Spring 2017

Assessment of Sea Level Rise in Middlesex County and Its Influence on Future Storm Surges and Waterfront Property

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Abstract

There is currently an upward trend of sea level rise in the Chesapeake Bay region and many other areas around the world. Sea level rise in itself is a major impact on the environment and humans, and it has become a factor in the severity of other natural disasters like hurricanes. With increasing sea level rise, storm surges are much higher, and together with wind driven waves will cause more destruction to the coast. The 1933 hurricane was considerably stronger than Hurricane Isabel, creating record high tide level from storm surge, but because of the 42.7 cm increase in average tide level over the next 70 years, Hurricane Isabel comparatively seemed equal in power to the 1933 hurricane. Using the 2016 Middlesex County Geography Information System, land value of both waterfront and inland properties were taken and recorded, along with the amount of acreage that is associated with the value. Using the sea level trend data from NOAA, graphs were created that modeled actual tide level from historic hurricanes with the addition of projected sea level rise for Middlesex County, Virginia. The mean hurricane water level is estimated to rise from 98.01 cm to 111.38 cm, with a projected sea level increase of 13.37 cm in 30 years. Data show that at all three locations waterfront properties were statistically much more valuable compared to inland property values. Waterfront property owners should be aware of how much more susceptible their property is to flooding due to future sea level rise. Increases in development along the shorelines raises vulnerability of infrastructure, and changes in city planning are essential to mitigate the effects of floods and erosion.

Introduction

There is currently an upward trend of sea level rise in the Chesapeake Bay region and many other areas around the world. Since the late 19th century, sea level measurement gauges have determined an average increase of 1.7 ± 0.3 millimeters per year. By the 1990s, precise satellite measurements now gauge the sea level rise with an average increase of 3.3 ± 0.4 millimeters per year (Nicholls et al., 2014). Sea level rise in itself is a major impact on the environment and humans, and it also stressed the severity and frequency of other natural disasters. One case of such impact are storm surges. Hurricane storm surges are caused by the low atmospheric pressure in the center of the hurricane, uplifting the water below and driving it toward shore with land falling storms. With increasing sea level rise, storm surges are much higher, thus stronger, and together with wind driven waves will cause increasing destruction to the coast (Kleinosky et al., 2006). With climate change and elevated sea level rise, hurricanes, storm surges, and floods will have increased wave energy, a higher risk for occurrence, and cause greater damage to coastal communities (Reay, 2011).

In 1933 a hurricane, commonly recognized as the "storm of the century" for the Chesapeake Bay, produced a storm surge in Hampton Roads that parallels with Hurricane Isabel's maximum tide level. The 1933 hurricane and Hurricane Isabel both produced a peak tide level of just under 250 centimeters above the mean lower low water (Boon et al., 2016). The 1933 hurricane was considerably stronger than Hurricane Isabel, creating record high tide levels from storm surge, but because of the 42.7 centimeter increase in average tide level over the next 70 years, Hurricane Isabel comparatively seemed equal in power to the 1933 hurricane (Tompkins et al., 2014).

In recent decades, there has been intense development along coastal shorelines of the mid-Atlantic and Chesapeake Bay region (USGS, 2016). Population in the Virginia coastal zone has increased over 1.6 million people over the past 30+ years and coastal counties now have the highest population density in the state (NOAA, 2004). There has been a 48% increase in the coastal population since 1980, this increase in coastal population is parallel with increase in land development, and those properties are threatened by changing shorelines due to rising sea level (USGS, 2016). Future increases in development along coastal shorelines is risky due to the vulnerability to flooding and erosion, and can result in significant economic loss for the affected counties.

Studies have shown that property values have a correlation with distance from the water. Although not all studies yield the same result, a mass of those studies have presented data that properties close to or overlooking the water has a higher value compared to properties that are farther away from the water (Dumm et al., 2014). In a study of assessing changes in waterfront value over long periods, the study shows that there has been an “up and down” cycle in waterfront properties; such a pattern was visible from 1990 to 2009, with the rise and fall alternating every few years (Hansen et al., 2013).

The purpose of this research project is to create a prediction of how current sea level rise trends combined with storm surges will impact waterfront properties into the future. Sea level rise has been widely accepted, and this project will use tide level data to further verify the occurrence of such phenomenon. This study is based on how sea level rise combined with storm surge and tides will impact not only the waterfront properties, but also the economies of the county surrounding the surveyed area. This project will use published NOAA data of observed peak tide level during past hurricanes to predict the effects of elevated sea levels on future storm surges. Using the published current local rate of sea level rise, added to the peak of observed tide level during past hurricanes, a model for the future was created of how much higher the tide level could occur in future hurricanes. Property data was collected for all three sites with two categories each, waterfront and inland values. Comparison was made between the two categories to show variance in value.

Hypotheses

Ha_1: If there is an increase in sea level rise, then it will create higher tide level during hurricanes.

Ho_1: If there is an increase in sea level rise, then it will not have any effect on tide level during hurricanes.

The independent variable in this study is the past hurricane observed water level and the dependent variable is predicted water level rise due to sea level. Constants are the data collection and analysis methods and source of data from NOAA.

Ha_2: If the property is on or overlooking the water, then its value will be higher than those that are inland.

Ho_2: If the property is on or overlooking the water, then its value will be not be different to those that are inland.

The independent variable is the distance from the shoreline and the dependent variable is the value of the property. The constants are the database of values from Middlesex County and the acreage of each property assessed was constant.

Materials and Methods

Due to lack of data for Middlesex County tide level, nearby Windmill Point was chosen for its close proximity to Middlesex County (Figure 1). Using stations from the Nation Oceanic and Atmospheric Administration (NOAA), the peak tide levels during 11 hurricanes that affected

Virginia of varying dates and category were taken and recorded. Then using the sea level trend data, also from NOAA, graphs were created with the addition of sea level rise that modeled how the tide level of the hurricanes would be if they were to occur years later.

The three sites chosen for the study of property values are within Middlesex County, Virginia: Deltaville, Water View, and Urbanna (Figure 1). Data collection for all three sites were divided into two categories, waterfront and inland. 30 data points were randomly chosen for each category, producing a total of 180 data points. Using the 2016 Middlesex County Geography Information System, land value of both waterfront and inland properties were taken and recorded, along with the amount of acreage that is associated with each value. Analysis derived the value of one acre for all 180 data points, then for each category the mean value of one acre of land with structures was averaged and compared within its respective site.

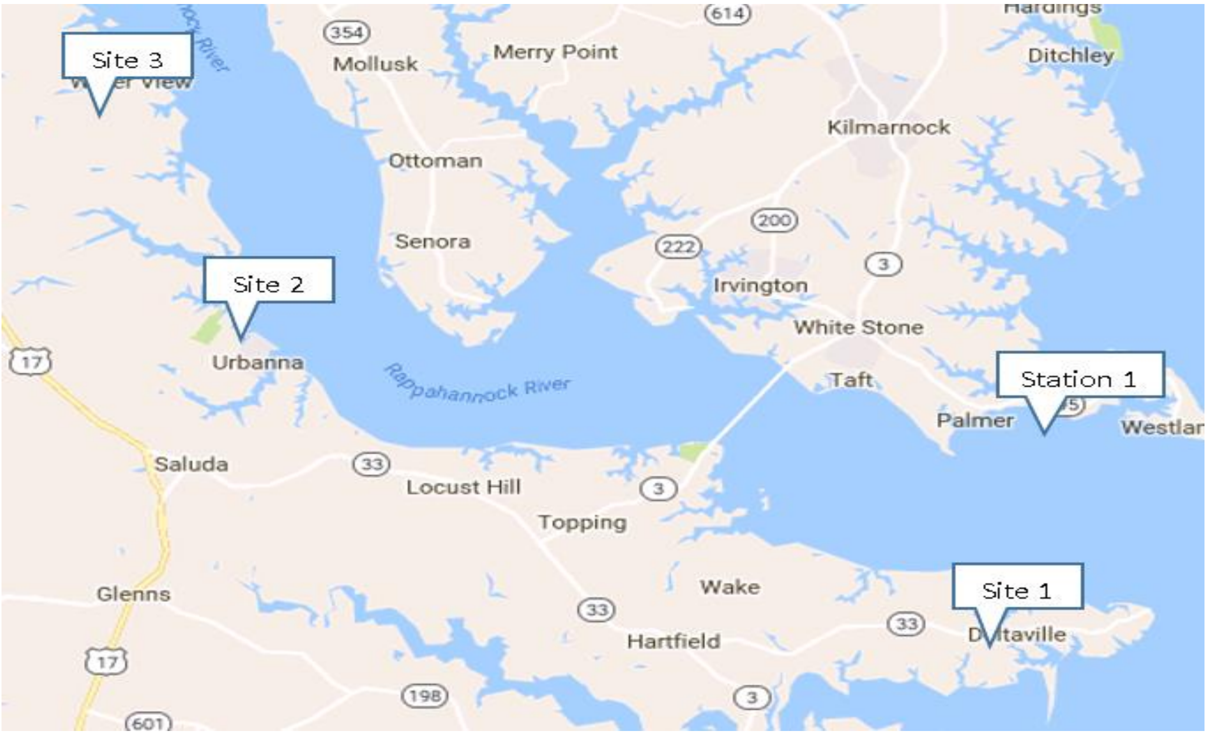

Figure 1. Site 1 located at Deltaville; Site 2 located at Water View; Site 3 is located at Urbanna, Virginia. Station 1 is located across the Rappahannock at Windmill Point, Virginia.

Results

Eleven major hurricanes that have impacted the Middlesex County were analyzed based on the amount of water level rise that was experienced and average sea level rise 0.44 mm/year was superimposed on the sea level rise data (Figures 2 and 3). The resulting graphs are an indication of potential combined effected of hurricane flooding and sea level rise effects in the future 30 years. The mean hurricane water level rise is estimated to go from 98.01 cm to 111.38 cm, an increase of 13.37 cm. Thirty years into the future, the residents of Middlesex county should expect to experience an average hurricane flood level of 110 cm in tide level.

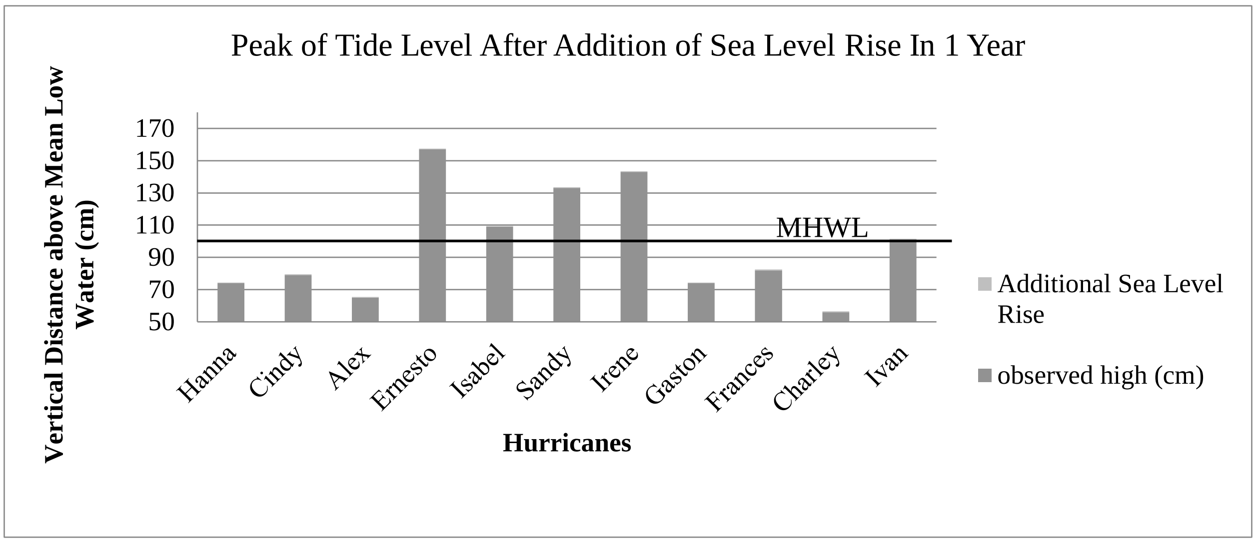

Figure 2. Peak of Tide Level After Addition of Sea Level Rise in 1 Year. Hurricane tide level above MLW (cm), from left to right; 74.461, 79.461, 65.461, 157.461, 109.461, 133.461, 143.461, 74.461, 82.461, 56.461, 101.461. The Mean Hurricane Water Level is 98.01 cm.

Three different locations of Middlesex County were selected to collect land value data, with each location differentiated by waterfront and inland values (Figure 4). Data at all three locations of waterfront properties were statistically much more valuable compared to inland property values. T-test analysis of these values yielded p=2.419E-13; 1.150E-7; and 0.0001.

Deltaville's waterfront value is 721% of inland value; Water View's waterfront value is 382% of inland value. Urbanna's waterfront value is 190% of inland value.

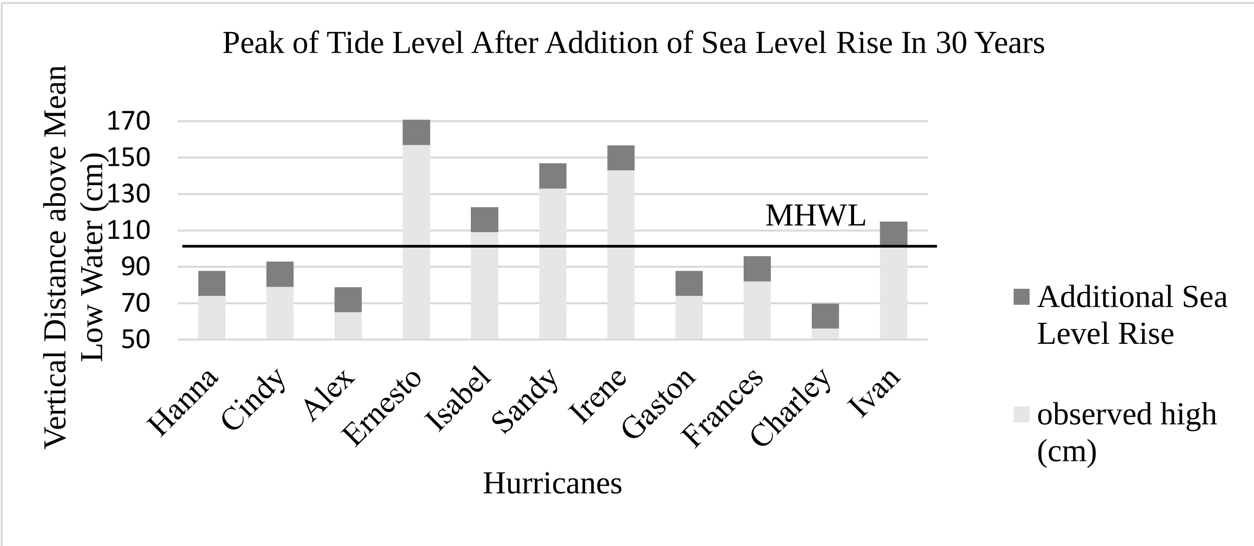

Figure 3. Peak of Tide Level After Addition of Sea Level Rise in 30 Years. Hurricane tide level above MLW (cm), from left to right; 87.83, 92.83, 78.83, 170.83, 122.83, 146.83, 156.83, 87.83, 95.83, 69.83, 114.83. The Mean Hurricane Water Level is 111.38 cm.

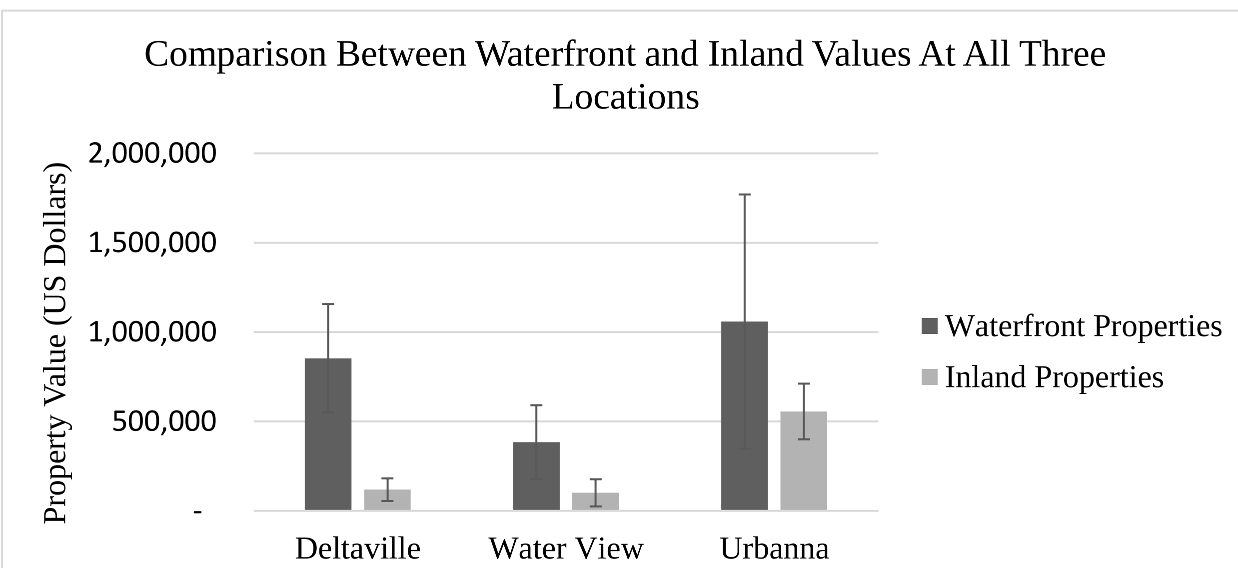

Figure 4. Property value comparisons at three locations in Middlesex County. Deltaville water front is 721% higher; Water View is 382% higher, and Urbanna is 190% higher in value. T-test $p << 0.05$ for all t-test statistical comparisons of waterfront and inland values. ($p=2.419E-13$; 1.150E-7; and 0.0001 respectively).

Conclusion

Based on the results for property values compared between the waterfront and inland areas of the county, the data show a statistically significant difference between the two categories at all three sites, $p<<0.05$. Therefore, the null value hypothesis: If the property is on or overlooking the water, then its value will be not be different to those that are inland is rejected, t-test p= 9.53E-06. For tide level, the height of tide level data modeled for thirty years into the future showed increased height for the eleven hurricanes.

This study has been parallel with a similar study done regarding tide level and waterfront properties. Though the value of waterfront properties has an alternating cycle, it is consistently greater in value compared with nearby inland property values (Hansen et al., 2013; Dumm et al., 2014). Waterfront property owners should be aware of how their land is much more susceptible to future flooding. Data show that the mean hurricane water level (MHWL) of past hurricanes is at 98cm, but after 30 years the MHWL has risen to 110cm, which will result in more frequent and severe flooding. By 2003, 48% of Virginia population is living in coastal communities. Increase in development along the shorelines raises vulnerability of numerous infrastructures, and changes in planning are essential to mitigate the effects of future floods and keep its resulting erosion to the minimum. By doing so, those waterfront properties and infrastructures can help its community to achieve a more secure county tax base income into future years. The Virginia Coastal Zone Management Program has encouraged the development of living shorelines as opposed to the hardened shorelines. The living shorelines has beneficial value to water quality and habitats, and allows the wetlands to move up land as sea level rises (VCZMP, 2016).

Further studies for this project can increase sample locations to increase confidence level of accuracy of data. More station's data should be collected to confirm increasing trends of sea level rise, and factoring in tide level during other events other than hurricanes to examine alternate impacts of sea level rise. The sea level rise used here is based on the average observed values, if the rate of rise were to increase, the results would potentially be far worse.

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<https://tidesandcurrents.noaa.gov/waterlevels.html?id=8636580>

Appendix A: Sea Level Rise

<u>Windmill Point, VA</u>

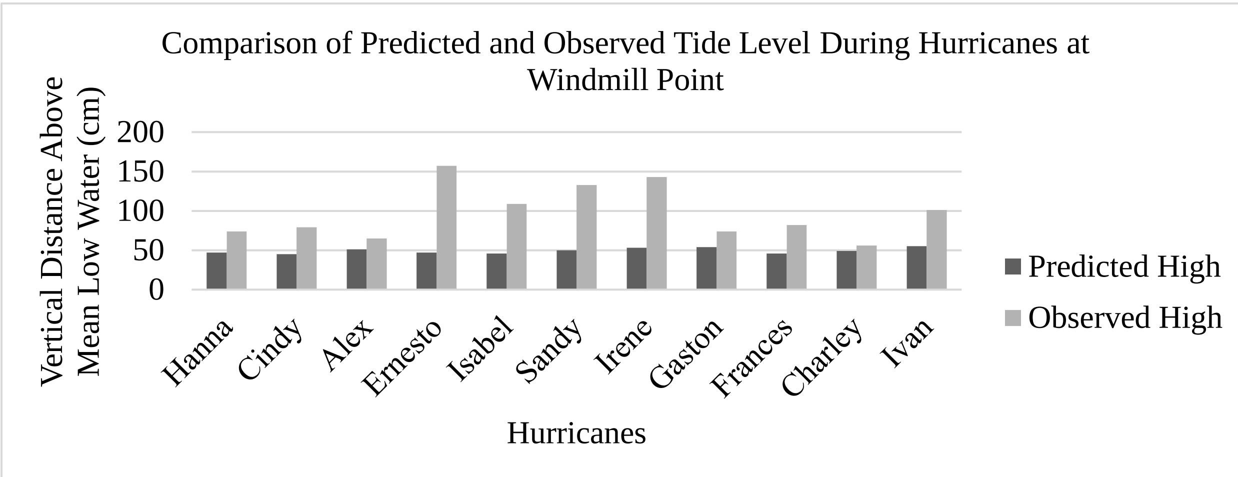

Figure 5. Comparison of predicted and observed tide level during 11 varying categories of hurricanes at Windmill Point.

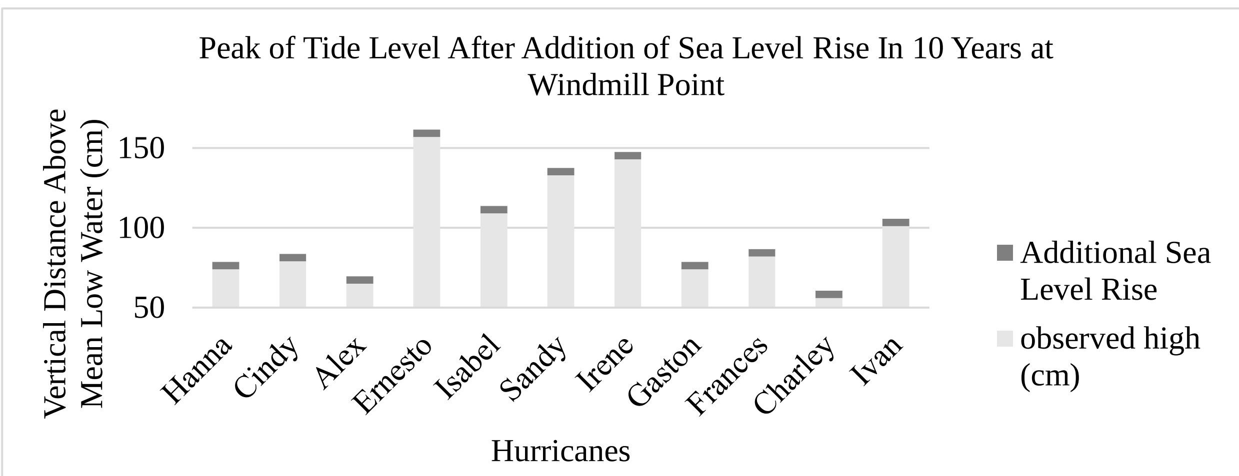

Figure 6. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 10 years.

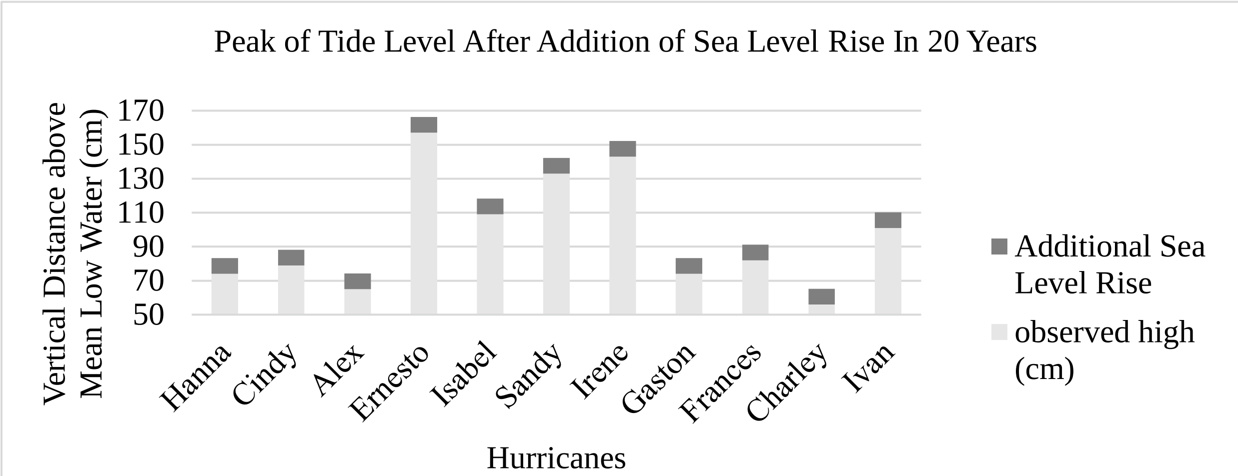

Figure 7. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 20 years.

<u>Kiptopeke, Virginia</u>

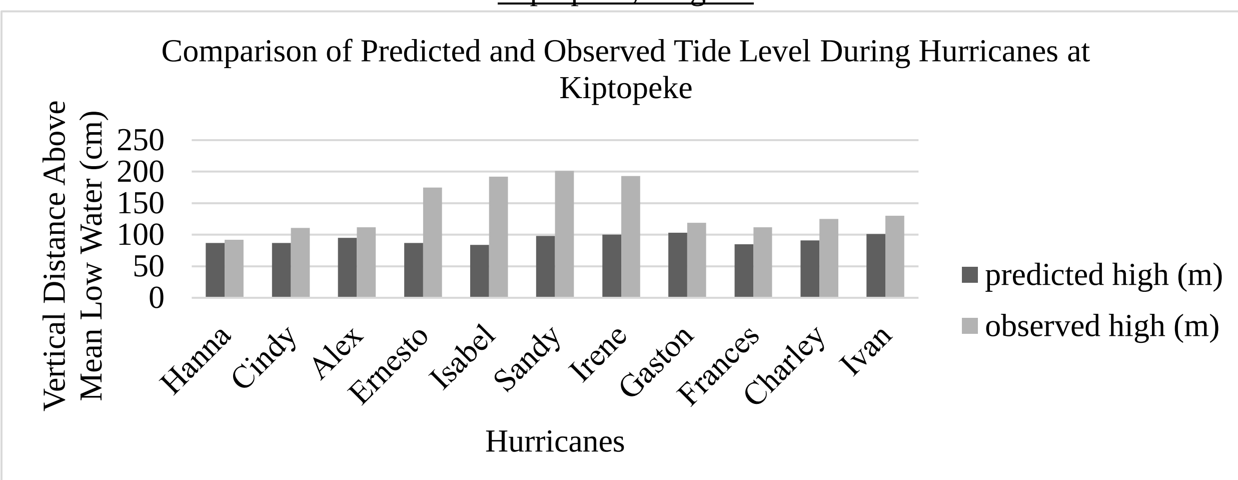

Figure 8. Comparison of predicted and observed tide level during 11 varying categories of hurricanes at Kiptopeke.

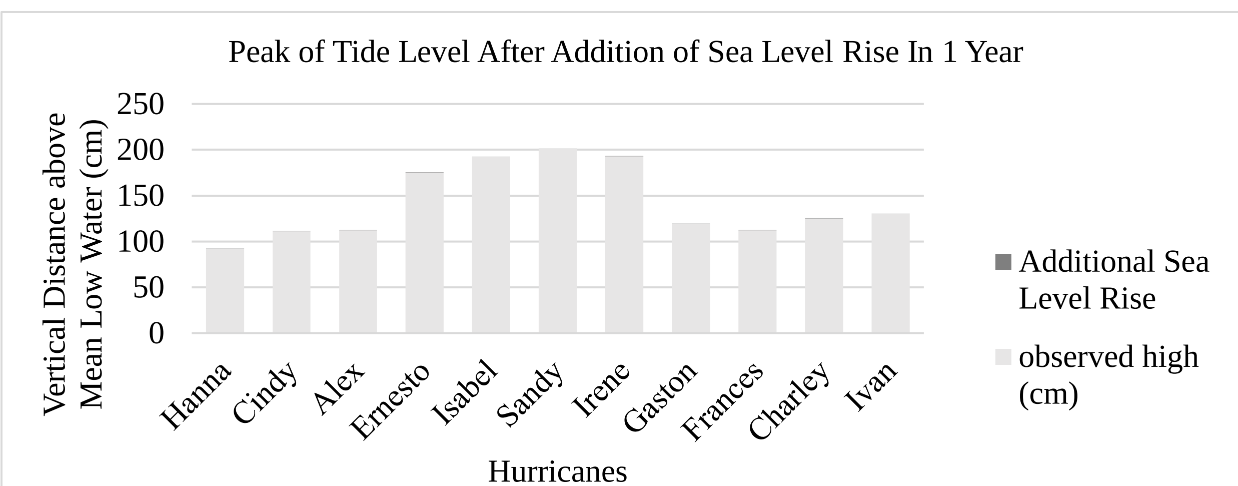

Figure 9. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 1year.

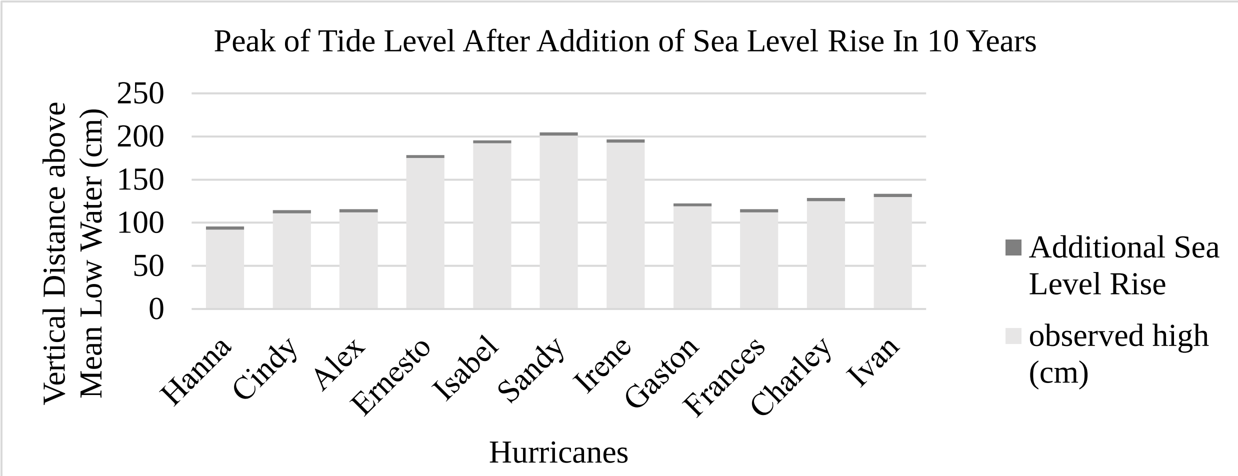

Figure 10. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 10 years.

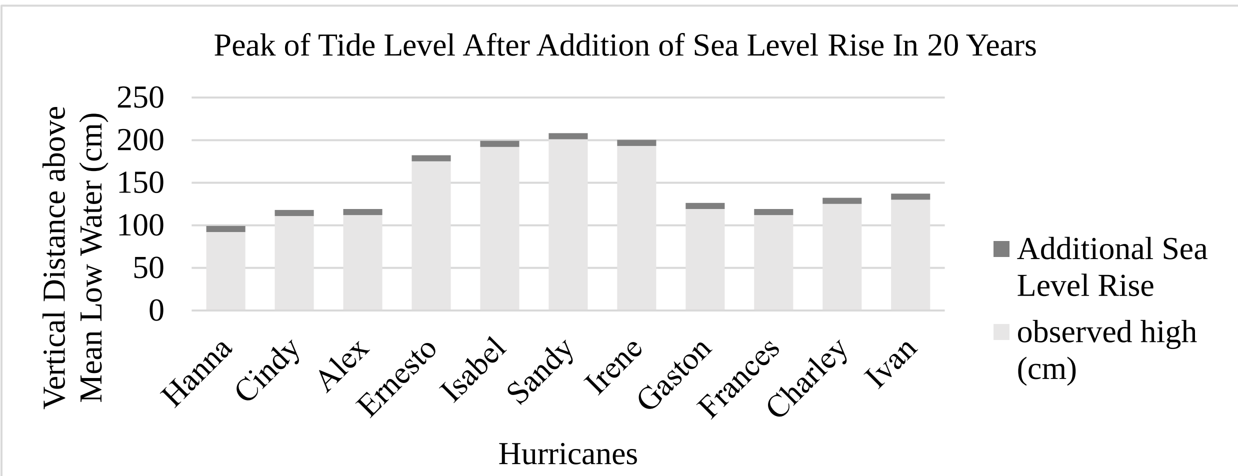

Figure 11. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 20 years.

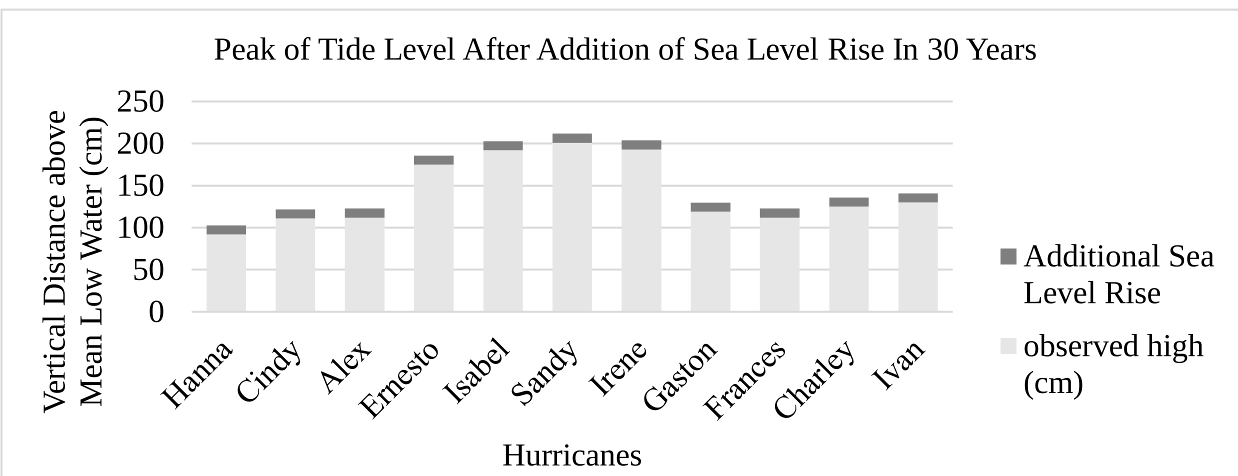

Figure 12. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 30 years.

Chesapeake Bay Bridge Tunnel

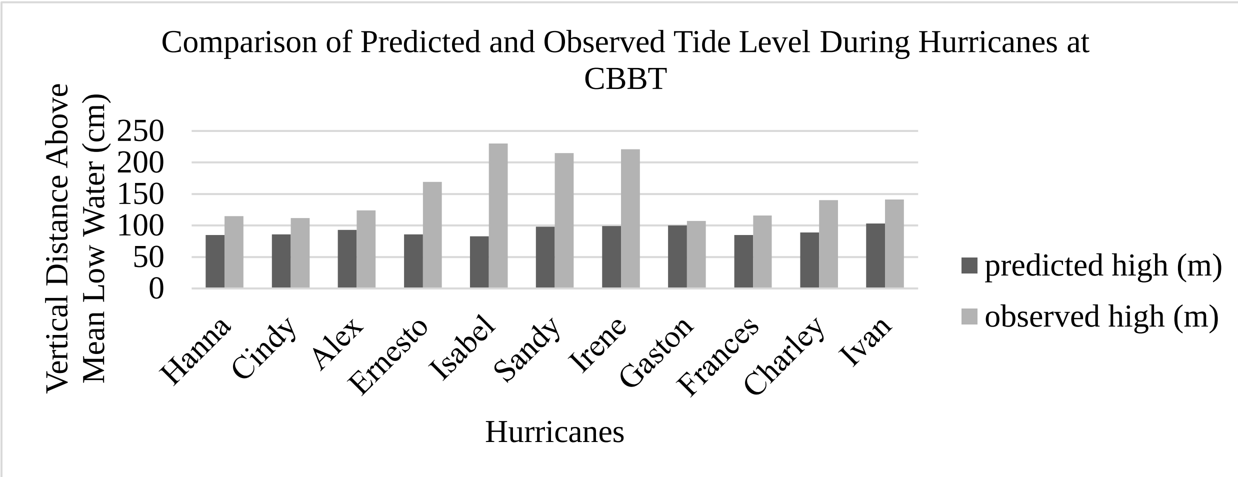

Figure 13. Comparison of predicted and observed tide level during 11 varying categories of hurricanes at Chesapeake Bay Bridge Tunnel.

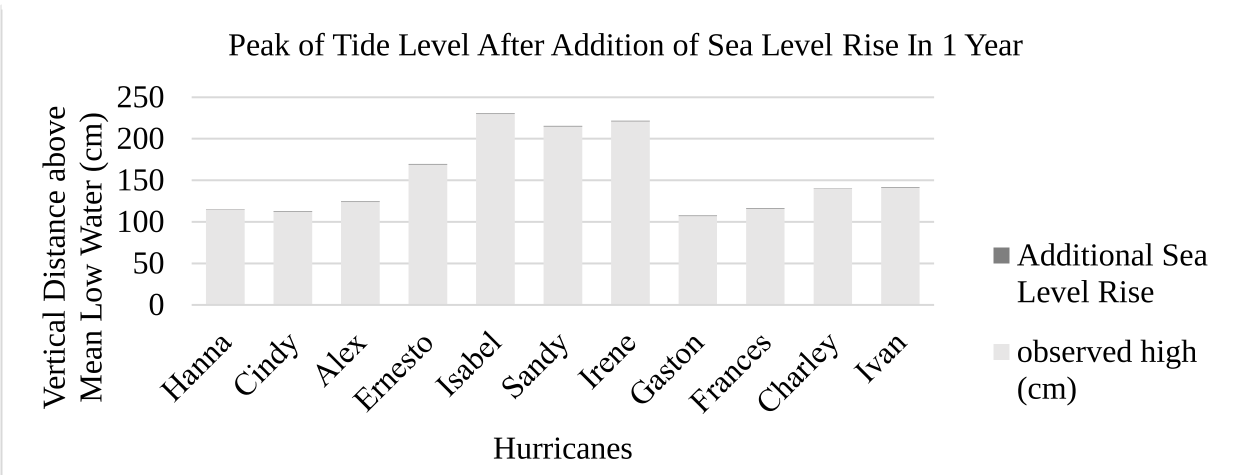

Figure 14. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 1 year.

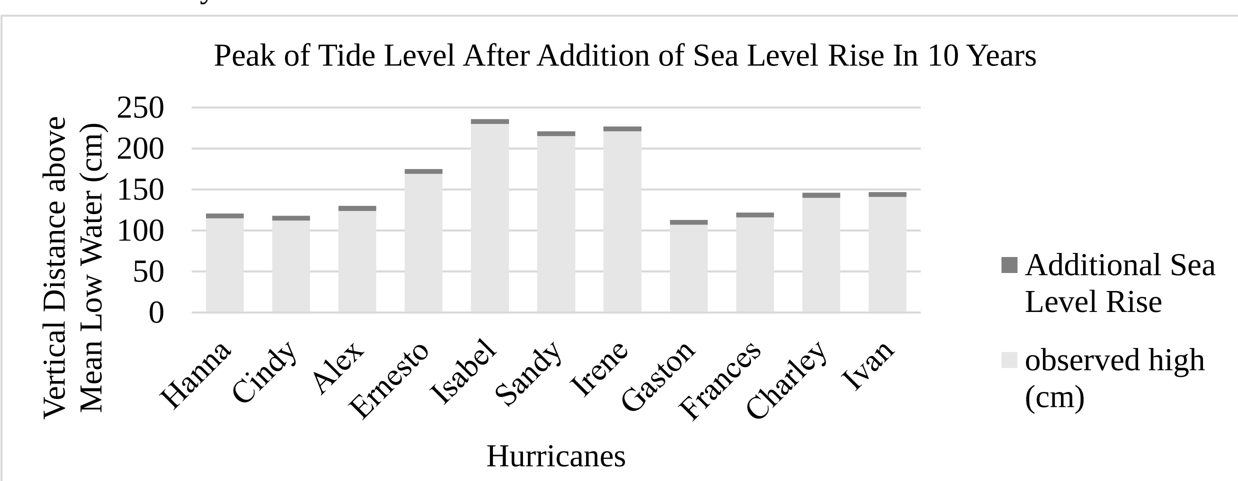

Figure 15. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 10 years.

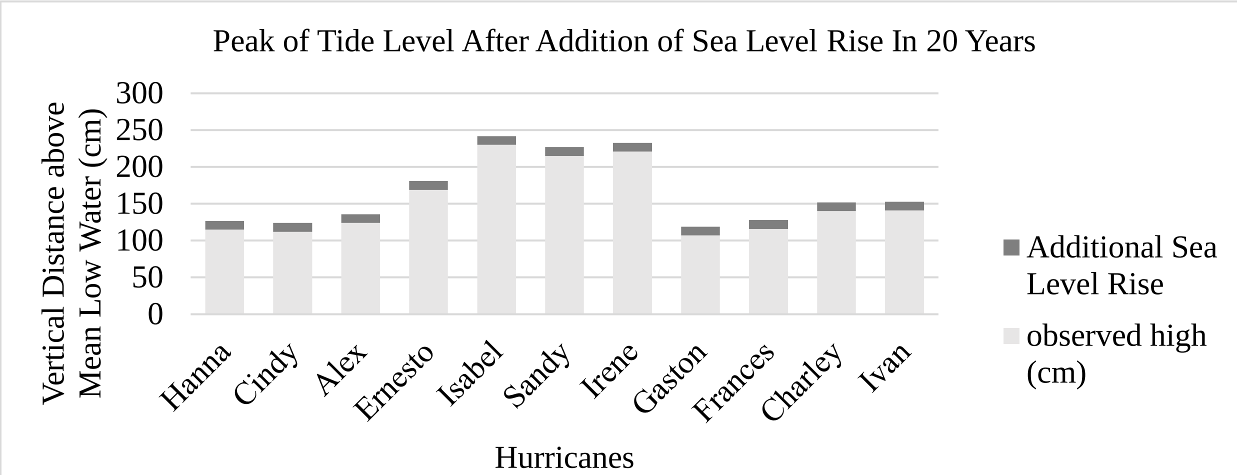

Figure 16. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 20 years.

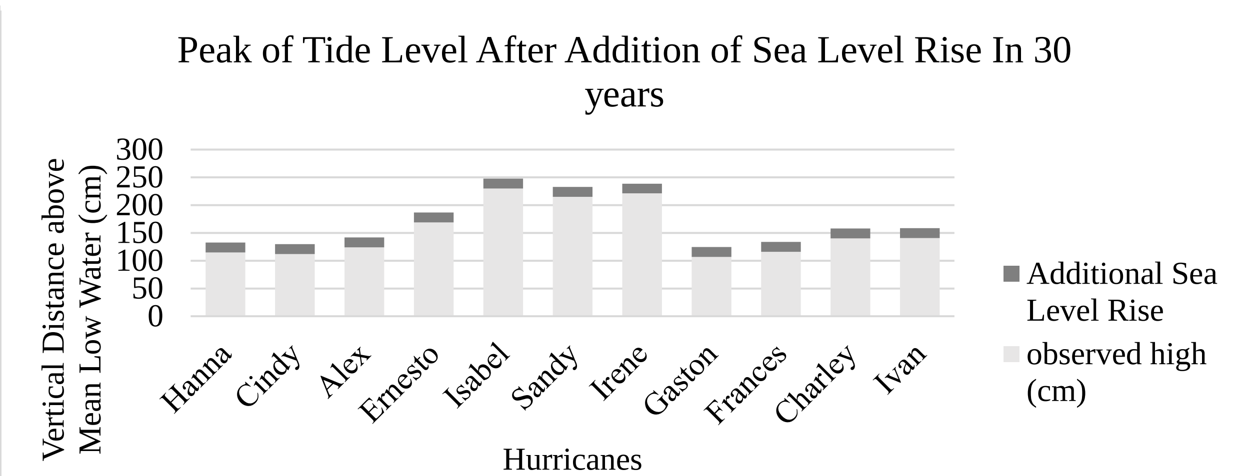

Figure 17. Peak of tide level after addition of sea level rise to previous recorded tide levels of hurricanes in 30 years.

Appendix B: Property Value

Deltaville (Waterfront)							
Map #	Value	actual acre	calculated 1 acre value	**Map #**	Value	actual acre	calculated 1 acre value
41 68	617,100	1.1	561,000	**46 6 56**	610,400	0.86	709,767
46 2 1	657,800	0.75	877,067	**46 6 57**	588,700	0.8	735,875
46 2 15	587,900	1	587,900	**46 6 58**	484,500	0.8	605,625
46 2 17	553,000	1	553,000	**46 7 59**	456,000	0.8	570,000
46 2 18	784,500	1	784,500	**46 7 60**	621,200	0.8	776,500
46 2 19	703,000	0.79	889,873	**46 7 61**	650,600	0.7	929,429
46 2 20	688,600	0.8	860,750	**46 7 62**	463,700	0.8	579,625

46 2 21	817,800	0.8	1,022,250	**46 7 63**	478,600	0.61	784,590
46 2 22	639,700	0.83	770,723	**46 7 64**	742,100	0.81	916,173
46 2 25	564,100	0.87	648,391	**46 7 65**	804,000	0.57	1,410,526
46 2 27	800,200	1	800,200	**46 7 66**	827,400	0.75	1,103,200
46 2 30	603,600	0.95	635,368	**46 7 67**	865,800	0.47	1,842,128
46 3 C	734,300	1.28	573,672	**46 7 68**	745,500	0.65	1,146,923
46 4 36	678,000	0.8	847,500	**46 7 71**	925,600	0.6	1,542,667
46 6 55	671,100	0.8	838,875	**46 8 14**	924,200	1.31	705,496

Deltaville (Inland)							
Map #	Value	actual acre	calculated 1 acre value	**Map #**	Value	actual acre	calculated 1 acre value
40 102 1	197,600	1.43	138,182	**45 2D**	37,100	1.53	24,248
40 243	201,100	0.806	249,504	**45 2F**	37,000	1.499	24,683
40 248A	194,900	1.1	177,182	**45 9 1**	146,600	0.97	151,134
40 367A	208,700	1	208,700	**45 9 2**	188,200	0.94	200,213
40 367B	40,000	0.89	44,944	**45 9 3**	158,700	0.91	174,396
40 367C	194,400	0.966	201,242	**40 367E**	171,700	2.46	69,797
40 52 A A	189,500	2.537	74,695	**40 73 1**	42,200	1.54	27,403
40 73 3	109,300	0.878	124,487	**40 246**	465,600	3.637	128,018
40 73 4	42,500	1.637	25,962	**40 122 1**	256,400	2.417	106,082
40 76 B	207,200	1.33	155,789	**40 122 2**	142,200	3.421	41,567
40 76 C	237,500	1.866	127,278	**40 55 1**	146,900	1.775	82,761
40 85 1	174,800	1.228	142,345	**40 55 3**	109,900	0.898	122,383
40 85 2	161,700	1.25	129,360	**40 55 3B**	137,800	0.7205	191,256
45 12	77,300	0.81	95,432	**40 102 2**	179,800	1.651	108,904
45 1A	35,000	0.989	35,389	**40 243A**	150,500	0.887	169,673

Water View (Waterfront)							
Map #	Value	actual acre	calculated 1 acre value	**Map #**	Value	actual acre	calculated 1 acre value
9 11 12	607,600	1.1	552,364	**9 7 1**	929,200	3.7	251,135
9 2 10	269,100	2.91	92,474	**9A 1 2**	617,100	0.67	921,045
9 2 4	720,700	1.6	450,438	**9A 1 3**	425,900	0.9	473,222
9 2 4A	276,000	1.42	194,366	**9A 1 5**	290,400	0.6	484,000
9 2 5	700,900	2.01	348,706	**9A 1 7A**	30,700	0.19	161,579
9 2 6	529,100	1.9	278,474	**9A 1 8**	266,400	0.398	669,347
9 2 7	520,900	1.81	287,790	**9A 1 9A**	127,500	0.17	750,000
9 2 8	538,500	1.29	417,442	**9A 3 3**	329,700	0.6	549,500
9 2 9	522,600	1.68	311,071	**9A 3 4**	287,000	0.6	478,333
9 2 9A	435,600	1.69	257,751	**9A 3 5**	360,000	0.65	553,846
9 2 A	3,400	0.128	26,563	**9A 3 6**	298,500	0.6	497,500
9 46	152,500	0.86	177,326	**9A 3 7**	294,700	0.6	491,167
9 53	940,300	3.84	244,870	**9A 6 1**	250,500	0.6	417,500
9 54	502,900	2.09	240,622	**9A 6 2**	32,700	0.6	54,500
9 55B	731,300	2.09	349,904	**9A 6 3**	339,000	0.6	565,000

Water View (Inland)							
Map #	Value	actual acre	calculated 1 acre value	**Map #**	Value	actual acre	calculated 1 acre value
9 3 1	158,100	1	158,100	**9 9 1**	168,100	1.0298	163,236
9 3 1A	105,800	0.998	106,012	**9 9 2**	40,700	0.9688	42,011
9 3 2	106,700	1.4	76,214	**9 11**	148,600	0.5	297,200
9 3 2A	166,600	0.882	188,889	**9 13**	69,800	0.72	96,944
9 3 2B	147,900	0.6	246,500	**9 14**	24,600	1	24,600
9 3 3	206,200	1.571	131,254	**9 15B**	20,000	0.991	20,182
9 3 3A	212,200	1.217	174,363	**9 25**	324,700	10	32,470
9 3 3B	106,100	0.529	200,567	**9 27**	57,400	1	57,400
9 35	116,200	1.0114	114,890	**9 27A**	135,700	0.6039	224,706
9 4 2	148,200	2.8	52,929	**9 30A**	177,300	1.809	98,010
9 41	27,800	1.1172	24,884	**9 4 1**	32,200	2.8	11,500
9 42B	177,300	1.499	118,279	**9 4 2**	148,200	2.8	52,929
9 43A	139,300	3.068	45,404	**9 4 3**	32,200	2.8	11,500
9 48	198,700	3	66,233	**9 6**	25,800	1.16	22,241
9 8 9	198,100	2.773	71,439	**8 43B**	96,000	1.083	88,643

Urbanna (Waterfront)							
Map #	Value	actual acre	calculated 1 acre value	**Map #**	Value	actual acre	calculated 1 acre value
20A 1 116	493,400	1.51	326,755	**20A 2 15**	423,100	0.5	846,200
20A 1121A	310,600	0.2227	1,394,701	**20A 2 23**	811,000	1.26	643,651
20A 1 122	382,100	1.029	371,331	**20A 2 29A**	11,100	0.19	58,421
20A 1 13	287,300	0.4	718,250	**20A 2 32**	482,200	0.75	642,933
20A 1 22D	157,700	0.38	415,000	**20A 2 4**	379,600	0.15	2,530,667
20A 1 75A	156,900	0.33	475,455	**20A 2 6**	437,800	0.23	1,903,478
20A 1 78	383,100	0.58	660,517	**20A 2 8**	513,500	0.39	1,316,667
20A 1 81	524,100	0.69	759,565	**20A 2 A**	652,900	2.5191	259,180
20A 1 83	60,000	0.296	202,703	**20A 20 9**	521,000	0.366	1,423,497
20A 1 87	640,600	0.35	1,830,286	**20A 28 4**	290,700	0.58	501,207
20A 10 1	278,600	0.43	647,907	**20A 30 10**	834,200	0.36	2,317,222
20A 10 2	346,400	0.37	936,216	**20A 6 25**	728,800	0.3	2,429,333
20A 10 3	524,200	0.4	1,310,500	**20A 6 27**	509,600	0.24	2,123,333
20A 15 G2	881,200	1.63	540,613	**20A 9 1**	690,100	0.4	1,725,250
20A 2 11	473,300	0.45	1,051,778	**20A 9 2**	533,800	0.38	1,404,737

Urbanna (Inland)							
Map #	Value	actual acre	calculated 1 acre value	**Map #**	Value	actual acre	calculated 1 acre value
20A 29 1	205,200	0.395	519,494	**20A 8 B**	192,000	0.2533	757,994
20A 29 2	254,900	0.3807	669,556	**20A 6 54**	152,300	0.53	287,358
20A 29 3	153,200	0.365	419,726	**20A 7 B**	152,900	0.266	574,812
20A 29 4	191,800	0.4	479,500	**20A 1 2A**	146,000	0.298	489,933
20A 29 5	240,600	0.4	601,500	**20A 13 1**	129,100	0.226	571,239
20A 29 10	208,900	0.3	696,333	**20A 25 3**	161,000	0.475	338,947
20A 29 9	158,300	0.3444	459,640	**20A 1 5**	136,900	0.205	667,805
20A 29 8	212,900	0.35	608,286	**20A 1 27**	382,000	0.547	698,355
20A 29 7	163,900	0.345	475,072	**20A 1 27A**	123,200	0.2925	421,197
20A 29 6	204,400	0.35	584,000	**20A 1 26**	198,500	0.389	510,283
20A 6 67	187,500	0.223	840,807	**20A 1 22A**	60,000	0.321	186,916
20A 6 69	160,300	0.228	703,070	**20A 33 17**	194,800	0.409	476,284
20A 6 77	156,700	0.172	911,047	20A 33 16	175,500	0.41	428,049
20A 7 A	195,600	0.335	583,881	20A 33 15	198,000	0.4068	486,726
20A 6 61	193,900	0.2912	665,865	20A 33 19	213,900	0.3788	564,678