Natural Resources Canada | Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8093

NORTHWEST TERRITORIES GEOLOGICAL SURVEY
NWT OPEN REPORT 2016-019

Report on 2010-2015 Permafrost Thermal Investigations in the Yellowknife Area, Northwest Territories

C. Duchesne, P.D. Morse, S.A. Wolfe and S.V. Kokelj

2016

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8093

NORTHWEST TERRITORIES GEOLOGICAL SURVEY
NWT OPEN REPORT 2016-019

Report on 2010-2015 Permafrost Thermal Investigations in the Yellowknife Area, Northwest Territories

C. Duchesne[1], P.D. Morse[1], S.A. Wolfe[1], and S.V. Kokelj[2]

[1] Geological Survey of Canada, Ottawa, ON
[2]Northwest Territories Geological Survey, Yellowknife, NWT

2016

doi:10.4095/299189

This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

Recommended citation
Duchesne, C., Morse, P.D., Wolfe, S.A., and Kokelj, S.V., 2016. Report on 2010-2015 Permafrost Thermal Investigations in the Yellowknife Area, Northwest Territories; Geological Survey of Canada, Open File 8093; Northwest Territories Geological Survey, NWT Open Report 2016-019, 54 p. doi:10.4095/299189

Publications in this series have not been edited; they are released as submitted by the author.

ABSTRACT

Natural Resources Canada (NRCan) and the Northwest Territories Geological Survey (NTGS), in collaboration with the former Environment and Conservation Division of Indigenous and Northern Affairs Canada (INAC), the Government of the Northwest Territories Departments of Transportation, and Environment and Natural Resources, as well as BGC Engineering Inc., have conducted a field initiative to collect baseline geoscience data in support of the land-based transportation project in the Climate Change Geoscience Program (NRCan). The present initiative is focused on addressing transportation risk in the arctic to climatic sensitivity (TRACS) in the Great Slave region. In this report, air, ground surface, near-surface, and shallow ground temperature data collected between 2010 and 2015 are presented. This report is an output of the NTGS's NWT Permafrost Database project and contains digital ground temperature data.

DISCLAIMER

Her Majesty the Queen in right of Canada, as represented by the Minister of Natural Resources ("Canada"), does not warrant or guarantee the accuracy or completeness of the information ("Data") and does not assume any responsibility or liability with respect to any damage or loss arising from the use or interpretation of the Data.

The Data are intended to convey regional trends and should be used as a guide only. The Data should not be used for design or construction at any specific location, nor are the Data to be used as a replacement for the types of site-specific geotechnical investigations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Permafrost is an important component of the landscape in the south central Northwest Territories (NWT), which lies within the extensive discontinuous permafrost zone of Canada (Fig. 1). Permafrost and its associated ground ice can affect entire ecosystems through their influence on drainage patterns and ground stability, and can present challenges to northern development. In particular, permafrost can have a significant influence on ground-based transportation infrastructure, which is critical for northern development. Mineral resources in the Slave Geological Province (north of Yellowknife, NWT) are important for economic development in the region. Presently, ground transportation requires all-weather road access across discontinuous permafrost terrain, and winter-road access primarily across frozen lakes. Climate warming in the region poses risks to existing road and highway infrastructure and requires adaptation measures to increasingly unreliable ice-roads.

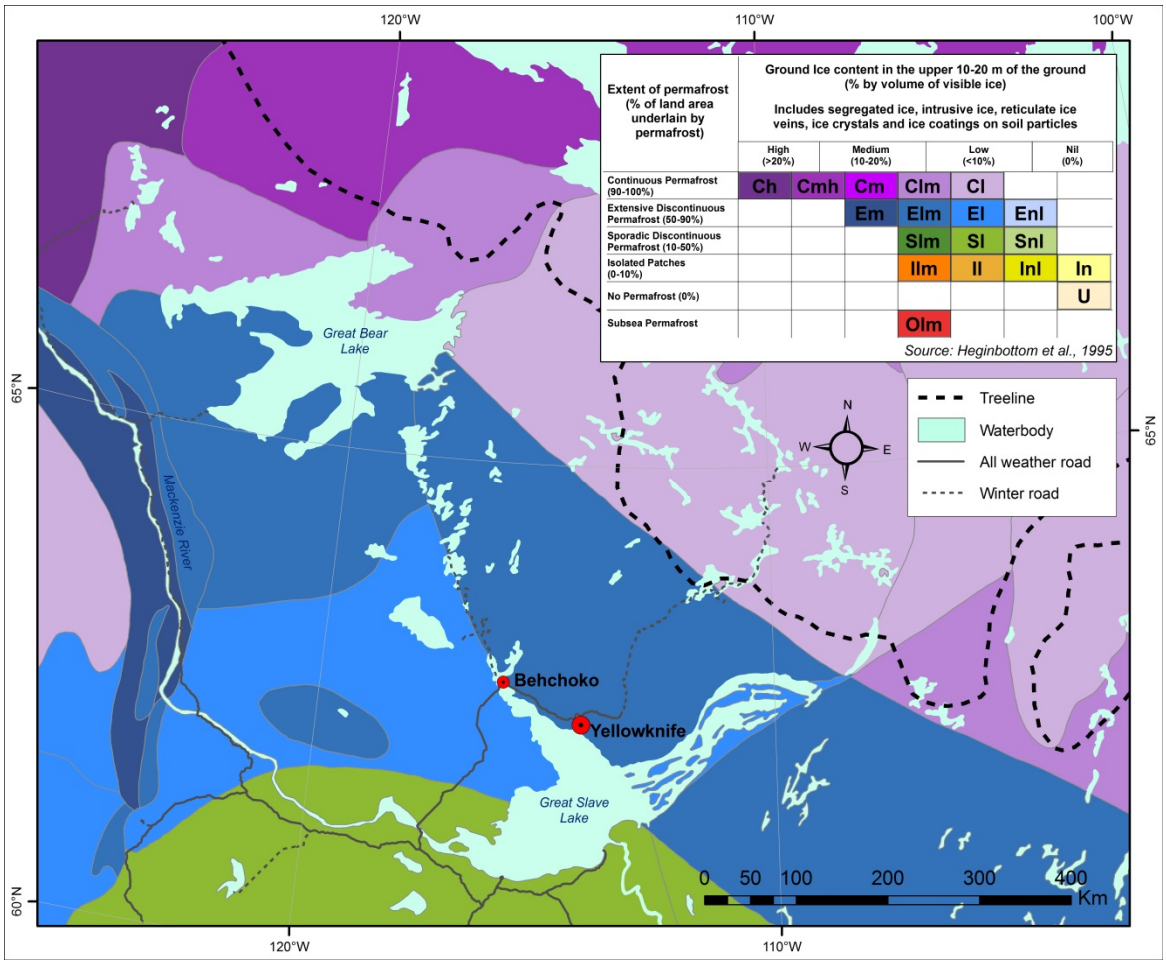


Figure 1. Permafrost and ground ice in western Canada. The Great Slave region is found within the extensive discontinuous permafrost zone with a low-to-medium ground ice content (adapted from Heginbottom et al., 1995).

Geological Survey of Canada (GSC) and Northwest Territories Geological Survey (NTGS) conducted a field initiative to collect baseline geoscience data in support of the GSC's land-based transportation project in the Climate Change Geoscience Program. The present initiative is focused on addressing transportation risk in the arctic to climatic sensitivity (TRACS) in the Great Slave region, mainly along the Behchoko to Tibbitt Lake corridor (Fig. 2). The objective of this report is to present data collected between 2010 and 2015 in collaboration with the former Environment and Conservation Division of Indigenous and Norther Affairs Canada (INAC), Government of the Northwest Territories' (GNWT) Department of Transportation, and Department of Environment and Natural Resources, and BGC Engineering Inc. This project and these data have been reported and compiled as a part of the NWT Permafrost Database project. Appendix A demonstrates the NWT standardized Permafrost Database report. Appendix B presents the detailed metadata and raw data in the NWT Permafrost Database format.

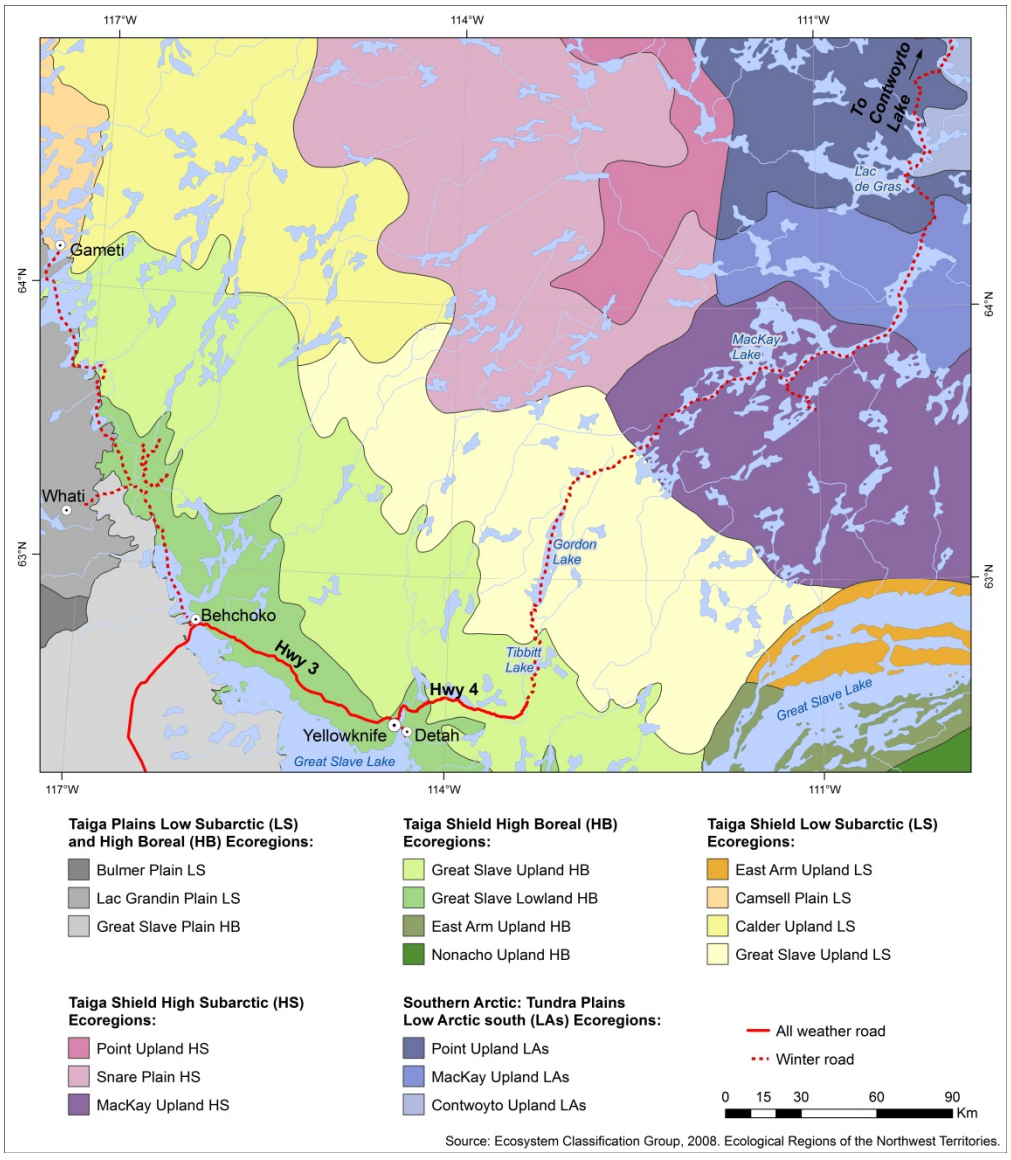


Figure 2. Ecoregions north of Yellowknife. Areas surrounding Yellowknife include the Great Slave Lowland and Great Slave Upland High Boreal Ecoregions. All-weather roads are shown as solid red lines and winter roads are shown as dashed red lines (adapted from Ecosystem Classification Group, 2008).

2 GEOMORPHOLOGIC CONTEXT

The area between the City of Yellowknife and the community of Behchoko, along the north shore of Great Slave Lake, resides within the Great Slave Lowland High Boreal Ecoregion (Fig. 2). Bedrock, fens and bogs are typically devoid of permafrost in this area, whereas spruce and deciduous forests and peatlands are usually underlain by permafrost, though at relatively warm ground temperatures (Wolfe, 1998; Gaanderse, 2011; Morse et al., 2015). Thus, the presence of permafrost in this region is spatially variable, with abrupt transitions from frozen to unfrozen ground usually occurring over short distances. In addition, thick ice lenses and even massive ground ice in excess of 2.5 m thick can be found in the area (Aspler, 1978; EBA, 1995). More common, however, are thinner (1 to 20 mm thick) ice lenses found primarily in clays of glaciolacustrine and lacustrine origin. These clays represent the dominant surficial unit in the region, and were deposited by Glacial Lake McConnell between about 10 and 8.5 ka BP (Lemmen et al., 1994; Smith, 1994), and by ancestral Great Slave Lake from 8.5 ka BP to present (Wolfe and Morse, 2016).

3 GROUND-BASED TRANSPORTATION NETWORK

The only all-weather ground-based transportation access to and from Yellowknife is via Highway 3, which lies within the discontinuous permafrost zone and the high boreal ecoregion (Figs. 1 and 2). During the mid-1960s, the first all-weather road access was constructed along the route between Yellowknife and Behchoko (formerly Rae-Edzo). The road embankment was built from local surficial sediment in the area (primarily Glacial Lake McConnell glaciolacustrine silts and clays). This route largely avoided bedrock and water bodies, thus resulting in a sinuous alignment. Between 1999 and 2006, the highway route between Yellowknife and Behchoko was realigned to straighten the road and maximize the portion of the road that is on bedrock (EBA, 1995). North of Behchoko, a winter road extends 194 km to the communities Whatì and Gamètì as well as Wekweti which lies in the centre of the Slave Geological Province.

An all-weather road (Highway 4 also known as Ingraham Trail) extends an additional 73 km east of Yellowknife to Tibbitt Lake (Fig. 2). At this point, the Tibbitt to Contwoyto Winter Road begins (Fig. 2) and extends some 300 km northeastward to Lac de Gras, continuing further north another 350 km to Contwoyto Lake. This winter road access is, at present, the only transportation route in and out of the resource-rich Slave Geologic Province.

4 STUDY SITE AND INSTRUMENTATION

Several field sites were established from 2010 to 2014 to characterize the ground thermal regime in this region. Most of these sites were located along the Highway 3 and Highway 4 corridors between Behchoko, Yellowknife and Tibbitt Lake. Figures 3 to 5 present maps of the instrumented sites. For some sites, installation details and site description can be found in Wolfe et al. (2011). The sites were instrumented to measure: air and ground surface temperatures, near-surface ground temperature (mainly in the active layer), and/or shallow ground temperature (extending below the active layer). Most sites were visited at least once a year and have continuous data recorded with data loggers. The following sections describe the specific

instrumentation and methodology used to measure each parameter as well as a metadata table with site locations and general descriptions.

4.1 Air and Ground Surface Temperatures

Air and ground surface temperature sites were instrumented with dual-channel data loggers (OnSET U23 HOBO® Pro v2). The first temperature sensor was mounted within a radiation shield at 1.2 m above ground and the second sensor was inserted at a nominal depth of 5 cm below the ground surface. The temperature sensors have a range of -40°C to 70°C, an accuracy of +/-0.5°C and a resolution of 0.02°C from 0 to 25°C. In most cases, temperatures have been recorded continuously at one hour intervals, though some sites and for some years the data were recorded at two hour intervals.

Figure 3 presents the locations of the air and ground surface temperature measurement sites and Table 1 provides the location coordinates and metadata for these sites. Refer to Appendix C for annual mean temperature graphs for sites where data were available for at least 350 days per year. Daily mean air and surface temperatures for each site can be found in the accompanying database of CSV files.

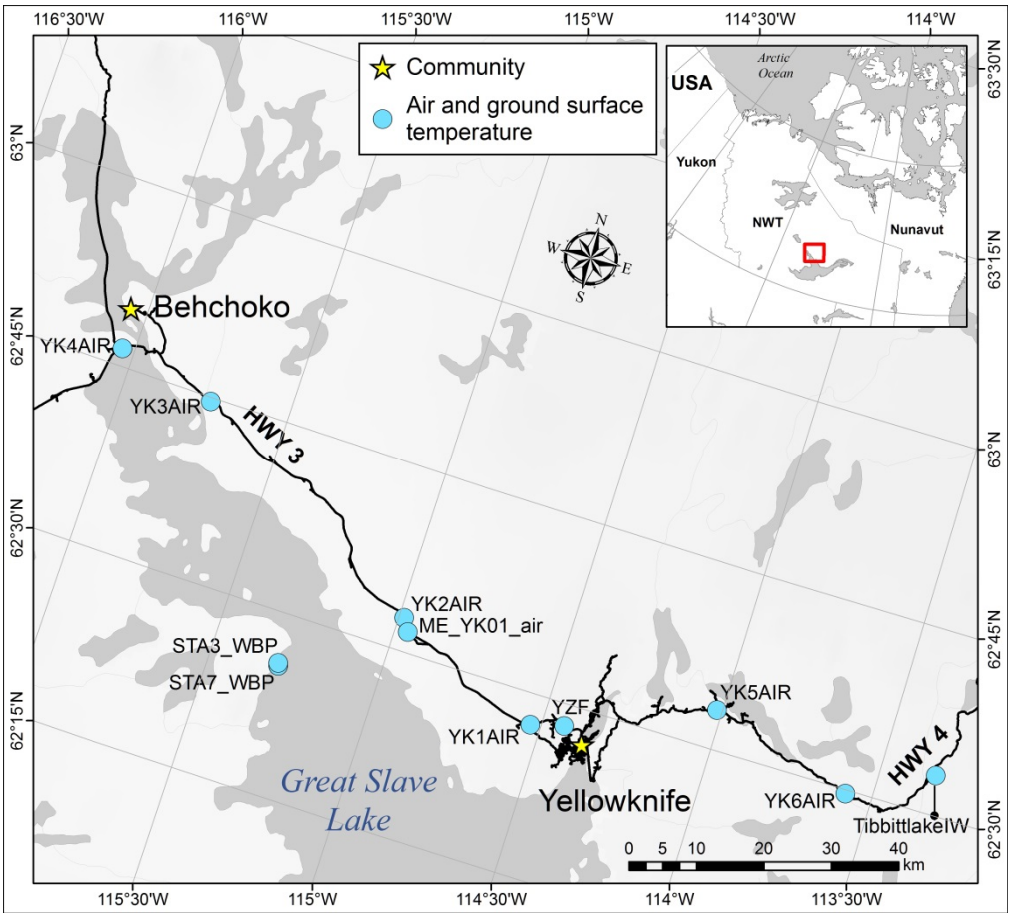


Figure 3. Site locations of air and ground surface temperature installations.

Table 1. Location coordinates and site descriptions of air and ground surface temperature sites.

Site Code	Latitude (°)	Longitude (°)	Site Description	Available Data	Vegetation and Organic[1]	Site Owner
ME_YK01_air	62.5280	-114.9613	Boundary Creek - South side of HWY3	2011-2015	Coniferous - very thick organic	GSC / S. Wolfe
STA3_WBP	62.4284	-115.2952	White Beach Point - Sand Wedge Polygons	2012-2015	No Vegetation - thin organic	GSC / S. Wolfe
STA7_WBP	62.4323	-115.2975	White Beach Point - Blow Out	2012-2015	No Vegetation - thin organic	GSC / S. Wolfe
TibbittlakeIW	62.5549	-113.3371	Tibbitt Lake - IWPolygon2	2014-2015	Coniferous - very thick organic	GSC / P. Morse
YK1AIR	62.4585	-114.5315	HWY3 – North side	2010-2015	Black Spruce - Peatland	GSC / S. Wolfe
YK2AIR	62.5448	-114.9847	HWY3 – North side	2010-2015	Jack Pine - Bedrock Upland	GSC / S. Wolfe
YK3AIR	62.7440	-115.7353	HWY3 – North side	2010-2012	Jack Pine - Bedrock Upland	GSC / S. Wolfe
YK4AIR	62.7741	-116.0370	HWY3 – North side	2010-2011	Black Spruce - Peatland	GSC / S. Wolfe
YK5AIR	62.5539	-114.0160	HWY3 – South side	2010-2015	Black Spruce - Peatland	GSC / S. Wolfe
YK6AIR	62.4955	-113.5792	HWY3 – North side	2010-2015	Black Spruce - Peatland	GSC / S. Wolfe

[2] Organics: Thin (0-10 cm), Moderate (11-40 cm), Thick (41-100 cm), Very Thick (>100 cm).

4.2 Near-surface Ground Temperatures

Near-surface ground temperature installations consisted of four temperature sensors mounted on a probe and separated by 15, 25 and 50 cm such that typical ground temperature measurements were made at 5, 25, 50 and 100 cm depth. The actual measurement depths relative to the surface varied with local conditions. The maximum sensor depth at a site ranged from 0.50 to 3.0 m but was typically 1.0 m. Measurements were made with OnSET HOBO® thermistor strings, with a range of -20°C to 70°C, an accuracy of +/- 0.35°C at 25°C and a resolution of +/- 0.03°C at 25°C. Measurements were recorded with OnSET HOBO® U12 4-channel external input data loggers. Measurements at most sites were recorded every 2 hours, though some sites, and for some years, measurements were recorded every 4 hours.

Most of the near-surface ground temperature measurements were made in the active layer. However, depending upon local surface and ground conditions at a site, permafrost may be absent, in which case the near surface ground temperatures do not, by definition, record active layer temperatures but simply seasonal near surface ground temperatures.

Figure 4 presents the location of the near-surface ground temperature measurement sites and Table 2 provides location coordinates and metadata for these sites. Refer to Appendix C for annual mean temperature graph for sites where data was available for at least 350 days per year. Daily mean temperatures for each site can be found in the accompanying database of CSV files.

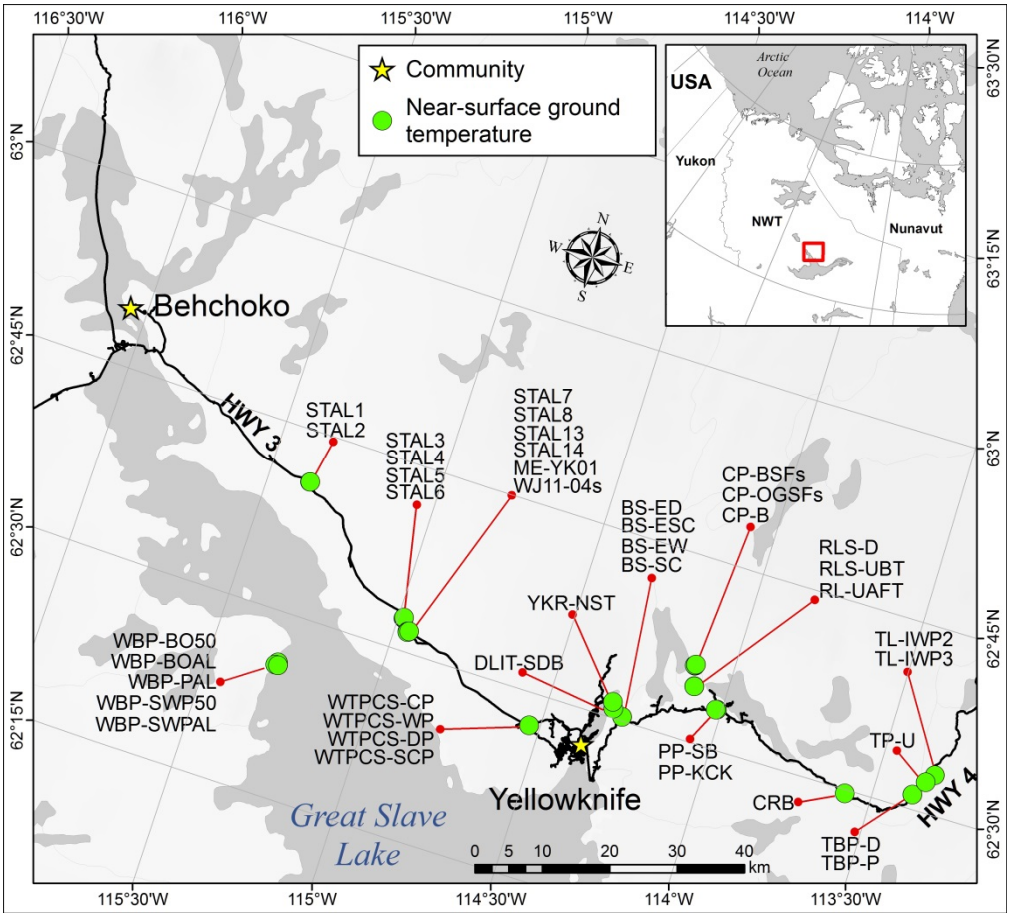


Figure 4. Site locations of near-surface ground temperature installations.

Table 2. Location coordinates and site descriptions of near-surface ground temperature sites.

Site Code	Latitude (°)	Longitude (°)	Site Description	Available Data	Inst. Depth[1]	Vegetation / Organic [2]	Site Owner	Meta ID [3]
BS-ED	62.5063	-114.2771	Birch syrup site experiment - dry	2013-2015	1 m	Broadleaf	NTGS / S. Kokelj	3
BS-ESC	62.5063	-114.2771	Birch syrup site experiment - snow clearing	2013-2015	1 m	Broadleaf	NTGS / S. Kokelj	4
BS-EW	62.5063	-114.2771	Birch syrup site experiment - wet	2013-2015	1 m	Broadleaf	NTGS / S. Kokelj	5
BS-SC	62.5063	-114.2771	Birch syrup site shallow control	2010-2015	1 m	Broadleaf	NTGS / S. Kokelj	2
CP-B	62.6046	-114.1128	Century Pond – Birch	2013	1 m	Broadleaf / Moderate	NTGS / S. Kokelj	73
CP-BSFs	62.6025	-114.1150	Century Pond - burnt spruce forest	2010-2013	1 m	Coniferous	NTGS / S. Kokelj	11
CP-OGSFs	62.6030	-114.1158	Century Pond - old growth spruce forest	2010-2013	1 m	Coniferous	NTGS / S. Kokelj	10
CRB	62.4955	-113.5785	Cameron River Bridge	2011-2015	1 m	Wetland / Very Thick	NTGS / S. Kokelj	46
DLIT-SDB	62.5135	-114.3091	Drained lake site (Ingraham Trail) - shallow dead birch	2010-2011	1 m	Broadleaf	NTGS / S. Kokelj	68

Table 2. (Continued)

Site Code	Latitude (º)	Longitude (º)	Site Description	Available Data	Inst. Depth[1]	Vegetation / Organic [2]	Site Owner	Meta ID [3]
ME-YK01	62.5280	-114.9613	Boundary Creek - South side of HWY3	2011-2015	0.5 m	Coniferous / Very thick	GSC / S. Wolfe	32
PP-KCK	62.5544	-114.0141	Pontoon Peatland KCK	2012-2013	1 m	Coniferous / Very thick	NTGS / S. Kokelj	49
PP-SB	62.5539	-114.0178	Pontoon Peatland Shallow Bedrock	2012-2015	1.6 m	Coniferous / Very thick	NTGS / S. Kokelj	50
RLS-D	62.5755	-114.0989	River Lake Skidoo - Downslope	2011-2013	1 m	Coniferous	NTGS / S. Kokelj	51
RLS-UBT	62.5753	-114.0984	River Lake Skidoo - Upslope beside trail	2011-2013	1 m	Coniferous	NTGS / S. Kokelj	52
RL-UAFT	62.5753	-114.0984	River Lake - Upslope Away From Trail	2011-2012	1 m	Coniferous	NTGS / S. Kokelj	53
STAL1	62.6809	-115.3758	South side of HWY3, pond at edge of embankment	2010-2011	0.65 m	Wetland / None	GSC / S. Wolfe	33
STAL2	62.6811	-115.3752	North side of HWY3	2010-2011	0.9 m	Wetland / None	GSC / S. Wolfe	34
STAL3	62.5431	-114.9836	South side of HWY3	2010-2012	0.65 m	Wetland / None	GSC / S. Wolfe	35
STAL4	62.5434	-114.9843	South side of HWY3	2010-2015	1 m	Broadleaf / Moderate	GSC / S. Wolfe	36
STAL5	62.5436	-114.9834	North side of HWY3	2010-2012	1 m	Shrub / Thin	GSC / S. Wolfe	37
STAL6	62.5443	-114.9834	North side of HWY3	2010-2015	1 m	Coniferous / Moderate	GSC / S. Wolfe	38
STAL7	62.5285	-114.9566	North side of HWY3	2011-2015	1 m	Coniferous / Thin	GSC / S. Wolfe	39
STAL8	62.5279	-114.9605	South side of HWY3	2011-2015	1 m	Wetland / Very Thick	GSC / S. Wolfe	40
STAL13	62.5277	-114.9585	Clay Ridge; South side of HWY3	2011-2014	1 m	Broadleaf / Thin	GSC / S. Wolfe	41
STAL14	62.5271	-114.9606	South side of HWY3	2013-2015	1 m	Broadleaf / Thin	GSC / S. Wolfe	42
TBP-D	62.5205	-113.3851	Tibbitt burned peatland site - Depression	2010-2015	1 m	Wetland	NTGS / S. Kokelj	44
TBP-P	62.5205	-113.3851	Tibbitt burned peatland site - Plateau	2010-2015	1 m	Wetland	NTGS / S. Kokelj	45
TL-IWP2	62.5549	-113.3371	Tibbitt Lake - IWPolygon2	2014-2015	1.5 m	Coniferous / Very Thick	GSC / P. Morse	54
TL-IWP3	62.5549	-113.3371	Tibbitt Lake - IWPolygon3	2014-2015	1.5 m	Coniferous / Very Thick	GSC / P. Morse	55
TP-U	62.5420	-113.3577	Tibbitt peatland site - Undisturbed	2011-2015	1 m	Wetland / Very Thick	NTGS / S. Kokelj	43
WBP-BO50	62.4323	-115.2975	White Beach Point - Blow Out 50cm	2012-2014	0.5 m	No Vegetation / Thin	GSC / S. Wolfe	63
WBP-BOAL	62.4323	-115.2975	White Beach Point - Blow Out AL	2012-2015	1 m	No Vegetation / Thin	GSC / S. Wolfe	62
WBP-PAL	62.4284	-115.3036	White Beach Point - Peatland AL	2013-2015	1 m	Coniferous / Very Thick	GSC / S. Wolfe	58
WBP-SWP50	62.4284	-115.2952	White Beach Point - Sand Wedge Polygons 50cm	2012-2014	0.5 m	No Vegetation / Thin	GSC / S. Wolfe	60
WBP-SWPAL	62.4284	-115.2952	White Beach Point - Sand Wedge Polygons AL	2012-2015	1 m	No Vegetation / Thin	GSC / S. Wolfe	59
WJ11-04s	62.5285	-114.9566	WJ11-04_Shallow; North side of HWY3	2013-2015	3 m	Broadleaf / Thin	GSC / S. Wolfe	30
WTPCS-CP	62.4569	-114.5326	WhiteTruck Peatland Collapse Scar – Control peat	2010-2012	1 m	Coniferous / Very thick	NTGS / M. Palmer	69
WTPCS-WP	62.4569	-114.5326	WhiteTruck Peatland Collapse Scar – Wet peat	2010-2011	1 m	Coniferous / Very thick	NTGS / M. Palmer	70

Table 2. (Continued)

Site Code	Latitude (º)	Longitude (º)	Site Description	Available Data	Inst. Depth[1]	Vegetation / Organic [2]	Site Owner	Meta ID [3]
WTPCS-DP	62.4569	-114.5326	WhiteTruck Peatland Collapse Scar – Dry peat	2010-2011	1 m	Coniferous / Very thick	NTGS / M. Palmer	71
WTPCS-SCP	62.4569	-114.5326	WhiteTruck Peatland Collapse Scar – Snow clear peat	2010-2012	1 m	Coniferous / Very thick	NTGS / M. Palmer	72
YKR-NST	62.5216	-114.3160	Weledeh / YK River CimpYKR_CIMP_5cm Near Surface Ground Temperature	2011-2013	1 m	Coniferous	GSC / S. Wolfe	57

[1] Installation depth in metre.

[2] Organics: Thin (0-10 cm), Moderate (11-40 cm), Thick (41-100 cm), Very Thick (>100 cm).

[3] Refers to metadata unique identifier in Appendix C

4.3 Shallow Ground Temperatures

Twelve boreholes were water-jet drilled in late August 2010, along HWY 3 at proposed test sections locations for highway remediation (site code prefix BGCBH). This drilling program was undertaken by BGC Engineering Inc., GSC and GNWT Department of Transport. The boreholes were located on the highway right-of-way at the toe of the highway embankment and within undisturbed terrain off the right-of-way. All of the boreholes were drilled to refusal on probable bedrock. The average depth to probable bedrock was 6.6 m and ranged from 3.82 to 10.02 m. All but one of the boreholes encountered probable frozen ground at depth, based upon the rate of penetration and difficulty of drilling. The average depth of thaw (measured with a frost probe) at the time of drilling in undisturbed sites was 1.03 m (ranging from 0.38 to 2.0 m) and was 1.62 m (ranging from 0.84 to 2.78 m and with one borehole completely thawed) in disturbed terrain within the highway right-of-way. The general stratigraphy observed in the washed cuttings was clay overlying sand and silt or gravel overlying bedrock. More information on local site conditions and stratigraphy can be found in Wolfe et al. (2011). An additional 14 boreholes were drilled by GSC and NTGS between 2010 and 2015, in undisturbed and naturally disturbed locations. Not all of these boreholes were drilled to refusal.

Shallow ground temperatures were measured with multi-sensor temperature cables installed in the boreholes generally up to 11 m in depth. Data loggers were connected to the temperature cables to record temperatures every 1 to 4 hours and provide a continuous record of ground temperature throughout the year. Sites without data loggers were intermittently read manually. The shallow ground temperature measurements have a resolution of ±0.01°C and an accuracy of ±0.1°C.

Figure 5 presents the location of the shallow ground temperature measurement sites and Table 3 provides location coordinates and metadata for these sites. Refer to Appendix C for annual mean temperature graph for each site where data was available for at least 350 days per year. Daily mean temperatures for each site can be found in the accompanying database of CSV files.

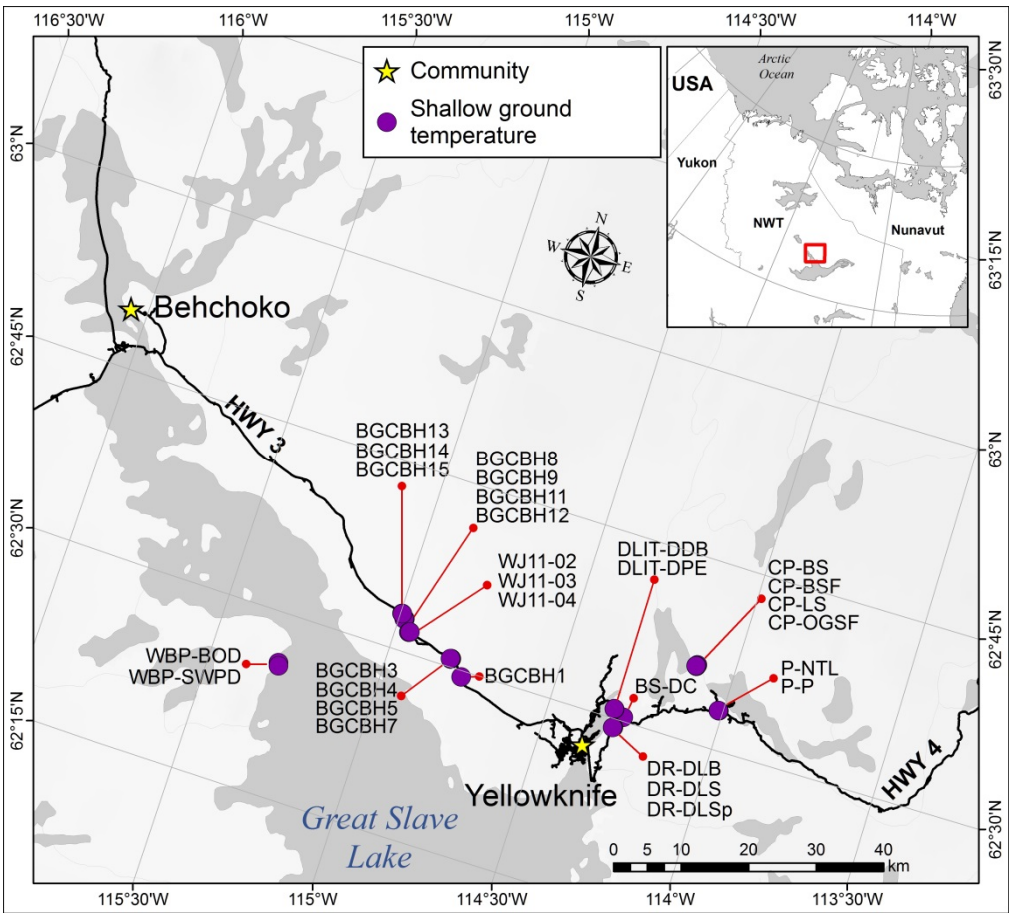


Figure 5. Site locations of shallow ground temperature installations.

Table 3. Location coordinates and site descriptions of ground temperature.

Site Code	Latitude (°)	Longitude (°)	Site Description	Available Data	BH Depth[1]	Vegetation / Organic [2]	Site Owner	Meta ID [3]
BGCBH1	62.4916	-114.7711	Undisturbed	Manual 2013-2015	5.05 m	Shrub / Thick	GSC / S. Wolfe	19
BGCBH3	62.5110	-114.8153	Disturbed ROW	Manual 2010-2015	3.82 m	Herbaceous / None	GSC / S. Wolfe	20
BGCBH4	62.5113	-114.8152	Undisturbed	Manual 2010-2013	6.81 m	Coniferous / moderate	GSC / S. Wolfe	21
BGCBH5	62.5106	-114.8165	Undisturbed	2010-2014	8.5 m	Coniferous / Thin	GSC / S. Wolfe	31
BGCBH7	62.5111	-114.8180	Undisturbed	2011-2015	9.37 m	Coniferous / Thick	GSC / S. Wolfe	25
BGCBH8	62.5435	-114.9829	Disturbed ROW	2010-2014	6.3 m	Shrub / None	GSC / S. Wolfe	16
BGCBH9	62.5434	-114.9827	Undisturbed	2010-2011	5.5 m	Mixed Forest / Thin	GSC / S. Wolfe	17
BGCBH11	62.5435	-114.9841	Disturbed ROW	Manual 2010-2015	7.02 m	Shrub / None	GSC / S. Wolfe	22

Table 3. (Continued)

Site Code	Latitude (º)	Longitude (º)	Site Description	Available Data	BH Depth[1]	Vegetation / Organic [2]	Site Owner	Meta ID [3]
BGCBH12	62.5433	-114.9845	Undisturbed	Manual 2010-2015	8.06 m	Mixed Forest/ Moderately Thick	GSC / S. Wolfe	23
BGCBH13	62.5497	-114.9959	Undisturbed	Manual 2010-2015	5.22 m	Shrub / None	GSC / S. Wolfe	24
BGCBH14	62.5497	-114.9955	Disturbed ROW	2010-2014	6.42 m	Wetland	GSC / S. Wolfe	18
BGCBH15	62.5494	-114.9948	Undisturbed	2011-2015	6.48 m	Coniferous / None	GSC / S. Wolfe	26
BS-DC	62.5063	-114.2771	Birch syrup site deep cable	2010-2015	10 m	Broadleaf	NTGS / S. Kokelj	1
CP-LS	62.6033	-114.1153	Century Pond - lakeshore	2010-2013	10 m	Coniferous	NTGS / S. Kokelj	9
DLIT-DDB	62.5135	-114.3091	Drained lake site (Ingraham Trail) - deep in dead birch	2012-2013	5.15 m	Broadleaf	NTGS / S. Kokelj	66
DLIT-DPE	62.5136	-114.3099	Drained lake site (Ingraham Trail) - deep pond edge	2012-2013	7.9 m	Wetland / Very thick	NTGS / S. Kokelj	65
DR-DLB	62.4892	-114.2962	Dettah Road DL Bottom; drained lake basin	Manual 2015	7.7 m	No Vegetation	GSC / P. Morse	12
DR-DLS	62.4888	-114.2977	Dettah Road DL Shoreline; lake shoreline prior to drainage	2013-2014	5.3 m	n/a	GSC / P. Morse	13
DR-DLSp	62.4885	-114.2981	Dettah Road DL Spruce; Hummocky closed spruce forest	2013-2015	7.5 m	Coniferous	GSC / P. Morse	14
P-NTL	62.5537	-114.0122	Pontoon Nearshore Thaw Lake; peatland edge, adjacent to thaw pond, shallow, wet, standing dead spruce trees	2010-2013	10 m	Coniferous / Very Thick	NTGS / S. Kokelj	47
P-P	62.5537	-114.0136	Pontoon Peatland (STA5)	2010-2012	2.5 m	Coniferous / Very Thick	NTGS / S. Kokelj	48
WBP-BOD	62.4327	-115.2982	White Beach Point - Blowout Deep	2014-2015	3.4 m	No Vegetation /	GSC / S. Wolfe	64
WBP-SWPD	62.4284	-115.2952	White Beach Point - Sand Wedge Polygons Deep	2014-2015	4.4 m	No Vegetation / Thin	GSC / S. Wolfe	61
WJ11-02	62.5280	-114.9592	South side of HWY3	2011-2015	10.3 m	Broadleaf / Thin	GSC / S. Wolfe	27
WJ11-03	62.5279	-114.9594	South side of HWY3	2011-2015	10.3 m	Broadleaf / Thin	GSC / S. Wolfe	28
WJ11-04	62.5285	-114.9566	North side of HWY3	2011-2015	11.5 m	Broadleaf / Thin	GSC / S. Wolfe	29

[1] Borehole depth in metres.

[2] Organics: Thin (0-10 cm), Moderate (11-40 cm), Thick (41-100 cm), Very Thick (>100 cm).

[3] Refers metadata unique identifier in Appendix C

5 DATABASE STRUCTURE

The temperature record acquired from data loggers was checked visually and any irregular data were removed from the record. Daily averages were then calculated for days with a complete record. An accompanying database presents data in comma delimited format. Each parameter measured is located in separate directory. The file name convention refers to the site code (see table 1-3). The following section provides a description of field for mean daily.

Directories:

\data\Air_ground	Air and ground surface temperature
\data\Near_surface	Near-surface temperature
\data\Shallow	Shallow ground temperature

Filename convention: SiteCode.csv

Heading	Description
Site Code:	Unique site code
Date:	Date field (yyyy-mm-dd)
T at D X m (Celsius):	Daily mean Temperature (ºC) at specified Depth X in metres[abc]

[a] For sites with manual reading, value represents a singular reading at the specified date and depth.
[b] #N/A indicates that no values were available for that day.
[c] Some sites can have two sensors located at same depths.

6 SUMMARY

This report provides an overview of all thermal investigations of permafrost undertaken collaboratively with the Great Slave TRACS activity in the Climate Change Geoscience Program for 2010-2015. The information provided herein form a public release of data collected in the activity to date, and will be used in order to fulfill the three focus themes of the activity, including: i) development permafrost maps for the area, ii) release of new geoscience information pertaining to permafrost geothermal and geotechnical conditions, and iii) risk assessments and sensitivity analysis of permafrost terrain and transportation infrastructure. Further, this report serves to demonstrate the reporting standards established by the NWT Permafrost Database project for ground temperature data (Appendices A and B).

ACKNOWLEDGEMENTS

A number of personnel from various organizations are thanked for their assistance with permafrost field activities in 2010-2015, including Mark Ednie GSC, Steve Schwarz and Michael Palmer GNWT ENR, Kumari Karunaratne, Landen Powell and Sarah Gervais GNWT NTGS, Stefan Goodman AANDC, Silvio Pastore and Jan Stirling BGC Engineering Inc., Christopher Stevens SRK Consulting, Adrian Gaanderse, and Dan Fehr. Data presented in Appendix B were compiled by Timothy Ensom of Golder and Associates, Yellowknife. This Open File further benefitted from thoughtful review by Anne-Marie Leblanc of the GSC and Kumari Karunaratne of NTGS.

REFERENCES

Aspler, L. 1978. Surficial geology, permafrost and related engineering problems, Yellowknife area, part of 85J/8; EGS 1978-08, NWT Geology Division, Indian and Northern Affairs Canada, Yellowknife, text and one map, 16 p., scale 1: 6,000.

Ecosystem Classification Group (2007), Ecological Regions for the Northwest Territories – Taiga Plains, Department of Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NWT, Canada, viii + 149 p. + insert map.

EBA Engineering Consultants Limited. 1995. Yellowknife Highway (No. 3), N.W.T. km 242 to km 256, Preliminary Geotechnical Evaluation. Report 0701-95-11776, 130 p.

Gaanderse, A. 2011. Seasonal Thaw Depths in Relation to Surficial Characteristics in the Taiga Shield High Boreal Ecoregion Surrounding Yellowknife, Northwest Territories. BSc Thesis, Department of Geography and Environmental Studies, Carleton University, 59 p.

Heginbottom, J.A., Dubreuil, M.A., and Harker, P.A. 1995. Canada-Permafrost, in National Atlas of Canada, 5th ed., MCR 4177, Plate 2.1, National Atlas Information Service, Natural Resources Canada, Ottawa, ON.

Morse, P.D., Wolfe, S.A., Kokelj, S.V., and Gaanderse, A.J. 2015. The Occurrence and Thermal Disequilibrium State of Permafrost in Forest Ecotopes of the Great Slave Region, Northwest Territories, Canada. Permafrost and Periglacial Processes, 27: 145-162. doi: 10.1002/ ppp.1858.

Lemmen, D.S., Duk-Rodkin, A., and Bednarski, J.M. 1994. Late glacial drainage systems along the northwest margin of the Laurentide ice sheet. Quaternary Science Reviews, 13: 805-828.

Smith, D.G. 1994. Glacial Lake McConnell paleogeography, age, duration, and associate river deltas, Mackenzie River Basin, western Canada. Quaternary Science Reviews, 13: 829-843.

Wolfe, S.A. (Ed.) 1998. Living with Frozen Ground: a field guide to permafrost in Yellowknife, Northwest Territories. Geological Survey of Canada, Miscellaneous Report 64 , 71 p.

Wolfe, S.A., Duchesne, C., Gaanderse, A., Houben, A.J., D'Onofrio, R.E., Kokelj, S.V., and Stevens, C.W. 2011. Report on 2010–2011 Permafrost Investigations in the Yellowknife area, Northwest Territories; Geological Survey of Canada, Open File 6983; Northwest Territories Geoscience Office, NWT Open Report 2011-009, 1 CD-ROM. doi: 10.4095/289596.

Wolfe, S.A., and Morse, P.D. 2016. Lithalsa Formation and Holocene Lake-Level Recession, Great Slave Lowland, Northwest Territories. Permafrost and Periglacial Processes, (available in Early View online). doi: 10.1002/ppp.1901.

APPENDIX A – NWT PERMAFROST DATABASE: PERMAFROST GROUND TEMPERATURE REPORT

Title: Permafrost Ground Temperature Report: *Permafrost Thermal Investigations in the Yellowknife Area, Northwest Territories, 2010-2015*

First Author: *Caroline Duchesne*
First Author Affiliation: *Geological Survey of Canada, 601 Booth Street, Ottawa, ON*

Second Author: *Peter D. Morse*
Second Author Affiliation: *Geological Survey of Canada, 601 Booth Street, Ottawa, ON*

Third Author: *Stephen A. Wolfe*
Third Author Affiliation: *Geological Survey of Canada, 601 Booth Street, Ottawa, ON*

Fourth Author: *Steven V. Kokelj*
Fourth Author Affiliation: *Northwest Territories Geological Survey, 4601-B 52 Avenue, Yellowknife, NWT*

Introduction

Stephen Wolfe and Peter Morse of Natural Resources Canada (NRCan) and Steven Kokelj of Northwest Territories Geological Survey (NTGS) conducted a field initiative to collect baseline geoscience data in support of the land-based transportation project in the Climate Change Geoscience Program (NRCan). The present initiative is focused on addressing transportation risk in the arctic to climatic sensitivity (TRACS) in the Great Slave region. The primary objective of this report is to present data collected between 2010 and 2015 in collaboration with Environment and Conservation Division of Aboriginal Affairs and Northern Development Canada, Government of the Northwest Territories Department of Transportation and Department of Environment and Natural Resources, and BGC Engineering Inc.

Ground temperature data collected from a variety of undisturbed and disturbed sites allow fulfillment of the three focus themes of the TRACS activity, including: i) development permafrost maps for the area, ii) release of new geoscience information pertaining to permafrost geothermal and geotechnical conditions, and iii) risk assessments and sensitivity analysis of permafrost terrain and transportation infrastructure. These data have been compiled and reported as a part of the NWT Permafrost Database project. The data published herein are available for Unrestricted Data Usage.

Data Collection Approach

Several field sites were established and instrumented from 2010 to 2014 to collect data used to characterize the ground thermal regime in this region. Most of these sites were located along the Highway 3 and Highway 4 corridors between Behchoko, Yellowknife and Tibbitt Lake. Some of the site initial installation and description can be found in Wolfe et al. (2011). Data collected include near-surface and shallow ground temperatures.

Air and ground surface temperature sites were instrumented with a dual-channel data logger (OnSet U23 HOBO® Pro v2), the first temperature sensor mounted within a radiation shield at 1.2 m height and the second sensor at a nominal depth of 5 cm below the ground surface. The factory calibrated temperature sensors have a range of -40°C to 70°C, an accuracy of +/-0.5°C and a resolution of 0.02°C from 0 to 25°C.

Ground temperatures are measured with multi-sensor temperature cables installed in boreholes generally up to 11 m in depth, frequently to the depth of refusal (bedrock). RBR Concerto® or XR-420® data loggers connected to factory calibrated thermistor cables allowing a resolution of ±0.01°C and an accuracy of ±0.1°C.

Ground Temperature Record
Periods of record range from one to five years, between 2010 and 2015. Most sites were visited at least once a year and have a continuous data records. Some sites are discontinuous due to equipment malfunction or damage. In most cases, near-surface temperatures have been recorded continuously at one hour intervals, though some sites and for some years the data were recorded at two hour intervals. Shallow ground temperatures are recorded by data loggers that measure temperatures every one to four hours and provide a continuous record of ground temperature throughout the year. Site without data loggers are intermittently read manually. At present, data collection, care and maintenance of these sites are ongoing.

Site Conditions
Sites 2 to 5 are part of an experimental site investigating the effects of soil moisture on ground temperatures. Sites 16 to 26 and 31 were drilled in late August 2010, in locations of proposed test sections for highway remediation, undertaken by BGC Engineering Inc. and GNWT Department of Transport. The boreholes were located on the highway right-of-way at the toe of the highway embankment and within undisturbed terrain off the right-of-way. All of the boreholes were drilled to refusal on probable bedrock. Sites 58 to 64 were established to examine the thermal regime of unconsolidated, coarse-grained materials. Remaining sites were established to determine ground thermal regimes of sites representative of the variable sites conditions within the study region.

Available Supplementary Data
Supplementary data on vegetation conditions, soil pit results, snow depth, and climate data are available from Wolfe et al. (2011) and Morse et al. (2015a).

References

Morse, P.D., Wolfe, S.A., Kokelj, S.V., and Gaanderse, A.J. 2015a. The Occurrence and Thermal Disequilibrium State of Permafrost in Forest Ecotopes of the Great Slave Region, Northwest Territories, Canada. Permafrost and Periglacial Processes, (Published online in Wiley Online Library). doi: 10.1002/ ppp.1858.

Morse, P.D., Wolfe, S.A., Kokelj, S.V., and Gaanderse, A.J. 2015b. Permafrost occurrence in subarctic forests of the Great Slave region, Northwest Territories, Canada. 7th Canadian Conference on Permafrost, 20 – 23 September 2015, Québec, QC. Paper No. 113.

Wolfe, S.A., Duchesne, C., Gaanderse, A., Houben, A.J., D'Onofrio, R.E., Kokelj, S.V., and Stevens, C.W. 2011. Report on 2010–2011 Permafrost Investigations in the Yellowknife area, Northwest Territories; Geological Survey of Canada, Open File 6983; Northwest Territories Geoscience Office, NWT Open Report 2011-009, 1 CD-ROM. doi:10.4095/289596

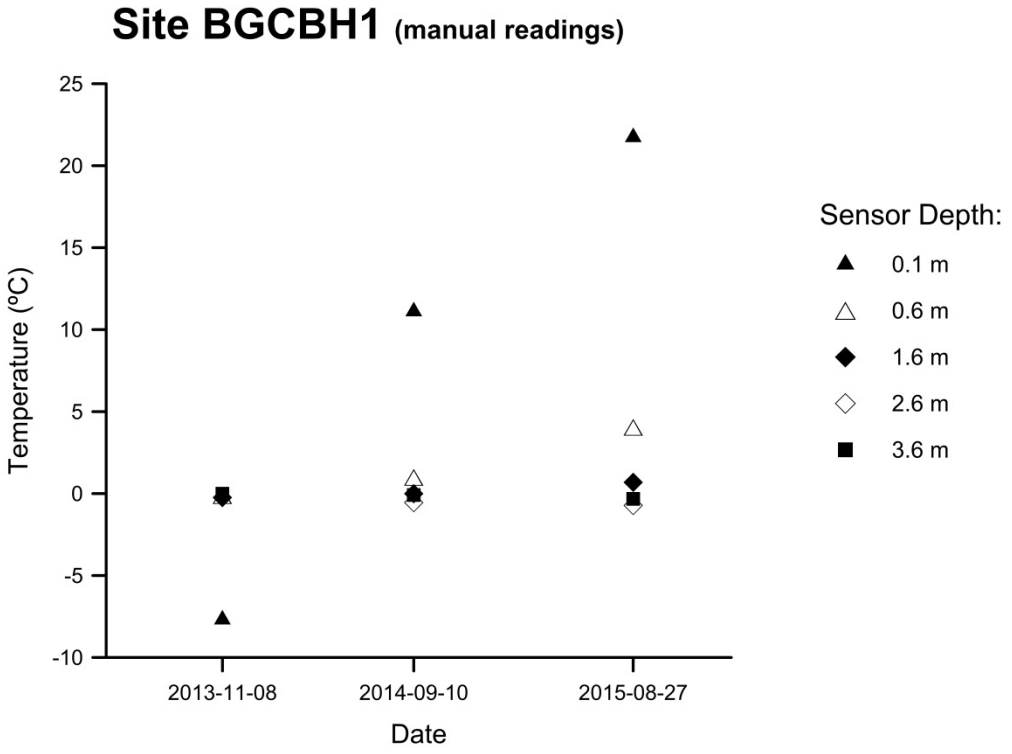
Wolfe, S.A., Morse, P.D., Hoeve, E., Sladen, W., Kokelj, S.V., and Arenson, L. 2015. Disequilibrium permafrost conditions on NWT Highway 3. 7th Canadian Conference on Permafrost, 20 – 23 September 2015, Québec, QC. Paper No. 115.

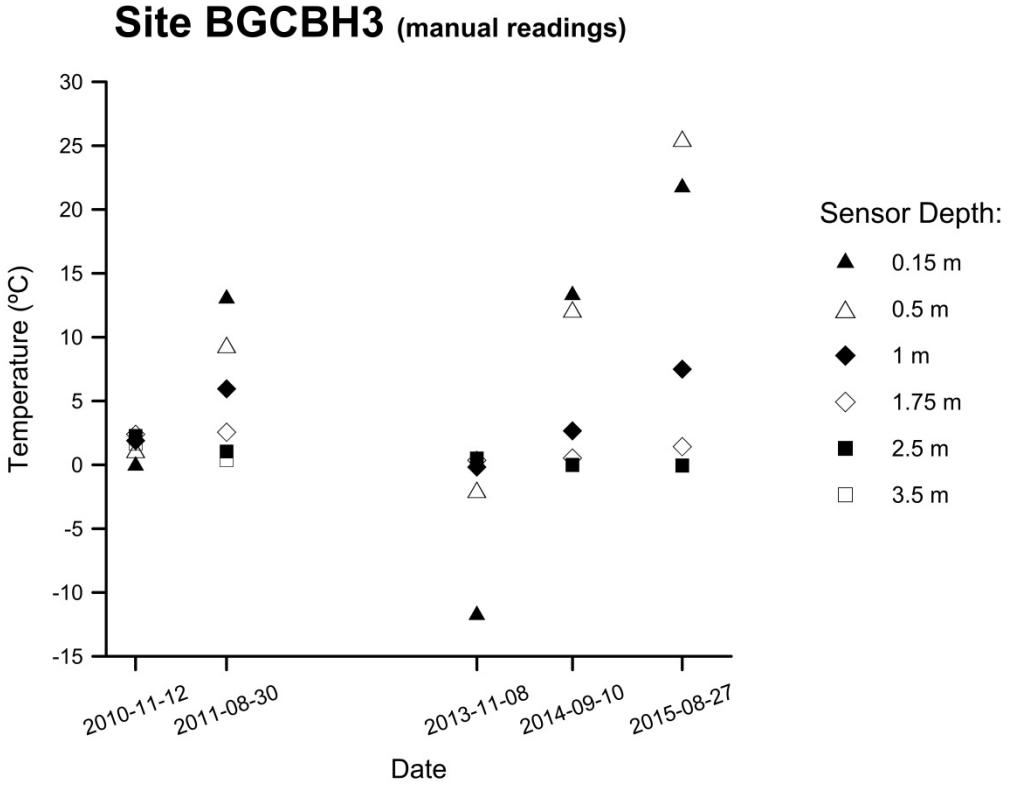
APPENDIX B – NWT PERMAFROST METADATA AND RAW DATA

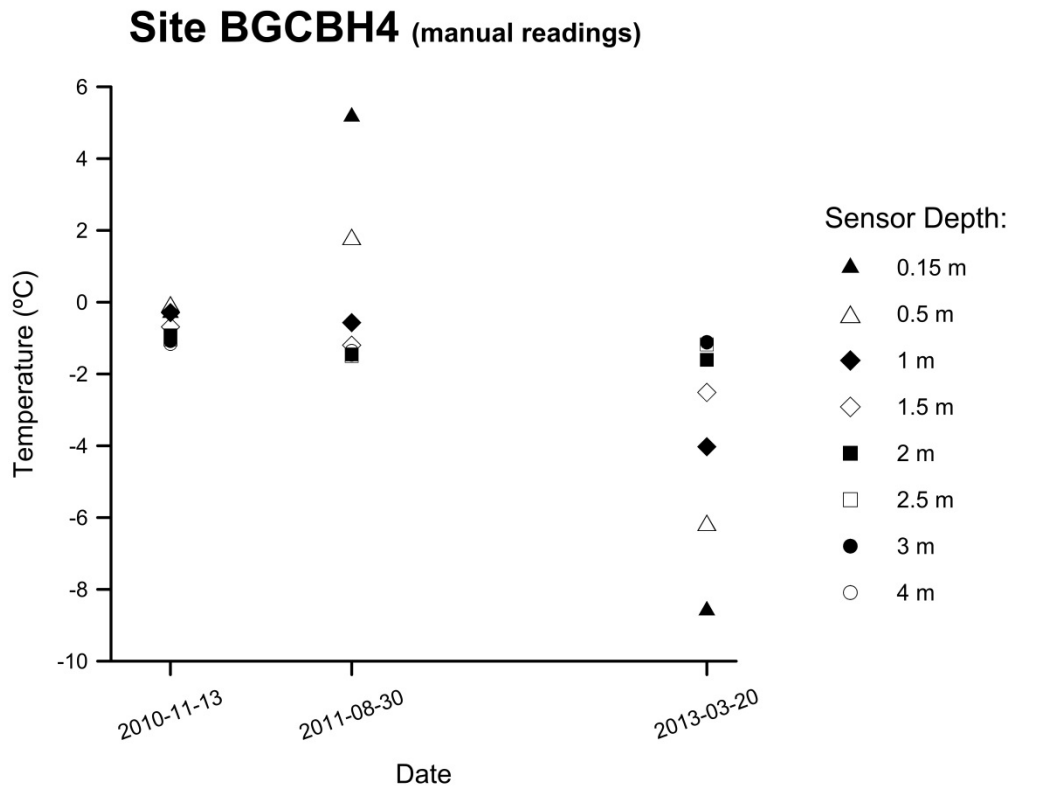
See “Open_Report_Metadata-Raw_Data.xlsx” located in root of the data directory included with this Open File/Open Report.

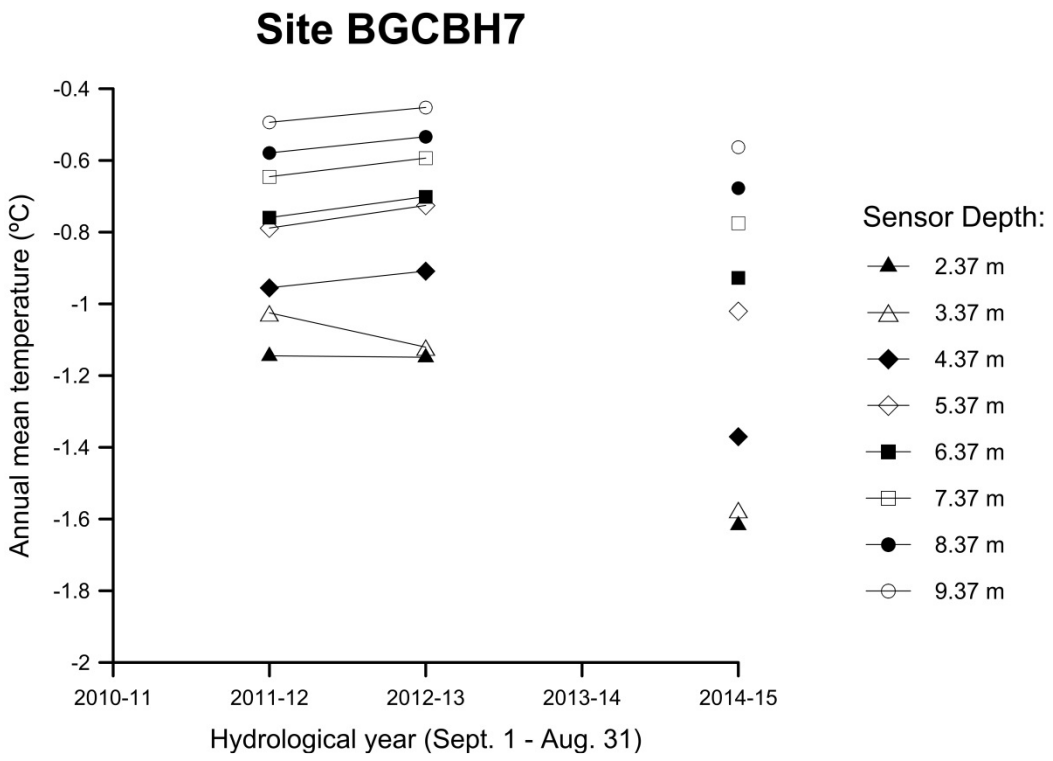
Data compiled by Timothy Ensom of Golder and Associates, Yellowknife.

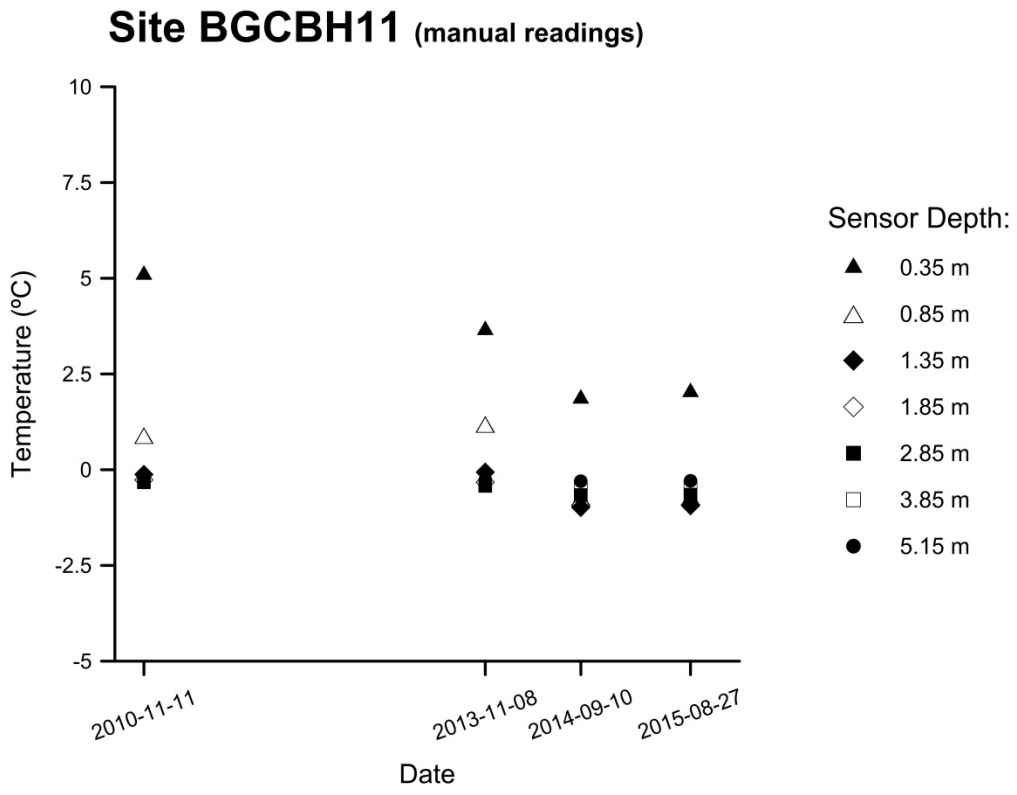
APPENDIX C – GRAPHICAL PRESENTATION OF ANNUAL MEAN TEMPERATURE
(Sorted alphabetically)

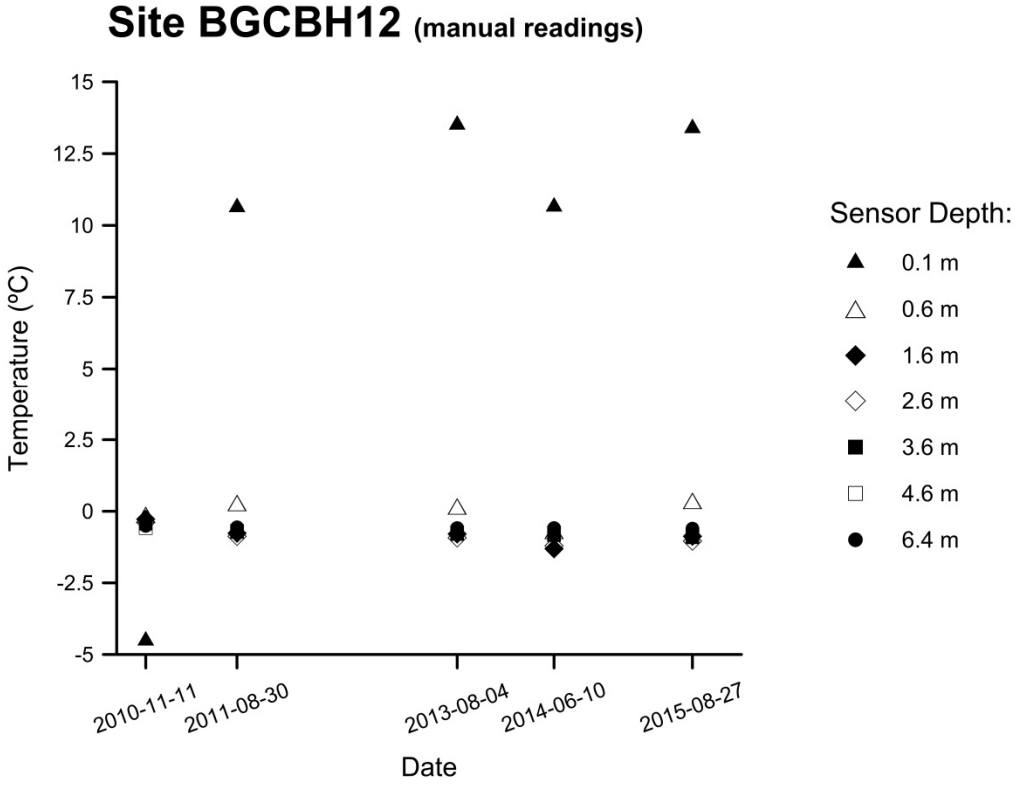


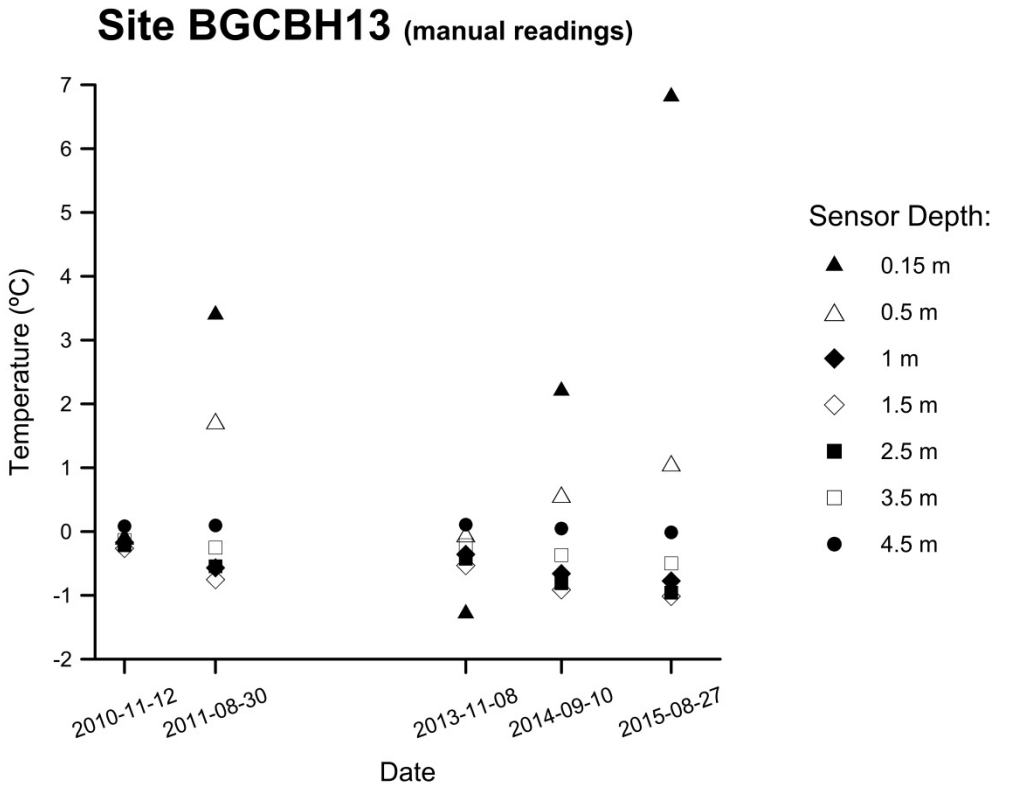


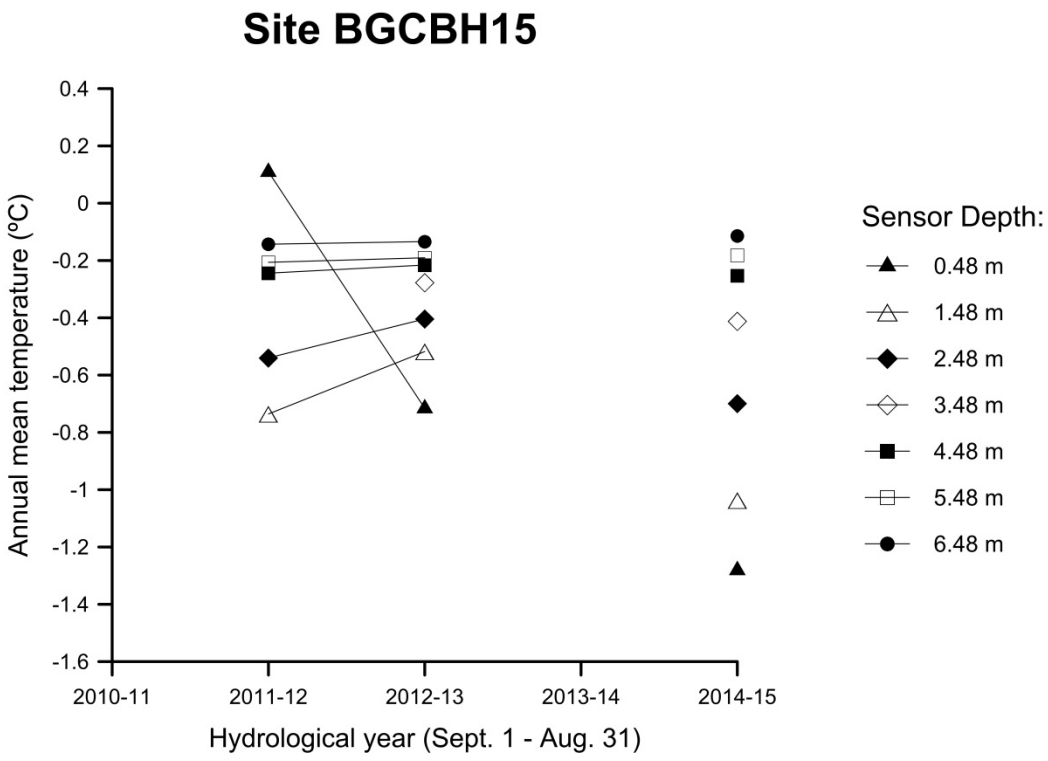

Site BGCBH4 (manual readings)
Temperature (ºC)
6
4
2
0
-2
-4
-6
-8
-10
2010-11-13
2011-08-30
2013-03-20
Date
Sensor Depth:
0.15 m
0.5 m
1 m
1.5 m
2 m
2.5 m
3 m
4 m

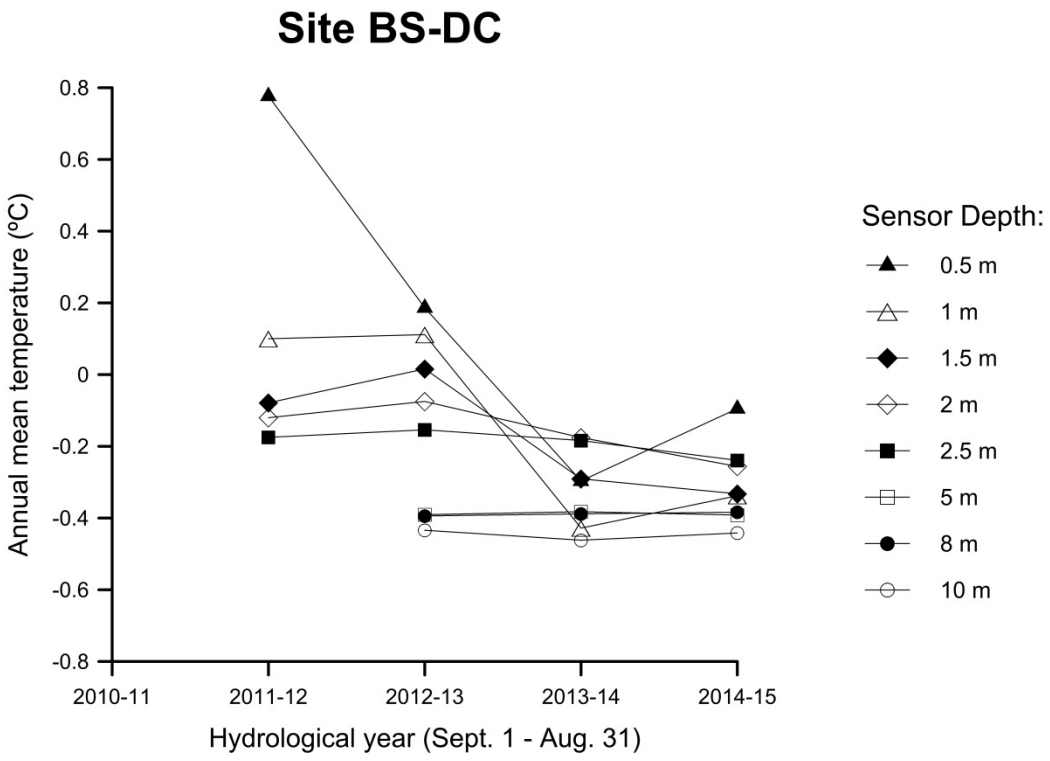

Site BGCBH7
Annual mean temperature (ºC)
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
2.37 m
3.37 m
4.37 m
5.37 m
6.37 m
7.37 m
8.37 m
9.37 m

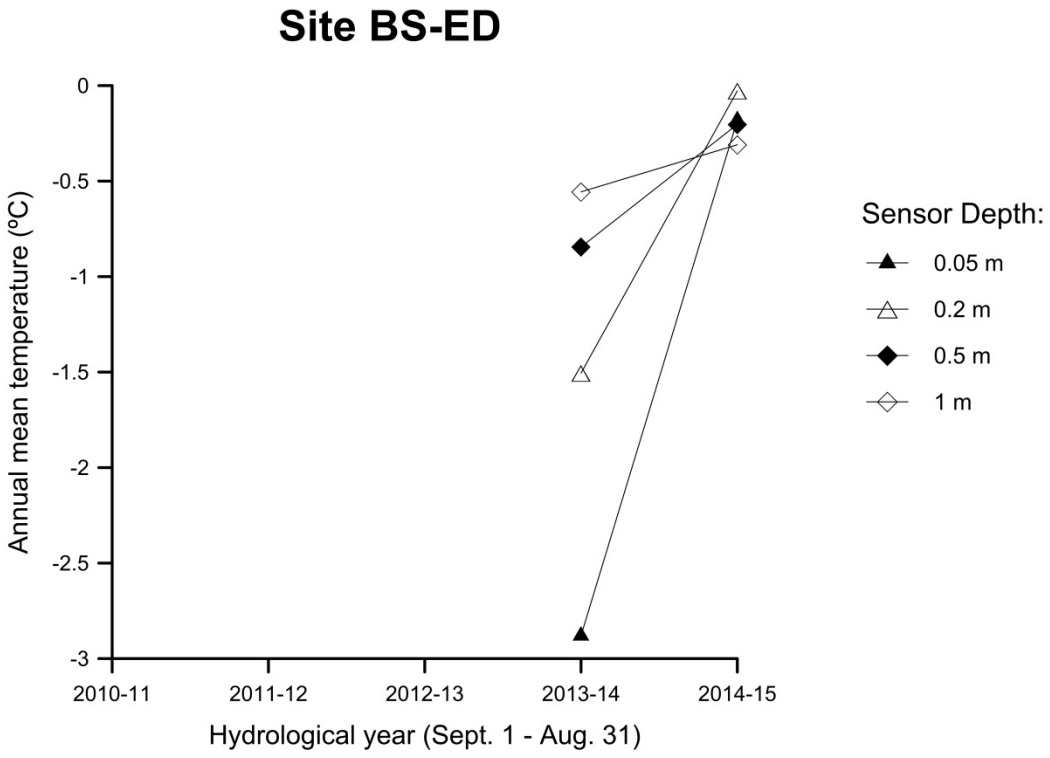

Site BGCBH11 (manual readings)
Temperature (ºC)
10
7.5
5
2.5
0
-2.5
-5
2010-11-11
2013-11-08
2014-09-10
2015-08-27
Date
Sensor Depth:
0.35 m
0.85 m
1.35 m
1.85 m
2.85 m
3.85 m
5.15 m

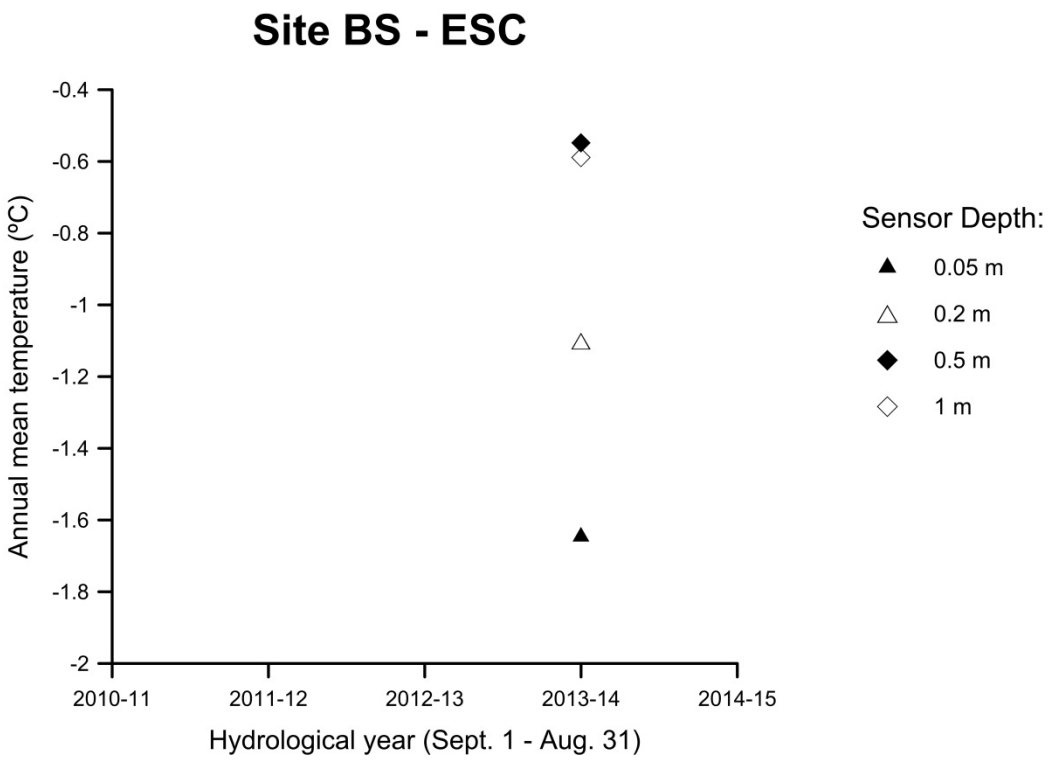

Site BGCBH12 (manual readings)
Temperature (ºC)
15
12.5
10
7.5
5
2.5
0
-2.5
-5
2010-11-11
2011-08-30
2013-08-04
2014-06-10
2015-08-27
Date
Sensor Depth:
0.1 m
0.6 m
1.6 m
2.6 m
3.6 m
4.6 m
6.4 m

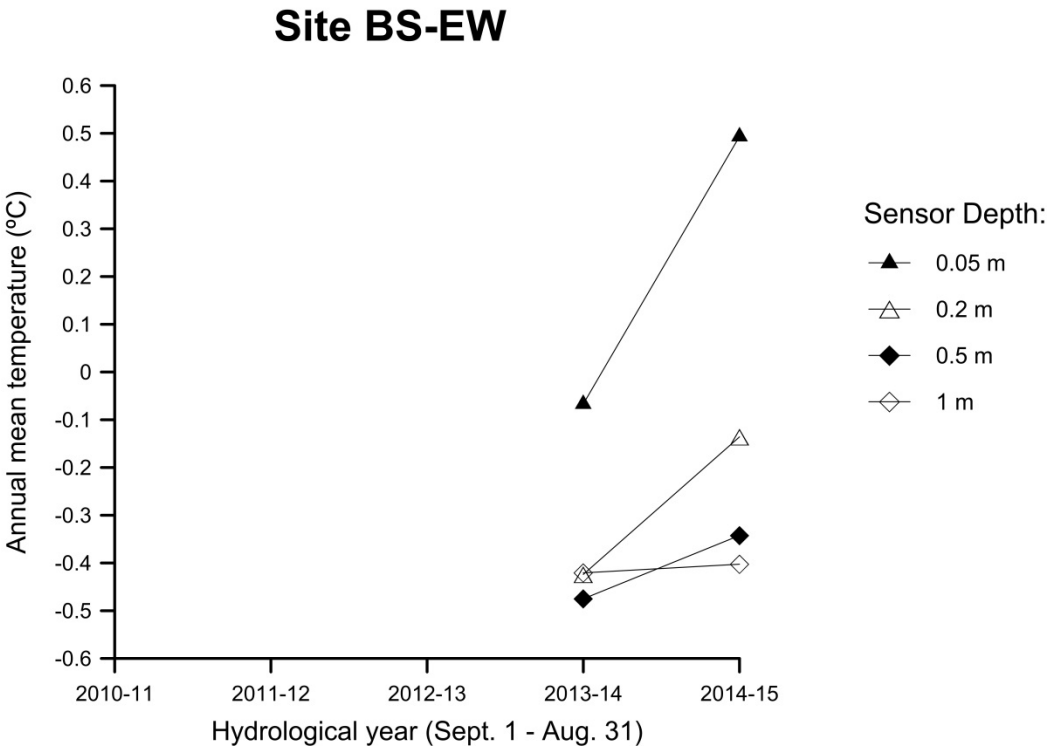

Site BGCBH13 (manual readings)
Temperature (ºC)
7
6
5
4
3
2
1
0
-1
-2
2010-11-12
2011-08-30
2013-11-08
2014-09-10
2015-08-27
Date
Sensor Depth:
0.15 m
0.5 m
1 m
1.5 m
2.5 m
3.5 m
4.5 m

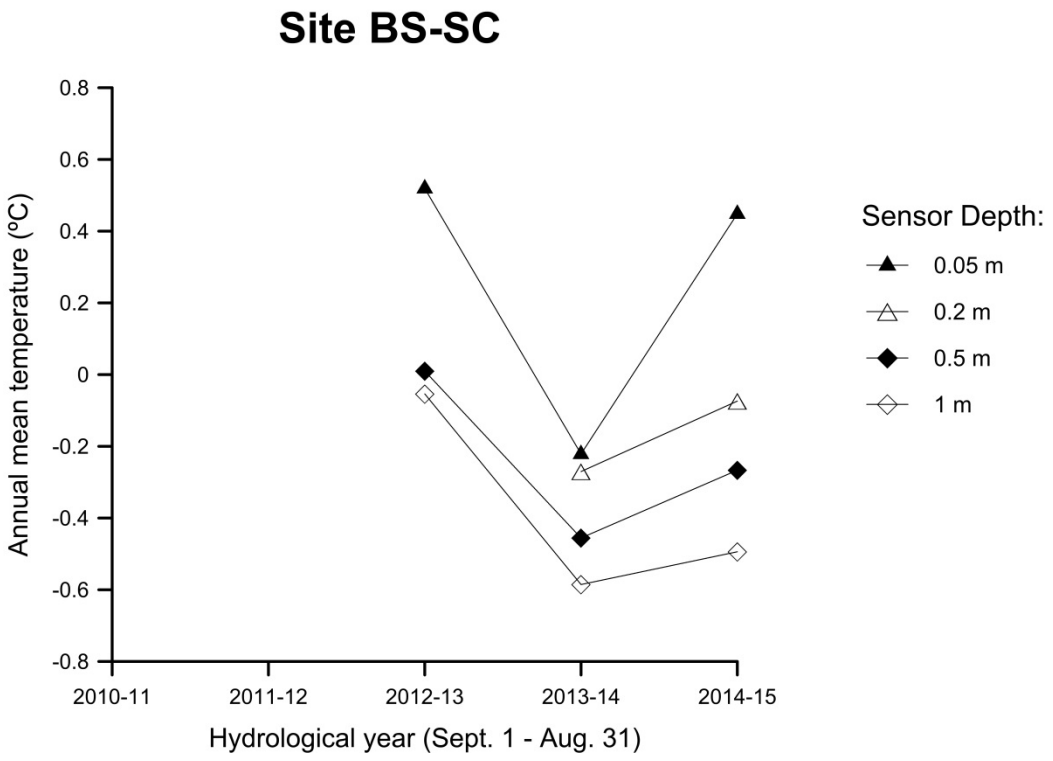

Site BGCBH15
Annual mean temperature (ºC)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.48 m
1.48 m
2.48 m
3.48 m
4.48 m
5.48 m
6.48 m

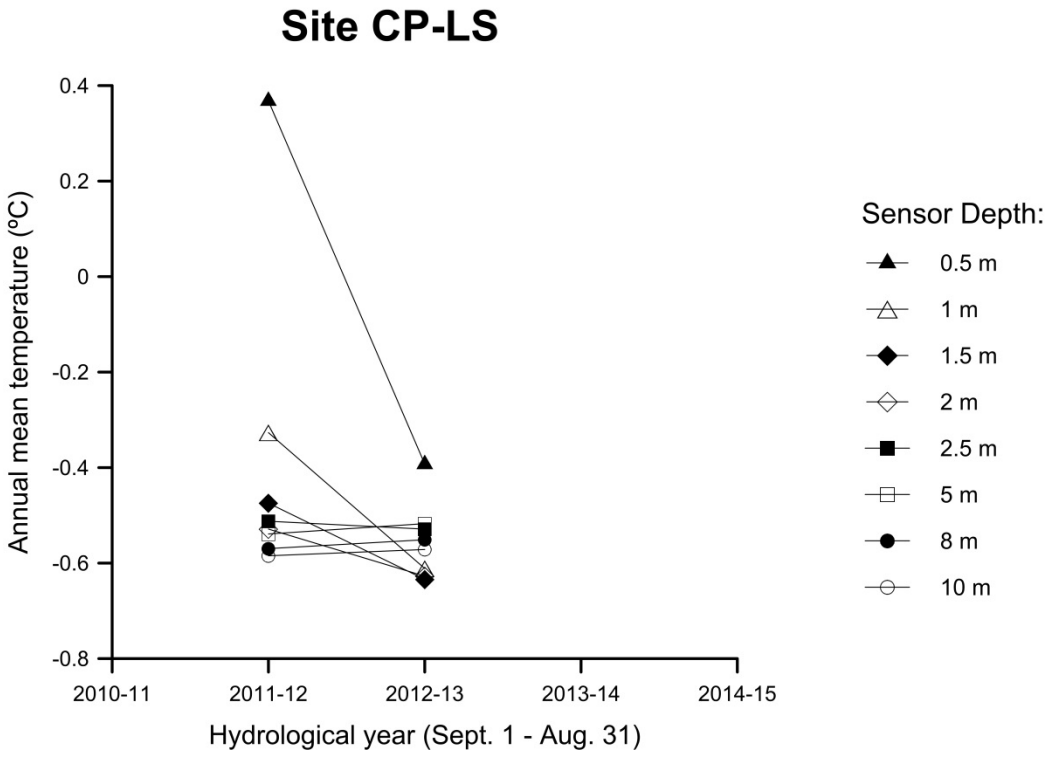

Site BS-DC
Annual mean temperature (ºC)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m
1 m
1.5 m
2 m
2.5 m
5 m
8 m
10 m

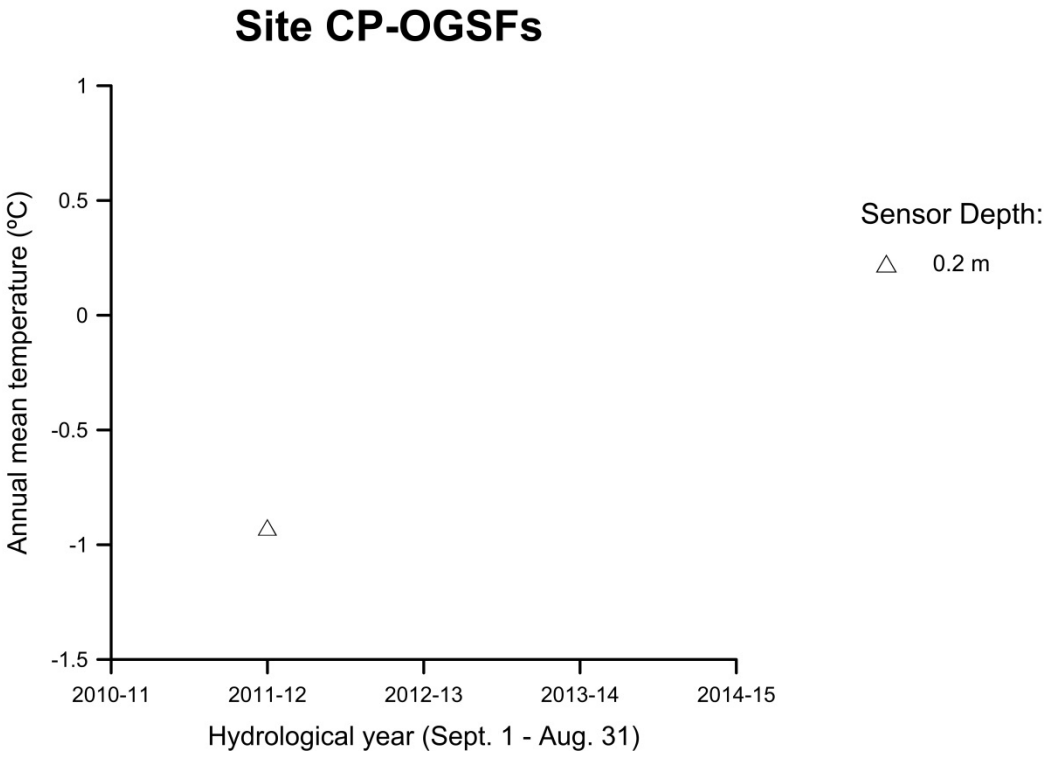

Site BS-ED
Annual mean temperature (ºC)
0
-0.5
-1
-1.5
-2
-2.5
-3
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

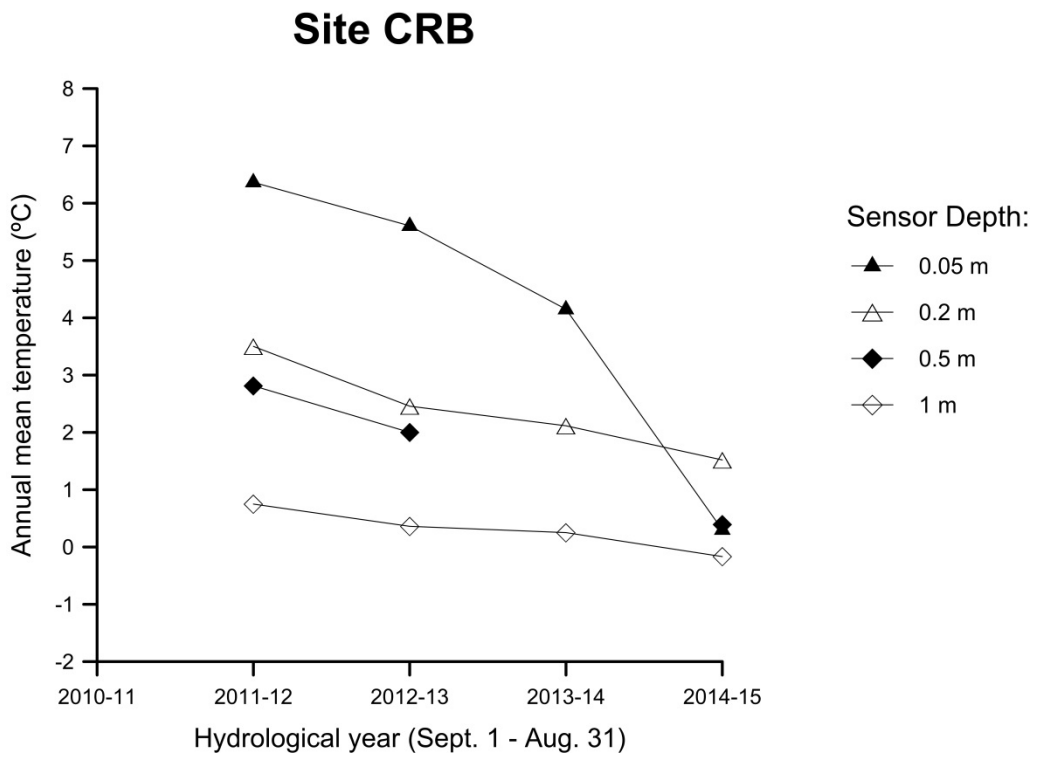

Site BS - ESC
Annual mean temperature (ºC)
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

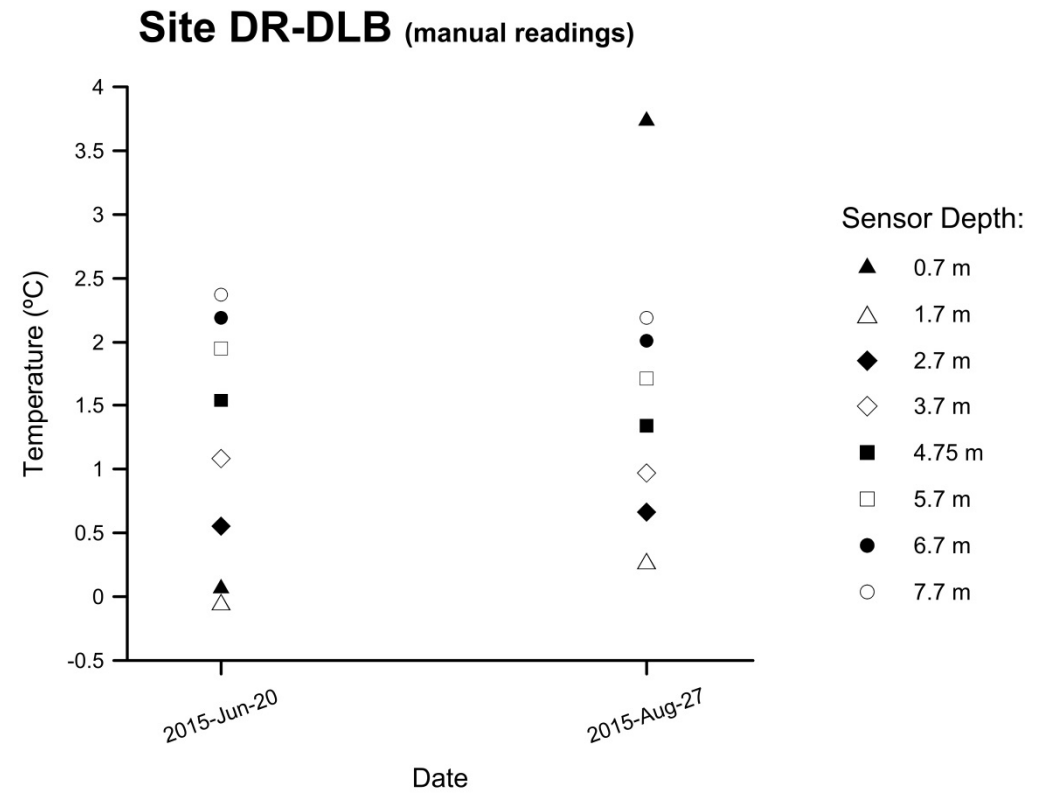

Site BS-EW
Annual mean temperature (ºC)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

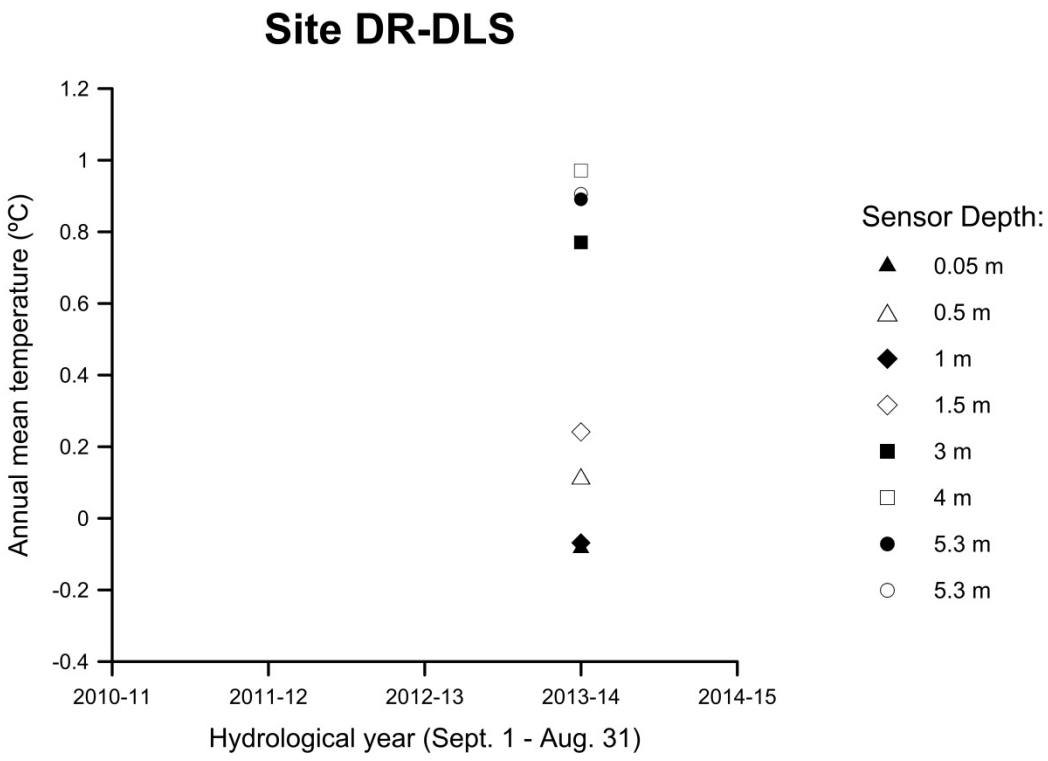

Site BS-SC
Annual mean temperature (ºC)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

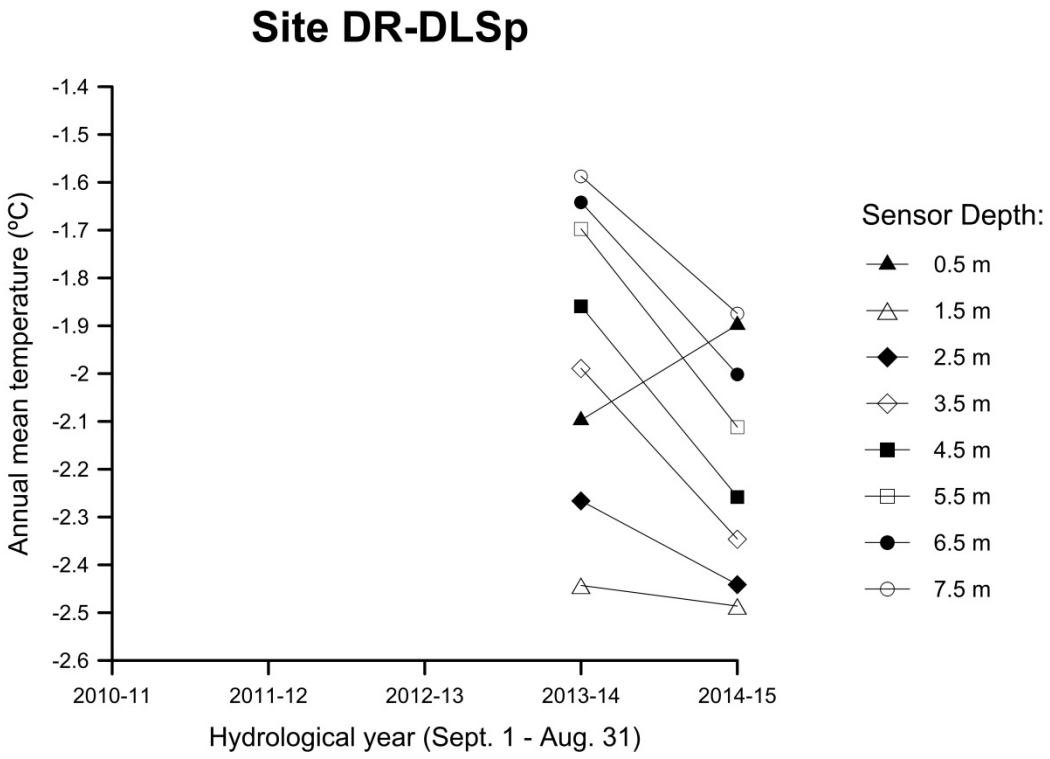

Site CP-LS
Annual mean temperature (ºC)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m
1 m
1.5 m
2 m
2.5 m
5 m
8 m
10 m

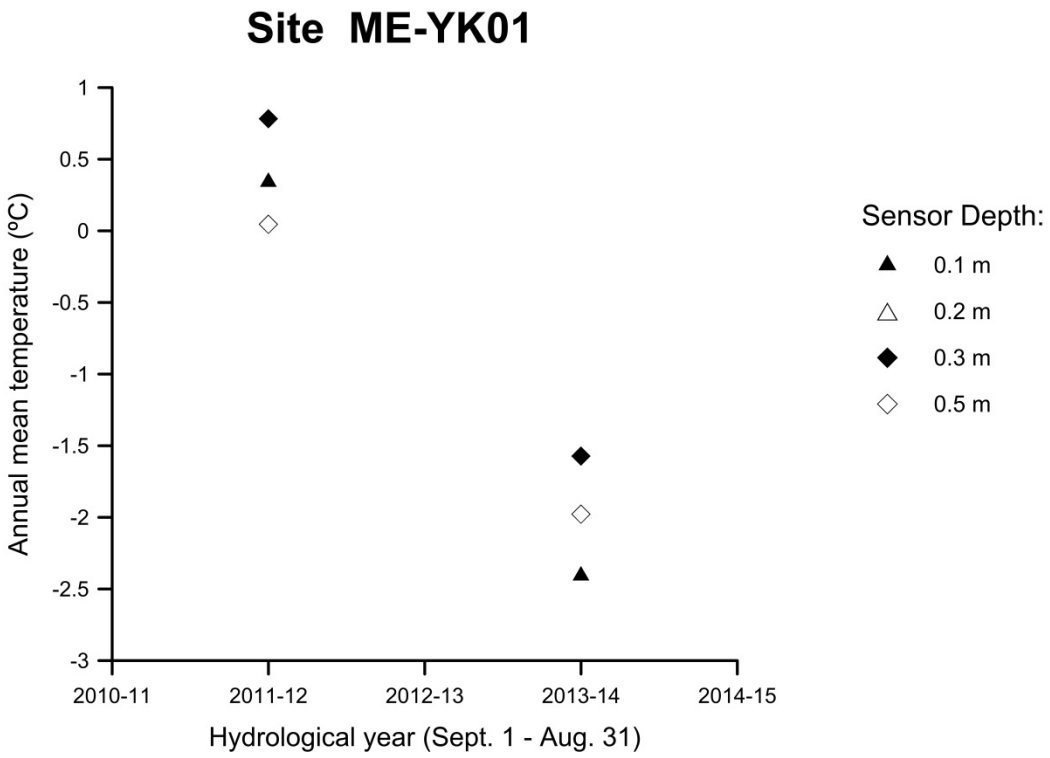

Site CP-OGSFs
Annual mean temperature (ºC)
1
0.5
0
-0.5
-1
-1.5
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.2 m

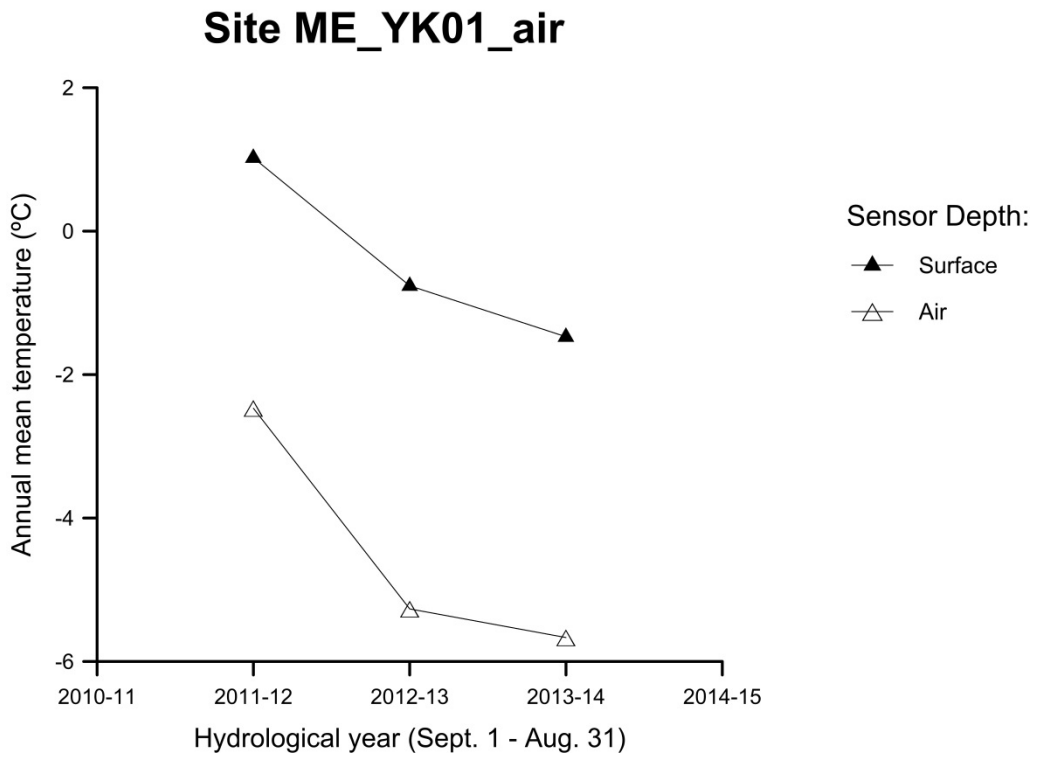

Site CRB
Annual mean temperature (ºC)
8
7
6
5
4
3
2
1
0
-1
-2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

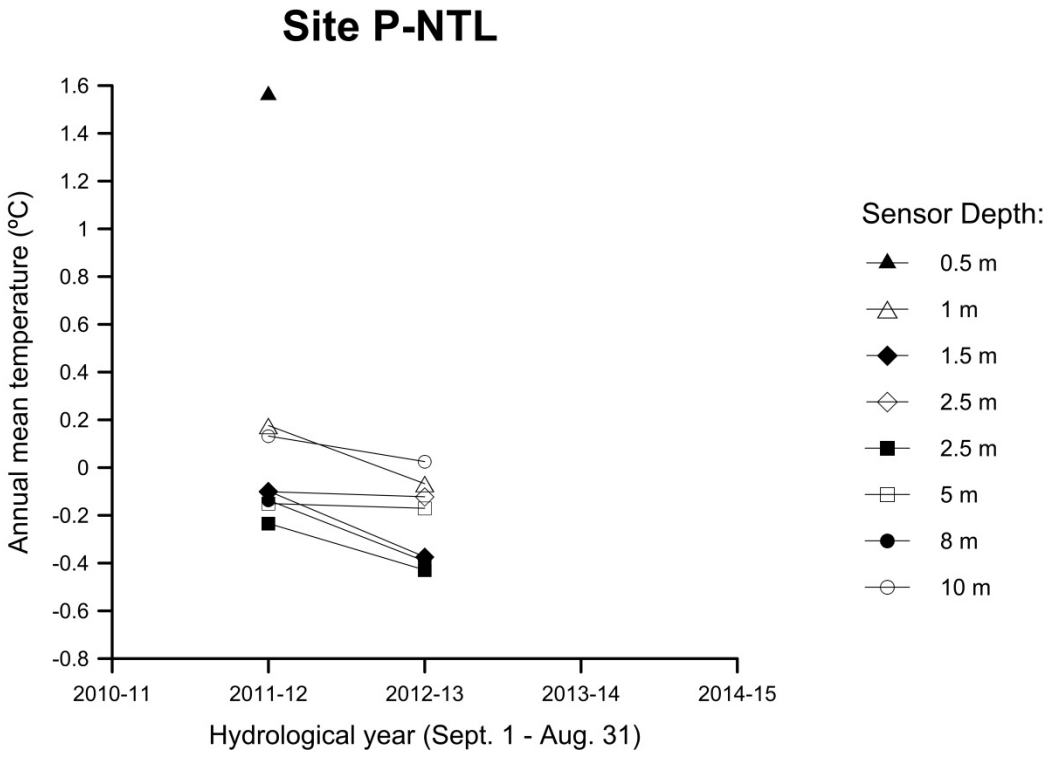

Site DR-DLB (manual readings)
Temperature (ºC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
2015-Jun-20
2015-Aug-27
Date
Sensor Depth:
0.7 m
1.7 m
2.7 m
3.7 m
4.75 m
5.7 m
6.7 m
7.7 m

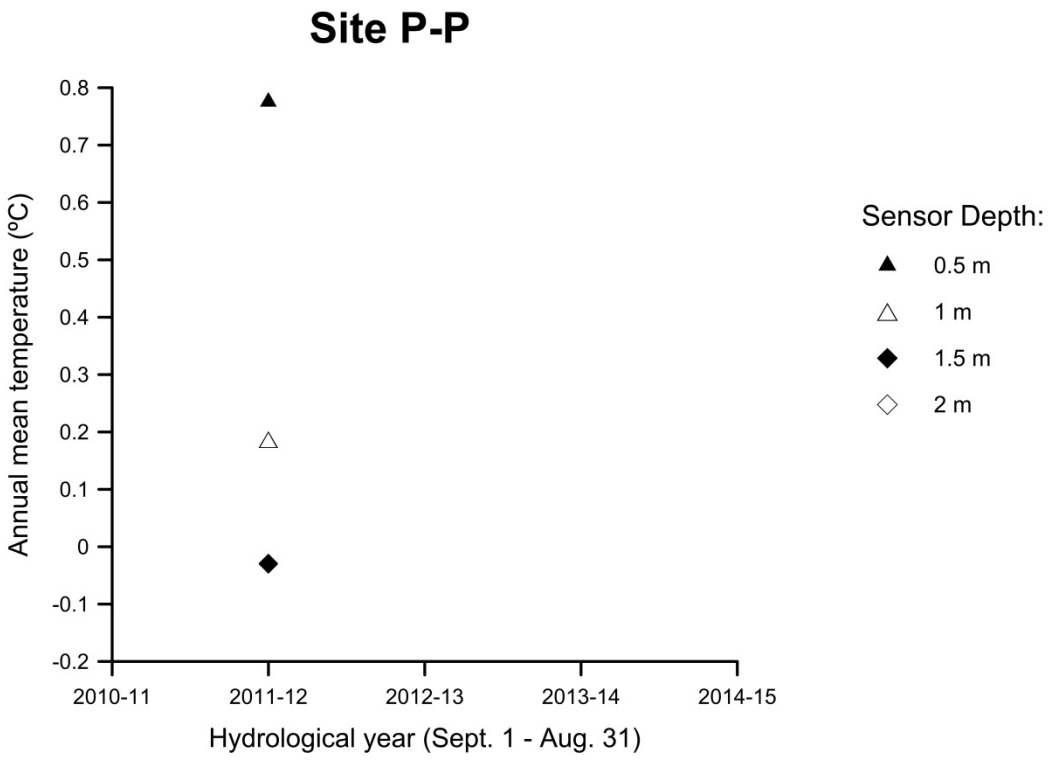

Site DR-DLS
Annual mean temperature (ºC)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.5 m
1 m
1.5 m
3 m
4 m
5.3 m
5.3 m

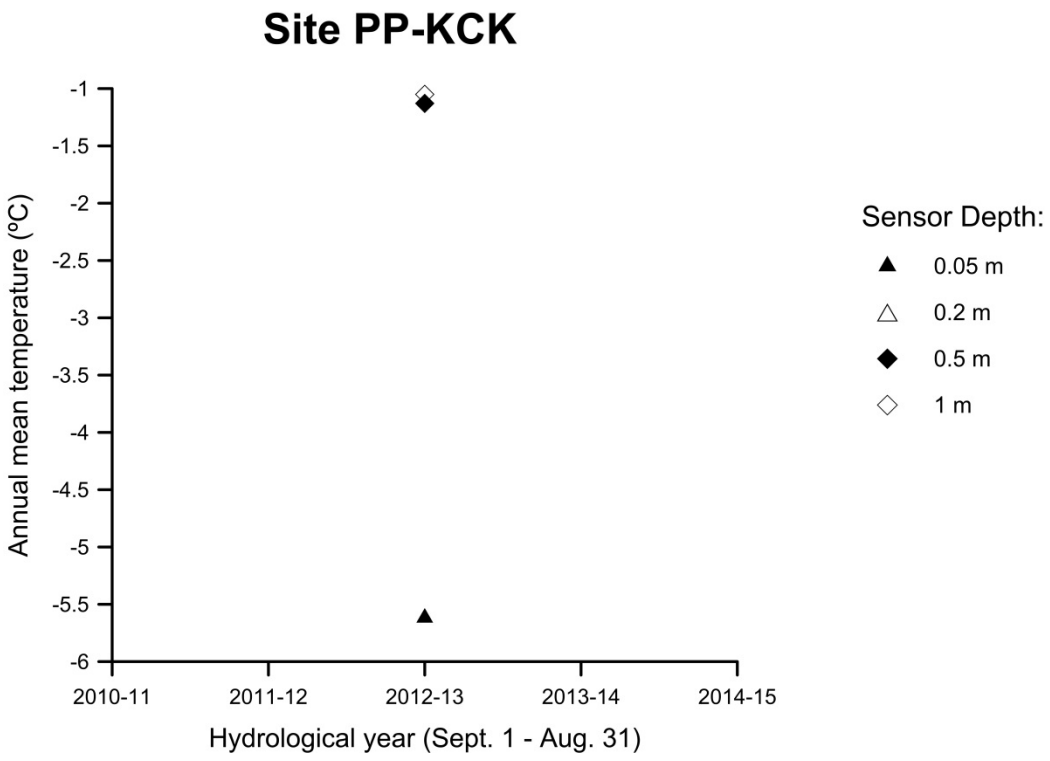

Site DR-DLSp
Annual mean temperature (ºC)
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2
-2.1
-2.2
-2.3
-2.4
-2.5
-2.6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m
1.5 m
2.5 m
3.5 m
4.5 m
5.5 m
6.5 m
7.5 m

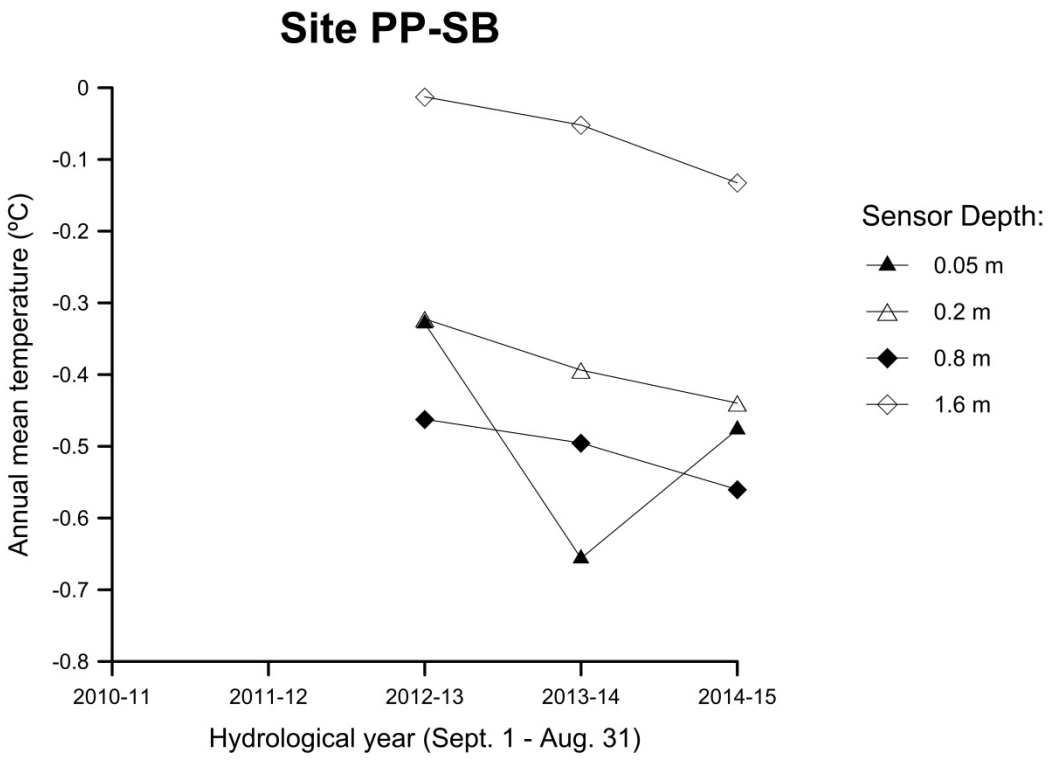

Site ME-YK01
Annual mean temperature (ºC)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.1 m
0.2 m
0.3 m
0.5 m

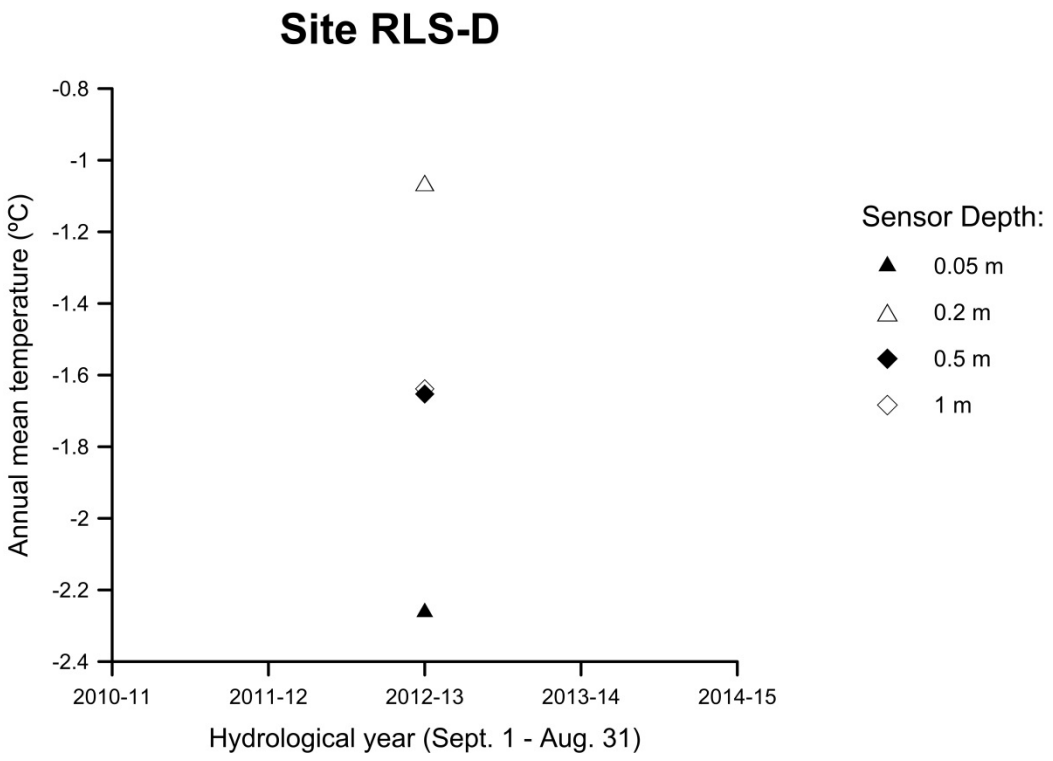

Site ME_YK01_air
Annual mean temperature (ºC)
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air

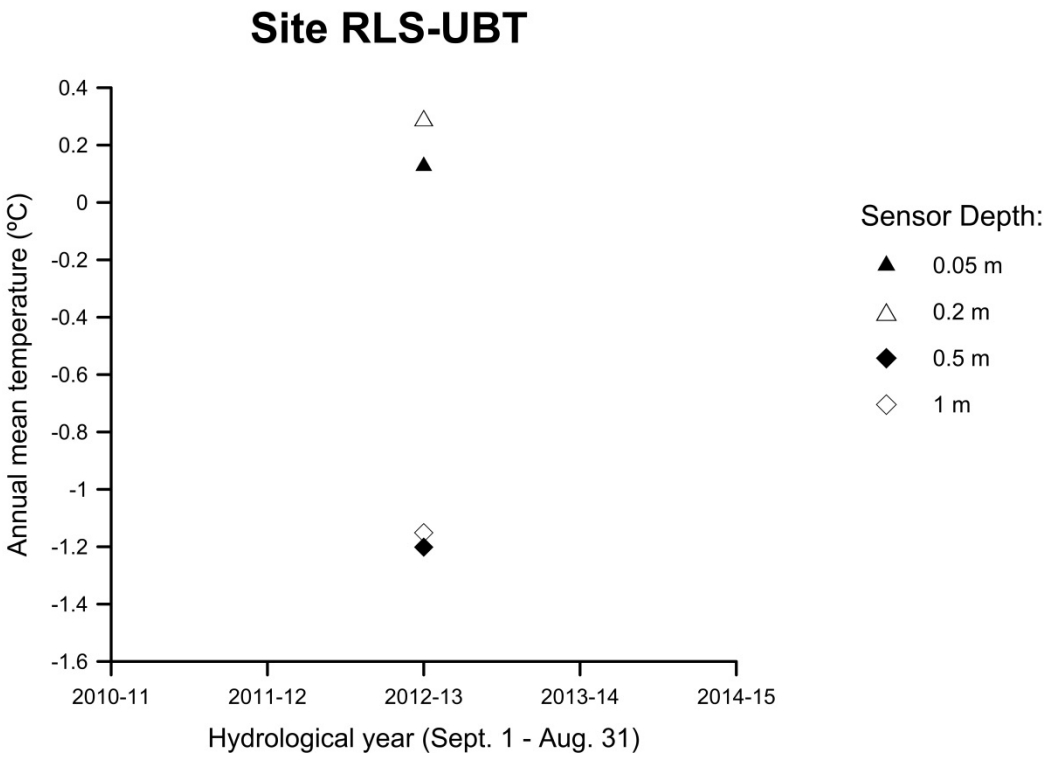

Site P-NTL
Annual mean temperature (ºC)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m
1 m
1.5 m
2.5 m
2.5 m
5 m
8 m
10 m

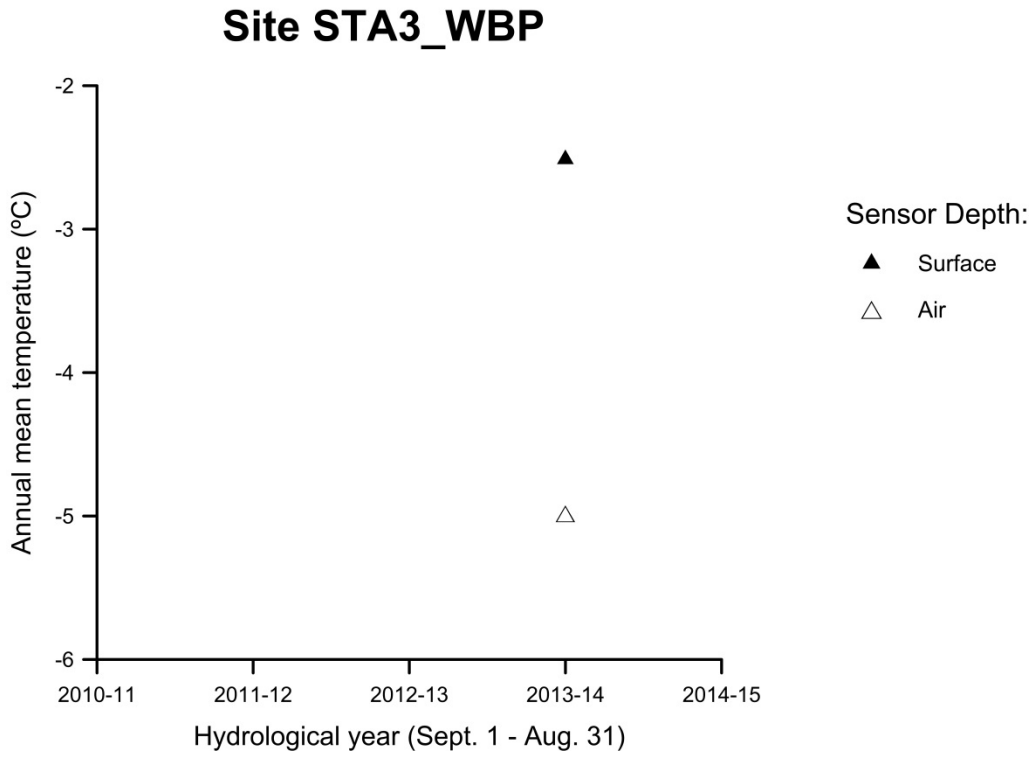

Site P-P
Annual mean temperature (ºC)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m
1 m
1.5 m
2 m

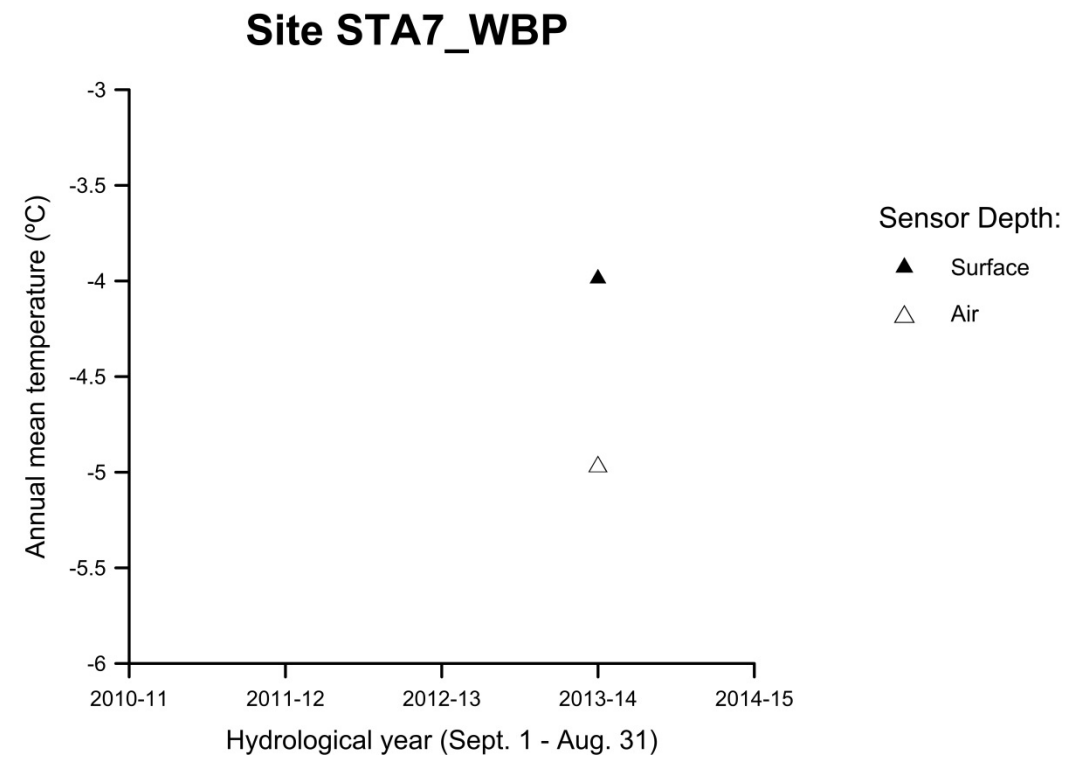

Site PP-KCK
Annual mean temperature (ºC)
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

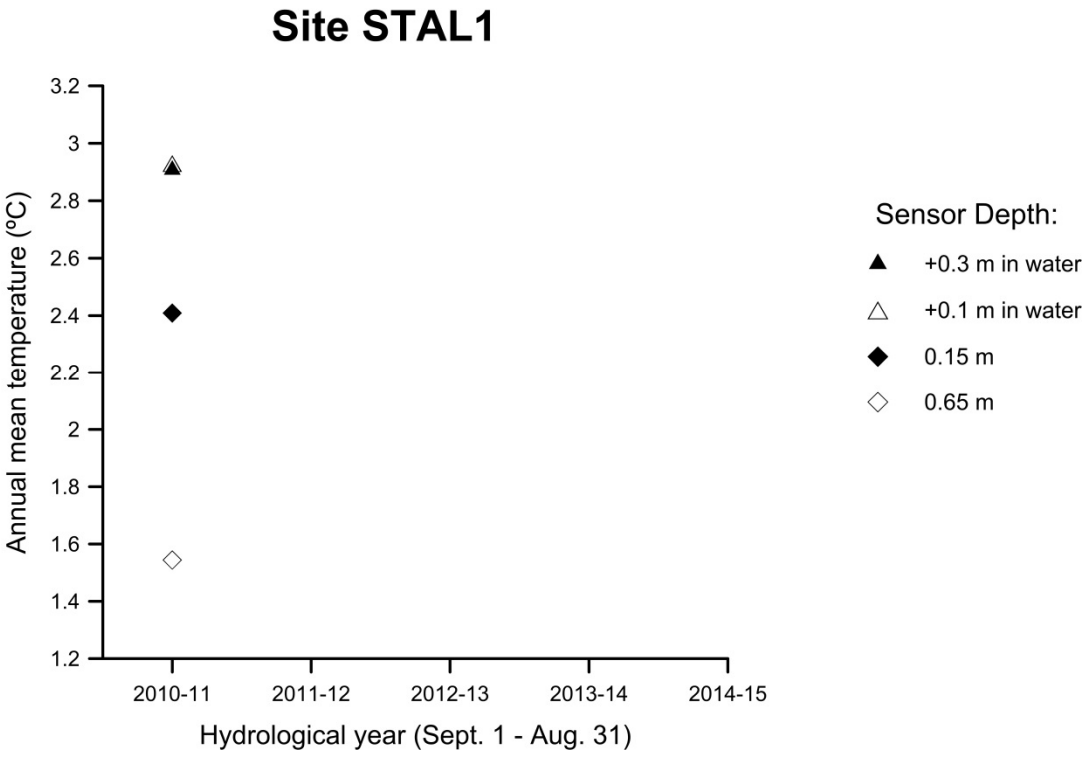

Site PP-SB
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
Annual mean temperature (ºC)
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.8 m
1.6 m

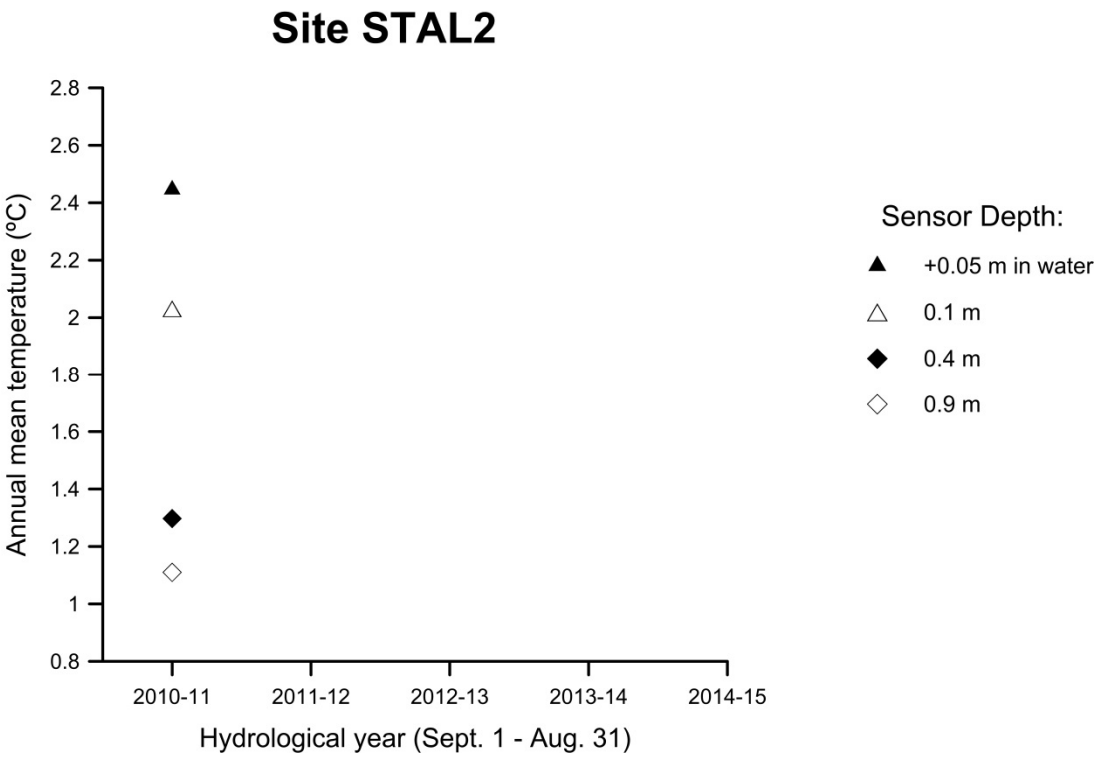

Site RLS-D
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
Annual mean temperature (ºC)
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

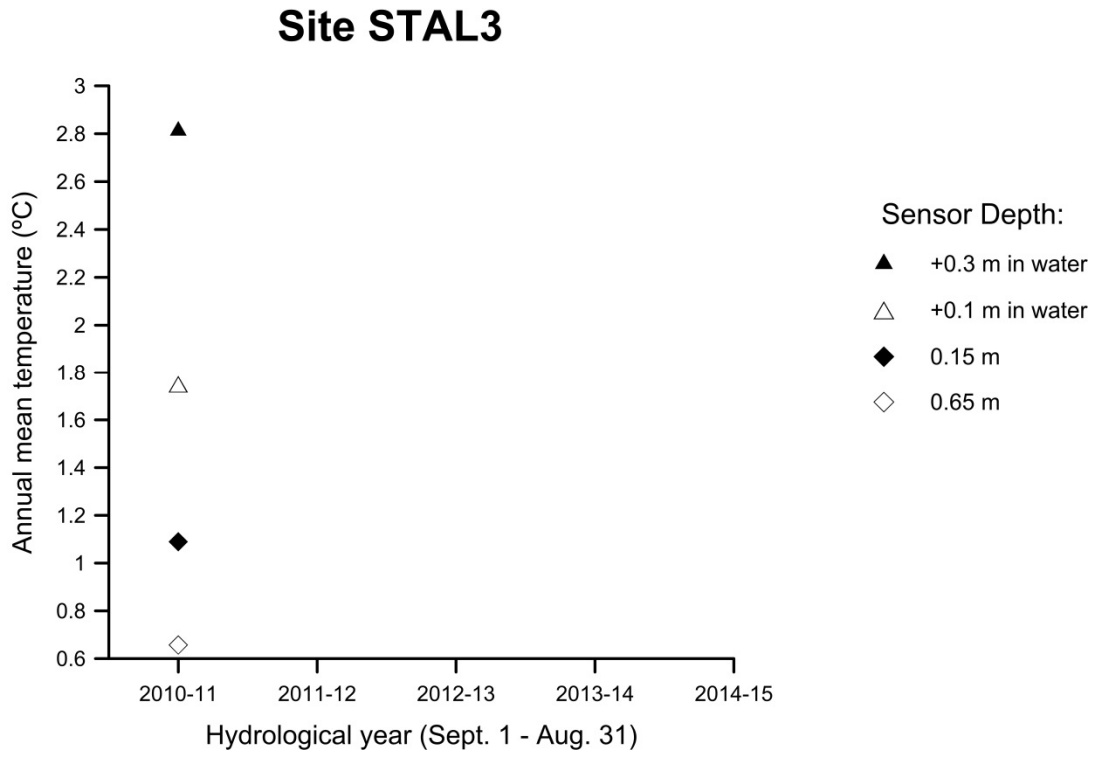

Site RLS-UBT
Annual mean temperature (ºC)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

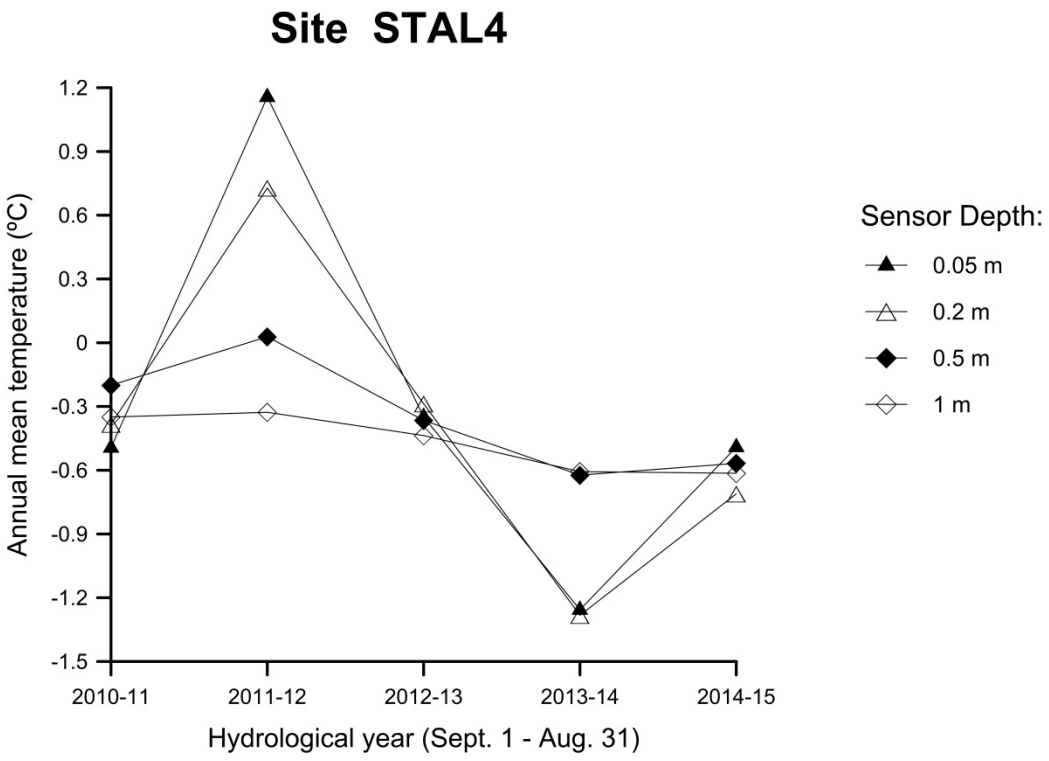

Site STA3_WBP
Annual mean temperature (ºC)
-2
-3
-4
-5
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air

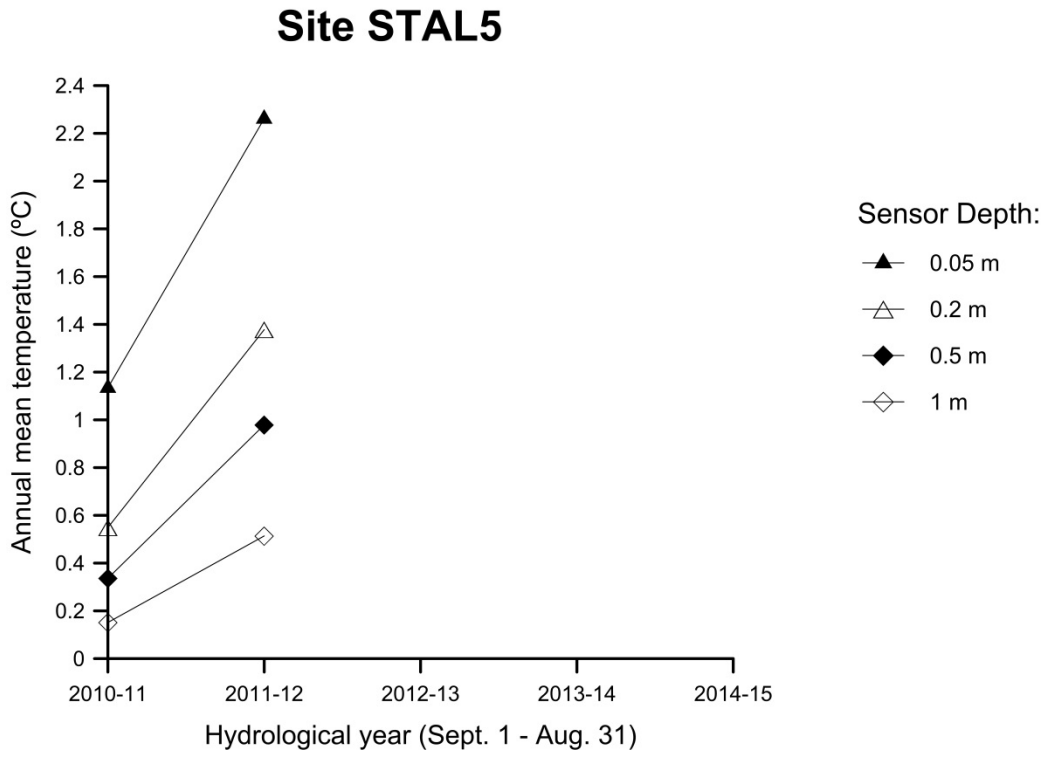

Site STA7_WBP
Annual mean temperature (ºC)
-3
-3.5
-4
-4.5
-5
-5.5
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air

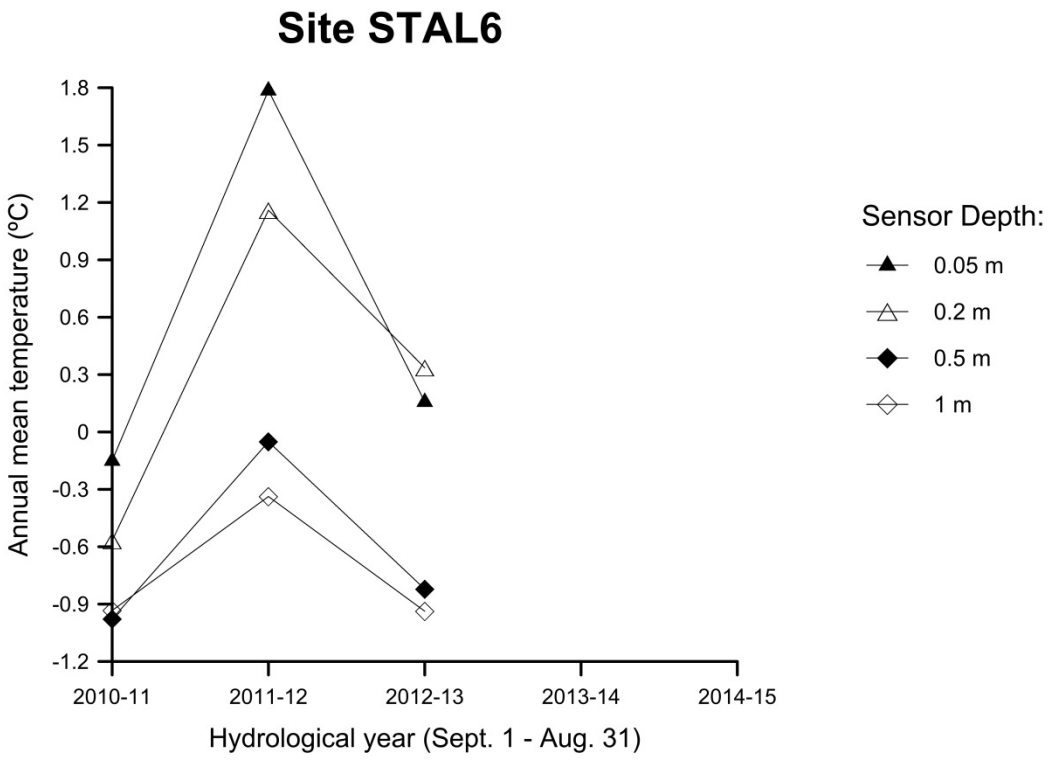

Site STAL1
Annual mean temperature (ºC)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
+0.3 m in water
+0.1 m in water
0.15 m
0.65 m

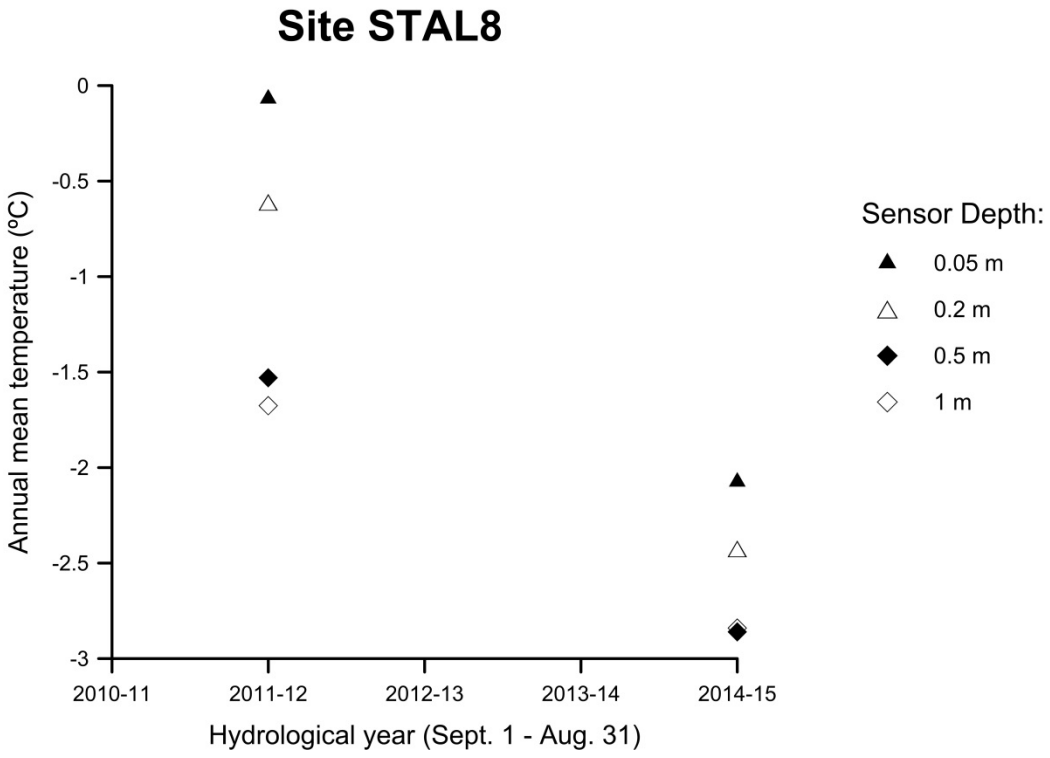

Site STAL2
Annual mean temperature (ºC)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
+0.05 m in water
0.1 m
0.4 m
0.9 m

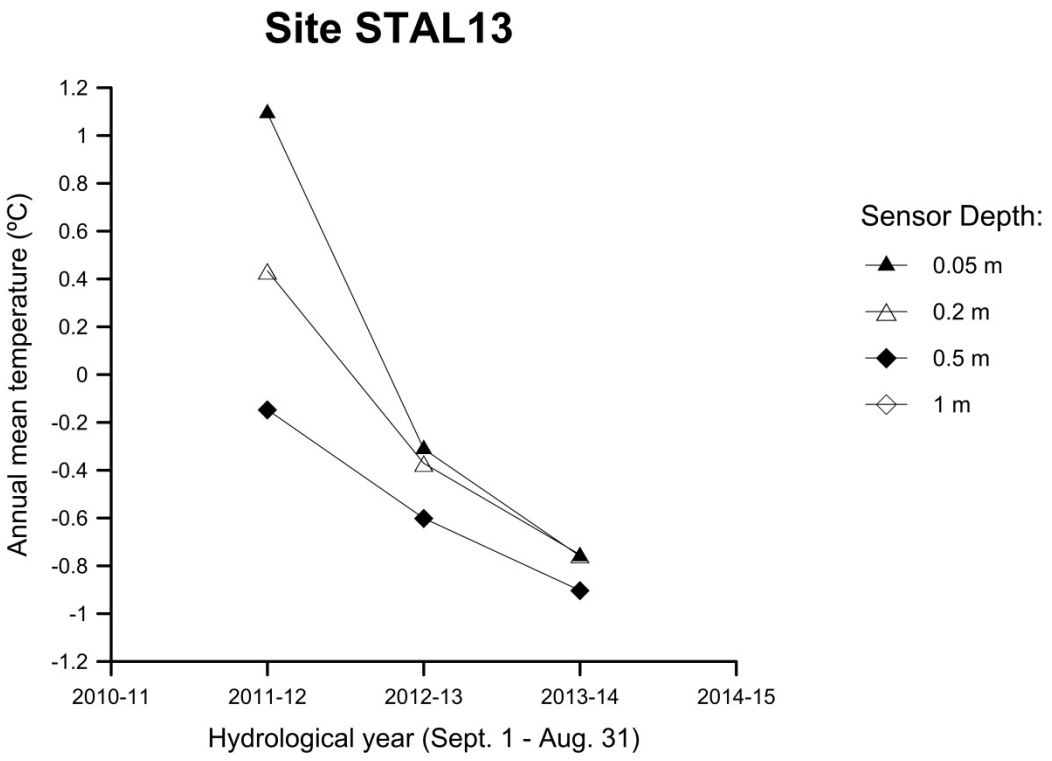

Site STAL3
Annual mean temperature (ºC)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
+0.3 m in water
+0.1 m in water
0.15 m
0.65 m

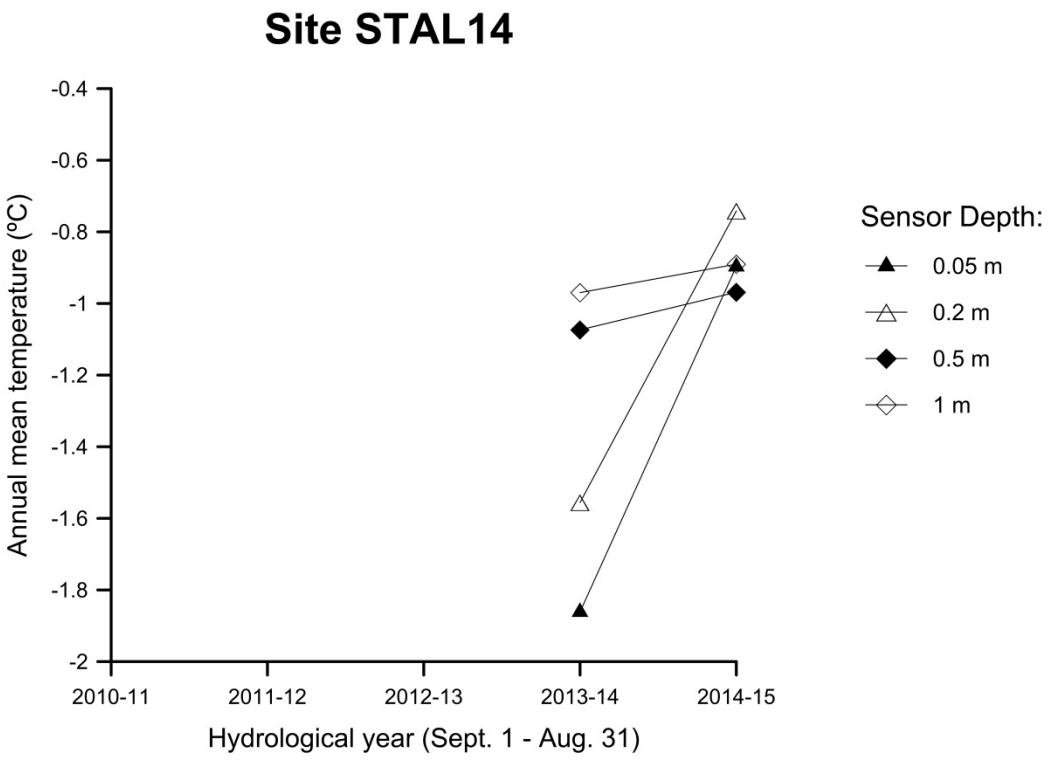

Site STAL4
Annual mean temperature (ºC)
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
-1.5
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

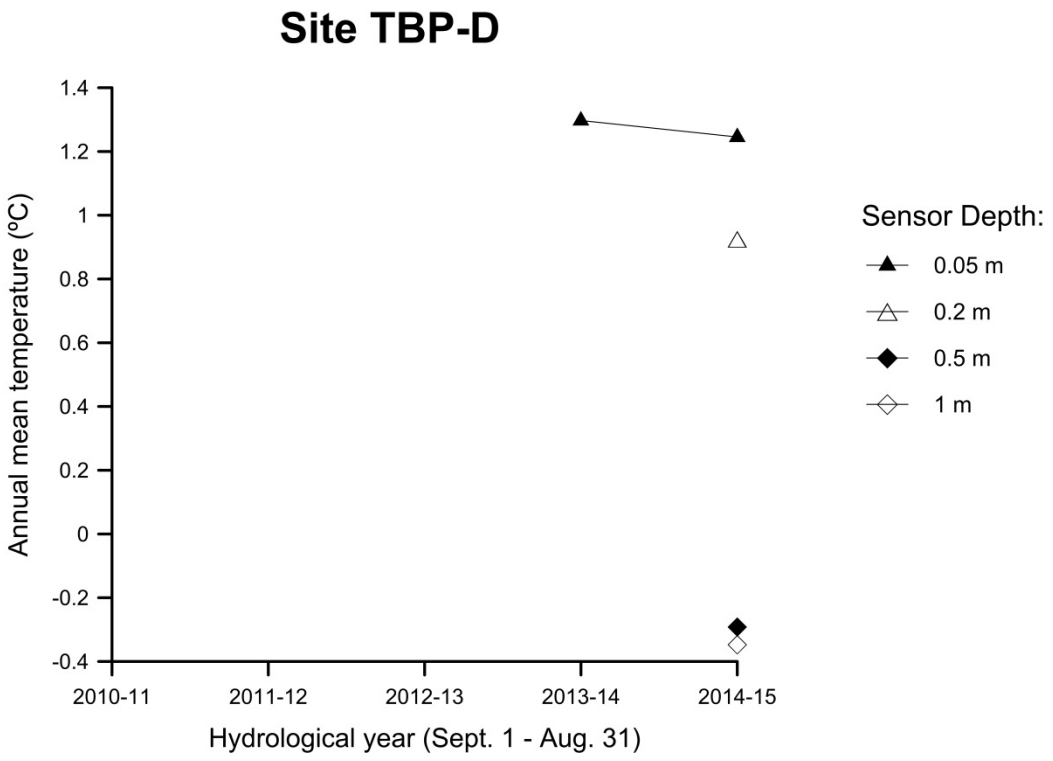

Site STAL5
Annual mean temperature (ºC)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

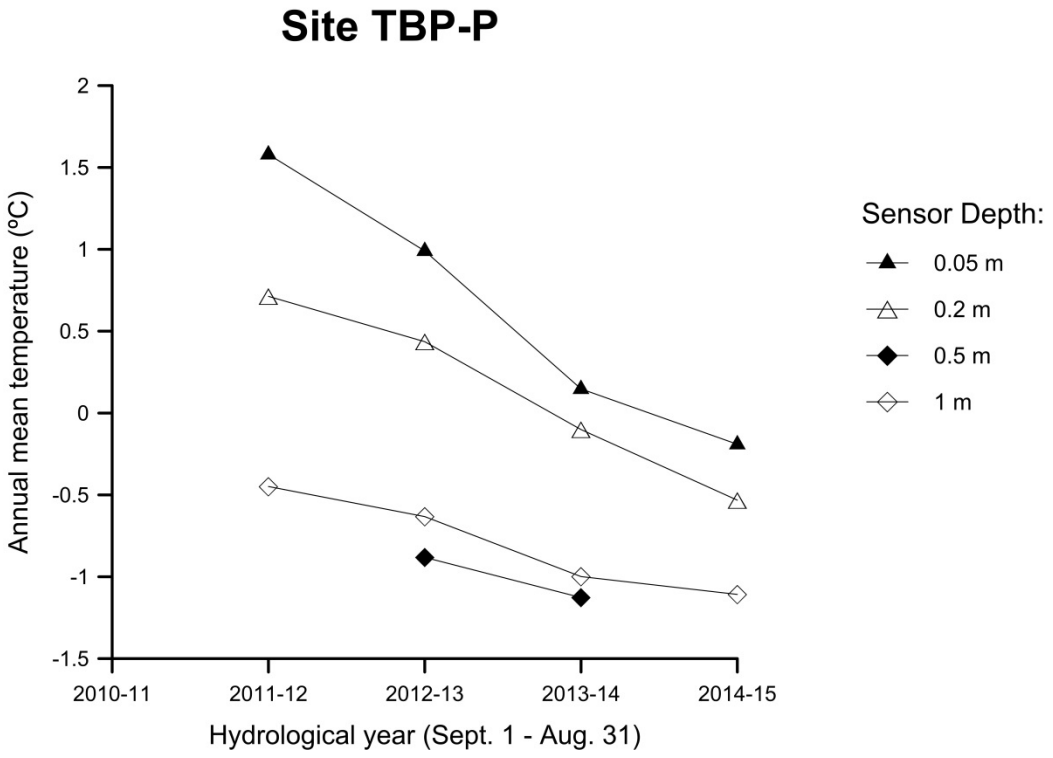

Site STAL6
Annual mean temperature (ºC)
1.8
1.5
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

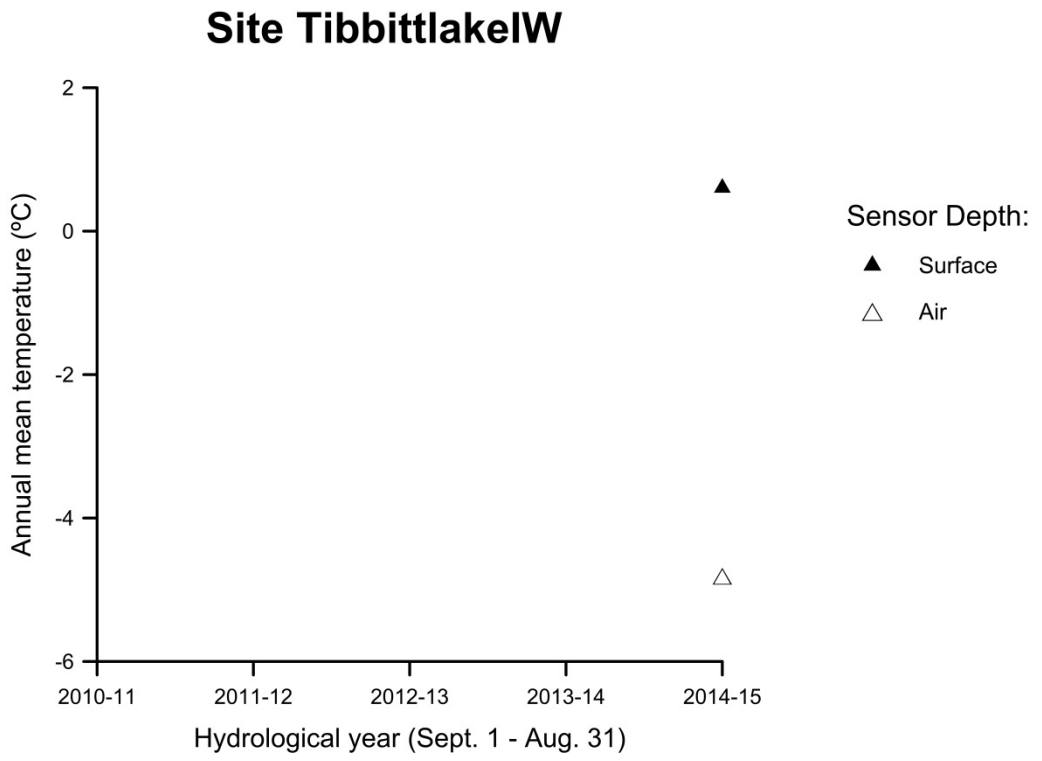

Site STAL8
Annual mean temperature (ºC)
0
-0.5
-1
-1.5
-2
-2.5
-3
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

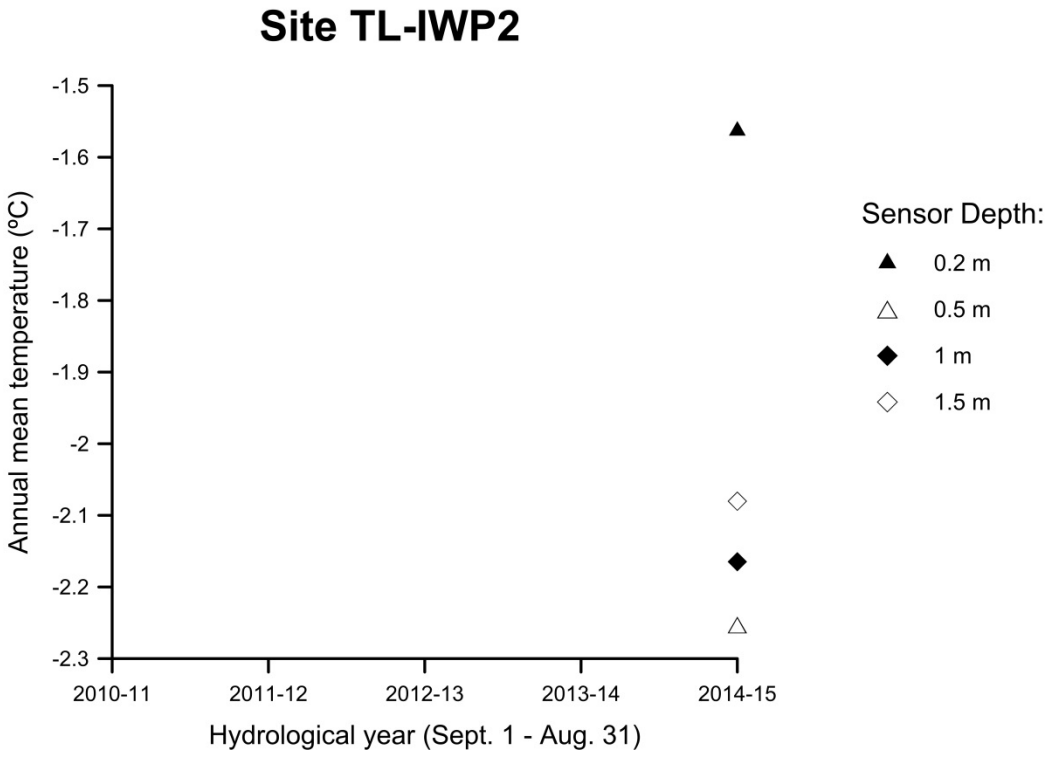

Site STAL13
Annual mean temperature (ºC)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

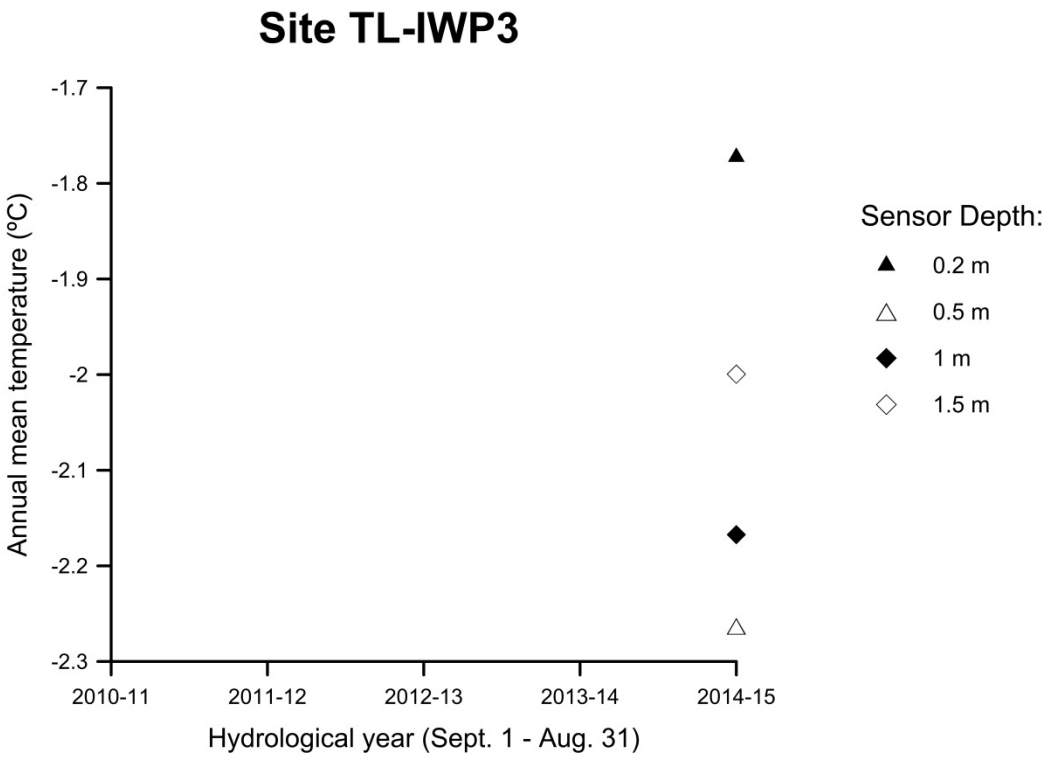

Site STAL14
Annual mean temperature (ºC)
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

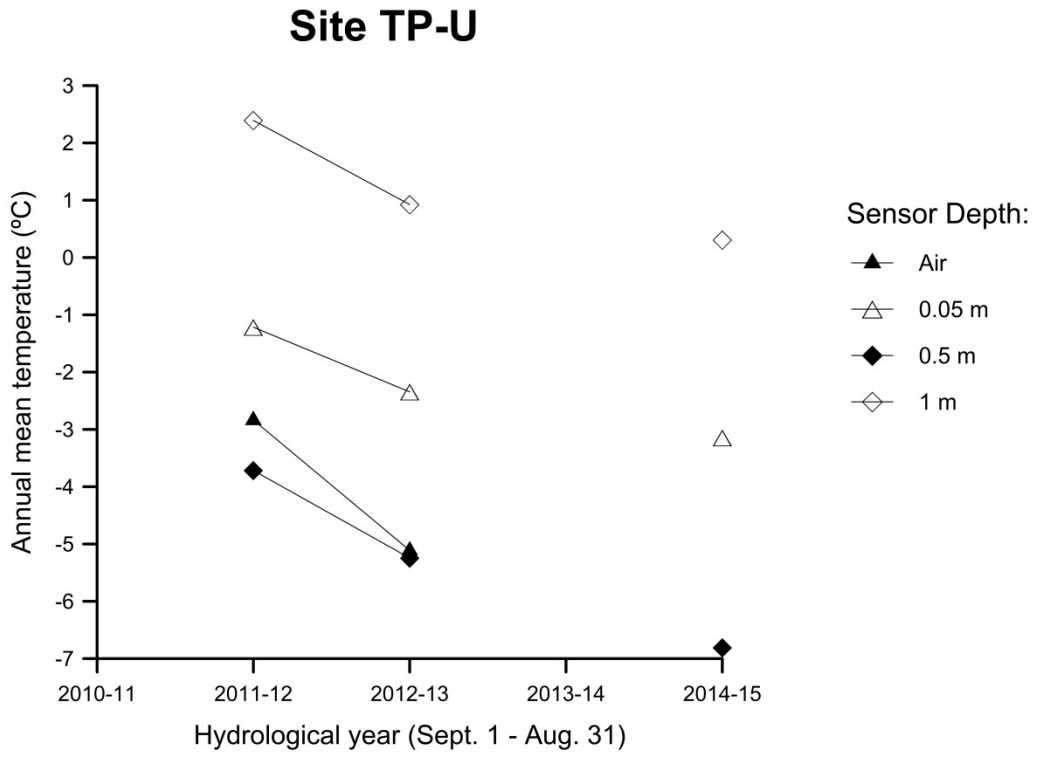

Site TBP-D
Annual mean temperature (ºC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

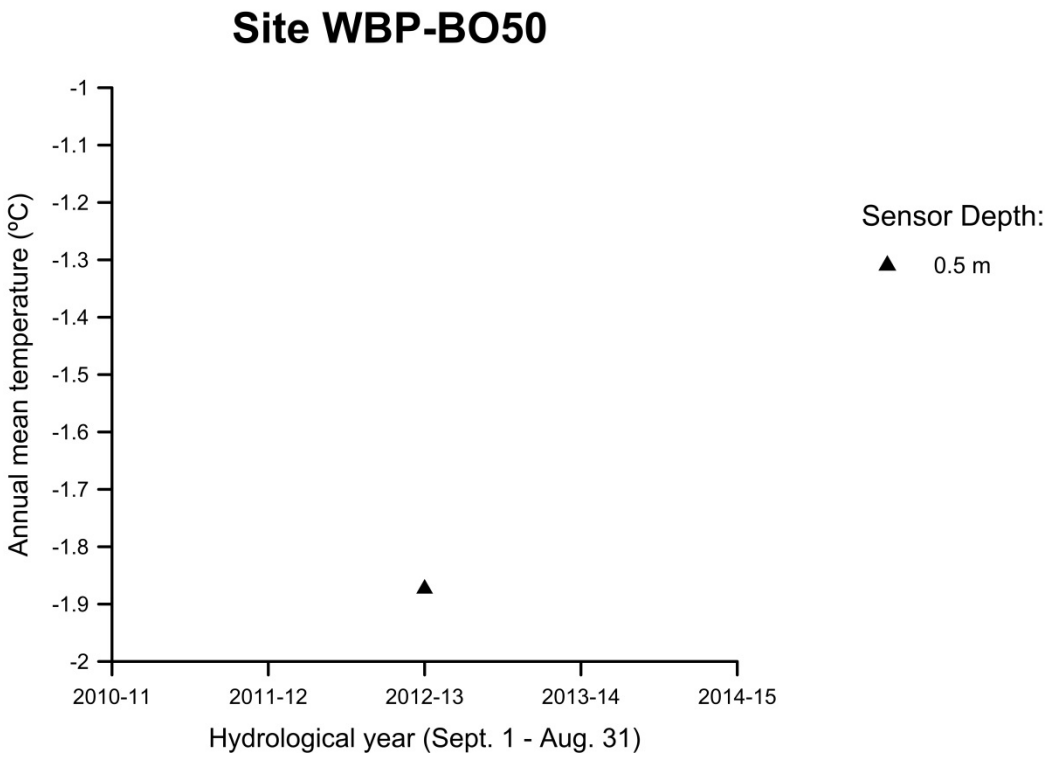

Site TBP-P
Annual mean temperature (ºC)
2
1.5
1
0.5
0
-0.5
-1
-1.5
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

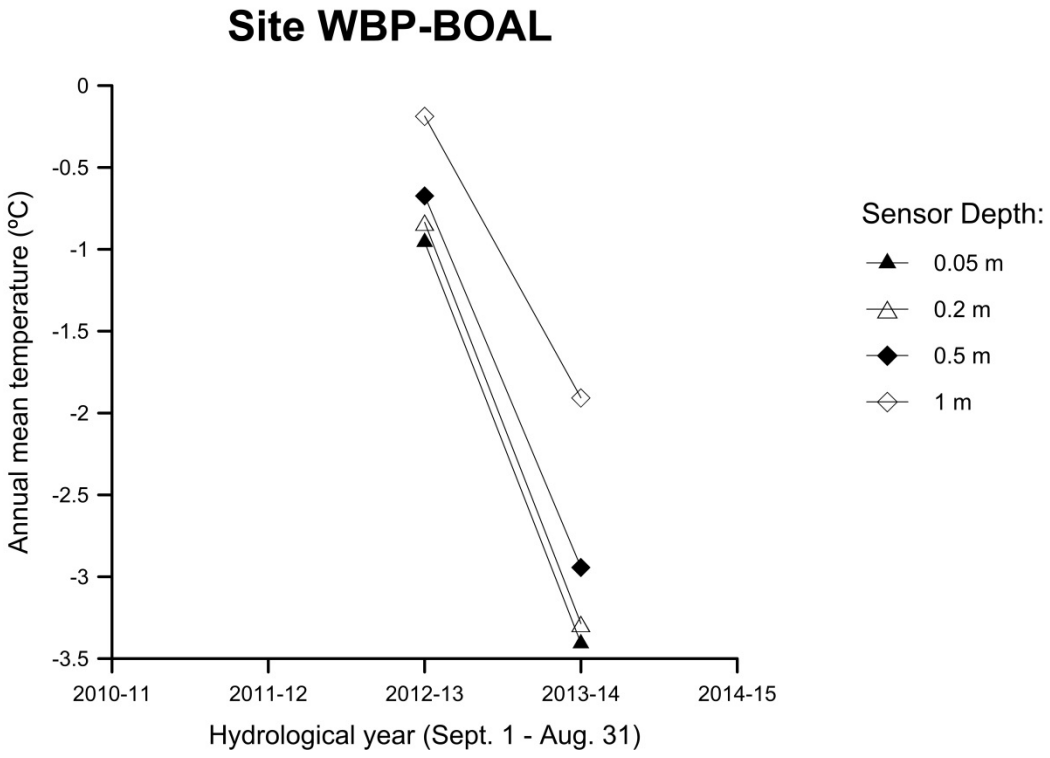

Site TibbittlakeIW
Annual mean temperature (ºC)
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air

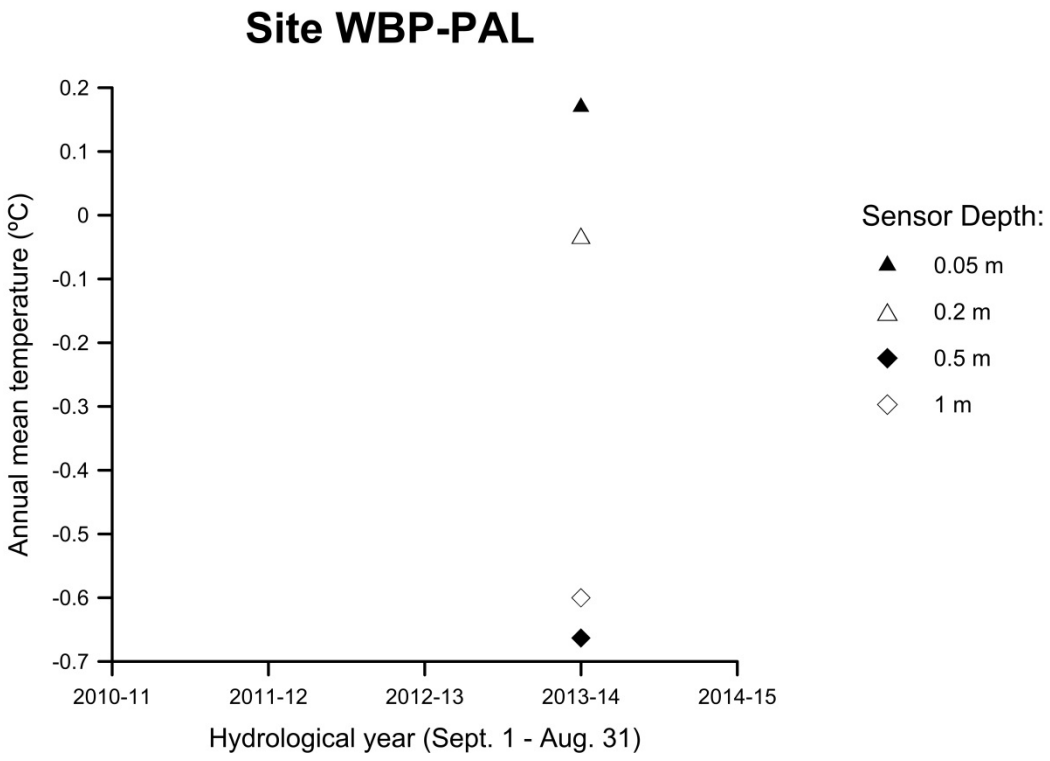

Site TL-IWP2
Annual mean temperature (ºC)
-1.5
-1.6
-1.7
-1.8
-1.9
-2
-2.1
-2.2
-2.3
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.2 m
0.5 m
1 m
1.5 m

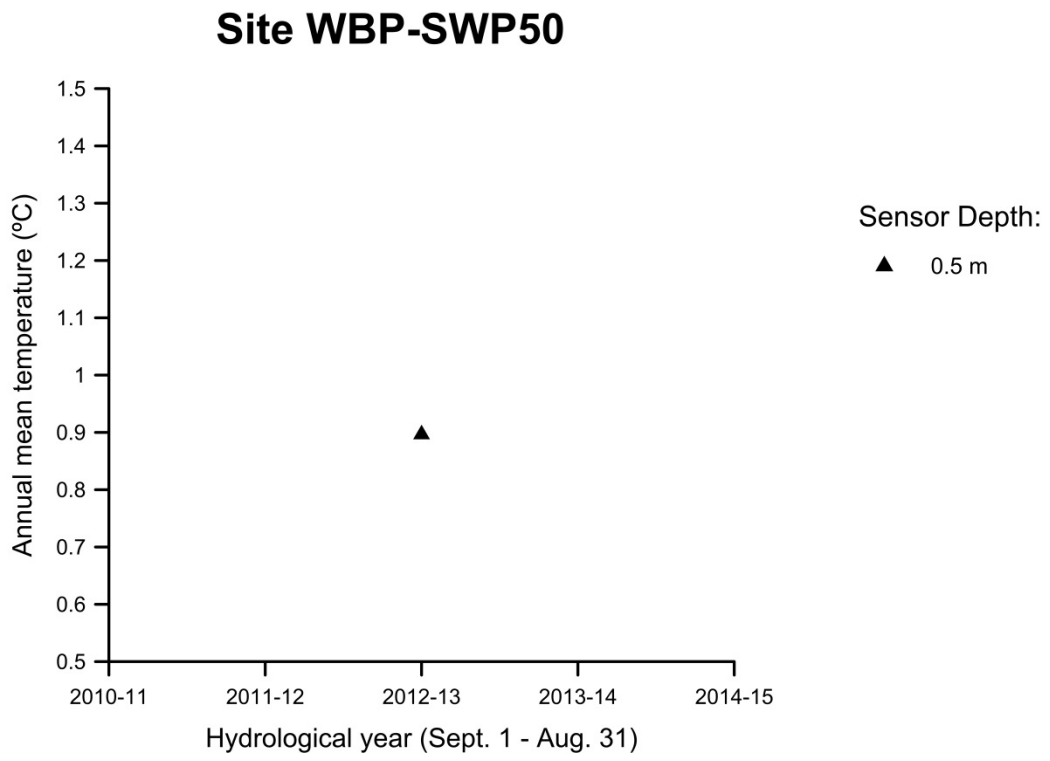

Site TL-IWP3
-1.7
-1.8
-1.9
-2
-2.1
-2.2
-2.3
Annual mean temperature (ºC)
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.2 m
0.5 m
1 m
1.5 m

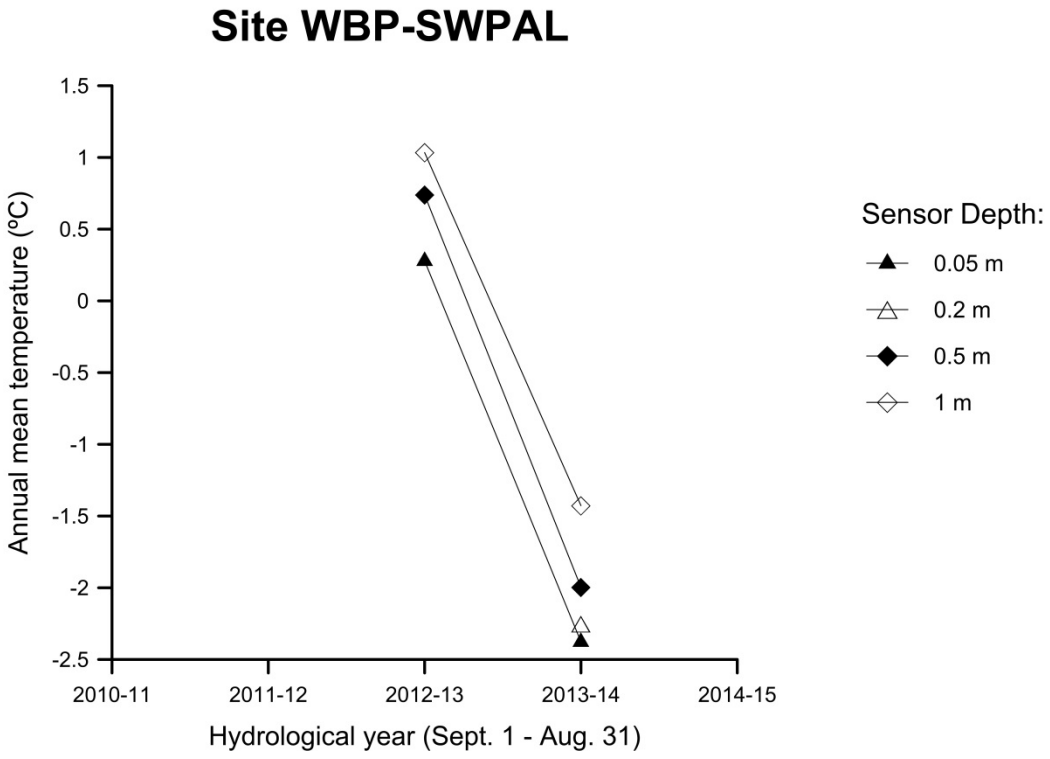

Site TP-U
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Annual mean temperature (ºC)
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Air
0.05 m
0.5 m
1 m

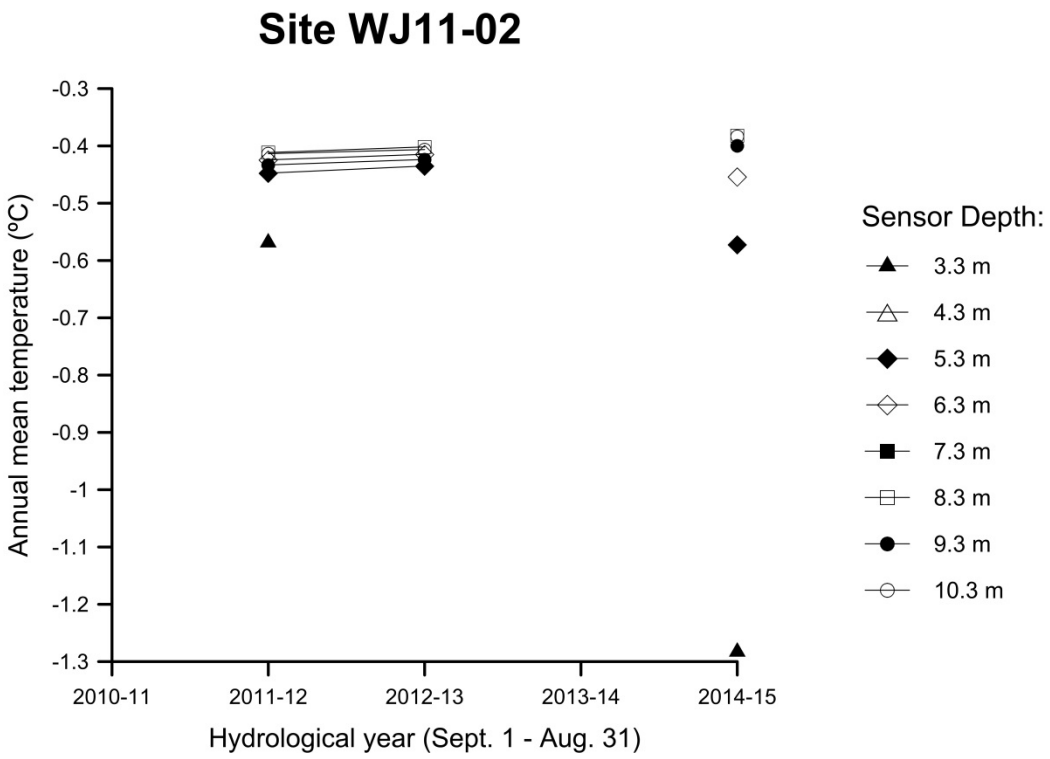

Site WBP-BO50
Annual mean temperature (ºC)
-1
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m

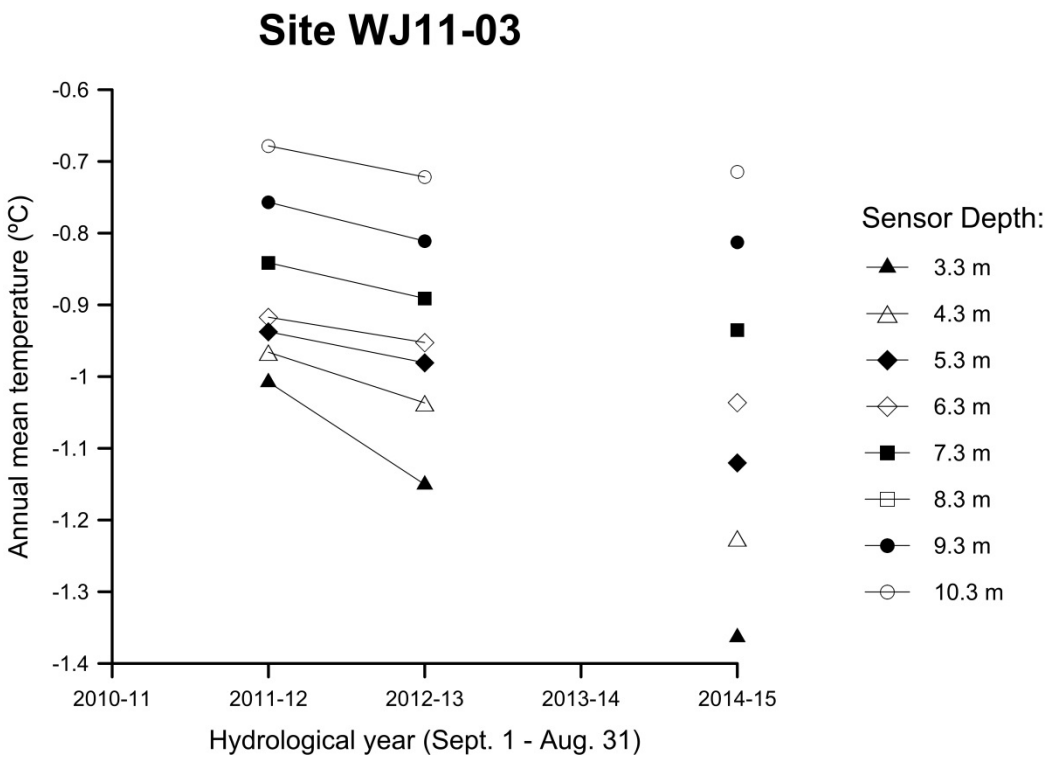

Site WBP-BOAL
Annual mean temperature (ºC)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

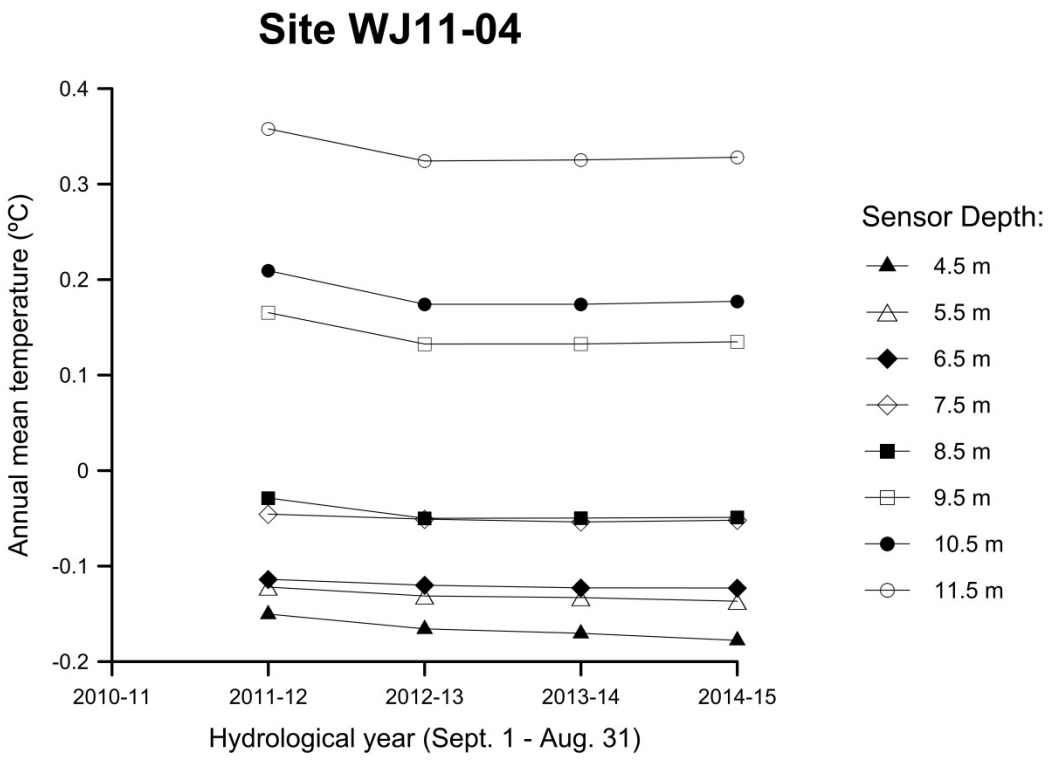

Site WBP-PAL
Annual mean temperature (ºC)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

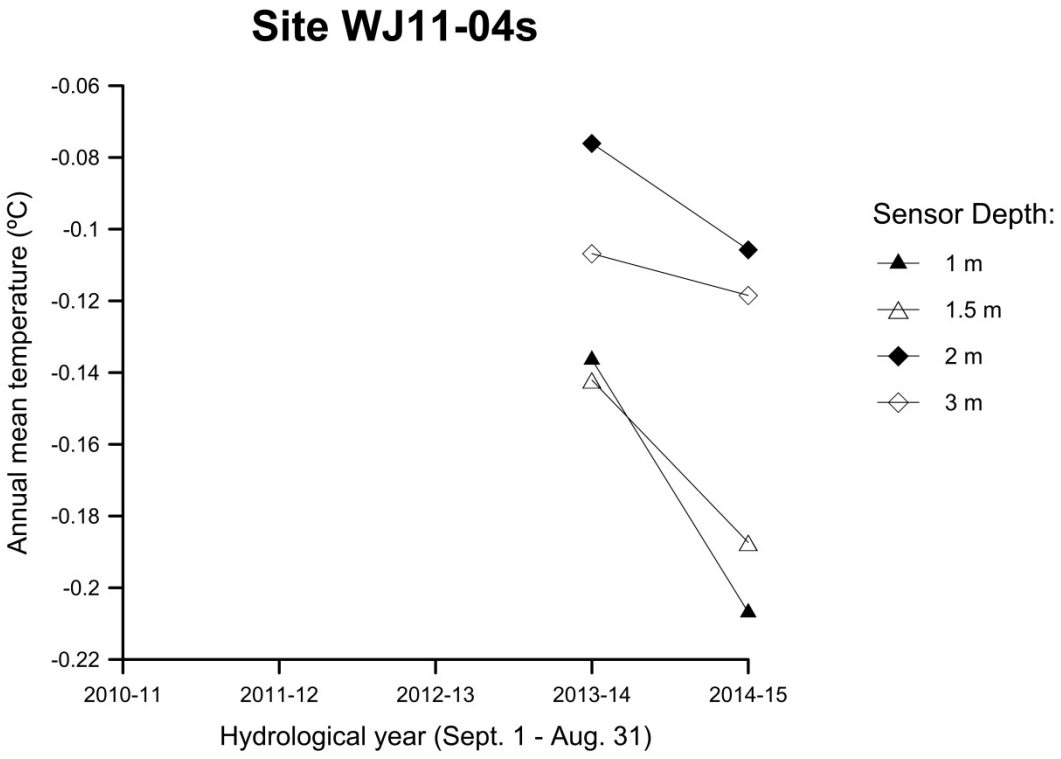

Site WBP-SWP50
Annual mean temperature (ºC)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.5 m

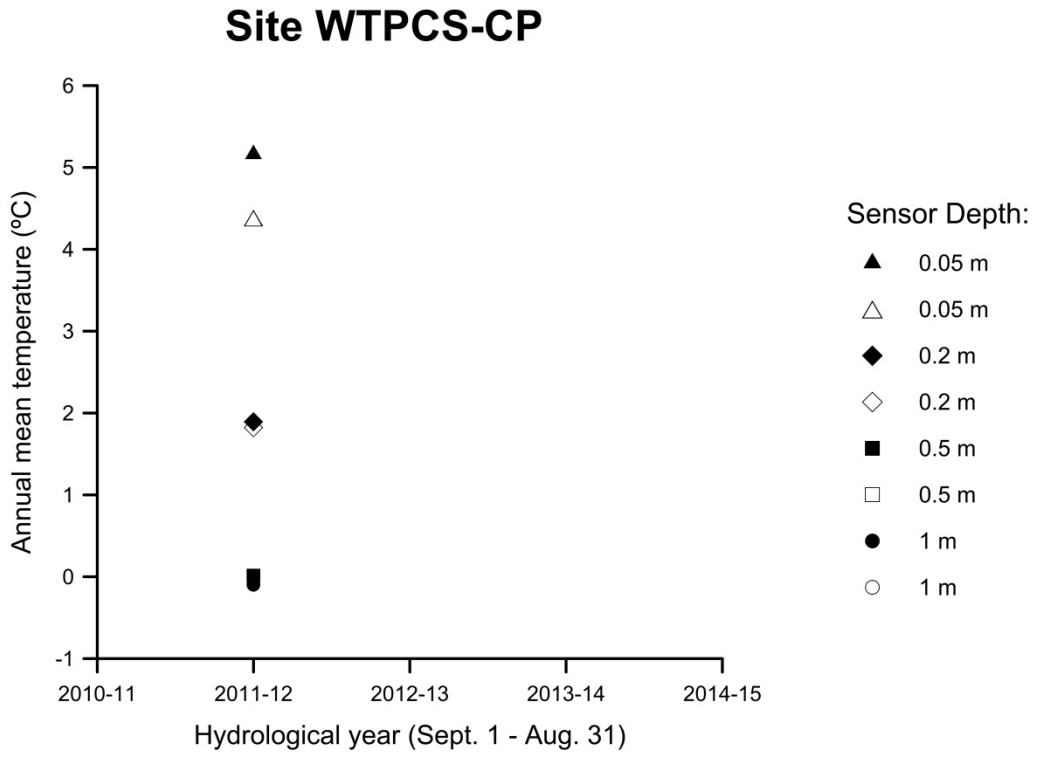

Site WBP-SWPAL
Annual mean temperature (ºC)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m

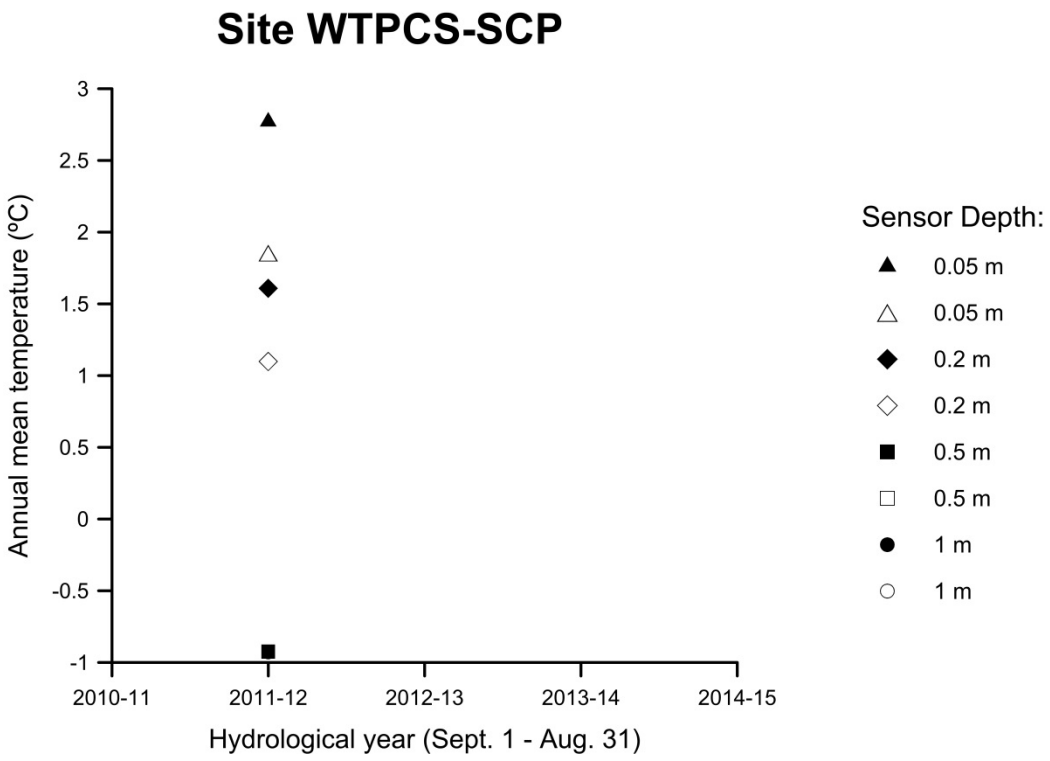

Site WJ11-02
Annual mean temperature (ºC)
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-1.2
-1.3
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
3.3 m
4.3 m
5.3 m
6.3 m
7.3 m
8.3 m
9.3 m
10.3 m

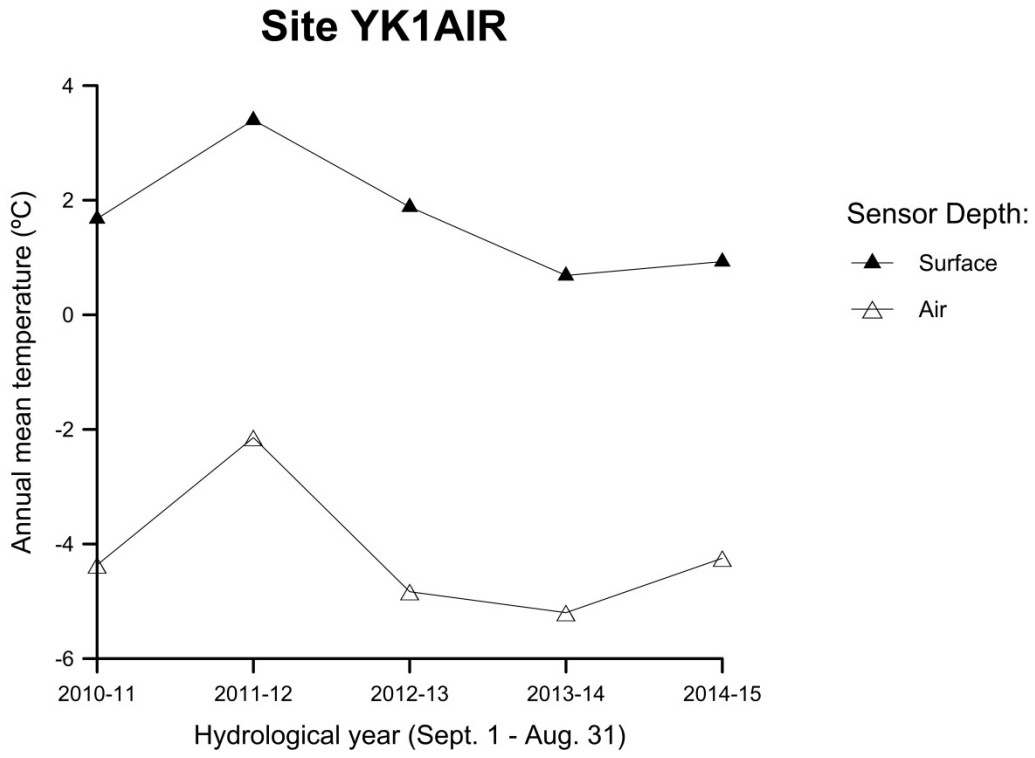

Site WJ11-03
Annual mean temperature (ºC)
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-1.2
-1.3
-1.4
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
3.3 m
4.3 m
5.3 m
6.3 m
7.3 m
8.3 m
9.3 m
10.3 m

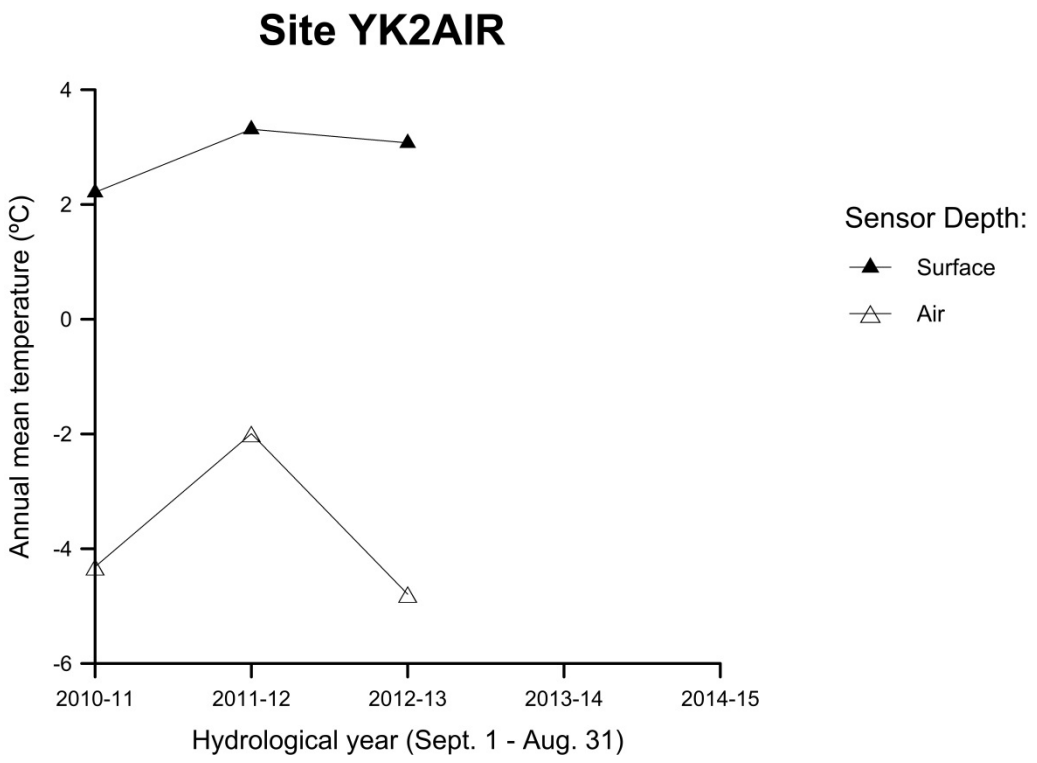

Site WJ11-04
Annual mean temperature (ºC)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
4.5 m
5.5 m
6.5 m
7.5 m
8.5 m
9.5 m
10.5 m
11.5 m

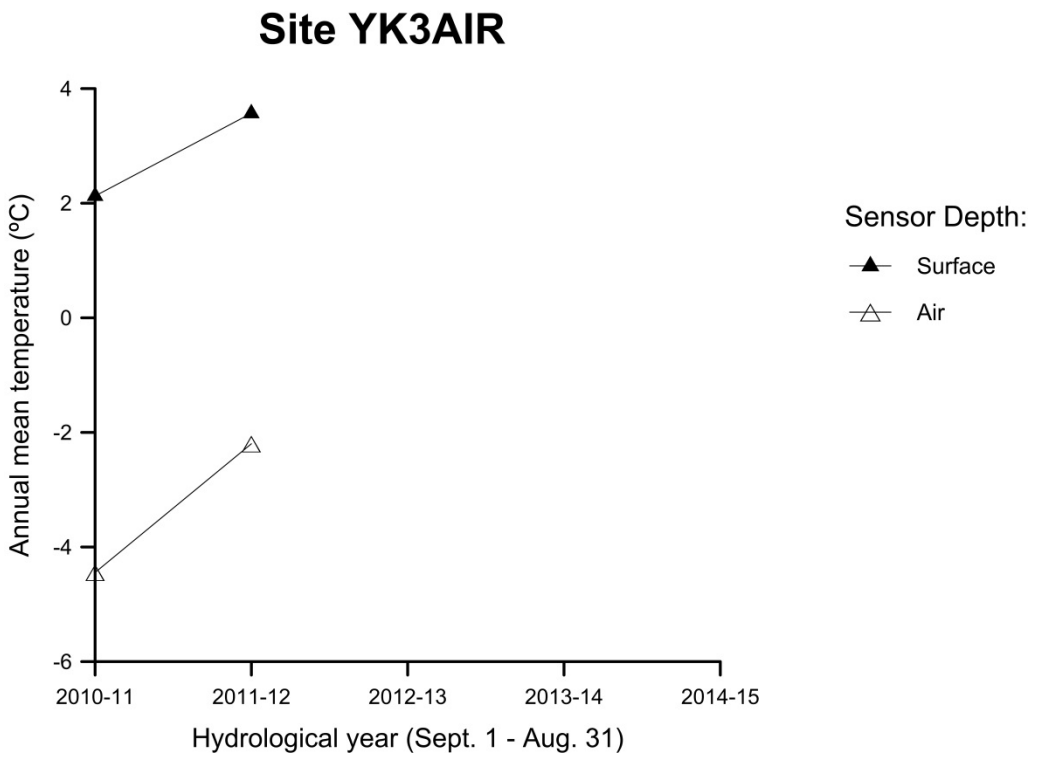

Site WJ11-04s
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
-0.22
Annual mean temperature (ºC)
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
1 m
1.5 m
2 m
3 m

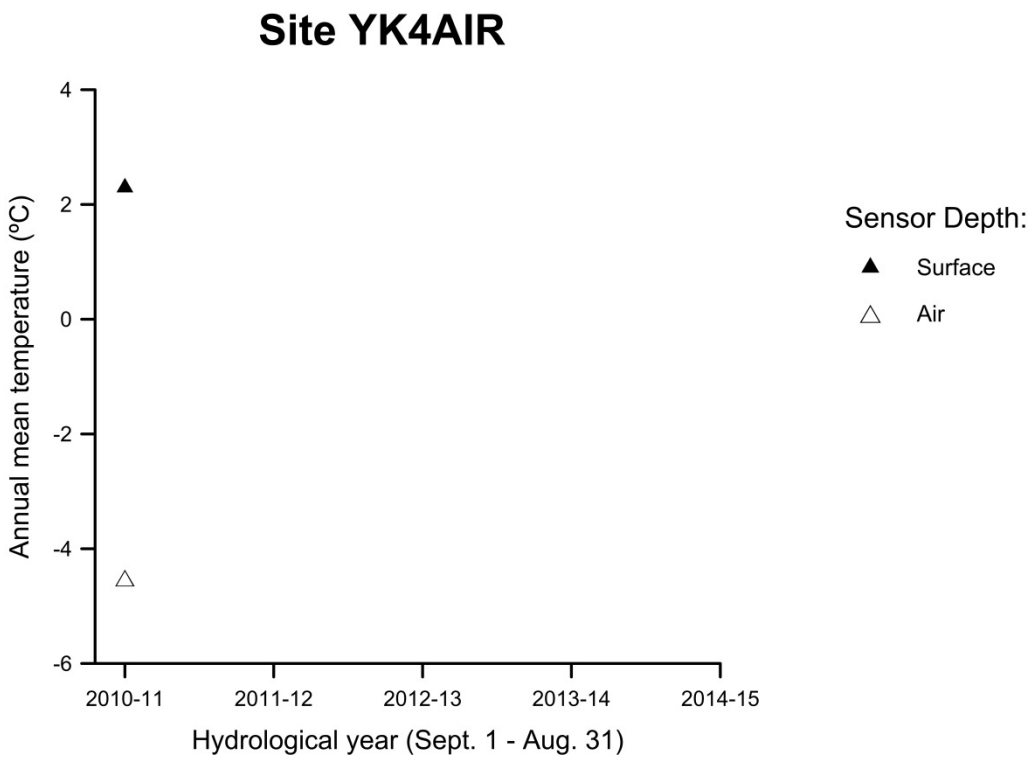

Site WTPCS-CP
6
5
4
3
2
1
0
-1
Annual mean temperature (ºC)
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.05 m
0.2 m
0.2 m
0.5 m
0.5 m
1 m
1 m

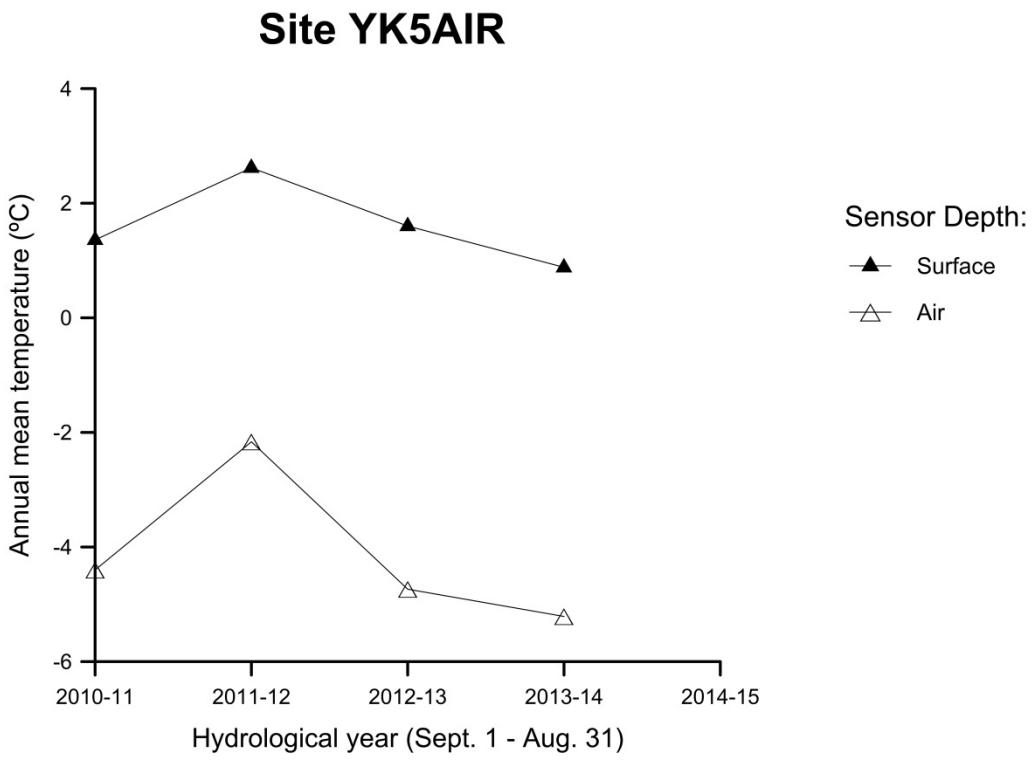

Site WTPCS-SCP
Annual mean temperature (ºC)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.05 m
0.2 m
0.2 m
0.5 m
0.5 m
1 m
1 m

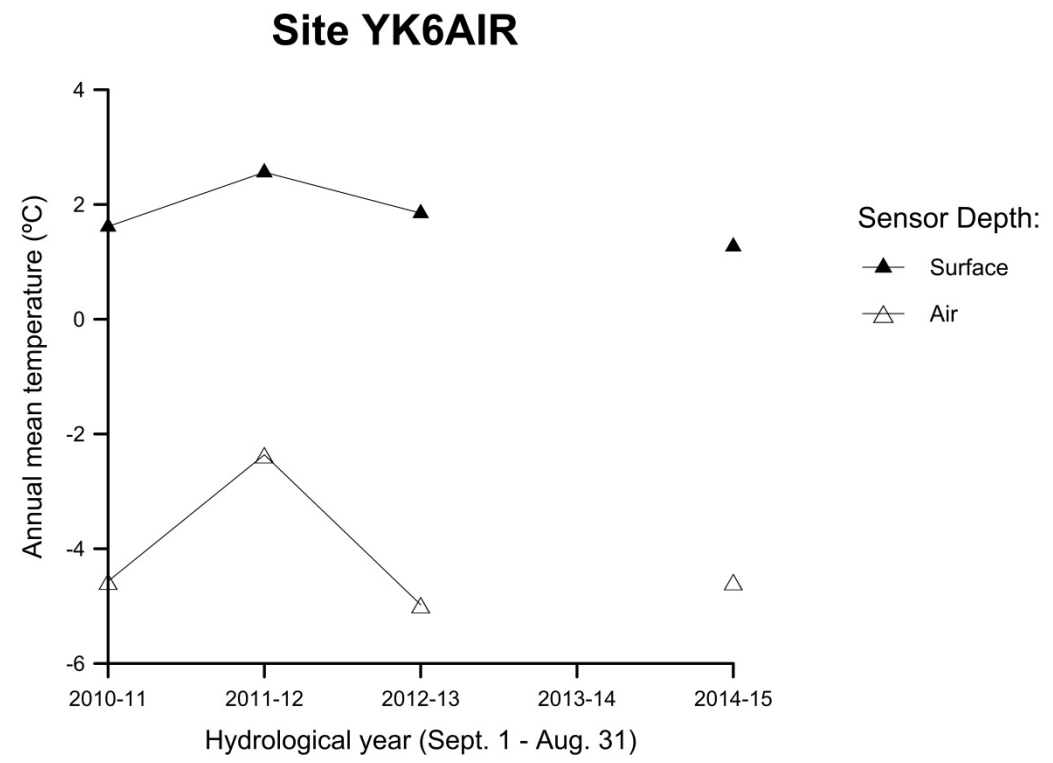

Site YK1AIR
Annual mean temperature (ºC)
4
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air

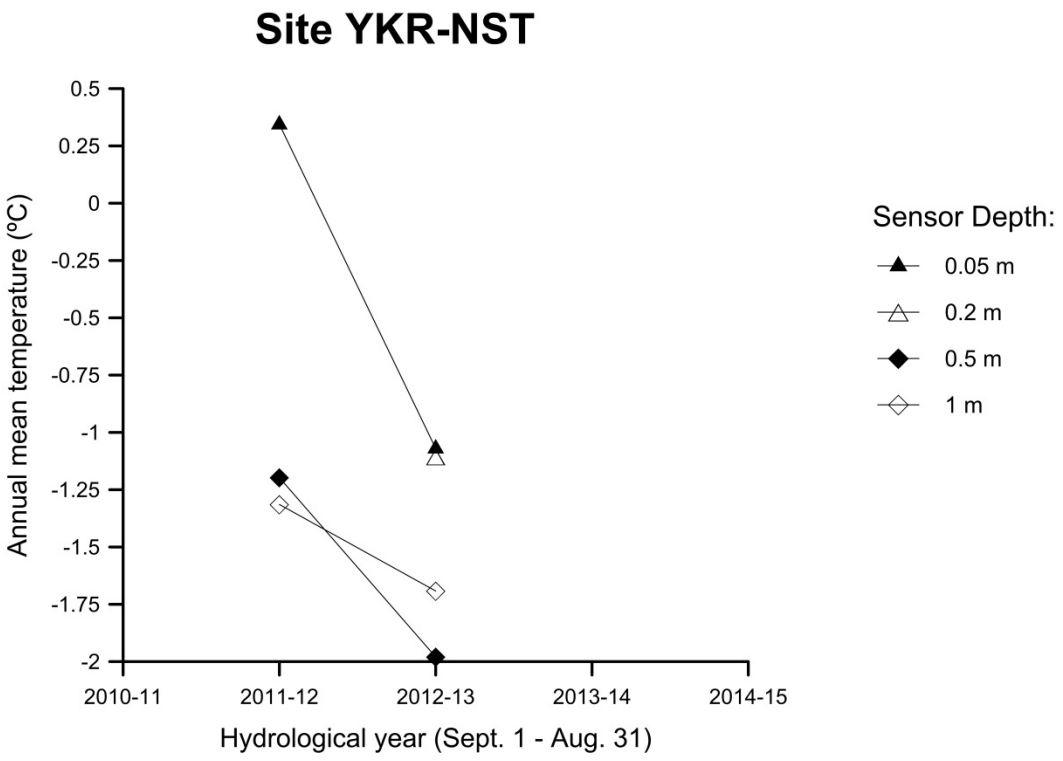

Site YK2AIR
Annual mean temperature (ºC)
4
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air


Site YK3AIR
Annual mean temperature (ºC)
4
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air


Site YK4AIR
Annual mean temperature (ºC)
4
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air


Site YK5AIR
Annual mean temperature (ºC)
4
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air


Site YK6AIR
Annual mean temperature (ºC)
4
2
0
-2
-4
-6
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
Surface
Air


Site YKR-NST
Annual mean temperature (ºC)
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
-1.75
-2
2010-11
2011-12
2012-13
2013-14
2014-15
Hydrological year (Sept. 1 - Aug. 31)
Sensor Depth:
0.05 m
0.2 m
0.5 m
1 m