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Managing Water in the West

Hydraulic Laboratory Technical Memorandum PAP-1180

2018 Canal Lining Drawdown Test for the Charles Hansen Feeder Canal

Colorado Big Thompson Project

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

September 2019

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Introduction

This test follows previously performed canal lining drawdown tests on the two sections of the Charles Hansen Feeder Canal (CHFC) performed during the fall of 2011 (550 section) and the spring of 2012 (930 section). The objective of the current drawdown test is to identify the rate at which pore pressure behind the concrete canal lining drops as the water level in the canal is lowered in accordance with the modified drawdown criteria developed following the 2011/2012 drawdown tests.

Staff of Reclamation's Hydraulic Investigations & Laboratory Services (HILS) Group of the Technical Service Center in Denver, including engineers Tom Gill, Christopher Shupe and craftsman Marty Poos worked with engineer Stephen Middlekauff of Reclamation's Eastern Colorado Area Office (ECAO) in Loveland to set up and perform the 2018 drawdown test. "Wetted" components were installed during a canal outage over the period of 4/23-26/2018. Final setup tasks were performed on 6/11/2018. The canal drawdown was initiated at 2:00 AM on 6/12/2018 as flow in the canal was gradually reduced with the final flow reduction being made at 3:00 AM on 6/14/2018.

Background

Following the 2011 and 2012 drawdown test an empirically-based revised drawdown criteria was developed for this canal. Results of these tests and the revised drawdown criteria are documented in the report entitled *Canal Lining Drawdown Tests and Development of New Drawdown Criteria for the Charles Hansen Feeder Canal, Colorado-Big Thompson Project* Hydraulic Laboratory Technical Memorandum PAP-1071 (Wahl & Duke, 2012).

For the 2011 and 2012 tests, piezometer taps were installed and sealed in holes drilled through the concrete canal lining near the canal invert at a spacing of $^1/_8$ to $^1/_2$ miles apart. Transparent vinyl tubing attached to each piezometer tap was installed to extend from the tap to the top of the canal bank. Wooden yardsticks were installed adjacent to the vinyl tubes in the upper flow range to facilitate determination of the distance along the canal side slope between the water level in the piezometer tubes and the canal water surface.

Along the extent of canal there is a well-maintained service road along one side of the canal only. The service road segments run generally along the right bank with one segment in the 550 section where the service road is on the left bank. For

much of the length of the canal there is limited access to the side of the canal opposite the service road. For the previous and current drawdown tests piezometers were installed on the opposite side of the canal from the service road. During each of the tests manual observations of the distance along the sloping canal side between the water level in the piezometer tubes and the canal water surface were made from across the canal along the service road.

During the initial stage of the 2011 drawdown test on the 550 section it became apparent that the water level in the vinyl tubes was difficult to identify from across the canal. As the test progressed, dyed water was poured into piezometer tubes that were in locations reasonably accessible by foot to enhance the ability to detect the pore pressure level.

A second issue encountered during the 2011 test was related to the method that had been used to attach the piezometer tubes to the canal lining and to the attachment of the tubing to the piezometer taps. The tubing was held in place using strap-type pipe clamps secured to the lining with concrete anchors. The lower end of the tubing was affixed to a hose barb fitting mounted to the piezometer tap. The tubing-hose barb connection apparently relied on tightness of fit with no hose clamps installed. Over the course of the test there was concern that at least some of the tubes may have become detached from the piezometer tap fittings due to drag of the flowing water.

For the 2012 test on the 930 section, the clear tubing was secured to the piezometer tap barb fittings with hose clamps. Galvanized ½" diameter steel conduit was attached to the canal lining running from the piezometer tap location to the top of the lining. The clear piezometer tubes were placed along the galvanized conduit to which the tubing was attached using several nylon tie wraps. Detachment of the tubes from the piezometer taps was not a concern for the 2012 930 section drawdown test.

The 2018 drawdown test was performed with the objectives of obtaining a follow-up assessment of sites where observed pore pressure drop had lagged behind reductions in canal levels during the 2011/2012 tests and to re-examine locations where there was uncertainty associated with observations from the 2011/2012 drawdown tests.

Scope of 2018 Drawdown Test

Based on examination of the data from the 2011/2012 tests the piezometer sites could be separated into the following groups:

- Sites where good readings were obtained, and pore pressures dropped rapidly (or remained below the canal level) as the canal water level was lowered.

- Sites where good readings were obtained and drop in pore pressures lagged behind drop in canal levels.
- Sites with uncertainty in the pore pressure readings. These included difficult to access sites where dyed water was not added, sites where it was suspected the clear piezometer tubing may have become detached from the piezometer tap, and one site where "inconsistent behavior" was noted. In addition, notes from one site indicated that the piezometer level remained static after being filled with dyed water.

The sites in the first bullet group were deemed to be locations with well-drained soils behind the canal lining and unnecessary to include in the 2018 tests. Sites in the second bullet group included the Piezometers #4, #6, #10, #11 and #16 in the 930 section and the Amy 3 & 5 and Mike 2 sites in the 550 section. Observations of positive pore pressured during the previous tests made these sites of obvious interest for re-testing.

Sites in the third bullet group included the Piezometer #19 site in the 930 section plus the Amy 1 & 2, Nicole 2, 3, 4 & 6, Ribha 2 & 4, Brandon 1, 2, 3 & 6, and Gabriel 1 & 2 sites in the 550 section. These sites were retested in the 2018 to address uncertainties from the 2011/2012 tests. Hence the 2018 tests included 17 of the 31 sites in the 2011 test on the 550 section plus 6 of the 27 sites in the 2012 test on the 930 section.

All piezometer sites in the 2018 drawdown test were installed using the same installation method employed for the 2012 930 section test. In addition to visual monitoring of piezometers, six sites – Piezometer #4, Piezometer #6 and Piezometer #19 in the 930 section and the Amy 5, Nicole 6 and Mike 2 sites in the 550 section – were also equipped for electronic head differential monitoring. The Mike 2 site was a location near the lower end of the 550 section where positive pore pressure readings were observed during the 2011 test. The Piezometer #4 and Piezometer #6 sites were locations in the upper reach of the 930 section at which positive pore pressure readings were observed during the 2012 test. The Piezometer #19, Amy 5 and Nicole 6 sites were included for electronic monitoring to attain a degree of spatial distribution of electronically monitored sites along the canal.

At the sites equipped for electronic monitoring, additional equipment included two bubbler level sensor tubes that were installed inside a section of ½" diameter PVC conduit. The PVC conduit was secured to the canal lining side slope, parallel to piezometer tubing, with the lower end of the PVC approximately 3-4" above the piezometer tap.

One of the ¼" bubbler tubes was attached to a 90° barb fitting secured to the lower end of the PVC pointing outward from the canal lining to monitor the canal level. The second ¼" tube was attached to a tee fitting installed in the clear piezometer tubing at the same elevation as the canal monitoring bubbler tap. For the electronic monitoring, a bubbler level sensor equipped with a two-output

solenoid valve was used to monitor the differential between the canal level and the pore pressure in the piezometer tubes.

The electronically monitored sites were programmed to measure and record the vertical pore pressure differential at five-minute intervals. All piezometer sites included in the 2018 tests are shown in Table 1 (using the identifiers from the 2011/2012 tests). Figure 1 is a project map showing the locations of sites included in the test. Figure 2 is a photo showing the installed "wetted components" of a piezometer site set up for both visual and electronic monitoring.

Table 1. Piezometer sites included in the 2018 Charles Hansen Feeder Canal Drawdown Test.

2018 Charles Hansen Feeder Canal Drawdown Test - Piezometer Sites			
Site Identifier	Latitude	Longitude	Notes
930 Section			
Piezometer #4	40° 22.691'N	105° 13.456'W	Bubbler
Piezometer #6	40° 22.923'N	105° 13.187'W	Bubbler
Piezometer #10	40° 23.344'N	105° 13.001'W	
Piezometer #11	40° 23.410'N	105° 12.955'W	
Piezometer #16	40° 24.013'N	105° 13.101'W	
Piezometer #19	40° 24.302'N	105° 13.144'W	Bubbler
550 Section			
Amy 1	40° 25.388'N	105° 13.586'W	
Amy 2	40° 25.511'N	105° 13.600'W	
Amy 3	40° 25.717'N	105° 13.632'W	
Amy 5	40° 25.931'N	105° 13.679'W	Bubbler
Nicole 2	40° 26.536'N	105° 13.152'W	
Nicole 3	40° 26.689'N	105° 13.200'W	
Nicole 4	40° 26.797'N	105° 13.248'W	
Nicole 6	40° 27.025'N	105° 13.314'W	Bubbler
Ribha 2	40° 27.300'N	105° 13.426'W	
Ribha 4	40° 27.624'N	105° 13.568'W	
Brandon 1	40° 27.986'N	105° 13.462'W	
Brandon 2	40° 28.043'N	105° 13.505'W	Not Functional
Brandon 3	40° 28.227'N	105° 13.561'W	
Brandon 6	40° 28.713'N	105° 13.521'W	

Gabriel 1	40º 29.524'N	105º 12.302'W	
Gabriel 2	40º 29.434'N	105º 12.086'W	Not Functional
Mike 2	40º 30.190'N	105º 11.968'W	Bubbler

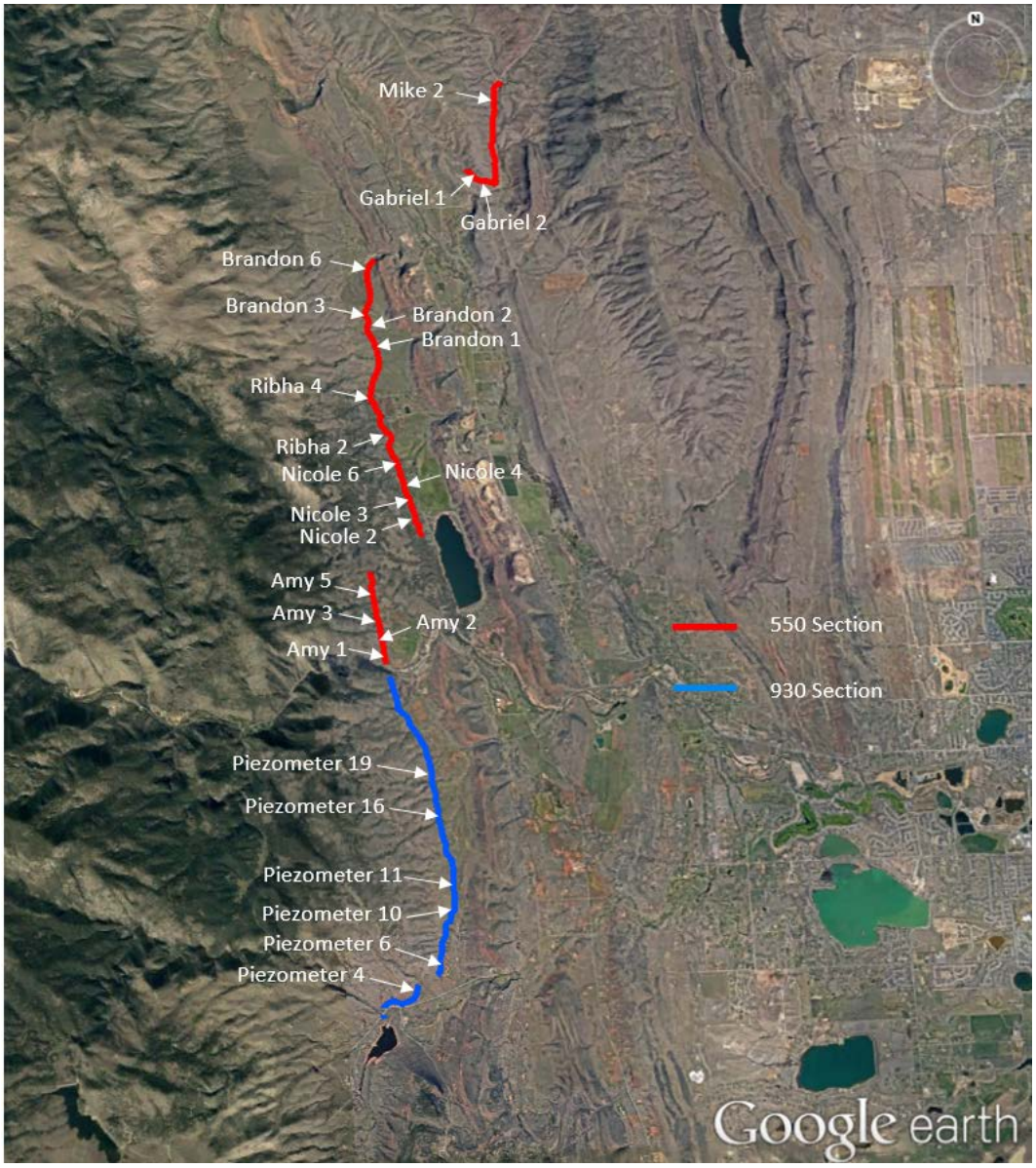

Figure 1. Locations of Piezometer Sites in the 2018 Drawdown Test

The gaps between canal reaches highlighted in Figure 1 represent sites where water is conveyed through tunnels. The gap shown between the 930 and 550 sections is the location of the inverted siphon at the mouth of the Big Thompson Canyon.

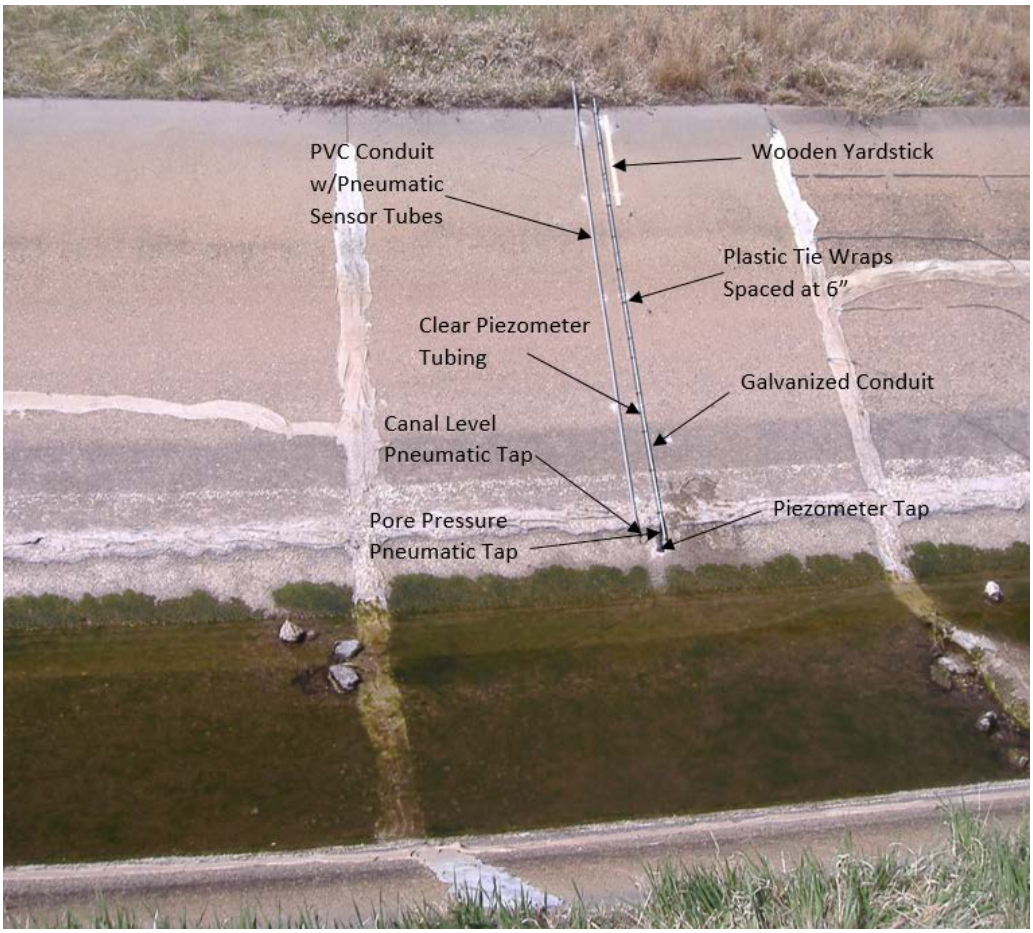

Figure 2. "Wetted Components" of a Piezometer Site set up for Visual and Electronic Monitoring

As may be seen in Figure 2, at the time the piezometers were being installed there was a residual level of water in the canal that varied from approximately 4” to 18” in depth, depending on the location along the canal. During most of the test observations canal levels were below the yard sticks that extended down from the high-water line. The 6” spacing of black plastic tie wraps that secured the clear tube to the galvanized conduit was the reference for the visually observed distance along the canal side slope between the canal water level and positive pore pressure levels in the piezometer tubes.

Site Configurations for the 2018 Test

Piezometer installation for the 2018 test followed the method used for the 2012 test for the 930 sections. Piezometers were installed over a four day period beginning on 4/23/2018. This schedule was concurrent with a canal outage for replacement of failed lining panels.

- Piezometers were installed in approximately the same locations (based on GPS coordinates) as had been used in the 2011/2012 tests at the selected sites.
- Holes were drilled through the lining into the underlying soil using a $^5/_8$" diameter masonry bit.
- Holes drilled in the lining were located approximately 18" above the canal invert. (The distance above the invert was governed in some reaches by the residual depth of water in the canal.)
- The piezometer taps consisted of a stainless steel fitting with a long tapered coarse thread on one end and a $^3/_8$" male pipe thread on the other end. A plastic sleeve was inserted into the hole drilled through the concrete. The end of the stainless fitting with the coarse tapered thread was threaded into the plastic sleeve and tightened using a cordless impact wrench. The plastic sleeves expanded as the stainless fitting was screwed into them creating a water tight seal in the canal lining.
- A 90° elbow was installed on the pipe thread end of the stainless fitting with a ½" hose barb fitting extending in the direction of the top of the canal lining.
- Galvanized ½" steel conduit was attached to the lining, secured with metal conduit clamps and concrete anchors extending from the piezometer tap to the top of the lining.
- Clear ½" vinyl tubing was pushed over the hose barb fitting attached to the piezometer tap and secured with a hose clamp. The clear tubing extended to the top of the canal lining along the upstream side of the galvanized conduit to which the clear tubing was attached using black nylon tie wraps.
- Wooden yard sticks 3' long were installed on the canal lining adjacent to the clear tubing extending down from the high-water mark. Marks were made across the yard sticks using a black felt-tipped marker every 6".
- The tie wraps holding the clear tubing to the galvanized conduit were spaced in line with the black marks on the yard stick with a 6" spacing on the tie wraps continuing downward from the bottom of the yard stick to the piezometer tap.
- The top-of-canal ends of each of the bubbler tubes – where installed – were sealed with electrical tape to prevent debris or insects from entering the tube prior to the drawdown test.
- The upper end of the clear piezometer tube at each site was also taped shut to keep out debris and insects prior to the test.

Final Drawdown Test Setup Tasks

Tasks that could be performed while the canal was in service were left to be addressed shortly before beginning the drawdown test. At all sites (including difficult-to-access sites where dyed water had not been added during the 2011

tests) tape sealing the upper end of the piezometer tubes was removed and water dyed with red food coloring was poured into the piezometer tubes to an initial height above the water surface in the canal.

Electronic equipment stations were put in place at the six sites being set up for electronic monitoring and datalogging. For the temporary duration that the equipment would be in use, a simple equipment station configuration was utilized consisting of a programmable controller, a two-output bubbler level sensor plus a battery installed in a plastic tool box. Two holes were drilled in the side of each plastic box through which the bubbler tubes fit snugly making the plastic box enclosure weather tight.

A “tool box” instrument station was placed on the canal bank directly above the respective piezometer stations. Tape sealing the upper ends of the bubbler level sensor tubes was removed and the tubes were attached to barb fittings on the two-way solenoid valve on the bubbler level sensors.

2018 Drawdown Test Schedule

At the time the piezometers were being installed tentative plans were discussed for scheduling the drawdown test. ECAO staff indicated that transfer of water into Horsetooth Reservoir was behind target due to the outage for replacing canal lining panels. Following these repairs it was anticipated that the canal would remain in service for several weeks before an outage for the drawdown test could be scheduled. ECAO stated the intention to provide at least two weeks advance notice once a time frame for performing the drawdown test had been identified.

The intended advance notice was shortened significantly when a leak in the canal was detected near the trifurcation at the lower end of the 930 section in early June, requiring an otherwise unplanned outage. On Thursday (6/7/18) the HILS project team was contacted to inquire if it would be possible to perform the drawdown test during the following week. With a compressed schedule for preparations, final setup tasks were performed on Monday (6/11/2018) for all sites except the three furthest downstream locations with final setup for those sites performed on the morning of Tuesday (6/12/2018) as the drawdown was underway.

2018 Drawdown Test Procedure

Canal operators began lowering the flow rate in the Charles Hansen Feeder Canal at the Flatiron Reservoir outlet at 2:00 AM on 6/12/2018. Logged data records track the flow rates at the Flatiron Reservoir outlet at the head of the 930 section and in the upper reach of the 550 section.

Theoretical flow-stage tables for the 930 and 550 sections were supplied by ECAO. These tables were generated using Manning's equation to identify normal depths associated with flow rates in 5 ft^3/s increments. Table 2 shows the stepped flow reductions and associated reductions in normal depth for each canal section.

Table 2. 2018 Charles Hansen Feeder Canal Drawdown Test									
930 Section					550 Section				
Date & Time	Elapsed Time (hrs)	Flow Rate (ft^3/s)	Normal Depth (ft)	Change (ft)	Date & Time	lapsed Tim (hrs)	Flow Rate (ft^3/s)	Normal Depth (ft)	Change (ft)
6/12/2018 2:00	0	500	6.38		6/12/2018 2:00	0	500	7.81	
6/12/2018 7:00	5	390	5.59	0.79	6/12/2018 3:00	1	500	7.81	0.00
6/12/2018 12:00	10	340	5.19	0.4	6/12/2018 8:00	6	390	6.94	0.87
6/12/2018 17:00	15	290	4.76	0.43	6/12/2018 13:00	11	340	6.49	0.45
6/12/2018 22:00	20	240	4.29	0.47	6/12/2018 18:00	16	290	6.01	0.48
6/13/2018 3:00	25	200	3.88	0.41	6/12/2018 23:00	21	240	5.47	0.54
6/13/2018 8:00	30	160	3.42	0.46	6/13/2018 4:00	26	200	5.00	0.47
6/13/2018 13:00	35	120	2.9	0.52	6/13/2018 9:00	31	160	4.46	0.54
6/13/2018 18:00	40	85	2.38	0.52	6/13/2018 14:00	36	120	3.85	0.61
6/13/2018 23:00	45	60	1.95	0.43	6/13/2018 19:00	41	85	3.21	0.64
6/14/2018 3:00	49	35	1.42	0.53	6/14/2018 0:00	46	60	2.66	0.55
					6/14/2018 4:00	50	35	1.98	0.68

The logged flow data record supplied by ECAO indicates that flow in the canal had been steady at 500 ft^3/s from the beginning of the supplied data record on 6/10/2018 at 0:00 hrs. until the start of the drawdown test on 6/12/2018 at 2:00 hrs. The 15-minute interval logged flow data recorded during the drawdown test is plotted in Figure 3, beginning three hours prior to the initial flow reduction step. As the plot shows, the stepped flow reductions evident at the head of the 930 section become a more gradual flow rate transition by the time flow changes reach the 550 section as would be expected. The lag time for the leading edge of each flow reduction to arrive at the 550 section was approximately one hour.

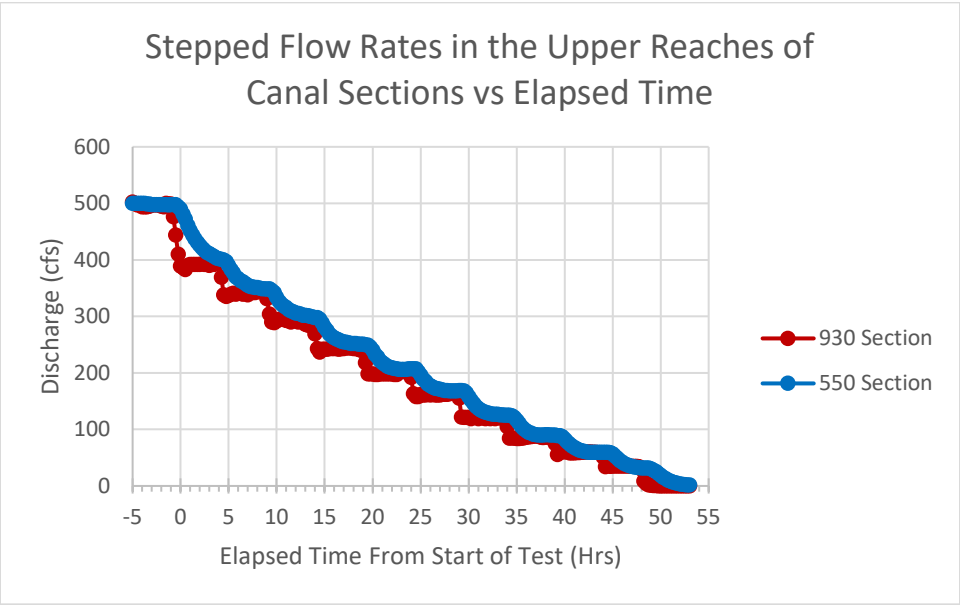

Figure 3. Flow Rates Entering the 930 and 550 Sections during the 2018 Test

Calculated stage changes associated with the flow reductions shown in Figure 3 (based on the derived normal depths for the respective canal sections shown in Table 2) are presented in Figure 4.

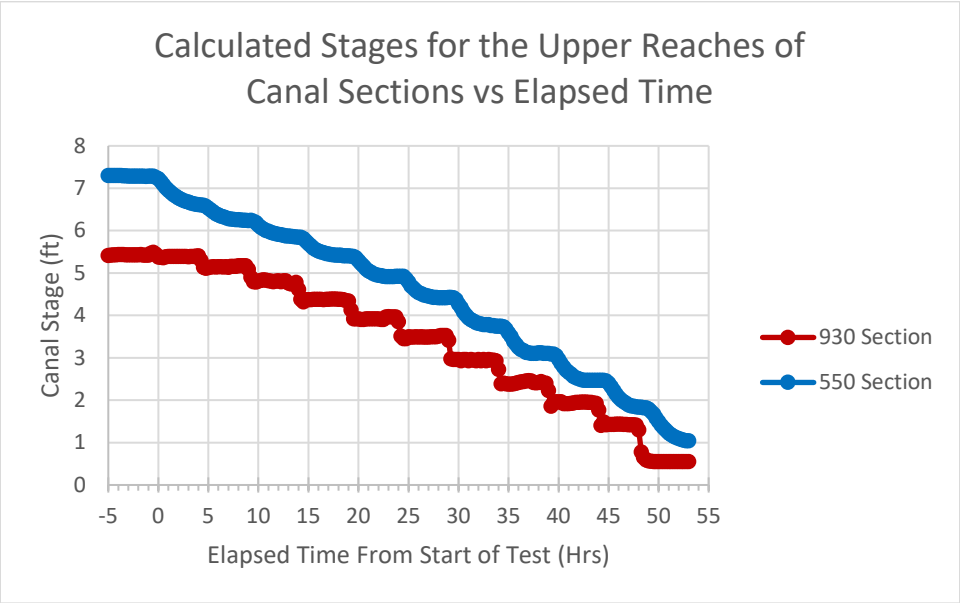

Figure 4. Theoretical Stage Reductions Associated with the Stepped Flow Reductions

The revised drawdown criteria developed for the CHFC following the 2011/2012 drawdown tests using a five-hour time interval between flow reduction steps calls for an initial stage reduction of 1 foot with subsequent stage reductions of 0.5 feet (Wahl & Duke, 2012). As Figure 4 illustrates, for the 930 section (in which Piezometer #6 – the site identified as the critical location following the 2011/2012 tests – is located) the theoretical stage reductions for the 2018 tests were near or below the revised drawdown criteria.

Manual Data Collection

During the drawdown test visual observations of the piezometer levels were performed by two teams. Stephen Middlekauff and Christopher Shupe monitored the 6 sites in the 930 section plus the Gabe 1, Gabe 2 and Mike 2 sites on the 550 section. Tom Gill and Marty Poos monitored the remaining 14 sites on the 550 section. The designation of sites to be monitored by each team was based on the fact that the 5 of the 6 sites on the 930 section and the three furthest downstream sites on the 550 section required a key for access. The rest of the 550 sites were accessible without needing a key.

During daylight hours on 6/12 and 6/13, each team traveled by vehicle from site to site to view and record the observed water level distance differential along the sloped canal wall. Following the test, the recorded values were processed to

convert the observed distances along the canal sidewall slope to a vertical head differential. With the sites monitored by Stephen and Christopher being on opposite ends of the CHFC, their median return time between observations at a given site was approximately 2.5 hours. For the more closely grouped sites monitored by Tom and Marty, the median return time was approximately 1.3 hours.

Manual Data Collection Results

930 Section

Positive pore pressures were observed at three of the six piezometer sites in the 930 section. Sites where no positive pore pressure readings were observed during the test include:

- Piezometer #11
- Piezometer #16
- Piezometer #19

For the Piezometer #11 site this differs with results from the 2012 drawdown test where a positive pore pressure was recorded at each reading cycle. A maximum positive vertical head differential of approximately 0.55 ft was recorded for this site in the 2012 test. During the 2012 test small positive pore water pressures were also observed for the Piezometer #16 site with a maximum value of about 0.15 ft. No positive pore pressure heads were reported for the Piezometer #19 site in the 2012 tests. Plotted information is presented below in Figures 5, 6 & 7 for the 930 section sites where positive pore pressures were observed during the 2018 test.

At the request of ECAO the calculated changes at the upper reach of the respective canal section are plotted along with the observed pore pressure differentials as a means of correlating fluctuations in observed positive pore pressure with the timing of the stepped flow reductions. It should be noted that with increasing distance from the upper reach of the canal section the effects of stepped flow changes will be lagged and more gradual.

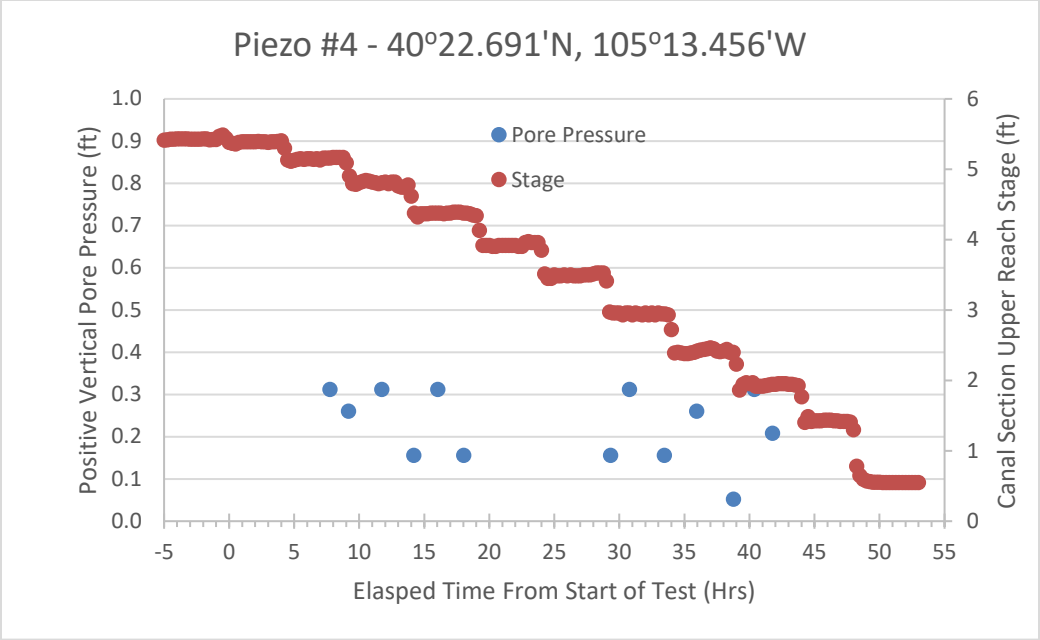

Figure 5. Piezometer #4 Observed Positive Pore Pressure Values

Positive pore pressure readings were observed during each reading cycle for the Piezometer #4 location within a range of 0.31 ft or less. Values exhibited a similar range in values for both days of the test. This compares with positive pore pressure readings from the 2012 tests with maximum positive pore pressure differential of approximately 1 ft (Wahl & Duke, 2012).

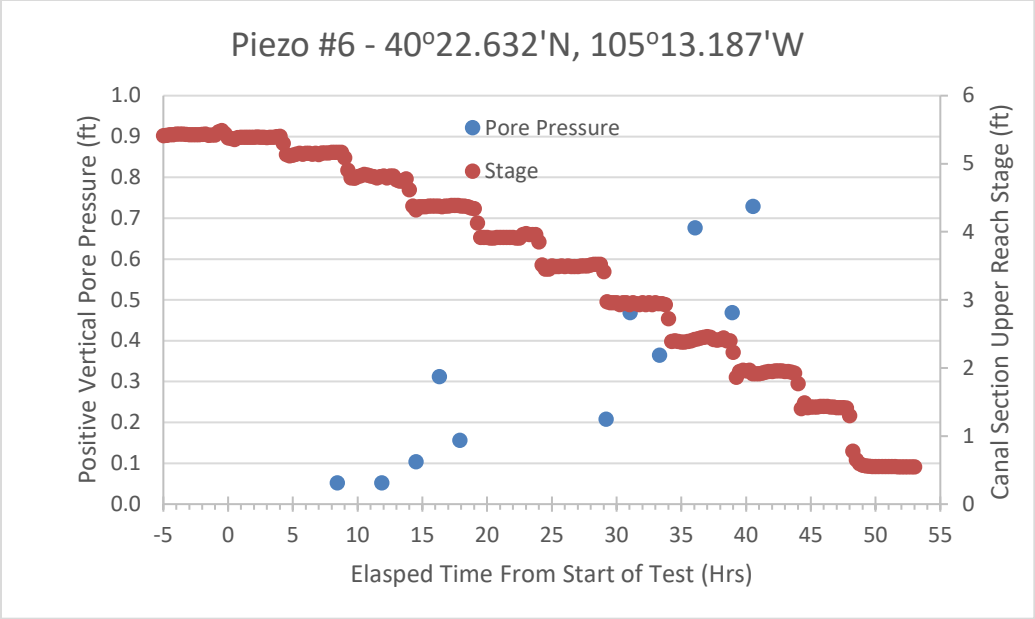

Figure 6. Piezometer #6 Observed Positive Pore Pressure Values

Positive pore pressures observed for the Piezometer #6 site were at or below a value of 0.31 ft on the first day of the test then ranged generally higher with a maximum value of 0.73 ft observed during the second day. This compares with observed positive head differentials generally in the 1.0 ft range with a maximum positive head of about 1.5 ft from the 2012 test (Wahl & Duke, 2012).

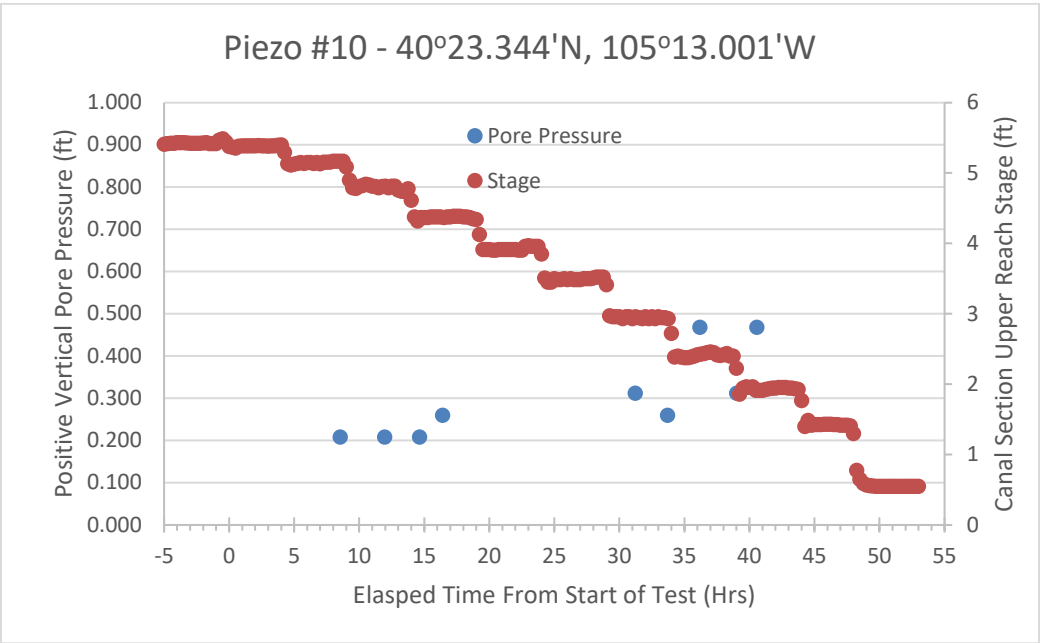

Figure 7. Piezometer #10 Observed Positive Pore Pressure Values

Positive pore pressure observations for the Piezometer #10 site were fairly steady with a maximum value of 0.26 ft on the first day. Values observed during the second day of this test were also generally higher with a maximum value of 0.47 ft. The positive pore pressure values observed during the 2012 test for this site were all in a range of 0.25 ft or less (Wahl & Duke, 2012).

550 Section

The piezometer at the Brandon 2 site in the 550 section appeared to be non-functional. Dyed water in the piezometer tube remained at or near the top of the canal lining from the time dyed water was poured into it. This was the lone site where a piezometer installation hole bored through the lining for the 2011/2012 tests was reused for the 2018 test. A rubberized caulk seal installed after the 2011 550 section test was removed prior to installing the piezometer for the 2018 test. The performance (or lack thereof) seen at this site may be linked to the previous usage – or subsequent sealing – of the piezometer tap hole.

No positive pore pressure values were observed during the 2018 test in the 550 section for the following sites:

- Amy 1
- Amy 2
- Amy 5
- Nicole 2
- Nicole 3
- Nicole 4
- Ribha 4
- Brandon 1
- Brandon 3
- Brandon 6
- Mike 2

Of these sites, notes from the 2011 test on the 550 sections indicated that dye was not added to the Amy 1, Amy 2, Nicole 2, Nicole 3, and Nicole 4 sites, without which piezometer levels could not be observed. Positive pore pressures recorded for the Amy 5 site from the 2011 test were at or below 0.2 ft. Notes from the 2011 test indicate that piezometer heads at the Ribha 4 site were "mostly below canal level". 2011 Test notes regarding the Brandon 1, Brandon 3 and Brandon 6 sites question whether the piezometer tubes might have become disconnected at each of these sites. The Mike 2 site was noted as "consistently showed a positive reading behind the lining" during the 2011 test (Wahl & Duke, 2012).

For the sites in the 550 section where positive readings were observed during the 2018 test, plots of the observed values, along with the calculated canal stage reductions at the upper end of the 550 section are shown below in Figures 8, 9, 10 & 11. As with the plots for the 930 section the actual stage reduction for the

respective piezometer sites will be lagged and become more gradual with increasing distance from the head of the 550 section.

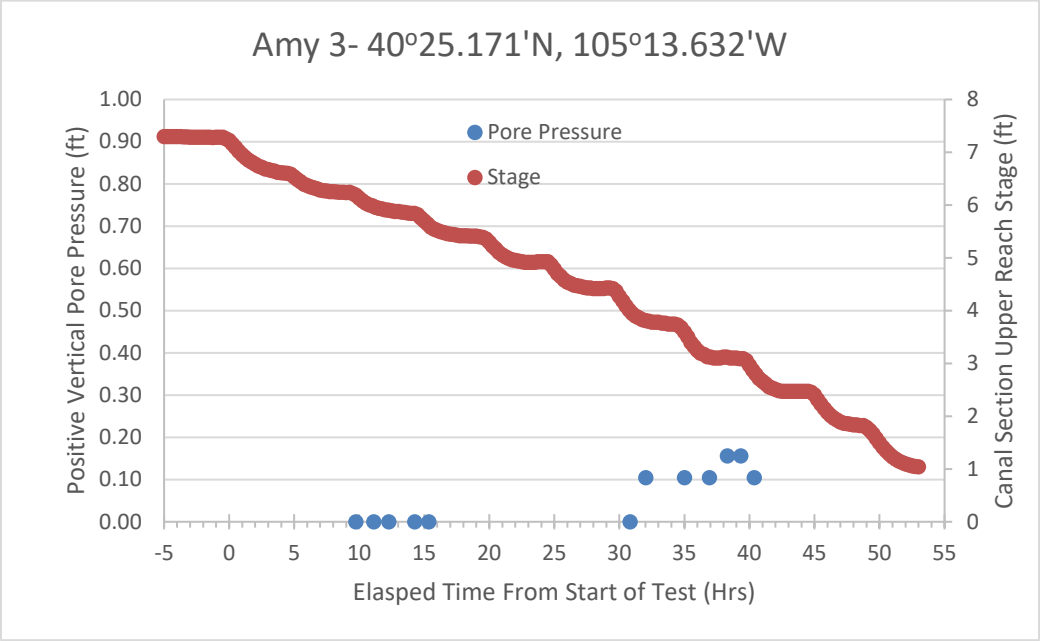

Figure 8. Amy 3 Site: Observed Positive Pore Pressure Values

No positive pore pressure readings were observed for the Amy 3 site during the first day of the test. Positive readings observed during the second day were in a range of 0.16 ft or less. For the 2011 test, at this site (identified as station 94+36) the observed positive pore pressures were in the same range with a maximum value of about 0.18 ft.

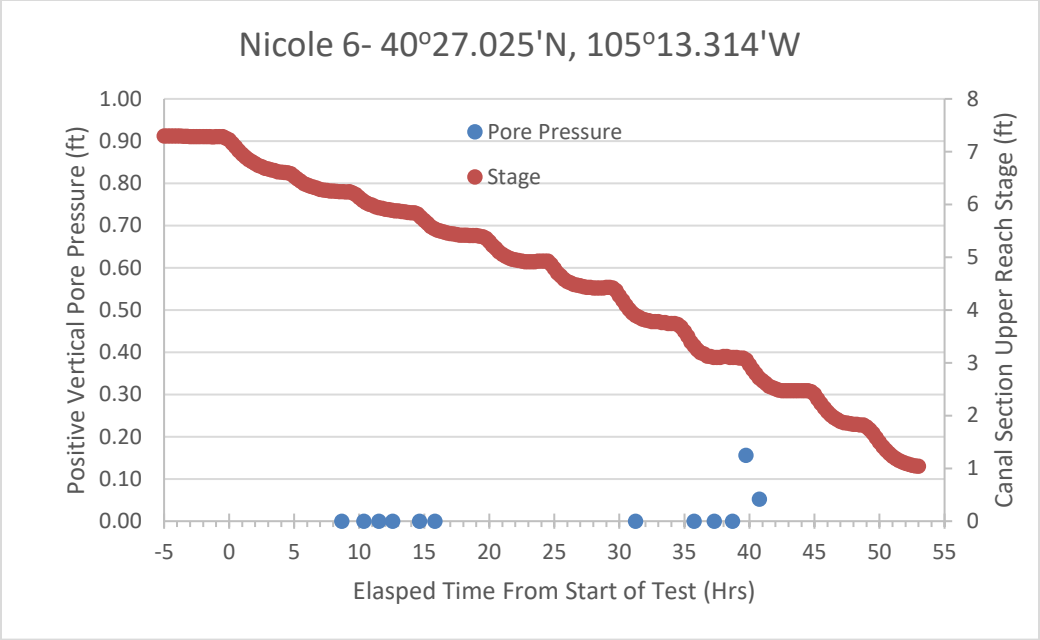

Figure 9. Nicole 6 Site Observed Positive Pore Pressure Values

For the Nicole 6 site the only positive pore pressure readings from the two days of testing were the last two readings taken on the second day by which time the canal water level had been dropped considerably. The maximum positive pore pressure observed at this site was 0.16 ft. Notes from the 2011 test for this site were "inconsistent behavior – below canal level most of the time". No positive pore pressures for this site were reported for the 2011 test.

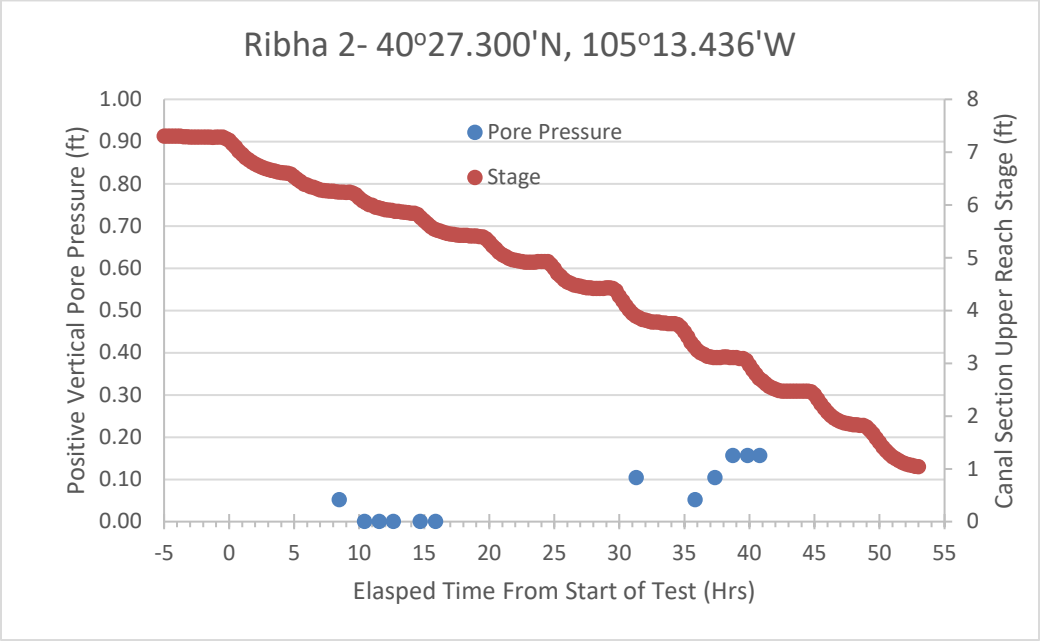

Figure 10. Ribha 2 Site Observed Positive Pore Pressure Values

For the first day of the test only the first reading of the day at the Ribha 2 site showed positive pore pressure. During the second day, each of the readings indicated a modest positive pressure with no observed pore pressure differential exceeding 0.16 ft for the two-day test. Notes from the 2011 test indicate that this is a site where there was concern that the piezometer tube might have become detached from the piezometer tap.

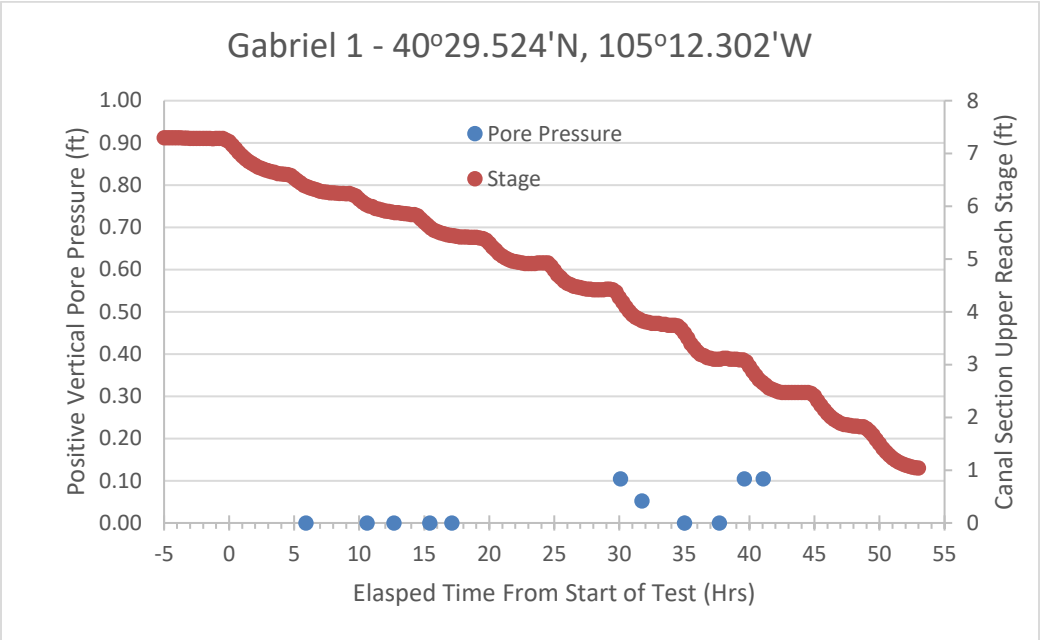

Figure 11. Gabriel 1 Site Observed Positive Pore Pressure Values

Similar to the Amy 3, Nicole 6 and Ribha 2 sites, some small positive pore pressure observations were made at the Gabriel 1 site during the second day of the test following no observations of positive pore pressure during the first day of the test.

The Gabriel 2 site does not appear to have been a normally functioning site during this test. Large positive pore pressure values that were observed at this site in the lower reach of the 550 section as the canal level lowered are plotted in Figure 12. Interestingly the observed positive pore pressures appeared to track the drop in canal level in the range of one foot of positive pore pressure. Notes from the 2011 test at this site indicate that observed piezometer levels closely tracked the water surface. It is not apparent what factors may have been associated with the significant difference in values observed for the 2011 and 2018 tests.

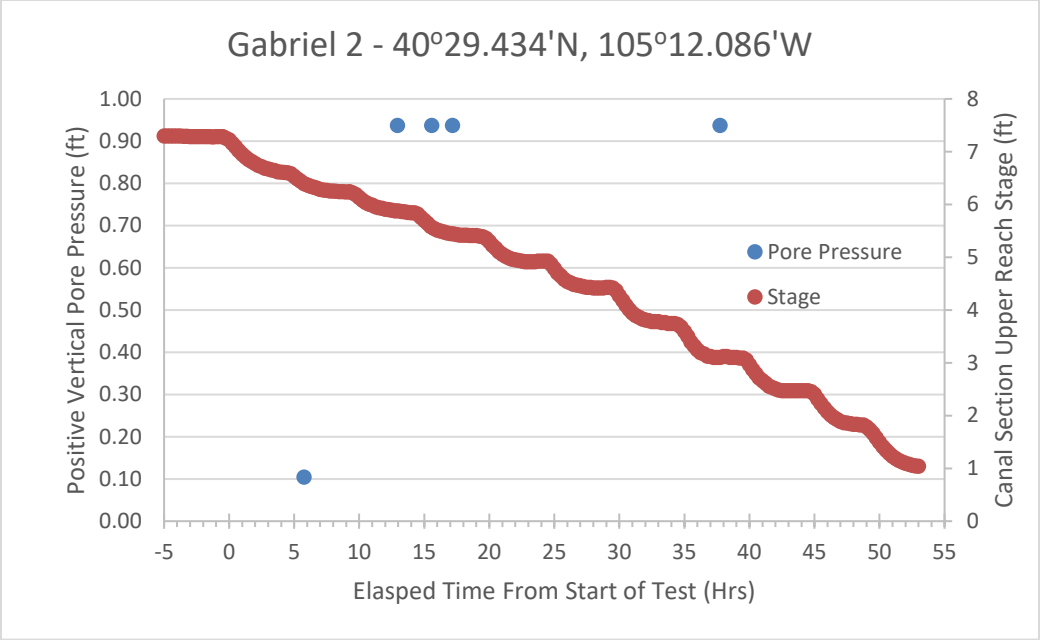

Figure 12. Gabriel 2 Site Observed Positive Pore Pressure Values

Electronic Data Collection

The electronic data collection component of the 2018 drawdown test was impacted by the compressed schedule for preparation and final setup tasks. The same type of equipment had previously been used on selected sites as part of a drawdown test on the Brock Inlet Canal on the All American Canal system in Southern California in 2014 (Gill and Wahl, 2014). For that test solar charging systems were set up to power the electronic devices. The electronic equipment performed as anticipated for Brock Inlet Canal test.

For the 2018 CHFC test, a simpler “plastic tool box” installation configuration was devised that could be rapidly put in place. This was due in part to the limited set-up time available and also by budget constraints. The equipment was powered using cordless hand tool (DeWalt 18 volt) batteries.

The HILS project team had previously made use of the cordless hand tool batteries as a temporary power source for the programmable control units for tasks such as performing radio pathways checks. The cordless tool batteries had not previously been utilized as a power source for more than 8 hours at a time, thus it was not known how long the cordless tool batteries could be expected to perform before needing to be recharged.

With the piezometers located on the limited access side of the CHFC it was not practical to make regular checks of the electronic equipment once the drawdown test was underway. Freshly recharged batteries were installed during the morning

of the second day of the test. By that time, at each site, the initially installed battery had become discharged prior to replacing the batteries. Hence there were unfortunate gaps in the electronically collected data.

Electronic Data Collection Results

Of the six total sites equipped with electronic monitoring equipment, only three were sites where positive pore pressure head was detected in the manual observations – Piezometer #4 and Piezometer #6 in the 930 section and the Nicole 6 site in the 550 section. Unfortunately no useful electronic data was obtained at the Piezometer #6 site. At the Piezometer #6 site logged positive pore pressure values were in the unrealistic range of 6-8 ft suggesting that the bubbler line linked to the piezometer had become plugged or pinched. Since this site had been the location with the highest positive pore pressures observed in the 2011/2012 tests, a logged data record at this site would have been of particular interest.

The Electronic data from the Nicole 6 site and the Piezometer #4 site are displayed along with the manually observed values obtained over the same time periods in Figures 13 & 14 respectively. At both sites the available logged test data begins after replacement batteries were installed during the second day of the test.

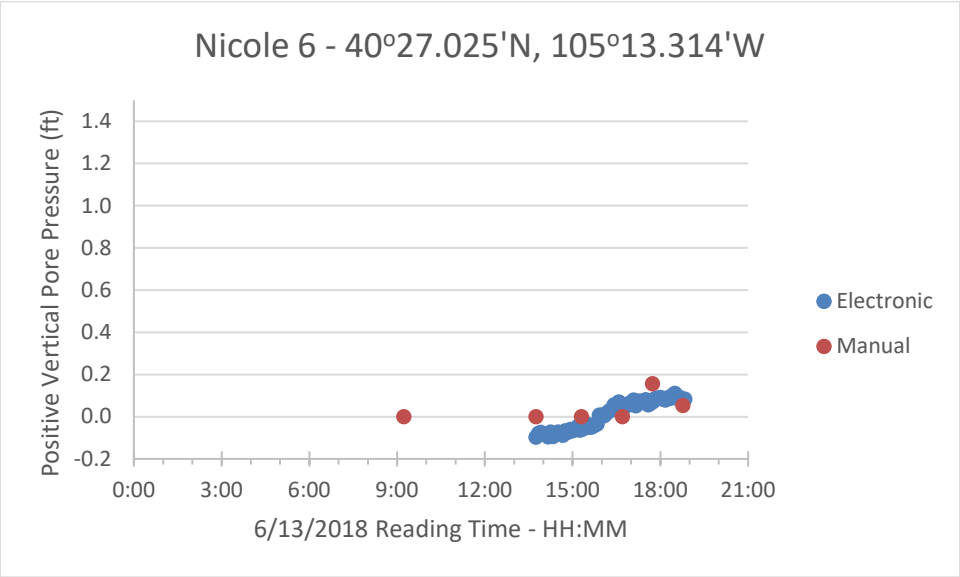

Figure 13. Electronic and Manually Observed Positive Pore Pressures at Nicole 6 Site

Only the last two manually observed readings at the Nicole 6 site showed positive pore pressure readings. All previous observations were "at or below" the canal water level and were recorded as a "zero" value. The limited record of logged

electronic data at the site is in general agreement with the manual observations, with positive pore pressure readings appearing only late in the test.

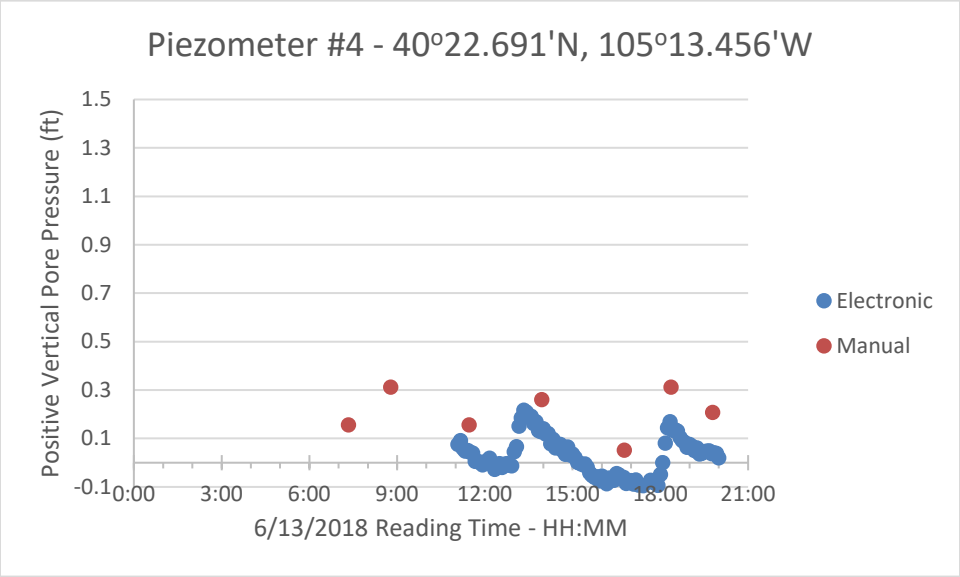

Figure 14. Electronic and Manually Observed Pore Pressures at Piezometer #4

The effects of the bubbler canal level tap and the bubbler piezometer tap not being at precisely the same elevation at the Piezometer #4 site may be seen in Figure 14. A comparison of the electronic values obtained at essentially the same time as the last five manual readings shows the electronic values fall in a range of 0.11 to 0.17 ft less than the manually observed positive pore pressures. The average differential for the five readings is 0.134 ft. This "calibrated offset" value was added to each of the electronically logged values to produce the values plotted in Figure 15.

Comparing the shifted, continuous, electronically collected data to the intermittent manually-read values shows how the continuous data provides much more insight into the range of pressure differentials applied to the canal lining during the drawdown test. The Figure 15 plot provides an indication of the potential utility of the electronic monitoring equipment for a drawdown test.

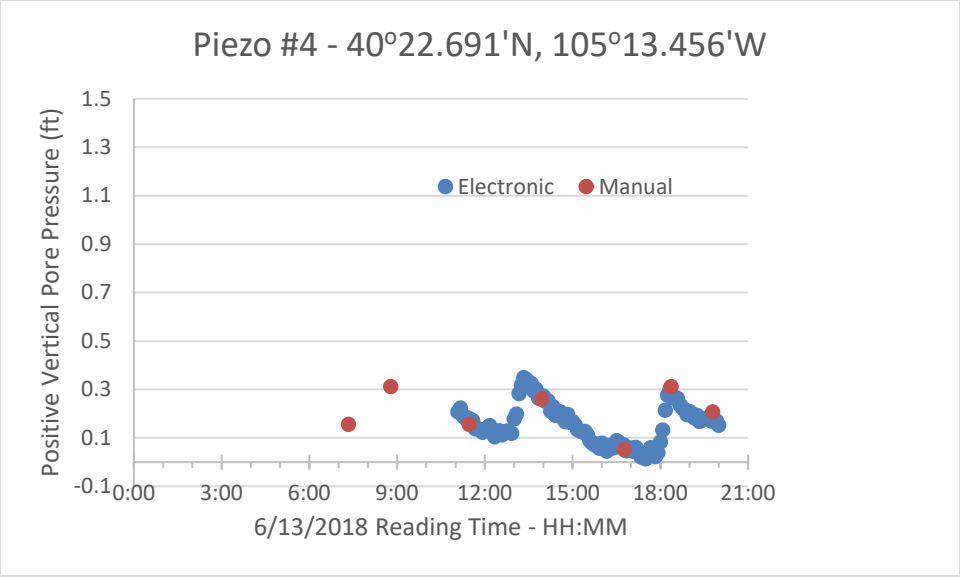

Figure 15. Manual and Adjusted Electronic Pore Pressures at Piezometer #4

Discussion of Test Results

As previously noted, the Brandon 2 and Gabriel 2 sites in the 550 section did not appear to be normally functioning piezometer locations during this test. The high piezometer levels observed at each of these sites were in direct contrast with notes from the 2011/2012 test report describing both locations as "fast" in responding to canal level reductions. The behavior of the Brandon 2 site, where the level in the piezometer tube dropped extremely slowly after being filled with dyed water and did not lower to the pre-test canal level during the two days of observation, seems highly likely to be due to factors linked to re-use of the same hole drilled through the concrete lining for the 2011 test and not representative of the actual pore pressure behind the lining in that vicinity. It is unclear what factors may have contributed to the high piezometer readings during this test at the Gabriel 2 site.

The Piezometer #6 site in the 930 section – which was deemed the critical site following the 2011/2012 tests – was the site with highest observed positive pore pressures for which there can be a strong level of confidence in the observed values during this test. The highest positive pore pressure value observed at this site during the test was approximately 14 in along the slope (or about 0.73 ft vertically). Given the lengthy time intervals between manual readings during this test, higher peak-value positive pore pressures may have occurred at this location immediately following canal level drops; however it does appear unlikely that the target limit of 1 ft pressure differential would have been exceeded to a significant degree.

It may be useful to consider differences in the manner in which the 2011/2012 tests and the 2018 drawdown tests were conducted. There were three drawdown

steps for both the 2011 drawdown test of the 550 section and the 2012 drawdown test of the 930 section. Each of the first two were targeted to produce 6 in. vertical stage reduction with the third targeted to produce a 12 in. vertical stage reduction. Both of the previous tests were performed in a single day with all data collection being performed within an eight-hour time period (Wahl & Duke 2012).

The 2018 drawdown test ended up being in conjunction with a complete canal shutdown needed to address an unplanned maintenance issue. From the initial flow reduction at 2:00 AM on 6/12/2018, stepped flow reductions were made over a period of 49 hours, with the final flow shutdown occurring at 3:00 AM on 06/14/2018. Key differences in the tests included significant differences in the duration and the associated degree of stage reduction, along with differing canal stage reduction rates.

Observed canal stage reductions from the 2011/2012 tests are plotted alongside theoretical canal stage reductions from the 2018 test (based on calculated normal depths corresponding to measured flow rates logged during the test) for the Piezometer #4 site in the 930 section and for the Amy 3 site (94 + 36) site in the 550 section. This information is displayed in Figures 16 & 17 respectively.

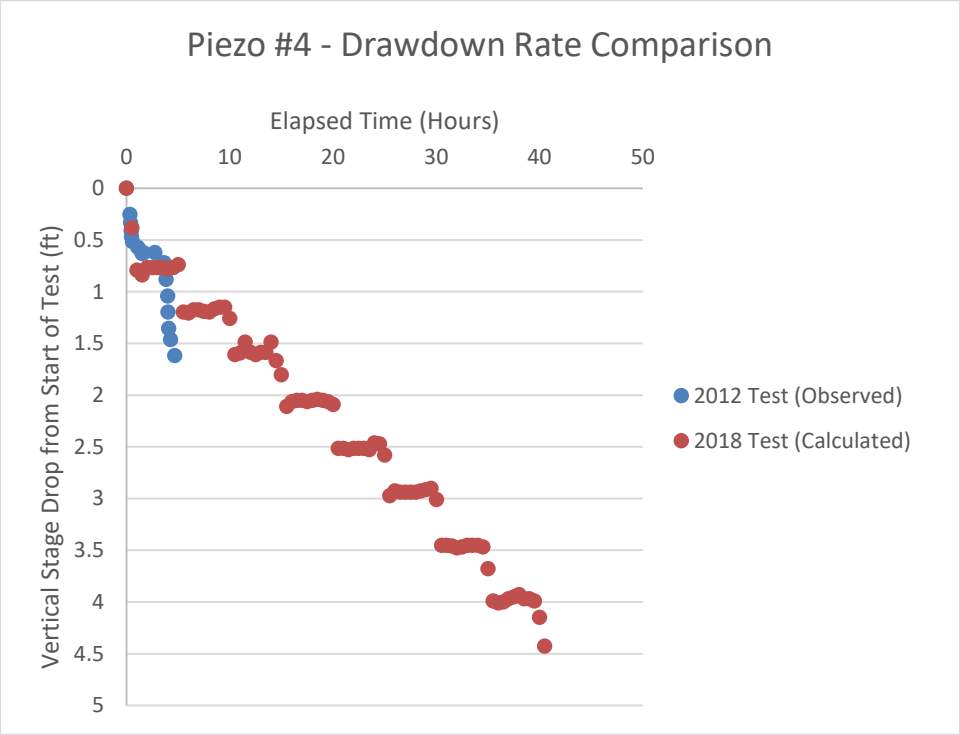

Figure 16. Piezometer #4 Site: Comparative Drawdown Rates, 2012 & 2018 Tests

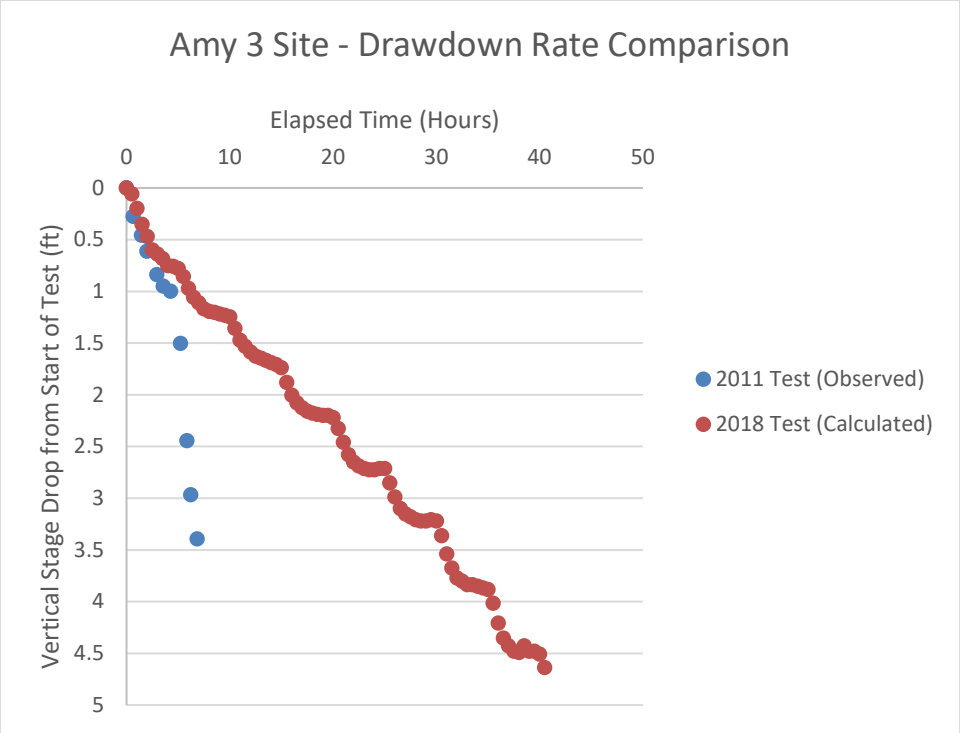

Figure 17. Amy 3 (94 + 36) Site: Comparative Drawdown Rates, 2011 & 2018 Tests

For sites that appeared to function correctly in the 2018 test, positive pore pressure observations were in each case smaller than pressures observed for the same locations during the 2011/2012 tests. As Figures 16 & 17 indicate, canal stage reduction rates during the duration of the 2011/2012 tests appear to have been significantly more rapid than the stage reductions during the duration of the 2018 test. The more gradual rate of stage reduction during the 2018 test would be a key factor contributing to the lower observed positive pore pressures.

Summary

The observations from this test provide a level of assurance that the modified drawdown criteria developed for this canal following the 2011/2012 drawdown tests appears to produce results within the target range of net positive pore pressure behind the canal lining during a canal de-watering event. Of the 17 sites in the 550 section included in the 2018 test, excessive pore pressure concerns may be eliminated for all sites exhibiting proper performance of the piezometric equipment. Positive pore pressures were observed at only three of the six sites in the 930 section included in the 2018 test.

Of the three 930 section sites where positive pore pressure were observed, the highest pore pressures were observed at the Piezometer #6 site (as was the case during the 2012 930 section test). The Piezometer #6 site continues to be a

primary location of interest and the known constraining location in drafting drawdown criteria.

For future drawdown tests it is suggested that piezometer tubes be filled with dyed water immediately after the piezometers are installed, while the canal is dewatered. This should provide an immediate indication of piezometers that are behaving unexpectedly. This would afford an opportunity to relocate a questionable piezometer tap to a different location in the same proximity before the canal is put back into service.

If electronic monitoring stations using the bubbler level sensors are to be used in future tests it would be advisable to perform a preliminary test with the canal dewatered to ensure that there is no blockage in the bubbler lines, which may have been the case for the Piezometer #6 site on the 930 section. The bubbler tube being linked to the piezometer should be routed such that it is secured to the lining and not allowed to extend out into the flow to reduce potential for the line being pinched or otherwise affected by flowing water in the canal. It would also be beneficial if sites equipped with electronic monitoring equipment could be configured with solar charging capability or more durable battery power.

An additional recommendation for future drawdown testing would be to consider devising a staff gage that provides readings in vertical depth to install on the sloped wall at each piezometer location adjacent to the piezometer tube. This might be accomplished by using a stencil for a section representing two or three feet of vertical depth and spray painting over it. The stencil could be re-positioned as many times as needed for the canal wall length. A staff gage of this nature would simplify taking manual readings, and where electronic monitoring equipment is also used, the staff gage would provide a means of calibrating electronic level sensors. Given that any future testing is likely to include a small number of piezometer locations, this would not add a significant amount of effort to the set up tasks for a test.

References

Wahl, Tony L. and Duke, Wylie C. 2012. *Canal Lining Drawdown Tests and Development of New Drawdown Criteria for the Charles Hansen Feeder Canal, Colorado Big Thompson Project.* Hydraulic Laboratory Technical Memorandum PAP-1071. US Department of Interior. Bureau of Reclamation. Technical Service Center. Denver CO.

Gill, Tom and Wahl, Tony L. 2014. *Canal Lining Drawdown Tests for the Brock Reservoir Inlet Canal.* Hydraulic Laboratory Technical Memorandum PAP-1102. US Department of Interior. Bureau of Reclamation. Technical Service Center. Denver CO.

Appendix

Table A-1: Drawdown criteria developed for the Charles Hansen Feeder Canal based on results of the 2011/2012 drawdown tests (Wahl & Duke, 2012).

Table 1. — Drawdown criteria for the Charles Hansen Feeder Canal for a range of values of periodic step change. This table is designed to limit the differential head across the lining to no more than 1 ft, and was generated based on data collected from Piezo 6. The current drawdown criteria are also shown for comparison.

Alternative drawdown criteria for the Charles Hansen Feeder Canal.				
Initial step change in canal depth **(must have been at equilibrium for preceding 48 hours)**	Subsequent step change in canal depth, Δy	Required interval between changes	Time required to drain…	
			550 section (8.2-ft depth)	930 section (8.8-ft depth)
(inches)	(inches)	(hours)	(hours)	(hours)
12	3	2	58	62
12	4	3	65	70
12	5	4	69	75
12	6	5	72	78
12	7	7	86	94
12	8	8	86	94
12	9	10	96	104
12	10	13	112	122
Existing drawdown criteria (* 6 inches in one hour, maximum of 12 inches per day)				
6	6	12*	192	204