

SUPERSTORM SANDY AND THE VERDANT POWER RITE PROJECT

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ABSTRACT

On October 29, 2012 Superstorm Sandy (formerly Hurricane Sandy) made landfall in New Jersey. With unprecedented size, extreme central low pressure, and full-moon timing, it created a storm surge that inundated New York City with record-breaking water levels, resulting in tremendous destruction of buildings and infrastructure. All along the East River, large areas of the adjacent boroughs were impacted by Sandy, including flooding of the subway tunnels under the river.

When Sandy struck, Verdant Power was operating two acoustic Doppler current profilers (ADCPs) at its Roosevelt Island Tidal Energy (RITE) Project in New York City's East River, measuring water velocities and depth.

The East River water speed and level data acquired during Sandy is revelatory, not only indicating the extent and timing of the extraordinarily high levels, but also significant changes to the very sense of the tidal flows.

As a Federal Energy Regulatory Commission (FERC) licensee for a commercial pilot project to install up to 30 turbines in the East River, Verdant is keenly interested in the effects such an extreme storm could have on turbines, instruments and navigational aids. This unique observational data provides a valuable insight for Verdant Power and the marine and hydrokinetic (MHK) industry.

In this paper, Verdant first presents the East River data collected during Superstorm Sandy, indicating what actually happened during the storm. The potential for yet more extreme water levels with a different storm timing relative to the astronomical tides is then examined. Finally, of interest to a kinetic hydropower developer, the data is analyzed to estimate how a different storm timing could affect the water velocities through the river. These findings are related to the design criteria for Verdant's equipment and the potential impact of an extreme storm on a commercial array of kinetic hydropower turbines.

INTRODUCTION

On October 29, 2012, Superstorm Sandy (formerly Hurricane Sandy) made landfall in New Jersey. While deadly, and, at about \$65 billion, the second-costliest hurricane in US history [1], its characteristic most relevant to this discussion is that even as its winds weakened to 80 mph as it approached landfall in New Jersey, it was the largest Atlantic hurricane on record, with a diameter of 1,600 km (1,000 miles) [2]. It was this massive size, low central pressure, northerly landfall, and full-moon timing that created a storm surge in the New York City region with record-breaking water levels and tremendous destruction of buildings and infrastructure.



FIGURE 1. NOAA SATELLITE IMAGE OF SANDY APPROACHING THE COAST OF NEW JERSEY ON THE MORNING OF OCTOBER 29, 2012 [3]

While Sandy was a synoptic, macro-scale phenomenon affecting several countries and two dozen US states, the focus of this paper is on its effects on the Roosevelt Island Tidal Energy (RITE) Project (East River – New York, NY), the world's first tidal power array project, and the potential effects on tidal or other marine renewable energy (MRE) projects on the meso-scale of about 1 km.

Almost half of both the deaths and total estimated cost of Sandy occurred within New York State. In New York City, when the storm surge hit, it flooded streets, tunnels and subways, and cut power in and around the city. Over 2 million households lost electrical power and 40,000 residents were displaced. Along the East River, large areas of the adjacent boroughs were flooded, along with the subway tunnels under the river, resulting in the subway system's worst disaster, itself costing about \$5 billion [4].

At its RITE Project site in the East River, Verdant Power had recently concluded an in-water test of a new rotor for its Gen5 KHPS (kinetic hydropower system) turbine. While the test turbine had been removed from the river in September 2012, Verdant continually maintains navigational safety and water measurement equipment within the project area. As Verdant anticipates a 10-year commercial tidal power build-out of this river reach with up to 30 turbines under its 2012 FERC Pilot license (for further information see www.theriteproject.com), the company is keenly interested in the effects such an extreme storm could have on tidal turbines installed in the river for long periods of time.

Verdant operates two acoustic Doppler current profilers (ADCPs) on the river bottom that continually measure the water velocity and level, with the data recorded by computer in the RITE Project control room. The East River water speed and level data acquired during Sandy is a valuable resource for Verdant Power, the MRE industry, and New York City emergency preparedness planners.

BACKGROUND OF THE RITE PROJECT SITE

Verdant's RITE Project site is located in the East Channel of the East River, on the east side of Roosevelt Island, just north of the Roosevelt Island Bridge, approximately equivalent to 73rd Street in Manhattan, and 36th Avenue in Long Island City in Queens. Since 2005 Verdant has operated a permitted tidal energy test and demonstration site, conducting multiple deployments of grid-connected turbines along with associated environmental monitoring and reporting.

Figure 2 shows the location of the RITE Project site in the East River, which is actually a tidal strait connecting New York Harbor (and the Atlantic Ocean) with the western end of Long Island Sound (and ultimately the Atlantic Ocean, about 200 km to the northeast). At RITE, a flood tide is the flow in a northerly direction from The Battery towards Long Island Sound (Kings Point).

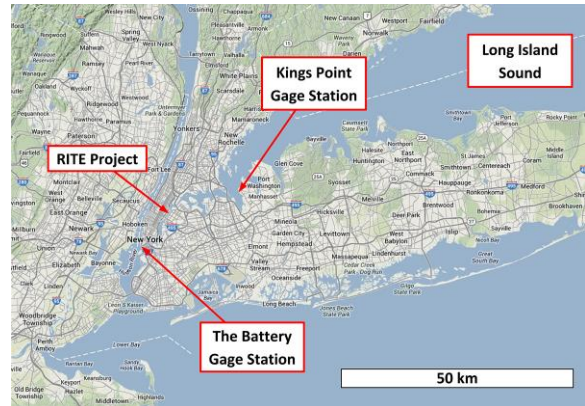


FIGURE 2. LOCATION OF THE RITE PROJECT AND LEVEL GAGES AT KINGS POINT AND THE BATTERY

Figure 3 is a diagram of the RITE Project site showing its location and various features, including the navigation buoys that mark the site, and the location of the two ADCPs.

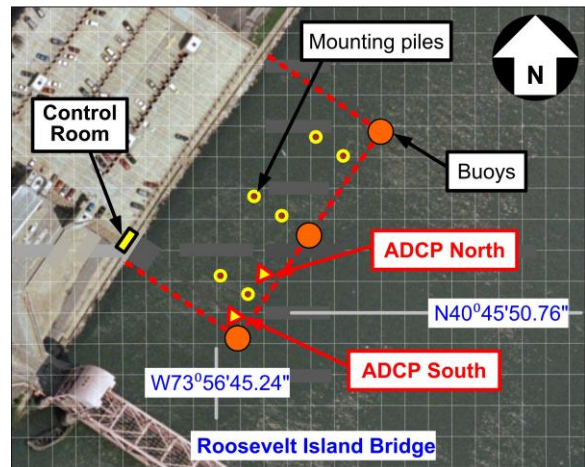


FIGURE 3. THE RITE PROJECT TEST SITE

Normally, the astronomically-predictable tide heights and currents in the East River are unaffected by the weather. Verdant relies on this regularity both to understand the loads on the turbines, structures and other equipment in the river, and to predict the specific amount and timing of power production.

The average chart depth (MLLW) of the RITE site is about 30 feet (9.1m), with a normal tidal range of about 5 feet and an extreme range of about 7 feet.

Figure 4 diagrams a vertical elevation of the ADCPs used to measure the water speed and level relative to an end-on view of a turbine. The ADCP points upward from the bottom and is able to measure water velocity in three dimensions in several slices (or "bins") in the water column as shown.

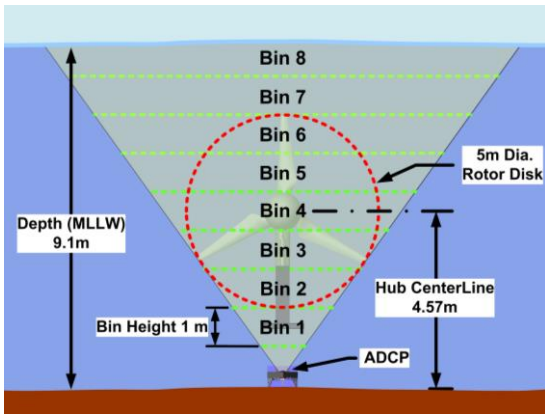


FIGURE 4. RITE ADCP MEASUREMENT ARRANGEMENT

Usually, for turbine measurements, a weighted average of the water speed through the five bins (#2 - #6) that cover the area of the rotor disk is used. For the purposes of this paper, only the single value of Bin 4, centered at the hub height (or centerline) of the turbine, is used.

Figure 5a shows the water level for a typical four-month period at the RITE Project site, typically ranging from 9 to 11m. Figure 5b shows current speed data for the same period, ranging from slack to about 2.5 m/s with very brief excursions near 3 m/s.

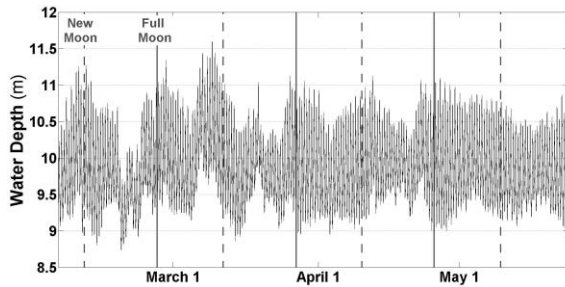


FIGURE 5A. RITE WATER LEVEL, 4 MONTHS, 2013

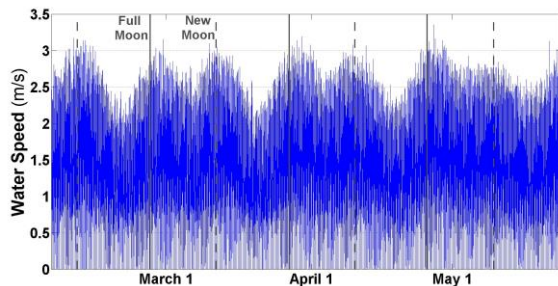


FIGURE 5B. RITE WATER CURRENT SPEED, 4 MONTHS, 2013

Figure 6a shows a typical four-day sample of current speed at RITE. Because the water speed fluctuates very widely over short (sub-second) time periods, a plot of the data averaged over six minutes is also shown. Figure 6b shows the 6-minute average water speed along with the water

level (or “depth”) measured over the same four-day period.

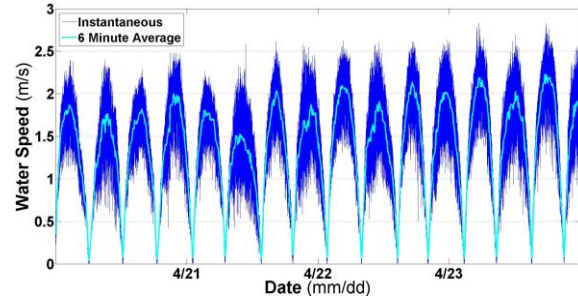


FIGURE 6A. RITE TYPICAL WATER CURRENT SPEED, 4-DAY SAMPLE

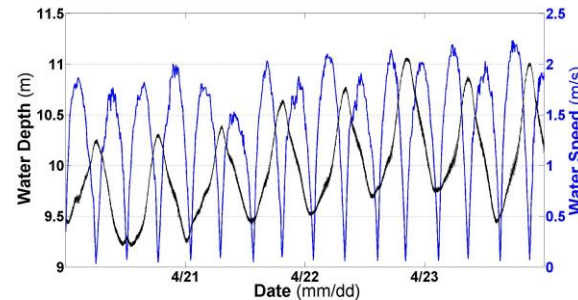


FIGURE 6B. RITE TYPICAL WATER LEVEL AND CURRENT SPEED, 4-DAY SAMPLE

SANDY’S WATER LEVELS AT THE RITE SITE

The effect of Sandy on the water level at RITE is seen in Fig. 7, which shows the one-month period centered on the storm. Sandy’s peak water level is clearly visible, as greatly exceeding the normal extreme range by about 2.7 meters.

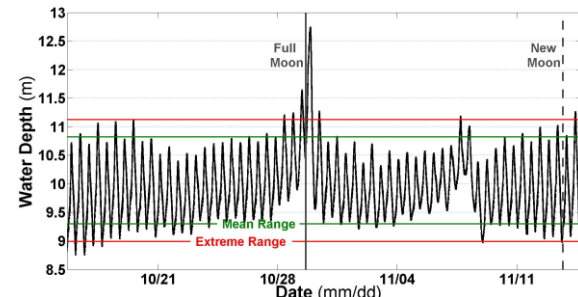


FIGURE 7. RITE WATER LEVEL DURING A ONE-MONTH PERIOD INCLUDING SANDY

During Sandy, the water levels experienced at RITE were unlike anything seen during the ten years of Verdant’s measurements at the site. Yet, fortunately, the RITE Project site experienced little damage, and the key safety elements – the navigation buoys – continued to operate normally. Understanding why this was so, and whether more serious damage could have occurred under different circumstances, motivated this examination.

Effectively illustrating the Sandy event, an amateur video made during the storm and posted on YouTube [5] showed the water level at the RITE site, with water submerging a solar light mounted on top of the site’s navigational warning sign, which is mounted on a concrete block on the riprap (large stone blocks at the water’s edge that protect the concrete seawall). Although normally high above the water, the solar light is shown in the video to be submerged, illuminating the water from below. Two onshore warning signs were damaged by the elevated water levels and repaired after the storm.

The water rose to near the top of the seawall, just short of the RITE control room floor, so it, and its electronic equipment, remained dry. Although the internet connection was lost (a local provider issue), and thus remote video data during the storm as well, the Control Room never lost power, and Verdant’s acquisition and storage of the East Channel’s water speed and level data was not interrupted. Meanwhile, the nearby USGS level gage stopped updating data right at the time of flood level [6].

If the water level had been about one foot higher, some damage due to flooding of the RITE Control Room floor would have likely resulted. (The Verdant Power office, located on the ground level of the Octagon building on the west side of Roosevelt Island was flooded.)

SANDY’S WATER SPEEDS AT THE RITE SITE

Figure 8 shows water speed and level during a one-week period that includes Sandy. The black line indicates the water level, while the blue trace is the water speed (either flood or ebb direction), measured at turbine hub height (ADCP Bin 4), about 4.7m above the bottom. (The usual “shear profile,” the nominal increase in water velocity with increasing distance from the bottom, continued through Sandy.)

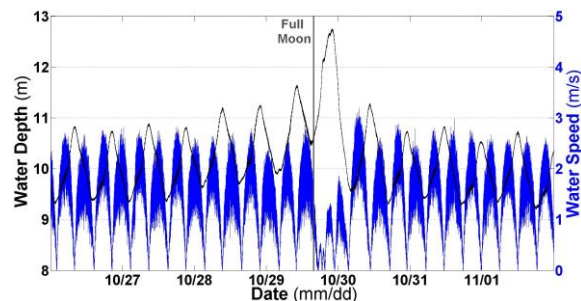


FIGURE 8. RITE WATER SPEED AND LEVELS DURING THE SANDY WEEK

These extraordinary water levels, culminating with the peak storm surge at 12.73m on October 29th, had a profound effect on the speed of the tidal currents. However, contrary to what might

have been expected, the effect was an unprecedented suppression of tidal currents. Only once, on the flood tide immediately following the storm surge flood, did the water speed reach the typical high speed of about 3.1 m/s.

Figure 9 shows in greater detail the water speed and direction during the 24-hour period that includes Sandy. Two tidal periods (or one complete cycle) constituting what would normally be a flood and an ebb, centered about 11 PM on October 29th, were dramatically affected by Sandy. The first period, which would normally have been a flood (labeled in black), was converted by Sandy into an extremely small flood, a similar ebb, and then a small flood (labeled in red), all providing a mere fraction of normal tidal current velocities.

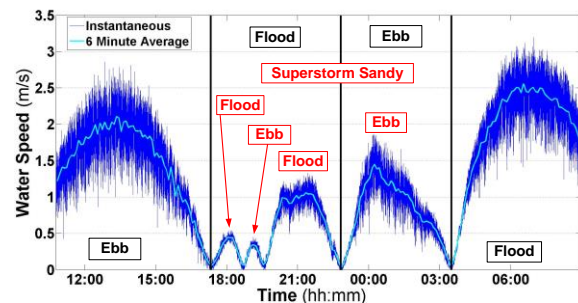


FIGURE 9. RITE WATER SPEED AND DIRECTION (AT HUB-HEIGHT) DURING SUPERSTORM SANDY

Altogether, Sandy caused no water speeds beyond the usual values, so that if the operating KHPS turbines had been installed at RITE during Sandy, they would have been unaffected by the storm. In fact, the main operational effect of the storm would have been that the suppressed water speeds during two tides would have lowered power production for about a ten-hour period. This was a critical finding for Verdant at RITE and potentially useful to the MRE industry.

POTENTIAL WATER LEVEL EFFECTS FROM SHIFTING SANDY’S TIMING

While the actual direct impacts of Sandy on the RITE site and project were small, this paper examines the effect of such a storm with a different timing relative to the normal astronomical tidal cycle.

Sandy occurred in New York City during a full moon with higher than average, but not extremely high, astronomical tides. For context, Fig. 10 shows two months, centered on Sandy, of predicted tide heights at RITE using a convenient online tide model provided by the University of South Carolina (USC) [7]. The higher tides following new moons (when the Sun and Moon are on the same side of the Earth), and to a lesser extent after the full moon, can be seen.

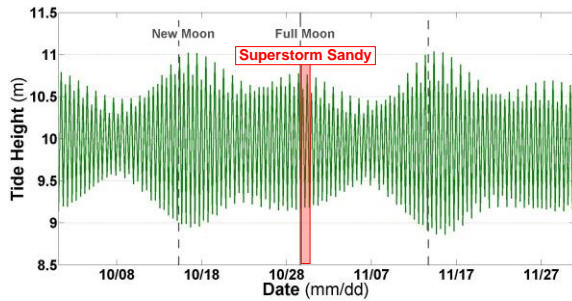


FIGURE 10. SANDY PERIOD RELATIVE TO RITE PREDICTED ASTRONOMICAL TIDE HEIGHTS

Figure 11 compares the RITE water levels during the Sandy week with the predicted astronomical levels, again using the USC tide prediction tool. Clearly seen is that the timing of the Sandy surge, which created a measured peak at RITE at 22:01 ET on 10/29/2012, nearly coincided with a normal (not extremely high) high tide that itself coincided almost exactly with a full moon.

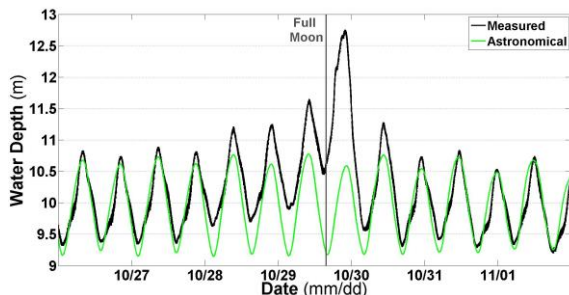


FIGURE 11. RITE WATER LEVELS DURING SANDY COMPARED TO PREDICTED ASTRONOMICAL LEVELS

The surge raised the water level in the river over a period of about two days before, and one day after the peak. This secular rise, however, did not generally affect the tide-to-tide level difference (normally about 1.6m), which provides the driving force for the currents through the strait. Thus, it did not drive higher than normal water speeds. However, even though the low water immediately before the surge peak high was unusually high, the step from that low water to the surge peak still provided an extremely large delta-H, at about 2.2m, but still without driving correspondingly high water speeds. Instead, what could have been expected to be a powerful flood tide was divided into two small flood flows and two small ebb flows.

One possible explanation is that this was due to the timing of the storm's filling of Long Island Sound at its northeastern end, or equivalently, a lowering of the level in the outer New York Harbor. This might be supported by the finding that the storm surge levels were higher at Kings

Point at the western end of Long Island Sound (12.65 ft.) than at The Battery (9.40 ft.) in New York Harbor, although this is without regard to specific timing [8]. Thus, despite the suppressed water flows through the East River during Sandy, two questions arise with regard to what could have occurred with a different storm timing.

First is how the timing of the Sandy-driven water levels relative to the usual tidal cycle affected water levels at RITE, and whether a different timing could have resulted in significantly different levels. For example, if the large storm ebb at the beginning of October 30 had occurred a couple of hours earlier and coincided with the normal ebb timing, could that last small ebb flow have been extremely large? This first timing question is examined in the analysis that follows.

A second and more complicated question is how the timing of the Sandy-driven rise in the levels at the western end of Long Island Sound relative to the Sandy levels in New York Harbor affected water currents in the East River, and how they could have been different. It is this water level differential that results in the driving force for the water currents through the East River. Since the currents were relatively slow with Sandy's actual timing, this differential was likely to have been moderate, but with a different timing, the differential, and thus the currents, might have been different. This question involves the size, strength and forward speed of the storm relative to the coastal topography, along with other macro-scale weather phenomena that influenced the storm as it approached the greater New York area.

To address the first question, the measured Sandy-driven tide heights are subtracted from the normal astronomically-predicted tides (both shown in Fig. 11) to derive the Sandy surge as shown in Fig. 12. The highest Sandy surge peak of 7.55m occurred at 18:57 ET on 10/29/12, about three hours before the actual measured peak.

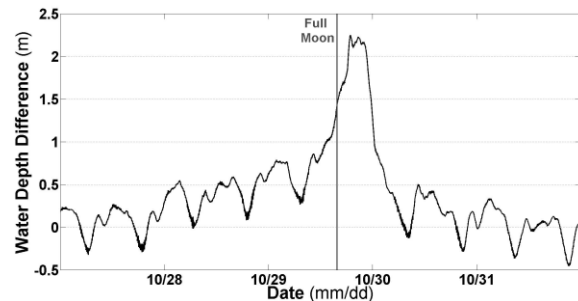


FIGURE 12. RITE WATER LEVEL SANDY SURGE

The Sandy surge is the storm's unique effect on water levels at a specific location and can be

independently added back to the underlying normal predicted astronomical values with its relative timing shifted to see what the resulting peak water levels could have been.

Figure 13 shows the RITE-measured water levels (black), which peaked at 12.73m. It also shows the Sandy surge added back to the astronomical levels, but shifted 211 minutes later to the following flood tide peak (purple), resulting in a new peak level of 12.84m, an increase of 0.11m above the actual observed value.

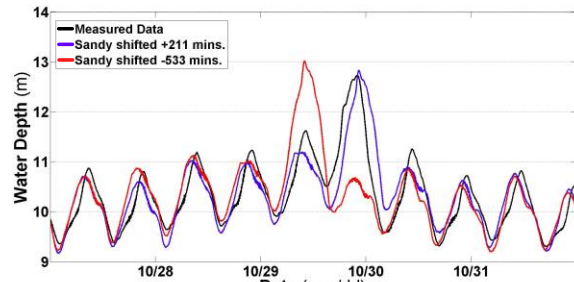


FIGURE 13. WATER LEVELS OBTAINED BY SHIFTING THE SANDY SURGE RELATIVE TO NORMAL PREDICTED HEIGHTS

Alternatively, a shift of Sandy’s timing about nine hours earlier (-533 mins.) to the previous astronomical flood peak (red) could have raised the total Sandy level to 13.02m, an increase of 0.29m. An increase of this magnitude could be expected to have had increased flooding and damage potential for facilities on Roosevelt Island including the RITE Project control room.

A further shift of Sandy’s timing to the following peak new moon flood tide two weeks later on November 14 could have resulted in an even higher rise to 13.29m at the RITE site. This potential 0.56m increase over the actual storm would have been even more damaging to the New York City area, and should be of importance to those who perform detailed modeling and storm emergency preparedness planning.

WATER LEVELS IN THE GREATER SANDY AREA

The second question relating Sandy water levels and currents in the East River at RITE and New York Harbor with those at the western end of Long Island Sound can be illustrated by some of the images published by the National Hurricane Center (NHC) [8].

Figure 14 is an image of Sandy superimposed on a map of the east coast, showing the large counterclockwise circulation with a radius greater than the length of Long Island. This magnitude of storm could conceivably have been pushing water into Long Island Sound for many hours prior to and after the center of the storm’s landfall on the coast of New Jersey.

Similarly, Sandy’s wind field as modeled by the NHC and shown in Fig. 15, indicates sustained winds of greater than 34 knots (39 mph, 17.5 m/s) in the direction of pushing water westward into the eastern entrance to Long Island Sound.

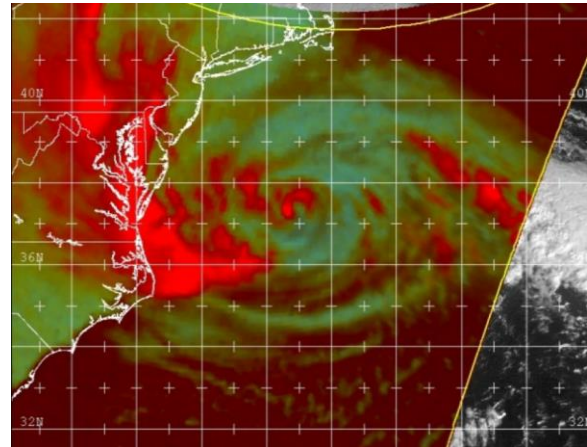


FIGURE 14. MICROWAVE IMAGE OF SANDY ON OCT. 29 APPROACHING LANDFALL IN NEW JERSEY [8]

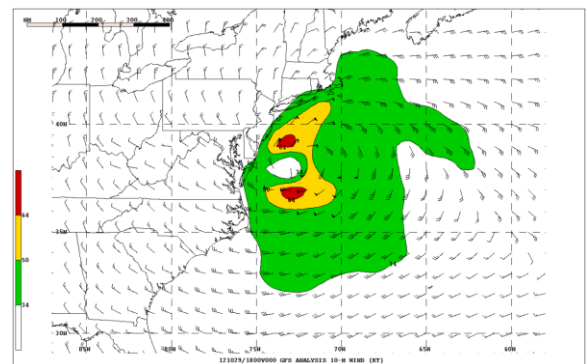


FIGURE 15. SANDY WIND FIELD AS MODELED BY THE NHC AS IT APPROACHED LANDFALL IN NEW JERSEY [8]. (THE COLORED AREAS INDICATE WIND THRESHOLDS OF 34, 50, AND 64 KNOTS.)

To compare the water levels that give rise to tidal currents on the broader geographic scale, reference is made to the map in Fig. 2, which shows the level gage locations at Kings Point, at the western end of Long Island Sound, and at The Battery in New York Harbor, about 24 km to the southwest. The RITE Project site in the East Channel of the East River is shown between those two locations, about one-third of the distance from The Battery. Ultimately, the difference between the levels at these two locations provides the driving force for the currents through the East River tidal strait at RITE.

Without regard to specific timing, but relative to the normal astronomical tide level, Sandy’s storm surge level at The Battery in New York Harbor was 2.87m (9.40 ft.). Altogether, at The Battery the storm crested (the highest water level

measured) at a record high (since 1920) of 4.29m (14.06 ft.) above MLLW [9].

At Kings Point on the Long Island (south) side of the western end of Long Island Sound, the peak storm surge reached 3.86m (12.65 ft.). At the Kings Point gage, Sandy's storm tide crest was the third highest level on record, as shown in Table 1.

TABLE 1. HISTORICAL STORM CRESTS AT THE KINGS POINT LEVEL GAGE

Rank	Level (ft)	Level (m)	Date
1 st	16.75	5.11	09/21/1938
2 nd	14.76	4.50	08/31/1954
3 rd	14.31	4.36	10/29/2012 (Sandy)

Figure 16 is a plot from NOAA CO-OPS [9] six-minute level data at Kings Point, NY at the western end of Long Island Sound. The plot also includes the NOAA astronomically-predicted values at Kings Point, along with the calculated difference (delta) between the two. To find a timing that results in worst-case water levels, this Kings Point Sandy surge can be shifted to an astronomical peak.

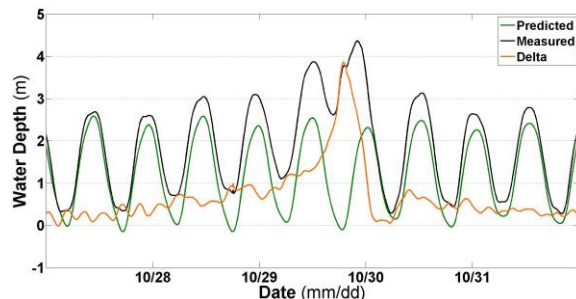


FIGURE 16. SANDY WATER LEVELS AT KINGS POINT

In Fig. 17, the same data is shown with the Kings Point Sandy surge shifted in time relative to the predicted values, so that the Kings Point Sandy surge peak coincides with the prior predicted peak. This is a small shift in time, about seven hours, to a slightly higher flood peak, within the same full moon period.

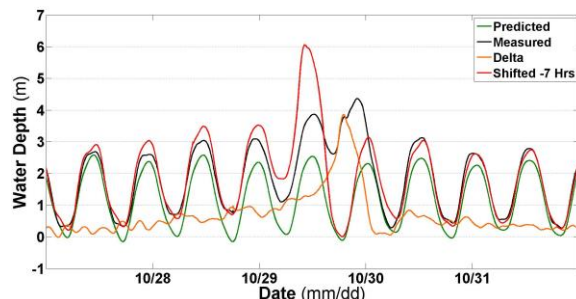


FIGURE 17. SANDY WATER LEVELS AT KINGS POINT SHIFTED 7 HOURS EARLIER

The result is a calculated total peak of almost 6.1 m (20 ft.) as compared to the actual measured peak of 4.36 m (14.3 ft.) – a highly significant difference of over 1.7m (5.6 ft.), which would have exceeded the 1938 record crest of 5.11 m (16.75 ft.) by about 1.0 m (3.3 ft.).

If the timing was shifted by about two weeks either way to one of the adjacent new moons, when the underlying astronomical tides were even greater (refer to Fig. 10), the maximum total peak would have been higher yet. Specifically, a shift to the following new moon high tide peak at 10:38 AM on November 14 could have resulted in a peak of 6.74m (22.11 ft.). This would have been 2.38m (7.8 ft.) higher than the actual Sandy peak level at Kings Point, exceeding the 1938 record by about 1.6m (5.3 ft.).

As before, this analysis is intended only to suggest a possible range of outcomes. Still, it is sobering in that it suggests that despite the devastation of the flooding due to Sandy, the water level rise, and its consequences, could have been significantly worse, for at least some portions of the region.

Meanwhile, examining the similar NOAA CO-OPS data for the level gage at The Battery gives the plot in Fig. 18. At this site, the Sandy surge already coincided almost perfectly with the astronomical high tide, thus the time-shifting exercise is not performed, although it should be noted that the adjacent high-water levels 6 hours either way were, not insignificantly, about 0.18m (0.6 ft.) higher.

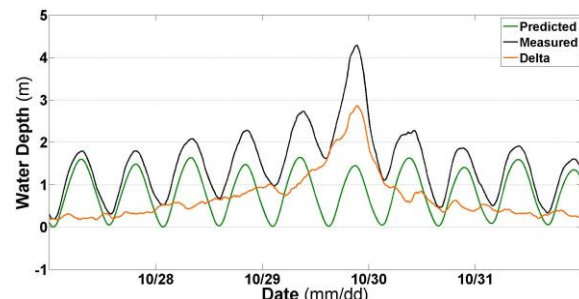


FIGURE 18. SANDY WATER LEVELS AT THE BATTERY

Table 2 summarizes the times and heights of the local Sandy surge peak (measured water level - astronomical) listed from north to south. These are the times shown as the local Sandy Peak in the figures.

TABLE 2. TIMES AND HEIGHTS OF THE LOCAL SANDY SURGE PEAK

	Time	Height (m)
Kings Point	10/29/12 19:00:00	3.86
RITE	10/29/12 18:57:00	2.25
The Battery	10/29/12 21:24:00	2.87

While the time of the local Sandy peak at RITE appears to be almost the same as at Kings Point (in fact 3 minutes earlier), as shown in Fig. 12, there is essentially a sustained Sandy peak at RITE that lasts for about 3 hours, placing the RITE peak effectively between the times of Kings Point and The Battery, as one would expect.

EFFECT OF SANDY ON RITE CURRENTS

With the data and range of possibilities for both Kings Point (KP) and The Battery (TB), the question of the maximum possible water current speed in the East River can be explored. Figure 19 shows the observed KP-TB water level difference (ΔH_{KP-TB}) for five days around Sandy. It is this ΔH_{KP-TB} that should provide the driving force for the current through the East River.

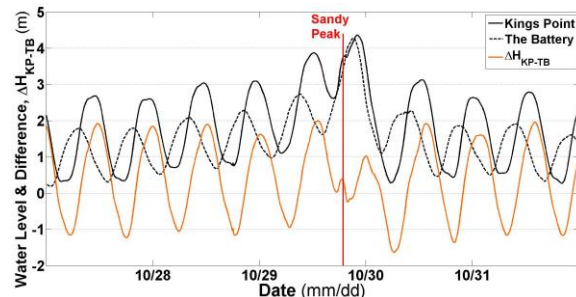


FIGURE 19. SANDY WATER LEVELS AT KINGS POINT, THE BATTERY, AND THE DIFFERENCE

Comparing this ΔH_{KP-TB} signal and the RITE water speed data during Sandy results in the plot shown in Fig. 20. There is a clear relationship between the difference in water level between Kings Point and The Battery and the water current speed at RITE, indicating that this term does describe the driving force for the current. (A positive ΔH_{KP-TB} , where the KP level is greater than the TB level, represents an ebb flow in the East River.)

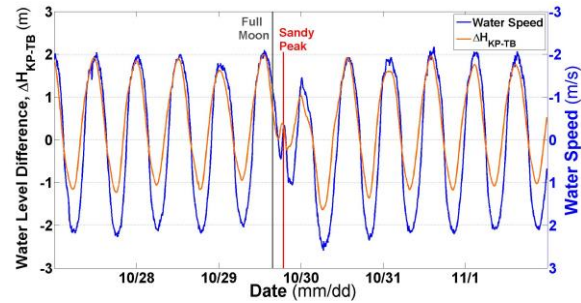


FIGURE 20. SANDY KP-TB LEVEL DIFFERENCE AND RITE WATER CURRENT SPEED

Figure 21 shows the same data as Fig. 20 but only the immediate day around the local Sandy peak.

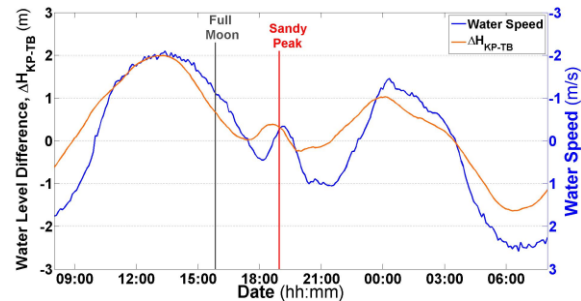


FIGURE 21. SANDY KP-TB LEVEL DIFFERENCE, AND RITE CURRENT SPEED (OCT. 29, 2012)

In this one-day plot during Sandy, the expected relationship between the ΔH_{KP-TB} and water speed at RITE is seen to be very strong. Still, there are clearly additional factors that further affect the timing and magnitude of the water speed. Again, these water speeds are highly perturbed from normal, with shifted timings and lowered magnitudes.

To examine possible changes to the RITE water current speeds from Sandy timing changes, the functions relating ΔH_{KP-TB} to the RITE water speed are derived. Using the KP and TB water level data from the Sandy week, Fig. 22 is a plot of ΔH_{KP-TB} against the RITE water speed. Both the ΔH_{KP-TB} and water speed are shown here in absolute value. Also shown are curve fits for the four distinct sections of this data: waxing flood, waning flood, waxing ebb and waning ebb. These describe, for example, the different flood and ebb water speed magnitudes seen in Fig. 21. (During the immediate Sandy surge, the data is anomalous, so for clarity in this plot, about ten hours of data (from 10/29/12 17:10:18 to 10/30/12 03:26:06) has been removed.)

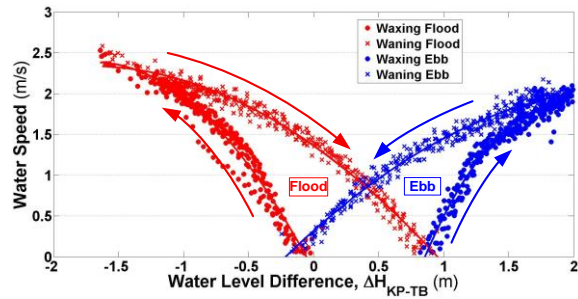


FIGURE 22. RITE WATER SPEED VS. KP-TB LEVEL DIFFERENCE

What this data shows, along with similar data from typical weeks, is that the slopes of the functions relating water speed at RITE to ΔH_{KP-TB} are very shallow near their maximum values. Consequently, even a large further increase in the water level difference between Kings Point and The Battery cannot significantly increase the water speed at RITE. This “speed limit” is a function of the natural (and perhaps, to a degree, man-made) design of the water bodies involved, and is akin to the limiting hull speed of a ship.

As an extreme example, if the shifted Sandy peak that maximizes the KP level as shown in Fig. 17 is used while limiting the level at TB to merely its simultaneous astronomical prediction (lower than the Sandy level), the exaggerated ΔH_{KP-TB} of 4.7 m results. Yet even this value, according to the ebb curves shown in Fig. 22, would only result in a water speed at RITE of between 2.3 and 2.6 m/s. In the most extreme case, where we posit the record high at TB (4.29 m, which did occur during Sandy) and 0 m at KP (far lower than during Sandy), the ΔH_{KP-TB} of -4.285 m gives a (flood) water speed of less than 3.1 m/s at RITE.

Since the Verdant Power Gen5 KHPS equipment is designed to regularly experience and survive such water speeds, it appears, based on the data from these sites, that neither Sandy nor a retimed Sandy representing an even more extreme storm scenario could cause damaging water speed increases at RITE.

CONCLUSIONS

The opportunity presented by the concurrent measurement of water levels and velocities at a FERC-licensed tidal power array site during an extreme storm provided a unique case study of operational risk for the nascent MRE industry.

As damaging as Sandy was, with slightly different timing, the storm could have caused even more damage due to increased water levels around the New York City region. Potential water level increases from a different timing of Sandy could have been very significant in at least certain areas. At Kings Point, NY an increase of more than 1.7 m (5.6 ft.) over the actual Sandy level could

have been possible, which would have set a new record crest by about 1.0 m (3.3 ft.).

With specific regard to Verdant’s RITE Project, the data and analysis indicate that kinetic hydropower turbines and related equipment in the river would not have been affected by Sandy’s extreme water levels, or even those of a Sandy-type storm with more perfectly extreme timing. However, for the commercial build-out of the RITE Project, this analysis will inform the location of onshore equipment to avoid the potential for damage from yet higher extreme storm water levels.

Superstorm Sandy actually resulted in dramatically lower than normal water speeds at the RITE site, and through examining the nature of the tidal flows driven by water level differences between the western end of Long Island Sound and New York Harbor, we conclude that no storm could increase the water speed through the East River strait to the point that the RITE Project installation would be threatened by excessive water speeds and loads.

Whether there will be an increased frequency of such extreme storms, and how their effects may increasingly coincide with background sea level rise, is for climate and hurricane researchers, and indeed, urban planners to pursue.

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