Ducks Unlimited Canada
Conserving Canada's Wetlands

WETLAND ROAD CROSSINGS HYDROLOGICAL MONITORING DESIGN AND DATA SUMMARY

A report to the Sustainable Forestry Initiative in partial fulfillment of deliverables to the Conservation and Community Grants Program

Final Report

2014

Wetland Road Crossing Hydrological Monitoring

Design and Data Summary

Final Report

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June, 2014

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INTRODUCTION:

The Canadian Boreal Forest is globally significant in terms of the aquatic resources it contains. In particular it is home to what may be the world's largest total area of wetland habitats extending over more than 1.19 million km2 (294 million acres) and representing 25 percent of the world's wetlands. Boreal wetlands vary from deep organic peatlands (bogs and fens) to shallow organic, mineral wetlands that include swamps, marshes and shallow open water ponds. The forestry sector manages private and public lands which include extensive wetland areas. It has been recognized that land managers in the boreal forest should become familiar with the different types of wetlands and be aware of the special conservation needs of these sites (Sheehy 1993).

Road networks, both temporary and permanent, are necessary for accessing natural resources in the boreal forest. However, forest road construction can result in adverse environmental impacts such as fragmentation of ecosystems, and can affect the movement of water and sediment (Luce and Wemple, 2001). In general it is accepted that forest roads alter hydrology by 1) reducing infiltration, 2) capturing and channelizing surface runoff, and 3) by modifying subsurface flow paths (Dutton et al., 2005).

While the impacts of forest roads on creeks, streams, and rivers have been examined there has been relatively little research into the effects of roads on boreal wetlands. Given that the boreal forest is rich in wetlands, specifically peatlands, it is important to understand how forestry roads may impact the hydrology of these systems and to determine the best management practices available to insure that natural hydrological conditions are maintained.

Study Objectives:

To test the effectiveness of proposed best management practices used to construct wetland road crossings to maintain the natural hydrological regime of boreal wetlands.

Study Location:

Various sites in the Duck and Porcupine Mountains (MB) and Pasquia Hills (SK) were monitored (Figure 1).

Study Period:

June 2012 – December 2013

METHODS:

Study Design:

This study focused on monitoring water table levels and chemistry in response to road construction designed to accommodate predicted water flow rates and dynamics to assess whether or not wetland hydrology has been impacted. We established monitoring transects at six wetland road crossing sites (Figure 2). A shrub swamp (SS1), two conifer swamps (CS1 & CS2), and a treed fen (TF1) in the Porcupine Hills in Manitoba, a shrub swamp in the Duck Mountains (SS2) in Manitoba and a treed fen in the Pasquia Hills (TF2) in Saskatchewan. Logging roads were either previously constructed or are planned to be constructed through these wetlands to access merchantable stands (Table 1). At each crossing two transects of groundwater monitoring wells were established upstream and downstream of the road crossings for a total of four transects per site. Transects were located 5m and 25m away from the road edge. Each transect consisted of three monitoring wells. The first well was centrally located in the wetland being crossed. These monitoring wells were equipped with an RDS Ecotone® WM Water Level Instrument. The Ecotone WM is a specially designed, battery powered, instrument for the measurement of shallow ground and surface water levels. This device combines the data logger, water level sensor and custom well screen in one package. In addition to this centrally located well, two manual groundwater monitoring wells were also installed on either side of the centrally located well at a distance of 15m (see figure 2). However, this distance changed for some crossings depending on local site characteristics and topography. Sites with narrow wetland area upstream of the road (CS1) and narrow wetland area upstream and downstream of the road (SS2) had alternate well placements due to the wetlands restricted size of being less than 30 meters wide near the road crossing. Upstream of Site CS1 had 2 wells equipped with continuous RDS Ecotone® WM Water Level Instrument installed 5 and 25 meters from the road in the center of the wetland and 2 manual wells were installed each 2.5 meters from the center of the wetland 15 meters from the road. Both upstream and downstream of SS2 had this specific setup (see Table 1 for explanation).

We chose to use monitoring wells as opposed to piezometers as our study is focusing on changes in the water table occurring in the top 1 to 2 m of peat in these systems. As such we are working in unconfined aquifers and will be focusing mostly on the horizontal flow of groundwater as opposed to the vertical flow.

Well Deployment

Wells were installed at all sites between June 20-21, 2012 (with the exception of the sites located in the Paquia Hills and Ducks Mountains which were installed between July 11-12, 2012). Prior to well deployment a well sock was placed over the well screen to prevent clogging of the well screen. Holes for the wells were excavated using a soil auger to a maximum depth of 1.5 meters, where peat depth was sufficient. At these sites longer wells (2.0 m) were deployed. Where sites had shallow peat layers (50 cm or less) underlain by mineral soils, shorter wells (1.0 m) were deployed. Wells were inserted into the holes as soon as the auger was removed. The unconsolidated nature of the overlying peat layers at most sites meant that the walls of the hole usually self-sealed around the well casing. Where this did not occur, material bored from the hole was used to fill in the spaces between the walls of the hole and well casing (see detailed description of well deployment in FP Innovations Field Note 2013, Appendix 1).

After the wells were installed they were developed by pumping out the water that filled the wells to remove sediment or other material that may have blocked the screen upon installation. This procedure ensures that groundwater isn't impeded as it is flowing into the well and that it is not artificially increasing the turbidity in the well which might interfere with chemical analyses (Hudak 1996).

The water level recorder began recording in June of 2012 and 2013 and logged data continuously until they were removed towards the end of October in each year.

Data Collection, Water Quality Sampling, and Precipitation

Groundwater level measurements and water samples were collected in June, July, and October of 2012 and in June, August, and October of 2013. Continuous Ecotone Water level Instruments were downloaded using Ecotone WM PC Software at each site visit. Manual water-table depth measurements were made using a bubbler which is comprised of a measuring stick with a hose attached along the side. The individual conducting the measurements lowers the measuring stick down the well while blowing air through the hose at the same time. Upon hearing the sound of bubbles, the distance from the top of the well to the water is recorded in millimeters. Other measurements recorded include the top of the well to the calibration point on the well and the top of the well to ground. Manual water-table depth measurements were also made on the center (continuous) wells.

Water samples were collected at all wells but composited across individual transects to yield a total of 4 water samples on each sampling date per site (2 upstream of road crossing and 2 downstream of road crossing). Prior to collecting groundwater samples the water level in each well was recorded. Wells were then pumped to remove stagnant water which may not be representative of the chemistry of the flowing groundwater at the site in question. All water samples were stored in coolers and shipped to ALS Laboratories in Winnipeg for analysis. Samples were analyzed for total and dissolved nutrients, major anions and cations, as well as routine parameters such as pH, conductivity, and hardness. These analyses allow us to determine the range of variation in groundwater and surface water chemistry within these wetlands as well as if there are any systematic changes in chemistry between upstream and downstream areas of road crossings. We also measured the temperature, dissolved oxygen, pH, and conductivity of groundwater in-situ using a YSI water quality sonde. When the well diameter was too narrow to accommodate the sonde we pumped water from the wells into a bucket where measurements could be taken.

Although the direction of groundwater flow was initially assumed based on local knowledge and observations, verification of groundwater flow directions took place based on water table measurements at each site.

Precipitation data was downloaded from Environemnt Canada's website for weather stations situated near the three study sites. For the monitoring site in the Duck Mountains, data from the Environment Canada weather station situated in Roblin, Manitoba was used (Climate ID: 5012469; WMO ID: 71553). Precipitation data from the Environment Canada weather station situated in Mafeking, Manitoba (Climate ID:5041685) was used for the sites situated in the Porcupine Hills. Precipitation data from the Environment Canada weather station situated in Hudson Bay, Saskatchewan (Climate ID: 4083324; WMO ID: 71868) was used for the study site in the Pasquia Hills.

Elevation Survey

All groundwater wells have a 'Calibration Point' on the outside of the well casing near the top of the well below the cap. These calibration points were surveyed in October of 2012 and again in August of 2013. Using ground to satellite transmissions, the calibration points were shot with a laser to provide us with accurate elevation data for each calibration point for each well. This will permit the back-calculation of the groundwater elevation from our manual and digital measurements.

RESULTS AND DISCUSSION

Porcupine Hills – Shrub Swamp (SS1)

[Steeprock Operating Area; Crossing ID: SR-18-C4]:

The approximate length of the crossing at this site is 93m. The vegetation of this shrub swamp consisted of a shrub layer 2-3 m in height, comprised mainly of speckled alder (approx. 80% cover). The herbaceous layer contained the following dominant species: equisetum sp. and grass sp. The canopy consisted of only black spruce that was approximately 6 m tall. Canopy closure for black spruce was estimated to be about 20%. Soil profile (depth to mineral soil) indicated that there was approximately 30 cm of peat overtop silty clay mineral soil.

Water table surface elevation at this site decreased from the most upstream transect to the most downstream transect (Figure 3 and 4) in both 2012 and 2013. Water table elevation at this site seemed to remain consistent throughout most of the sampling season, with only temporary increases observed in response to precipitation events. The monitoring well site immediately downstream of the crossing (SS1-DA2) appeared to respond much more rapidly to precipitation events and may indicate some hydrological effects immediately adjacent to the crossing (Figure 3 and 4). However, this trend was not observed for the transect located 25m downstream from the crossing. This is also supported by the net change in water table elevation (Figure 5) where the site immediately downstream of the crossing responded more dramatically to drying and wetting conditions.

In general, total and dissolved nutrients (nitrogen and phosphorus) as well as most major anions and cations were found at higher concentrations at the downstream transects (Table 2 and 3) in both 2012 and 2013. Nutrient concentrations appeared to be particularly elevated at the transect located immediately downstream of the crossing. This was also the case for the site immediately upstream of the crossing (PO-SS1-UA) in 2013. These increases in nutrient concentrations at transects located near the road crossing are likely due to erosion of the fill material used for the road during precipitation events. This was observed on a number of occasions and at a number of monitoring sites. Conductivity also appeared to be higher at downstream transects whereas dissolved organic carbon (DOC) concentrations were lower at these sites relative to transects situated upstream of the crossing. This seems to suggest that there is some localized ponding of water upstream which causes the site immediately downstream to dry out faster resulting in higher conductivity levels. However, the furthest site downstream of the road crossing also has elevated levels of conductivity relative to those upstream even though the absolute and relative changes in water table elevation appear to be similar to those upstream. This may indicate that there is naturally occurring influences on water quality downstream of the road crossing that we were not able to measure or detect.

Porcupine Hills – Conifer Swamp(CS1)

[Steeprock Operating Area; Crossing ID: SR-22-GEO1]:

The approximate length of the crossing at this site is 60m. The vegetation of this conifer swamp consisted mainly of black spruce (20 m in height) with approximately 65% canopy closure. There was also some balsam fir present. The shrub layer was approximately 2 m in height (10% cover), and was comprised mainly of speckled alder and bog birch as well as some Labrador tea. The herbaceous layer contained the following dominant species: equisetum sp., feather moss, sphagnum moss, cloudberry, and false solomon’s seal. Soil profile (depth to mineral soil) indicated that there was approximately 2.0 m of peat overtop of clay mineral soil.

Water table surface elevation at this site decreased from the most upstream transect to the most downstream transect (Figure 6 and 7) in both 2012 and 2013. Water table elevations were generally below the peat surface in 2012 with the exception of the most downstream site (PO-CSI-DA4) where water table elevations rose above the peat surface temporarily in response to rain events (Figure 6). In 2013 water table elevations at both sites downstream of the crossing (PO-CS1-DA1 & PO-CSI-DA4) rose above the peat surface in response to precipitation events (Figure 7). Water table elevation at this site seemed to remain consistent throughout most of the sampling season at transects situated upstream of the crossing, with only temporary increases observed in response to precipitation events. Water table elevations at the sites downstream of the crossing appeared to respond more dramatically to precipitation events. This is supported by the net change in water table elevation recorded at these sites (Figure 8). Additionally, sites situated downstream of the crossing experienced extended water table drawdowns from late August to late September in 2012 and 2013. Differences in the response to of water table levels upstream and downstream of the crossing may indicate some hydrological effects associated with the crossing. The generally consistent and higher water table levels upstream of the crossing may indicate potential ponding of surface water upstream of the crossing. However, there is a fairly well defined channel downstream of the crossing which may be facilitating the conveyance of water relative to the upstream site. This may at least partially explain the greater water table drawdown experienced at the downstream transects.

Water was only sampled once at this site in October of 2012, therefore it is difficult to assess any potential difference in water quality between the monitoring transects. In general, total and dissolved nutrients (nitrogen and phosphorus) as well as most major anions and cations were similar across all three transects (Table 4), with the exception of total dissolved phosphorus which was noticeably higher at the site immediately downstream of the crossing (PO-CS1- DA) relative to those upstream (Table 4). Additionally, DOC concentrations appeared to be lower at the most upstream transect relative to those transects located immediately upstream and downstream of the crossing. In 2013, mean concentrations for cations such as calcium, magnesium, and potassium were elevated at the transect immediately downstream of the crossing. This is likely a result of erosion of mineral material used in the road base during precipitation events which would be preferentially accumulate at this transect. In general, all measures of phosphorus were noticeably higher for transect situated downstream of the crossing (Table 5). Similarly, dissolved inorganic concentrations were also noticeably higher at downstream transects. While some of these changes may be due to crossing impacts on hydrology it may also be related to the noticeable change in the shape of the wetland being crossed. Where the wetland was much broader upstream of the crossing and more narrow and channelized downstream of the crossing.

Porcupine Hills – Conifer Swamp (CS2)

[Steeprock Operating Area; Crossing ID: SR-22-GEO3]:

The approximate length of the crossing at this site is 35m (the site had approximately 15.4 m of corduroy installed at the time wells were installed). The vegetation of this conifer swamp consisted mainly of black spruce (approximately 17 m in height) with approximately 90% canopy closure. There was also some tamarack present. The shrub layer was approximately 2-3 m in height (10-15% cover), and was comprised mainly of speckled alder. Labrador tea was also present (10-15% cover). The herbaceous layer contained equisetum sp., feather moss, and sphagnum moss. Soil profile (depth to mineral soil) indicated that there was approximately 0.65 to 0.85 m of peat overtop of clay mineral soil.

As at the other sites water table surface elevation at this site decreased from the most upstream transect to the most downstream transect (Figure 9 and 10). Water table elevation at this site seemed to vary more dramatically at the upstream transects relative to the downstream transects in response to precipitation events, the opposite of what was observed at PO-CS1. In both 2012 and 2013 water table elevations varied with precipitation events in the early part of the growing season and then experienced an extended drawdown from late August until late September or early October when the water table increased across all transects in response to fall rains. While these trends were evident across all transects the increases in water table elevation in response to precipitation as well as the extended drawdown that was experienced were much more pronounced for the upstream transects as demonstrated in the net change in water table elevation in 2012 and 2103 (Figure 11).

There were no notable trends in water quality parameters at this site when upstream and downstream transects were compared in 2012 (Table 6). However, concentrations of magnesium and sulfate appeared somewhat higher at the transect immediately upstream of the crossing. Similarly in 2013, sulfate, magnesium as well as sodium again appeared to be somewhat elevated at the transect immediately upstream of the crossing relative to the other transects. Additionally, in 2031 total phosphorus and ammonia concentrations were higher at transects downstream of the crossing relative to those upstream. Conversely, nitrite-nitrate concentrations were higher at the upstream transects relative to the downstream transect. The higher concentrations of total phosphorus and ammonia downstream of the crossing may be explained by the relatively higher water table elevations with respect to the peat surface at the downstream transects compared to the upstream transects. This is especially evident in the extended water table drawdown experienced in late summer at the upstream sites relative to the downstream sites. As a result, oxygen levels would likely have been lower at the downstream transects allowing for anaerobic biogeochemical processes to take place which could lead to higher concentrations of phosphorus and ammonia.

Porcupine Hills – Treed Fen (TF1)

[Steeprock Operating Area; Crossing ID: SR-22/32-GEO1]:

The approximate length of the crossing at this site is 66m. The vegetation of this treed rich fen consisted of black spruce approximately 6m in height with 50% crown closure in combination with tamarack. The shrub layer consisted of bog birch approximately 1m in height. The herbaceous layer consisted mostly of sphagnum moss. Soil profile (depth to mineral soil) indicated that there was greater than 2.0m of peat overtop clay mineral soil.

As at the other sites in the Steeprock Operating Area water table surface elevation at this site decreased from the most upstream transect to the most downstream transect (Figure 12) in 2012. Furthermore, unlike the other sites in the Steeprock Operating Area, trends in water table elevation did not vary across ransects and were similar upstream and downstream of the crossing. As with the other sites in the Steeprock Operating Area water table surface elevation at this site seemed to increase with precipitation events. Water table elevations at all transects decreased substantially from late August to early October, 2012, and then rose rapidly in response to precipitation events in October. It is important to note here that the crossing was not complete in 2012 and was only stumped prior to construction. Trends in water table elevations recorded in 2013 were similar to those in 2013 with the exception that the water table elevations recorded at the most upstream transect (PO-TF1-UB) seem to have increased relative to those at the remaining three transects. This change may be the result of an error in the elevation of the calibration point on the well which was re-surveyed in 2013. The fact that the net change in water table elevation across all transects in 2012 and 2013 (Figure 14), also suggest that the crossing had no effect on water table elevations.

In general, there were no noticeable differences in water quality parameters measured upstream and downstream of the planned crossing at this site (Table 8) in 2012. In 2013, potassium concentrations were higher downstream relative to upstream transects. This might be due to leaching of potassium from the log corduroy base that was installed in 2013 and not present in 2012. Additionally, concentrations of ammonia, total phosphorus, particulate phosphorus, and dissolved organic carbon appeared to be higher at the transect immediately upstream and downstream of the road. This suggests that the corduroy log base or perhaps the soil material placed over the corduroy is causing increases in the concentrations of these parameters through erosion and/or leaching. This would be more evident at this site as both matrices were in contact with water for longer periods of time given the height of the water table.

Duck Mountains – Shrub Swamp (SS2)

[Upper Dam Operating Area; Crossing ID: UPD-C25]:

The approximate length of the crossing at this site is 7m. The vegetation of this shrub swamp consisted of willow and alder species approximately 1-2 m in height. Soil profile (depth to mineral soil) indicated that there was approximately 45-60 cm of peat overtop clay mineral soil. There is a small channel present with some flowing water.

Water table surface elevation at this site decreased from the most upstream transect to the most downstream transect (Figure 15 and 16) in both 2012 and 2013. Water table elevation at this site seemed to remain consistent throughout most of the sampling season in 2012, with only very small increases observed in response to precipitation events. Water table fluctuations at this site appeared to be greatly reduced compared to those observed in the Steeprock operating area in 2012. However, this may be due to the fact that the water level recorders were only deployed in mid-July at this site, after most of the major summer precipitation events. Conversely, in 2013 this site demonstrated the greatest increase in water table elevations in response to precipitation events that occurred late in June (Figure 15 and 16). Additionally, it appears that after the installation of the crossing in 2012 the water table elevations at transects immediately upstream and downstream of each other were more similar to one another during 2013 (Figure 16). Net change in water table elevation in both 2012 and 2013 (Figure 17) was generally similar across all transects.

In 2012 an unequal number of water samples were collected from this site as a result of some of the wells being dry at the time of sample. For this reason it is difficult to compare water quality parameters across transects. However, based on the samples collected it appears that there were no noticeable differences in water quality parameters measured upstream and downstream of the crossing (Table 10). In 2013, there were no apparent differences in water quality between transects upstream and downstream (Table 11). However for a number of parameters (dissolved Kjeldahl nitrogen, ammonia, total dissolved nitrogen, and dissolved inorganic nitrogen appeared to decrease from upstream transects to downstream transects. This is likely related to the fact that this was the only site with observed surface channel flow that connected all four transects. Resulting changes in water quality parameters were likely related to biogeochemical changes occurring over distance within the channel as opposed to being affected by the crossing. As with many of the other sites there were some indications that calcium and magnesium concentration were elevated at transects immediately upstream and downstream of the crossing relative to those located further away (Table 11). Again, this suggests that the soil material used to cover the corduroy at the crossing may be increasing concentrations of these constituents wither through dissolution or erosion.

Pasquia Hills – Treed Fen (TF2)

[Mile 23 Operating Area; Crossing ID: SR-22/32-GEO1]:

The crossing at this treed fen site has been in place for over 10 years. This site has one culvert (approximately 40-60 cm in diameter. While water is able to flow through the culvert there is significant ponding of water on the upstream side of the crossing. (Soil profile (depth to mineral soil) indicated that there was greater than 2.0m of peat overtop clay mineral soil.

Water table surface elevation at this site decreased from the most upstream transect to the most downstream transect in 2012 and 2013 (Figures 18 and 19). Water table elevation (both upstream and downstream of the crossing) at this site seemed to remain consistent throughout most of the sampling season, with only very small increases observed in response to precipitation events. Furthermore, the net change in water table elevations across all transects at this site were very similar to one another (Figure 20). Overall, water table fluctuations at this site appeared to be greatly reduced compared to those observed in the Steeprock operating area. However, water did appear to pool upstream of the crossing. This effect is demonstrated in the steeper decline in water table elevation downstream of the crossing relative to those upstream of the crossing after precipitation events (Figure 18 and 19). Additionally, water table elevation had a greater tendency to rise above the peat surface in response to precipitation events at the upstream transects relative to those downstream. This likely occurred as a result of only one small culvert serving to move water under the relatively impervious crossing at this site.

Calcium and magnesium appeared to be higher at downstream transects relative to upstream transects in both 2012 and 2013 (Table 12 and 13). However, these differences were greater in 2012. The reduced concentration in 2013 may be explained by greater snowmelt runoff in 2013 and hence a dilution effect. Similarly, conductivity was also higher at downstream transects relative to upstream transects in both 2012 and 2013. Conversely, DOC concentrations were higher at upstream transects relative to those downstream. For all remaining water quality parameters there were no noticeable differences between samples collected upstream and downstream of the planned crossing. Water quality differences at this site seemed to be more pronounced relative to all of the other crossings as evidenced by observed changes at the transects located at distance from the crossing. This is the oldest of all the crossing sites (see Table 1) and it employed conventional crossing designs at the time of construction which may not be as conducive to passing water as the techniques that were applied at all other crossing sites monitored in this study. However, it is possible that these same expanded changes in water quality could occur at the new crossings over time.

CONCLUSIONS

Overall, changes in water table elevations at all study crossings appeared to be driven by local precipitation events. At most sites, water table response and net change in water table elevation was similar for upstream and downstream transects. Where differences were observed these seemed to be confined to the transects located nearest to the crossing and appeared to dissipate with distance from the crossing. Other topographic differences, such as the presence of a channel appeared to play a larger role in water table elevation differences compared to the influence of the crossing. We only observed noticeable differences in water table elevation and water quality at the one conventional crossing that was monitored in the Pasquia Hills. However, even at this site the differences observed seemed fairly minor although they did extend further from the crossing relative to the new designs used at the crossing that were monitored in the Porcupine Hills and Duck Mountains. In addition there was evidence of dead trees upstream. This would seem to suggest that impacts of any one crossing are fairly minor overall.

While the new crossing designs generally appeared to maintain natural flow regimes and water table elevations in the first two years of use it is possible that the impacts of the crossings on hydrology and water chemistry may only become detectable after a number of years. Similarly, water quality impacts were generally only observed at transects immediately adjacent to the crossing but this could also change over time. On numerous occasions precipitation was observed to cause erosion of the road base material and it is suspected that this caused many of the differences in water quality parameters observed immediately upstream and downstream of the crossings. Based on this it seems possible that additional effort to reduce erosion from the crossings could mitigate some of the water quality differences that were observed.

The nature of this study does not allow for statistical comparison between the various sites that were monitored. Further analyses will be conducted to determine if the slopes of water table recession after precipitation events can be used to further quantify impacts of the various crossings on boreal wetland hydrology.

Future studies should focus on landscape and watershed effects of a network of crossings. While the impact of any one crossing may be minimal, the cumulative impacts of many crossings situated within a boreal watershed may be greater than the sum of its parts. Additionally, future studies should strive to include reference conditions, as well as pre and post-construction monitoring to fully understand how the new crossing designs being implemented function at the watershed level.

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Table 1. Site information

Site ID	Location	Crossing status	Well distribution	Installation date
SS1	Porcupine Hills, MB	2011 complete	2 transects of 3 wells each, at 5m and 25m upstream and downstream of the crossing.	June 18, 2012
CS1	Porcupine Hills, MB	2011 cleared, construction ongoing	1 well at 5m, 2 wells at 15m, and 1 well at 25m downstream of crossing. 2 transects of 3 wells each, at 5m and 25m upstream of the crossing.	June 19, 2012
CS2	Porcupine Hills, MB	2011 cleared, construction ongoing	2 transects of 3 wells each, at 5m and 25m upstream and downstream of the crossing.	July 7, 2012
TF1	Porcupine Hills, MB	2011 roadway stumped	2 transects of 3 wells each, at 5m and 25m upstream and downstream of the crossing.	July 7, 2012
TF2	Pasquia Hills, SK	>10 years complete	2 transects of 3 wells each, at 5m and 25m upstream and downstream of the crossing.	July 8, 2012
SS2	Duck Mountains, MB	completed August 2012	1 well at 5m, 2 wells at 15m, and 1 well at 25m upstream and downstream of crossing.	July 9, 2012

Table 2. Mean water quality for upstream and downstream water table monitoring wells at SS1 (shrub swamp, Porcupine Hills, Manitoba) in 2012.

	PO-SS1-UB		PO-SS1-UA		PO-SS1-DA		PO-SS1-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.4	0.1	0.4	0.1	0.5	0.1	0.4	0.1
Calcium (Ca)-Dissolved (mg/L)	15.7	1.5	14.3	2.2	24.2	5.7	18.8	9.6
Sulfate (mg/L)	0.4	0.1	0.3	0.0	0.7	0.5	0.7	0.3
Magnesium (Mg)-Dissolved (mg/L)	6.6	0.7	7.1	0.3	9.8	1.7	7.4	3.7
Potassium (K)-Dissolved (mg/L)	1.2	0.5	0.9	0.4	0.7	0.1	0.6	0.3
Sodium (Na)-Dissolved (mg/L)	0.5	0.1	0.6	0.1	0.6	0.1	0.5	0.1
Total Kjeldahl Nitrogen (mg/L)	1.83	0.28	1.24	0.23	2.54	1.16	1.11	0.20
Diss. Kjeldahl Nitrogen (mg/L)	0.91	0.14	0.85	0.16	1.06	0.44	0.76	0.16
Ammonia, Total (as N) (mg/L)	0.105	0.039	0.083	0.045	0.227	0.172	0.124	0.054
Nitrate and Nitrite as N (mg/L)	0.010	0.001	0.009	0.007	0.253	0.149	0.350	0.301
Total Nitrogen (mg/L)	1.84	0.28	1.24	0.22	2.79	1.01	1.46	0.10
Total Dissolved Nitrogen (mg/L)	0.92	0.14	0.86	0.17	1.31	0.29	1.11	0.31
Particulate Nitrogen (mg/L)	0.92	0.39	0.39	0.39	1.48	0.72	0.35	0.23
Dissolved Inorganic Nitrogen (mg/L)	0.11	0.04	0.09	0.05	0.56	0.12	0.47	0.31
Phosphorus (P)-Total (mg/L)	0.086	0.029	0.090	0.025	0.203	0.037	0.193	0.099
Phosphorus (P)-Total Dissolved (mg/L)	0.038	0.010	0.047	0.002	0.084	0.016	0.125	0.081
Particulate Phosphorus (mg/L)	0.048	0.023	0.043	0.023	0.132	0.076	0.068	0.018
Conductivity (umhos/cm)	123	24	105	12	149	9	169	35
Dissolved Organic Carbon (mg/L)	30	3	33	9	28	4	28	6

Table 3. Mean water quality for upstream and downstream water table monitoring wells at SS1 (shrub swamp, Porcupine Hills, Manitoba) in 2013.

	PO-SS1-UB		PO-SS1-UA		PO-SS1-DA		PO-SS1-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.3	0.2	0.2	0.1	0.3	0.2	0.3	0.2
Calcium (Ca)-Dissolved (mg/L)	13.4	0.6	14.8	2.9	29.2	7.4	26.8	7.4
Sulfate (mg/L)	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0
Magnesium (Mg)-Dissolved (mg/L)	6.8	0.3	7.0	1.2	11.8	1.4	11.5	2.8
Potassium (K)-Dissolved (mg/L)	0.7	0.1	0.4	0.0	0.7	0.1	0.7	0.0
Sodium (Na)-Dissolved (mg/L)	0.4	0.0	0.4	0.1	0.5	0.1	0.5	0.1
Total Kjeldahl Nitrogen (mg/L)	0.98	0.07	2.70	1.72	2.90	1.92	1.34	0.58
Diss. Kjeldahl Nitrogen (mg/L)	0.64	0.06	0.84	0.17	0.75	0.32	0.58	0.04
Ammonia, Total (as N) (mg/L)	0.050	0.034	0.176	0.162	0.224	0.166	0.090	0.077
Nitrate and Nitrite as N (mg/L)	0.003	0.000	0.008	0.005	0.015	0.002	0.003	0.000
Total Nitrogen (mg/L)	0.98	0.07	2.71	1.71	2.91	1.91	1.34	0.58
Total Dissolved Nitrogen (mg/L)	0.64	0.06	0.85	0.16	0.76	0.31	0.58	0.04
Particulate Nitrogen (mg/L)	0.35	0.01	1.86	1.55	2.15	1.60	0.76	0.54
Dissolved Inorganic Nitrogen (mg/L)	0.05	0.03	0.18	0.16	0.24	0.16	0.09	0.08
Phosphorus (P)-Total (mg/L)	0.037	0.009	0.225	0.179	0.244	0.162	0.152	0.117
Phosphorus (P)-Total Dissolved (mg/L)	0.018	0.011	0.078	0.051	0.021	0.006	0.033	0.002
Particulate Phosphorus (mg/L)	0.019	0.003	0.147	0.128	0.219	0.143	0.112	0.109
Conductivity (umhos/cm)	95	1	96	14	221	66	235	2
Dissolved Organic Carbon (mg/L)	31	4	34	5	23	6	24	1

Table 4. Mean water quality for upstream and downstream water table monitoring wells at CS1 (conifer swamp, Porcupine Hills, Manitoba) in 2012.

	PO-CS1-UB		PO-CS1-UA		PO-CS1-DA		PO-CS1-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.1	-	0.1	-	0.5	-	-	-
Calcium (Ca)-Dissolved (mg/L)	50.7	-	41.6	-	44.9	-	-	-
Sulfate (mg/L)	0.3	-	0.3	-	0.3	-	-	-
Magnesium (Mg)-Dissolved (mg/L)	15.4	-	12.4	-	14.0	-	-	-
Potassium (K)-Dissolved (mg/L)	1.3	-	1.4	-	3.7	-	-	-
Sodium (Na)-Dissolved (mg/L)	0.8	-	0.9	-	0.9	-	-	-
Total Kjeldahl Nitrogen (mg/L)	3.38	-	6.16	-	4.13	-	-	-
Diss. Kjeldahl Nitrogen (mg/L)	0.75	-	1.06	-	1.37	-	-	-
Ammonia, Total (as N) (mg/L)	0.204	-	0.337	-	0.261	-	-	-
Nitrate and Nitrite as N (mg/L)	0.016	-	0.003	-	0.003	-	-	-
Total Nitrogen (mg/L)	3.40	-	6.16	-	4.13	-	-	-
Total Dissolved Nitrogen (mg/L)	0.77	-	1.06	-	1.37	-	-	-
Particulate Nitrogen (mg/L)	2.63	-	5.10	-	2.76	-	-	-
Dissolved Inorganic Nitrogen (mg/L)	0.22	-	0.34	-	0.26	-	-	-
Phosphorus (P)-Total (mg/L)	0.288	-	0.116	-	0.272	-	-	-
Phosphorus (P)-Total Dissolved (mg/L)	0.029	-	0.037	-	0.153	-	-	-
Particulate Phosphorus (mg/L)	0.259	-	0.079	-	0.119	-	-	-
Conductivity (umhos/cm)	343	-	283	-	298	-	-	-
Dissolved Organic Carbon (mg/L)	18	-	31	-	35	-	-	-

Table 5. Mean water quality for upstream and downstream water table monitoring wells at CS1 (conifer swamp, Porcupine Hills, Manitoba) in 2013.

	PO-CS1-UB		PO-CS1-UA		PO-CS1-DA		PO-CS1-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.2	0.1	0.4	0.2	0.4	0.1	0.4	0.2
Calcium (Ca)-Dissolved (mg/L)	44.3	0.8	36.9	1.9	51.4	1.5	41.8	-
Sulfate (mg/L)	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0
Magnesium (Mg)-Dissolved (mg/L)	14.9	0.2	12.7	0.6	16.9	1.3	13.4	-
Potassium (K)-Dissolved (mg/L)	1.3	0.1	2.0	0.1	3.8	0.7	2.5	-
Sodium (Na)-Dissolved (mg/L)	0.7	0.01	0.8	0.0	0.8	0.03	0.8	-
Total Kjeldahl Nitrogen (mg/L)	0.94	0.00	3.27	0.25	3.28	0.74	2.86	1.66
Diss. Kjeldahl Nitrogen (mg/L)	0.33	0.01	0.67	0.04	1.25	0.18	0.49	-
Ammonia, Total (as N) (mg/L)	0.077	0.046	0.108	0.031	0.496	0.185	0.202	0.184
Nitrate and Nitrite as N (mg/L)	0.003	0.000	0.003	0.000	0.001	0.000	0.002	0.001
Total Nitrogen (mg/L)	0.94	0.00	3.27	0.25	3.29	0.74	2.89	1.66
Total Dissolved Nitrogen (mg/L)	0.33	0.01	0.67	0.04	1.26	0.18	0.27	0.24
Particulate Nitrogen (mg/L)	0.62	0.01	2.60	0.28	2.03	0.92	2.62	1.91
Dissolved Inorganic Nitrogen (mg/L)	0.080	0.046	0.111	0.031	0.502	0.180	0.228	0.187
Phosphorus (P)-Total (mg/L)	0.086	0.018	0.219	0.027	0.968	0.042	0.436	0.337
Phosphorus (P)-Total Dissolved (mg/L)	0.020	0.007	0.047	0.032	0.450	0.387	0.196	0.173
Particulate Phosphorus (mg/L)	0.066	0.011	0.173	0.059	0.519	0.429	0.240	0.164
Conductivity (umhos/cm)	295	2	238	15	335	22	264	0
Dissolved Organic Carbon (mg/L)	13	2	29	1	33	5	30	6

Table 6. Mean water quality for upstream and downstream water table monitoring wells at CS2 (conifer swamp, Porcupine Hills, Manitoba) in 2012.

	PO-CS2-UB		PO-CS2-UA		PO-CS2-DA		PO-CS2-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.2	0.1	0.4	0.1	0.4	0.03	0.3	0.05
Calcium (Ca)-Dissolved (mg/L)	31.6	3.9	46.5	2.1	45.1	5.7	41.2	5.1
Sulfate (mg/L)	0.9	0.2	3.2	0.3	0.9	0.4	0.8	0.2
Magnesium (Mg)-Dissolved (mg/L)	10.4	0.8	16.0	0.9	14.2	1.4	14.0	1.3
Potassium (K)-Dissolved (mg/L)	0.4	0.1	0.5	0.1	0.9	0.04	0.6	0.1
Sodium (Na)-Dissolved (mg/L)	0.7	0.01	1.1	0.05	0.9	0.03	0.9	0.04
Total Kjeldahl Nitrogen (mg/L)	2.30	1.58	1.29	0.51	2.09	1.24	1.28	0.51
Diss. Kjeldahl Nitrogen (mg/L)	0.57	0.09	0.45	0.02	0.59	0.07	0.50	0.03
Ammonia, Total (as N) (mg/L)	0.085	0.062	0.170	0.073	0.078	0.023	0.105	0.049
Nitrate and Nitrite as N (mg/L)	0.014	0.002	0.016	0.007	0.010	0.008	0.010	0.009
Total Nitrogen (mg/L)	2.31	1.57	1.31	0.52	2.10	1.24	1.29	0.51
Total Dissolved Nitrogen (mg/L)	0.58	0.09	0.32	0.15	0.60	0.07	0.51	0.03
Particulate Nitrogen (mg/L)	1.73	1.67	0.99	0.52	1.50	1.24	0.78	0.50
Dissolved Inorganic Nitrogen (mg/L)	0.10	0.06	0.19	0.08	0.09	0.02	0.11	0.04
Phosphorus (P)-Total (mg/L)	0.126	0.034	0.110	0.033	0.165	0.084	0.081	0.027
Phosphorus (P)-Total Dissolved (mg/L)	0.053	0.020	0.031	0.011	0.080	0.023	0.029	0.006
Particulate Phosphorus (mg/L)	0.073	0.054	0.060	0.036	0.085	0.073	0.052	0.027
Conductivity (umhos/cm)	166	4	247	13	265	51	263	42
Dissolved Organic Carbon (mg/L)	23	2	16	2	20	2	14	2

Table 7. Mean water quality for upstream and downstream water table monitoring wells at CS2 (conifer swamp, Porcupine Hills, Manitoba) in 2013.

	PO-CS2-UB		PO-CS2-UA		PO-CS2-DA		PO-CS2-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.3	0.2	0.4	0.04	0.4	0.1	0.3	0.1
Calcium (Ca)-Dissolved (mg/L)	23.1	3.1	52.5	5.4	37.7	6.3	41.7	5.1
Sulfate (mg/L)	0.9	0.3	4.2	1.1	0.3	0.0	1.0	0.2
Magnesium (Mg)-Dissolved (mg/L)	8.2	0.8	18.6	2.0	12.9	1.8	14.7	1.8
Potassium (K)-Dissolved (mg/L)	0.6	0.04	0.7	0.1	1.2	0.1	1.0	0.1
Sodium (Na)-Dissolved (mg/L)	0.4	0.1	1.1	0.1	0.6	0.1	0.7	0.1
Total Kjeldahl Nitrogen (mg/L)	1.08	0.14	0.65	0.25	1.63	0.88	0.97	0.22
Diss. Kjeldahl Nitrogen (mg/L)	0.55	0.04	0.23	0.07	0.40	0.08	0.34	0.06
Ammonia, Total (as N) (mg/L)	0.019	0.014	0.018	0.013	0.035	0.007	0.060	0.029
Nitrate and Nitrite as N (mg/L)	0.022	0.019	0.053	0.045	0.004	0.001	0.003	0.000
Total Nitrogen (mg/L)	1.10	0.15	0.71	0.22	0.75	0.07	0.97	0.22
Total Dissolved Nitrogen (mg/L)	0.57	0.06	0.28	0.04	0.35	0.09	0.34	0.06
Particulate Nitrogen (mg/L)	0.53	0.10	0.43	0.19	0.41	0.03	0.63	0.16
Dissolved Inorganic Nitrogen (mg/L)	0.041	0.033	0.071	0.039	0.036	0.009	0.063	0.029
Phosphorus (P)-Total (mg/L)	0.056	0.020	0.078	0.052	0.345	0.227	0.104	0.021
Phosphorus (P)-Total Dissolved (mg/L)	0.020	0.009	0.011	0.003	0.023	0.007	0.024	0.010
Particulate Phosphorus (mg/L)	0.037	0.012	0.067	0.055	0.322	0.230	0.080	0.024
Conductivity (umhos/cm)	156	23	357	32	251	35	290	34
Dissolved Organic Carbon (mg/L)	22	0	11	2	19	1	13	2

Table 8. Mean water quality for upstream and downstream water table monitoring wells at TF1 (treed fen, Porcupine Hills, Manitoba) in 2012.

	PO-TF1-UB		PO-TF1-UA		PO-TF1-DA		PO-TF1-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.2	0.0	0.2	0.1	0.2	0.0	0.2	0.0
Calcium (Ca)-Dissolved (mg/L)	20.5	1.5	18.4	0.8	17.0	1.5	27.5	8.1
Sulfate (mg/L)	0.4	0.1	0.4	0.2	0.4	0.1	0.7	0.2
Magnesium (Mg)-Dissolved (mg/L)	7.5	0.4	6.7	1.0	6.3	0.4	10.0	2.2
Potassium (K)-Dissolved (mg/L)	0.3	0.1	0.3	0.1	0.3	0.2	0.3	0.1
Sodium (Na)-Dissolved (mg/L)	0.6	0.1	0.7	0.0	0.6	0.1	0.7	0.1
Total Kjeldahl Nitrogen (mg/L)	2.45	1.03	2.12	0.74	1.95	0.53	1.43	0.59
Diss. Kjeldahl Nitrogen (mg/L)	1.14	0.31	1.37	0.48	1.25	0.38	0.88	0.29
Ammonia, Total (as N) (mg/L)	0.219	0.163	0.320	0.189	0.245	0.116	0.202	0.119
Nitrate and Nitrite as N (mg/L)	0.010	0.008	0.010	0.008	0.010	0.008	0.010	0.008
Total Nitrogen (mg/L)	2.46	1.02	2.13	0.73	1.96	0.52	1.44	0.58
Total Dissolved Nitrogen (mg/L)	1.15	0.30	1.38	0.47	1.26	0.37	0.89	0.28
Particulate Nitrogen (mg/L)	1.32	0.75	0.75	0.27	0.70	0.16	0.55	0.30
Dissolved Inorganic Nitrogen (mg/L)	0.23	0.16	0.33	0.18	0.26	0.11	0.21	0.11
Phosphorus (P)-Total (mg/L)	0.181	0.077	0.157	0.068	0.178	0.063	0.128	0.072
Phosphorus (P)-Total Dissolved (mg/L)	0.101	0.044	0.114	0.054	0.145	0.065	0.093	0.063
Particulate Phosphorus (mg/L)	0.080	0.036	0.043	0.018	0.033	0.009	0.035	0.014
Conductivity (umhos/cm)	126	9	114	1	105	10	180	51
Dissolved Organic Carbon (mg/L)	34	6	29	14	33	5	28	1

Table 9. Mean water quality for upstream and downstream water table monitoring wells at TF1 (treed fen, Porcupine Hills, Manitoba) in 2013.

	PO-TF1-UB		PO-TF1-UA		PO-TF1-DA		PO-TF1-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.2	0.1	0.2	0.1	0.3	0.1	0.3	0.2
Calcium (Ca)-Dissolved (mg/L)	15.8	3.7	16.8	3.4	16.8	2.1	15.1	3.1
Sulfate (mg/L)	0.4	0.1	0.3	0.0	0.3	0.0	0.3	0.0
Magnesium (Mg)-Dissolved (mg/L)	6.7	1.5	6.9	1.5	7.2	1.1	6.7	1.3
Potassium (K)-Dissolved (mg/L)	0.3	0.1	0.6	0.2	1.3	0.5	1.2	0.4
Sodium (Na)-Dissolved (mg/L)	0.4	0.1	0.5	0.1	0.4	0.0	0.4	0.0
Total Kjeldahl Nitrogen (mg/L)	1.98	0.79	2.29	0.69	2.49	0.15	2.26	1.16
Diss. Kjeldahl Nitrogen (mg/L)	0.52	0.12	0.69	0.14	0.85	0.21	0.63	0.17
Ammonia, Total (as N) (mg/L)	0.063	0.020	0.199	0.090	0.112	0.044	0.087	0.052
Nitrate and Nitrite as N (mg/L)	0.003	0.000	0.003	0.000	0.003	0.001	0.003	0.000
Total Nitrogen (mg/L)	1.98	0.79	2.30	0.69	2.49	0.15	2.27	1.16
Total Dissolved Nitrogen (mg/L)	0.53	0.12	0.69	0.14	0.85	0.21	0.63	0.17
Particulate Nitrogen (mg/L)	1.45	0.67	1.60	0.56	1.64	0.06	1.63	1.00
Dissolved Inorganic Nitrogen (mg/L)	0.066	0.020	0.201	0.090	0.115	0.044	0.090	0.052
Phosphorus (P)-Total (mg/L)	0.091	0.038	0.195	0.076	0.214	0.067	0.106	0.055
Phosphorus (P)-Total Dissolved (mg/L)	0.029	0.017	0.056	0.015	0.054	0.026	0.046	0.017
Particulate Phosphorus (mg/L)	0.062	0.021	0.139	0.079	0.160	0.051	0.060	0.042
Conductivity (umhos/cm)	113	27	114	23	118	13	105	20
Dissolved Organic Carbon (mg/L)	24	2	31	5	33	4	27	1

Table 10. Mean water quality for upstream and downstream water table monitoring wells at SS2 (shrub swamp, Duck Mountains, Manitoba) in 2012.

	DU-SS2-UC		DU-SS2-UA		DU-SS2-DA		DU-SS2-DC	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.3	0.0	-	-	0.3	-	0.3	-
Calcium (Ca)-Dissolved (mg/L)	95.7	23.4	-	-	105	-	82.1	-
Sulfate (mg/L)	1.6	1.3	-	-	0.3	-	3.3	-
Magnesium (Mg)-Dissolved (mg/L)	35.7	6.3	-	-	36.1	-	31.2	-
Potassium (K)-Dissolved (mg/L)	4.4	1.2	-	-	3.6	-	3.4	-
Sodium (Na)-Dissolved (mg/L)	3.4	1.0	-	-	3.9	-	3.2	-
Total Kjeldahl Nitrogen (mg/L)	3.01	1.53	2.93	-	2.13	-	2.99	-
Diss. Kjeldahl Nitrogen (mg/L)	1.74	0.68	-	-	1.45	-	0.93	-
Ammonia, Total (as N) (mg/L)	0.623	0.618	0.393	-	0.459	-	0.209	-
Nitrate and Nitrite as N (mg/L)	0.013	0.006	-	-	0.008	-	0.018	-
Total Nitrogen (mg/L)	3.02	1.52	2.93	-	2.14	-	3.01	-
Total Dissolved Nitrogen (mg/L)	1.75	0.67	-	-	1.46	-	0.95	-
Particulate Nitrogen (mg/L)	1.27	0.85	2.93	-	0.68	-	2.06	-
Dissolved Inorganic Nitrogen (mg/L)	0.64	0.61	0.39	-	0.47	-	0.23	-
Phosphorus (P)-Total (mg/L)	0.226	0.150	0.202	-	0.281	-	0.205	-
Phosphorus (P)-Total Dissolved (mg/L)	0.011	0.001	-	-	0.004	-	0.005	-
Particulate Phosphorus (mg/L)	0.215	0.149	0.202	-	0.277	-	0.200	-
Conductivity (umhos/cm)	650	141	-	-	691	-	569	-
Dissolved Organic Carbon (mg/L)	21	2	37	-	24	-	16	-

Table 11. Mean water quality for upstream and downstream water table monitoring wells at SS2 (shrub swamp, Duck Mountains, Manitoba) in 2013.

	DU-SS2-UC		DU-SS2-UA		DU-SS2-DA		DU-SS2-DC	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	0.3	0.03	0.4	0.1	0.6	0.2	0.3	0.1
Calcium (Ca)-Dissolved (mg/L)	64.5	9.8	76.7	9.2	95.4	3.5	66.6	3.2
Sulfate (mg/L)	6.8	2.2	5.0	2.8	4.1	3.8	6.2	2.4
Magnesium (Mg)-Dissolved (mg/L)	26.7	3.8	32.5	4.4	34.1	1.5	27.2	2.0
Potassium (K)-Dissolved (mg/L)	3.5	0.6	3.7	0.6	3.6	0.3	3.0	0.2
Sodium (Na)-Dissolved (mg/L)	2.6	0.2	2.8	0.3	2.9	0.4	2.5	0.1
Total Kjeldahl Nitrogen (mg/L)	6.84	4.66	2.21	0.74	2.27	0.59	3.60	0.99
Diss. Kjeldahl Nitrogen (mg/L)	1.61	0.70	1.59	0.47	1.15	0.20	0.88	0.16
Ammonia, Total (as N) (mg/L)	0.553	0.424	0.646	0.405	0.372	0.141	0.212	0.050
Nitrate and Nitrite as N (mg/L)	0.022	0.014	0.017	0.012	0.008	0.003	0.016	0.006
Total Nitrogen (mg/L)	6.87	4.67	2.22	0.75	2.28	0.59	4.55	0.58
Total Dissolved Nitrogen (mg/L)	1.63	0.71	1.60	0.48	1.16	0.20	1.03	0.18
Particulate Nitrogen (mg/L)	5.24	3.96	0.62	0.31	1.12	0.44	3.53	0.39
Dissolved Inorganic Nitrogen (mg/L)	0.575	0.437	0.663	0.417	0.380	0.141	0.266	0.070
Phosphorus (P)-Total (mg/L)	1.091	0.793	0.196	0.031	0.559	0.255	0.437	0.133
Phosphorus (P)-Total Dissolved (mg/L)	0.016	0.003	0.038	0.025	0.012	0.003	0.069	0.053
Particulate Phosphorus (mg/L)	1.075	0.790	0.158	0.056	0.547	0.257	0.550	0.047
Conductivity (umhos/cm)	517	45	565	62	638	6	472	16
Dissolved Organic Carbon (mg/L)	17	2	19	2	17	2	15	1

Table 12. Mean water quality for upstream and downstream water table monitoring wells at TF2 (treed fen, Pasquia Hills, Saskatchewan) in 2012.

	PA-TF2-UB		PA-TF2-UA		PA-TF2-DA		PA-TF2-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	1.0	0.03	1.0	0.2	1.2	0.04	1.0	0.3
Calcium (Ca)-Dissolved (mg/L)	41.7	1.8	51.7	7.0	117.7	58.3	78.5	28.6
Sulfate (mg/L)	1.2	0.9	1.1	0.9	0.9	0.4	1.8	1.2
Magnesium (Mg)-Dissolved (mg/L)	16.7	0.0	19.2	1.6	53.5	32.0	29.0	11.3
Potassium (K)-Dissolved (mg/L)	0.4	0.1	0.4	0.1	0.5	0.2	0.5	0.2
Sodium (Na)-Dissolved (mg/L)	2.4	0.1	2.5	0.1	3.0	0.0	3.0	0.2
Total Kjeldahl Nitrogen (mg/L)	1.55	0.07	2.73	1.38	1.79	0.06	1.07	0.20
Diss. Kjeldahl Nitrogen (mg/L)	0.98	0.21	1.23	0.51	1.01	0.12	0.79	0.03
Ammonia, Total (as N) (mg/L)	0.087	0.045	0.153	0.082	0.046	0.021	0.031	0.001
Nitrate and Nitrite as N (mg/L)	0.008	0.006	0.003	0.000	0.005	0.002	0.022	0.011
Total Nitrogen (mg/L)	1.55	0.07	2.73	1.38	1.79	0.06	1.09	0.18
Total Dissolved Nitrogen (mg/L)	0.99	0.22	1.23	0.51	1.01	0.12	0.81	0.04
Particulate Nitrogen (mg/L)	0.57	0.15	1.50	0.87	0.78	0.18	0.28	0.23
Dissolved Inorganic Nitrogen (mg/L)	0.09	0.05	0.16	0.08	0.05	0.02	0.05	0.01
Phosphorus (P)-Total (mg/L)	0.102	0.022	0.178	0.134	0.346	0.175	0.073	0.014
Phosphorus (P)-Total Dissolved (mg/L)	0.010	0.005	0.022	0.007	0.009	0.004	0.008	0.004
Particulate Phosphorus (mg/L)	0.092	0.017	0.156	0.127	0.337	0.170	0.065	0.010
Conductivity (umhos/cm)	285	14	311	4	389	7	385	50
Dissolved Organic Carbon (mg/L)	27	2	32	6	23	0	23	3

Table 13. Mean water quality for upstream and downstream water table monitoring wells at TF2 (treed fen, Pasquia Hills, Saskatchewan) in 2013.

	PA-TF2-UB		PA-TF2-UA		PA-TF2-DA		PA-TF2-DB	
ANALYTE	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error
Chloride (mg/L)	1.0	0.3	0.8	0.4	0.9	0.4	1.2	0.3
Calcium (Ca)-Dissolved (mg/L)	37.5	4.5	35.8	4.4	44.9	2.2	56.4	9.9
Sulfate (mg/L)	1.7	1.1	1.6	0.9	1.1	0.7	1.6	0.3
Magnesium (Mg)-Dissolved (mg/L)	15.9	1.5	16.4	1.8	17.5	2.1	20.0	2.3
Potassium (K)-Dissolved (mg/L)	0.4	0.1	0.3	0.0	0.3	0.04	0.3	0.04
Sodium (Na)-Dissolved (mg/L)	2.1	0.2	2.1	0.2	2.4	0.2	3.4	0.3
Total Kjeldahl Nitrogen (mg/L)	2.15	0.90	1.44	0.16	1.66	0.30	1.98	0.52
Diss. Kjeldahl Nitrogen (mg/L)	0.50	0.09	0.59	0.08	0.80	0.18	0.41	0.02
Ammonia, Total (as N) (mg/L)	0.041	0.022	0.054	0.027	0.066	0.022	0.026	0.021
Nitrate and Nitrite as N (mg/L)	0.003	0.000	0.003	0.000	0.004	0.002	0.003	0.000
Total Nitrogen (mg/L)	2.16	0.90	1.45	0.16	1.67	0.30	1.98	0.52
Total Dissolved Nitrogen (mg/L)	0.51	0.09	0.59	0.08	0.80	0.18	0.41	0.02
Particulate Nitrogen (mg/L)	1.65	0.84	0.85	0.12	0.86	0.45	1.57	0.54
Dissolved Inorganic Nitrogen (mg/L)	0.043	0.022	0.057	0.027	0.070	0.024	0.029	0.021
Phosphorus (P)-Total (mg/L)	0.207	0.086	0.082	0.007	0.178	0.039	0.237	0.065
Phosphorus (P)-Total Dissolved (mg/L)	0.032	0.025	0.028	0.016	0.043	0.036	0.003	0.001
Particulate Phosphorus (mg/L)	0.175	0.102	0.054	0.019	0.136	0.066	0.234	0.066
Conductivity (umhos/cm)	270	23	267	26	309	29	383	49
Dissolved Organic Carbon (mg/L)	23	1	24	1	21	2	15	1

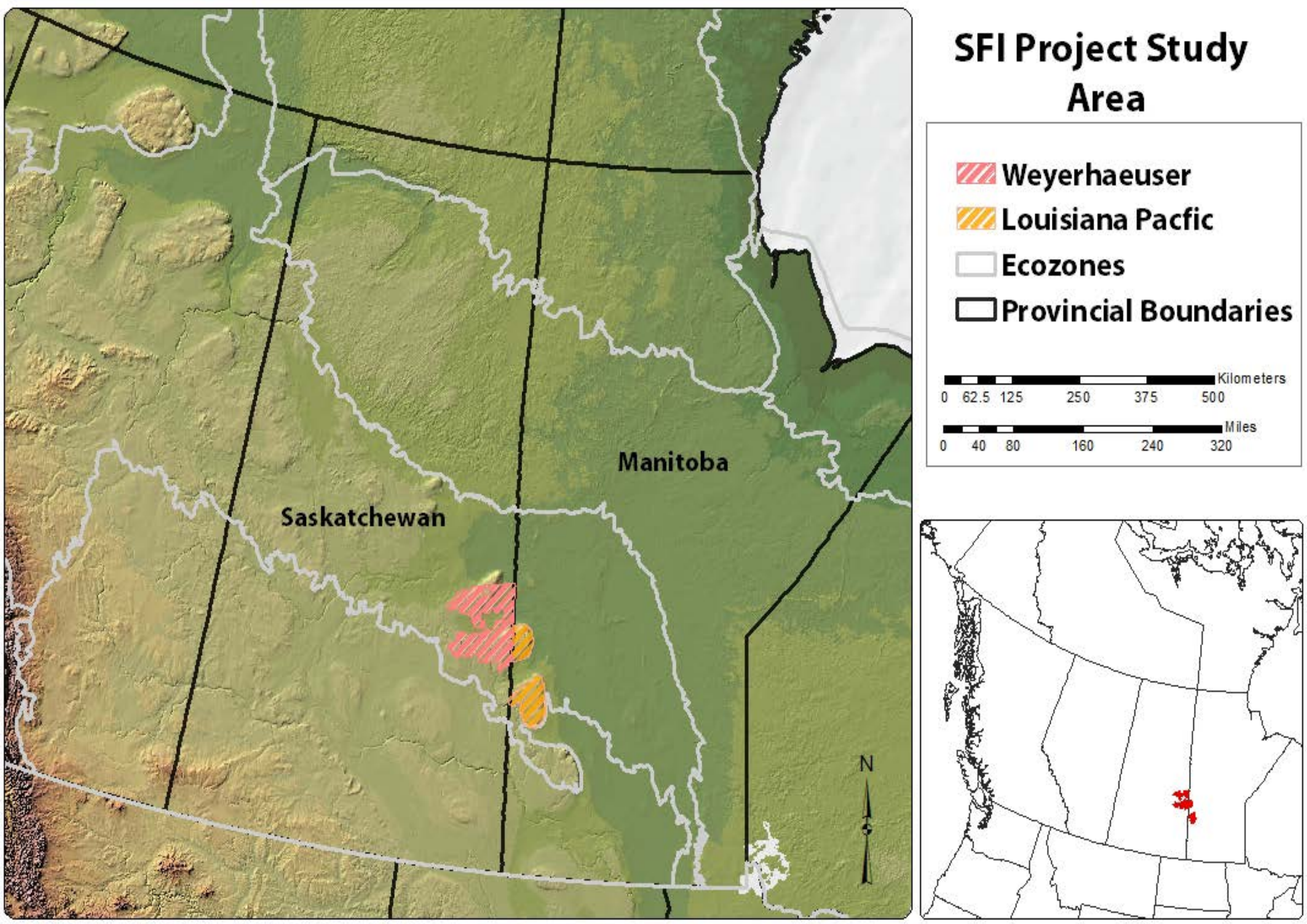

Figure 1. SFI Project Study Area.

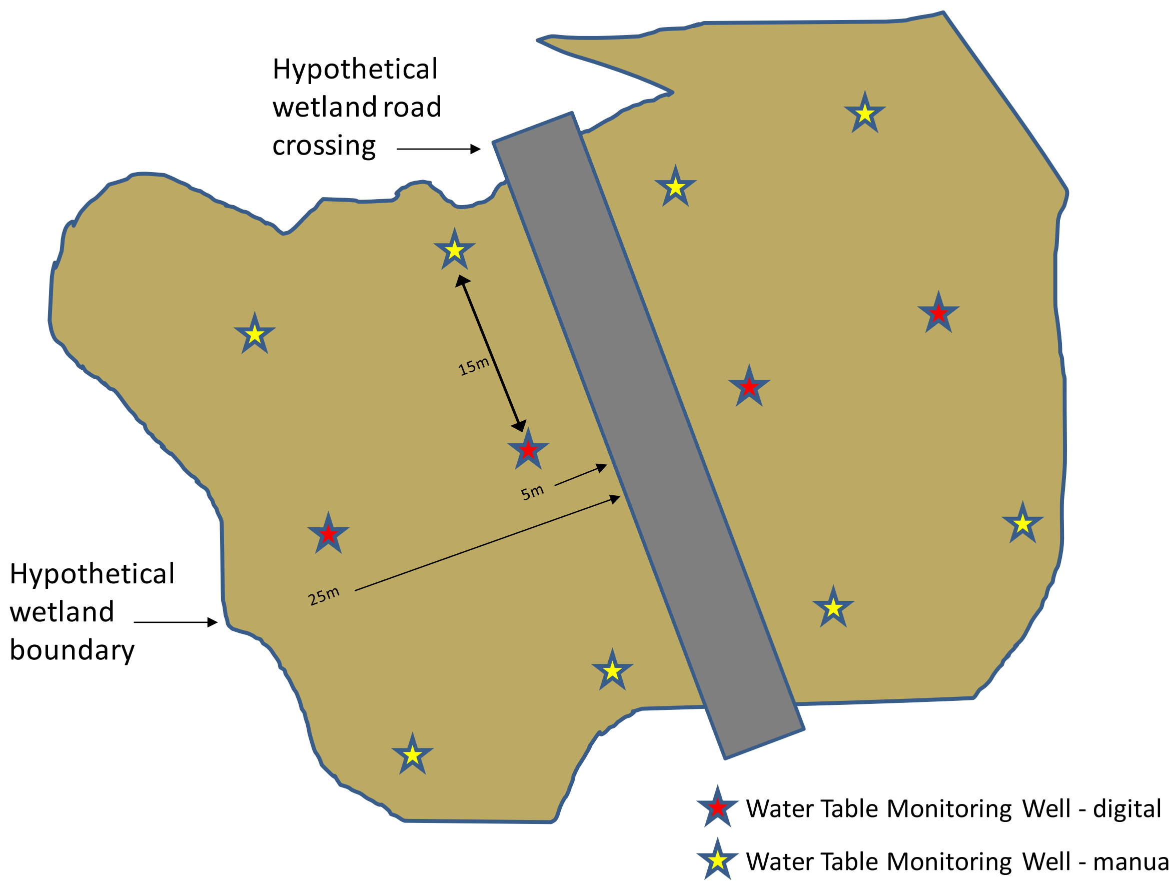

Figure 2. Hypothetical wetland road crossing monitoring site.

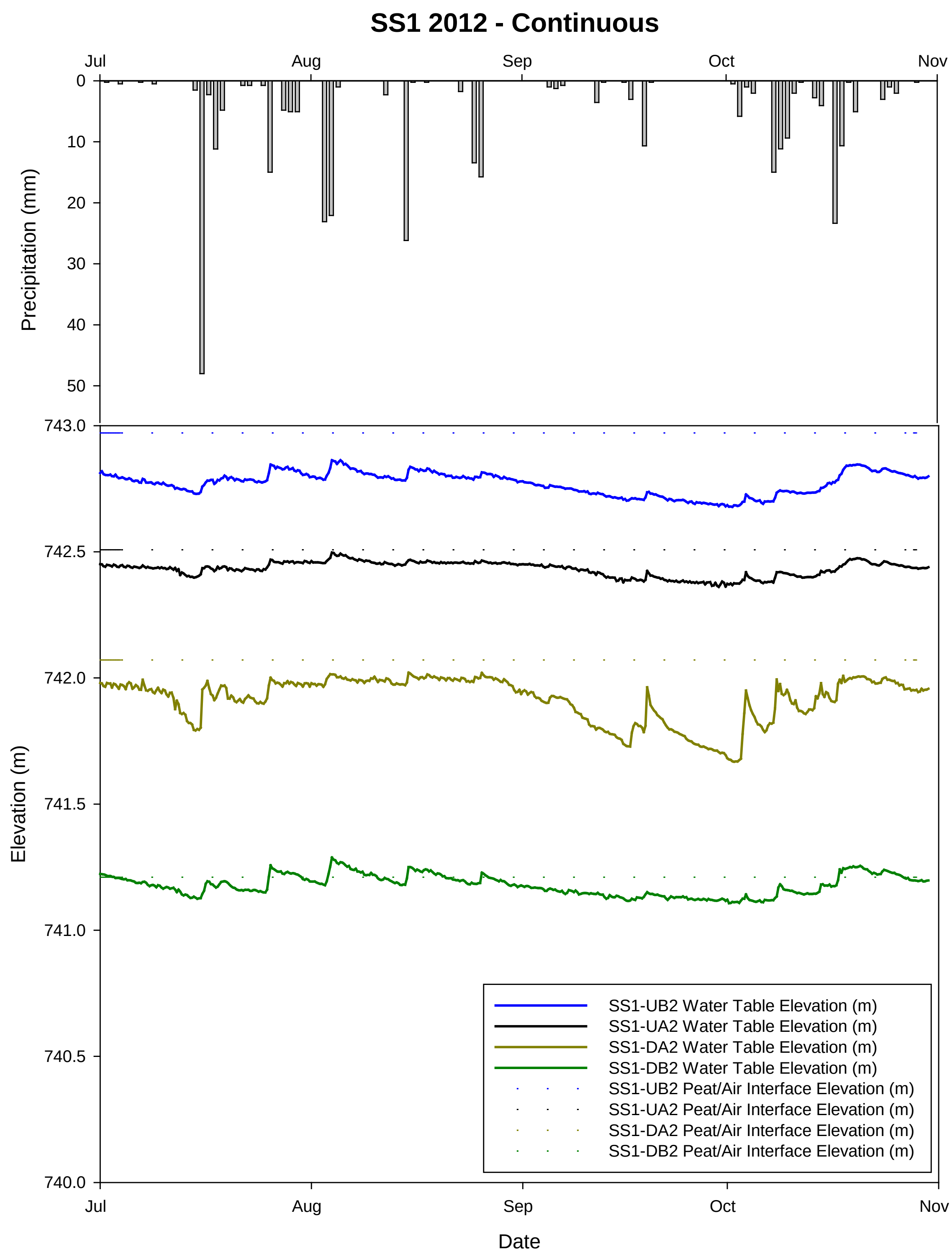

Figure 3. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for SS1 in 2012, Porcupine Hills, Manitoba (Steeprock Operating Area).**

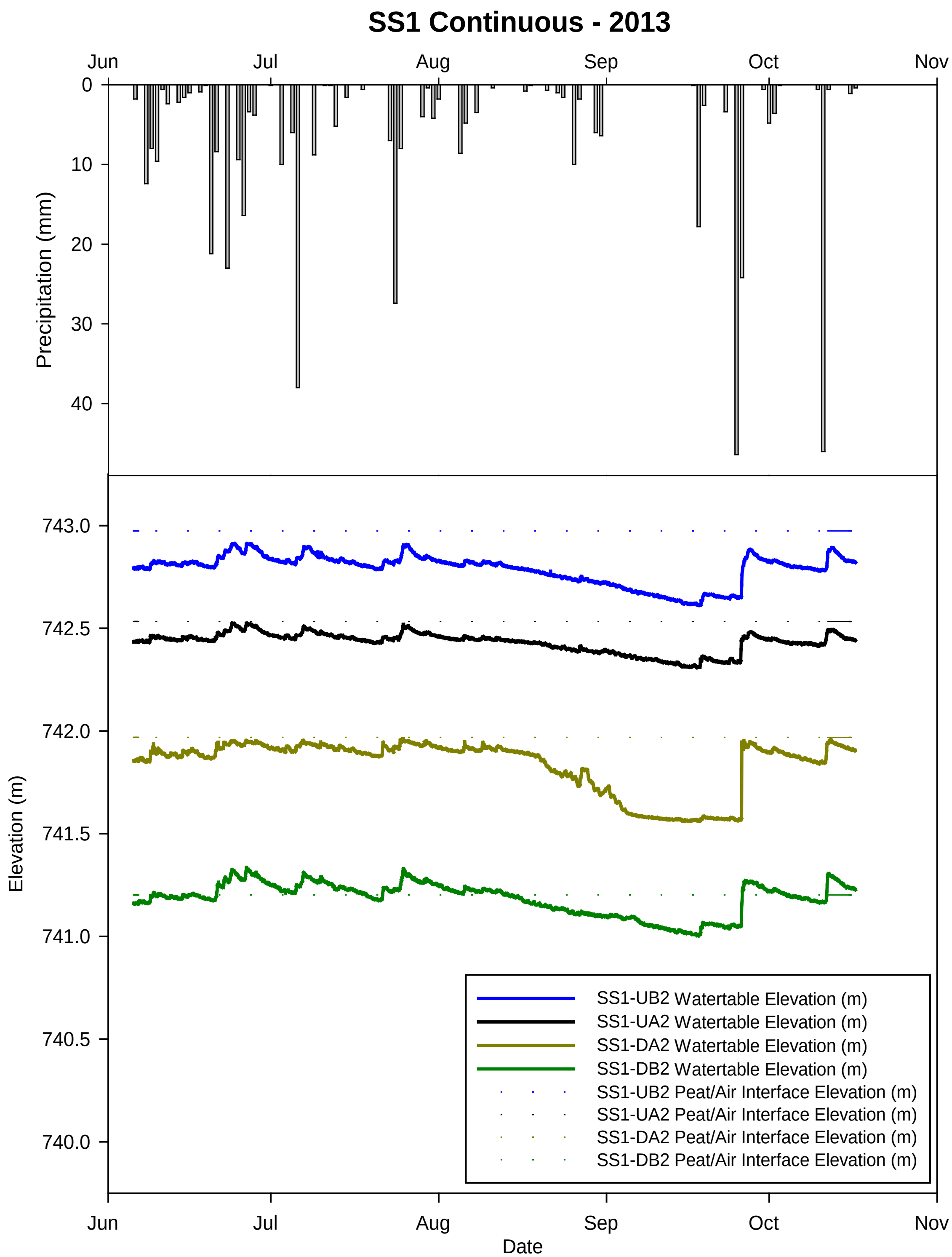

Figure 4. Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for SS1 in 2013, Porcupine Hills, Manitoba (Steeprock Operating Area).

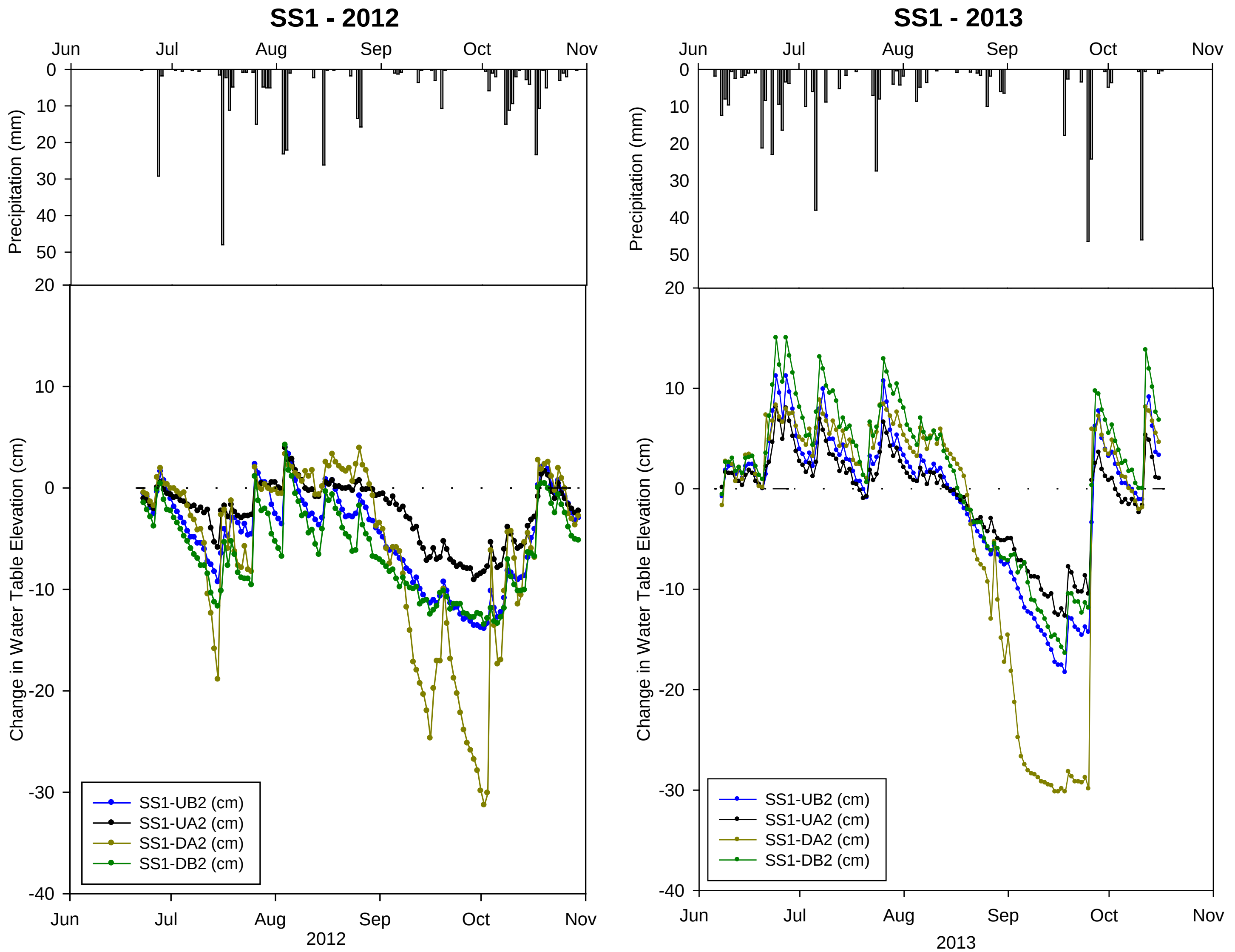

Figure 5. Net change in water table elevation after initial reading and daily precipitation in 2012 and 2013 at site SS1 in Porcupine Hills, Manitoba (Steeprock Operating Area).

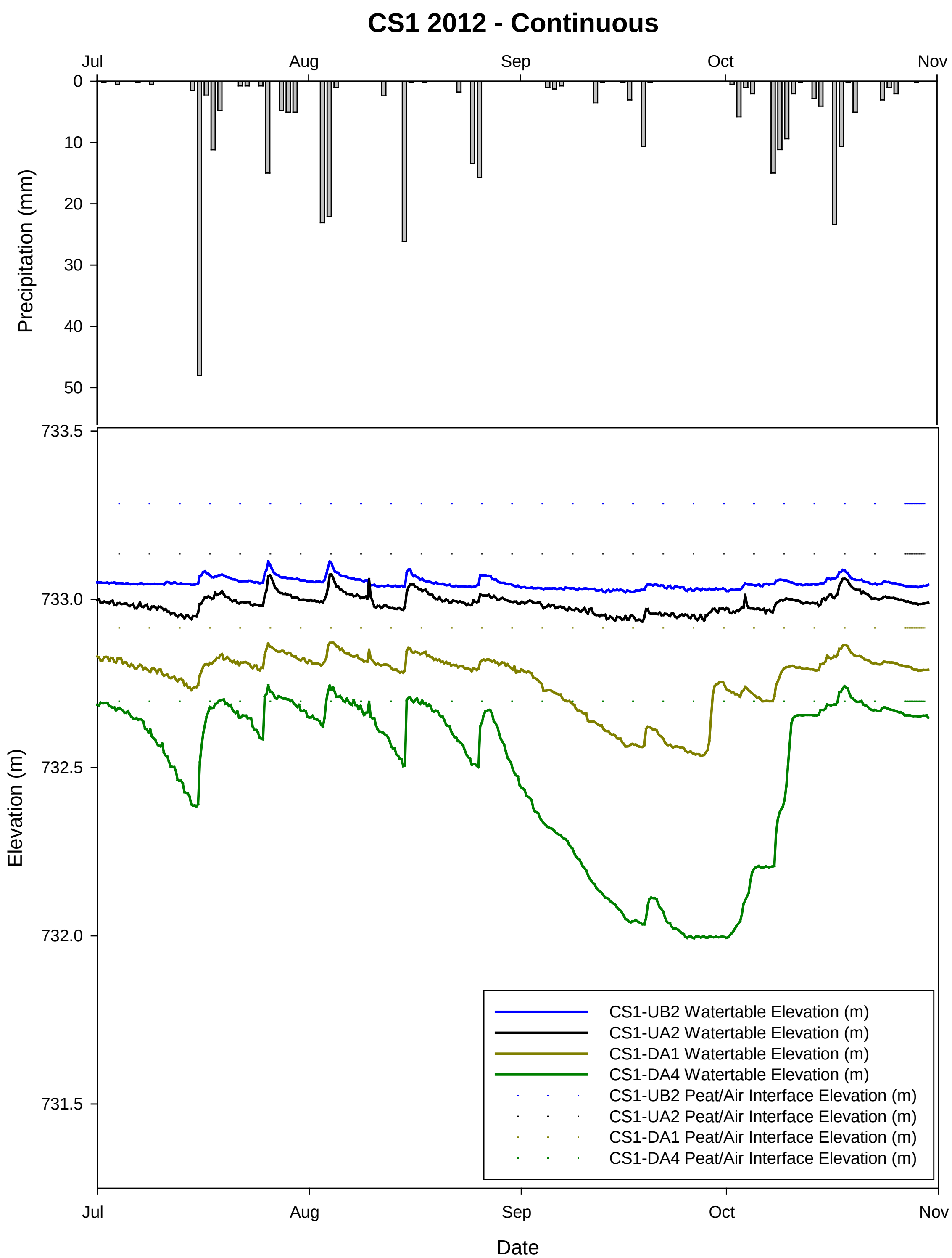

Figure 6. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for CS1 in 2012, Porcupine Hills, Manitoba (Steeprock Operating Area).**

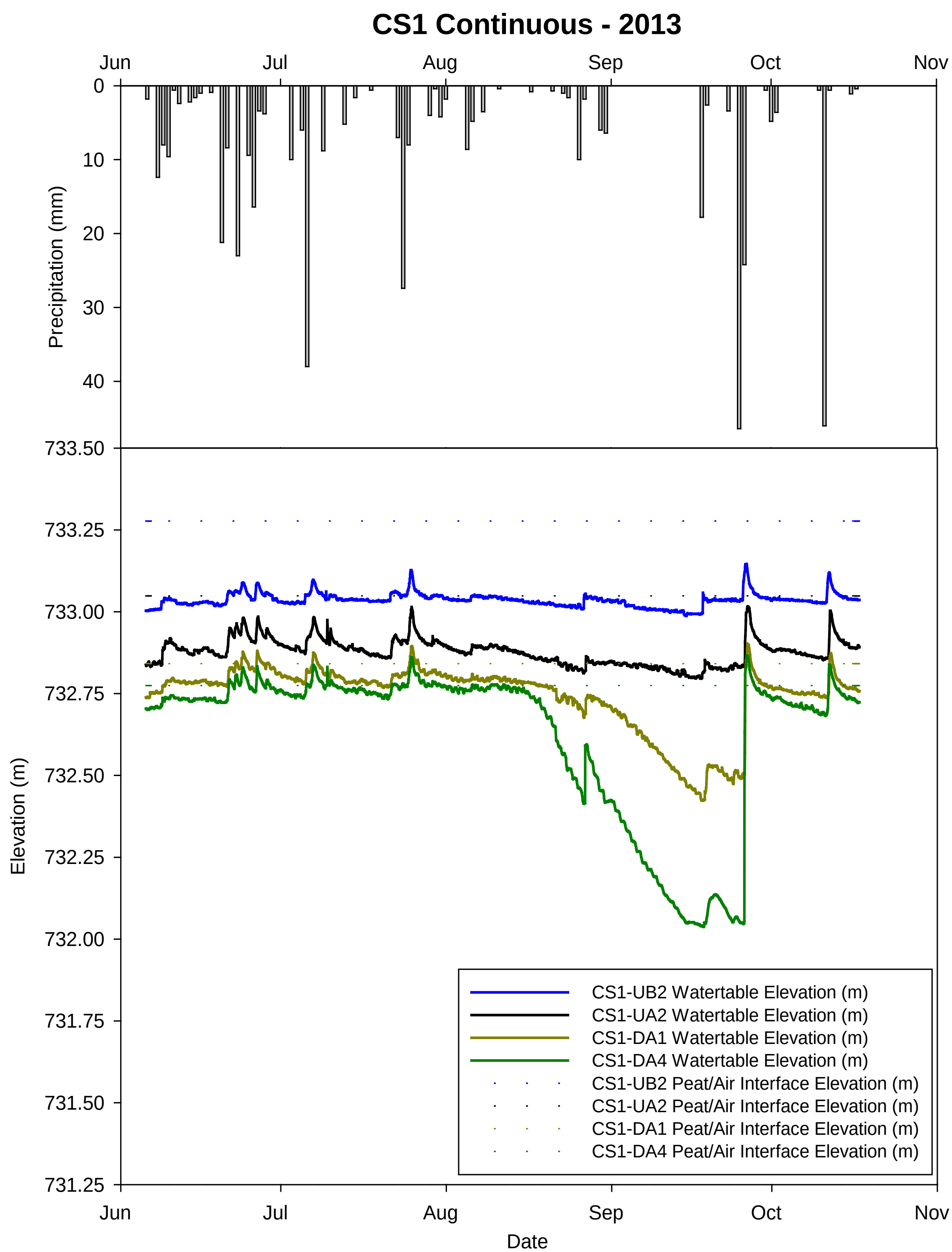

Figure 7. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for CS1 in 2013, Porcupine Hills, Manitoba (Steeprock Operating Area).**

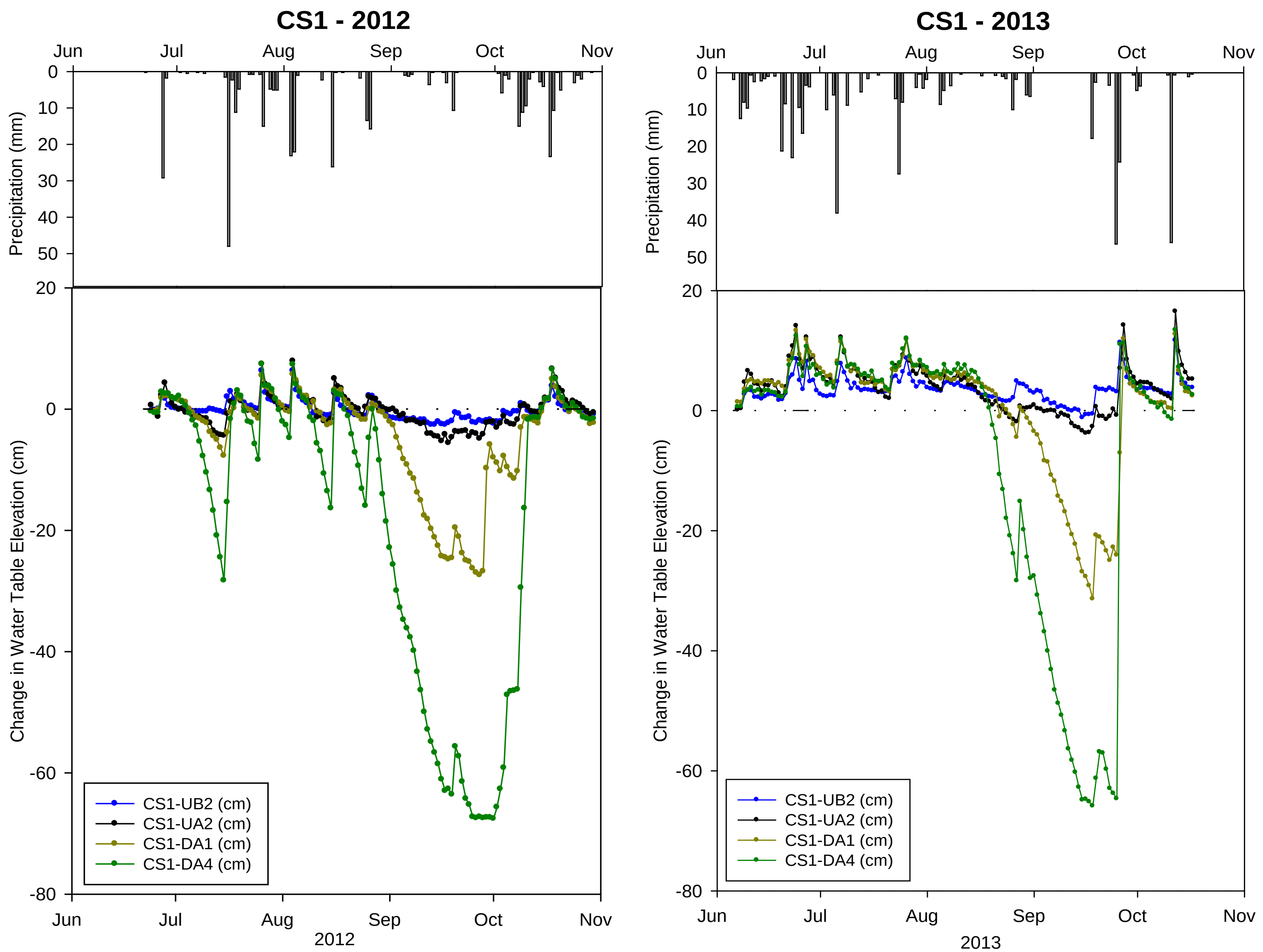

Figure 8. **Net change in water table elevation after initial reading and daily precipitation in 2012 and 2013 at site CS1 in Porcupine Hills, Manitoba (Steeprock Operating Area).**

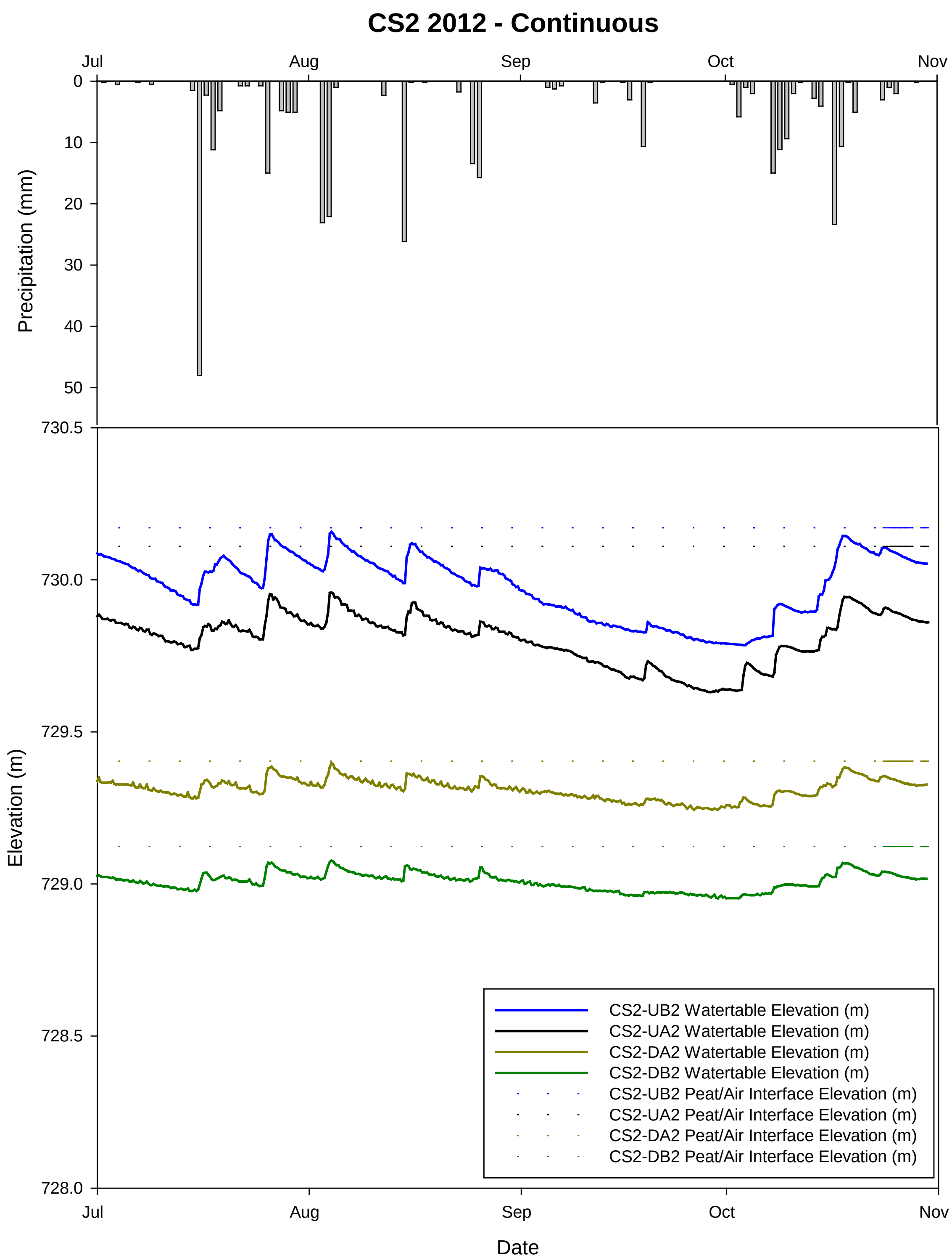

Figure 9. Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for CS2 in 2012, Porcupine Hills, Manitoba (Steeprock Operating Area).

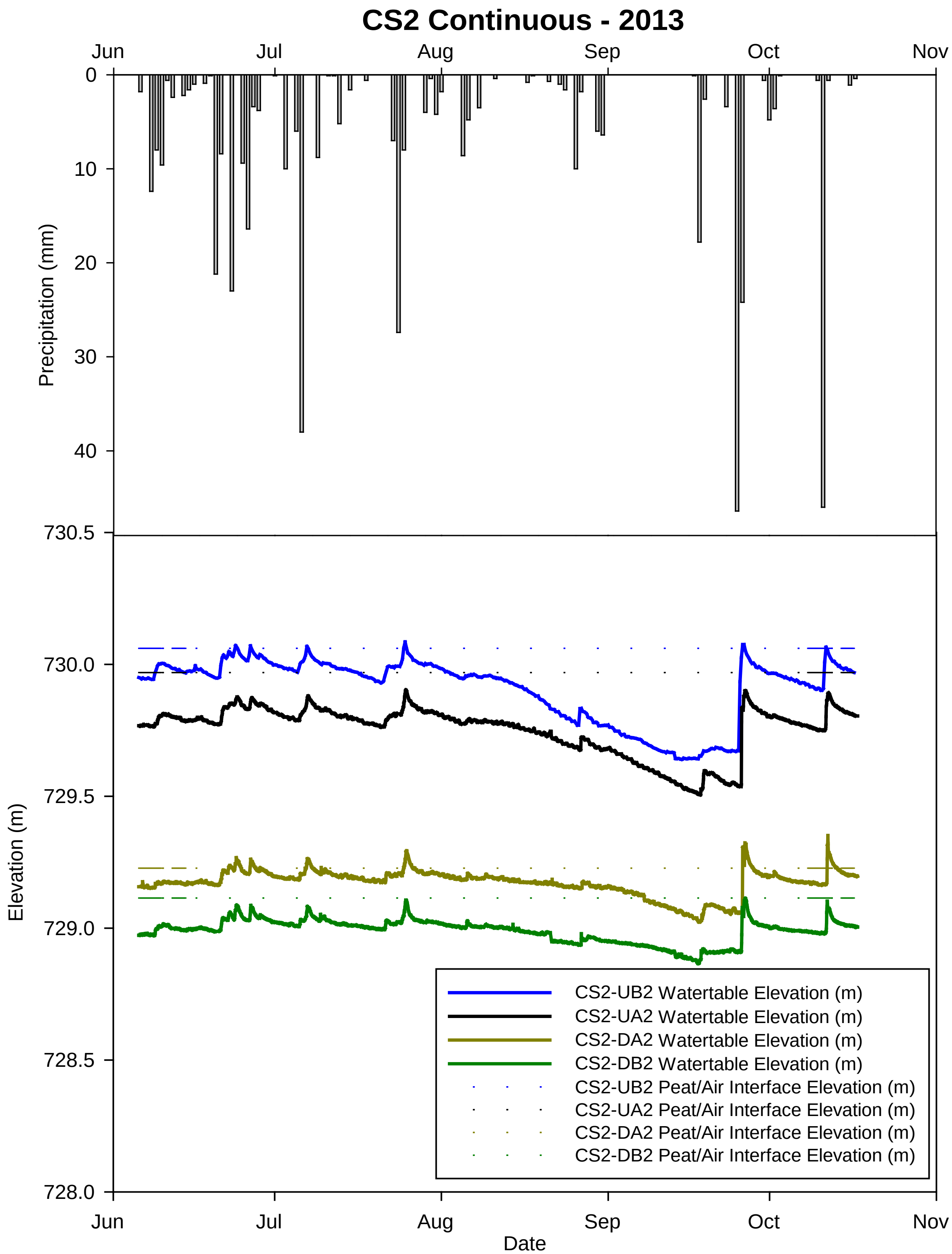

Figure 10. Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for CS2 in 2013, Porcupine Hills, Manitoba (Steeprock Operating Area).

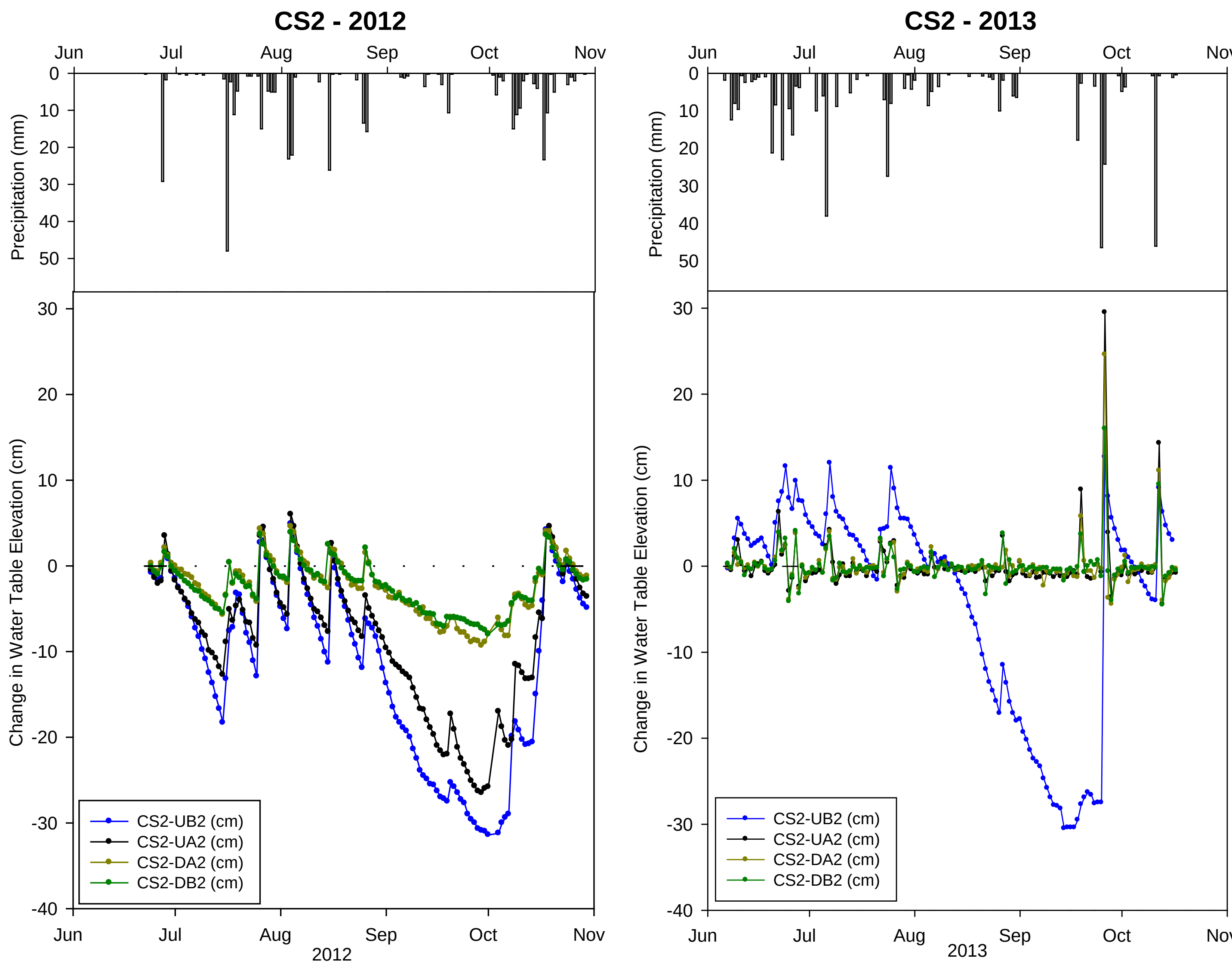

Figure 11. Net change in water table elevation after initial reading and daily precipitation in 2012 and 2013 at site CS2 in Porcupine Hills, Manitoba (Steeprock Operating Area).

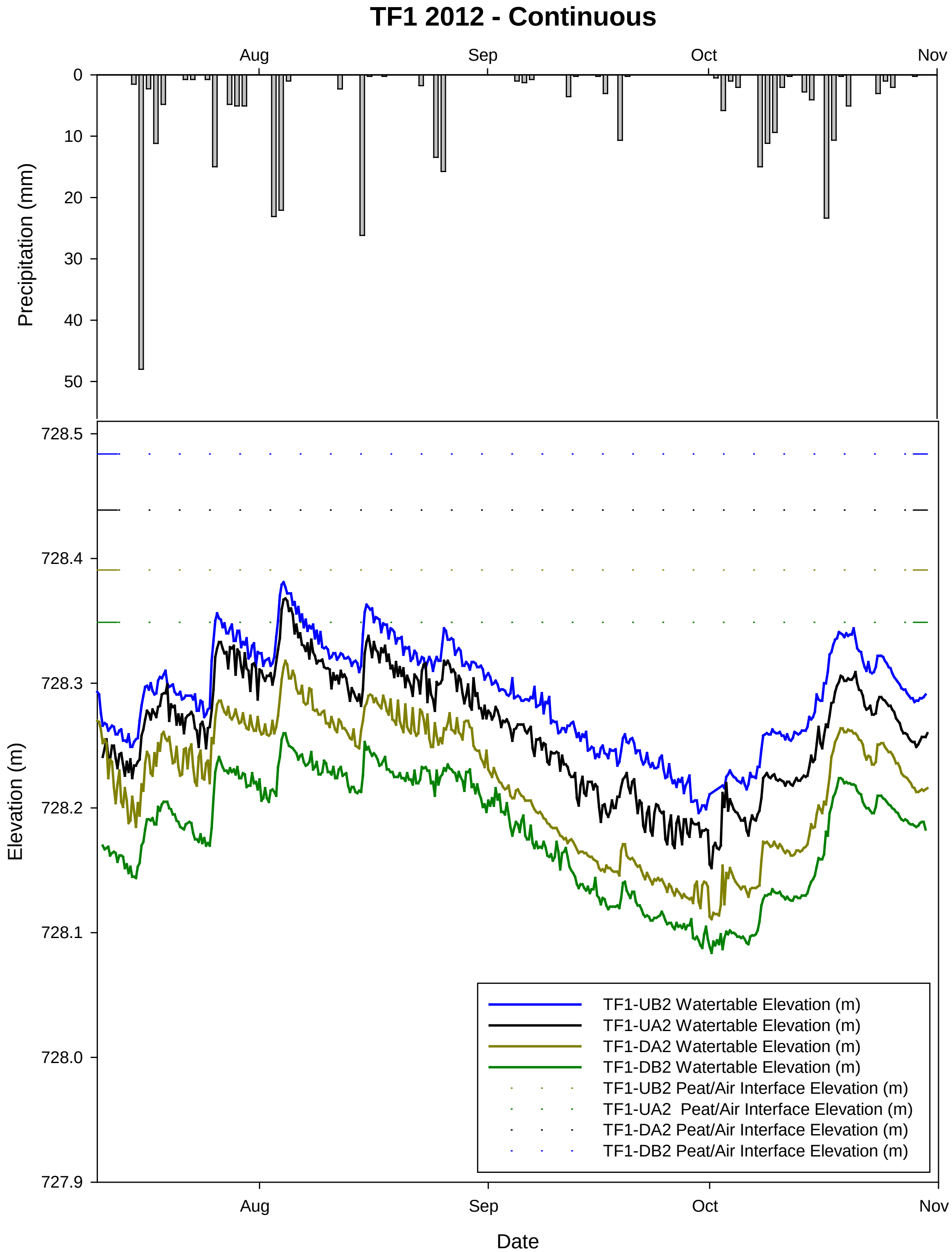

Figure 12. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for TF1 in 2012, Porcupine Hills, Manitoba (Steeprock Operating Area).**

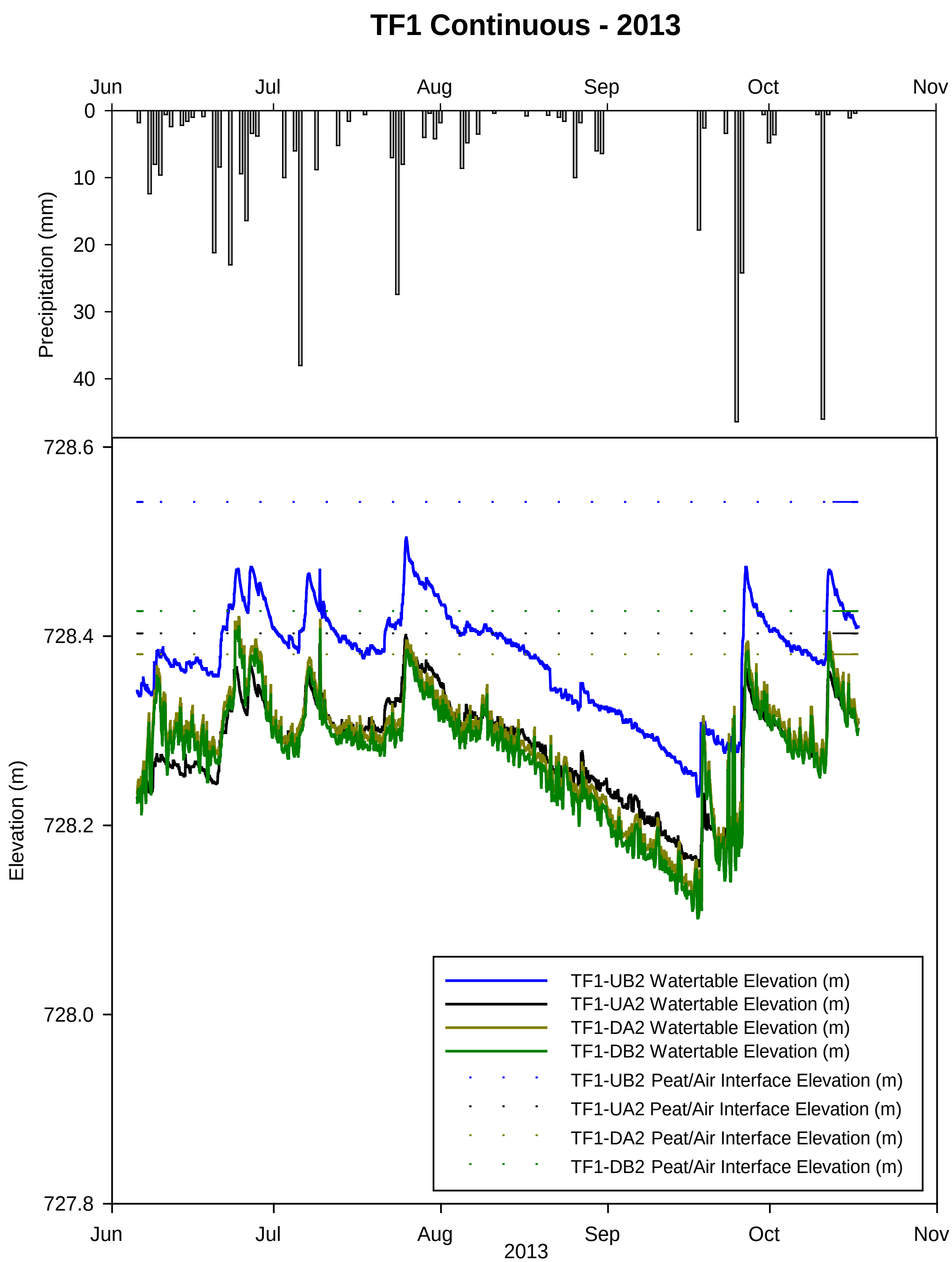

Figure 13. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for TF1 in 2013, Porcupine Hills, Manitoba (Steeprock Operating Area).**

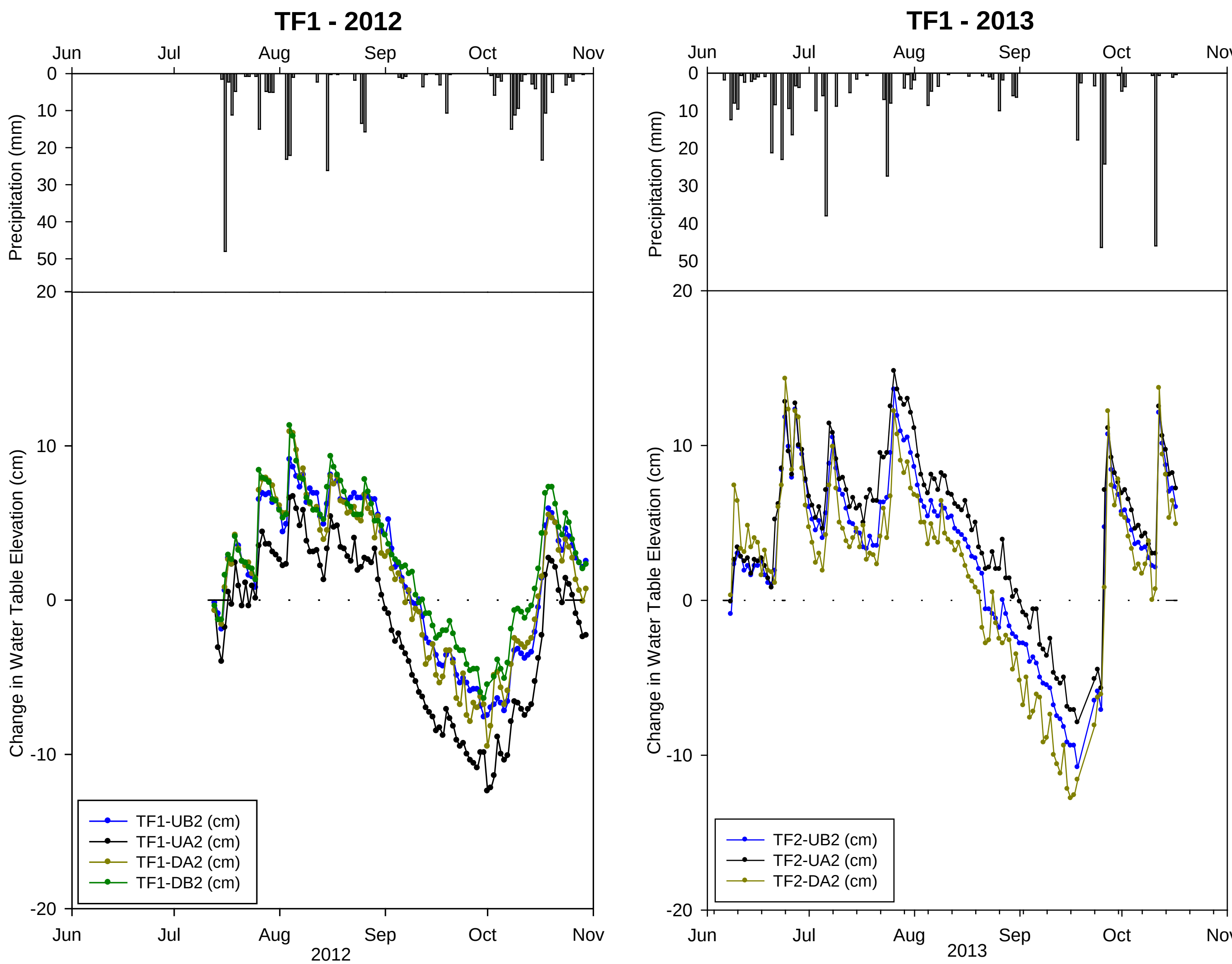

Figure 14. Net change in water table elevation after initial reading and daily precipitation in 2012 and 2013 at site TF1 in Porcupine Hills, Manitoba (Steeprock Operating Area).

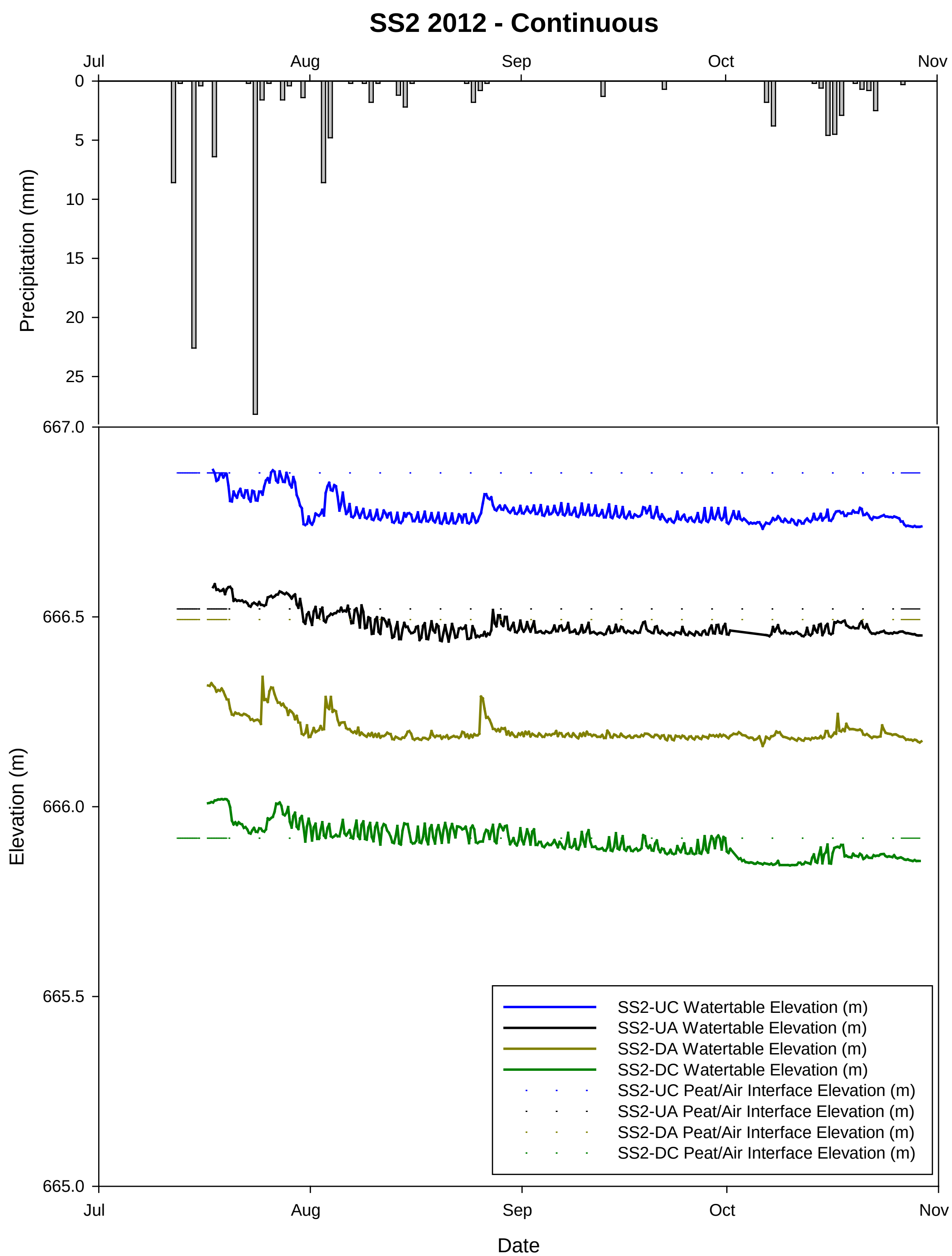

Figure 15. Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for SS2 in 2012, Duck Mountians, Manitoba (Upper Dam Operating Area).

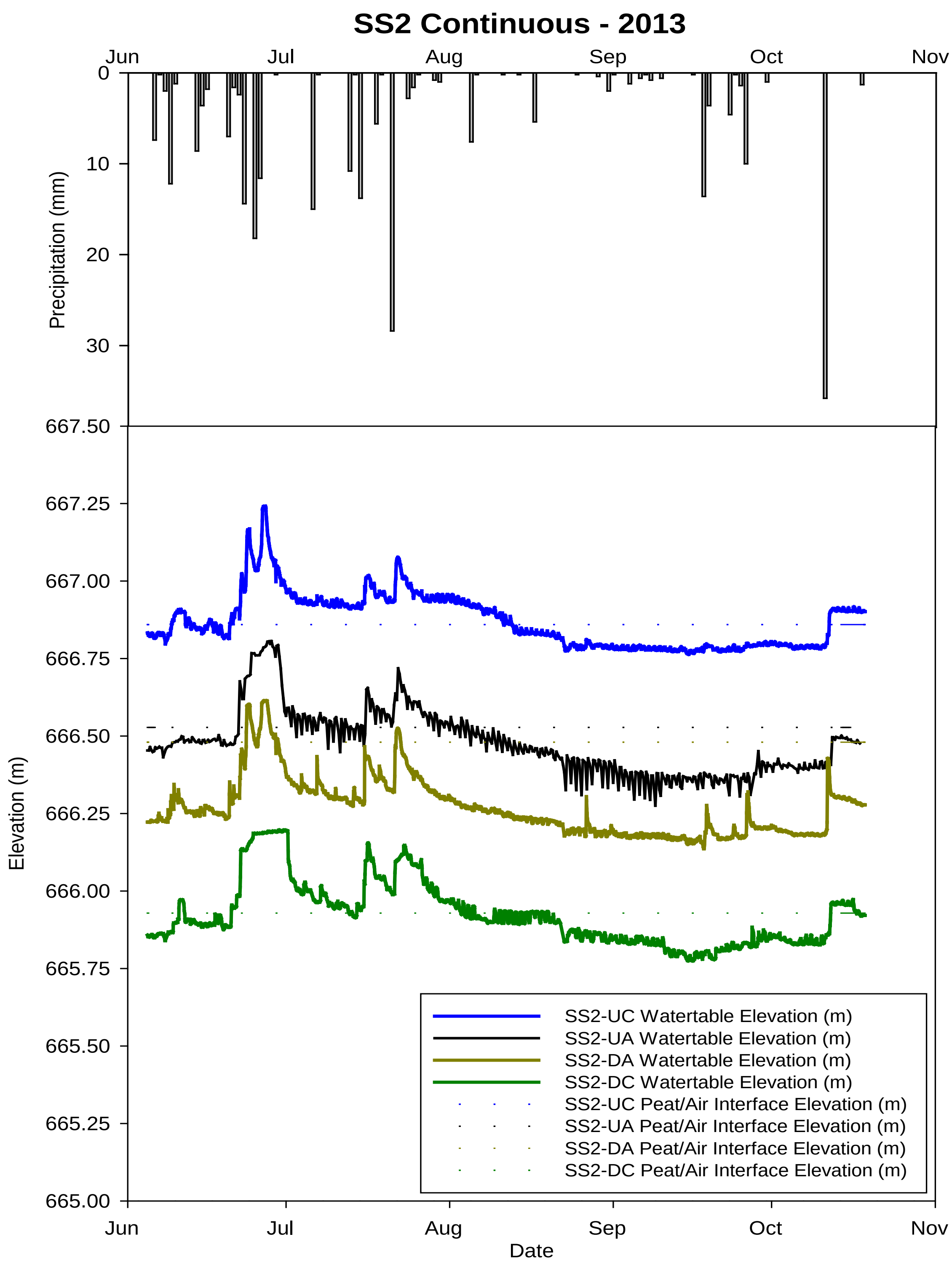

Figure 16. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for SS2 in 2013, Ducks Mountains, Manitoba (Upper Dam Operating Area).**

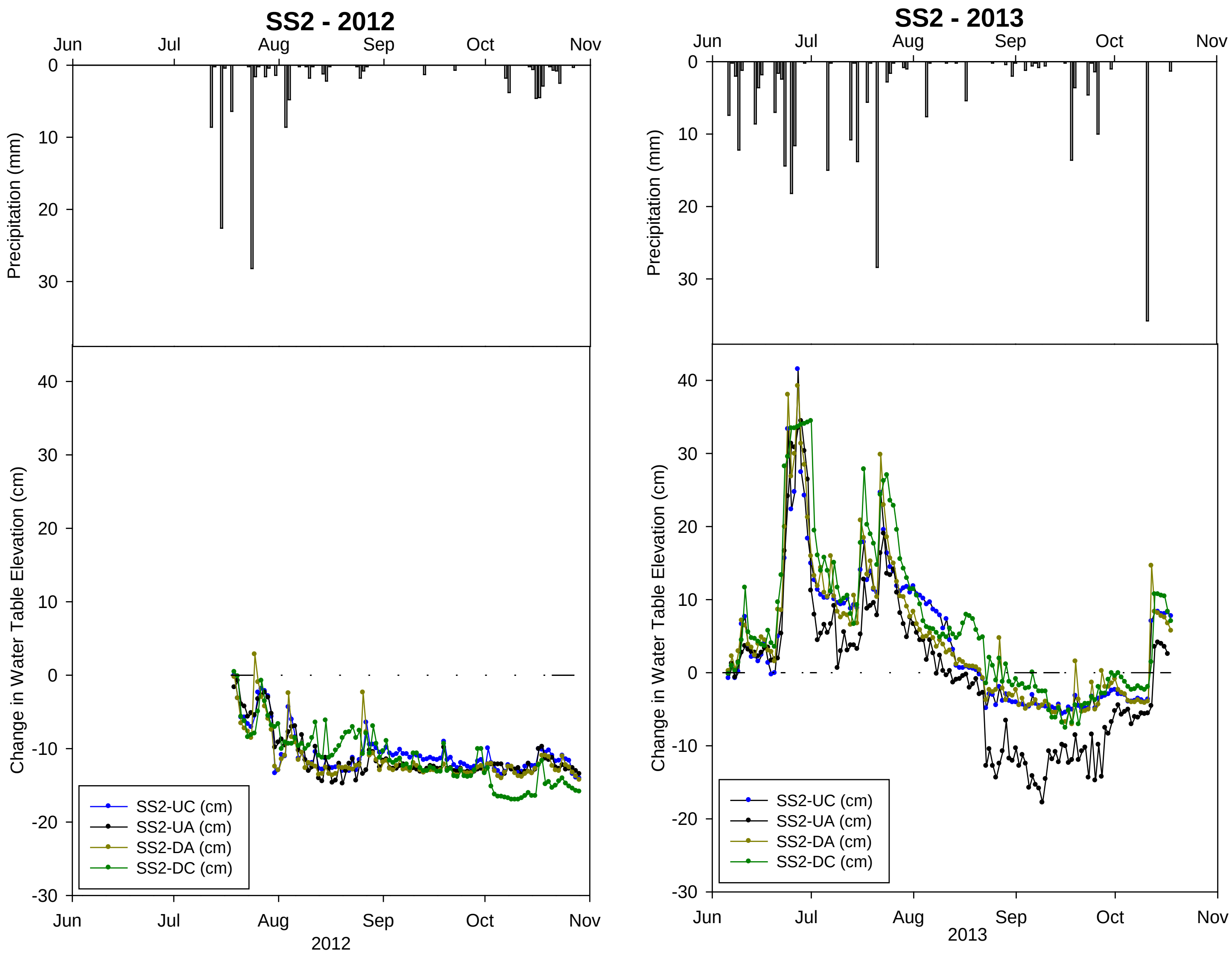

Figure 17. **Net change in water table elevation after initial reading and daily precipitation in 2012 and 2013 at site SS2 in Duck Mountains, Manitoba (Upper Dam Operating Area).**

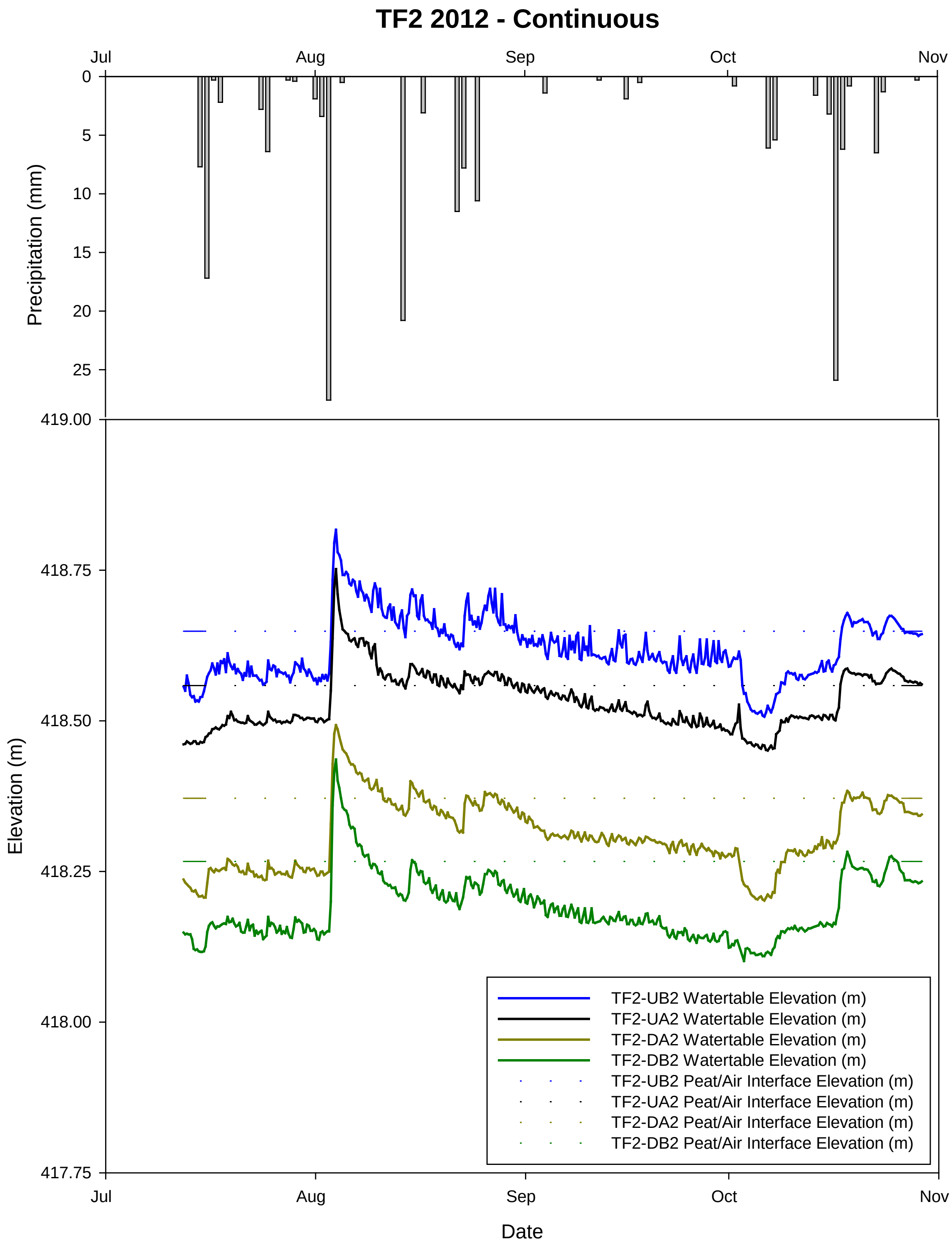

Figure 18. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for TF2 in 2012, Pasquia Hills, Saskatchewan.**

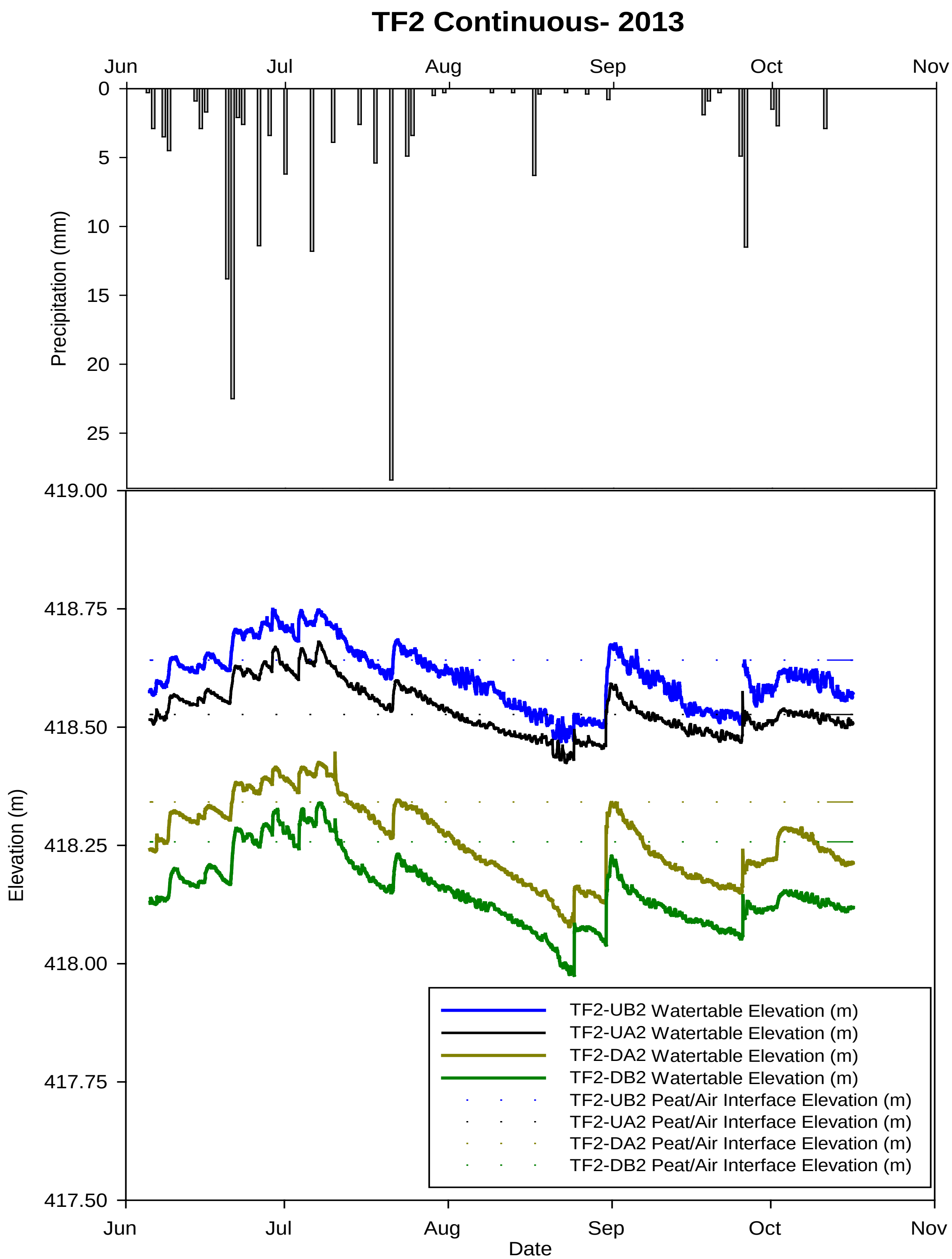

Figure 19. **Water table elevation (m), peat/air interface elevation (m) and daily precipitation (mm) for TF2 in 2013, Pasquia Hills, Saskatchewan.**

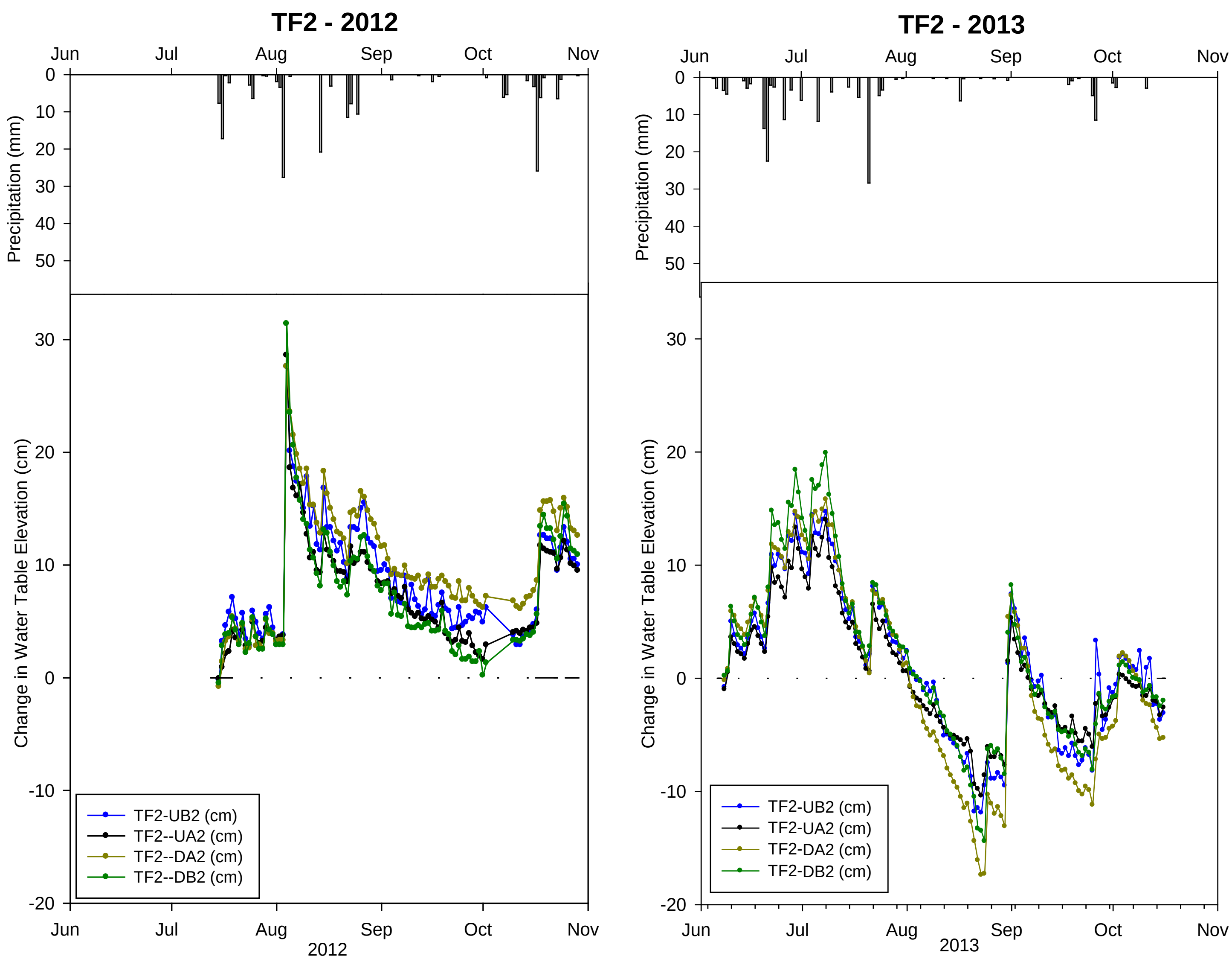

Figure 20. Net change in water table elevation after initial reading and daily precipitation in 2012 and 2013 at site TF2 in Pasquia Hills, Saskatchewan.

Appendix 1:

FP Innovations Field Note 2013

FPInnovations

FIELD NOTE

Installation of water table monitoring wells at resource road wetland crossings

Philip Kochuparampil, Jr. Eng.

Canadian forested landscapes feature numerous wetlands, such as fens, bogs and swamps that present environmental and operational challenges for resource roads that are constructed through them.

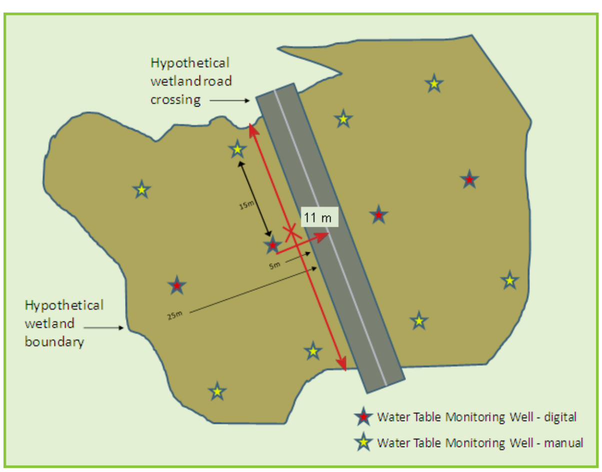

Figure 1. Layout of sampling design showing placement and location of digital and manual water table monitoring wells. Courtesy of Ducks Unlimited Canada.

Figure 2. View of a well next to the road. The crossing structure being monitored is a log-corduroy crossing with a plastic culvert (red arrow points to culvert inlet).

The effects of these roads on the many ecological functions of wetlands are of increasing concern to Canada's resource-based industries, governments and conservation organizations. As part of a resource road and wetland crossing project, water table monitoring wells were installed to assess hydrologic conditions (water level, water chemistry). Water monitoring wells have been installed at six resource road crossing trials near Swan River, MB and Hudson Bay, SK. The crossing trials are part of a collaborative research effort by Ducks Unlimited Canada, Louisiana Pacific Canada Ltd., Weyerhaeuser Company Limited, Spruce Products Limited, and FPInnovations funded, in part, through the Sustainable Forestry Initiative Conservation and Community Partnership Grant Program. One goal of this collaborative research effort is to determine best practices for designing and building resource roads across wetland ecosystems.

This field note briefly describes the preparation and installation of water table monitoring wells.

Design and apparatus

The design for the placement of wells is shown in Figure 1. The center of the wetland crossing was established on-site. Four transects were established for well placements, two upstream and two downstream of the road crossing. The transects were established at a set distance from the ditchline or edge of the road; one was located at a distance of 5m and the other at 25m.

The placements of the wells were surveyed, including the height of the calibration marks (located on each well) which will allow any relative changes in water table to be assessed. Three wells were installed along each transect; the centre well was instrumented with a digital water level recorder and the outer two wells were established for manual readings (Figure 2).

Installation techniques and considerations

The installation of water table monitoring wells is a labour intensive manual procedure. The monitoring well installation can be facilitated by having the proper tools on site. Two different sizes (diameter and length) of wells were available for installation. A peat probe was used to determine the depth of peat at a monitoring location and the longer wells (2m) were assigned to the sites with deeper peat and the shorter wells (1m) were used where peat depths were shallower (less than 50 cm).

A pounding tool and a gas-powered auger were both used during the installation of the wells (Figure 3). The pilot hole created by the auger matched the 10cm diameter of the well. The pounding tool provided the downward force to help insert the well into the pilot hole / ground. The wells are made from perforated PVC plastic, have a conical shaped bottom to allow for easier penetration into the ground, and have a removable cap at the top (Figure 4). Wells / PVC pipe were covered with a stretchable fabric cover (sock) to prevent fine material from blocking the numerous small slits / openings along the length of the well. A geotextile fabric can also be used as an alternative to the prepared stretchable fabric covers.

The digital recorder used at the monitoring sites is an RDS Ecotone® WM Water Level Instrument designed for the measurement of shallow ground and surface water levels. The recorder combines the data logger, water level sensor and custom well screen (sock) in one package. The purchase cost for these units varies by water level sensor range; the range is from 0.5 m to 2.0 m. The cost is approximately $750 to $1050.

Figure 3. View of the two tools used to install the monitoring wells. A typical pounding tool was used to drive the well tubes into place (left). The job was made easier when a gas-powered auger was used to first create a pilot hole (right).

Figure 4. Monitoring wells were made of perforated PVC plastic pipe with conical shaped bottoms. A stretchable fabric sock installed around the pipe (not shown in picture) kept sediment and debris from entering the well through the perforations. Wells had either a removable cap on top to allow for manual water level measurements and sampling (left) or a digital water level recorder as the cap (right).

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Funding provided by Natural Resources Canada under the NRCan/FPInnovations CFS Contribution Agreement