Yeh and Associates, Inc.
Consulting Engineers & Scientists

December 5, 2016 Project No. 216-216

Shelly St. Pierre
Contracts & Risk Analyst
City of Steamboat Springs
137 10th Street
Steamboat Springs, Colorado 80477

Subject: Summary of Inclinometer and LiDAR Monitoring, Vibrating Wire Piezometer (VWP) Instillation and Monitoring, Howelsen Hill Ski Area, Steamboat Springs, Colorado.

Dear Ms. St. Pierre,

This letter presents a summary of services performed for *Task 3-LiDAR and Vibrating Wire Piezometer (VWP) installation and monitoring*, of our Masters Service Agreement (MSA) with the City of Steamboat Springs, Yeh Project No. 216-216. As of November 29, 2016, additional inclinometer readings have been performed, LiDAR initial data readings have been acquired, and vibrating wire piezometers (VWP) have been installed with active monitoring being performed at the time of this letter. Maps of the instrument locations for Area A in the ski jump area, and Areas B and C on the east face, are attached. This letter summarizes our services to date. Periodically, additional summary letters will be provided to update the City of Steamboat Springs on instrument data. A final report for Task 3 will be provided at a later date.

Inclinometer Monitoring Summary. Under Task 2 of our MSA, 18 inclinometers were installed and initial readings were performed with a summary report dated September 15, 2016 provided to the City of Steamboat Springs. Additional readings were performed on or around September 20, October 18, and November 16, 2016 with data graphs attached in Appendix A. In general, the movement observed in our previous report at locations A-2 and A-4 have continued. The degree of movement appears to have slowed between the October and November readings, however total movement is now beyond 0.25 inches. Movement is occurring around a depth of 22 feet at A-2, and 16 feet at A-4. Apparent movement is observed around a depth of 20 feet at A-5 after additional readings, but should be verified with additional readings. Apparent movement at other inclinometer locations appear variable, and at this time inconclusive, and further readings are needed. As previously stated in our report, we anticipate that by the end of June 2017 we will have acquired the data needed to provide preliminary evaluation as to the depth and magnitude of the specific landslide features of the area.

LiDAR Baseline Data Acquisition. On October 20, 2016, representatives from Firmatek, LLC visited the project site to acquire baseline data using LiDAR technology. A GPS base was established at the bottom of the ski hill near the poma lift/ski patrol shack, as shown in Photo 1. A remote data logger was positioned as shown in Photo 2 at various points on the hillside to measure locations of structures and hillside features. A subsequent visit in the Spring of 2017 is scheduled for updated data acquisition for comparison with the original data, at which time a summary report of the findings will be provided.

Photo 1. GPS base station for LiDAR initial data acquisition.

Photo 2. Remote LiDAR data logger set up for data acquisition.

Vibrating Wire Piezometer (VWP) Installation Summary. As requested, representatives of Yeh and Associates (YA) installed vibrating wire piezometers and smaller diameter PVC standpipe piezometers into existing PVC standpipe piezometers at selected locations at

Howelsen Hill Ski Area. As described in the detailed installation method below, manual readings can also be taken along side the VWP installations through a 0.5-inch pvc standpipe. Installation occurred between October 24 and November 4, 2016. Subsequent visits were performed after November 6, 2016 to complete the installation of transmission equipment, confirm data acquisition and to replace a faulty transmission node device. Information on locations, depths, and data received from VWP instruments can be found in Table 1. This table shows depths of groundwater measuring instruments, and apparent increases in the water table during two selected precipitation events during which snowmaking operations were also active.

Table 1 – Groundwater Level Comparisons November 4 – December 1, 2016

Multiplexer/ Transmission Node	Vibrating Wire Piezometer (VWP) Location	Vibrating Wire Piezometer Elevation (feet)	Measured Elevation of Water 11/15/16 (feet)*	Apparent VWP Observed water level increase after 11/17/16 precipitation (inches)	Apparent VWP Observed water level increase after 11/21/16 precipitation (inches)
Tower 6	B-2	7029.5	dry	8.3	4.3
	B-3	6967.2	6948.1	7.1	3.4
	C-2A	6964.8	6950.0	10.4	6.4
	C-2B	6969.4	6924.4	11.0	8.7
	C-3	6998.1	dry	9.6	5.8
	C-4	6959.3	6944.5	7.4	4.5
	C-5	6893.0	6875.4	9.9	4.5
Judge's Tower	A-2A	6828.7	6786.7	7.4	2.8
	A-2B	6828.5	dry	9.8	1.6
	A-4	6809.3	6772.8	9.0	4.5
	A-5	6792.2	dry	10.2	5.8
B-0	B-0	7109.2	7066.4	NA	5.8
A-1	A-1	6878.9	6849.8	8.4	4.8

*Graphs in Appendix use a surface reference point as '0' with depths below surface a negative value in feet, this may be changed in future reports.

Existing standpipe piezometers consisted of a 2 inch factory slotted PVC inserted into a previously drilled borehole and completed with silica sand and grout, and a protective flush mounted cap. A Geokon model 4500S-350kPa vibrating wire piezometer transducer, wrapped in a protective sock, was installed with blue transmission cable within the existing 2-inch diameter PVC to the depths indicated, as shown in Photo 3. The transducers and cables together are referred to as vibrating wire piezometers (VWP). Zero readings were obtained on transducers as per Geokon manual instructions prior to installation. The VWP was attached with duct tape to a sacrificial 0.5 inch diameter PVC tremie tube to the depths shown in Table 1. The tremie tube was slotted in the lower 10 feet and wrapped with filter fabric to form a PVC standpipe piezometer to allow manual water readings. The annulus outside of the tremie tube, including the area around the VWP, was filled with silica sand and capped with bentonite. VWPs were completed with the existing flush mount well covers.

Photo 3 – Top view of VWP and tremie tube PVC standpipe piezometer inside existing standpipe.

Trenching equipment was used to bury the blue transmission cable, which was connected to a transceiver location as listed in Table 1 and in locations shown on Area A and Area's B and C maps. Trenches were approximately 6 inches deep and approximately 4 inches wide. See Photo 4 and Photo 5.

Photo 4 – Typical set up of trenching equipment.

Photo 5 – Typical trench with cable.

Four transceiver nodes were installed at four locations: A-1, B-0, the ski jump judging tower west of the Magic Carpet, and at chair lift Tower 6. The transceiver nodes use wireless technology to relay VWP data to a centralized location called a 'supervisor'. The supervisor was installed on the southeast corner near the roof of the poma lift/ski patrol shack at the bottom of the ski hill. Data collected by the supervisor is relayed via modem and the internet to YA designated sites. The A-1 node is shown in Photo 6. Using a multiplexer connection, multiple VWP cables were connected to the node at chair lift Tower 6 as shown in Photo 7. Preliminary readings began on November 4, 2016. During the preliminary reading period, data acquisition trouble shooting and the replacement of a faulty transceiver node were performed. Full time data acquisition for all VWPs began on November 15, 2016.

Photo 6 – Transceiver node at location A-1.

Photo 7 – Multiplexer (bottom) and transceiver node (top) at chair lift Tower 6.

A preliminary data acquisition period, shown graphically in Appendix B, for VWPs occurred from November 4 to November 14, 2016. Days where precipitation occurred and snowmaking operations commenced are shown on graphs. Precipitation was verified using National Oceanic and Atmospheric Administration (NOAA) information and general snowmaking schedules communicated to YA by Howelsen Hill Ski Area staff. Data acquisition for all VWPs began on November 16, 2016. We understand regular nightly snowmaking operations began around November 15, 2016.The acquisition period between November 16 and November 29, 2016 is depicted graphically in Appendix C with precipitation and snowmaking events.

Fluctuations in water levels were observed and initially appear to coincide with weather events and snowmaking operations, and are on the order of a few inches up to two feet. As snowmaking thus far has generally occurred during periods of precipitation, it is difficult to separate their impact on the water table. Specific areas of snowmaking with respect to VWP locations were not provided to us at the time of this letter. Further monitoring will continue and additional summary letters will be provided until readings appear to stabilize through the winter months.

Summary. As of November 16, 2016, our study indicates that 17 inclinometers are providing data, and based on recent readings subsurface movement is occurring at the ski jump area. Initial acquisition of baseline data using LiDAR technology has been performed and subsequent surveys are scheduled for the summer of 2017. Additionally, 13 vibrating wire piezometers (VWPs) have been installed and continuous data acquisition at all locations has been successful. Preliminary monitoring of VWPs indicate water level fluctuations likely coincide with precipitation events. It is unclear if data suggests snowmaking operations coincides with water level fluxuations. Data to date should be considered preliminary and more monitoring is necessary. At the time of this letter, continued collection of inclinometer, VWP and LiDAR data is imperative to the evaluation and analysis of the existing hillside conditions. A report of our findings under Task 3 of our MSA will be provided in the summer of 2017, as requested.

We appreciate the opportunity to be of service to you during this investigation. If you have any questions, please feel free to contact us.

Sincerely,

YEH AND ASSOCIATES, INC.

Scott W. Richards, P.E., P.G.
Colorado Northwest Region Manager

Attachments:
Area A Map
Areas B and C Map
Appendix A: Inclinometer reading graphs
Appendix B: VWP preliminary monitoring period data graphs
Appendix C: VWP initial monitoring period data graphs

Vibrating Wire Piezometers and Trenches Area A

Instrumentation

- Vibrating Wire Piezometer
- Inclinometer
- Manual-Read Piezometer
- Approximate Locations of Vibrating Wire Cable Trench, 6 inches deep

N

0 12.5 25 50 Feet

Figure 1: Area A Map

Background Image: Google Earth 2014

Vibrating Wire Piezometers and Trenches Areas B and C

Instrumentation

- Vibrating Wire Piezometer
- Inclinometer
- Manual-Read Piezometer
- Approximate Locations of Vibrating Wire Cable Trench, 6 inches deep

N

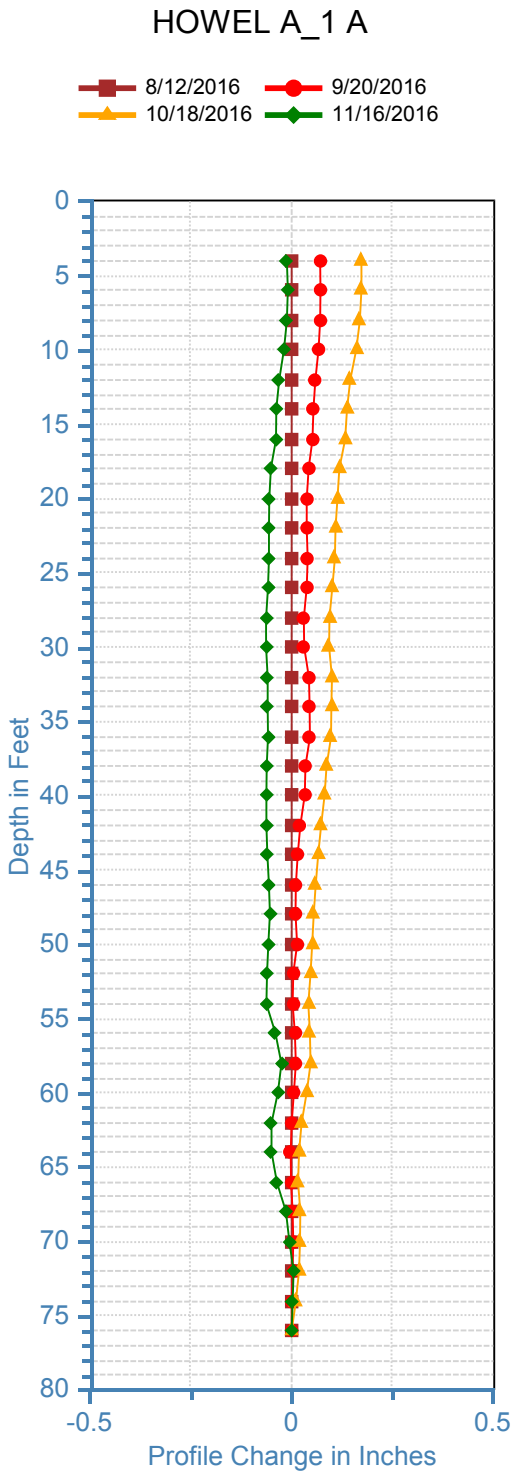
0 25 50 100 Feet

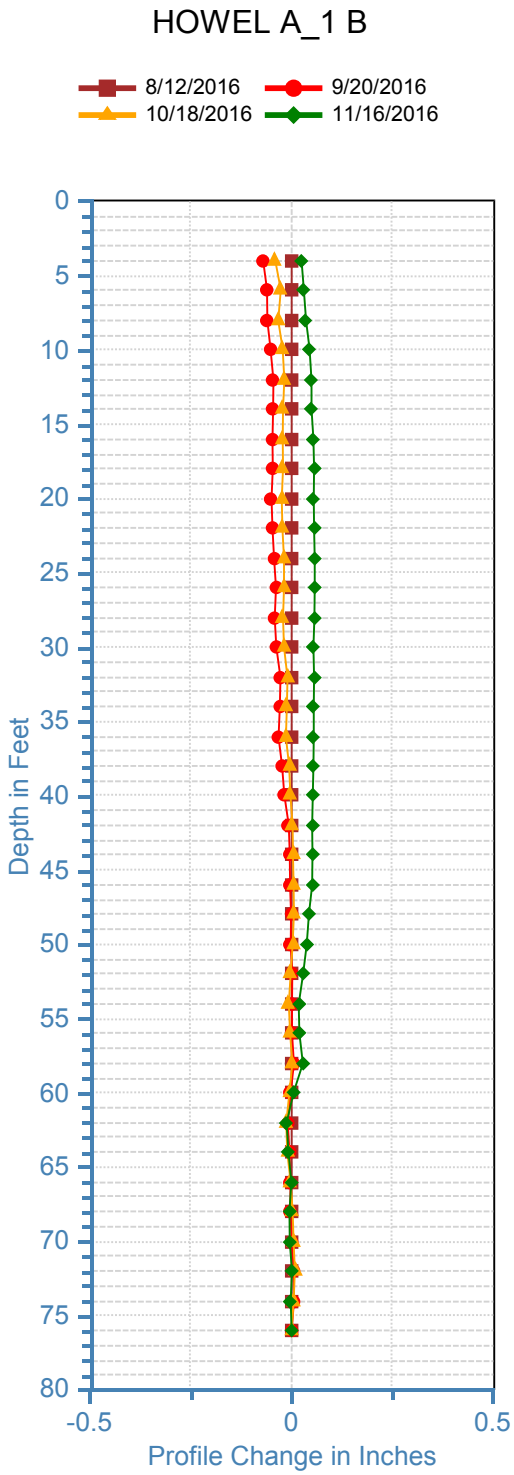
Figure 2: Area B-C Map

Background Image: Google Earth 2014

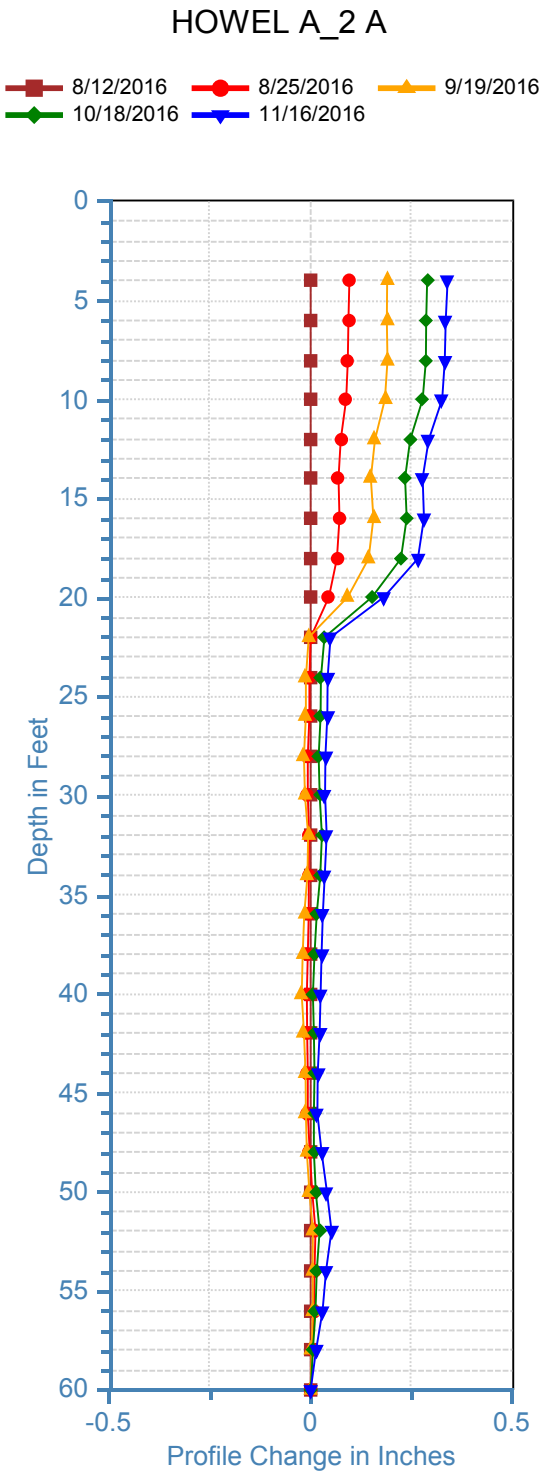
APPENDIX A

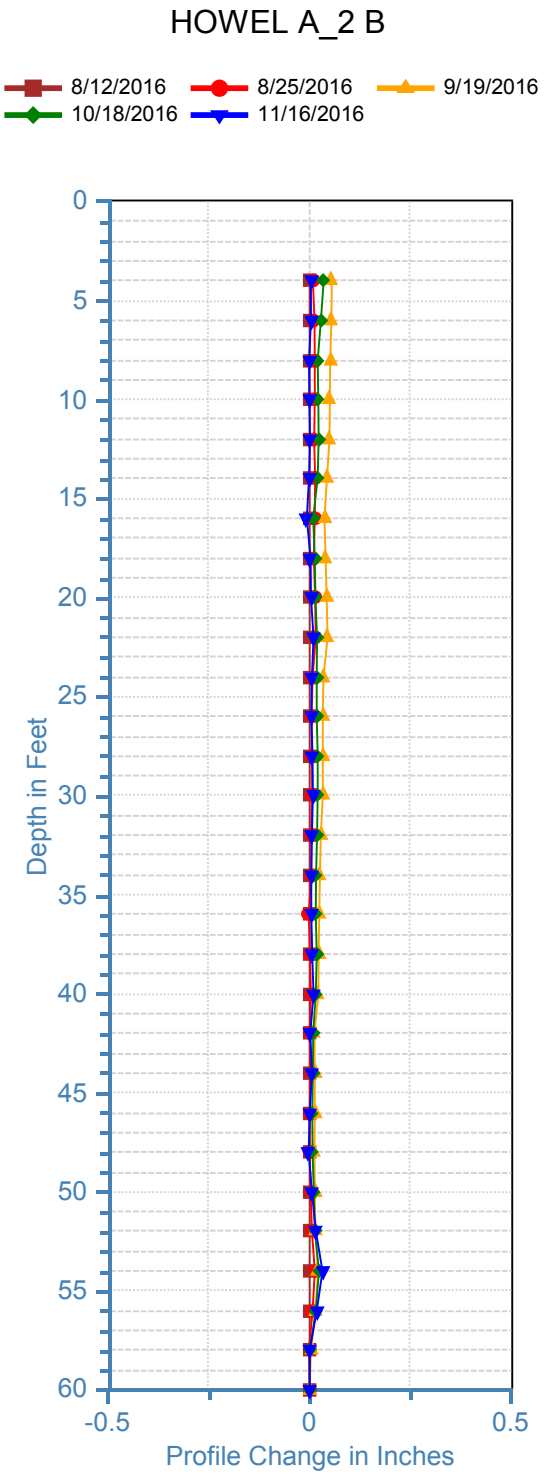
Inclinometer Monitoring Period Data Graphs



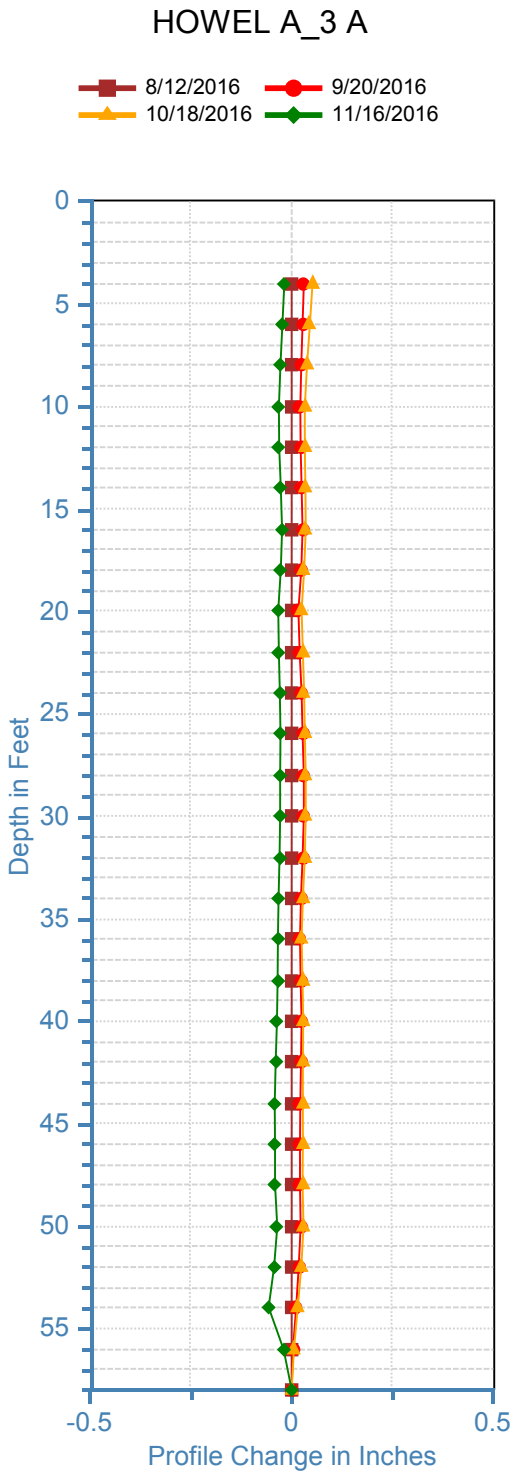


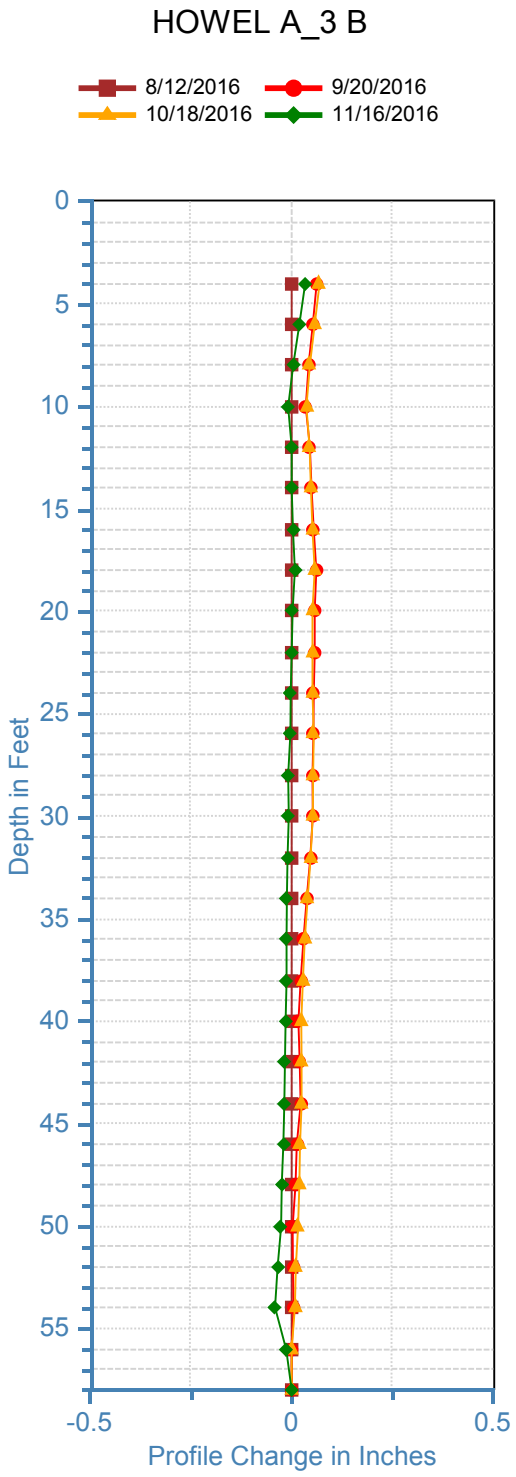
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer A-1



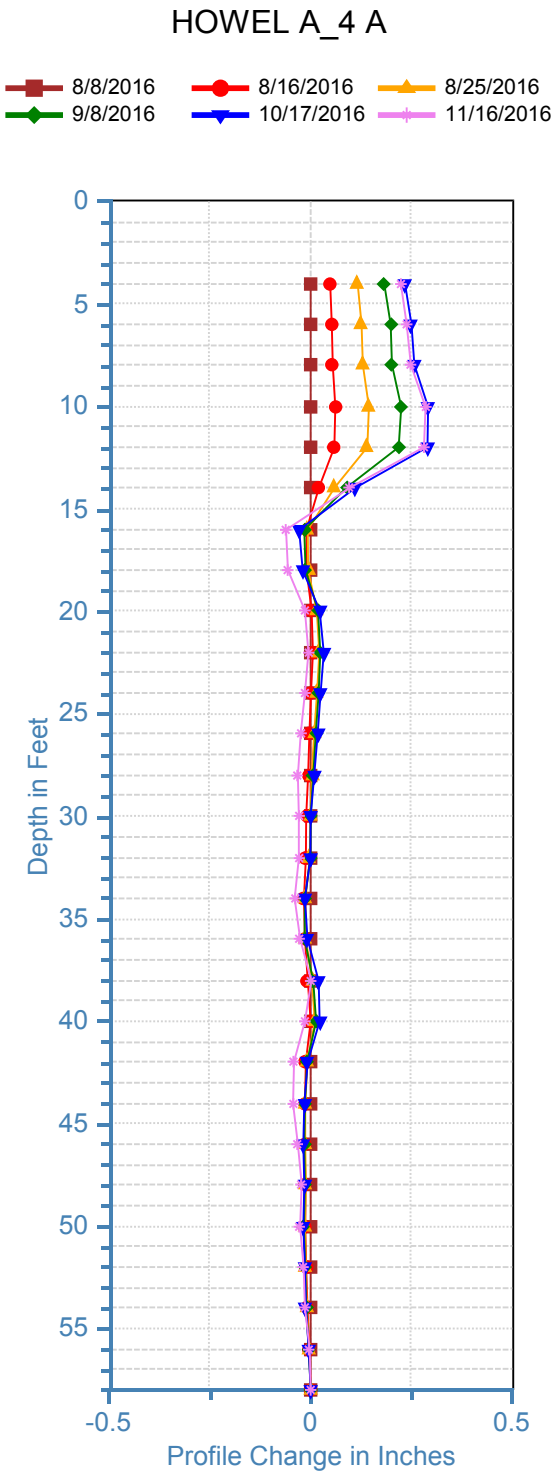


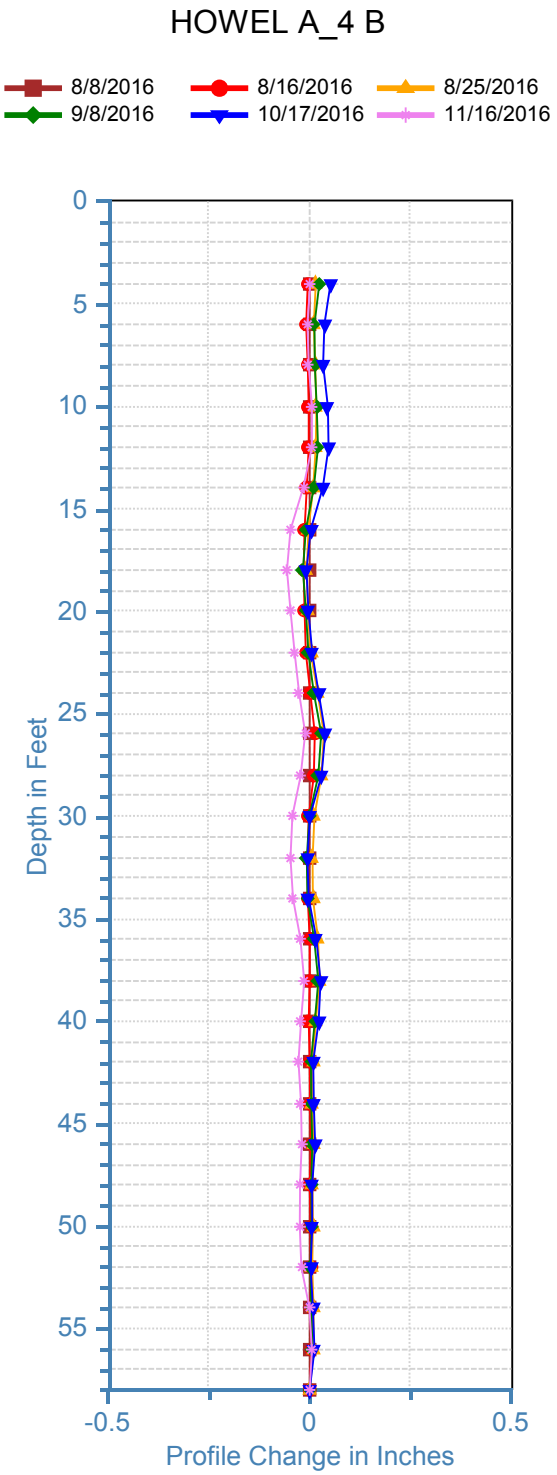
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer A-2



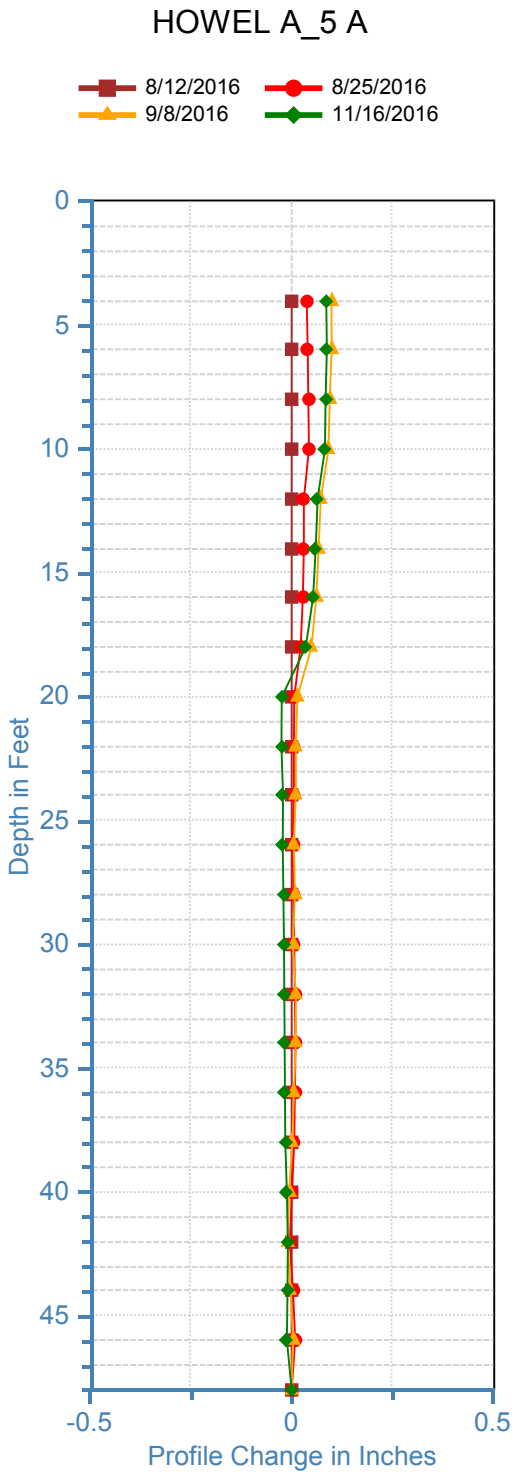


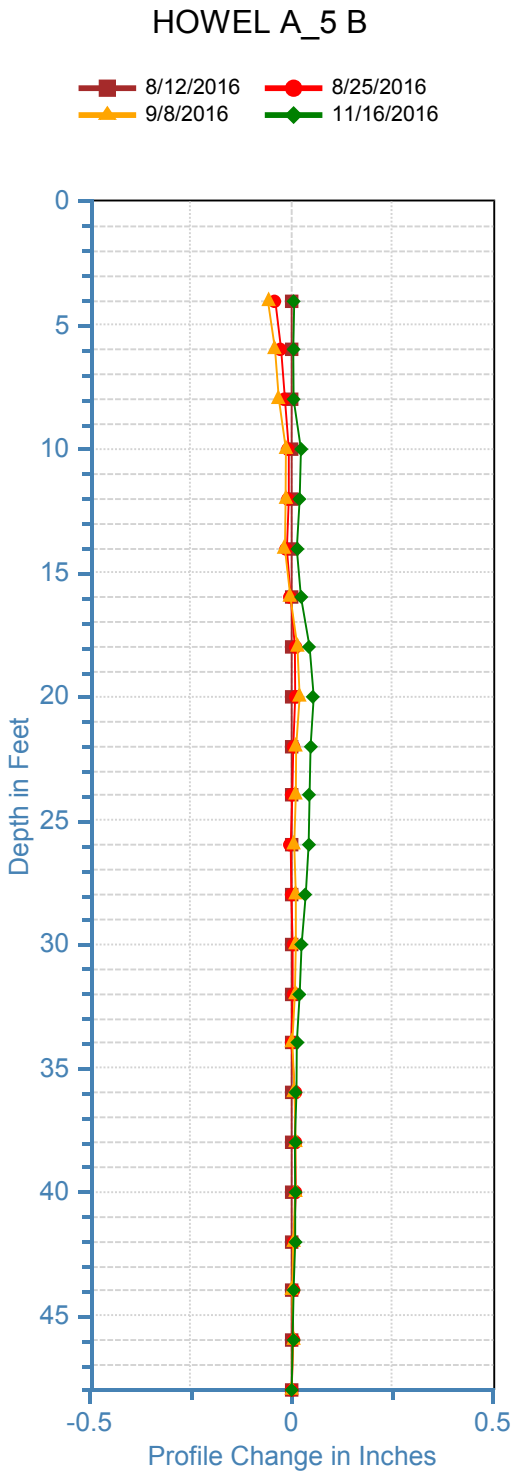
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer A-3



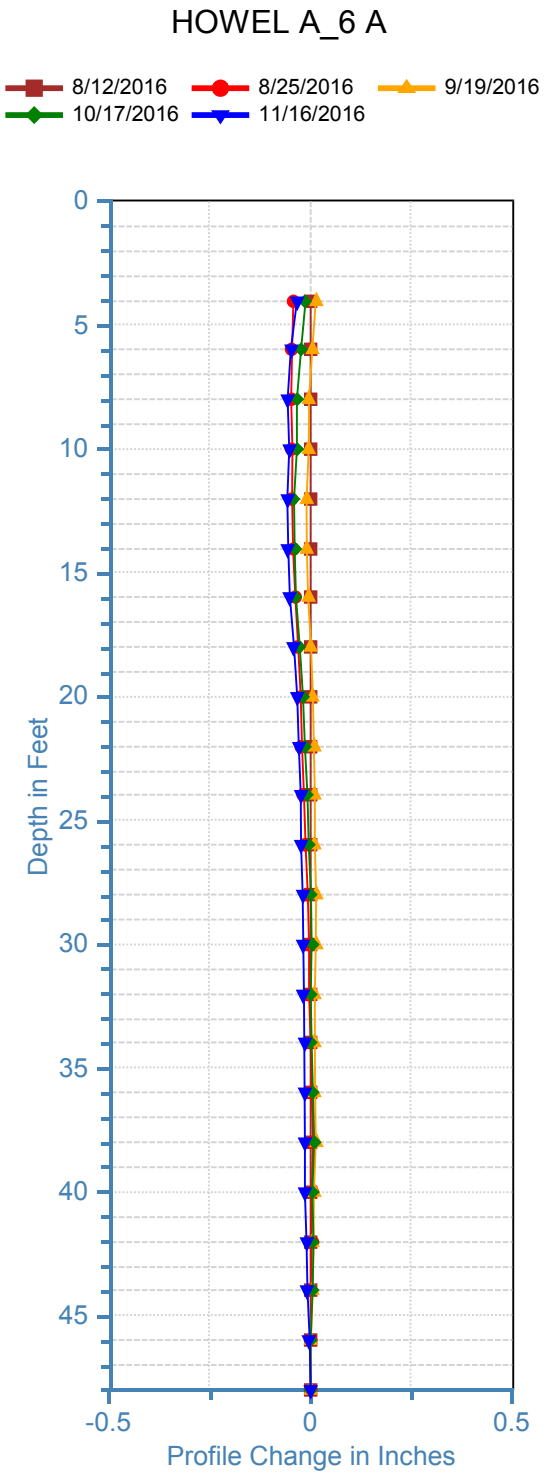


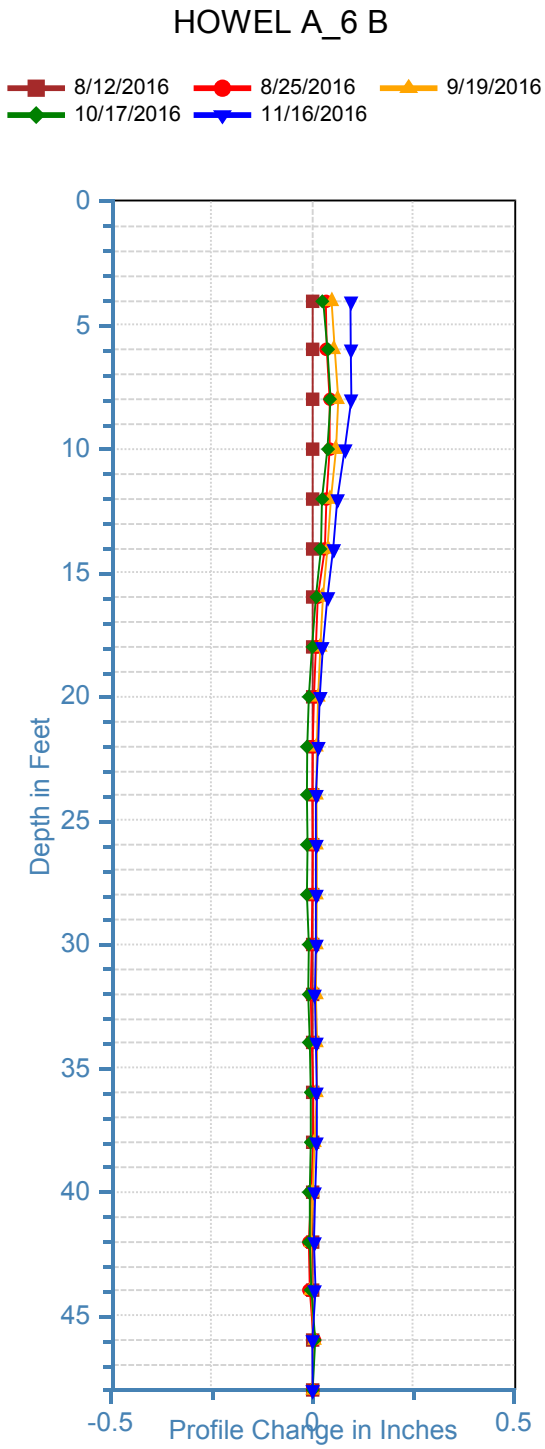
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer A-4



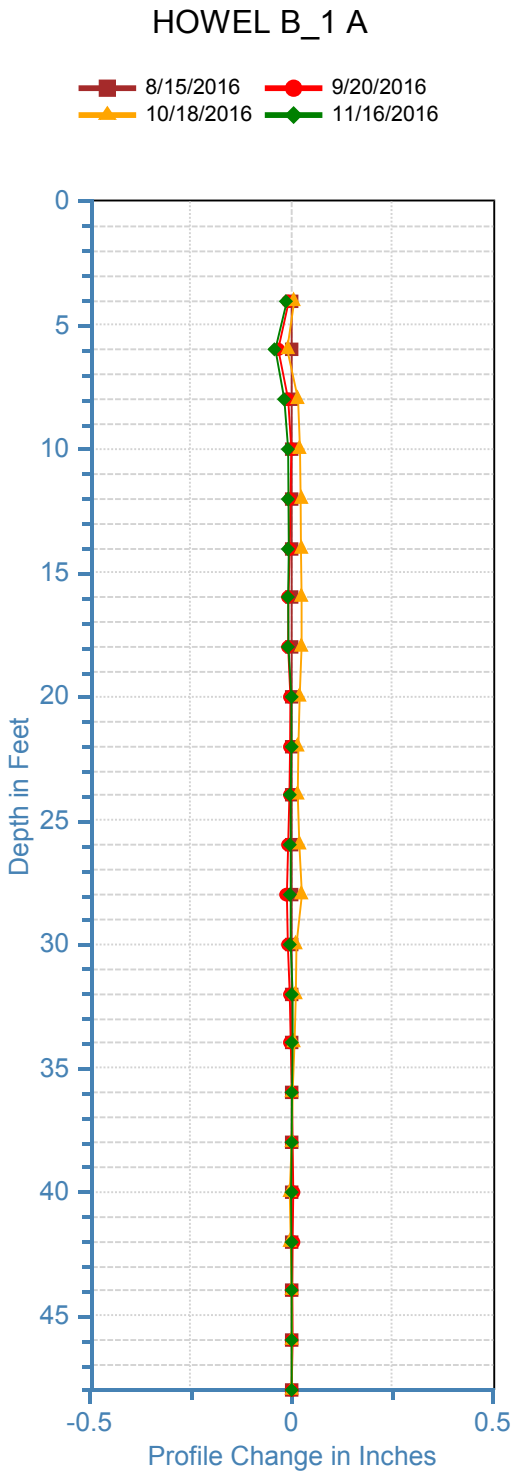


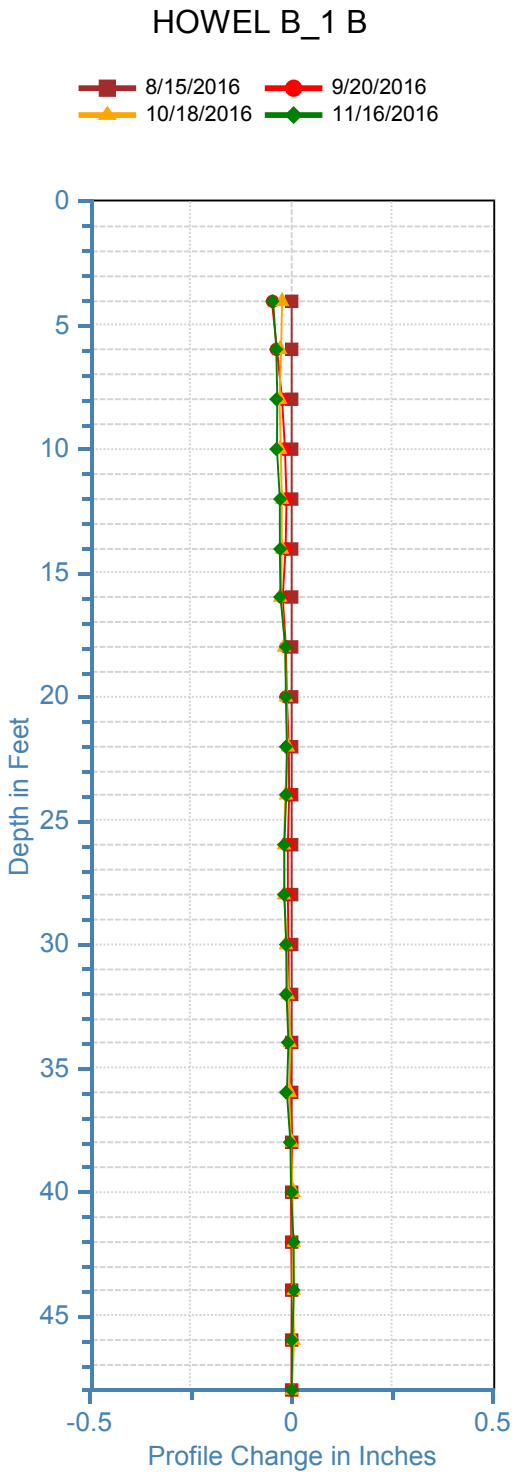
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer A-5



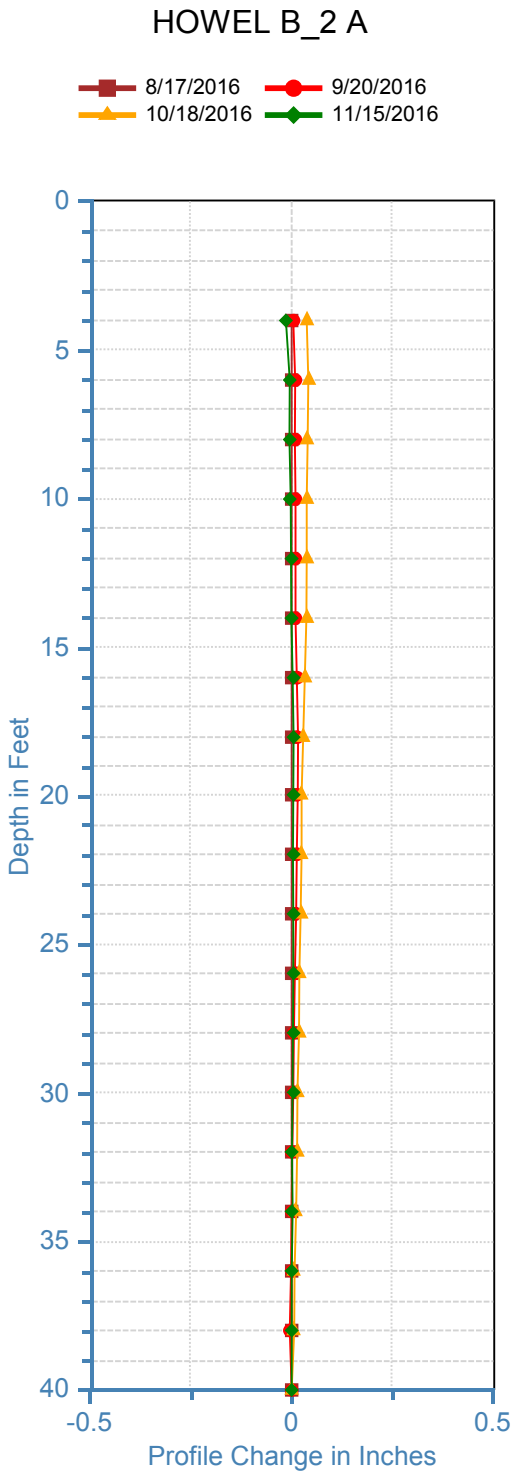


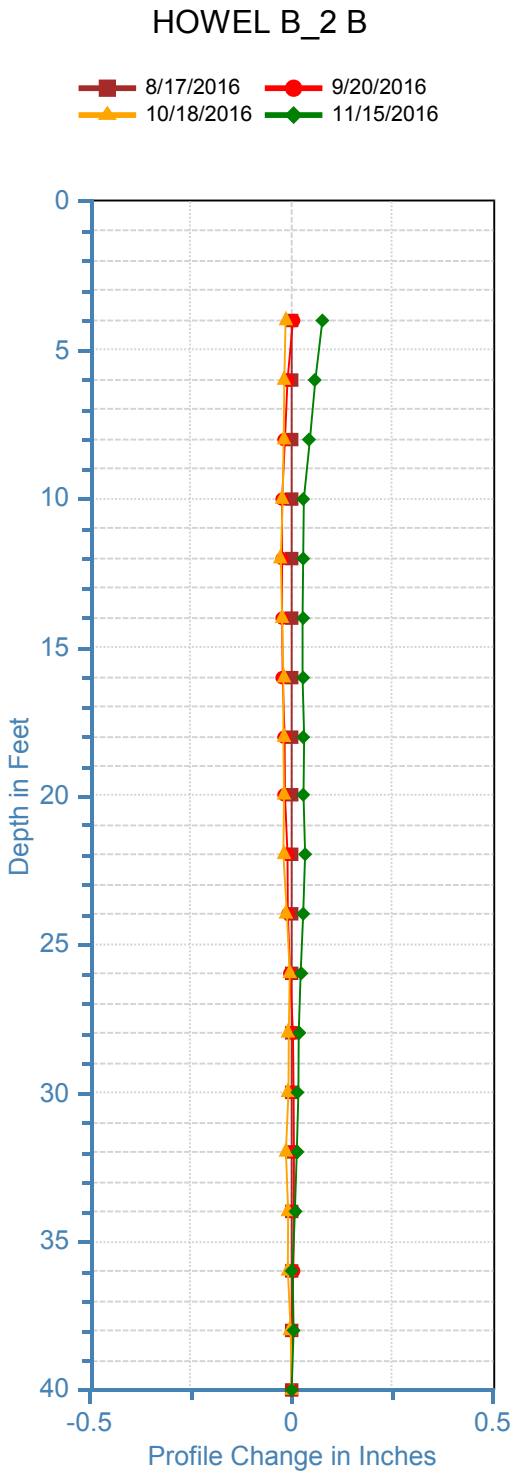
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer A-6



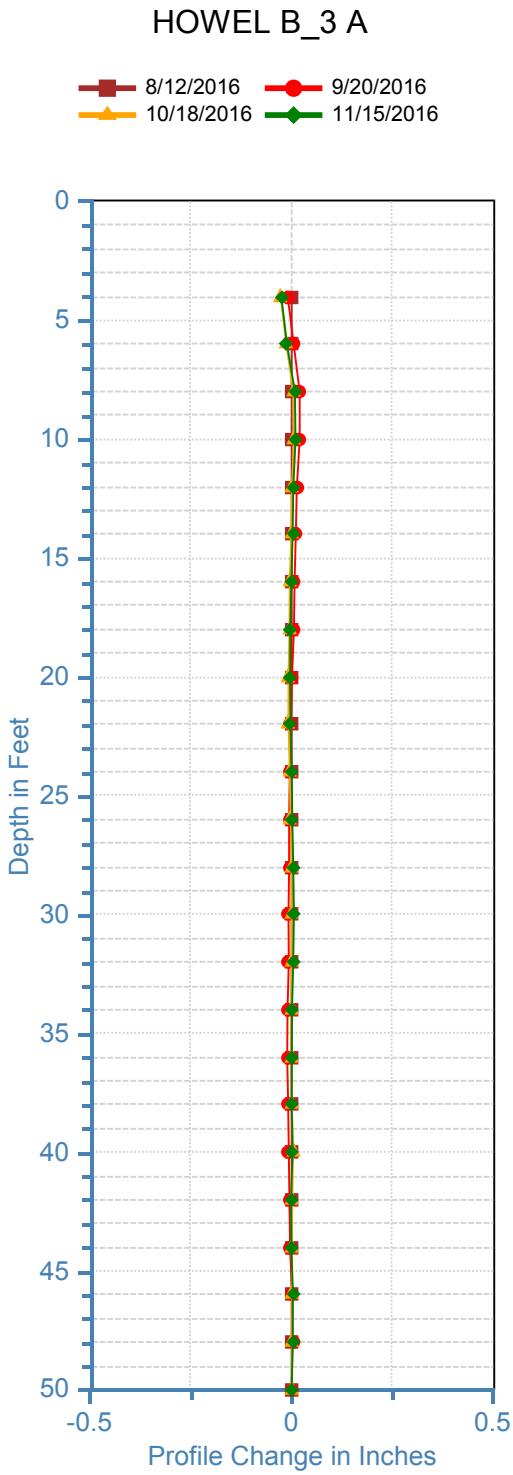


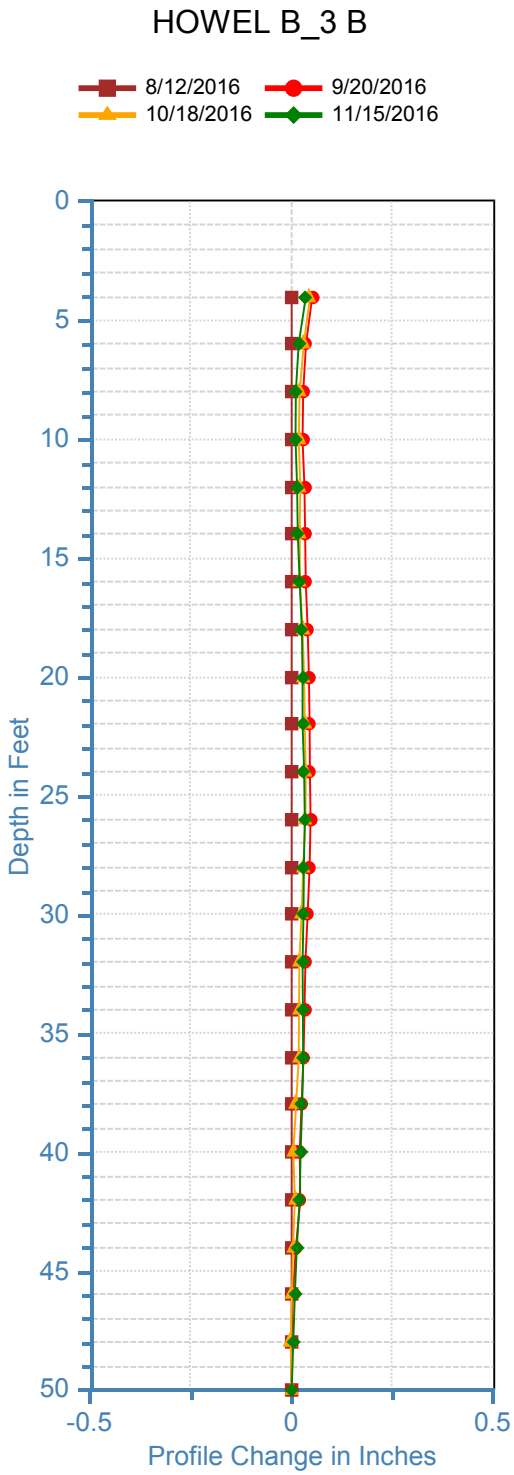
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer B-1



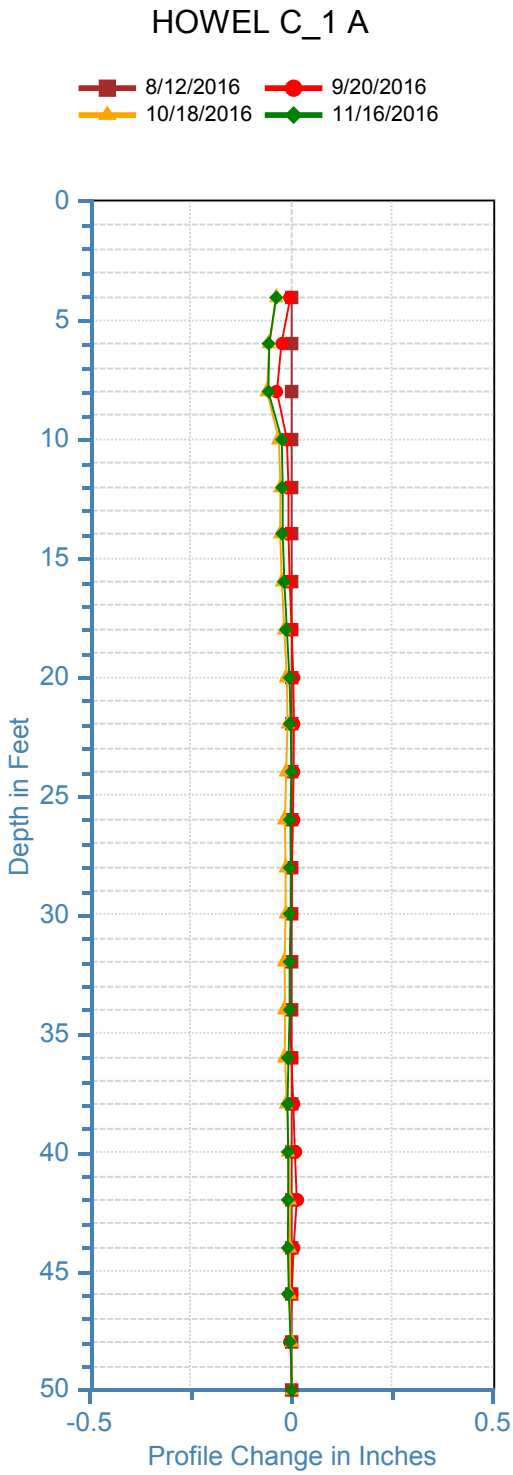


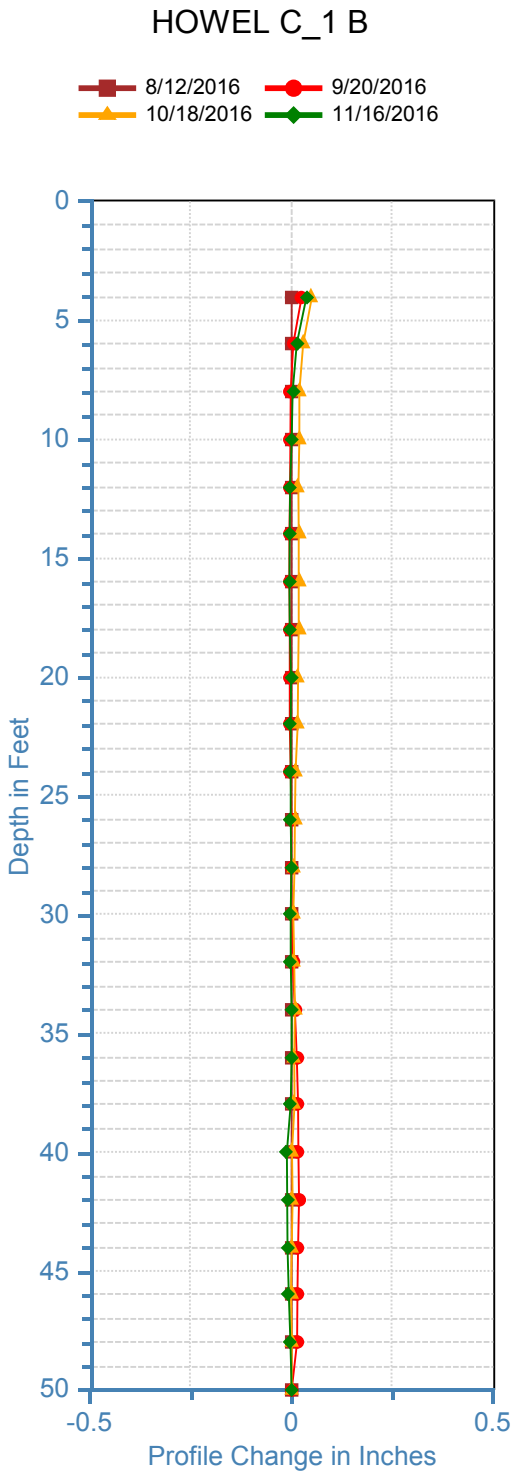
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer B-2



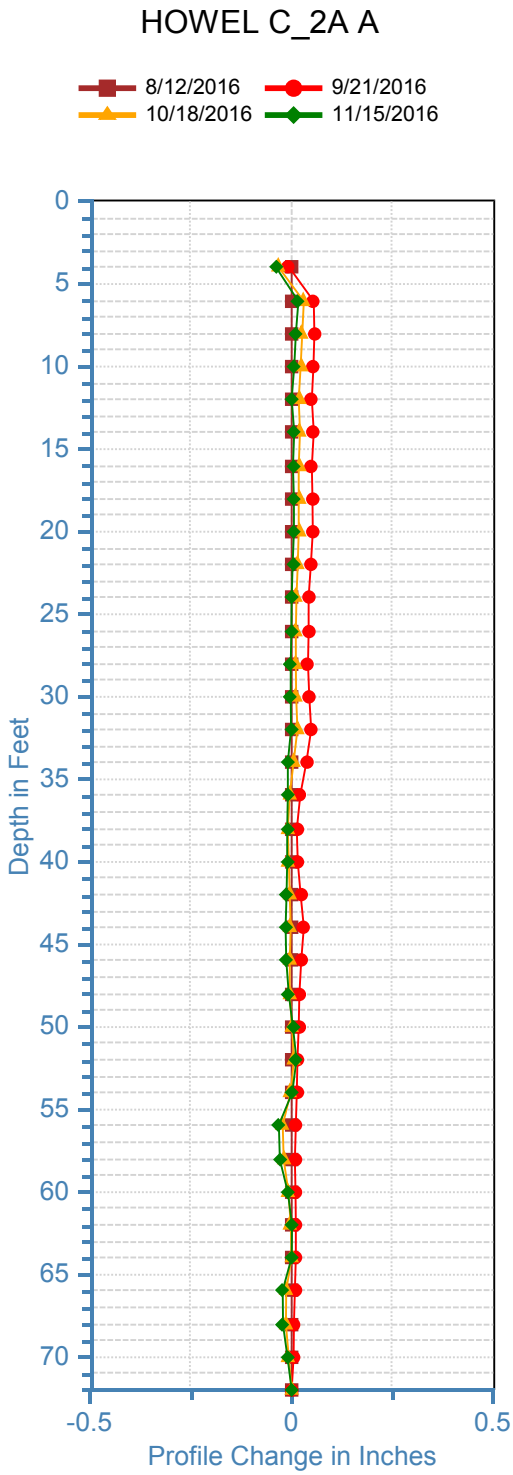


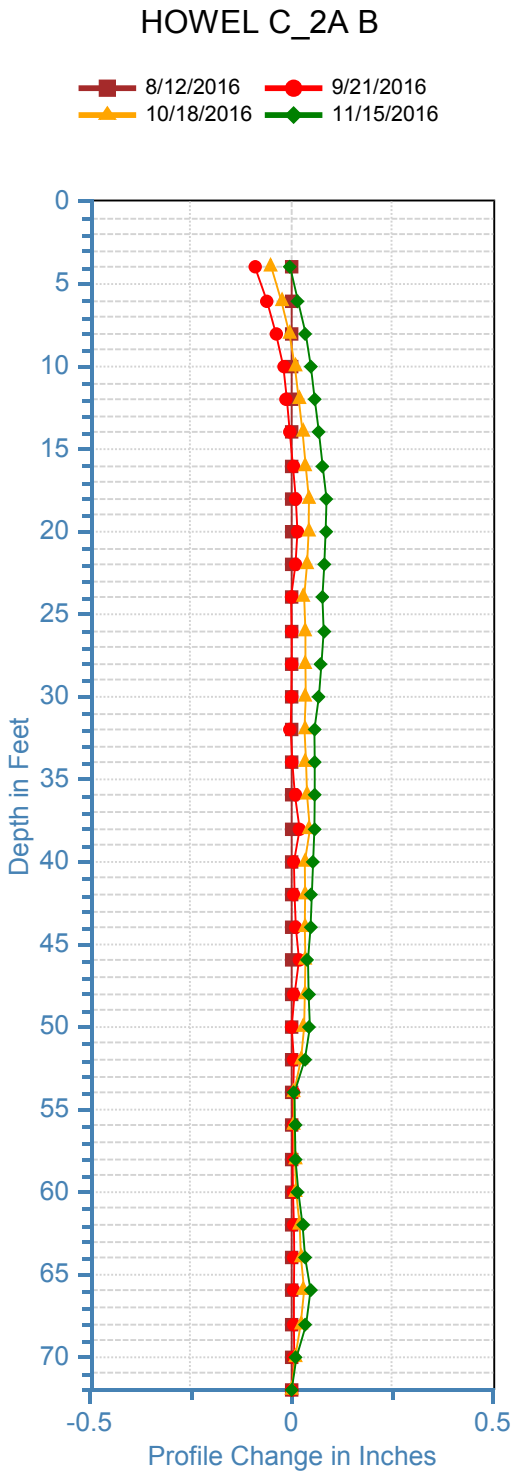
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer B-3



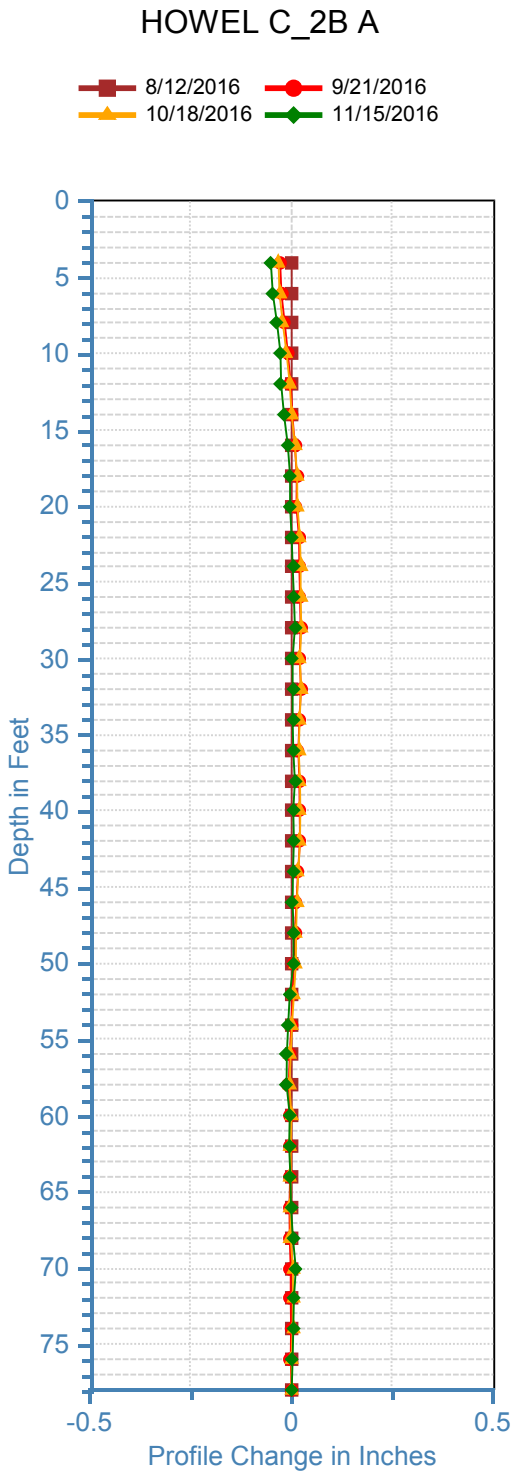


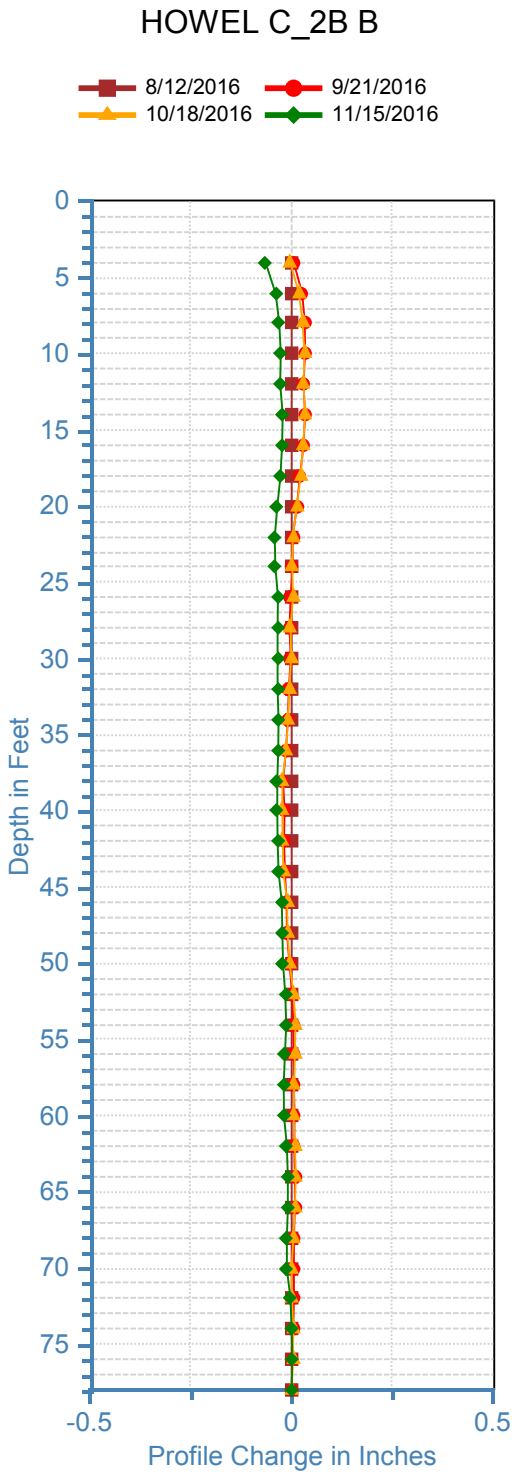
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer C-1



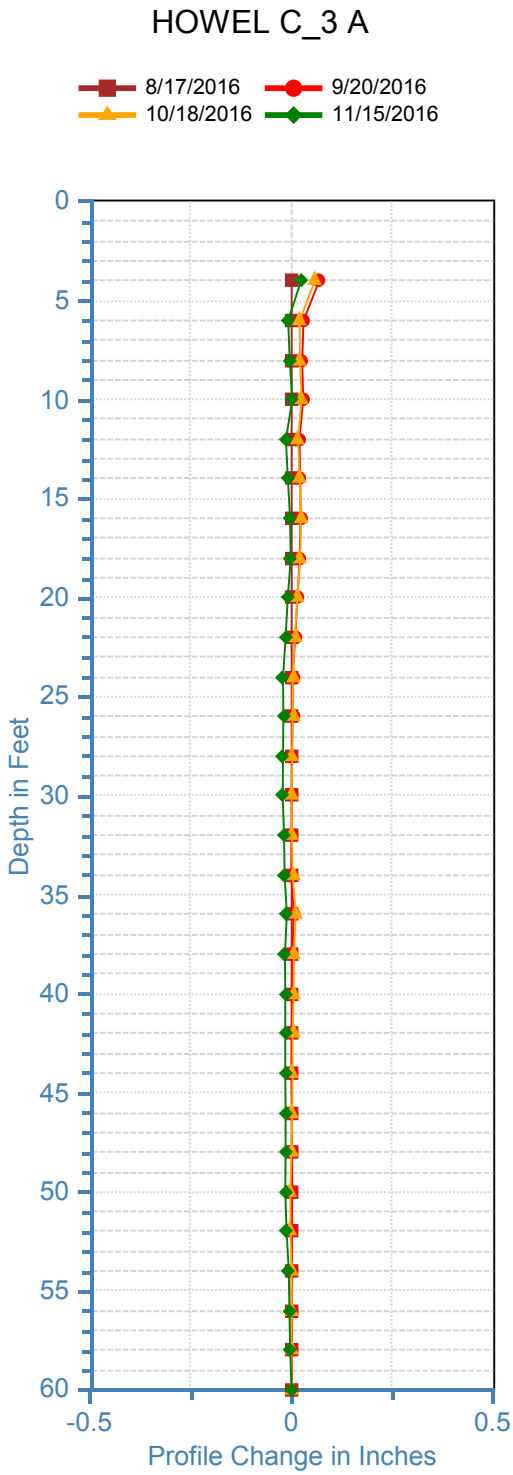


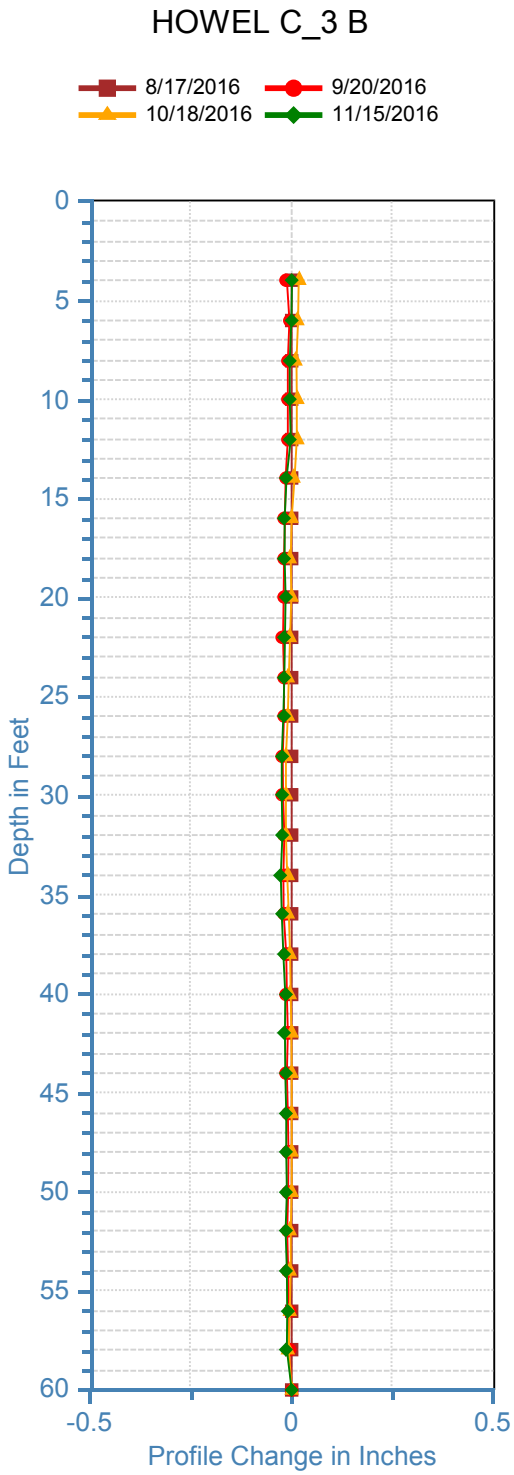
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer C-2A



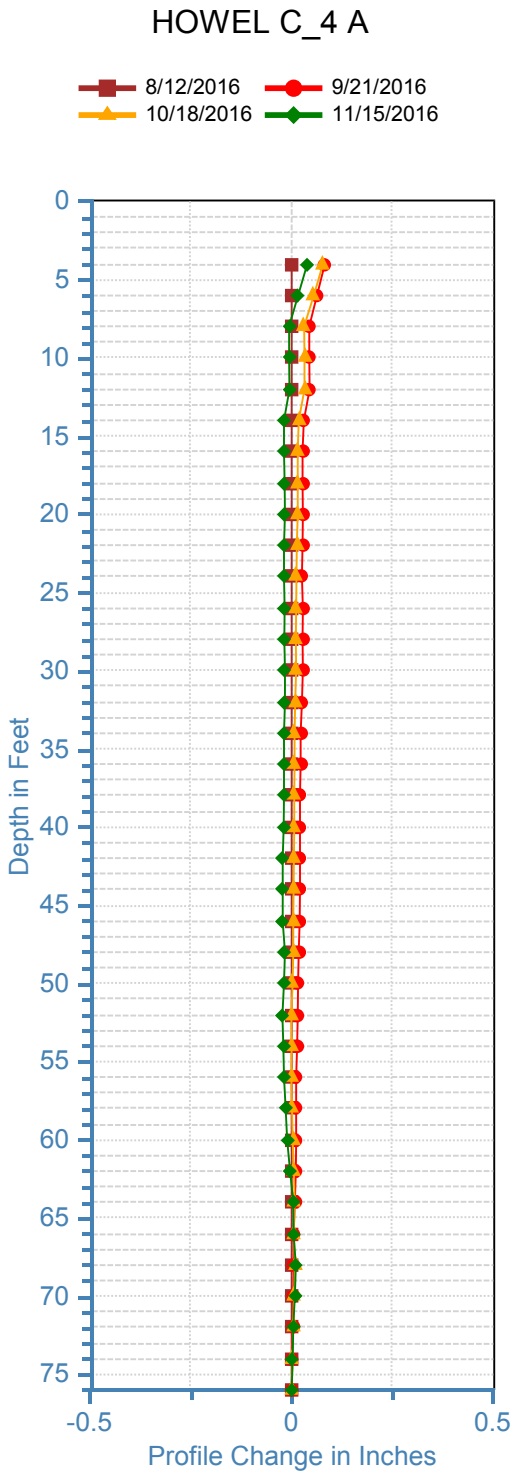


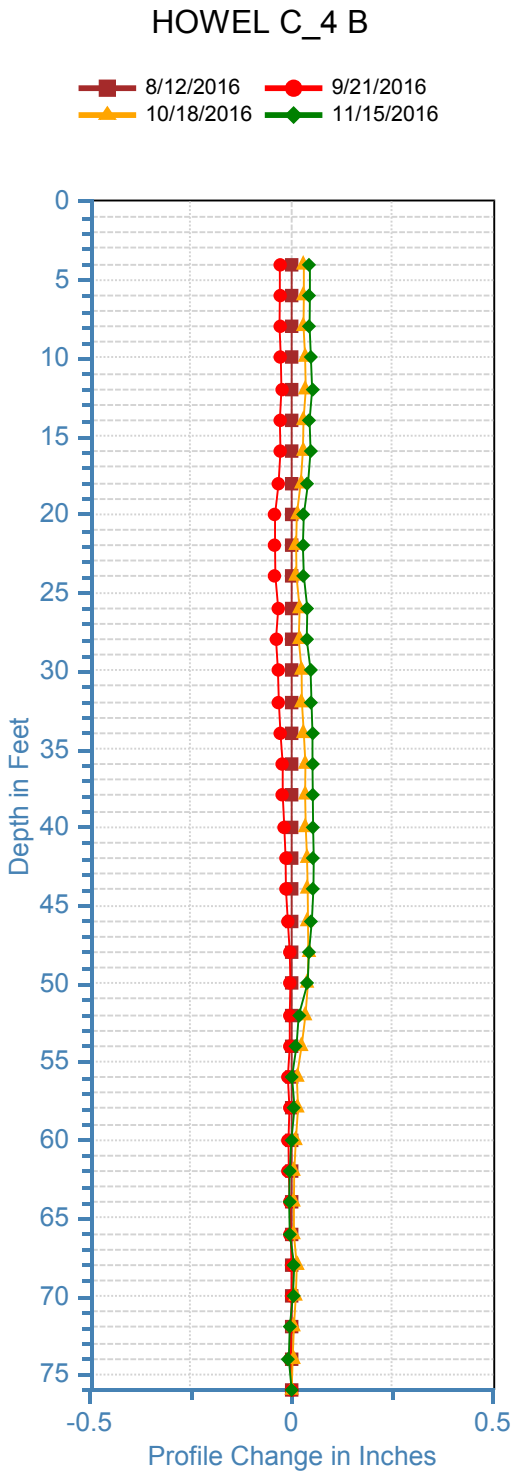
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer C-2B



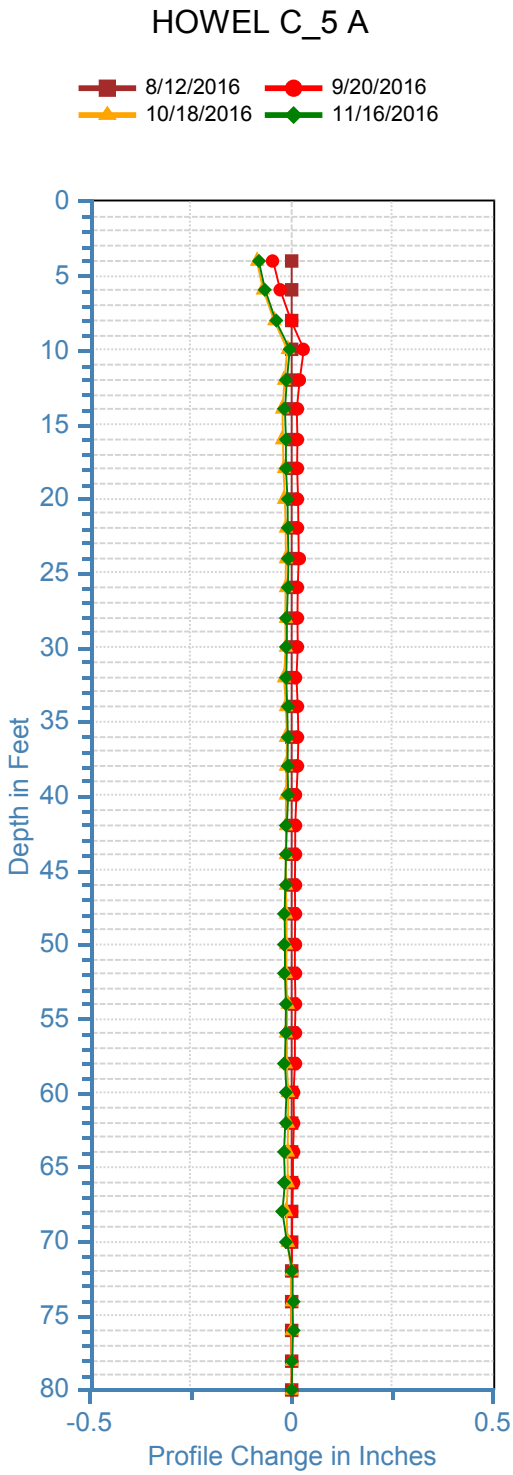


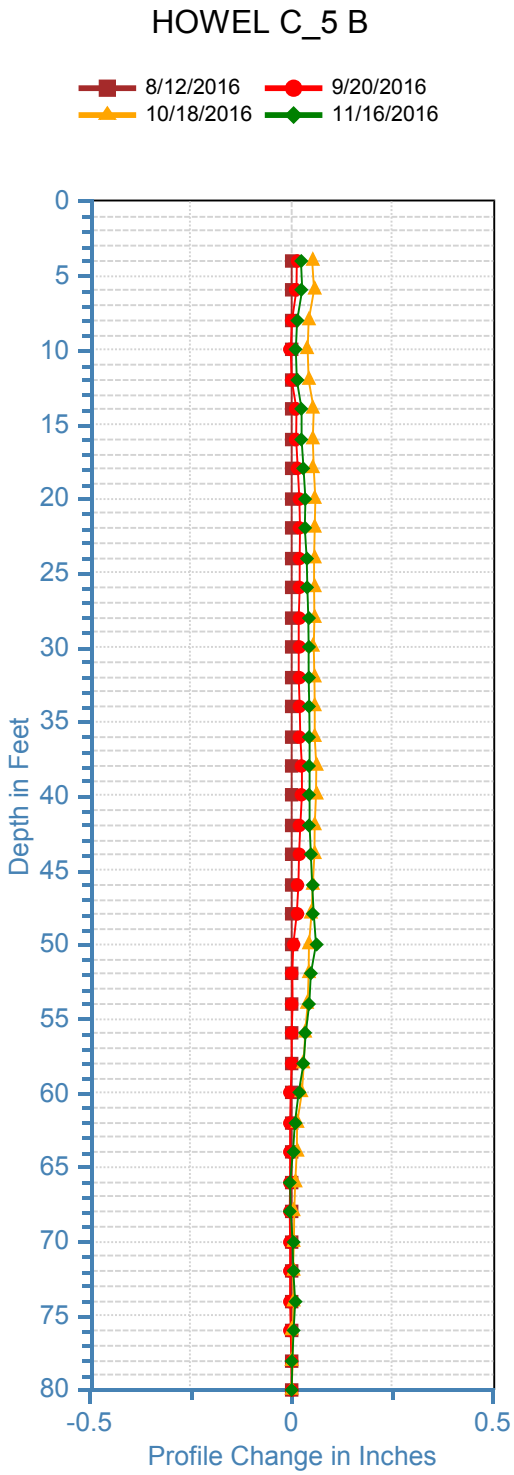
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer C-3



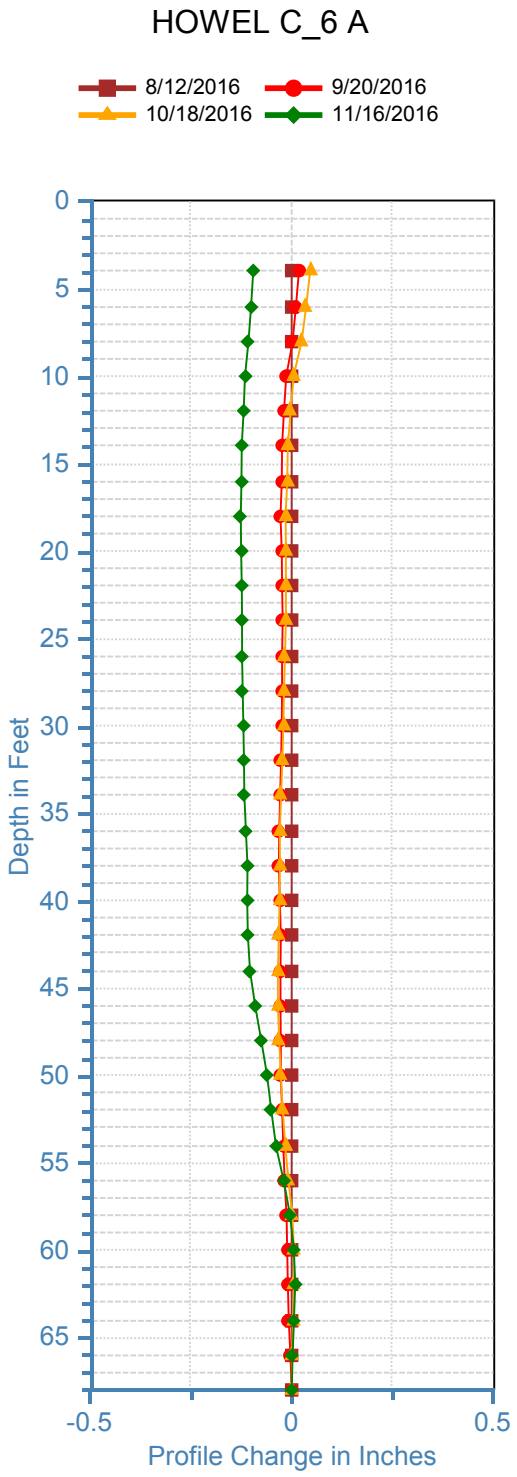


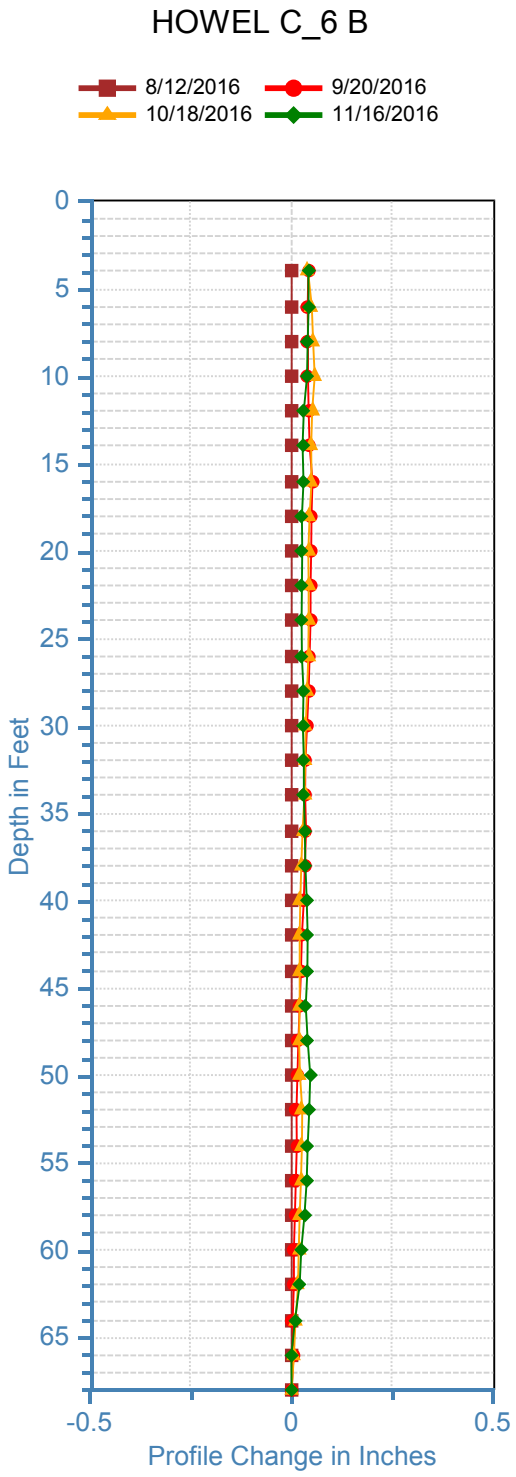
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer C-4



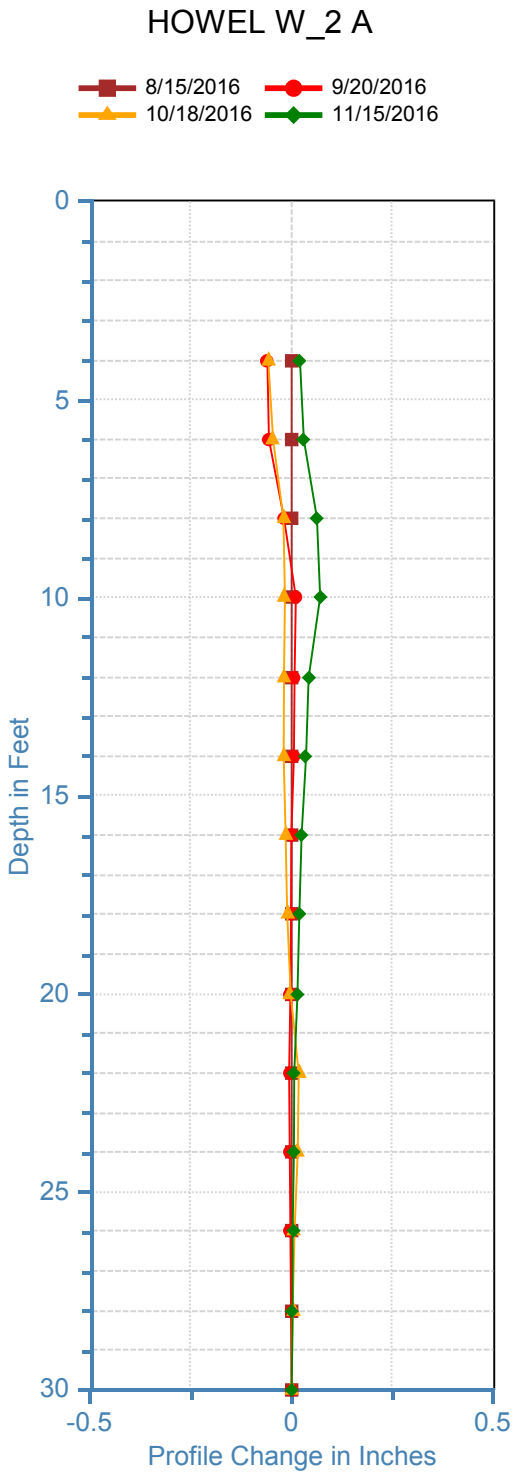


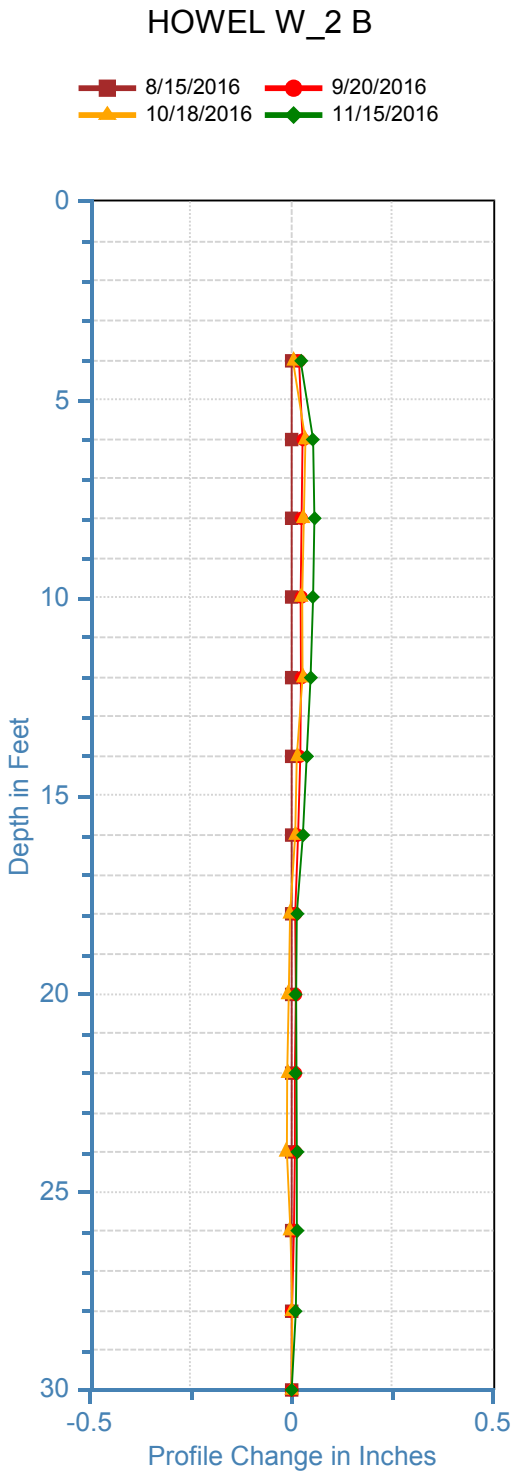
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer C-5



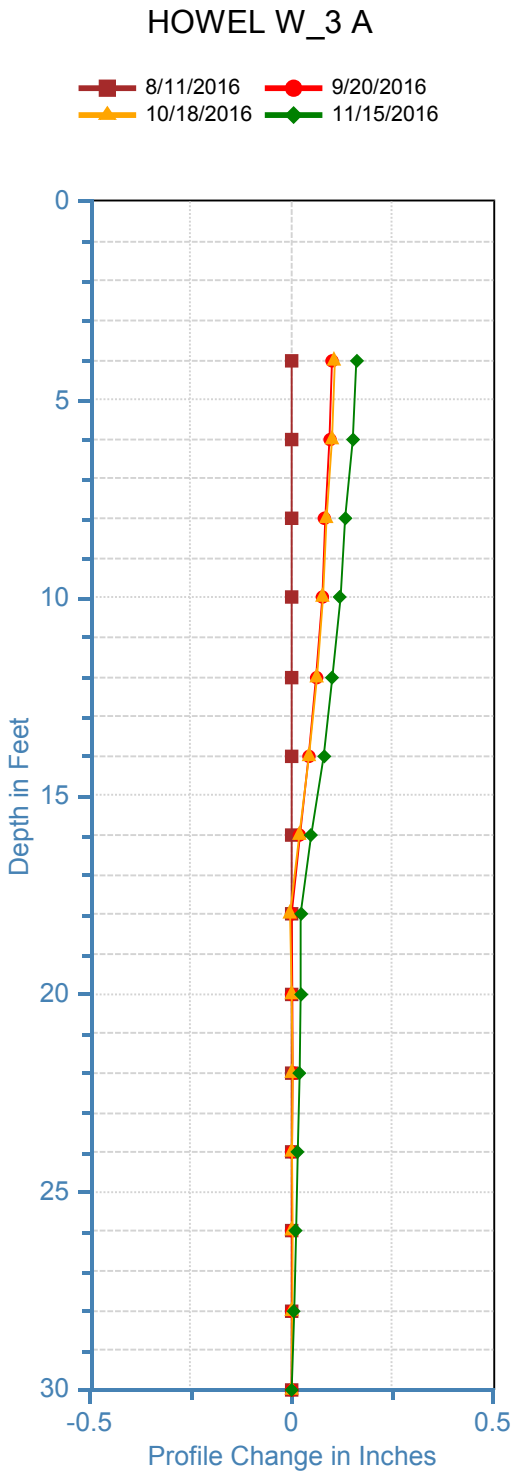


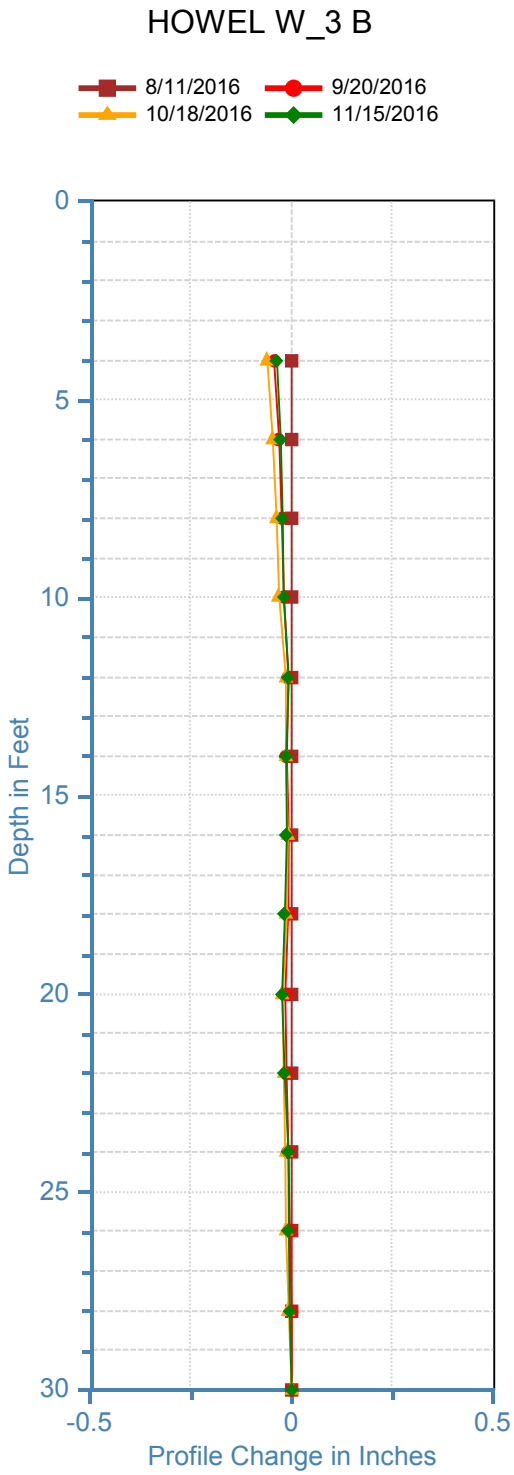
Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 16, 2016
Inclinometer C-6





Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer W-2





Howelsen Hill Ski Area Slope Conditions Project
Yeh and Associates, Inc.
November 15, 2016
Inclinometer W-3

APPENDIX B

VWP Preliminary Monitoring Period Data Graphs

Vibrating Wire Piezometer A-1

11-4 to 11-14

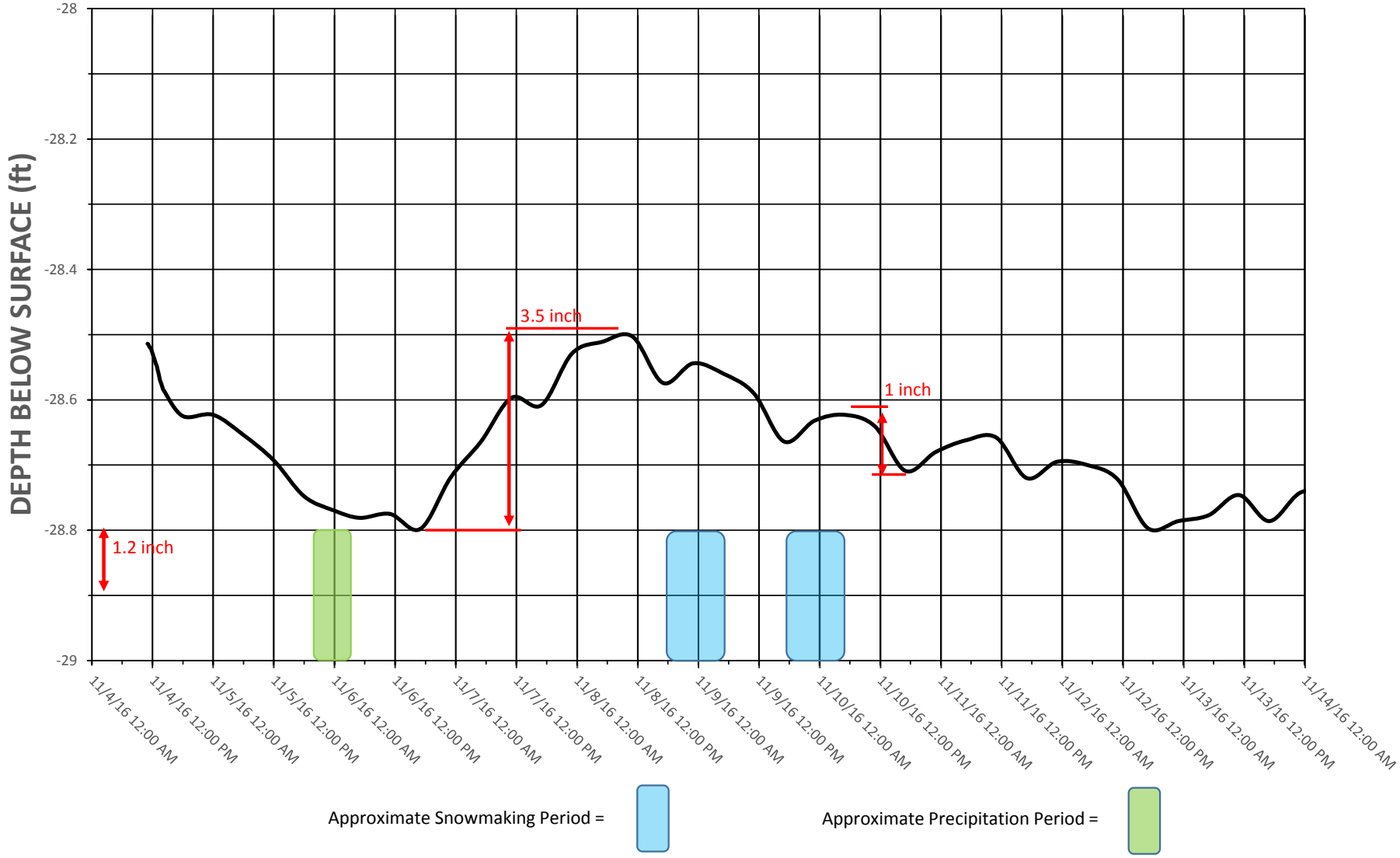


Figure B-1

Vibrating Wire Piezometer A-2A

11-4 to 11-14

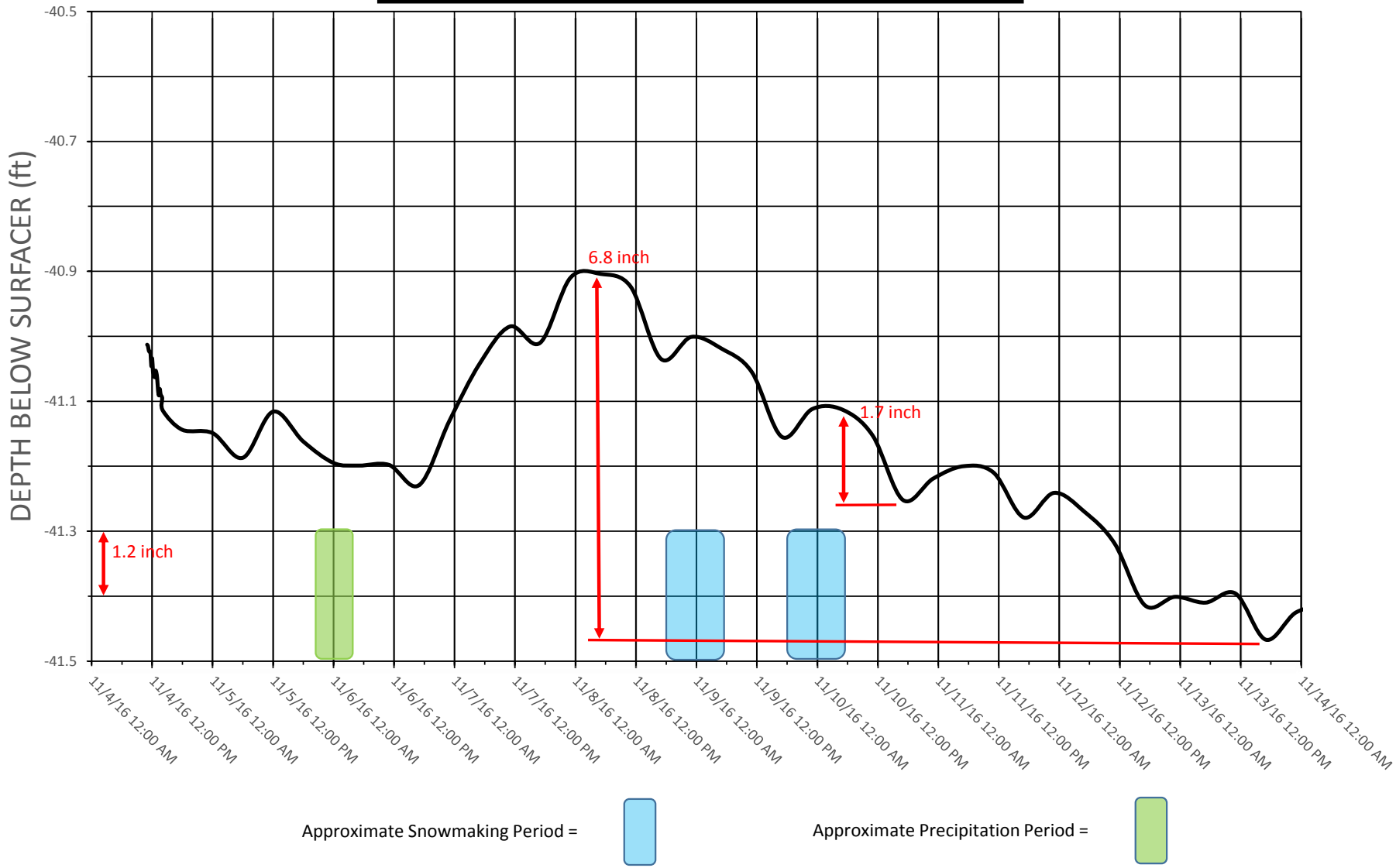


Figure B-2

Vibrating Wire Piezometer A-2B

11-4 to 11-14

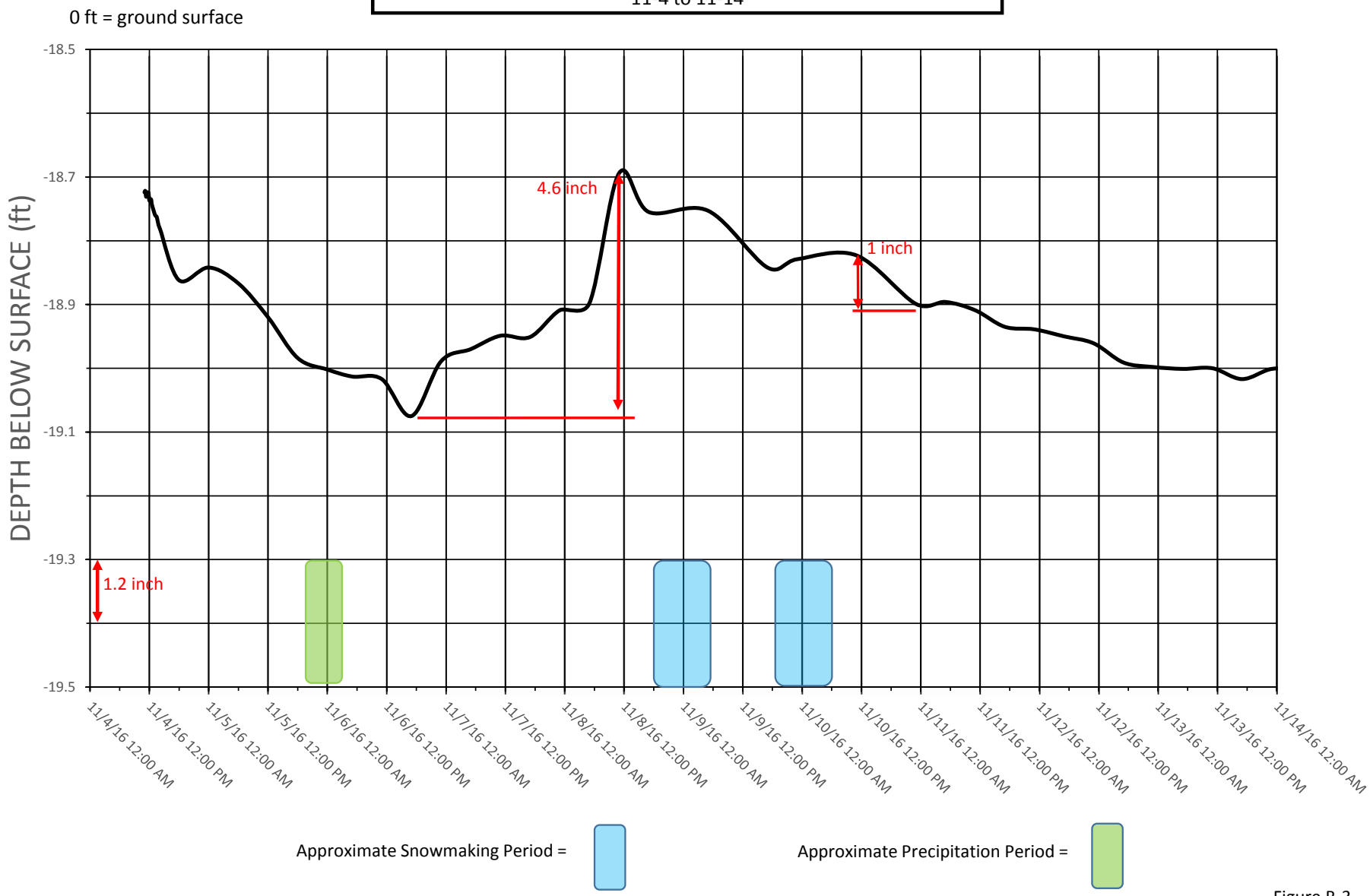
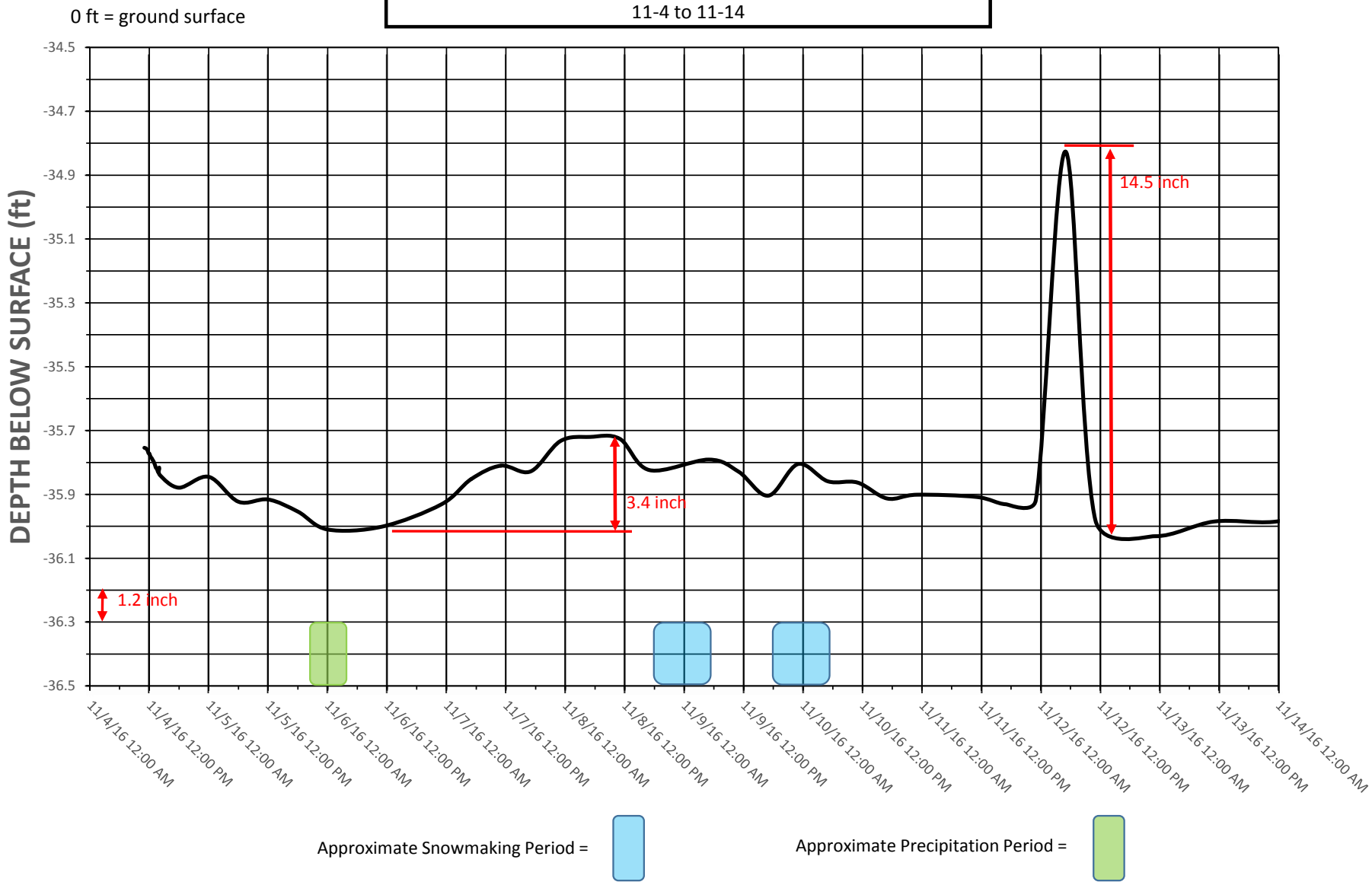


Figure B-3

Vibrating Wire Piezometer A-4

11-4 to 11-14



Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure B-4

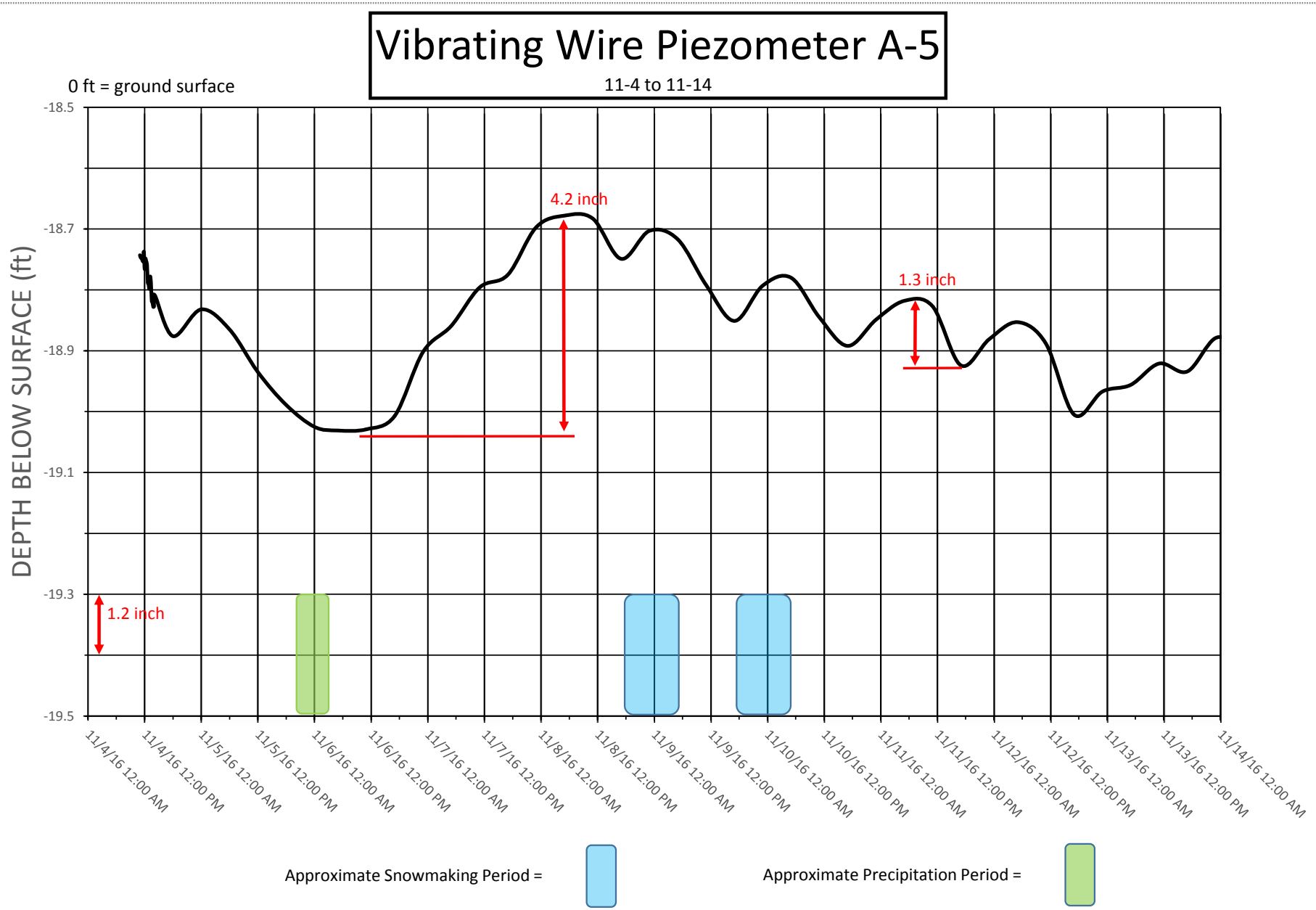

Vibrating Wire Piezometer A-5
11-4 to 11-14
0 ft = ground surface
DEPTH BELOW SURFACE (ft)
-18.5
-18.7
-18.9
-19.1
-19.3
-19.5
4.2 inch
1.3 inch
1.2 inch
11/4/16 12:00 AM
11/4/16 12:00 PM
11/5/16 12:00 AM
11/5/16 12:00 PM
11/6/16 12:00 AM
11/6/16 12:00 PM
11/7/16 12:00 AM
11/7/16 12:00 PM
11/8/16 12:00 AM
11/8/16 12:00 PM
11/9/16 12:00 AM
11/9/16 12:00 PM
11/10/16 12:00 AM
11/10/16 12:00 PM
11/11/16 12:00 AM
11/11/16 12:00 PM
11/12/16 12:00 AM
11/12/16 12:00 PM
11/13/16 12:00 AM
11/13/16 12:00 PM
11/14/16 12:00 AM
Approximate Snowmaking Period =
Approximate Precipitation Period =

Figure B-5

Vibrating Wire Piezometer B-0

11-4 to 11-14

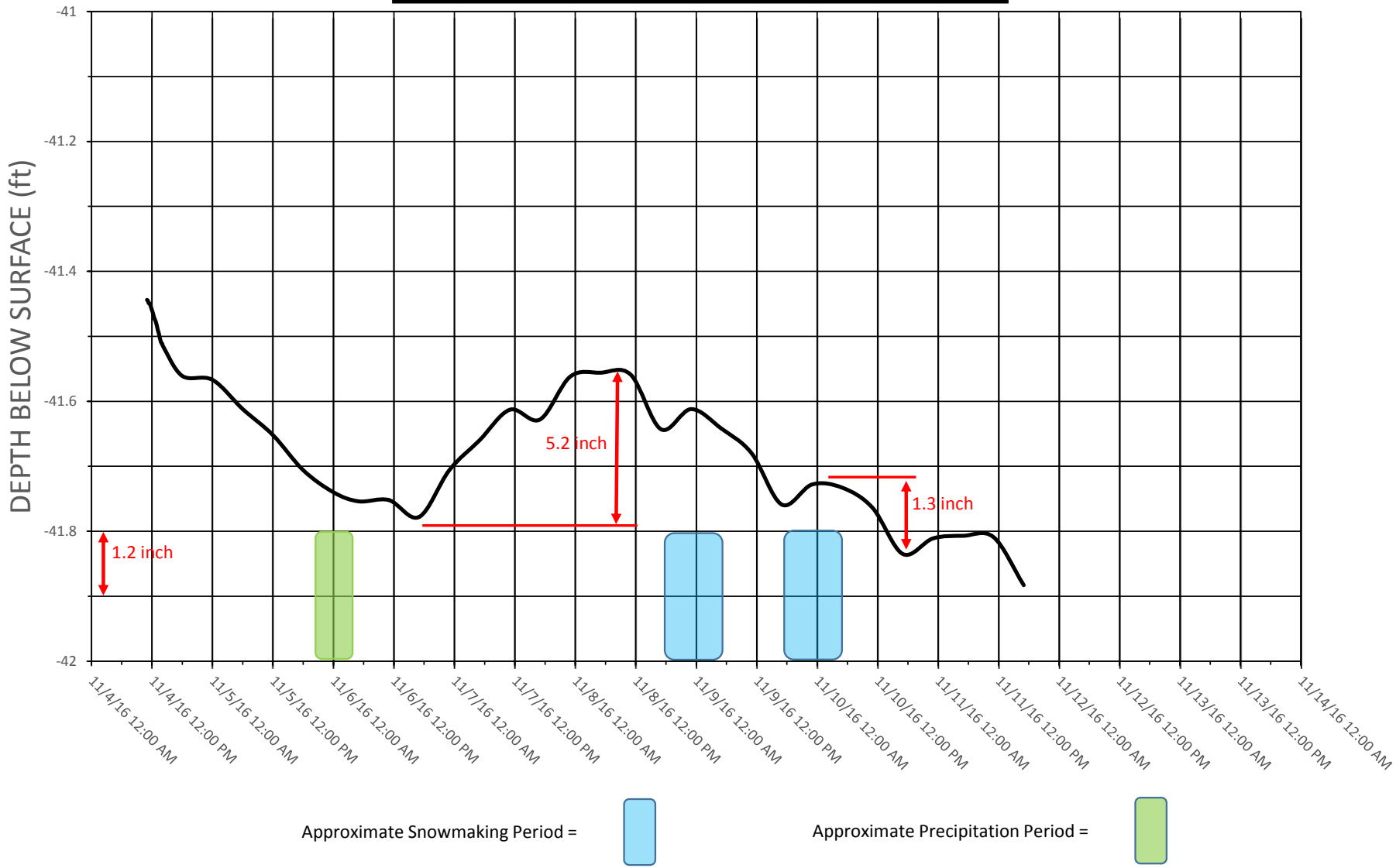
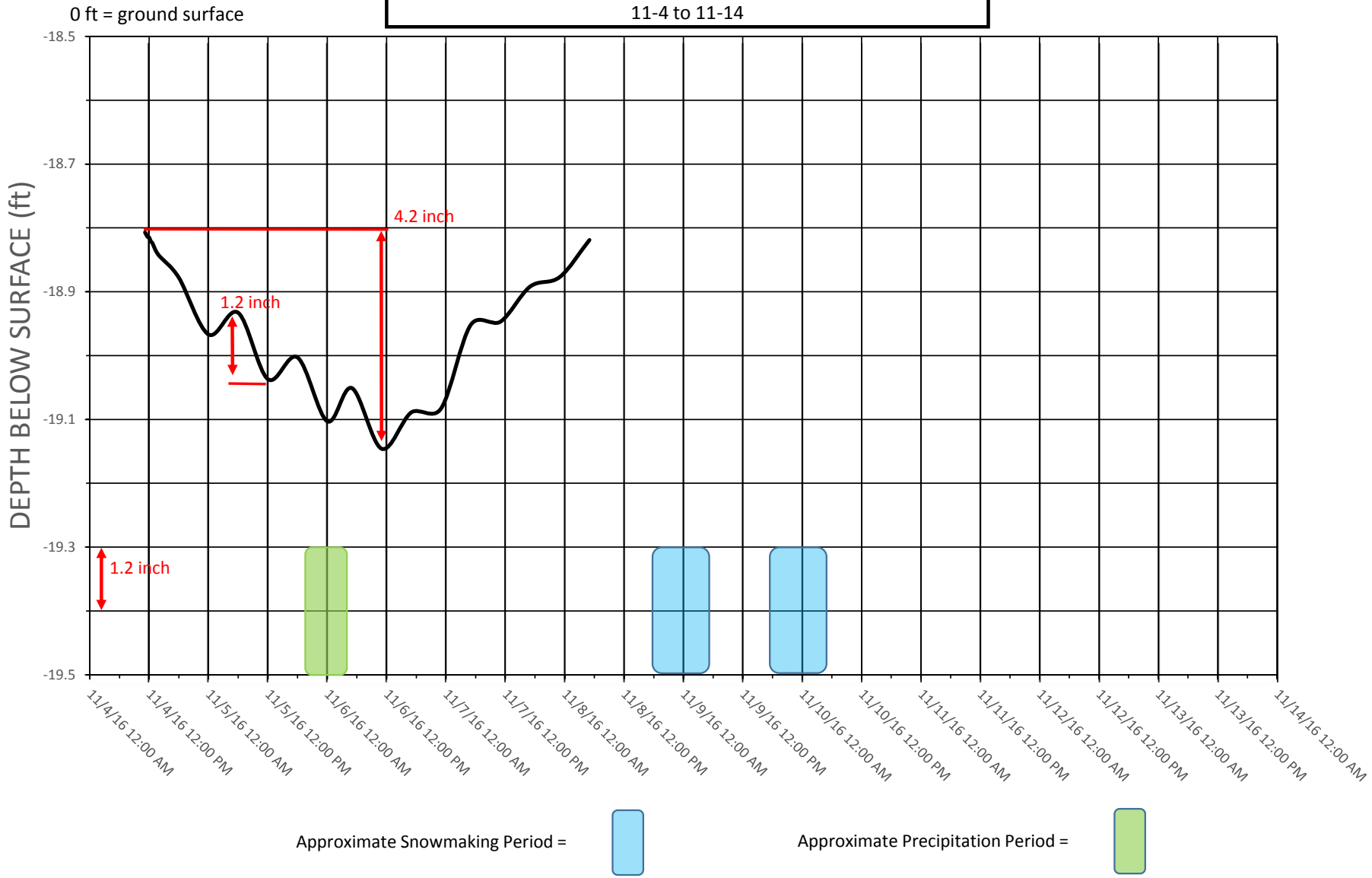


Figure B-6

Vibrating Wire Piezometer B-2

11-4 to 11-14



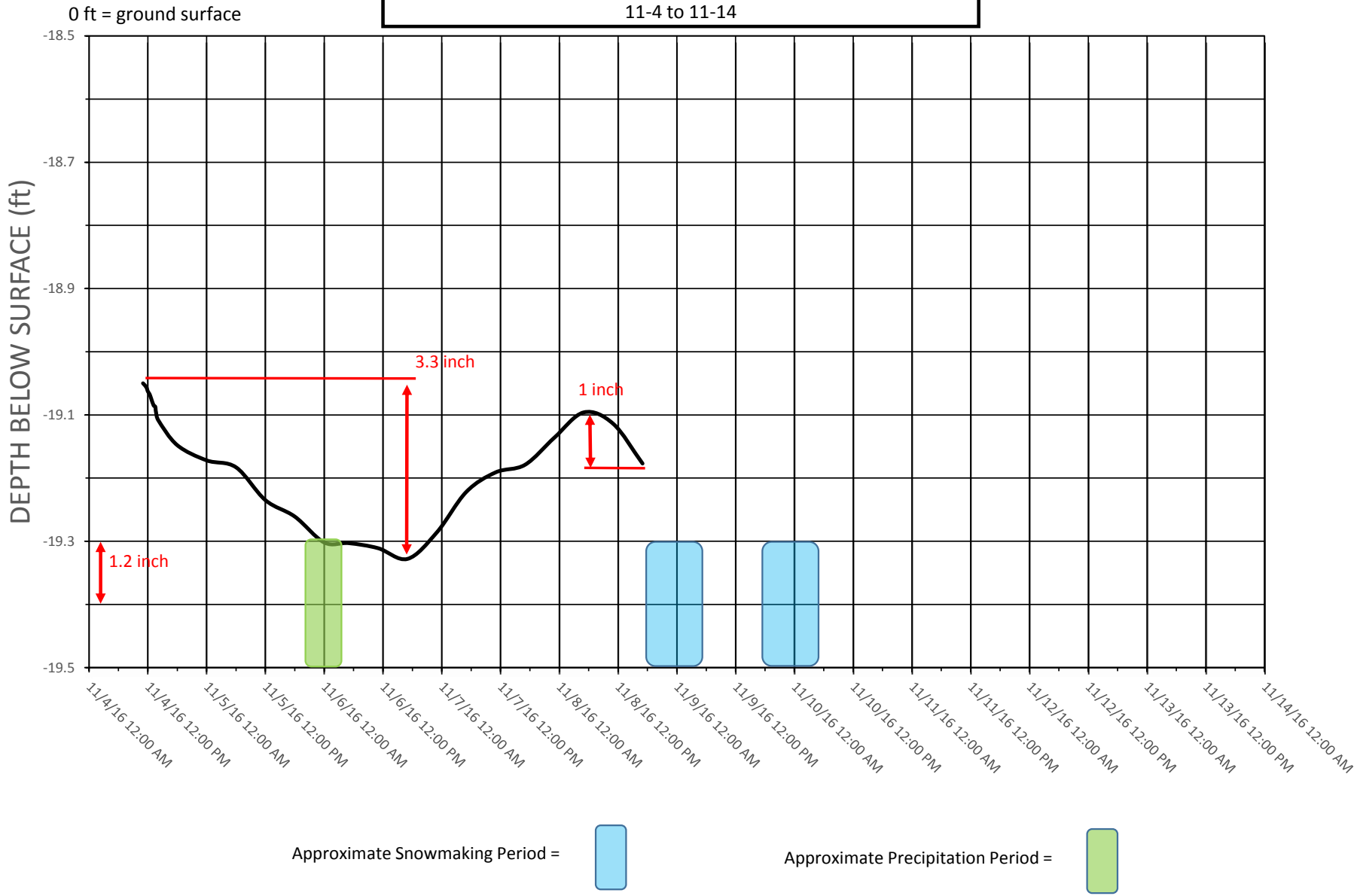
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure B-7

Vibrating Wire Piezometer B-3

11-4 to 11-14



Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure B-8

Vibrating Wire Piezometer C-2A

11-4 to 11-14

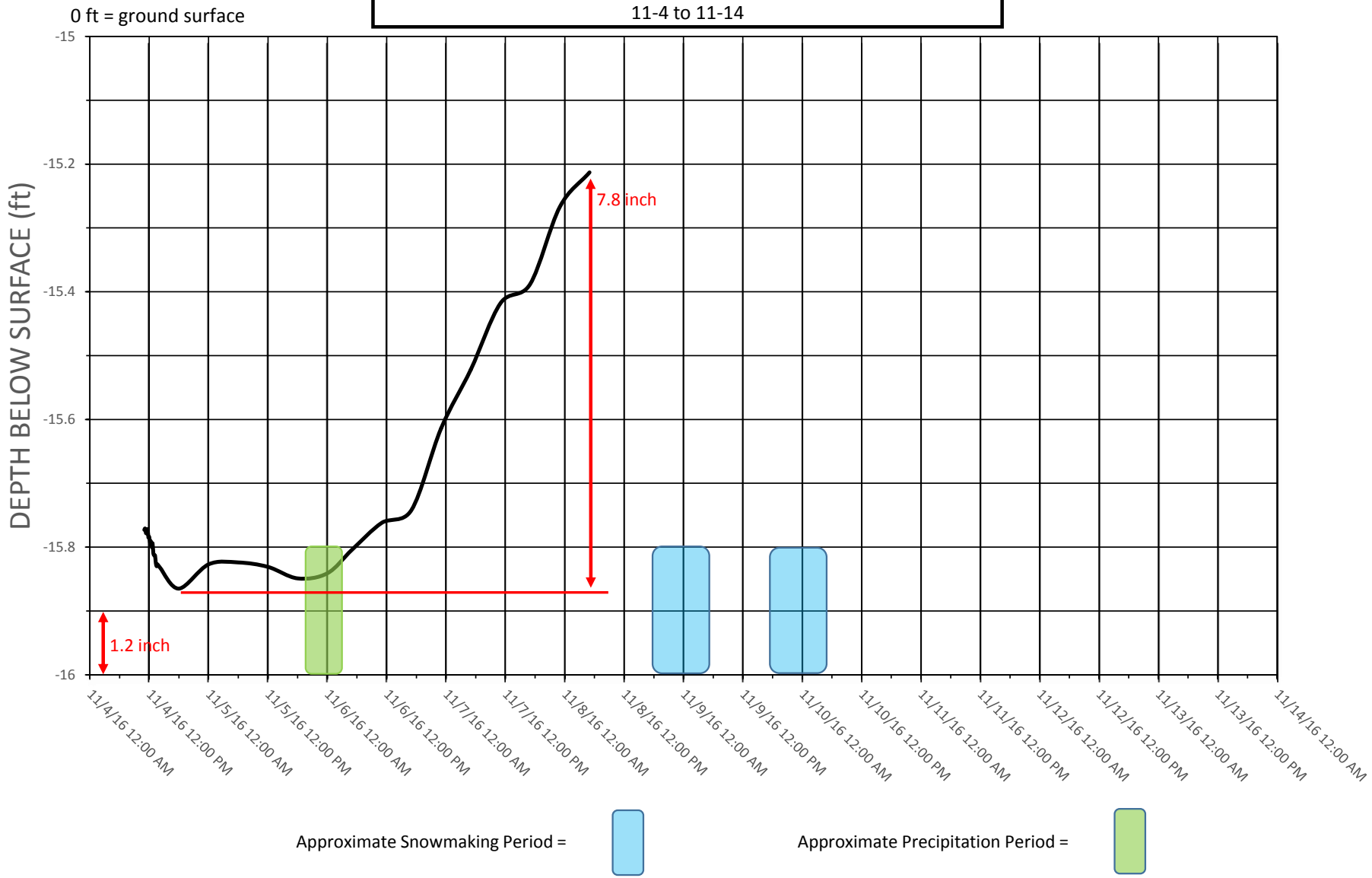
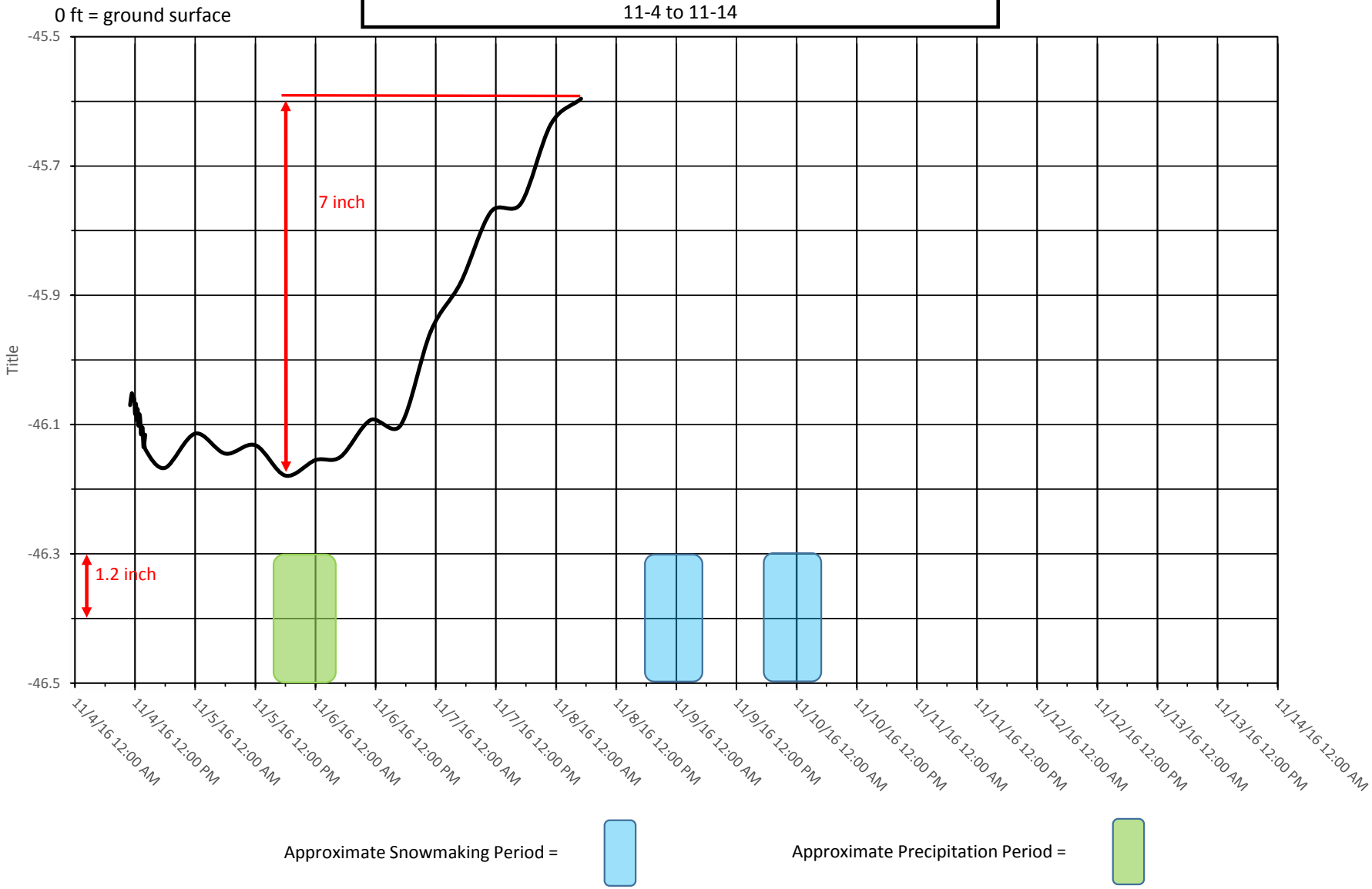


Figure B-9

Vibrating Wire Piezometer C-2B

11-4 to 11-14



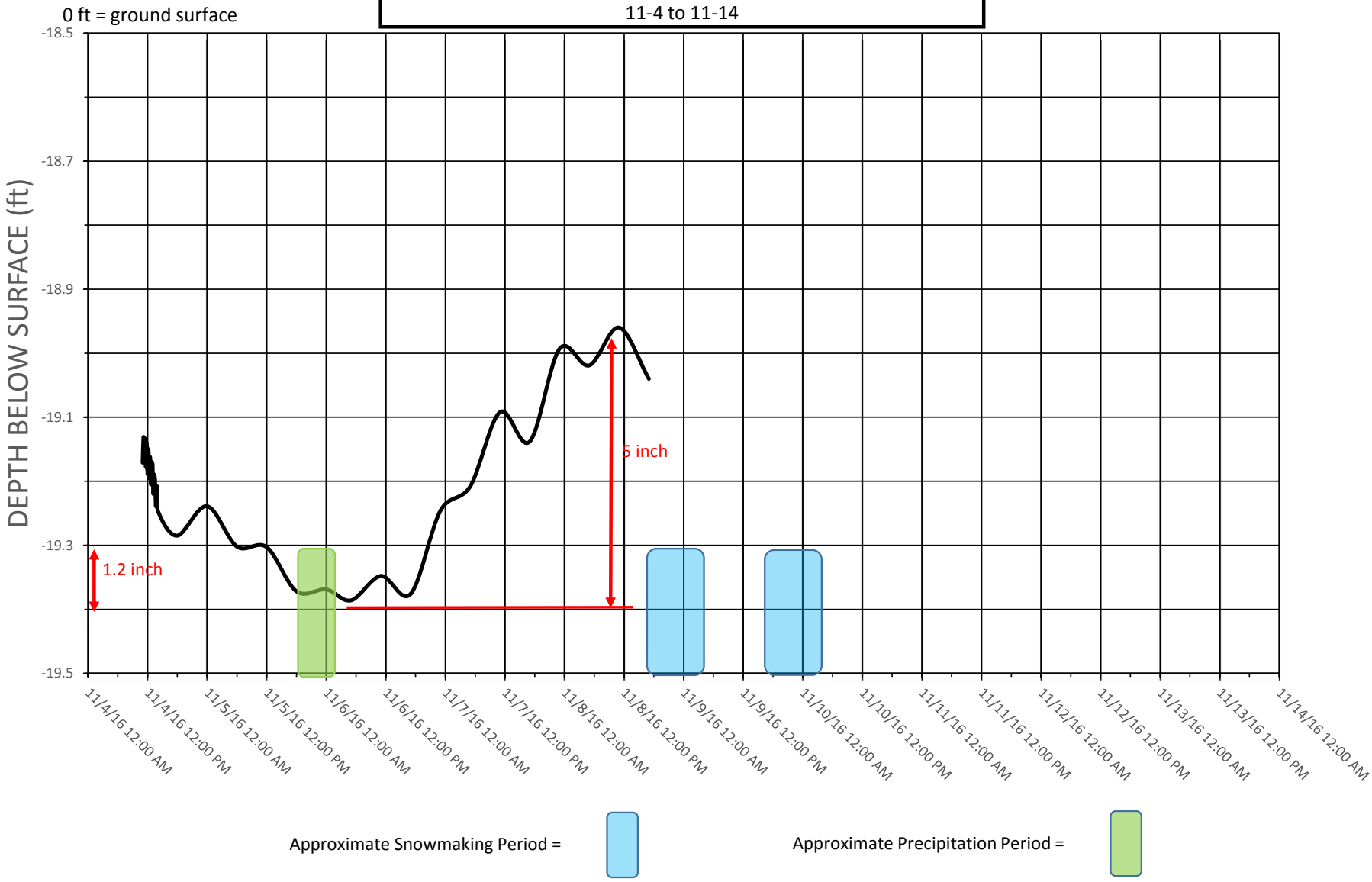
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure B-10

Vibrating Wire Piezometer C-3

11-4 to 11-14



Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure B-11

Vibrating Wire Piezometer C-4

11-4 to 11-14

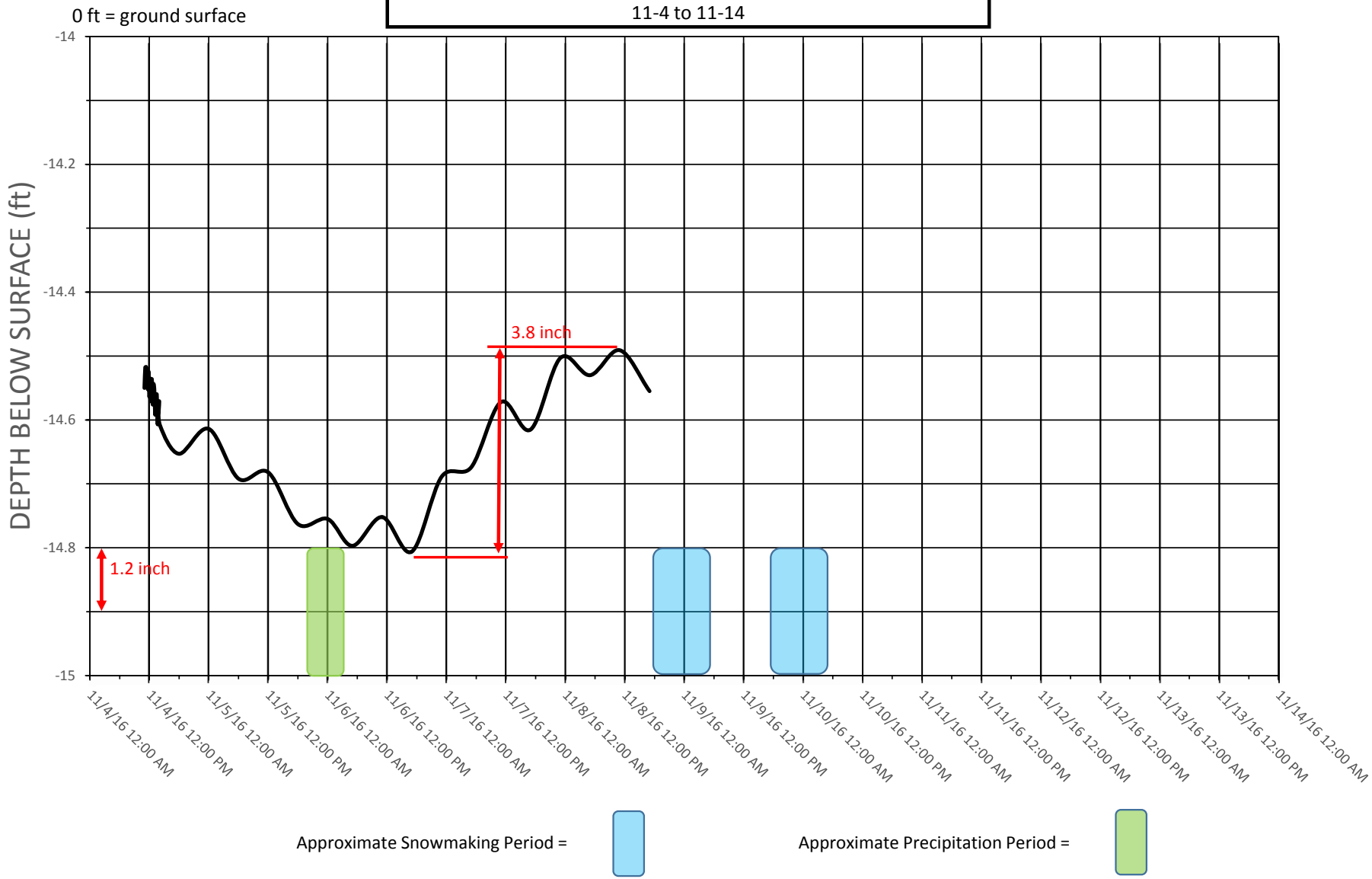


Figure B-12

Vibrating Wire Piezometer C-5

11-4 to 11-14

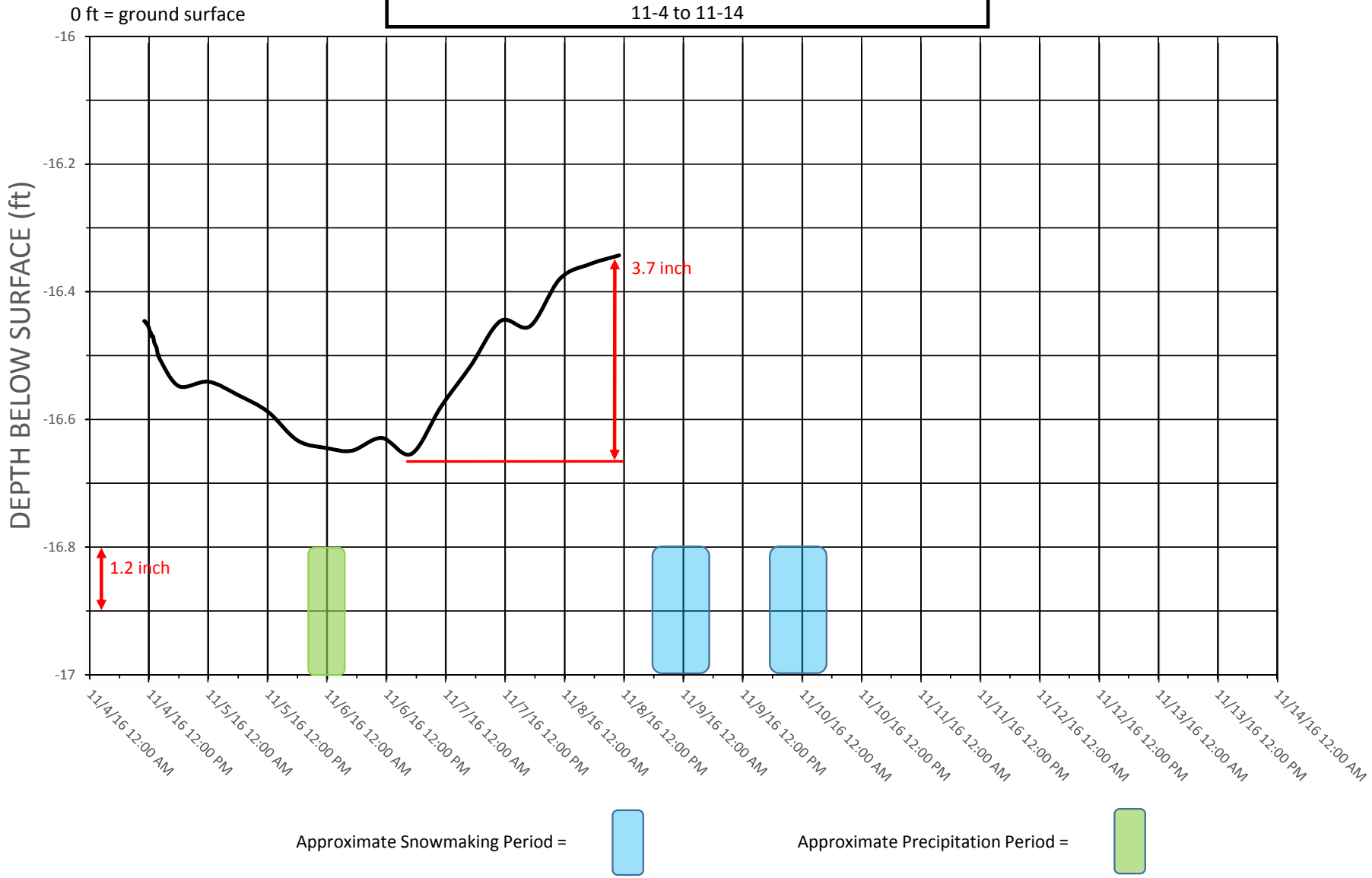


Figure B-13

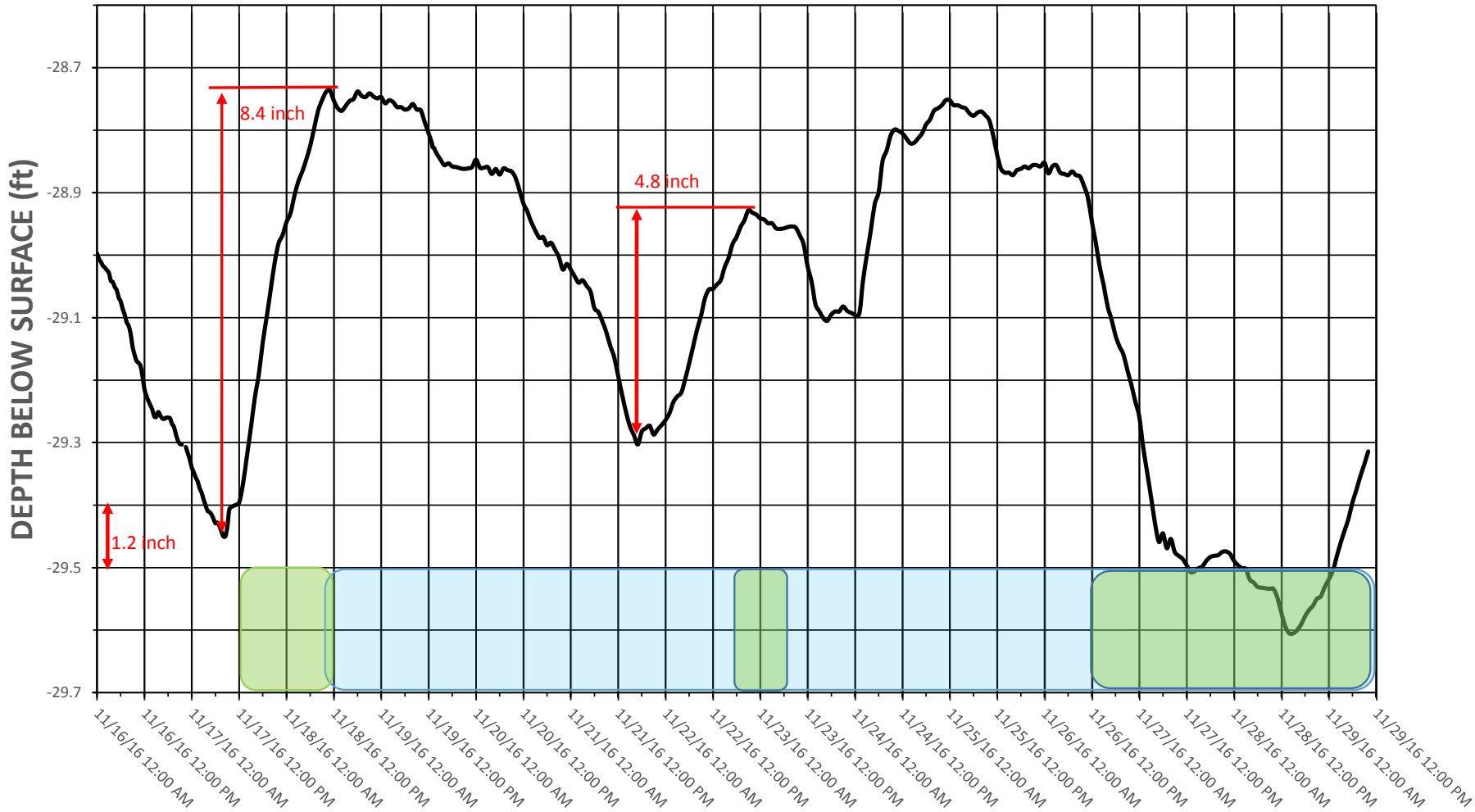
APPENDIX C

VWP Acquisition Monitoring Period Data Graphs

Vibrating Wire Piezometer A-1

11-16 to 11-29

0 ft = ground surface



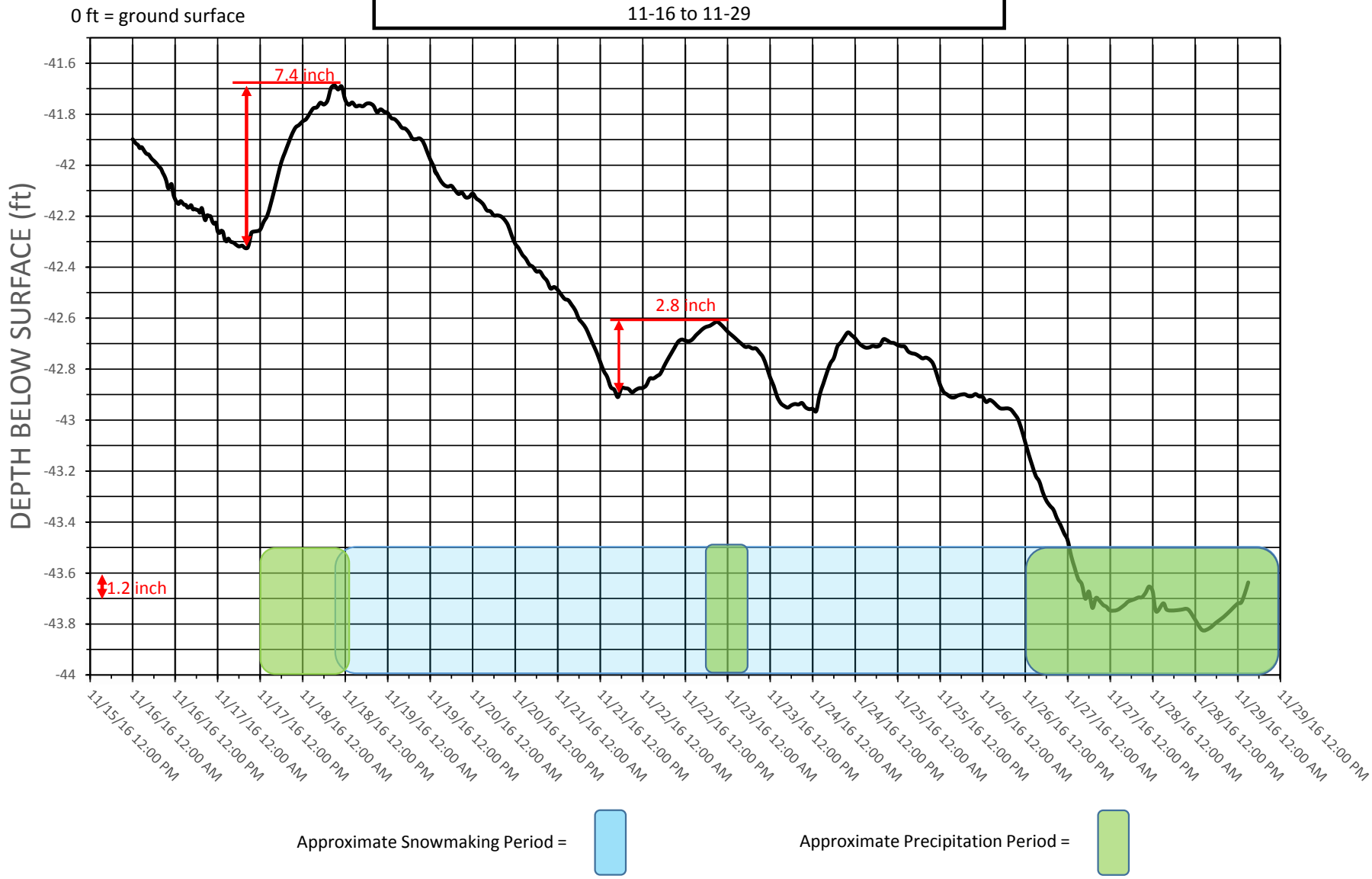
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-1

Vibrating Wire Piezometer A-2A

11-16 to 11-29



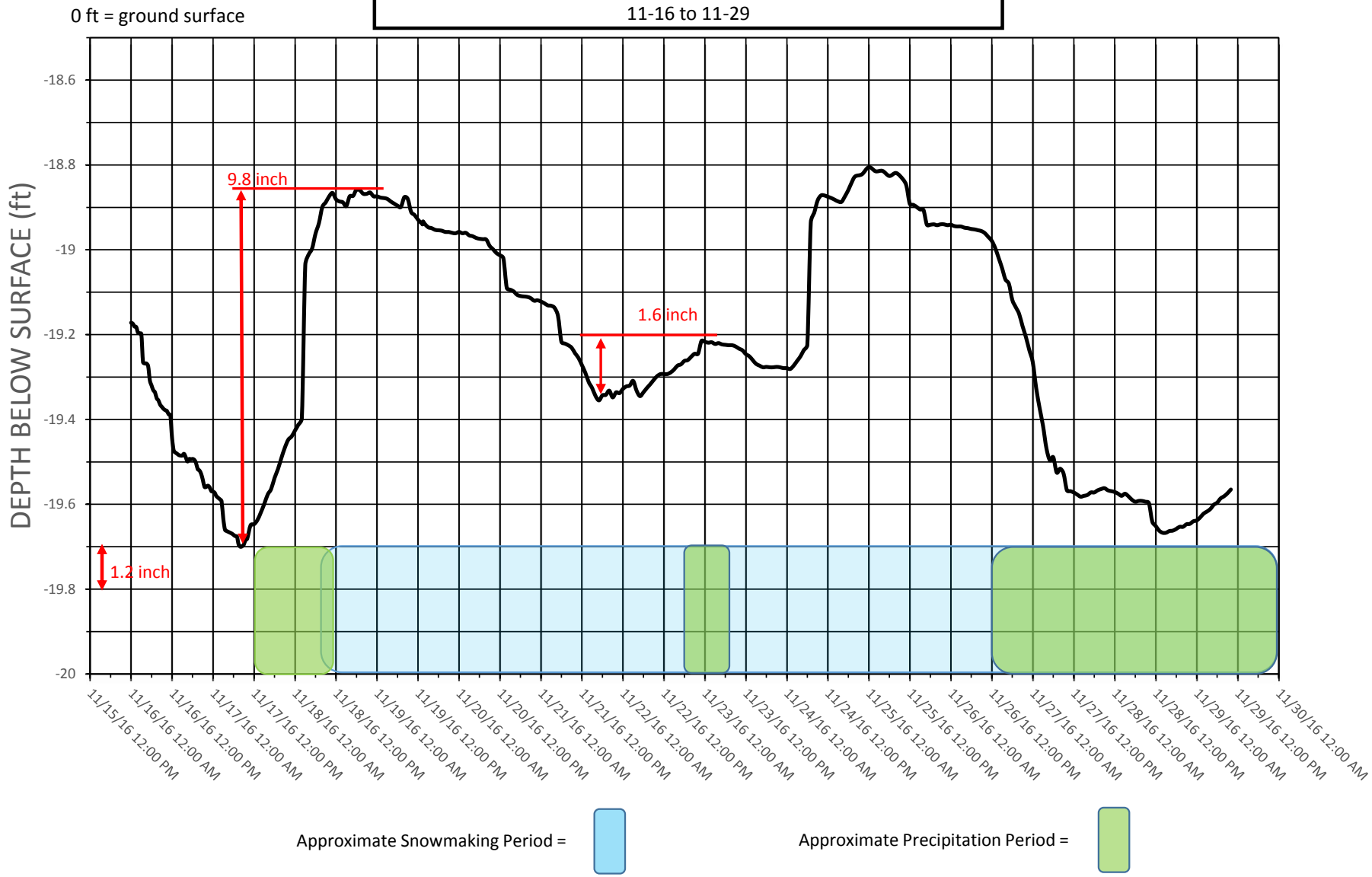
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-2

Vibrating Wire Piezometer A-2B

11-16 to 11-29



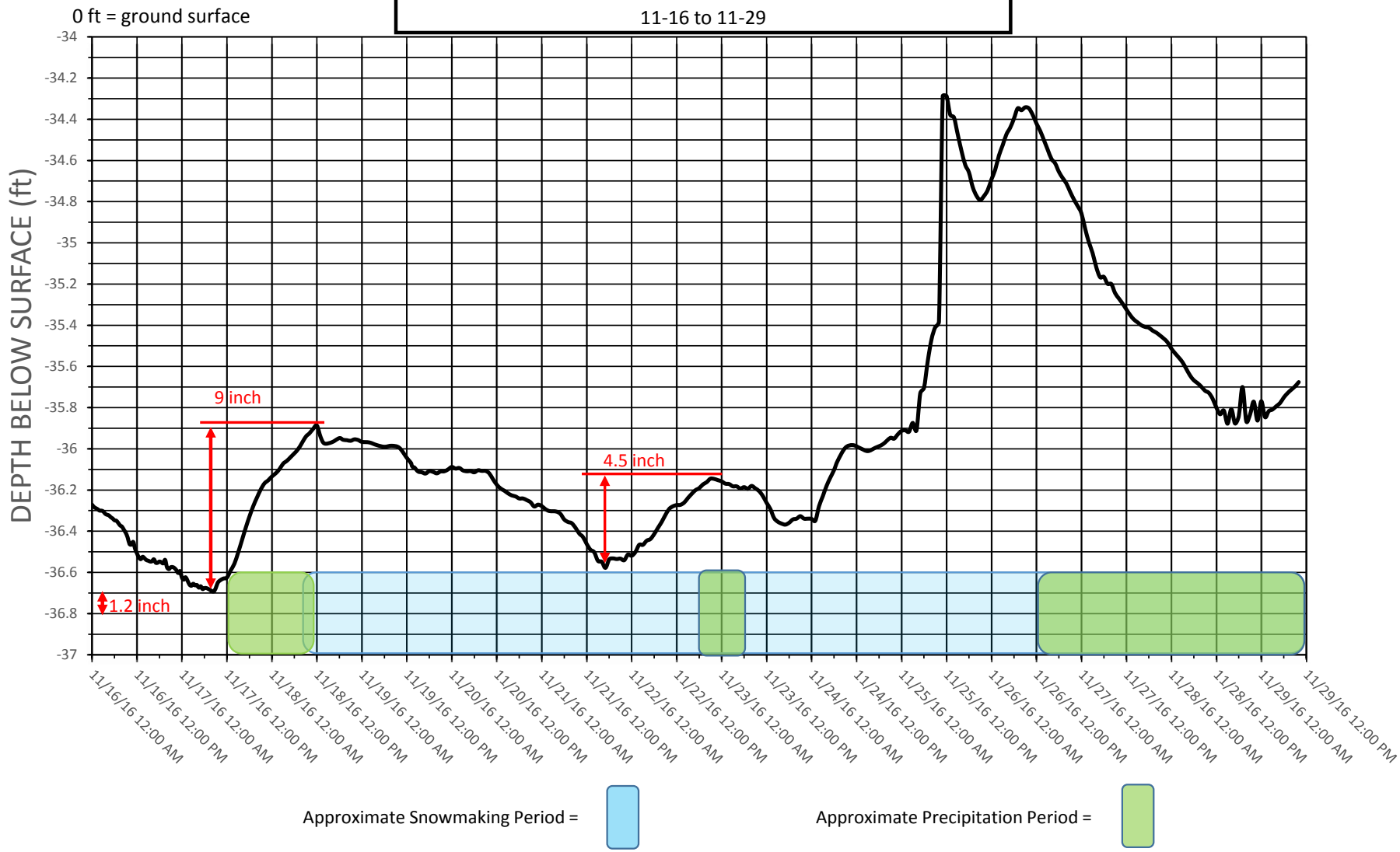
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-3

Vibrating Wire Piezometer A-4

11-16 to 11-29



Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-4

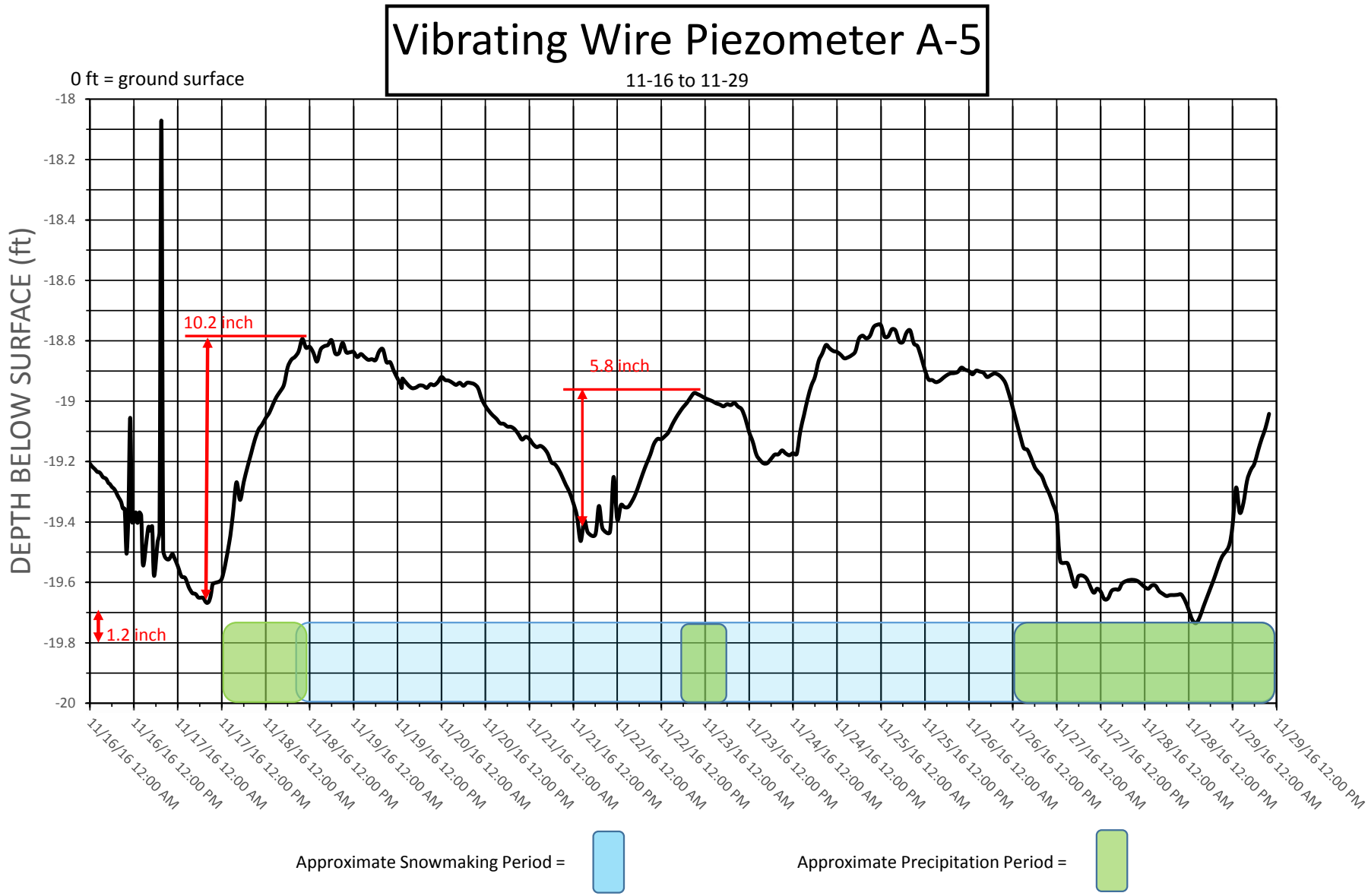
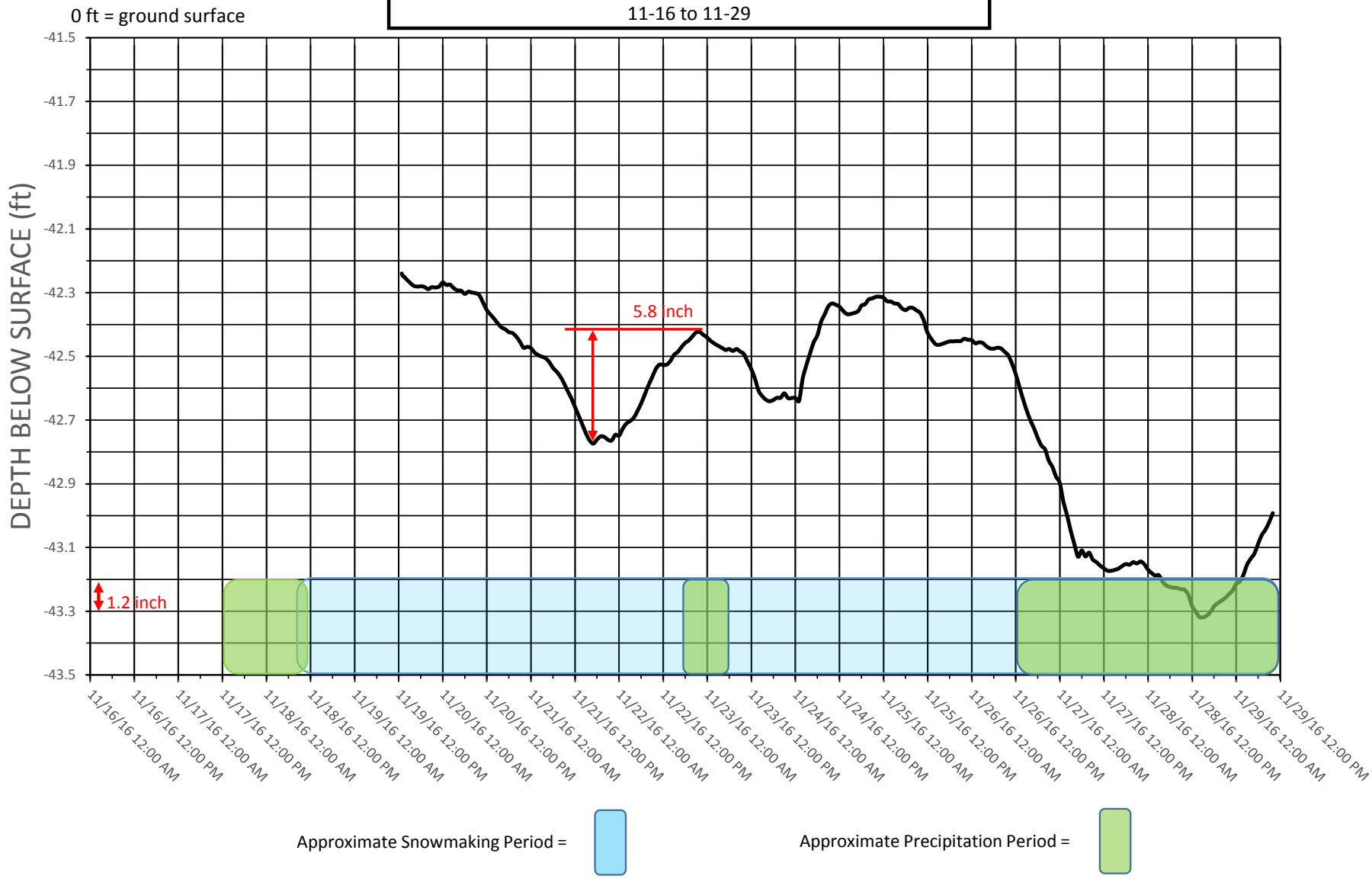

Vibrating Wire Piezometer A-5
11-16 to 11-29
0 ft = ground surface
DEPTH BELOW SURFACE (ft)
-18
-18.2
-18.4
-18.6
-18.8
-19
-19.2
-19.4
-19.6
-19.8
-20
10.2 inch
5.8 inch
1.2 inch
11/16/16 12:00 AM
11/16/16 12:00 PM
11/17/16 12:00 AM
11/17/16 12:00 PM
11/18/16 12:00 AM
11/18/16 12:00 PM
11/19/16 12:00 AM
11/19/16 12:00 PM
11/20/16 12:00 AM
11/20/16 12:00 PM
11/21/16 12:00 AM
11/21/16 12:00 PM
11/22/16 12:00 AM
11/22/16 12:00 PM
11/23/16 12:00 AM
11/23/16 12:00 PM
11/24/16 12:00 AM
11/24/16 12:00 PM
11/25/16 12:00 AM
11/25/16 12:00 PM
11/26/16 12:00 AM
11/26/16 12:00 PM
11/27/16 12:00 AM
11/27/16 12:00 PM
11/28/16 12:00 AM
11/28/16 12:00 PM
11/29/16 12:00 AM
11/29/16 12:00 PM
Approximate Snowmaking Period =
Approximate Precipitation Period =

Figure C-5

Vibrating Wire Piezometer B-0

11-16 to 11-29



Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-6

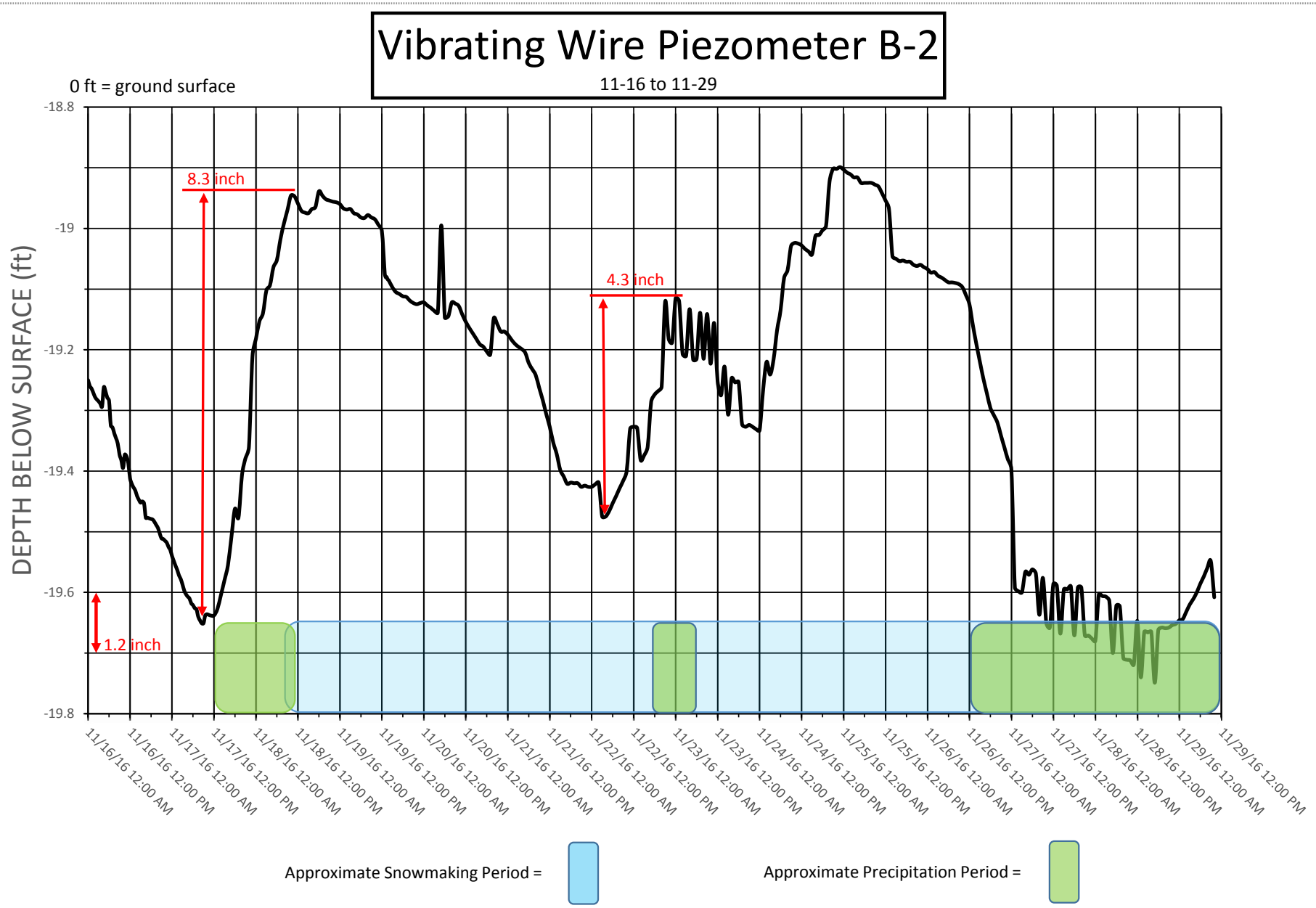
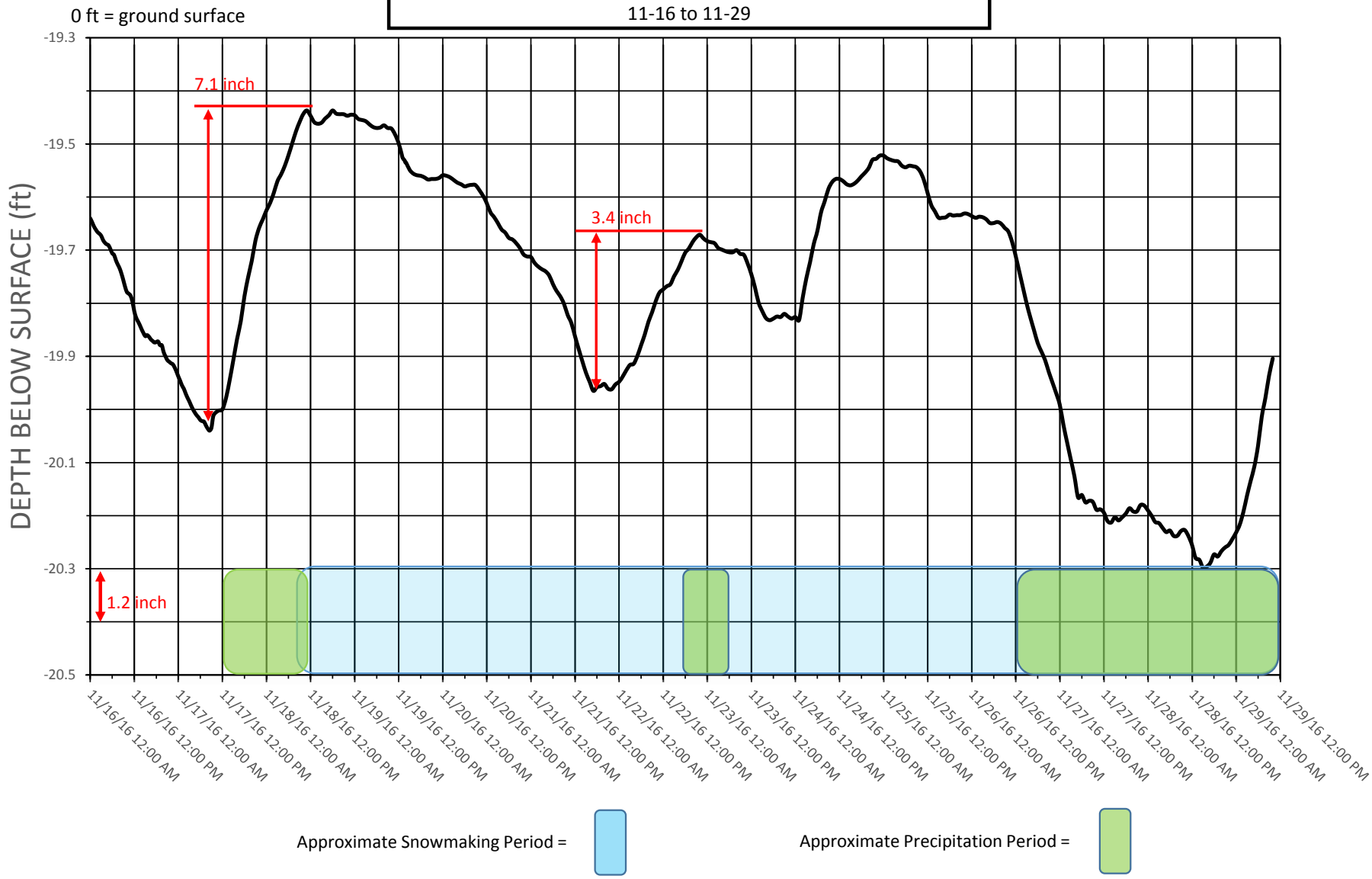

Vibrating Wire Piezometer B-2
11-16 to 11-29
0 ft = ground surface
DEPTH BELOW SURFACE (ft)
-18.8
-19
-19.2
-19.4
-19.6
-19.8
8.3 inch
4.3 inch
1.2 inch
11/16/16 12:00 AM
11/16/16 12:00 PM
11/17/16 12:00 AM
11/17/16 12:00 PM
11/18/16 12:00 AM
11/18/16 12:00 PM
11/19/16 12:00 AM
11/19/16 12:00 PM
11/20/16 12:00 AM
11/20/16 12:00 PM
11/21/16 12:00 AM
11/21/16 12:00 PM
11/22/16 12:00 AM
11/22/16 12:00 PM
11/23/16 12:00 AM
11/23/16 12:00 PM
11/24/16 12:00 AM
11/24/16 12:00 PM
11/25/16 12:00 AM
11/25/16 12:00 PM
11/26/16 12:00 AM
11/26/16 12:00 PM
11/27/16 12:00 AM
11/27/16 12:00 PM
11/28/16 12:00 AM
11/28/16 12:00 PM
11/29/16 12:00 AM
11/29/16 12:00 PM
Approximate Snowmaking Period =
Approximate Precipitation Period =

Figure C-7

Vibrating Wire Piezometer B-3

11-16 to 11-29



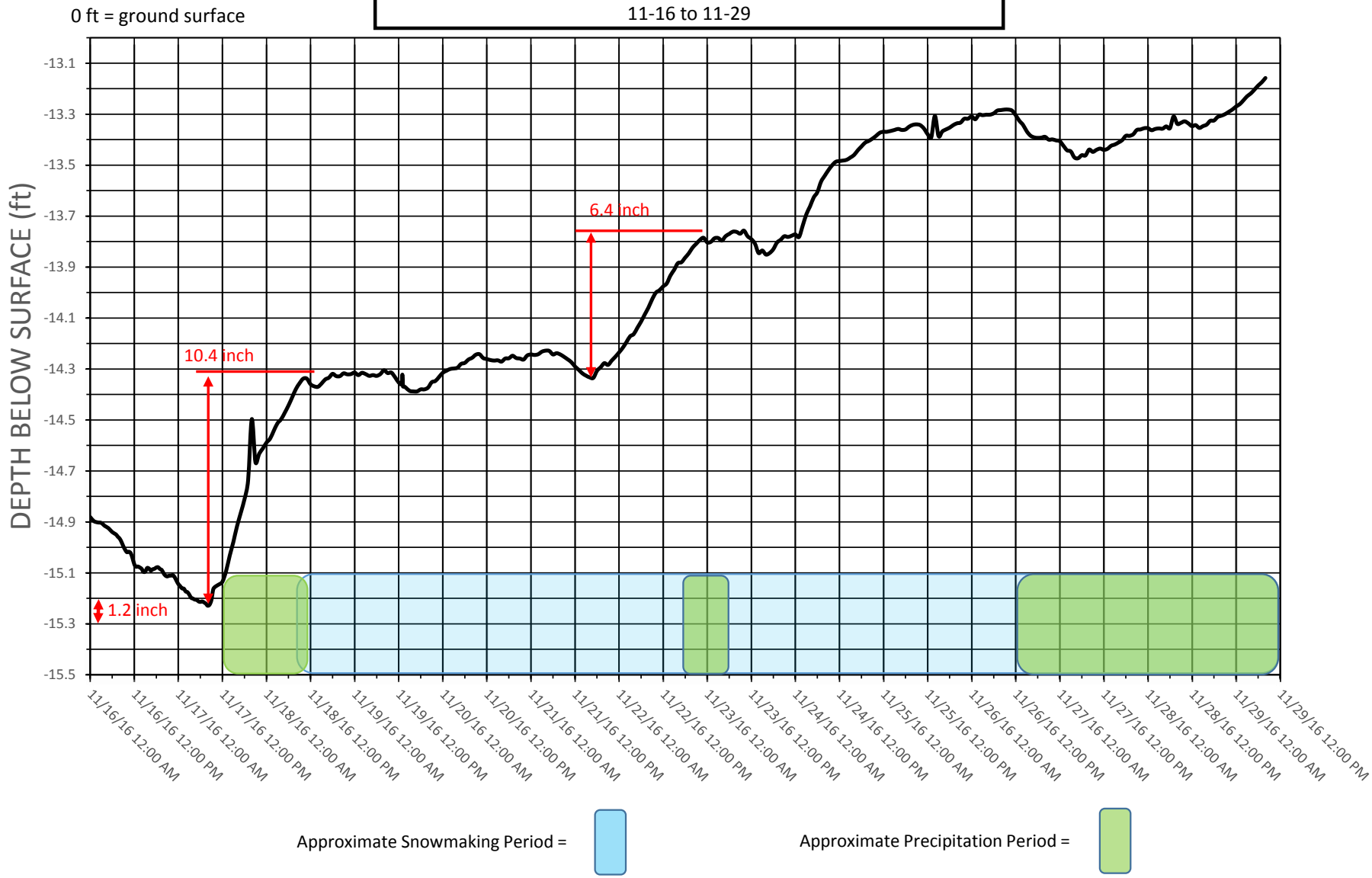
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-8

Vibrating Wire Piezometer C-2A

11-16 to 11-29



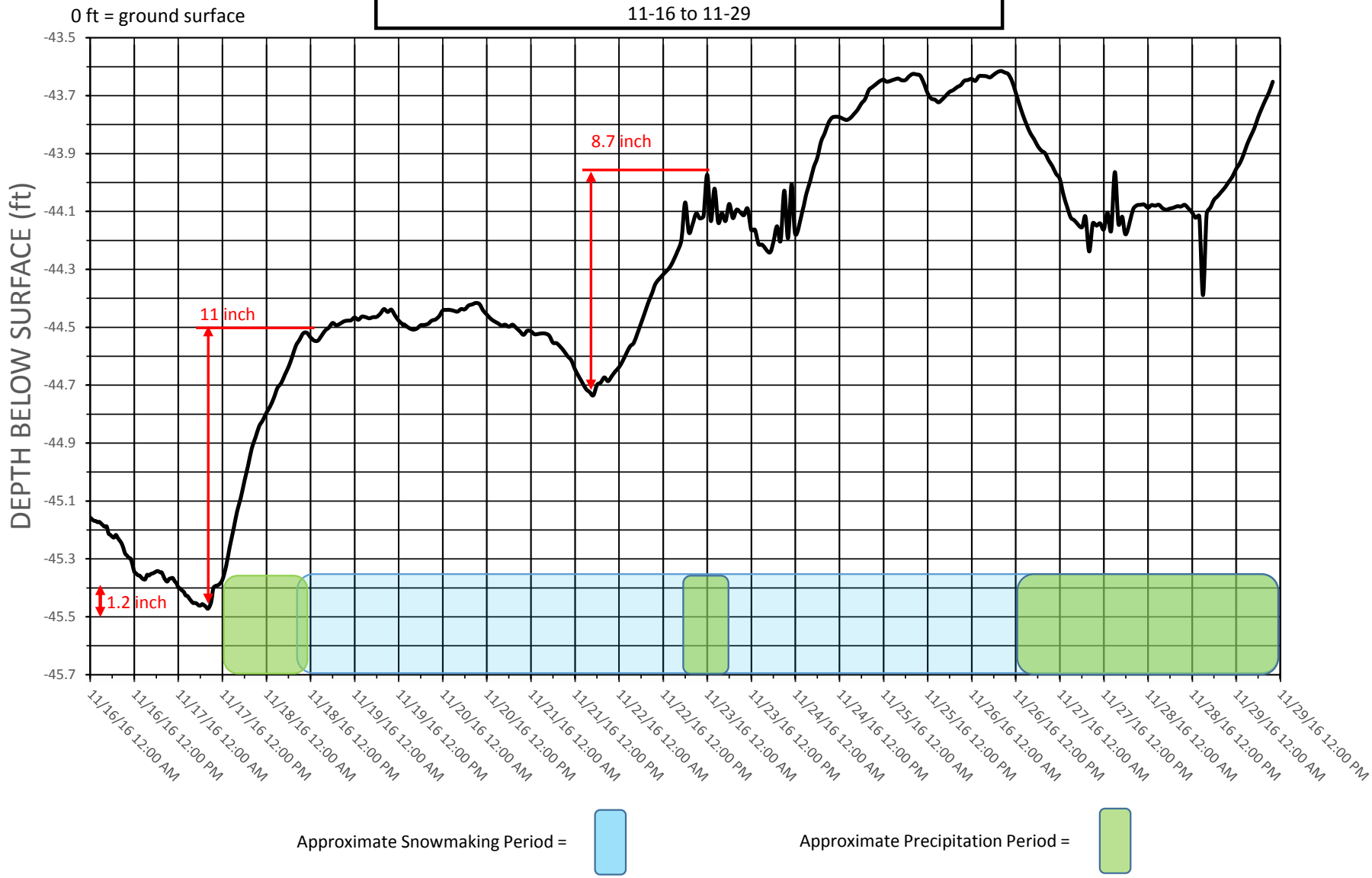
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-9

Vibrating Wire Piezometer C-2B

11-16 to 11-29



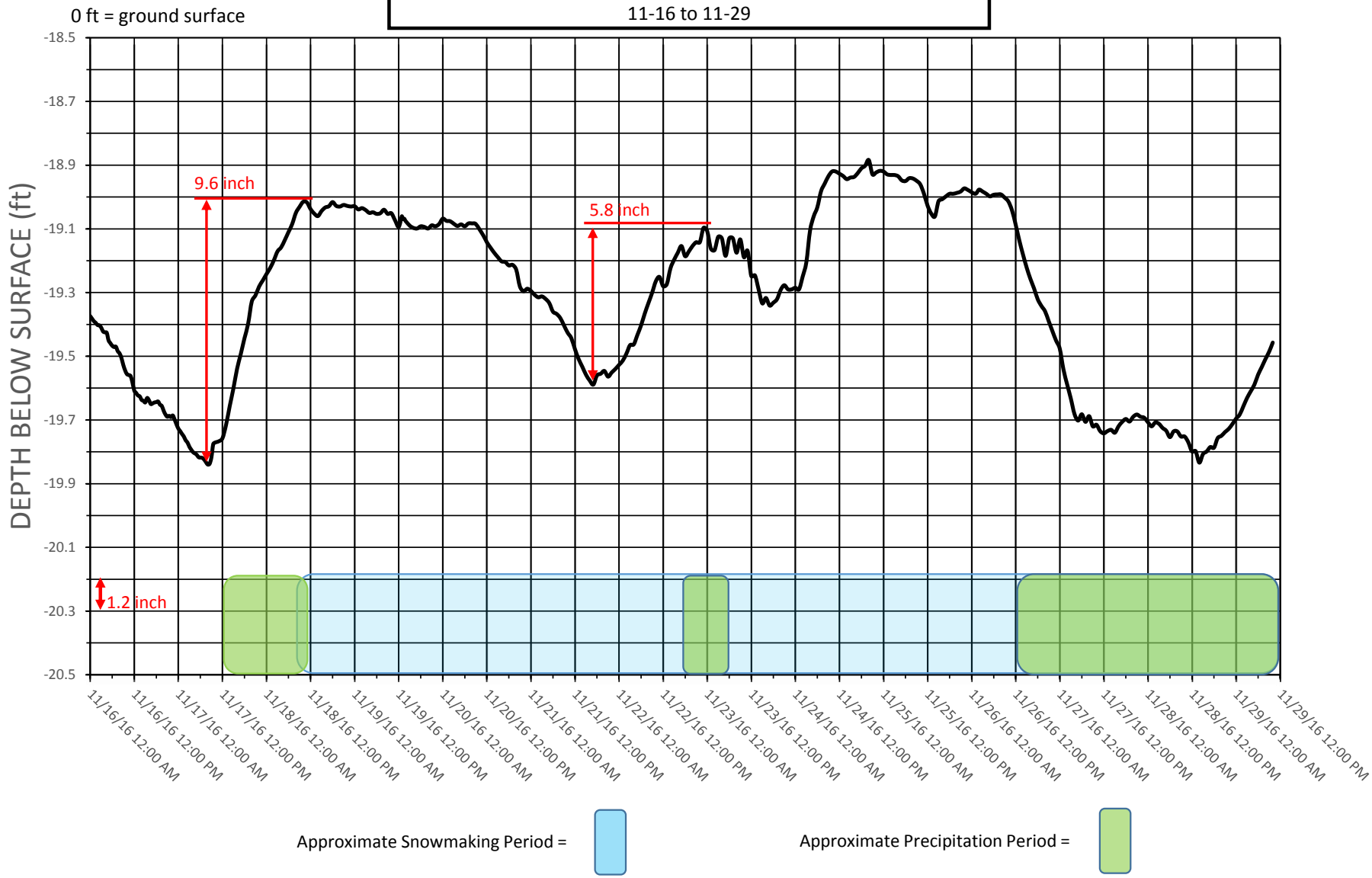
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-10

Vibrating Wire Piezometer C-3

11-16 to 11-29



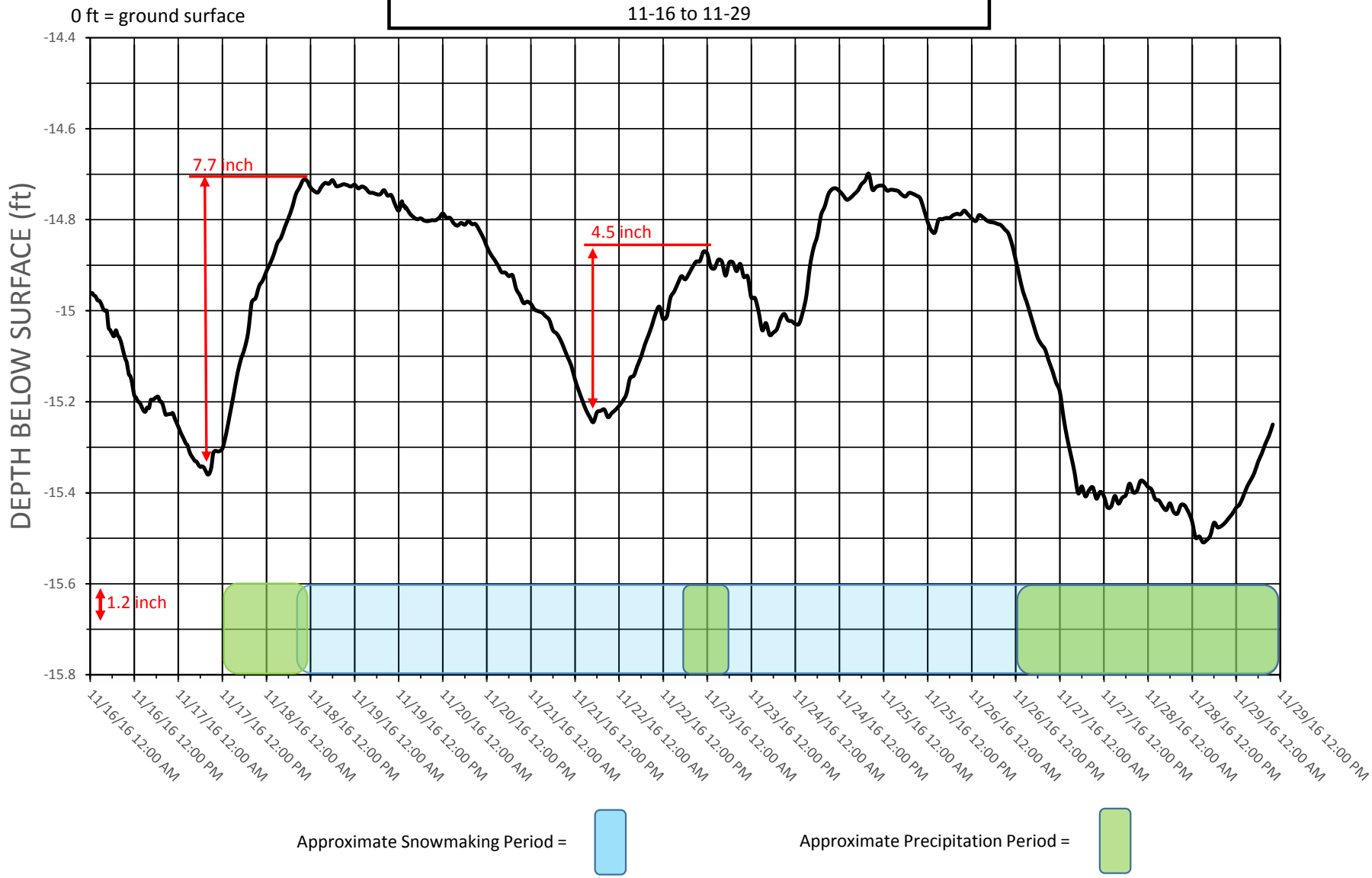
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-11

Vibrating Wire Piezometer C-4

11-16 to 11-29



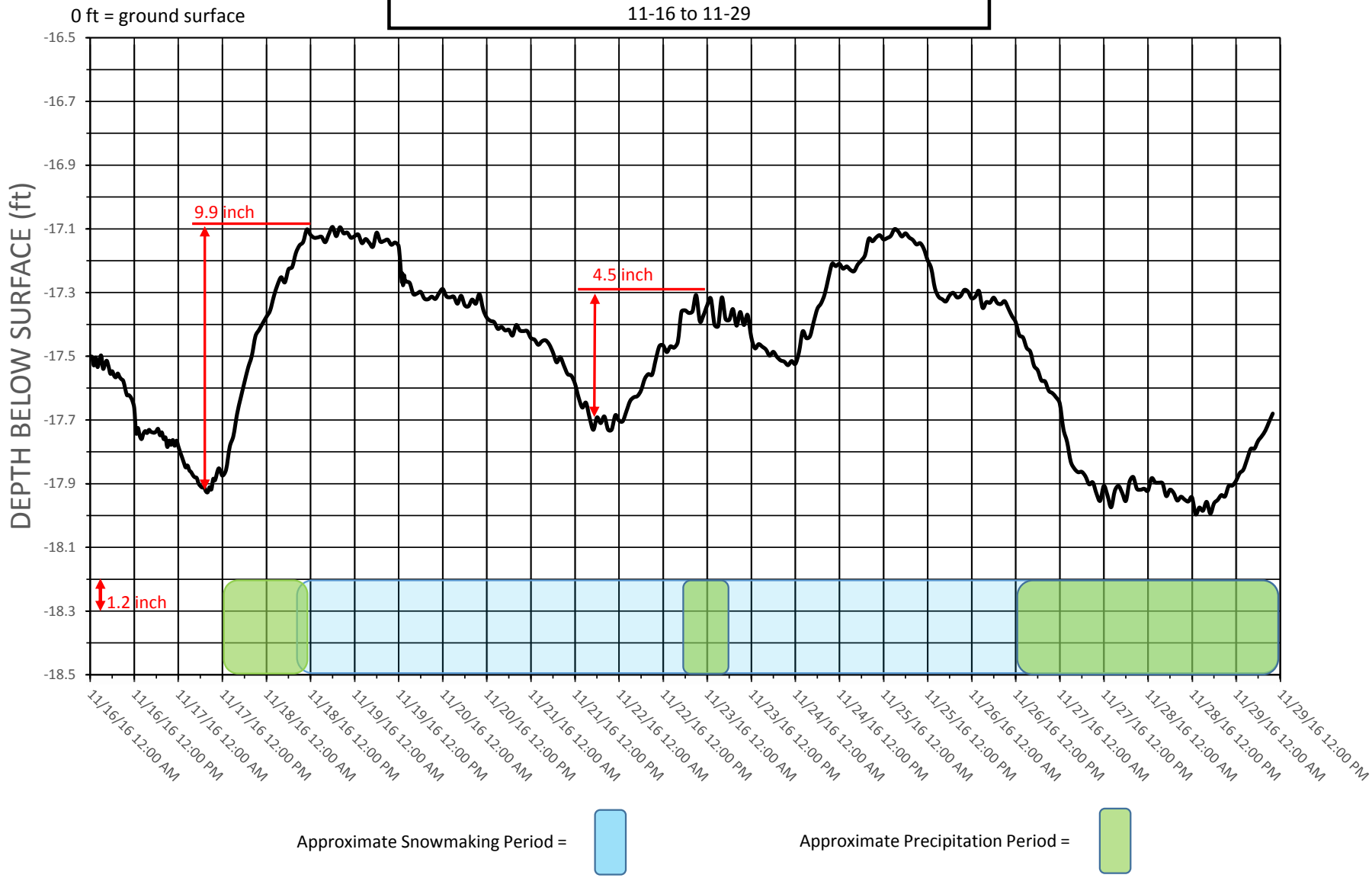
Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-12

Vibrating Wire Piezometer C-5

11-16 to 11-29



Approximate Snowmaking Period =

Approximate Precipitation Period =

Figure C-13