Kiawah Island
2006 East End Beach Restoration Project
Survey Report No. 14

2020
MONITORING REPORT

Prepared for

Town of Kiawah Island
Kiawah Island, South Carolina

COASTAL SCIENCE & ENGINEERING

2006 BEACH MONITORING PROGRAM

Kiawah Island – South Carolina

SURVEY REPORT NO 14

Annual Beach and Inshore Surveys

Prepared for:

Town of Kiawah Island, South Carolina

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[CSE 2481–YR3]
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COVER PHOTO: Oblique aerial image (taken 16 November 2020) of the Ocean Course Club House and practice facilities. The 2015 East End project left a large shallow pond between the outer beach and the Club House. The pond has gradually filled in with sand and silt when high water events like storms and cold fronts deposit sediment in the basin. By late November 2020, non-submerged areas around the pond had grown in with native dune vegetation. Without major storm impacts, this process is expected to continue.

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Synopsis

This report is the 14th in a series of annual monitoring reports initiated following the 2006 East End beach restoration project. It contains survey results from the oceanfront beach along Kiawah Island (SC), with particular focus given to the eastern third of the island around the Ocean Course and Stono Inlet. There, shoals and channels of Stono Inlet can create episodic erosional issues that deserve special attention.

The Town of Kiawah Island has completed two projects at the east end of the island to address localized erosion and facilitate flushing of an evolving lagoon adjacent to the Ocean Course. The 2006 project moved about 550,000 cubic yards (cy) of sand and restored a wide, dry-sand beach in front of the Ocean Course while relocating a channel. By 2014, the flushing channel was again migrating toward the Ocean Course. Another channel relocation event was completed in the spring of 2015 and involved moving a total of 100,000 cy. Each of these projects occurred in designated critical habitat for piping plovers and incorporated methods to reduce impacts and promote suitable habitat formation for protected species.

Kiawah Island has now suffered direct impacts from several storms over the past five years, including hurricanes *Joaquin* (2015), *Matthew* (2016), *Irma* (2017), *Florence* (2018), *Michael* (2018), and *Dorian* (2019). Hurricane *Matthew* caused dune recession ranging from ~15 feet (ft) to 40 ft along most of the residential beachfront, and even higher rates of loss were observed west of Beachwalker Park. The storm also damaged walkovers, but there was no significant property damage. Hurricanes *Irma* (September 2017), *Florence* (September 2018), and *Michael* (October 2018) caused high surf and winds, but fortunately not as much beach and dune erosion. In September 2019, Hurricane *Dorian* caused similar impacts. Each successive storm has interrupted the natural rebuilding of the beach needed since the erosion due to *Matthew*.

Despite the string of storm impacts, the island has generally been in a state of beach recovery since 2016. CSE tracks conditions by section of the island ('reaches') in terms of sand volumes in the dunes, along the visible beach, and in the underwater zone. As of November 2020, much of the island continued to show growth of the dry-sand beach and foredune. Along the entire shoreline from Captain Sams Inlet to Stono Inlet, the island gained ~255,700 cy of sand from November 2019 to November 2020 (Table A). Most of these gains (~262,400 cy) occurred along the East End Lagoon. Since 2011, the Lagoon and Stono Inlet Reaches have lost sand between nearly every survey. The losses are related to the volume of sand migrating onshore from the tidal delta shoals. The next shoal bypass event is underway, reflected in the increase in beach volume along the Lagoon reach and losses along the Ocean Course.

The central three reaches (West Beach, Turtle Point, and Ocean Course) lost a total of ~44,000 cy (1.3 cy/ft) between November 2019 and November 2020. At the western end of the island, Kiawah Spit gained ~29,600 cy due to extension of the spit towards Seabrook Island. Volume changes for each reach are provided in Table A.

Figure A shows the change in dune position by monitoring station (Line Number) since August 2007. Positive values indicate a more seaward position of the dune crest, whereas negative values mark erosion. The greatest dune movement since 2007 has occurred near the Beach Club and Captain Sams Inlet. Elsewhere along the shorefront, the majority of CSE stations have experienced horizontal (ie seaward or landward) dune crest movement of less than 40 ft in either direction over the past ~14-15 years.

Figure B shows the average unit sand volumes (to –10 ft NAVD, approximately 10 ft below mean sea level) by Reach from 1999/2006 to 2020. The largest volumes occur in Reach 5 around the east end of the island, where accreting shoals are incorporated into Kiawah's beach zone. This area of excess volume feeds the developed part of the island over time by longshore transport to the west. The most important trends illustrated in the graph are along reaches 2, 3, and 4 (West Beach to the Ocean Course). Note the gradual increase in volumes since 1999. Along Kiawah Island, a gain of 50 cy/ft equates to beach/dune widening of ~75 ft. These data support the long-held observation that Kiawah Island is healthy and growing, unlike many other beach communities.

CSE recommends the Town regularly assess the foredune through photographs or dune-line GPS surveys. CSE does not believe additional emergency-type action is required at this time. However, if the Town or other parties desire to restore the dune system beyond what was accomplished by the Town's restoration efforts, upland sand can be used for minor improvements. CSE does not believe sand fencing is warranted; however, if sand fencing is installed, it should be installed as close to the primary dune as possible. The next monitoring event will occur in fall/winter 2021–2022.

TABLE A. Beach volumes and unit volumes*, along with respective changes for applicable time periods, for each reach and the entire island between 2007 and 2020. Volumes are to −10 ft NAVD. Reach boundaries are described in the report. Red indicates erosion since the prior survey. Average unit volumes for all reaches are weighted by the applicable reach length.

			Reach Total Volume (cy)															
Reach	Name	Length	Apr-99	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Oct-12	Oct-13	Oct-14	Nov-15	Jan-17	Nov-17	Jan-19	Nov-19	Nov-20
1	Kiawah Spit	8,820	2,527,990		3,309,434	3,308,176	3,360,442	3,482,539	3,403,430	3,385,060	3,387,780	3,355,774	2,426,028	2,421,235	2,587,554	2,516,429	2,545,308	2,574,957
2	West Beach	11,798	2,925,119		3,018,972	2,973,269	3,002,842	3,016,726	3,023,391	3,143,512	3,200,438	3,247,900	3,246,474	3,109,992	3,123,811	3,186,466	3,153,949	3,204,546
3	Turtle Point	13,614	3,119,193		3,768,036	3,711,347	3,791,886	3,780,710	3,783,778	3,973,563	4,103,395	4,242,815	4,328,658	4,133,108	4,083,240	4,087,595	4,041,965	4,019,325
4	Ocean Course	9,000		2,881,490	3,008,223	2,946,188	3,047,332	3,071,534	3,182,156	3,301,984	3,403,054	3,535,481	3,599,780	3,562,542	3,577,236	3,690,347	3,707,191	3,635,228
5	Lagoon	8,000		6,559,380	6,462,016	6,840,138	7,055,611	7,419,125	7,222,197	7,071,272	6,946,031	6,993,814	6,787,731	6,325,250	6,139,954	5,939,621	5,936,206	6,198,619
6	Stono Inlet	6,000		1,464,695	1,460,076	1,447,219	1,406,546	1,422,719	1,427,296	1,448,756	1,408,636	1,328,992	1,248,369	1,052,076	966,215	845,351	707,753	715,353
1-6	**All**	**57,232**			**21,026,757**	**21,226,337**	**21,664,658**	**22,193,353**	**22,042,249**	**22,324,146**	**22,449,334**	**22,704,776**	**21,637,039**	**20,604,203**	**20,478,010**	**20,265,811**	**20,092,373**	**20,348,028**
			Reach Unit Volume (cy/ft)															
Reach	Name	Length	Apr-99	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Oct-12	Oct-13	Oct-14	Nov-15	Jan-17	Nov-17	Jan-19	Nov-19	Nov-20
1	Kiawah Spit	8,820	286.6		375.2	375.1	381.0	394.8	385.9	383.8	384.1	380.5	275.1	274.5	293.4	285.3	288.6	291.9
2	West Beach	11,798	247.9		255.9	252.0	254.5	255.7	256.3	266.4	271.3	275.3	275.2	263.6	264.8	270.1	267.3	271.6
3	Turtle Point	13,614	229.1		276.8	272.6	278.5	277.7	277.9	291.9	301.4	311.7	318.0	303.6	299.9	300.2	296.9	295.2
4	Ocean Course	9,000		320.2	334.2	327.4	338.6	341.3	353.6	366.9	378.1	392.8	400.0	395.8	397.5	410.0	411.9	403.9
5	Lagoon	8,000		819.9	807.8	855.0	882.0	927.4	902.8	883.9	868.3	874.2	848.5	790.7	767.5	742.5	742.0	774.8
6	Stono Inlet	6,000		244.1	243.3	241.2	234.4	237.1	237.9	241.5	234.8	221.5	208.1	175.3	161.0	140.9	118.0	119.2
1-6	**All**	**57,232**			**368.0**	**369.5**	**379.2**	**387.2**	**384.3**	**391.6**	**394.2**	**398.4**	**378.6**	**365.4**	**361.7**	**354.3**	**337.2**	**338.1**
			Reach Volume Change Since Previous (cy)															
Reach	Name	Length			Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Oct-12	Oct-13	Oct-14	Nov-15	Jan-17	Nov-17	Jan-19	Nov-19	Nov-20
1	Kiawah Spit	8,820				-1,258	52,266	122,097	-79,109	-18,370	2,719	-32,006	-929,746	-4,793	166,319	-71,125	28,879	29,649
2	West Beach	11,798				-45,703	29,573	13,884	6,665	120,120	56,926	47,462	-1,426	-136,481	13,818	62,656	-32,517	50,598
3	Turtle Point	13,614				-56,689	80,539	-11,176	3,068	189,784	129,833	139,419	85,843	-195,550	-49,869	4,356	-45,630	-22,641
4	Ocean Course	9,000			126,733	-62,036	101,144	24,202	110,622	119,828	101,070	132,427	64,299	-37,239	14,695	113,111	16,844	-71,963
5	Lagoon	8,000			-97,364	378,122	215,473	363,514	-196,928	-150,924	-125,241	47,784	-206,084	-462,481	-185,296	-200,333	-3,415	262,413
6	Stono Inlet	6,000			-4,620	-12,857	-40,673	16,174	4,577	21,459	-40,119	-79,644	-80,624	-196,292	-85,861	-120,864	-137,598	7,600
1-6	**All**	**57,232**				**199,580**	**438,321**	**528,695**	**-151,105**	**281,897**	**125,188**	**255,442**	**-1,067,737**	**-1,032,836**	**-126,194**	**-212,199**	**-173,437**	**-173,437**
			Reach Unit Volume Change Since Previous (cy/ft)															
Reach	Name	Length			Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Oct-12	Oct-13	Oct-14	Nov-15	Jan-17	Nov-17	Jan-19	Nov-19	Nov-20
1	Kiawah Spit	8,820				-0.1	5.9	13.8	-9.0	-2.1	0.3	-3.6	-105.4	-0.5	18.9	-8.1	3.3	3.4
2	West Beach	11,798				-3.9	2.5	1.2	0.6	10.2	4.8	4.0	-0.1	-11.6	1.2	5.3	-2.8	4.3
3	Turtle Point	13,614				-4.2	5.9	-0.8	0.2	13.9	9.5	10.2	6.3	-14.4	-3.7	0.3	-3.4	-1.7
4	Ocean Course	9,000			14.1	-6.9	11.2	2.7	12.3	13.3	11.2	14.7	7.1	-4.1	1.6	12.6	1.9	-8.0
5	Lagoon	8,000			-12.2	47.3	26.9	45.4	-24.6	-18.9	-15.7	6.0	-25.8	-57.8	-23.2	-25.0	-0.4	32.8
6	Stono Inlet	6,000			-0.8	-2.1	-6.8	2.7	0.8	3.6	-6.7	-13.3	-13.4	-32.7	-14.3	-20.1	-22.9	1.3
1-6	**All**	**57,232**				**3.5**	**7.7**	**9.2**	**-2.6**	**4.9**	**2.2**	**4.5**	**-18.7**	**-18.0**	**-2.2**	**-3.7**	**-3.0**	**-3.0**

**Shoreline change from year to year depends on which contour is chosen for comparison (eg – mean high water – MHW, mean sea level – MSL, mean lower low water – MLLW, etc.) and can vary greatly with some contours showing shoreline recession while others mark seaward movement over the same period. CSE uses beach volume measures because they provide a more objective result, integrating all small-scale changes between the foredune and some defined offshore depth representing the area over which nearly all sand movement occurs in the littoral zone. Unit volumes are derived from two-dimensional (2D) profiles by extrapolating changes in square feet by one-unit shore length, such as one foot. This yields a unit volume in cubic feet per foot of shoreline, which we convert to cubic yards per foot (cy/ft) by standard convention. Such results at individual profiles can then be extrapolated to the next profile to yield 'beach volumes.'*

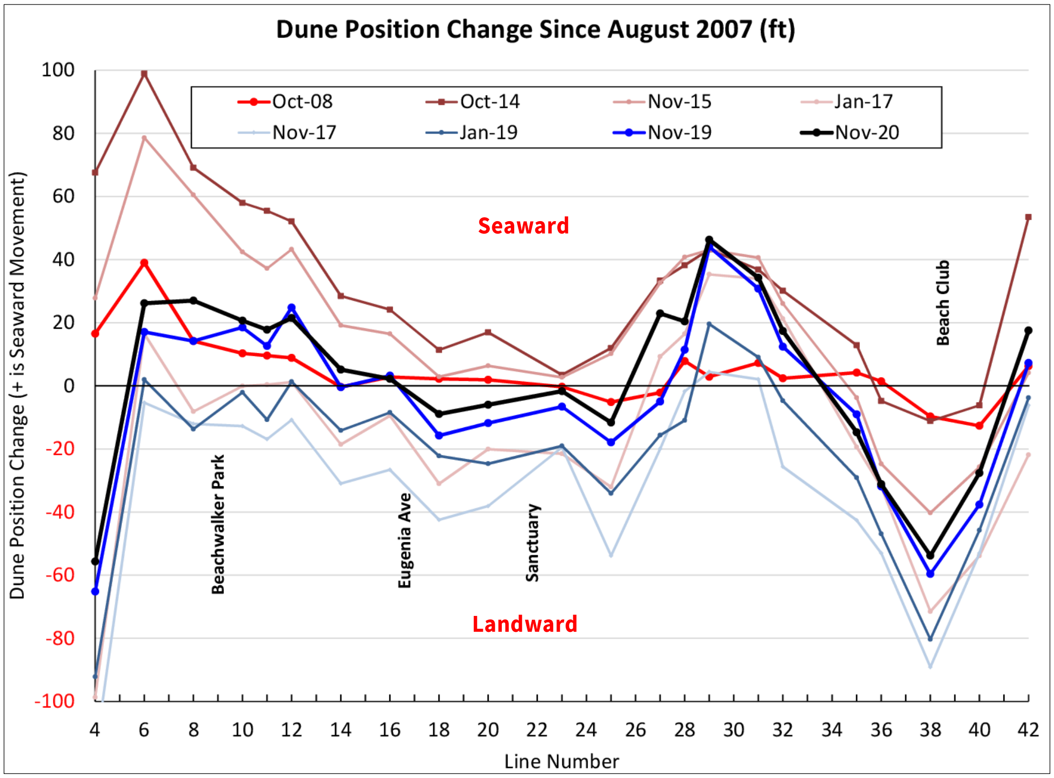

FIGURE A. Yearly dune position changes since August 2007 (negative values indicate erosion of the dune since that survey). Hurricanes *Joaquin* (2015), *Matthew* (2016), *Irma* (2017), *Florence* (2018), *Michael* (2018), and *Dorian* (2019) all resulted in foredune erosion along Kiawah Island in recent years.

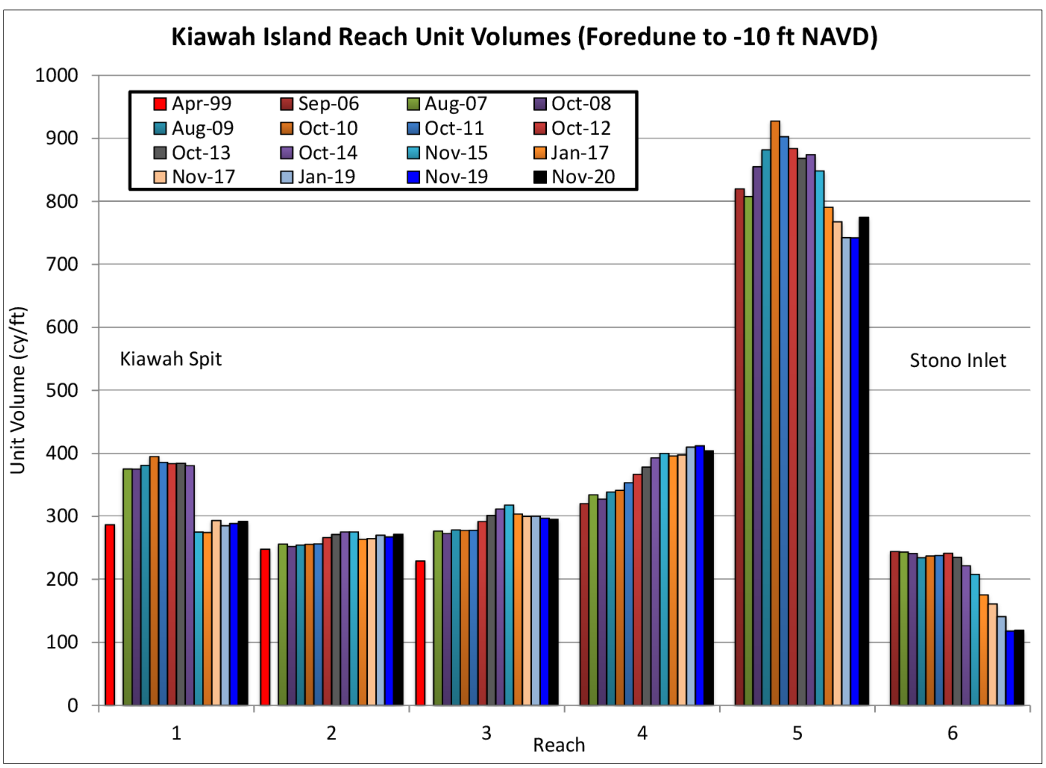

FIGURE B. Unit volumes as measured by reach since April 1999 (September 2006 along the Ocean Course and East End). Overall, the beach had less sand in November 2019 than October 2008 as a result of ~7 years of accretion followed by ~5 years of erosion (on average). However, as this figures illustrates, more than half of the island had more sand on the beach above –10 ft NAVD as of November 2020 than in September 2006 (April 1999 for the three westernmost reaches – Turtle Point, West Beach, and Kiawah Spit).

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1.0 INTRODUCTION

This report is part of a series of annual beach monitoring reports initiated following the 2006 East End restoration project (see CSE 2005, 2007). The Town of Kiawah Island (SC) sponsors annual surveys of the beach for purposes of determining rates and directions of sand movement within the project area as well as the remainder of the island. This fourteenth report of the series follows over a dozen shoreline erosion reports prepared by Research Planning Institute (RPI) and Coastal Science & Engineering (CSE) for Kiawah Island since the 1980s (eg – Kana et al 1983, CSE 1999). Annual post-project surveys have been conducted in the fall of every year between 2007 and 2020, in addition to periodic post-storm surveys in January 2017 (post-*Matthew*) and January 2019 (post –*Florence* and -*Michael*). The present survey was completed in November 2020, to provide a beach condition assessment since the prior monitoring survey completed in November 2019.

The purpose of annual beach monitoring reports is to describe the current health of the beaches along Kiawah Island as compared to past conditions. To do so, survey data are collected along the entire island from Stono River Inlet to Captain Sams Inlet in order to document sand volume changes. Profile lines run from the landward side of the seaward-most dune out to at least 2,500 feet (ft) offshore. Volume calculations are made within boundaries established using offshore distance and range from 1,000 ft to 2,500 ft. Most volume calculations represent the changes in sand volume above ~–10 ft NAVD* elevation. A positive change indicates accretion, while a negative change indicates erosion. Over multiple years of survey data, volumetric changes can be used to infer sediment transport patterns along the shoreline. This information is used in turn to assess current erosion hot spots and predict future areas of concern before hazardous situations arise.

The scope of work for the annual monitoring effort includes:

- Ground surveys of the dunes, beach, and inshore zone
- Oblique aerial photography
- Data analysis and production of a technical report describing beach volume changes

The next section of this report presents a brief description of Kiawah Island and its historical shoreline changes. A summary of the methods used during surveying and data analysis follows in Section 3. Section 4 includes the results of the survey, while Section 5 presents a meteorological and sea level summary to associate beach volume changes with particular weather events or water level increases. Section 6 presents a discussion of CSE's findings and recommendations for this year.

**NAVD – North American Vertical Datum of 1988, which is approximately 0.5 ft above present mean sea level (MSL). The datum provides a fixed reference plane for setting grades and 1st-floor elevations in the coastal zone regardless of tide range.*

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2.0 SETTING AND HISTORY

Kiawah Island is a ~10-mile-long barrier island situated ~10–15 miles southeast of Charleston, SC (Fig 2.1). The adjacent Stono Inlet provides enough sand so that erosion occurs in minor, localized hotspots as sand migrates down the beach from Stono Inlet towards the west. Due to the long-term healthy sand supply, the island contains a diverse array of barrier habitats including marshes, dense coastal forests, and dune ridges. The diversity of native habitats, along with an adaptive beachfront management strategy, make Kiawah one of the healthiest barrier islands in South Carolina.

Large quantities of sand migrate onto the eastern end of the island from Stono Inlet and provide beach-quality material that builds dunes along the entire shorefront (Fig 2.2). This sand supply, along with the foresight of the island's developers to thoroughly understand the processes and landforms of the island (see Hayes et al 1975, Hayes 1977) make Kiawah an excellent example of beachfront development and an aesthetically unique community along the South Carolina coast. The role of Stono Inlet in shaping the beach along Kiawah Island is explored in greater detail in Section 2.2.

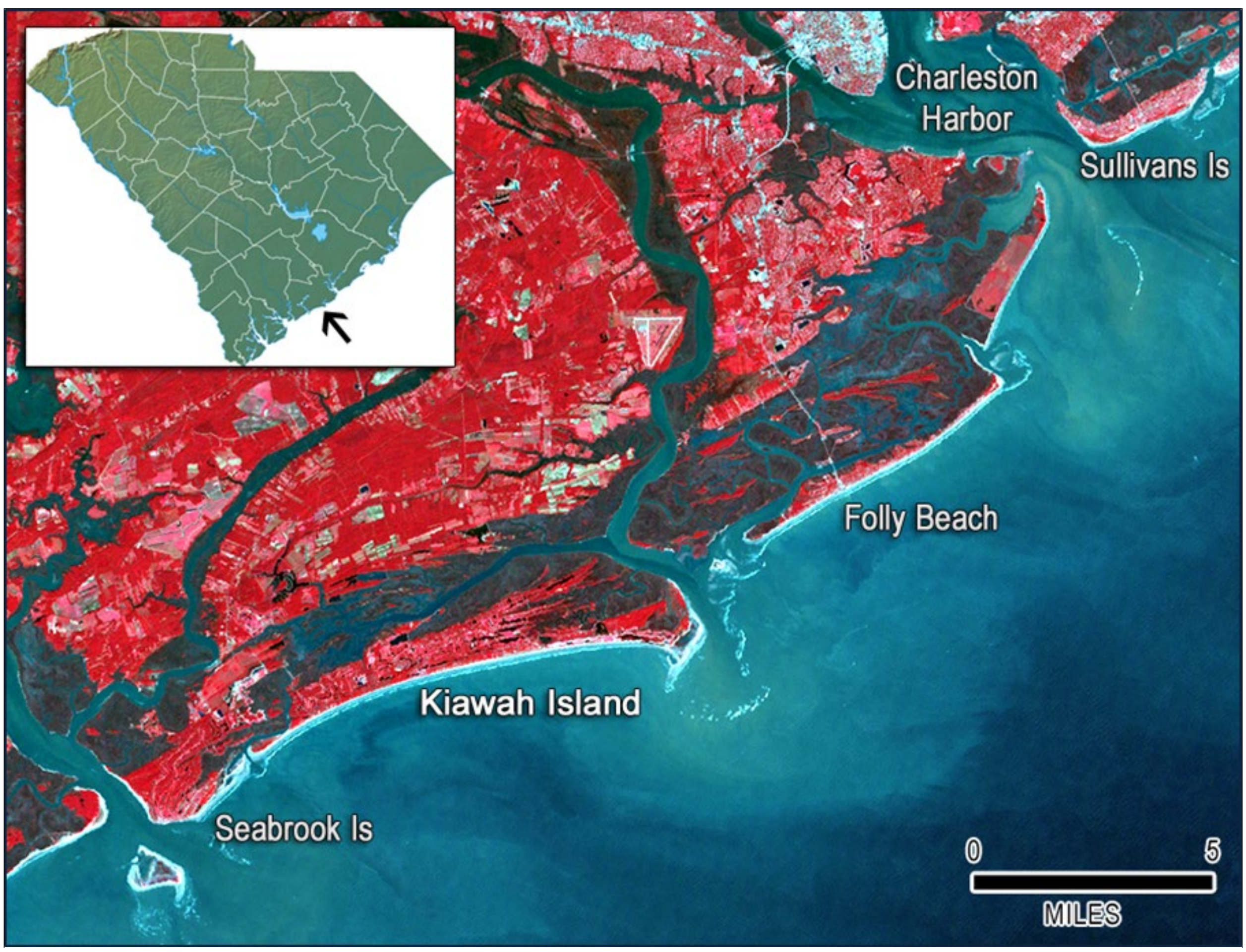

FIGURE 2.1. South Carolina coastline from Seabrook Island to Charleston Harbor. [Image courtesy Research Planning Inc and SCDNR].

FIGURE 2.2. The East End of Kiawah Island in November 2020. Unlike beaches with a relatively high dune ridge, here there is little to stop beach sand washing over interior marsh areas. This leads to the exposure of marsh mud as seen in the foreground here (blue arrow). This erosional pattern will continue until the next shoal migrates onshore and adds new sand to the area. An incoming shoal (red circle) is expected to help mitigate the erosion along this portion of the island.

2.1 Geologic History of Kiawah Island

Kiawah Island was first studied in detail in the mid-1970s when Professor Miles O. Hayes and colleagues at the University of South Carolina initiated field investigations of the geologic history of the island. Using Kiawah as a prototype, Hayes described the geologic evolution of 'drumstick' barrier islands along South Carolina as well as other 'mixed-energy' coasts like the Gulf of Alaska and the Netherlands, (see Hayes 1977, Hayes 1994, Hayes and Michel 2008, Hayes and FitzGerald 2013, FitzGerald et al 2018).

The island is bound by Stono Inlet on the east and Captain Sams Inlet on the west (see Fig 2.1). The eastern end episodically gains sand through shoal bypassing events (Williams & Kana 1986, Gaudiano 1998), and the sand eventually spreads to downcoast portions of the island all the way to Kiawah Spit. From there, smaller bypassing events transport the sand to Seabrook Island. Larger bypassing events across Stono Inlet create large surpluses of beach sand along Kiawah. These shoal-bypassing cycles are responsible for the long-term (century) growth of Kiawah Island, but can also cause localized, temporary erosion (discussed later). The processes controlling sand movement along the island are discussed in greater detail in CSE (1999)

The oldest part of the island, uplands adjacent to the Kiawah River, is at least ~4,000 years old (Moslow 1980). The most dynamic portion of the island is the northeastern end, where shoal bypassing and channel migration of the Stono River Inlet has caused the island to advance seaward by 1,000's of feet since the mid-19th century. Such large changes in shoreline position near the inlets can have a cascading effect on nearshore wave patterns leading to persistent erosion such as the decadal trends around Eugenia Avenue in the 1980s and 1990s (see CSE 1999).

2.2 Previous Shoreline Studies

The first shoreline assessment of Kiawah Island was performed by Hayes and his students in the 1970s (Hayes et al 1975). Based on the geomorphology of the island, Hayes identified five zones along the beach and recommended two middle zones (West Beach and Turtle Point) as suitable for development landward of the second dune ridge (Figs 2.3 and 2.4). Early development on the island was based on the findings of these studies, and it became one of the first localities in the state to implement more landward setback lines than called for under coastal zone management rules.

From 1981 to 1987, regular monitoring efforts were conducted by RPI and CSE (cf – Sexton et al 1981, Williams & Kana 1987). In July 1988, the Beach Management Act (BMA) of South Carolina was passed, and by 1989 the management of beach monitoring programs was taken over by the State. In 1994, CSE was again contracted by the Town of Kiawah Island and conducted monitoring through 1999. From 1981 to 1999, Kiawah Island either gained sand or remained stable. Isolated erosion did occur, but was generally small in magnitude.

The West Beach area (encompassing Windswept Villas, Mariners Watch Villas, Eugenia Avenue, West Beach Village, and Kiawah Inn) remained stable, losing only 0.21 cubic yards per foot per year (cy/ft/yr*) from 1983 until 1999 (with episodic accretion and erosion events). All other areas showed gains in sand volume between 1983 and 1999. Details of volume changes from 1983 to 1999 are provided in CSE (1999).

**CSE's beach monitoring surveys emphasize volumetric changes rather than linear movement of the shoreline, because quantities of interest are the amounts of sand gained or lost across the entire beach zone. By breaking the measurements down on a per-foot, per-year basis, changes from one place to another are easy to compare and track over time. Along Kiawah Island, loss of ~1.0 cy/ft/yr is equivalent to ~1.5 ft of beach/dune recession.*

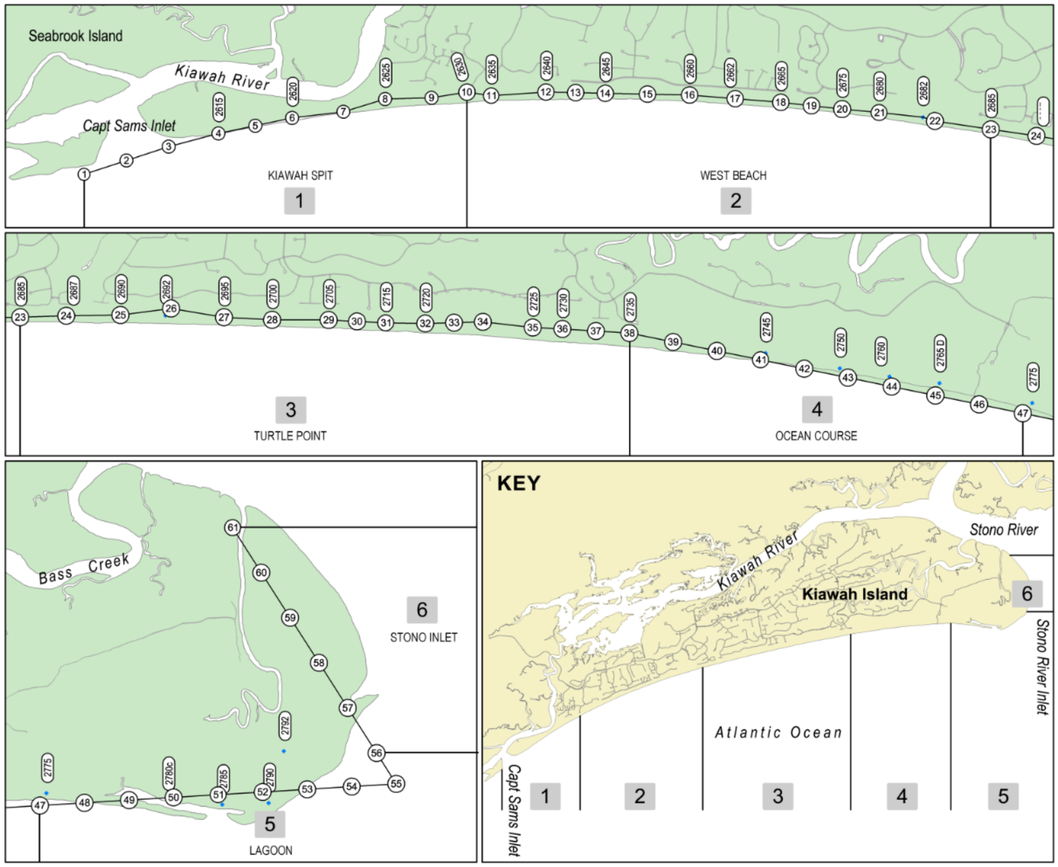

FIGURE 2.3. General location of beach stations and reaches monitored for the present report. Line numbers are shown in circles. State surveys (c/o OCRM) are the 2700s profile markers.

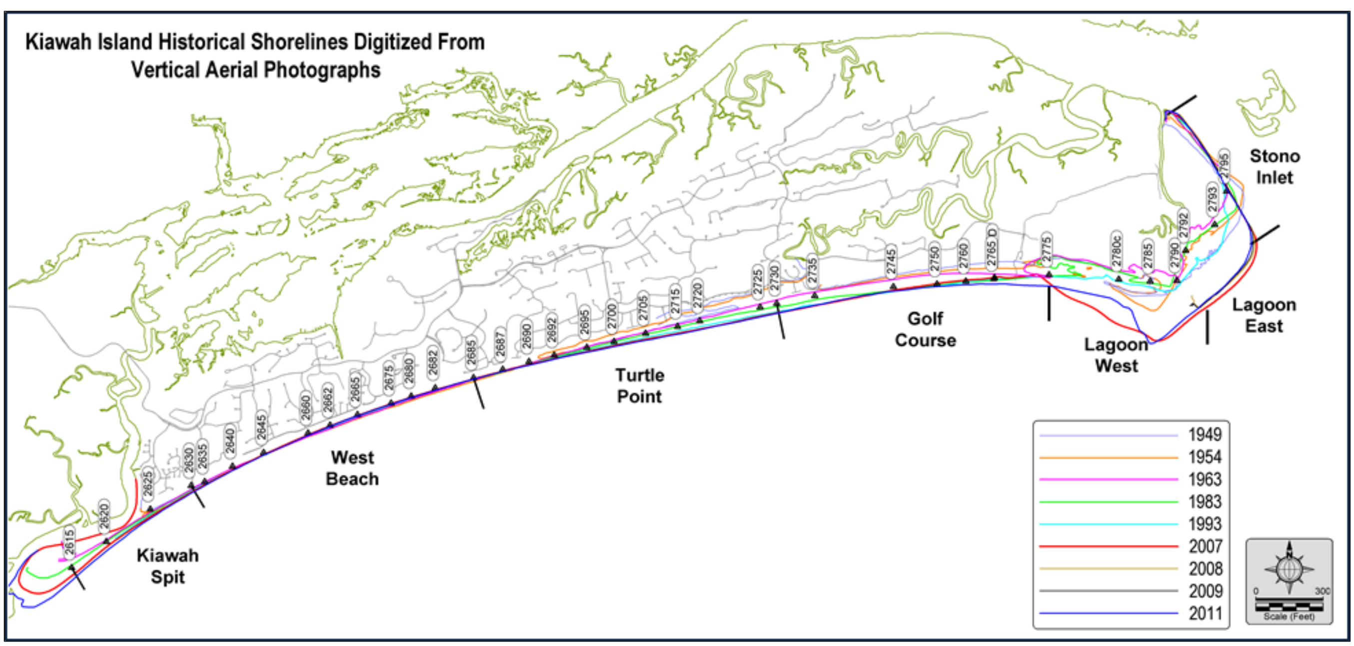

FIGURE 2.4. Historical shorelines (seaward vegetation lines). West Beach has been slightly erosional whereas all other reaches have been accretional since 1949. [Updated from CSE 1995]

2.2.1 Stono Inlet – Kiawah Island's sand source

Sand from Stono Inlet is the primary source of beach sand for Kiawah Island (Kana et al 1981). Inlet ebb-tidal deltas often contain as much or more sand than the adjacent barrier islands along the South Carolina coast south of the Santee River mouth (Sexton & Hayes 1996). In this mixed energy environment (Hayes 1994), waves and tidal currents both have a significant impact on morphology and processes. Powerful tidal currents with a dominant flow at ebb tide move sand seaward, out of the inlet channel into the ebb delta (Fig 2.5). Waves then reshape the sands into shoals and bars, some of which break free from the delta and migrate onto the beach. This produces several characteristic features found along the South Carolina coast, including large delta complexes extending miles offshore, marginal flood channels (small channels near the beach flanking the main channel that are dominated by flood currents), and migrating shoals (cf – Fig 2.1 and Fig 2.2).

Periodically, sand stored in the ebb-tidal delta of Stono Inlet is released when the channel shifts position. Shoals on the downcoast (west) side of the channel are freed from the delta and pushed shoreward by wave action. During this process, the beach in the lee of the shoal builds due to decreased wave energy ('Stage 1, Fig 2.6). Adjacent to the accreting beach, erosional arcs are formed by refracting wave crests bending shoreward around the offshore shoal ('Stage 2', Fig 2.6). This process continues until the shoal is fully attached, and sand moves laterally in both directions along the shoreline. The final stage of shoal bypassing ('Stage 3', Fig 2.6) occurs as waves continue to push the shoal landward and upward while sand spreads laterally along the beach. Shoal spreading provides natural nourishment with sand moving downcoast via longshore currents.

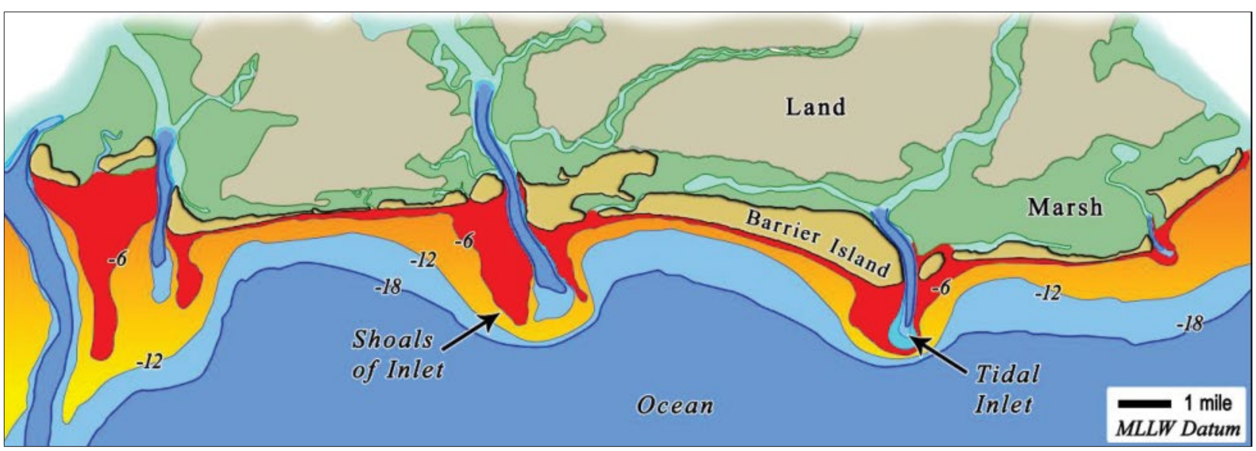

FIGURE 2.5. Nearshore bathymetry for a typical section of the central and southern South Carolina coast. Ebb-tidal deltas contain large amounts of sand, which alter the local bathymetry. This in turn directs wave energy and sediment transport patterns along the adjacent beaches. [From *Coastal Erosion and Solutions — A Primer* (Kana 2011) — CSE]

The time between episodic releases of sand by the inlet, and subsequent attachment and spreading, depends on the size of the inlet and its ebb-tidal delta. Large inlets, such as Stono Inlet, tend to initiate shoal bypassing events every seven to eight years with individual shoal volumes often exceeding 0.5 million cubic yards (Gaudiano & Kana 2001).

Kiawah Island has experienced two impressively large shoal bypassing events over the past ~25 years. The first shoal formed offshore in 1994 and was completely attached by 1997. The second shoal began attaching in 1998 and continued until ~2004 (Fig 2.7). These two events were the largest ever documented in South Carolina (CSE 2005), and collectively contained such a large quantity of sand that wave action was not able to completely weld the shoal to the beach. As a result, a new beach-dune system developed in place up to ~2,000 ft seaward of the shoreline as measured in 1984. This created a lagoon between the 'new' and 'old' shorelines, along with a ~2-mile-long barrier beach (Fig 2.7). CSE (2005) estimates the two shoals added ~5 million cubic yards to Kiawah Island. With sheltering by the new outer beach, marsh grasses propagated naturally around the margins of the lagoon where elevations were close to mean high water. So what had been open ocean area just a few years before, became protected tidal wetlands (Kana 2002).

By 2004, the shoals had completely attached at their eastern edge but remained detached at the western end. Shoal sands were migrating westward and were reaching near the (old) Ocean Course Clubhouse (Fig 2.7), but tidal flushing maintained a natural channel between the main shoal complex and that point. Due to the overwhelming quantity of sand gained at the eastern end, the shoreline near the Ocean Course jumped seaward and changed orientation. This effectively paused the shoal-bypassing cycle somewhere between Stage 2 and Stage 3, altered the direction of approaching waves along the northeastern end of the Island, and caused focused erosion along the Ocean Course.

As longshore transport moved the shoal westward, the flushing channel migrated likewise and encroached on the 16th and 18th holes of the famed Kiawah Ocean Course. The beach at the original Ocean Course Clubhouse (near OCRM monument 2775) retreated over 500 ft between the years 2000 and 2005. The magnitude of the bypassing event was enough to generate severe erosion for several years before the cycle could be completed (Gaudiano & Kana 2001). The Ocean Course remained vulnerable to erosion as the shoal and flushing channel migrated westward. This led to the plan for beach restoration proposed by CSE (2005).

THE THREE STAGES OF SHOAL BYPASSING

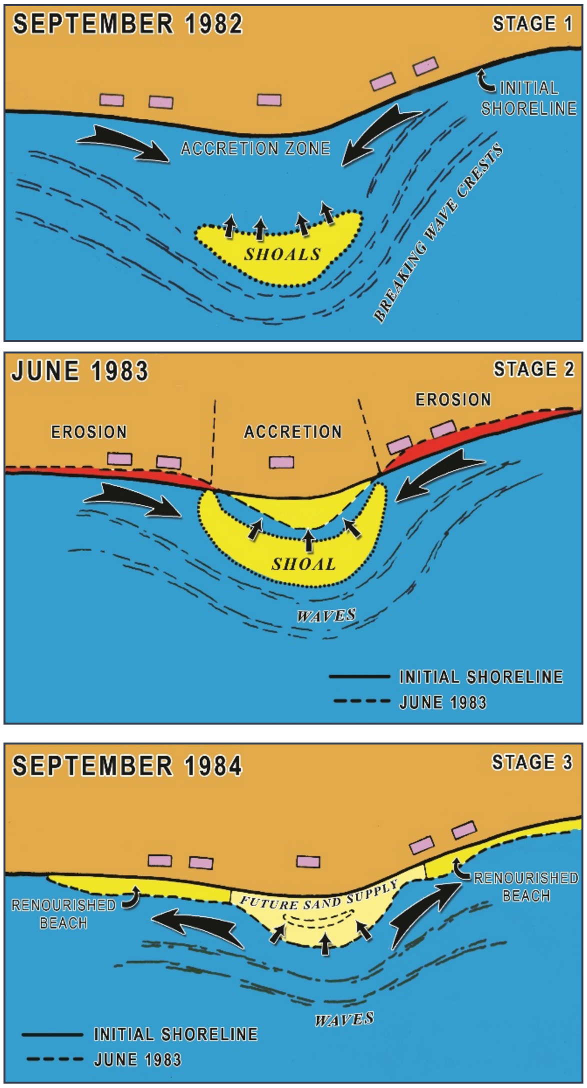

FIGURE 2.6.

[LEFT]
Schematic of the shoal-bypass cycle originally modeled from a bypass event at Isle of Palms (SC). During Stages 1 and 2 of the cycle, accretion in the lee of the shoal is accompanied by erosion on either side of the attachment site. (After Kana et al 1985)

[RIGHT]
Shoal bypassing at the eastern end of Kiawah Island.

Stage 1 in 1977 **[UPPER]**. Stage 2 in January 1979 **[UPPER MIDDLE]** (courtesy of Research Planning Institute Inc). Stage 3 in 1983 **[LOWER MIDDLE]**. Stage 1 in 1986 **[LOWER]**. Note the similarity between the 1977 shoal and the 1986 shoal, but the additional sand accumulated on Kiawah in 1986. [After Kana et al 1999]

FIGURE 2.7. The eastern end of Kiawah Island in December 1998 **[UPPER]** and February 2005 **[LOWER]**. Note the 1989 shoreline situated well inland from the outer beach. Shoals 1 and 2 added upward of 5 million cubic yards to Kiawah in the 1990s. As waves pushed the new sand shoreward, an incipient barrier island/lagoon/marsh formed. The new lagoon was flushed via a channel at the western end of the accreted beach. [From CSE 2007]

2.3 2006 East End Beach Restoration Project

In June and July of 2006, the East End beach restoration project (SCDHEC–OCRM permit No P/N 2005–1W–310–P, USACE permit No 2005–1W–310) was completed by L. Dean Weaver Company Inc. The enclosure dike spanned ~2,000 ft towards the southwest from the Ocean Course driving range, and the excavation area was along ~6,000 ft of shoreline between the dike and new channel area (Fig 2.8). This project sought to artificially create Stage 3 of the shoal-bypassing cycle and avoid further erosion of the Ocean Course. The details of the project are given in the final report '2006 East End Erosion and Beach Restoration Project: Kiawah Island' (CSE 2007). The objectives of the project were to:

- Accelerate the shoal-bypassing cycle so as to restore westerly sand transport along Kiawah Island
- Eliminate rapid erosion along the Ocean Course (particularly around the 16th, 17th, and 18th fairways and the driving range)
- Maintain viable piping plover beach habitat along the newly accreted barrier spit east of the Ocean Course, including areas of frequent washovers and the adjacent incipient dune habitat
- Preserve the environmental, cultural, and aquatic resources of the Town
- Provide protection to oceanfront recreational facilities and community infrastructure as a resource of tax revenue and income
- Maintain the economic viability of tourism, the Town's largest industry
- Make a new source of sand from the accreting shoal more readily available for natural nourishment along downcoast areas

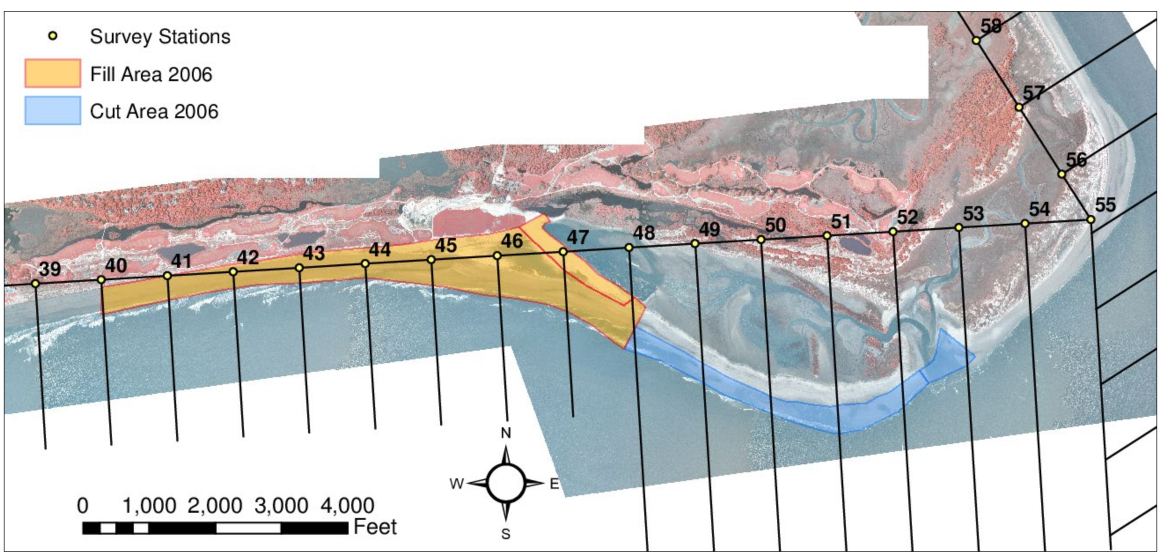

FIGURE 2.8 Excavation and fill areas used in the 2006 project. Approximately 550,000 cy of sand was transferred from the excavation area to the fill. The background image was collected in September 2006 using an infrared camera, so vegetation appears red instead of green.

The project consisted of the closure of the existing flushing channel, creation of a new channel to maintain the tidal environment of the lagoon, and excavation and transfer of nourishment sand from the new inlet and accreted shoal areas to eroded downcoast areas. These actions were designed to provide a smoother transition between Kiawah's main beach and the accreted shoal. The contracted volume for the project was 550,000 cubic yards (cy), the majority of which was placed between the new clubhouse and just west of the old flushing channel. The new flushing channel was positioned at the apex of the attached shoal (Fig 2.9).

FIGURE 2.9. Before (February 2006) and after (July 2006) aerial photos of the 2006 East End beach restoration project. [After CSE 2007]

2.4 2015 East End Channel Realignment Project

The 2006 beach restoration project proved effective in restoring the dry-sand beach along the Ocean Course. The new flushing channel migrated naturally in 2007 to a point in the middle of the open lagoon area. Between 2007 and 2013, the channel meandered across the intertidal beach; however, the throat of the channel remained east of the 2006 closure dike. In early 2014, the channel began to encroach on the closure dike, and the Town began planning for another channel relocation in the event the channel continued to migrate west.

The plan called for periodic relocation of the flushing channel, using the minimal amount of sand necessary, if the channel migrated west beyond its position in February 2014. A permit application was submitted with the intended construction window of September/October; however, by the fall of 2014, the migration of the channel had quickened and eroded much of the dunes protecting the Ocean Course driving range. The Town applied for a one-time modification to the construction window to allow for construction during the spring-summer season, which was granted by regulatory agencies.

The 2015 project was constructed between May and June 2015 by Lake Moultrie Construction Company Inc DBA Lake Moultrie Water Company, and Ashridge Inc, A Joint Venture (St Stephen SC) at a cost of $538,000. A total of 100,000 cy of sand was transferred, and the new inlet was opened ~3,000 ft to the east (Fig 2.10). A closure dike was built across the original channel, connecting to the remaining portion of the 2006 closure dike (Fig 2.11). Excess sand was placed along the seaward edge of the driving range to facilitate recovery of the eroded areas and protect the range. The completed project accomplished the goal of eliminating the cause of erosion along the Ocean Course while minimizing the construction impacts and manipulation of the beach.

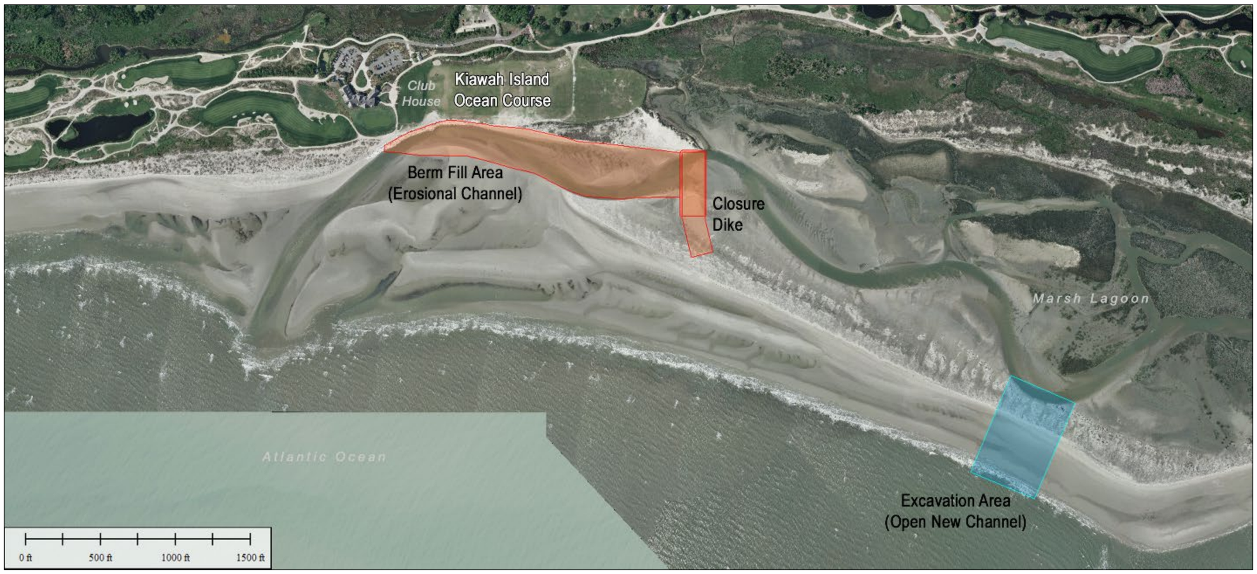

FIGURE 2.10. **[UPPER]** Excavation and fill areas used in the 2015 project. Approximately 100,000 cy of sand was transferred from the excavation area to the area around the driving range. **[LOWER]** Project area on 7 July 2015 after project completion showing closure dike in center of image and new flushing channel at upper right. Encroachment by the 'erosional channel' destroyed hundreds of feet of dunes, leaving no protection in front of the driving range.

FIGURE 2.11. **[UPPER]** Aerial image of the completed 2015 channel relocation project in July 2015. **[LOWER]** The relocated channel area on August 2020 (highlighted in blue) showing complete closure and continuous washover beach. A new channel had formed naturally between 2015 and 2017 (see upper-center portion of image near the 'old dune line', yellow arrow). The new oulet now drains the marsh in the foreground of the lower panel. All areas seaward of the old dune line were open water as recently as 1995, demonstrating how rapidly a barrier beac hand sheltered marsh lagoon can form along the South Carolina coast.

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3.0 METHODOLOGY

This section describes the methodologies of the topographic survey and habitat mapping used by CSE to monitor changes at Kiawah Island.

3.1 Survey

The present survey was conducted by RTK-GPS* (Trimble™ R10 GNSS system) in November 2020. Profiles along Kiawah are surveyed perpendicular to the local shoreline (CSE baseline) azimuth from the control points to at least –12 ft NAVD (equivalent to the seaward limit of sand exchange with the beach in this setting) or at least 3,000 ft from the primary dune ridge. Surveys were conducted by combining a land-based survey and bathymetric surveys (Fig 3.1). Land surveys were accomplished using an RTK-GPS between the foredune and low-tide wading depth (~–6 ft NAVD), whereas hydrographic surveys were collected by combining the RTK-GPS with a precision echo-sounder mounted on CSE's shallow-draft survey vessel, the *RV Southern Echo*.

[**Real-time kinematic global positioning system*]

FIGURE 3.1.

CSE's monitoring methods include land-based data collection via RTK-GPS **[UPPER LEFT]** and hydrographic data collection via RTK-GPS linked to a precision echo-sounder. CSE's shallow-draft vessel, the *R/V Southern Echo,* is shown in the lower image.

Working around the tidal cycle, data collected on land extended into shallow depths at low tide. Data were collected from the boat at high tide to ensure overlap of the two surveys close to shore (Fig 3.2). Appendix A includes profiles for the most recent survey compared to earlier surveys. CSE has updated profile sheets to include profile volumes and aerial images showing profile locations.

Surveys conducted from 2007 to 2011 involved 23 stations west of the East End project area (using existing OCRM monuments spaced ~1,000 to 2,500 ft apart) and 64 stations in the project area spaced 400 ft apart. The present baseline reduces the maximum spacing in the downcoast profiles to ~1,000 ft. CSE also reduced the total number of lines in the project area from 64 to 24 by increasing the spacing from 400 ft to 1,000 to 1,200 ft. The baseline was also modified at the East End to reduce the number of turns in the baseline and to simplify volume calculations.

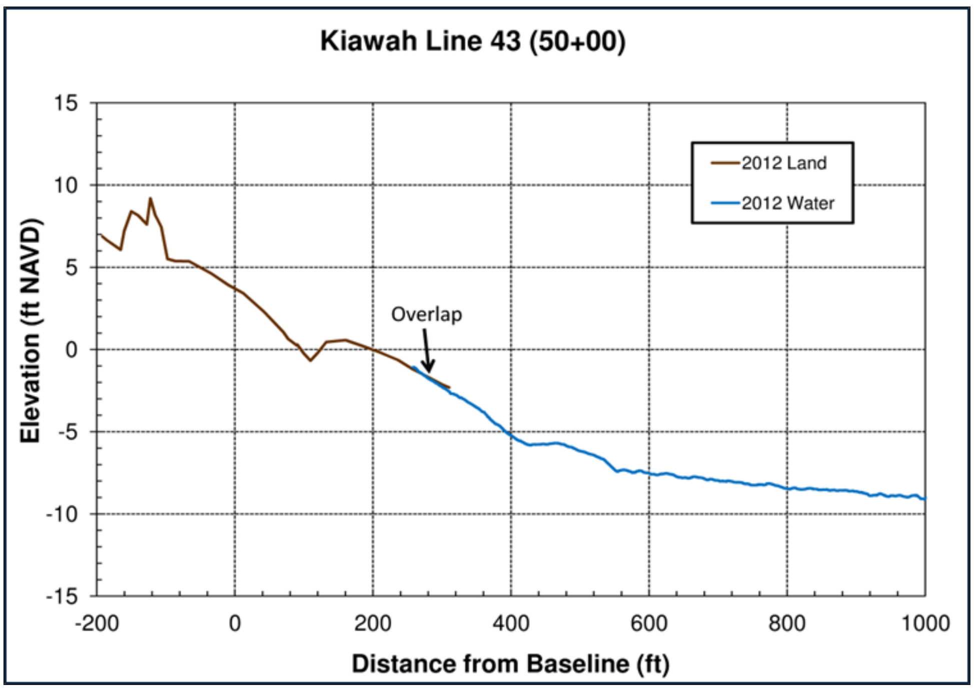


FIGURE 3.2. CSE combines land-based and hydrographic data collection to produce continuous profiles of the beach. Land-based work is accomplished at low tide, while hydrographic work is performed at high tide. This allows for overlap of the two data collection methods and ensures quality data and a complete profile.

The present baseline anchors 61 profiles, with Lines 1–37 representing the shoreline west of the 2006 project and Lines 38–61 representing the project area and eastern end of the island (Table 3.1). The baseline is shown in Figure 2.3. Line numbering increases from west to east – Line 1 is near Captain Sams Inlet ~1.2 miles southwest of the Beachwalker Park vehicle access. Line 61 is at the tip of the sand spit at the junction of the Stono River and Penny's Creek. OCRM monument names and CSE project stationing are indicated where the new profile lines coincide with previous stations (ie – Line 35 is OCRM station 2725). The current reaches (see Fig 2.3) are defined in Table 3.2.

Volume calculations for the lagoon were obtained via digital terrain models (DTMs) produced from CSE survey data. This eliminates the need for volume adjustments due to differing baseline and beach configurations. However, profiles are still used for inferring changes to the beach shape, position of shoals and channels, and berm elevations in this area.

3.2 Volume Calculations

To estimate changes in the sand volume along Kiawah Island, survey data (collected in x-y-z format) were entered into CSE's in-house custom software, Beach Profile Analysis System (BPAS), which calculates volumes based on 2D data (converted to x-z format along profiles) and distances between survey lines. The resulting volumes provide a quantitative method of determining beach condition, including the ideal minimum beach profile and how sand quantities at a site (volume per unit length of shoreline) compare with some desired condition (Kana 1993). Volume results calculated this way integrate all the small-scale perturbations across the beach and yield a simple measure of its condition. This measure is less susceptible to seasonal fluctuations in the profile, which is a common problem with shoreline change studies derived from a single contour or interpreted from aerial photos (like a wet-dry line or mean high water).

For the present survey, sand volumes were calculated between the primary dune and –10 ft NAVD. The –6 ft NAVD contour has been included in some reports for the sake of consistency with earlier studies and the limitations of data collection in reports before 2007. While most sand movement on Kiawah occurs above –6 ft NAVD, some profile changes do occur between –6 ft and –10 ft NAVD. Significant changes can occur within this lens when underwater bars form or change and as shoals move onshore and alter morphology. Especially along the dynamic northeastern end of the Island, volume calculations are cut off at a set distance due to data coverage or morphological considerations (ie – the profile flattens over the ebb-tidal delta before reaching –10 ft NAVD). Profiles and calculation limits are shown in Appendix A.

TABLE 3.1. Kiawah Island beach monitoring stations referenced in the present report. Order is generally west to east. Offset and cutoff refer to distances from the benchmark/baseline for the start and end of beach volume calculations.

Reach	Line	Name	Offset	Cutoff	Distance to Next	Easting	Northing
1	1		-200	2,500	1,000	2262721.7	271034.2
	2		0	2,500	997	2263451.4	271718.0
	3		250	2,500	1,153	2264178.6	272399.3
	4	OCRM 2615	140	1,500	844	2265064.0	273138.6
	5		93	2,500	845	2265739.8	273644.8
	6	OCRM 2620	86	1,500	1,157	2266414.9	274152.4
	7		95	2,500	978	2267397.7	274763.4
	8	OCRM 2625	189	1,500	1,040	2268125.0	275417.0
	9		100	1,500	806	2269055.6	275882.0
2	10	OCRM 2630	152	1,500	547	2269723.8	276332.8
	11	OCRM 2635	41	1,500	1,232	2270247.2	276490.7
	12	OCRM 2640	94	1,500	665	2271326.8	277083.3
	13		67	1,400	665	2271935.3	277351.5
	14	OCRM 2645	47	1,200	945	2272543.9	277619.7
	15		27	1,400	946	2273408.4	278001.2
	16	OCRM 2660	28	1,100	1,025	2274273.9	278383.2
	17		15	1,400	1,026	2275234.5	278740.9
	18	OCRM 2665	5	1,000	691	2276196.1	279099.0
	19		0	1,400	692	2276850.6	279320.6
	20	OCRM 2675	0	1,100	831	2277505.6	279542.3
	21	OCRM 2680	46	1,300	1,266	2278288.1	279822.4
	22		0	1,400	1,267	2279502.6	280179.9
3	23	OCRM 2685	10	1,200	1,033	2280718.1	280537.6
	24	OCRM 2687	40	1,500	1,215	2281707.1	280837.2
	25	OCRM 2690	80	1,300	1,145	2282876.3	281167.0
	26	OCRM 2692	279	1,500	1,205	2283935.3	281602.5
	27	OCRM 2695	119	1,400	1,080	2285131.1	281719.2
	28	OCRM 2700	100	1,400	1,269	2286187.8	281943.8
	29	OCRM 2705	130	1,500	635	2287413.8	282268.9
	30		143	1,500	643	2288034.7	282401.8
	31	OCRM 2715	145	1,500	889	2288663.4	282536.4
3	32	OCRM 2720	208	1,500	645	2289526.0	282752.7
	33		309	1,700	646	2290143.9	282937.6
	34	OCRM 2722	390	1,600	1,125	2290763.1	283122.9
	35	OCRM 2725	322	1,600	666	2291875.6	283288.9
	36	OCRM 2730	316	1,600	666	2292526.8	283430.6
	37		300	1,700	752	2293263.8	283580.0
4	38	0+00	300	1,600	1,000	2294001.1	283729.5
	39	10+00	165	1,700	1,000	2294999.2	283790.2
	40	20+00	30	1,500	1,000	2295997.4	283850.9
	41	30+00	-55	1,500	1,000	2296995.5	283911.6
	42	40+00	-140	1,500	1,000	2297993.6	283972.3
	43	50+00	-219	1,500	1,000	2298991.7	284033.0
	44	60+00	-295	1,500	1,000	2299989.8	284093.8
	45	70+00	-370	1,500	1,000	2300988.0	284154.5
	46	80+00	-300	1,500	1,000	2301986.1	284215.2
5	47	90+00	-374	1,800	1,000	2302984.2	284275.9
	48	100+00	-250	2,000	1,000	2303982.3	284336.6
	49	110+00	0	2,500	1,000	2304980.4	284397.3
	50	120+00	350	3,200	1,000	2305978.6	284458.0
	51	130+00	780	3,500	1,000	2306976.7	284518.8
	52	140+00	1100	3,500	1,000	2307974.8	284579.5
	53	150+00	500	2,800	1,000	2308972.9	284640.2
	54	160+00	65	1,500	1,000	2309971.0	284700.9
	55	170+00	-775	1,000	0	2310969.2	284761.6
6	56	Inlet 0+00	300	1,300	1,200	2310528.3	285452.3
	57	Inlet 12+00	700	1,420	1,200	2309882.6	286463.7
	58	Inlet 24+00	900	1,420	1,200	2309237.0	287475.2
	59	Inlet 36+00	920	1,420	1,200	2308591.3	288486.6
	60	Inlet 48+00	912	1,720	1,200	2307945.7	289498.1
	61	Inlet 60+00	640	1,520	0	2307300.1	290509.5

TABLE 3.2. Kiawah Island reaches referenced in the present report.

Reach	Approximate Geographic Boundaries	Line Numbers	Reach Length (ft)
Kiawah Spit	West end of Kiawah Island to Beachwalker Park	1–10	8,820
West Beach	Beachwalker Park to Turtle Point	10–23	11,798
Turtle Point	Turtle Point Area	23–38	13,614
Ocean	Ocean Course Area	38–47	9,000
Lagoon	Lagoon Area	47–55	8,000
Stono Inlet	Stono Inlet Shoreline	56–61	6,000

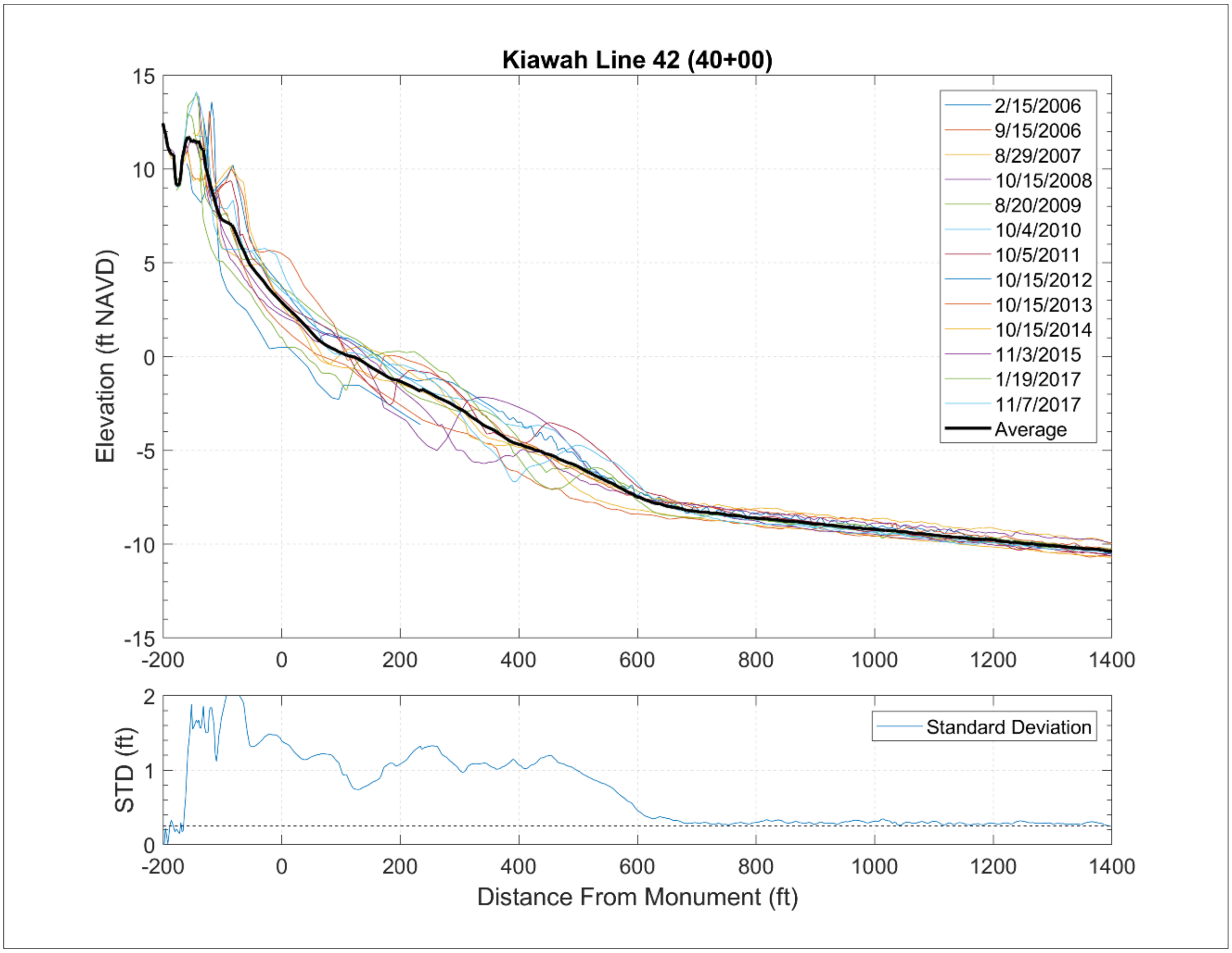


FIGURE 3.3. Comparison of repetitive profiles at a monitoring station along Kiawah Island and computation of standard deviation. Where the profiles converge, the standard deviation is low and is an indicator of little sediment exchange (approximate closure depth).

Figure 3.3 shows a representative profile from Kiawah Island over an approximate 12-year period. The lower portion of the graph tracks the standard deviation in elevation based on the mean profile elevation of the set of profiles at the station. A standard deviation of <0.25 ft over several hundred feet at the outer end of a profile is evidence of little change in bottom elevation over the data collection period. This statistically confirms nearly all measurable volume changes along Kiawah occur above –10 ft NAVD and a realistic value for depth of closure (DOC) at decadal-or-longer time scales is ~–10 ft NAVD (see Barrineau et al., 2019 for a more detailed discussion).

DOC is the depth where little sand movement to or from the beach occurs. At longer time scales (eg – 10 yrs), or under storm conditions with rough waves, DOC may become deeper. However, our surveys account for the vast majority of sand movement under 'normal' conditions. Unit-volume calculations allow us to distinguish the quantity of sediment at different lens depths, for instance in the dunes, on the dry beach, in the intertidal zone, and beyond wading depth. Reference boundaries are site-specific but ideally encompass the entire zone over which sand moves across shore in a given year. This means the survey data incorporate all changes from the dune to the DOC, which constitutes the 'active beach system' under normal conditions.

Unit volumes for each survey date and unit volume changes between selected dates were used to calculate the net volume between stations (called the 'profile volume'). Profile volumes are generated using the average-end-area method. In this method, the average of the area under two profiles at either end of a length of shoreline is multiplied by the length of the cell to determine the total volume between the two stations. When these profile volumes are added for discrete portions of the shoreline, they represent sub-reach and reach volumes, and finally the net volume for the entire project area.

These net volumes by reach can be subdivided by applicable reach lengths to yield weighted average unit volumes. The weighting takes into account the variations in applicable shoreline distances between individual stations. If they are not evenly spaced, the station-to-station net volumes will be proportional to the distance between stations and some accuracy in reach- or project-wide profile volumes will be lost. Changes in unit volume can be determined by comparing individual surveyed profiles and computing differences in cross-sectional areas. The change in cross-section can be extrapolated (1) over a 1-ft length of shoreline to yield unit volume changes (in cy/ft) and (2) over a much longer section of beach to yield net volume changes in that particular section of shoreline.

4.0 RESULTS

Results of the November 2020 monitoring survey are particularly focused on the areas affected by the 2015 East End Channel Realignment Project, the 2015 relocation of Captains Sams Inlet, and recent storm activity. Section 4.1 discusses each project and the impacts they had on sediment transport patterns and morphology. Section 4.2 provides detailed sand volume changes for reaches along the eastern end of Kiawah Island. Section 4.3 provides results of the downcoast reaches along the remainder of the island. Both of these sections compare recently-surveyed volumes with selected conditions from previous years.

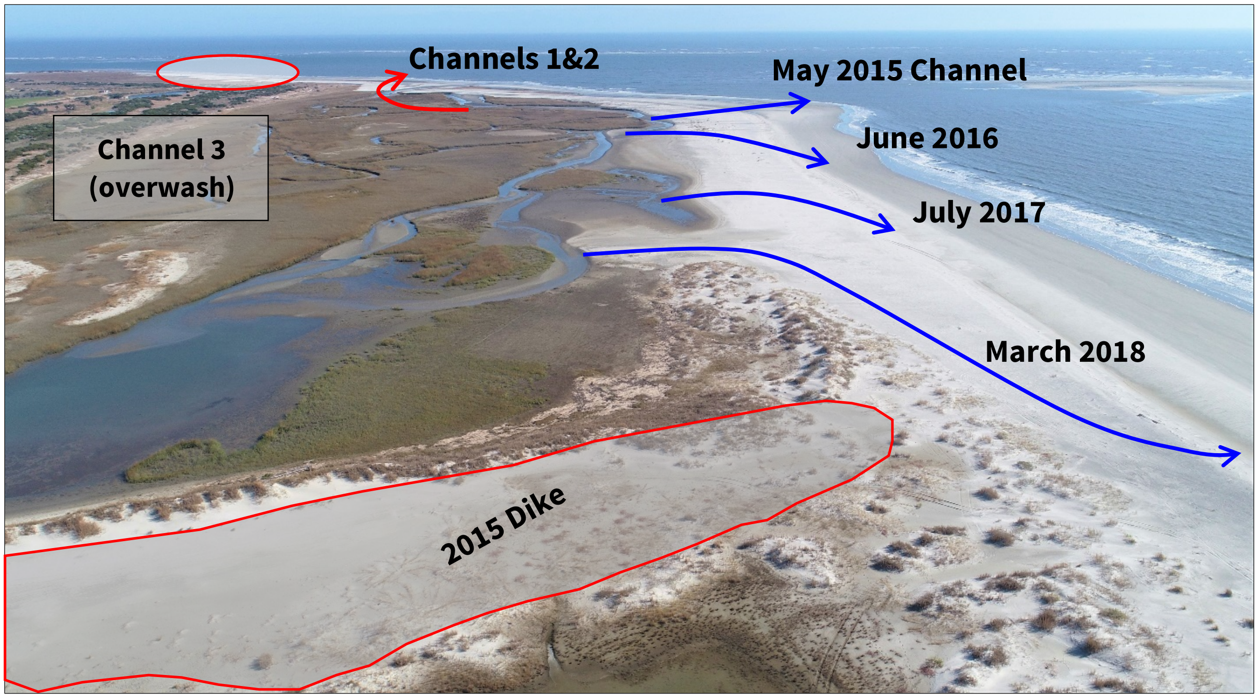
4.1 2015 Inlet Realignment Projects

4.1.1 Kiawah Island East End Channel Realignment Project

A general description of the 2015 Kiawah Island East End channel realignment project was provided in Section 2. Additional details of the construction and post-project condition were provided in the 2015 monitoring report (CSE 2016). The present report focuses on changes occurring between November 2019 and November 2020, and CSE's opinion on likely changes to occur over the next few years.

By late 2019, the 2015 flushing channel cut near the northeast 'corner' of the Stono Inlet shoreline had closed (Fig 4.1 upper). As the flushing channel migrated west, the discharged volume of water moving through the channel decreased and led to increased water levels within the lagoon. As a result, two channels were cut naturally during hurricanes *Matthew* (2016) and *Irma* (2017) to facilitate more effective drainage. The first is located around the approximate location as the 2006 constructed channel. The second is positioned ~1,000 ft to the east (Fig 4.1 lower). The first (western) outlet opened in 2016 following *Matthew*, and the second (eastern) outlet opened following *Irma* in 2017. A third outlet nearly formed ~8,000 ft east of the 2015 dike, following Hurricane *Michael*'s impact in 2018, but remains a low overwash fan as of November 2020. This outlet may form a third open passage to the ocean in the coming years.

The dike constructed during the 2015 project has performed well through several storm events over the past six years. The beach berm seaward of the driving range has overwashed a few times, which helps naturally fill the pond in front of the Ocean Club clubhouse (Line 45) and increase the elevation of the berm in front of the driving range (Line 46) (Fig 4.2). The small flushing channel draining the pond has decreased in size as the pond has filled in. This decreases the volume of water moving in and out of the pond with each tidal cycle. CSE expects the ponded area to continue filling with sediment.



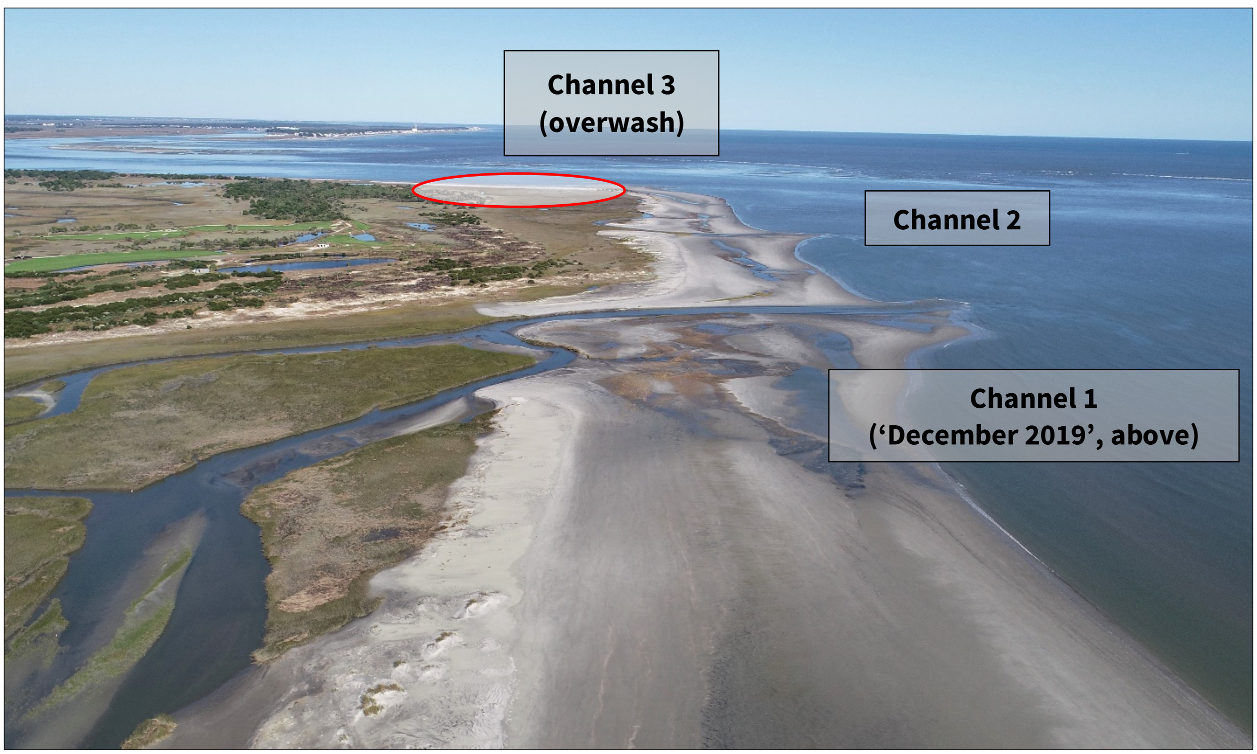
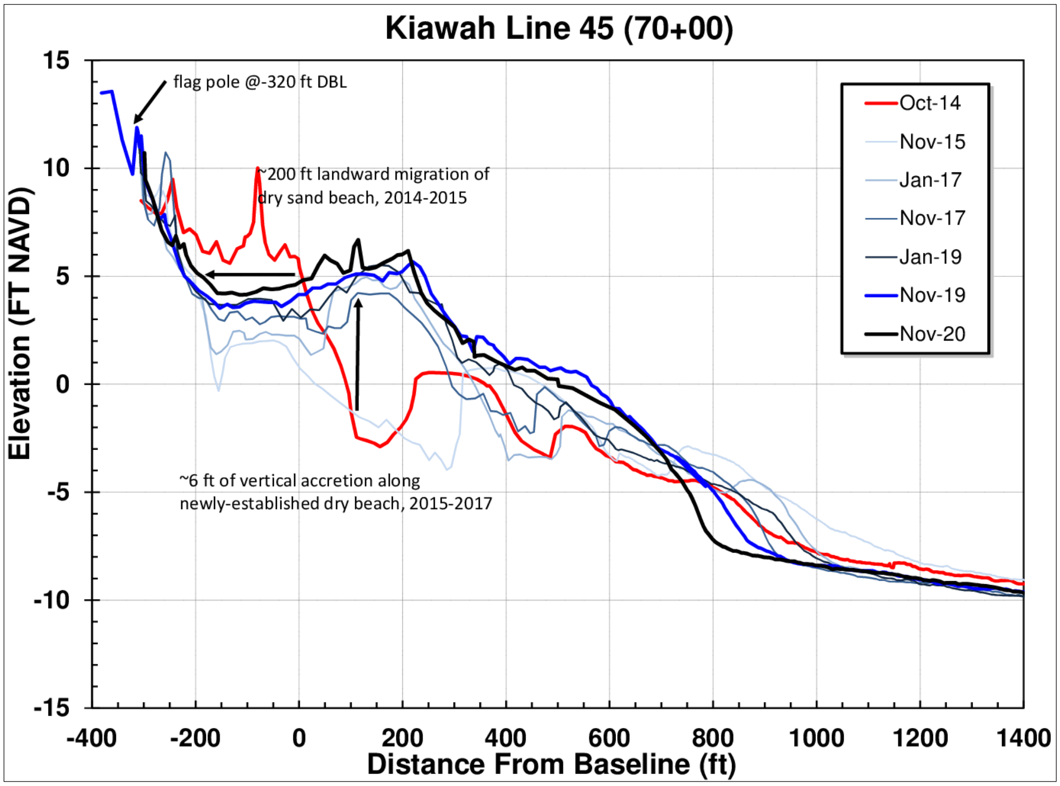


FIGURE 4.1. [UPPER] Aerial images of the 2015 project area in December 2019 looking east towards Stono River Inlet. The post-construction flushing channel for the west lagoon migrated steadily west until 2018, when it shoaled completely. Three new outlets, located on the eastern end of this portion of the marsh, opened following Hurricanes *Matthew, Irma,* and *Dorian* ('Channels 1, 2, and 3'). **[LOWER]** Storm waves have opened three new passages near the island's southeastern point since the 2015 project. The first ('Channel 1') was opened following Hurricane *Matthew* and the second ('Channel 2') opened following Hurricane *Irma*. A third incipient channel ('Channel 3') was created following overwash from Hurricane *Dorian* and may develop into an open passage (image collected via UAV 16 November 2020).



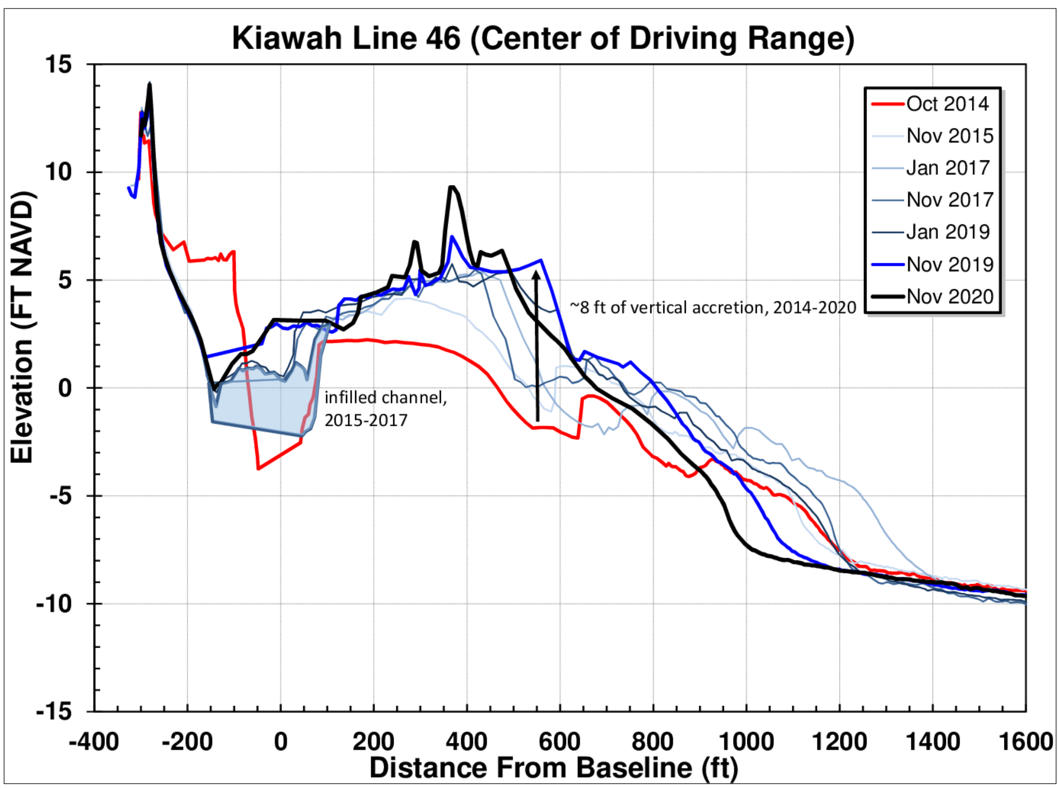


FIGURE 4.2a. Profiles from the 2015 East End project area; **[UPPER]** Line 45 is at the Ocean Course beach access. **[LOWER]** The ponded area has infilled over 6 ft since 2015, as shown in Line 46. A high berm has built seaward of the pond, stretching from west of the clubhouse to the constructed inlet.

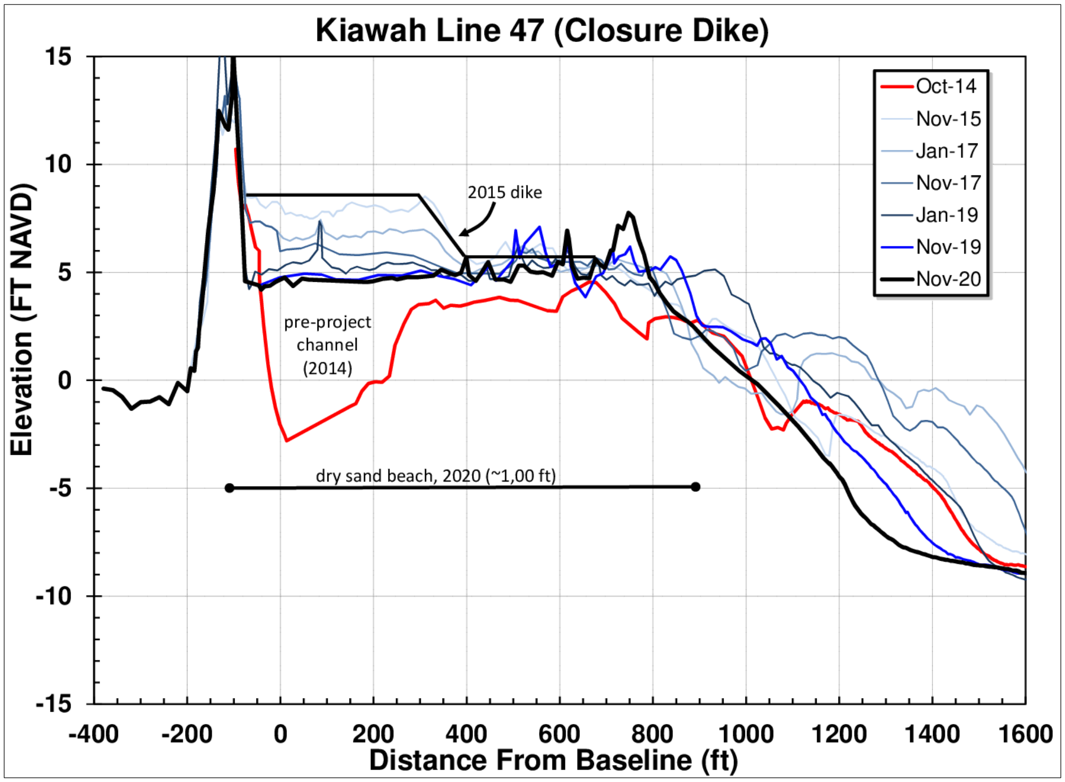


FIGURE 4.2b. The closure dike was placed over a low marshy channel, and reached almost 400 ft from the baseline at completion. Dry beach widths along portions of the driving range beach have tripled since project completion.

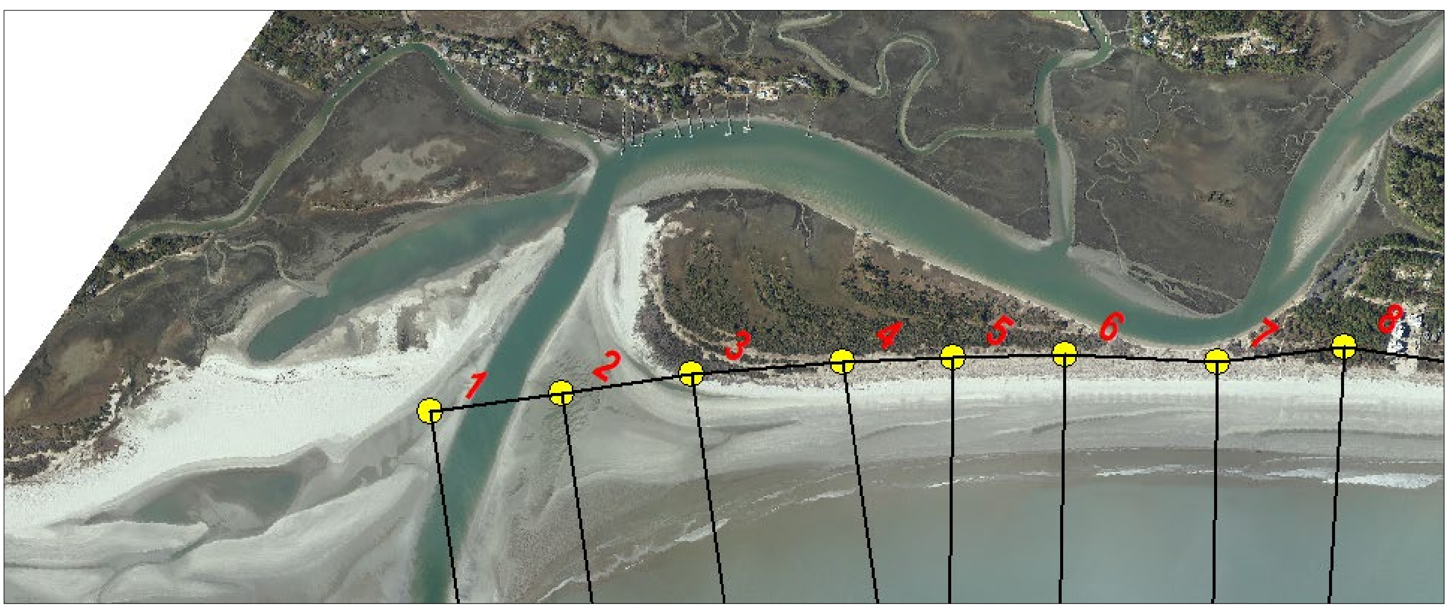


FIGURE 4.3. Post-project map (image March 2018) of the west end of Kiawah Island and Town beach monitoring stations. Line 1 remains on the Seabrook side of the new inlet, while Line 2 is now on the Kiawah side.

4.1.2 2015 Captain Sams Inlet Relocation

The Seabrook Island Property Owners Association (SIPOA) sponsored and implemented the third relocation of Captain Sams Inlet along the western boundary of Kiawah Island in the spring of 2015. Similar projects were completed in 1983 and 1996 in an effort to prevent the channel from migrating into developed property and to maintain a sand supply to downcoast areas. The general design behind the project was the relocation of the inlet using land-based equipment to its ~1963 position by opening a new channel across Kiawah Spit and closing the old channel using a sand dike.

The project is similar to the channel relocation project at the eastern end of Kiawah, only larger in scale. Captain Sams Inlet historically migrates toward Seabrook Island at a rate of ~200–300 ft/yr. When it reaches a certain point, it begins to rapidly erode Seabrook Island's North Beach. As a result, sediment transport towards other portions of Seabrook is reduced, and the beach narrows. SIPOA executed a licensing agreement with the Town of Kiawah Island and owners of the spit property to relocate the channel back to its 1963 position in 2015. The corridor for the 2015 channel was actually positioned about 400 ft south of the 1983 and 1996 inlet relocation positions by mutual agreement among all parties. The 2015 relocation was conducted under permits obtained by SIPOA with an allowable construction window of 15 May to 15 August. The new channel was opened on 2 June 2015. Additional sand was stockpiled on both sides of the old channel, which was closed on the night of 11–12 June. A total of ~140,000 cy of sand was excavated and transferred from the channel basin and intertidal area during the project before natural processes completed the opening.

The project resulted in the western ~2,800 ft of Kiawah Spit being shifted to Seabrook Island. This reduced the sand volume along the spit by ~750,000 cy, a quantity that Kiawah Island is rapidly regaining as the spit resumed its migration to the west. Figure 4.3 (previous page) shows a post-construction photo from March 2018 and the locations of monitoring stations along the spit. As of November 2020, Profile Line 1 remained on the Seabrook side of Captain Sams Inlet, but Line 2 is already on the Kiawah side once more. As the inlet migrates over time, lines will be reincorporated into the Kiawah volume results as applicable. CSE anticipates the spit will return to its pre-project location within the next 5–10 years. Due to longshore drift feeding sand from West Beach and the rest of the island, sand accumulates along the Kiawah side of Captain Sams Inlet. This leads to elongation of the spit and volume increases in the growing inlet delta on the Kiawah side of the channel. For example, Line 3 (just north of the inlet) has gained 44.1 cy/ft of sand, mostly in the intertidal beach zone. Line 2 has also gained sand at a rate of 16.9 cy/ft. CSE expects continued growth of the spit towards Seabrook Island over the next few years. Storm activity triggered erosion along most of the spit's profiles between 2015 and 2017, but the past ~2–3 years have been relatively calm along the South Carolina coast (see Section 5.0 for a meteorological summary). So long as conditions do not return to a stormy interval, the spit will likely continue elongating towards Seabrook and resume growing seaward.

4.2 Beach Volume Changes (November 2019 – November 2020)

Beach volume changes are reported from the eastern end of the island (Reach 6 – Stono Inlet) to the western end (Reach 1 – Captain Sams spit). Methods for volume calculations are given in Section 3. Total volumes and changes are given in Table 4.1. Unit volumes for each station and survey data are provided in Table 4.2. Between November 2019 and November 2020, portions of Kiawah Island influenced by shoals along Stono Inlet generally gained sand. The Ocean Course and Turtle Point reaches lost some sand (~–8.0 cy/ft and –1.7 cy/ft, respectively), likely due to wave refraction resulting from the shoal migrating onshore at Stono Inlet reach. West Beach gained ~4.3 cy/ft and Kiawah Spit gained ~3.4 cy/ft.

4.2.1 Reach 6 – Stono Inlet

Stono Inlet (Reach 6) spans ~6,000 ft from Line 56 to Line 61 (see Fig 2.3). Beach profiles in this reach are steeper than the front-beach reaches, due to the presence of Stono Inlet and reduced wave energy. The slope of the intertidal beach is related to wave height (high waves = gentler slopes) and sediment grain size (coarser sediments = steeper slopes) (Komar 1998). Unit volumes from Stono Inlet are shown in Figure 4.4. Between November 2019 and November 2020, the Stono Inlet Reach gained ~7,600 cy (1.3 cy/ft) of volume. Since August 2007, the reach has lost a total of ~744,700 cy, which is an average annual erosion rate of 9.4 cy/ft/yr. Total volume losses from 2006 to 2012 measured ~11,300 cy (1.9 cy/ft), but have increased to –124.1 cy/ft from 2012 to November 2020. Erosion has been more severe towards the easternmost end of the reach, near the 'corner' of the island's shoreline between Stono Inlet and the open ocean.

The magnitude of changes along Stono Inlet generally decreases moving landward (~northwest) with unit volumes decreasing by 294.4 cy/ft since August 2007 at Line 56 and increasing by 76.7 cy/ft at Line 61 over the same period. In general, erosion is greatest around Line 56, and transitions to increases in volume farther up the Stono River shoreline. The maximum volume increase observed from November 2019 to November 2020 (Line 60; +21.1 cy/ft) was at the second-to-last station from the inland terminus of CSE's baseline. This pattern of erosion towards Line 56 and accretion towards Lines 60–61 likely reflects the extension of a sand spit between Penny's Creek and Stono Inlet. Along this portion of the shoreline, the beach is eroding but there is no marsh landward of the dunes. Injections of beach sand provided by migrating inlet shoals make some profiles gain sand rapidly, while other nearby areas erode. The lower portion of the foredune near Line 56, for example, was undermined during Hurricane *Matthew* in 2016, and again by *Irma* in 2017, leaving scarps and low backshore elevations. Continued impacts by *Dorian* (2019) and a series of rough nor'easters have led to a persistent overwash state in the beach along the Stono Inlet Reach. A large influx of beach sand, or rapid dune stabilization, will be needed to mitigate this change in the beach system.

TABLE 4.1. Total volumes for monitoring profiles at Kiawah Island (measured to –10 ft NAVD).

			Reach Total Volume (cy)														
Reach	**Name**	**Length**	**Apr-99**	**Sep-06**	**Aug-07**	**Oct-08**	**Aug-09**	**Oct-10**	**Oct-11**	**Oct-12**	**Oct-13**	**Oct-14**	**Nov-15**	**Jan-17**	**Nov-17**	**Jan-19**	**Nov-19**	**Nov-20**
1	Kiawah Spit	8,820	2,527,990		3,309,434	3,308,176	3,360,442	3,482,539	3,403,430	3,385,060	3,387,780	3,355,774	2,426,028	2,421,235	2,587,554	2,516,429	2,545,308	2,574,957
2	West Beach	11,798	2,925,119		3,018,972	2,973,269	3,002,842	3,016,726	3,023,391	3,143,512	3,200,438	3,247,900	3,246,474	3,109,992	3,123,811	3,186,466	3,153,949	3,204,546
3	Turtle Point	13,614	3,119,193		3,768,036	3,711,347	3,791,886	3,780,710	3,783,778	3,973,563	4,103,395	4,242,815	4,328,658	4,133,108	4,083,240	4,087,595	4,041,965	4,019,325
4	Ocean Course	9,000		2,881,490	3,008,223	2,946,188	3,047,332	3,071,534	3,182,156	3,301,984	3,403,054	3,535,481	3,599,780	3,562,542	3,577,236	3,690,347	3,707,191	3,635,228
5	Lagoon	8,000		6,559,380	6,462,016	6,840,138	7,055,611	7,419,125	7,222,197	7,071,272	6,946,031	6,993,814	6,787,731	6,325,250	6,139,954	5,939,621	5,936,206	6,198,619
6	Stono Inlet	6,000		1,464,695	1,460,076	1,447,219	1,406,546	1,422,719	1,427,296	1,448,756	1,408,636	1,328,992	1,248,369	1,052,076	966,215	845,351	707,753	715,353
1-6	**All**	**57,232**			**21,026,757**	**21,226,337**	**21,664,658**	**22,193,353**	**22,042,249**	**22,324,146**	**22,449,334**	**22,704,776**	**21,637,039**	**20,604,203**	**20,478,010**	**20,265,811**	**20,092,373**	**20,348,028**

			Reach Unit Volume (cy/ft)														
Reach	**Name**	**Length**	**Apr-99**	**Sep-06**	**Aug-07**	**Oct-08**	**Aug-09**	**Oct-10**	**Oct-11**	**Oct-12**	**Oct-13**	**Oct-14**	**Nov-15**	**Jan-17**	**Nov-17**	**Jan-19**	**Nov-19**	**Nov-20**
1	Kiawah Spit	8,820	286.6		375.2	375.1	381.0	394.8	385.9	383.8	384.1	380.5	275.1	274.5	293.4	285.3	288.6	291.9
2	West Beach	11,798	247.9		255.9	252.0	254.5	255.7	256.3	266.4	271.3	275.3	275.2	263.6	264.8	270.1	267.3	271.6
3	Turtle Point	13,614	229.1		276.8	272.6	278.5	277.7	277.9	291.9	301.4	311.7	318.0	303.6	299.9	300.2	296.9	295.2
4	Ocean Course	9,000		320.2	334.2	327.4	338.6	341.3	353.6	366.9	378.1	392.8	400.0	395.8	397.5	410.0	411.9	403.9
5	Lagoon	8,000		819.9	807.8	855.0	882.0	927.4	902.8	883.9	868.3	874.2	848.5	790.7	767.5	742.5	742.0	774.8
6	Stono Inlet	6,000		244.1	243.3	241.2	234.4	237.1	237.9	241.5	234.8	221.5	208.1	175.3	161.0	140.9	118.0	119.2
1-6	**All**	**57,232**			**368.0**	**369.5**	**379.2**	**387.2**	**384.3**	**391.6**	**394.2**	**398.4**	**378.6**	**365.4**	**361.7**	**354.3**	**337.2**	**338.1**

			Reach Volume Change Since Previous (cy)														
Reach	**Name**	**Length**			**Aug-07**	**Oct-08**	**Aug-09**	**Oct-10**	**Oct-11**	**Oct-12**	**Oct-13**	**Oct-14**	**Nov-15**	**Jan-17**	**Nov-17**	**Jan-19**	**Nov-19**	**Nov-20**
1	Kiawah Spit	8,820				-1,258	52,266	122,097	-79,109	-18,370	2,719	-32,006	-929,746	-4,793	166,319	-71,125	28,879	29,649
2	West Beach	11,798				-45,703	29,573	13,884	6,665	120,120	56,926	47,462	-1,426	-136,481	13,818	62,656	-32,517	50,598
3	Turtle Point	13,614				-56,689	80,539	-11,176	3,068	189,784	129,833	139,419	85,843	-195,550	-49,869	4,356	-45,630	-22,641
4	Ocean Course	9,000			126,733	-62,036	101,144	24,202	110,622	119,828	101,070	132,427	64,299	-37,239	14,695	113,111	16,844	-71,963
5	Lagoon	8,000			-97,364	378,122	215,473	363,514	-196,928	-150,924	-125,241	47,784	-206,084	-462,481	-185,296	-200,333	-3,415	262,413
6	Stono Inlet	6,000			-4,620	-12,857	-40,673	16,174	4,577	21,459	-40,119	-79,644	-80,624	-196,292	-85,861	-120,864	-137,598	7,600
1-6	**All**	**57,232**				**199,580**	**438,321**	**528,695**	**-151,105**	**281,897**	**125,188**	**255,442**	**-1,067,737**	**-1,032,836**	**-126,194**	**-212,199**	**-173,437**	**-173,437**

			Reach Unit Volume Change Since Previous (cy/ft)														
Reach	**Name**	**Length**			**Aug-07**	**Oct-08**	**Aug-09**	**Oct-10**	**Oct-11**	**Oct-12**	**Oct-13**	**Oct-14**	**Nov-15**	**Jan-17**	**Nov-17**	**Jan-19**	**Nov-19**	**Nov-20**
1	Kiawah Spit	8,820				-0.1	5.9	13.8	-9.0	-2.1	0.3	-3.6	-105.4	-0.5	18.9	-8.1	3.3	3.4
2	West Beach	11,798				-3.9	2.5	1.2	0.6	10.2	4.8	4.0	-0.1	-11.6	1.2	5.3	-2.8	4.3
3	Turtle Point	13,614				-4.2	5.9	-0.8	0.2	13.9	9.5	10.2	6.3	-14.4	-3.7	0.3	-3.4	-1.7
4	Ocean Course	9,000			14.1	-6.9	11.2	2.7	12.3	13.3	11.2	14.7	7.1	-4.1	1.6	12.6	1.9	-8.0
5	Lagoon	8,000			-12.2	47.3	26.9	45.4	-24.6	-18.9	-15.7	6.0	-25.8	-57.8	-23.2	-25.0	-0.4	32.8
6	Stono Inlet	6,000			-0.8	-2.1	-6.8	2.7	0.8	3.6	-6.7	-13.3	-13.4	-32.7	-14.3	-20.1	-22.9	1.3
1-6	**All**	**57,232**				**3.5**	**7.7**	**9.2**	**-2.6**	**4.9**	**2.2**	**4.5**	**-18.7**	**-18.0**	**-2.2**	**-3.7**	**-3.0**	**-3.0**

TABLE 4.2. Unit volumes* for monitoring profiles at Kiawah Island (measured to –10 ft NAVD).

Kiawah Island 2020 (Nov) Monitoring Survey			Unit Volume (cy/ft)															
Reach	Line	Distance to Next (ft)	Apr-99	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Oct-12	Oct-13	Oct-14	Nov-15	Jan-17	Nov-17	Jan-19	Nov-19	Nov-20
1 - Kiawah Spit	1	1,000								601.9	577.7	576.6	694.4	667.9	592.4	479.6	485.4	573.7
	2	997								489.3	494.0	477.6	362.0	406.0	435.3	379.0	400.6	422.6
	3	1,153								339.7	346.1	337.0	252.8	256.5	302.0	296.9	278.0	271.2
	4	844	300.2		392.4	392.4	391.9	406.7	392.1	388.2	384.7	387.0	360.9	330.5	325.6	340.4	331.9	336.2
	5	845								384.3	384.5	386.4	372.2	351.2	341.0	292.9	342.9	349.5
	6	1,157	252.5		361.9	361.1	375.2	384.1	380.9	384.5	384.0	386.0	378.2	357.1	349.6	340.4	350.3	357.5
	7	978								316.7	315.3	312.7	310.8	300.4	293.9	296.0	292.6	296.0
	8	1,040	240.1		309.0	309.9	321.6	334.7	331.0	347.6	353.8	346.8	340.1	334.3	337.0	332.1	326.9	331.6
	9	806								334.9	335.6	334.6	329.3	320.7	321.5	321.7	324.5	326.3
2 - West Beach	10	547	268.3		300.9	299.1	303.6	318.7	317.3	335.8	339.8	339.1	333.3	323.1	328.4	328.4	330.9	328.3
	11	1,232	255.0		289.3	290.4	300.2	307.1	312.3	323.8	324.3	325.1	320.0	314.6	317.4	326.1	318.2	325.7
	12	665	232.5		261.1	257.9	273.1	273.1	275.4	284.8	293.0	294.6	292.5	278.8	285.4	292.5	285.8	298.7
	13	665								277.8	281.6	287.8	287.3	276.7	274.0	285.3	285.2	287.6
	14	945	251.9		252.3	248.5	257.7	258.2	259.3	270.8	278.3	280.9	276.1	272.5	269.5	273.8	273.0	280.8
	15	946								268.1	273.7	279.5	273.5	269.0	264.9	271.1	269.4	274.3
	16	1,025	235.6		254.5	252.6	258.3	260.3	253.0	265.4	269.6	278.3	277.4	268.6	270.2	267.8	270.5	273.4
	17	1,026								251.7	256.6	261.8	257.4	251.9	251.3	249.7	250.6	250.1
	18	691	242.2		251.2	243.9	245.2	246.7	242.8	252.0	262.1	267.4	259.9	252.8	249.7	254.3	248.2	261.7
	19	692								252.1	254.6	257.9	261.7	233.2	245.0	251.3	249.1	252.4
	20	831	272.6		243.8	239.0	239.3	238.1	239.8	248.2	253.0	260.3	261.7	240.6	240.5	252.9	247.4	250.9
	21	1,266					222.0	220.0	226.8	234.0	238.9	235.1	243.8	231.8	231.4	240.2	228.5	234.1
	22	1,627								258.2	257.5	267.0	271.9	252.0	257.4	262.2	265.1	263.8
3 - Turtle Point	23	1,033	234.3		253.9	249.0	252.2	253.0	257.3	261.3	271.3	270.5	285.4	272.7	271.5	275.0	272.4	267.2
	24	1,215					257.1	255.4	259.3	265.6	274.8	285.7	291.6	273.7	273.4	286.8	282.1	281.3
	25	1,145	229.2		260.3	254.0	258.4	254.0	257.9	271.9	280.7	291.7	299.0	274.0	278.7	283.9	284.5	290.1
	26	1,205					259.9	251.5	258.0	265.2	278.2	294.2	291.0	276.1	279.9	283.0	276.7	290.2
	27	1,080	266.2		262.7	274.3	279.7	270.2	277.2	287.6	304.5	314.5	324.5	307.8	306.5	311.6	302.3	304.8
	28	1,269	299.2		278.2	291.8	295.2	292.3	300.8	307.4	323.9	336.5	343.9	333.2	323.5	327.5	321.7	322.6
	29	635	268.3		321.9	313.4	325.8	323.1	322.1	344.5	360.4	370.5	381.7	368.2	365.6	358.8	359.6	354.2
	30	643								345.7	354.7	369.1	384.0	364.4	360.7	361.3	358.7	348.9
	31	889	265.3		322.6	325.1	326.1	331.3	326.6	346.8	353.7	373.8	382.8	372.2	360.9	355.5	348.3	352.7
	32	645	286.4		306.2	302.0	306.9	309.3	305.3	323.3	330.2	351.9	354.5	349.2	335.1	334.6	329.6	332.3
	33	646								282.4	299.6	310.3	318.6	299.1	297.4	294.2	289.4	295.1
	34	1,125					254.9	260.5	256.0	272.8	280.6	287.1	296.6	281.3	272.9	268.3	272.7	259.4
	35	666	217.0		252.1	250.3	253.3	254.3	245.3	269.3	267.0	273.8	277.2	273.3	264.2	256.2	258.5	239.5
	36	666	252.2		257.4	204.3	259.9	263.7	258.2	275.8	275.7	276.7	279.8	275.0	265.2	259.1	261.3	251.0
	37	752								283.9	288.2	285.3	288.7	267.7	269.4	262.6	250.4	245.1
4 - Ocean Course	38	1,000		255.8	260.4	261.1	264.7	269.7	264.0	280.1	279.4	282.8	273.3	260.4	260.7	260.8	259.7	249.4
	39	1,000								277.5	276.9	271.5	270.5	256.5	258.4	257.2	250.7	255.2
	40	1,000		253.1	251.6	257.3	276.6	279.3	277.3	288.9	291.4	286.3	279.5	255.7	266.1	276.5	273.9	266.0
	41	1,000								285.1	274.2	289.1	264.9	235.5	263.2	273.5	274.8	265.4
	42	1,000		231.3	247.4	262.8	273.9	287.0	288.0	297.0	297.7	291.4	262.4	255.0	269.6	295.4	296.1	290.1
	43	1,000								326.2	311.1	325.0	299.5	310.0	312.8	345.6	353.5	346.7
	44	1,000		294.9	355.1	346.9	351.5	362.9	356.3	371.2	364.1	424.1	514.2	429.6	419.1	441.0	454.0	473.0
	45	1,000								454.2	527.4	531.0	524.0	547.2	547.7	573.0	593.8	584.5
	46	1,000		505.6	500.1	453.5	465.3	441.4	486.7	537.7	572.5	551.5	581.0	651.8	633.4	646.9	651.6	621.5
5 - Lagoon	47	1,000								647.9	696.4	848.6	934.2	982.2	953.1	901.7	858.0	816.2
	48	1,000		617.4	578.8	541.8	561.5	562.6	689.5	758.3	839.2	879.5	903.6	898.4	904.3	862.9	830.8	819.7
	49	1,000								980.1	978.1	959.2	921.1	959.7	932.6	887.6	938.1	1003.5
	50	1,000								1012.4	1005.7	1025.4	1025.9	957.2	896.5	891.2	859.9	1011.1
	51	1,000								929.1	838.9	799.5	779.4	733.9	734.8	698.8	703.6	689.6
	52	1,000								708.2	622.4	561.9	541.3	480.5	472.6	465.6	414.7	349.6
	53	1,000								761.9	711.5	636.9	529.2	472.9	455.8	429.1	426.6	414.2
	54	1,000								574.6	563.2	519.3	414.7	357.1	342.5	330.6	319.4	306.0
	55	0								588.4	621.0	602.3	579.0	560.6	537.3	463.4	436.5	399.6
6 - Stono Inlet	56	1,200		465.8	456.2	413.3	363.2	331.0	366.5	385.7	378.6	350.4	324.7	224.3	195.3	146.7	118.5	161.8
	57	1,200		222.1	221.9	241.5	240.8	231.6	209.8	218.6	220.9	223.5	205.4	175.3	129.3	89.7	76.6	60.9
	58	1,200		158.9	156.1	153.2	149.7	169.2	176.4	182.1	171.1	154.6	122.6	101.9	94.0	73.7	64.9	48.5
	59	1,200		167.6	166.9	164.9	168.1	180.7	178.6	173.7	161.1	145.3	140.6	137.7	140.6	142.9	133.3	124.3
	60	1,200		150.0	156.8	154.5	157.1	173.5	172.5	160.8	146.9	131.3	137.2	130.8	141.2	156.9	166.5	187.6
	61	1,200		108.9	111.3	123.7	137.5	146.2	144.4	146.2	159.6	163.2	182.3	165.1	183.5	174.5	178.6	188.0

**Profile volumes along straight segments of beach away from inlets tend to have about 250–300 cy/ft and small variances (eg – Reaches 2 and 3); profiles in the lee of migrating inlet shoals tend to have widely varying volumes two to three times greater than typical oceanfront profiles (eg – Reach 5); volumes along inlet channels where wave energy is low tend to be steeper and narrower with the lowest unit volumes (eg – Reach 6).*

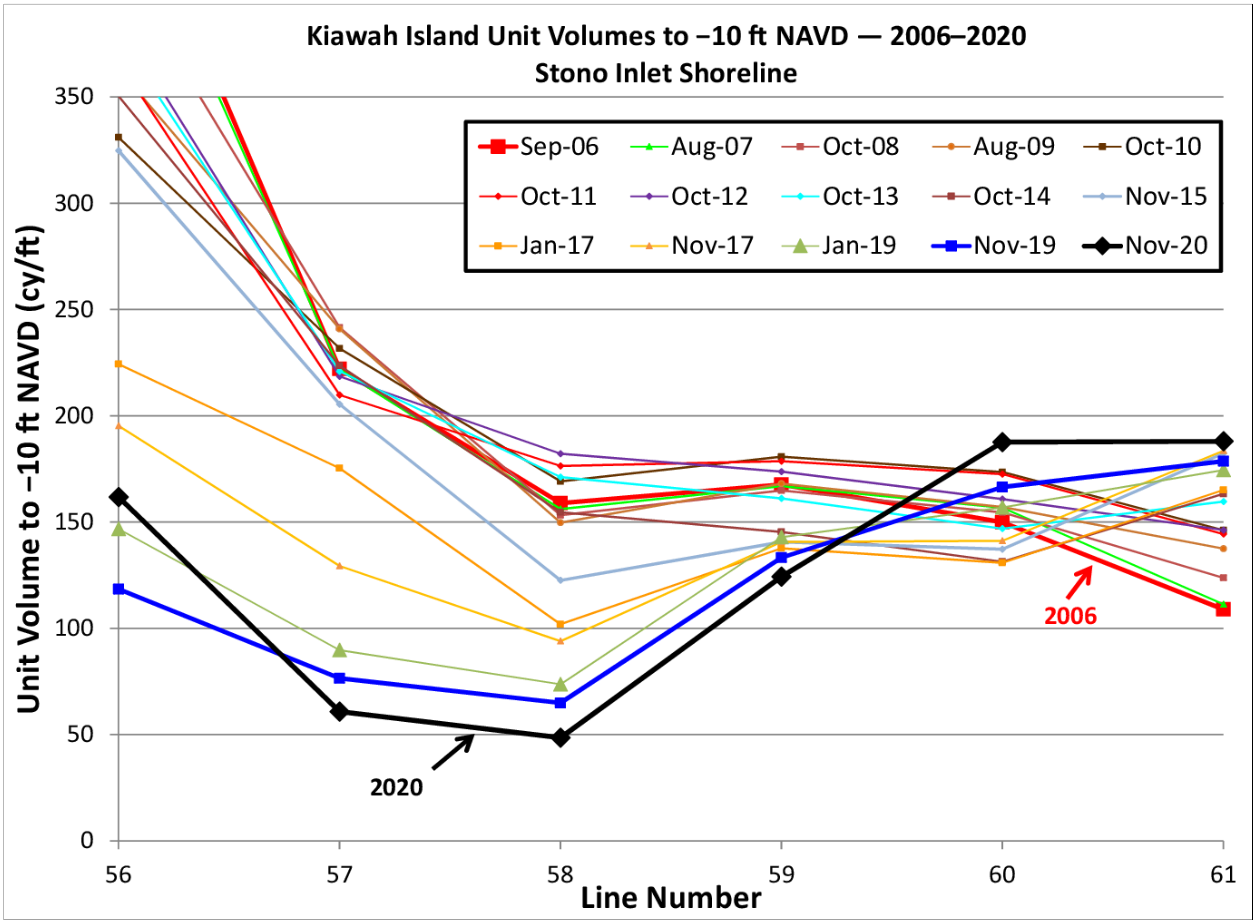
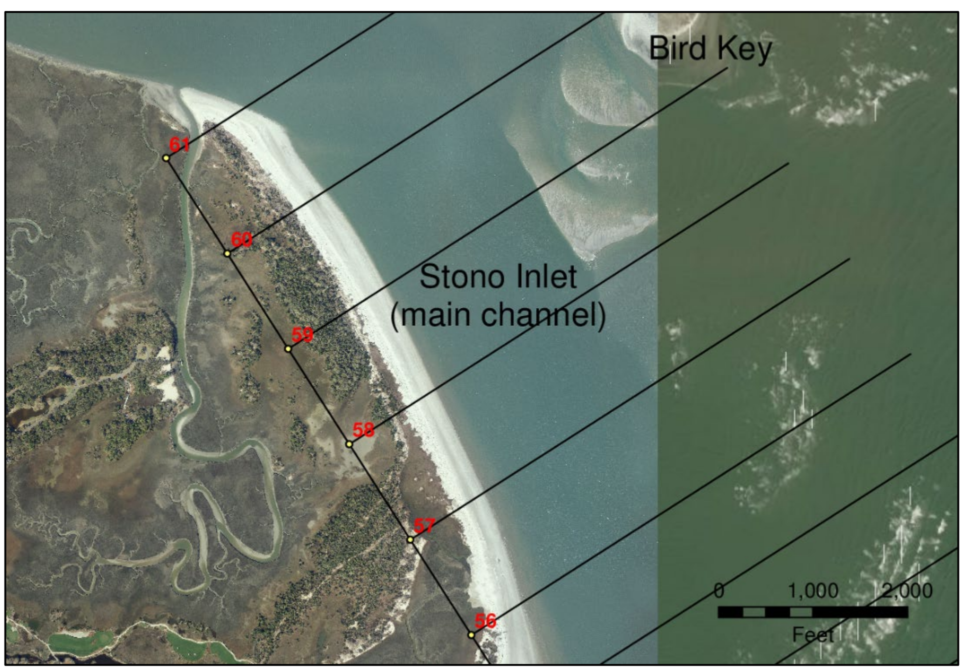


FIGURE 4.4. Unit volumes for stations along the Stono Inlet Reach. Line numbers run east to west. North is into the inlet along this reach.

FIGURE 4.5. Locations of Profiles 56 through 61, the Stono Inlet Reach. The main channel of Stono Inlet, and the western flank of Bird Key, are highlighted here.

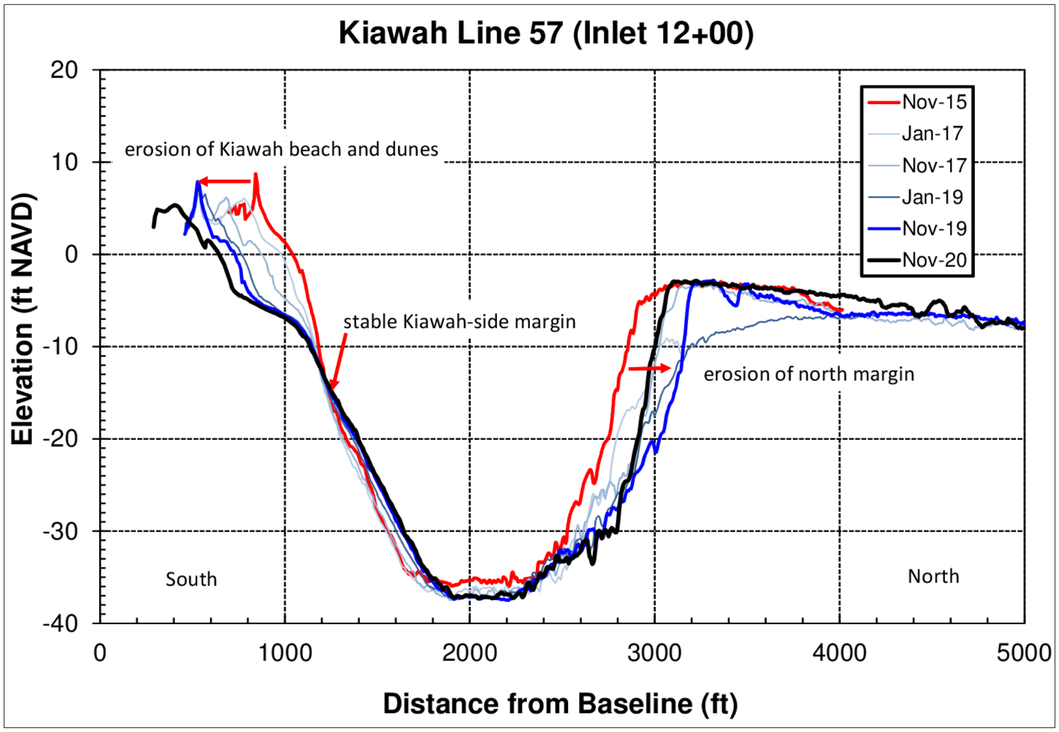


Storms created multiple connections between the east end lagoons and ocean, including one along the Stono Inlet Reach near Lines 56 and 57, where beach sand is able to move freely into the lagoon at high water. Because of the overwash, sand is being transported into the marsh between the beach and Ocean Course where it is effectively removed from the active beach-dune system. Ground photos and surveyed profiles show the eroded beach conditions continuing between Stations 56 and 60 as of November 2020 (Figs 4.5, 4.6). An overwashed beach tend sto lose sand more rapidly because even minor storms can overtop the berm and shift sand into low backshore areas.

In order to maintain a wide beach along Stono Inlet Reach, sand must be transported alongshore from the Lagoon Reach (ie – into the inlet). Since *Matthew*, overwash into the Lagoon Reach between the beach and the Ocean Course has created an outlet for beach and dune sand to be removed from the system instead of transported toward the Stono Inlet Reach. Until the next addition of sand from another shoal bypass event, or an end to the overwash pattern into the lagoon, the Lagoon Reach and Stono Inlet Reach are expected to continue eroding during the next several years (ie – Stage 3 sand spreading away from the shoal bypass center – see Fig 2.6).

While erosion has dominated along Stono Inlet since 2015, the main channel of the inlet has remained stable (Figure 4.7). This is a characteristic of many inlets around Charleston, which are located in the 'paleo' channels of ancient river beds that were active when sea level was much lower than now. The sediment around the base of Stono Inlet consists of *marl*, a dense deposit of semi-cemented sediment that is less erodible than beach and dune sand. Nearly all the changes in these channel cross-sections occur in shallow water in the beach zone, where sediments are more easily-erodible unconsolidated sand.

FIGURE 4.6. November 2019 and November 2020 ground images of the Stono Inlet Reach. **[UPPER]** Line 56, November 2019 **[LOWER]** Line 56, November 2020. The same mud outcrop is circled for reference between the images.



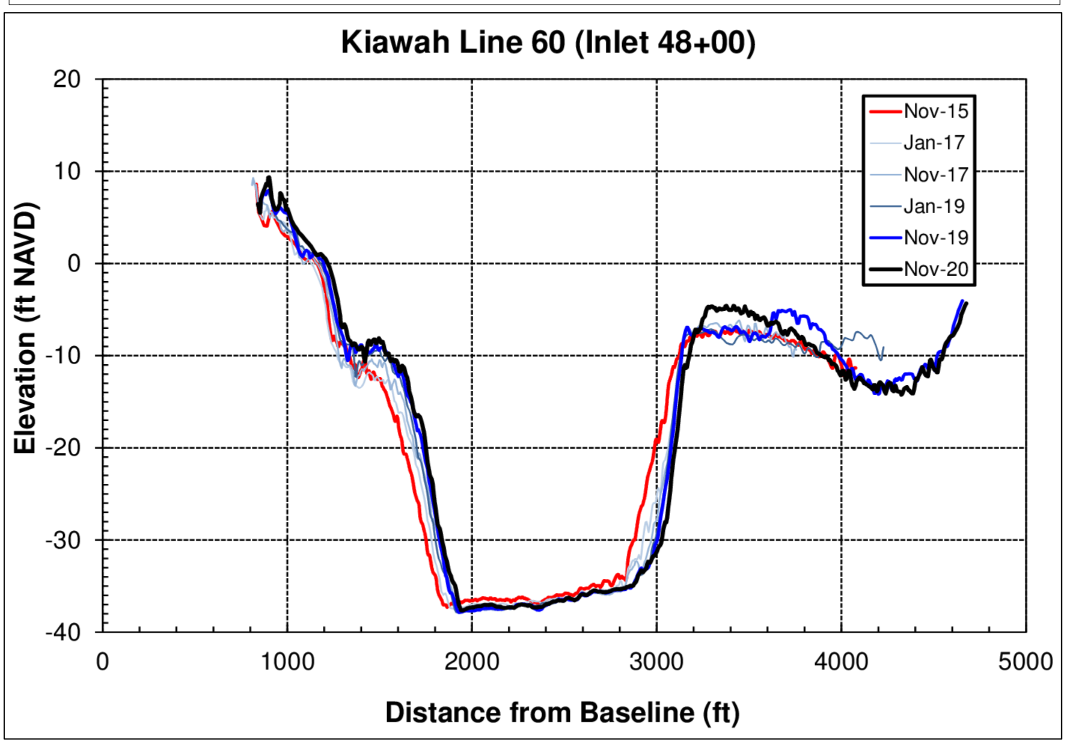


FIGURE 4.7. Profiles from Line 57 **[UPPER]** and Line 60 **[LOWER]** along the Stono Inlet shoreline. Hurricane *Matthew* eroded all of the remaining dunes in 2016. The berm shifted over 100 ft landward in 2017 (due largely to impacts of Hurricane *Irma*).

4.2.2 *Lagoon Reach*

The Lagoon Reach spans 8,000 ft from Line 47 to Line 55 at the eastern point of the island (Fig 4.8). Monitoring reports for the 2007–2011 surveys subdivided this reach into the eastern and western lagoons. The 2012 report combined these reaches and adjusted the baseline to simplify data collection and reporting, and the present report continues this method. This reach encompasses the area of the island most influenced by shoal bypass events (see Section 1 and Fig 4.8). The Lagoon Reach gained ~262,400 cy (8.6 cy/ft) of sand above –10 ft NAVD between November 2019 and November 2020.

Due to the rapid shoreline fluctuations and varying shoreline directions in this reach, CSE has elected to compute beach volumes using digital terrain models (DTMs) created from survey data. These volumes represent the volume of sand within the established boundaries and to a set depth. The analogy of a sandbox is often used, where the volume of sand is measured within the same sandbox each year. DTMs are also used to create contours at specified elevations for each survey, which can then be compared to provide a visual representation of the linear shoreline change.

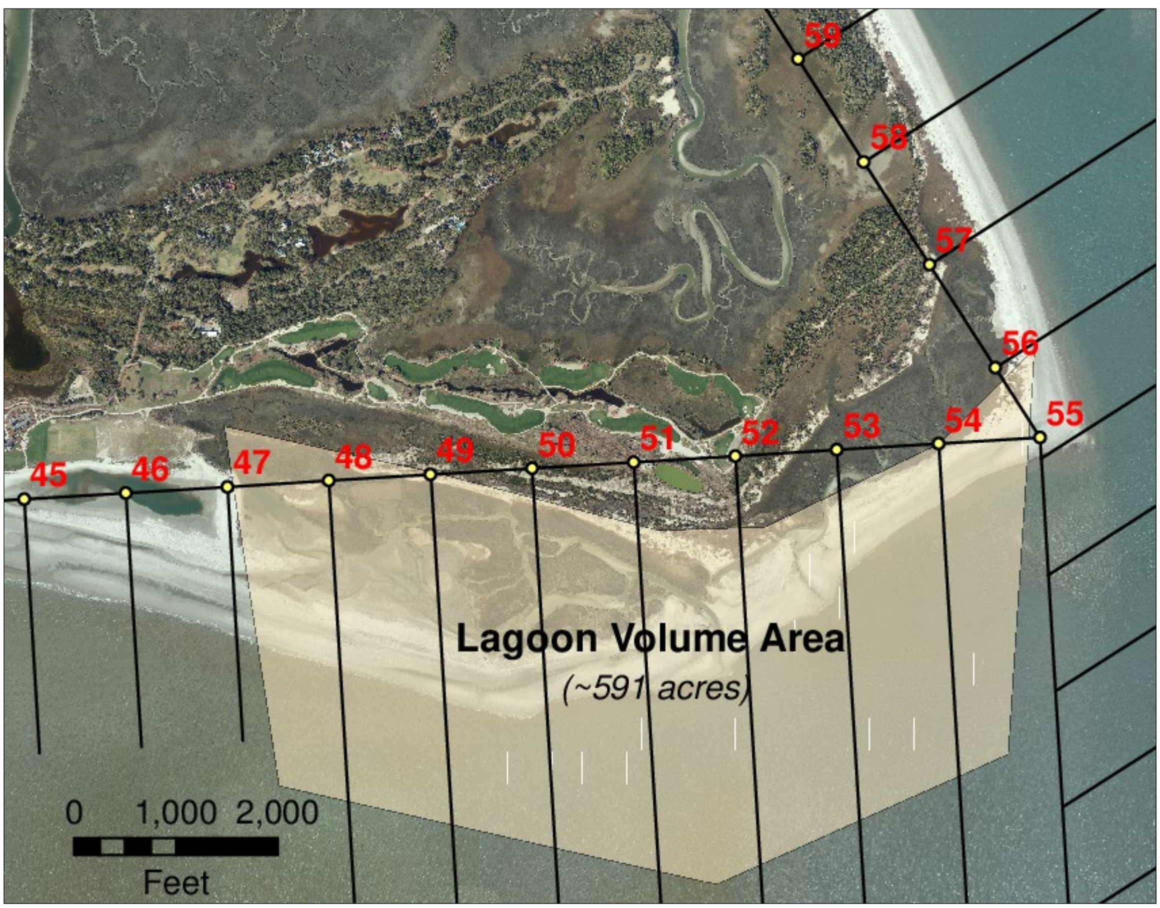


FIGURE 4.8. The Lagoon Reach extends from Line 47 to Line 55. Due to the dynamic nature of the area, the total volume for this reach is calculated from DTMs within the boundaries shown here (image: March 2018).

FIGURE 4.9. August 2020 aerial images of the Lagoon Reach. The 2015 dike is visible in the foreground of the upper image, while the channels created during hurricanes *Matthew* and *Irma* are visible in the lower image. Locations of each image, with viewsheds, are shown in the inset. The most recent shoal bypassing event (circled in upper image) is approaching Stage 2 (attachment).

A shoal bypass event occurred in the Lagoon Reach between 2007 and 2009, attaching in late 2009 at the southern apex of the lagoon. During the attachment process, the beach in the lee of the shoal accreted, gaining sand from nearby adjacent areas and creating a large protrusion in the shoreline. Once attached, sand spread rapidly from the attachment site, contributing to gains along the western lagoon and Stono Inlet shoreline between 2009 and 2012. Beginning in 2012, another shoal bypass event became visible in a similar location as the previous event.

In 2012, the incoming shoal was positioned ~1,700 ft from the beach and was still far enough offshore to have only limited impacts to the beach. Between 2012 and 2014, the shoal migrated ~1,200 ft landward. Between October and November 2015, the shoal continued to migrate landward, attaching to the beach at the −7 ft contour (low-tide wading depth). Interestingly, the shoal decreased in elevation, which may indicate the sand moved in a more alongshore direction rather than directly toward the beach. As of January 2017, the shoal had completely merged with the beach. By January 2019, the shoal bypass event was no longer immediately evident from aerial or ground photography. More information and photos of the evolution of these shoal events were provided in previous monitoring reports to the Town (ie – CSE 2015).

Another shoal emerged in January 2017, ~5,300 ft from the baseline. Between January and November 2017, the leading edge of the shoal migrated ~800 ft landward. Between November 2017 and January 2019, the shoal had grown vertically by ~2–3 ft and migrated landward an additional ~800 ft. This pattern has continued throughout 2019 and 2020; between January 2019 and November 2020, the shoal had migrated ~1,000 ft landward and grew vertically by ~1–3 ft (see Fig 4.9 upper; 4.10).

In typical shoal attachment events, the beach builds out in the lee (directly behind) of the shoal and erodes on either side of the attachment point until it fully merges. As of November 2020, the shoal is beginning to enter the attachment phase of the shoal bypassing process. Erosion will probably continue over the next ~1 to 2 years along the marsh to the east of the shoreline's corner between the Atlantic Ocean and Stono Inlet, as well as along the lagoon in front of the Ocean Course driving range. However, with a shoreline bulge already visible during low tide at the attachment point (Fig 4.11, upper), it is also likely that tens to hundreds of thousands cy of sand will attach to this portion of the island over the next ~12 to 18 months.

The erosional trend observed in the Lagoon Reach in recent years reversed between November 2019 and November 2020. This is likely due to a combination of new sand attaching via shoal bypassing, and longshore transport of that sand along the outer beach. These processes in tandem will continue to deliver shoal sands to the Lagoon Reach (as well as adjacent shorelines) until the shoal is fully attached and distributed alongshore.

Other than the attachment of the shoal at Stono Inlet, the most significant change in the lagoon area is the continued development of channels created by hurricanes *Matthew* and *Irma*, and shoaling of the 2015 constructed channel. CSE personnel observed the 2015 channel completely closed to flow in January 2019; at this point, the two newer channels to the east seem to provide most of the drainage of the east end marshes (Figure 4.11, lower). Smaller channels are more susceptible to rapid changes in position and cross-sectional area during storm events because the volume of sediment needed to shoal or erode a new channel is relatively small. So, these drainage channels should be monitored to document migration and potential changes in the channel cross-section or volume of water flushing the lagoon during each tide.

CSE expects continued accretion of the lagoon area over the next year as shoals attach to the beach. Presently, the reach contains ~263,400 cy **less** sand than the 2007 condition. Based on CSE's Line 50 survey, it is likely the shoal contains at least that volume of sediment and will eventually restore the eroded volume to the beach along the Lagoon and adjacent beaches. The sand from this event will continue to merge with earlier shorelines through washover action and alongshore spreading to downcoast areas. This is why many barrier islands along the SC coast feature a dense network of hummocky beach ridges; these are relicts from previous shoal bypassing events, which have been incorporated relatively seamlessly into the older portions of the barrier island over time. Sometimes these events create permanent wetlands in between the ridges, while other times storms push the beach sand into clustered mounds. Either way, as additional sand continues to periodically attach to the eastern end the landward retreat of the outer beach will pause, extending the life of the lagoon.

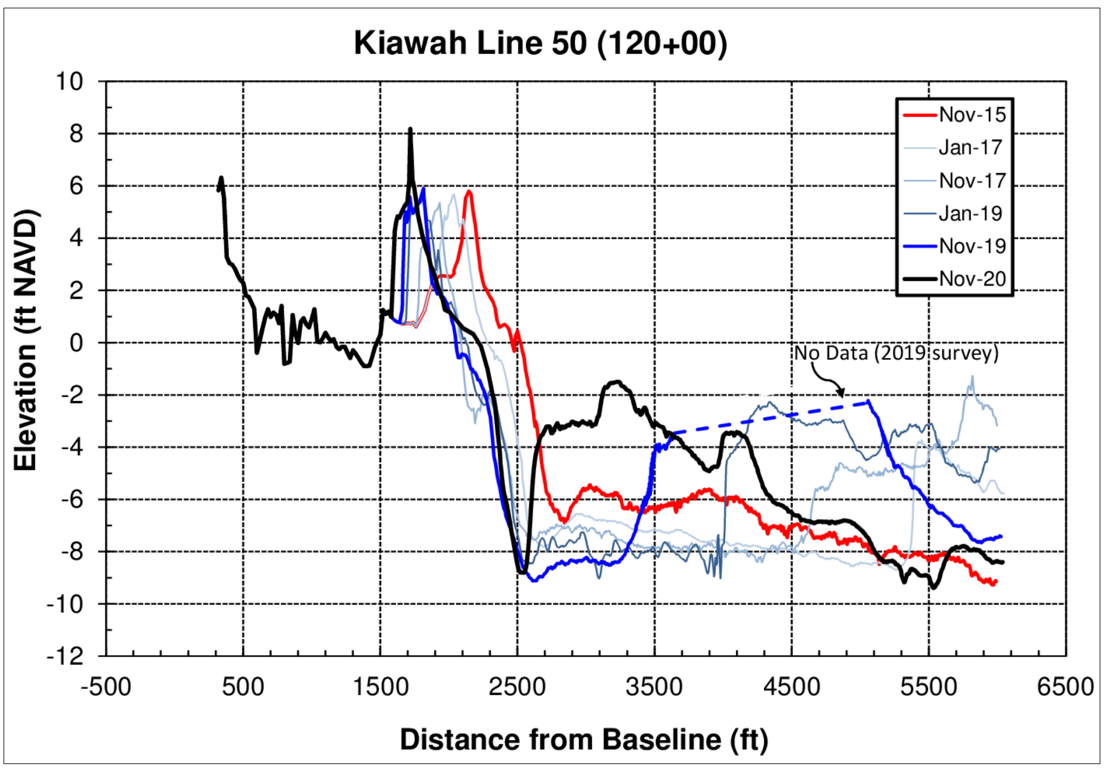


FIGURE 4.10. Profiles from Line 50 showing ~350 ft of dune recession over the past five to six years. Peak elevations of 4–5 ft are insufficient to prevent overwash during storms and spring tides, thus inhibiting dune growth. On a positive note, overwash helps maintain unvegetated beach habitat favored by the piping plover, a threatened species that utilizes the area. This profile line also marks the emergence and landward migration of the next bypassing shoal. In November 2020, the shoal was positioned ~500 ft seaward of the beach.

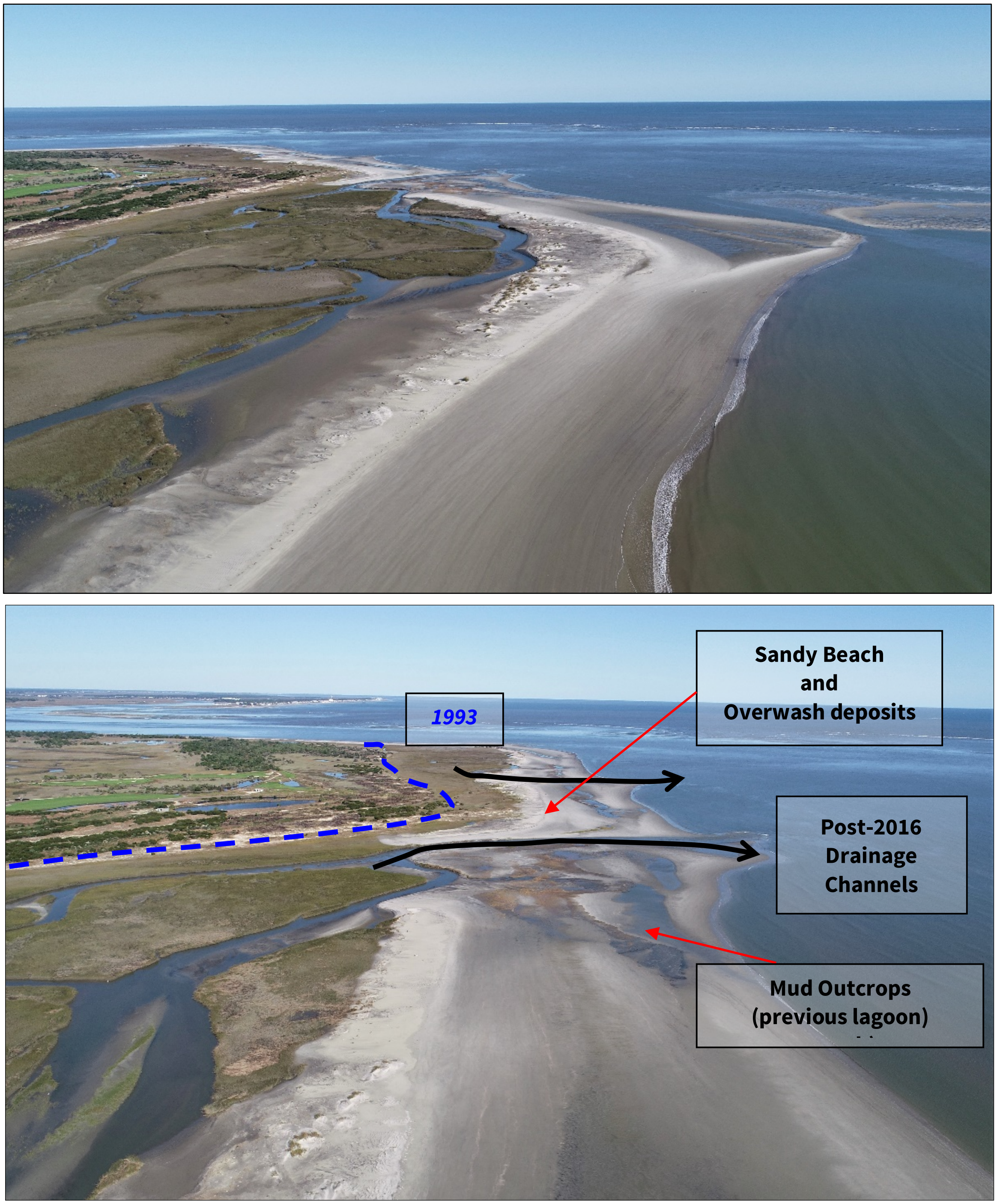


FIGURE 4.11. [UPPER] November 2020 aerial photo over the East End marshes showing a prominent bulge in the low-tide terrace, indicating the shoal is attaching and feeding sand to the beach. **[LOWER]** November 2020 aerial of the Lagoon Reach. The outer beach is retreating across the salt marsh of the lagoon, leaving mud outcrops along the wet sand beach (highlighted in foreground and center of image). Dashed line is the approximate 1993 shoreline. Black arrows indicate the two flushing channels opened following hurricanes *Matthew* (2016) and *Irma* (2017).

4.2.3 Reach 4 – Ocean Course

Ocean Course Reach is the transition zone between the developed shoreline with a typical strand beach, and the dynamic lagoon area (Fig 4.12). It spans ~9,000 ft between Line 38 (Kiawah Beach Club) and Line 47 (closure dike) (Fig 4.13). The Ocean Course Reach lost ~72,000 cy (–8.0 cy/ft) of sand between November 2019 and November 2020. This reach was the recipient of the majority of nourishment fill in the 2006 and 2015 projects. However, in the 2015 project, sand was shifted from the intertidal beach within the reach to higher in the profile, so the net volume gain was limited to only the sand quantity hauled from the new inlet area.

The Ocean Course Reach has generally gained sand since August 2007, with a total volume increase of ~627,000 cy (69.7 cy/ft) over that period (Fig 4.14). The reach lost ~37,200 cy (4.1 cy/ft) of sand between November 2015 and January 2017; however, the reach gained ~144,650 cy (16.1 cy/ft) between January 2017 and November 2019. The losses observed between November 2019 and November 2020 are most likely related to the attachment of a large shoal along the Lagoon Reach, ~5,000 ft southeast of the Ocean Course driving range.

As shoals attach to a barrier island, affected portions of the beach respond differently. Areas immediately 'behind' the shoal (see Fig 2.6) will accrete as the sand migrates onto the submerged beach. During this period of the shoal bypassing process, however, adjacent beaches will typically erode due to increased wave energy related to the refraction of crests around the seaward edge of the shoal. We believe this process is creating the erosional energy along the Ocean Course reach. Fortunately, on Kiawah Island shoal bypassing events typically move from Stage 2 to Stage 3 (see Fig 2.6) within ~12 to 18 months. So, sand will be transported from the Lagoon Reach into the Ocean Course reach as that process plays out. We expect to see a reversal *back* to accretion along the Ocean Course by the next annual monitoring survey scheduled for Autumn 2021.

Most of the reach lost sand between November 2019 and November 2020. However, Lines 40 and 44 did experience moderate volume increases probably related to individual bars migrating onshore at the time of our survey (Fig 4.15). A November 2020 aerial image is compared to the post-project condition in Figure 4.16.

FIGURE 4.12. The Ocean Course Reach lies along the transition zone from a 'strand' beach to the east end of the driving range. In January 2019, the lagoon and flushing channel fronting the Ocean Course Club House was nearly cut off from the ocean. However, between January 2019 and November 2020 a new flushing channel was opened naturally and appears to be effectively draining the lagoon. (*photo via UAV 16 November 2020*)

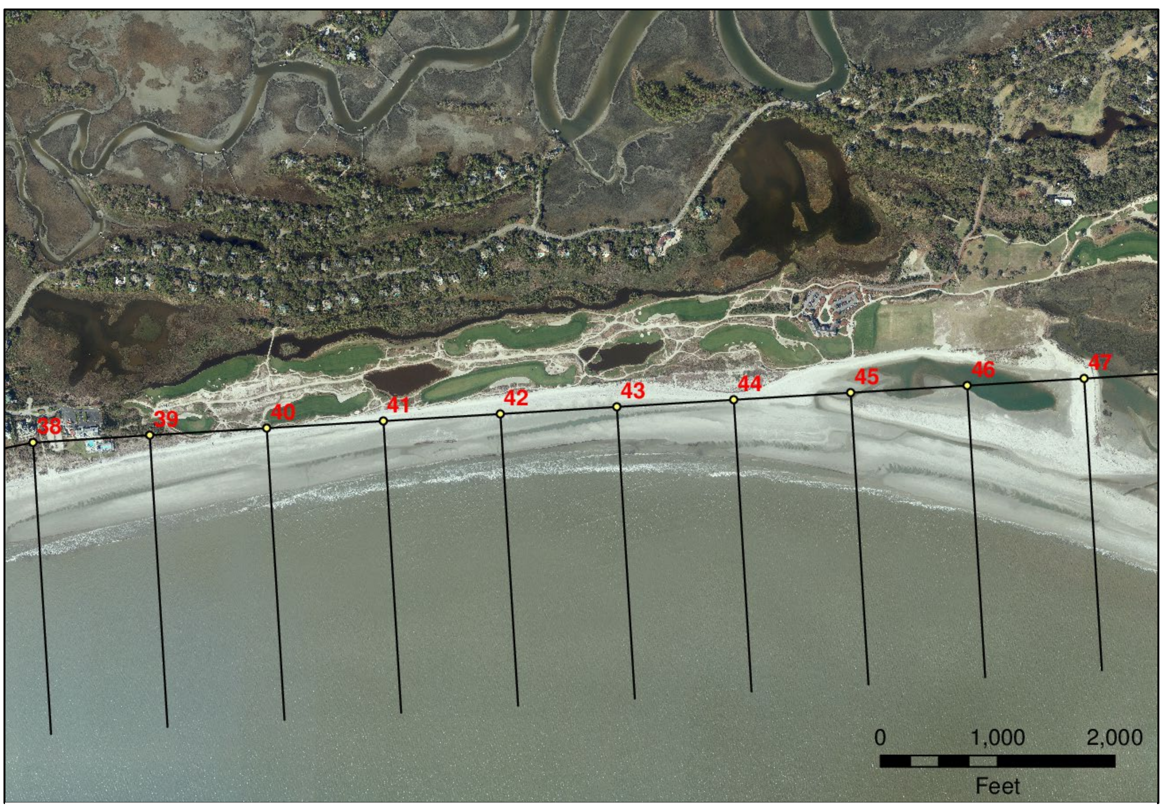
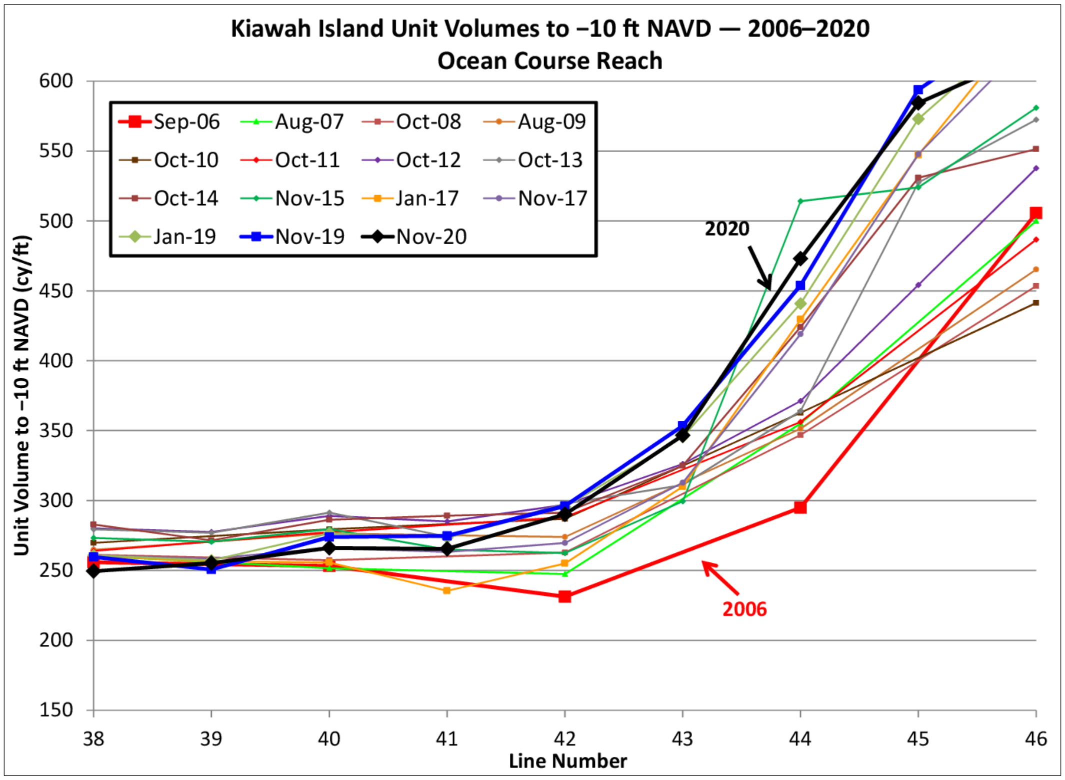


FIGURE 4.13. The Ocean Course reach consists of Survey Lines 38 to 47, and includes the East End Lagoon project area and dike (Lines ~44 to 47), along with several of the Ocean Course's beachfront holes (Lines 39 to 43).



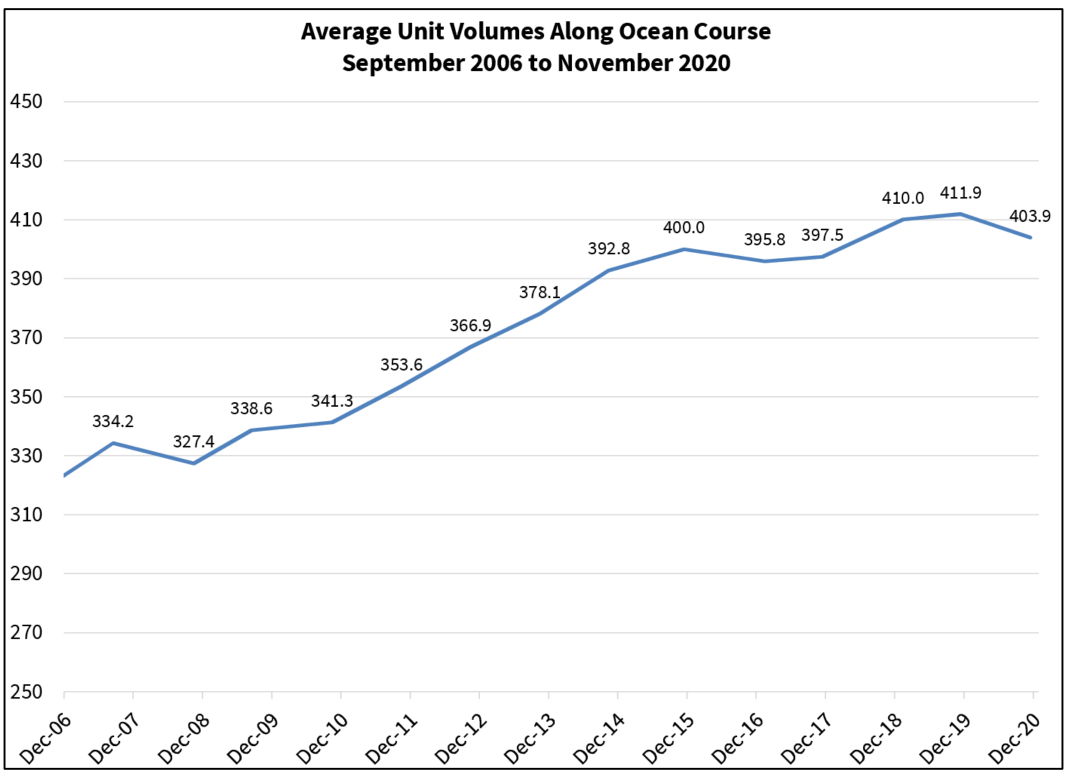
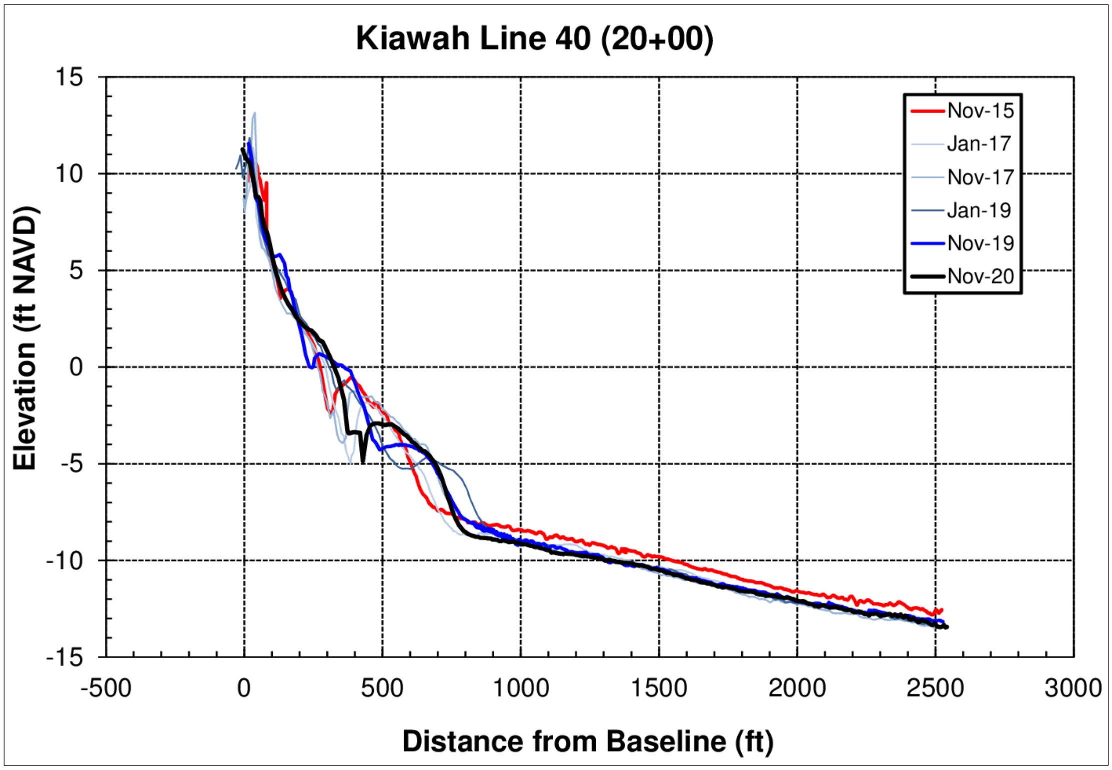


FIGURE 4.14. **[UPPER]** Unit volumes for the profiles of the Ocean Course Reach illustrating the transition between the 'strand beach' of Kiawah away from inlets (volumes ~250–300 cy/ft to the –10 ft NAVD contour) and the inlet-influenced zone where extensive intertidal bars add to volumes (volumes >>300 cy/ft above -10 ft NAVD). **[LOWER]** Average unit volumes for the entire Ocean Course from September 2006 to November 2020, indicating a progressive increase in beach volumes above -10 ft NAVD over the 15-year period.



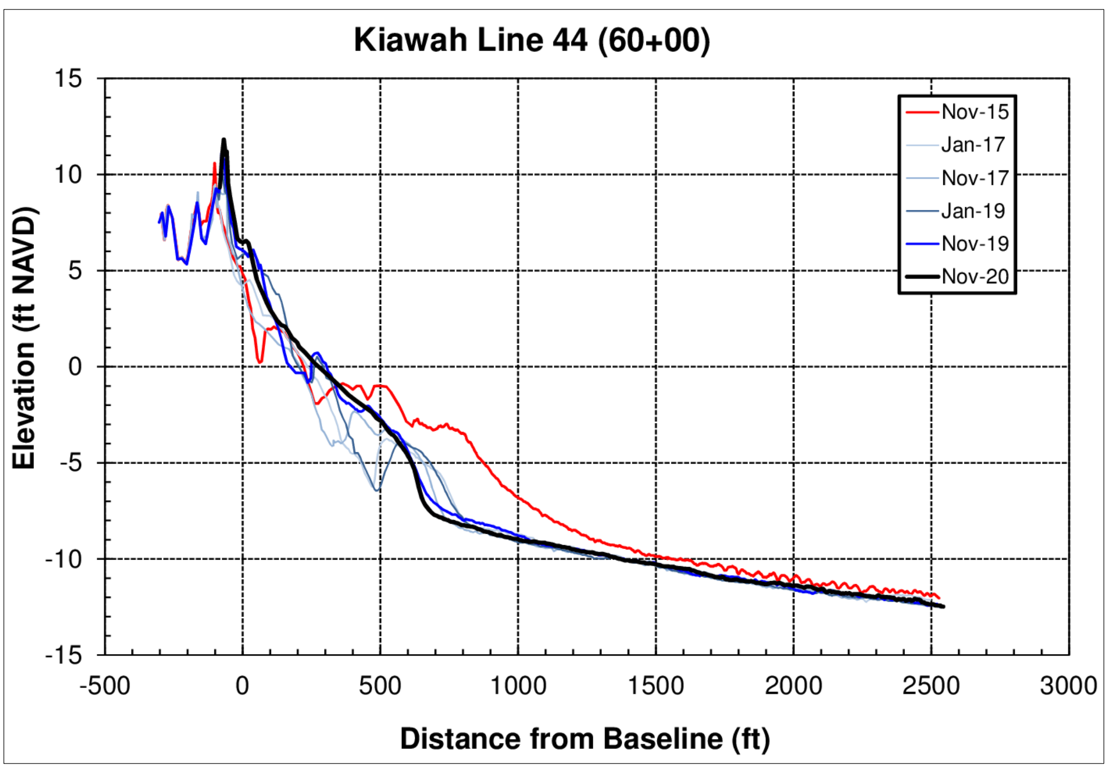


FIGURE 4.15. Profiles from Lines 40 **[UPPER]** and 44 **[LOWER]**. At line 40, the dunes have remained relatively stable with only a slight decrease in elevation since 2017; however, the dune at line 44 is more developed in 2020 than it was in 2017.

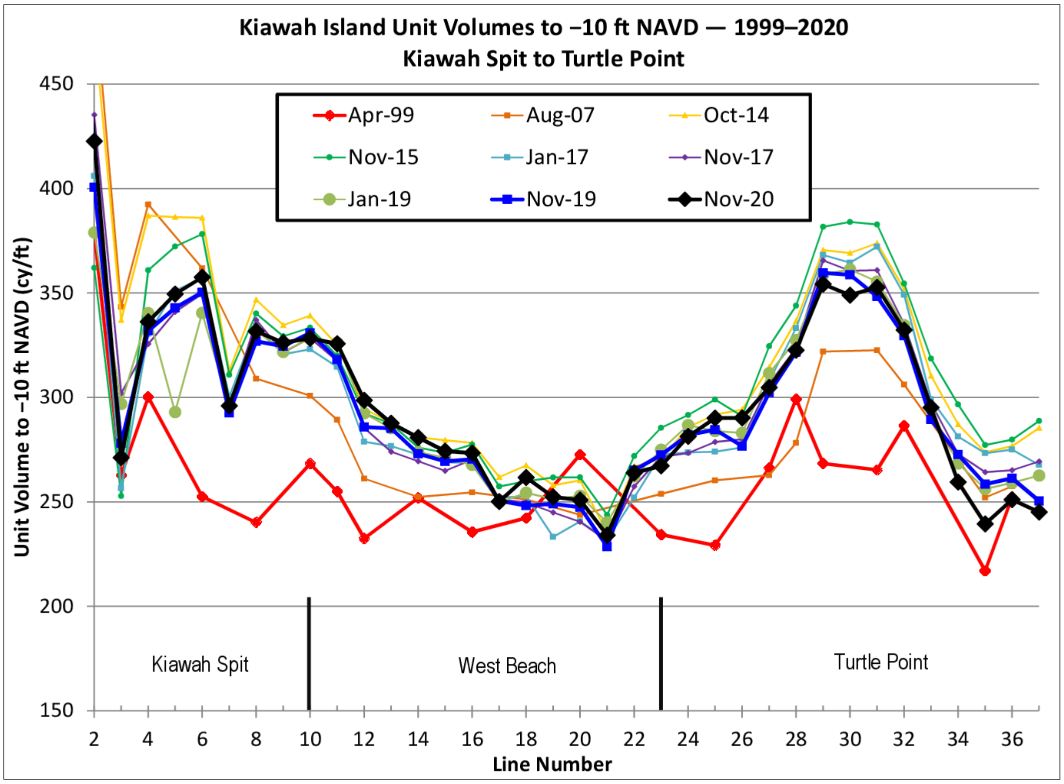
FIGURE 4.16. October 2017 aerial image **[UPPER]** compared to November 2020 aerial image **[LOWER]** of the Ocean Course Reach (eastern half). The ponded area is the relict channel basin from the 2015 project formed before the closure dike was constructed. Enough sedimentation has occurred within the ponded area that robust vegetation is now growing around the perimeter, forming an incipient dune ridge.

4.3 Downcoast Reaches

The November 2020 monitoring data for reaches downcoast (west) of the East End project area are compared to 1999 and 2006–2020 data. Profiles in these areas use OCRM monuments and newly (2012) created profiles so that profile spacing does not exceed 1,267 ft. CSE added these new lines to better monitor local beach changes along the 'populated' beach. CSE has collected data at certain downcoast stations since the early 1980s. Historically, the West Beach Reach has been stable, while the Turtle Point Reach and Kiawah Spit Reach have been accretional. Profiles are given in Appendix A.

At several of the downcoast stations, the 1999 profile lines terminate before reaching −10 ft NAVD. At these stations, volumes were computed to −6 ft NAVD and then adjusted by a factor of 1.95 to produce a representative volume to −10 ft. This scale factor was computed from volume analysis of the 1999 profiles which did extend to −10 ft NAVD.

Figure 4.17 (upper) shows unit volumes for each station in the downcoast reaches. While the typical trend along this area is accretion, yearly volume changes can vary in magnitude, and periods of erosion in some areas are common. The total changew as a gain of 57,6000 cy along the downcoast reaches, but ranged from –19.1 cy/ft to +88.2 cy/ft for individual stations. Due to the mixture of accretion and erosion, some areas of beach and dunes have receded ~100 ft while other areas gained ~25 ft of beach width. Despite this variability, nearly every station contains more sand in November 2020 than in August 2007 (Fig 4.17).



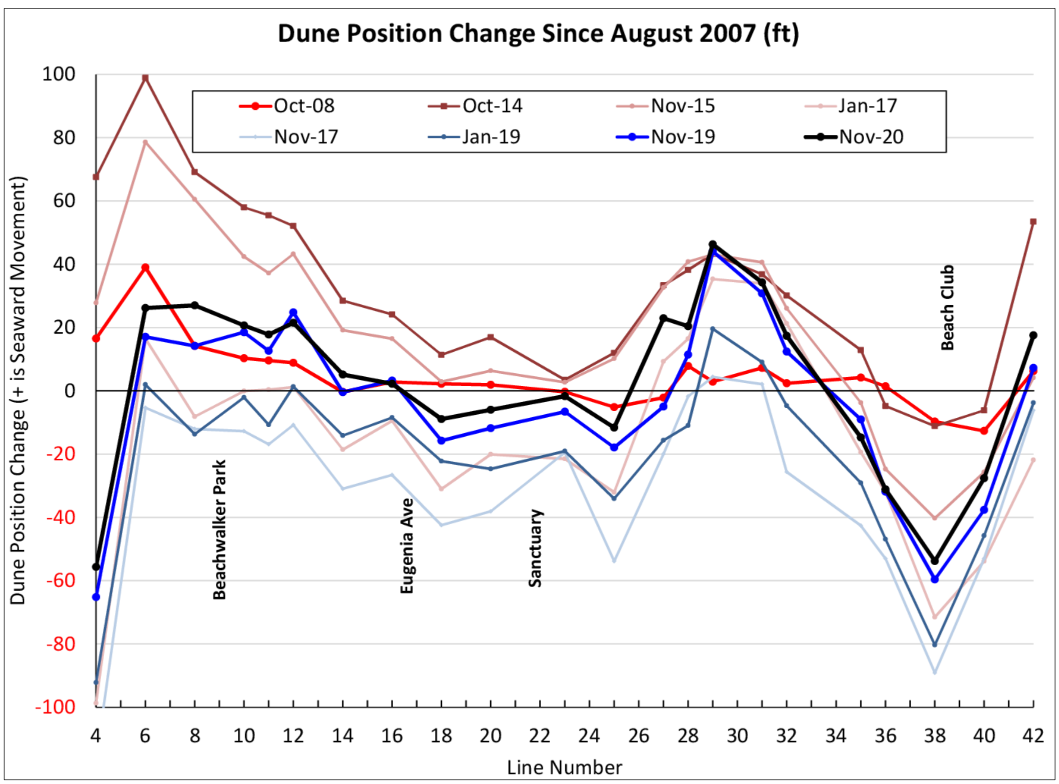


FIGURE 4.17. [UPPER] Unit volumes in the downcoast reaches between 1999 and 2020. Line 1 is on the Seabrook side of Captain Sams Inlet following the 2015 relocation project. **[LOWER]** Dune-line linear change (measured at the +7–ft NAVD contour)

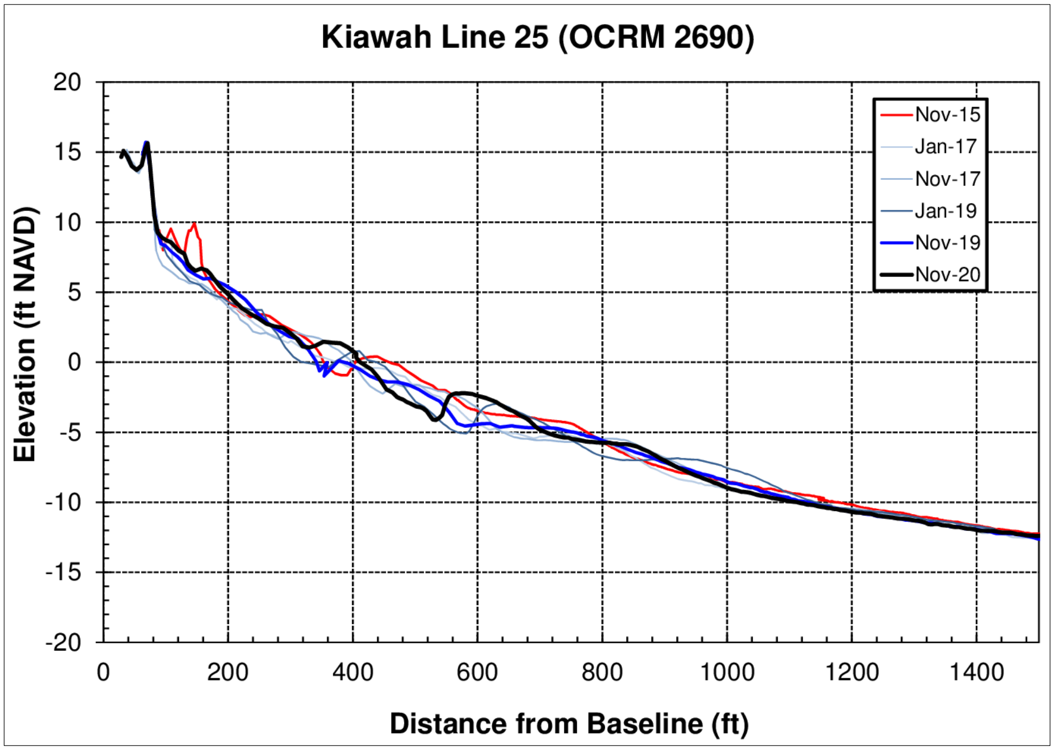
4.3.1 Turtle Point Reach

Turtle Point Reach extends 13,614 ft from Line 23 (16th Hole of Turtle Point Golf Course) to Line 38 (Kiawah Beach Club). Between November 2019 and November 2020, the reach lost ~22,600 cy (–1.7 cy/ft). The reach was fairly stable from 2007 to 2011, showing yearly unit volume changes ranging from −4.2 cy/ft to +5.9 cy/ft. From 2010 to 2015, the reach gained 548,000 cy. The reach lost 195,500 cy from November 2015 to January 2017 due to Hurricane *Matthew*. Since then, the reach has changed at a steadier rate, losing ~45,500 cy (–3.3 cy/ft) between January 2017 and January 2019 and ~68,300 cy (–5.0 cy/ft) between January 2019 and November 2020.

Unit volume change within the reach ranged from −19.1 cy/ft to +13.5 cy/ft between November 2019 and November 2020. In some locations, the dune eroded nearly 50 ft during Hurricane *Irma* but since November 2017 the beach has recovered with dunes growing seaward (Fig 4.18). Ground photos (Fig 4.19) reflect recovery along most of the reach following Hurricane *Irma*.

A dune was reconstructed along the Turtle Point Golf Course prior to the November 2017 survey, because this area was within the state's definition of an emergency condition following *Irma*. Since November 2017, the escarpments and dune damages from *Irma* have been naturally repaired through wind-blown sand transport and vegetation colonization (Fig 4.19). As along other portions of the island including the Ocean Course, West Beach, and Kiawah Spit reaches, consecutive hurricane seasons without significant overwash or flooding events in 2019 and 2020 have allowed backshore vegetation to colonize and begin growing along Turtle Point reach. The succession of grass and shrub species propagating on the dry beach and foredune help anchor the sand in place, so that future storm losses may be reduced.

The significant setbacks of properties and the historical accretion trend of the Turtle Point Reach suggest that the reach can recover without any additional action from the Town. Repeated storms over the past several years have eroded the primary dune along most of the reach; however, overall sand losses were relatively low (especially during *Dorian*). Every profile still shows a higher sand volume than the August 2007 condition; the entire reach contained ~251,300 cy (18.5 cy/ft) more sand in November 2020 than August 2007. What's more, as mentioned above, vegetation colonization along the backshore and dry beach indicates the dune system is recovering naturally and manipulation is not necessary at this time.



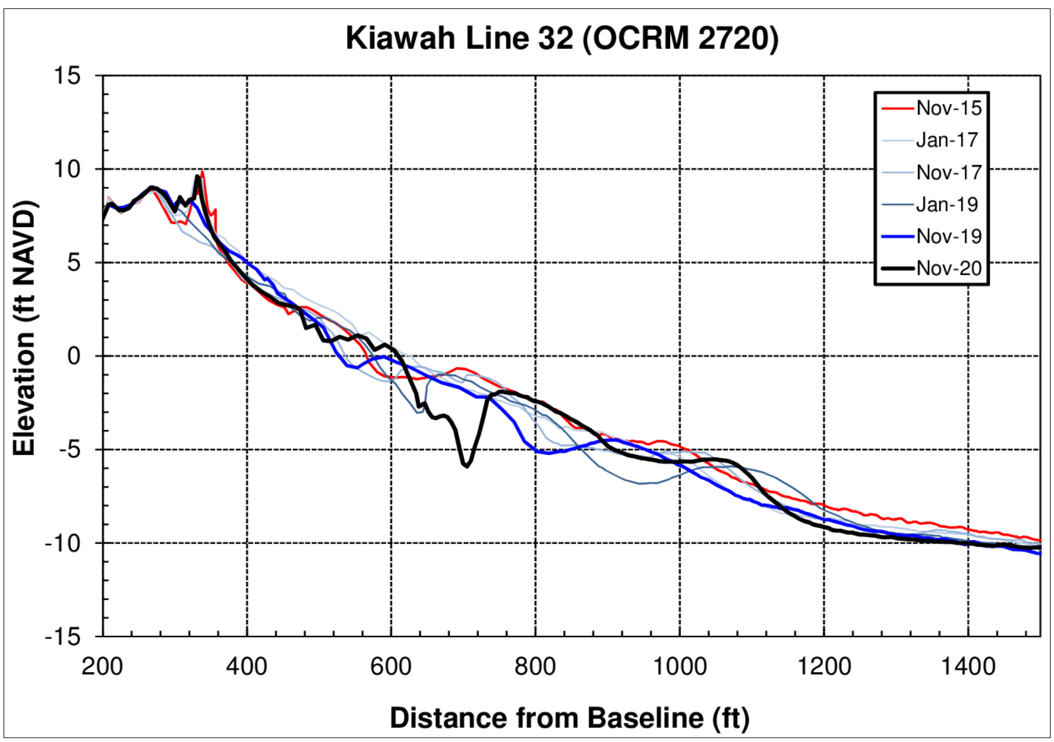


FIGURE 4.18. Profiles from the Turtle Point Reach. In recent years most of the profiles lost sand along the upper beach, but gained sand in the lower beach. Note the difference between red (November 2015) and black (November 2020) profiles; the dune ridge was washed away, but in 5–10 feet of water new bars have formed in the surf. This is typical of winter or storm profiles. Despite volume losses due to hurricanes in the past few years, the present beach remains much further seaward than the 1999 condition.

FIGURE 4.19. Ground photos near Line 28 post-*Irma* September 2017 **[UPPER]** November 2019 **[MIDDLE]** and November 2020 **[LOWER]**. The ramp (red circle) exposed by *Irma* is now hidden behind tall stands of sea oats.

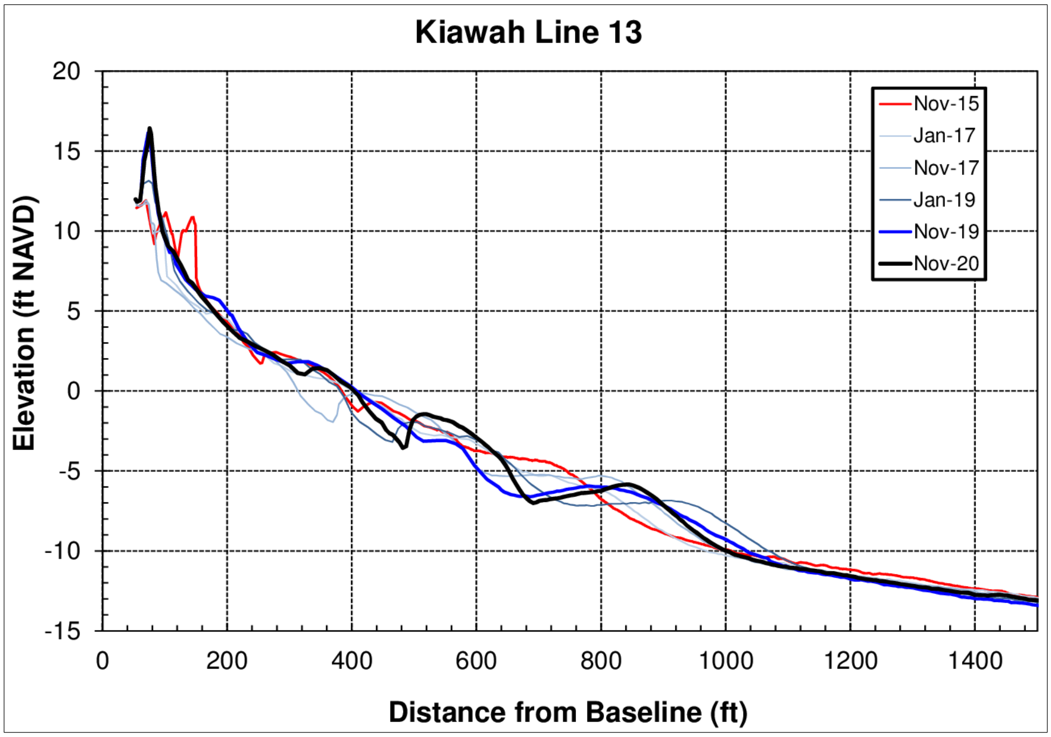
4.3.2 West Beach Reach

West Beach Reach encompasses 8,820 ft of beach between Lines 10 and 23 (Sand Alley to the 16th Tee of Turtle Point Golf Course). Historically, this reach has been fairly stable compared to the other reaches – although Hurricanes *Matthew, Irma,* and *Dorian* did cause some scarping of the foredune. Between November 2019 and November 2020, West Beach gained ~50,600 cy (4.3 cy/ft).

Although West Beach has experienced periods of erosion, properties within the reach are sufficiently set back to allow for a substantial vegetated buffer between the ocean and the structures. The reach lost 3.8 cy/ft of sand from 2007 to 2008 but accreted during every monitoring interval between 2008 and 2014. From 2014 to 2015, the reach was stable overall, although within the reach, the western half eroded and the eastern half accreted. The reach was highly erosional from 2015 to January 2017 (Hurricane *Matthew*), losing over 136,000 cy.

Since 2017, West Beach has varied between accretion and erosion at moderate rates ranging from –11.6 cy/ft at Line 21 between January 2019 and November 2019 to +13.4 at Line 18 between November 2019 and November 2020. Between January and November 2017, the reach gained 13,800 cy (1.2 cy/ft) with individual stations showing changes from −4.1 cy/ft to +11.8 cy/ft. There was a significant loss of sand along the dune following Hurricane *Irma* (September 2019), such that between January 2019 and November 2019, the reach lost ~32,500 cy (–2.8 cy/ft). As previously mentioned, sand from the dune shifted lower in the beach profile during the storm, but has since migrated back to the upper beach during calmer weather conditions. The reach now contains ~185,600 cy (15.7 cy/ft) more sand than the August 2007 condition.

Recent profiles from the reach (Fig 4.20) show a consistent pattern of erosion of the foredune from 2015 through 2017, leaving a pronounced escarpment along the foredune. As shown in Figure 4.21, the dune receded ~20 ft in some locations along the reach. With the combined effects of hurricanes *Joaquin*, *Matthew*, *Irma*, and *Dorian* and the pre-existing narrower setbacks of structures in the reach, several of the properties were left vulnerable to erosion. The Town obtained a permit for beach scraping to rebuild the dunes along Eugenia Avenue and seaward of the Sanctuary. This effort restored the storm protection offered by the foredune and also improved recreational access to the beach via walkovers. Additionally, these efforts provided a healthier habitat for nesting turtles. CSE generally recommends sand scraping only after significant storm events, because these efforts do not add new sand to the system; rather, it is a means to shift eroded sand back to the upper profile and accelerate natural recovery of the dry-sand beach.



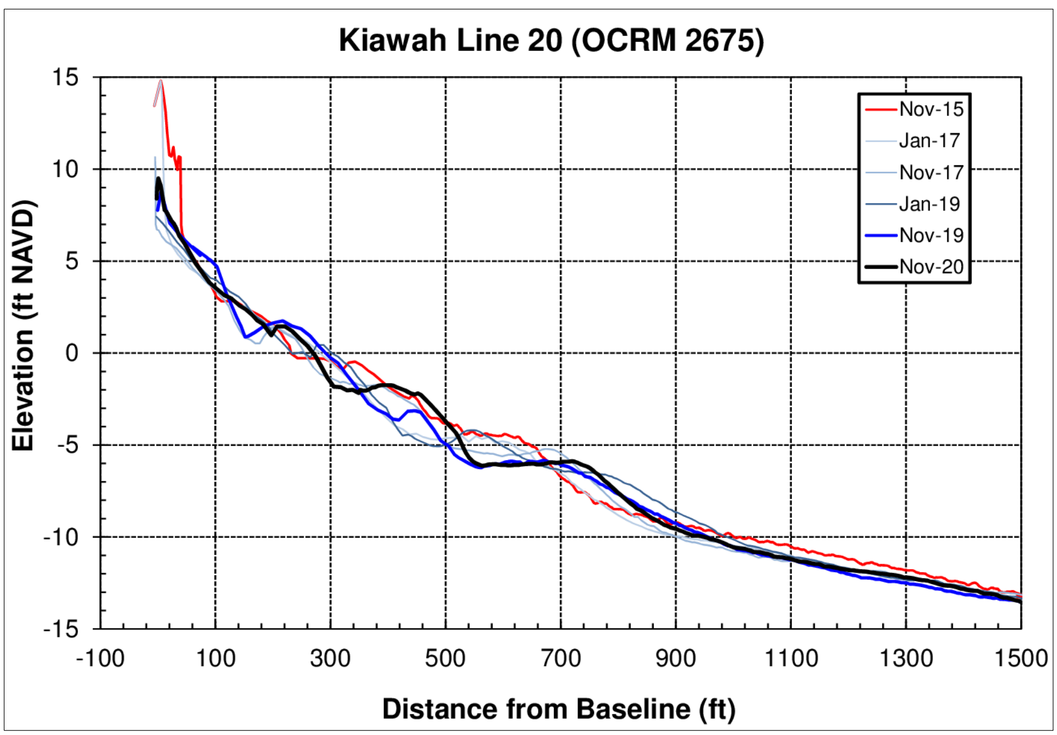


FIGURE 4.20. Representative profiles from West Beach Reach. Much of the reach has experienced erosion of the dune ridge in recent years. The eastern end of the reach (Lines 18–21) has shown the least amount of accretion over the past two decades. Line 20 is the only line showing less volume than the 1999 condition.

FIGURE 4.21. The West Beach Reach (Line 18 shown here) experienced dune erosion due to relatively rough hurricane seasons and nor'easters between 2015 and 2017. Hurricane *Irma* left a particularly noticeable scarp (top left panel, November 2017) in the dune. The Town of Kiawah Island elected to scrape the beach in order to rebuild a protective foredune, and the project has performed well. The scraped dune (top right panel, January 2019) evolved into a gentle sand ramp with colonizing dune grasses beginning to grow seaward (see bottom left panel, November 2019). This indicates longer-term recovery from stormy conditions. By November 2020 (bottom right panel), the scarped dune face was nearly completely buried by wind-blown sand and colonizing dune grasses had established small incipient dunes on the dry beach. The same roofline is circled in red, for reference.

4.3.3 Kiawah Spit Reach

Kiawah Spit Reach encompasses the downdrift end of the island. It acts as a collection site for sand transported by longshore currents from upcoast areas. As wave action transports sand to the west, it feeds the spit, causing growth into Captain Sams Inlet and forcing the inlet to migrate toward Seabrook Island (Fig 4.22). Between November 2019 and November 2020, Kiawah Spit gained ~29,700 cy (3.4 cy/ft) and elongated by about 300 ft. This is approximately equal the average annualized rate of change along Kiawah Spit since the last relocation of Captain Sams Inlet in June 2015 (November 2015 to November 2020; ~148,900 cy or ~3.4 cy/ft/yr).

Previous shoreline monitoring reports by CSE referenced three OCRM monuments in this reach. CSE has added six additional lines to better account for beach changes along the spit with the most westward line located near the 2012 position of Captain Sams Inlet (ie – hundreds of feet southwest of the Town of Seabrook Island / Kiawah Island easement line). To compare equivalent shoreline segments, CSE extrapolated volume to the western end of the spit for the lines without 1999–2011 data. This was accomplished by applying the percent of volume change at the most westward line with data (Line 4) to the lines without data, beginning at the 2011–2012 change and working back in time.

For example, the 2011–2012 volume change at Line 4 was −3.9 cy, which is <1 percent of the 2011 volume. This percentage was applied to the 2012 volume at Lines 1–3 to obtain 2011 volumes for each of those lines. The 2010–2011 volume change at Line 4 was then applied to these new 2011 volumes for Lines 1–3 to provide new 2010 volumes, and so on. While the method is obviously limited in accuracy, it does provide a rough volume estimate of the lines west of Line 4 for comparison with more recent results.

As mentioned in Section 4.1.2, Captain Sams Inlet was relocated ~3,000 ft to the east in June 2015. This placed the eastern margin of the inlet ~450 ft west of Line 3. The sand volume previously associated with Kiawah Island between Line 1 and this point became part of Seabrook Island. This accounts for the loss of sand volume in the reach between the 2014 and 2015 surveys. Between October 2014 and November 2015, the reach lost a total of 929,700 cy (105.4 cy/ft) of sand, mostly due to the inlet relocation. By 2017, the reach had regained ~166,000 cy (although most of the gain resulted from elongation of the spit rather than a buildup of the beach profile). Between January 2019 and November 2020, the Kiawah Spit Reach gained an additional ~58,500 cy (6.6 cy/ft).

The end of Kiawah Spit is growing to the west as Captain Sams Inlet continues its natural migration toward Seabrook Island. Immediately after the relocation project, the inlet channel was steeply sloped on the Kiawah side with minimal wet sand beach. Since then, intertidal bars have formed along the inlet margin and seaward on the Kiawah side of the channel in conjunction with the growth of a new ebb-tidal delta (Fig 4.22). The evolution of New Captain Sams Inlet and Kiawah Spit is generally following the same historical trends observed after the 1983 and 1996 inlet relocations: initially upon relocation, there is some sand loss along the downcoast end of the spit near the new channel. As sand accumulates around the new inlet, the ebb-tidal delta grows seaward. This protrusion in the shoreline then serves to backup sand along the spit, reversing the short-term erosion trend and resuming the long-term accretion trend.

This trend towards more accretion along Kiawah Spit is reflected in the presence of colonizing dune grasses along Beackwalker Park, which indicate seaward growth of the foredune and generally signify a relatively healthy sediment budget across the entire beach profile (Fig 4.23). A similar trend of backshore colonization and seaward dune growth has been observed along West Beach, Turtle Point, and the Ocean Course as well.

FIGURE 4.22. West end of the Kiawah Spit Reach in November 2020. Note oblique wave crests breaking at low tide over a shallow sand bar. This wave direction drives sand onshore and toward Capt Sams Inlet, producing the characteristic 'recurved' spit shaping and building the beach into the inlet. A general trend of accretion along the oceanfront has resumed in this area in the past year.

FIGURE 4.23. Aerial **[UPPER]** and ground **[LOWER]** photos (taken on 18 November 2020) of incipient dunes along Beachwalker Park at Kiawah Spit. The presence of low sand-trapping grasses on the backshore, along with high-water wrack lines located seaward of the foredune, indicate a relatively healthy dune system with a surplus of beach sand.

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5.0 COASTAL RESILIENCY UPDATE

5.1 Weather and Climate Conditions, November 2019 to November 2020

CSE gathered weather and climate data from outside sources (all NOAA-supported) to provide a comparison between observed changes to the beach and environmental conditions. Data reported in this document cover the time period 1 January 2019 to 30 November 2019 (the same as the survey data presented herein). Recent wind statistics are compared to historical data covering the period from 1945 to 2019.

Real-time and historical hourly wind data from across the United States are aggregated by the Midwestern Regional Climate Center (MRCC), a cooperative program between offices of the National Oceanic and Atmospheric Administration (NOAA) and Illinois State Water Survey (http://mrcc.isws.illinois.edu/). The closest operational station to Kiawah Island is located at Charleston International Airport (FAA identifier – CHS) in North Charleston.

The average wind speed and direction was ~14.9 mph from ~181° (approximately south, Fig 5.1). In this case, however, the linear average of all observations does not fully capture natural variability. There was a strongly bimodal distribution of winds in 2019, with both northeasterly (~30°) and southwesterly (~210°) components (Fig 5.1 lower). The observed linear average of those two separate wind directions over the entire study period would be approximately southeast (even though southeasterly winds only accounted for 14.2 percent of observed conditions in 2020).

Between November 2019 and November 2020, there was a slightly weaker northwesterly component of the winds than typically occur in the Lowcountry, according to the data from MRCC-NOAA. The typical proportion of winds out of that quadrant represent ~24 percent of the total observed from 1945 to 2020, while from November 2019 to November 2020 these winds represent only ~19 percent of the observations. This suggests there may have been weaker offshore winds between November 2019 and November 2020, compared to long-term trends. NOAA buoy data also show a weak northwesterly component during the same time period. Northwesterly winds along the South Carolina coast are typically recorded following the passage of nor'easter-type low pressue systems, or hurricanes moving parallel to the coast. In either case, these events typically result in relatively rough surf and are often associated with beach erosion. A lower proportion of these winds during the survey period suggests conditions were probably relatively calm, compared to the long-term record of wind directions around Kiawah Island.

Meteorological and oceanographic data are recorded by the National Data Buoy Center (NDBC) station 41004 (‘Edisto’), ~50 miles due east from Kiawah Island. This is the closest station recording continuous wave data for the entire period (https://www.ndbc.noaa.gov/station_page.php?station=41004). The average wave height from November 2019 to November 2020 at Station 41004 was ~4.3 ft with an average wave period of ~5.1 seconds. The maximum observed wave height was ~23.9 ft on 3 August 2020 (Fig 5.2). The average wave direction was ~138°.* The peak observed wind speed was a gust to 42.9 mph on 3 August 2020. Both peaks (wave height, wind speed) occurred during the passage of Hurricane *Isaias*.

**The normal convention for wave direction is the direction of propagation, whereas winds are recorded by the direction of origin. Thus, waves at ~132° are moving to the southeast, whereas winds from 132° are blowing toward the northwest.*

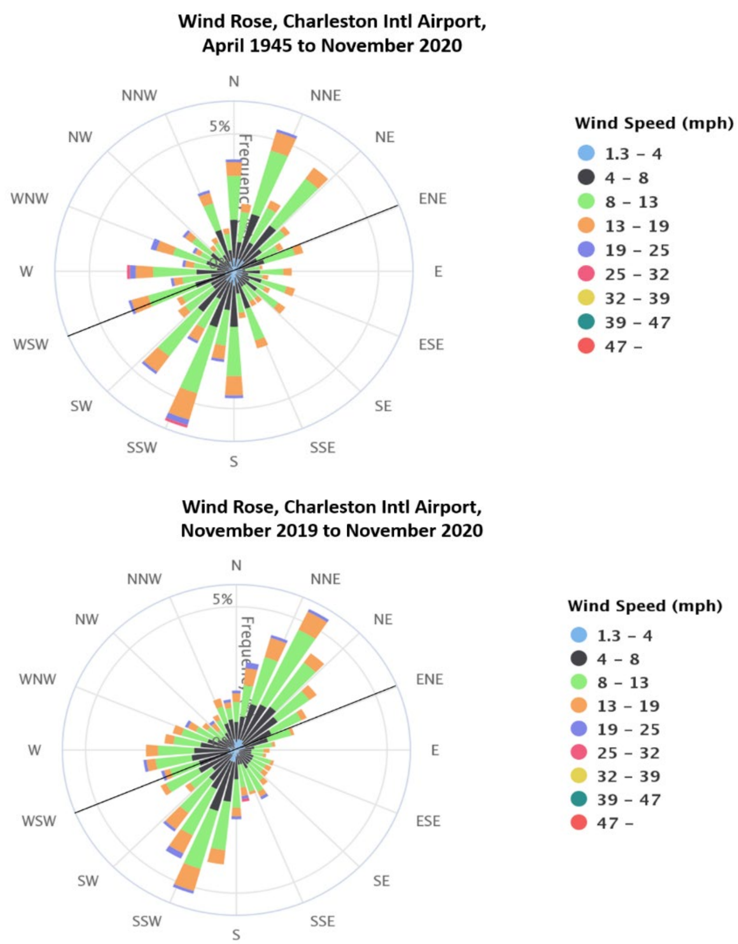


FIGURE 5.1. Wind roses showing direction and magnitude of winds observed at Charleston International Airport from April 1945 to November 2020 **[UPPER]** and from November 2019 to November 2020 **[LOWER]**. The line across the wind rose indicates the average shoreline orientation along Kiawah Island (~75° N). Winds observed over the course of 2019 have generally resembled long-term trends.

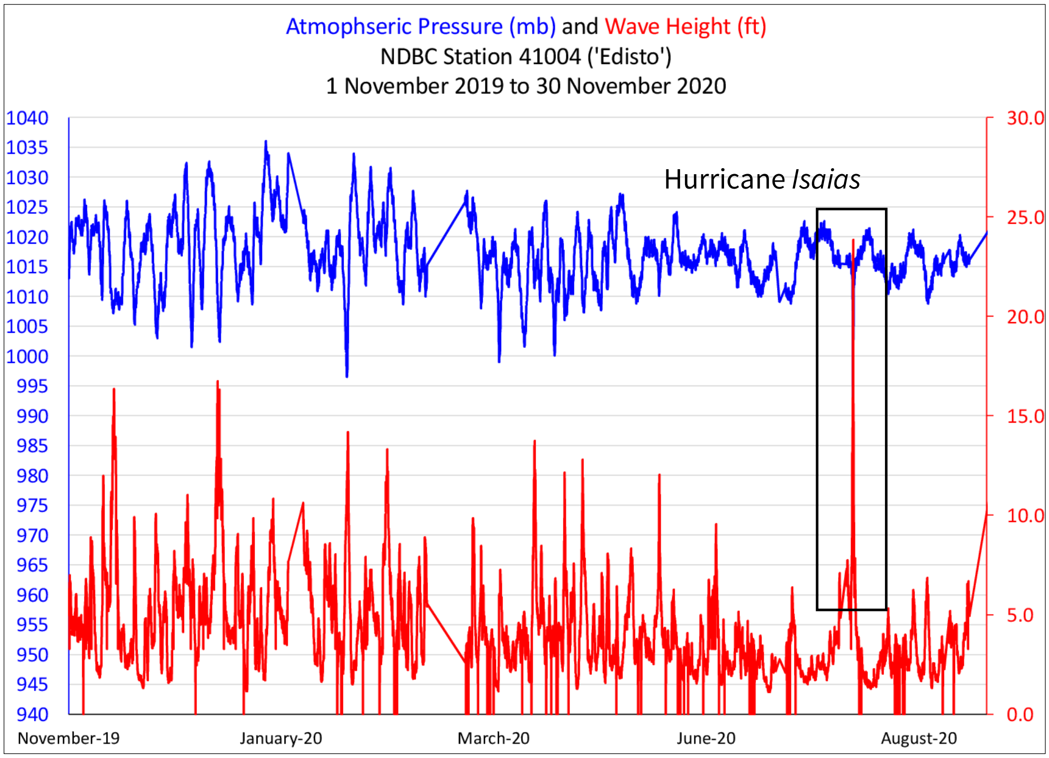


FIGURE 5.2. Atmospheric pressure and wave height at NDBC 41004 from 1 November 2019 to 30 November 2020. The only time during the entire study period in which pressure dipped below 1000 mb was during the passage of Hurricane *Isaias*. Measured atmospheric pressure at Station 41004 reached 988.8 mb on the afternoon of 3 August 2020. The highest wave observed over the same period (23.0 ft) occurred just a few hours later.

Beginning with Hurricane *Matthew* (2016), South Carolina has experienced a series of active hurricane seasons producing *Irma* (2017), *Florence* (2018), *Michael* (2018), and *Dorian* (2019) as well as numerous nor'easters. Repeated impacts from storms can prevent the recovery of the visible beach, and lead to progressively more severe erosion with each event. The latest impact occurred on 3 August 2020 as Hurricane *Isaias*'s eye passed ~60 miles southeast of Kiawah Island.

Like *Matthew* a few years earlier, *Isaias* approached from the south and generally followed the coastline from near Jacksonville to Cape Hatteras. As a result, much of the South Carolina coast was exposed to tropical storm conditions for 1–2 days as the system approached and passed to the northeast. Fortunately, as was the case during *Matthew*, the timing and track of *Isaias* precluded a more severe surge and rainfall event. The shore-parallel storm track kept most severe impacts to a narrow strip of coastal communities north of the Santee Delta, and the storm speed increased off South Carolina so impacts were generally kept to a minimum.

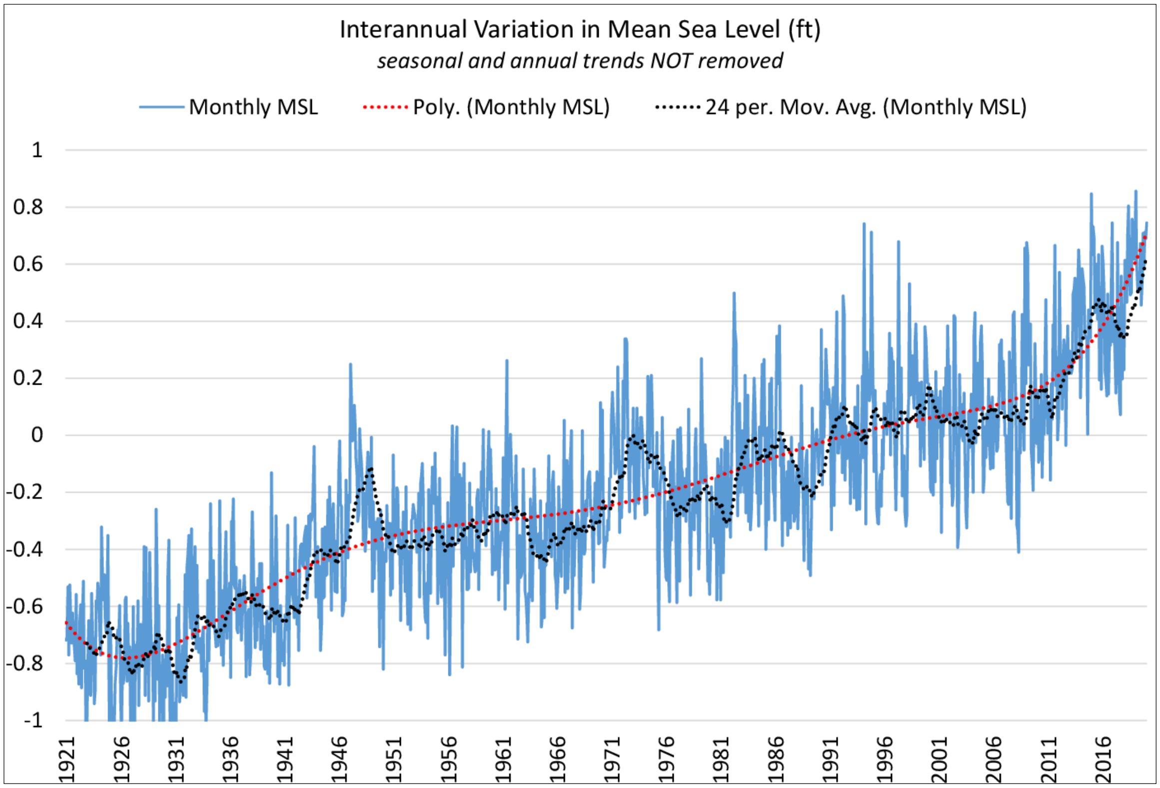
5.2 Sea Level Conditions and Trends

Sea level rise (SLR) is a concern in coastal communities due to the potential for increased flooding as well as beach erosion. While global trends of sea level show widespread increases in water levels over the past few decades, regional- and local-scale observations show a great amount of variability. For instance, sea level rise rates measured year-to-year vary by ~0.1 in/yr between the VA/NC Outer Banks and the SC/GA Lowcountry (NOAA 2020). This quantity represents ~2/3 of the average SLR rate measured at Charleston since 1947 (~0.13 in/yr; NOAA 2020).

The closest SLR observation station to Kiawah Island is a tide gauge located at the Cooper River entrance channel in Charleston, ~10 miles northeast of Stono Inlet. This station (NOAA 8665530) is part of a nationwide network of observation stations. Water level data have been collected continuously at Charleston since 1921. De-trending the SLR data allows us to observe fluctuations in the rate of SLR around that average long-term rate. Some years will experience a more rapid increase in water levels, while others will experience a slower increase or even decrease. Polynomial trend lines plotted over de-trended mean sea level observations from 1921 to 2020 suggest there is a ~20- to 30-year cycle where water levels are ~1 to 2 inches higher or lower than the long-term mean (Fig 6.3). This pattern has been observed at other locations along the US East Coast as well (see CSE 2020) and seems to agree with modeled estimates of SLR variability at regional and sub-regional scales (see Piecuch et al, 2018).

Calculating SLR rates based on running averages of mean sea level (MSL) helps smooth the long-term curves and reveals a shorter-term, ~5 to 10-year cycle wherein SLR rates vary by as much as ~2–3 in between given years ('moving average', Fig 6.3; 'Change From 2-year Average MSL', Fig 6.4). Because these cycles are shorter relative to the overall data observation period, they are more easily verified against the long-term record than the 20-year cycle in sea levels. As of November 2020, the long-term polynomial trend line and 2-year running averages suggest year-to-year SLR rates around Charleston will likely continue to increase (see green curve, Fig 6.4).

Sea level rise by itself does not cause erosion, but it results in beach narrowing as the mean tide level moves up the shoreface slope. Sea level does control the elevation at which waves do the work of moving sand, and that is of primary concern looking into the future. If sand volume is neither gained nor lost at a particular locality along Kiawah Island such as West beach, 4 inches of SLR (the approximate incrase since 1980) will produce an apparent recession of the shoreline of 8-10 ft. As this happens, the dry sand beach elevation will also gain height due to storms overtopping the berm and washing sand toward the toe of the dune. So, even with no volume lost, the narrower beach provides less protection to oceanfront development. CSE's monitoring is focused on tracking changes in profile volumes because with new sand grained from shoal bypassing events at Stono Inlet, Kiawah Island's oceanfront will continue to keep pace with SLR for the foreseeable future.



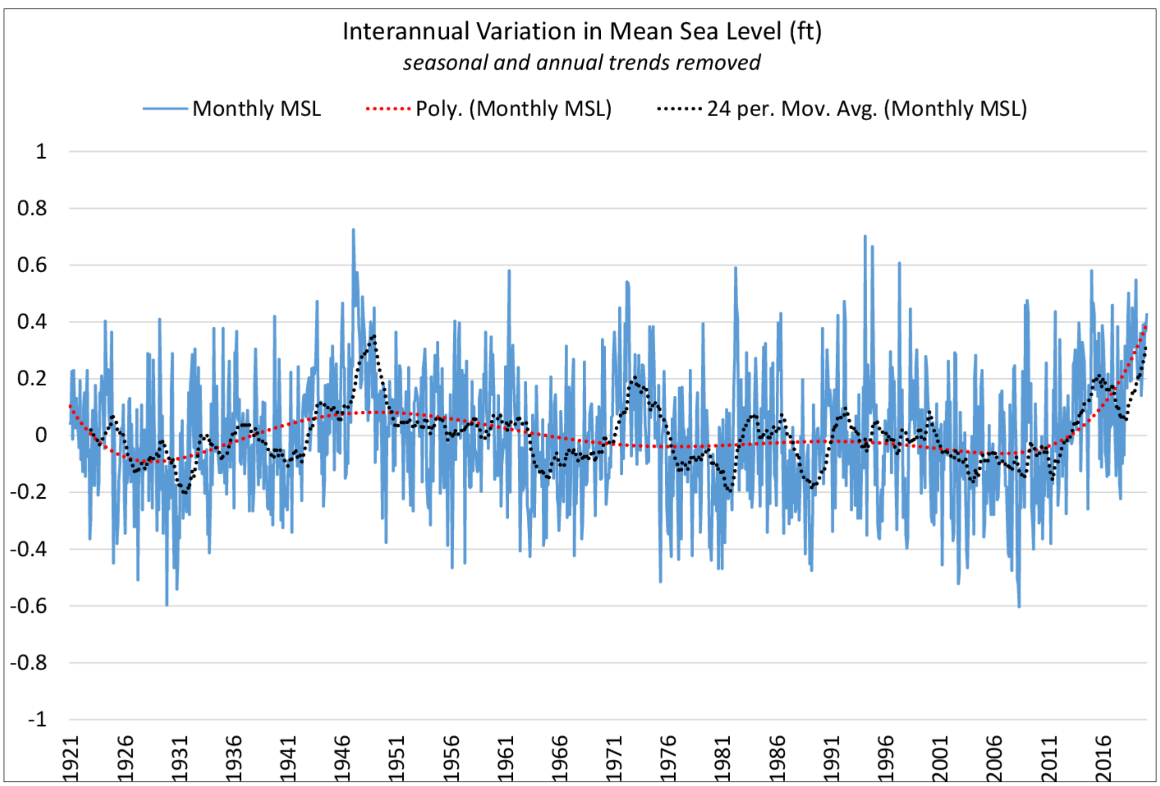


FIGURE 5.3. [UPPER] Interannual variations in MSL, with long-term linear and seasonal trends **not** removed. This curve indicates MSL has risen from ~–0.7 ft NAVD to ~+0.7 ft NAVD from 1921 to 2020 **[LOWER]** Changes in MSL with the linear trend removed from the data. This curve illustrates how SLR rates vary around the long-term mean. A polynomial trend line (sixth order) plotted over the curve helps to visualize oscillations in MSL observed since 1921 at Charleston. The maximum difference between observed and average MSL over these 20-year periods is on the order of ~3–4 inches. Shorter-term (~5–10 year periods) oscillations move about that longer-term trend, as well (see Fig 5.4).

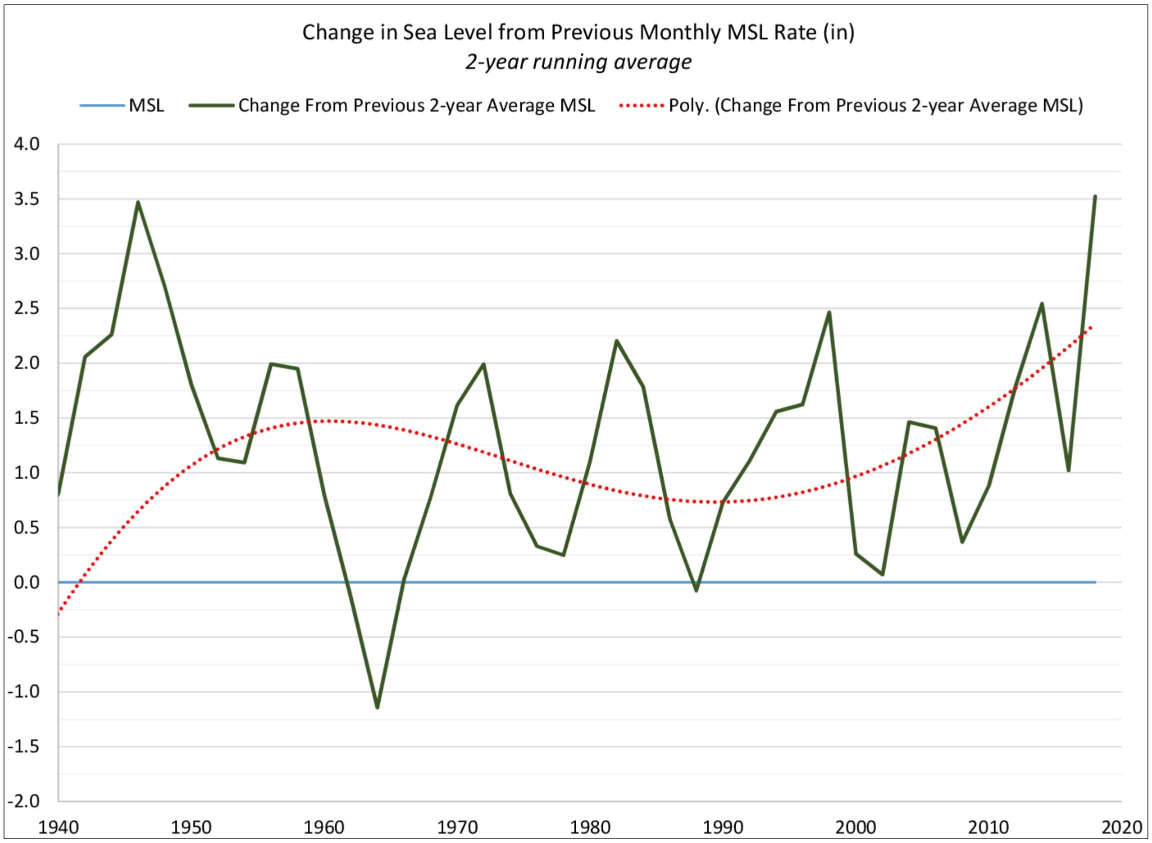


FIGURE 5.4 Differences in MSL calculated for 2-year periods. The light blue line ('MSL') represents the average MSL observed each month (the blue curve shown in Fig 5.3 Upper). The green curve and dotted polynomial trend line represent the difference in MSL between those 2-year periods – similar to a moving average of the blue curve in Fig 5.3. This de-trended moving average curve helps identify oscillations in SLR rates around the long-term mean SLR rate. These rates of change corroborate Fig 5.3, and suggest SLR rates can vary from the long-term mean by as much as ~3–4 inches in a given year at Charleston. Similar observations have been made from New York to Florida. As the text indicates, a 4-inch rise in sea level produces a landward shift of ~8-10 ft in the mean shoreline along Kiawah Island.

6.0 FINDINGS AND RECOMMENDATIONS

The most recent Kiawah Island beach survey, conducted in November 2020, is the 14th annual monitoring event since completion of the 2006 East End Beach Restoration Project and the sixth following the 2015 channel realignment project. It is also the sixth survey since Captain Sams Inlet was relocated by the Seabrook Island Property Owners Association in June 2015.

The recent string of hurricanes (*Joaquin*–2015, *Matthew*–2016, *Irma*–2017, *Florence*-2018, *Michael*-2018, *Dorian*-2019) has occurred at a frequency that has prevented a more complete post-storm foredune recovery. This has resulted in the dune line shifting further landward during each storm event. While storm impacts occur over a period of a few days, it can take several months or even years of sustained normal weather and accretion to allow sufficient wind-blown sand to accumulate, vegetation to regrow, and dune heights to return to their pre-storm condition.

Kiawah Island gained a total of ~255,700 cy (4.5 cy/ft) of beach sand between November 2019 and November 2020. This compares to a loss of over 1,000,000 cy of sand between November 2015 and January 2017, when the beach was impacted by Hurricane *Matthew*, and a volume loss of ~173,400 cy (–3.0 cy/ft) between January 2019 and November 2019 (Hurricane *Dorian*).

The Lagoon Reach at the eastern end of the island experienced the largest volume increase between November 2019 and November 2020, due to the attachment of a large shoal associated with Stono Inlet. The outer beach of the Lagoon Reach now has a bulge where the shoal is attaching to the submerged portions of the beach, which should help to re-establish a beach ridge and an incipient dune within the next year. It is important to note the lagoon continues to be highly dynamic, and a flushing channel that opened following Hurricane *Matthew* appears to contain the majority of tidal flow in and out of the new marsh. Changes in the flow regime or hydraulics within tidal channels along the Lagoon Reach can result in rapid changes in beach volume, as well as access to different portions of that part of the island.

West Beach gained ~50,600 cy (~4.3 cy/ft) and Turtle Point lost ~22,600 cy (~1.7 cy/ft) between November 2019 and November 2020. The volume increases measured along West Beach likely reflect ongoing recovery of the dune system there, which had been scarped during the relatively rough hurricane seasons from 2016 to 2019. The losses detected along Turtle Point reach are likely related to the ongoing attachment of a large tidal shoal to the Lagoon Reach. The same process has likely triggered the observed volume losses along the Ocean Course reach, as well. The erosional trend along the Ocean Course and Turtle Point is expected to reverse as sand from the attaching shoal migrates alongshore.

The ongoing shoal attachment, or bypassing (see Section 2.0), will provide excess sand measuring in the tens to hundreds of thousands of cy along the Lagoon Reach by the time it is fully attached. CSE expects the Lagoon Reach to continue to accrete over the next year as the shoal fully attaches to the low tide beach.

The Town should visually monitor the 2015 channel location and closure dike. If the dike begins to erode, another channel relocation project should be considered. The closure dike was nearly breached by Hurricane *Irma* (2018); however, the small dune protecting the Ocean Course driving range withstood the storm and held through Hurricane *Dorian* (2019). One low spot along the closure dike, located near the inland limit of the high ridge, appears particularly susceptible to breaching during high water periods (Fig 6.1). The Town may consider using some upland fill or a robust vegetation planting scheme to eliminate this low spot before any additional erosion occurs along the dike.

The lack of structural damage resulting from recent hurricane impacts is a testament to the building setbacks and accretional nature of Kiawah Island. While many communities along South Carolina's coast experienced significant property damage, had sand overwash onto public roads, and required emergency sand scraping after each storm, Kiawah was able to withstand significant dune recession with damage limited to walkovers. Beach scraping was only implemented following *Irma*. The long-term accretion trend for the island is expected to continue and contribute to recovery from the string of recent hurricane impacts. CSE is scheduled for another monitoring event in the fall/winter of 2020–2021.

FIGURE 6.1. A low spot along the closure dike showed evidence of flowing water during CSE's beach survey. This is the only location along the dike where the elevation of the crest drops to within ~3' of MSL, and may represent a hazard to the continuity of the dike during high water conditions. Under the right wind, rain, and tide conditions, this channel could be occupied by the tidal creek in the foreground and lead to undermining of the dike.

7.0 ACKNOWLEDGEMENTS

Sponsored by the Town of Kiawah Island, this report is the 14th in a series of annual beach monitoring reports following the 2006 East End beach restoration project and the second monitoring report following the 2015 channel relocation project.

We thank Mayor Craig Weaver and Jim Jordan (town wildlife biologist) for coordinating CSE's work and for providing access to the project site and related information on natural changes at the eastern end.

CSE's field surveys were directed by Drew Giles with assistance from Steven Traynum, Trey Hair, and Patrick Barrineau. Data reduction and analysis were accomplished by Steven Traynum and Drew Giles with assistance from Trey Hair and Dr. Tim Kana. The report was written by Patrick Barrineau and Steven Traynum with production assistance by Carrie Marks and Trey Hair.

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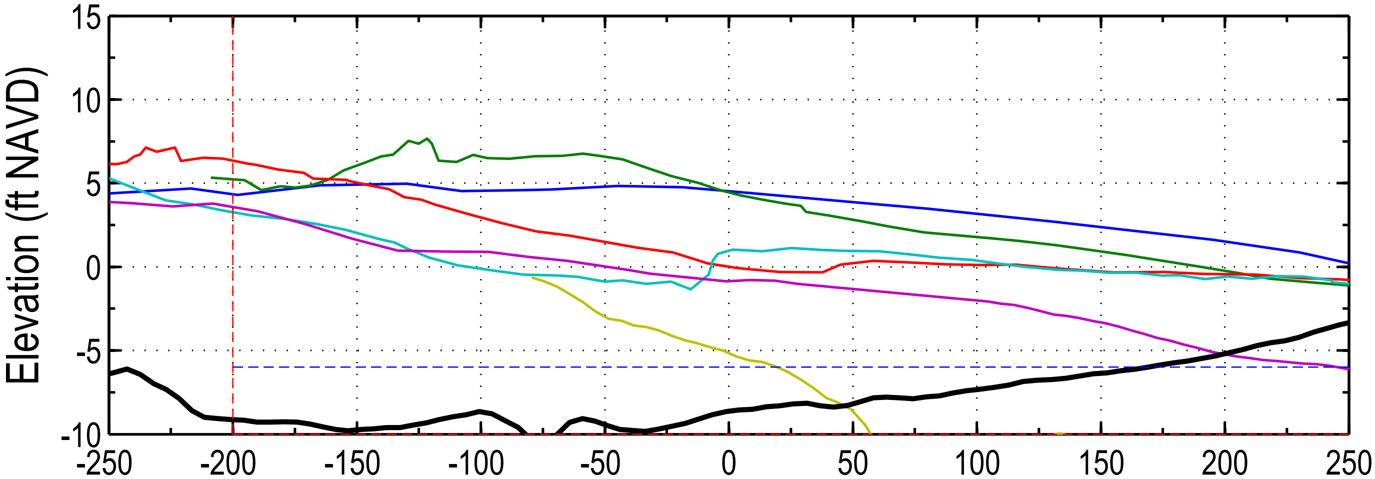
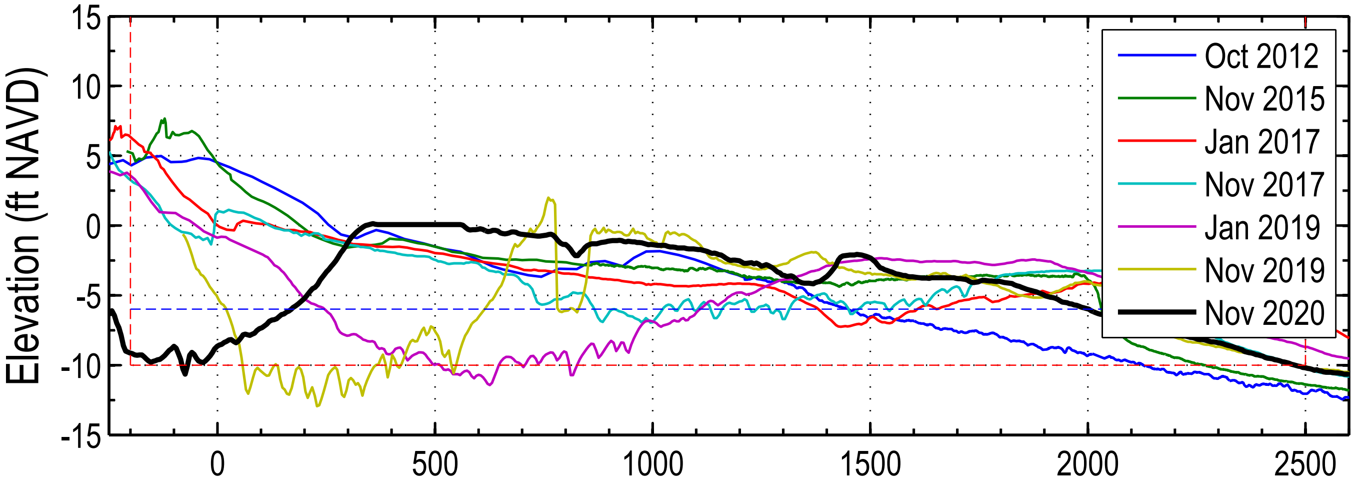
APPENDIX A

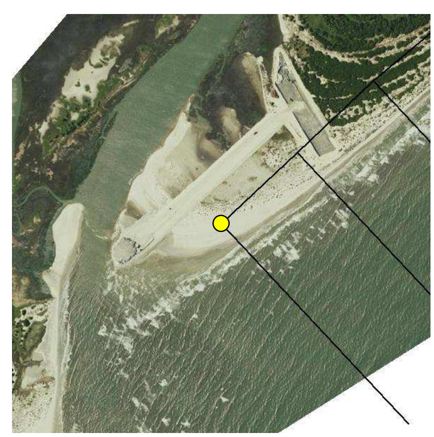
CSE Profiles

Kiawah Line 01

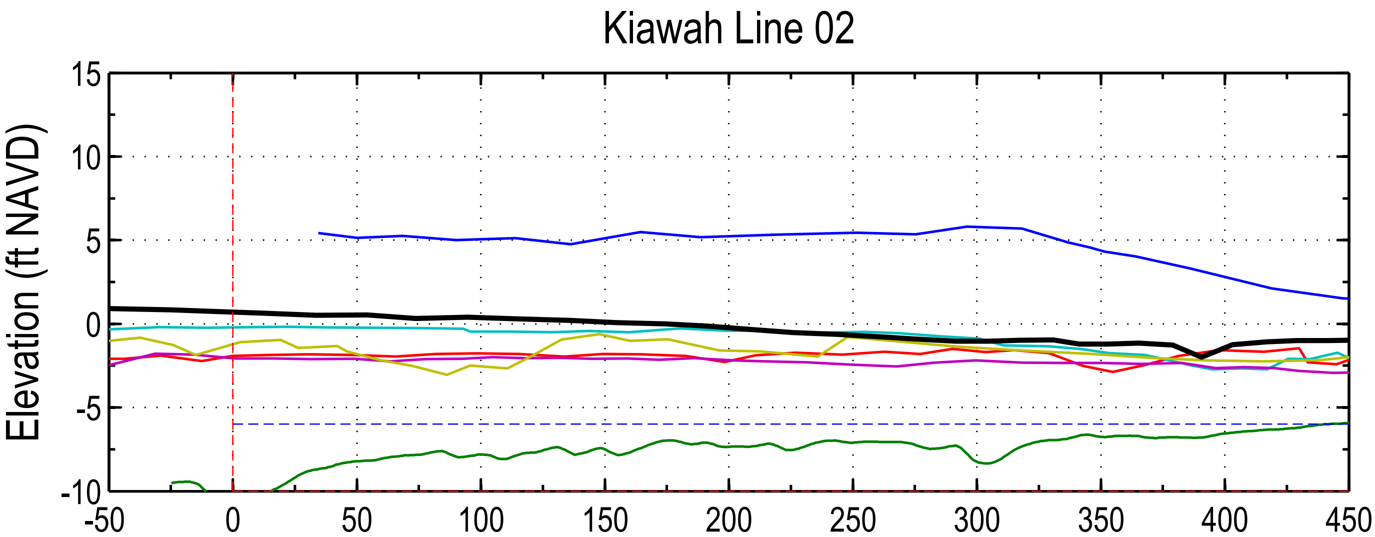


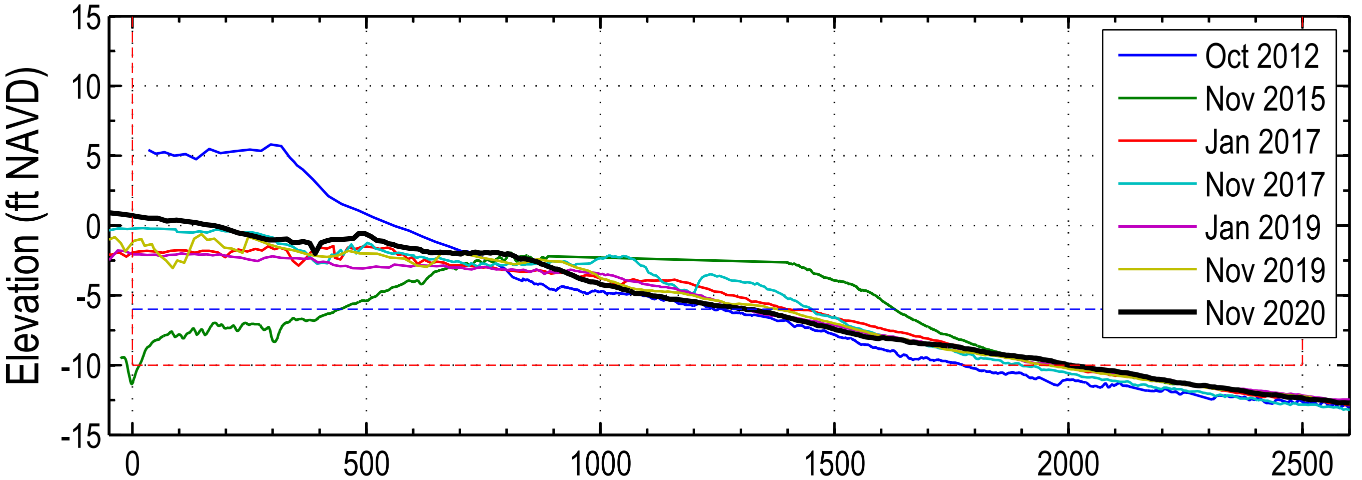


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	307.6	294.3	601.9
Nov 2015	353.0	341.4	694.4
Jan 2017	274.7	393.2	667.9
Nov 2017	225.3	367.1	592.4
Jan 2019	181.6	298.0	479.6
Nov 2019	196.5	288.9	485.4
Nov 2020	247.6	326.0	573.7



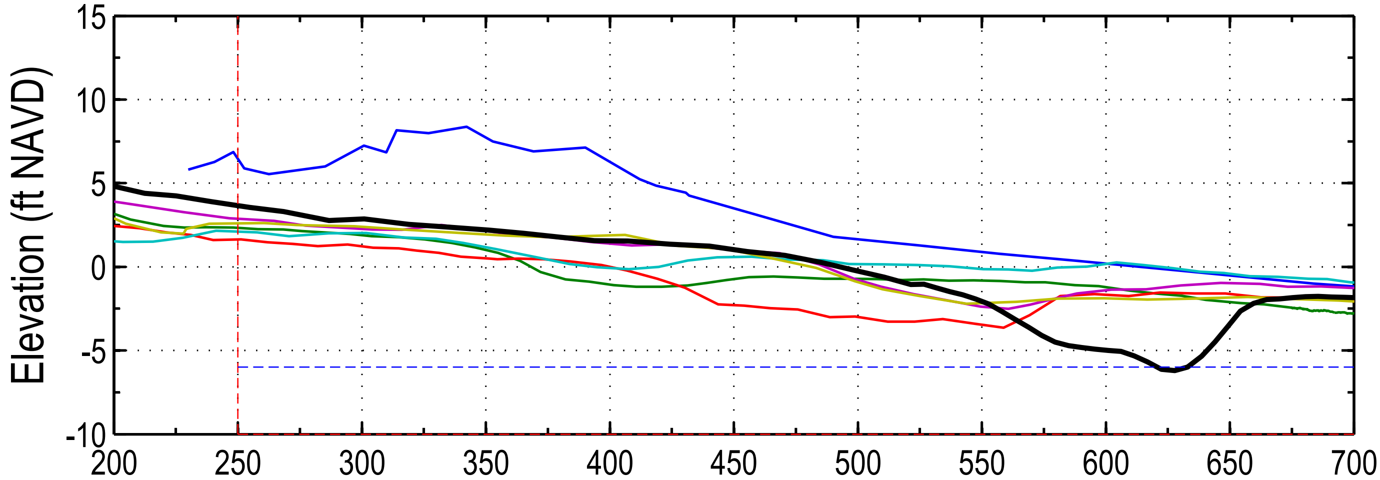
Kiawah Line 02

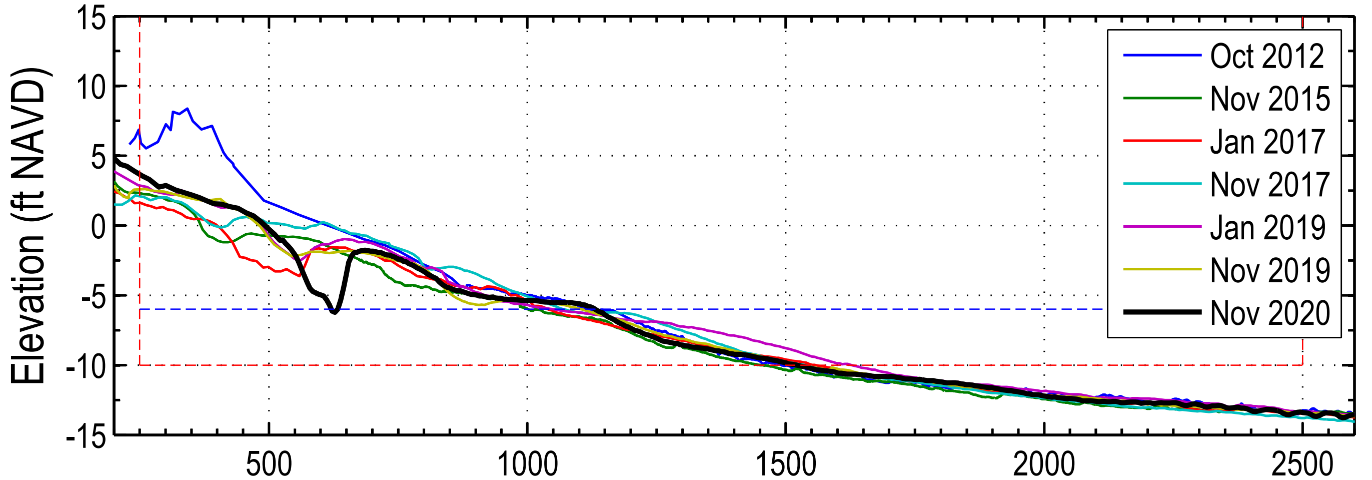




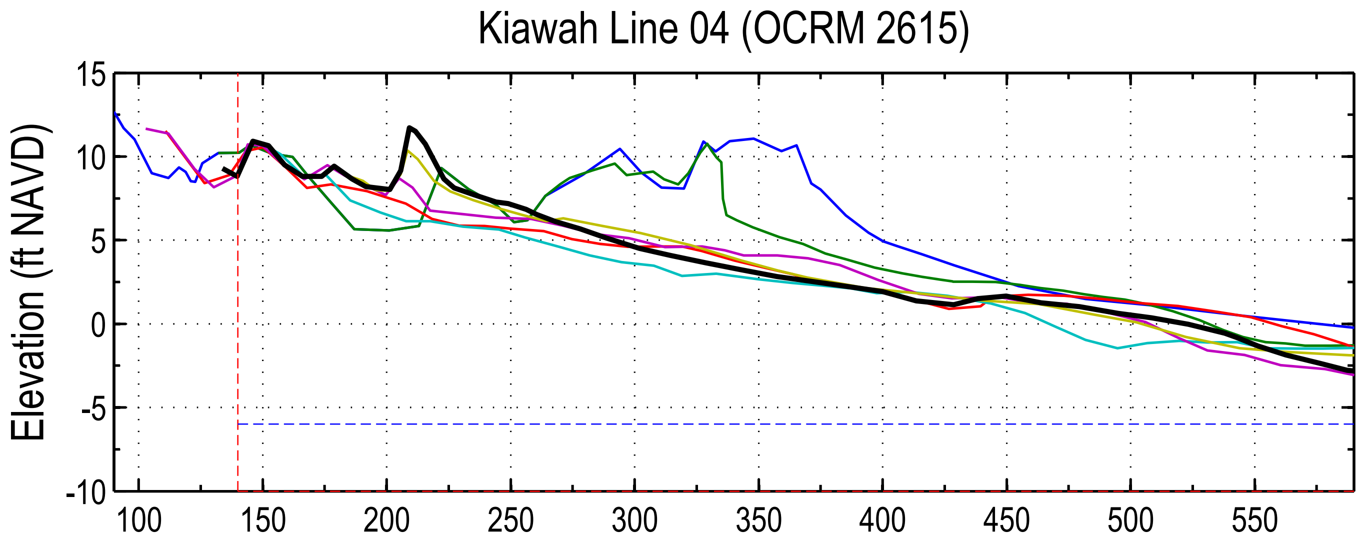
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	265.2	224.1	489.3
Nov 2015	123.9	238.2	362.0
Jan 2017	155.7	250.3	406.0
Nov 2017	192.4	242.9	435.3
Jan 2019	137.1	241.9	379.0
Nov 2019	157.9	242.8	400.6
Nov 2020	181.2	241.4	422.6

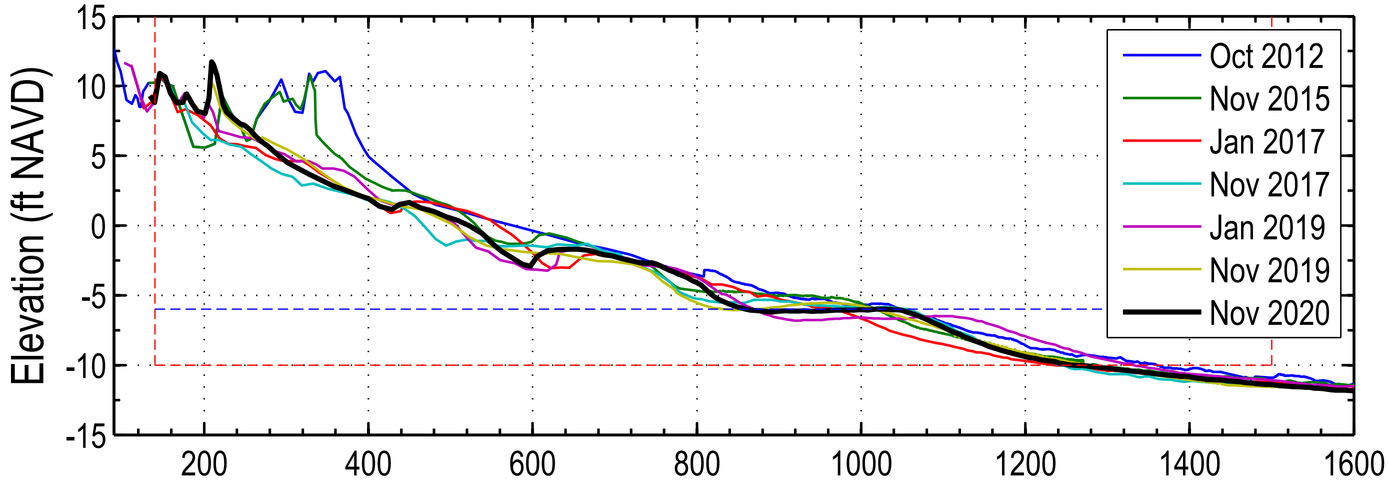
Kiawah Line 03





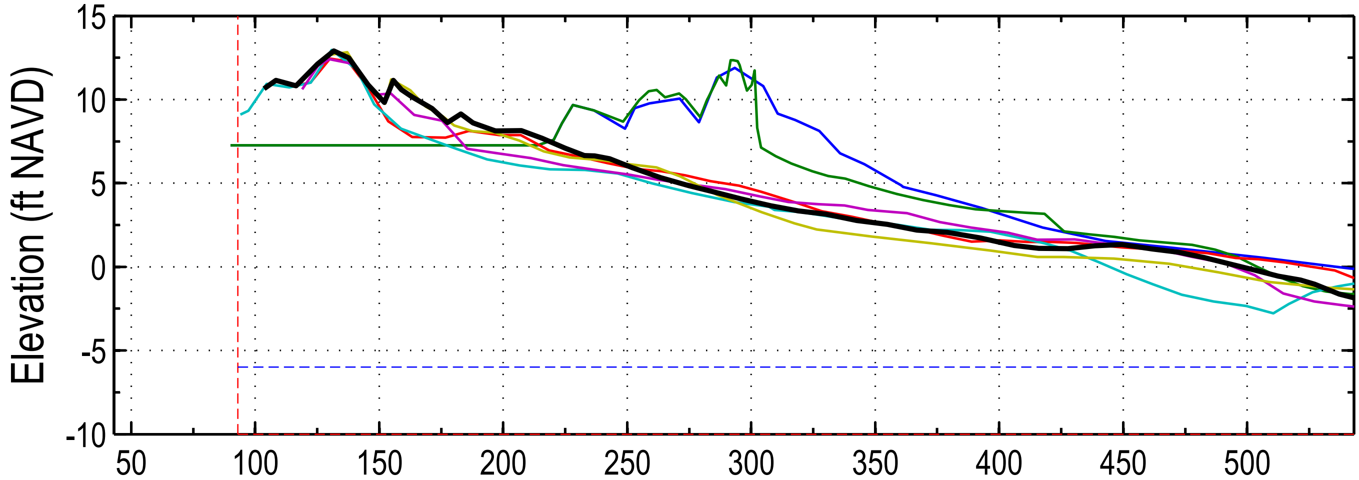
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	184.6	155.1	339.7
Nov 2015	107.4	145.4	252.8
Jan 2017	104.5	152.1	256.5
Nov 2017	141.6	160.4	302.0
Jan 2019	129.2	167.7	296.9
Nov 2019	122.6	155.4	278.0
Nov 2020	118.9	152.3	271.2

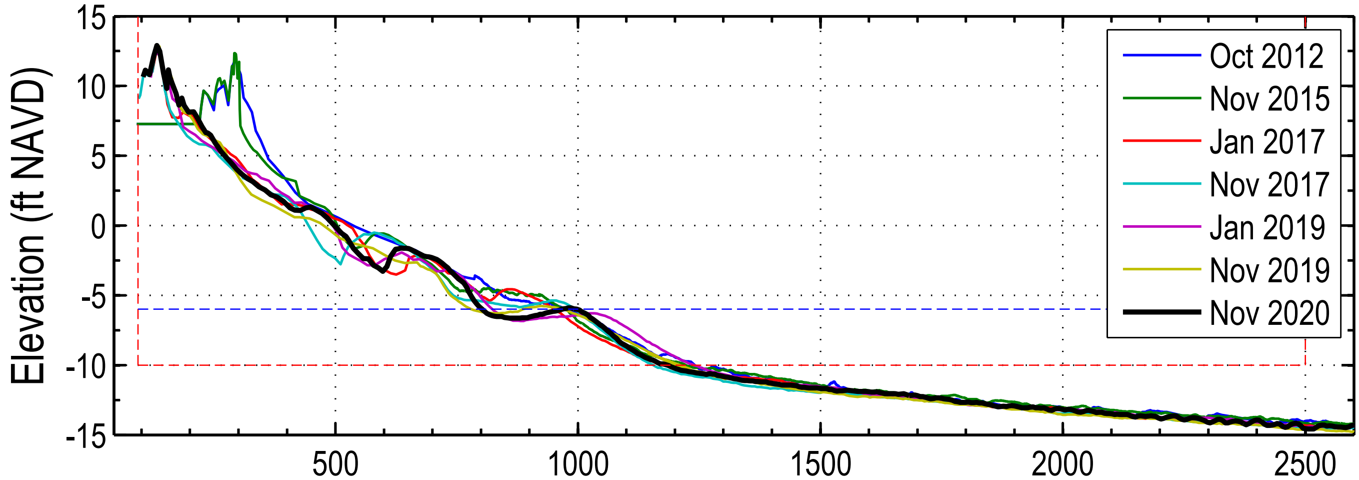




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	234.6	153.6	388.2
Nov 2015	214.7	146.2	360.9
Jan 2017	191.6	138.8	330.5
Nov 2017	177.4	148.2	325.6
Jan 2019	187.9	152.5	340.4
Nov 2019	184.7	147.3	331.9
Nov 2020	189.5	146.8	336.2

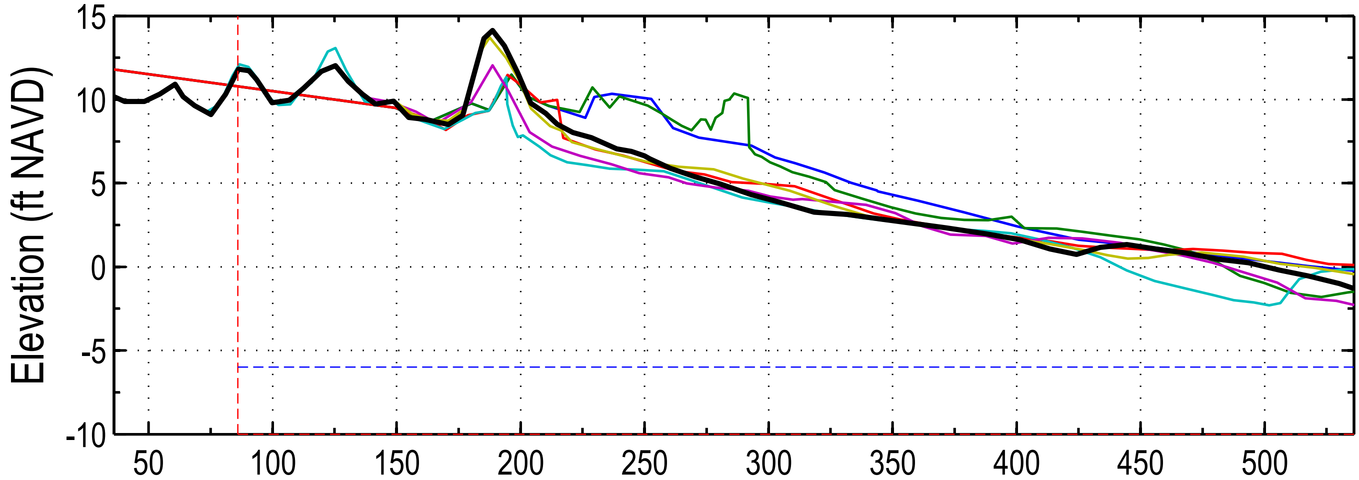
Kiawah Line 05

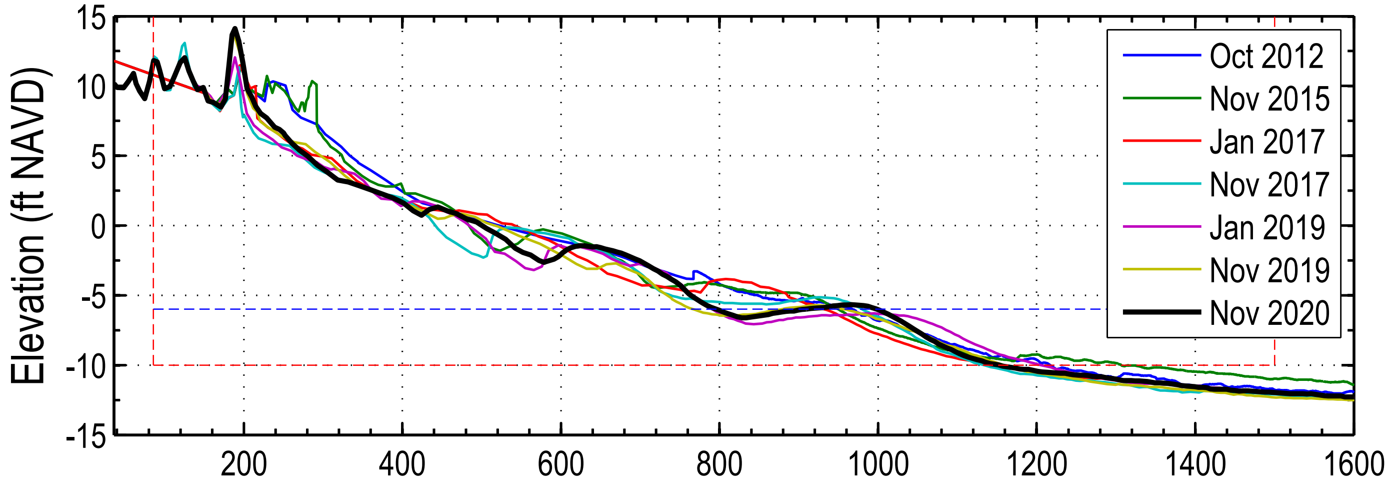




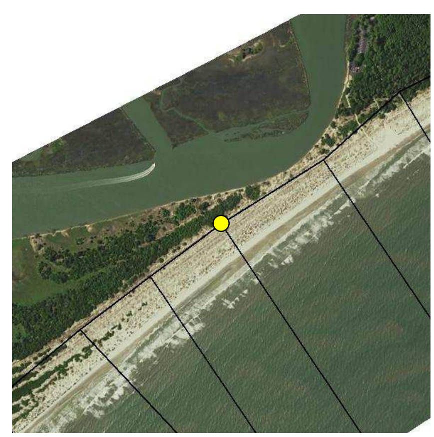
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	235.1	149.3	384.3
Nov 2015	227.3	145.0	372.2
Jan 2017	209.7	141.4	351.2
Nov 2017	196.4	144.6	341.0
Jan 2019	203.4	149.5	352.9
Nov 2019	196.2	146.7	342.9
Nov 2020	205.8	143.7	349.5

Kiawah Line 06 (OCRM 2620)

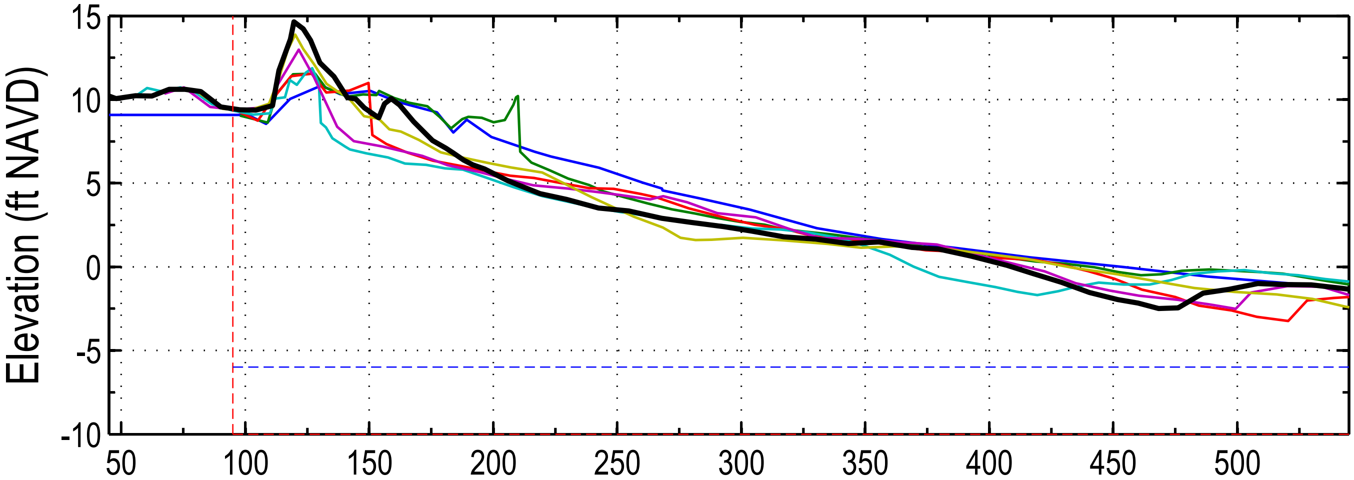


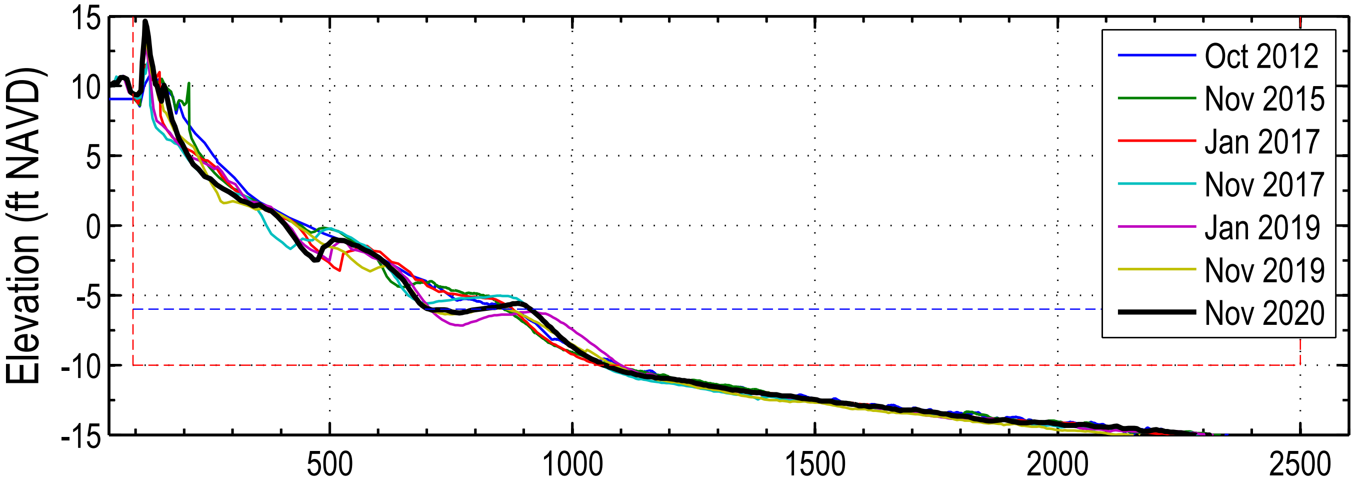


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	238.1	146.4	384.5
Nov 2015	234.1	144.1	378.2
Jan 2017	218.8	138.3	357.1
Nov 2017	206.8	142.8	349.6
Jan 2019	204.7	146.0	350.8
Nov 2019	206.9	143.4	350.3
Nov 2020	213.7	143.8	357.5



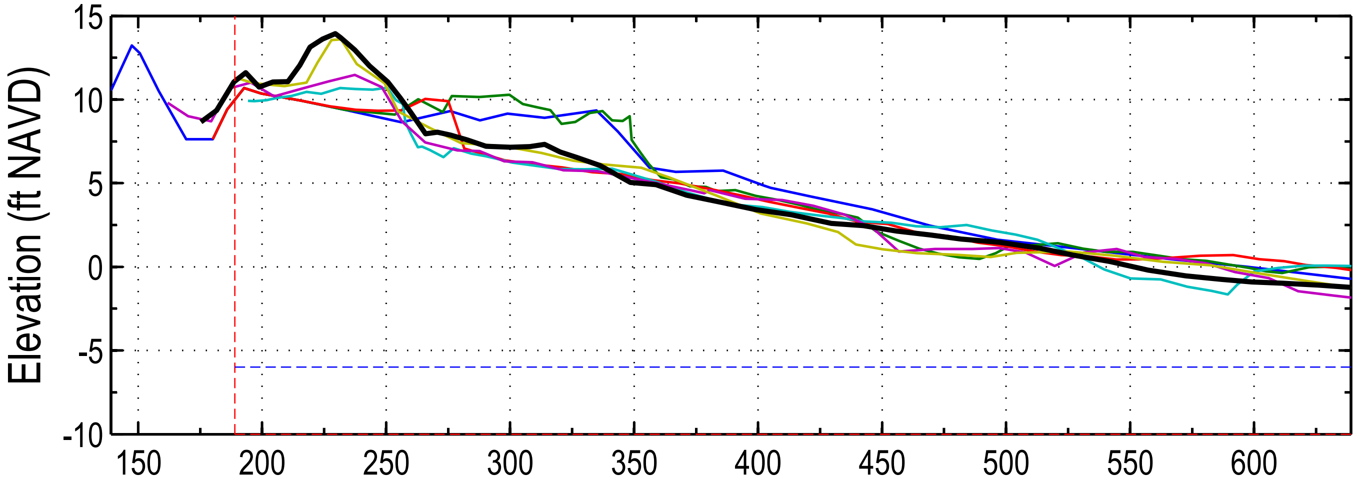
Kiawah Line 07

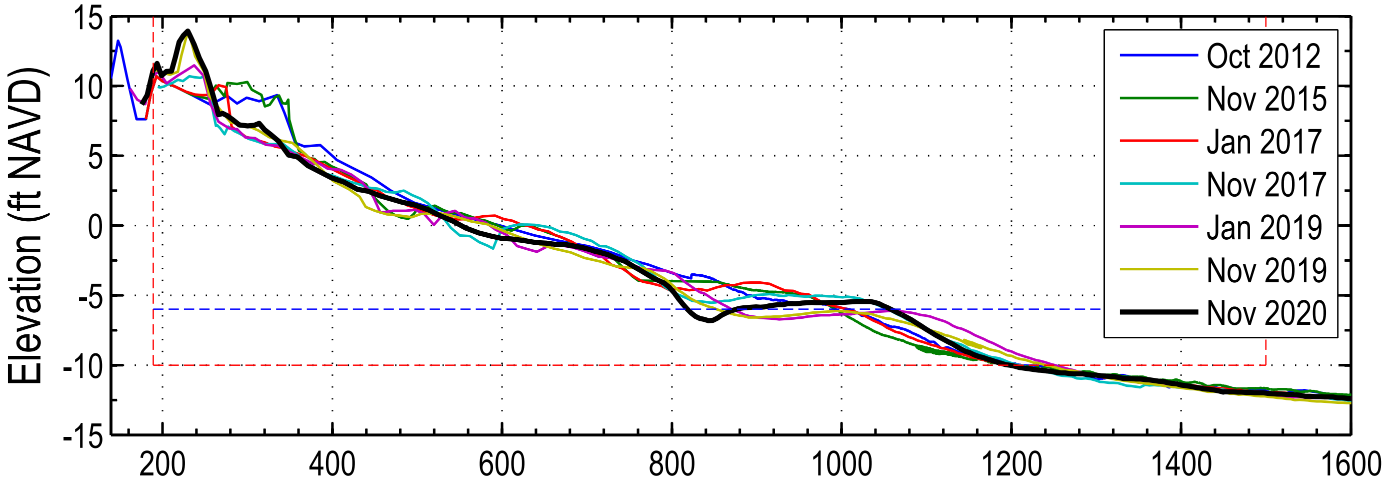




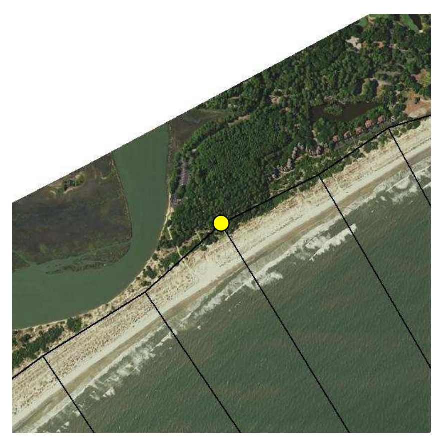
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	187.4	129.3	316.7
Nov 2015	184.3	126.6	310.8
Jan 2017	173.8	126.6	300.4
Nov 2017	162.7	131.2	293.9
Jan 2019	163.9	132.0	296.0
Nov 2019	162.6	129.9	292.6
Nov 2020	165.2	130.8	296.0

Kiawah Line 08 (OCRM 2625)

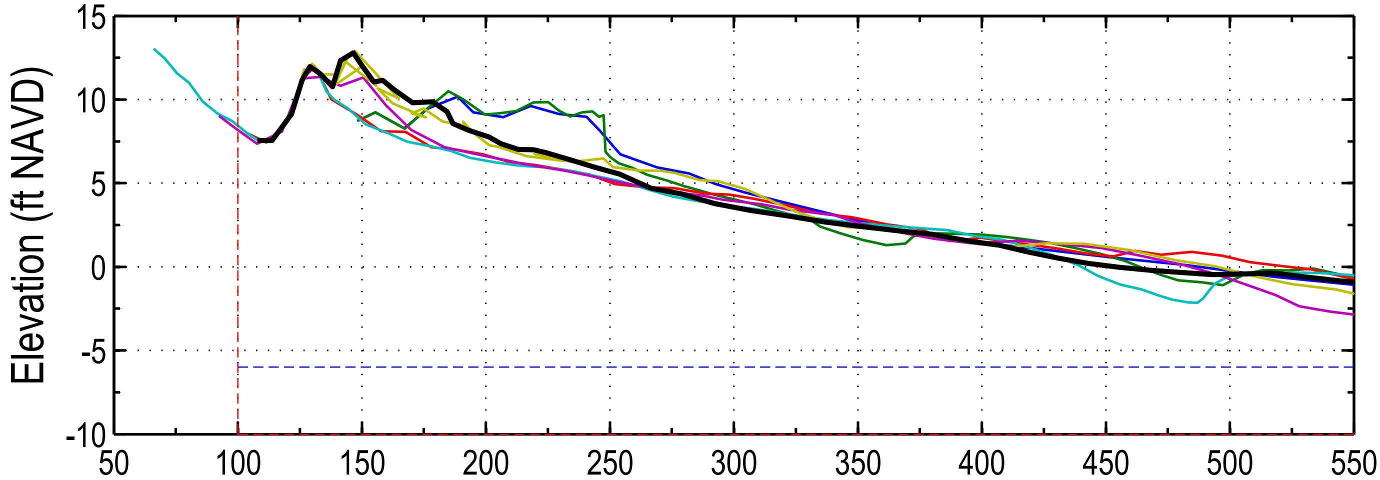


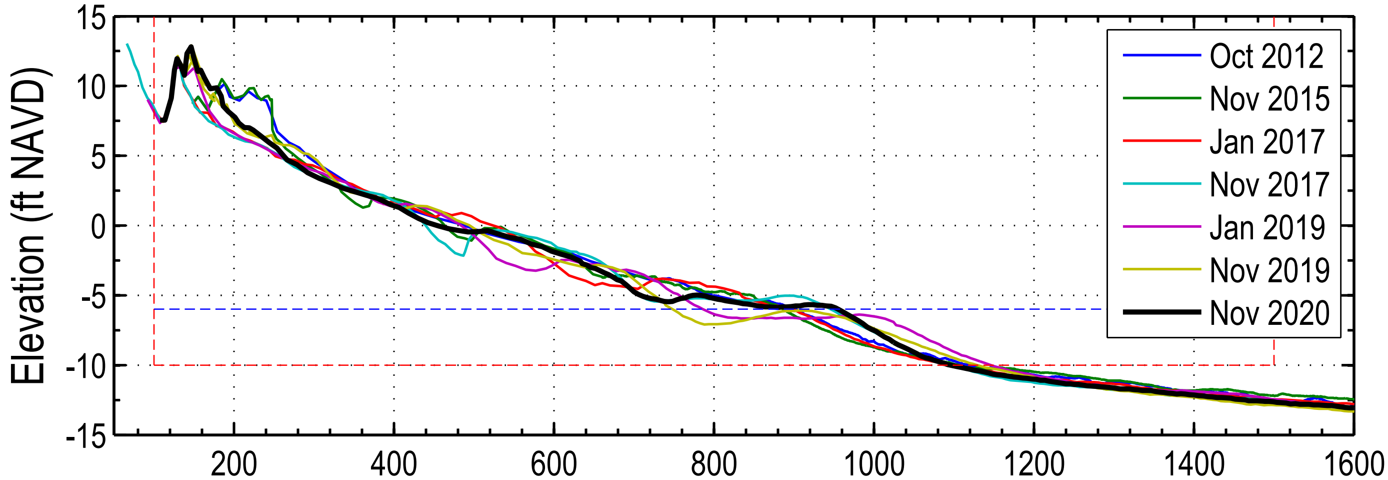


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	213.0	134.6	347.6
Nov 2015	209.6	130.5	340.1
Jan 2017	201.1	133.2	334.3
Nov 2017	198.6	138.4	337.0
Jan 2019	191.0	141.1	332.1
Nov 2019	189.9	137.0	326.9
Nov 2020	194.9	136.8	331.6

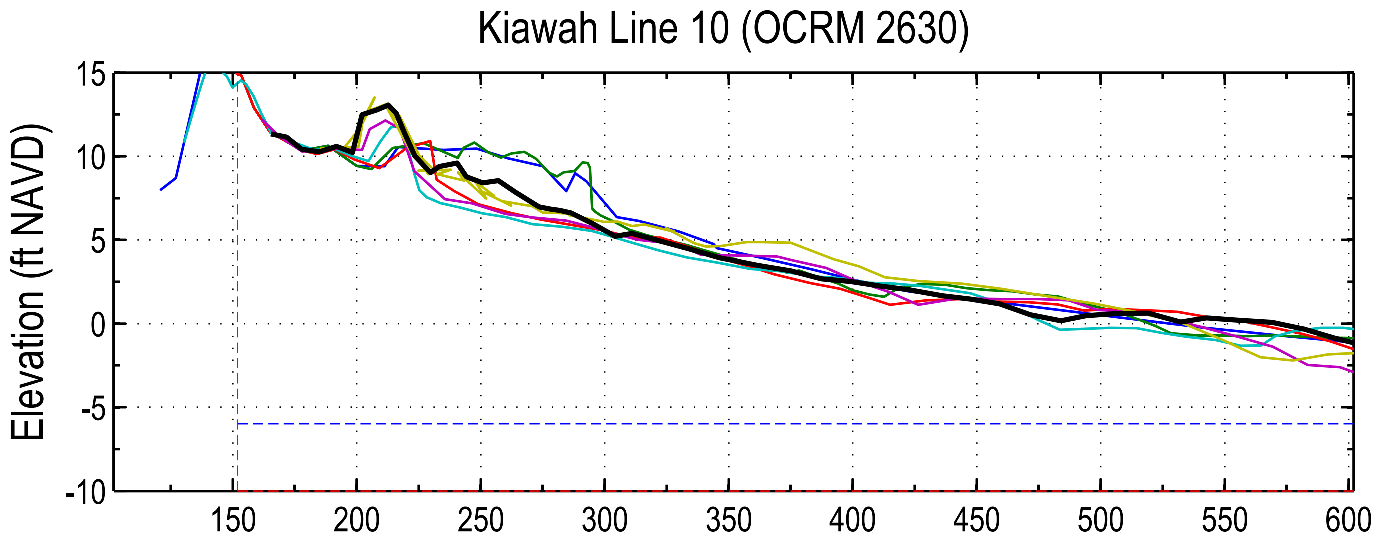


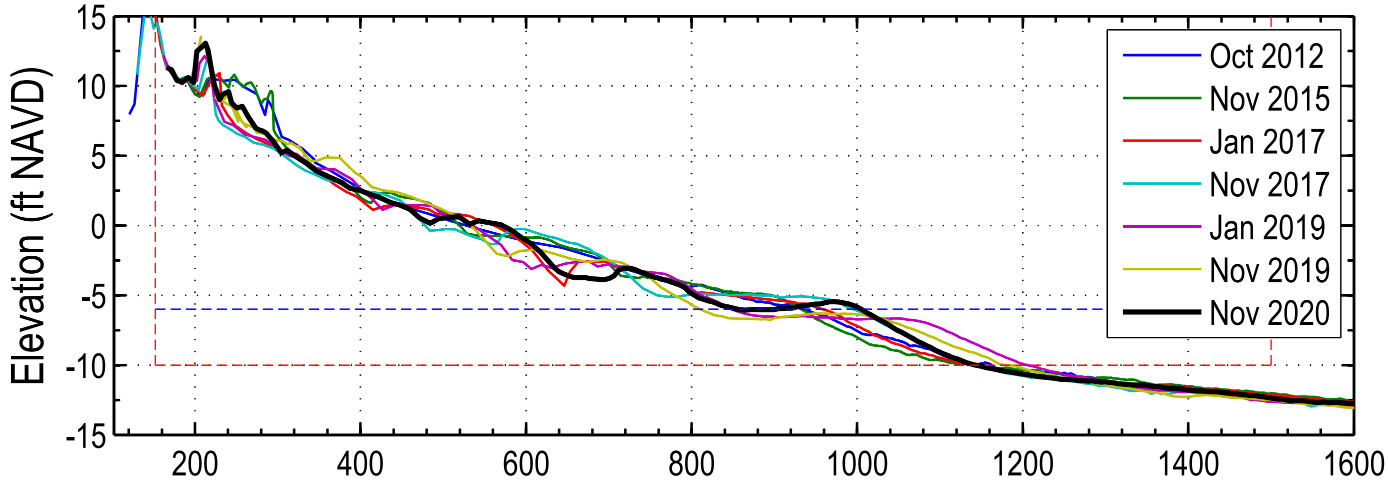
Kiawah Line 09





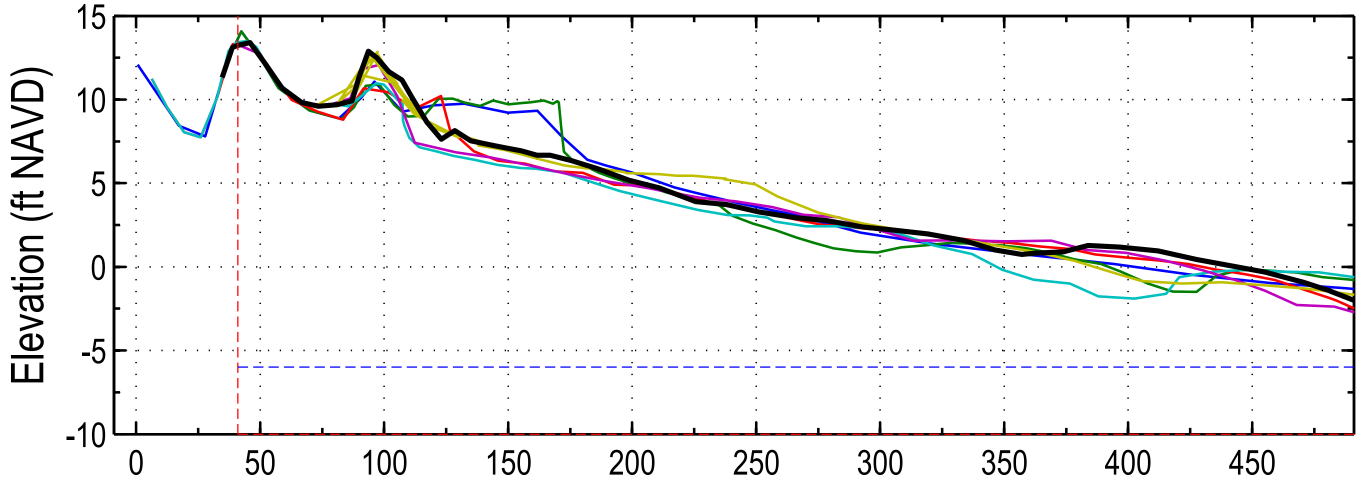
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	202.8	132.2	334.9
Nov 2015	200.0	129.3	329.3
Jan 2017	190.3	130.4	320.7
Nov 2017	185.9	135.6	321.5
Jan 2019	183.3	138.4	321.7
Nov 2019	190.7	133.8	324.5
Nov 2020	190.4	135.9	326.3

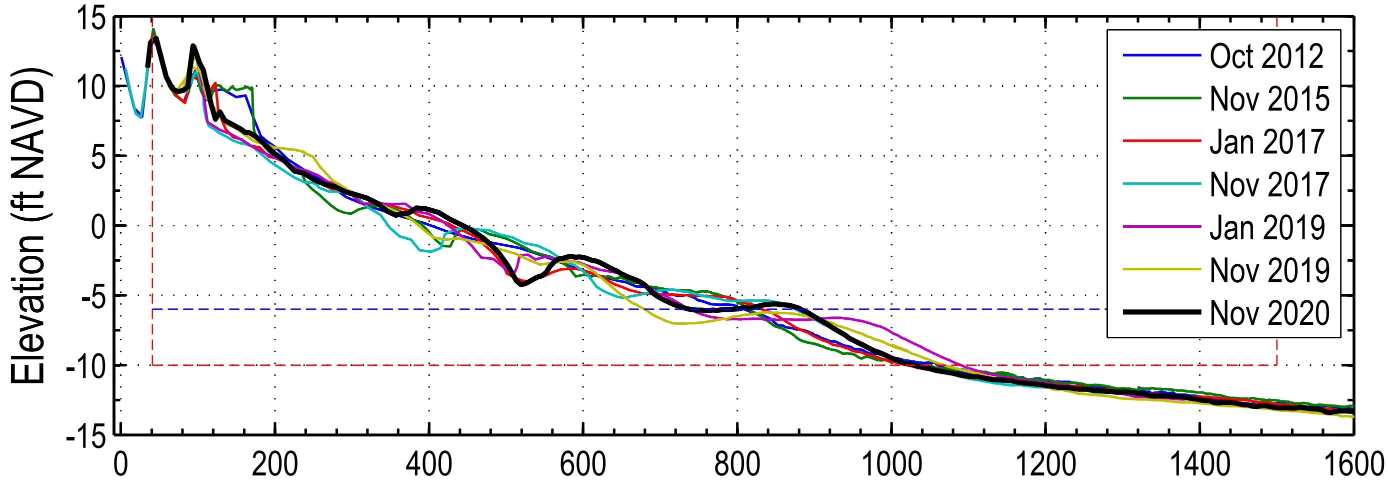




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	205.0	130.8	335.8
Nov 2015	206.5	126.9	333.3
Jan 2017	192.4	130.7	323.1
Nov 2017	193.3	135.2	328.4
Jan 2019	188.8	139.6	328.4
Nov 2019	195.5	135.4	330.9
Nov 2020	192.8	135.5	328.3

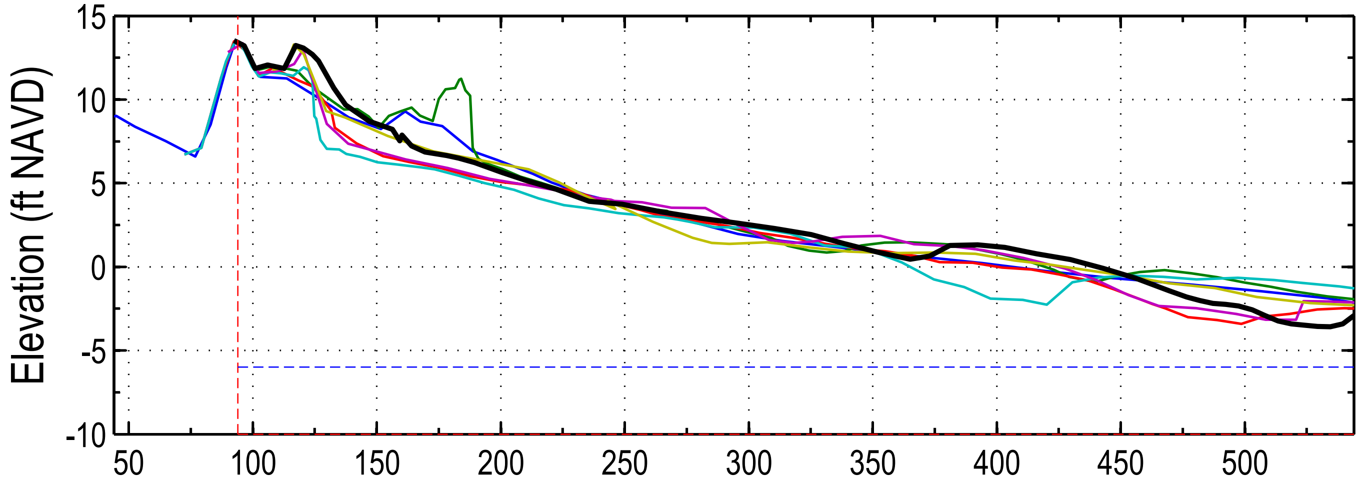
Kiawah Line 11 (OCRM 2635)

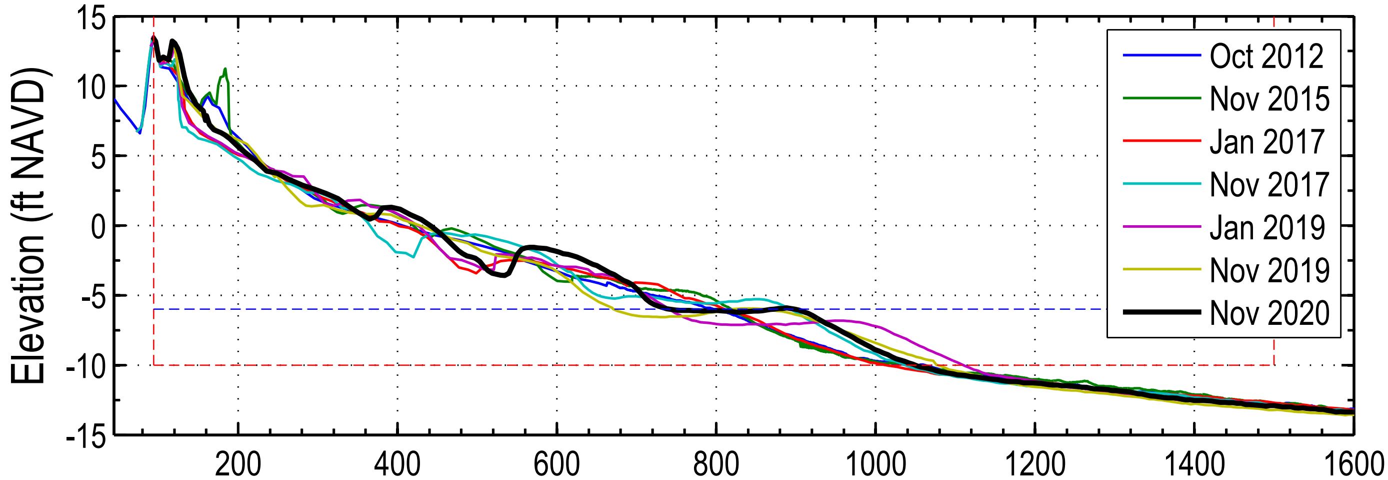




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	194.5	129.3	323.8
Nov 2015	194.0	126.1	320.0
Jan 2017	185.6	129.0	314.6
Nov 2017	183.3	134.1	317.4
Jan 2019	187.4	138.8	326.1
Nov 2019	184.9	133.3	318.2
Nov 2020	191.5	134.2	325.7

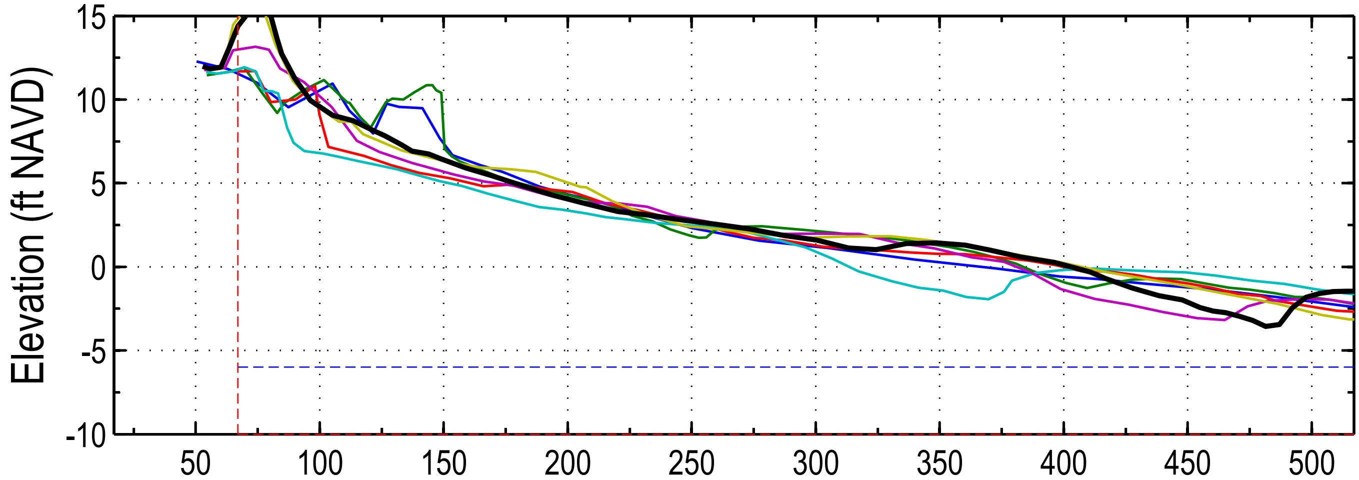
Kiawah Line 12 (OCRM 2640)

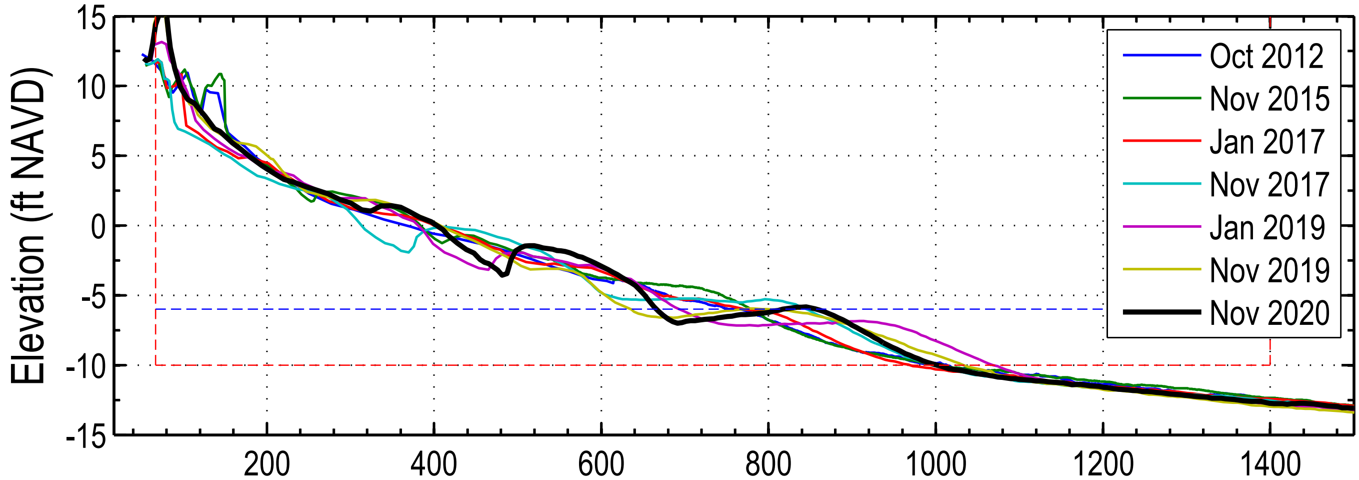




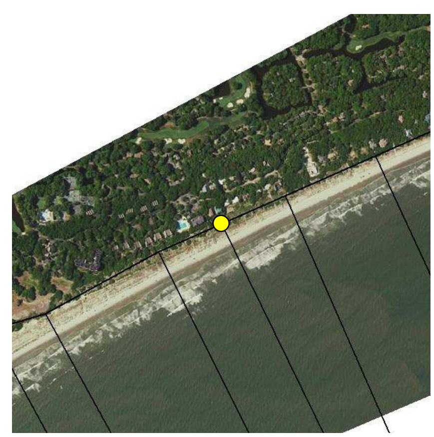
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	165.1	119.8	284.8
Nov 2015	173.4	119.1	292.5
Jan 2017	159.0	119.8	278.8
Nov 2017	157.4	128.0	285.4
Jan 2019	161.5	130.9	292.5
Nov 2019	156.5	129.3	285.8
Nov 2020	169.1	129.6	298.7

Kiawah Line 13

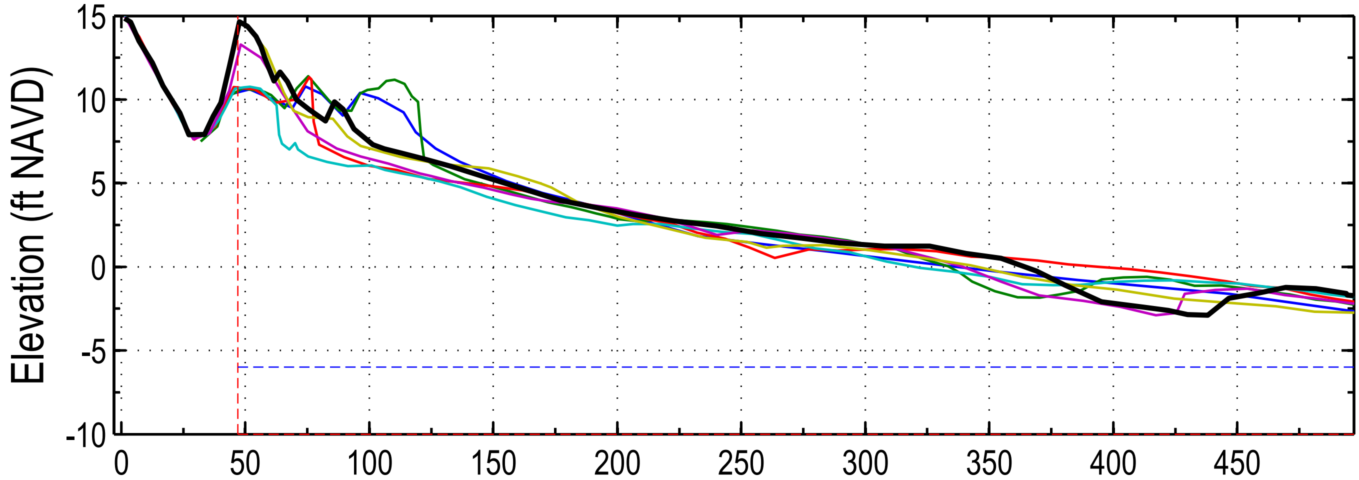


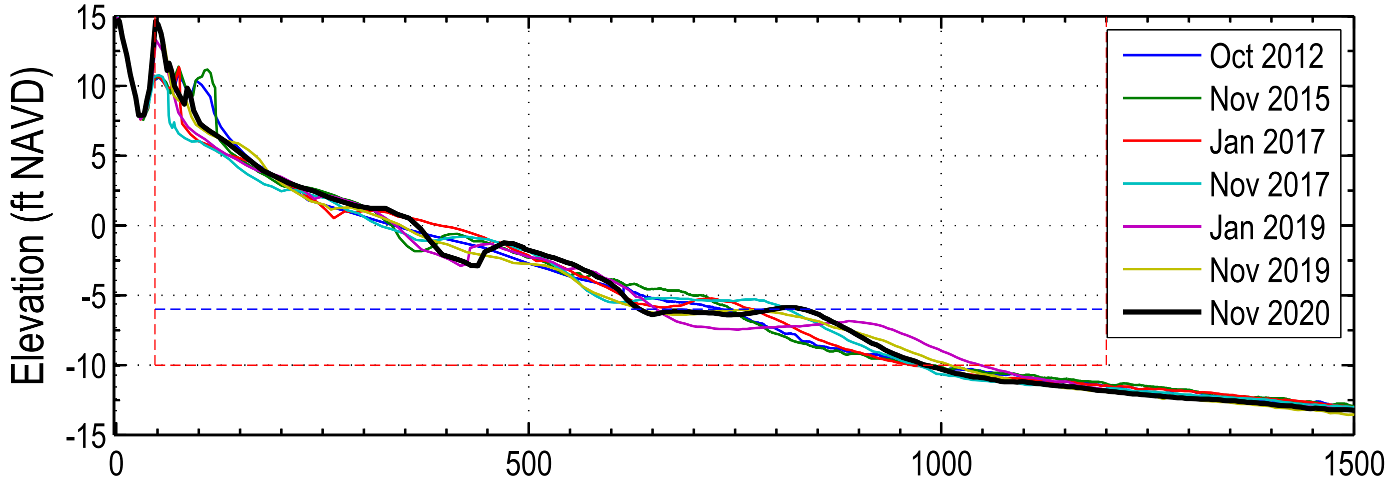


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	159.5	118.2	277.8
Nov 2015	169.3	118.0	287.3
Jan 2017	157.3	119.4	276.7
Nov 2017	148.3	125.7	274.0
Jan 2019	156.9	128.3	285.3
Nov 2019	158.2	127.0	285.2
Nov 2020	163.1	124.5	287.6



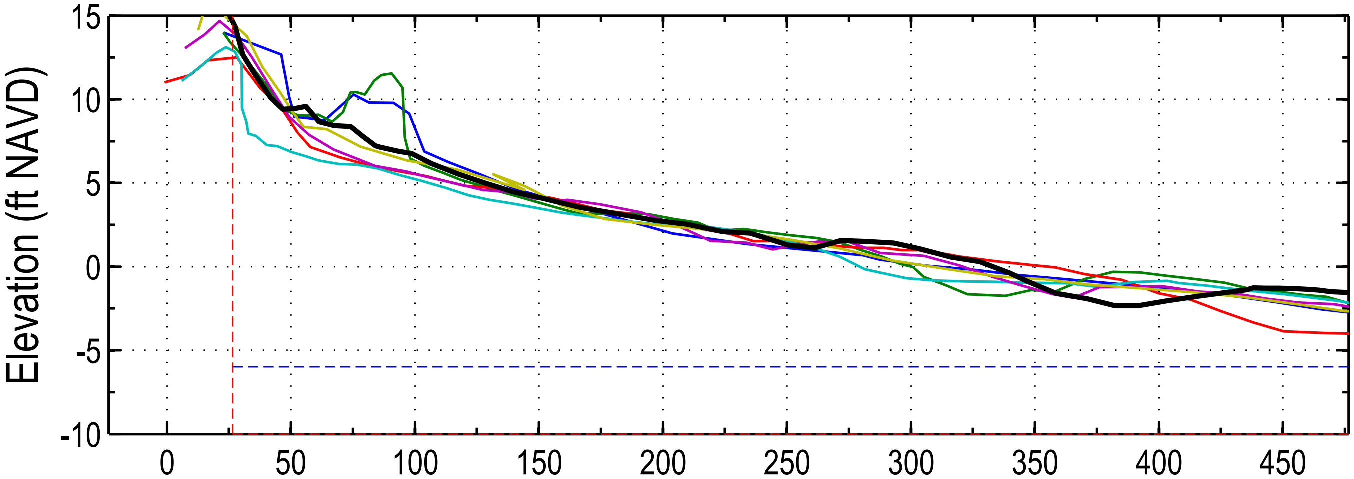
Kiawah Line 14 (OCRM 2645)

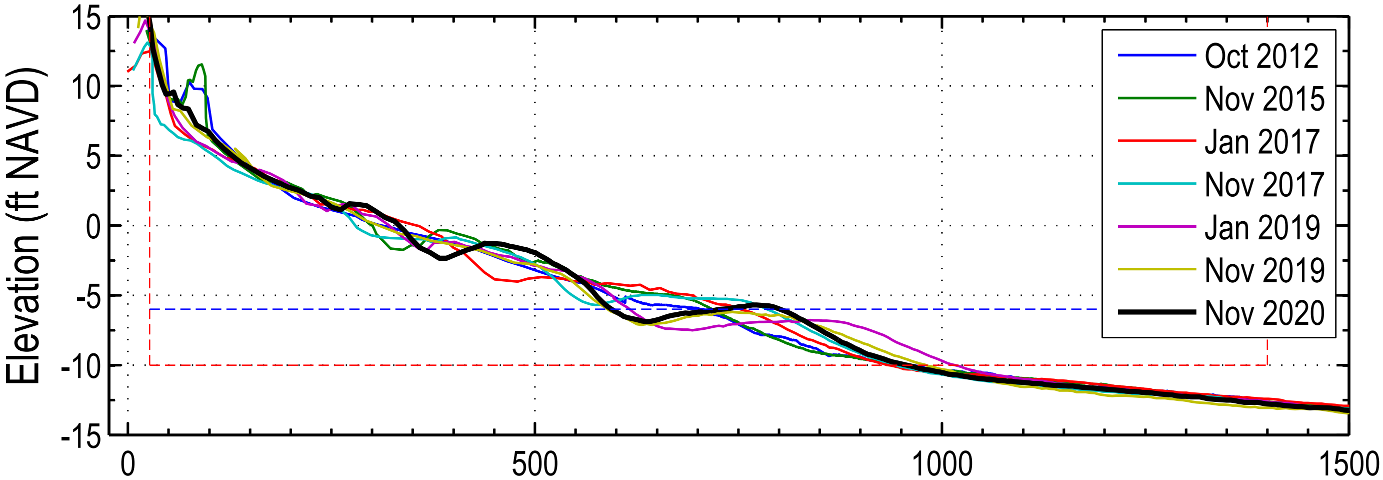




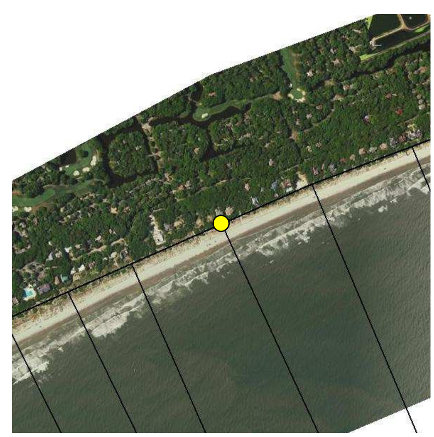
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	153.8	117.0	270.8
Nov 2015	160.4	115.7	276.1
Jan 2017	153.1	119.4	272.5
Nov 2017	145.4	124.1	269.5
Jan 2019	148.6	125.3	273.8
Nov 2019	146.7	126.4	273.0
Nov 2020	155.2	125.6	280.8

Kiawah Line 15

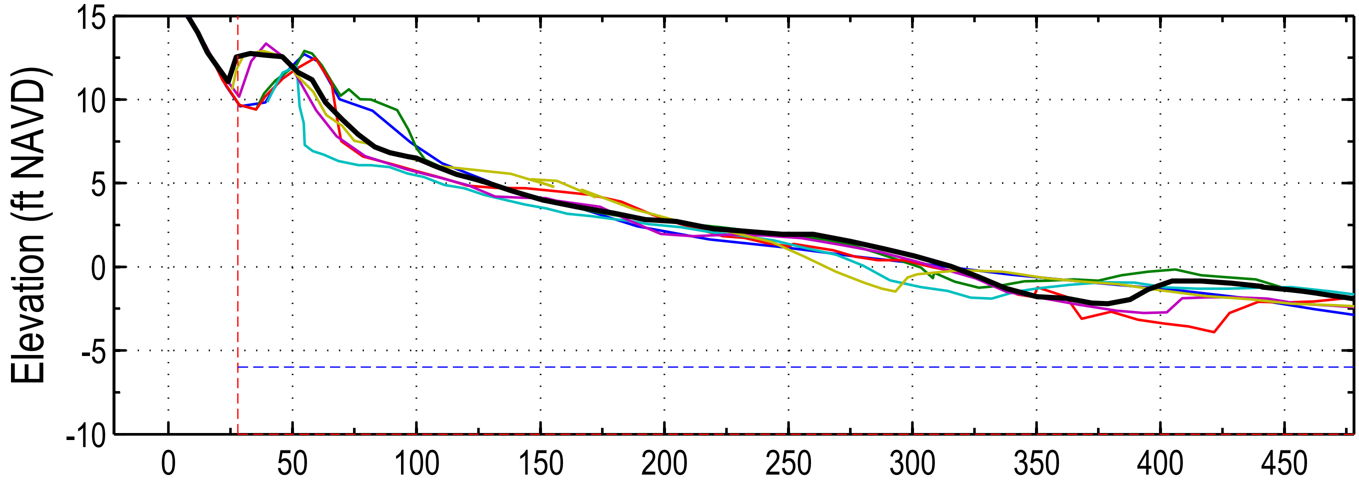


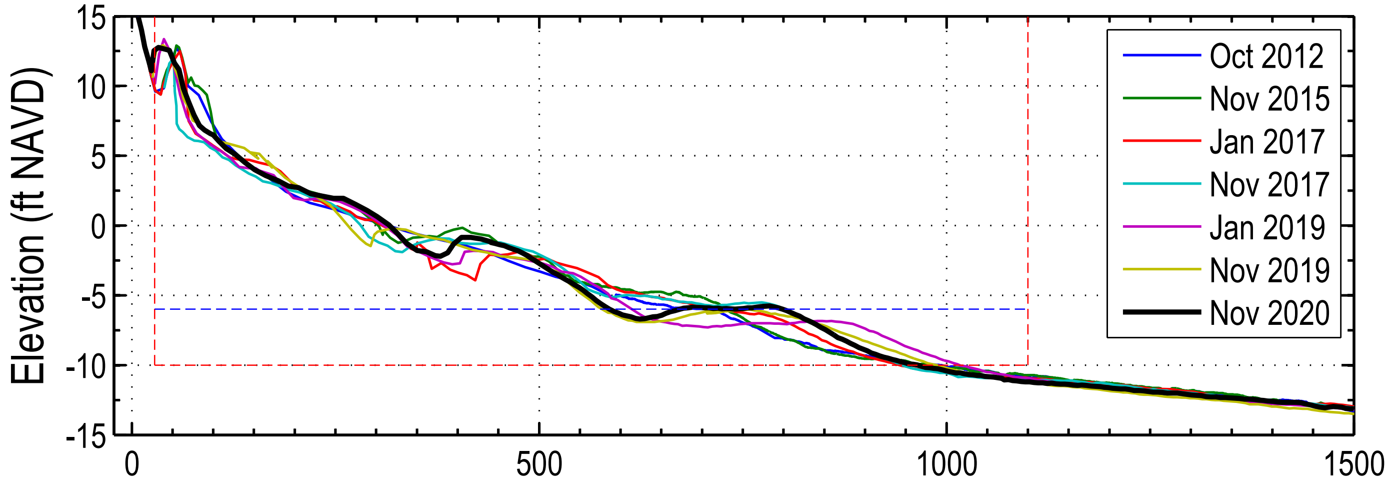


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	152.7	115.4	268.1
Nov 2015	158.4	115.0	273.5
Jan 2017	149.0	120.0	269.0
Nov 2017	141.8	123.1	264.9
Jan 2019	146.6	124.4	271.1
Nov 2019	146.7	122.7	269.4
Nov 2020	151.5	122.8	274.3

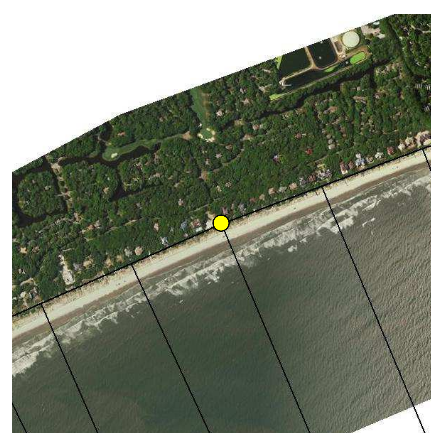


Kiawah Line 16 (OCRM 2660)

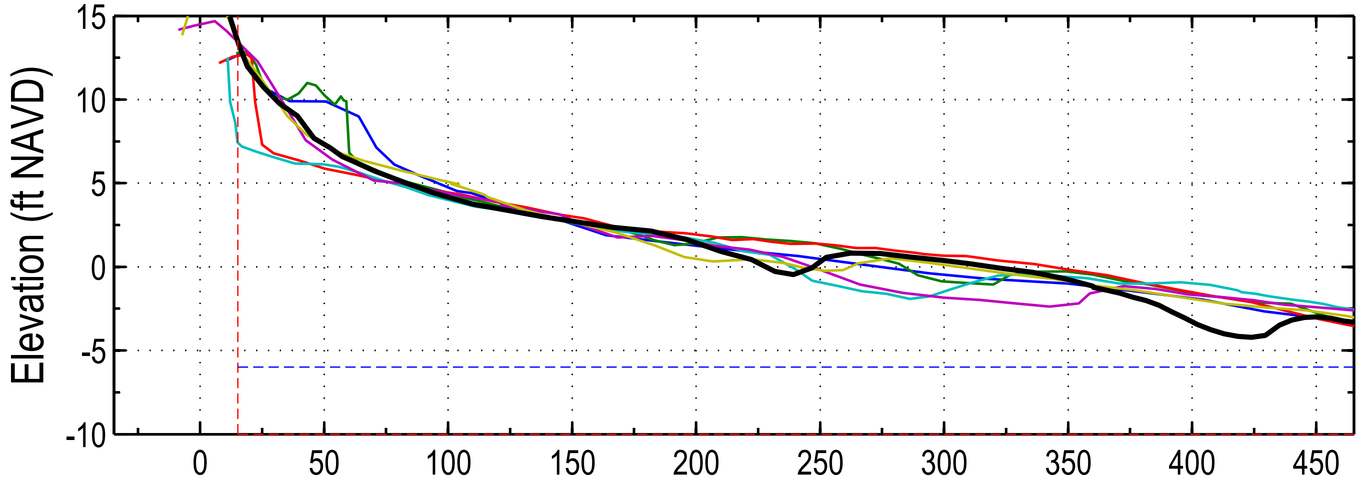


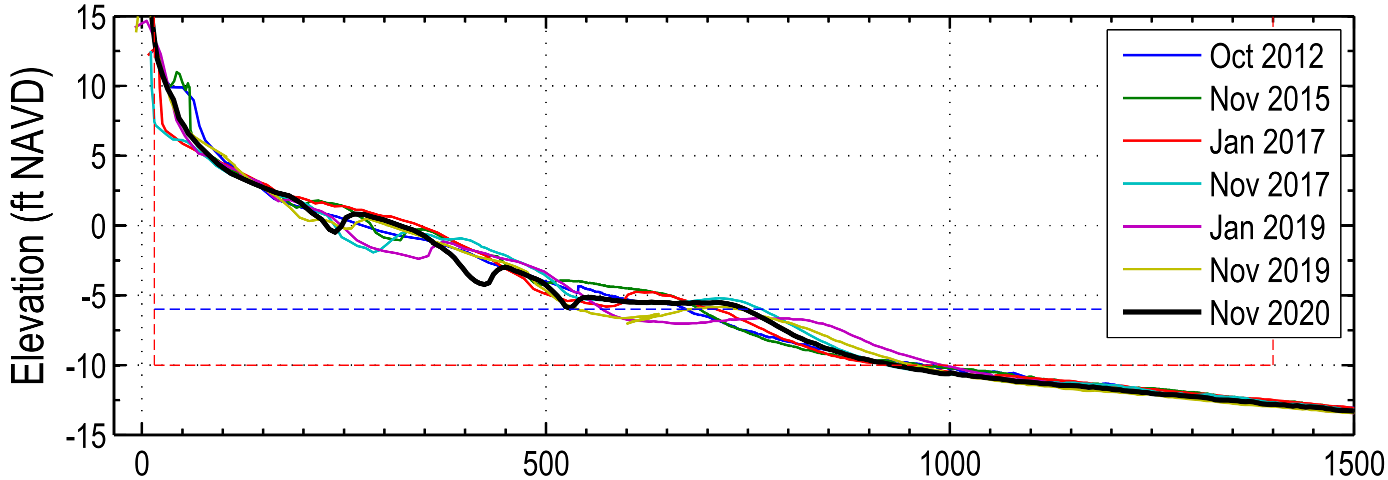


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	149.3	116.1	265.4
Nov 2015	161.1	116.4	277.4
Jan 2017	148.0	120.6	268.6
Nov 2017	145.5	124.7	270.2
Jan 2019	143.7	124.1	267.8
Nov 2019	146.7	123.8	270.5
Nov 2020	149.8	123.6	273.4



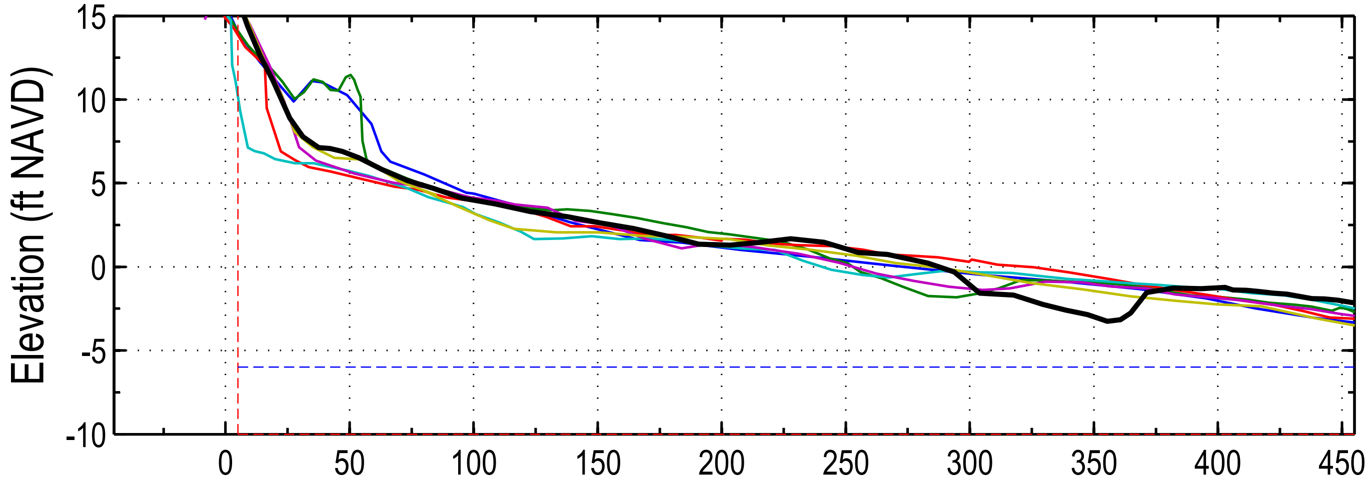
Kiawah Line 17

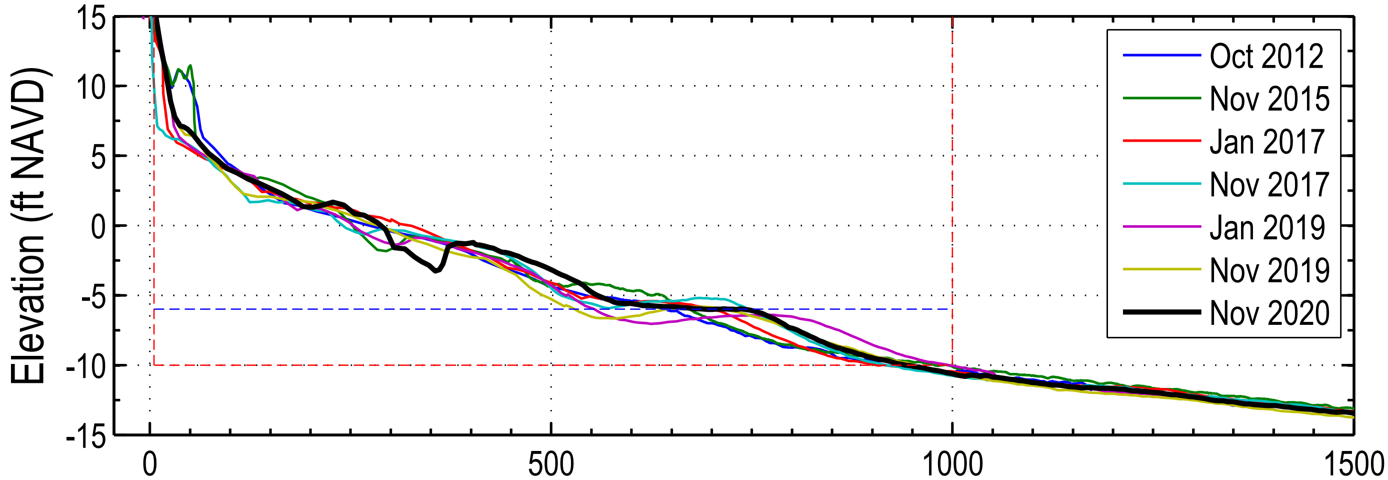




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	137.0	114.7	251.7
Nov 2015	143.8	113.6	257.4
Jan 2017	136.1	115.9	252.0
Nov 2017	129.7	121.6	251.3
Jan 2019	127.7	122.1	249.8
Nov 2019	129.3	121.3	250.6
Nov 2020	130.7	119.4	250.1

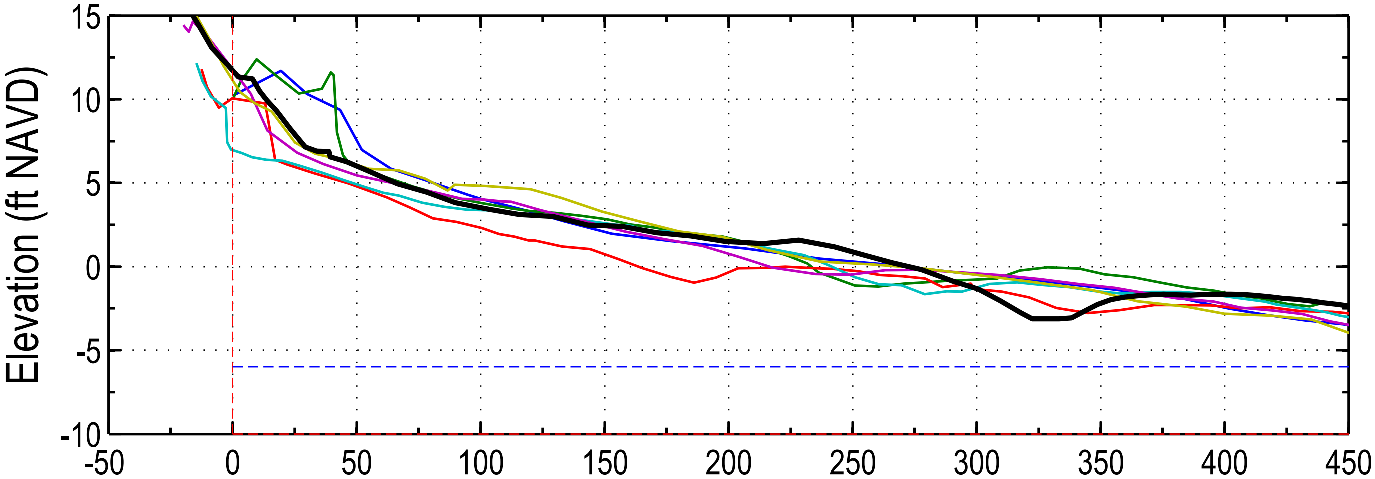
Kiawah Line 18 (OCRM 2665)

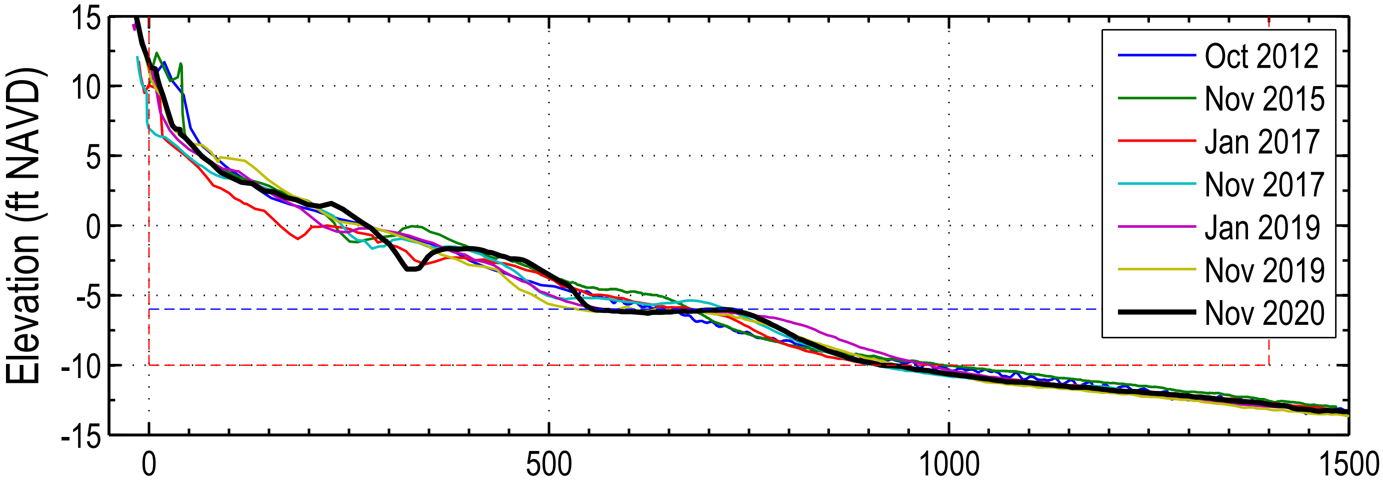




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	139.1	112.9	252.0
Nov 2015	144.8	115.1	259.9
Jan 2017	136.8	116.0	252.8
Nov 2017	129.2	120.5	249.7
Jan 2019	130.5	123.8	254.3
Nov 2019	127.7	120.5	248.2
Nov 2020	139.3	122.4	261.7

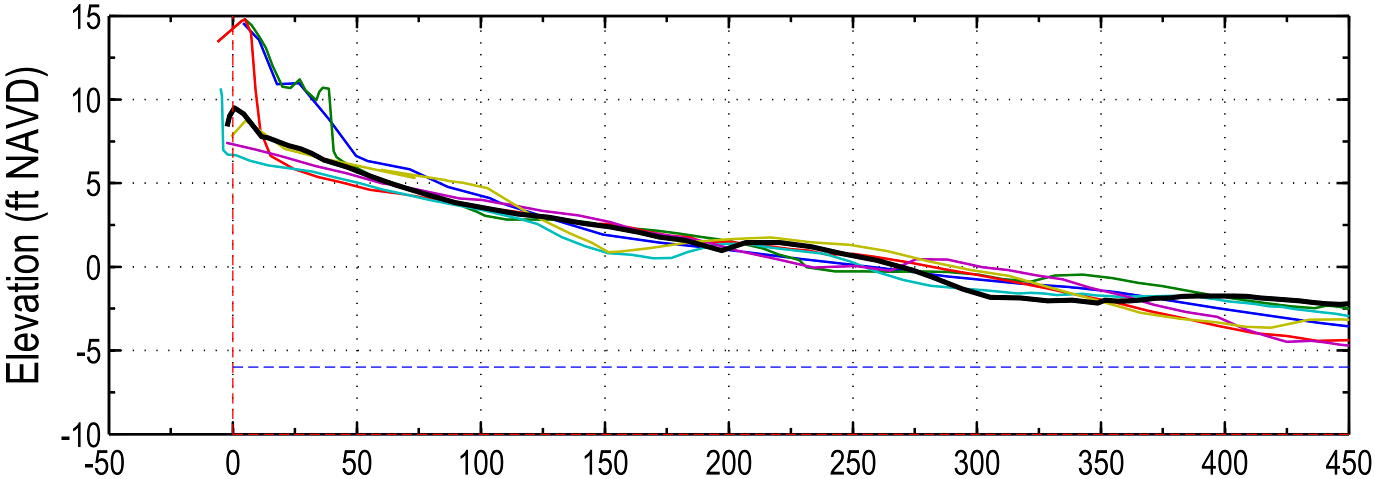
Kiawah Line 19

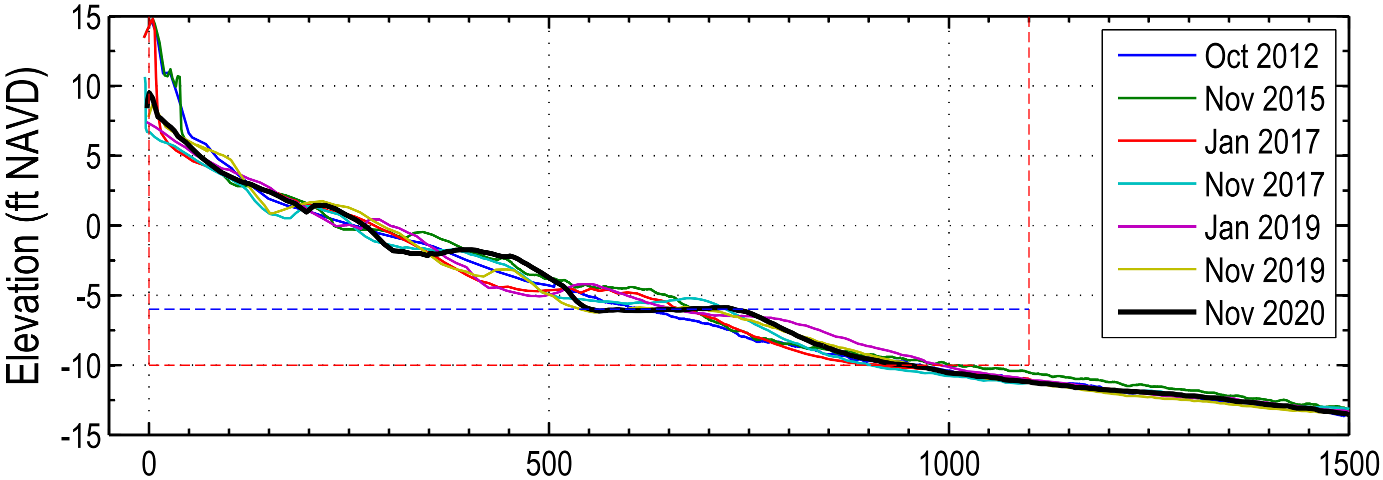




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	136.4	115.6	252.1
Nov 2015	145.1	116.6	261.7
Jan 2017	117.2	116.0	233.2
Nov 2017	125.9	119.1	245.0
Jan 2019	125.7	125.7	251.3
Nov 2019	128.9	120.2	249.1
Nov 2020	132.7	119.7	252.4

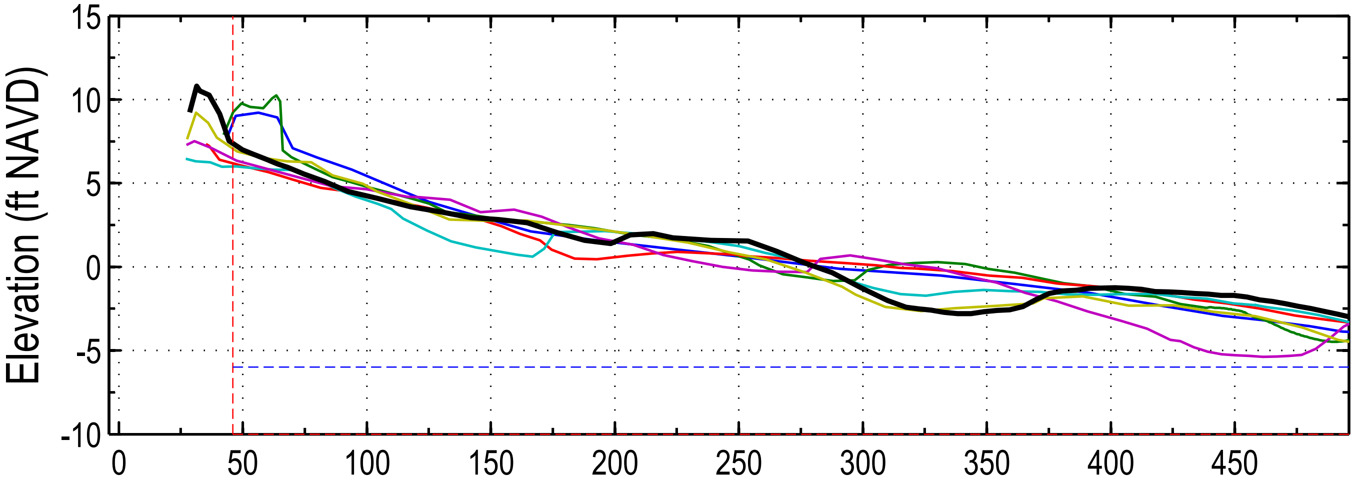
Kiawah Line 20 (OCRM 2675)

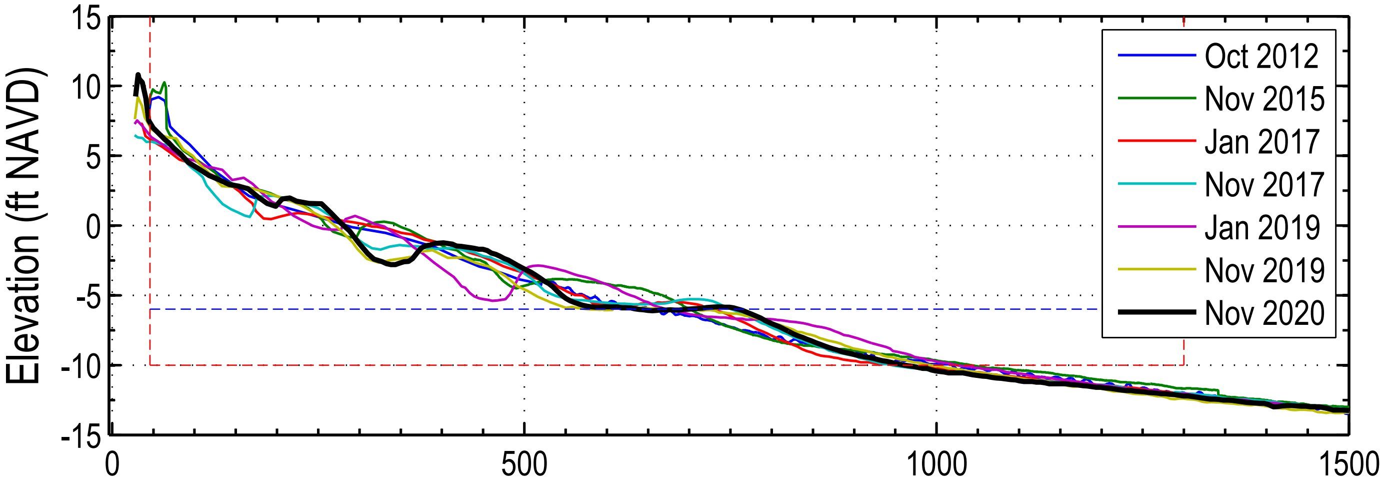




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	134.9	113.3	248.2
Nov 2015	144.6	117.2	261.7
Jan 2017	127.0	113.6	240.6
Nov 2017	122.4	118.0	240.5
Jan 2019	126.2	126.8	252.9
Nov 2019	125.8	121.6	247.4
Nov 2020	129.5	121.5	250.9

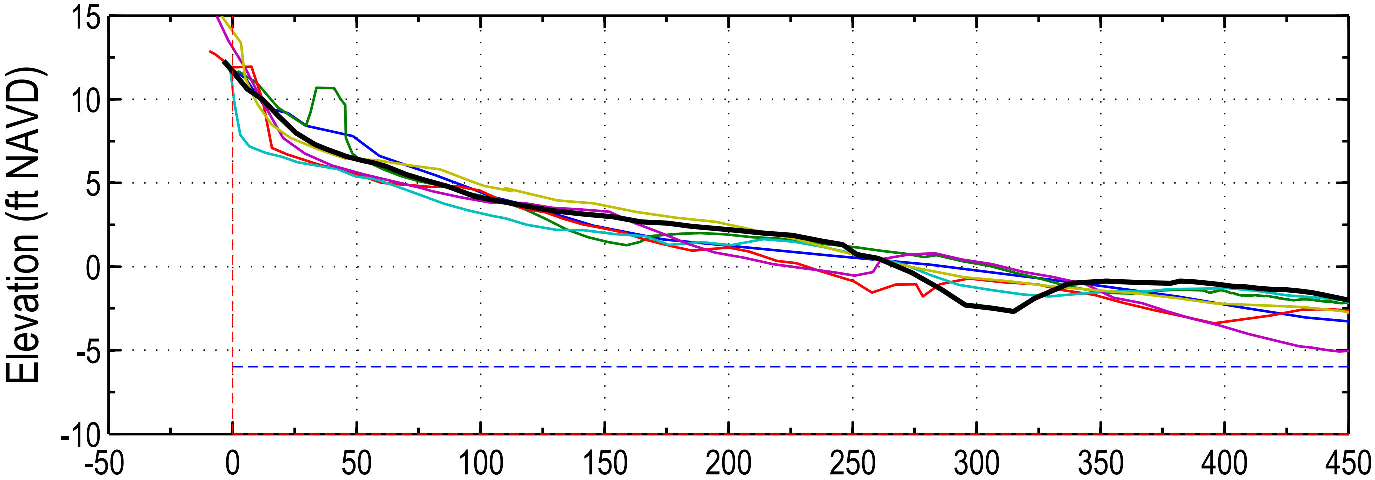
Kiawah Line 21 (OCRM 2680)

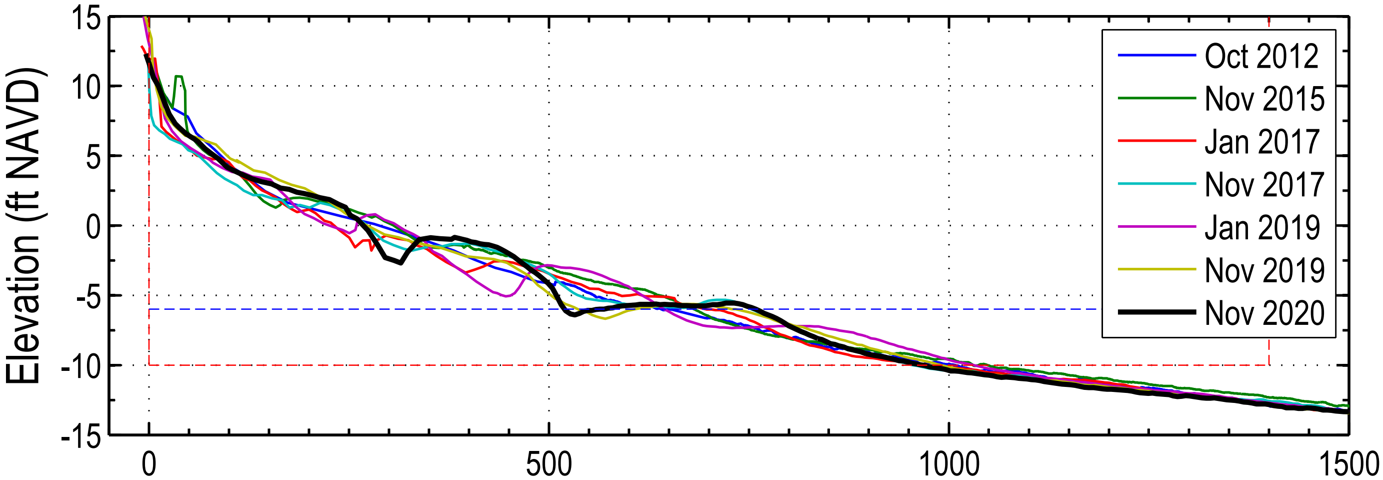




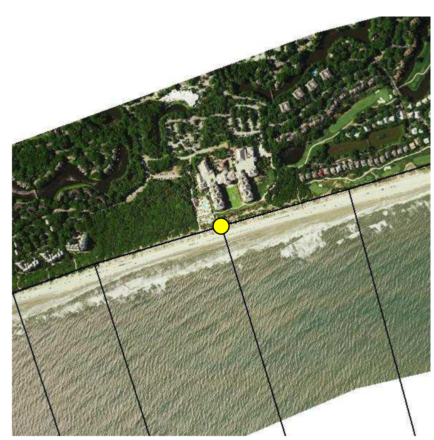
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	120.5	113.6	234.0
Nov 2015	128.7	115.1	243.8
Jan 2017	118.5	113.3	231.8
Nov 2017	114.6	116.8	231.4
Jan 2019	116.6	123.6	240.2
Nov 2019	108.4	120.1	228.5
Nov 2020	115.9	118.2	234.1

Kiawah Line 22 (Sanctuary)

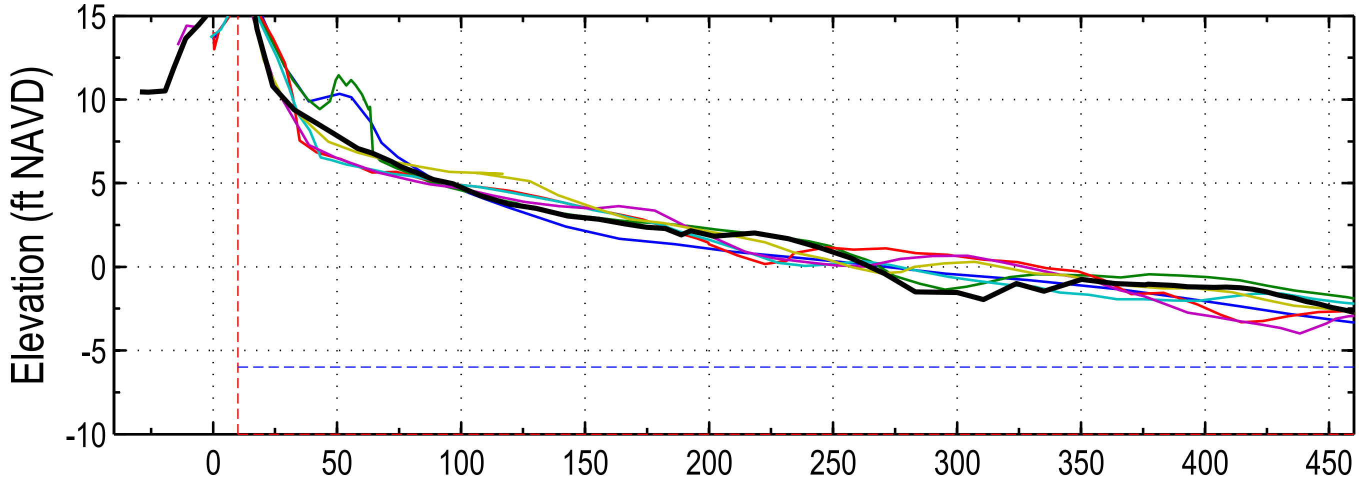


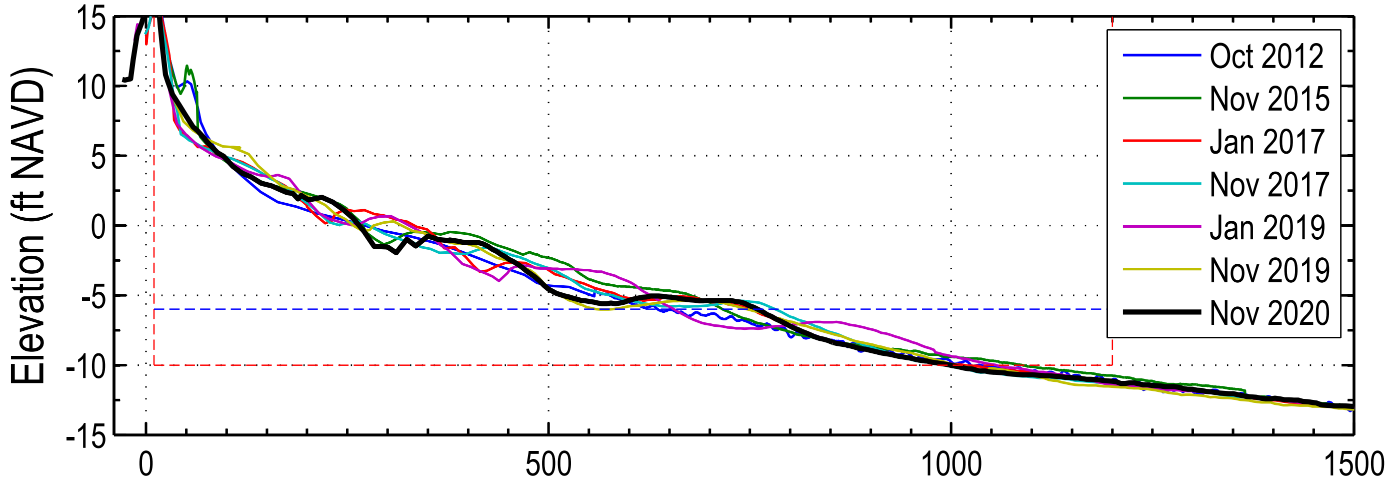


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	138.3	120.0	258.2
Nov 2015	150.2	121.6	271.9
Jan 2017	131.8	120.2	252.0
Nov 2017	132.7	124.6	257.4
Jan 2019	135.8	126.3	262.2
Nov 2019	138.9	126.2	265.1
Nov 2020	139.2	124.6	263.8



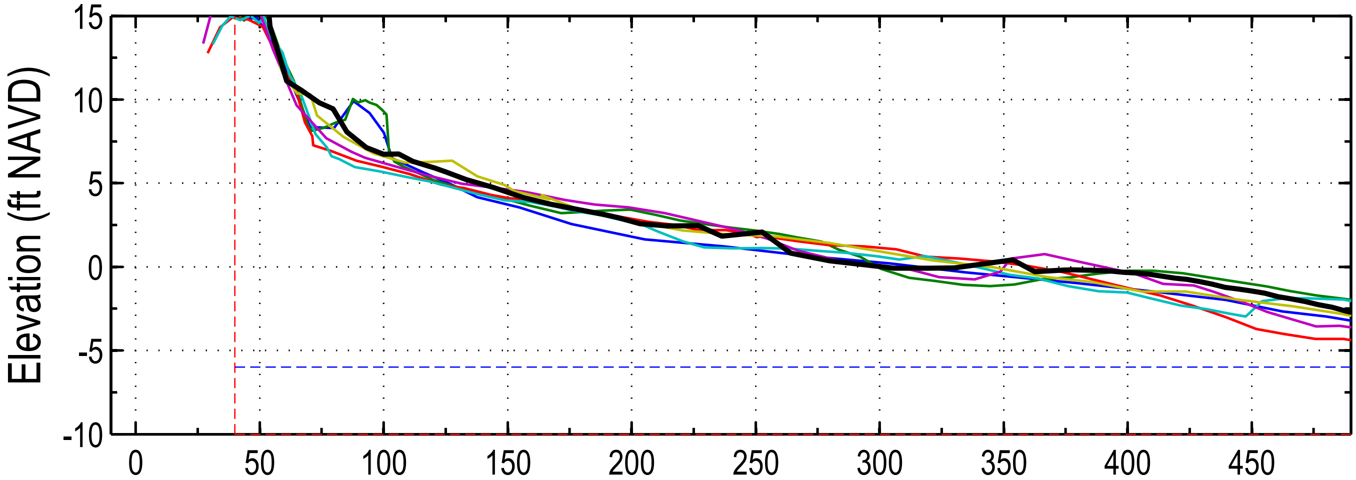
Kiawah Line 23 (OCRM 2685)

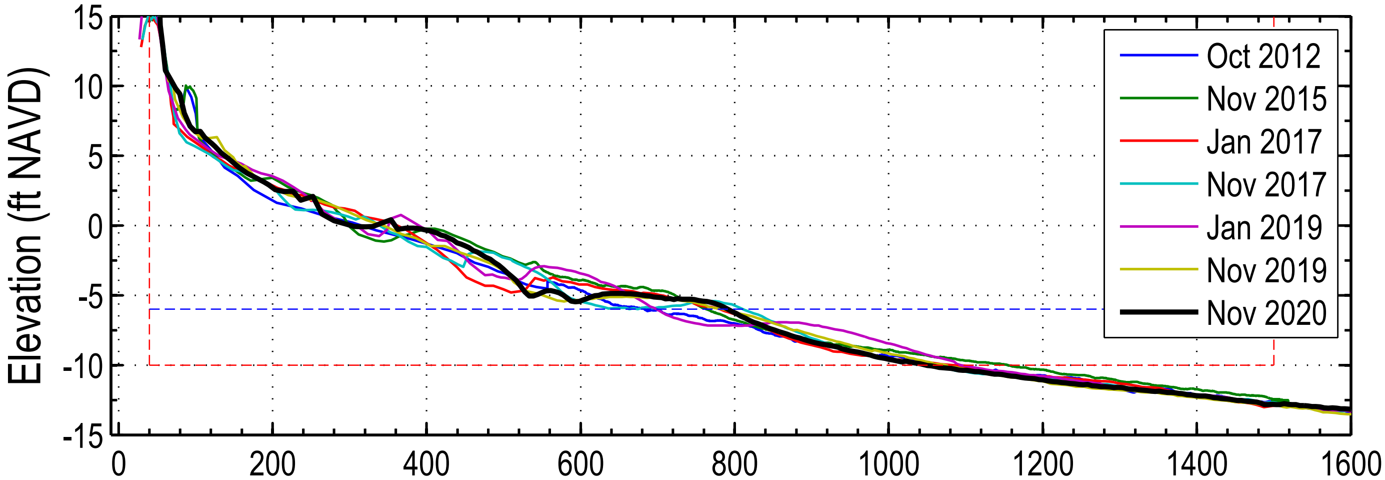




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	139.2	122.1	261.3
Nov 2015	160.0	125.5	285.4
Jan 2017	148.1	124.5	272.7
Nov 2017	144.0	127.5	271.5
Jan 2019	146.1	128.9	275.0
Nov 2019	144.8	127.6	272.4
Nov 2020	142.7	124.5	267.2

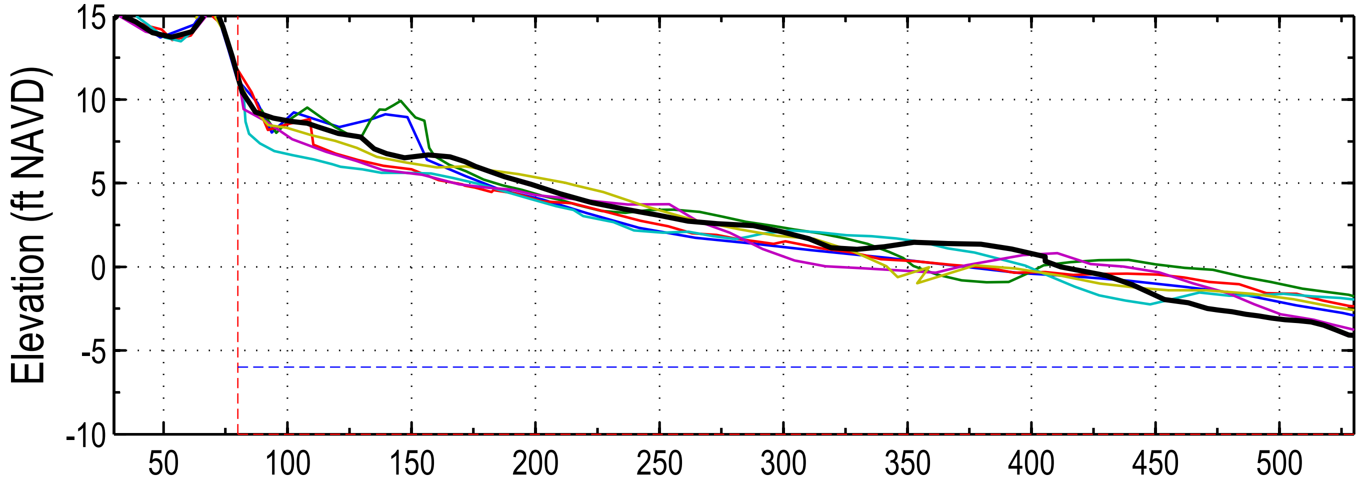
Kiawah Line 24 (OCRM 2687)

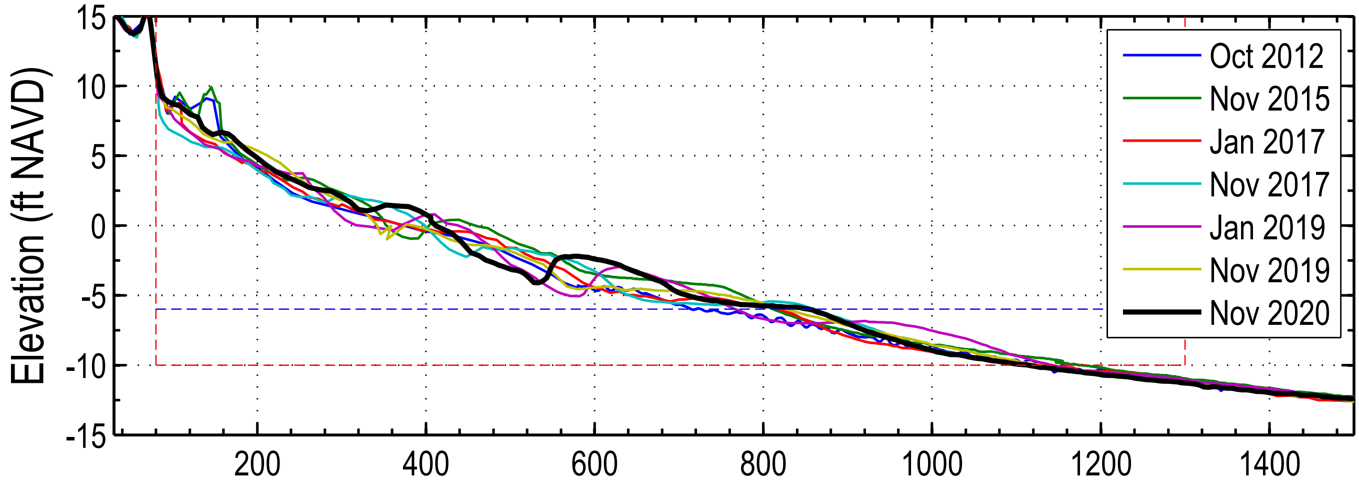




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	142.2	123.4	265.6
Nov 2015	162.4	129.2	291.6
Jan 2017	148.2	125.4	273.7
Nov 2017	144.9	128.5	273.4
Jan 2019	155.2	131.6	286.8
Nov 2019	151.9	130.2	282.1
Nov 2020	154.9	126.4	281.3

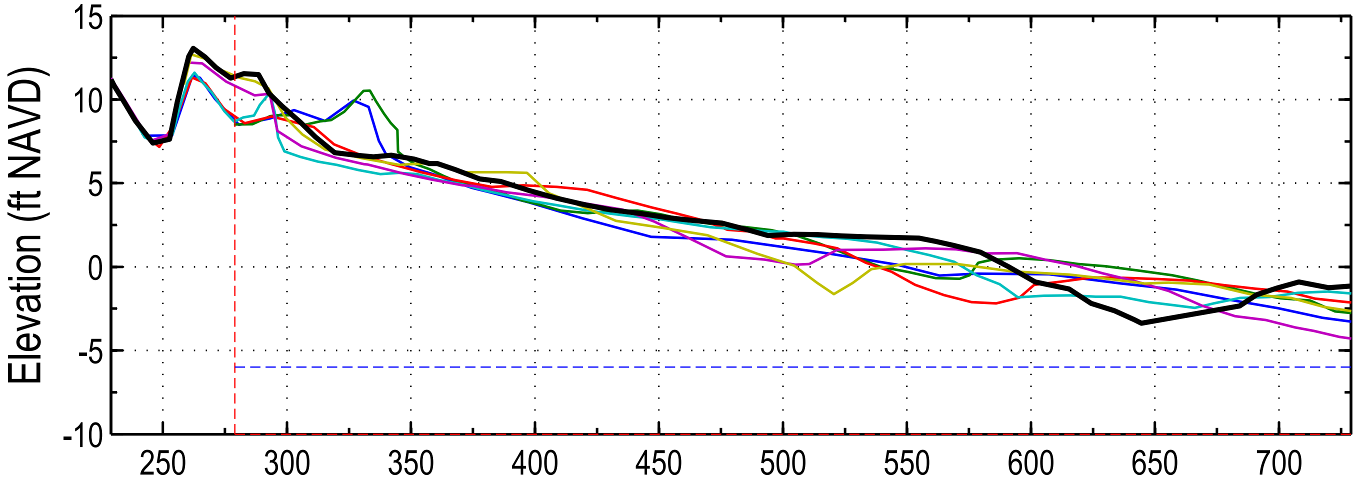
Kiawah Line 25 (OCRM 2690)

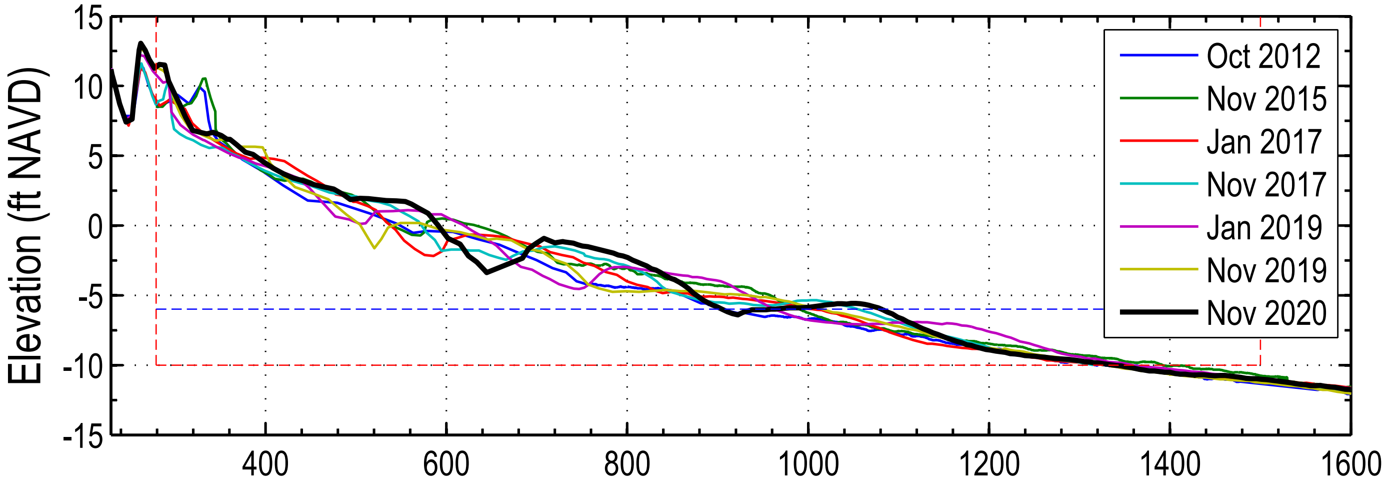




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	146.2	125.7	271.9
Nov 2015	168.1	130.9	299.0
Jan 2017	148.2	125.9	274.0
Nov 2017	147.8	130.8	278.7
Jan 2019	148.9	135.0	283.9
Nov 2019	153.2	131.3	284.5
Nov 2020	160.3	129.9	290.1

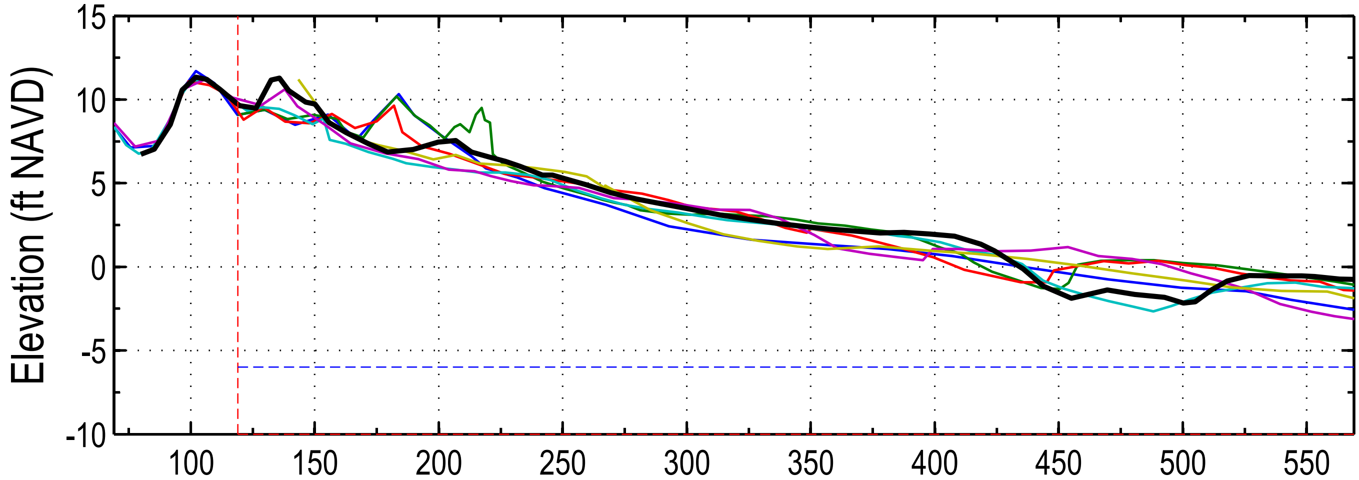
Kiawah Line 26 (OCRM 2692)

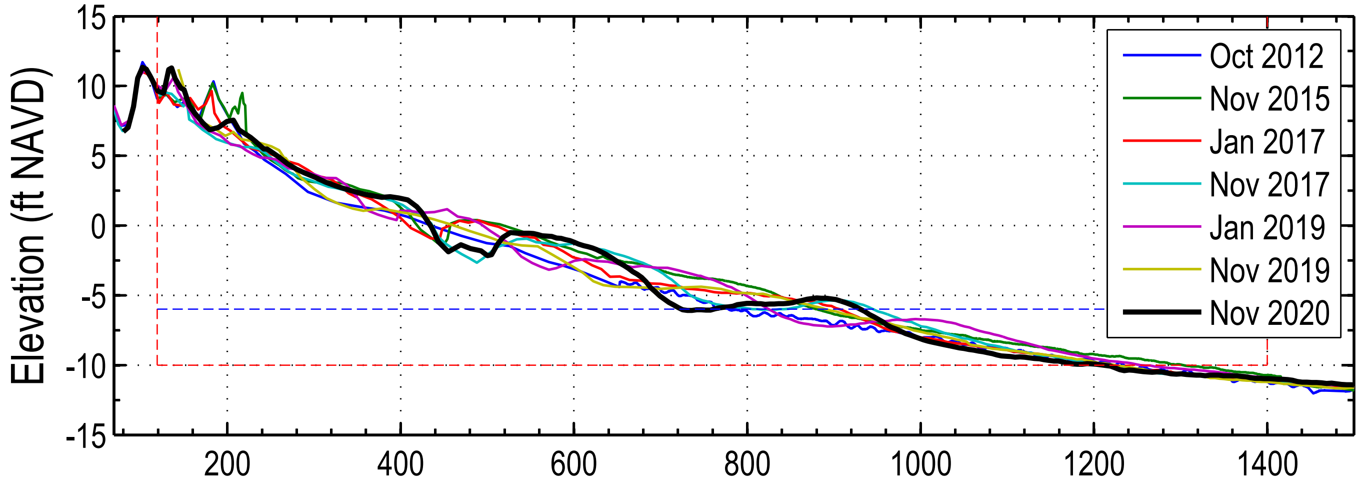




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	140.7	124.5	265.2
Nov 2015	160.4	130.6	291.0
Jan 2017	149.7	126.4	276.1
Nov 2017	148.8	131.2	279.9
Jan 2019	148.9	134.1	283.0
Nov 2019	146.6	130.1	276.7
Nov 2020	158.6	131.6	290.2

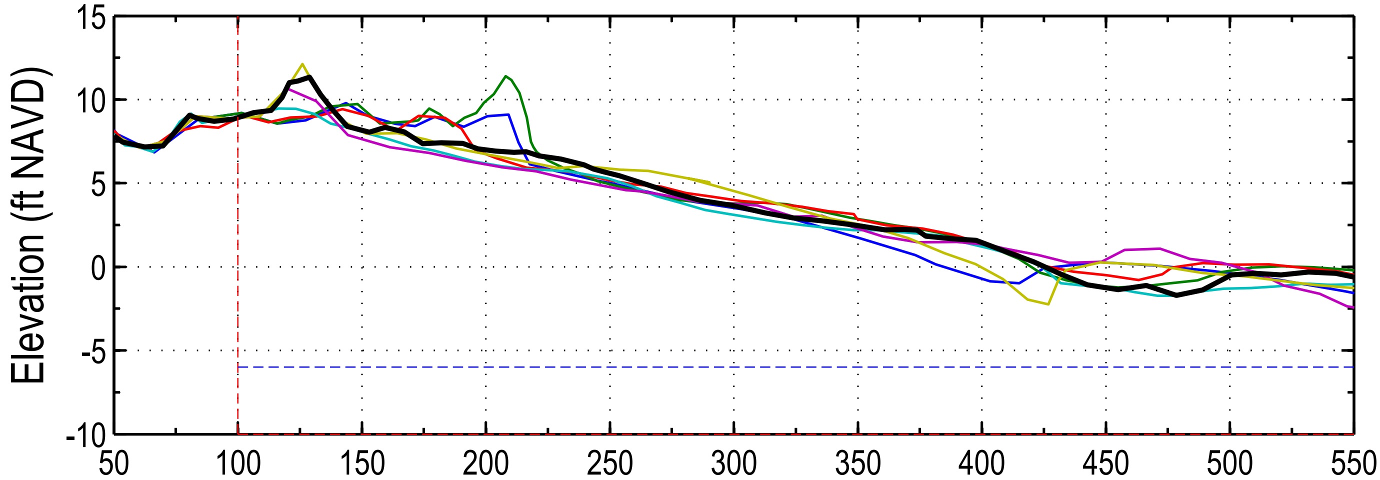
Kiawah Line 27 (OCRM 2695)

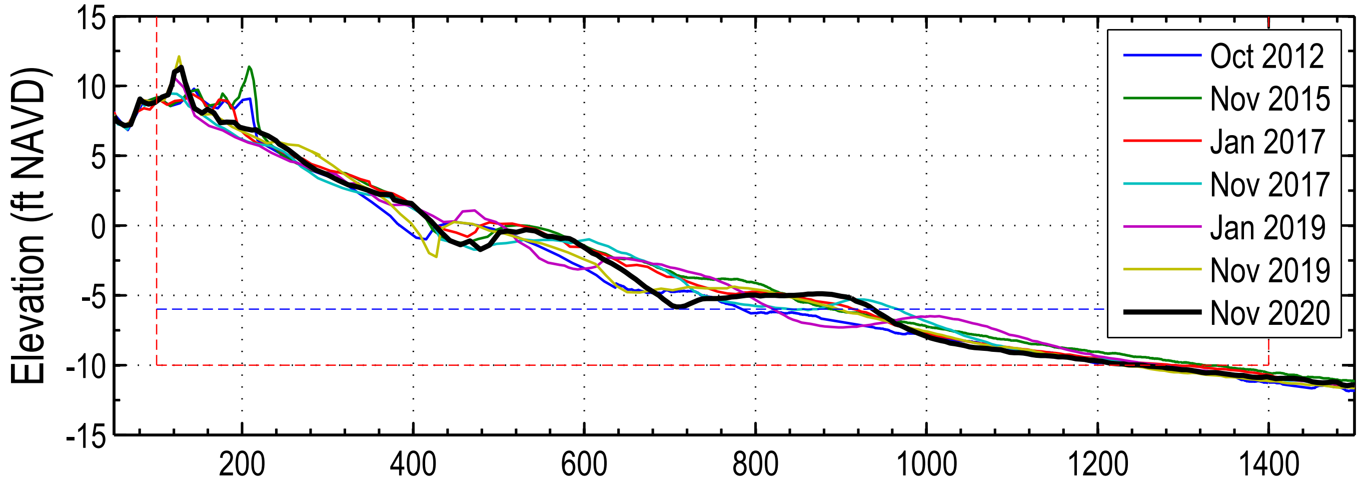




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	156.3	131.3	287.6
Nov 2015	183.9	140.5	324.5
Jan 2017	173.2	134.6	307.8
Nov 2017	167.6	138.9	306.5
Jan 2019	172.0	139.6	311.6
Nov 2019	166.1	136.2	302.3
Nov 2020	171.6	133.1	304.8

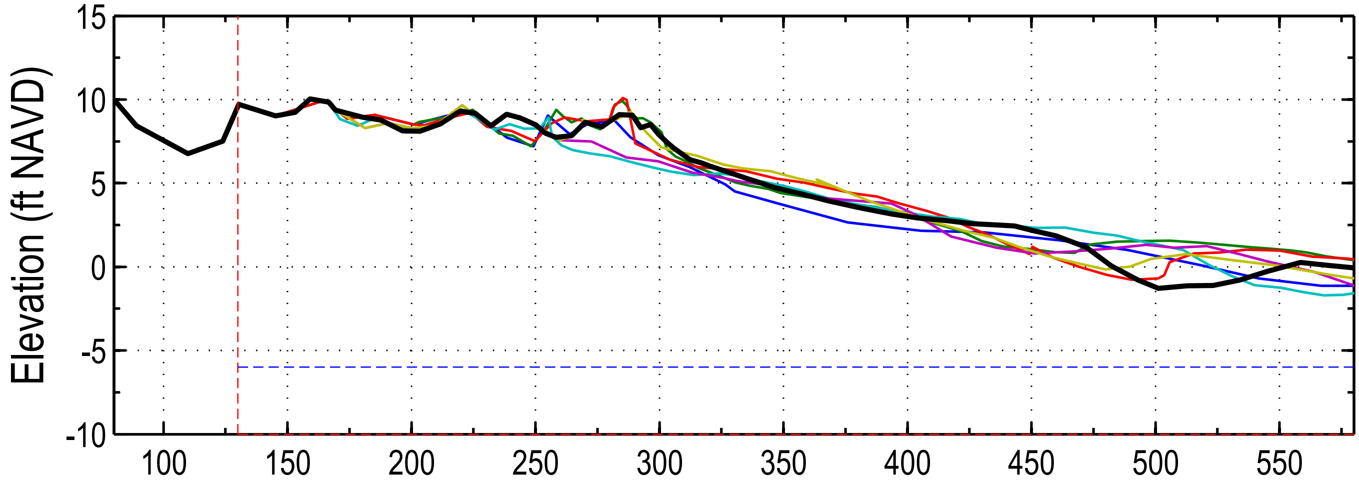
Kiawah Line 28 (OCRM 2700)

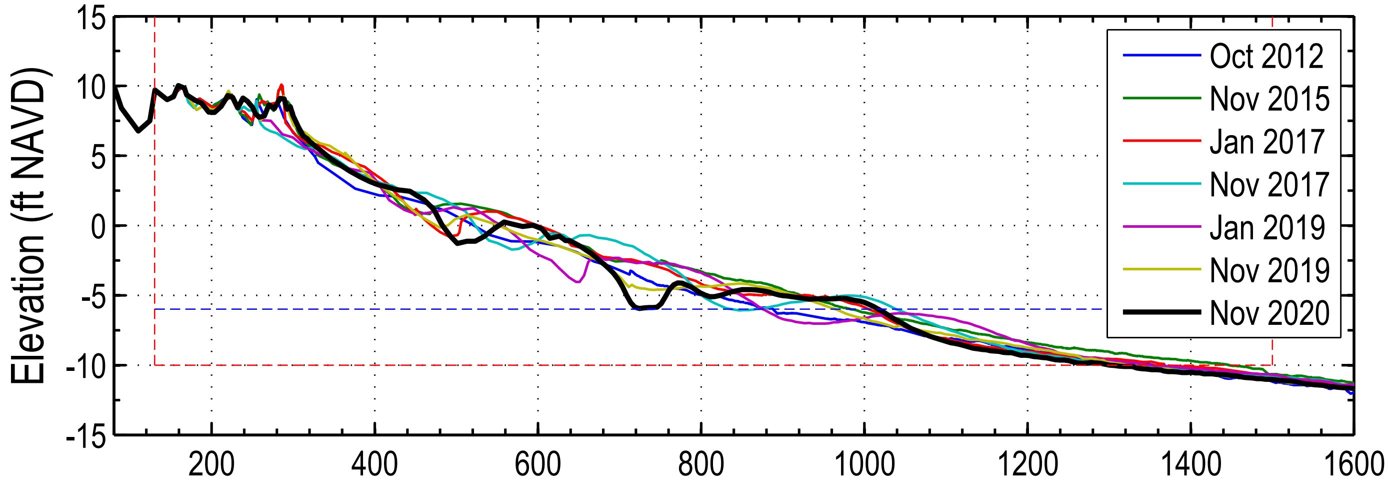




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	172.1	135.4	307.4
Nov 2015	197.5	146.4	343.9
Jan 2017	192.6	140.6	333.2
Nov 2017	180.0	143.5	323.5
Jan 2019	183.3	144.2	327.5
Nov 2019	182.2	139.5	321.7
Nov 2020	184.1	138.5	322.6

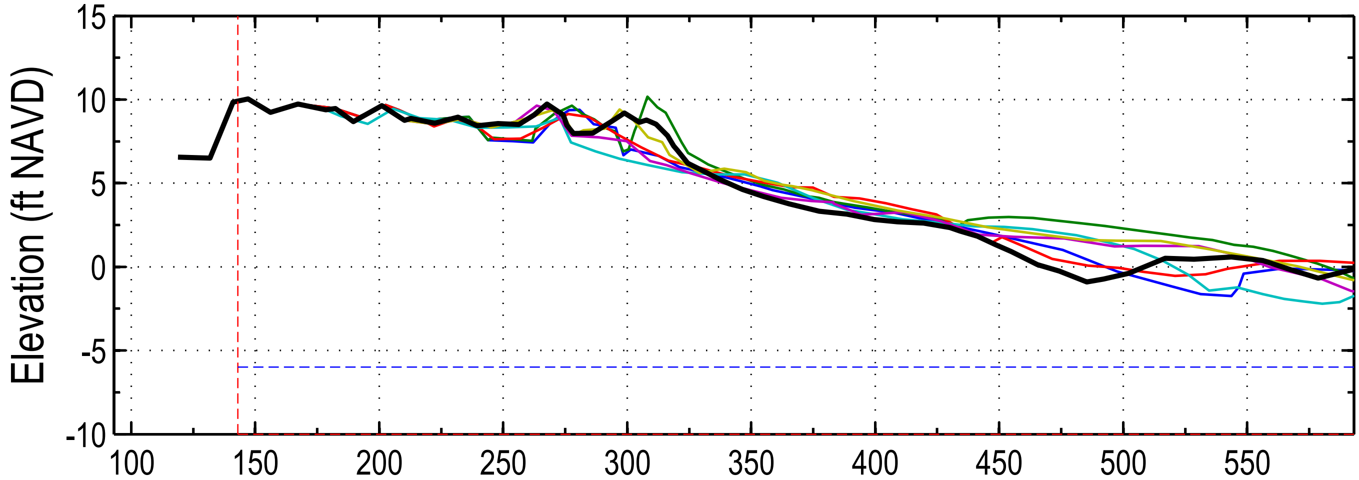
Kiawah Line 29 (OCRM 2705)

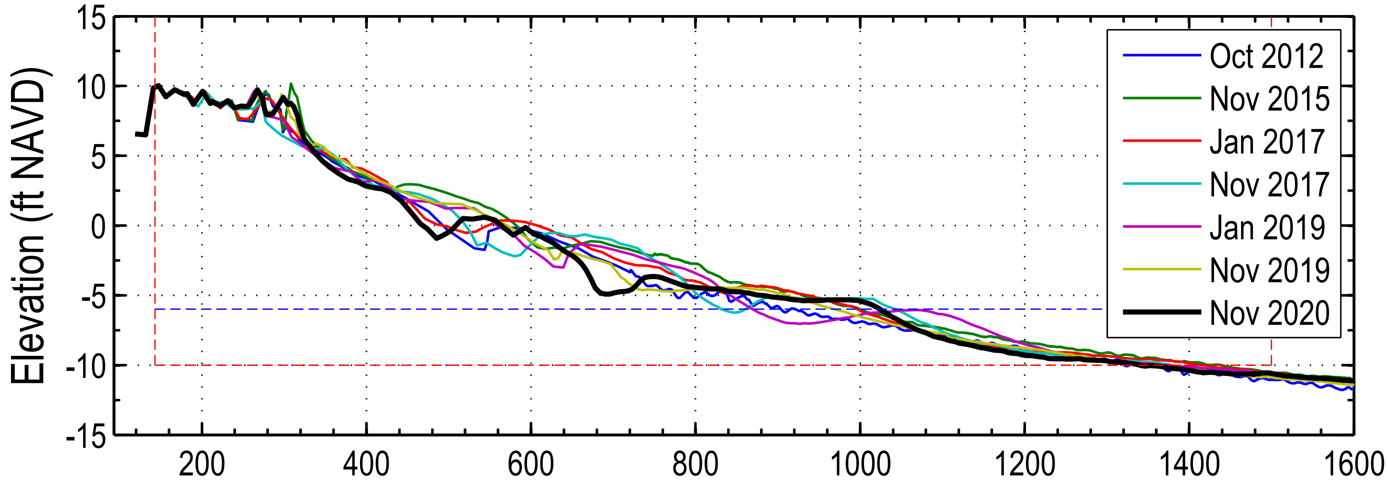




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	200.7	143.8	344.5
Nov 2015	225.9	155.8	381.7
Jan 2017	220.5	147.7	368.2
Nov 2017	215.5	150.1	365.6
Jan 2019	207.6	151.2	358.8
Nov 2019	211.9	147.7	359.6
Nov 2020	209.2	145.1	354.2

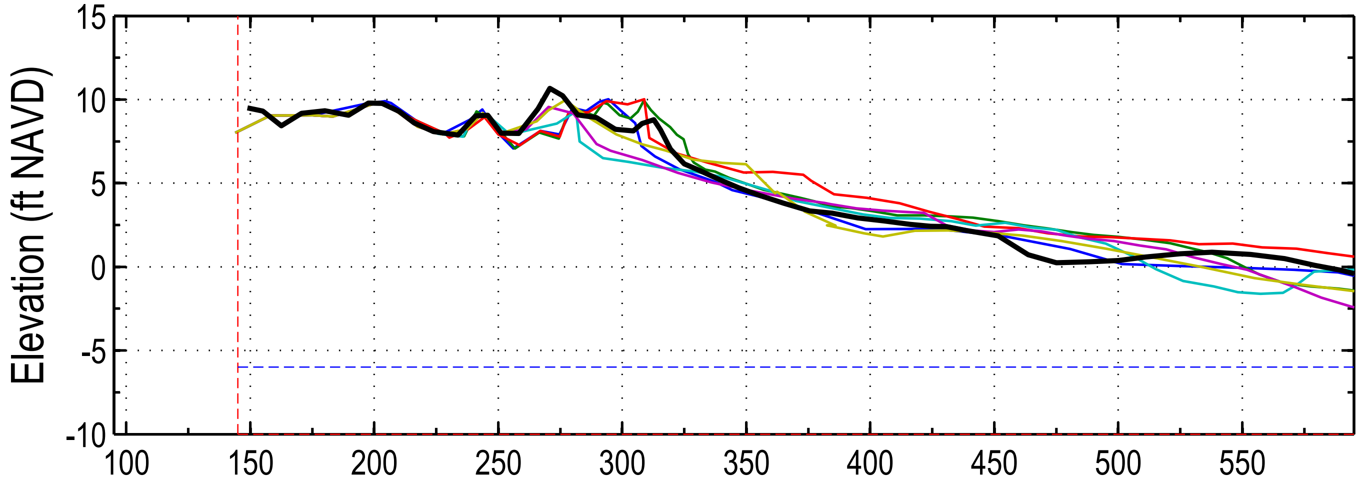
Kiawah Line 30

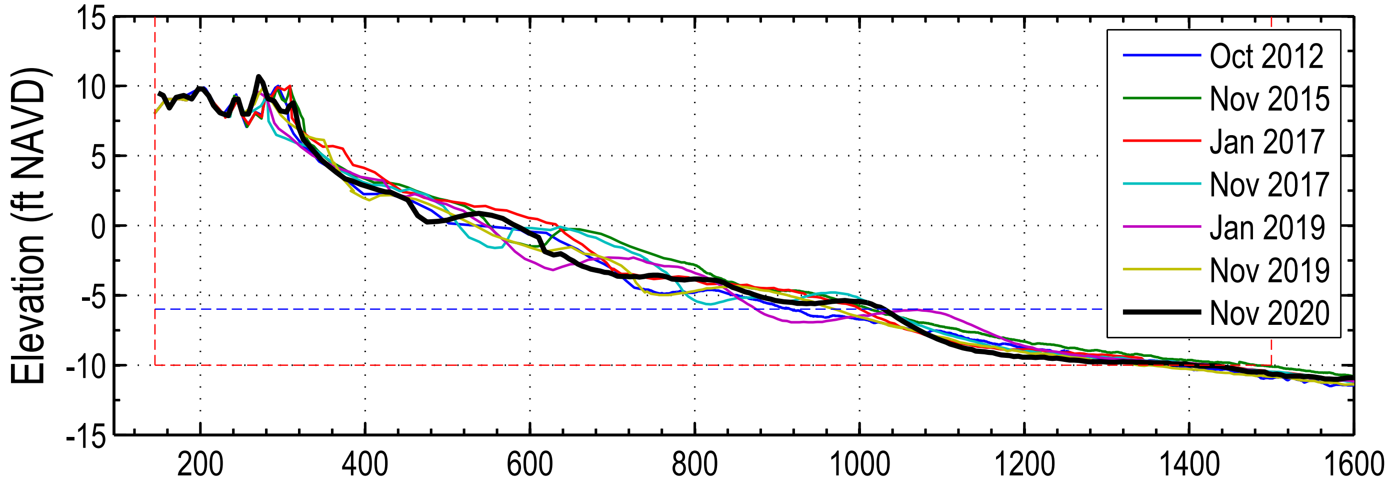




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	201.8	143.9	345.7
Nov 2015	230.7	153.3	384.0
Jan 2017	217.0	147.5	364.4
Nov 2017	211.9	148.8	360.7
Jan 2019	210.8	150.5	361.3
Nov 2019	212.4	146.3	358.7
Nov 2020	203.9	145.1	348.9

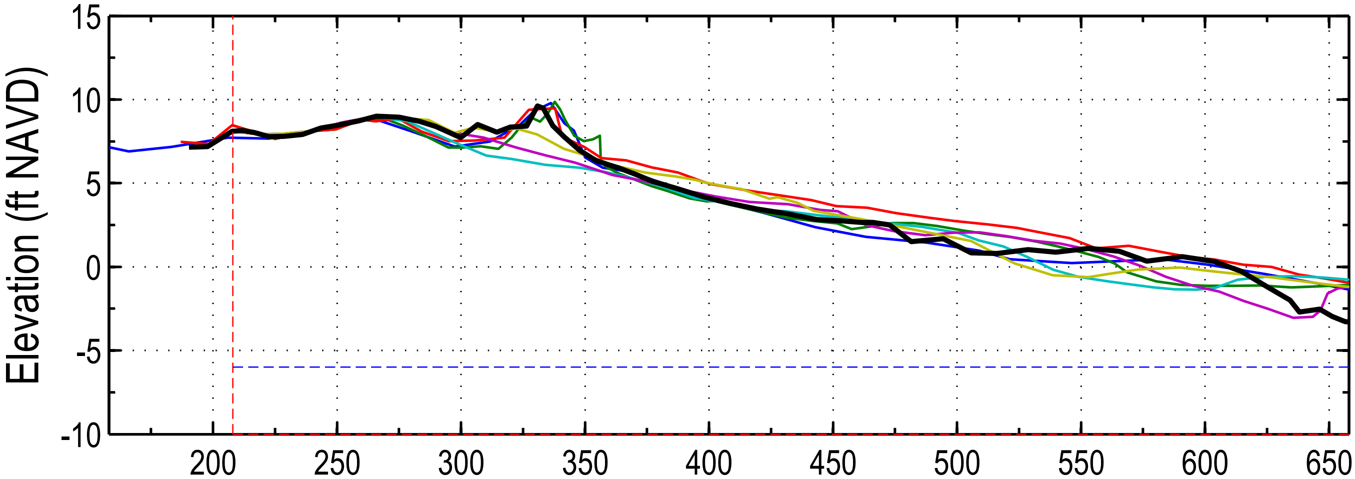
Kiawah Line 31 (OCRM 2715)

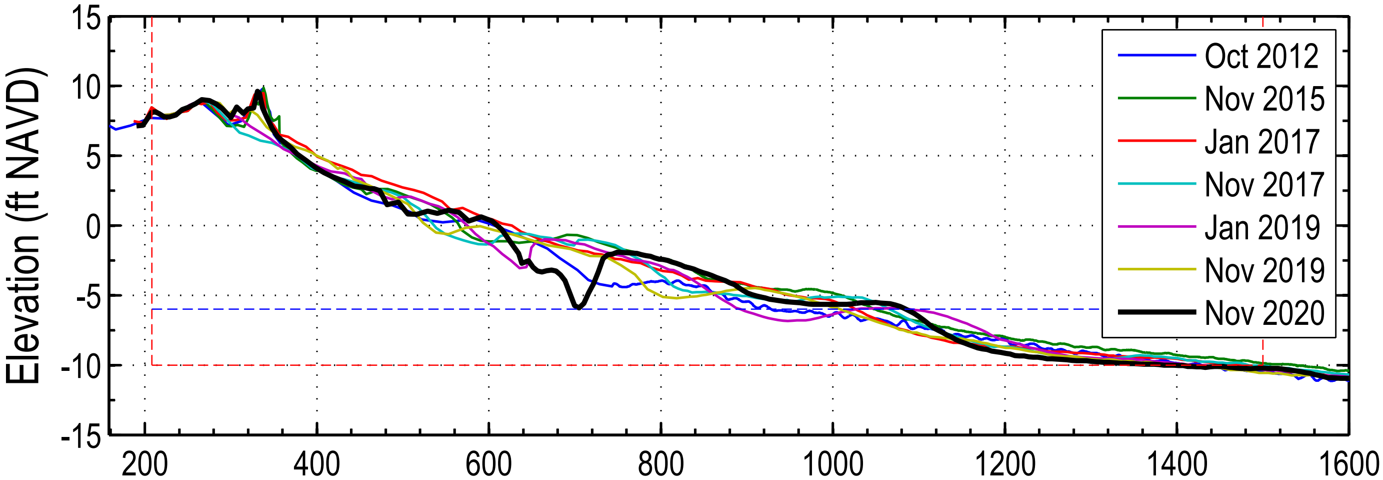




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	200.9	146.0	346.8
Nov 2015	227.6	155.2	382.8
Jan 2017	225.3	146.9	372.2
Nov 2017	212.0	148.8	360.9
Jan 2019	204.4	151.0	355.5
Nov 2019	204.3	144.0	348.3
Nov 2020	208.5	144.2	352.7

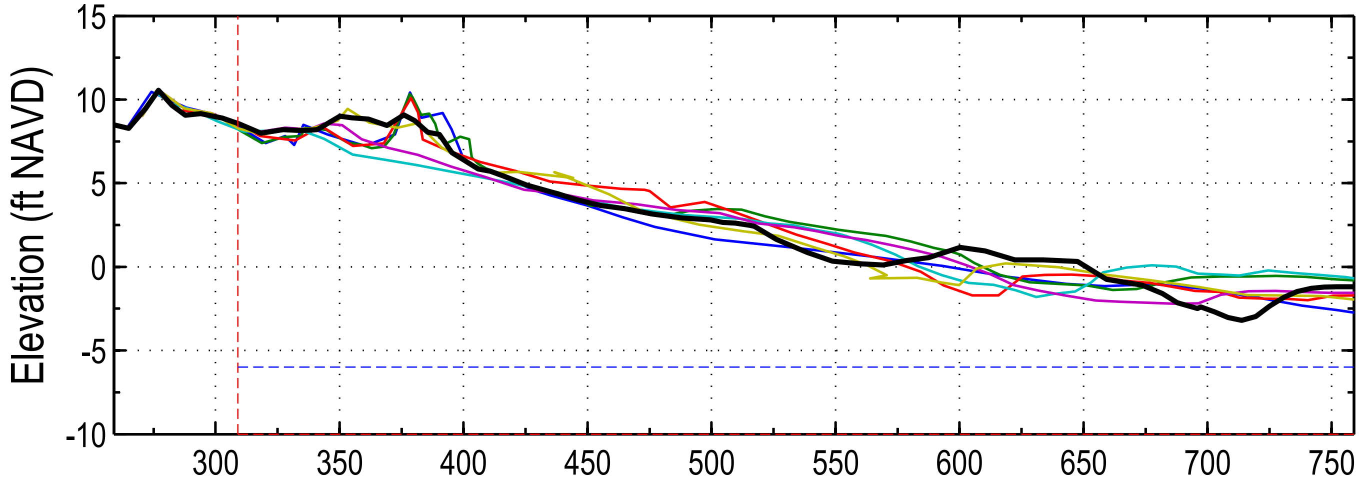
Kiawah Line 32 (OCRM 2720)

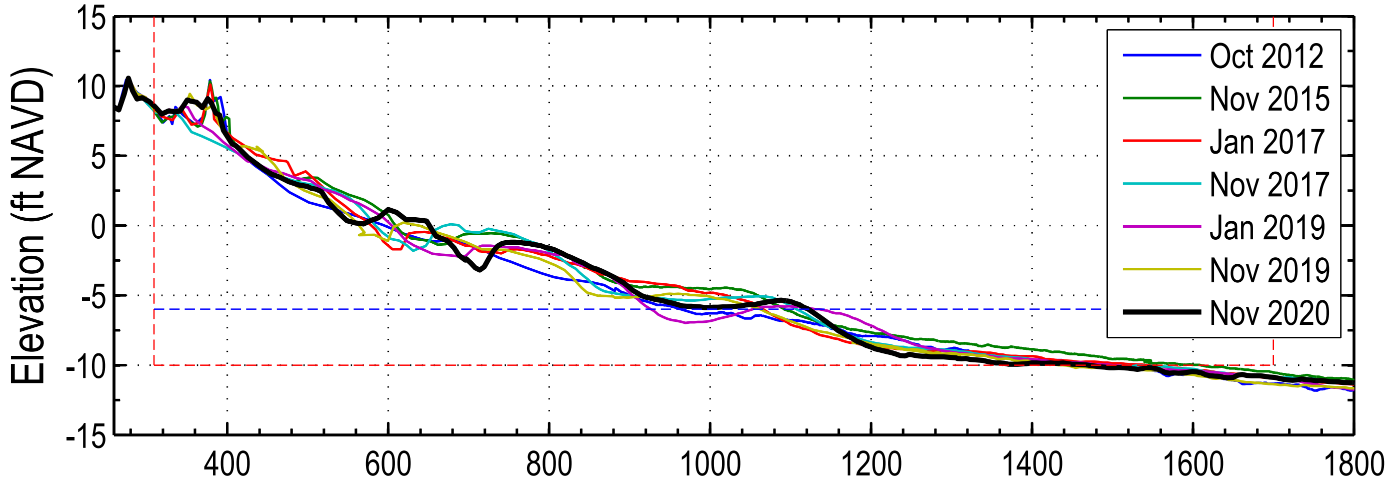




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	180.3	143.0	323.3
Nov 2015	202.7	151.8	354.5
Jan 2017	207.0	142.2	349.2
Nov 2017	190.4	144.7	335.1
Jan 2019	188.7	145.9	334.6
Nov 2019	190.0	139.5	329.6
Nov 2020	191.2	141.0	332.3

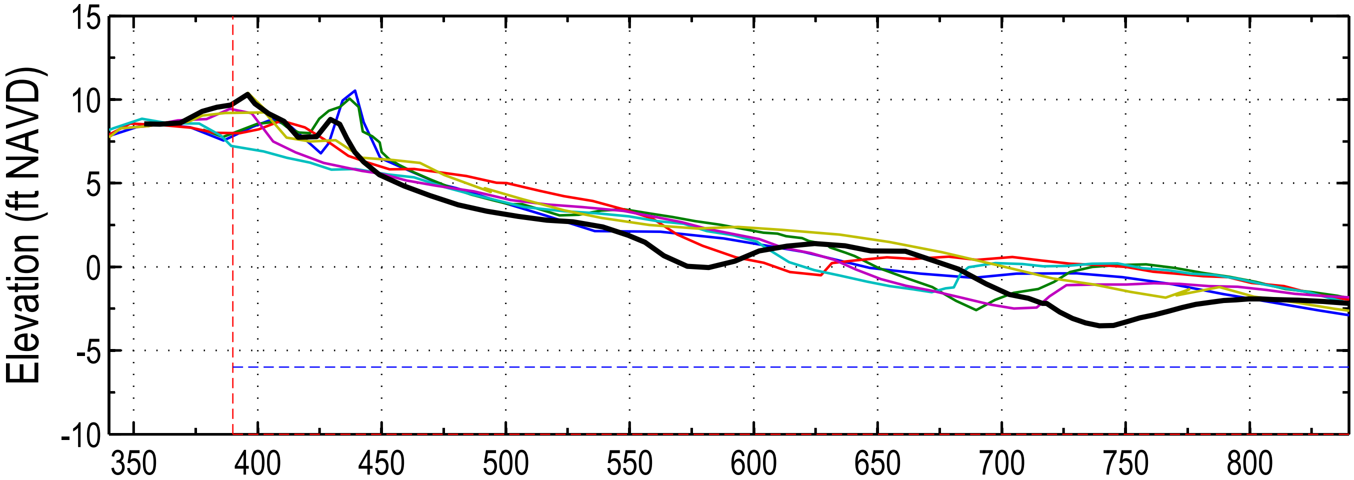
Kiawah Line 33

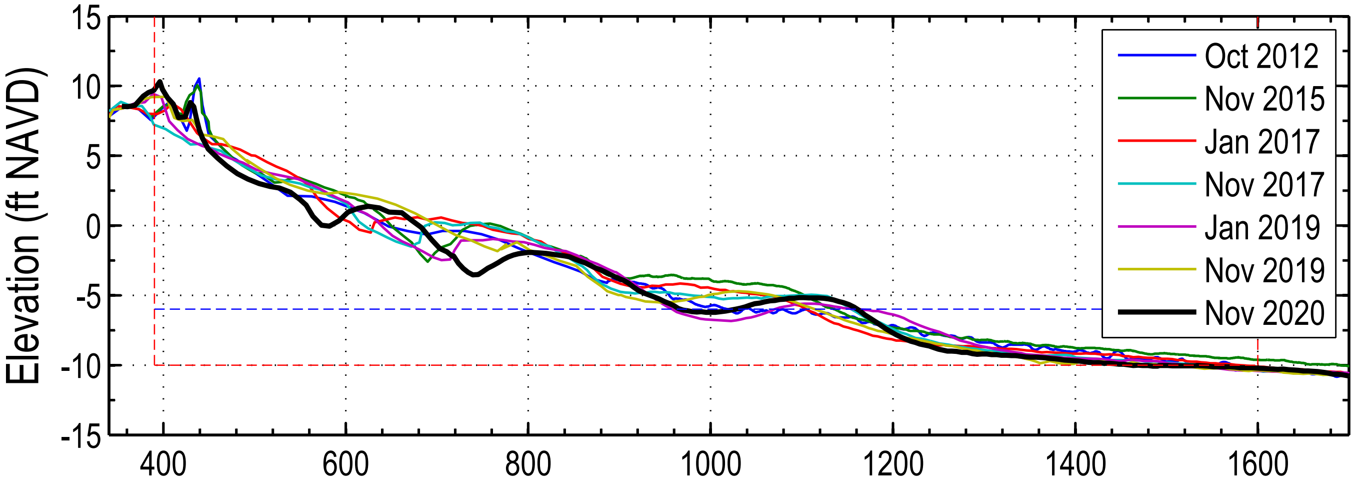




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	148.4	134.0	282.4
Nov 2015	174.2	144.4	318.6
Jan 2017	166.5	132.6	299.1
Nov 2017	162.1	135.2	297.4
Jan 2019	157.0	137.2	294.2
Nov 2019	158.3	131.1	289.4
Nov 2020	163.4	131.7	295.1

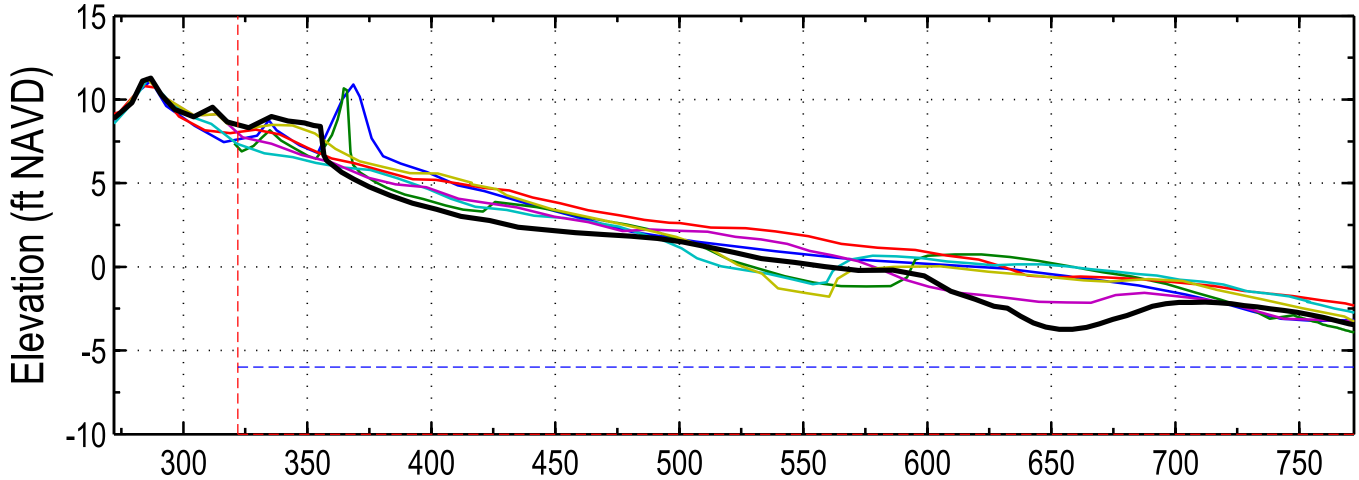
Kiawah Line 34 (OCRM 2722)

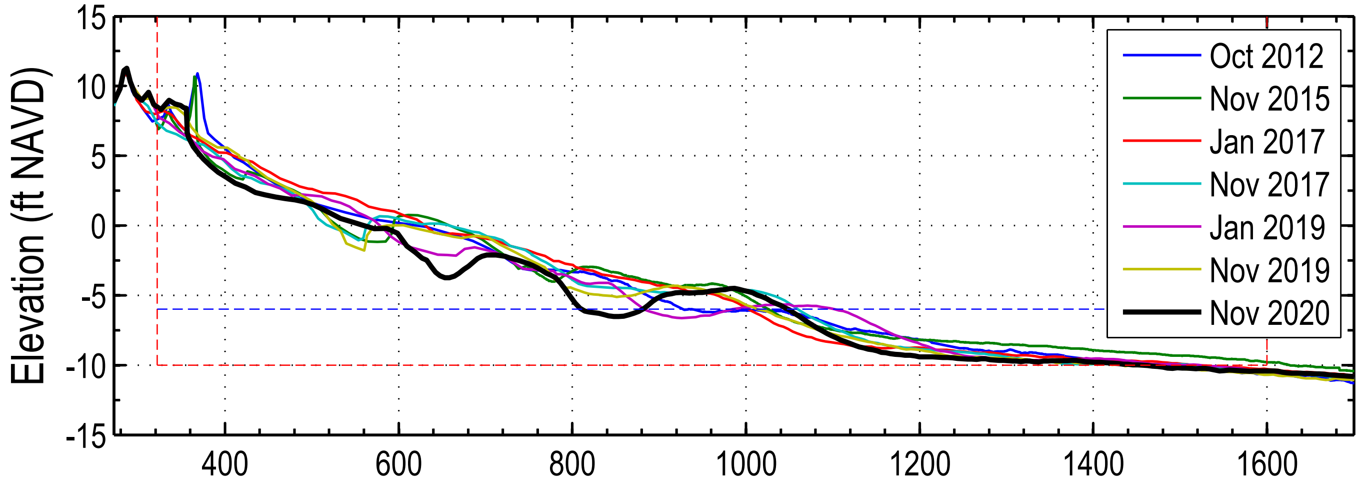




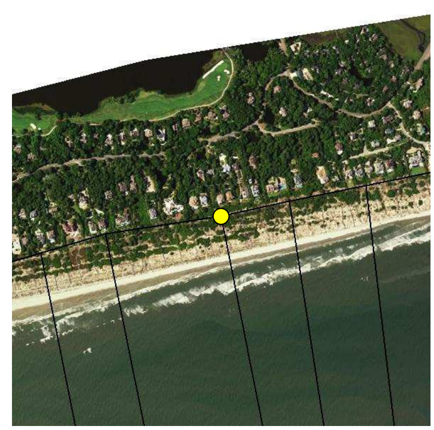
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	139.8	133.0	272.8
Nov 2015	158.6	138.0	296.6
Jan 2017	153.3	128.0	281.3
Nov 2017	143.6	129.3	272.9
Jan 2019	137.6	130.7	268.3
Nov 2019	147.9	124.8	272.7
Nov 2020	133.8	125.7	259.4

Kiawah Line 35 (OCRM 2725)

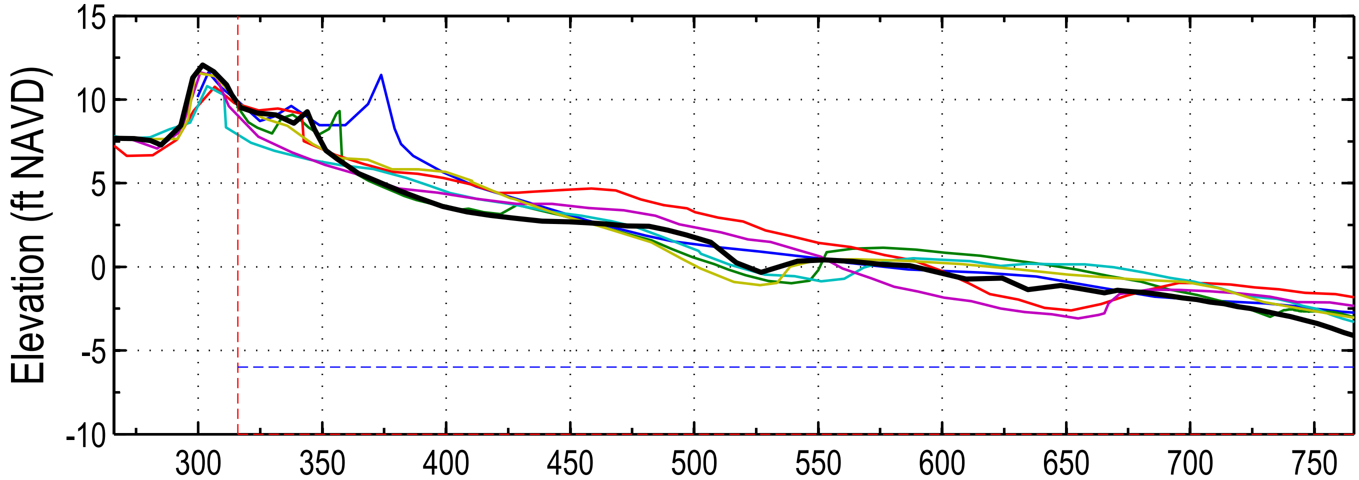


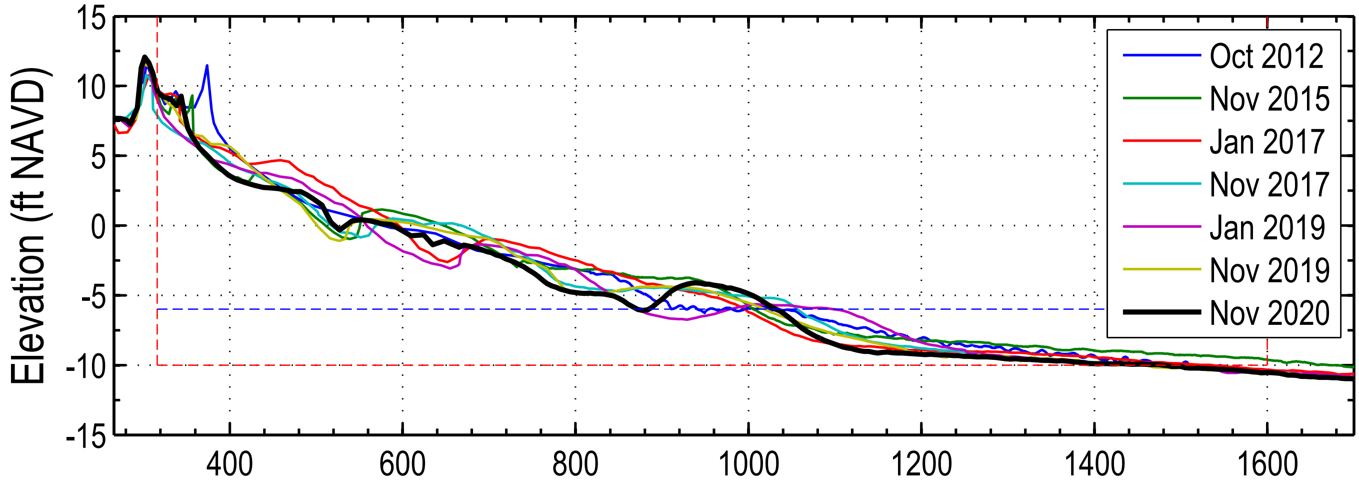


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	139.1	130.2	269.3
Nov 2015	140.6	136.6	277.2
Jan 2017	151.3	122.0	273.3
Nov 2017	139.2	125.0	264.2
Jan 2019	126.8	129.3	256.2
Nov 2019	136.7	121.8	258.5
Nov 2020	119.8	119.7	239.5

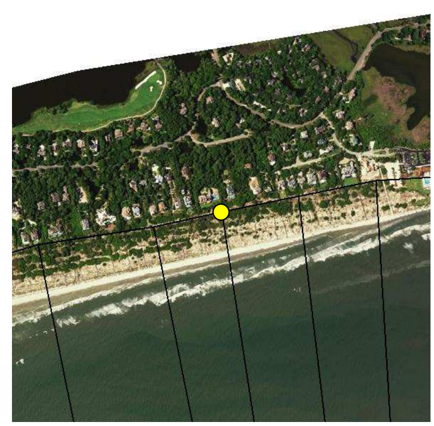


Kiawah Line 36 (OCRM 2730)

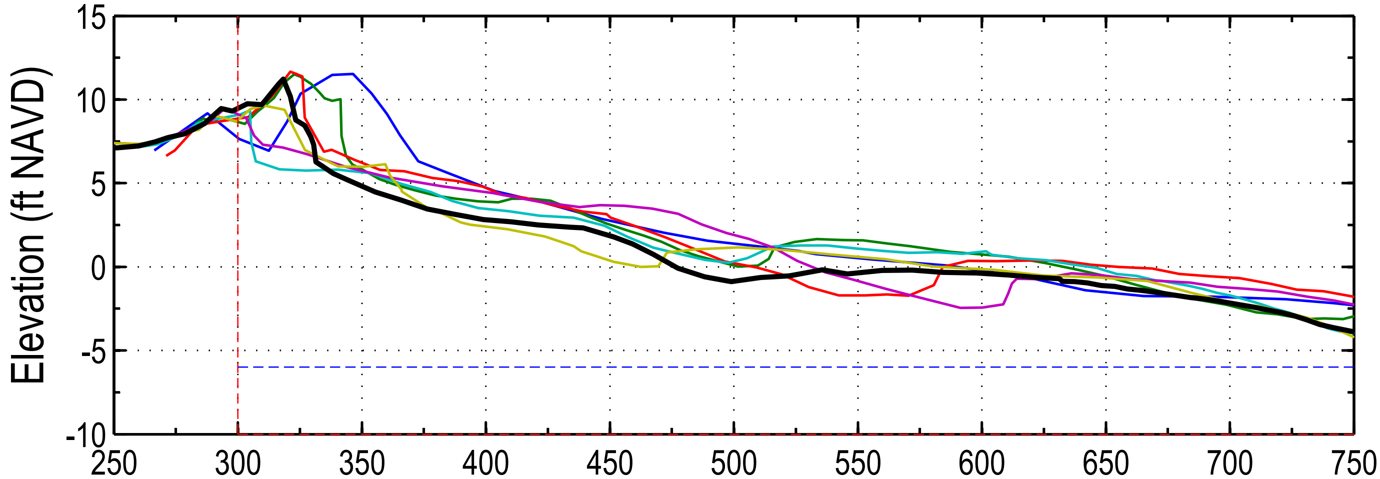


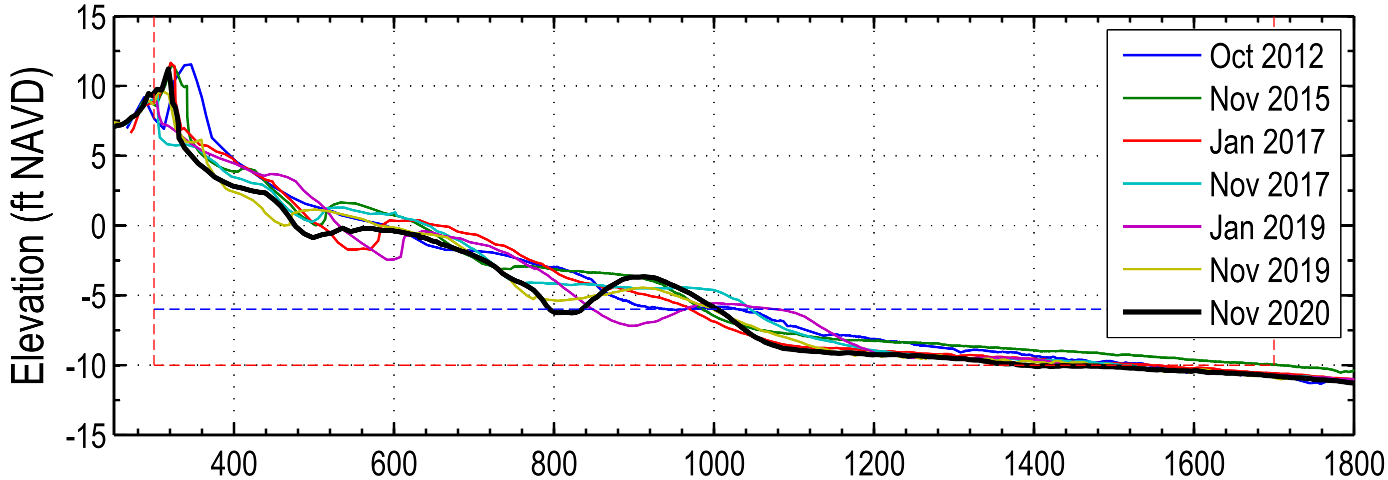


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	142.4	133.4	275.8
Nov 2015	143.7	136.1	279.8
Jan 2017	152.4	122.6	275.0
Nov 2017	139.1	126.1	265.2
Jan 2019	129.0	130.1	259.1
Nov 2019	138.4	123.0	261.3
Nov 2020	131.0	120.0	251.0



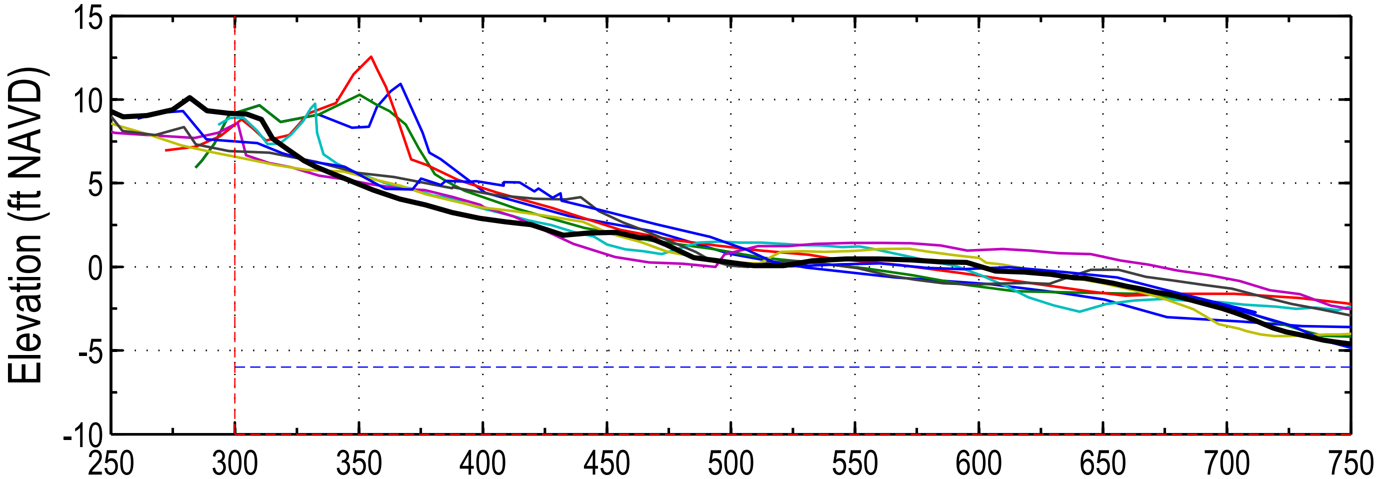
Kiawah Line 37

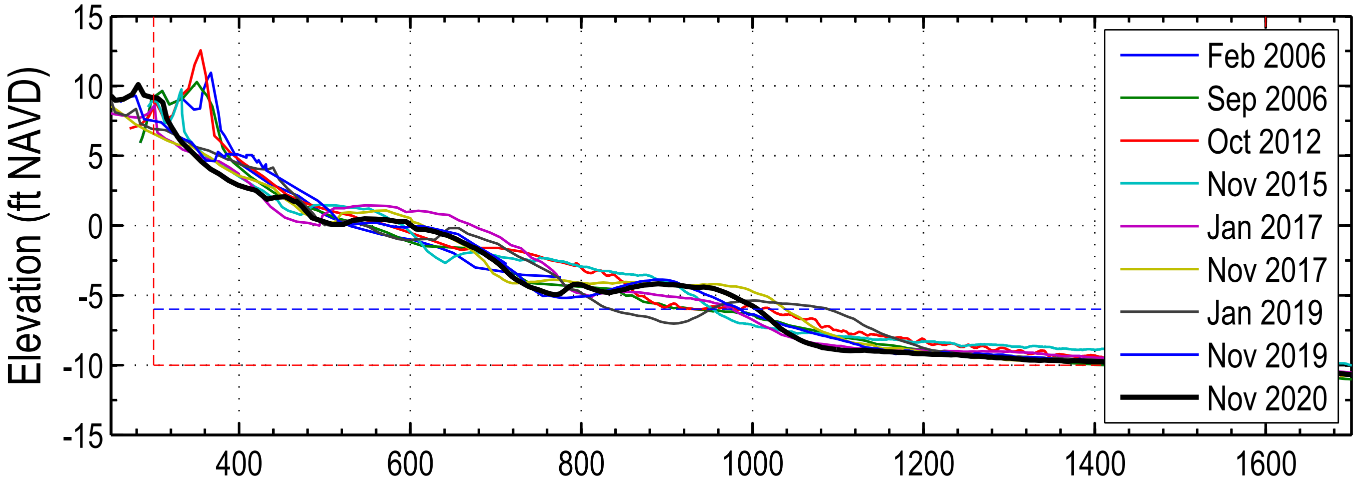




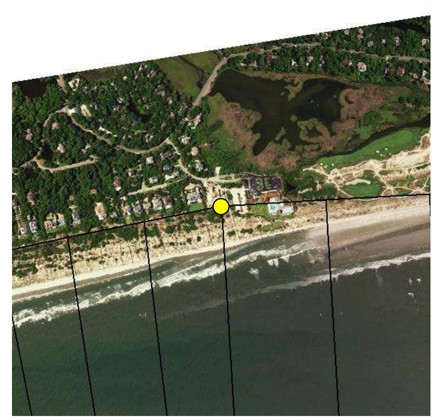
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	148.0	136.0	283.9
Nov 2015	151.3	137.5	288.7
Jan 2017	145.7	121.9	267.7
Nov 2017	141.3	128.1	269.4
Jan 2019	134.5	128.1	262.6
Nov 2019	128.3	122.1	250.4
Nov 2020	126.7	118.4	245.1

Kiawah Line 38 (0+00)

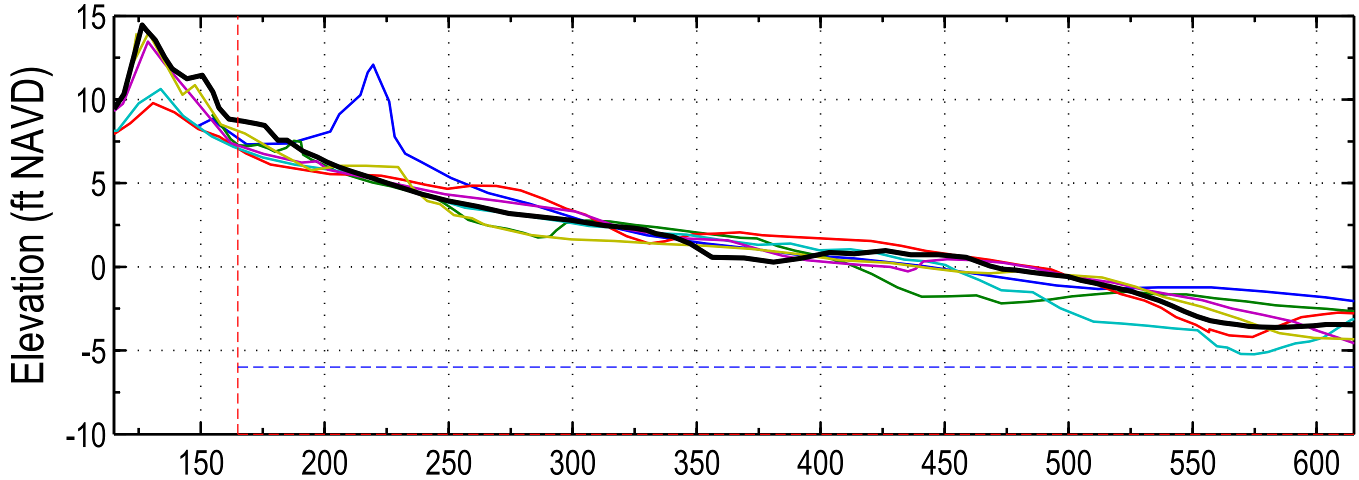


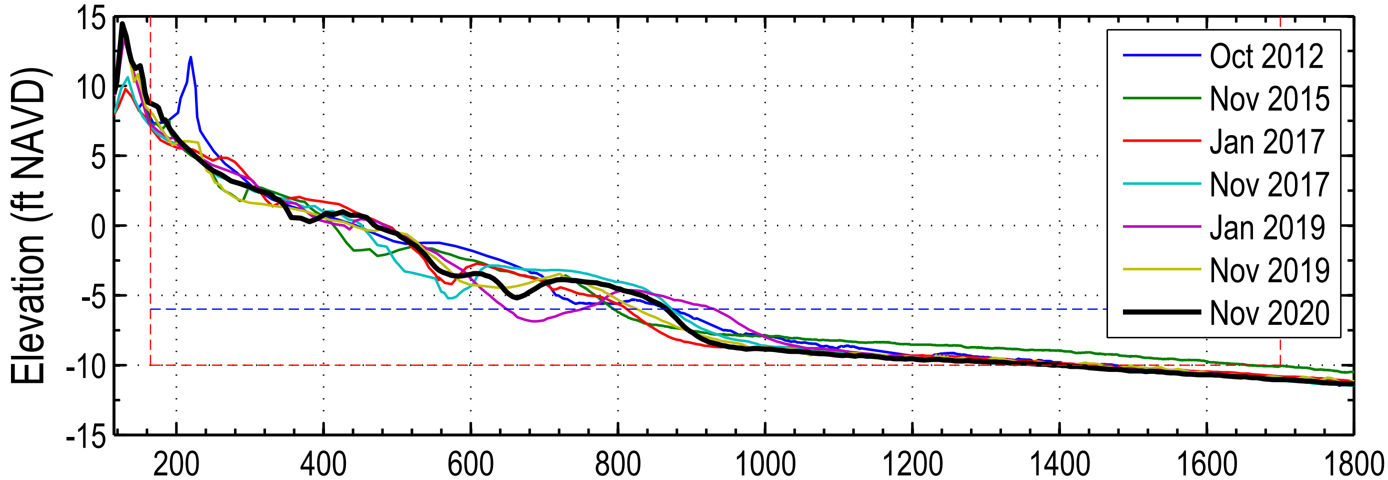


Date	Vol to -6	Vol -6 to -10	Vol to -10
Feb 2006	149.2	184.1	333.3
Sep 2006	132.8	123.1	255.8
Oct 2012	146.4	133.7	280.1
Nov 2015	138.9	134.4	273.3
Jan 2017	137.2	123.2	260.4
Nov 2017	135.9	124.8	260.7
Jan 2019	130.4	130.5	260.8
Nov 2019	136.3	123.3	259.7
Nov 2020	129.7	119.7	249.4



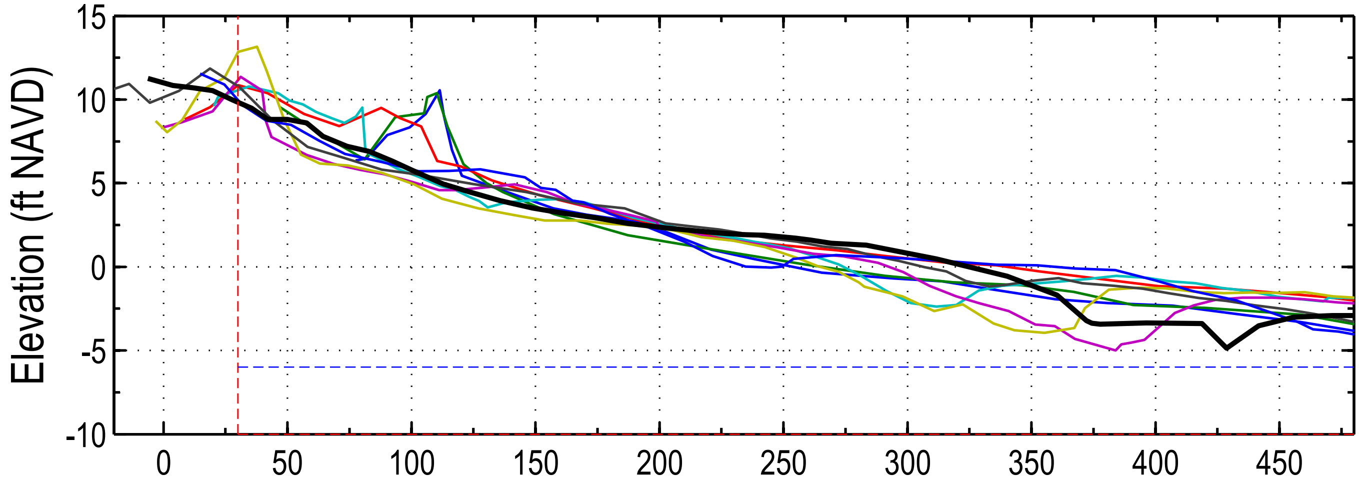
Kiawah Line 39 (10+00)

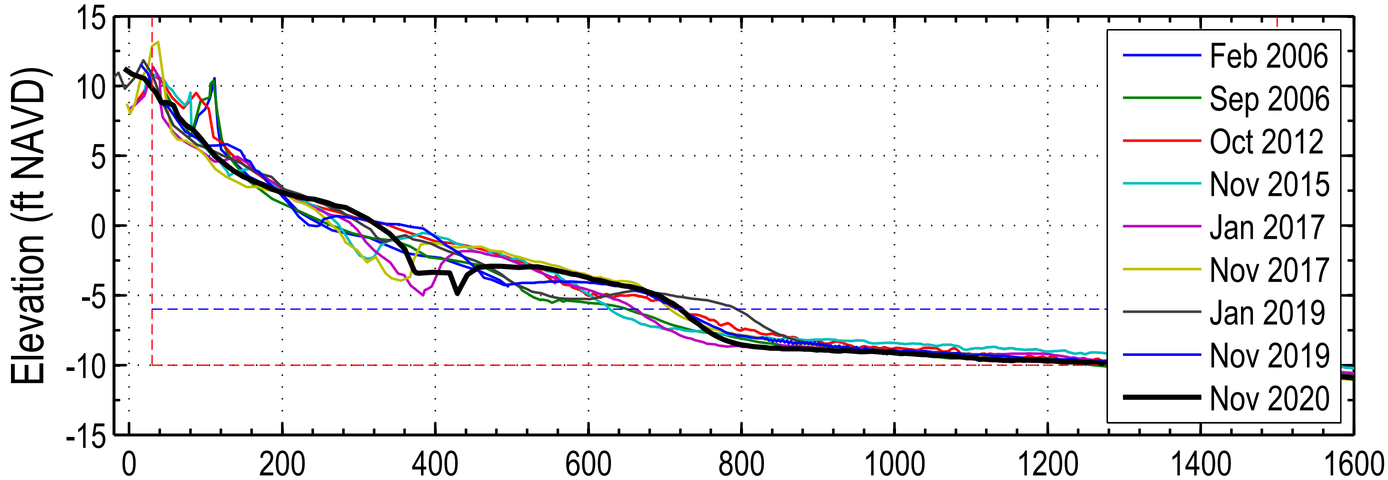




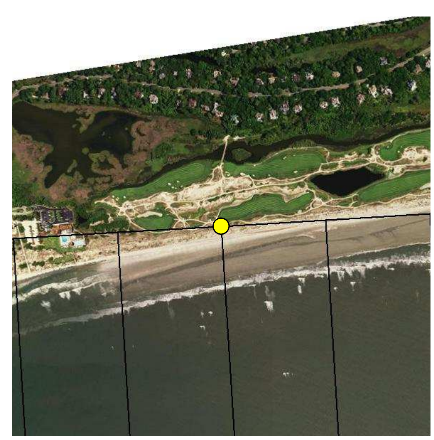
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	145.5	132.1	277.5
Nov 2015	130.1	140.4	270.5
Jan 2017	136.9	119.6	256.5
Nov 2017	133.9	124.6	258.4
Jan 2019	127.9	129.3	257.2
Nov 2019	128.9	121.8	250.7
Nov 2020	134.7	120.5	255.2

Kiawah Line 40 (20+00)

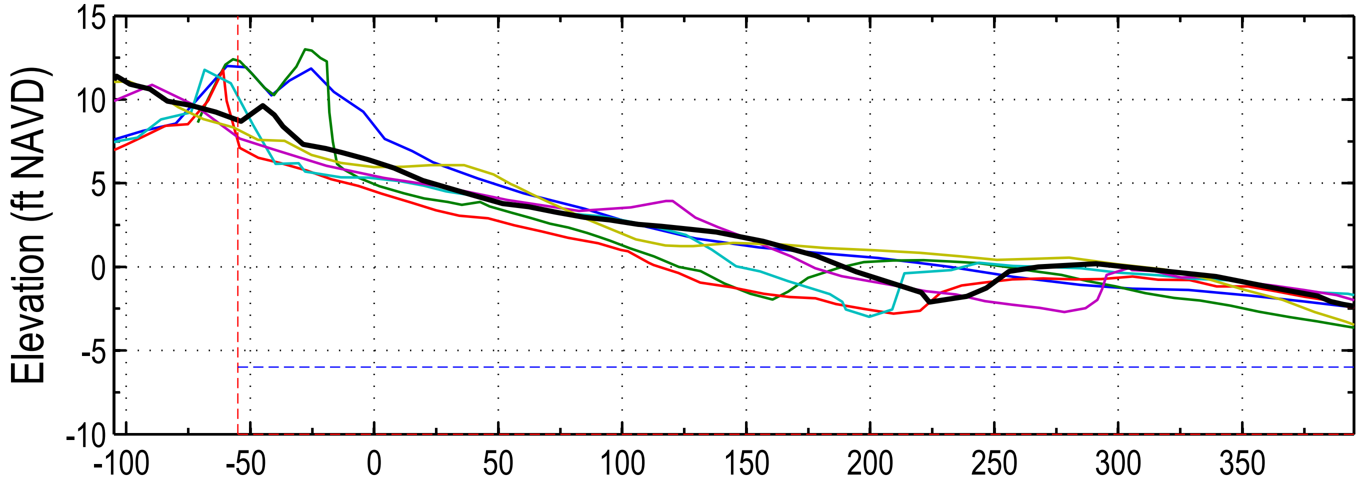


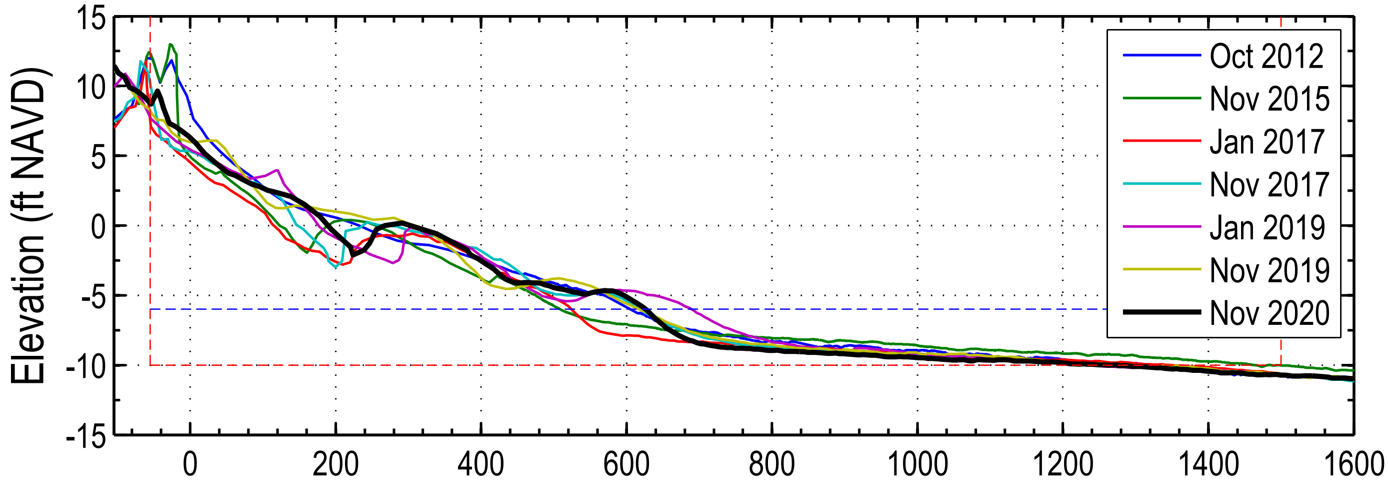


Date	Vol to -6	Vol -6 to -10	Vol to -10
Feb 2006	123.3	82.6	205.9
Sep 2006	131.3	121.9	253.1
Oct 2012	156.3	132.7	288.9
Nov 2015	144.3	135.2	279.5
Jan 2017	133.1	122.6	255.7
Nov 2017	140.3	125.8	266.1
Jan 2019	142.8	133.6	276.5
Nov 2019	145.4	128.4	273.9
Nov 2020	143.7	122.4	266.0



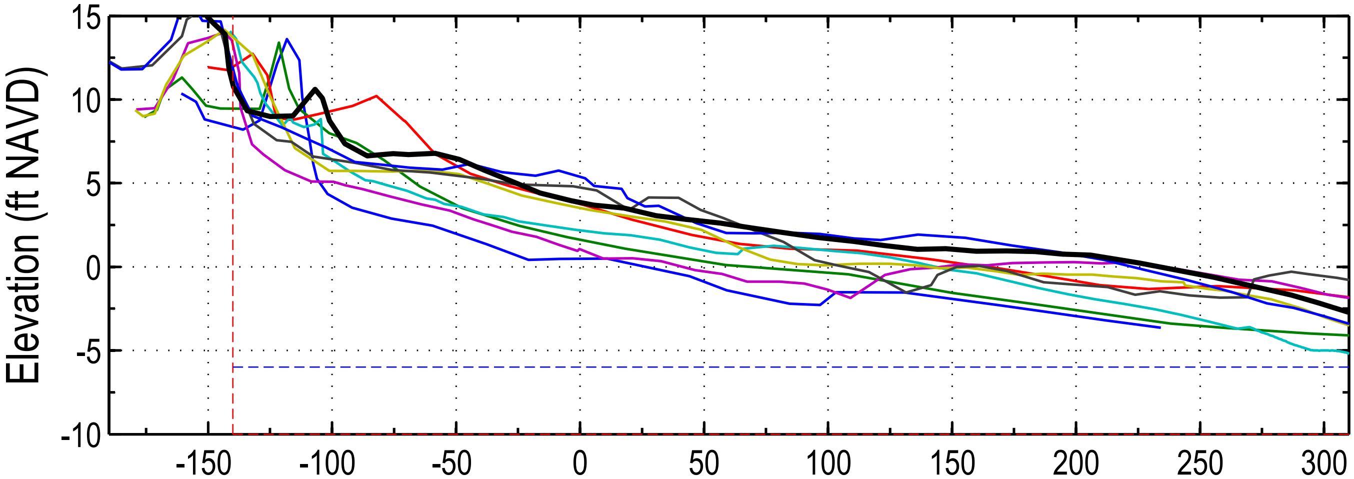
Kiawah Line 41 (30+00)

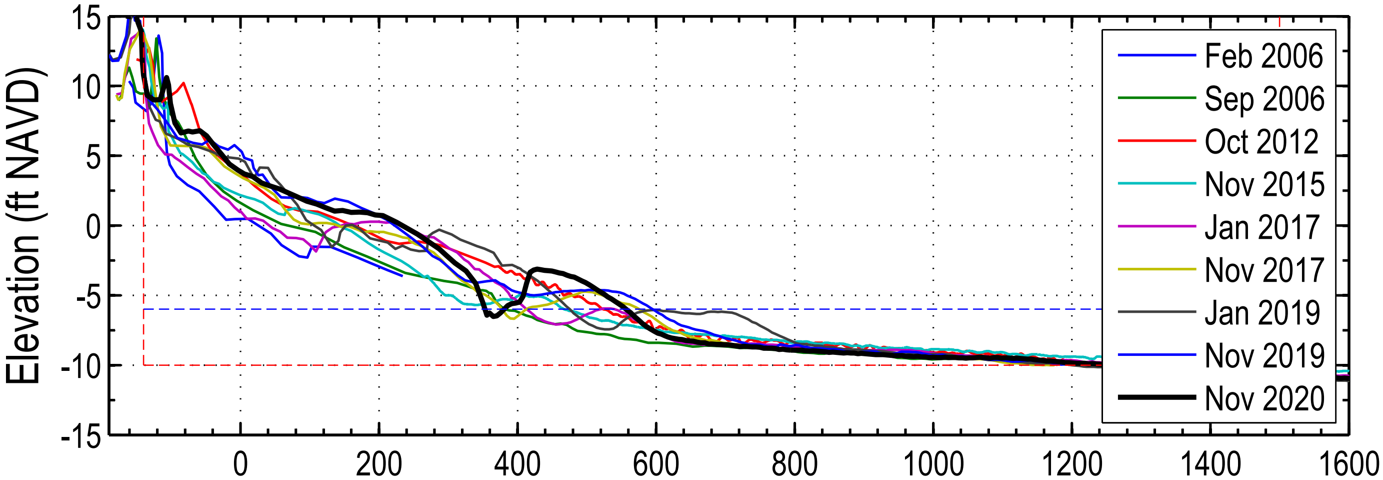




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	153.2	131.9	285.1
Nov 2015	127.5	137.5	264.9
Jan 2017	116.6	118.9	235.5
Nov 2017	138.0	125.1	263.2
Jan 2019	140.1	133.5	273.5
Nov 2019	146.9	127.9	274.8
Nov 2020	144.3	121.0	265.4

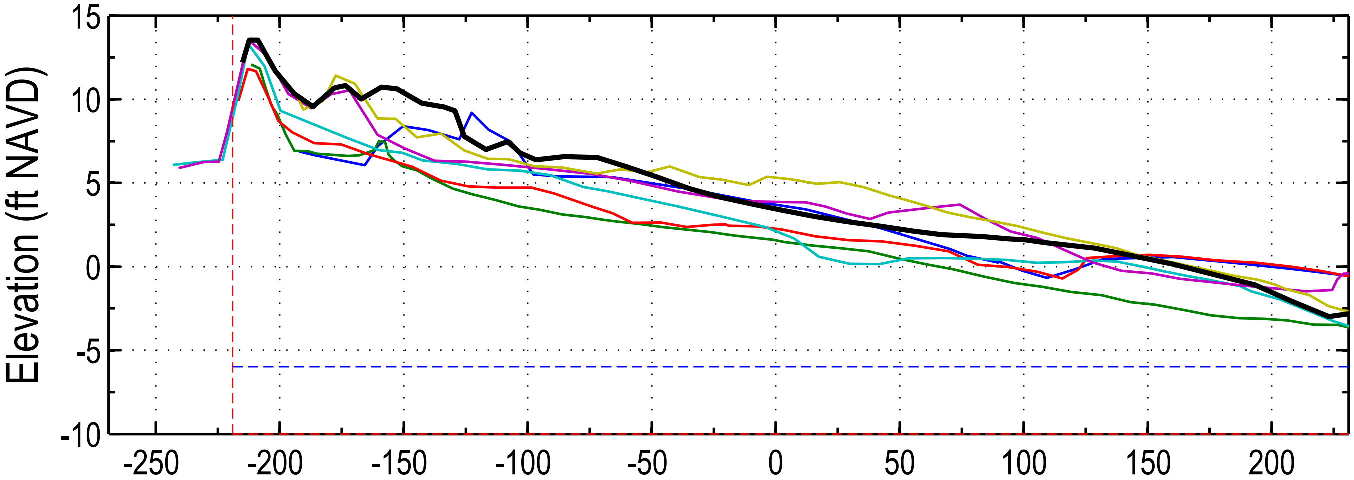
Kiawah Line 42 (40+00)

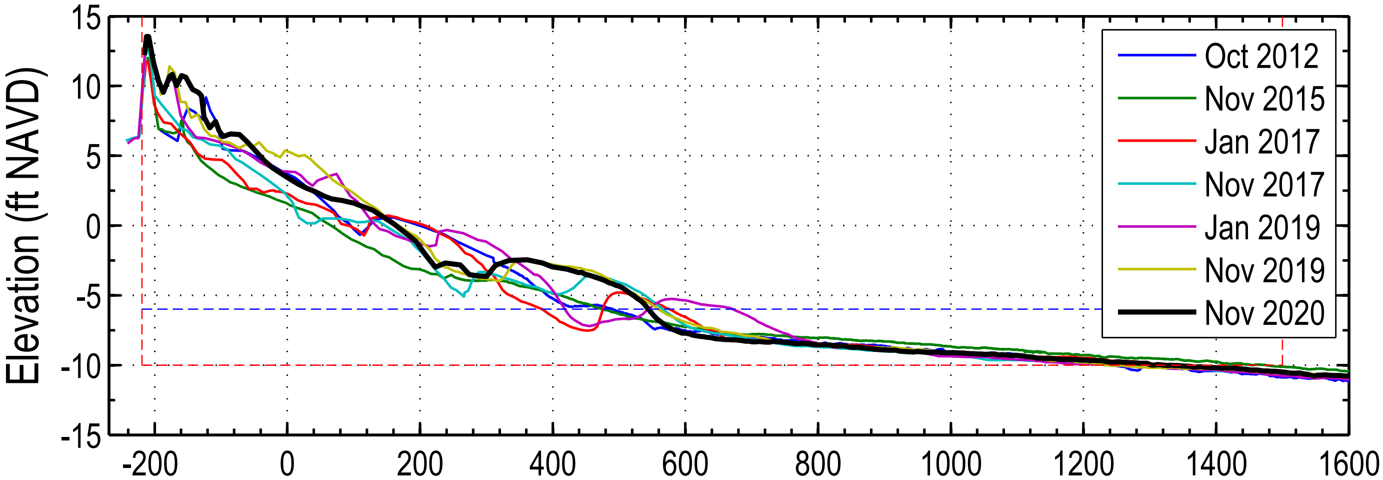




Date	Vol to -6	Vol -6 to -10	Vol to -10
Feb 2006	94.2	88.7	182.9
Sep 2006	115.4	115.8	231.3
Oct 2012	159.9	137.1	297.0
Nov 2015	122.2	140.2	262.4
Jan 2017	125.5	129.6	255.0
Nov 2017	139.8	129.8	269.6
Jan 2019	154.0	141.4	295.4
Nov 2019	160.3	135.8	296.1
Nov 2020	161.6	128.6	290.1

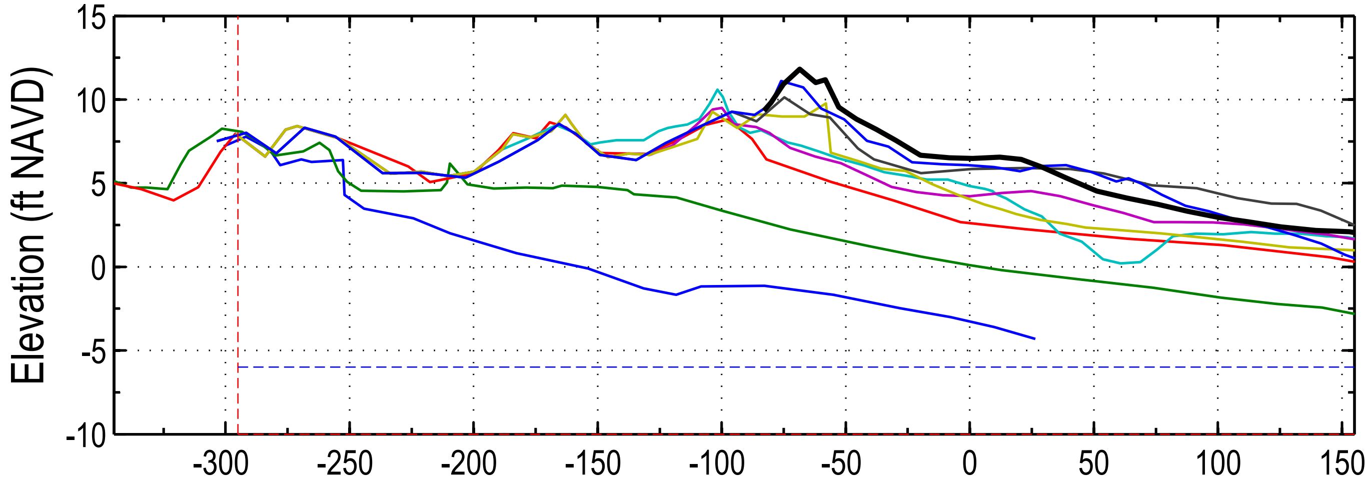
Kiawah Line 43 (50+00)

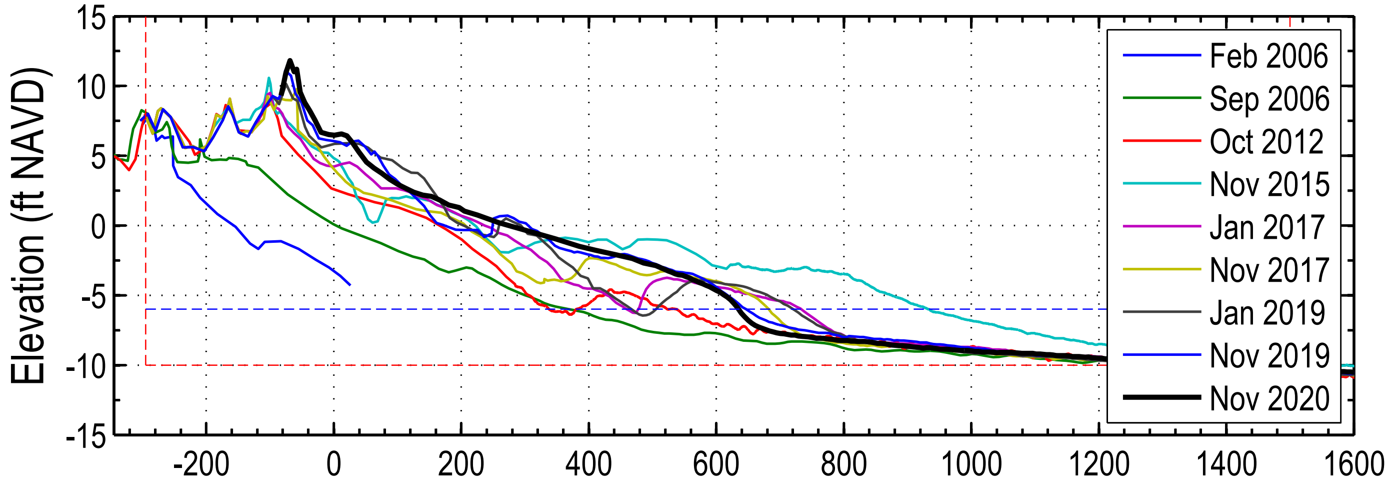




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	179.0	147.2	326.2
Nov 2015	141.0	158.5	299.5
Jan 2017	163.4	146.6	310.0
Nov 2017	167.9	144.9	312.8
Jan 2019	193.7	151.9	345.6
Nov 2019	203.7	149.9	353.5
Nov 2020	200.6	146.1	346.7

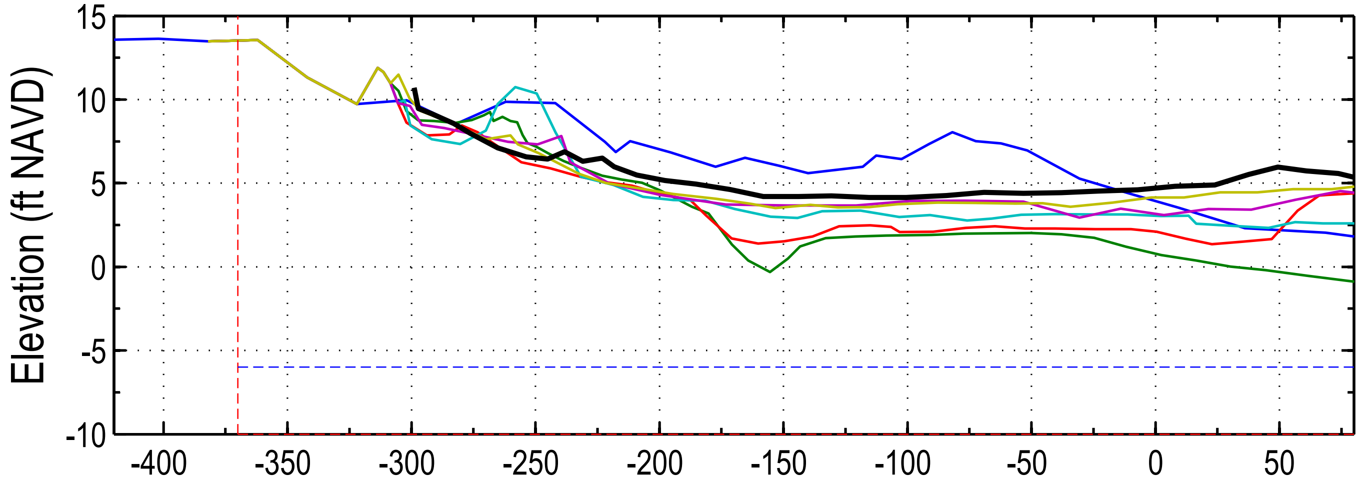
Kiawah Line 44 (60+00)

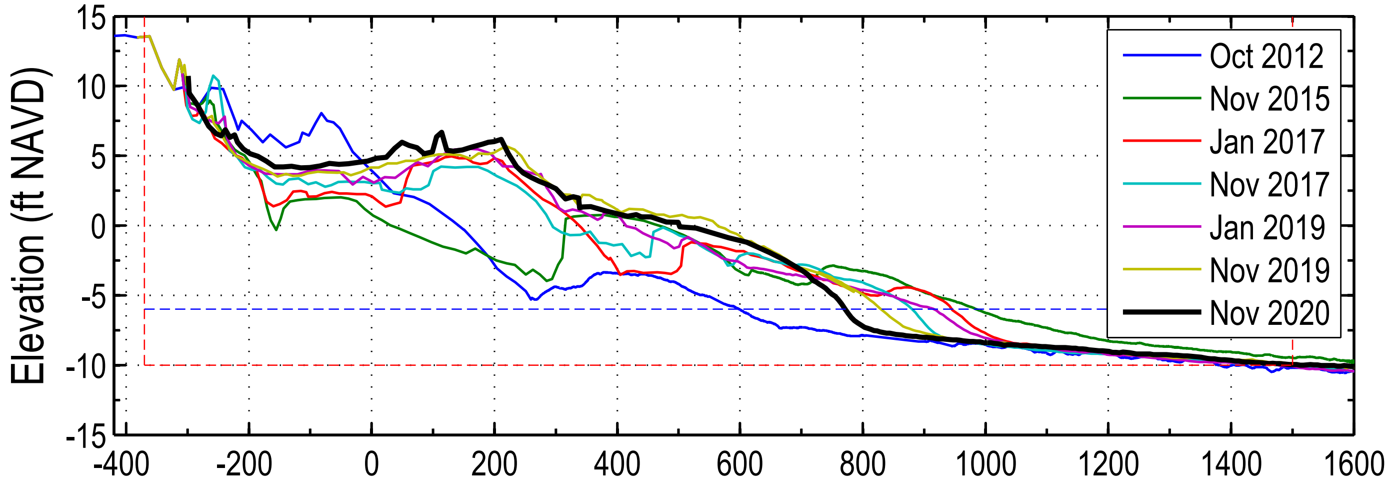




Date	Vol to -6	Vol -6 to -10	Vol to -10
Feb 2006	76.8	60.6	137.5
Sep 2006	148.6	146.3	294.9
Oct 2012	205.0	166.2	371.2
Nov 2015	298.5	215.7	514.2
Jan 2017	249.9	179.6	429.6
Nov 2017	249.1	170.0	419.1
Jan 2019	267.1	173.9	441.0
Nov 2019	278.8	175.1	454.0
Nov 2020	303.3	169.7	473.0

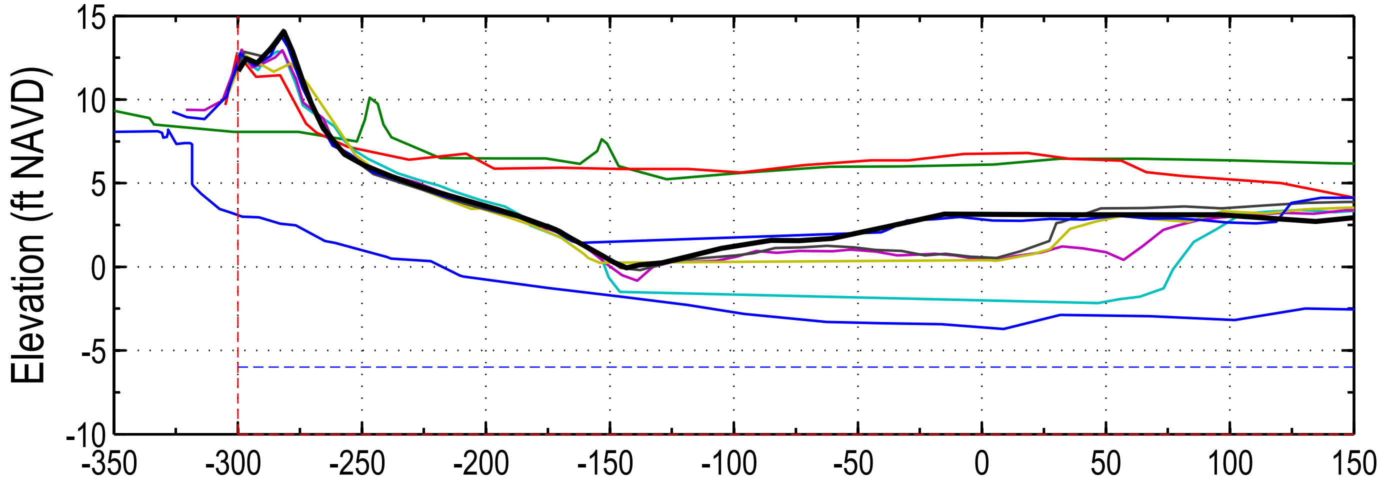
Kiawah Line 45 (70+00)

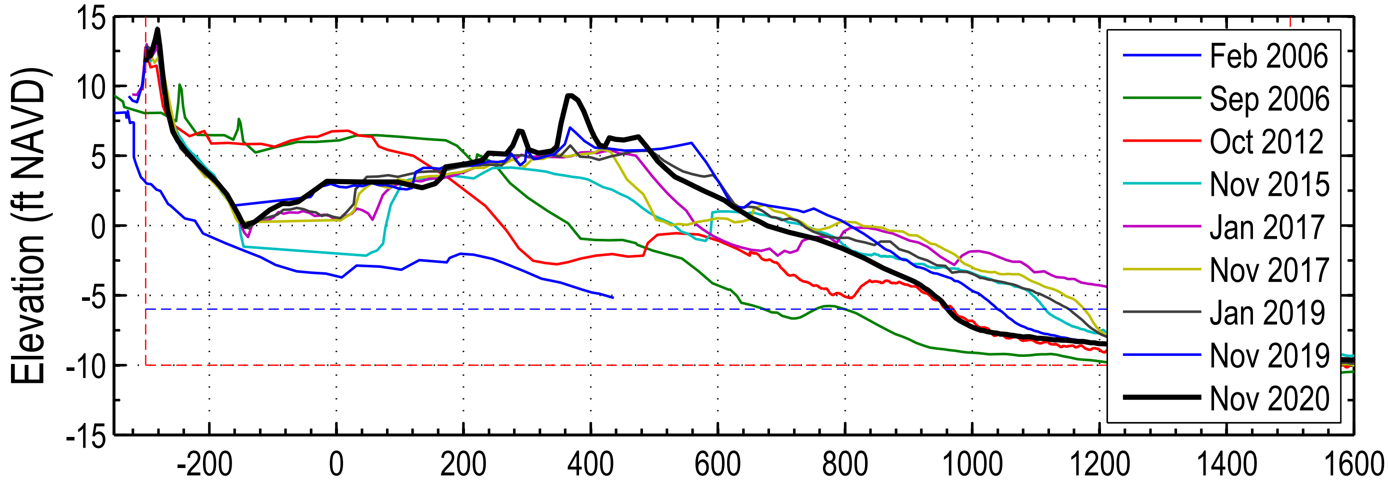




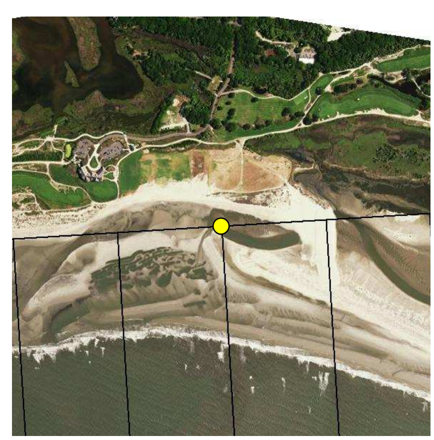
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	267.0	187.2	454.2
Nov 2015	289.1	234.9	524.0
Jan 2017	330.4	216.8	547.2
Nov 2017	340.5	207.3	547.7
Jan 2019	360.7	212.2	573.0
Nov 2019	386.1	207.8	593.8
Nov 2020	381.5	203.0	584.5

Kiawah Line 46 (Center of Driving Range)

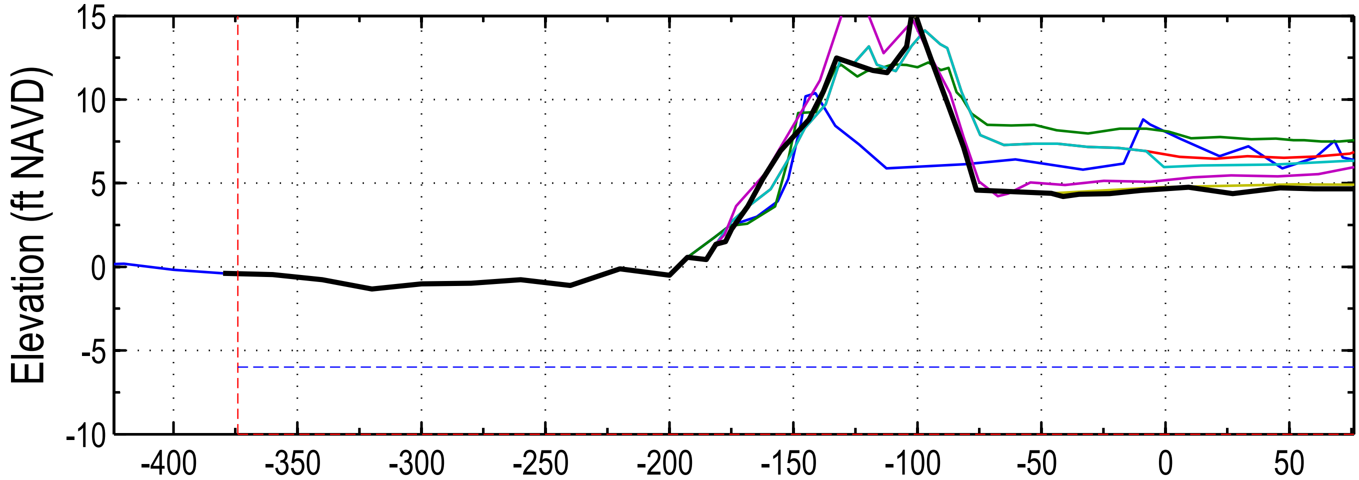


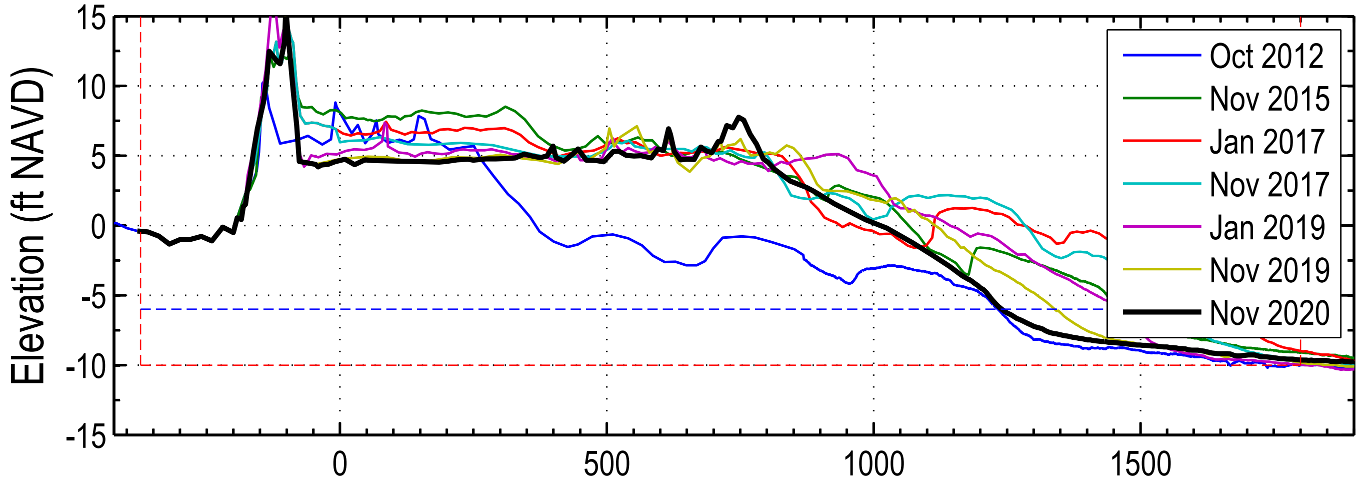


Date	Vol to -6	Vol -6 to -10	Vol to -10
Feb 2006	98.1	140.4	238.6
Sep 2006	322.4	183.2	505.6
Oct 2012	324.7	213.0	537.7
Nov 2015	345.2	235.8	581.0
Jan 2017	404.2	247.7	651.8
Nov 2017	401.4	232.0	633.4
Jan 2019	415.6	231.4	646.9
Nov 2019	427.0	224.5	651.6
Nov 2020	402.7	218.8	621.5



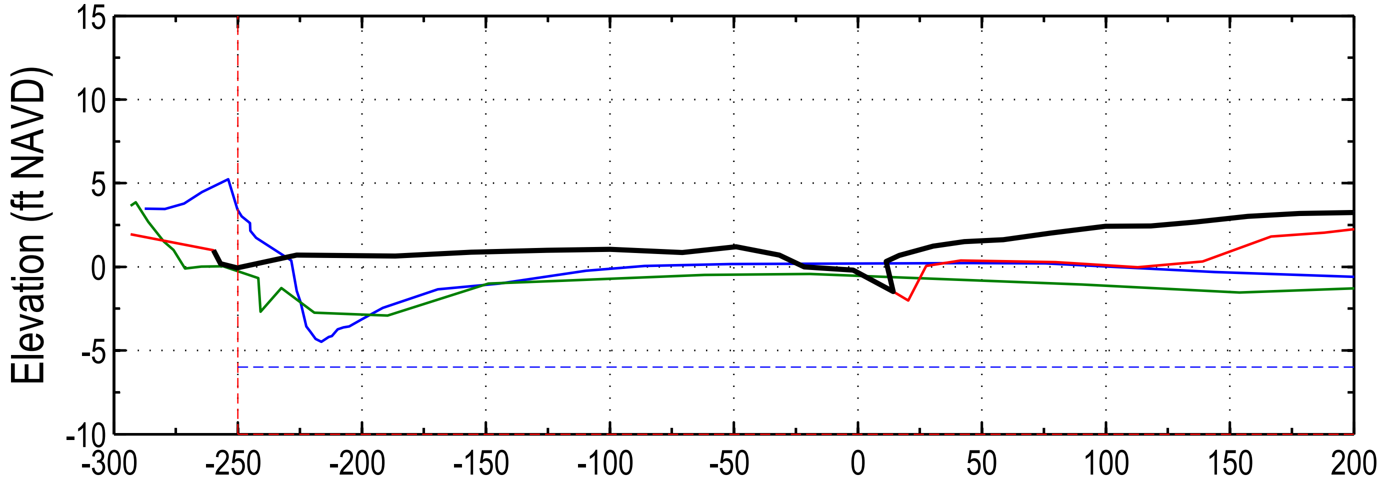
Kiawah Line 47 (Closure Dike)

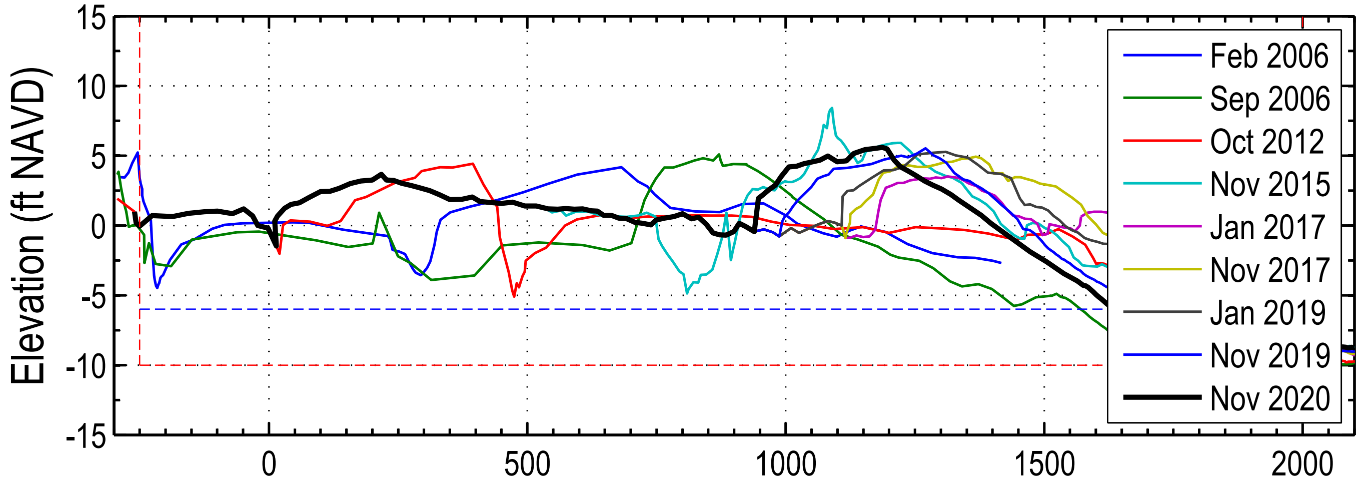




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	388.4	259.5	647.9
Nov 2015	638.9	295.3	934.2
Jan 2017	669.8	312.5	982.2
Nov 2017	652.3	300.8	953.1
Jan 2019	617.9	283.8	901.7
Nov 2019	580.8	277.2	858.0
Nov 2020	545.7	270.6	816.2

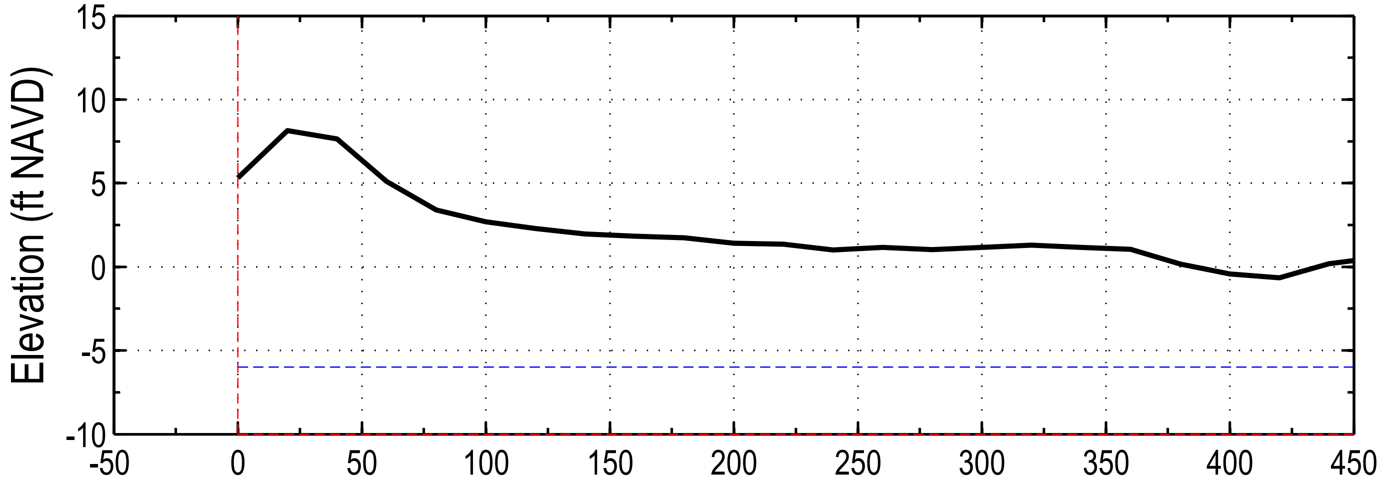
Kiawah Line 48 (100+00)

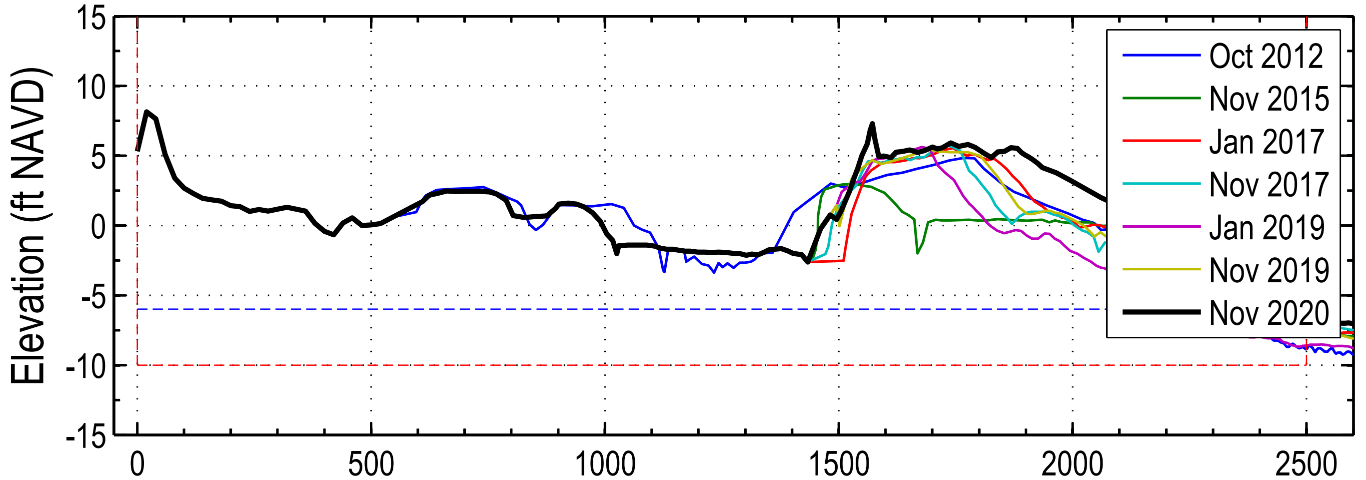




Date	Vol to -6	Vol -6 to -10	Vol to -10
Feb 2006	409.2	319.1	728.2
Sep 2006	329.2	288.2	617.4
Oct 2012	452.0	306.4	758.3
Nov 2015	570.8	332.8	903.6
Jan 2017	565.1	333.3	898.4
Nov 2017	573.3	331.0	904.3
Jan 2019	542.4	320.6	862.9
Nov 2019	518.8	312.0	830.8
Nov 2020	510.6	309.2	819.7

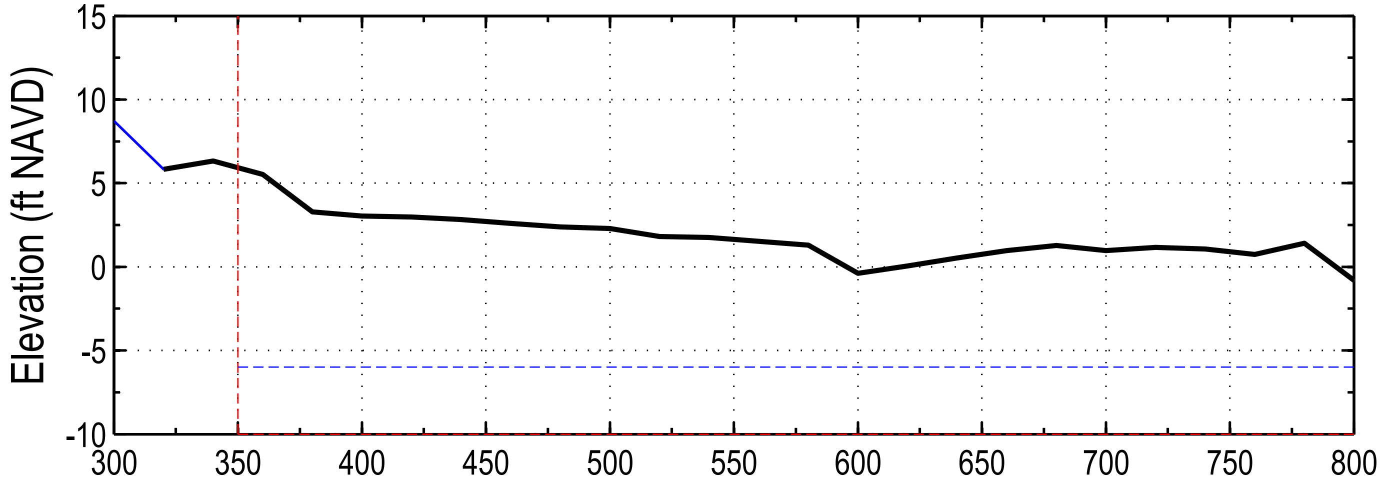
Kiawah Line 49 (110+00)

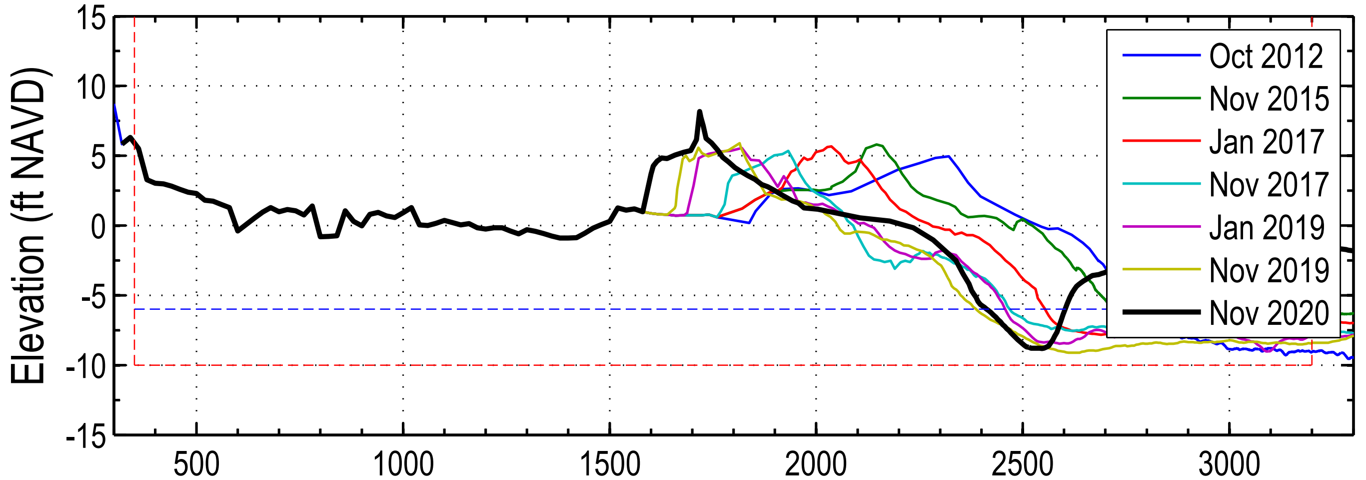




Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	619.1	361.0	980.1
Nov 2015	554.0	367.1	921.1
Jan 2017	594.2	365.5	959.7
Nov 2017	568.2	364.4	932.6
Jan 2019	534.6	353.0	887.6
Nov 2019	575.3	362.8	938.1
Nov 2020	634.4	369.1	1003.5

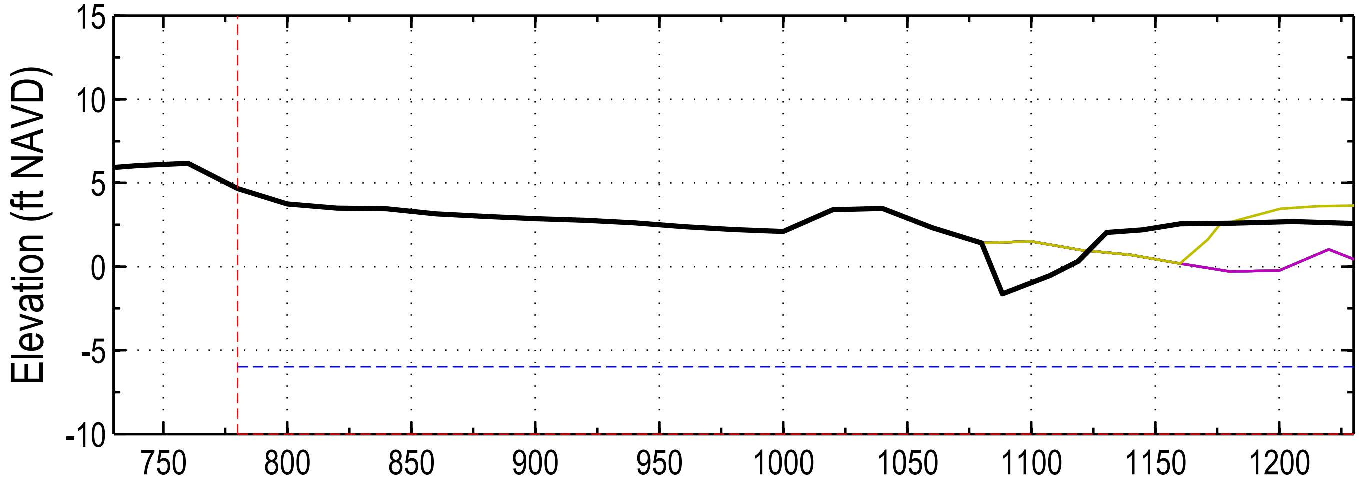
Kiawah Line 50 (120+00)

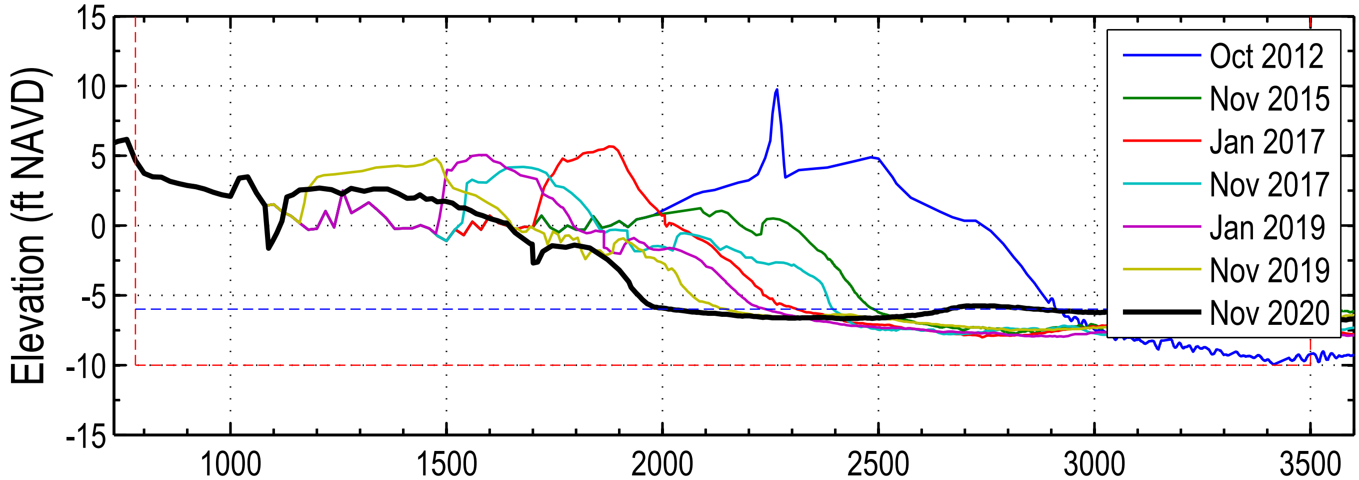




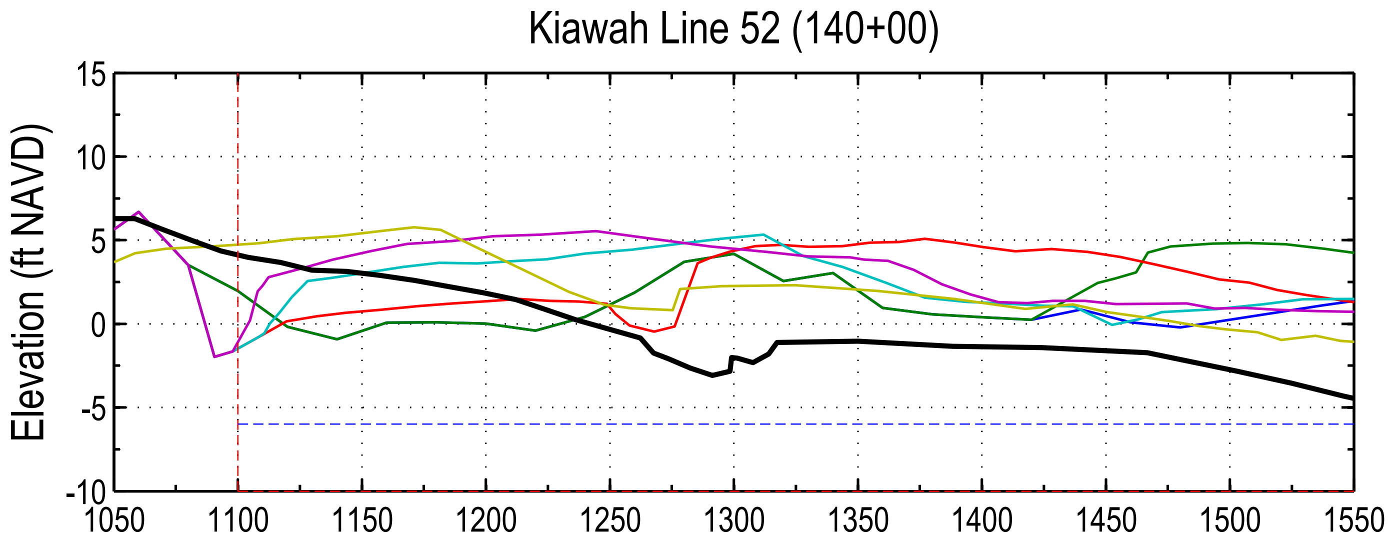
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	626.8	385.6	1012.4
Nov 2015	607.0	418.8	1025.9
Jan 2017	559.7	397.4	957.2
Nov 2017	505.6	390.9	896.5
Jan 2019	520.5	370.7	891.2
Nov 2019	507.9	352.0	859.9
Nov 2020	601.1	410.0	1011.1

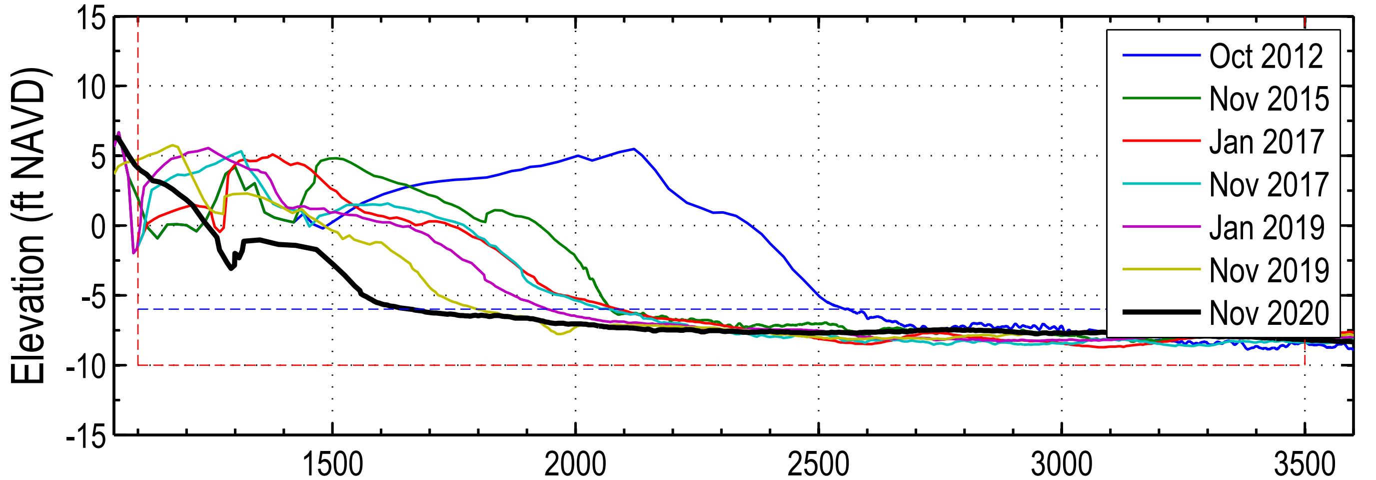
Kiawah Line 51 (130+00)





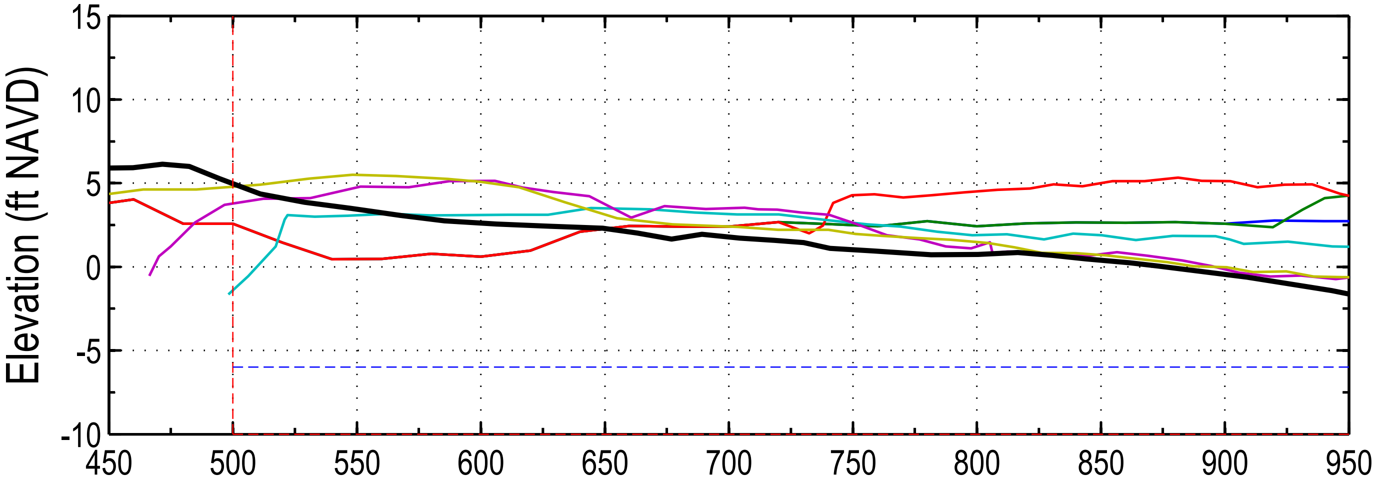
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	580.6	348.5	929.1
Nov 2015	407.7	371.7	779.4
Jan 2017	390.1	343.8	733.9
Nov 2017	395.0	339.8	734.8
Jan 2019	365.2	333.5	698.8
Nov 2019	356.2	347.4	703.6
Nov 2020	307.2	382.4	689.6

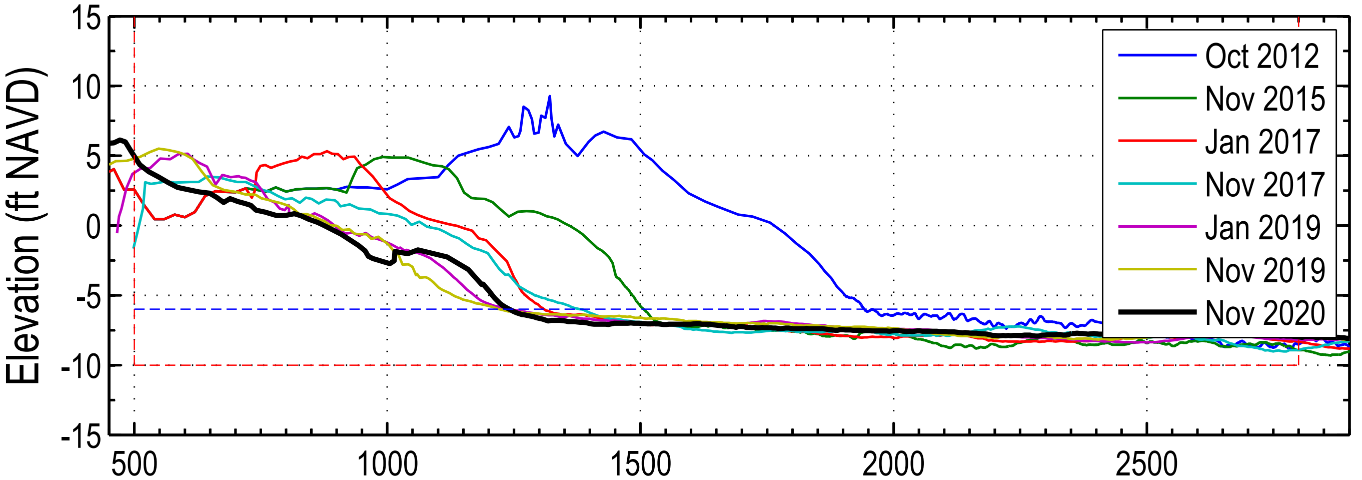




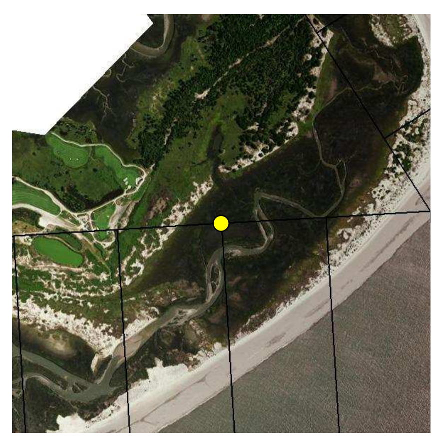
Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	411.2	296.9	708.2
Nov 2015	258.7	282.6	541.3
Jan 2017	222.0	258.5	480.5
Nov 2017	225.2	247.5	472.6
Jan 2019	206.9	258.6	465.6
Nov 2019	158.4	256.2	414.7
Nov 2020	92.9	256.8	349.6

Kiawah Line 53 (150+00)

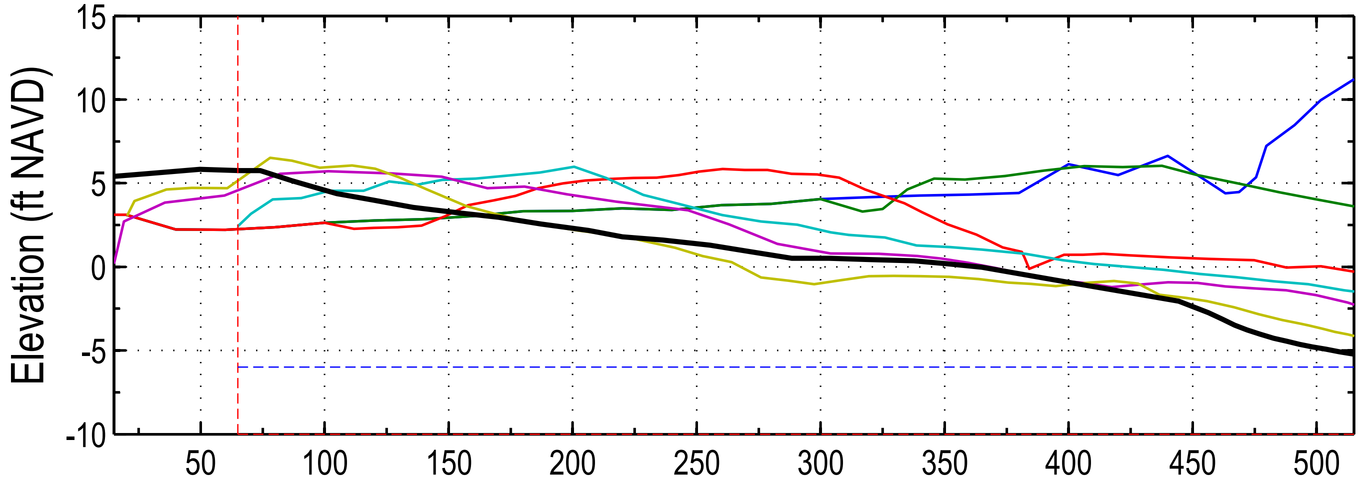


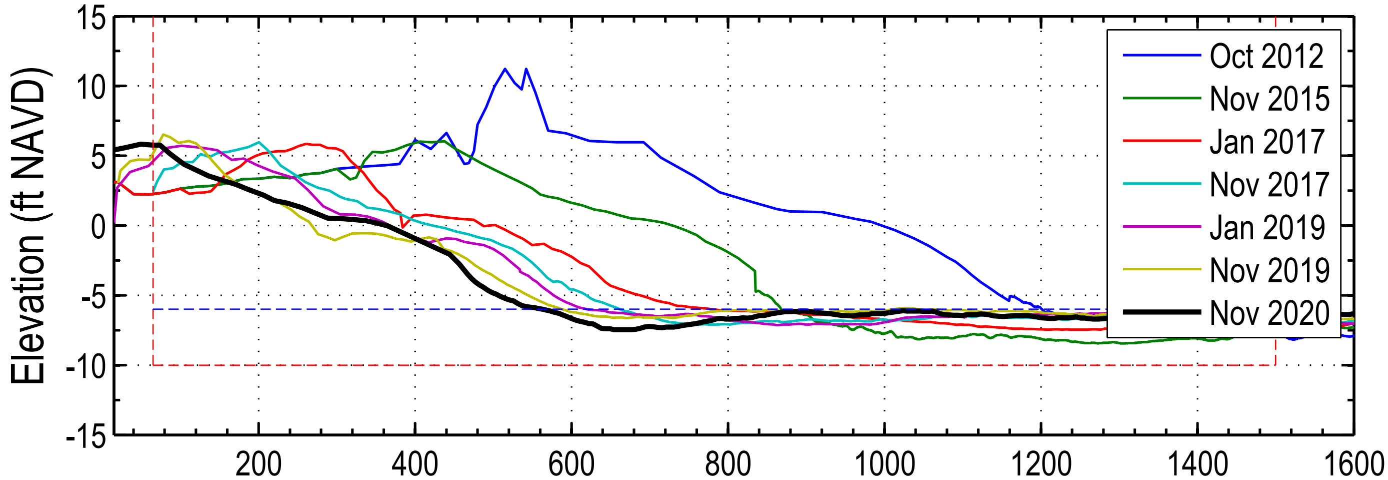


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	463.5	298.4	761.9
Nov 2015	286.4	242.8	529.2
Jan 2017	224.1	248.8	472.9
Nov 2017	203.8	252.0	455.8
Jan 2019	173.5	255.6	429.1
Nov 2019	164.7	261.9	426.6
Nov 2020	157.8	256.4	414.2

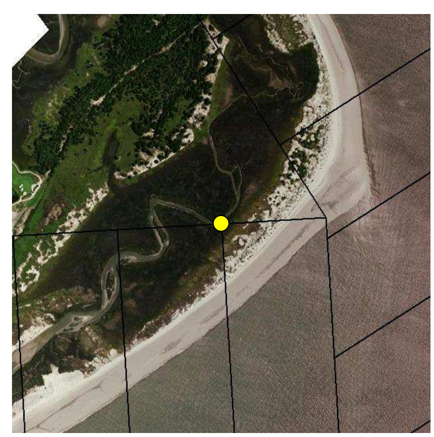


Kiawah Line 54 (160+00)

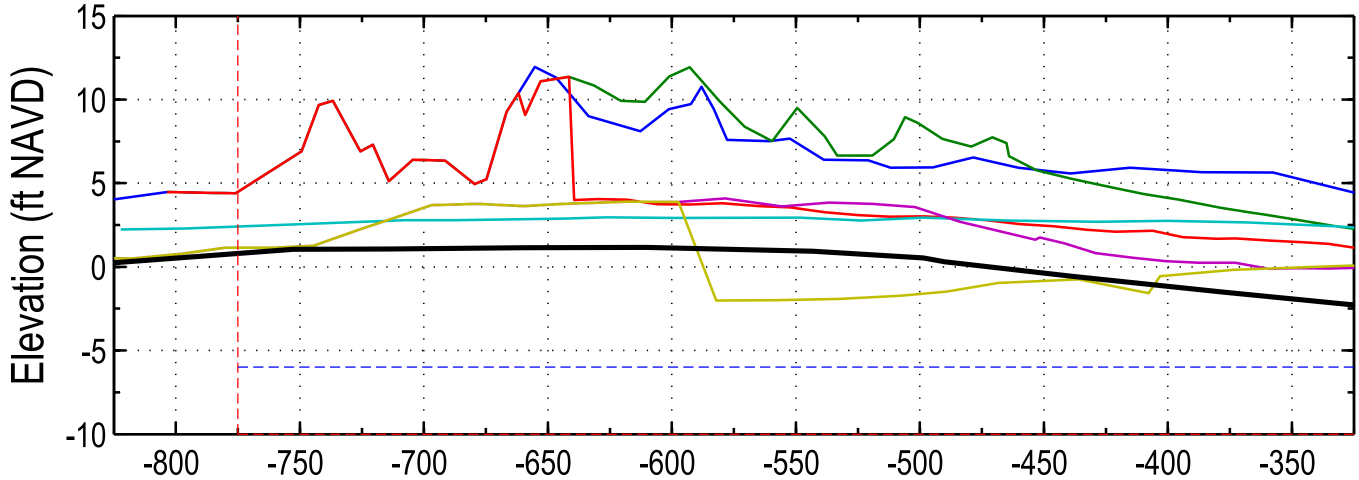


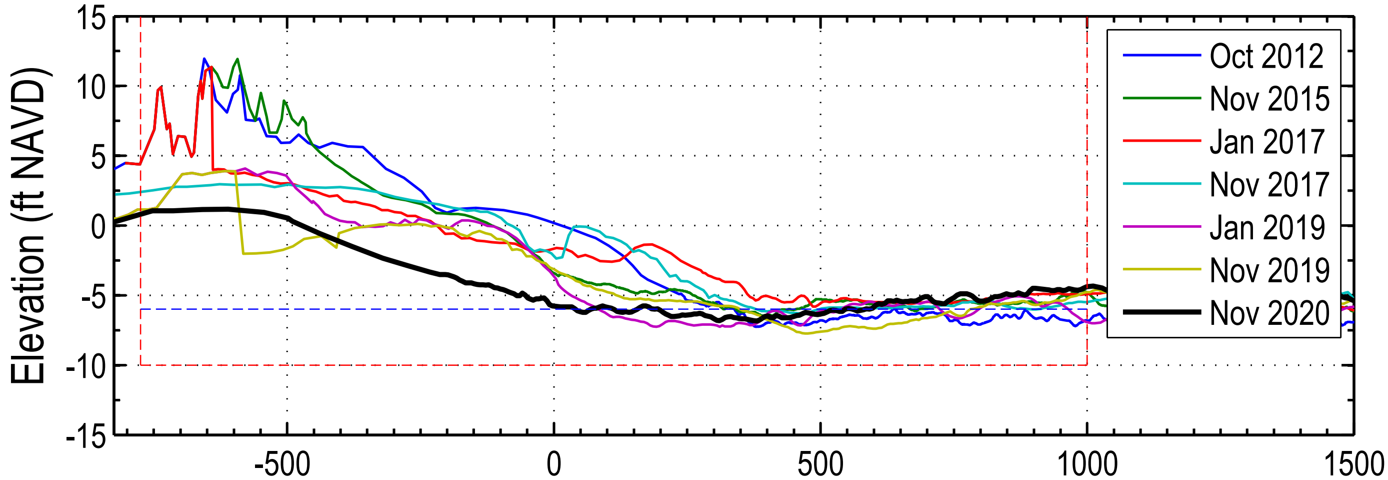


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	373.4	201.2	574.6
Nov 2015	245.4	169.3	414.7
Jan 2017	170.8	186.3	357.1
Nov 2017	151.3	191.2	342.5
Jan 2019	138.1	192.5	330.6
Nov 2019	115.8	203.6	319.4
Nov 2020	112.2	193.8	306.0

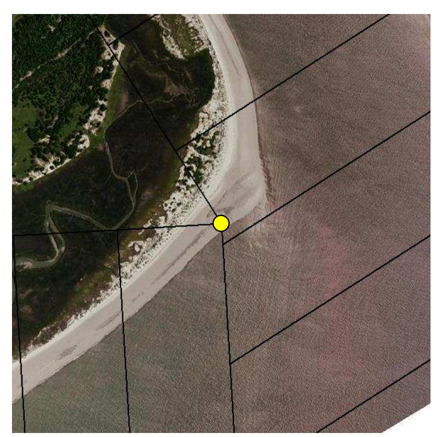


Kiawah Line 55 (170+00)

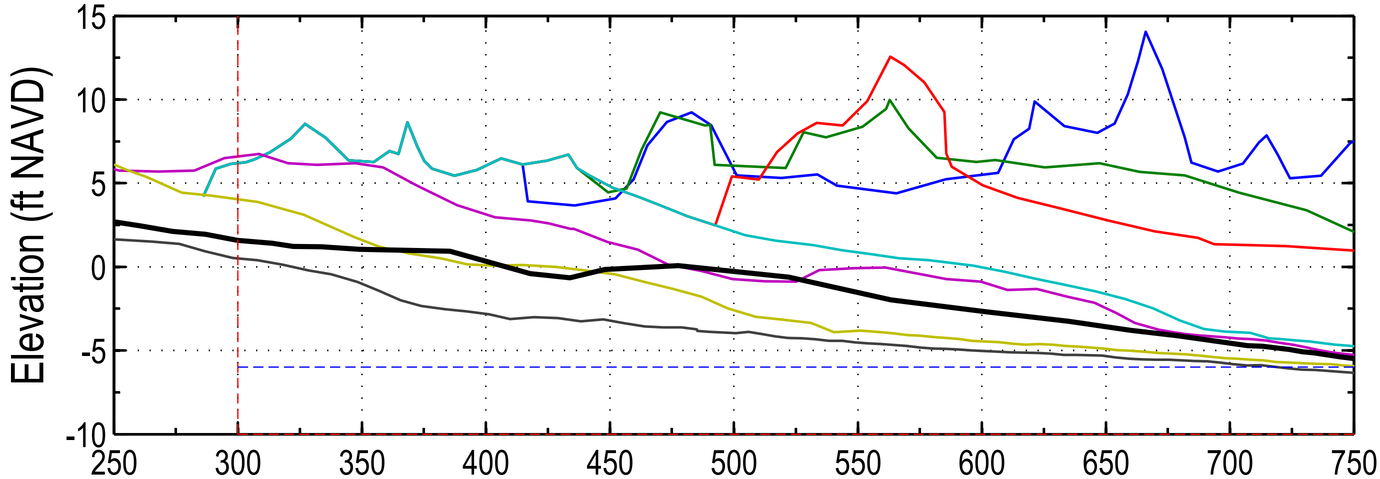


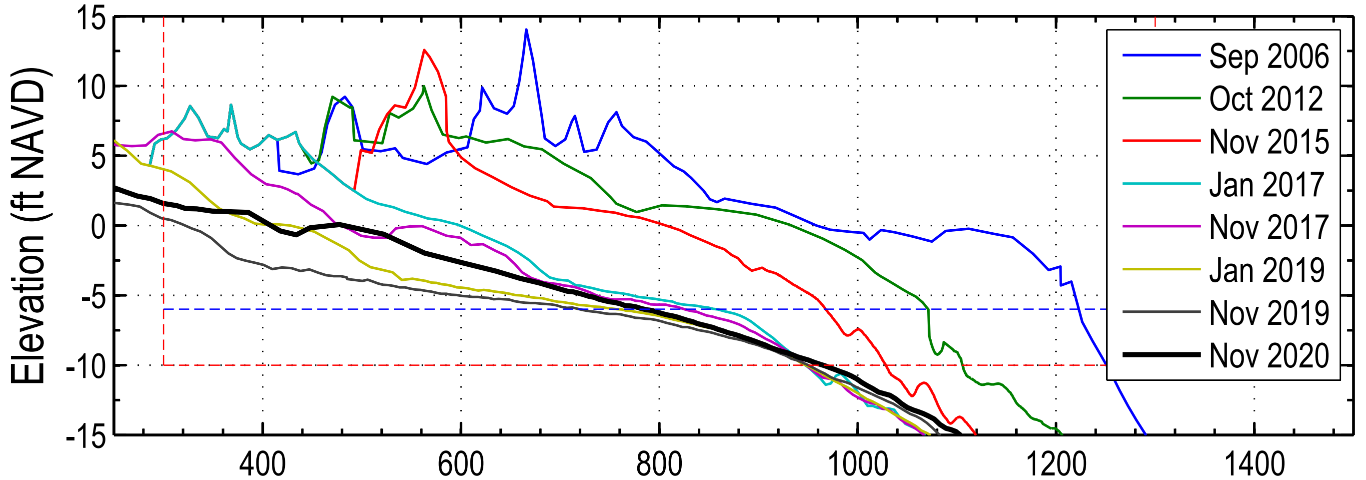


Date	Vol to -6	Vol -6 to -10	Vol to -10
Oct 2012	341.9	246.6	588.4
Nov 2015	317.0	262.0	579.0
Jan 2017	297.6	263.0	560.6
Nov 2017	275.0	262.2	537.3
Jan 2019	215.3	248.2	463.4
Nov 2019	189.1	247.5	436.5
Nov 2020	143.1	256.5	399.6

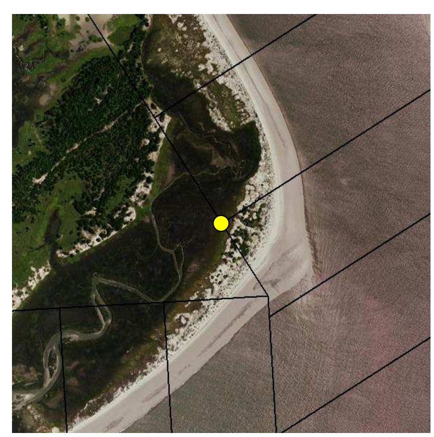


Kiawah Line 56 (Inlet 0+00)

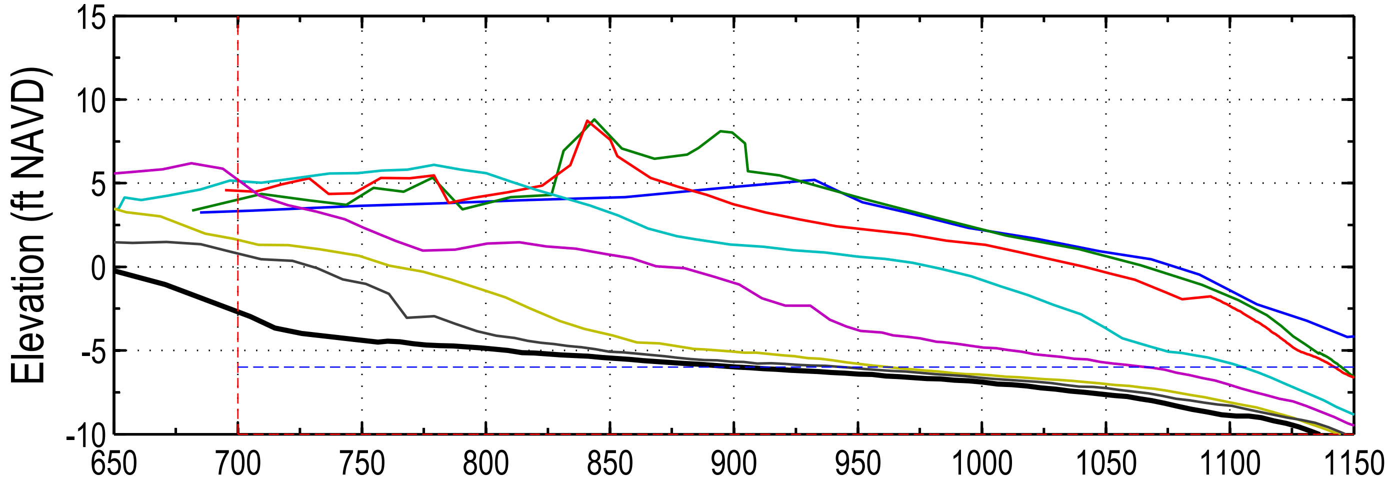


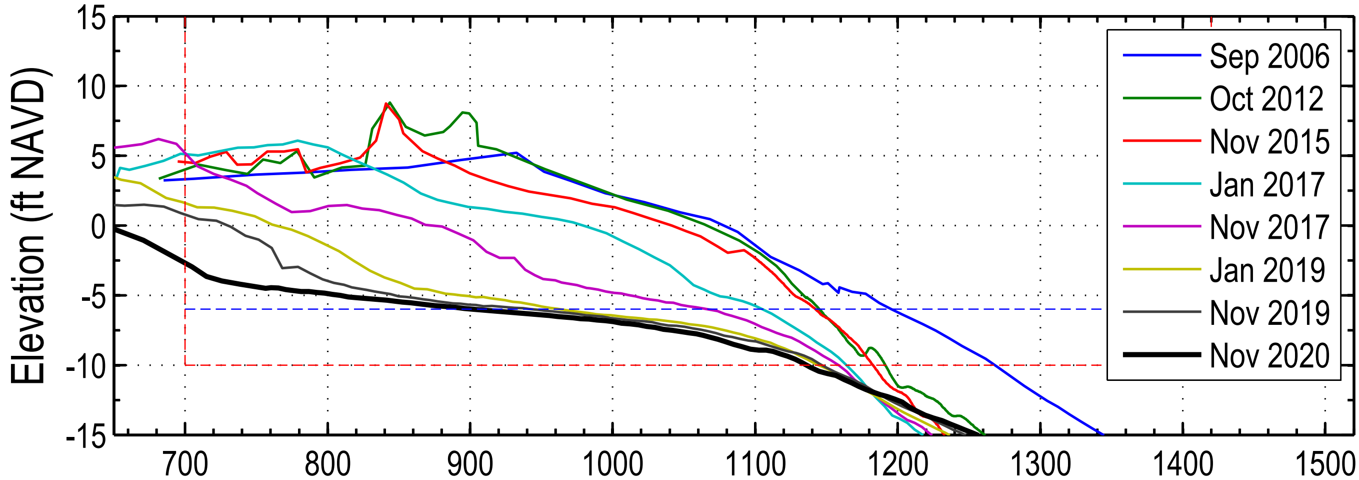


Date	Vol to -6	Vol -6 to -10	Vol to -10
Sep 2006	327.2	138.6	465.8
Oct 2012	269.9	115.7	385.7
Nov 2015	220.9	103.8	324.7
Jan 2017	133.7	90.6	224.3
Nov 2017	106.4	88.9	195.3
Jan 2019	61.7	85.1	146.7
Nov 2019	35.7	82.8	118.5
Nov 2020	75.7	86.1	161.8

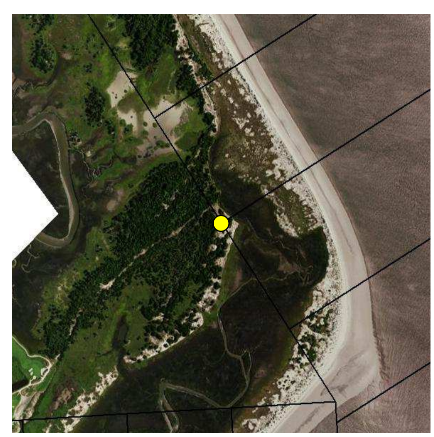


Kiawah Line 57 (Inlet 12+00)

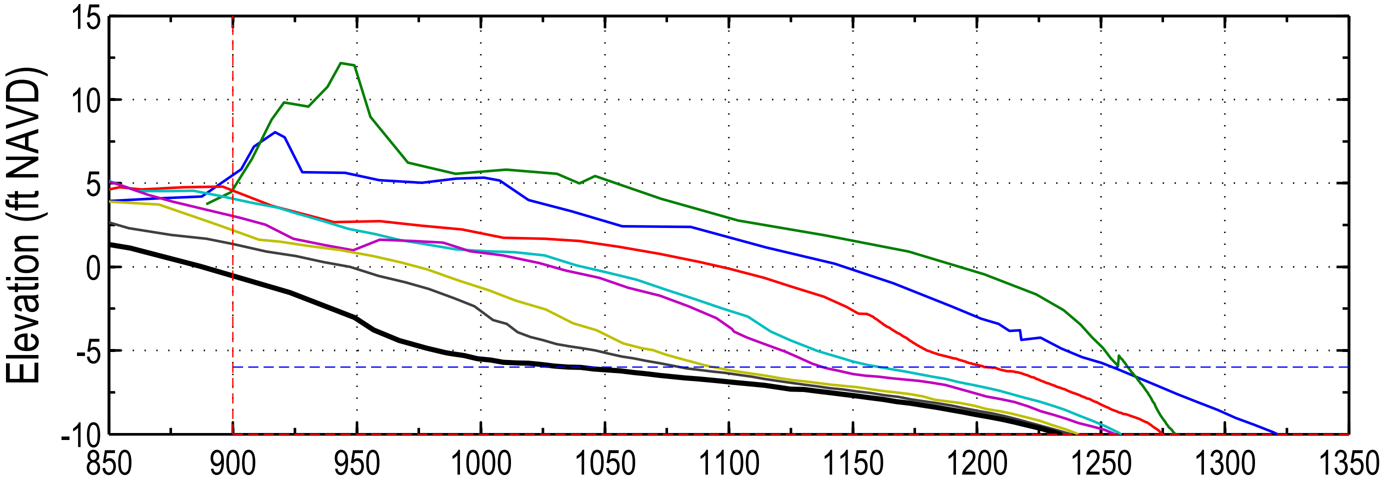


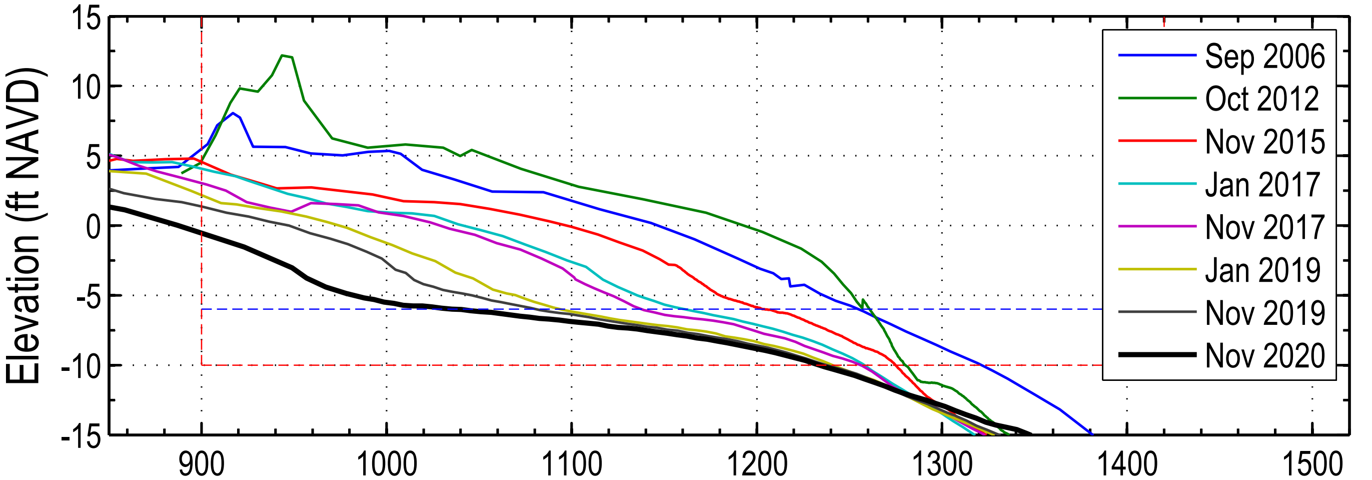


Date	**Vol to -6**	**Vol -6 to -10**	**Vol to -10**
Sep 2006	143.0	79.1	222.1
Oct 2012	149.6	69.0	218.6
Nov 2015	136.6	68.8	205.4
Jan 2017	110.6	64.8	175.3
Nov 2017	67.1	62.2	129.3
Jan 2019	33.1	56.6	89.7
Nov 2019	21.3	55.2	76.6
Nov 2020	8.6	52.2	60.9



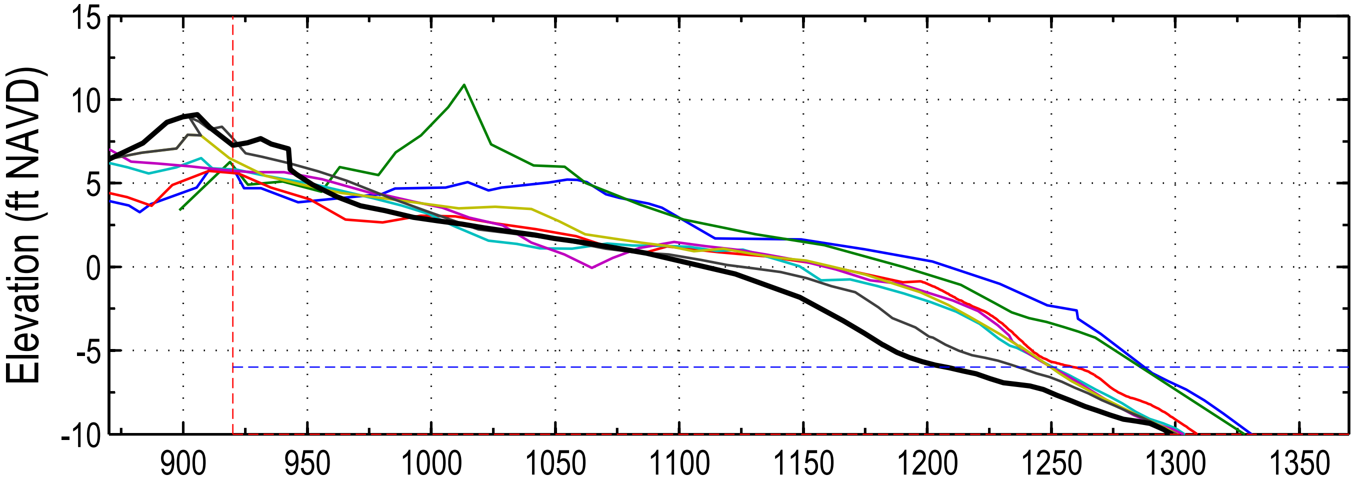
Kiawah Line 58 (Inlet 24+00)

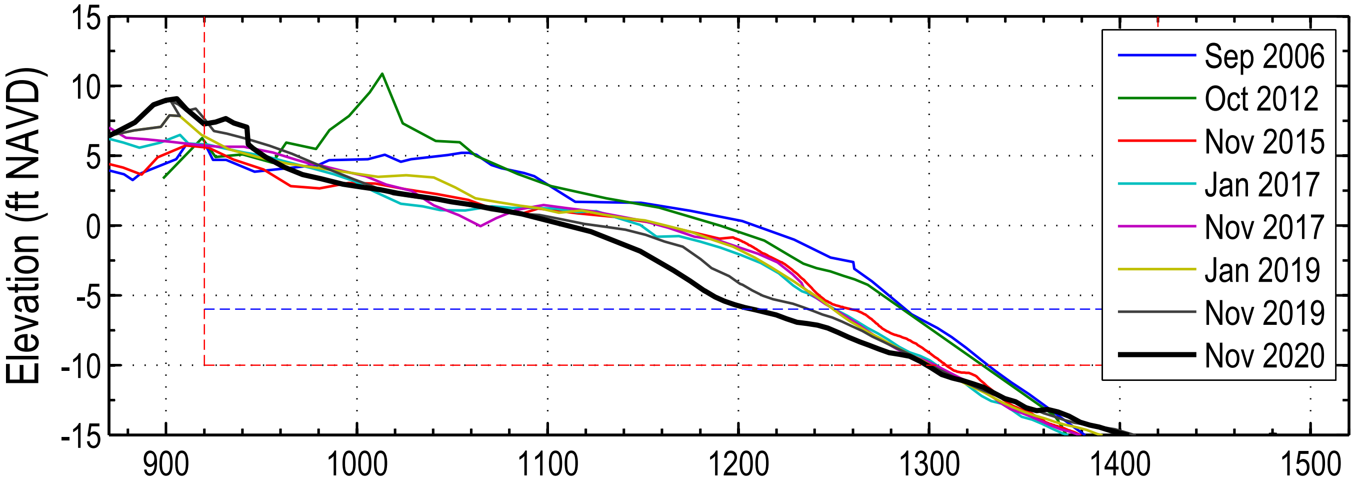




Date	**Vol to -6**	**Vol -6 to -10**	**Vol to -10**
Sep 2006	101.4	57.4	158.9
Oct 2012	127.2	54.9	182.1
Nov 2015	71.4	51.2	122.6
Jan 2017	54.7	47.2	101.9
Nov 2017	48.6	45.4	94.0
Jan 2019	32.3	41.3	73.7
Nov 2019	24.9	40.0	64.9
Nov 2020	10.8	37.8	48.5

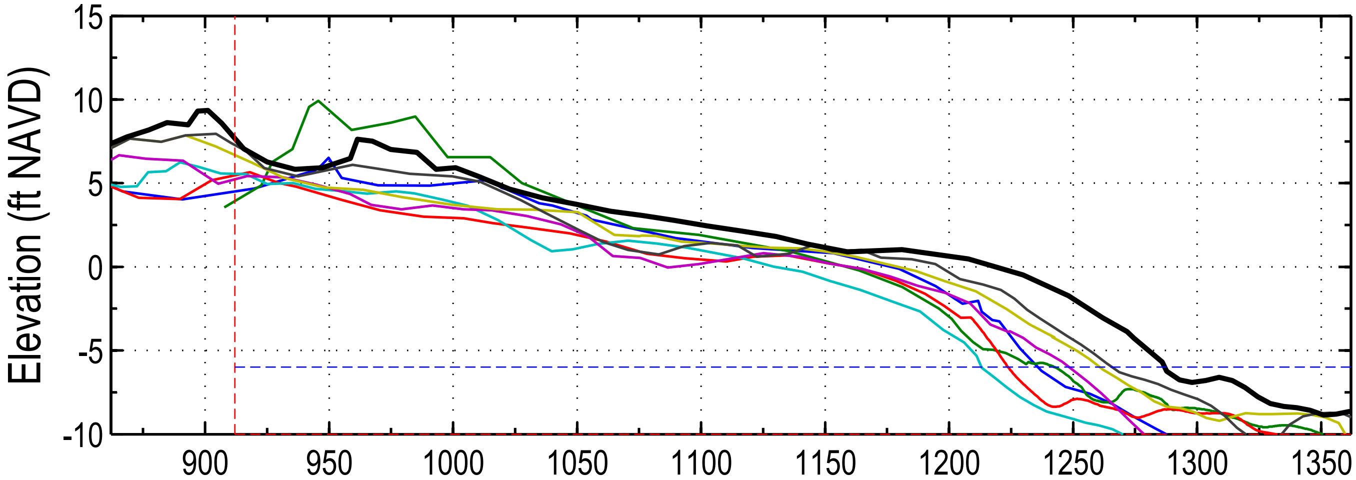
Kiawah Line 59 (Inlet 36+00)

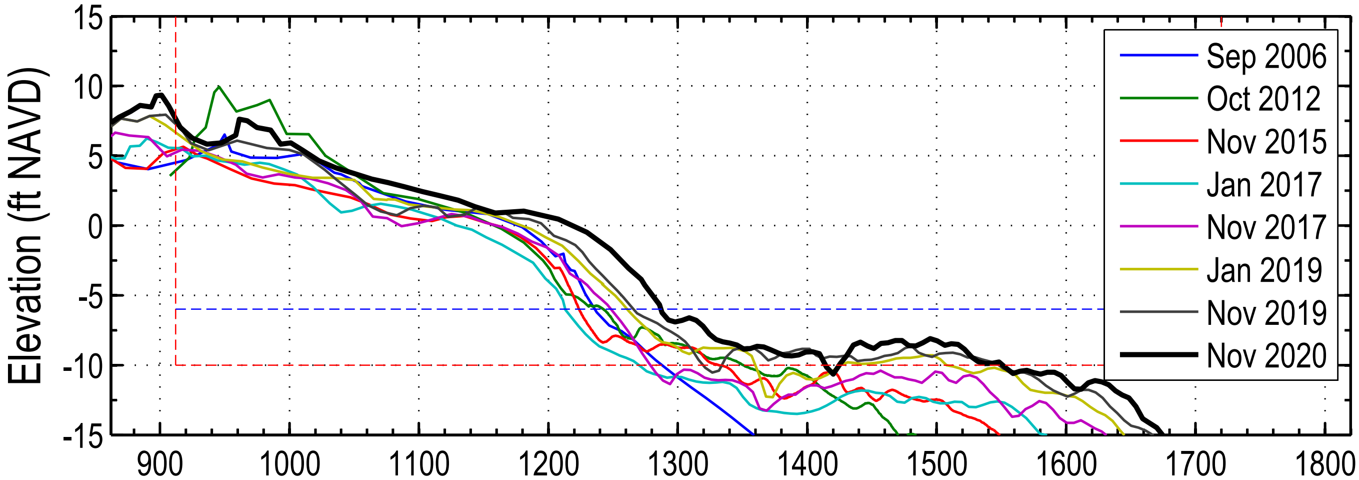




Date	Vol to -6	Vol -6 to -10	Vol to -10
Sep 2006	109.8	57.8	167.6
Oct 2012	116.4	57.3	173.7
Nov 2015	86.5	54.1	140.6
Jan 2017	84.8	52.8	137.7
Nov 2017	88.1	52.5	140.6
Jan 2019	90.5	52.4	142.9
Nov 2019	81.4	52.0	133.3
Nov 2020	74.4	49.9	124.3

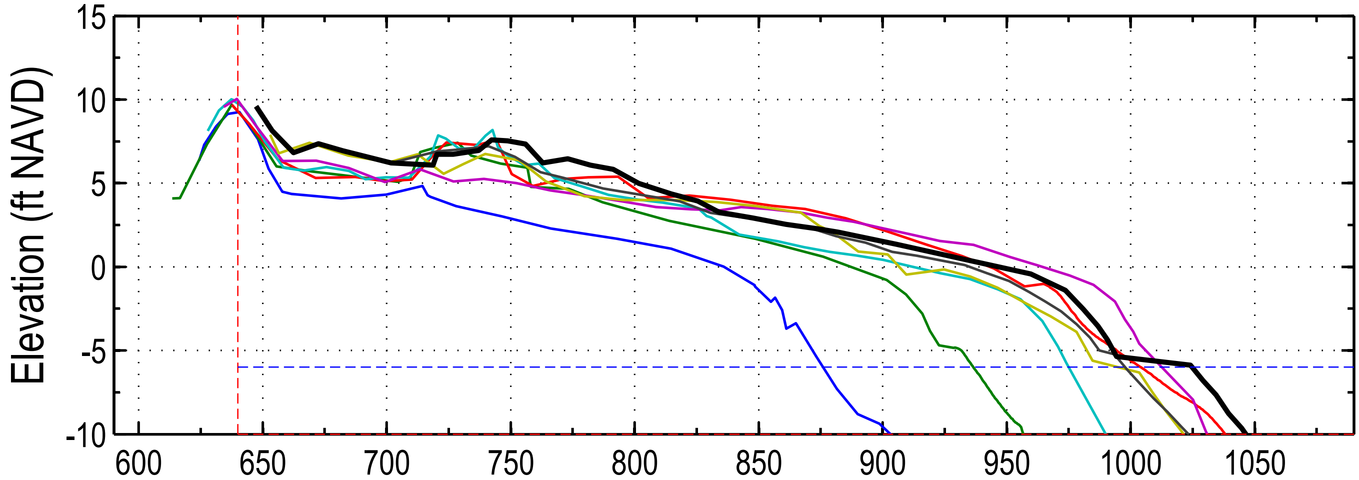
Kiawah Line 60 (Inlet 48+00)

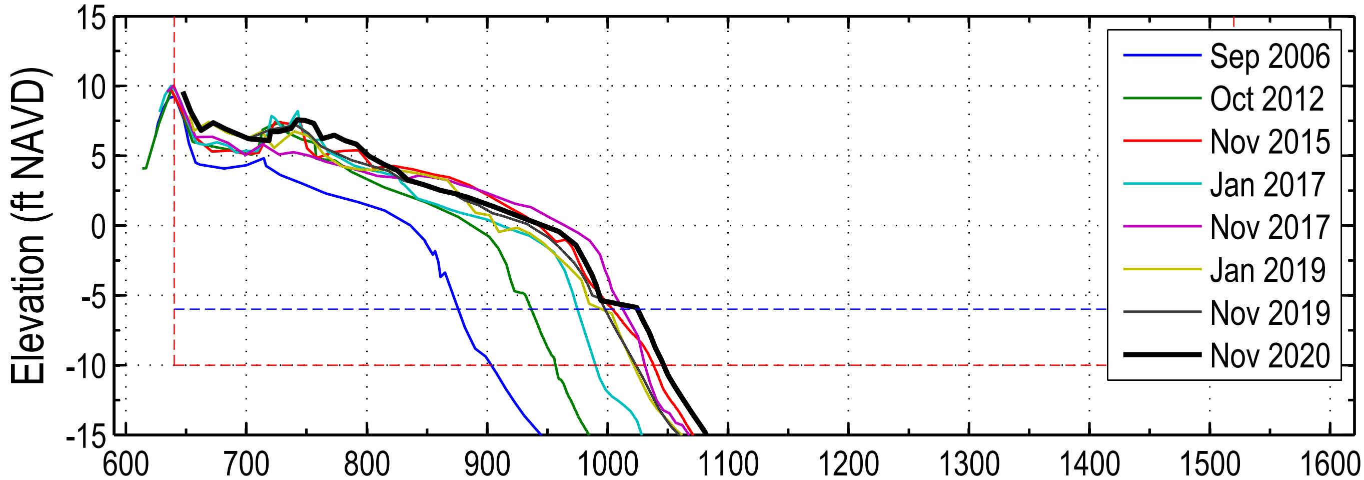




Date	**Vol to -6**	**Vol -6 to -10**	**Vol to -10**
Sep 2006	98.2	51.7	150.0
Oct 2012	105.5	55.3	160.8
Nov 2015	85.1	52.2	137.2
Jan 2017	82.9	47.9	130.8
Nov 2017	89.0	52.2	141.2
Jan 2019	98.4	58.5	156.9
Nov 2019	103.6	62.9	166.5
Nov 2020	118.4	69.2	187.6

Kiawah Line 61 (Inlet 60+00)





Date	Vol to -6	Vol -6 to -10	Vol to -10
Sep 2006	72.3	36.6	108.9
Oct 2012	100.8	45.4	146.2
Nov 2015	125.6	56.7	182.3
Jan 2017	114.4	50.7	165.1
Nov 2017	126.7	56.8	183.5
Jan 2019	119.5	55.0	174.5
Nov 2019	123.7	54.9	178.6
Nov 2020	129.3	58.6	188.0