Changes in Watertable Levels Due to Tidal Influences

Tidewater Big Data Enthusiasts
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1 Introduction

Several years ago (unfortunately I can't point to a specific source), I heard that water table level was affected by the same tidal forces that create ocean and sea tides. It seemed a little odd to me at the time, and didn't resurface until shortly before the time of this report. I was determined to see if the local water table rose and fell in accordance with local tides.

To that end, I formulated the question: how can I measure local water table level, and compare those measurements to local tidal predictions?

This report answers both parts of the question by using time-aligned internet available data from United States Geological Survey (USGS) near-real time water table measurements, and National Oceanic and Atmospheric Administration (NOAA) tide predictions.

2 Types of tides

2.1 General ideas

We can start with a very simple definition of a tide: "the alternate rising and falling of the sea, usually twice in each lunar day at a particular place, due to the attraction of the moon and sun[11]", and then we can start to pick it apart.

- **. . . the alternate rising and falling of the sea . . .** – Are tides limited to seas or oceans? If so, how and why? Can we have and detect tidal affects in other places?
- **. . . usually twice in each lunar day . . .** – Can there be more, or less that two cycles of rising and falling tides?
- **. . . in each lunar day . . .** – What is a lunar day, and how is it different than other days? There are several different types of days:

  Solar: The time between successive noons at a give location. This time is about 24 hours and 4 minutes.[12]

  Sidereal: The time it takes for the Earth to rotate about its axis so that the distant stars appear in the same position in the sky.[12]

  Lunar: The time it takes for a specific site on the Earth to rotate from an exact point under the moon to the same point under the moon. Unlike a solar day, however, a lunar day is 24 hours and 50 minutes.[9]

- **. . . the attraction of the moon and sun . . .** – The attractive forces of the moon and sun based on their relative positions to the earth, are major contributing factors to *direct* tides, there are *opposite* tides as well (see Figure 1).

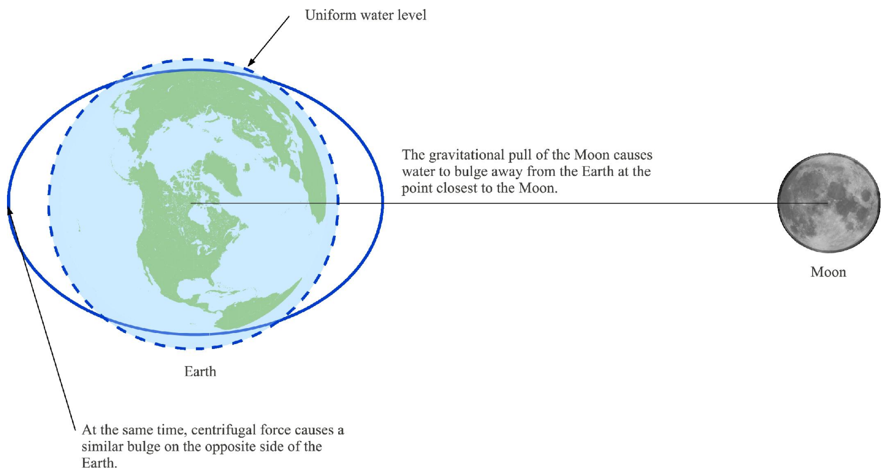

Figure 1: Notional direct and opposite tides The tidal bulge shown at the 3 o'clock line, is the *direct* tide. On the side of the earth directlly opposite the direct tide, is the *opposite* tide[10].

Creation of the *direct* tide is based on the relative attractiveness of the moon to all the objects on the Earth (in this case we are focusing on water). Creation of the *opposite* tide is based on the relative attractiveness of the moon and the rotation of the Earth. A more complete explanation (see Figure 2) is:

> *"3. The Net or Differential Tide-Raising Forces: Direct and Opposite Tides. It has been emphasized above that the centrifugal force under consideration results from the revolution of the center-of-mass of the earth around the center-of-mass of the earth-moon system, and that this centrifugal force is the same anywhere on the earth. Since the individual centers-of-mass of the earth and moon remain in equilibrium at constant distances from the barycenter, the centrifugal force acting upon the center of the earth (C) as the result of their common revolutions must be equal and opposite to the gravitational force exerted by the moon on the center of the earth. This fact is indicated at point C in Fig. 2 by the thin and heavy arrows of equal length, pointing in opposite directions. The net result of this circumstance is that the tide-producing force (Ft) at the earth's center is zero.*
> *At point A in Fig. 2, approximately 4,000 miles nearer to the moon than is point C, the force produced by the moon's gravitational pull is considerably larger than the gravitational force at C due to the moon. The smaller lunar gravitational force at C just balances the centrifugal force at C. Since the centrifugal force at A is equal to that at C, the greater gravitational force at A must also be larger than the centrifugal force there. The net tide-producing force at A obtained by taking the difference between the gravitational and centrifugal forces is in favor of the gravitational component - or outward toward the moon. The tide-raising force at*

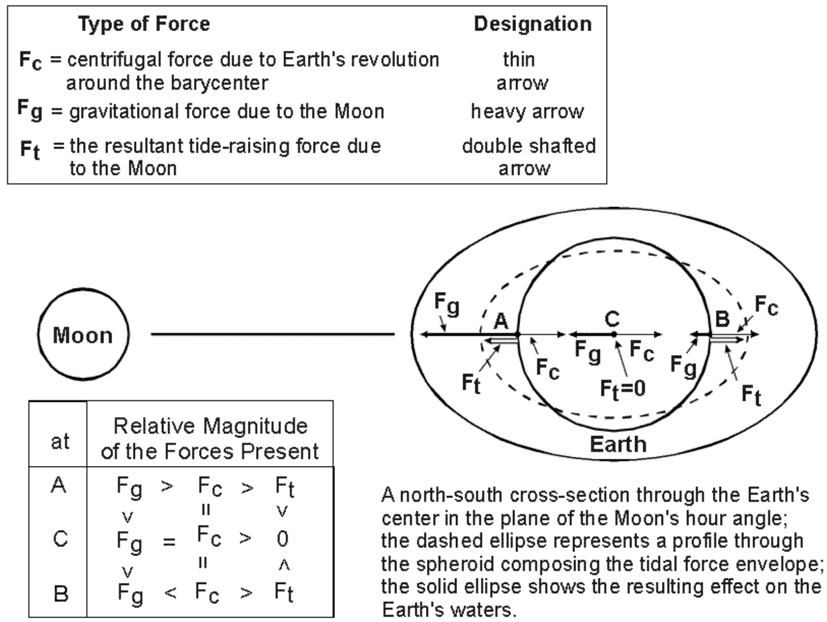

Figure 2: Vector diagram of direct and opposite tides. The lengthy quotation refers to "figure 2." That figure number is from the original document [3], and should not be confused with figure numbers in this document.

> *point A is indicated in Fig. 2 by the double arrow extending vertically from the earth's surface toward the moon. The resulting tide produced on the side of the earth toward the moon is know as the direct tide.*
> *At point B, on the opposite side of the earth from the moon and about 4,000 miles farther away from the moon than is point C, the moon's gravitational force is considerably less than at point C. At point C, the centrifugal force is in balance with a gravitational force which is greater than at B. The centrifugal force at B is the same as that at C. Since gravitational force is less at B than at C, it follows that the centrifugal force exerted at B must be greater than the gravitational force exerted by the moon at B. The resultant tide-producing force at this point is, therefore, directed away from the earth's center and opposite to the position of the moon. This force is indicated by the double-shafted arrow at point B. The tide produced in this location halfway around the earth from the sublunar point, coincidentally with the direct tide, is know as the opposite tide."*

NOAA Staff [3]

2.2 Specific types of tides

A whimsical list of different types of tides[1]:

- Bore – A tidal bore (or simply bore in context, or also aegir, eagre, or eygre) is a tidal phenomenon in which the leading edge of the incoming tide forms a wave (or waves) of water that travels up a river or narrow bay against the direction of the river or bay's current (see Figure 5).
- Brown – Brown Tide is a bloom (excessive growth) of small marine algae (Aureococcus anophagefferens). Although algae of many types are found in all natural freshwater and marine ecosystems, blooms of the Brown Tide organism literally turn the water deep brown, making it unappealing to swimmers and fishermen alike. While not harmful to humans, the presence of the Brown Tide is a problem for bay scallops and eelgrass, and to a lesser degree other finfish and shellfish. Brown Tide is unlike most other algal blooms because of its unusually high concentrations, the extent of area it covers and the length of time it persists (see Figure 6).
- Crimson – The Crimson Tide is a nickname for the University of Alabama football team (see Figure 7).
- Diurnal – These tides occur once a day. A body of water with diurnal tides, like the Gulf of Mexico, has only one high tide and one low tide in a 25-hour period (see Figure 3).
- High – A high tide is when the water reaches its highest point over a period of time.
- Low – Low tide is when the water has pulled out of the estuary or river system into the ocean.
- Mixed – Some bodies of water, including most of North America that's in contact with the Pacific Basin, have mixed tides, where a single low tide follows two high tides.
- Neap – When the Sun and Moon form a right angle, as when we see a half moon, their gravitational pulls fight each other and we notice a smaller difference between high and low tides (see Figure 8).
- Red – Harmful algal blooms, (HAB) occur when colonies of algae grow out of control while producing toxic or harmful effects on people, fish, shellfish, marine mammals and birds. The human illnesses caused by HABs, though rare, can be debilitating or even fatal. Many people call HABs 'red tides,' scientists prefer the term harmful algal bloom. One of the best known HABs in the nation occurs nearly every summer along Florida's Gulf Coast (see Figure 9).

- Rip – A rip current, commonly referred to simply as a rip, or by the misnomer rip tide, is a strong channel of water flowing seaward from near the shore, typically through the surf line. Typical flow is at 0.5 meter-per-second (12 feet-per-second), and can be as fast as 2.5 meters-per-second (8 feet-per-second), which is faster than any human swimmer. They can occur at any beach with breaking waves, including oceans, seas and even large lakes (see Figure 10).

- Semidiurnal – These are tides occurring twice a day. This means a body of water with semi-diurnal tides, like the Atlantic Ocean, will have two high tides and two low tides in one day, much like the eastern seaboard of North America (see Figure 3).

- Spring – When the Moon, Earth, and Sun fall in a straight line, which we call syzygy (siz-eh-gee), we notice the greatest difference between high and low tide water levels. These spring tides occur twice each month, during the full and new Moon. If the Moon is at perigee, the closest it approaches Earth in its orbit, the tides are especially high and low (see Figure 8).

Diurnal, semidiurnal, and mixed tides occur in different areas on the world (see Figures 3, and 4)[8].

3 Sources of data

To answer the original question using the most unbiased data available, meant going to publicly available government data sources. The USGS Groundwater Watch has near-real time groundwater measurement sites through out the United States. NOAA provides tide and current information for the United States. We used data from both of these sources.

3.1 USGS Groundwater Watch (USGS-GWW)

> *"The USGS has a distributed water database that is locally managed. Surface water, groundwater, and water quality data are compiled from these local, distributed databases into a national information system. The groundwater database contains records from about 850,000 wells that have been compiled during the course of groundwater hydrology studies over the past 100 years. Information from these wells is served via the Internet through NWISWeb, the National Water Information System Web Interface. NWISWeb provides all USGS groundwater data that are approved for public release. This large number of sites is excellent for some uses, but complicates retrievals when the user is interested in specific networks, or wells in an active water-level measurement program."*
>
> NOAA Staff [4]

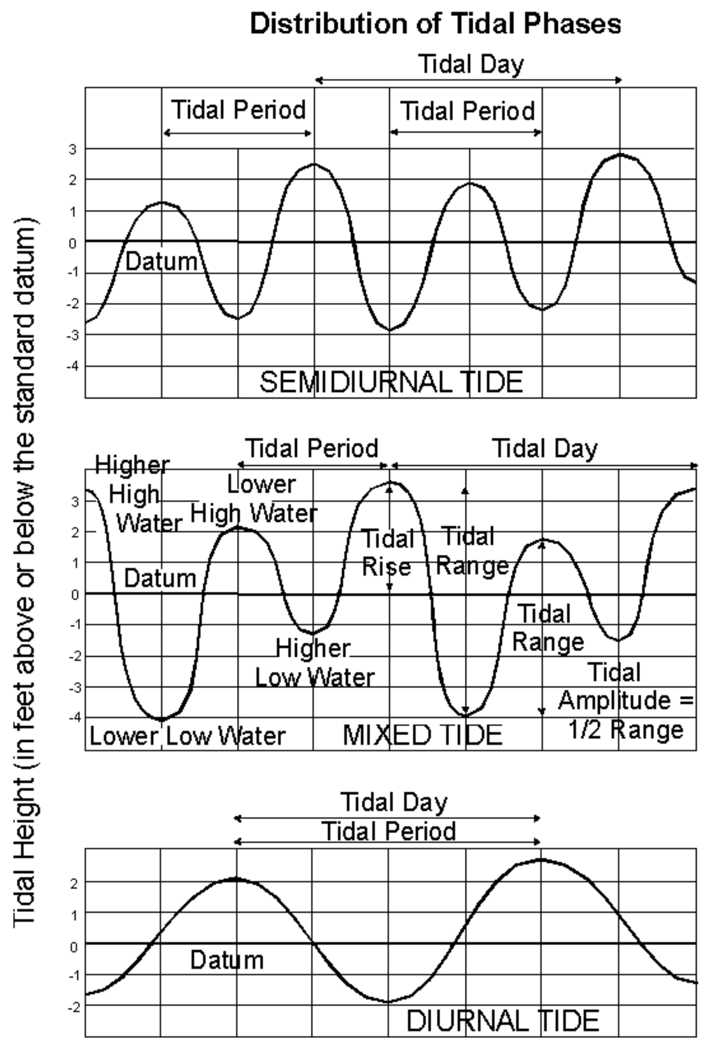

Figure 3: Time phase diffferences between diurnal, semidiurnal, and mixed tides.

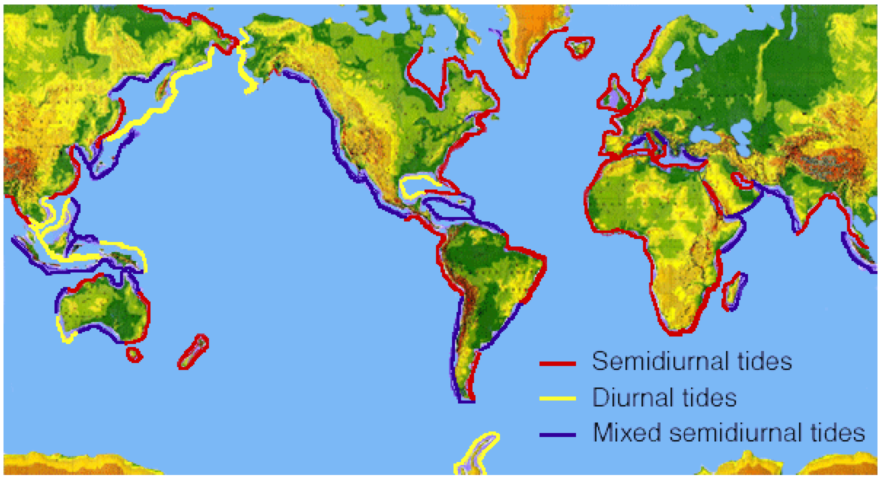

Figure 4: Geographic location of different tide types.

Figure 5: Bore tide in the Turnagain Arm with surfers. The wave can come twice a day and is often surfed by local riders, who are sometimes able to surf a very long time on 5-10 foot faces. It occurs 2-3 hours after the low tide time in Anchorage, Alaska. It is total luck on any given day to see the bore tide, as shifting, silty mud, icebergs and rivers of Turnagain Arm make for an ever-changing and unpredictable creature. Usually, a minus low tide and a high tide about 27 feet are required to make a wave big enough to surf.[2]

Figure 6: Brown tide in Indian River Lagoon Melbourne, Florida. Image showing associated fish kill on March 23, 2016[6].

Figure 7: Crimson Tide logo. A trademarked logo by the University of Allabama.

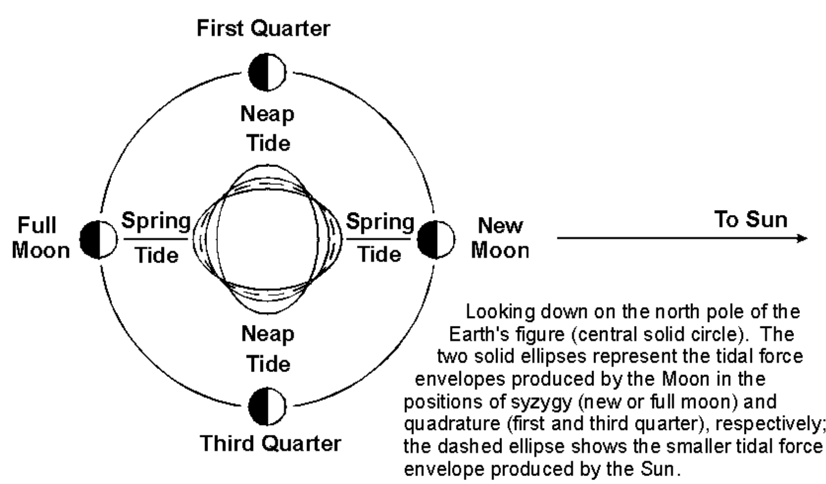

Figure 8: Spring and Neap tides. Embedded in the image is the text "Figure 3" that comes from the original document[3].

Figure 9: Red tide. A harmful algal bloom (HAB) offshore of San Diego County, California. Many people use the term "red tide" to refer to harmful algal blooms, but not all HABs turn the water red. Blooms may appear in a variety of colors depending on the species of algae involved and some HABs have no color at all[7]

Figure 10: Rip tide (dyed for easy identification). [5]

The USGS-GWW[1] provides a series of clickable maps that allow you to select a state of interest (see Figure 11). Each map shows the location of each well, the type of data available, and how the current data relates to prior data (lower, simular, higher, etc.). Zooming in on the Virginia Beach, Va. (Tidewater area) (see Figure 12). Based on the site map, well 365150076051101 (see Figure 14) is located at Virginia Beach Fire Station 20 (see Figure 13), and is within waking distance from our house. Near real-time measurement data is available via this URL (line broken for readability):

```
https://waterservices.usgs.gov/nwis/iv/?format=waterml,2.0&
  sites=365150076051101&period=P3D&parameterCd=72019&
  siteType=GW&siteStatus=all
```

Site 365150076051101 is described as:

- Latitude 36°51'50.40", Longitude 76°05'10.74" NAD83
- Virginia Beach City, Virginia, Hydrologic Unit 02080108
- Well depth: 140 feet
- Hole depth: 140 feet
- Land surface altitude: 15.51feet above NAVD88.
- Well completed in "Northern Atlantic Coastal Plain aquifer system" (S100NATLCP) national aquifer.
- Well completed in "Upper Chesapeake Group" (121CSPKU) local aquifer

3.2 NOAA Tides and Currents

The NOAA Tides and Currents service[2] provides a way to o access your local water levels, tide and current predictions, and other oceanographic and meteorological conditions (see Figure 15). Zooming in on the northern part of Virginia Beach, a site on the Chesapeake Bay Bridge Tunnel (station ID: 8638901) is the closest site that has water levels and meterological data (see Figure 16). The site is unmanned (see Figure 17). Near real-time measurement data is available via this URL:

```
https://tidesandcurrents.noaa.gov/noaatidepredictions.html?
id=8638901&units=standard&bdate=20200221&edate=20200222&
timezone=LST/LDT&clock=12hour&datum=MLLW&
interval=15&action=data
```

Site 8638901 is described as:

- Established: Oct 15, 2016

[1] https://groundwaterwatch.usgs.gov/usgsgwnetworks.asp

[2] https://tidesandcurrents.noaa.gov/

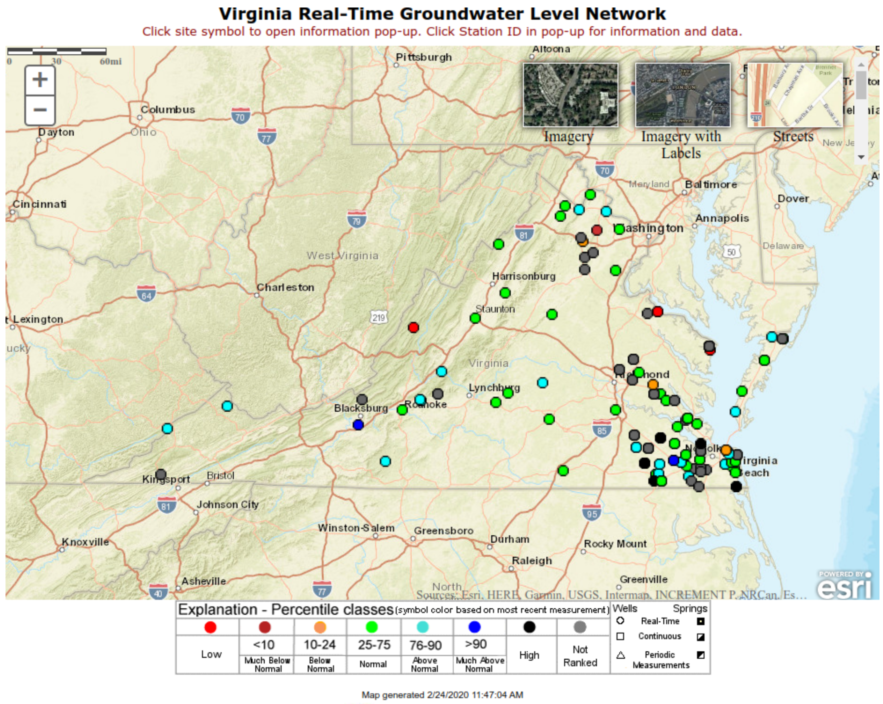

Figure 11: USGS GWW welll map for the state of Virginia.

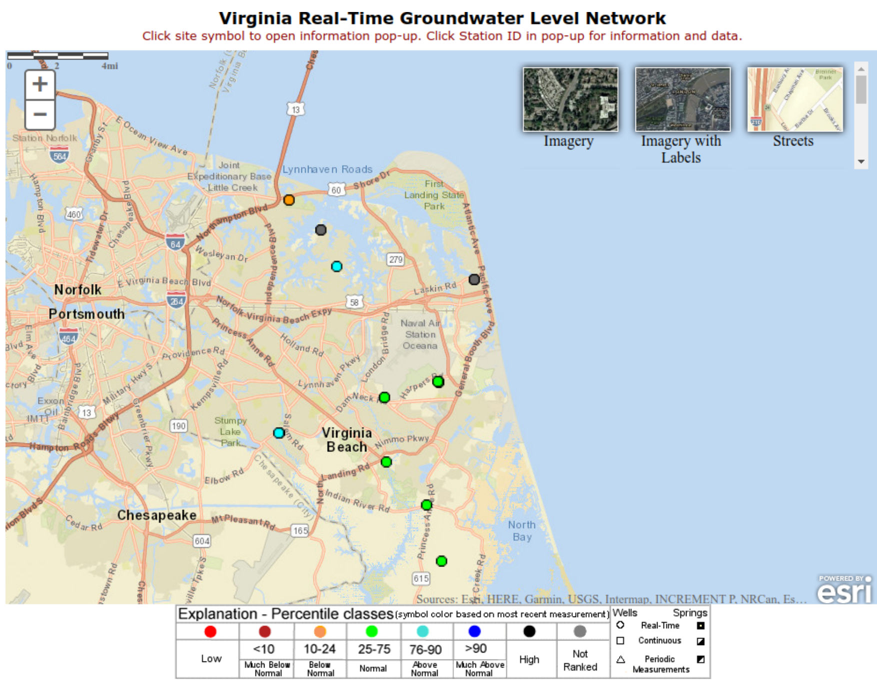

Figure 12: USGS GWW welll map for the city of Virginia Beach, Va.

Figure 13: Virginia Beach, Va, Fire Station 20.

- Time Meridian: 0° E
- Present Installation: Oct 11, 2016
- Date Removed: N/A
- Water Level Max (ref MHHW): 3.38 ft. Sep 06, 2019
- Water Level Min (ref MLLW): -1.49 ft. Jan 06, 2018
- Mean Range: 2.65 ft.
- Diurnal Range: 3.02 ft.
- Latitude 37° 2' N
- Longitude 76° 5' W
- NOAA Chart#: 12254
- Met Site Elevation: 28.8 ft. above MSL

4 Analysis

The basis analysis of the different data consisted of examination of well measurements, and then comparison of well and tidal data. Analysis was based on visual inspection of all data, interpretation of any anomalous data, and understanding of results.

Examination of the well measurement data showed a mostly smooth and regular pattern (see Figure 18). There were times with radically different patterns every around Mon-

Figure 14: USGS GWW site number: 365150076051101.

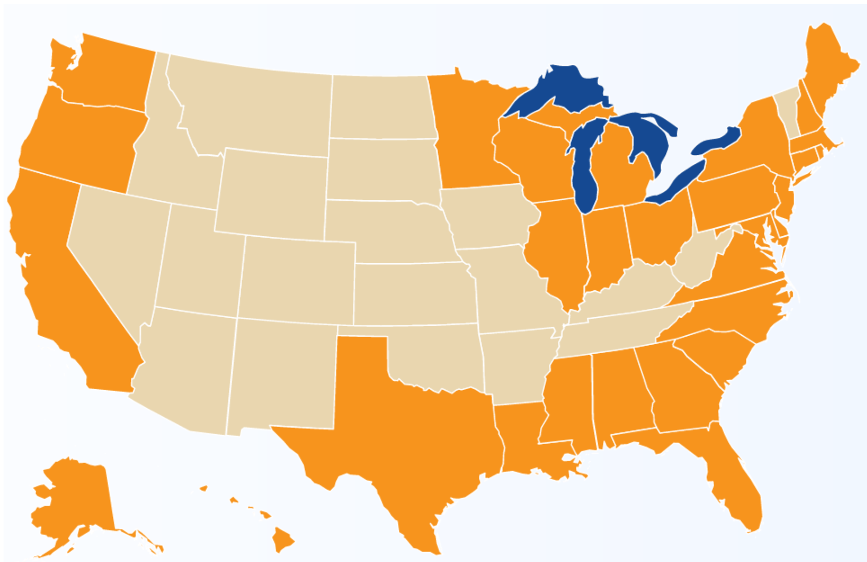

Figure 15: NOAA Tides and Current area selection clickable map.

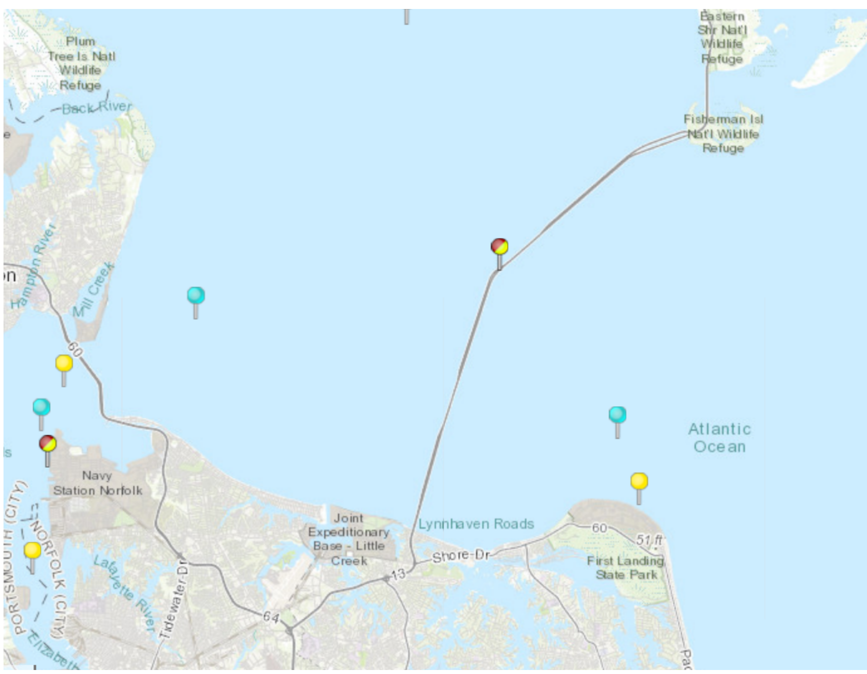

Figure 16: Location of the NOAA tidal prediction site on the Chesapeake Bay Bridge Tunnel.

Figure 17: NOAA station 8638901 on the Chesapeake Bay Bridge Tunnel.

day, Wednesday and Friday around 7AM. I spoke with Fire Station 20 personnel about these anomalies, and they felt outside technicians were performing maintenance on the well. Aside from these "strange" measurements, the remainder present a smooth and regular behavior[3].

[3]Causal examination of well data from 1 January 2020 through 21 February 2020 showed the same type of "maintenance" period behavior.o

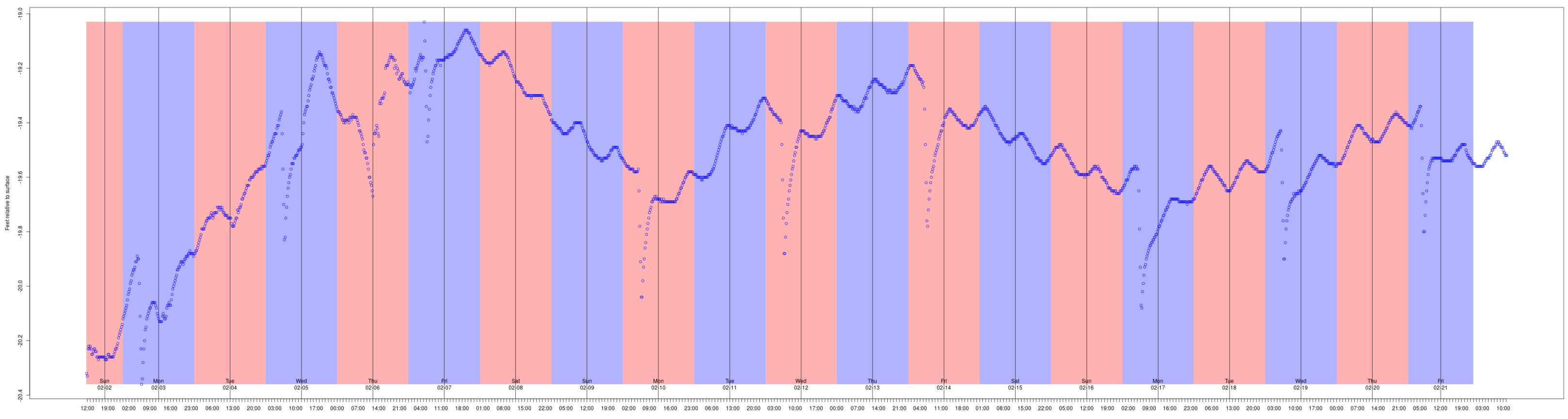

Figure 18: Groundwater measurements from USGS GWW site number: 365150076051101. The site measurements are all reported as positive values, for plotting purposes they were converted to negative values. Changing the “sign” of the data aided in understanding that when the values got larger, that meant that the water was further from the surface. Each measurement is time and date stamped at 15 minute intervals, these are converted to Unix seconds to allow time alignment with tidal predictions. The colored bands represent days, from midnight to midnight. Each band has a vertical line at noon for that day. A full sized image is in embedded (see Section A) in this report.

Tide predictions were downloaded, and date and times were converted to Unix seconds. Tidal prediction data, and well measurement data were plotted on the same time axis. Because well measurement data is reported in fractional feet below the datum ($\tilde{1}$9 to 20 feet), and tidal data is reported as fractional feet relative to mean low low water (MLLW) datum. Well measurement data were offset by a constant 21 feet to bring them within range of the tidal data (see Figure 19).

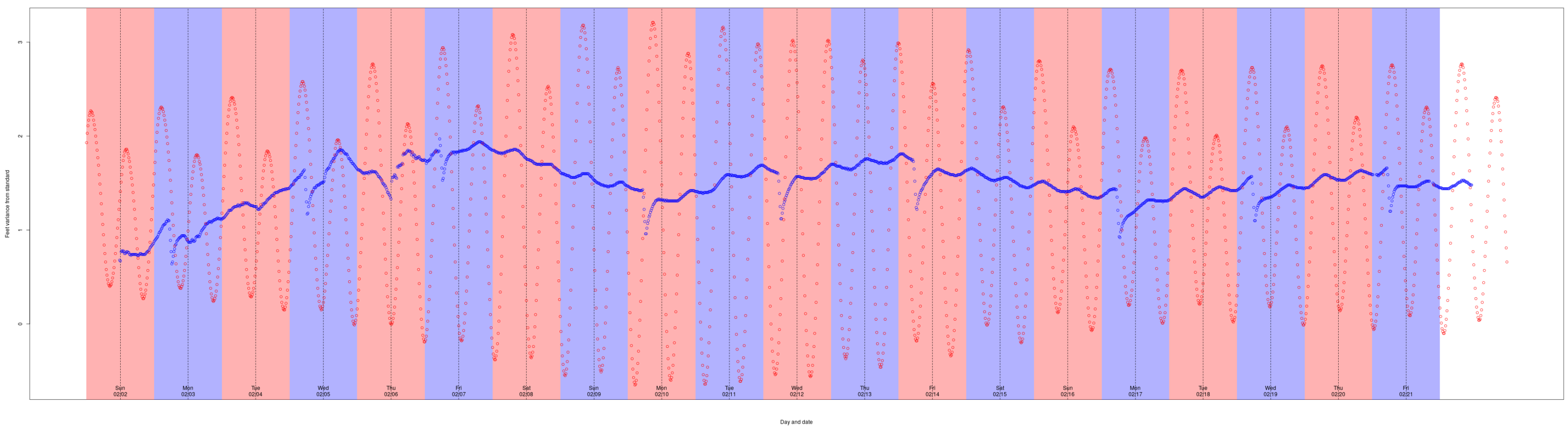

Figure 19: Groundwater measurements and tidal predictions. Tidal predictions are shown in red. Well measurements are shown in blue. Each measurement is time and date stamped at 15 minute intervals, these are converted to Unix seconds to allow time alignment between well measurements and tidal predictions. The colored bands represent days, from midnight to midnight. Each band has a vertical line at noon for that day. A full sized image is in embedded (see Section A) in this report.

Examination of the well measurement and tidal prediction data, show that well measurement "follow" the tidal predictions delayed by about 15 to 30 minutes. The range of well tidal measurements (difference between low and high measurements for one diurnal cycle) is approximately 1 - 2 inches.

5 Conclusion

Groundwater level measurements available from the United States Geological Survey (USGS) were compared to tidal predictions available from the National Oceanic and Atmospheric Administration (NOAA) for a site on very nearly the same longitude as the well. Groundwater measurements followed the tidal measurements delayed by about 15 - 30 minutes. The range of tidal well measurements based on tidal effects was about 1 - 2 inches.

Groundwater levels show tidal effects.

A Miscellaneous files

A collection of miscellaneous files mentioned in the report.

- plotData.R – R script file to read data files and create images
- wellMeasurements.xml – Well water level measurements file
- 8638901.txt – Tidal predictions for the Chesapeake Bay Bridge Tunnel
- wellData.png – Full size plot of well measurements.
- wellAndTideData.png – Full size plot of well measurements and tide predictions.
- longWellData.txt – Well water level measurements file from 1 January 2020 through 21 Febraury 2020

B References

[1] Boating Magazine Staff, *12 different types of tides explained*, https://www.boatingmag.com/photos/twelve-types-tides/, 2019.

[2] Girdwood Staff, *The alaska bore tide: What, when, where, why & who?*, https://girdwood.com/girdwood-turnagain-arm-bore-tide-what-when-where-why-and-who/, 2020.

[3] NOAA Staff, *Chapter 3 - detailed explanation of the differential tide producing forces*, https://tidesandcurrents.noaa.gov/restles3.html.

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[5] ______, *Rip current science*, https://oceantoday.noaa.gov/ripcurrentscience/.

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[7] ______, *To bloom or not to bloom*, https://www.noaa.gov/what-is-harmful-algal-bloom, 2016.

[8] ______, *Tides and water levels*, https://oceanservice.noaa.gov/education/tutorial_tides/tides07_cycles.html, 2020.

[9] ______, *Tides and water levels, frequency of tides - the lunar day*, https://oceanservice.noaa.gov/education/tutorial_tides/tides05_lunarday.html, 2020.

[10] ______, *Water going up, water going down*, https://coast.noaa.gov/data/estuaries/pdf/water-going-up-water-going-down-teacher-guide.pdf, 2020.

[11] Oxford Staff, *Quick reference: tide*, https://www.oxfordreference.com/view/10.1093/oi/authority.20110830142900185, 2020.

[12] Swinburne Staff, *Solar day*, http://astronomy.swin.edu.au/cosmos/S/Solar+Day, 2020.