CH2M
3120 Highwoods Boulevard
Suite 214
Raleigh, NC 27604
O +1 919 875 4311
F +1 919 875 8491
www.ch2m.com

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May 25, 2017

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Ms. Bobbi Coleman
South Carolina Department of Health and Environmental Control
Assessment Section, UST Management Division
Bureau of Land and Waste Management
2600 Bull Street
Columbia, SC 29201

Subject: Response to SCDHEC Letter titled "Corrective Action Plan, Response to Comments, and Monthly Report Review & request for a revised Corrective Action Plan Addendum" dated April 26, 2017
Plantation Pipe Line Company
Lewis Drive Remediation Site
Belton, South Carolina
Site ID #18693, "Kinder Morgan Belton Pipeline Release"

Dear Ms. Coleman,

On behalf of Plantation Pipe Line Company (Plantation), CH2M HILL Engineers, Inc. (CH2M) has prepared this response to comments received from the South Carolina Department of Health and Environmental Control (SCDHEC) in their letter date-stamped April 26, 2017, requesting that a revised Corrective Action Plan Addendum (CAPA) be provided within 30 days.

SCDHEC comments and Plantation's related responses are provided below.

Comment 1: *Free Product Recovery. Currently, the DHEC understands that free product removal is being conducted twice weekly. However, as agreed upon in the meeting held April 7, 2017, recharge rates for recovery wells RW-2, RW-4, RW-5, RW-6, RW-7, RW-8, RW-9, RW-10, RW-11, RW-12, RW-13, and RW-14 will be determined. This information will aid in the determination of effective frequency of recovery. As site conditions change, recharge rates will need to be evaluated to determine the most effective frequency of recovery.*

> **Response:** Refer to the Light Non-Aqueous Phase Liquid (LNAPL) Mobility Testing Evaluation technical memorandum, presented in Attachment 1. Average transmissivity values for the six wells on which successful mobility tests could be conducted (RW-04, RW-05, RW-07, RW-10, RW-11, and RW-13) ranged from 0.07 ft^2/day (at RW-13) to 0.54 ft^2/day (at RW-07). These values are within the published range of transmissivity thresholds of 0.1 ft^2/day to 0.8 ft^2/day, below which fluid recovery is considered an impractical method of LNAPL abatement[1]. Although

[1] Interstate Technology & Regulatory Council (ITRC). 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. LNAPL-2. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

the transmissivity levels do not warrant continued recovery, we will continue product recovery every other week on wells with higher transmissivity (RW-4, RW-7, and RW-10), on productive recovery sumps (RS-01, RS-05, RS-08, RS-09, RS-10, RS-11, RS-12, and RS-18) and at the recovery trench protecting Brown's Creek (RT-1). We will re-evaluate the recovery frequency and propose an alternate schedule as needed based on recovery data collected in the future. As discussed in our response to Comment 2, an interim goal is to transition from free-phase LNAPL recovery to *in situ* LNAPL destruction via sparging by the end of September 2017.

Comment 2: *<u>Interim Goals</u>. Regarding the previous request for interim goals in the January 31, 2017 Corrective Action Plan Review (Coleman to Aycock), the March 2, 2017 Response to Comments Document (Waldron to Coleman) provides a remedial goal of no surface water quality exceedances in the surface water protection zones within six months following startup of the sparging system. This proposal will need to be incorporated within the revised CAPA. Interim goals will need to be discussed for the remaining areas in the Annual Report.*

Response: The following interim goals are proposed in the revised CAPA:

1. No surface water quality exceedances within 6 months following startup of the sparging system in the Brown's Creek and Cupboard Creek Protection Zones.
2. Transition from free-phase LNAPL recovery to *in situ* destruction of LNAPL by the end of September 2017 (approximately 6 months after starting the sparging system).
3. Complete a bedrock sparging pilot test in the Shallow Bedrock Zone by the end of September 2017 so that full-scale bedrock sparging can be implemented in 2018.
4. Have an established treatment zone with stable air flows in the Brown's Creek and Cupboard Creek Protection Zones by the end of September 2017.
5. Have an established treatment zone with stable air flows in the Hayfield Zone horizontal sparging wells by the end of December 2017.

Once the system has reached a steady state of operation and some performance data have been collected, other interim goals may be established in consultation with SCDHEC.

Comment 3: *<u>Monitoring Frequency</u>. Quarterly monitoring for BTEX, Naphthalene, MTBE, 1,2-DCA, and dissolved oxygen should continue until stabilization has been determined. Upon review of data over time, alterations to the monitoring frequency can be evaluated. Evaluation of the monitoring frequency must be discussed in the Annual Report. Any changes to the monitoring frequency will need to be evaluated and approved by the DHEC. Any reference to semi-annual and/or annual monitoring in text or tables within the CAPA must be omitted.*

Response: All references to semi-annual or annual monitoring for BTEX, Naphthalene, MTBE, 1,2-DCA, and dissolved oxygen will be removed from the CAPA text and tables. Quarterly monitoring will be conducted during the first year of system operation. Any alterations to the monitoring frequency after the first year will be proposed to SCDHEC as needed and will be summarized in the Annual Report.

Comment 4: *<u>Brown's Creek Protection Zone Monitoring</u>. Given the proximity of Brown's Creek, groundwater monitoring wells MW-39, MW-40, and MW-41 should be added to the monthly monitoring well network in the area of Brown's Creek.*

Response: MW-39, MW-40, and MW-41 will be added to the Brown's Creek monitoring well network. Groundwater samples will be collected monthly using HydraSleeve™ no-purge samplers.

Comment 5: *<u>Cupboard Creek Protection Zone Monitoring</u>. Given the migration of contamination in the direction of Cupboard Creek, groundwater monitoring wells MW-20 and MW-23 should be added to the monthly monitoring well network in the area of Cupboard Creek.*

> **Response:** MW-20 and MW-23 will be added to the Cupboard Creek monitoring well network. Groundwater samples will be collected monthly using HydraSleeve™ no-purge samplers.

Comment 6: *<u>Shallow Bedrock Zone Monitoring</u>. In discussing the Shallow Bedrock Zone strategy with Plantation Pipe Line and CH2M, DHEC understands that a Pilot Study Evaluation Procedure will be provided. Based upon review of the data provided from the pilot study, a shallow bedrock effectiveness monitoring plan will be provided at a later date.*

> **Response:** The *Shallow Bedrock Zone – Biosparging Pilot Study Plan* was submitted to SCDHEC on May 8, 2017. As discussed in this plan, after the pilot study has been completed, results will be presented in a brief technical memorandum for SCDHEC's review.

Comment 7: *<u>Hayfield Zone Monitoring</u>. Based upon the meeting held April 7, 2017, DHEC understands that Plantation Pipe Line does not anticipate rapid changes to dissolved phase contamination. Groundwater monitoring wells MW- 2, MW-3, and MW-7 should be added to the monthly sampling network in the CAPA to monitor the Hayfield Zone.*

> **Response:** Because the initial focus of remediation in the Hayfield Zone is to reduce/eliminate LNAPL and contain the extent of impacts in the Hayfiend Zone, we disagree with monthly sampling of MW-02, MW-03, and MW-07. Rather, MW-02, MW-03, and MW-07 will be sampled quarterly to evaluate potential changes in dissolved hydrocarbon concentrations. Monthly groundwater level and product thickness gauging in the Hayfield Zone is sufficient to assess the goal of LNAPL reduction.

Comment 8: *<u>Surface Water Monitoring</u>. Surface water sampling should continue monthly during the first year of treatment after weekly sampling has been completed. As discussed in item #3, evaluation of the monitoring frequency must be discussed in the Annual Report. Any changes to the monitoring frequency will need to be evaluated and agreed upon. Surface water should continue to be sampled for BTEX, Naphthalene, and MTBE.*

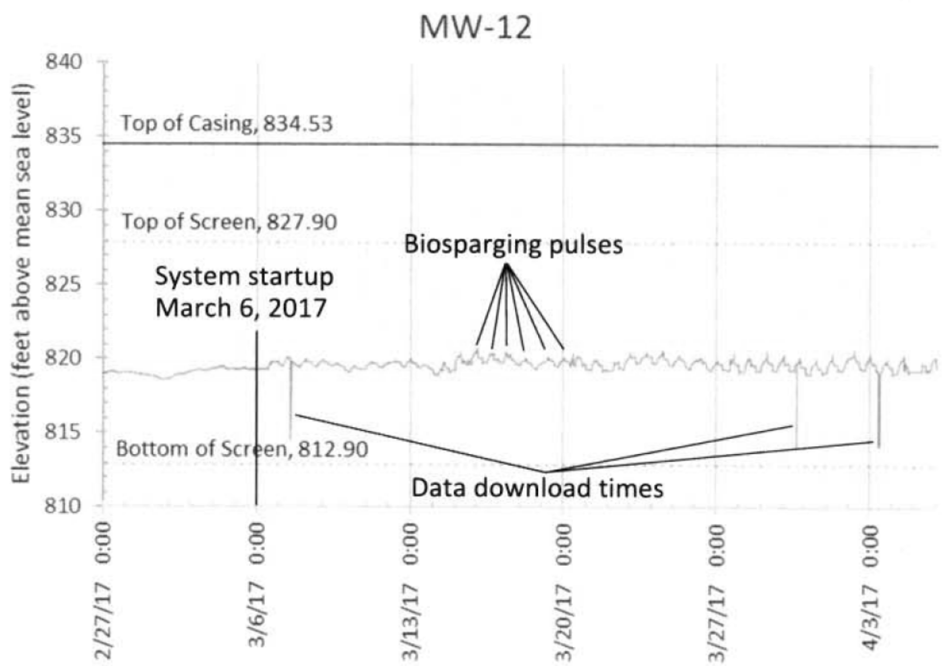
> **Response:** Surface water sampling will continue monthly for the first year of treatment. As needed, any alterations to the monitoring frequency will be proposed to SCDHEC and will be summarized in the Annual Report.

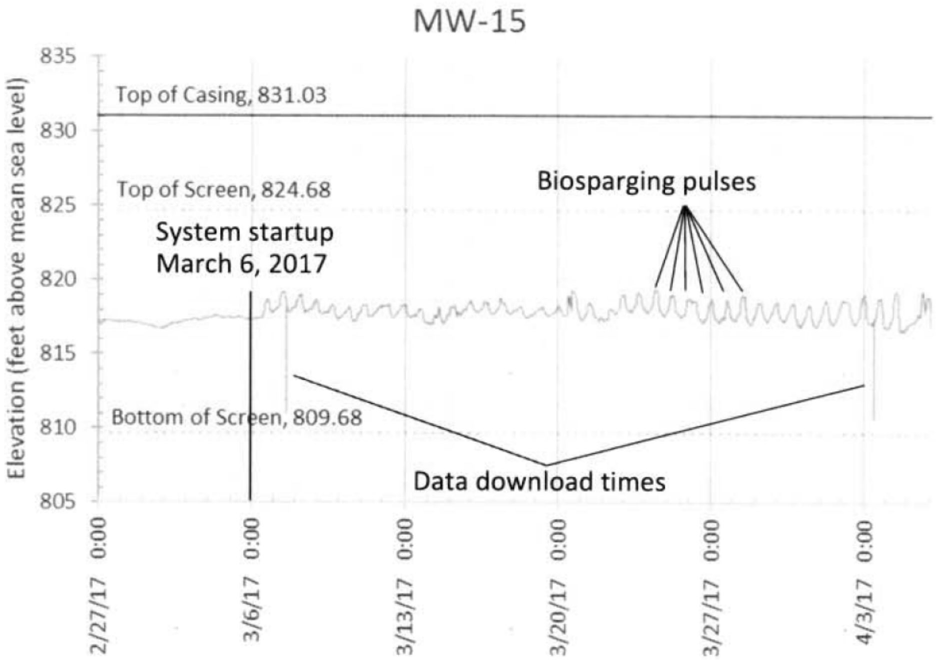
Comment 9: *<u>Biodegradation Monitoring</u>. Section 3.4 should be revised to state that biodegradation monitoring will be conducted quarterly, rather than annually to evaluate the progress of biodegradation. Monitoring frequency must be discussed in the Annual Report. Any changes to the monitoring frequency will need to be evaluated and agreed upon.*

> **Response:** Establishing a sustained, aerobically biodegradable environment for microbes that degrade hydrocarbons is a slow process, as oxygen transfer into groundwater is often slower than the rate that microbes consume the oxygen (United States Army Corps of Engineers Air Sparging Design Manual, 2008). Sufficient time is required for a steady-state, balanced population of microbes to establish after the initial operational period. Biodegradation monitoring of natural attenuation parameters on a quarterly basis is therefore considered unnecessary for adequate analysis. We recommend maintaining an annual sampling frequency for natural attenuation parameters.

Comment 10: *Flow Rate Evaluation (Mounding and Volatilization). In that groundwater mounding from displacement of water by air injection causing plume migration is a concern, adequate monitoring is necessary. The DHEC requests that a data logger be installed in recovery well RW-14, located down-gradient of the biosparging system lines towards Brown's Creek, in addition to data loggers proposed in groundwater monitoring wells MW-12 and MW-15.*

Response: RW-14 contains LNAPL and a data logger cannot be installed in the well without damaging the logger. The two Brown's Creek data loggers installed in monitoring wells MW-12 and MW-15 have been operational since system startup began on March 6, 2017 (refer to the *Startup Plan for Surface Water Protection Measures – Revision 2,* submitted to SCDHEC on February 23, 2017 and approved by SCDHEC on March 1, 2017). Changes in water levels at MW-12 and MW-15 in response to pulsed operation of the biosparge system are graphed below. The biosparge system is pulsed on a 6-hour cycle, as described in the *Startup Plan*. The plots show that groundwater mounding is temporary, that water levels revert to baseline levels as soon as the pulsing sequence is complete, and that there is no long-term trend of increasing water levels to support the supposition that water is being pushed by the sparge system to Brown's Creek. This is also well documented in the literature and should not be a focus of this remediation effort.





Comment 11: *<u>Flow Rate Evaluation (Mounding and Volatilization)</u>. The CAPA will need to specify the method used to measure the degree of volatilization used to determine flow rates. In addition to the method, the standard of comparison and the sampling locations will need to be provided.*

Response: As detailed in the approved *Startup Plan* and its attached *Air Monitoring Plan*, fixed and mobile air monitoring stations were established in both surface water protection zones to monitor changes in volatile organic compound (VOC) concentrations in the atmosphere during operation of the biosparging system. A sustained VOC concentration of 5 parts per million (ppm) was established as a conservative trigger level above which airflow rates would be lowered to minimize volatilization and limit the migration of VOCs to the atmosphere.

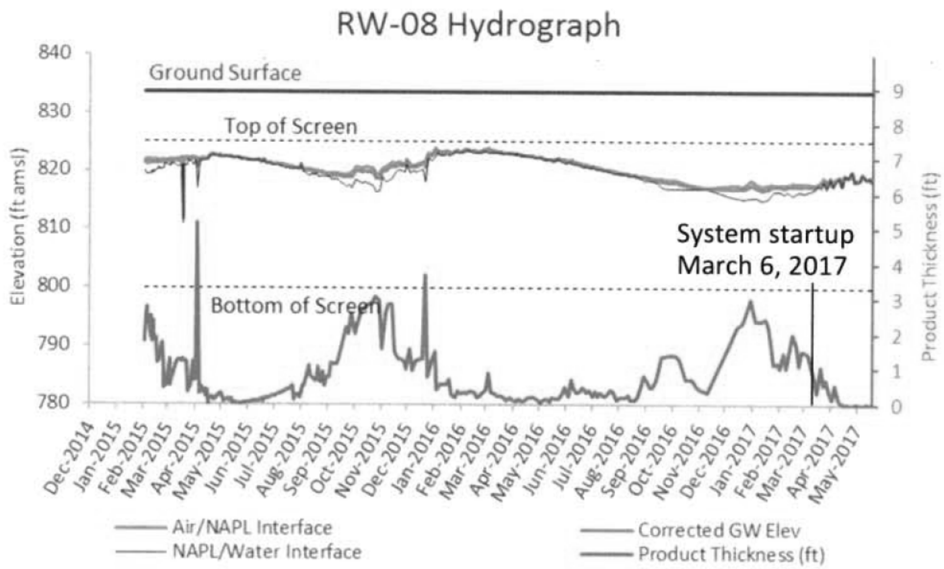
To date, sustained VOC readings greater than 5 ppm have not been recorded during operation of the biosparge system. However, short duration intermittent spikes in vapor concentrations have occurred during night time hours. Air monitoring data show that the temporal spikes occur primarily at night or in the hours before dawn when the air is cool and still. Test data collected to date indicate that operating the biosparging system is not causing excessive volatilization of hydrocarbons and is well within emission limits. No further methods to estimate emissions will be conducted. Sufficient data exist to identify or address any concerns.

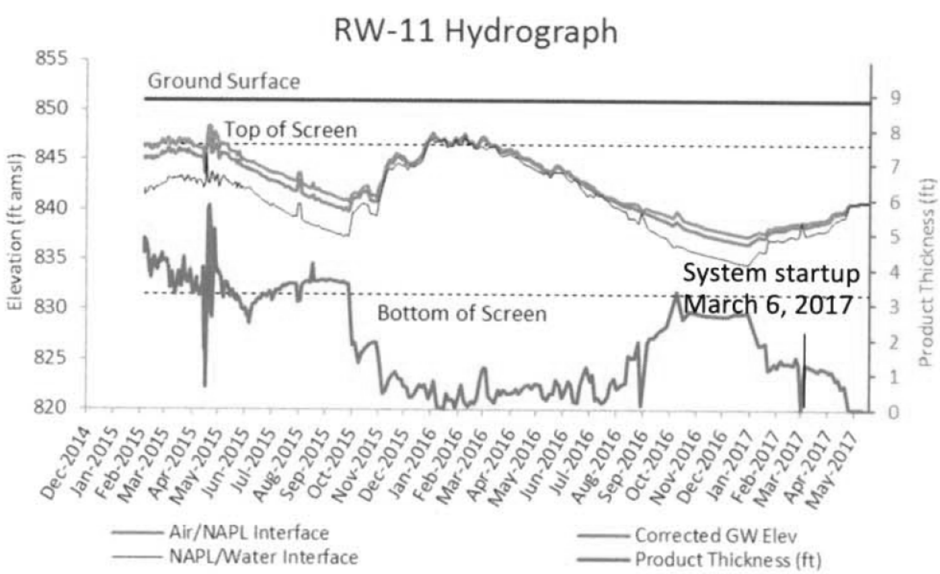
Comment 12: *<u>Visual Observations</u>. The revised CAPA should state that all observations of petroleum sheen, seeps, dead or distressed vegetation or biota, unusual odors will be noted in monthly reports and reported to the DHEC via phone regardless if previous occurrences have been noted.*

Response: As stated in the CAP addendum, the issuance of monthly reports ceased on March 31, 2017, and data transmittals will be provided to SCDHEC quarterly. The first quarterly data transmittal will be submitted to SCHDEC by August 30, 2017 and will describe the work performed from April 1 to June 30, 2017. We concur that unusual observations of petroleum sheen, seeps, dead or distressed vegetation or biota, and unusual odors will be reported to DHEC via phone and then provided in the quarterly data transmittals. Section 3.6 of the CAP Addendum Revision 1 has been revised accordingly.

Comment 13: *<u>Free Product</u>. Data provided in the February 2017 Monthly Status Update Report documented approximately 2 to 3.5 feet of free product present in groundwater monitoring wells MW-2, MW-12, MW-16, MW-18, and MW-20. Installation of additional recovery wells may be necessary in areas where recovery wells, sumps, or trenches are not present, or are not in close enough proximity to demonstrate connection to the free product, such as the areas where MW-2 and MW-18 are located.*

Response: Plantation believes that the current monitoring network is adequate to evaluate the extent of LNAPL and to monitor future changes in LNAPL distribution and thickness in response to sparging. As discussed on several occasions, Plantation is committed to using the biosparging system as a much more effective alternative to abate LNAPL site-wide than the use of recovery wells, which address only very small areas of the site. Preliminary results indicate the removal of nearly a foot of LNAPL in some areas after two months of system operation (compared to two years of vacuum recovery efforts). For example, the hydrographs below illustrate that LNAPL thickness has declined to 0.01 foot or less in recovery wells RW-08 (located in the vertical sparging curtain of the Brown's Creek Protection Zone) and RW-11 (located in the vertical sparging curtain of the Cupboard Creek Protection Zone) since starting the sparging system:





Comment 14: *Further Assessment. Based upon discussions during the April 7, 2017 meeting, DHEC understands that additional wells will be proposed to determine the extent of contamination.*

> **Response:** In a letter mailed to SCDHEC on May 8, 2017, four additional residuum monitoring wells and four additional bedrock monitoring wells were proposed to be installed to further determine the extent of hydrocarbons.

Comment 15: *Routine Sampling On Cupboard Creek. In that surface water samples have not been collected from SW-05 and SW-06 since February and March of 2016, additional locations that are more likely to contain water should be proposed in Cupboard Creek.*

> **Response:** In the letter mailed to SCDHEC on May 8, 2017, an additional surface water monitoring location (denoted SW-14) was proposed for Cupboard Creek downgradient of SW-05.

Comment 16: *Dissolved Plume Monitoring. Groundwater monitoring wells MW-33 and MW-33T should be added to the routine monitoring network.*

> **Response:** Monitoring wells MW-33 and MW-33T are located downgradient of wells MW-08, MW-10, and MW-32. These three wells are included in the proposed quarterly groundwater monitoring network, and hydrocarbon concentrations in each well are below the groundwater screening criteria. Therefore, adding MW-33 and MW-33T to the monitoring network is unnecessary at this time.

Comment 17: *Dissolved Plume Monitoring. A single map that highlights all wells that are proposed for quarterly sampling differentiated by the geology bracketed by screened intervals (shallow aquifer, transition zone, and the bedrock aquifer) in different colors would be helpful to visualize each interval that will be monitored. A scaled map should be provided one week prior to the next meeting so that the site wide sampling strategy can be discussed.*

> **Response:** Figure 1 of the CAPA already presents this information. Bedrock monitoring wells are distinguished from residuum monitoring wells by their shape (square and round symbols, respectively). Colors are used to identify the monitoring frequency. There is only one transition zone well at the site since the thickness of the transition zone observed at the site from a large number of bedrock wells is too thin to effectively monitor.

Comment 18: *Monthly Monitoring Reports. In the future, please provide updated free product isopach maps and iso-concentration maps when new data is collected.*

> **Response:** The last monthly monitoring report was submitted on April 28, 2017, for the month of March 2017. Isoconcentration maps and free product contours will be provided with the quarterly data transmittals going forward where data allow isopachs to be drawn. As LNAPL is removed from the site it may not be appropriate to draw such maps.

Comment 19: *Monthly Monitoring Reports. In the future, field data sheets should always be provided with data.*

> **Response:** Field data sheets will be included with quarterly data transmittals.

If you have any further questions or concerns, please call me at (919) 760-1777, Mr. Scott Powell/CH2M at (678) 530-4457, or Mr. Jerry Aycock/Plantation at (770) 751-4165.

Regards,
CH2M HILL Engineers, Inc.

William M. Waldron, P.E.
Senior Project Manager

Attachments:

Attachment 1 – Light Non-Aqueous Phase Liquid Mobility Testing Evaluation, Lewis Drive Site, Belton, South Carolina

cc: Jerry Aycock, Plantation (Digital, Jerry_Aycock@kindermorgan.com)
Mary Clair Lyons, Esq., Plantation (Digital, Mary_Lyons@kindermorgan.com)
Richard Morton, Esq., Womble Carlyle Sandridge & Rice, PLLC (Digital, rmorton@wcsr.com)

File

Attachment 1
Light Non-Aqueous Phase Liquid Mobility Testing Evaluation, Lewis Drive Site, Belton, South Carolina

TECHNICAL MEMORANDUM

Light Non-Aqueous Phase Liquid Mobility Testing, Lewis Drive Site, Belton, South Carolina

PREPARED FOR:	Mr. Bobbi Coleman, South Carolina Department of Health and Environmental Control
COPY TO:	Jerry Aycock, Plantation (Digital, Jerry_Aycock@kindermorgan.com) Mary Clair Lyons, Esq., Plantation (Digital, Mary_Lyons@kindermorgan.com) Richard Morton, Esq., Womble Carlyle Sandridge & Rice, PLLC (Digital, rmorton@wcsr.com)
PREPARED BY:	CH2M HILL Engineers, Inc. (CH2M)
DATE:	May 25, 2017
PROJECT NUMBER:	684910

On behalf of Plantation Pipeline Company (Plantation), CH2M HILL Engineers, Inc. (CH2M) completed light non-aqueous phase liquid (LNAPL) mobility testing at select recovery wells at the Lewis Drive Site (site) in Belton, Anderson County, South Carolina (Site ID # 18693). A map of existing site features is included as **Figure 1**. LNAPL mobility test locations are shown on **Figure 2**. Mobility testing was performed to quantify LNAPL transmissivity and evaluate the most effective method of LNAPL recovery.

Light Non-Aqueous Phase Liquid Mobility Tests

LNAPL mobility tests were completed at drilled recovery wells RW-04, RW-05, RW-07, RW-10, RW-11, and RW-13, all of which are screened in the residuum aquifer and typically have sufficient LNAPL thicknesses to perform LNAPL mobility testing. These locations are highlighted on **Figure 2**. The mobility tests were completed by CH2M between April 18 and April 21, 2017, with follow-up gauging continuing periodically until May 3, 2017. Recovery wells RW-02, RW-06, RW-08, RW-12, and RW-14 were also planned for mobility testing, but did not have sufficient LNAPL thickness to perform accurate mobility tests. LNAPL was removed from RW-09; however, the air sparging system interfered with the test and recovery data were biased and considered to not be representative of the formation recovery.

LNAPL mobility (baildown) tests were completed in general accordance with ASTM International (ASTM) *E2856-13: Standard Guide for Estimation of LNAPL Transmissivity* (ASTM 2013). Routine LNAPL recovery was suspended in the two weeks prior to testing to provide the greatest levels of LNAPL to allow for a good test. In general, the baildown tests involved gauging the depth to product and depth to water in each well using an electronic oil-water interface probe, and then removing the LNAPL present using a peristaltic pump (at RW-04, RW-05, and RW-07) or bailer (at RW-10, RW-11, and RW-13). Following the removal of LNAPL, the wells were gauged as the LNAPL recovered. Relevant findings from the LNAPL mobility tests are summarized in **Table 1** below.

Table 1. LNAPL Baildown Test Data Summary
Lewis Drive Remediation Site, Belton, South Carolina

Well	Pre-Test Thickness (ft)	Thickness after removing LNAPL (ft)	LNAPL Removed (gal)	LNAPL Removed (% of borehole volume)	Recovery Time (days)	Thickness (ft)	Percent Recovered
RW-04*	1.10	0.37	1.45	100%	3	1.03	94%
					9	1.10	100%
RW-05*	0.53	0.16	0.4	60%	2	0.31	58%
					9	0.39	73%
RW-07	1.63	0.43	4	> 100%	0.31	1.38	85%
RW-10	3.25	0.05	5.6	> 100%	2	3.03	93%
RW-11	0.55	0.04	0.55	80%	1	0.49	89%
RW-13*	1.81	0.07	1.75	75%	0.16	0.37	20%
					12	0.89	49%

Note:
">" = greater than
* Thickness and percent recovered data are presented for two subsequent time points at recovery wells RW-04, RW-05, and RW-13 due to the longer time required for LNAPL to recover at these locations.

The recovery data were also analyzed using the American Petroleum Institute LNAPL transmissivity spreadsheet to provide fitted LNAPL transmissivity values. The analysis workbooks are provided in **Attachment 1**. The resultant transmissivities from the tests are summarized in **Table 2**.

In some wells, the in-well LNAPL thickness was not reduced completely (that is, to zero thickness) during the removal portion of the test. Therefore, some of the recovery gauging data may represent recharge of LNAPL from the filter pack around the well screen, and not necessarily recharge from the formation, resulting in LNAPL transmissivity estimates that may be biased slightly high.

Table 2. 2017 LNAPL Mobility Test Results
Lewis Drive Remediation Site, Belton, South Carolina

		LNAPL Transmissivity (ft^2/day)			
Well	Date	Bouwer and Rice[a]	Cooper and Jacob[b]	Cooper et al.[c]	Average
RW-04	4/18/2017	0.10	0.30	0.33	0.24
RW-05	4/19/2017	0.01	0.20	0.10	0.10
RW-07	4/21/2017	0.32	0.60	0.70	0.54
RW-10	4/19/2017	0.18	0.25	0.30	0.24
RW-11	4/20/2017	0.08	0.30	0.20	0.19
RW-13	4/21/2017	0.04	0.09	0.08	0.07

Notes:
ft^2/day = square feet per day
[a] Bouwer and Rice, 1976
[b] Cooper and Jacob, 1946
[c] Cooper et al., 1967

Based on published literature, fluid recovery is considered impractical in wells with low transmissivities, ranging from 0.1 to 0.8 ft^2/day (ITRC, 2009). The results in Table 1 indicate that the average transmissivity at each well location is within or below this threshold of impracticality. Further recovery will produce diminishing recovery volumes, and the intervals between removal events and wells reaching equilibrium thickness will continue to increase overtime.

Recovery Frequency Recommendations

Each recovery well containing LNAPL is capable of storing LNAPL between recovery events. After LNAPL is removed from each recovery well, it takes a fixed amount of time (return time) for the well to fill back up, if sufficient LNAPL is available. Removing LNAPL from wells more frequently than the return time does not significantly increase the LNAPL recovery volume over time.

Recovery wells will continue to be monitored for changes in LNAPL thickness during routine weekly gauging and monthly sampling events. If significant changes in LNAPL thickness are observed, especially as the air sparge system continues to operate, additional baildown testing may be performed at these wells as needed.

The results of the transmissivity testing indicate continued recovery will not significantly remove additional LNAPL at the site. Given the concerns at the site, we recommend focusing ongoing recovery efforts to the following:

- Perform gauging of recovery sumps, recovery trenches, and recovery wells ("RS", "RT", and "RW" features) every two weeks.
- Gauge all groundwater features site-wide on a monthly basis.
- Perform vacuum recovery every two weeks on wells with higher transmissivity (RW-4, RW-7, and RW-10), on productive recovery sumps (RS-01, RS-05, RS-08, RS-09, RS-10, RS-11, RS-12, and RS-18) and at the recovery trench protecting Brown's Creek (RT-1).

Based on the results from proposed recovery work, adjustments to the recovery focus and frequency will be provided as necessary and will be documented in quarterly reports.

Plantation is committed to using the biosparging system as a much more effective alternative to abate LNAPL site-wide than the use of recovery wells, which address only very small areas of the site. An interim goal for the project is to transition from free-phase LNAPL recovery to *in situ* destruction of LNAPL by the end of September 2017 (approximately 6 months after starting the sparging system).

References

ASTM International. 2013. ASTM E2856-13 Standard Guide for Estimation of LNAPL Transmissivity.

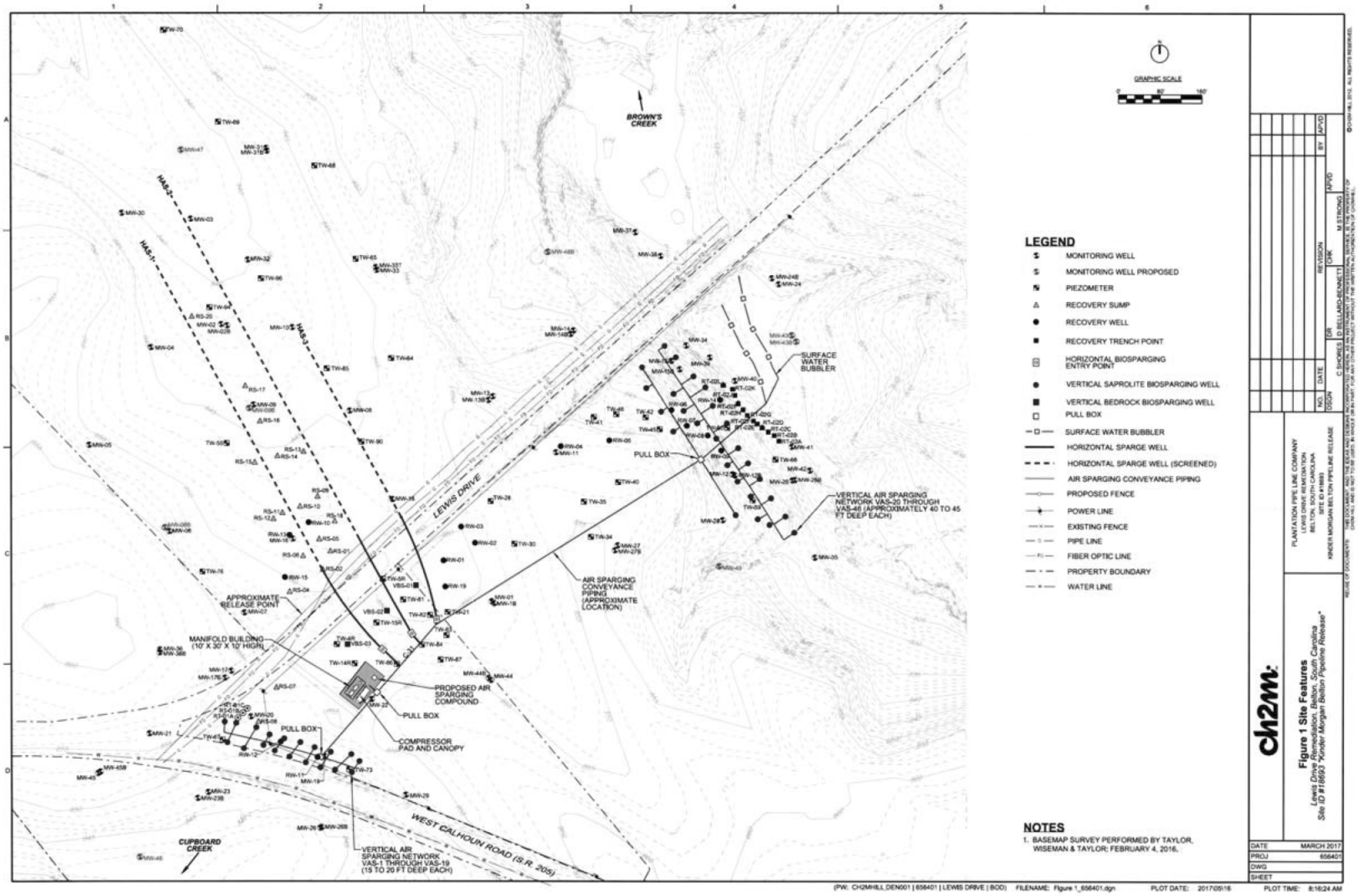
Bouwer, Herman and R.C. Rice. 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells." *Water Resources Research*. Vol. 12(3). pp. 423-428.

Cooper Jr., Hilton H., John G. Bredehoeft, and Istavros R. Papadopulos. 1967. "Response of a Finite-Diameter Well to an Instantaneous Charge of Water." *Water Resources Research*. Vol. 3(1). pp. 263-269.

Cooper, H.H. and C.E. Jacob. 1946. "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History." *American Geophysical Union Transactions*. Vol. 27. pp. 526-534.

Interstate Technology & Regulatory Council (ITRC). 2009. *Evaluating LNAPL Remedial Technologies for Achieving Project Goals*. LNAPL-2. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

Figures


BROWN'S CREEK
LEWIS DRIVE
WEST CALHOUN ROAD (S.R. 205)
CUPBOARD CREEK
HAS-1
HAS-2
HAS-3
GRAPHIC SCALE
APPROXIMATE RELEASE POINT
MANIFOLD BUILDING (10' X 30' X 10' HIGH)
PROPOSED AIR SPARGING COMPOUND
PULL BOX
COMPRESSOR PAD AND CANOPY
AIR SPARGING CONVEYANCE PIPING (APPROXIMATE LOCATION)
SURFACE WATER BUBBLER
VERTICAL AIR SPARGING NETWORK VAS-20 THROUGH VAS-46 (APPROXIMATELY 40 TO 45 FT DEEP EACH)
VERTICAL AIR SPARGING NETWORK VAS-1 THROUGH VAS-19 (15 TO 20 FT DEEP EACH)
LEGEND
MONITORING WELL
MONITORING WELL PROPOSED
PIEZOMETER
RECOVERY SUMP
RECOVERY WELL
RECOVERY TRENCH POINT
HORIZONTAL BIOSPARGING ENTRY POINT
VERTICAL SAPROLITE BIOSPARGING WELL
VERTICAL BEDROCK BIOSPARGING WELL
PULL BOX
SURFACE WATER BUBBLER
HORIZONTAL SPARGE WELL
HORIZONTAL SPARGE WELL (SCREENED)
AIR SPARGING CONVEYANCE PIPING
PROPOSED FENCE
POWER LINE
EXISTING FENCE
PIPE LINE
FIBER OPTIC LINE
PROPERTY BOUNDARY
WATER LINE
NOTES
1. BASEMAP SURVEY PERFORMED BY TAYLOR, WISEMAN & TAYLOR; FEBRUARY 4, 2016.
PLANTATION PIPE LINE COMPANY
LEWIS DRIVE REMEDIATION
BELTON, SOUTH CAROLINA
KINDER MORGAN BELTON PIPELINE RELEASE
ch2m
Figure 1 Site Features
Lewis Drive Remediation, Belton, South Carolina
Site ID #18693 "Kinder Morgan Belton Pipeline Release"
DATE MARCH 2017
PROJ 656401
DWG
SHEET
DSGN C SHORES
DR D BELLARD-BENNETT
CHK M STRONG
FILENAME: Figure 1_656401.dgn
PLOT DATE: 2017/05/16
PLOT TIME: 8:16:24 AM

VICINITY MAP

LEGEND

- ☆ Release Point
- Proposed Shallow Monitoring Well (not yet surveyed)
- Proposed Bedrock Monitoring Well (not yet surveyed)
- Residuum Monitoring Well
- Bedrock Monitoring Well
- ● Piezometer ("R" indicates Replacement)
- Recovery Sump
- Recovery Trench Point
- Recovery Well (4" diameter)
- Surface Water Sampling Location
- Recovery Wells with Drawdown Test Completed
- Pipeline
- Recovery Trench
- Stream (NHD)
- Horizontal Air Sparging Well Riser (not yet surveyed)
- Horizontal Air Sparging Well Screen (not yet surveyed)

Source Data:
Environmental Systems Research Institute (ESRI)
World Imagery Layer, 2015
United States Geological Survey (USGS) National Hydrography Dataset (NHD)

0 175 350
Scale in feet

Figure 2. Drawdown Tested Recovery Wells
Lewis Drive Release, Belton, South Carolina
Site ID #18693 "Kinder Morgan Belton Pipeline Release"

ch2m

Attachment 1
Analysis Workbooks

Generalized Bouwer and Rice (1976)

Well Designation:	RW-04
Date:	18-Apr-17

$$T_n = \frac{r_e^2 \ln(R/r_e)\ln(s_n(t_1)/s_n(t))}{2(-J)(t-t_1)}$$

Enter early time cut-off for least-squares model fit

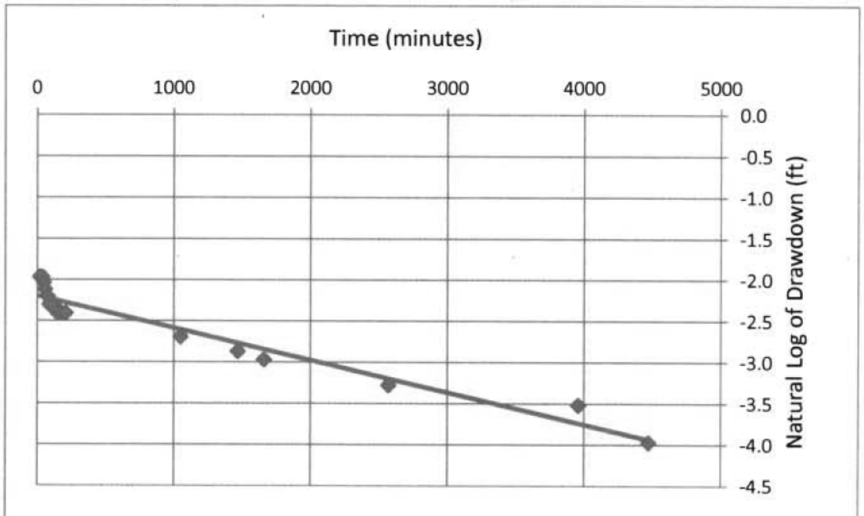
$Time_{cut}$	30	<- Enter or change value here

Model Results: T_n (ft²/d) = 0.10 +/- 0.01 ft²/d

L_e/r_e
4.6
C
0.98
R/r_e
2.93

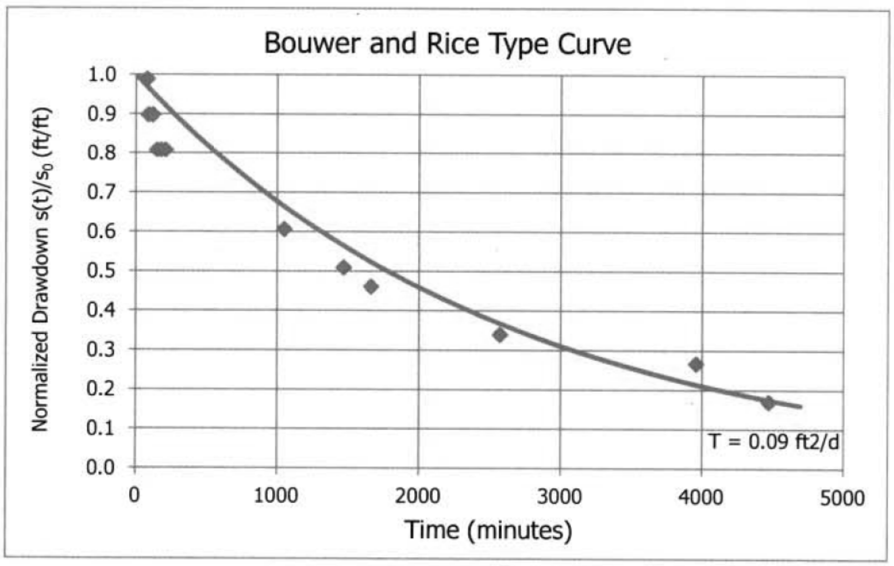
J-Ratio
-0.174

Coef. Of Variation
0.07



Bouwer and Rice Model

C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	RW-04
Date:	18-Apr-17

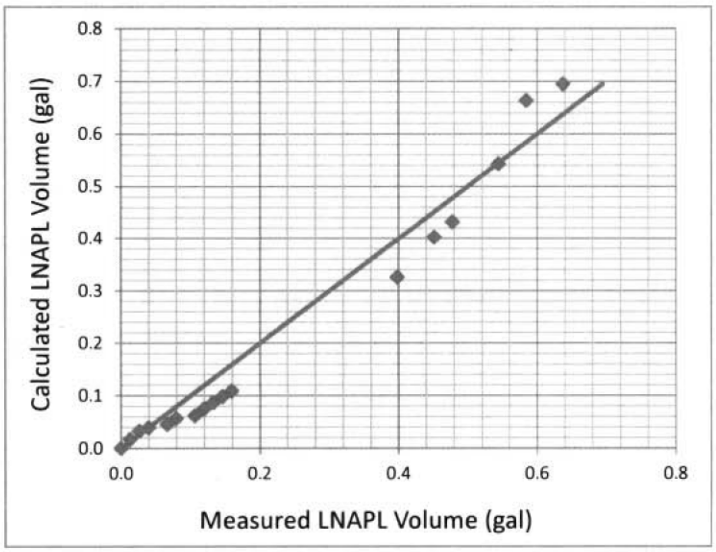
$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

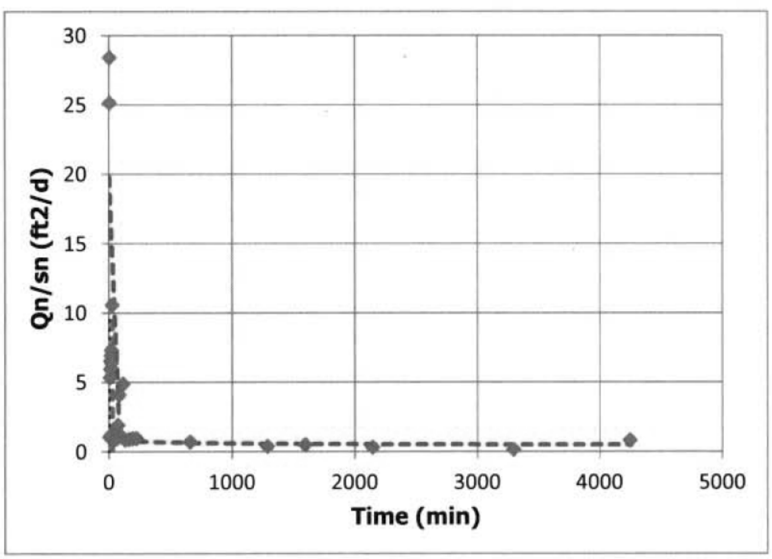
Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	30	<- Enter or change values here
Time Adjustment (min):	1	
Trial S_n:	d	<-- Enter d for default or enter S_n value
Root-Mean-Square Error:	0.176	<-- Minimize this using "Solver"
	0.014	<-- Working S_n
Trial T_n (ft^2/d):	0.300	<-- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result: T_n (ft^2/d) = **0.30**





Height

10

Cooper, Bredehoeft and Papadopulos (1967)

Well Designation:	RW-04
Date:	18-Apr-17

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	30	<- Enter or change values here
Initial Drawdown s_n (ft):	0.15	

Trial S_n: d <-- Enter d for default

Root-Mean-Square Error: 0.552 <-- Minimize this using "Solver"

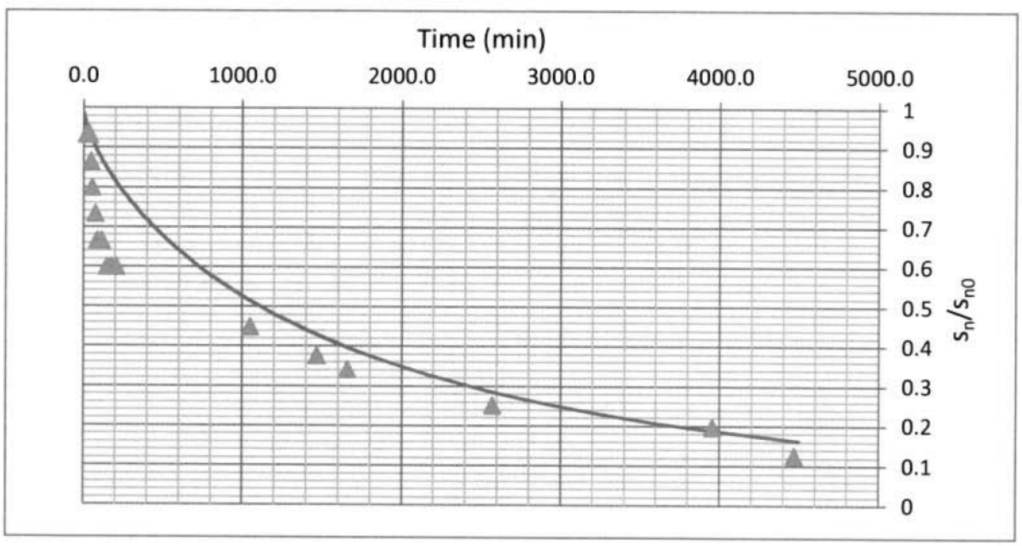
Trial T_n (ft^2/d): 0.330 <-- By changing T_n through "Solver"

0.014 <-- Working S_n

Add constraint Tn > 0.00001

Model Result: T_n (ft^2/d) = **0.33**

T_{min}	3
T_{max}	4500



J-Ratio
-0.174

Generalized Bouwer and Rice (1976)

Well Designation:	RW-05
Date:	19-Apr-17

$$T_n = \frac{r_e^{\ 2} \ln(R/r_e)\ln(s_n(t_1)/s_n(t))}{2(-J)(t-t_1)}$$

Enter early time cut-off for least-squares model fit

$Time_{cut}$	45

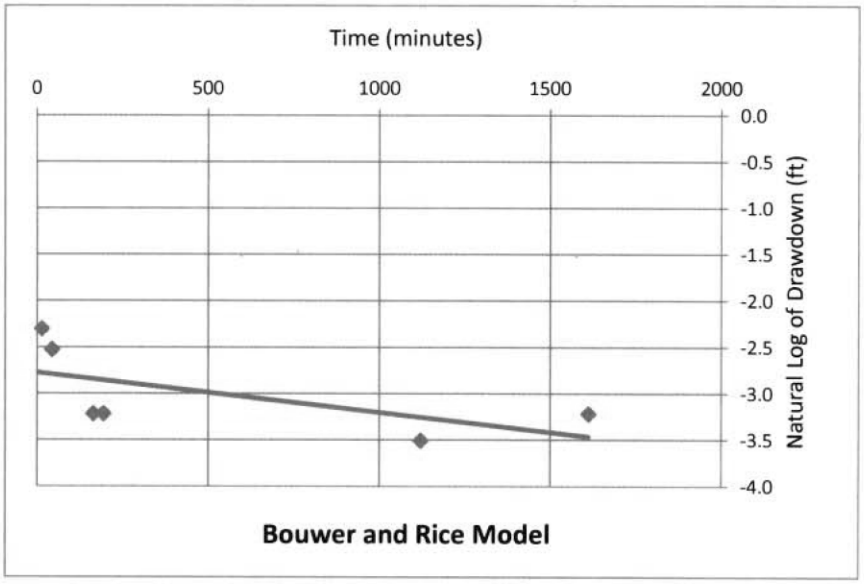
<- Enter or change value here

Model Results: T_n (ft^2/d) = 0.01 +/- 0.01 ft^2/d

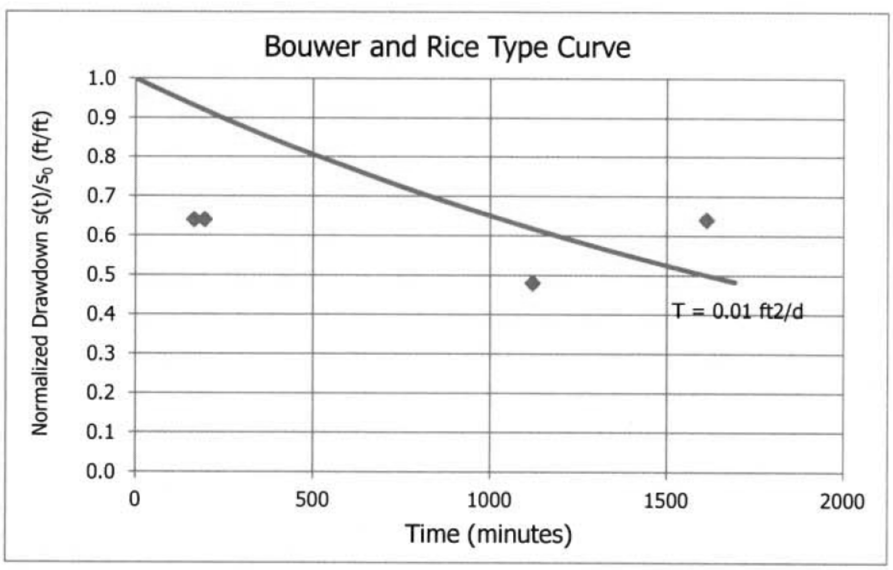
L_e/r_e 2.2
C 0.88
R/r_e 1.76

J-Ratio -0.857

Coef. Of Variation 0.65



C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	RW-05
Date:	19-Apr-17

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^{\,2} S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	45	<- Enter or change values here
Time Adjustment (min):	10	

Trial S_n: 0.008 <-- Enter d for default or enter S_n value

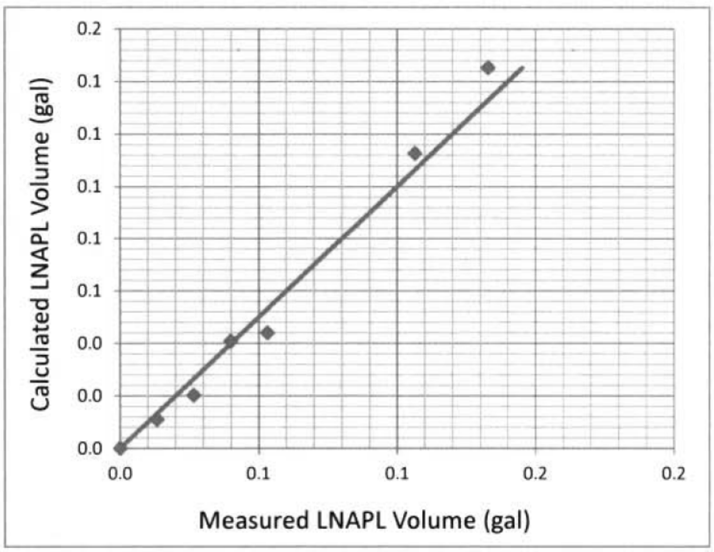
Root-Mean-Square Error: 0.018 <-- Minimize this using "Solver"

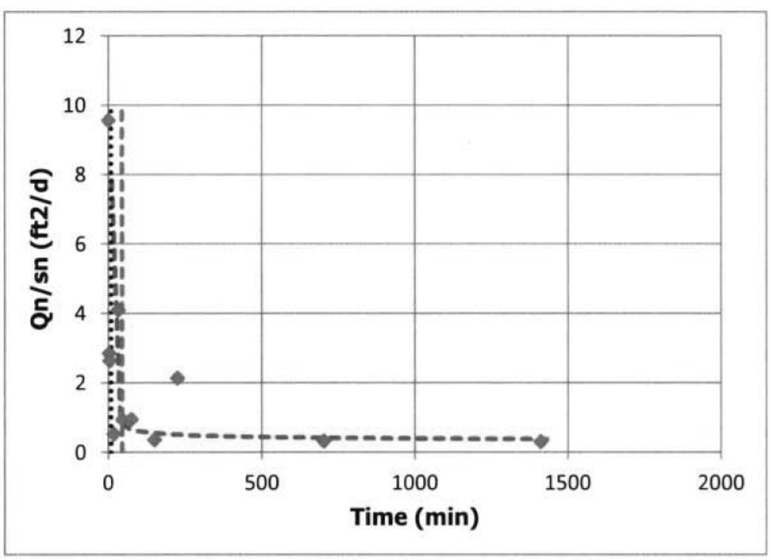
0.008 <-- Working S_n

Trial T_n (ft^2/d): 0.200 <-- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result: T_n (ft^2/d) = **0.20**





Height

10

Cooper, Bredehoeft and Papadopulos (1967)

Well Designation:	RW-05
Date:	19-Apr-17

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	45	<- Enter or change values here
Initial Drawdown s_n (ft):	0.1	

Trial S_n: d <-- Enter d for default

Root-Mean-Square Error: 0.606 <-- Minimize this using "Solver"

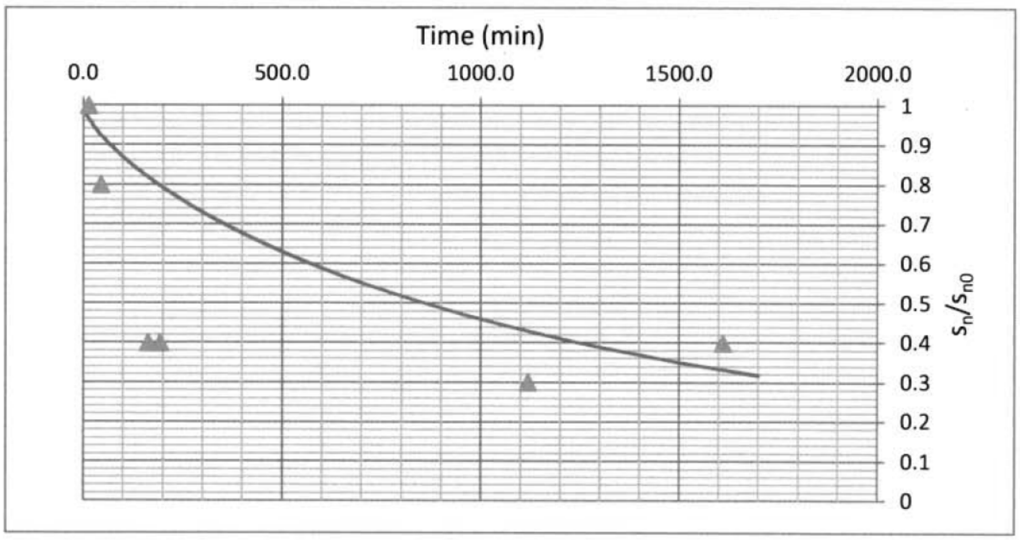
Trial T_n (ft^2/d): 0.100 <-- By changing T_n through "Solver"

0.008 <-- Working S_n

Add constraint Tn > 0.00001

Model Result: T_n (ft^2/d) = **0.10**

T_{min}	3
T_{max}	1700



J-Ratio
-0.857

Generalized Bouwer and Rice (1976)

Well Designation:	RW-7
Date:	21-Apr-17

$$T_n = \frac{r_e^{\ 2} \ln(R/r_e)\ln(s_n(t_1)/s_n(t))}{2(-J)(t-t_1)}$$

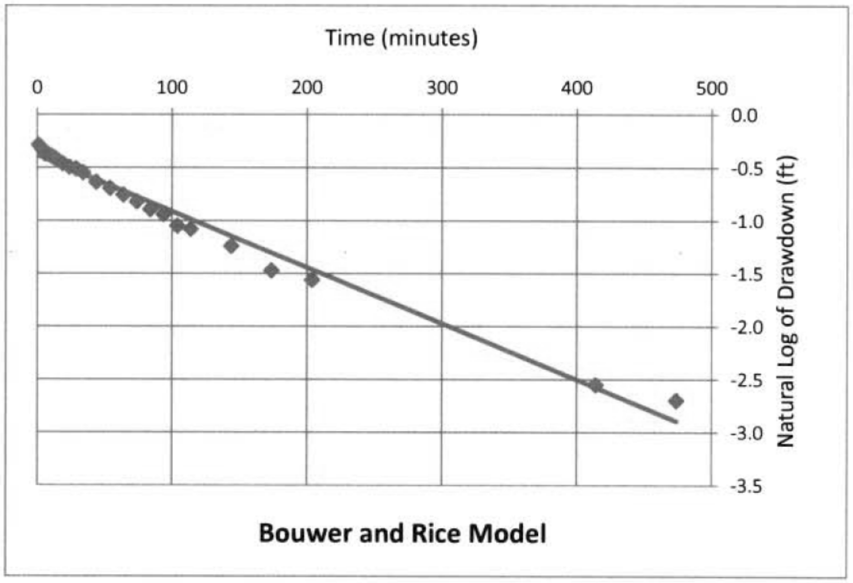
Enter early time cut-off for least-squares model fit

$Time_{cut}$	6

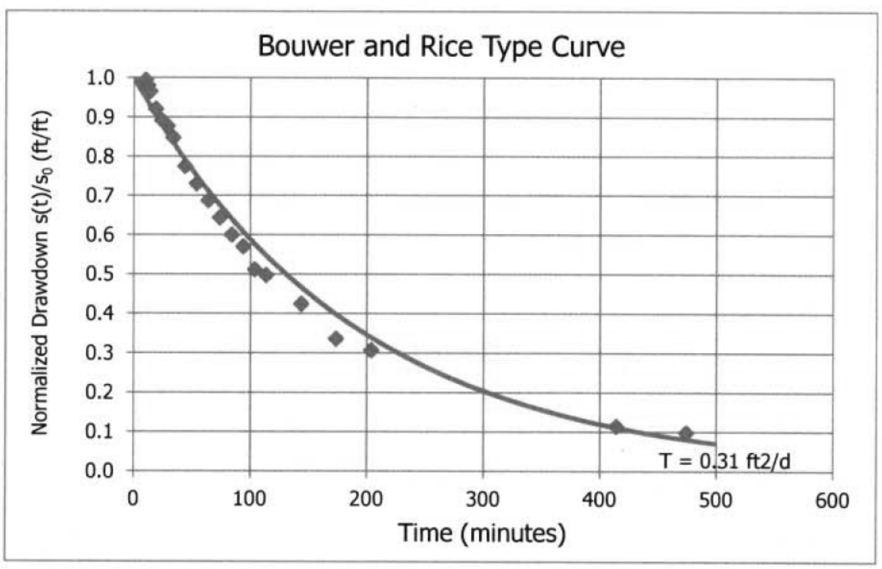
<- Enter or change value here

Model Results: T_n (ft^2/d) = 0.32 +/- 0.01 ft^2/d

L_e/r_e	6.9
C	1.07
R/r_e	3.96
J-Ratio	-0.933
Coef. Of Variation	0.03



C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	RW-7
Date:	21-Apr-17

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

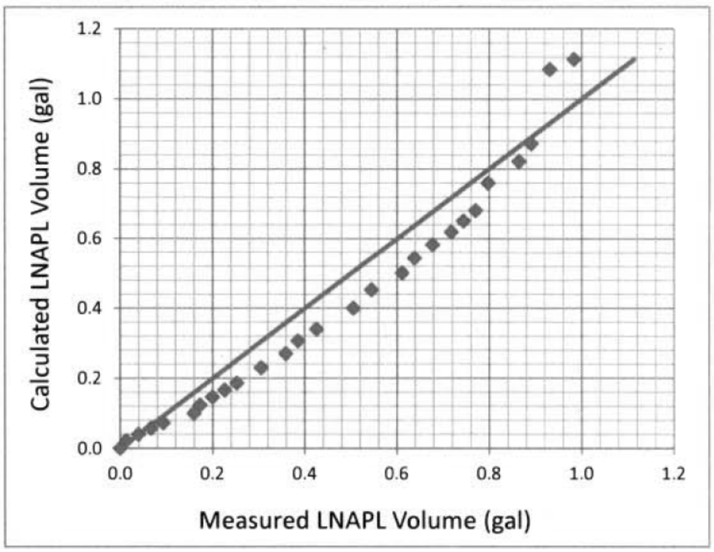
Enter early time cut-off for least-squares model fit

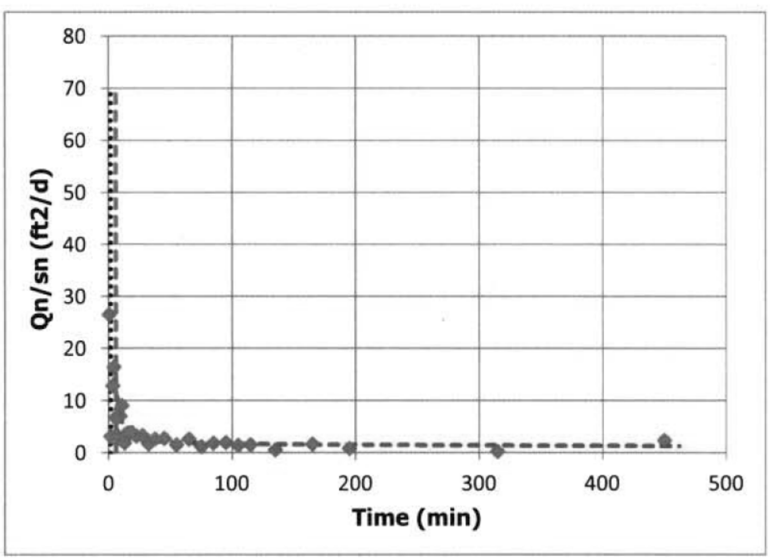
$Time_{cut}$ (min):	6	<- Enter or change values here
Time Adjustment (min):	2	

Trial S_n:	d	<-- Enter d for default or enter S_n value
Root-Mean-Square Error:	0.405	<-- Minimize this using "Solver"
	0.019	<-- Working S_n
Trial T_n (ft^2/d):	0.600	<-- By changing T_n through "Solver"

Add constraint $T_n > 0.00001$

Model Result: T_n (ft^2/d) = **0.60**





Height

70

Cooper, Bredehoeft and Papadopulos (1967)

Well Designation:	RW-7
Date:	21-Apr-17

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	6	<- Enter or change values here
Initial Drawdown s_n (ft):	0.76	

Trial S_n: d <-- Enter d for default

Root-Mean-Square Error: 0.179 <-- Minimize this using "Solver"

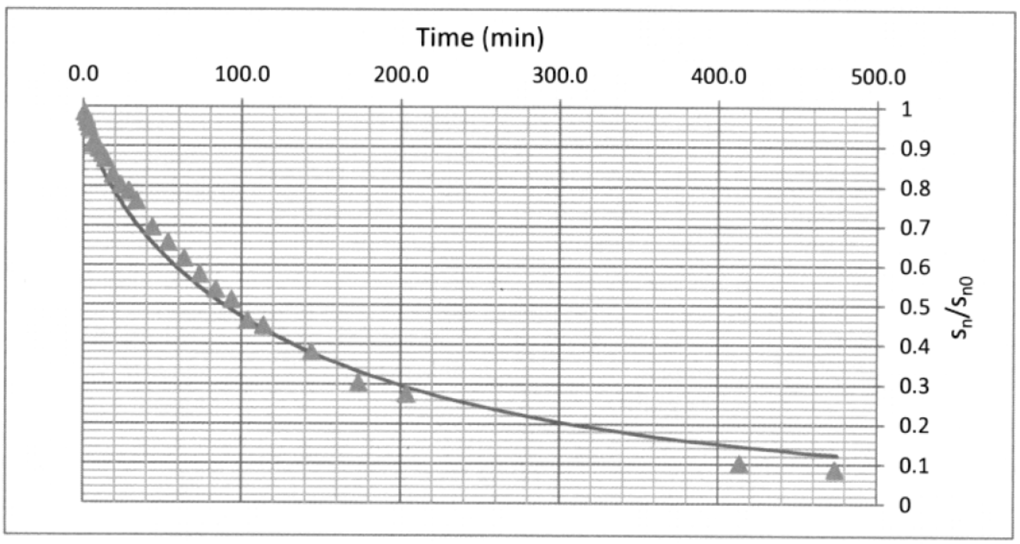
Trial T_n (ft^2/d): 0.700 <-- By changing T_n through "Solver"

0.021 <-- Working S_n

Add constraint Tn > 0.00001

Model Result: T_n (ft^2/d) = **0.70**

T_{min}	6
T_{max}	475



J-Ratio
-0.933

Generalized Bouwer and Rice (1976)

Well Designation:	RW-10
Date:	19-Apr-17

$$T_n = \frac{r_e^{\,2}\ln(R/r_e)\ln(s_n(t_1)/s_n(t))}{2(-J)(t-t_1)}$$

L_e/r_e
13.7
C
1.34
R/r_e
6.88

J-Ratio
-0.326

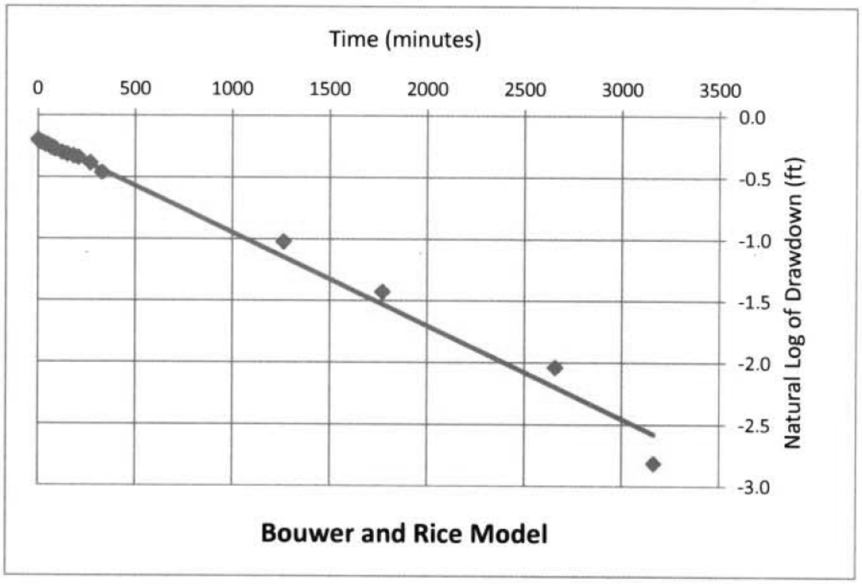
Coef. Of Variation
0.02

Enter early time cut-off for least-squares model fit

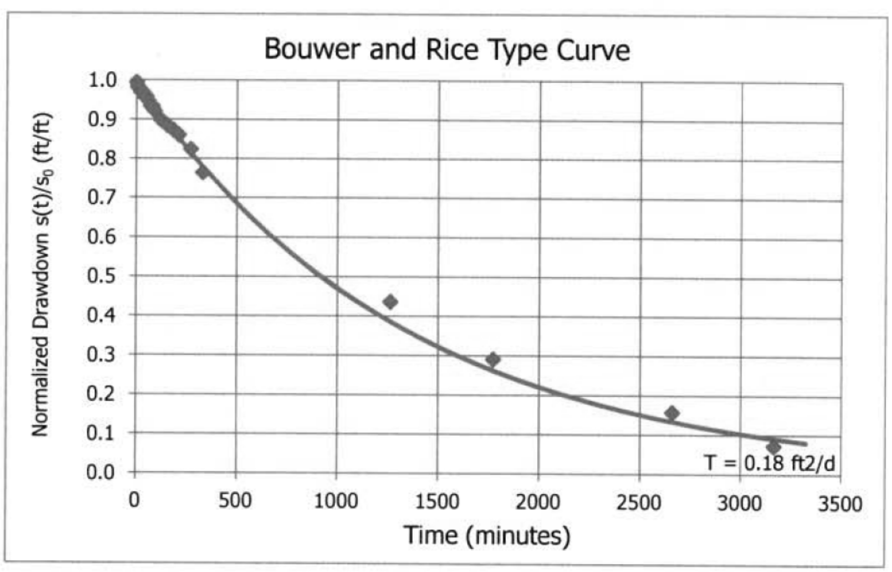
$Time_{cut}$	30

<- Enter or change value here

Model Results: T_n (ft^2/d) = 0.18 +/- 0.00 ft^2/d



C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	RW-10
Date:	19-Apr-17

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25\,T_n t_j}{r_e^{\,2} S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

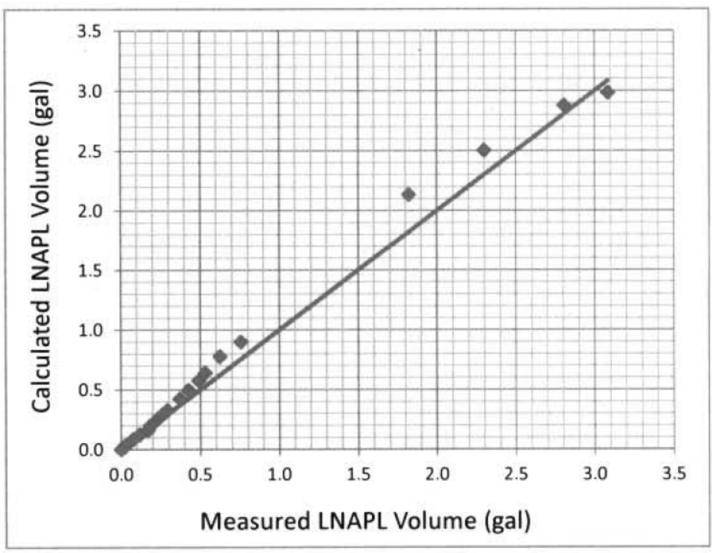
$Time_{cut}$ (min):	30	<- Enter or change values here
Time Adjustment (min):	3	

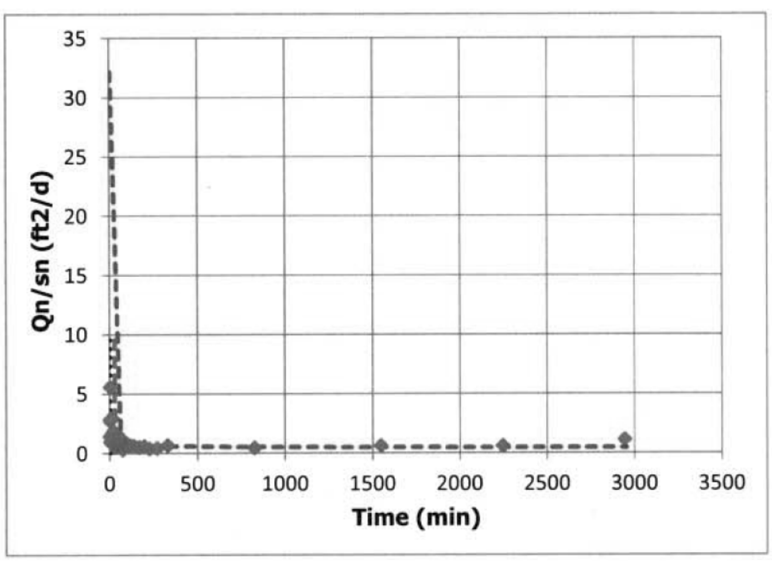
Trial S_n: d <-- Enter d for default or enter S_n value

Root-Mean-Square Error:	0.477	<-- Minimize this using "Solver"
	0.013	<-- Working S_n
Trial T_n (ft^2/d):	0.250	<-- By changing T_n through "Solver"

Add constraint $T_n > 0.00001$

Model Result: T_n (ft^2/d) = **0.25**





Height

10

Cooper, Bredehoeft and Papadopulos (1967)

Well Designation:	RW-10
Date:	19-Apr-17

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	30	<- Enter or change values here
Initial Drawdown s_n (ft):	0.82	

Trial S_n: d <-- Enter d for default

Root-Mean-Square Error: 0.361 <-- Minimize this using "Solver"

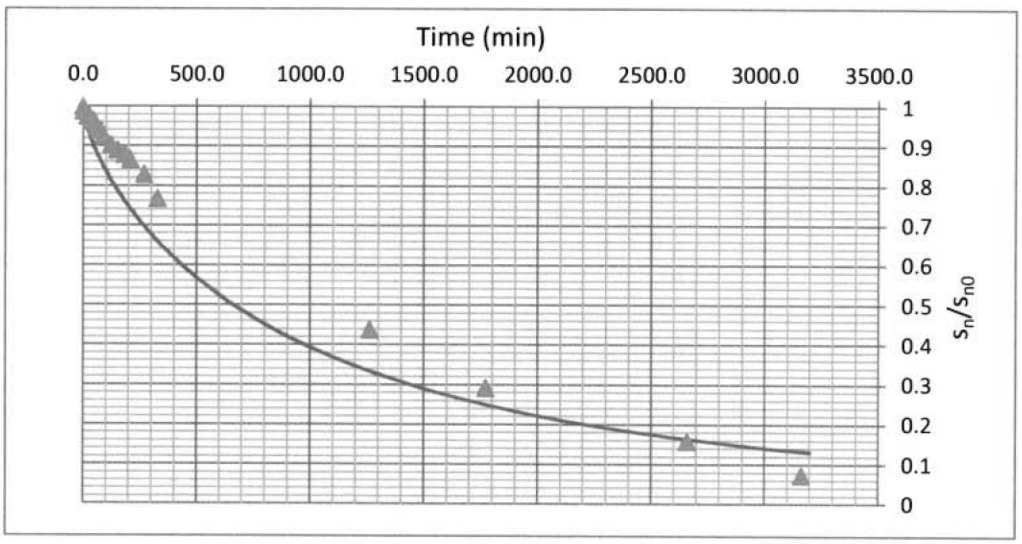
Trial T_n (ft^2/d): 0.300 <-- By changing T_n through "Solver"

0.014 <-- Working S_n

Add constraint Tn > 0.00001

Model Result: T_n (ft^2/d) = **0.30**

T_{min}	8
T_{max}	3200



J-Ratio
-0.326

Generalized Bouwer and Rice (1976)

Well Designation:	RW-11
Date:	20-Apr-17

$$T_n = \frac{r_e^{\,2}\ln(R/r_e)\ln(s_n(t_1)/s_n(t))}{2(-J)(t-t_1)}$$

Enter early time cut-off for least-squares model fit

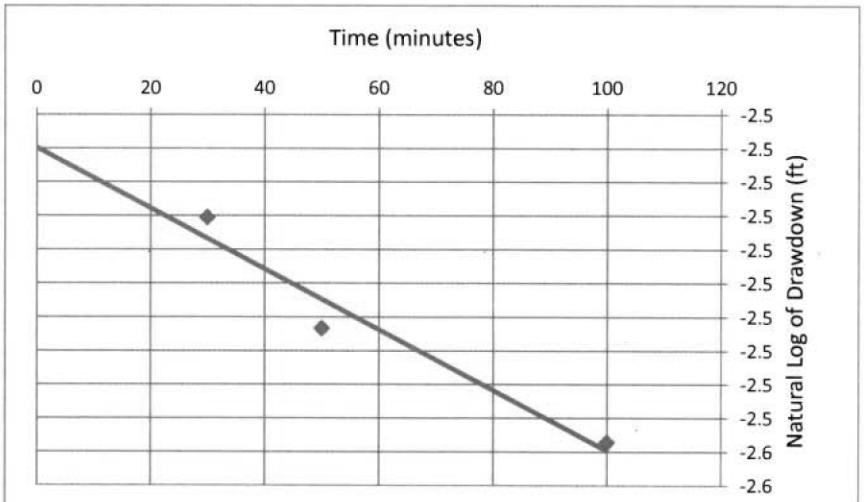
$Time_{cut}$	50	<- Enter or change value here

Model Results: T_n (ft^2/d) = 0.08 +/- 0.02 ft^2/d

L_e/r_e
2.3
C
0.88
R/r_e
1.80

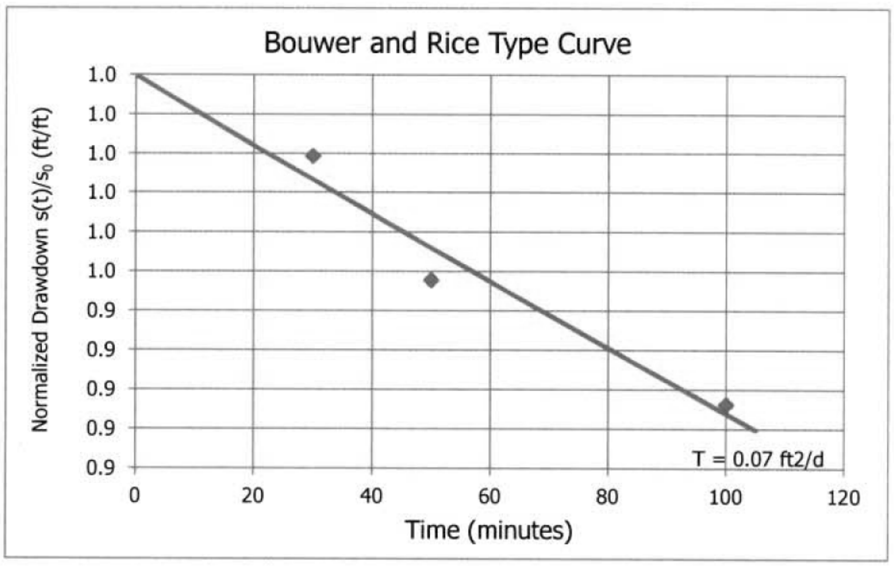
J-Ratio
-0.273

Coef. Of Variation
0.24



Bouwer and Rice Model

C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	RW-11
Date:	20-Apr-17

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	50	<- Enter or change values here
Time Adjustment (min):	10	

Trial S_n: d <-- Enter d for default or enter S_n value

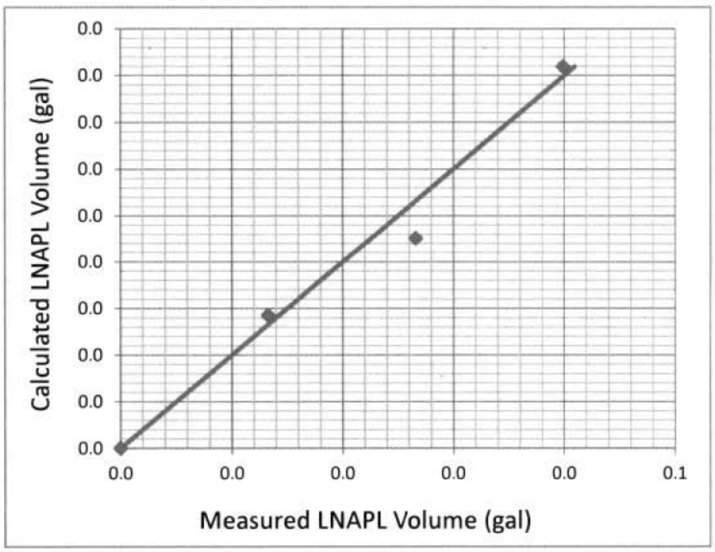
Root-Mean-Square Error: 0.004 <-- Minimize this using "Solver"

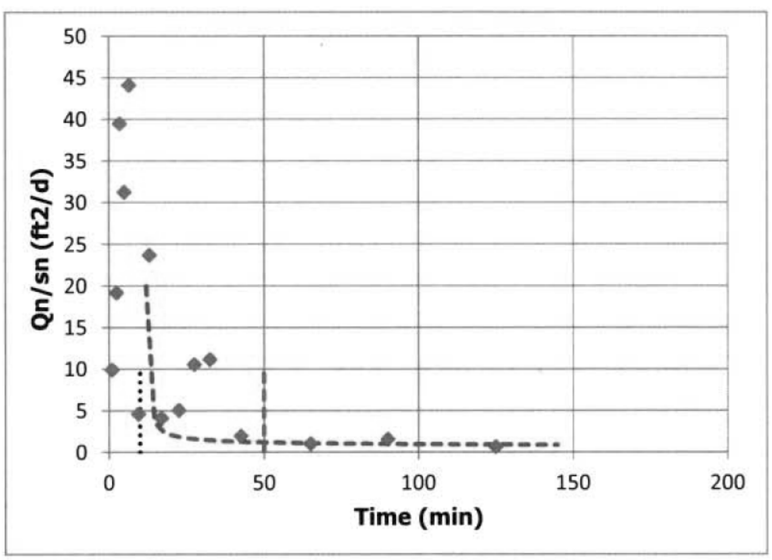
0.014 <-- Working S_n

Trial T_n (ft^2/d): 0.300 <-- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result: T_n (ft^2/d) = **0.30**





Height

10

Cooper, Bredehoeft and Papadopulos (1967)

Well Designation:	RW-11
Date:	20-Apr-17

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	50	<- Enter or change values here
Initial Drawdown s_n (ft):	0.086	

Trial S_n: d <-- Enter d for default

Root-Mean-Square Error: 0.030 <-- Minimize this using "Solver"

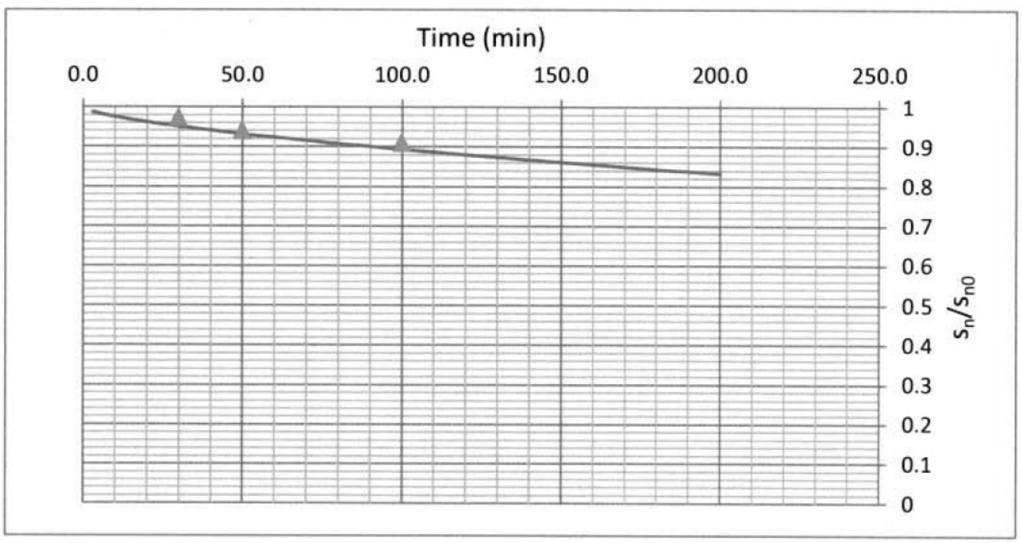
Trial T_n (ft^2/d): 0.200 <-- By changing T_n through "Solver"

0.011 <-- Working S_n

Add constraint Tn > 0.00001

Model Result: T_n (ft^2/d) = **0.20**

T_{min}	3
T_{max}	200



J-Ratio
-0.273

Generalized Bouwer and Rice (1976)

Well Designation:	RW-13
Date:	

$$T_n = \frac{r_e^{\,2}\ln(R/r_e)\ln(s_n(t_1)/s_n(t))}{2(-J)(t-t_1)}$$

Enter early time cut-off for least-squares model fit

$Time_{cut}$	30

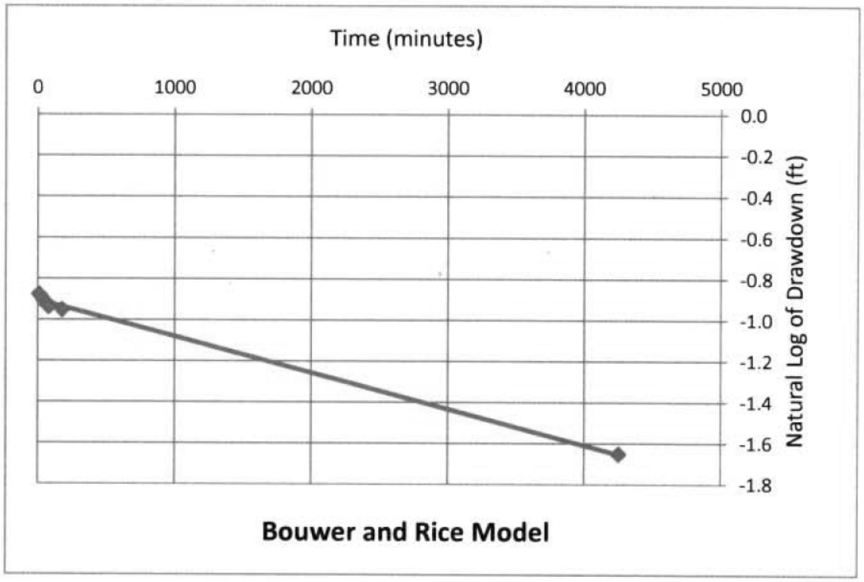
<- Enter or change value here

Model Results: T_n (ft^2/d) = 0.04 +/- 0.00 ft^2/d

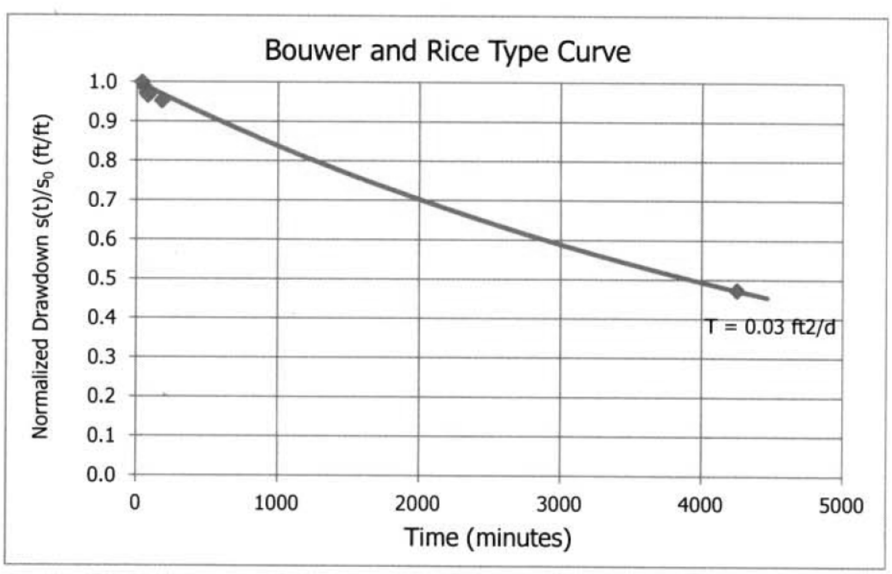
L_e/r_e
7.6
C
1.10
R/r_e
4.30

J-Ratio
-0.272

Coef. Of Variation
0.03



C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	RW-13
Date:	

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	30	<- Enter or change values here
Time Adjustment (min):	10	

Trial S_n: d <-- Enter d for default or enter S_n value

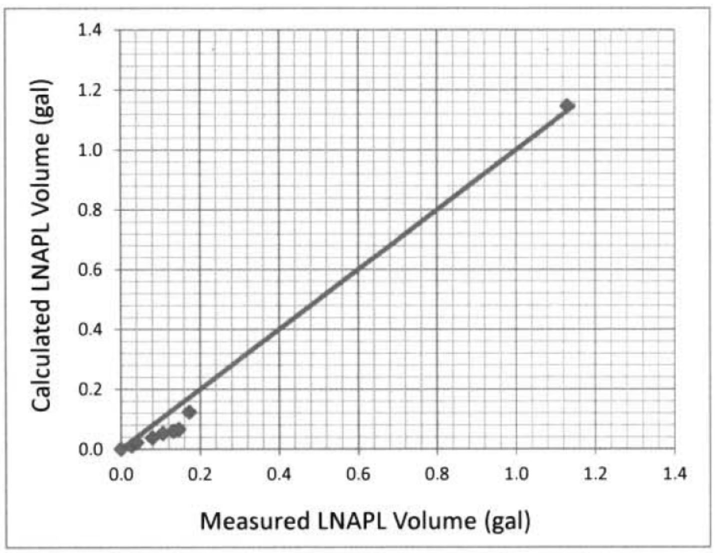
Root-Mean-Square Error: 0.140 <-- Minimize this using "Solver"

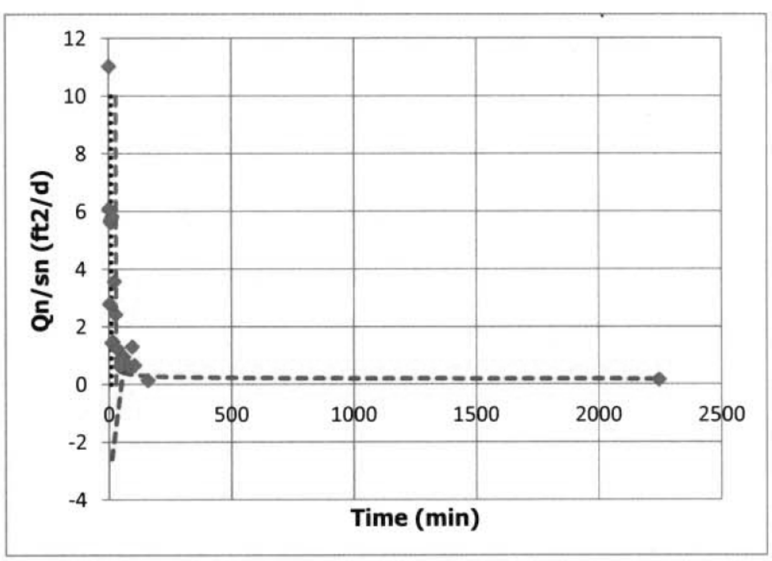
0.007 <-- Working S_n

Trial T_n (ft^2/d): 0.088 <-- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result: T_n (ft^2/d) = **0.09**





Height

10

Cooper, Bredehoeft and Papadopulos (1967)

Well Designation:	RW-13
Date:	

Enter early time cut-off for least-squares model fit

$Time_{cut}$ (min):	30	<- Enter or change values here
Initial Drawdown s_n (ft):	0.42	

Trial S_n: d <-- Enter d for default

Root-Mean-Square Error: 0.037 <-- Minimize this using "Solver"

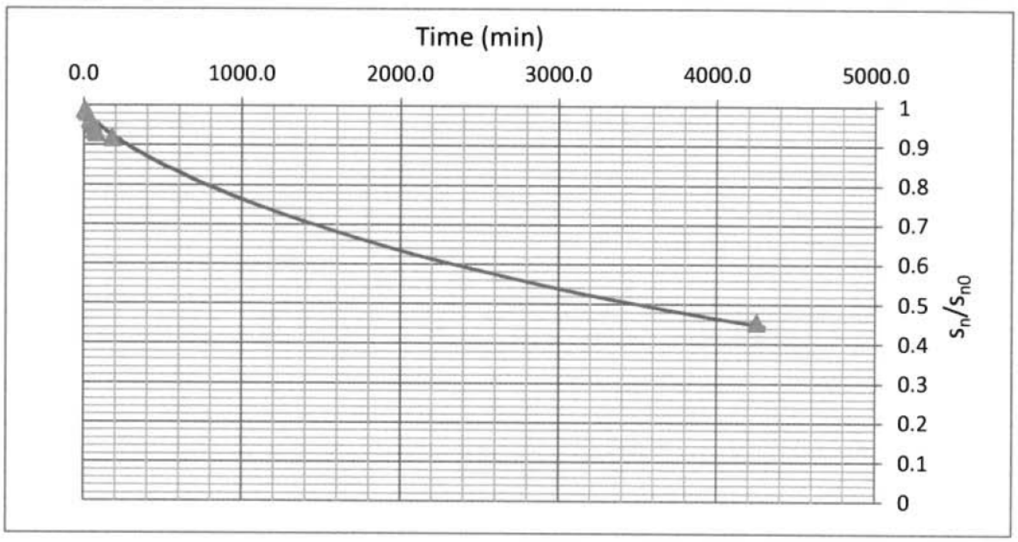
Trial T_n (ft^2/d): 0.079 <-- By changing T_n through "Solver"

0.007 <-- Working S_n

Add constraint Tn > 0.00001

Model Result: T_n (ft^2/d) = **0.08**

T_{min}	3
T_{max}	4300



J-Ratio
-0.272