Will a Reduction of Submarine Groundwater Discharge Cause Salinity in SGD to Increase in the Chassahowitzka and Homosassa Rivers?

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Background

During the peer review process of the MFL re-evaluations for Chassahowitzka and Homosassa Rivers, a question was raised regarding the potential increase of salinity in SGD when the SGD is reduced. The following documents an effort trying to find any correlation between SGD salinity and SGD itself, and thereby answer the question if a reduction of SGD will increase salinity in SGD (or spring vents.)

Previous data collections in the region have indicated that in some spring vents, salinity does vary slightly during the tidal cycle. As tides directly affect SGD, salinity in the spring vent appears to be correlated with SGD. From the available data, correlations between SGD and salinity in SGD seem to be mixed, with the salinity – SGD relationship being positive in some spring vents, but negative in other spring vents. In freshwater vents, SGD generally has no effects on salinity at all.

Because there is not a subterranean estuary model available for the region, it is impossible to conduct a comprehensive study on how the groundwater withdrawal would affect salinity in groundwater, especially in the proximity of spring vents, in a timely manner to address panel's concern. Existing groundwater water quality and withdrawal data are not suitable for an appropriate analysis, which would give us an answer either. As such, we choose to take a close examination of available discharge and salinity data collected in surface water in the upstream areas of the Chassahowitzka and Homosassa Rivers. Hopefully, the analysis of the surface water data could shed some light on this issue.

Analysis of the Raw Real-Time Data by the USGS

For simplicity, let's focus on USGS discharge and salinity data at the USGS SE Fork Homosassa Spring at Homosassa Springs (#02310688), Homosassa Springs at Homosassa Springs (#02310678), and Halls River at Homosassa Springs (#02310689) stations for the Homosassa River system and the Chassahowitzka River near Homosassa (#02310650) station for the Chassahowitzka River during a 12-month period from June 2015 to June 2016. As a side note, the MS Excel on my computer does not permit me to do a quick and effective analysis of the data for the POR at these stations because of a limitation on the number of rows allowed in the spreadsheet.

Figures 1 - 4 show time series of discharge (red lines) and salinity (green lines), with a 15-minute interval, at these four USGS stations during June 1, 2015 through June 25, 2016. The top panels on these figures are data for the entire 12-month period. To get a better view of the short-term variabilities of the discharge and salinity, four selected 10-day periods were zoomed in and shown in the middle and bottom panels.

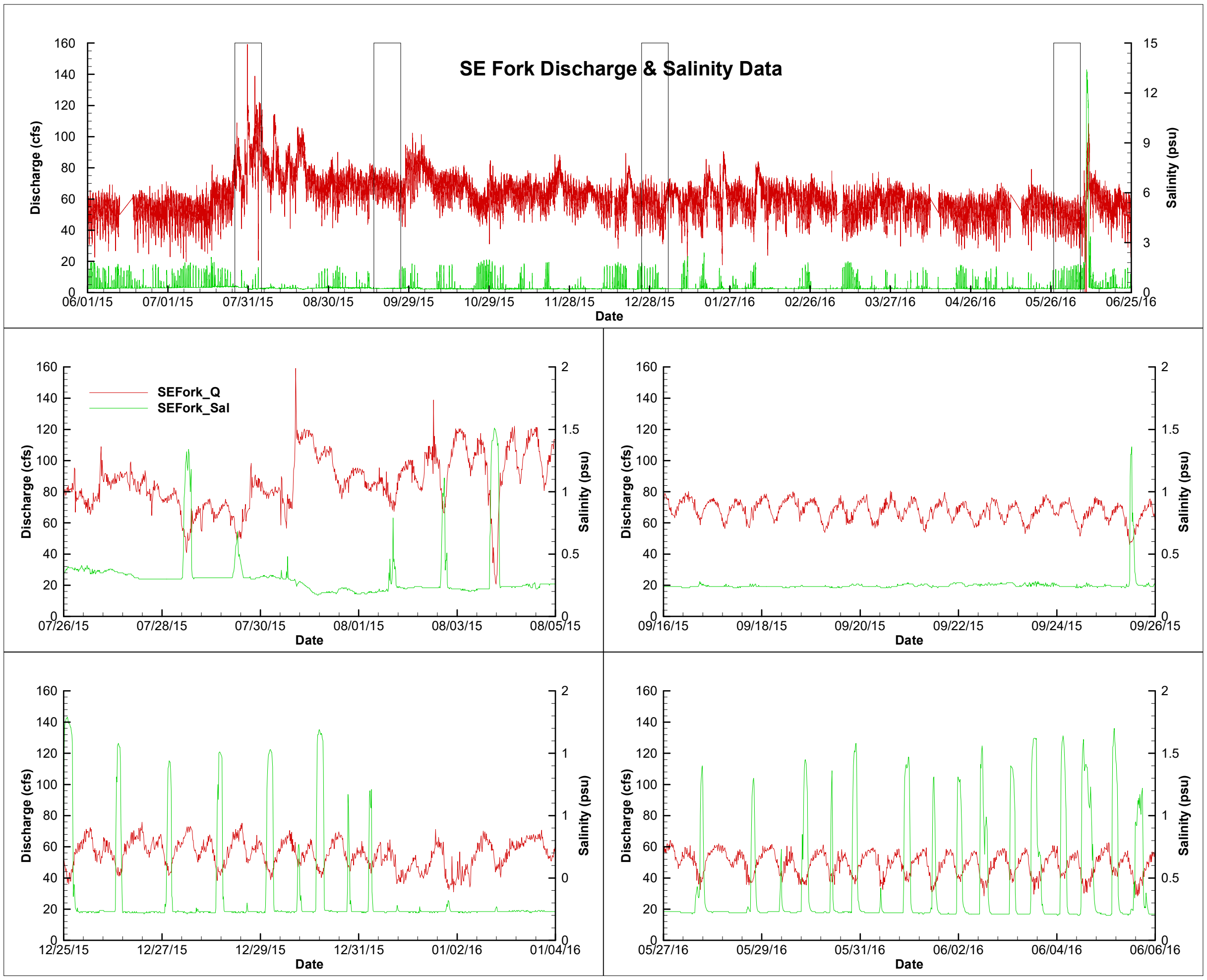

Figure 1. Discharge (red lines) and salinity (green lines) data collected at the USGS SE Fork station during June 1, 2015 through June 25, 2016 (top panel). Data for four 10-day windows (7/20/15 – 7/30/15, 9/16/15 – 9/26/15, 12/23/15 – 1/2/16, and 5/31/16 – 6/10/16) were plotted in the middle and bottom four panels.

It should be pointed out that the discharge time series shown in Figures 1 – 4 are estimated net SGDs, instead of direct plots of the discharge data reported by the USGS, which contain tidal fluxes associated with tidal prisms upstream of the data stations (Chen 2019a & 2019b). In order to obtain discharge data which are close to true SGDs, these tidal prism - related fluxes were deducted from the USGS discharge data. The estimation of the tidal prism - related flux was carried out using water level data at the site, which were also recorded by the USGS, and estimated water surface area upstream of the station. Because of the complexity of the topography in the area, some relatively small tidal flats, creeks, and wetlands which are tidally influenced may be missed in the tidal prism calculation, resulting in an estimation of the tidal flux prism which is most likely under-predicted. As such, estimated SGDs shown in Figures 1 - 4 could still contain certain amount of tidal flux. This is especially true for the Halls River, as an upstream tributary of the river is not included in the calculation of tidal prism – related flux.

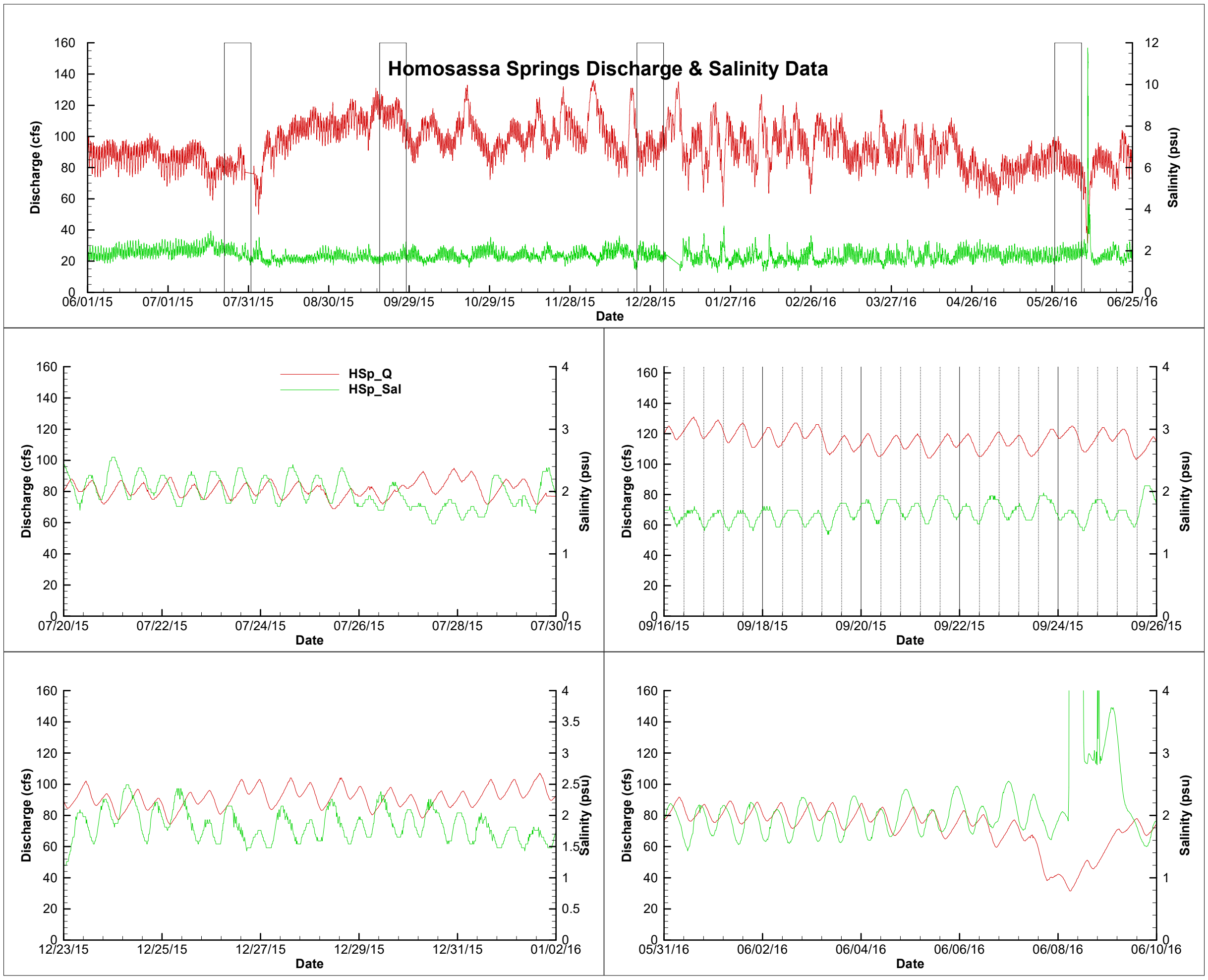

Figure 2. Discharge (red lines) and salinity (green lines) data collected at the USGS Homosassa Springs station during June 1, 2015 through June 25, 2016 (top panel). Data for four 10-day windows (7/20/15 – 7/30/15, 9/16/15 – 9/26/15, 12/23/15 – 1/2/16, and 5/31/16 – 6/10/16) were plotted in the middle and bottom four panels.

From Figures 1 – 4, it can be seen that SGD and salinity at all four USGS stations exhibit significant tidal variations. At the SE Fork station, salinity is generally low and below 0.5 psu most of time. Only during high tides, when SGD was relatively low, were salinity at the SE Fork station greater than 0.5 psu and peaked above 1.5 psu sometimes. In other words, the freshwater-salt water interface moves back and forth around the SE Fork station, with its location being downstream of the station most of the time. During the wet season or when the area receives relatively a large amount of rainfall, the SE Fork station is almost always fresh.

Figure 5 shows a plot of salinity versus SGD data at the SE Fork station during the 12-month period from Jun1, 2015 through May 31, 2016. Although the plot shows a negative correlation between SGD and salinity at the SE Fork station, the regression line is quite flat with a very low R^2 of 0.11. Because the SE fork station is some distance away from the upstream spring water sources, saline water at this station is from the downstream estuary instead of from the upstream spring vents. Although a reduction of SGD sometimes corresponds to a slight increase of salinity at the site, it is not expected to cause any salinity increase in the upstream spring vents under the normal condition.

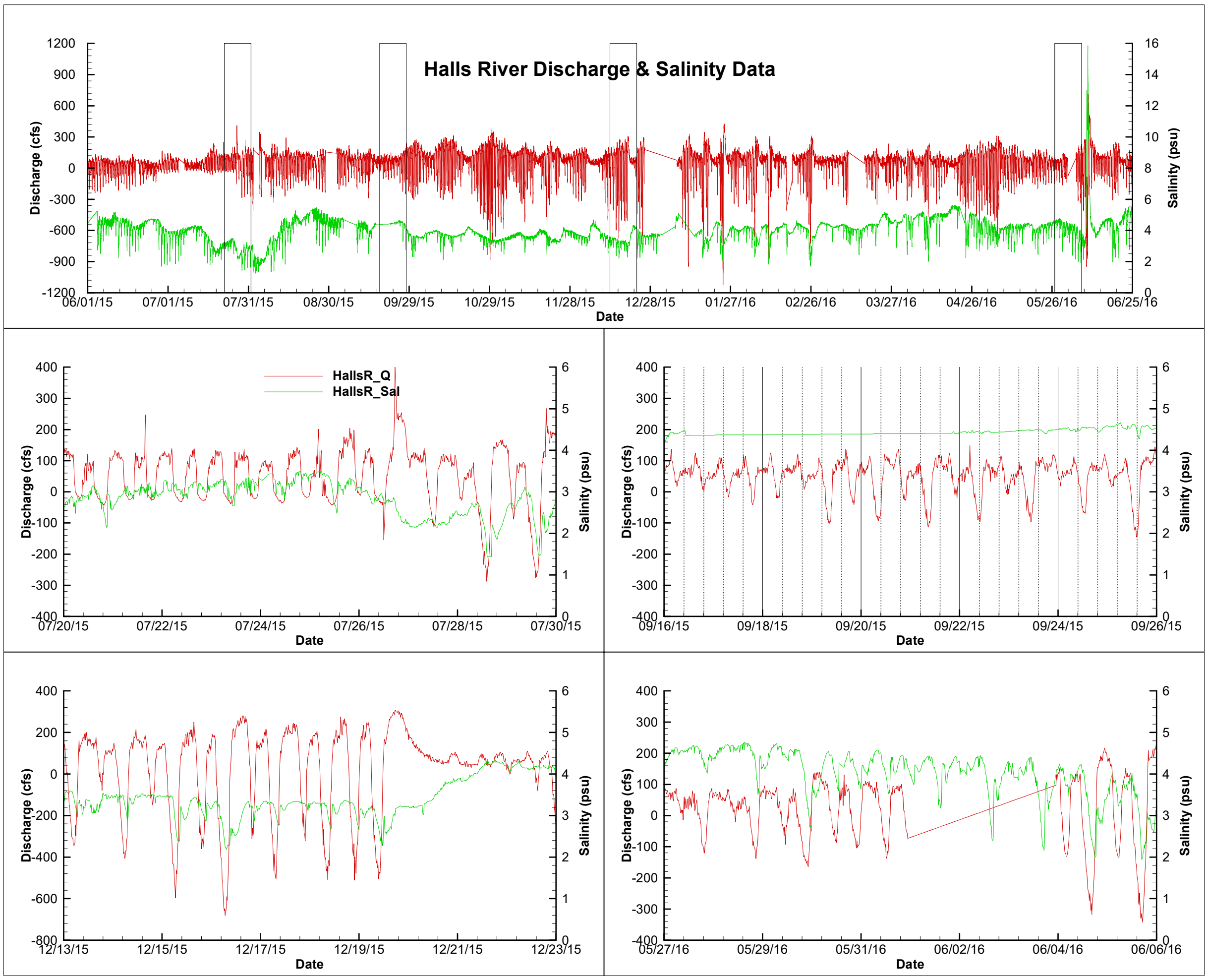

Figure 3. Discharge (red lines) and salinity (green lines) data collected at the USGS Halls River at Homosassa Springs station during June 1, 2015 through June 25, 2016 (top panel). Data for four 10-day windows (7/20/15 – 7/30/15, 9/16/15 – 9/26/15, 12/13/15 – 1/23/16, and 5/27/16 – 6/6/16) were plotted in the middle and bottom four panels.

At the Homosassa Springs station (Figure 2), salinity generally varied at around 2 psu without any apparent seasonality. The inverse relationship between SGD and salinity at this station is as weak as that at the SE Fork station. In fact, the data sometimes exhibit a direct relationship between SGD and salinity at the Homosassa Springs station, with salinity aligned with SGD in phase in the wet season better than in the dry season, during which salinity leads SGD by a phase of less than π/2 rad. During a 10-day period in September 2015, SGD was significantly higher than in the dry period; however, salinity only decreased slightly in comparison with other 10-day periods.

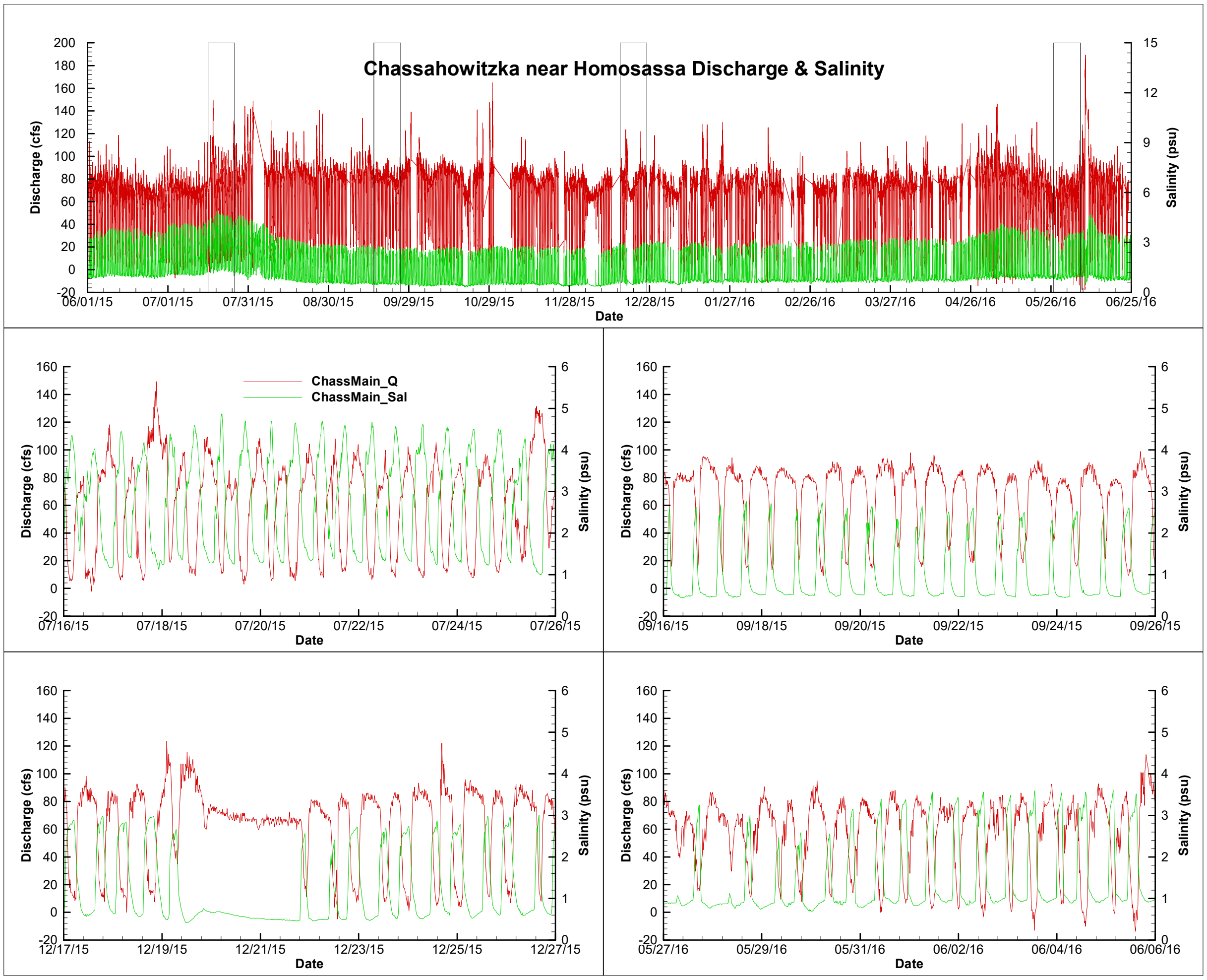

Figure 4. Figure. Discharge (red lines) and salinity (green lines) data collected at the USGS Chassahowitzka River near Homosassa station during June 1, 2015 through June 25, 2016 (top panel). Data for four 10-day windows (7/16/15 – 7/26/15, 9/16/15 – 9/26/15, 12/17/15 – 12/27/15, and 5/27/16 – 6/06/16) were plotted in the middle and bottom four panels.

Figure 6 is a plot of salinity versus SGD for the Homosassa Springs station during the 12-month period from Jun1, 2015 to May 31, 2016. Again, the overall correlation between salinity and SGD is low, with the regression line being very flat and having a low R^2 of 0.11. The regression shown in Figure 5 is not strong enough to conclude that a reduction of SGD will definitely cause an increase of salinity for the Homosassa Springs.

As mentioned above, the SGD data at the Halls River at Homosassa Spring station still contains certain amount of tidal flux associated with the tidal prism. As shown in Figure 3, tidal signals in both the SGD and salinity were strong during dry periods, in which salinity slightly lags the SGD. During the 10-day period in September 2015, salinity was relatively stable and higher than most of other days of the 390-day period. Except for the last two weeks in July 2015 when salinity at this station had an apparent dip, salinity in the wet season was a little higher than that in the dry season.

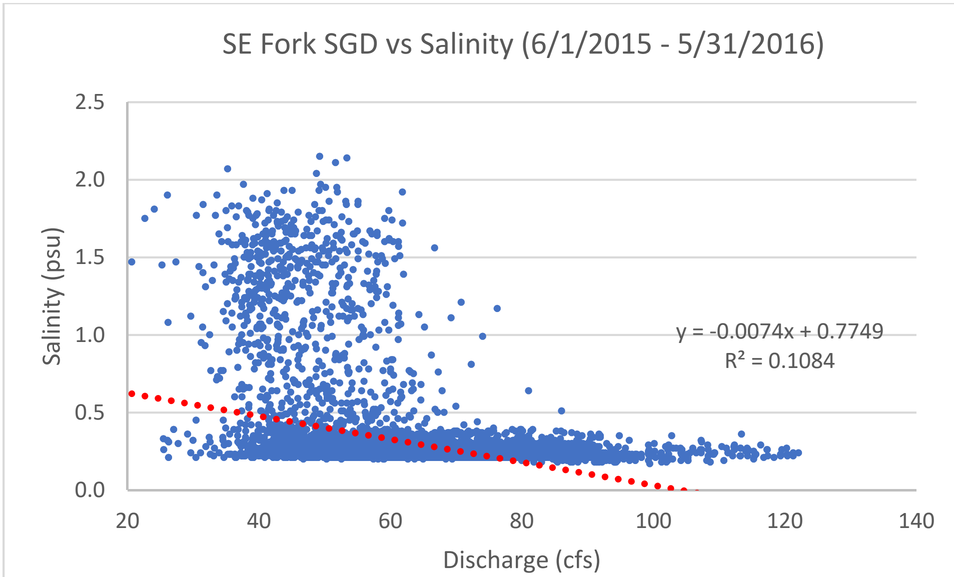

Figure 5. Plot of SGD versus salinity at the USGS SE Fork station during the 12-month period of June 1, 2015 through May 31, 2016.

Figure 7 shows a plot of salinity versus SGD for the Halls River at Homosassa Springs station during the 12-month period from Jun1, 2015 through May 31, 2016. With a R^2 value of 0.004, there is practically no correlation between salinity and SGD for this station. A comparison of the salinity data at the Halls River at Homosassa Springs with those at Halls River near Homosassa , which is about 1.82 KM downstream of the Halls River at Homosassa Springs station, shows that salinity at the upstream station is consistently higher than that at the downstream station (Figure 8), suggesting that the isohaline in Halls River is reversed and SGD from the Halls River is a source of salinity for the Homosassa River system. Unless an SGD reduction causes a significant increase of salinity, a reduction of SGD in Halls River will generally result in a reduced salt water loading to the estuarine system.

Time series plots of salinity and SGD at the USGS Chassahowitzka River near Homosassa station (Figure 4) show a clear pattern for salinity and SGD. Although SDG and salinity do not necessarily have an exact phase difference of π, almost every salinity peak occurs when an SGD trough occurs. It appears that salinity at this site is closely related to the SGD. Figure 9 is a plot of salinity versus SGD at the Chassahowitzka River near Homosassa station. As can be seen from the figure, a negative correlation between salinity and SGD, with a R^2 value of 0.37, can be obtained for the Chassahowitzka River near Homosassa station. Although this R^2 value is still considered low, it is much higher than those for the three USGS stations in the Homosassa River.

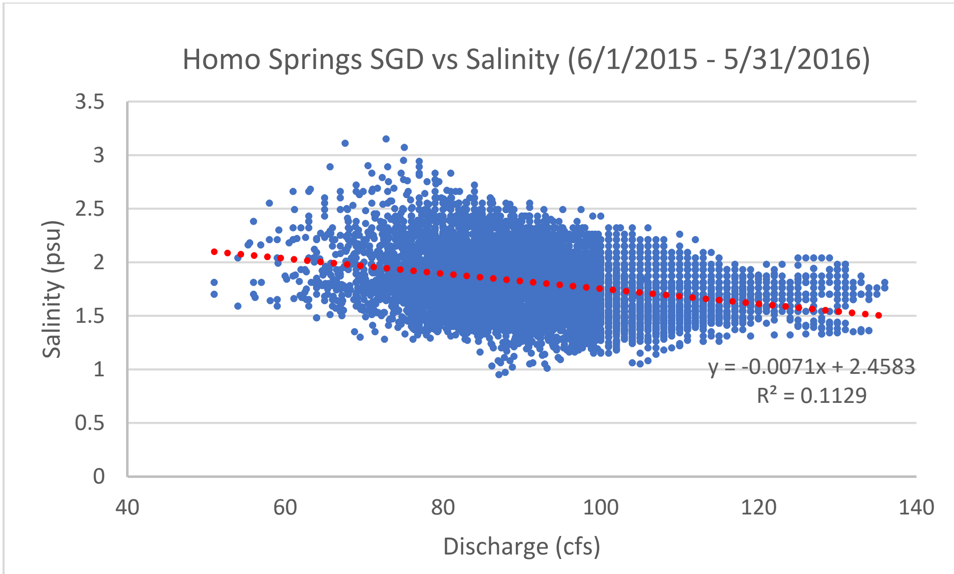

Figure 6. Plot of SGD versus salinity at the USGS Homosassa Springs station during the 12-month period of June 1, 2015 through May 31, 2016.

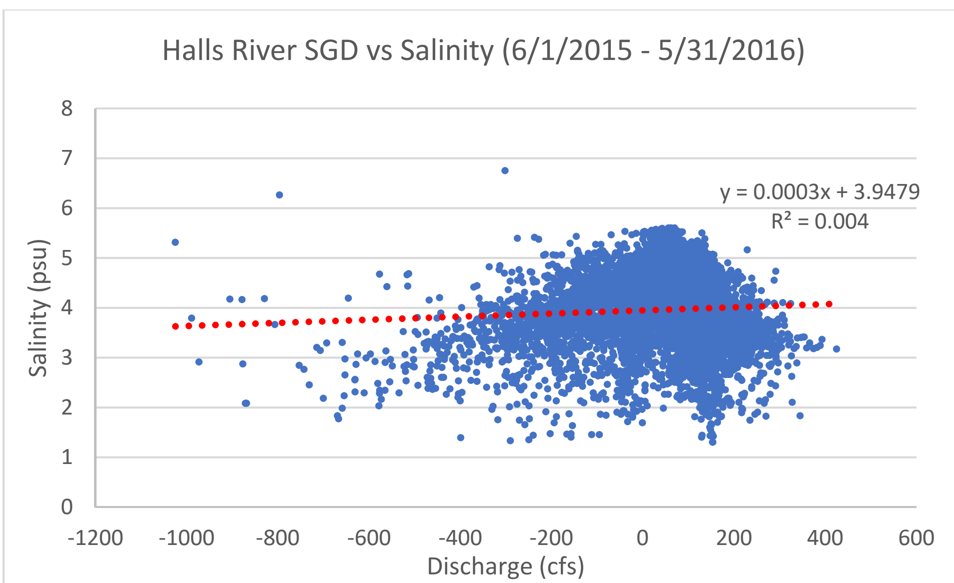

Figure 7. Plot of SGD versus salinity at the USGS Halls River at Homosassa Springs station during the 12-month period of June 1, 2015 through May 31, 2016.

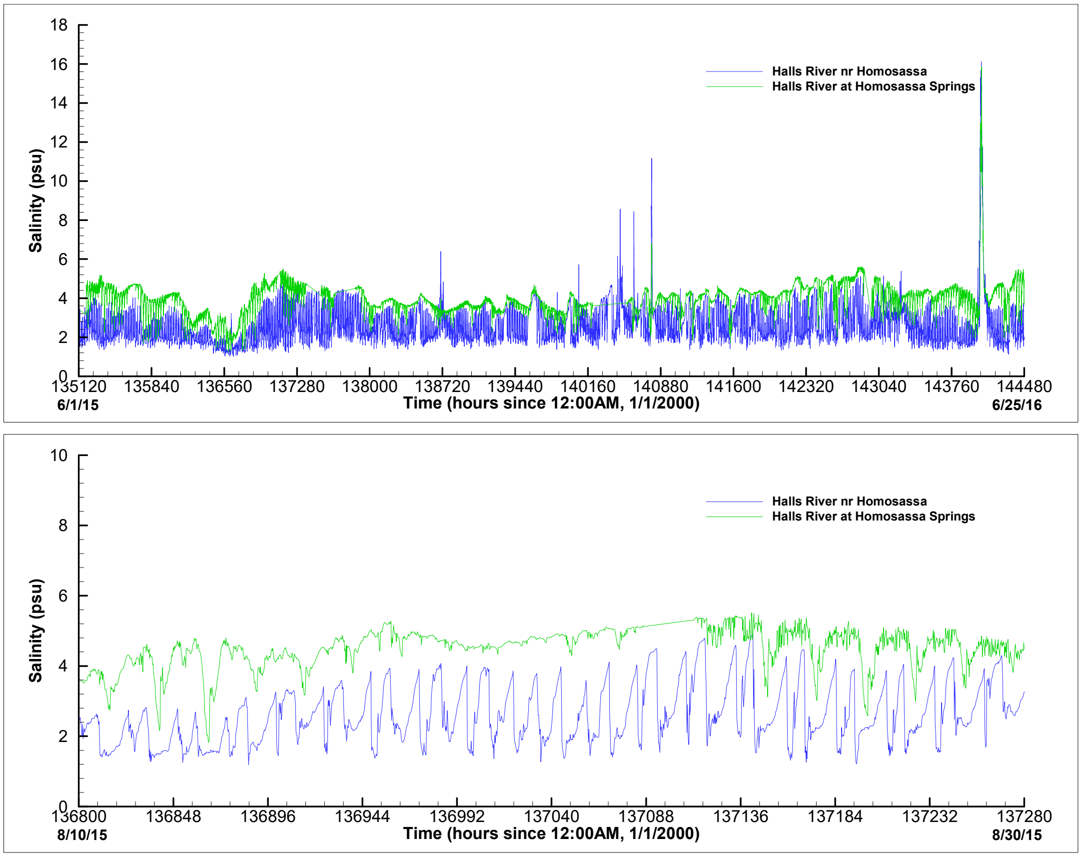

Figure 8. Measured salinities at the Halls River near Homosassa (blue lines) and Halls River at Homosassa Springs (green lines) stations during June 1, 2015 through June 25/2016.

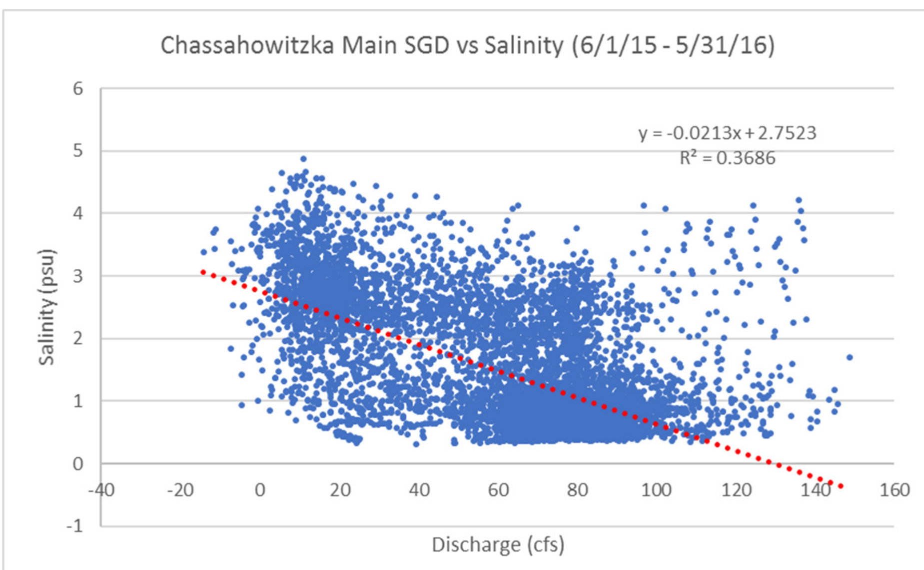

Figure 9. SGD versus salinity at the USGS Chassahowitzka River near Homosassa station during the 12-month period of June 1, 2015 through May 31, 2016.

Analysis of Tidally Filtered Data

Because both salinity and SGD in the Chassahowitzka and Homosassa are tidally influenced, considerable tidal variabilities are included in the salinity and SGD data. Generally, a high tide will cause SGD to become low but salinity to become high. On the other hand, a low tide will cause SGD to increase but salinity to decrease. Therefore, tides cause both salinity and SFD to vary but in opposite directions. Although it appears that sometimes a low salinity corresponds to a high SGD and vise verse, the low salinity may not necessarily be caused by a high SGD. In other words, even when there is a good correlation between salinity and SGD, there is not definitely a cause-and-effect relationship between the two parameters, because they are both affected by the third parameter (tides). As such, it is meaningful to eliminate tidal signals in both the SGD and salinity data and try to find any correlations between tidally filtered SGD and tidally filtered salinity.

There are several low-pass filters available which can be used to take tidal signals out of the salinity and SGD data. The simplest one is the running mean with a moving time window (e.g., 24 hours.) As noted on the USGS websites for their Chassahowitzka and Homosassa stations (e.g., https://waterdata.usgs.gov/fl/nwis/uv/?site_no=02310650&PARAmeter_cd=00065,00060 and https://waterdata.usgs.gov/fl/nwis/uv/?site_no=02310688&PARAmeter_cd=00065,00060), tides at these stations contain significant tidal cycles of approximately 24.84 hours. Because USGS data were recorded every 0.25 hours, 2484 continuous records (or 621 hours) make up exactly 25 cycles of 24.84 hours. As such, a time window of 621-hour was chosen and running means of SGD and salinity were calculated at the four USGS stations in the Chassahowitzka and Homosassa Rivers. Figure 10 shows tidally filtered SGDs and salinities at the SE Fork (top panel), Homosassa Springs (middle panel), and Halls River at Homosassa Springs (bottom panel) stations in the Homosassa River system during the 12-month period between June 2015 and June 2016, while Figure 11 shows tidally filtered SGD and salinity at the Chassahowitzka River near Homosassa station during the same 12-month period. Plots of tidally filtered salinity versus tidally filtered SGD for the SE Fork, Homosassa Springs, Halls River at Homosassa Springs stations are shown in Figures 12 – 14, respectively. Figure 15 is a plot of tidally filtered salinity versus tidally filtered SGD for the Chassahowitzka River near Homosassa station.

From Figures 12 – 15, it can be seen that the correlation between SGD and salinity in SGD is poor, with R^2 values for the SE Fork, Homosassa Spring, Halls River at Homosassa Springs and Chassahowitzka River near Homosassa stations being 0.04, 0.24, 0.06, and 0.0004 respectively. Clearly, the Chassahowitzka River near Homosassa River show no correlation between salinity and SGD after tidal signals are filtered out. Both the SE Fork and Halls River at Homosassa Springs stations in the Homosassa River system virtually show no correlation between tidally filtered SGD and tidally filtered salinity either, as their R^2 values are only 0.06 or lower. A small R^2 value of 0.24 show some weak correlation between tidally filtered SGD and tidally filtered salinity for the Homosassa Spring station; however, the correlation is not good enough to make any irrefutable conclusion. As the discharge at this station was calculated from a regression relationship, which relates the discharge with the groundwater level in a Weeki Wachee well, which is more than 30 KM away, tidally filtered SGD at the Homosassa Spring station represents groundwater level more than 30 KM away. Unless the groundwater level in the upstream area of the Homosassa River has a perfect linear correlation with that in the Weeki Wachee well, there is a certain degree of additional uncertainty associated with the use of the groundwater level more than 30 Km away. As a result, it is skeptical if this improved R^2 value for the Homosassa Springs station is true for the real SGD and salinity at the station.

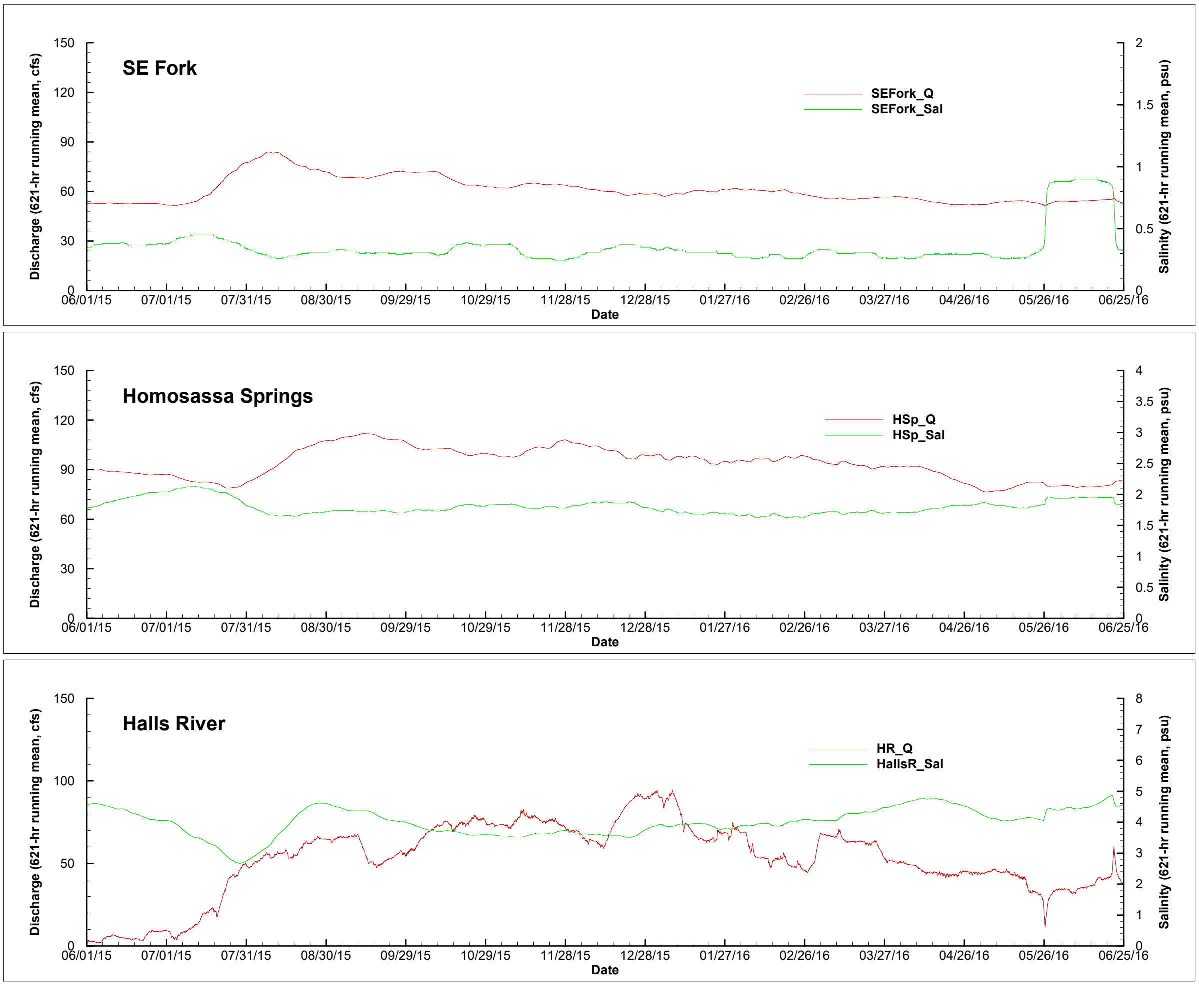

Figure 10. 621-hour running means of discharge (red lines) and salinity (green lines) at the USGS SE Fork (top panel), Homosassa Springs (middle panel), and Halls River at Homosassa Springs (bottom panel) stations during June 1, 2015 through June 25, 2016.

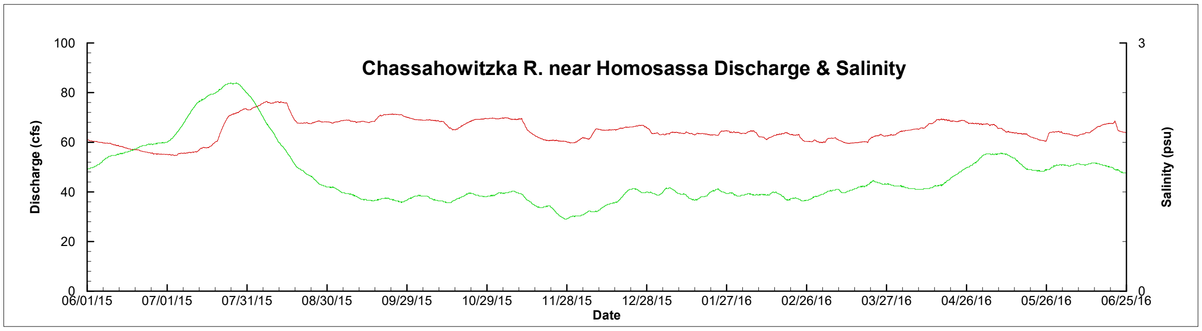

Figure 11. 621-hour running means of discharge (red lines) and salinity (green lines) at the USGS SE Fork (top panel), Homosassa Springs (middle panel), and Halls River at Homosassa Springs (bottom panel) stations during June 1, 2015 through June 25, 2016.

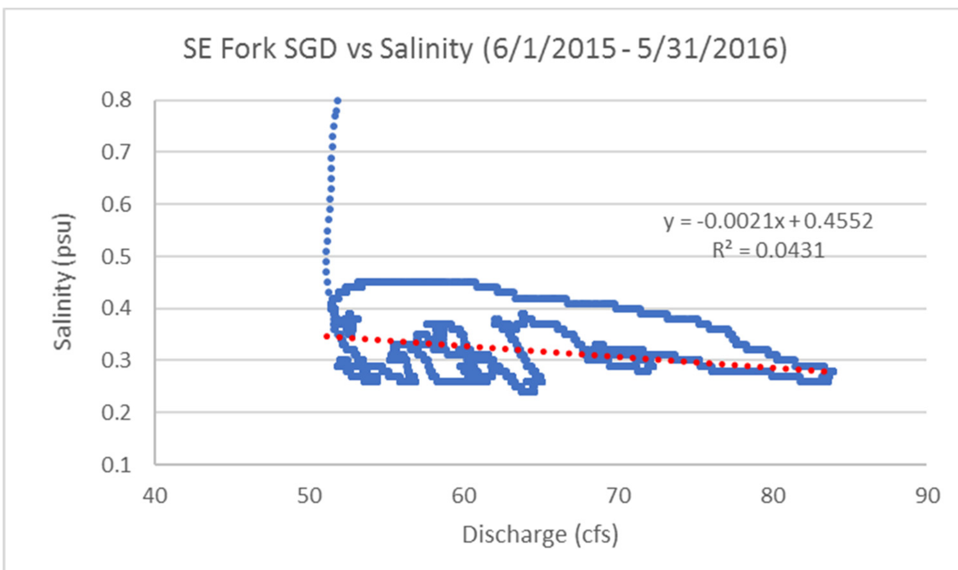

Figure 12. Plot of tidally filtered SGD versus tidally filtered salinity at the USGS SE Fork station during the 12-month period of June 1, 2015 through May 31, 2016.

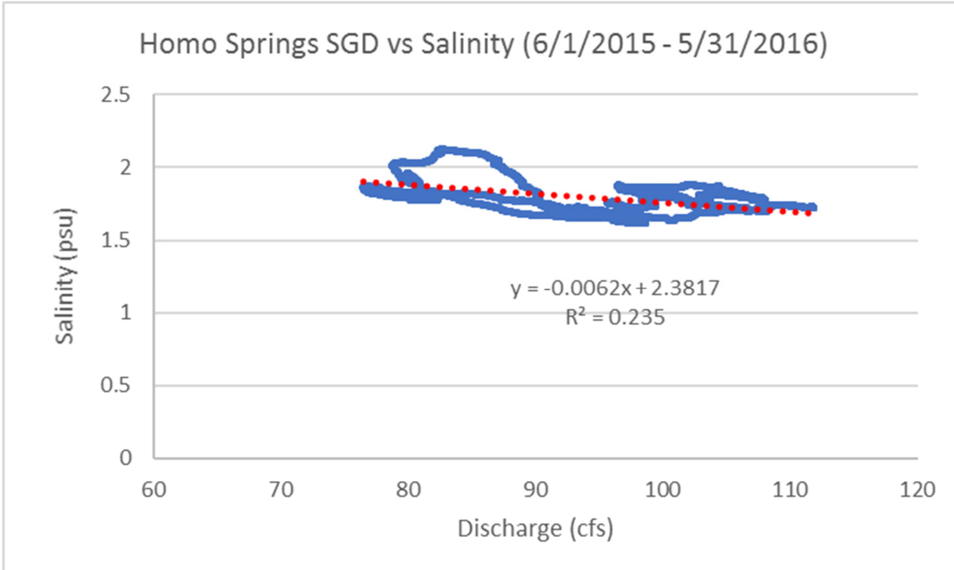

Figure 13. Plot of tidally filtered SGD versus tidally filtered salinity at the USGS Homosassa Springs station during the 12-month period of June 1, 2015 through May 31, 2016.

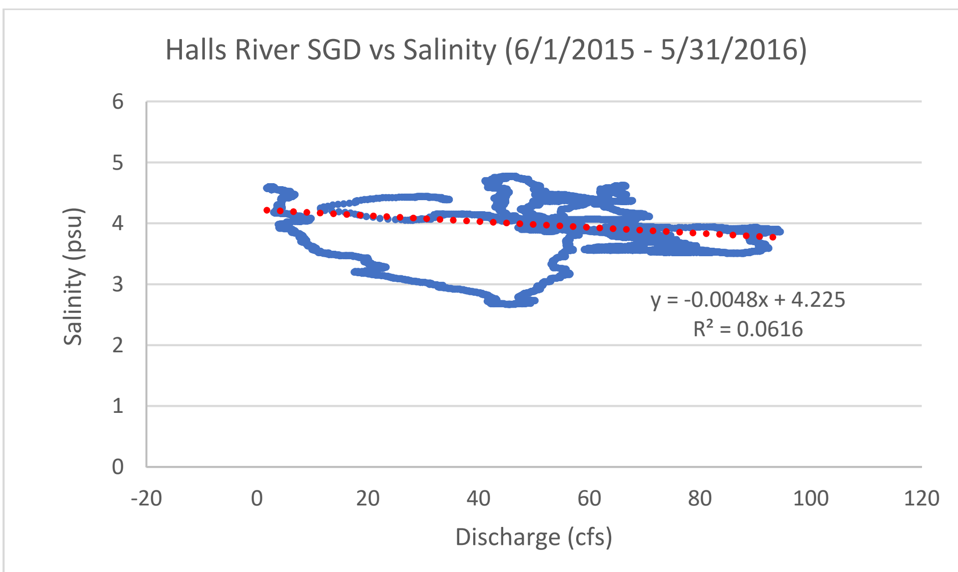

Figure 14. Plot of tidally filtered SGD versus tidally filtered salinity at the USGS Halls River at Homosassa Springs station during the 12-month period of June 1, 2015 through May 31, 2016.

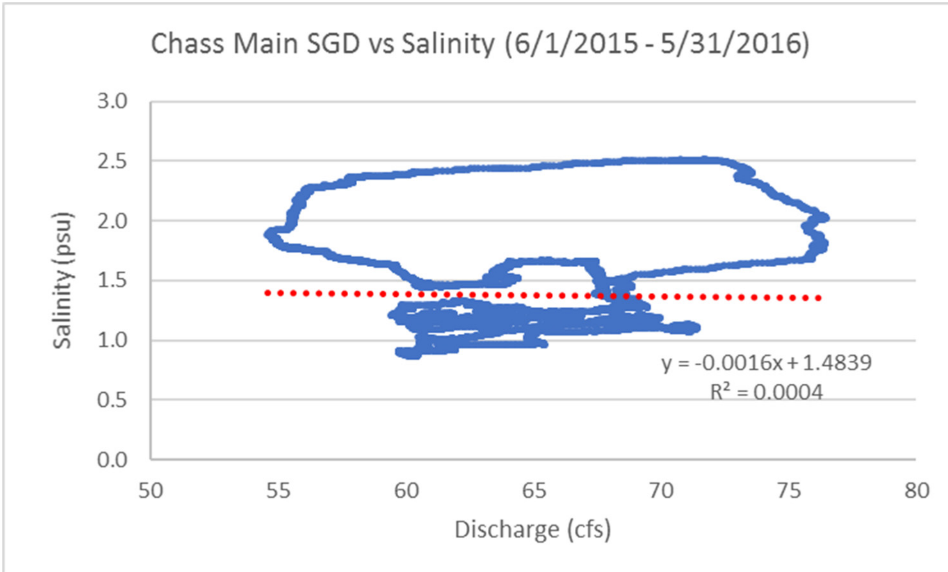

Figure 15. Tidally filtered SGD versus tidally filtered salinity at the USGS Chassahowitzka River near Homosassa station during the 12-month period of June 1, 2015 through May 31, 2016.

Conclusions

Because there is not a subterranean estuary model available for the region, a comprehensive modeling study on how groundwater withdrawal affects salinity distributions in groundwater, especially in the proximity of spring vents of the Chassahowitzka and Homosassa Rivers, is impossible. Existing groundwater water quality and withdrawal data are not suitable for an appropriate analysis, which would give us a correlation between salinity in spring vents and spring flow discharge. This article reports an effort trying to find such a correlation through an analysis of salinity and SGD data collected in surface water of the upstream areas of the Chassahowitzka and Homosassa Rivers.

From raw data, only the USGS Chassahowitzka River near Homosassa station shows a poor correlation between salinity and SGD, with a ^{R2} of 0.37 for linear regression. All three USGS stations in the Homosassa River system exhibit very poor or no correlations between salinity and SGD.

Because salinity and SGD are both affected by tides in the Chassahowitzka and Homosassa Rivers, any correlation obtained from the raw data, which contain tidal signals, may not necessarily represent the true cause-and-effect relationship between salinity and SGD. To eliminate tidal variabilities in both SGD and salinity, a simple low-pass filter, or a running mean with a moving time window of 621 hours, was used to process the SGD and salinity data at the three Homosassa River stations and the one Chassahowitzka station. Except for the Homosassa Springs station, which has increased R^2 value for tidally filtered data in comparison with raw data, all other stations have decreased R^2 values, varying between 0.0004 and 0.06, suggesting that at the SE Fork and Halls River at Homosassa stations in the Homosassa River system and at the Chassahowitzka River near Homosassa station, there is basically no correlation between salinity and SGD because of the very low R^2 values. Although the Homosassa Springs station has a low R^2 value of 0.24 between tidally filtered salinity and tidally filtered SGD, it is not certain how reliable this R^2 value is, because the tidally filtered SGD represent groundwater level variation about 30 kilometers south of the Homosassa River.

Based on the above analyses, no definitive conclusions can be drawn about the effect of reduced SGD on salinity in SGD. To answer the question if a reduced SGD will cause SGD salinity to increase, future studies are needed, including more data collections and analyses and development of a subterranean estuary model which is capable of simulating interactions between groundwater movement and coastal water hydrodynamics and salinity transport processes in coastal groundwater flow.

References

Chen, X., 2019a. *A Modeling Study of Effects of Flow Reduction on Salinity and Thermal Habitats in the Chassahowitzka River*. Technical Report (Final Draft), Southwest Florida Water Management District, Tampa, Fla. 33637. 264p.

Chen, X., 2019b. *Hydrodynamic Modeling of Effects of Flow Reduction on Salinity and Thermal Habitats in the Homosassa River*. Technical Report (Final Draft), Southwest Florida Water Management District, Tampa, Fla. 33637. 247p.