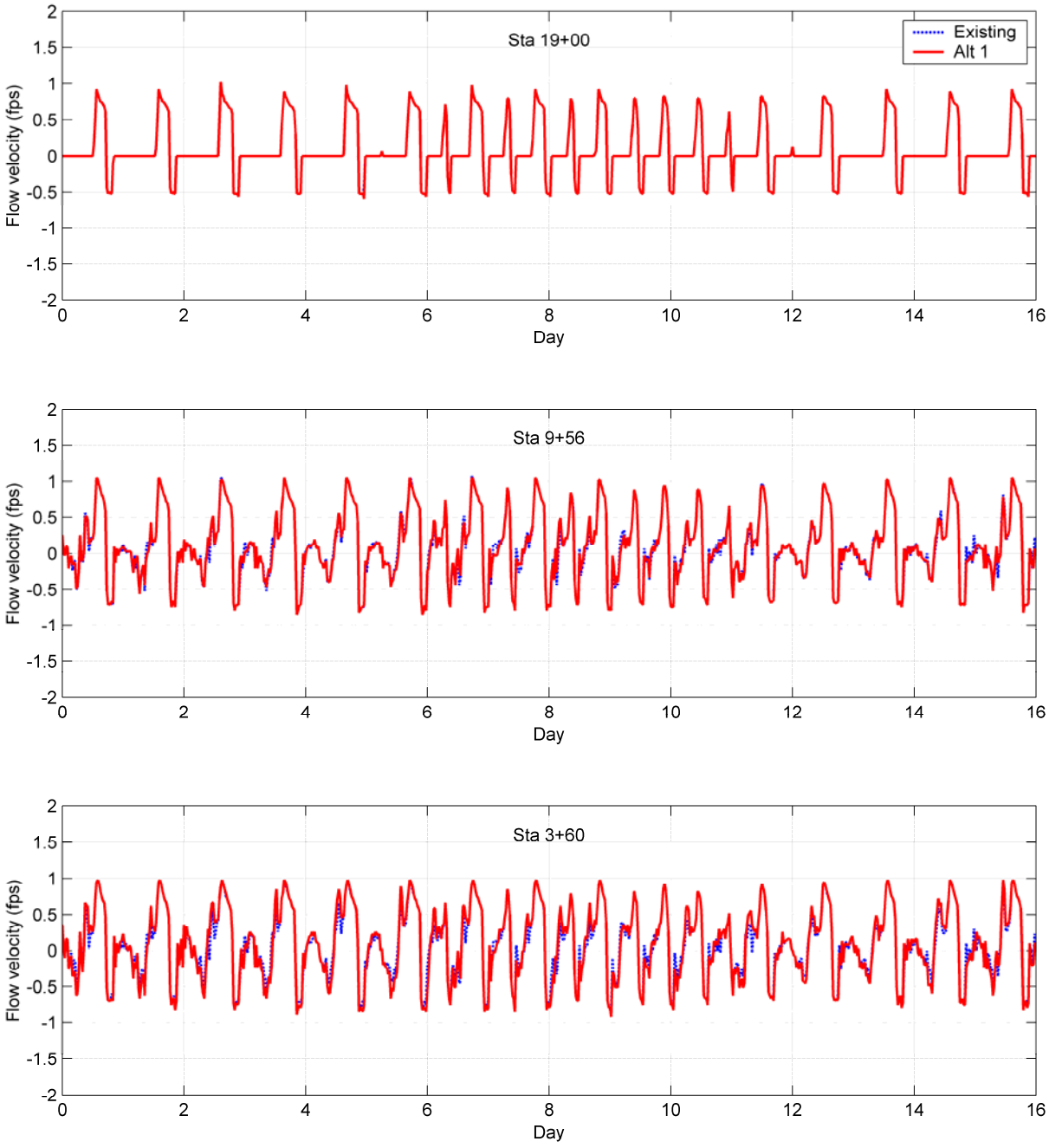


Figure 58. Flow Velocities in Northern Drainage Channel for WRA's Alternative 1 (Apr 1 – Aug 15)

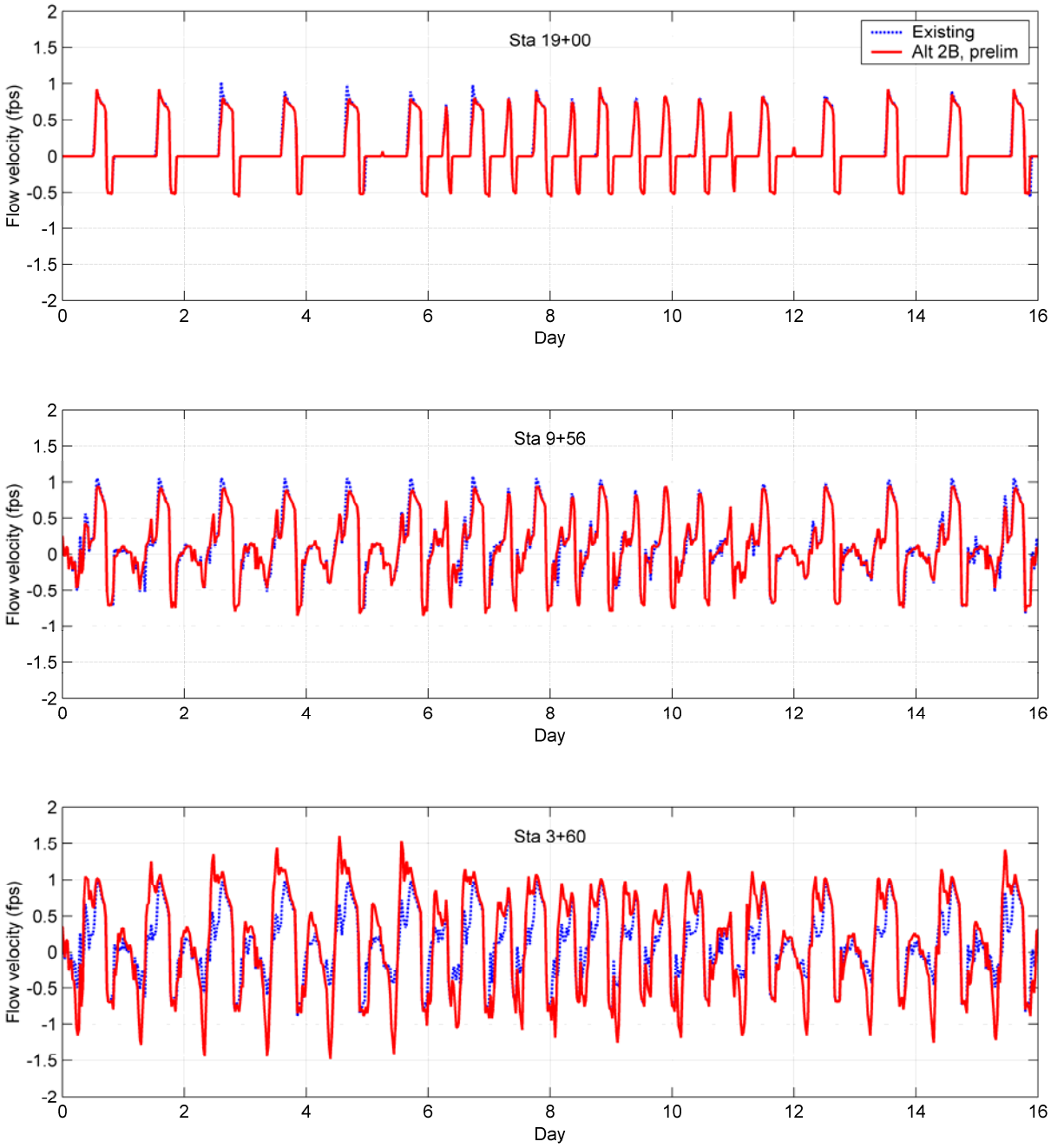


Figure 59. Flow Velocities in Northern Drainage Channel for WRA's Alternative 2B (Apr 1 – Aug 15)

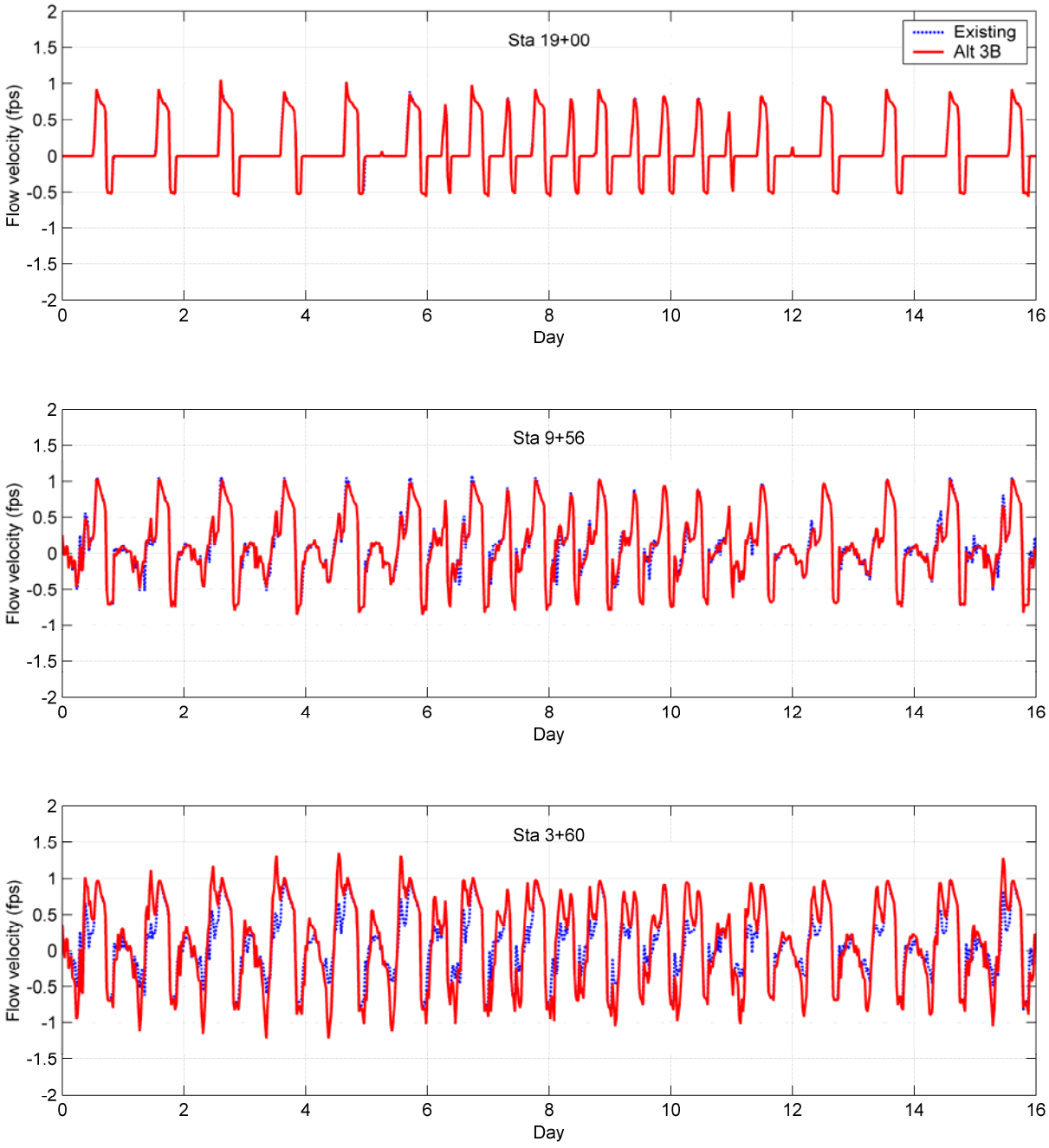


Figure 60. Flow Velocities in Northern Drainage Channel for WRA's Alternative 3B (Apr 1 – Aug 15)

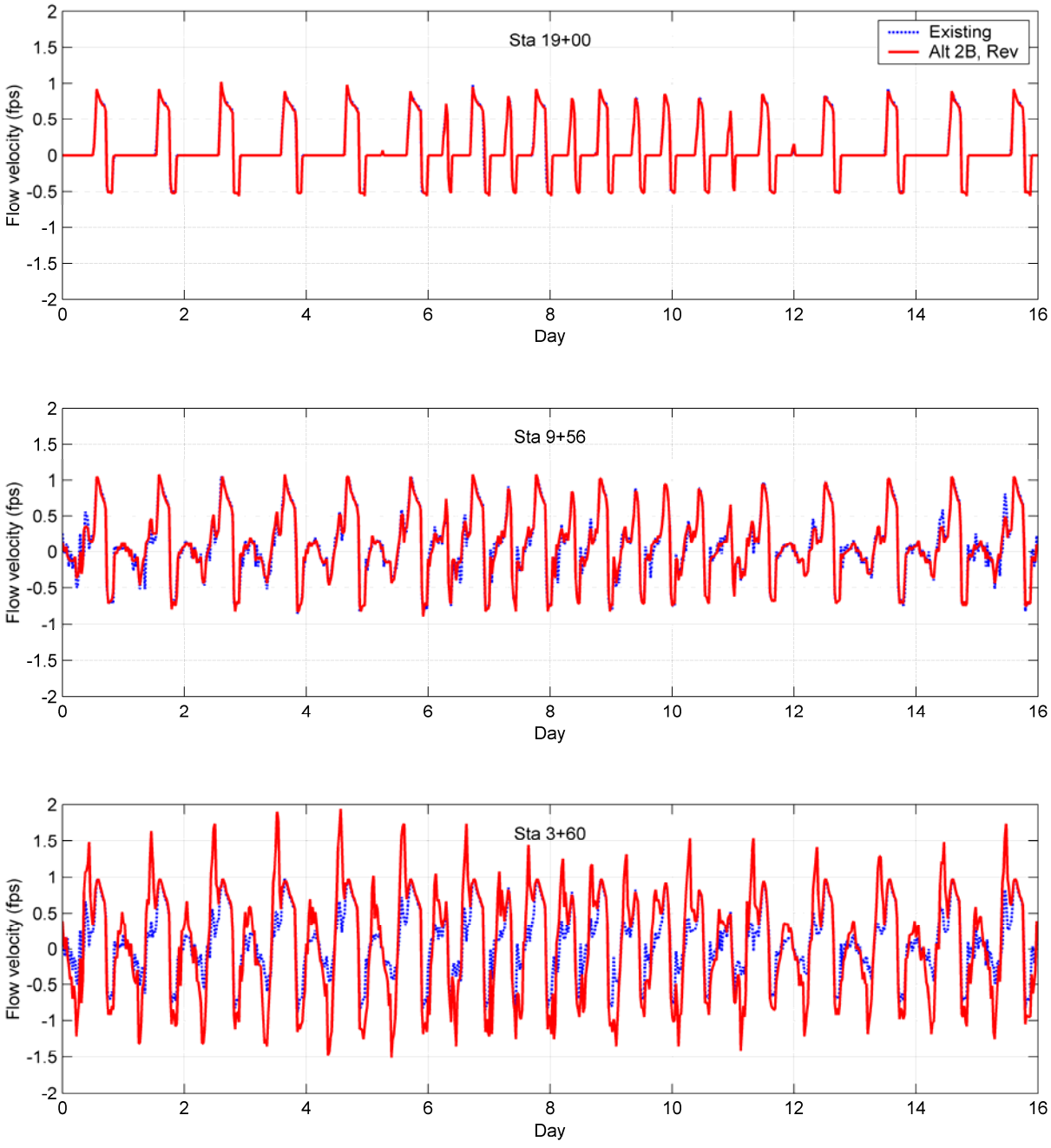


Figure 61. Flow Velocities in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Apr 1 – Aug 15)

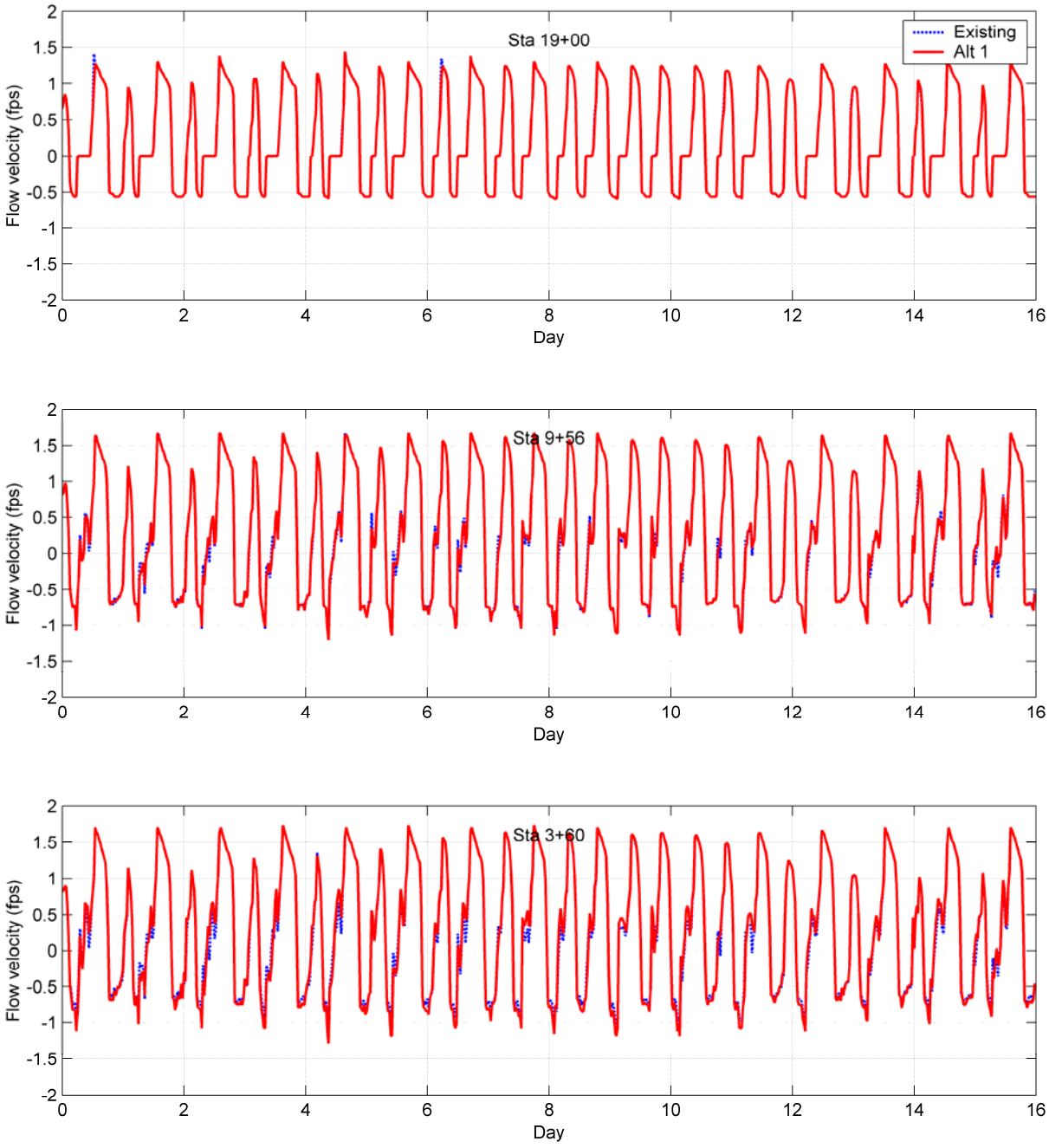


Figure 62. Flow Velocities in Northern Drainage Channel for WRA's Alternative 1 (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

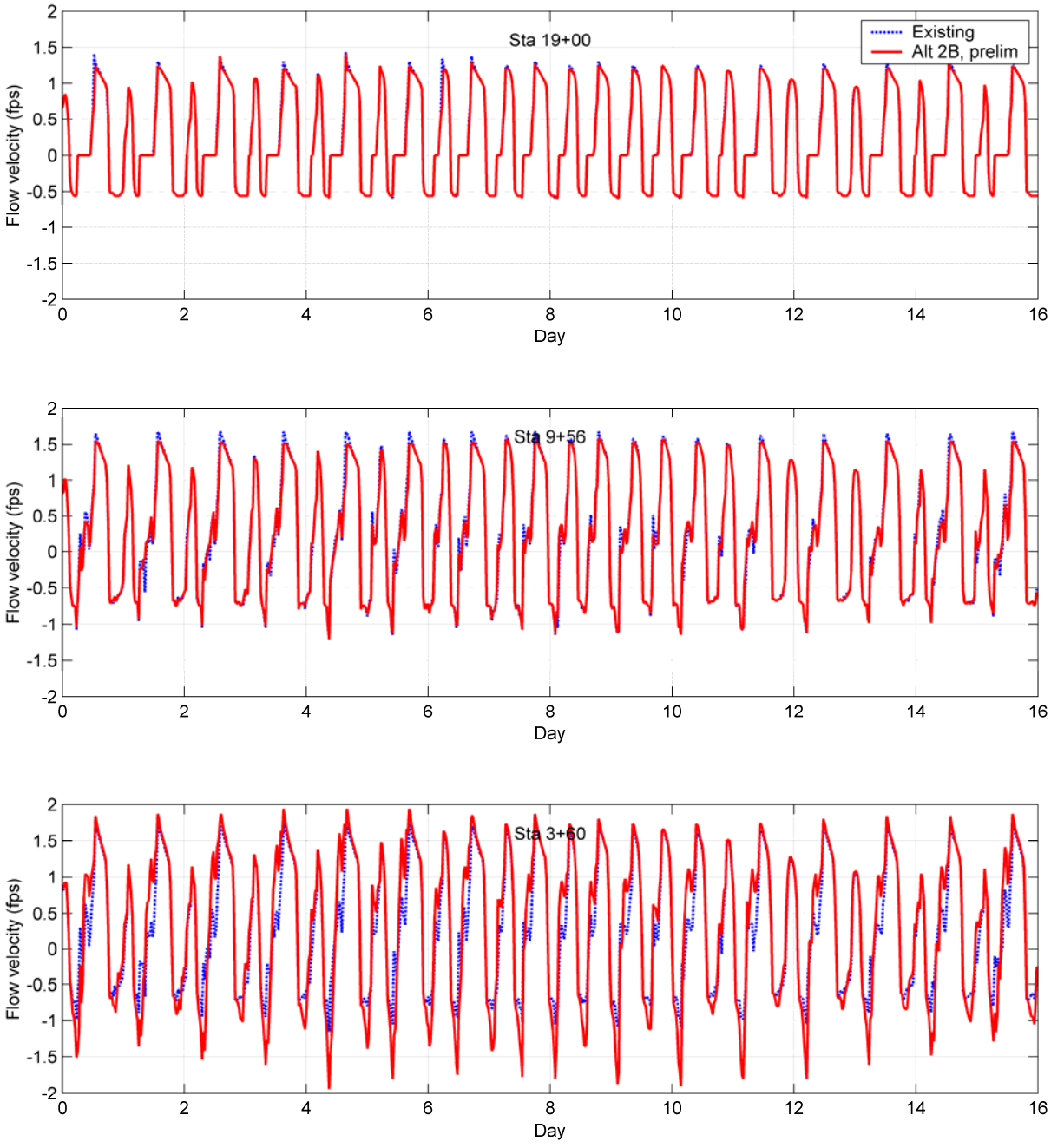


Figure 63. Flow Velocities in Northern Drainage Channel for WRA's Alternative 2B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

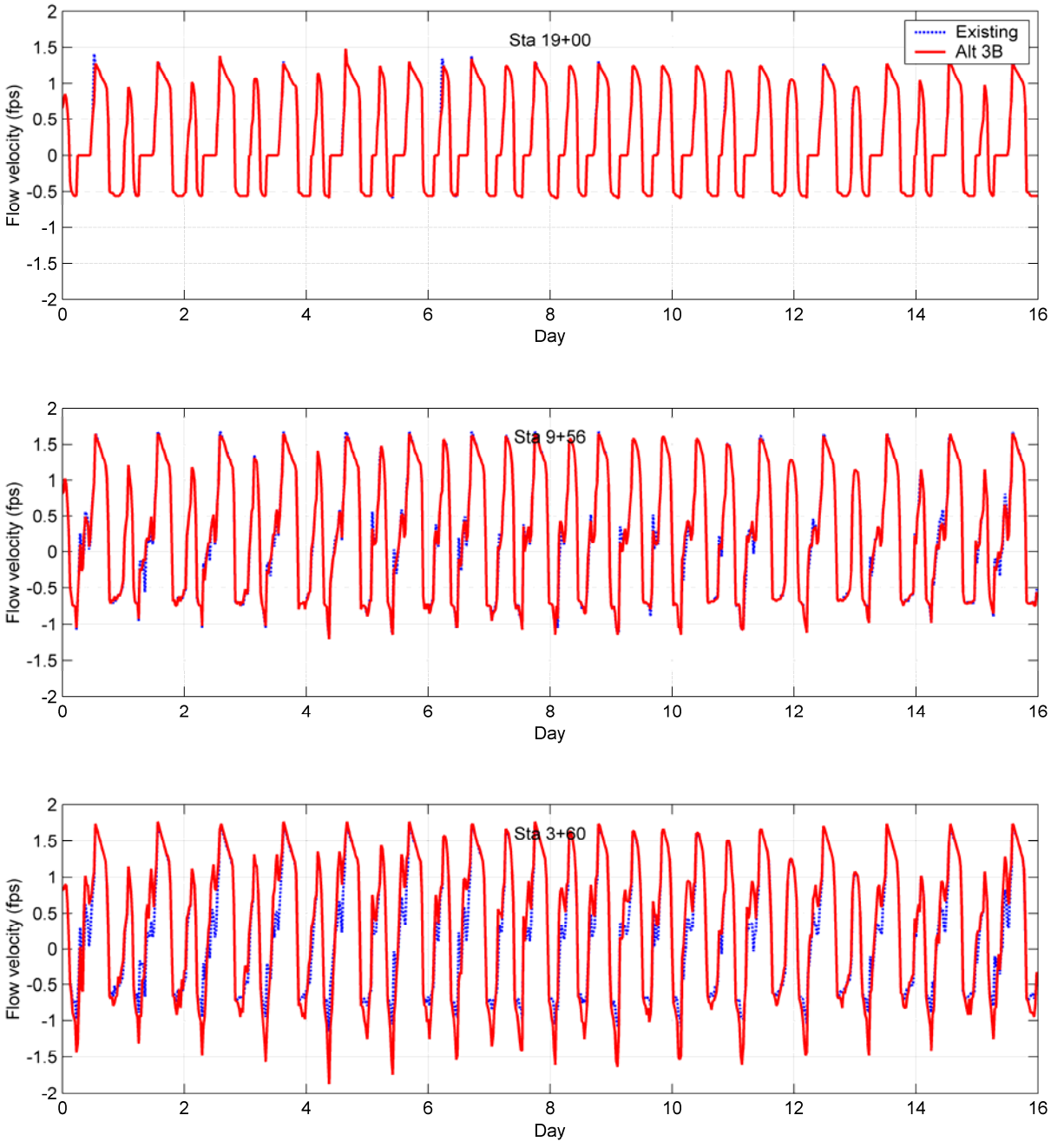


Figure 64. Flow Velocities in Northern Drainage Channel for WRA's Alternative 3B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

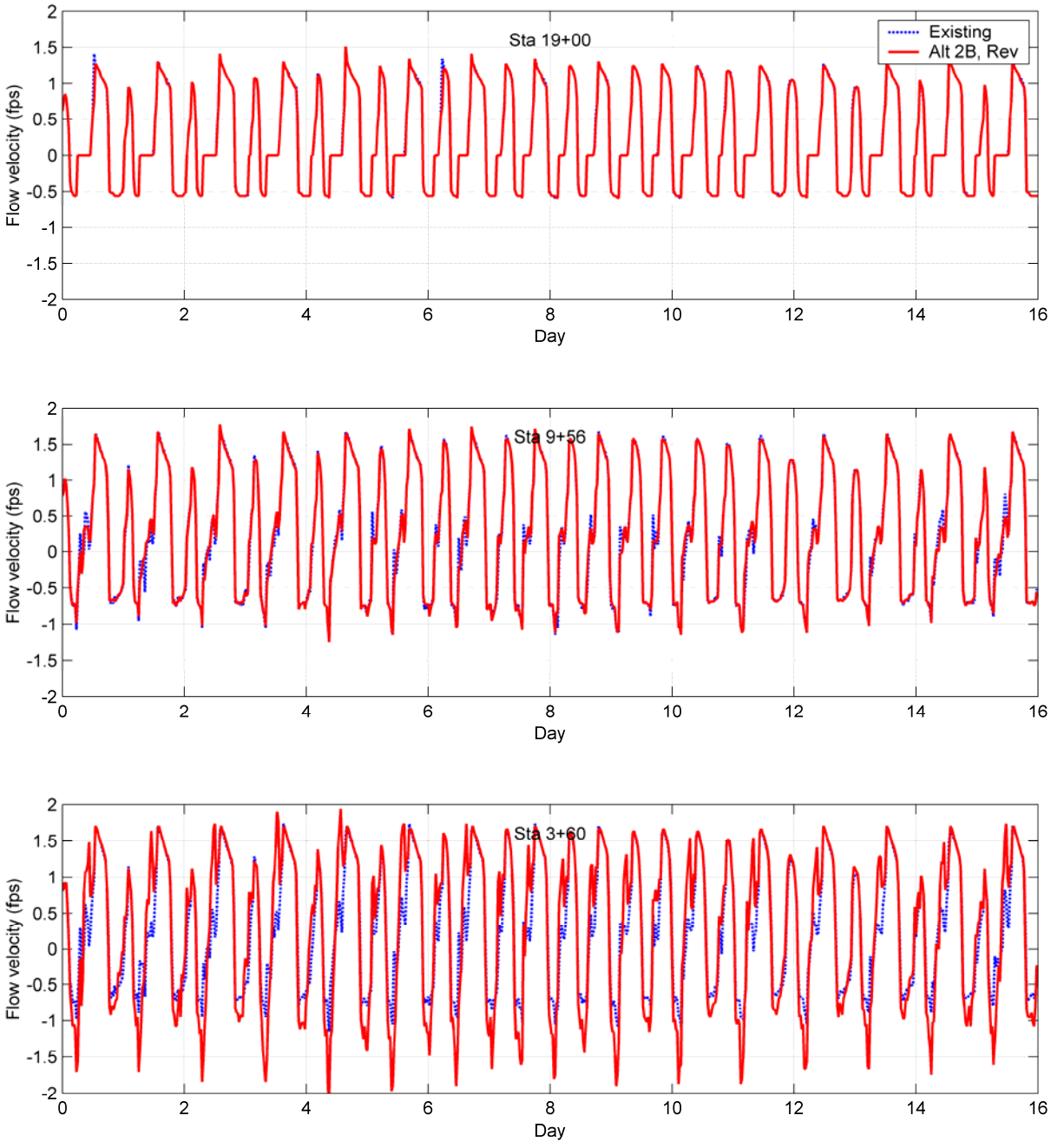


Figure 65. Flow Velocities in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

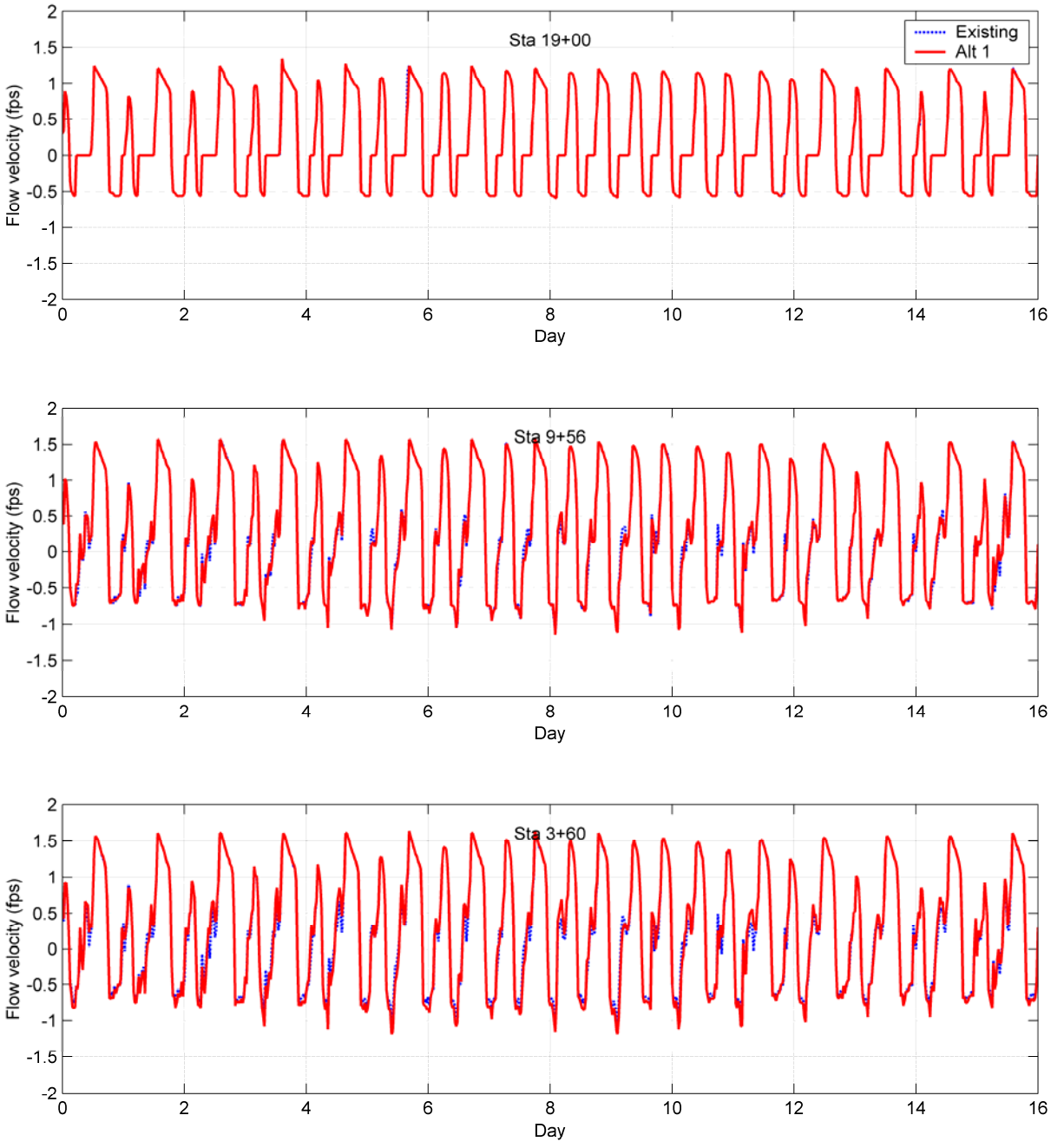


Figure 66. Flow Velocities in Northern Drainage Channel for WRA's Alternative 1 (Winter with No Precipitation Forecasted)

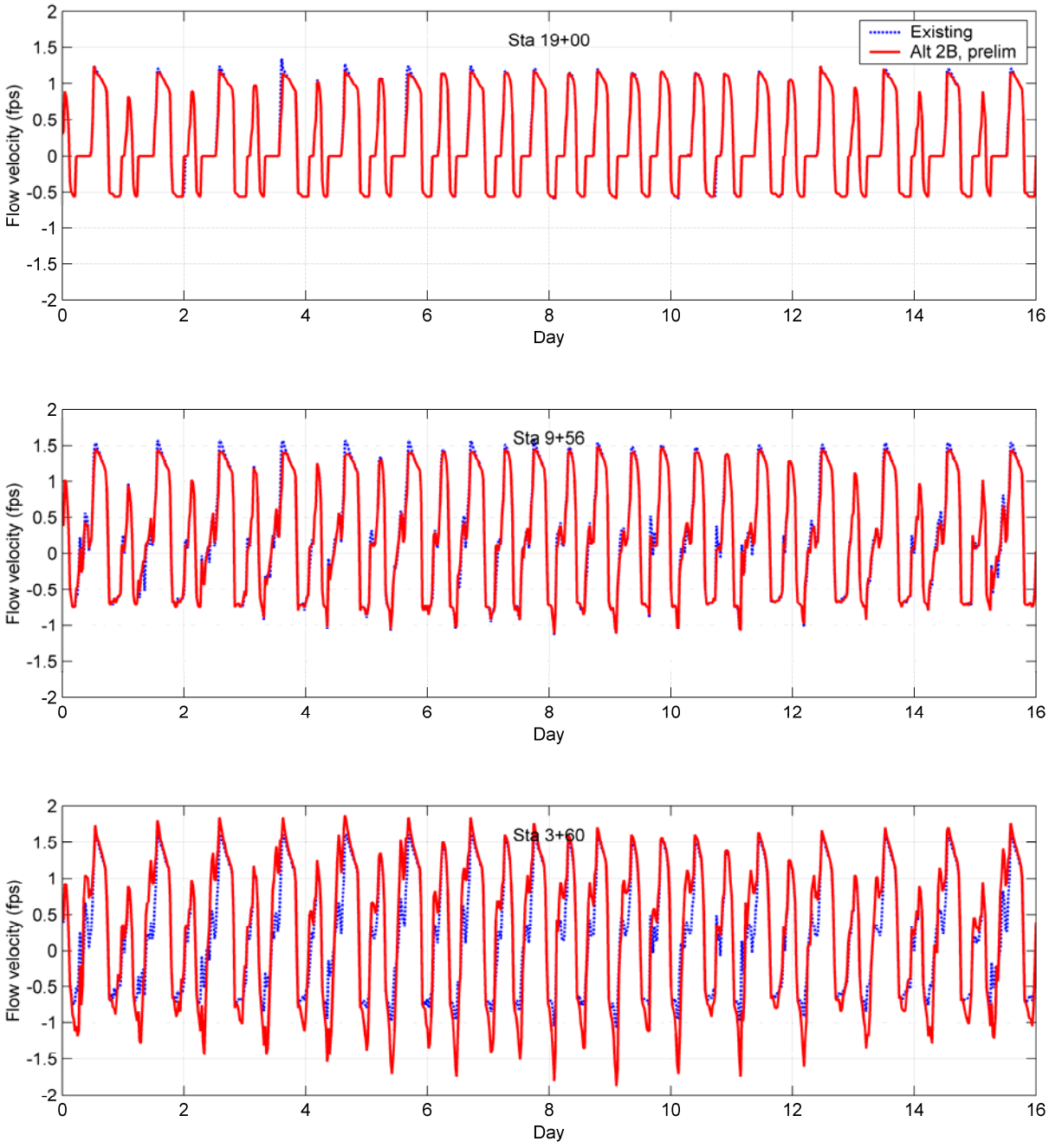


Figure 67. Flow Velocities in Northern Drainage Channel for WRA's Alternative 2B (Winter with No Precipitation Forecasted)

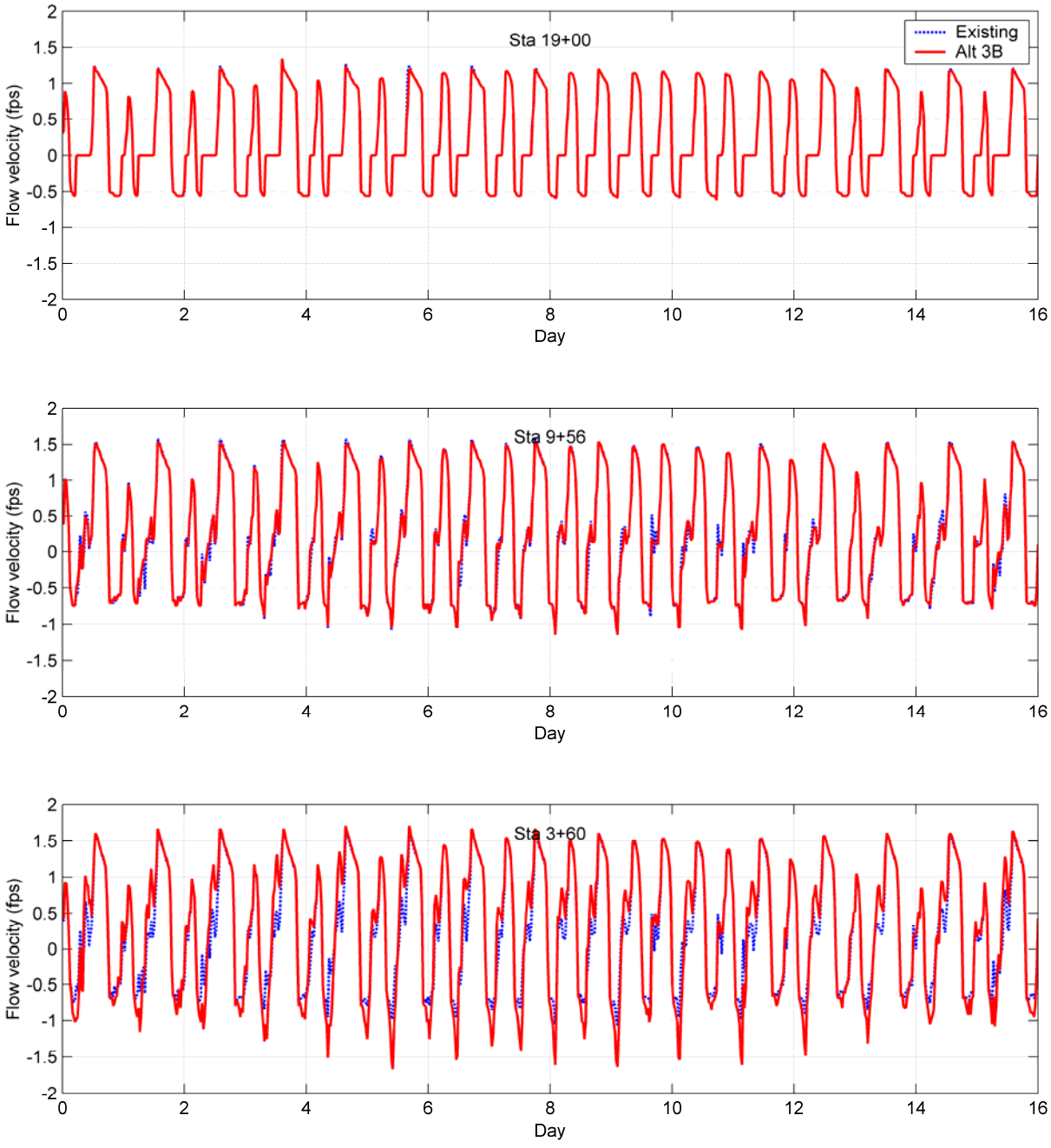


Figure 68. Flow Velocities in Northern Drainage Channel for WRA's Alternative 3B (Winter with No Precipitation Forecasted)

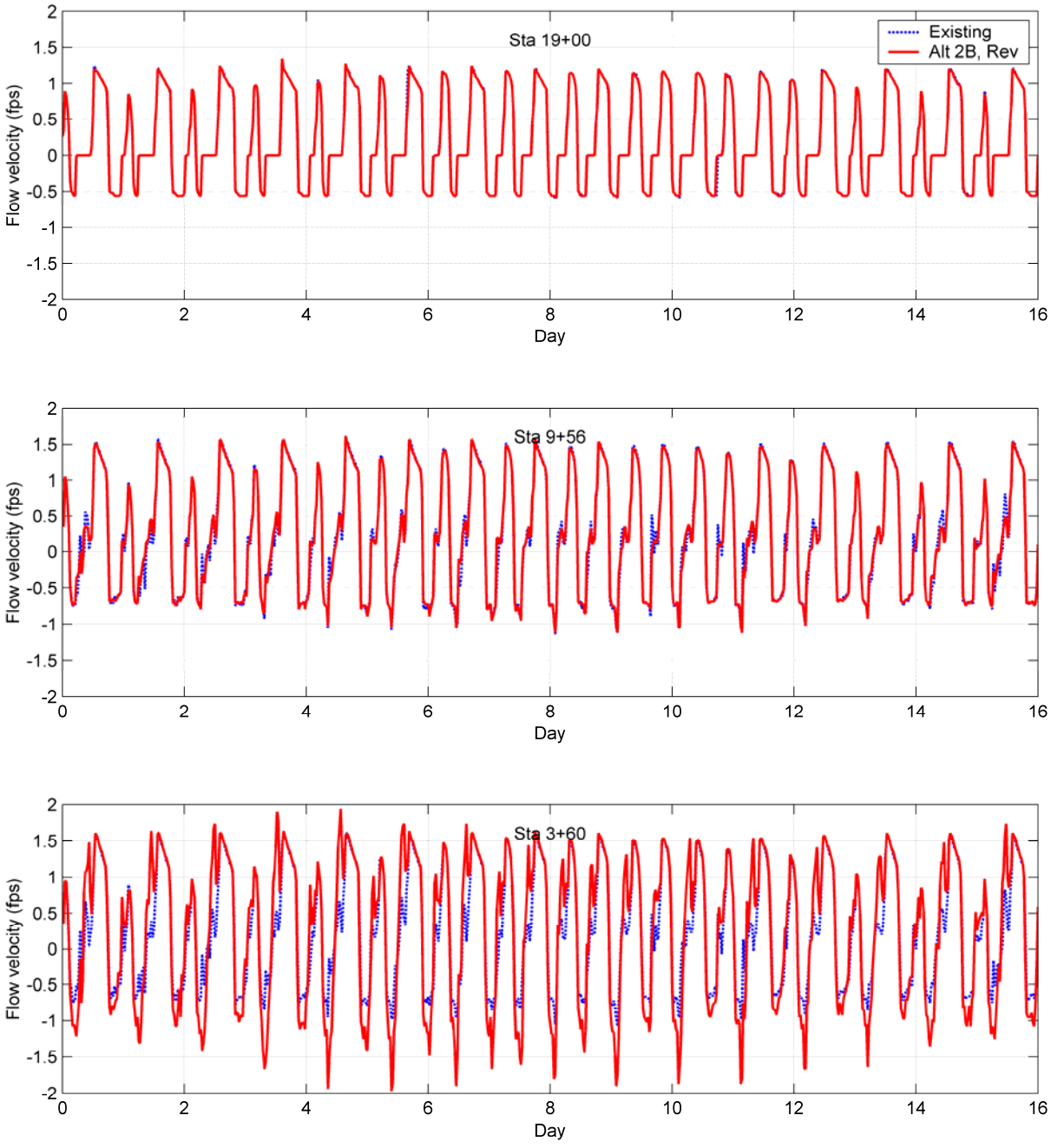


Figure 69. Flow Velocities in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Winter with No Precipitation Forecasted)

Bottom Shear Stresses in Existing Northern Drainage Channel

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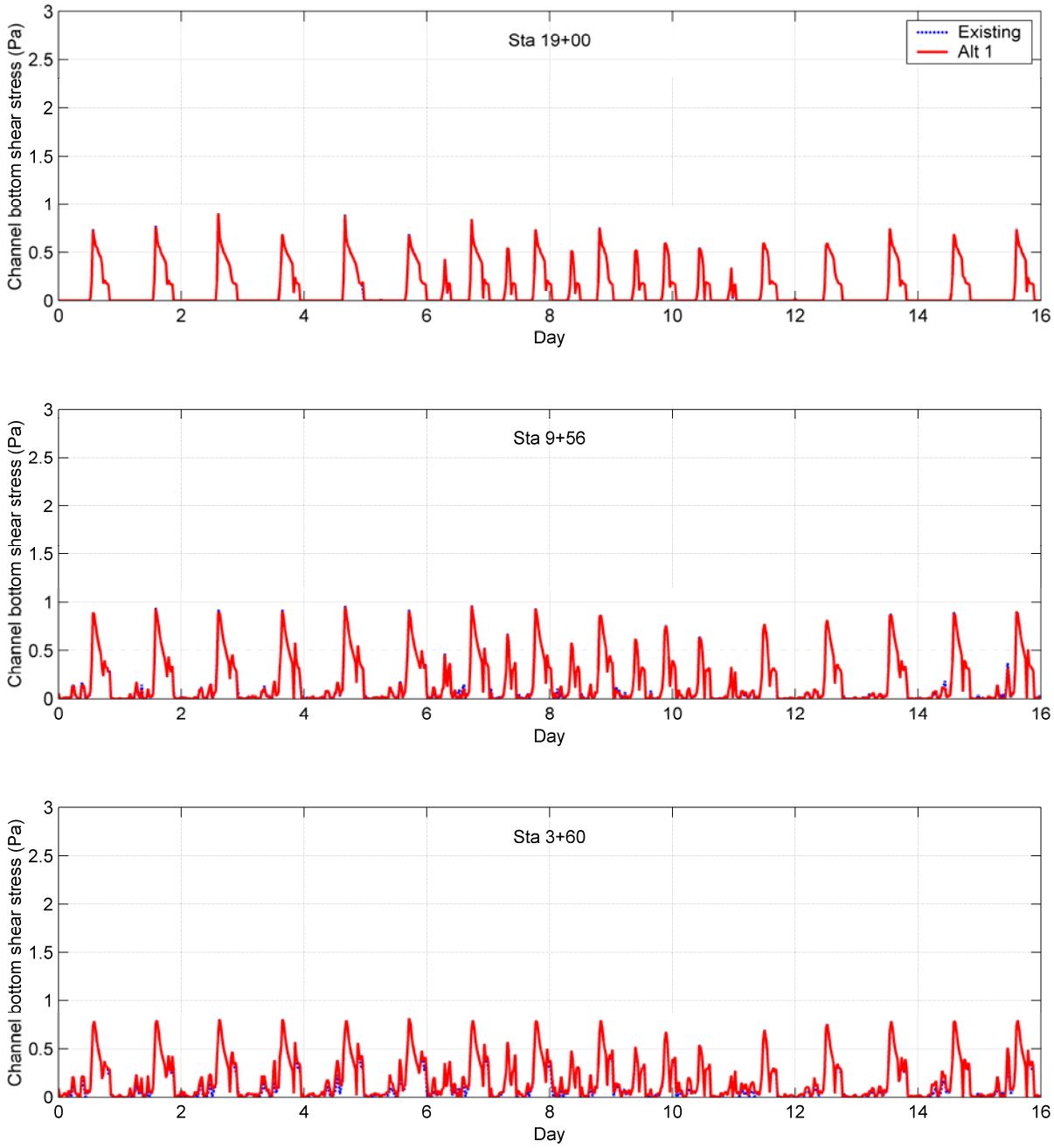


Figure 70. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 1 (Apr 1 – Aug 15)

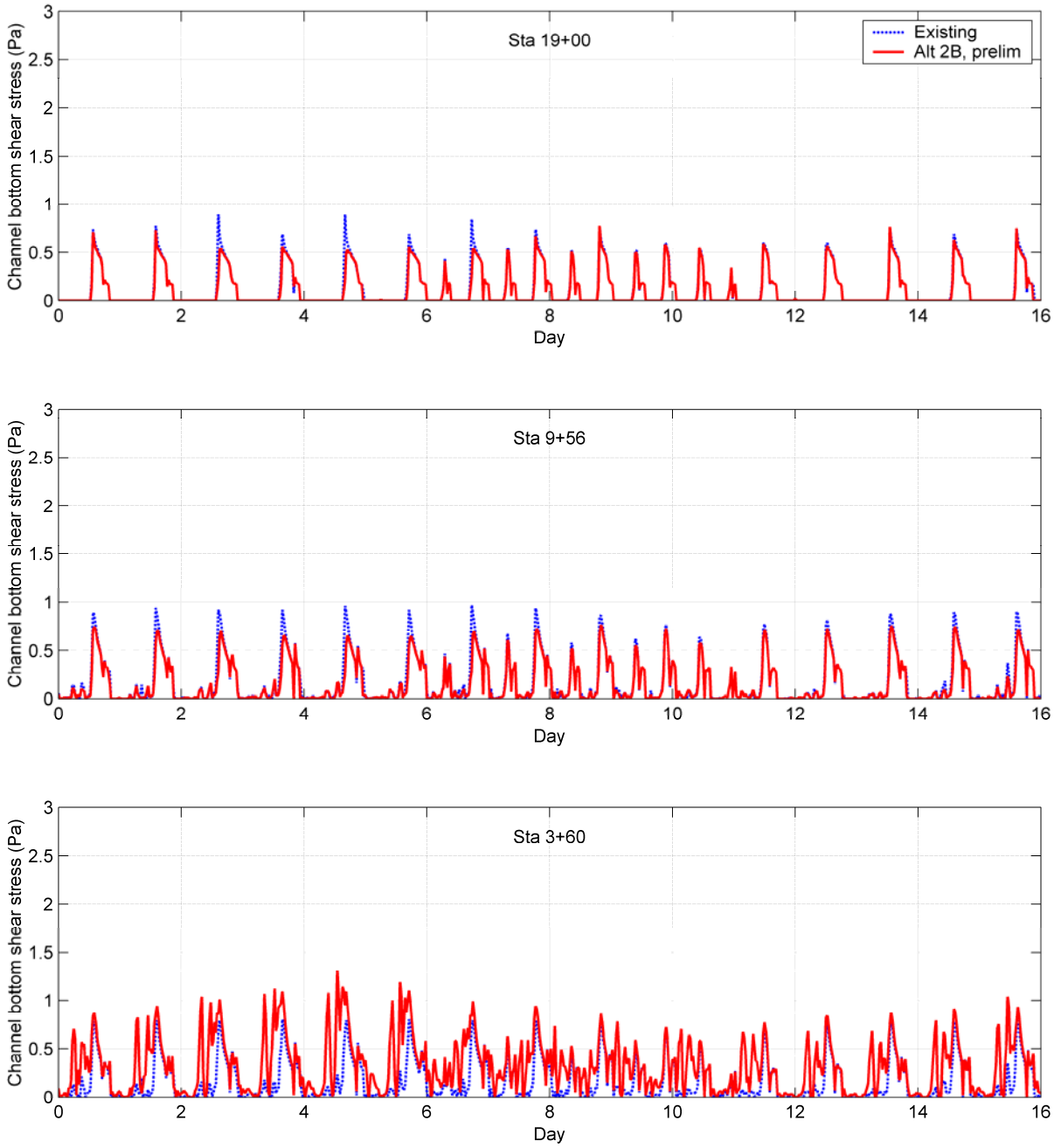


Figure 71. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 2B (Apr 1 – Aug 15)

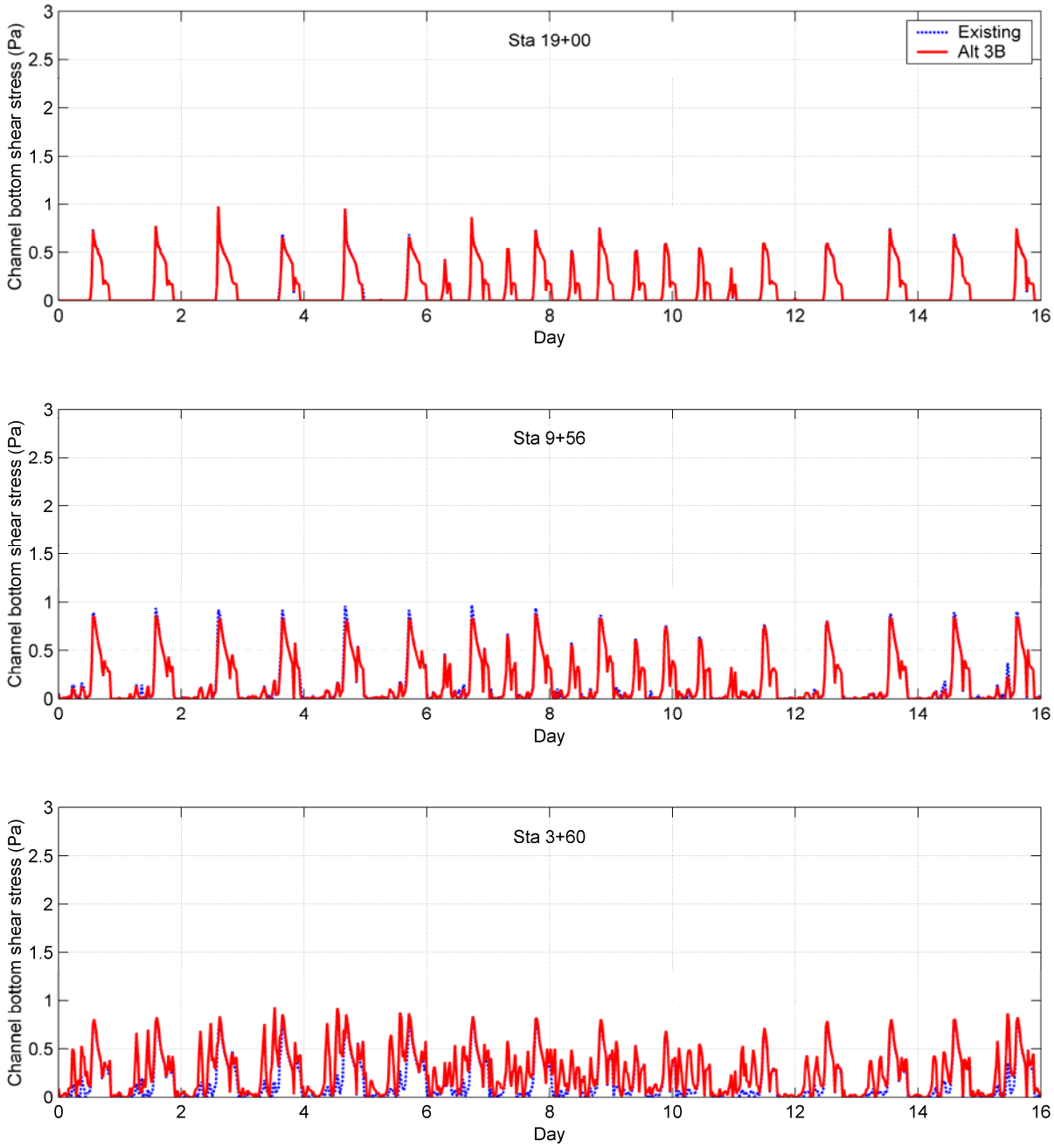


Figure 72. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 3B (Apr 1 – Aug 15)

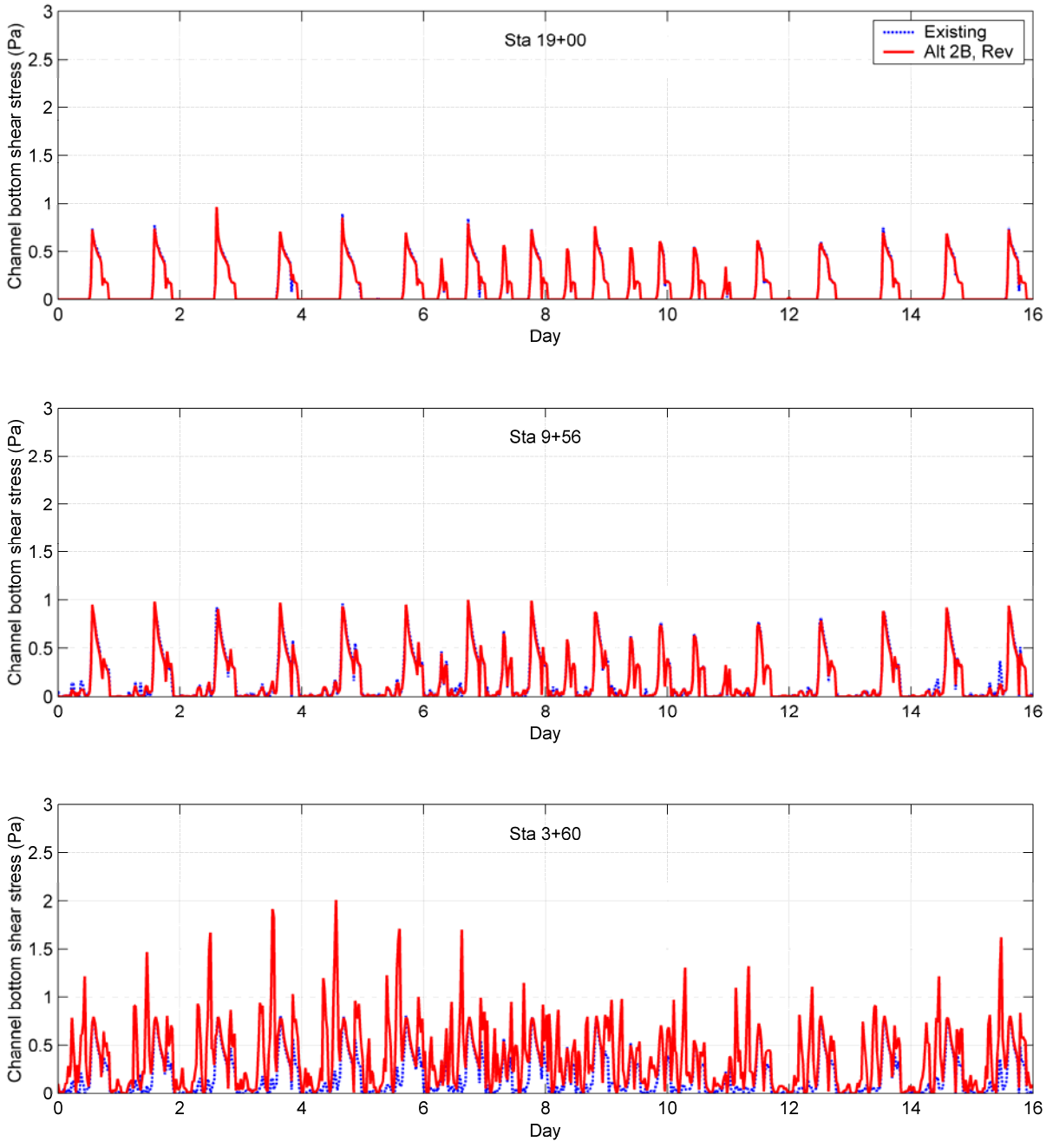


Figure 73. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Apr 1 – Aug 15)

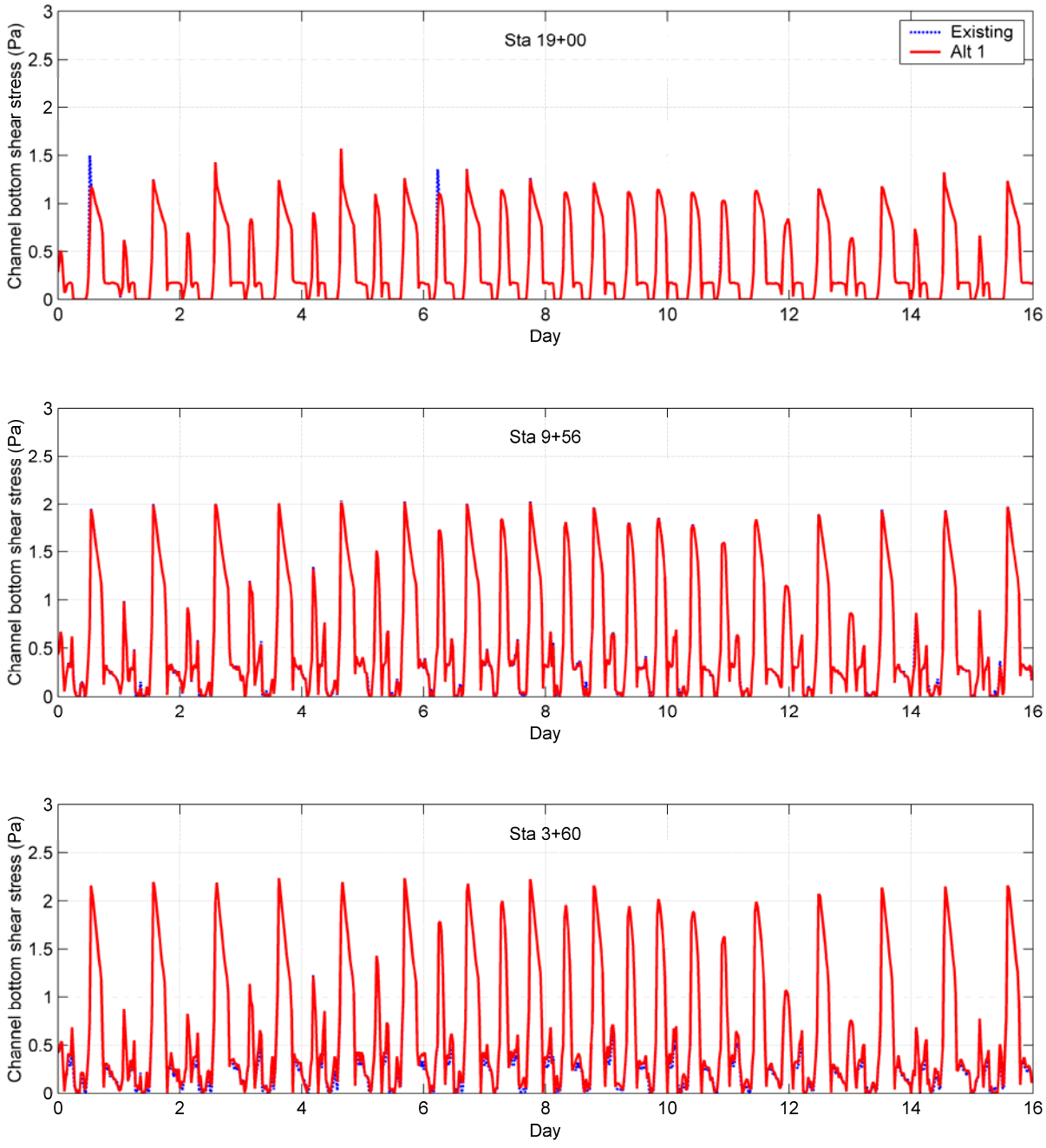


Figure 74. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 1 (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

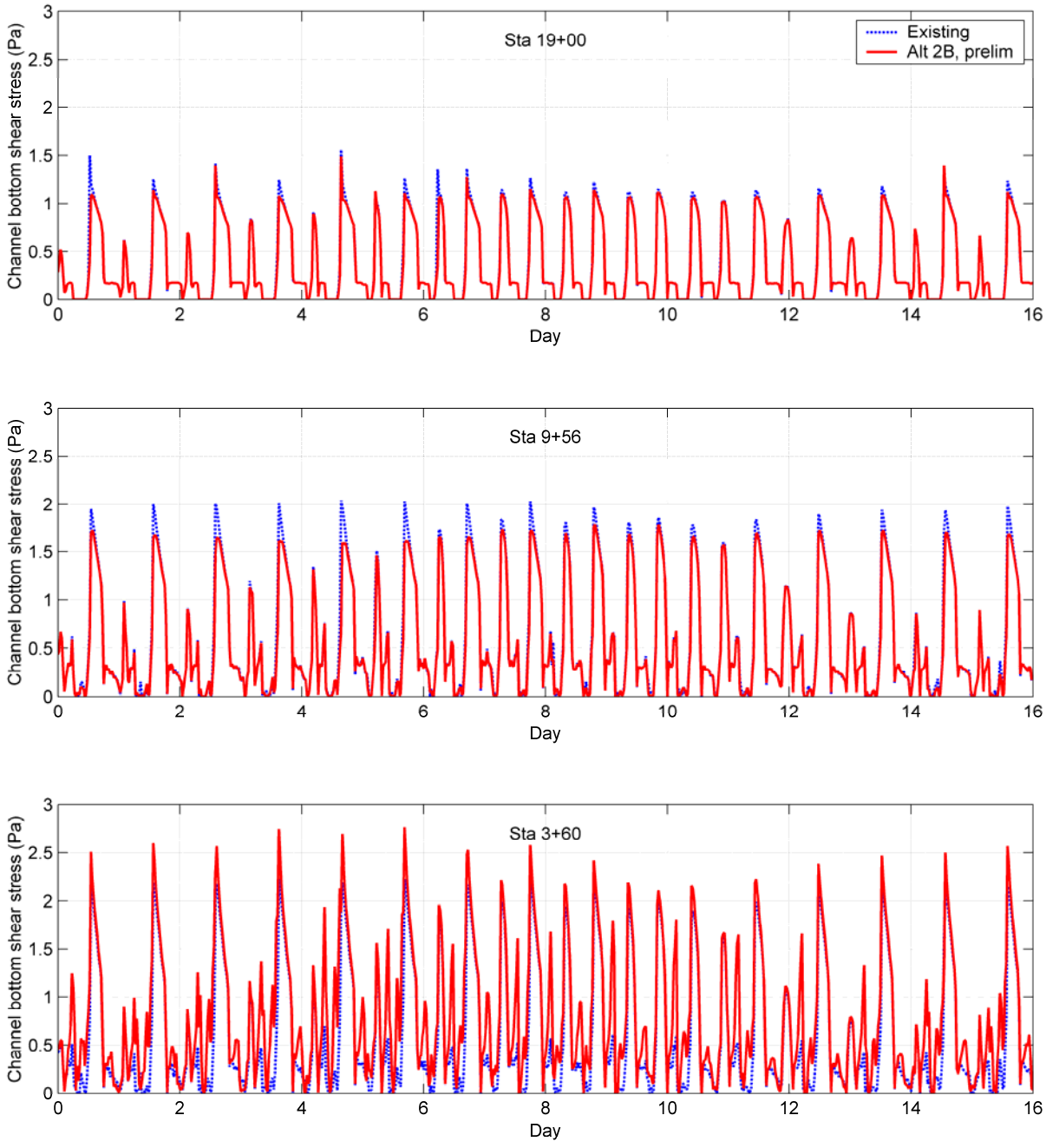


Figure 75. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 2B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

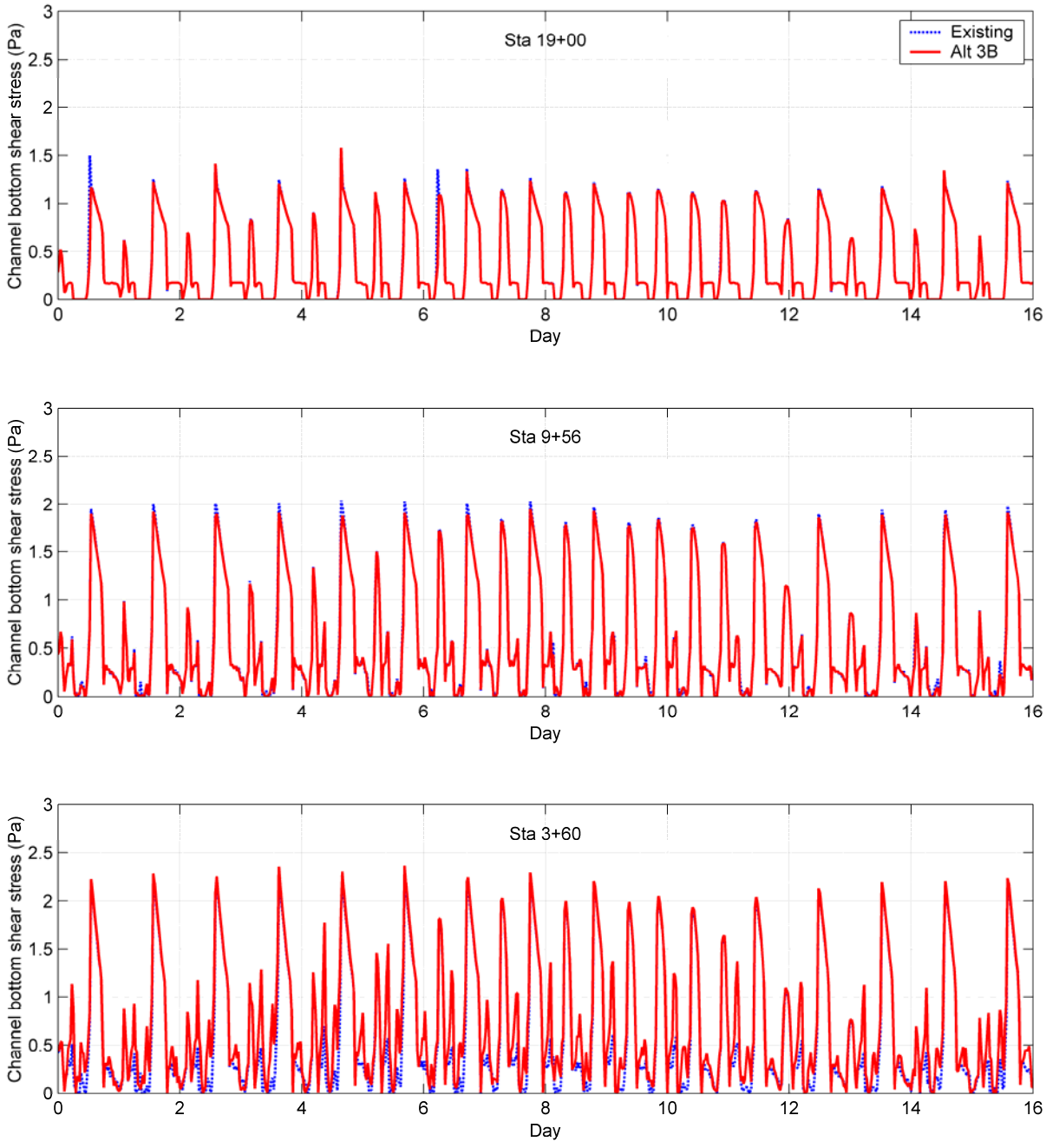


Figure 76. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 3B (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

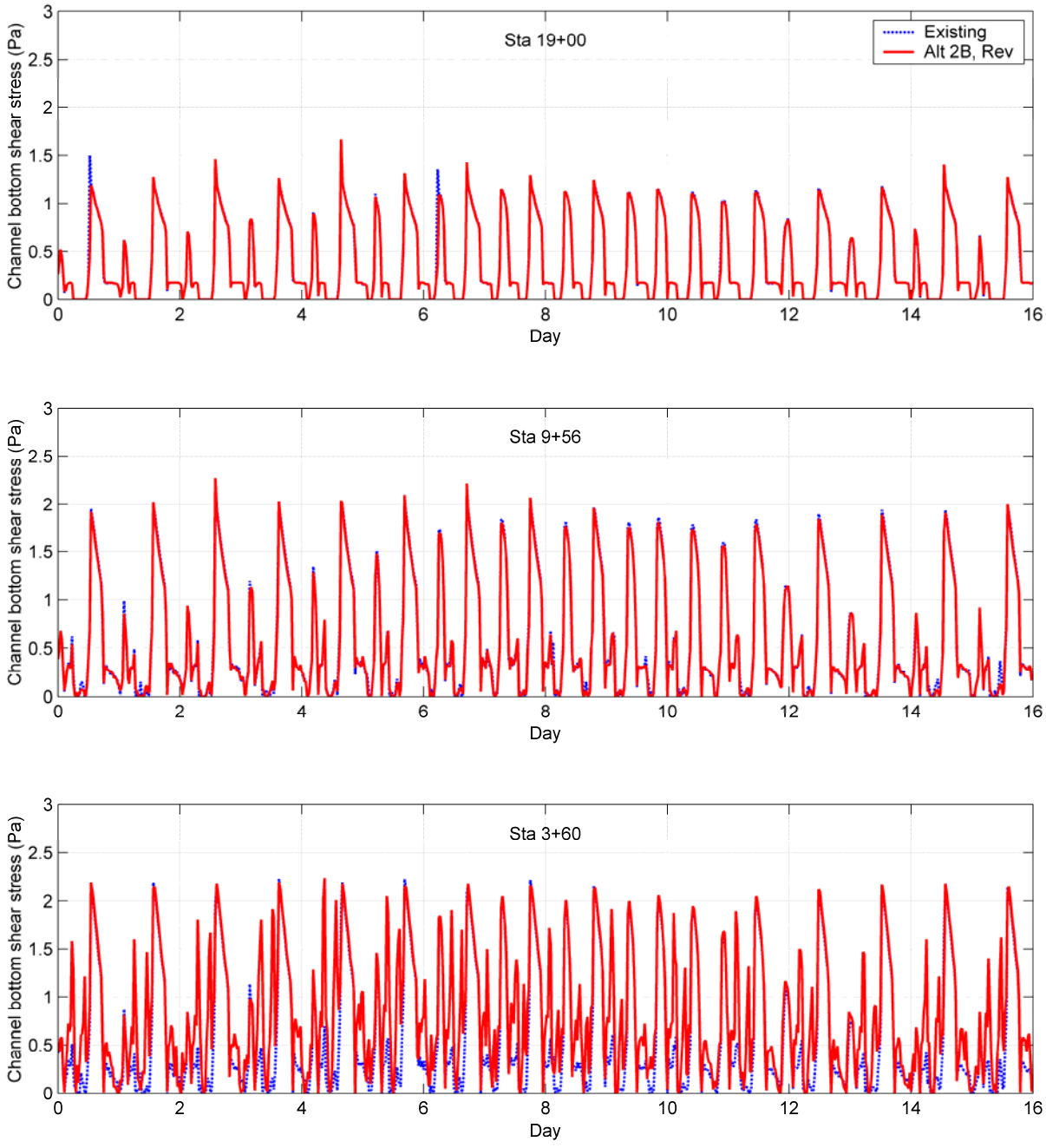


Figure 77. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 2B with Optimized Channel Size for Breach and Internal Tidal Channels (Aug 15 – Beginning of Shorebird Marsh Fall Maintenance)

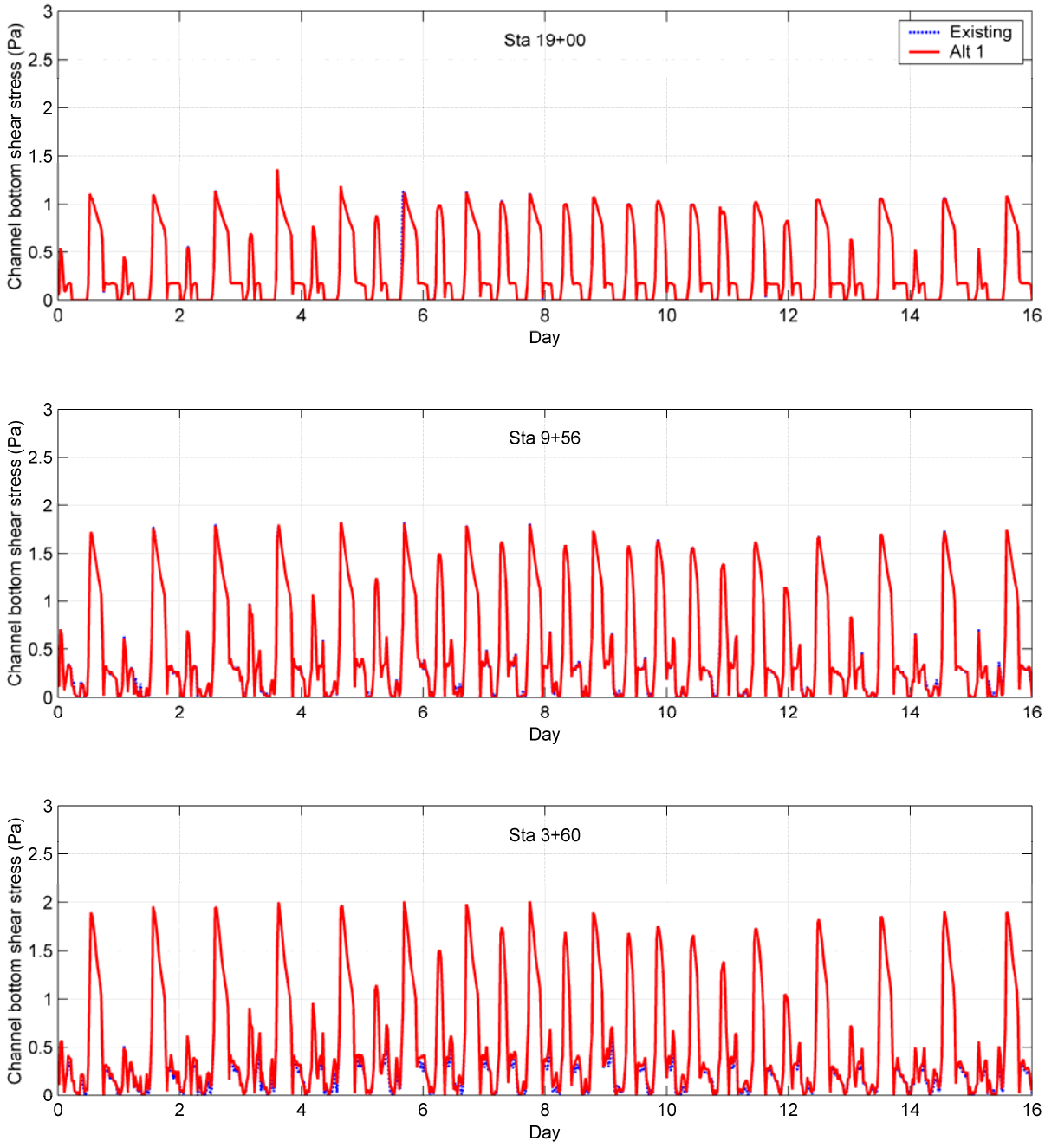


Figure 78. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 1 (Winter with No Precipitation Forecasted)

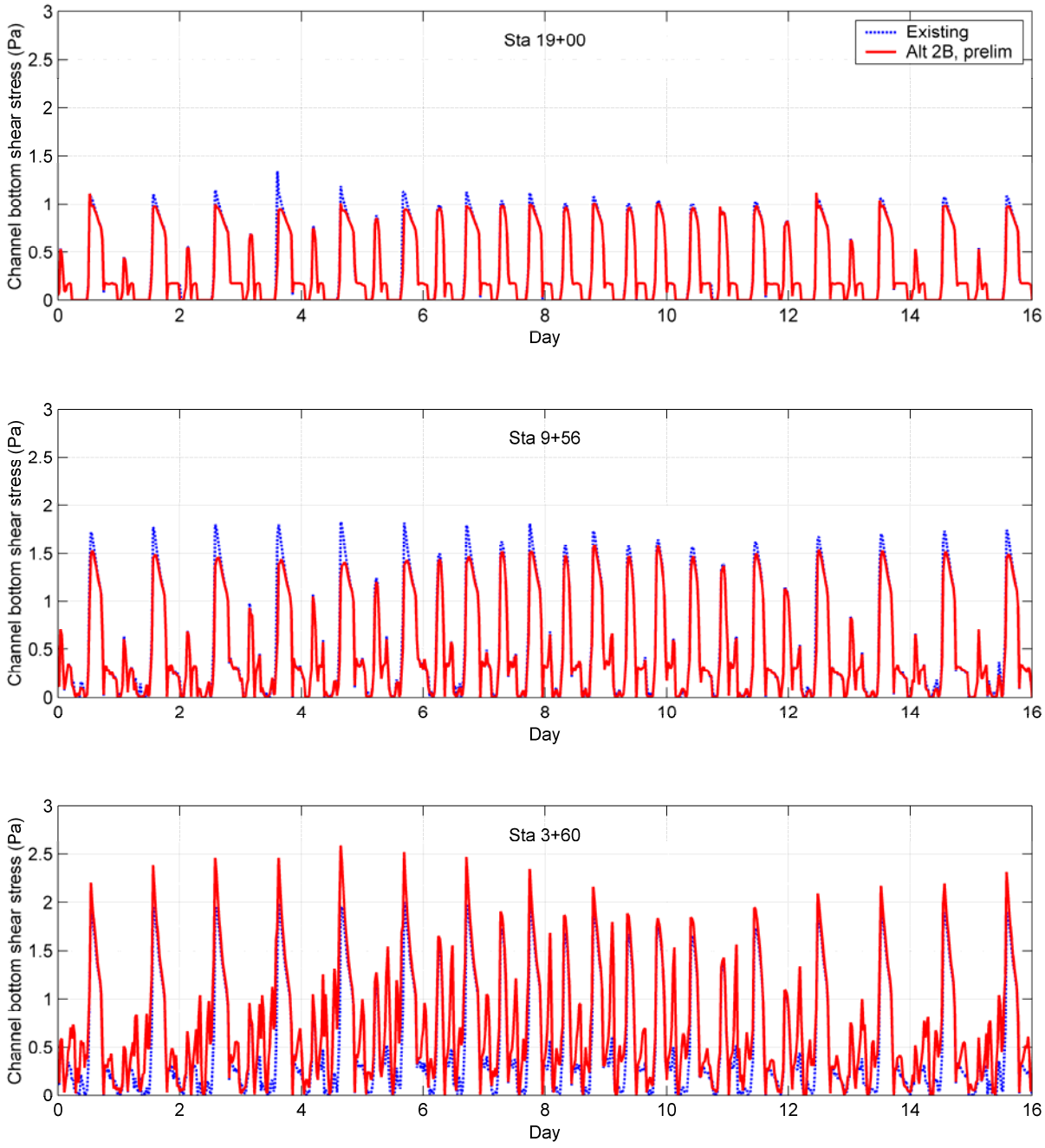


Figure 79. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 2B (Winter with No Precipitation Forecasted)

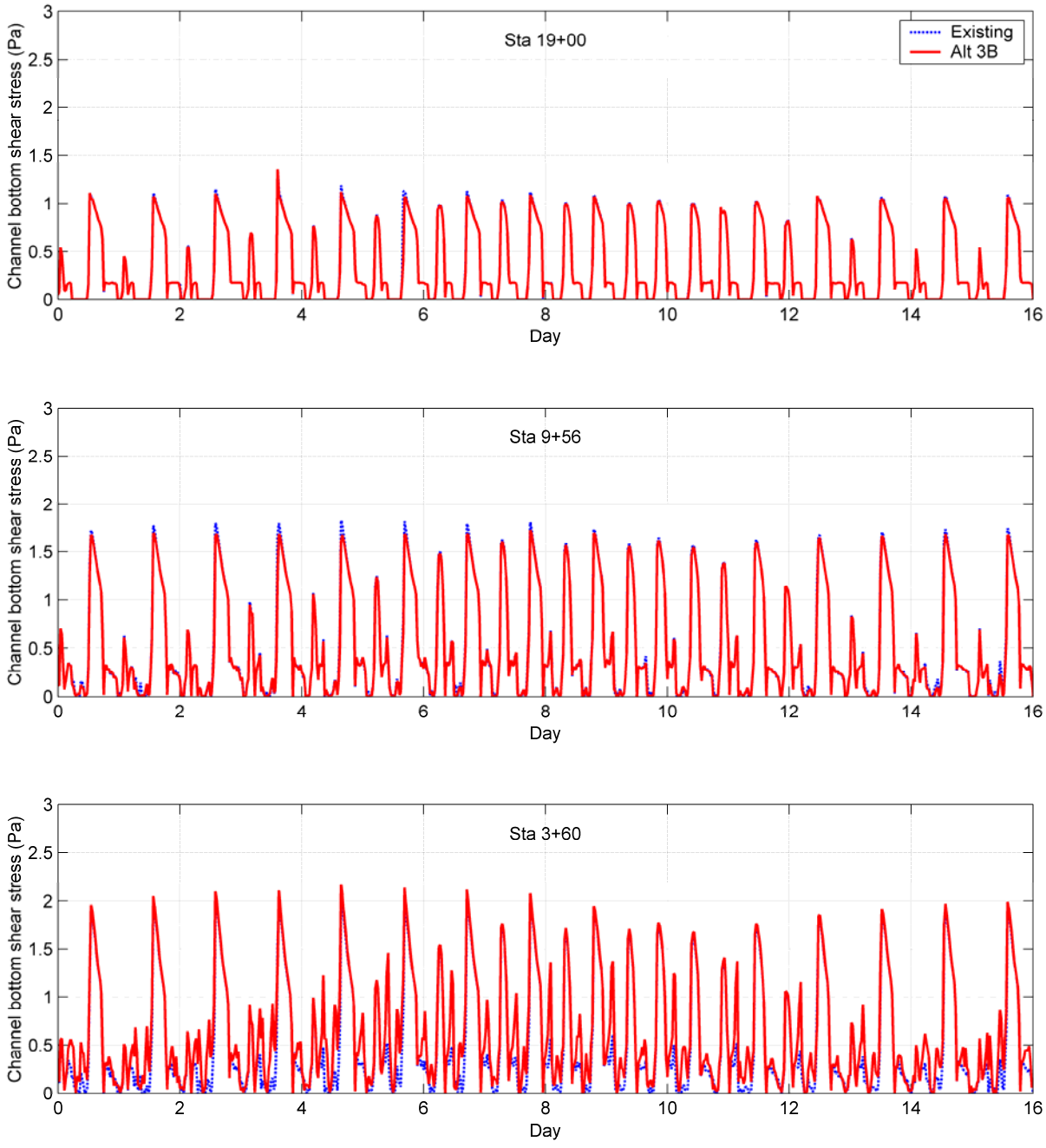


Figure 80. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 3B (Winter with No Precipitation Forecasted)

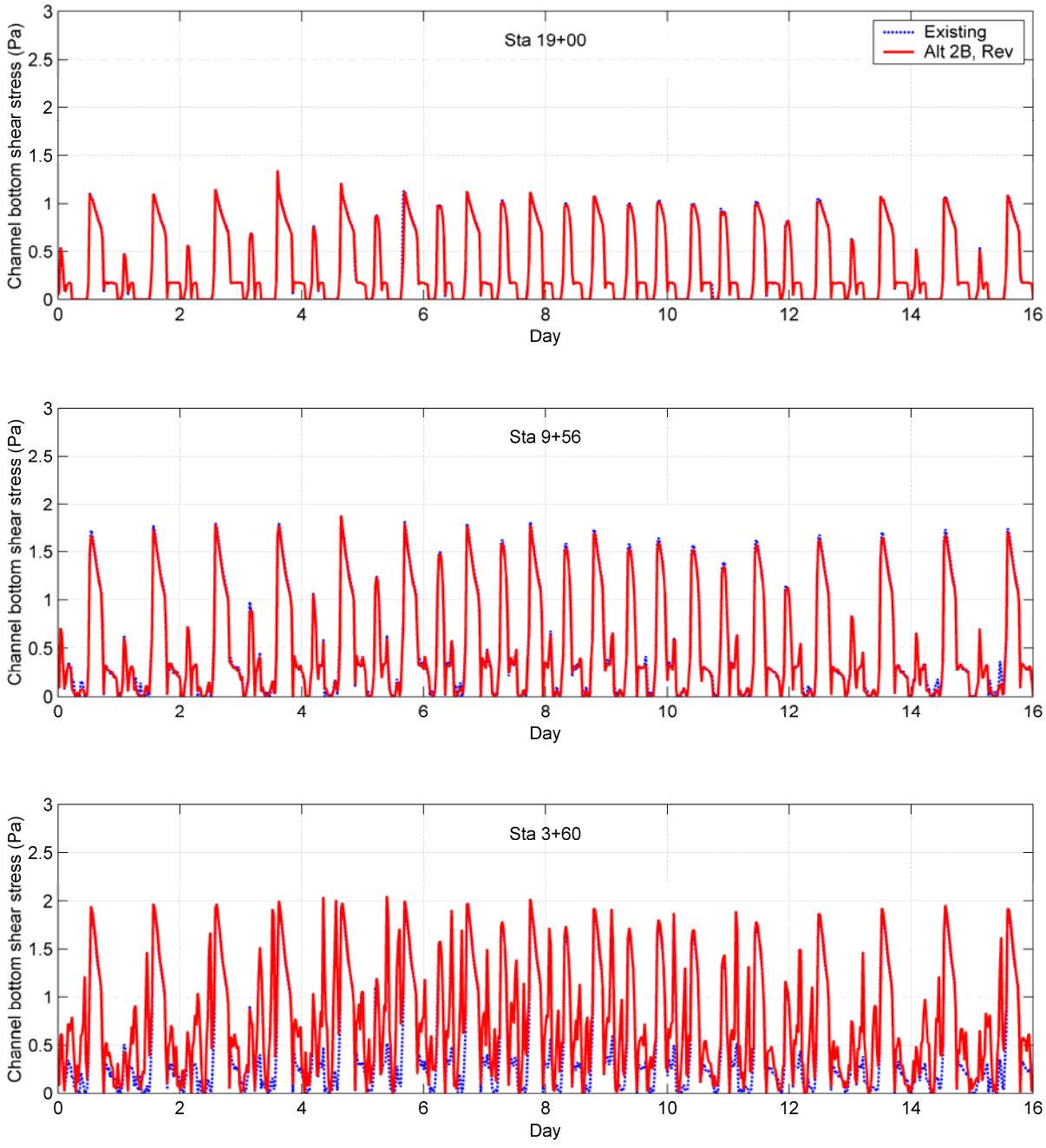


Figure 81. Bottom Shear Stresses in Northern Drainage Channel for WRA's Alternative 3B with Optimized Channel Size for Breach and Internal Tidal Channels (Winter with No Precipitation Forecasted)

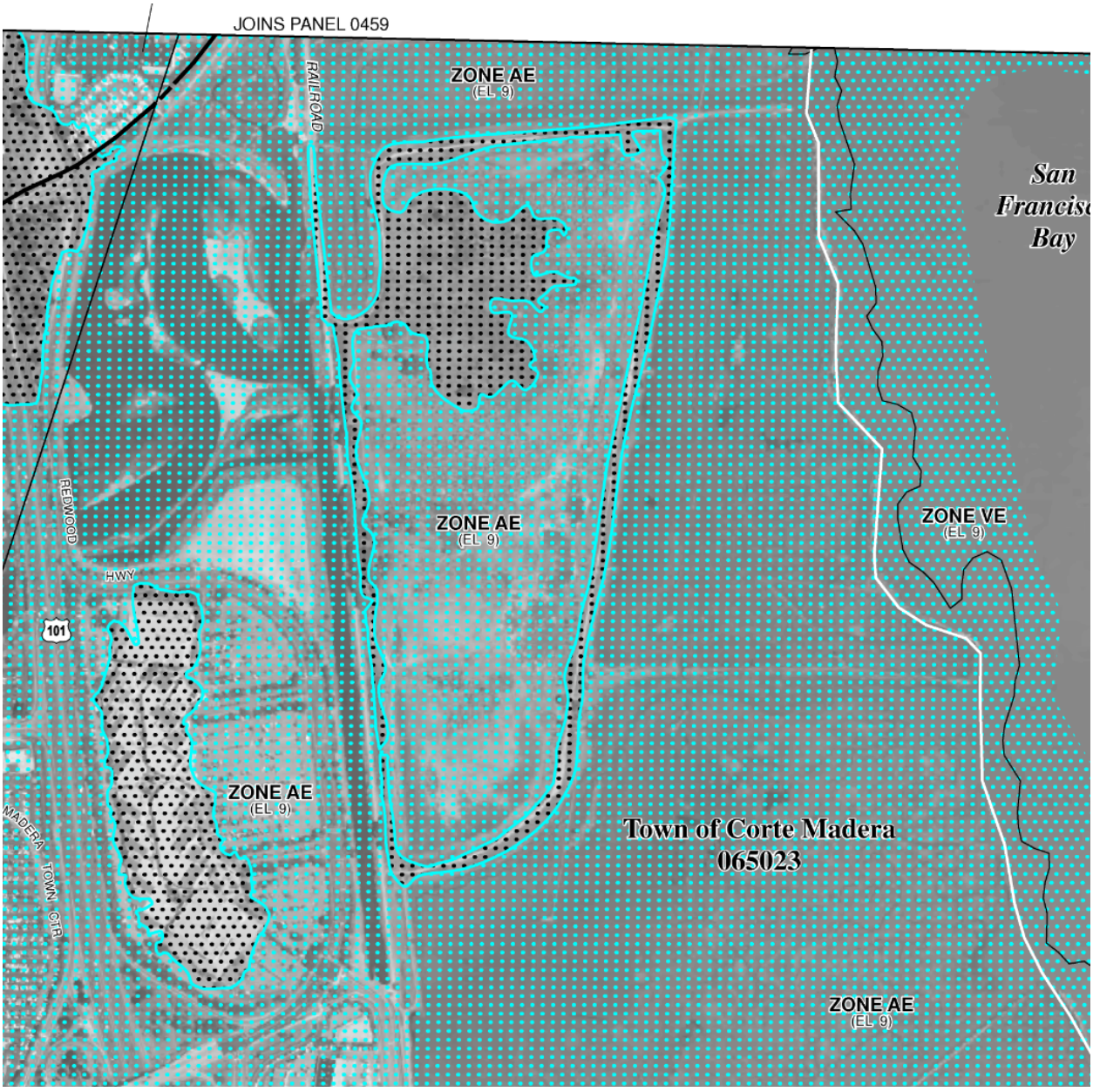


Figure 82. FEMA Flood Insurance Rate Map (FIRM, Panel 0467E) for the Project Site