Monitoring seasonal variability of the soil profile with paired deep and shallow Surface Elevation Tables (SET) in the southwest coastal Everglades.

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July 2012

Introduction

Monitoring elevation change is important to understand the vulnerability of wetland environments to sea level rise and to predict their survival. Sea level has risen 0.2 m in the past century (Jevrejeva et al. 2008) and is expected to accelerate with a rise of 0.6 m by 2100 (Nicholls and Cazenave 2010). However, rapid decline of the polar ice sheets and stronger warming scenarios could raise estimates of sea level rise to 1 m or more by 2100 (Rahmstorf 2007). The survival of wetlands is dependent on their ability to vertically buildup sediment. Surface elevation change is controlled by a number of processes that occur within the soil profile. These processes include sedimentation, erosion, compaction and changes in groundwater (Whelan et al. 2005, Cahoon et al. 2011).

Precise methods for measuring elevation changes are necessary to determine the rate of change and to understand the processes that are driving the changes (Boumans and Day 1993). The paired surface elevation table (SET) design allows for partitioning of the soil profile into its components such as shallow root zone and deeper soil zones to determine where change is occurring (Whelan et al. 2005).

Wetland hydrology can influence surface elevation both directly and indirectly. Local hydrology indirectly effects surface elevation by exerting control over the oxidative state of the soil thereby regulating root growth, decomposition and organic matter accumulation (Cahoon et al. 2011, Mitsch and Gosselink 2007). Sediment deposition and erosion are driven by hydrologic conditions and contribute to vertical buildup of wetland sediment surfaces (Cahoon and Reed 1995). Water storage in wetland soils regulates the shrink-swell response of the soil profile.

Water infiltration into the soil causes displacement of gases from the pores and the sediment swells (Nuttle et al. 1990).

We present a study of surface elevation dynamics in the southwest coast of Everglades National Park (ENP) using paired surface elevation tables. The objective of this study was to determine the relationship between surface elevation change and changes in surface water and groundwater levels. By partitioning the soil profile we can determine the contribution each soil zone contributes to surface elevation. Understanding the relationship between hydrology and surface elevation across the Everglades system is important. The southwest coast of the Everglades is susceptible to sea level rise as well as impacts from freshwater inputs from the Comprehensive Everglades Restoration Plan (CERP).

Methods

SETs

The surface elevation table (SET) is a portable non destructive instrument placed onto a fixed and immovable pipe set in sediment in order to precisely and consistently measure soil surface elevation change over a long duration of time (Boumans and Day 1993). The original SET instrument is placed in a permanent base pipe that is driven into the soil to refusal (not necessarily bedrock). The SET consists of a portable arm that is attached to a benchmark and leveled, providing a constant reproducible reference measurement plane (Boumans and Day 1993, Cahoon et al. 2002a). Four fixed measurement locations (directions) are established where nine fiberglass measuring pins are lowered until they lightly rest upon the soil surface. The elevation is the mean of 108 measuring pins per site. SETs are used extensively in wetlands, mangrove forests and shallow subtidal systems throughout the world because they are simple to construct and provide reliable sediment change measurements that are comparable by other investigators in similar sediments (Cahoon et al. 2002a).

New SET designs were developed to measure elevation change over different portions of the soil profile (e.g. root zone and below the root zone; Cahoon et al. 2002b). The rod SET (rSET) works on the same principle as the original SET design, but can be attached to either shallower or deeper benchmarks (Cahoon et al. 2002b). A more detailed description of the design and accuracy of the SETs can be found in Boumans and Day (1993) and Cahoon et al. (2002 a, b). Figure 1 shows the three SET designs and the depth of soil profile which they measure.

Study Sites

Two linear transects were established on major drainages in the southwest coastal Everglades: one along the Shark River (SH sites) and one along the Lostmans River (LO sites) (Figure 2). Three sites were set up along each transect: one upstream in the freshwater marsh (SH1, LO1), one midstream along the ecotone (SH2, LO2), and one downstream in the mangrove forest (SH3, LO3). Each site has a water gage station and surface elevation tables.

Three pairs of surface elevation tables were installed at each site. The shallow rod SET benchmarks are installed in the active zone of the soil profile (0.35m). The deep rod SET benchmarks are driven into bedrock and measure the entire soil profile. Since sediment is shallow moving downstream to upstream, the original-SET acts as a deep rSET at the freshwater marsh and ecotone sites (SH1, LO1, SH2 and LO2). Soil elevation measurements were taken quarterly from 2006 to 2011 at each site.

Analysis

Elevation was determined by averaging the 108 measuring pins during each sampling. To determine the daily rate of change (DRC) between sampling dates the following formula was used:

$$DRC = \frac{surface\ elevation\ at\ T_1 - surface\ elevation\ at\ T_0}{number\ of\ days\ in\ interval}$$

The DRC for both groundwater and surface water levels were calculated using the same formula.

Statistical analysis will be used to determine significance of the surface elevation samples. Linear regression was used to investigate the relationship between soil elevation daily rate of change (DRC) of the deep SET and groundwater level daily rate of change. Regression was also run on the relationship between elevation change of the shallow SETs and surface water level changes for the downstream sites. Data will be analyzed using statistical software SPSS version 20 (SPSS Inc., 2001).

Results

Surface Elevation

Changes in deep rod-SET surface elevation vary from upstream to downstream sites. The upstream sites (LO1 and SH1) show the greatest variation in elevation. Variation in elevation at LO1 ranges from a loss of 15 mm to a gain of 20 mm with the highest elevation measured during the dry season (-64.32 mm on January 27, 2011) and the lowest measured elevation at the start of the wet season (-102.79 mm on May 8, 2007, Figure 3a). At SH1 variation ranges from a loss of 20 mm to a gain of 35 mm. The highest measured elevation was during the wet season (-73.87

mm on May 20, 2009) and the lowest elevation was measured during the dry season (-127.24 mm on December 4, 2007, Figure 3b). Patterns in elevation change at the ecotone sites (LO2 and SH2) are different from each other. At LO2 elevation varies with a loss of 15 mm to a gain of 11 mm (Figure 4a). The highest elevation was measured in the dry season (-159.53 mm on November 19, 2007) and the lowest recorded elevation was measured in the wet season (-186.60 mm on August 8, 2011). Variation at SH2 is less with a loss of 10 mm to a gain of 10 mm (Figure 4b). The highest and lowest elevation was measured in the wet season (-59.47 mm on October 15, 2007 and -75.75 mm on May 18, 2011, respectively). Downstream site LO3 shows elevation loss of 16 mm to gains of 19 mm with the highest elevation measured in the dry season (372.97 mm on February 24, 2010) and the lowest elevation measured at the start of the wet season (346.29 mm on May 14, 2007, Figure 5a). Downstream site SH3 patterns of elevation change show a loss of 21 mm to gains of 19 mm (Figure 5b). Highest elevation measured at the end of the wet season (21.12 mm on October 28, 2010) and the lowest elevation measured during the dry season (11.58 mm on February 2, 2009).

The shallow rod SETs at the upstream sites show the highest variation in elevation measurements. At both sites the highest and lowest elevations were measured in the wet season (Figure 3). At LO1 the highest elevation was -38.14 mm measured on June 12, 2008 and the lowest elevation was -105.49 mm measured on August 23., 2007. At SH1 the highest elevation was -61.27 mm measured on May 12, 2011 and the lowest elevation was -124.08 mm measured on June 12, 2007. Ecotone sites shows similar patterns of elevation with the highest elevation measured in the dry season and lowest elevation measured in the wet season (Figure 4). The highest elevation at LO2 was -145.88 mm on April 21, 2010 and the lowest elevation was

-183.99 mm on October 29, 2010. The highest elevation at SH2 was measured on January 22, 2010 (-64.79 mm) and the lowest elevation was measured on July 11, 2007 (-75.53 mm). The two downstream sites have slightly different patterns of elevation (Figure 5). LO3 shows the highest elevation during the dry season (358.50 mm on February 14, 2011) and the lowest in the wet season (342.85 mm on July 27, 2007). SH3 elevation patterns are opposite, with the highest elevation measured in the wet season (32.84 mm on August 3, 2011) and the lowest measured in the dry season (11.58 mm on March 10, 2008).

Elevation Change and Hydrology

Significant relationships were found between surface elevation and groundwater levels for LO2, SH1 and SH3 (Table 1). At the upstream and ecotone sites the daily rate of change in surface elevation of the deep SETs is explained by a negative relationship with the DRC in groundwater levels (Table 1). This means that as groundwater levels increase the surface elevation decreases (Figures 6 and 7). DRC of surface elevation of the deep SETs at the downstream sites is positively related to the DRC of groundwater levels (Table 1, Figure 8).

No significance was found between surface elevation and surface water levels for the downstream sites.

Relationship between peat depth and groundwater

Sediment depth increases moving from the upstream sites to the downstream sites. Table 2 shows the average peat depth at the study sites. Linear regression results show a significant relationship between the slope of the regressions and peat depth ($F_{1,5} = 11.5$, $p=0.03$, $R^2 = 0.74$). The sites with that have negative slopes (upstream and ecotone) have thinner layers of peat and the sites with positive slopes (downstream) have thicker layers of peat.

Discussion

Wetlands in the coastal Everglades are faced with impacts from global climate change such as, sea level rise, altered precipitation and temperature, in addition to impacts from freshwater inputs from CERP. In order for wetlands to avoid submergence, rates of vertical buildup must equal or exceed rates of sea level rise (Cahoon and Lynch 1997, Cahoon et al. 2011).

Patterns of surface elevation change of the two types of SETs were different from each other for all study sites (Figures 3-5).

Our results show that groundwater influences surface elevation change at a number of sites in the coastal Everglades. Previous studies have reported changes in hydrology can have a significant influence on wetland elevation (Nuttle et al. 1990, Whelan et al. 2005, Cahoon et al. 2006, Cahoon et al. 2011).

Our findings also show that this relationship changes depending on the sites location (upstream, ecotone or downstream). The negative relationship at the upstream and ecotone sites is unusual. This relationship may be explained by the particulate material found at the sites that settles and becomes cohesive as water levels decrease. The relationship at the downstream sites is explained by a dilation of the sediment. At these locations the sediment takes in water and will expand during increasing water levels and shrink with decreasing water levels. Nuttle et al. (1990) reported similar dilation of wetland sediments in New England salt marshes.

This observation of shrink-swell was reported in Whelan et al. (2005) at a single location. This study shows that the relationship between groundwater and elevation change is a regional effect and not a local one. This is an important concept for restoration projects and predicting long term stability of wetlands in the face of sea level rise.

Acknowledgements

I'd like to thank the many people and organizations that have supported me during my time at graduate school. I thank Thomas Smith for his support while completing my degree and his assistance in selecting a project. I thank Gordon Anderson for his words of encouragement. I thank my advisor, Rex Ellis, for all his guidance. I thank my committee members Todd Osborne and Mark Clark for their support. I thank the USGS and U.S. Army Corps of Engineers for providing funding. I thank Everglades National Park for permitting this study.

References

Boumans, RMJ and J.W. Day Jr. 1980. High precision measurements of sediment elevation in shallow coastal areas using a sedimentation-erosion table. *Estuaries* 16 (2): 375-380.

Cahoon, D.R., and D.J. Reed. 1995. Relationships among marsh surface topography, hydroperiod, and soil accretion in a deteriorating Louisiana salt marsh. *Journal of Coastal Research* 11(2): 357-369.

Cahoon, D.R. and J.C. Lynch. 1997. Vertical accretion and shallow subsidence in a mangrove forest of southwestern Florida, U.S.A. *Mangroves and Salt Marshes* 1: 173-186.

Cahoon, D.R., J.C. Lynch, P. Hensel, R. Boumans, B.C. Perez, B. Segura and J.W. Day 2002a. High precision measurements of wetland sediment elevation: I. Recent improvements to the sedimentation-erosion table. *Journal of Sedimentary Research* 72: 730-733.

Cahoon, D.R., J.C. Lynch, B.C. Perez, B. Segura, R.D. Holland, C. Stelly, G. Stephenson, P. Hensel. 2002b. High precision measurements of wetland sediment elevation: II. The rod surface elevation table. *Journal of Sedimentary Research* 72: 734-739.

Cahoon, D.R., P.E. Hensel, T. Spencer, D.J. Reed, K.L. McKee and N. Saintilan. 2006. Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. In: Verhoeven, J.T.A., B. Beltman, R. Bonnink and D.F. Whigham (Eds)., Wetlands and Natural Resource Management. Springer-Verlag, Berlin, pp 271-292.

Cahoon, D.R., B.C. Perez, B.D. Segura, and J.C. Lynch. 2011. Elevation trends and shrink-swell response of wetland soils to flooding. *Estuarine, Coastal and Shelf Science* 91: 463-474.

Jevrejeva, S., J.C. Moore, A. Grinsted and P.L. Woodworth. 2008. Recent global sea level acceleration started over 200 years ago? *Geophys. Res. Lett.* 35, L08715.

Mitsch, W.J. and J.G. Gosselink. 2007. Wetlands 4th edition. John Wiley & Sons, Inc. Hoboken, New Jersey.

Nicholls, R.J. and A. Cazenave. 2010. Sea-level rise and its impact on coastal zones. *Science* 328: 1517-1520.

Nuttle, W.K., H.F. Hemond and K.D. Stolzenbach. 1990. Mechanisms of water storage in salt marsh sediments: the importance of dilation. *Hydrological Process* 4: 1-13.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315: 368-370.

SPSS, Inc. 2001. SPSS for Windows 20.0.0. Chicago, Illinois.

Whelan, K.R.T., T.J. Smith III, D.R. Cahoon, J.C. Lynch and G.H. Anderson. 2005. Groundwater control of mangrove surface elevation: shrink and swell varies with soil depth. *Estuaries* 28 (6): 833-843.

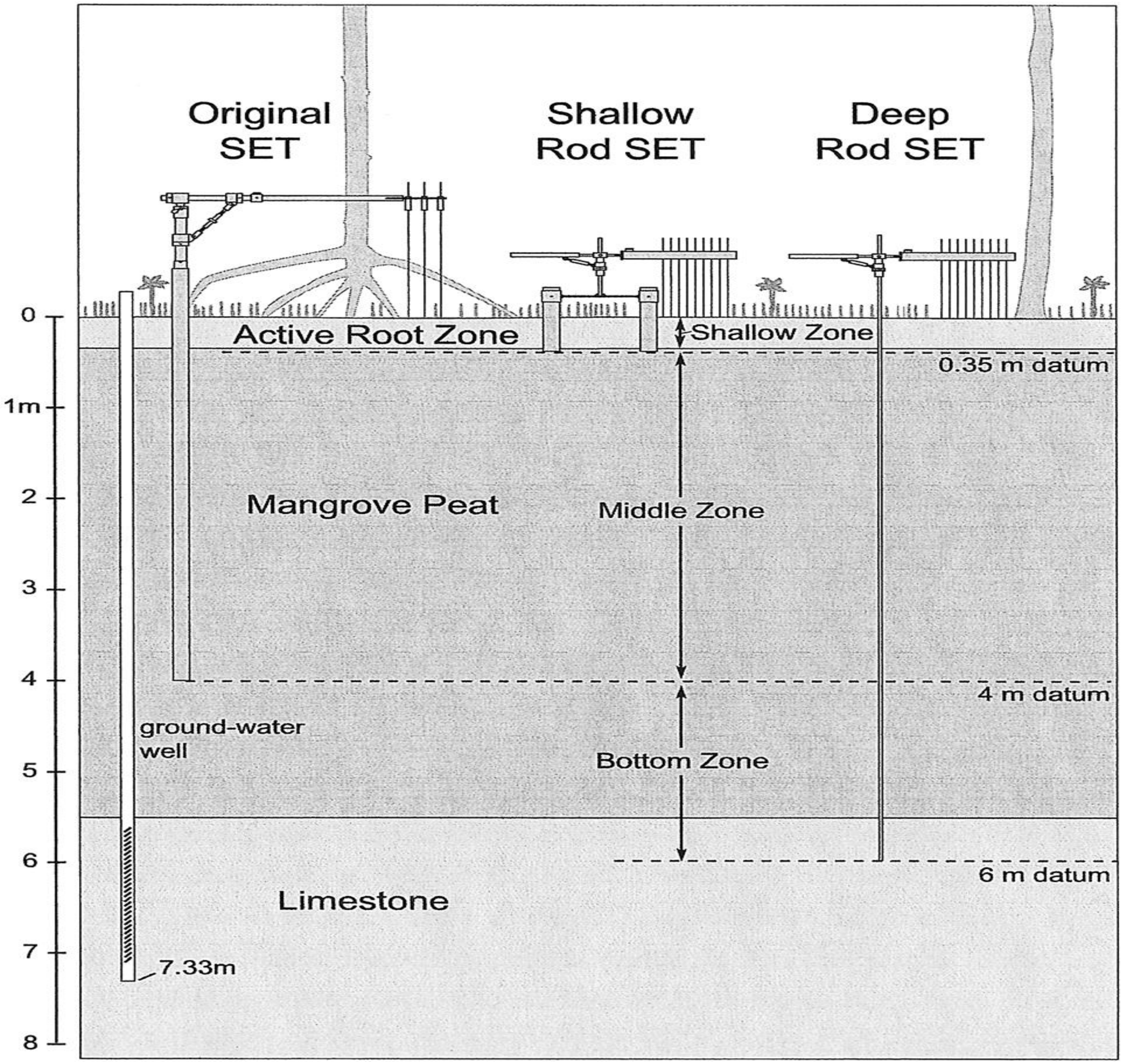


Figure 1. Profile of the substrate showing the original-SET, shallow-rSET deep-rSET, and groundwater well, and relative depth of each benchmark (Whelan et al. 2005).

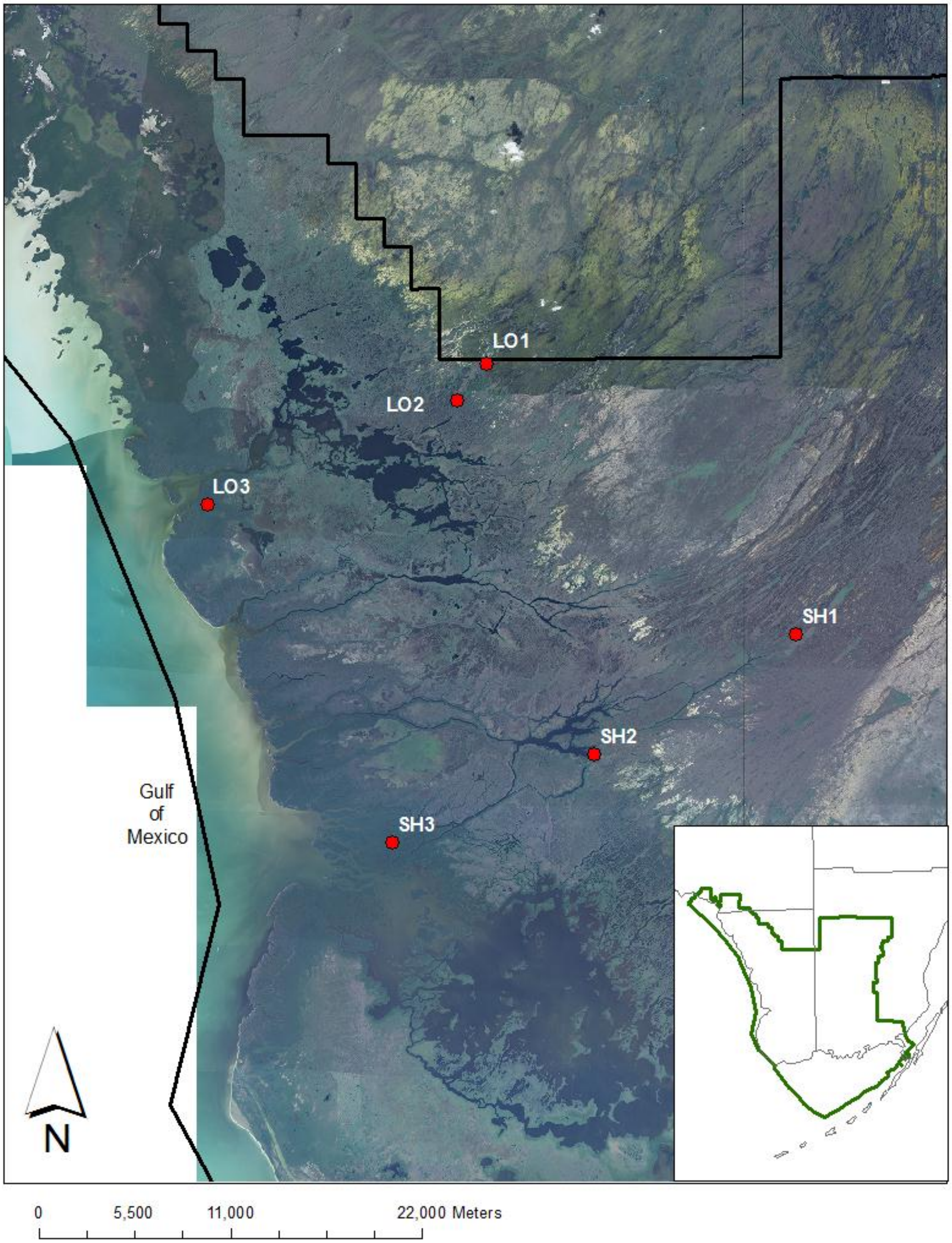
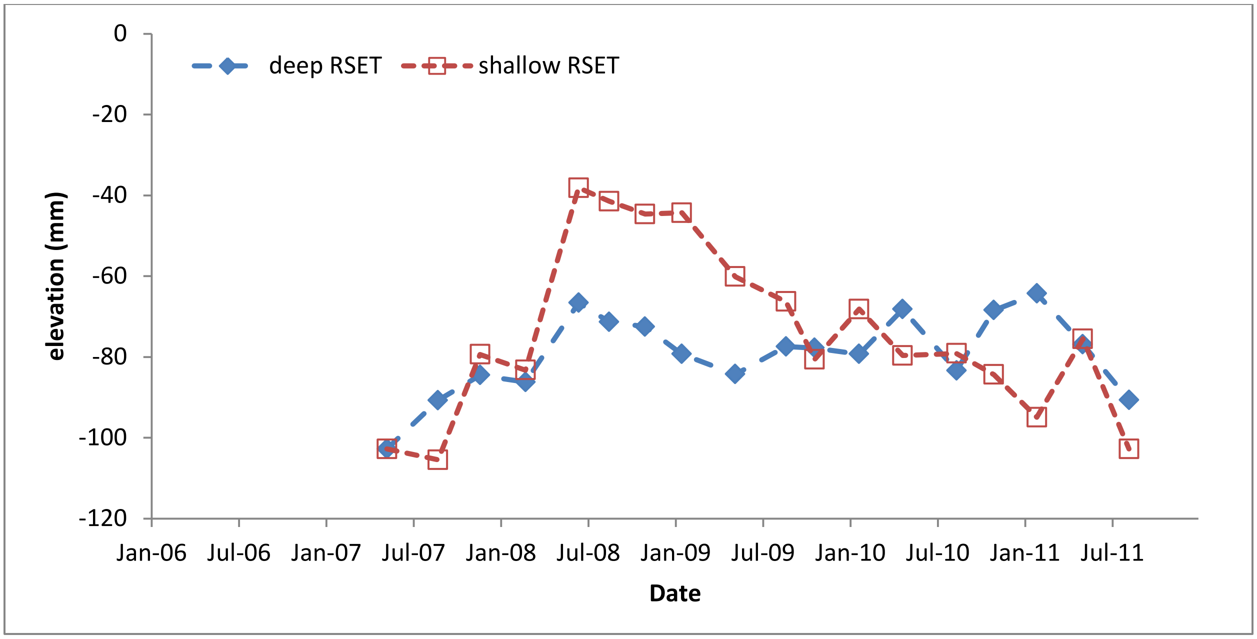


Figure 2. Map of study sites in the southwest coastal Everglades.

A. Upstream Site LO1



B. Upstream Site SH1

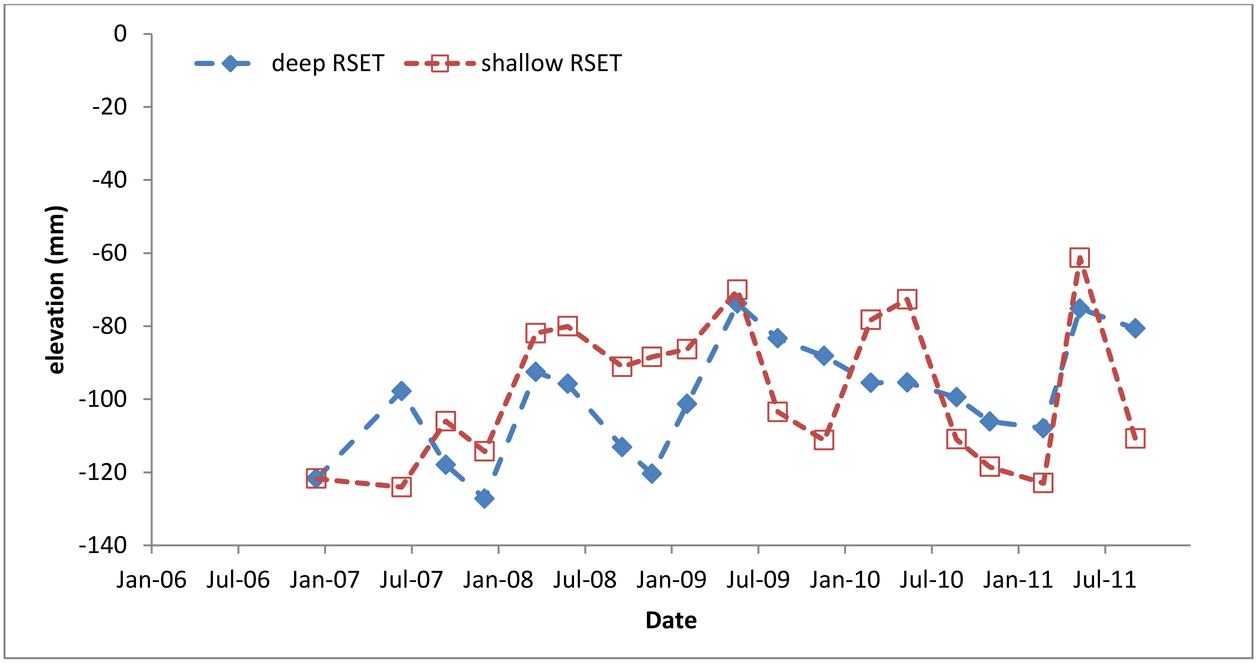
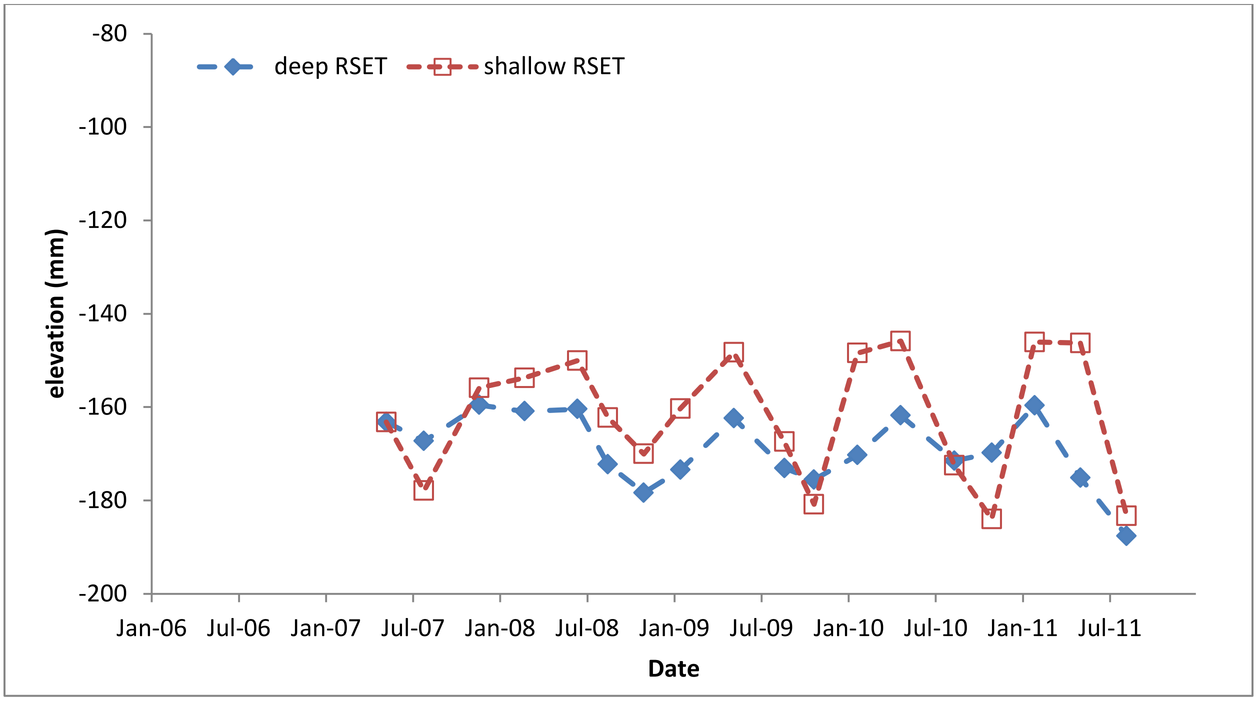


Figure 3. Surface elevation change at the upstream sites.

A. Ecotone Site LO2



B. Ecotone Site SH2

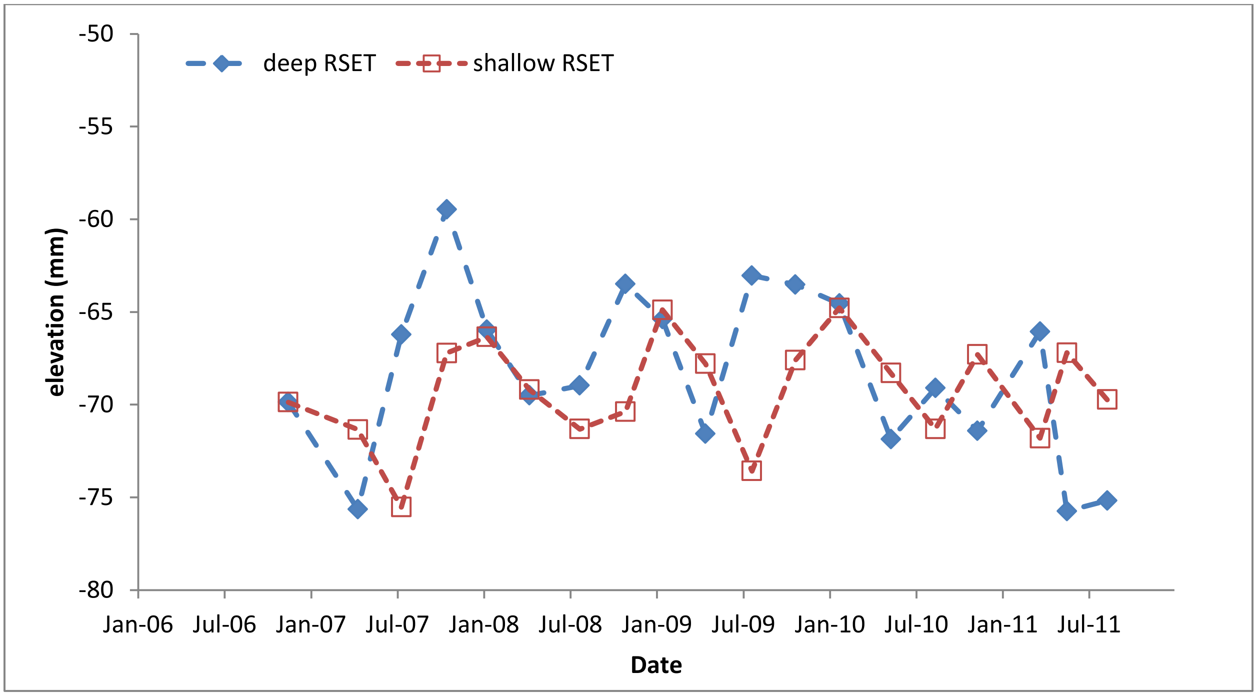
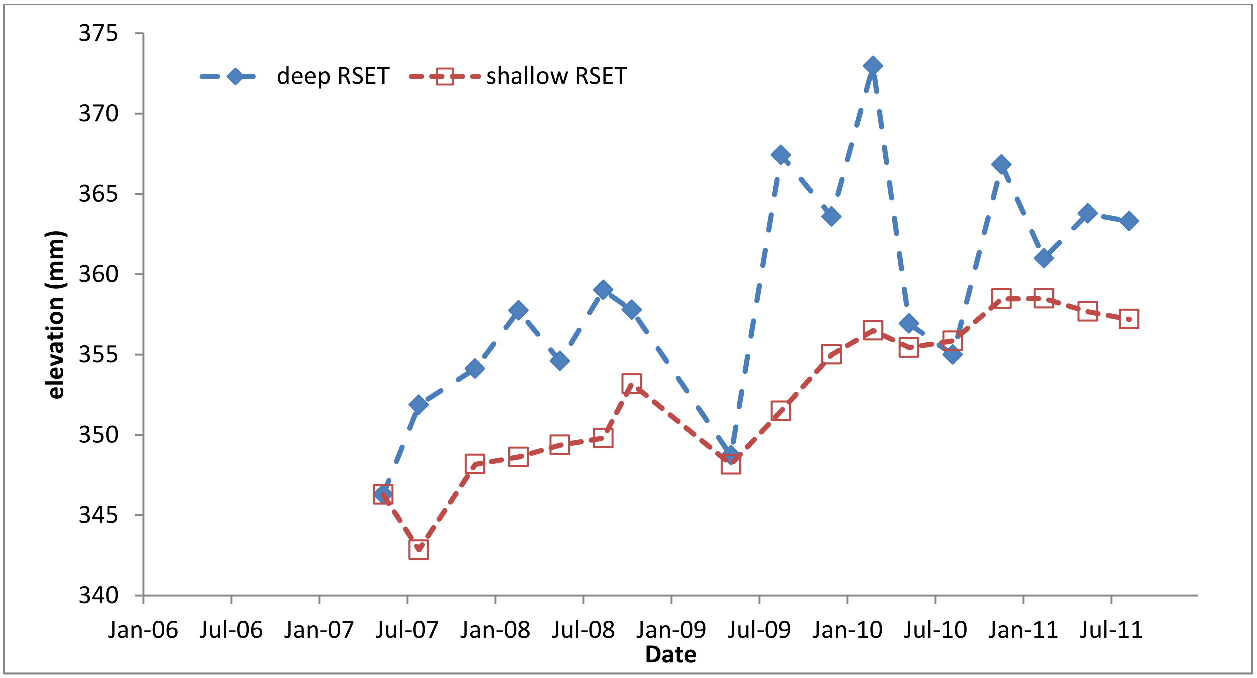


Figure 4. Surface elevation change at the ecotone sites.

A. Downstream Site LO3



B. Downstream Site SH3

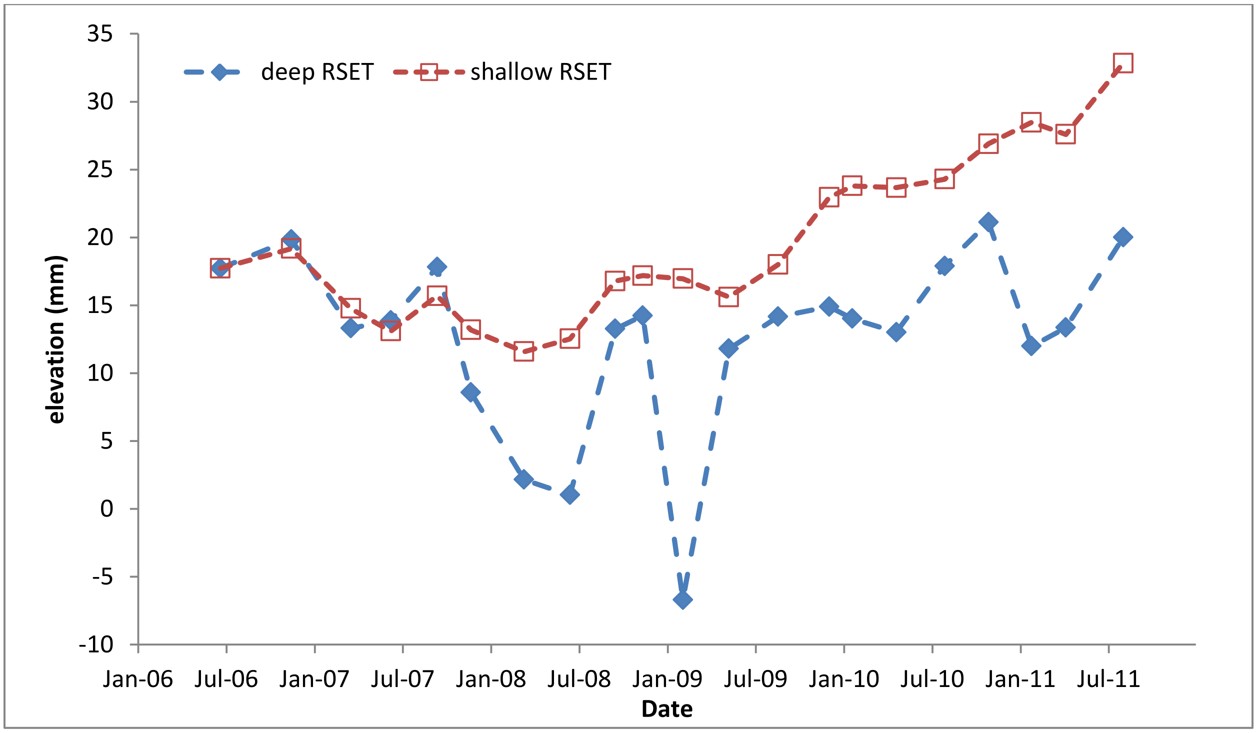


Figure 5. Surface elevation change at the downstream sites.

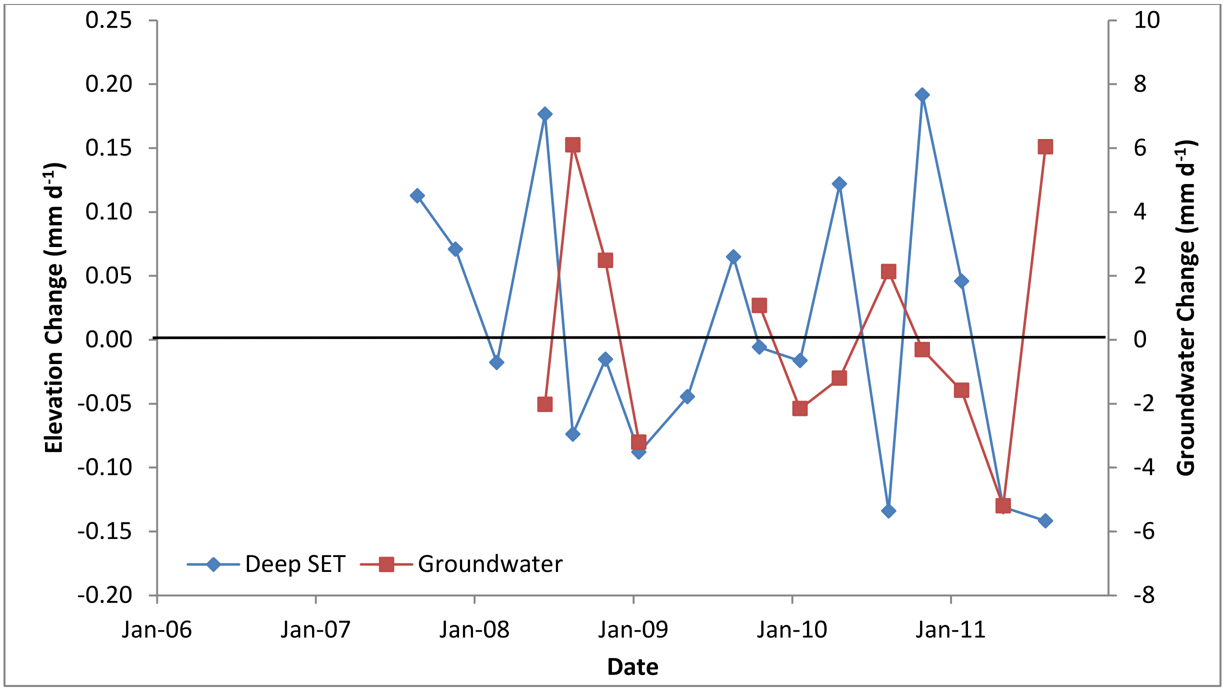
Table 1. Results from linear regression for the daily rate of change of surface elevation and daily rate of change of groundwater levels for each site.

Site	**Slope**	**Intercept**	**F**	**df**	**R^2**	**p value**
LO1	-0.009	-0.004	0.832	1,10	0.077	0.383
LO2	-0.035	-0.015	15.086	1,14	0.519	**0.002**
LO3	0.010	-0.001	0.359	1,8	0.043	0.566
SH1	-0.037	-0.005	5.324	1,12	0.307	**0.040**
SH2	-0.005	-0.011	0.255	1,12	0.021	0.623
SH3	0.029	0.006	21.722	1,16	0.576	**0.000**

Table 2. Slope from linear regression and average peat depth for each site.

Site	slope regression	peat depth (m)
LO1	-0.009	0.51
LO2	-0.035	0.52
LO3	0.01	3.28
SH1	-0.037	1.25
SH2	-0.005	1.87
SH3	0.029	4.06

A. Upstream site LO1



B. Upstream site SH1

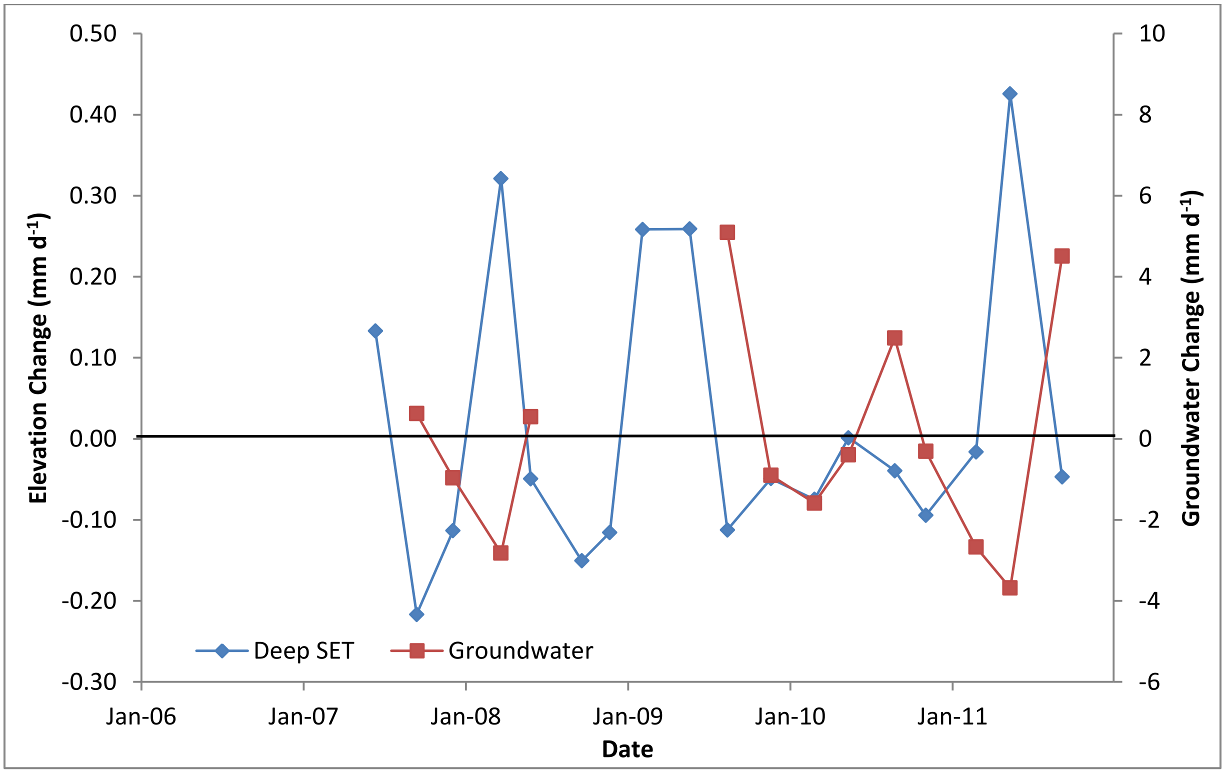
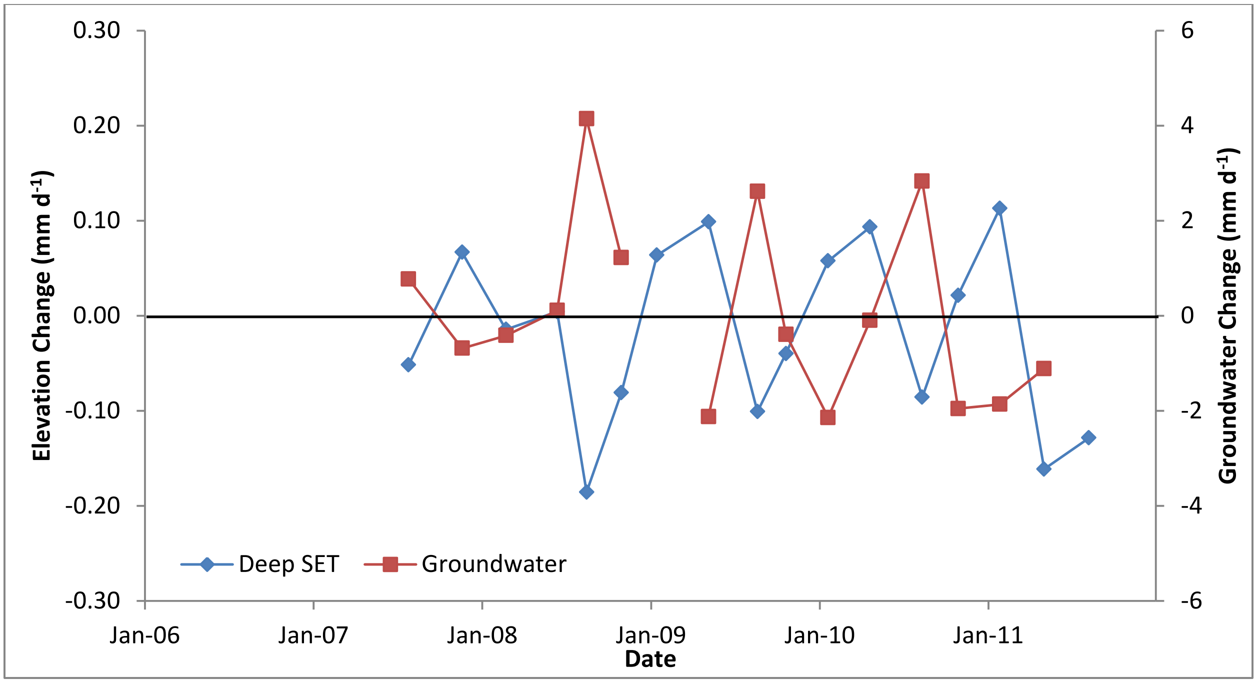


Figure 6. Rate of change for the deep SETs and rate of change in groundwater levels for the upstream sites.

A. Ecotone site LO2



B. Ecotone site SH2

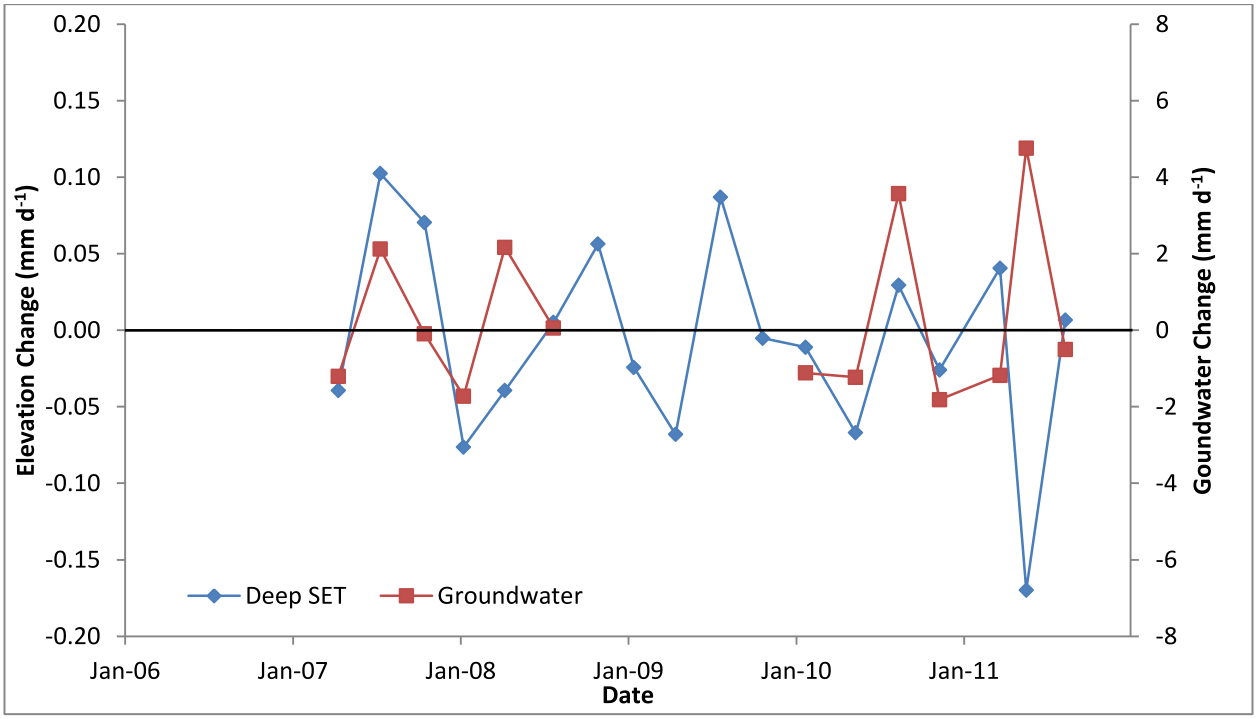
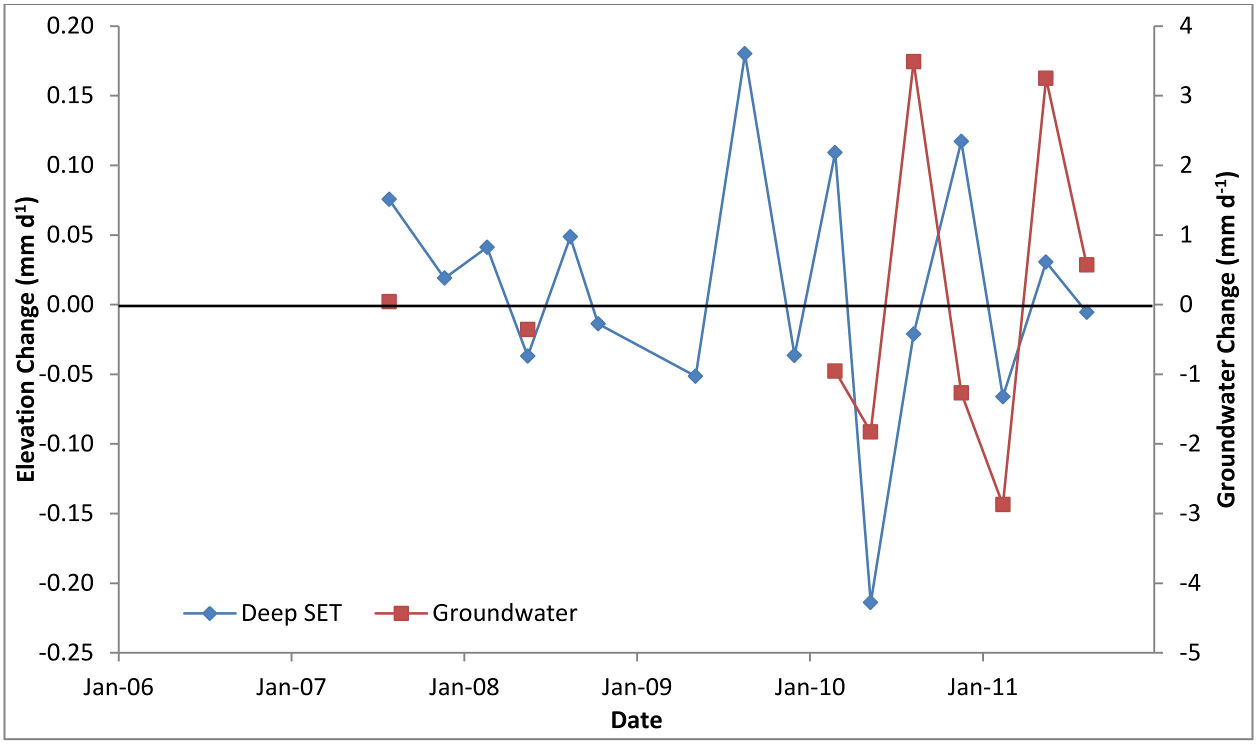


Figure 7. Rate of change for the deep SETs and rate of change in groundwater levels for the ecotone sites.

A. Downstream site LO3



B. Downstream site SH3

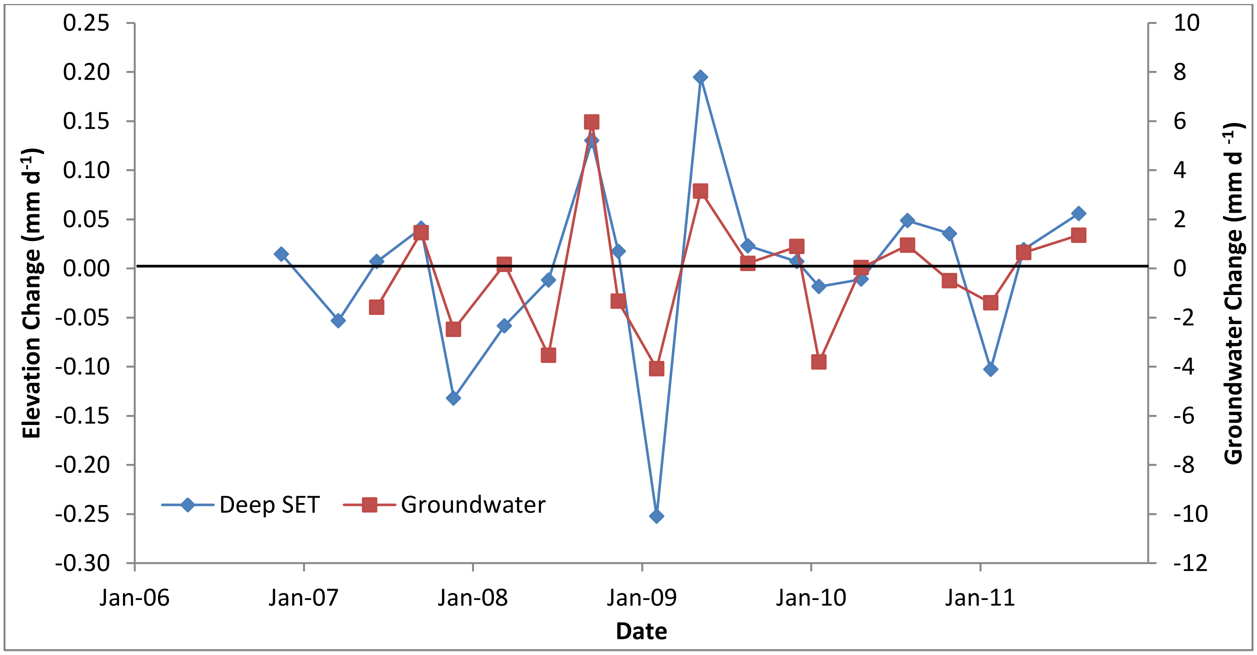


Figure 8. Rate of change for the deep SETs and rate of change in groundwater levels for the downstream sites.