Drill Stem Test (DST) Data Entry & Quantitative Analysis Applet

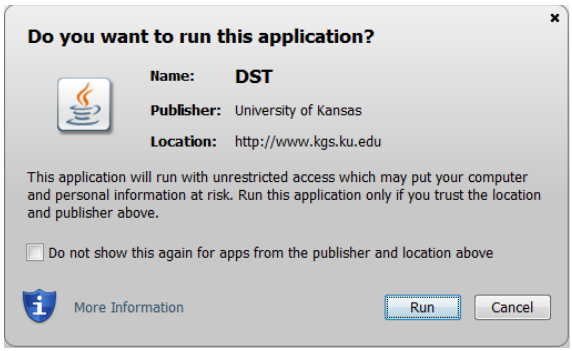
by John R. Victorine

Introduction

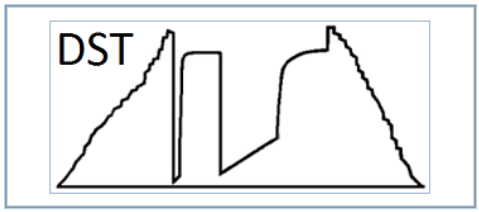
The DST web app has 2 sources for importing well data, 1) the user's PC or 2) the Kansas Geological Survey (KGS) Server & ORACLE Database. This program allows the user to import Well Header Information and Drill Stem Test Data.

There will be occasions when the user would like to inspect the contents of a LAS file. So, for example, the user may wish to find the identity of the well, the types of logs, depth range, well or log parameters. Alternatively, the user can suspect that the file is not coded correctly in LAS format if the Import LAS function fails, and wishes to examine the file to troubleshoot the problem. The LAS file is an ASCII file and can be read by any text editor, i.e. Notepad, WordPad, TextPad, etc.

To access Drill Stem Test (DST) Data Entry & Quantitative Analysis Applet (http://www.kgs.ku.edu/software/DST/applet.html) go to the top of the web page there is a menu "Main Page|Description|Applet|Help|Copyright & Disclaimer|". Select the "Applet" menu option a "Warning - Security" Dialog will appear.



This program has to be able to read and write to the user's PC and access the Kansas Geological Survey (KGS) Database and File Server, ORACLE requires this dialog. The program does not save your files to KGS, but allows you to access the KGS for well information that may be missing in your Kansas logs. The program does not use Cookies or any hidden software it only reads the LAS file for the DST Session and writes a LAS 3.0 File to your PC to save your DST Session and the well data imported. The blue shield on the warning dialog is a symbol that the Java web app is created by a trusted source, which is the University of Kansas. Select the "Run" Button, which will show the DST "Enter" Panel illustrated below,



Enter

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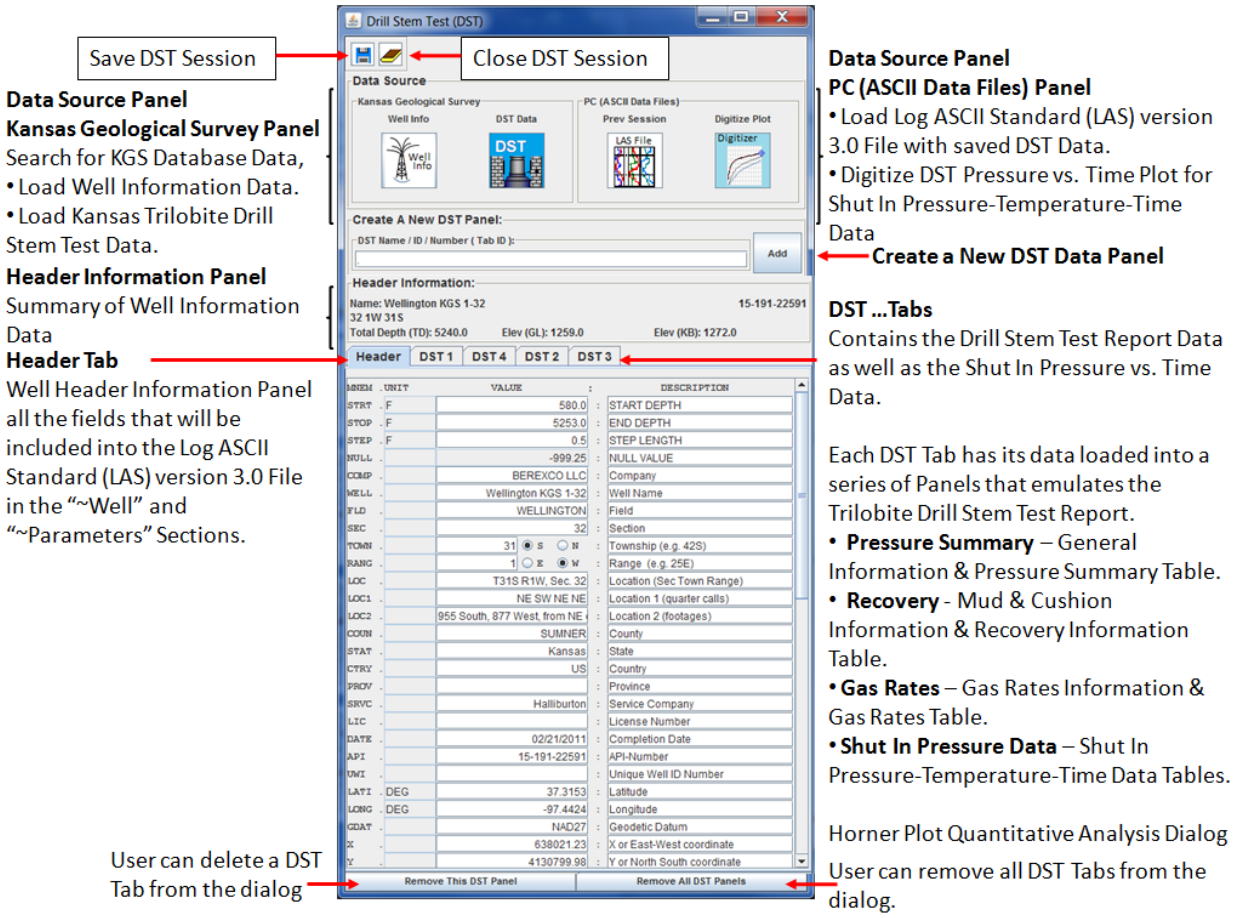
Drill Stem Test (DST) Control Dialog

Click the "DST Enter" Icon Button, which will show the "Drill Stem Test (DST)" dialog. The dialog below displays an example of the Wellington KGS 1-32 well DST data loaded from the "Prev *(Previous)* Session" image icon button with the data. The icon buttons in the Data Source Panel assists the user in loading well data into the DST Applet.



Data Source Panel

The Data Source Panel provides two methods of importing data into the Profile Web App. The Kansas Geological Survey (KGS) Database and the user's PC, a Digitizer is also provided to convert a DST Pressure/Temperature vs. Time Image to digital data. A number of icon buttons are provided to assist the user in importing the specific data type of interest.

Kansas Well Information
This button allows the user to access well information stored in the Kansas database.

Drill Stem Test (DST) Data
This button allows the user to download Drill Stem Test Data stored in the Kansas database.

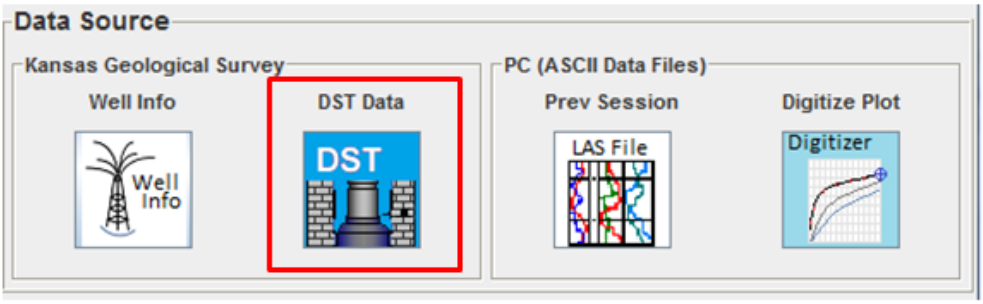
Log ASCII Standard (LAS) File Read
This version will read Log ASCII Standard (LAS) Files, versions 2.0 & 3.0. This read process does not necessarily distinguish between the two versions. The LAS Java Read classes follow the rules set up by the Canadian Well Logging Society for both versions.

Digitizer
This button allows the user to digitize the Pressure/Temperature vs. Time Plot. The DST Pressure vs. Time must be a PNG (Portable Network Graphics), JPEG (Joint Photographic Experts Group) or GIF (Graphics Interchange Format) image file.

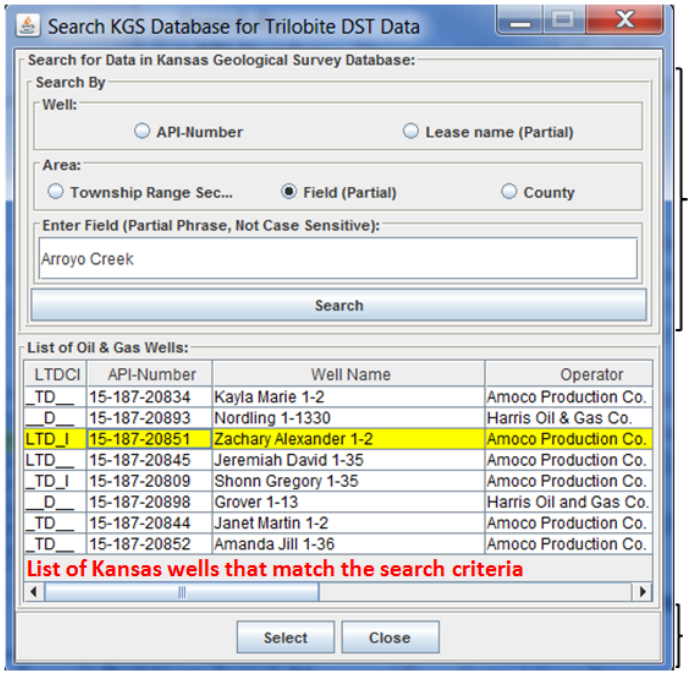
Importing KGS (Database) Data

KGS (Database) - Importing Drill Stem Test Data

The Kansas Geological Survey (KGS) has a good collection of well data stored in the ORACLE Database. In this example the user will download the well header information & Drill Stem Test Data from the KGS database. The ORACLE Database is accessed by making Stored Procedure PL/SQL calls to the ORACLE Database from which an Extensible Markup Language (XML) data stream is created containing the well data that is passed back to the web app making the request.



Left Click on the DST Image Icon Button in the Data Source Panel to display the "Search KGS Database for Trilobite DST Data" dialog.



Search KGS Database for Trilobite DST Data

Search By:

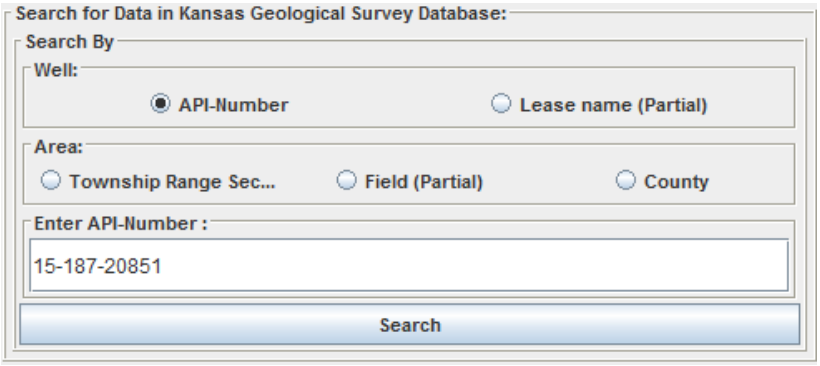
- **API-Number** – The user can search the KGS Database for well data by API-Number. The Format for the API is SS-CCC-99999 where
  - SS - Two Digit State Code
  - CCC - Three Digit County Code
  - 99999 - 5 Digit Well Number
- **Lease name** – The user can search for well data by lease partial phrase, i.e. "*Newby*", which will look for all wells with the phrase "Newby" in the lease name.
- **Township-Range-Section** – Search for a list of measured sections by a specific area..
- **Field name** – The user can search for well data by field name partial phrase, i.e. "*Arroyo Creek*", which will look for all wells with the phrase "Arroyo Creek" in the field name.
- **County** – The user can look for wells with DST Data by Kansas County.

Select – Select Drill Stem Test Data from KGS Server and transfer to the DST dialog.
Close – Close this Dialog.

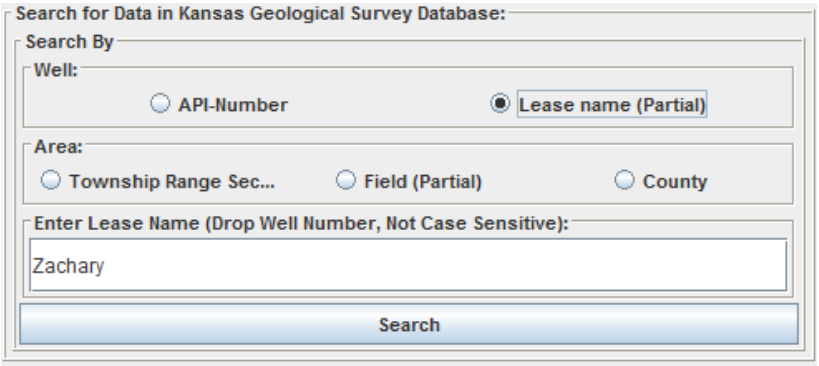
NOTE: LTDCI Column in Table: L-LAS Files; T-Formation Tops; D-Drill Stem Test; C-Measured Core Data; I-Core Images

As the Summary image suggests there are 5 methods for searching for the Trilobite Drill Stem Test Data in the KGS Database,

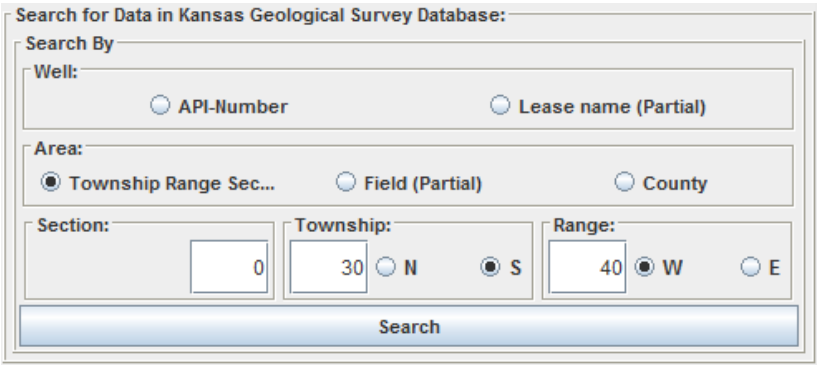
- By API-Number – KGS has a specific format for the API-Number, i.e.SS-CCC-99999 where SS is the state code for Kansas 15, CCC is the county code for Zachary Alexander 1-2 it is 187 for Stanton County and the 5-Digit Well Number for the Zachary Alexander 1-2 is 20851.



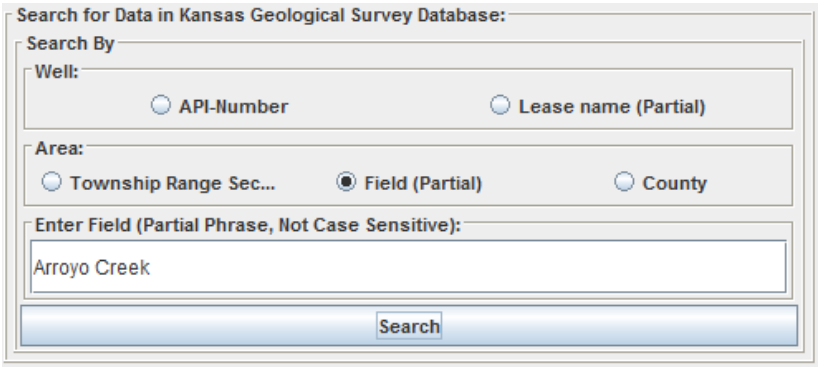
- By (Partial) Lease name - The stored procedure used to retrieve the well header information allows the user to enter a partial phrase, in this example Zachary. The program places a '%' in front and back of the phrase and sends the request to the Database, i.e. "%Zachary%".



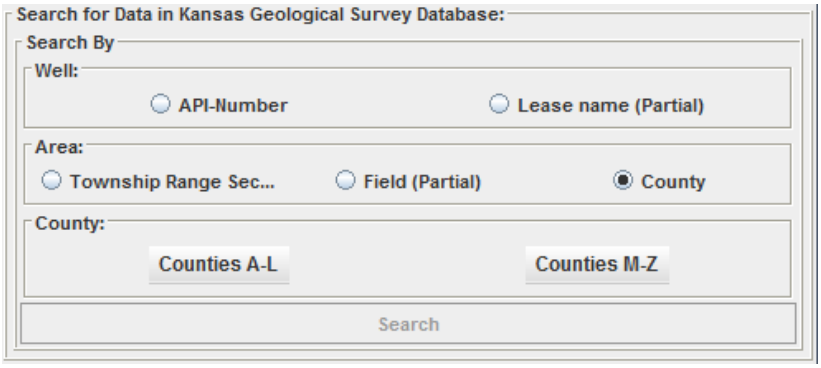
- By Township Range Section – This search is by area in Kansas, this search also allows the user to enter just the Township and Range to search for wells, e.g. to look for the Zachary Alexander 1-2, enter Township as 30 set the S (South) Radio button and Range as 40 set the W (West) Radio button.



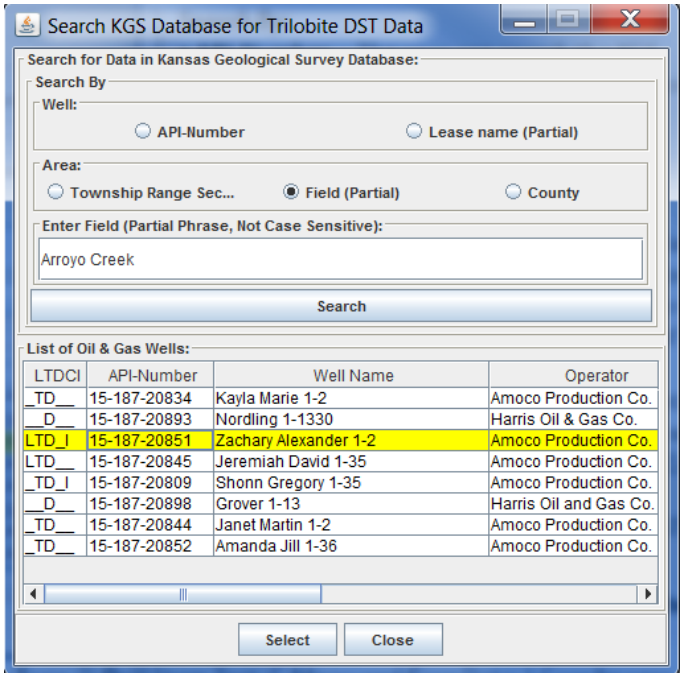
- By (Partial) Field name - This search is by area in Kansas, the stored procedure used to retrieve the Drill Stem Test Data allows the user to enter a partial field name phrase, in this example Arroyo Creek. The program places a '%' in front and back of the phrase and sends the request to the Database, i.e. "%Arroyo Creek%".



- By County – This search is by area in Kansas, the user can search by county by selecting either the "Counties A-L" for counties that begin with the letter A through L or "Counties M-Z" menu for counties that begin with the letter M through Z. In this example Zachary Alexandra 1-2 is in the Stanton County so the user would select the "Counties M-Z" menu for a list of counties and select "Stanton" menu option to retrieve all wells with Trilobite Drill Stem Data from the KGS Database Table in Stanton County.



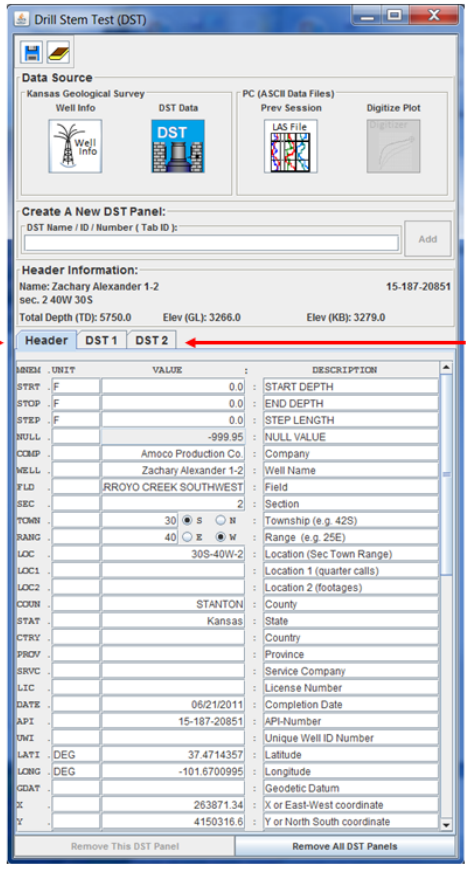
The user only needs to enter the above data and select the "Search" Button to display the list of Wells in the Kansas Database that match the search criteria. In the image below the Field Name "Arroyo Creek" is entered to search for all wells in Kansas with the Phrase Wellington in it. The user searches through the list until they find the well of interest. In this example it is the Wellington KGS 1-32, which is highlighted.



The user clicks on the "Select" button to transfer the header information to the Header Information Panel on the DST dialog and import the Drill Stem Test Data stored in the KGS Database to the DST Dialog panels.

Header Tab
Well Header Information Panel all the fields that will be included into the Log ASCII Standard (LAS) version 3.0 File in the "~Well" and "~Parameters" Sections.

As you can observe the contents in the KGS Well Header Database for the Zachary Alexander 1-2 well appears in this panel.



DST ...Tabs
Contains the Drill Stem Test Report Data as well as the Shut-In Pressure vs. Time Data.

Each DST Tab has its data loaded into a series of Panels that emulates the Trilobite Drill Stem Test Report.

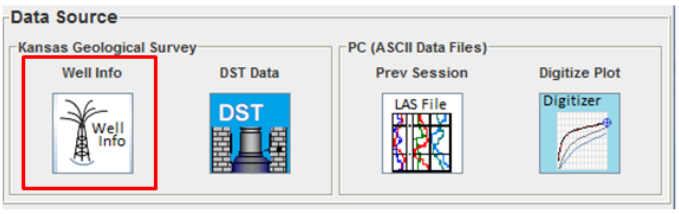
- **Pressure Summary** – General Information & Pressure Summary Table.
- **Recovery** - Mud & Cushion Information & Recovery Information Table.
- **Gas Rates** – Gas Rates Information & Gas Rates Table.
- **Shut In Pressure Data** – Shut In Pressure-Temperature-Time Data Tables.

Horner Plot Quantitative Analysis Dialog

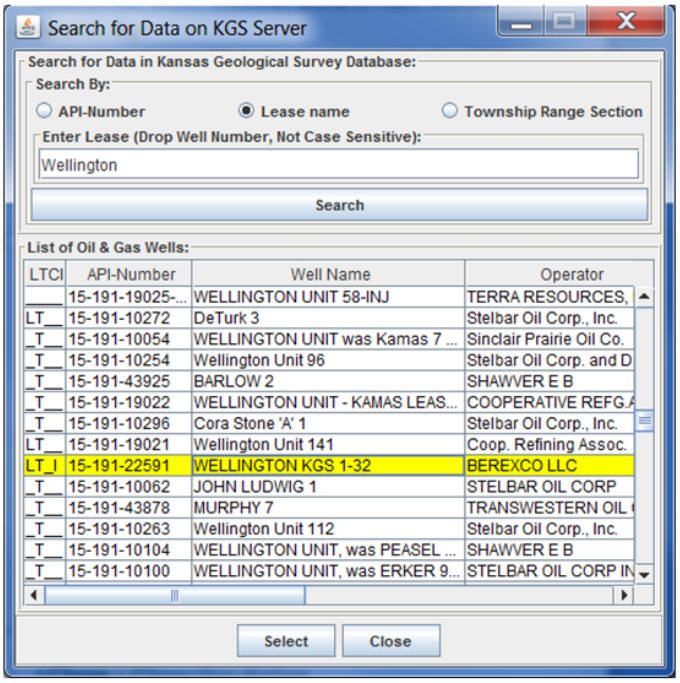
Example: Wellington KGS 1-32
Digitizing Pressure/Temperature vs. Time Plot

Import Well Header Information from Kansas Geological Survey (KGS) Database

The Kansas Geological Survey (KGS) has a good collection of well data stored in the ORACLE Database. In this example the user will download the well header information from the KGS database. The ORACLE Database is accessed by making Stored Procedure PL/SQL calls to the ORACLE Database from which an Extensible Markup Language (XML) data stream is created containing the well data that is passed back to the web app making the request.



Left Click on the "Well Info" Icon Button in the Data Source Panel.



Search for Well Header Data in KGS Database
Search By:
- **API-Number** – The user can search the KGS Database for well data by API-Number. The Format for the API is SS-CCC-99999 where
  - SS – Two Digit State Code
  - CCC – Three Digit County Code
  - 99999 – 5 Digit Well Number
- **Lease Name** – The user can search for well data by lease partial phrase, i.e. "Wellington", which will look for all wells with the phrase "Wellington" in the lease name.
- **Township-Range-Section** – Search for a list of Wells by a specific area.

List of Kansas wells that match the search criteria

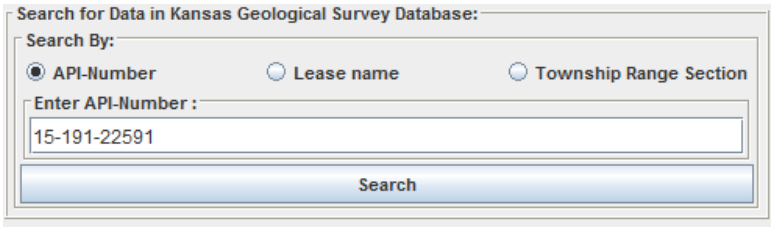
Load Well Header Buttons
- **Select** – Download the header information for the well selected.
- **Close** – Close this dialog

NOTE: LTDCI Column in Table: L-LAS Files; T-Formation Tops; C-Measured Core Data; I-Core Images

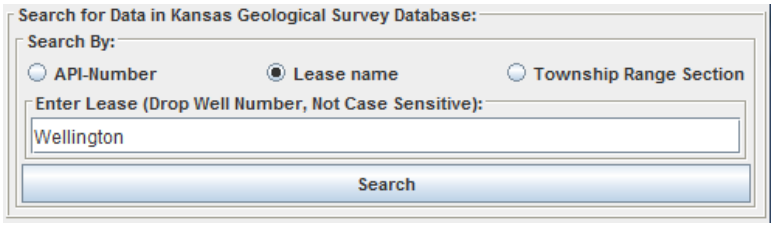
This will display the "Search for Data on KGS Server" Dialog, see above image. This dialog allows the user to search the KGS database for well header information. In this example, the well of interest will be the Wellington KGS 1-32. This example assumes the user will eventually digitize the DST Pressure/Temperature vs. Time Plots and eventually saving the data will require the Header Information Panel be filled with expected data and this search will help the user download well header information of the well of interest.

As the Summary image suggests there are 3 methods for searching for the well header information within this dialog,

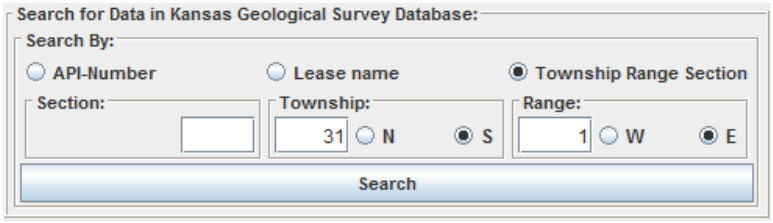
- By API-Number – KGS has a specific format for the API-Number, i.e.SS-CCC-99999 where SS is the state code for Kansas 15, CCC is the county code for Wellington KGS 1-32 it is 191 for Sumner County and the 5-Digit Well Number for the Wellington KGS 1-32 is 22591.



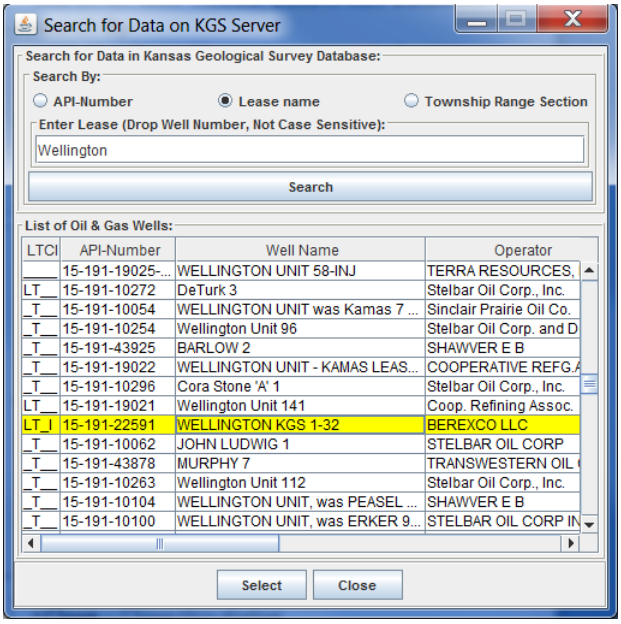
- By Partial Lease Name – The stored procedure used to retrieve the well header information allows the user to enter a partial phrase, in this example Wellington. The program places a '%' in front and back of the phrase and sends the request to the Database, i.e. "%Wellington%".



- By Township Range Section – This search is by location in Kansas, this search also allows the user to enter just the Township and Range to search for wells, e.g. to look for the Wellington KGS 1-32, enter Township as 31 set the S (South) Radio button and Range as 1 set the E (East) Radio button.



The user only needs to enter the above data and select the "Search" Button to display the list of Wells in the Kansas Database that match the search criteria. In the image below the Lease Name "Wellington" is entered to search for all wells in Kansas with the Phrase Wellington in it. The user searches through the list until they find the well of interest. In this example it is the Wellington KGS 1-32, which is highlighted.

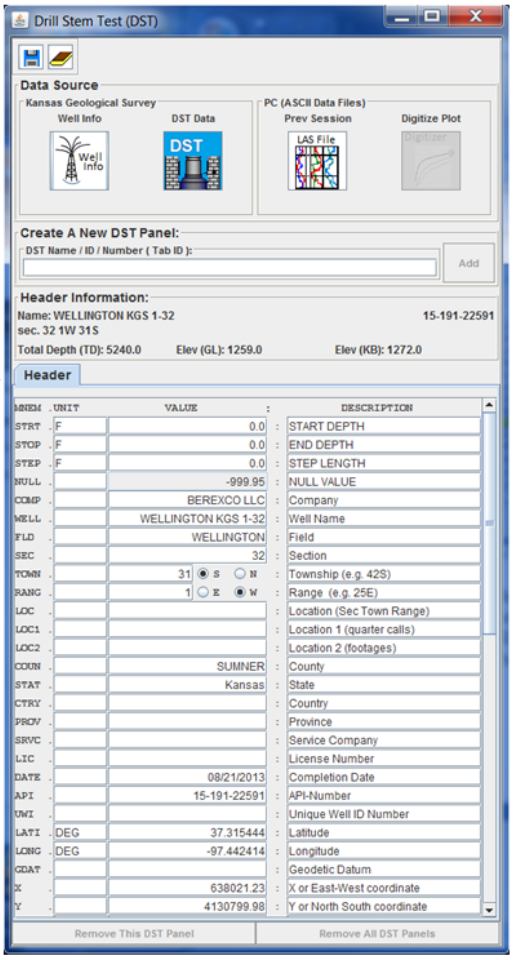


The user clicks on the "Select" button to transfer the header information to the Header Information Panel on the DST dialog.

Header Tab

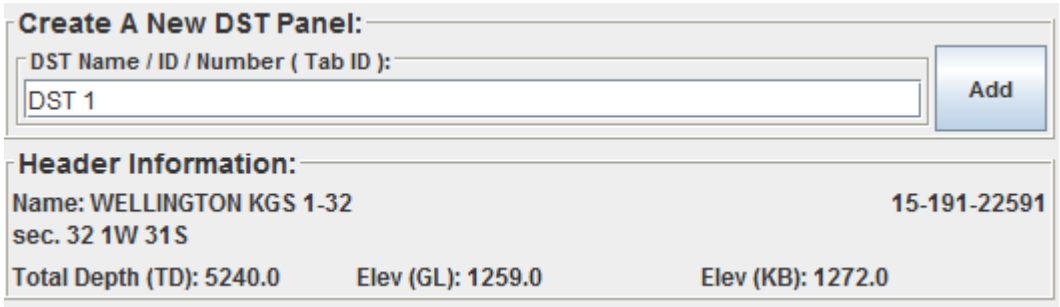
Well Header Information Panel all the fields that will be included into the Log ASCII Standard (LAS) version 3.0 File in the "~Well" and "~Parameters" Sections.

As you can observe the contents in the KGS Well Header Database for the Wellington KGS 1-32 well appears in this panel.



Add New DST Panel Tab

The user has to create a DST Data Tab before the user can access the digitizer. Enter the name for the first DST "DST 1" in the "DST Name / ID / Number (Tab ID)" text field and then tab out of the text field, the "Add" button will them be enabled. Select the "Add" Button to create the "DST 1" tab with all embedded panels to collect the DST 1 Report Data.



The information that is contained in a drill-stem test report will contain the following,

- Factual data including statistical well information and a description of the testing tools.
- Measured data concerning the recovered fluids and their properties, the time periods the recovered fluids and their properties, the time periods involved and general remarks based on observations during the test
- Recorded pressure and temperature data as a Pressure/Temperature vs. time plot, which will require digitizing to retrieve the data for the Horner Plot and Quantitative Analysis.
- Interpretation calculations, where applicable.

The DST data panels are designed to emulate the Trilobite Drill Stem Test Report Format as an example. The GEMINI Project created a DST Database table was created so donated Trilobite Test Data could be loaded into the table. In this example the DST report was provided but the digital drill stem test data is not just the Temperature/Pressure vs. time plot. This web app does not replace the original DST Report, but provides a method for saving the data in a format that can be shared with other programs. Once the DST Report data is transferred to this web app and the DST plot is digitized the data can be saved to a Log ASCII Standard (LAS) version 3.0 file.

The next three panels illustrate the Trilobite Drill Stem Test Report pages and the corresponding Drill Stem Test Dialog Panels for the "DST 1" Tab.

The DST 1 Tab Panel contains General Information Panel that displays will hold the General Information in the Drill Stem Test Report. The lower have of the DST 1 Tab Panel contains 4 tabs, Pressure Summary, Recovery, Gas Rates and Shut-In Pressure Data panels. The first three is for DST information; the Gas Rates panel is only filled if the DST Report was done for a Gas DST test. The Shut-In Pressure Data panel holds the digital data for the Pressure/Temperature vs. Time Data. The Wellington KGS 1-32 DST tests was done on a Fluid based well so for the last page another well is shown to illustrate the contents of the Gas Rates panel.

Pressure Summary Tab (Trilobite DST Report - 1st Page)
General Information & Pressure Summary Table

Header Information:

Name: WELLINGTON KGS 1-32 — 15-191-22591
32 1W 31S
Total Depth (TD): 5240.0 — Elev (GL): 1259.0 — Elev (KB):

Header | DST 1

General Information

Formation: Miss — Interval: 3664 ft To 3690 ft
Deviated: ◉ No ○ Yes — Test Type: Conventional Bottom Hole
Whipstock: 0.0 ft — Company: Trilobite Testing, Inc.
Start Date-Time: 01/09/2011 — Tester: Esak Handley
End Date-Time: 01/10/2011 — Unit No: 34
Hole Diameter: 7.88 in — Hole Condition: Poor

Pressure Summary | Recovery | Gas Rates | Shut In Pressure Data

Serial Number: 6773 ◉ Inside ○ Outside
Pressure @ Run Depth: 414.10 psi @ 3665 ft Capacity: 8000.0 psi

Test Comments:

IF Weak blow. Slow increase to 4"
ISI No blow.
FF Weak blow. BOB in 37 min.
FSI No blow.

Pressure Summary

Time	Pressure	Temp	Annotation
0	1,916.58	108.15	Initial Hydrostatic
12	68.92	110.06	Open to Flow 1
44	239.67	115.88	Shut-in 1
109	1,047.57	114.85	End Shut-in 1
109	257.73	114.46	Open to Flow 2
168	414.1	117.63	Shut-in 2
348	1,049.42	116.7	End Shut-in 1
357	1,804.33	114.39	Final Hydrostatic

TRILOBITE TESTING, INC

DRILL STEM TEST REPORT

Berexco LLC — Wellington KGS#1-32
2020 N Bramblewood — 32 31s 1w Sumner KS
Wichita KS 67206 — Job Ticket: 37411 — DST#: 1
ATTN: Ganganath Koralegedarichita KS 67206 — Test Start: 2011.01.09 @ 19:35:20

GENERAL INFORMATION:

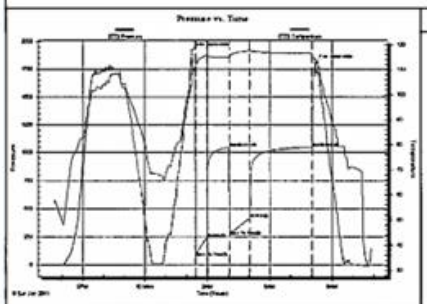
Formation: Miss
Deviated: No Whipstock: ft (KB)
Time Tool Opened: 02:26:20
Time Test Ended: 10:55:35
Interval: 3664.00 ft (KB) To 3690.00 ft (KB) (TVD)
Total Depth: 3690.00 ft (KB) (TVD)
Hole Diameter: 7.88 inches Hole Condition: Poor

Test Type: Conventional Bottom Hole
Tester: Esak Hadley
Unit No: 34
Reference Elevations: 1272.00 ft (KB)
1259.00 ft (CF)
KB to GR/CF: 13.00 ft

Serial #: 6773 Inside
Press@RunDepth: 414.10 psig @ 3665.00 ft (KB)
Start Date: 2011.01.09 End Date: 2011.01.10
Start Time: 19:35:25 End Time: 10:55:35

Capacity: 8000.00 psig
Last Calib.: 2011.01.10
Time On Btm: 2011.01.10 @ 02:14:35
Time Off Btm: 2011.01.10 @ 08:11:20

TEST COMMENT: IF Weak blow. Slow increase to 4".
ISI No blow.
FF Weak blow. BOB in 37 min.
FSI No blow.



PRESSURE SUMMARY

Time (Min.)	Pressure (psig)	Temp (deg F)	Annotation
0	1916.58	108.15	Initial Hydro-static
12	68.92	110.06	Open To Flow (1)
44	239.67	115.88	Shut-In(1)
109	1047.57	114.85	End Shut-In(1)
109	257.73	114.46	Open To Flow (2)
168	414.10	117.63	Shut-In(2)
348	1049.42	116.70	End Shut-In(2)
357	1804.33	114.39	Final Hydro-static

Recovery

Length (ft)	Description	Volume (bbl)
55.00	MCW 40%m 60%w	0.27
190.00	MCW 25%m 75%w	0.93
555.00	MCW 10%m 90%w	5.04

Gas Rates

	Choke (inches)	Pressure (psig)	Gas Rate (Mcf/d)

Trilobite Testing, Inc — Ref. No: 37411 — Printed: 2011.01.25 @ 09:12:18 Page 1

The time on bottom, time off bottom are not included in the Java data panels. All other information is present. The well information is part of the "Header" Panel.

Recovery Tab (Trilobite DST Report - 2nd Page)
Mud & Cushion Information & Recovery Information Table

Header Information:

Name: WELLINGTON KGS 1-32 — 15-191-22591
32 1W 31S
Total Depth (TD): 5240.0 — Elev (GL): 1259.0 — Elev (KB):

Header | DST 1

General Information

Formation:	Miss	Interval:	3664 ft To 3690 ft
Deviated:	◉ No ○ Yes	Test Type:	Conventional Bottom Hole
Whipstock:	0.0 ft	Company:	Trilobite Testing, Inc.
Start Date-Time:	01/09/2011	Tester:	Esak Handley
End Date-Time:	01/10/2011	Unit No:	34
Hole Diameter:	7.88 in	Hole Condition:	Poor

Pressure Summary | Recovery | Gas Rates | Shut In Pressure Data

Mud and Cushion Information

Mud Type:	Gel Chem		Cushion Type:		
Mud Weight:	9.00	lb/gal	Cushion Length:	0.0	ft
Viscosity:	47.00	sec/qt	Cushion Volume:	0.0	bbl
Water Loss:	5.97	in^3	Gas Cushion Type:		
Resistivity:	0.0	ohm-m	Gas Cushion Pressure:	0.0	psi
Salinity:	3000.00	ppm	Oil API:	0.0	deg API
Filter Cake:	0.20	in	Water Salinity:	85000.0	ppm

Recovery Information

Length	Description	Volume
55	MCW 40%m 60%w	0.27
190	MCW 25%m 75%w	0.934
555	MCW 10%m 90%w	5.043

800.0 — Add Row | Sum Data | Remove — 6.247

Recovery Comments:

RW .14 @ 47F = 85000 ppm

TRILOBITE TESTING, INC

DRILL STEM TEST REPORT — FLUID SUMMARY

Berexco LLC — Wellington KGS#1-32
2020 N Bramblewood — 32 31s 1w Sumner KS
Wichita KS 67206 — Job Ticket: 37411 — DST#: 1
ATTN: Ganganath Koralegedarichita KS 67206 — Test Start: 2011.01.09 @ 19:35:20

Mud and Cushion Information

Mud Type:	Gel Chem	Cushion Type:	-	Oil API:	deg API
Mud Weight:	9.00 lb/gal	Cushion Length:	ft	Water Salinity:	85000 ppm
Viscosity:	47.00 sec/qt	Cushion Volume:	bbl		
Water Loss:	5.97 in³	Gas Cushion Type:			
Resistivity:	0.00 ohm.m	Gas Cushion Pressure:	psig		
Salinity:	3000.00 ppm				
Filter Cake:	0.20 inches				

Recovery Information

Recovery Table

Length ft	Description	Volume bbl
55.00	MCW 40%m 60%w	0.270
190.00	MCW 25%m 75%w	0.934
555.00	MCW 10%m 90%w	5.043

Total Length: 800.00 ft — Total Volume: 6.247 bbl
Num Fluid Samples: 0 — Num Gas Bombs: 0 — Serial #:
Laboratory Name: — Laboratory Location:
Recovery Comments: RW .14 @ 47F = 85000 ppm

Trilobite Testing, Inc — Ref. No: 37411 — Printed: 2011.01.25 @ 09:12:19 — Page 2

To compute the fluid flow rate / day in the quantitative analysis section the volume sum must have a value. The user only needs to push the "Sum Data" Button to compute the sum to the Recovery Information Table.

Gas Rates Tab (Trilobite DST Report - 3rd Page)
Gas Rates Information & Gas Rates Table

Header Information:

Name:

Total Depth (TD): Elev (GL): Elev (KB):

Header | DST 6

General Information

Formation: Spergen | Interval: 5303 ft To 5322 ft

Deviated: ◉ No ◯ Yes | Test Type: Conventional Straddle

Whipstock: 0.0 ft | Company: Trilobite Testing, Inc.

Start Date-Time: 05/27/2011 | Tester: Mike Roberts

End Date-Time: 05/27/2011 | Unit No: 48

Hole Diameter: 7.88 in | Hole Condition: Fair

Pressure Summary | Recovery | Gas Rates | Shut In Pressure Data

Gas Rates Information

Formation Temperature: 98 deg F

Specific Gravity of Gas (G): 0.0

Super Compressibility Factor (Z): 0.2

Gas Rates Table

Period	Time (min)	Choke (in)	Pressure (psi)	Gas Rate (Mcf/d)
1	5	1	100	3,655.99
1	5	1	100	2,952.71
1	5	1	100	2,952.71
2	10	1	100	2,952.71
2	20	1	100	2,952.71
2	30	1	100	2,952.71
2	40	1	100	2,952.71

Add Row | Remove

TRILOBITE TESTING, INC.

DRILL STEM TEST REPORT — GAS RATES

Vecta Oil & Gas Ltd. — Humboldt 41-8

575 Union Blvd.#208, Lakewood CO 80228 — 8/14/47 Cheyenne CO

Job Ticket: 041223 — DST#: 6

ATTN: Mat Godsby — Test Start: 2011.05.27 @ 11:42:15

Gas Rates Information

Temperature: 98 deg C

Relative Density: 3

Z Factor: 0.2

Gas Rates Table

Flow Period	Elapsed Time	Choke (mm)	Pressure (kPaa)	Gas Rate (m³/d)
1	5	1.00	100.00	3655.99
1	5	1.00	100.00	2952.71
1	5	1.00	100.00	2952.71
2	10	1.00	100.00	2952.71
2	20	1.00	100.00	2952.71
2	30	1.00	100.00	2952.71
2	45	1.00	100.00	2952.71

Trilobite Testing, Inc — Ref. No: 041223 — Printed: 2011.06.01 @ 10:35:40 Page 4

This page is only for Gas DST Data and it is shown as an example. In the Java Gas Rates Panel Page The Relative Density is replaced with the Specific Gravity of Gas (G), which is useful for the quantitative analysis section of the Horner Plot Dialog.

Digitize DST 1 Pressure/Temperature vs. Time Plot

This example the user can download DST 1 report & a Portable Network Graphics (PNG) image file from the KGS Server. Download the following files into your PC.

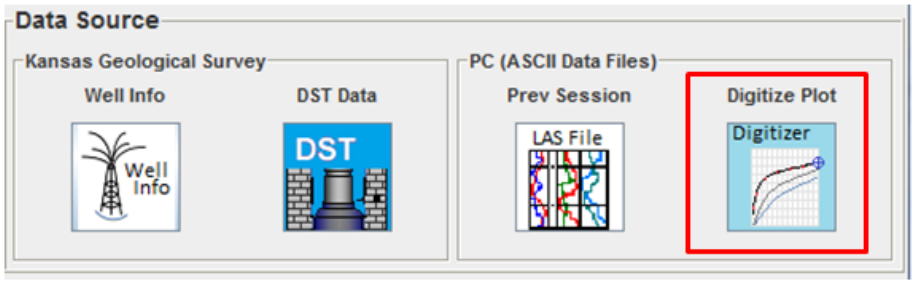
Wellington KGS 1-32: Drill Stem Test 1 Report and Pressure/Temperature vs. Time PNG Image.

Type	File URLs
Report	http://www.kgs.ku.edu/Gemini/Tools/documentation/Wellington_KGS_1-32-DST-1-Report.pdf
DST 1	http://www.kgs.ku.edu/Gemini/Tools/documentation/Wellington_KGS_1-32-Miss.png

The first file is the Portable Document Format (PDF) Document of the DST 1 Report. The Second file is an image capture of the Pressure/Temperature vs. Time Portable Network Graphics (PNG) Image that will be used in the digitizing process to capture the Shut-In 1 Pressure, Temperature and Time data and the Shut-In 2 Pressure, Temperature and Time data.

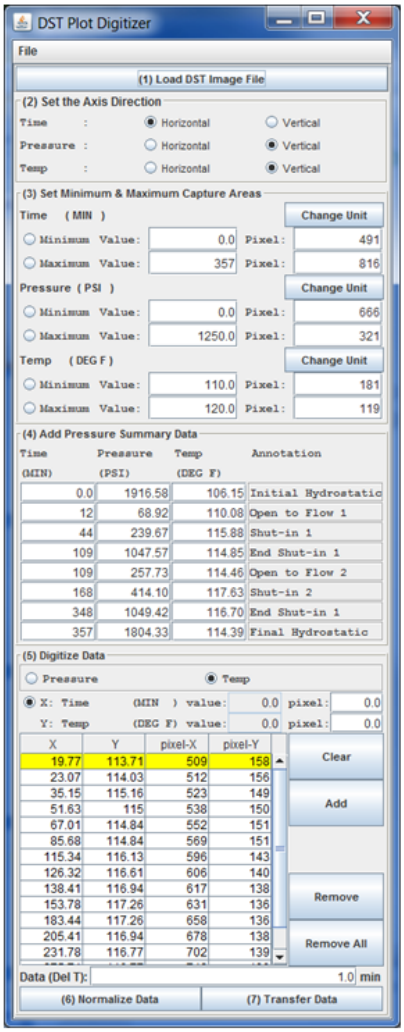
Both Shut-In Pressure/Temperature vs. Time data is needed to compute the Initial static reservoir pressure, P_i.

Left Click the on the "Digitizer Plot" image icon button to display the "DST Plot Digitizer" dialog.



The Digitizer was set up as a 7 step process. The following web pages will walk the user through each step to load a DST Pressure vs. Time Plot into the digitizer dialog. To set the data collection areas and to digitize and normalize the shut in pressure temperature and time data for the Horner Plot & Quantitative Analysis dialog.

Note: The DST Pressure vs. Time must be a PNG (Portable Network Graphics), JPEG (Joint Photographic Experts Group) or GIF (Graphics Interchange Format) image file.



(1) Load a PNG, JPEG or GIF Image Pressure vs. Time Plot into program

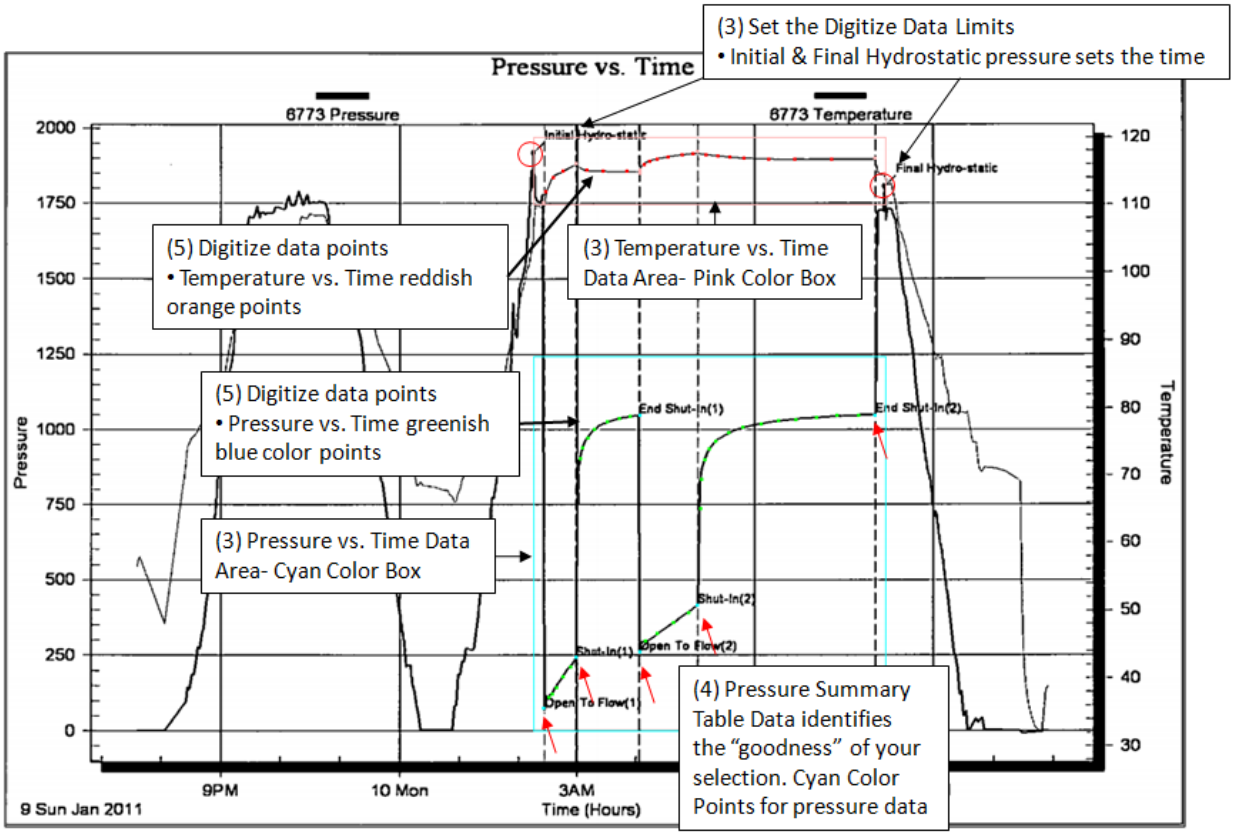
(2) Set the Orientation of the Axis. Default is Time on the horizontal axis and Temperature and Pressure are the vertical axis

(3) Set the Limits – Boxes will be drawn around the data areas. Set Time using the Initial & Final Hydrostatic Pressures, since they are generally marked on the Trilobite Pressure vs. Time Plot. In this example the Initial Hydrostatic Pressure starts the cycle as 0 and the Final Hydrostatic Pressure ends the cycle at 357 minutes. The program shows the pixel values selected. The Pressures and Temperature limits must be less than the lowest Shut In Value and greater than the highest Shut In Value. A cyan color box will be drawn around the Pressure vs. Time Data and a pink color box will be drawn around the Temperature vs. Time Data.

(4) Enter the Pressure Summary Data, which will show on the plot how well the limits in (3) above were selected. A cyan color dot will appear for each Pressure vs. Time value and a pink color dot will appear for each Temperature vs. Time value within the boxes drawn above.

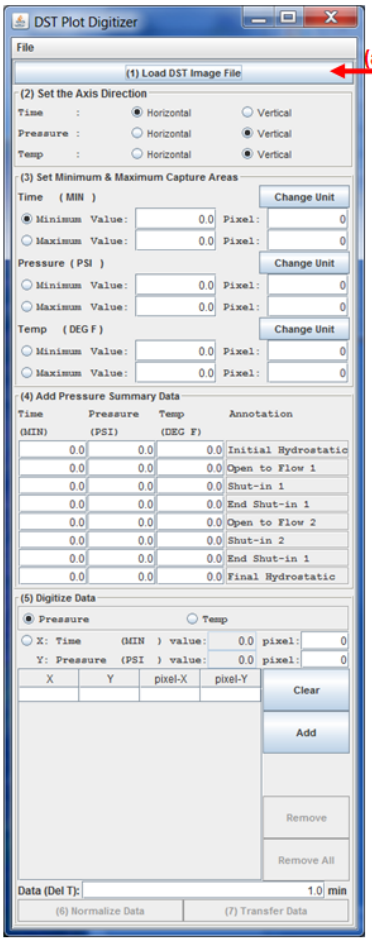
(5) There are 2 Tables of data being created depending on radio buttons.
- Pressure vs. Time – Pressure Radio Button is selected.
  Digitize from Open to Flow 1 to End Shut In 2
- Temperature vs. Time – Temperature Radio Button is selected.
  Digitize from Open to Flow 1 to End Shut In 2

(6) Normalize the Shut In Data to equal spaced time (minute) intervals.
(7) Move Shut In Pressure-Temperature-Time Data to Horner Plot Dialog.

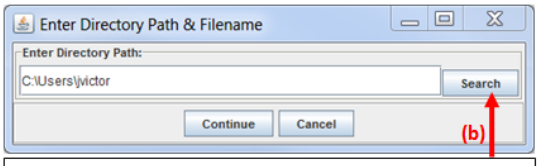


(2) Check data orientation – Time is horizontal axis and Temperature and Pressure are vertical axis.

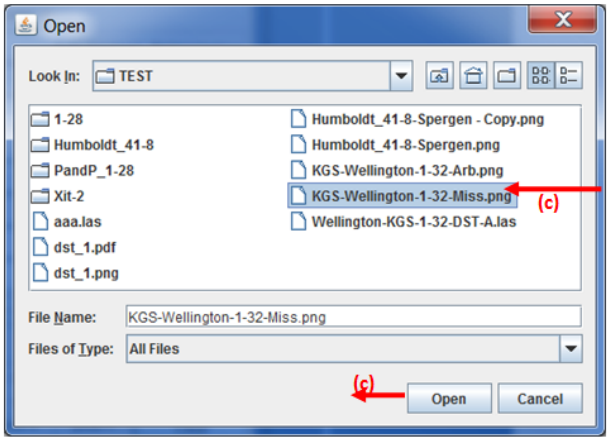
(1) Load DST Image File



Step a: Select the "(1) Load DST Image File" Button to display the "Enter Directory Path & Filename" Dialog.

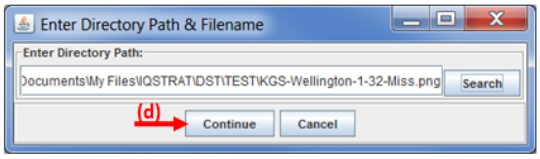


Step b: Select the Search Button to search your PC for the correct DST Pressure vs. Time Plot.
NOTE: The starting directory is your home directory.

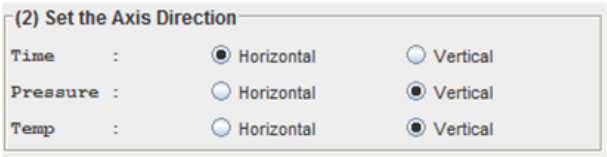


Step c: Highlight the DST Pressure vs. Time Plot to load into the digitizer. Select the "Open" Button.

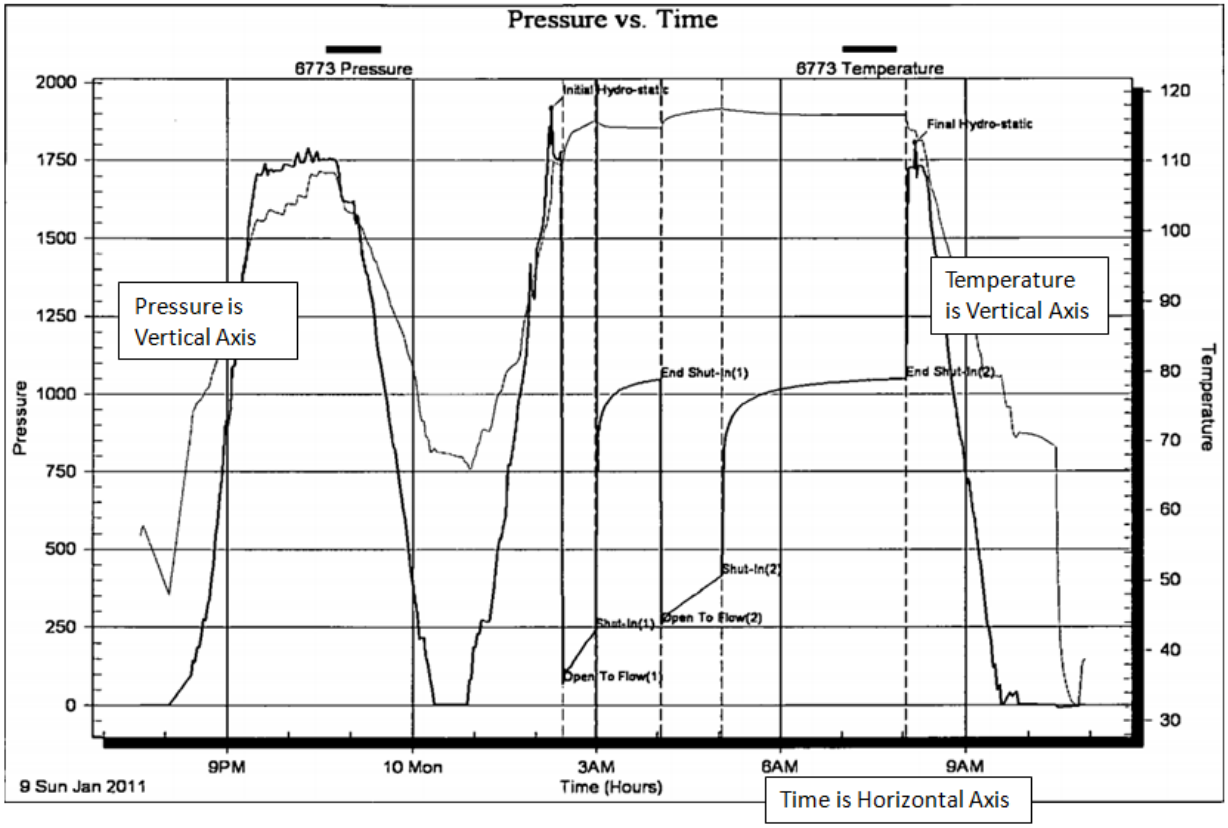
Step d: The DST Pressure vs. Time Plot directory & filename will be loaded. Select the "Continue" Button to load the image into the program.



(2) Set the Axis Direction



Check data orientation – This example, Time is horizontal axis and Temperature and Pressure are vertical axis, which is the default radio buttons selection in the "(2) Set the Axis Direction" Panel.



(3) Set Minimum & Maximum Capture Areas

TRILOBITE TESTING, INC

DRILL STEM TEST REPORT

Berexco LLC
2020 N Bramblewood
Wichita KS 67206
ATTN: Ganganath Koralegedarichita KS 67206

Wellington KGS#1-32
32 31s 1w Sumner KS
Job Ticket: 37411 **DST#: 1**
Test Start: 2011.01.09 @ 19:35:20

GENERAL INFORMATION:

Formation: **Miss**
Deviated: No Whipstock: ft (KB)
Time Tool Opened: 02:26:20
Time Test Ended: 10:55:35

Test Type: Conventional Bottom Hole
Tester: Esak Hadley
Unit No: 34

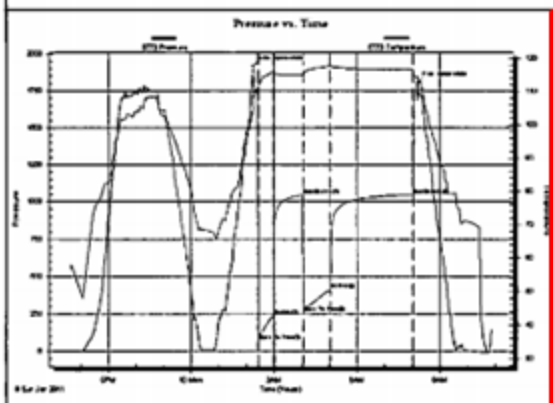
Interval: 3664.00 ft (KB) To 3690.00 ft (KB) (TVD)
Total Depth: 3690.00 ft (KB) (TVD)
Hole Diameter: 7.88 inches Hole Condition: Poor

Reference Elevations: 1272.00 ft (KB)
1259.00 ft (CF)
KB to GR/CF: 13.00 ft

Serial #: 6773 **Inside**
Press@RunDepth: 414.10 psig @ 3665.00 ft (KB)
Start Date: 2011.01.09 End Date: 2011.01.10
Start Time: 19:35:25 End Time: 10:55:35

Capacity: 8000.00 psig
Last Calib.: 2011.01.10
Time On Btm: 2011.01.10 @ 02:14:35
Time Off Btm: 2011.01.10 @ 08:11:20

TEST COMMENT: IF Weak blow. Slow increase to 4".
ISI No blow.
FF Weak blow. BOB in 37 min.
FSI No blow.



PRESSURE SUMMARY

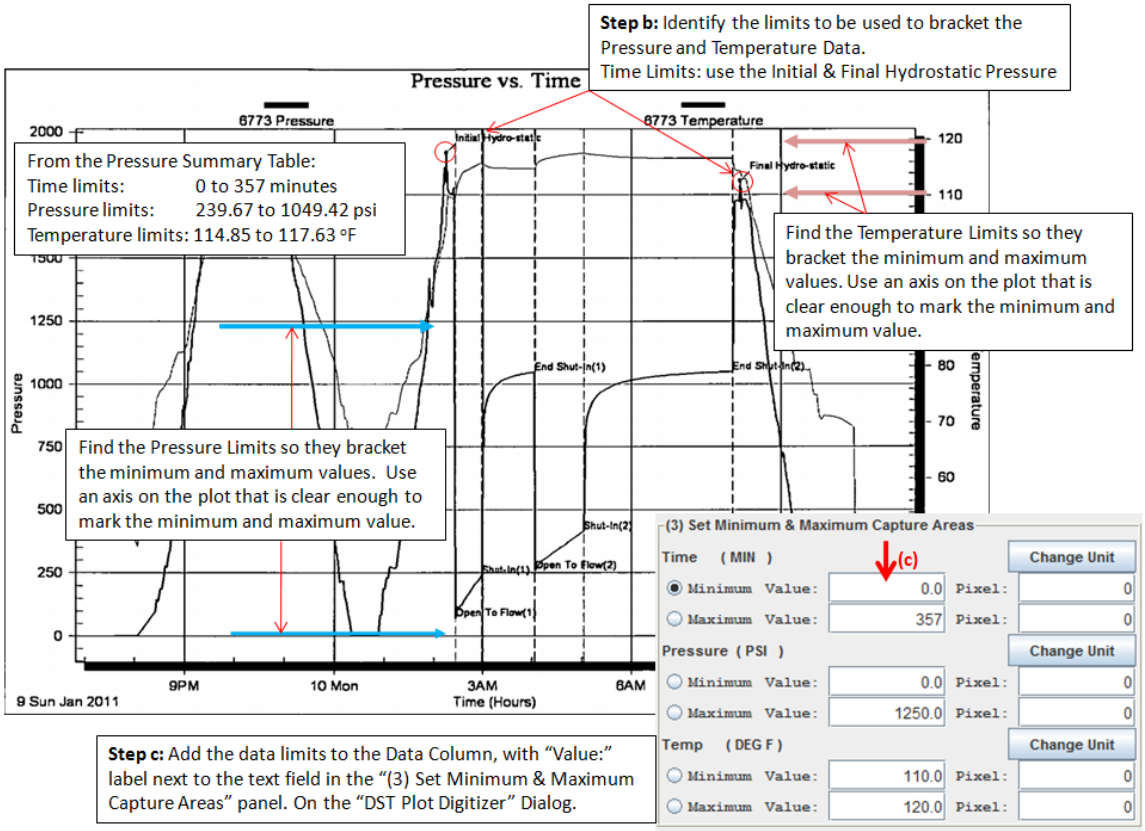
Time (Min.)	Pressure (psig)	Temp (deg F)	Annotation
0	1916.58	106.15	Initial Hydro-static
12	68.92	110.06	Open To Flow (1)
44	239.67	115.88	Shut-In(1)
109	1047.57	114.85	End Shut-In(1)
109	257.73	114.46	Open To Flow (2)
168	414.10	117.63	Shut-In(2)
348	1049.42	116.70	End Shut-In(2)
357	1804.33	114.39	Final Hydro-static

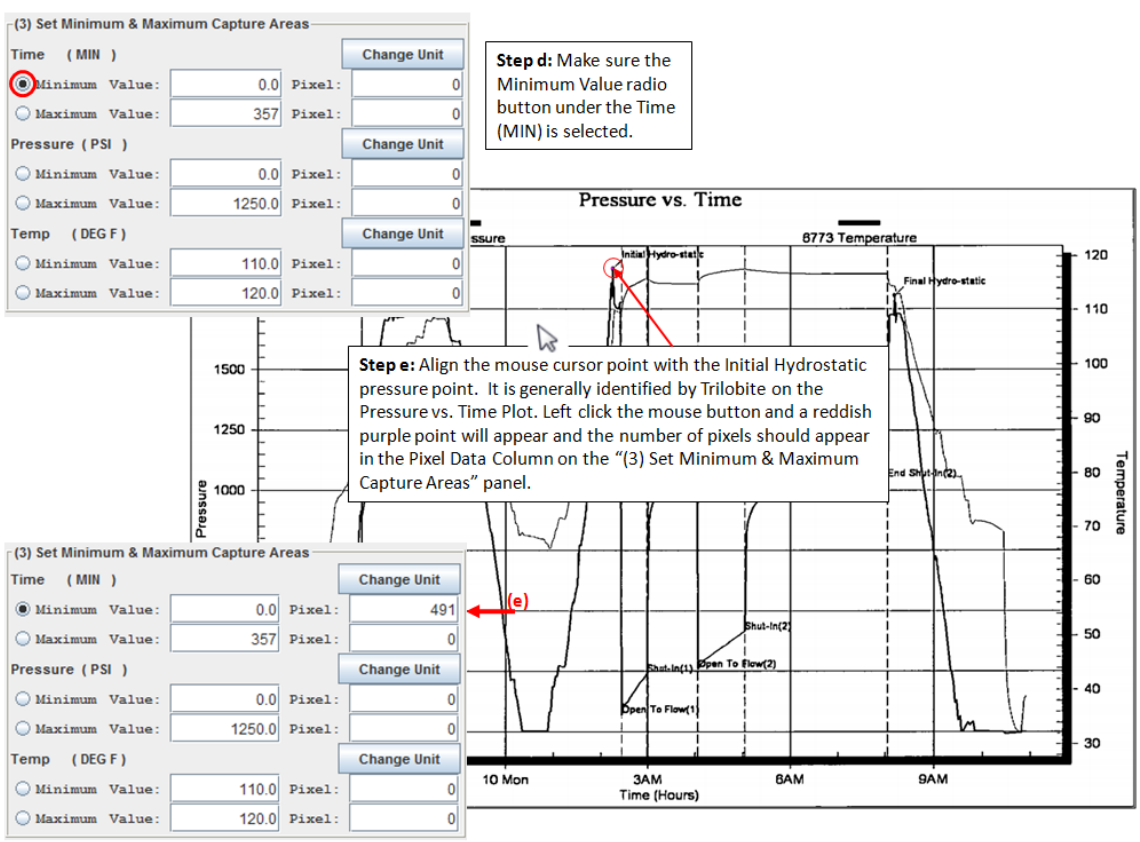
Recovery

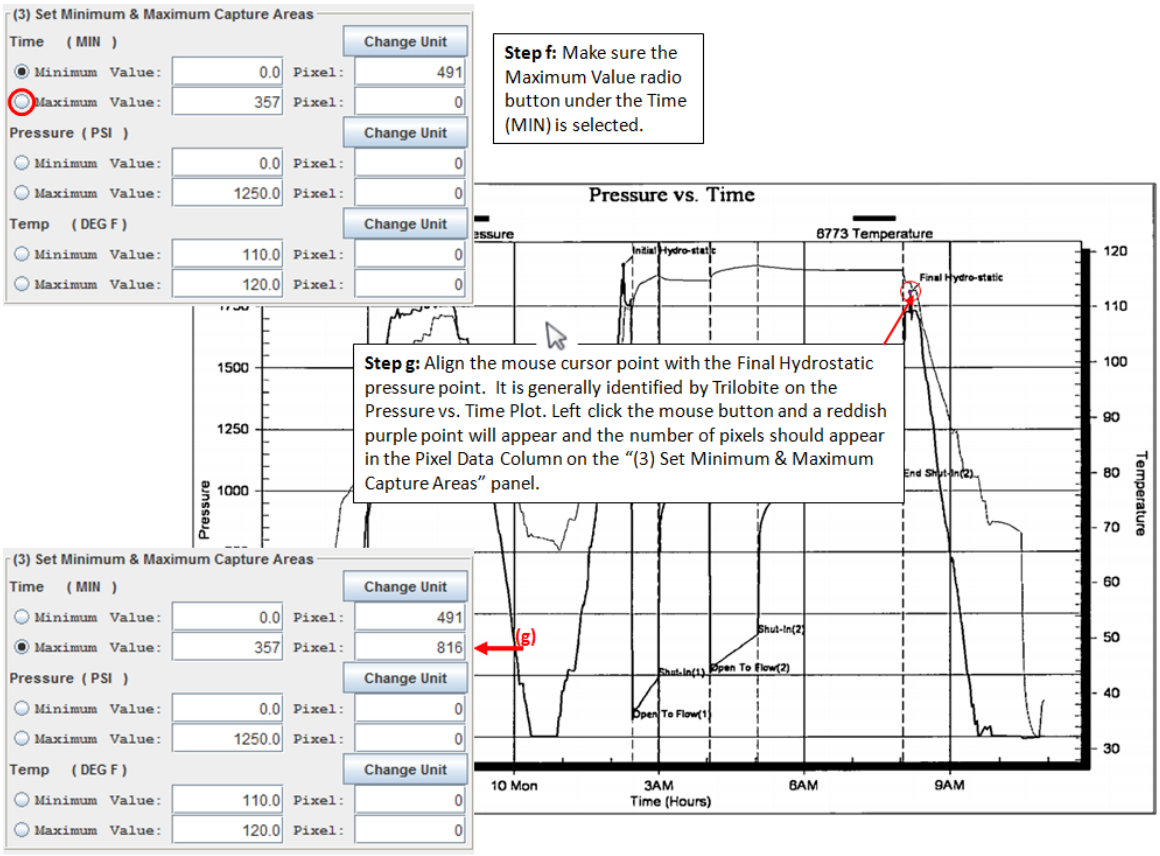
Length (ft)	Description	Volume (bbl)
55.00	MCW 40%m 60%w	0.27
190.00	MCW 25%m 75%w	0.93
555.00	MCW 10%m 90%w	5.04

Step a: Identify the Pressure Summary Table Data on the Drill Stem Test Report. You will need this for both Step 3 and Step 4 .

Trilobite Testing, Inc Ref. No: 37411 Printed: 2011.01.25 @ 09:12:18 Page 1

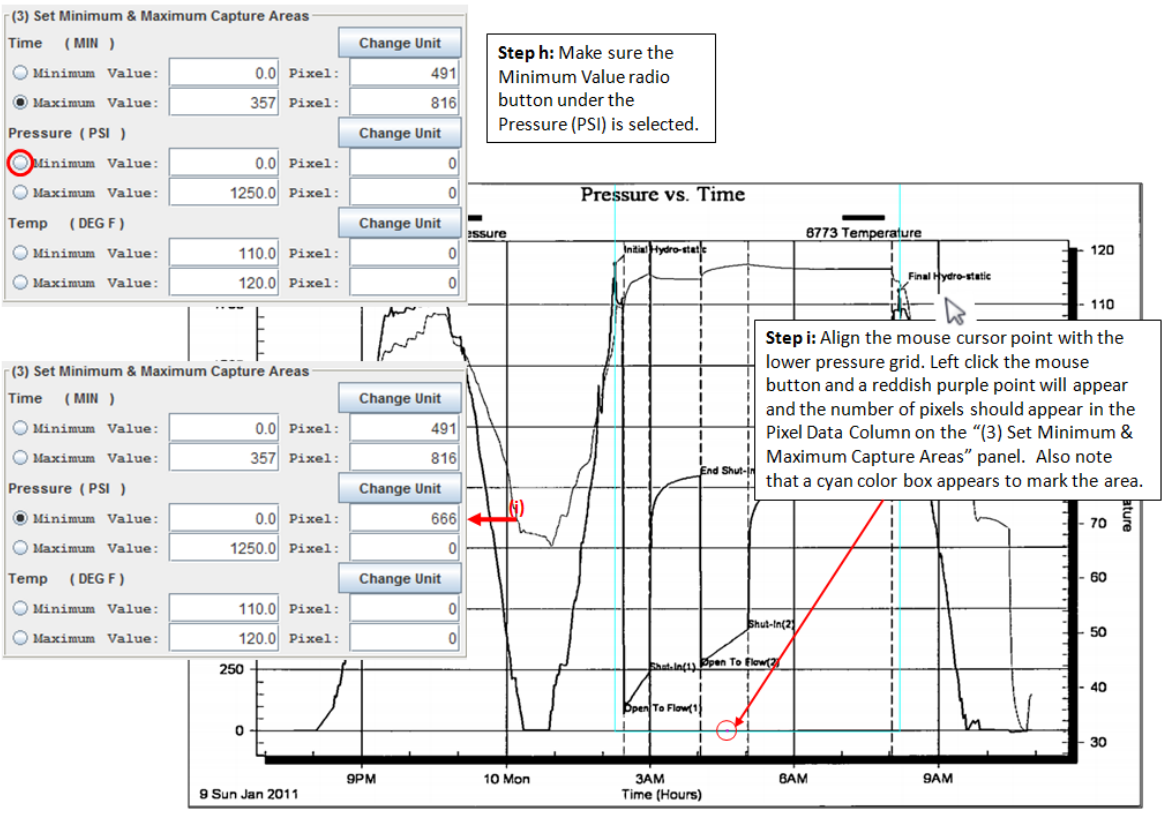

Step b: Identify the limits to be used to bracket the Pressure and Temperature Data.
Time Limits: use the Initial & Final Hydrostatic Pressure
Pressure vs. Time
6773 Pressure
6773 Temperature
From the Pressure Summary Table:
Time limits: 0 to 357 minutes
Pressure limits: 239.67 to 1049.42 psi
Temperature limits: 114.85 to 117.63 °F
Find the Temperature Limits so they bracket the minimum and maximum values. Use an axis on the plot that is clear enough to mark the minimum and maximum value.
Find the Pressure Limits so they bracket the minimum and maximum values. Use an axis on the plot that is clear enough to mark the minimum and maximum value.
Initial Hydro-static
Final Hydro-static
End Shut-In(1)
End Shut-In(2)
Shut-In(2)
Shut-In(1)
Open To Flow(2)
Open To Flow(1)
Pressure
Temperature
9PM
10 Mon
3AM
6AM
9 Sun Jan 2011
Time (Hours)
(3) Set Minimum & Maximum Capture Areas
(c)
Time (MIN)
Change Unit
Minimum Value: 0.0 Pixel: 0
Maximum Value: 357 Pixel: 0
Pressure (PSI)
Minimum Value: 0.0 Pixel: 0
Maximum Value: 1250.0 Pixel: 0
Temp (DEG F)
Minimum Value: 110.0 Pixel: 0
Maximum Value: 120.0 Pixel: 0
Step c: Add the data limits to the Data Column, with "Value:" label next to the text field in the "(3) Set Minimum & Maximum Capture Areas" panel. On the "DST Plot Digitizer" Dialog.


(3) Set Minimum & Maximum Capture Areas
Time (MIN)
Change Unit
Minimum Value: 0.0 Pixel: 0
Maximum Value: 357 Pixel: 0
Pressure (PSI)
Minimum Value: 0.0 Pixel: 0
Maximum Value: 1250.0 Pixel: 0
Temp (DEG F)
Minimum Value: 110.0 Pixel: 0
Maximum Value: 120.0 Pixel: 0
Step d: Make sure the Minimum Value radio button under the Time (MIN) is selected.
Pressure vs. Time
6773 Temperature
Step e: Align the mouse cursor point with the Initial Hydrostatic pressure point. It is generally identified by Trilobite on the Pressure vs. Time Plot. Left click the mouse button and a reddish purple point will appear and the number of pixels should appear in the Pixel Data Column on the "(3) Set Minimum & Maximum Capture Areas" panel.
(e)
Minimum Value: 0.0 Pixel: 491
Pressure
Temperature
10 Mon
3AM
6AM
9AM
Time (Hours)



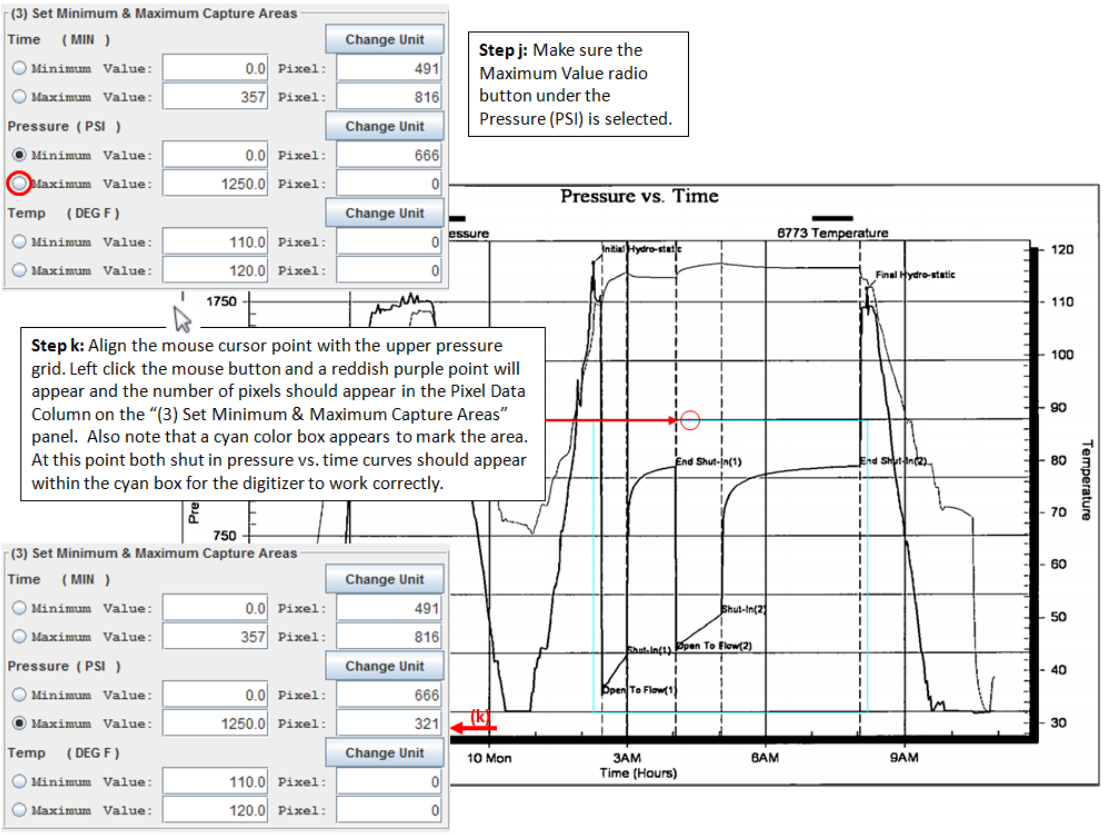
Step f: Make sure the Maximum Value radio button under the Time (MIN) is selected.

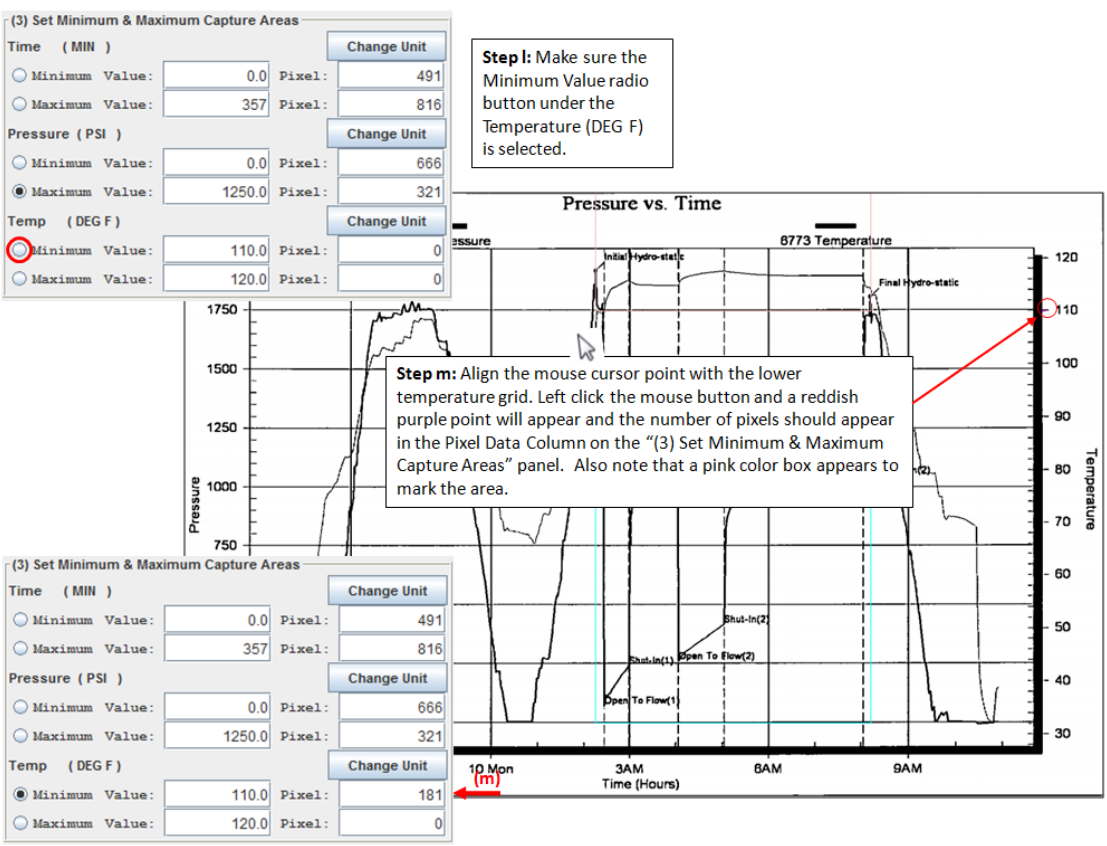
Step g: Align the mouse cursor point with the Final Hydrostatic pressure point. It is generally identified by Trilobite on the Pressure vs. Time Plot. Left click the mouse button and a reddish purple point will appear and the number of pixels should appear in the Pixel Data Column on the "(3) Set Minimum & Maximum Capture Areas" panel.

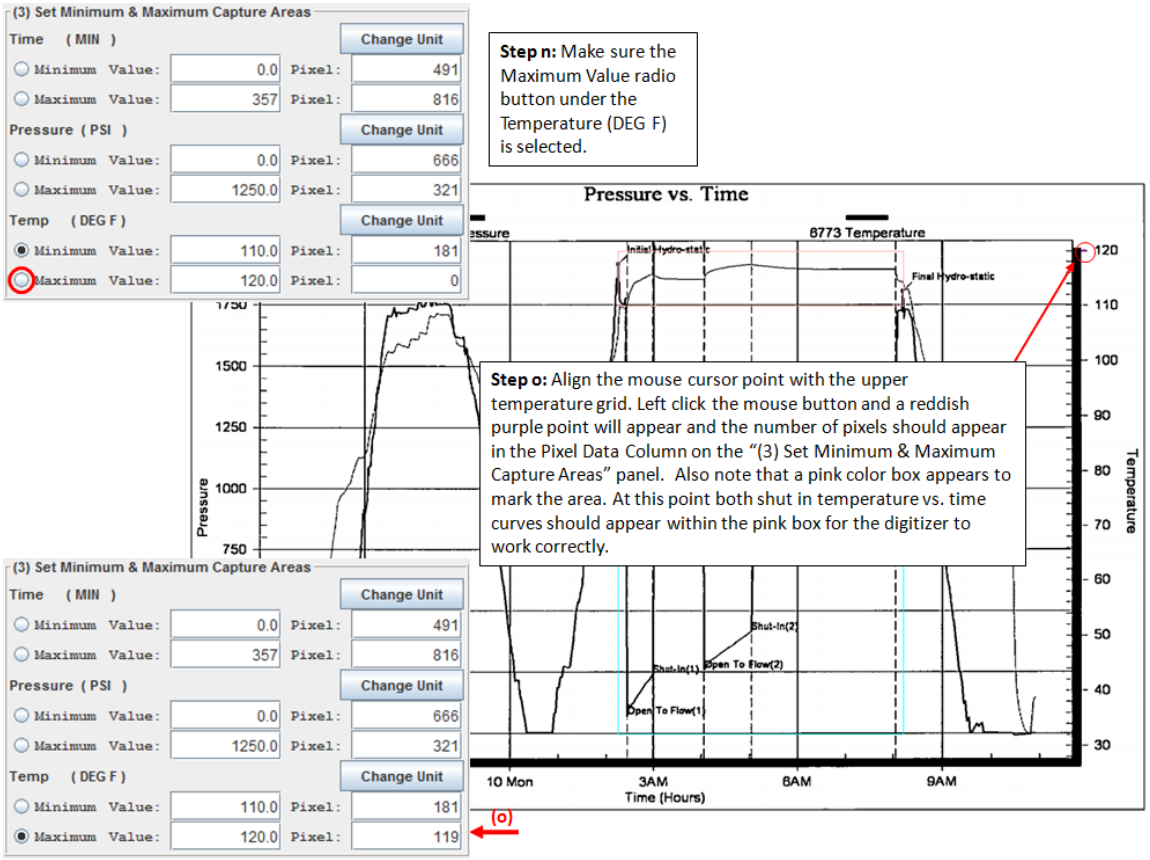


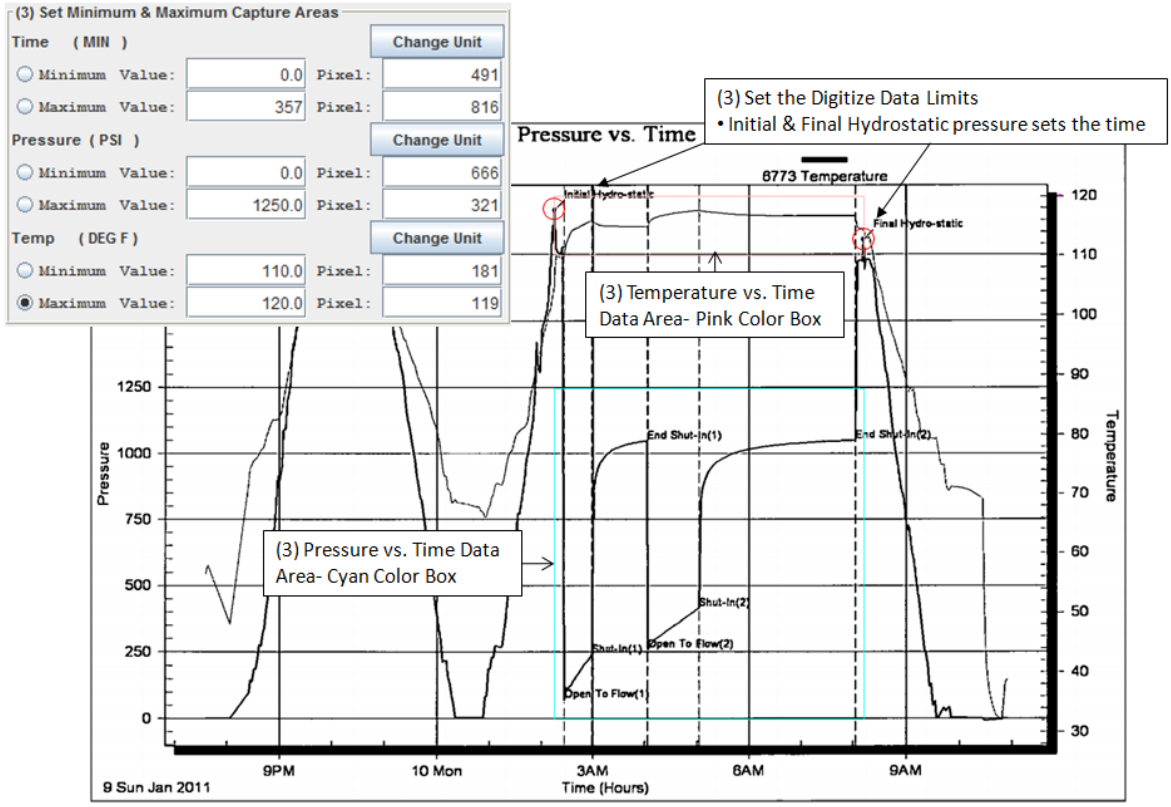
Step h: Make sure the Minimum Value radio button under the Pressure (PSI) is selected.

Step i: Align the mouse cursor point with the lower pressure grid. Left click the mouse button and a reddish purple point will appear and the number of pixels should appear in the Pixel Data Column on the "(3) Set Minimum & Maximum Capture Areas" panel. Also note that a cyan color box appears to mark the area.

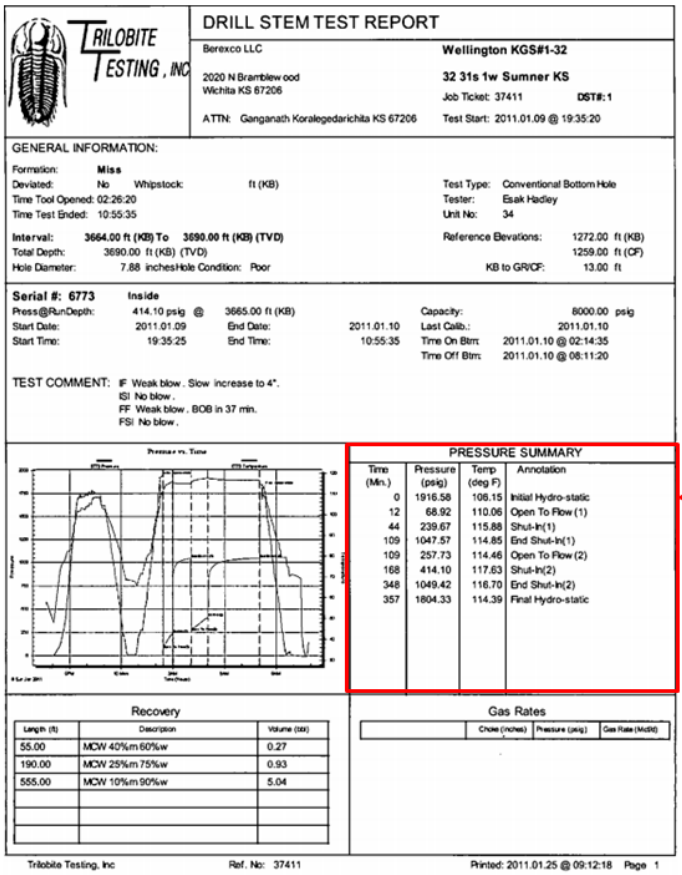

(3) Set Minimum & Maximum Capture Areas
Time (MIN)
Change Unit
Minimum Value: 0.0 Pixel: 491
Maximum Value: 357 Pixel: 816
Pressure (PSI)
Change Unit
Minimum Value: 0.0 Pixel: 666
Maximum Value: 1250.0 Pixel: 0
Temp (DEG F)
Change Unit
Minimum Value: 110.0 Pixel: 0
Maximum Value: 120.0 Pixel: 0
Step j: Make sure the Maximum Value radio button under the Pressure (PSI) is selected.
Step k: Align the mouse cursor point with the upper pressure grid. Left click the mouse button and a reddish purple point will appear and the number of pixels should appear in the Pixel Data Column on the "(3) Set Minimum & Maximum Capture Areas" panel. Also note that a cyan color box appears to mark the area. At this point both shut in pressure vs. time curves should appear within the cyan box for the digitizer to work correctly.
Pressure vs. Time
6773 Temperature
Initial Hydro-static
Final Hydro-static
End Shut-In(1)
Shut-In(2)
Open To Flow(2)
Shut-In(1)
Open To Flow(1)
1750
750
Temperature
120
110
100
90
80
70
60
50
40
30
10 Mon
3AM
6AM
9AM
Time (Hours)
(k)
Minimum Value: 0.0 Pixel: 491
Maximum Value: 357 Pixel: 816
Minimum Value: 0.0 Pixel: 666
Maximum Value: 1250.0 Pixel: 321
Minimum Value: 110.0 Pixel: 0
Maximum Value: 120.0 Pixel: 0


(3) Set Minimum & Maximum Capture Areas
Time (MIN)
Change Unit
Minimum Value: 0.0 Pixel: 491
Maximum Value: 357 Pixel: 816
Pressure (PSI)
Change Unit
Minimum Value: 0.0 Pixel: 666
Maximum Value: 1250.0 Pixel: 321
Temp (DEG F)
Change Unit
Minimum Value: 110.0 Pixel: 0
Maximum Value: 120.0 Pixel: 0
Step l: Make sure the Minimum Value radio button under the Temperature (DEG F) is selected.
Pressure vs. Time
6773 Temperature
Initial Hydro-static
Final Hydro-static
Step m: Align the mouse cursor point with the lower temperature grid. Left click the mouse button and a reddish purple point will appear and the number of pixels should appear in the Pixel Data Column on the "(3) Set Minimum & Maximum Capture Areas" panel. Also note that a pink color box appears to mark the area.
Pressure
1750
1500
1250
1000
750
Temperature
120
110
100
90
80
70
60
50
40
30
10 Mon
3AM
6AM
9AM
Time (Hours)
(m)
Shut-In(2)
Open To Flow(2)
Shut-In(1)
Open To Flow(1)
Minimum Value: 0.0 Pixel: 491
Maximum Value: 357 Pixel: 816
Minimum Value: 0.0 Pixel: 666
Maximum Value: 1250.0 Pixel: 321
Minimum Value: 110.0 Pixel: 181
Maximum Value: 120.0 Pixel: 0


(3) Set Minimum & Maximum Capture Areas
Time (MIN)
Change Unit
Minimum Value: 0.0 Pixel: 491
Maximum Value: 357 Pixel: 816
Pressure (PSI)
Change Unit
Minimum Value: 0.0 Pixel: 666
Maximum Value: 1250.0 Pixel: 321
Temp (DEG F)
Change Unit
Minimum Value: 110.0 Pixel: 181
Maximum Value: 120.0 Pixel: 0
Step n: Make sure the Maximum Value radio button under the Temperature (DEG F) is selected.
Pressure vs. Time
6773 Temperature
Initial Hydro-static
Final Hydro-static
Step o: Align the mouse cursor point with the upper temperature grid. Left click the mouse button and a reddish purple point will appear and the number of pixels should appear in the Pixel Data Column on the "(3) Set Minimum & Maximum Capture Areas" panel. Also note that a pink color box appears to mark the area. At this point both shut in temperature vs. time curves should appear within the pink box for the digitizer to work correctly.
Pressure
Temperature
Shut-In(2)
Open To Flow(2)
Shut-In(1)
Open To Flow(1)
10 Mon
3AM
6AM
9AM
Time (Hours)
(o)
Maximum Value: 120.0 Pixel: 119


(3) Set Minimum & Maximum Capture Areas
Time (MIN)
Change Unit
Minimum Value: 0.0 Pixel: 491
Maximum Value: 357 Pixel: 816
Pressure (PSI)
Change Unit
Minimum Value: 0.0 Pixel: 666
Maximum Value: 1250.0 Pixel: 321
Temp (DEG F)
Change Unit
Minimum Value: 110.0 Pixel: 181
Maximum Value: 120.0 Pixel: 119
(3) Set the Digitize Data Limits
• Initial & Final Hydrostatic pressure sets the time
Pressure vs. Time
6773 Temperature
Initial Hydro-static
Final Hydro-static
(3) Temperature vs. Time Data Area- Pink Color Box
End Shut-In(1)
End Shut-In(2)
(3) Pressure vs. Time Data Area- Cyan Color Box
Shut-In(2)
Open To Flow(2)
Shut-In(1)
Open To Flow(1)
Pressure
Temperature
9PM
10 Mon
3AM
6AM
9AM
9 Sun Jan 2011
Time (Hours)

(4) Add Pressure/Temperature Summary Data



TRILOBITE TESTING, INC

DRILL STEM TEST REPORT

Berexco LLC
2020 N Bramblewood
Wichita KS 67206

Wellington KGS#1-32
32 31s 1w Sumner KS
Job Ticket: 37411 DST#: 1
ATTN: Ganganath Koralegedarichita KS 67206
Test Start: 2011.01.09 @ 19:35:20

GENERAL INFORMATION:

Formation: Miss
Deviated: No Whipstock: ft (KB)
Time Tool Opened: 02:26:20
Time Test Ended: 10:55:35
Interval: 3664.00 ft (KB) To 3690.00 ft (KB) (TVD)
Total Depth: 3690.00 ft (KB) (TVD)
Hole Diameter: 7.88 inches Hole Condition: Poor
Test Type: Conventional Bottom Hole
Tester: Esak Hadley
Unit No: 34
Reference Elevations: 1272.00 ft (KB)
1259.00 ft (CF)
KB to GR/CF: 13.00 ft

Serial #: 6773 Inside
Press@RunDepth: 414.10 psig @ 3665.00 ft (KB)
Start Date: 2011.01.09 End Date: 2011.01.10
Start Time: 19:35:25 End Time: 10:55:35
Capacity: 8000.00 psig
Last Calib.: 2011.01.10
Time On Btm: 2011.01.10 @ 02:14:35
Time Off Btm: 2011.01.10 @ 08:11:20

TEST COMMENT: IF Weak blow. Slow increase to 4".
ISI No blow.
FF Weak blow. BOB in 37 min.
FSI No blow.

PRESSURE SUMMARY

Time (Min.)	Pressure (psig)	Temp (deg F)	Annotation
0	1916.58	106.15	Initial Hydro-static
12	68.92	110.06	Open To Flow (1)
44	239.67	115.88	Shut-In(1)
109	1047.57	114.85	End Shut-In(1)
109	257.73	114.46	Open To Flow (2)
168	414.10	117.63	Shut-In(2)
348	1049.42	116.70	End Shut-In(2)
357	1804.33	114.39	Final Hydro-static

Recovery

Length (ft)	Description	Volume (bbl)
55.00	MCW 40%m 60%w	0.27
190.00	MCW 25%m 75%w	0.93
555.00	MCW 10%m 90%w	5.04

Gas Rates

	Choke (inches)	Pressure (psig)	Gas Rate (McfD)

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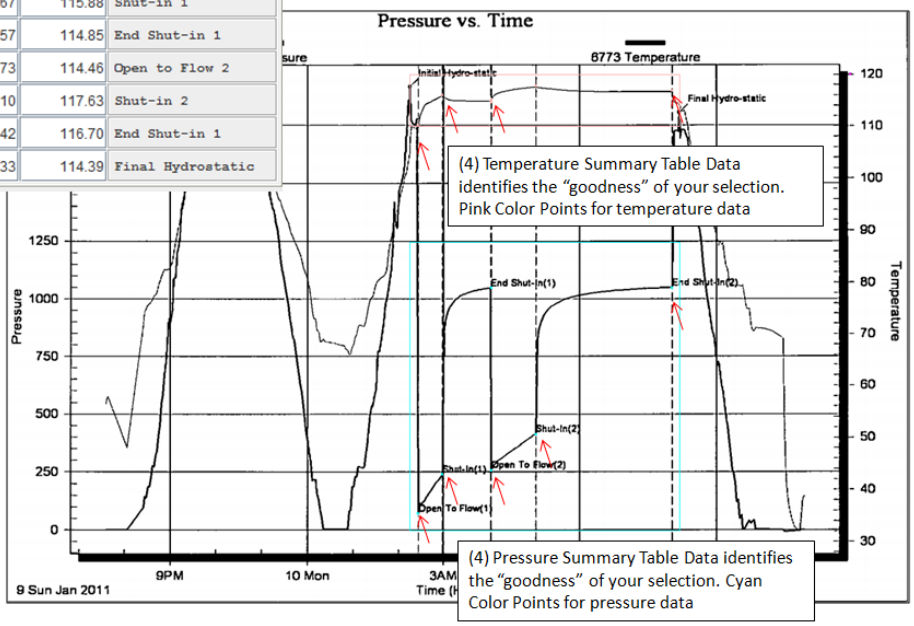
(4) Add Pressure Summary Data

Time (MIN)	Pressure (PSI)	Temp (DEG F)	Annotation
0.0	0.0	0.0	Initial Hydrostatic
0.0	0.0	0.0	Open to Flow 1
0.0	0.0	0.0	Shut-in 1
0.0	0.0	0.0	End Shut-in 1
0.0	0.0	0.0	Open to Flow 2
0.0	0.0	0.0	Shut-in 2
0.0	0.0	0.0	End Shut-in 1
0.0	0.0	0.0	Final Hydrostatic

(a) **Step a:** Identify the Pressure Summary Table Data on the Drill Stem Test Report. Enter the Pressure Summary Table Data into the "(4) Add Pressure Summary Data" Panel Text fields. The "(4) Add Pressure Summary Data" Panel data will be transferred to the DST Data Entry Dialog at the end.

(4) Add Pressure Summary Data

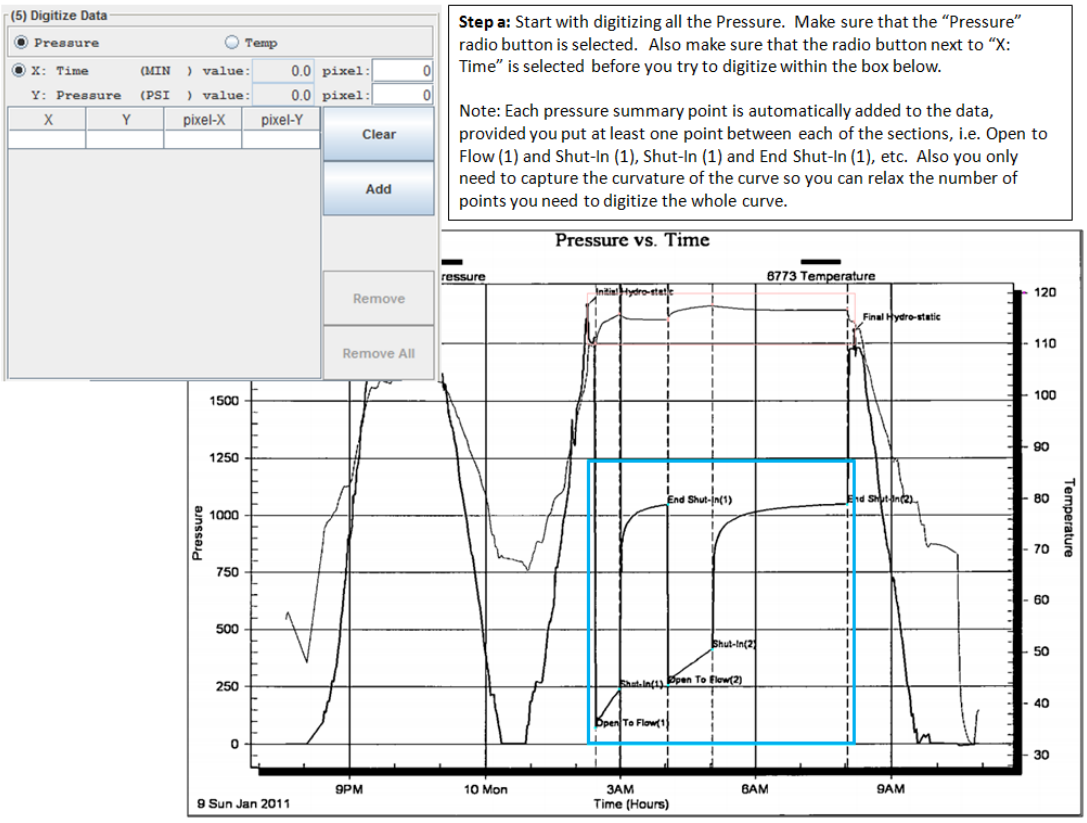
Time (MIN)	Pressure (PSI)	Temp (DEG F)	Annotation
0	1916.58	106.15	Initial Hydrostatic
12	68.92	110.06	Open to Flow 1
44	239.67	115.88	Shut-in 1
109	1047.57	114.85	End Shut-in 1
109	257.73	114.46	Open to Flow 2
168	414.10	117.63	Shut-in 2
348	1049.42	116.70	End Shut-in 1
357	1804.33	114.39	Final Hydrostatic



(4) Temperature Summary Table Data identifies the "goodness" of your selection. Pink Color Points for temperature data

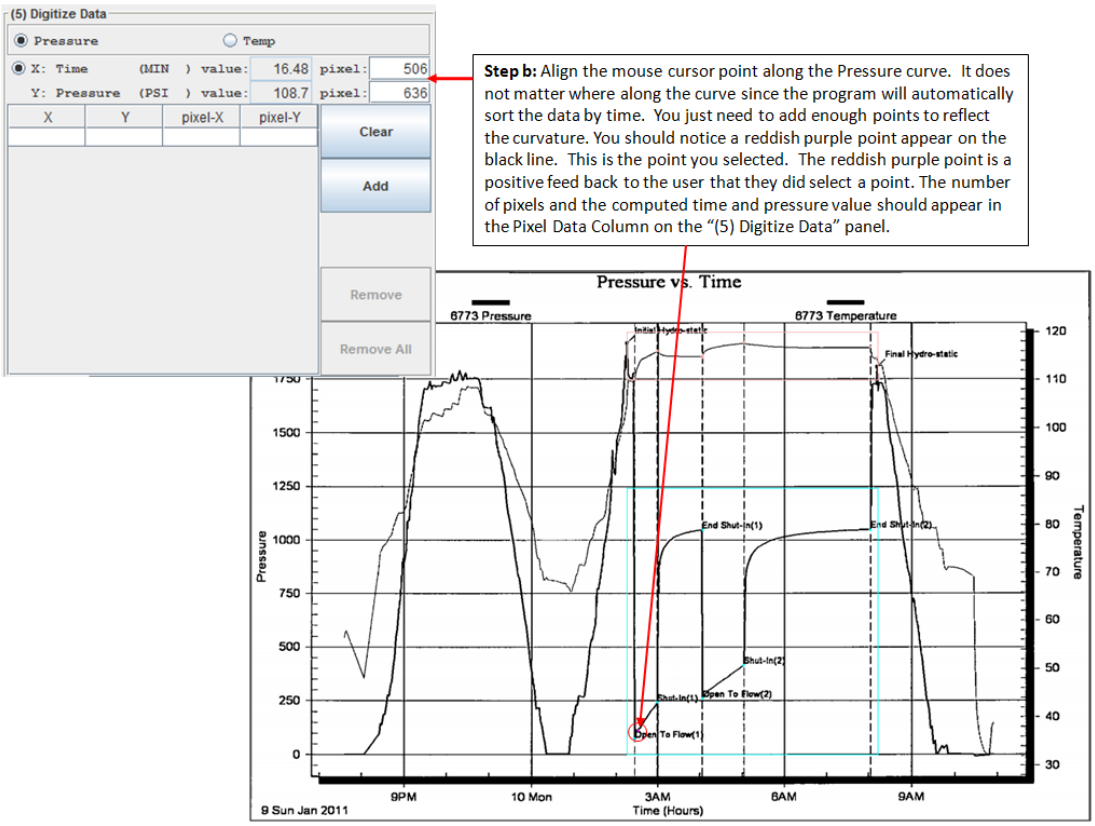
(4) Pressure Summary Table Data identifies the "goodness" of your selection. Cyan Color Points for pressure data

(5) Digitize Data - Pressure

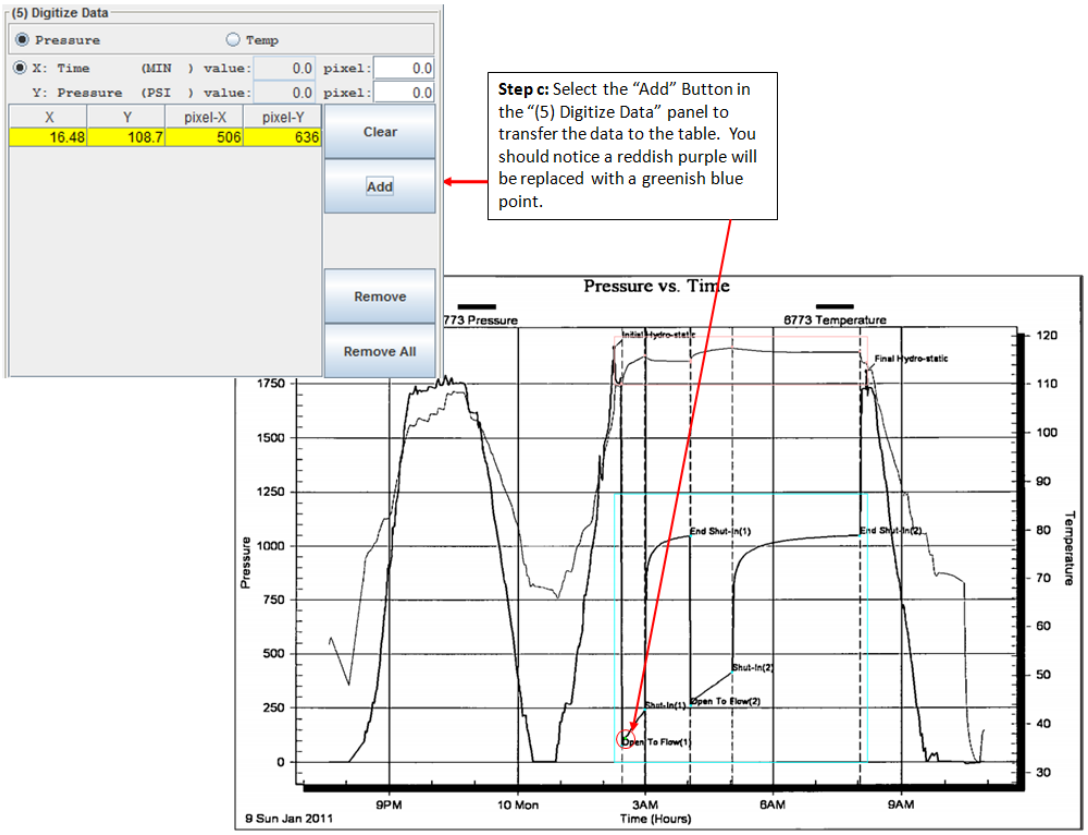


Step a: Start with digitizing all the Pressure. Make sure that the "Pressure" radio button is selected. Also make sure that the radio button next to "X: Time" is selected before you try to digitize within the box below.

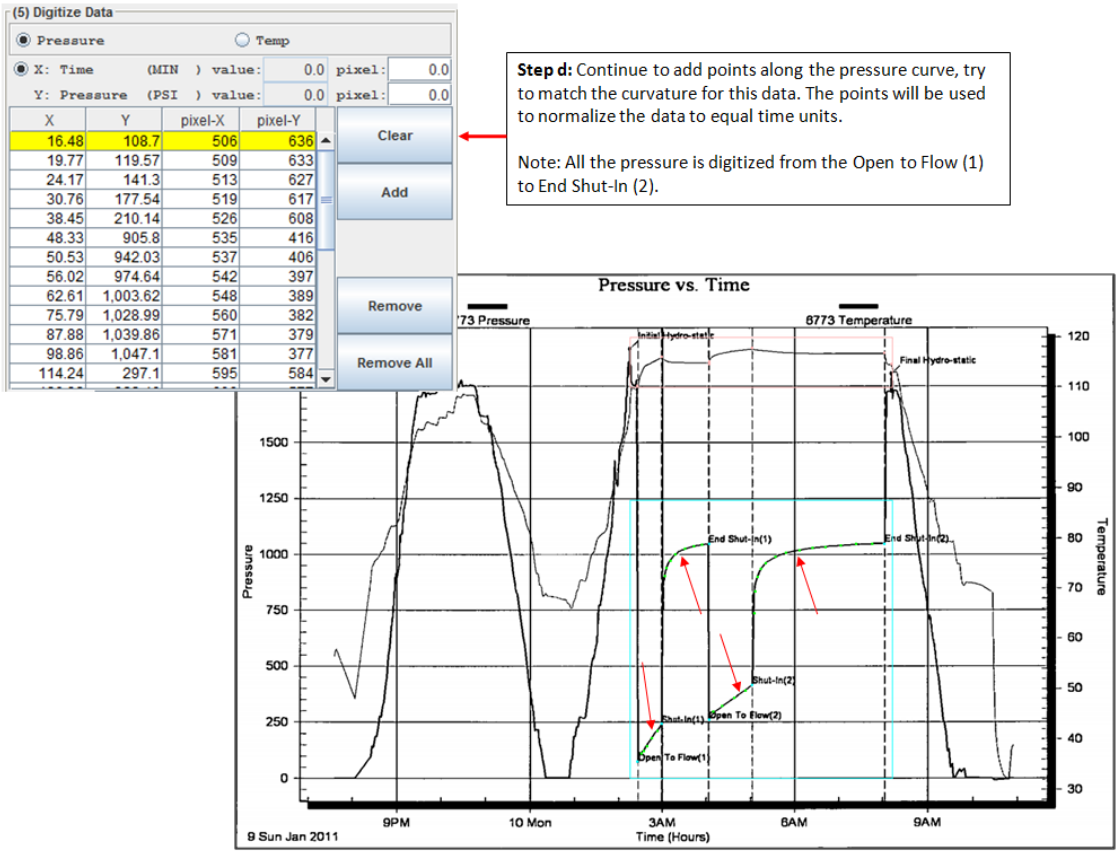
Note: Each pressure summary point is automatically added to the data, provided you put at least one point between each of the sections, i.e. Open to Flow (1) and Shut-In (1), Shut-In (1) and End Shut-In (1), etc. Also you only need to capture the curvature of the curve so you can relax the number of points you need to digitize the whole curve.



Step b: Align the mouse cursor point along the Pressure curve. It does not matter where along the curve since the program will automatically sort the data by time. You just need to add enough points to reflect the curvature. You should notice a reddish purple point appear on the black line. This is the point you selected. The reddish purple point is a positive feed back to the user that they did select a point. The number of pixels and the computed time and pressure value should appear in the Pixel Data Column on the "(5) Digitize Data" panel.



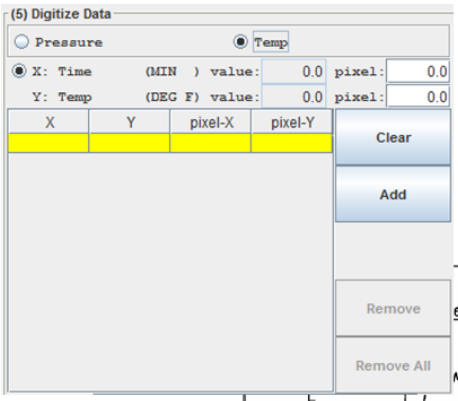
Step c: Select the "Add" Button in the "(5) Digitize Data" panel to transfer the data to the table. You should notice a reddish purple will be replaced with a greenish blue point.



Step d: Continue to add points along the pressure curve, try to match the curvature for this data. The points will be used to normalize the data to equal time units.

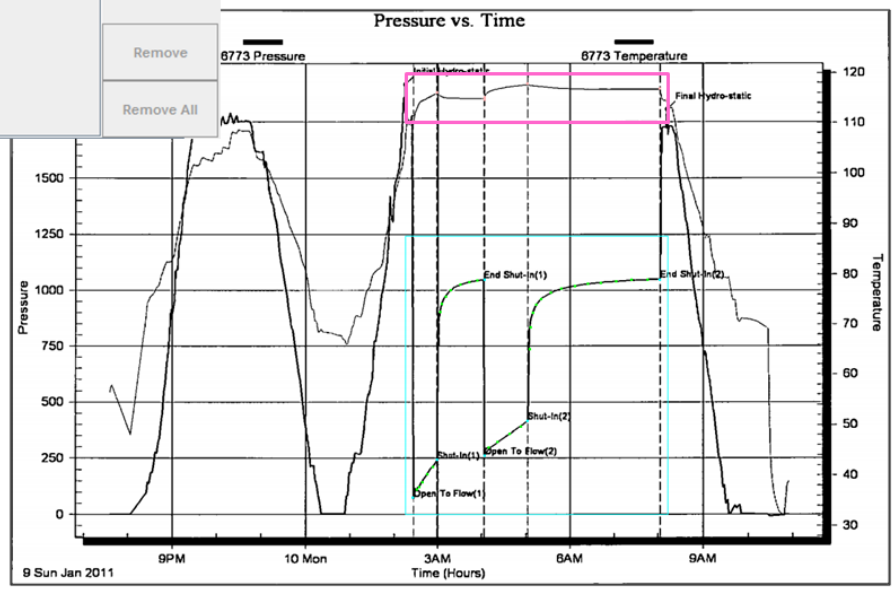
Note: All the pressure is digitized from the Open to Flow (1) to End Shut-In (2).

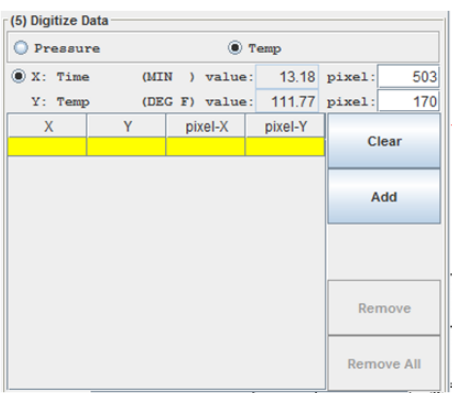
(5) Digitize Data – Temperature



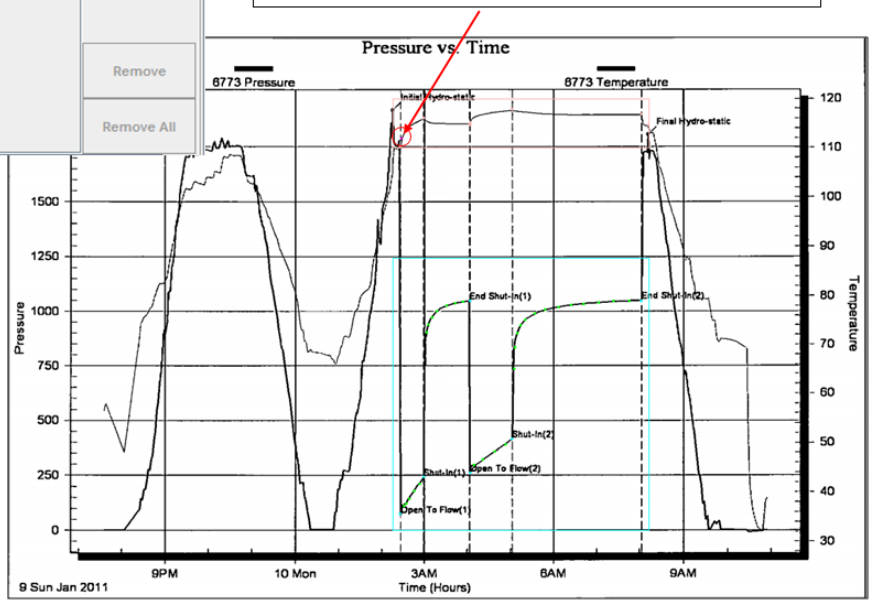
Step e: Now digitize the Temperature. Make sure that the "Temp" radio button is selected. Also make sure that the radio button next to "X: Time" is selected before you try to digitize within the box below.

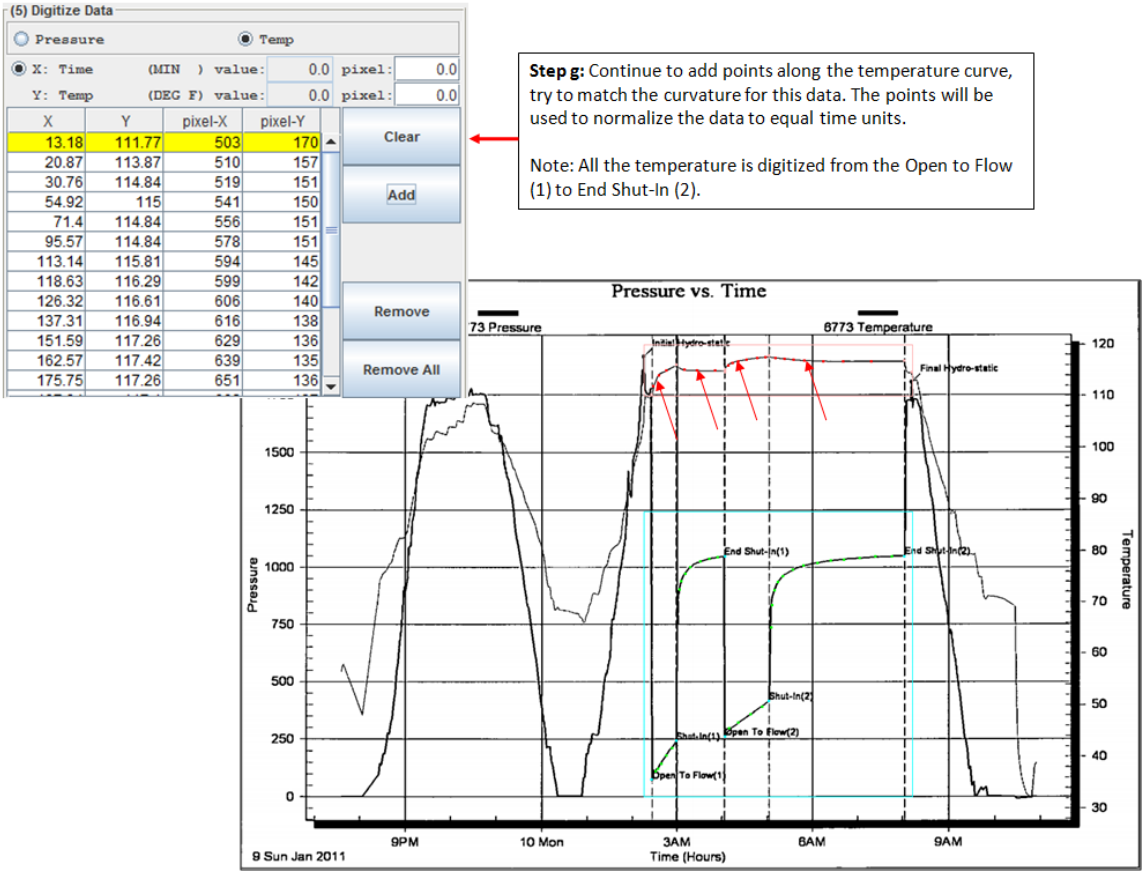
Note: Each temperature summary point is automatically added to the data, provided you put at least one point between each of the sections, i.e. Open to Flow (1) and Shut-In (1), Shut-In (1) and End Shut-In (1), etc. Also you only need to capture the curvature of the curve so you can relax the number of points you need to digitize the whole curve.





Step f: Align the mouse cursor point along the Temperature curve. It does not matter where along the curve since the program will automatically sort the data by time. You just need to add enough points to reflect the curvature. You should notice a red point appear on the black line. This is the point you selected. The red point is a positive feed back to the user that they did select a point. The number of pixels and the computed time and temperature value should appear in the Pixel Data Column on the "(5) Digitize Data" panel.

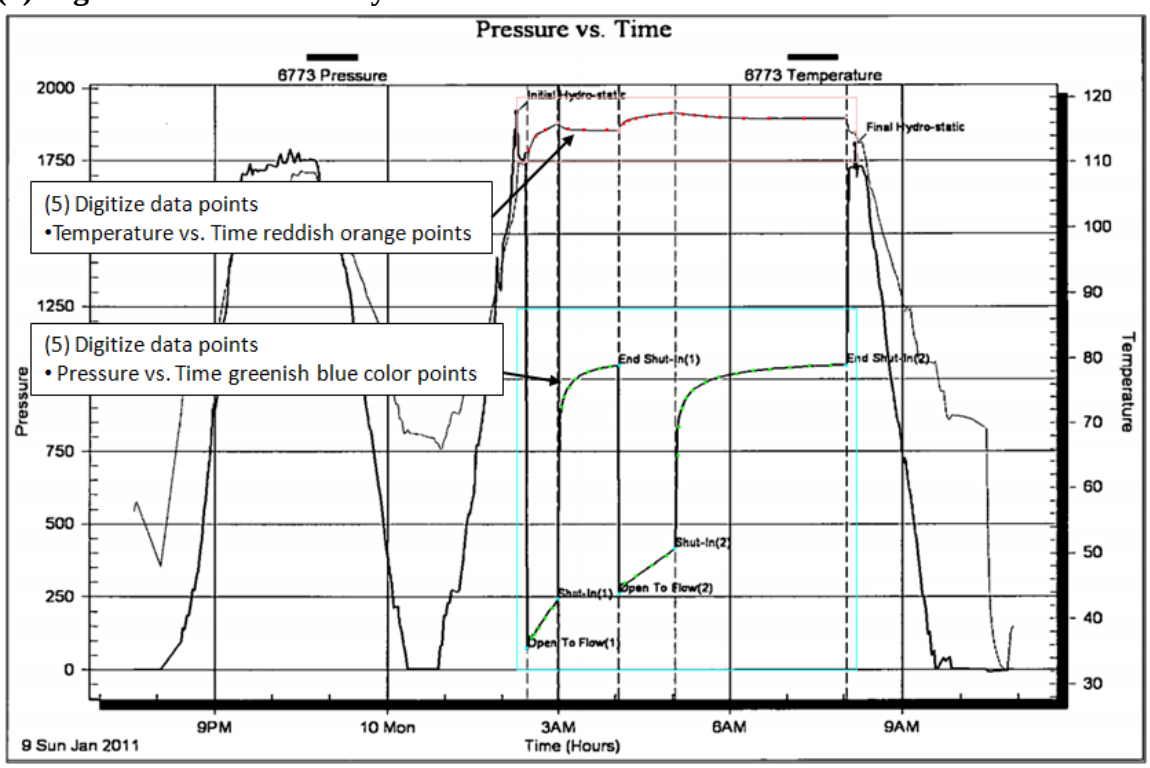




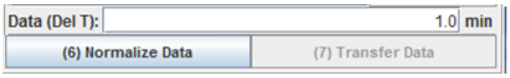
Step g: Continue to add points along the temperature curve, try to match the curvature for this data. The points will be used to normalize the data to equal time units.

Note: All the temperature is digitized from the Open to Flow (1) to End Shut-In (2).

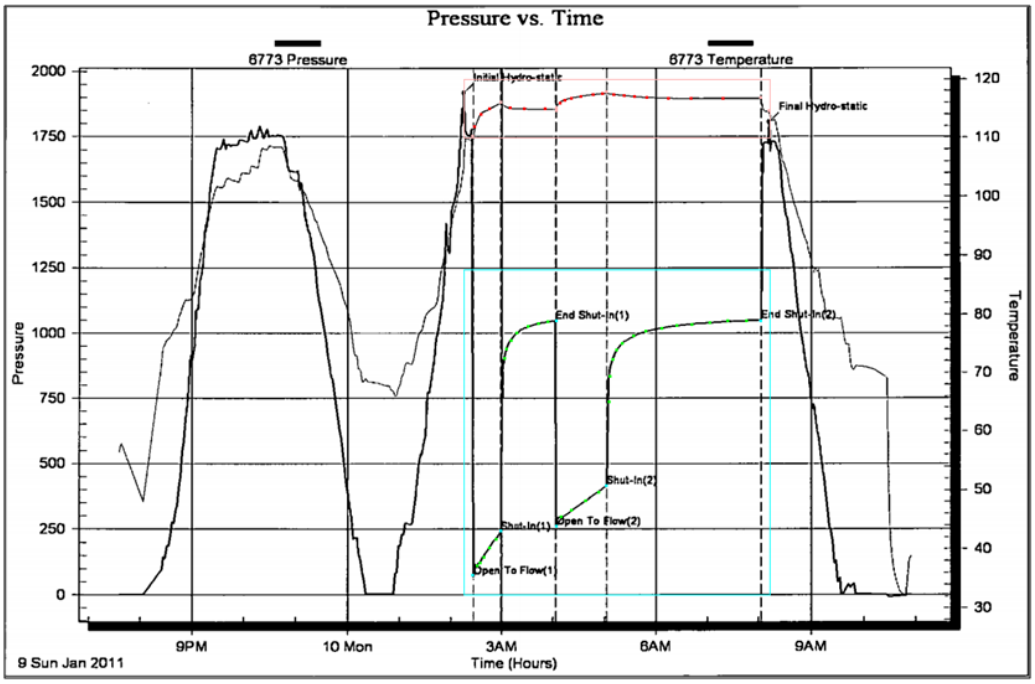
(5) Digitize Data – Summary

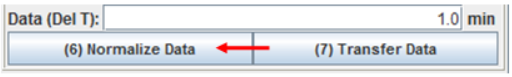


(6) Normalize Data

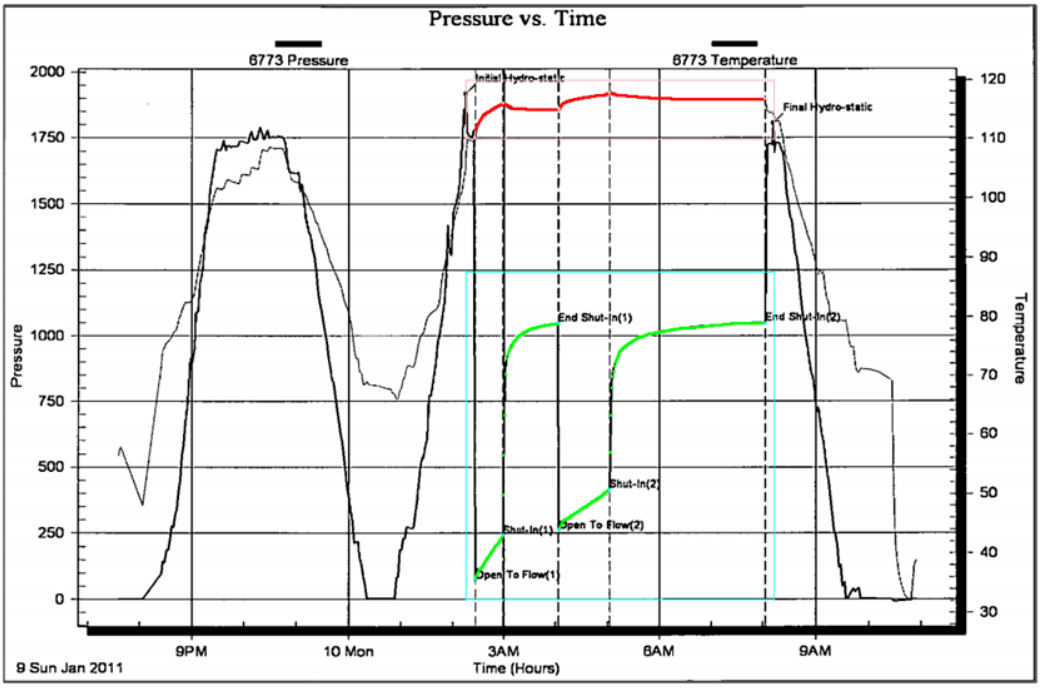


Step a: The next thing is to normalize the pressure-temperature-time data so the data is recomputed at equal time spacing. The user can set the number of minutes between each data point.



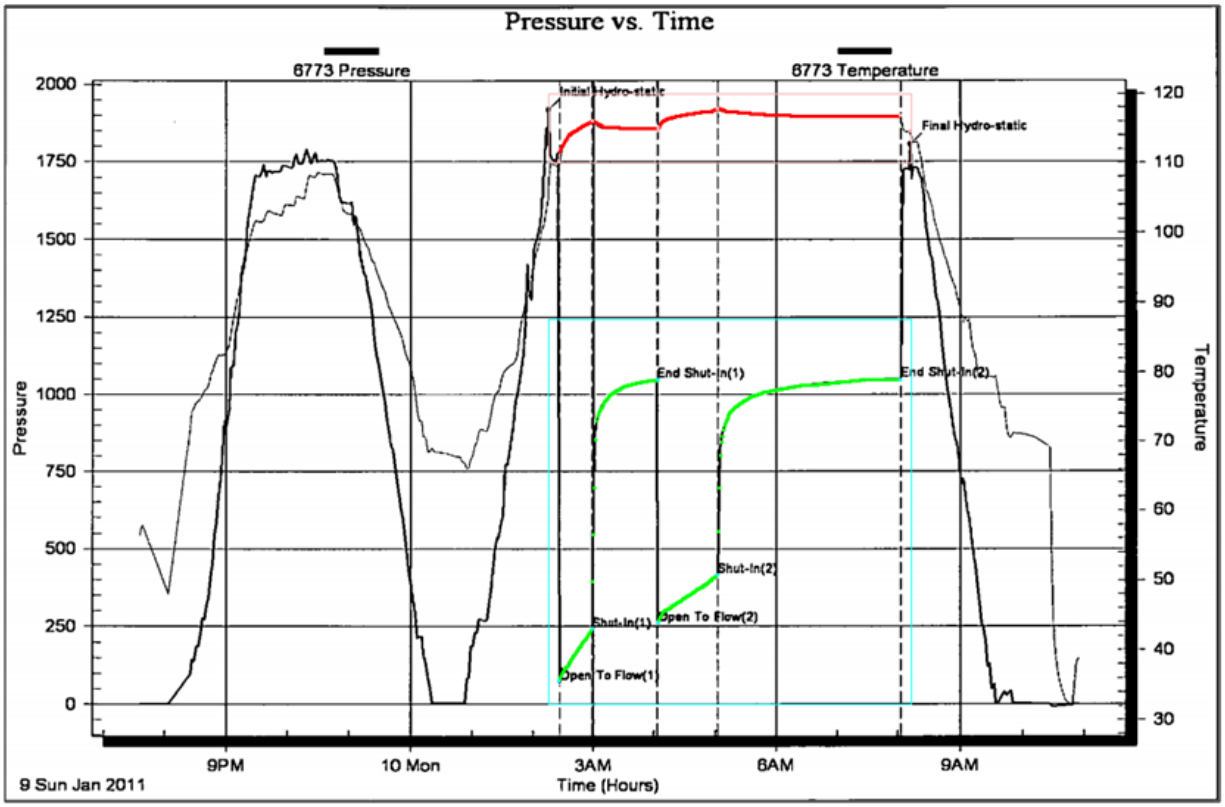


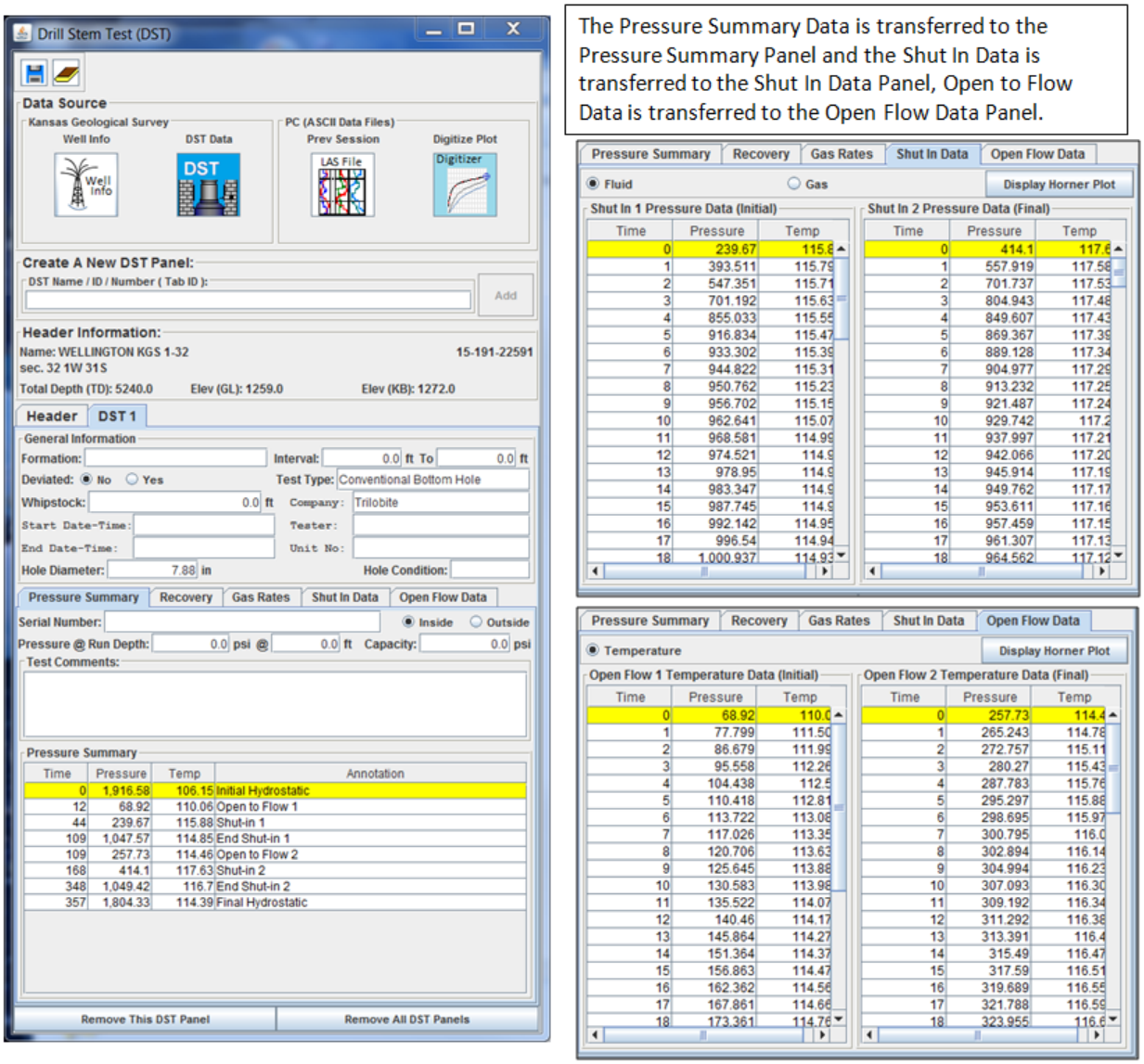
Step b: For this example I am selecting the sampling of the Data to be every 1.0 minute. Select the "(6) Normalize Data" Button and the program will compute the data every 1.0 minute.



(7) Transfer Data

This is the last step, just select the "(7) Transfer Data" Button to move the data from the digitizer to the DST Data Entry Panels. The digitizer will then close.





The Pressure Summary Data is transferred to the Pressure Summary Panel and the Shut In Data is transferred to the Shut In Data Panel, Open to Flow Data is transferred to the Open Flow Data Panel.

To display the “Horner Plot and Quantitative Analysis” dialog click on the “Display Horner Plot” button in the “Shut-In Data” panel.

Horner Plot – Fluid DST

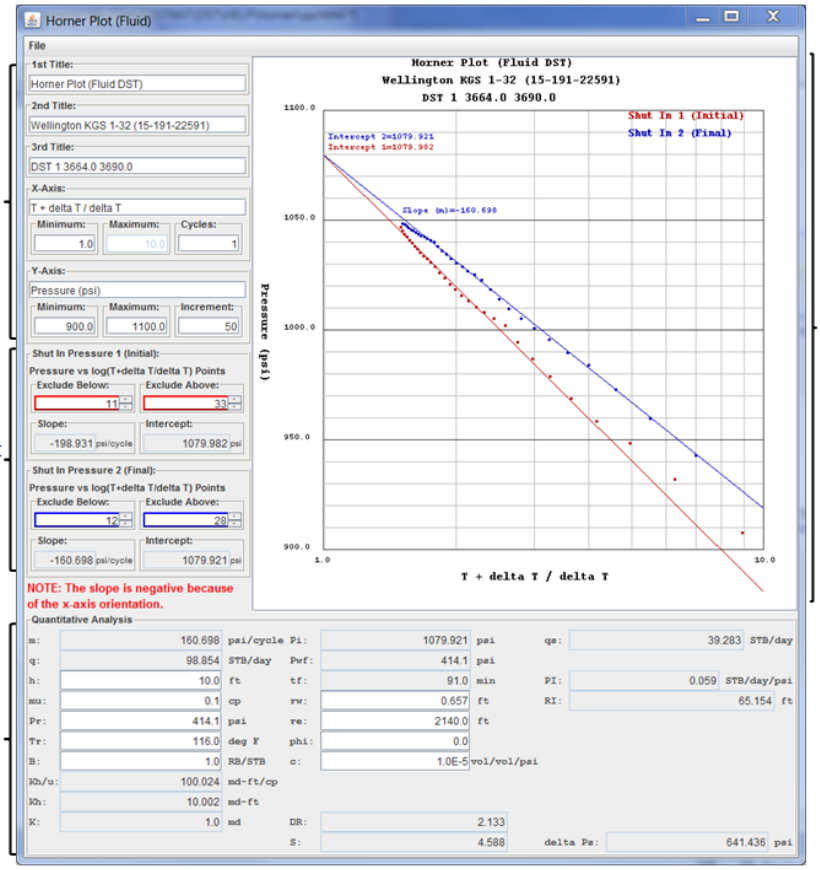
Horner Plot – Fluid DST

Click on the "Display Horner Plot" button on the "Shut In Pressure Data" Panel

Plot Parameters. The user can modify the titles to the Horner plot, the Axis Labels and the Axis. The program uses the data to determine initial values.

The spinner text fields allow the user to vary the slope and intercept for both shut in data. This version allows the user to exclude points from both ends of the data set.

Quantitative Analysis Panel allows the user to obtain reservoir parameters based on the results from the Horner plot analysis.



Horner plot a semi log plot of Pressure vs. dimensionless time function (or simply Horner Time) for a fluid DST. For a Gas DST it becomes a semi log plot of Pressure squared vs. Horner Time.

Much of this section is taken from the lecture notes "Modern Concepts in Drill Stem Testing Part 2 Quantitative Analysis"[2] by Hugh W. Read, Author & Instructor.

Conventional Horner Type Pressure Buildup Analysis Conditions Assumed for Analysis Procedure

For a discussion of the theory of pressure buildup interpretation and the derivation of the pertinent equations the reader is referred to the original now classical paper by Horner[(1)].

90% of all quantitative Drill Stem Test analysis is based on Horner's method of analysis which assumes the following ideal conditions:

i) Radial flow -Radial flow is flow into the well bore equally from all directions in the formation. By and large condition is met by most DST's through linear systems such as fractures, narrow channel sands etc. are obvious exception which may be handled separately.

ii) Homogeneous Reservoir - Homogeneity in a reservoir denotes constant characteristics throughout the length and thickness. Any values calculated from test data then become averages over the length and/or thickness.

iii) "Steady-State" conditions of flow - "Steady-state" flow conditions imply a rate and pressure drawdown (which is responsible for the flow) which is constant.

iv) Infinite Reservoir - An infinite reservoir is one in which there are no finite limits or depletion. All DST's in wildcat wells can be considered to test infinite reservoirs, except those testing very small local porosity or fracture developments which in any event deplete rapidly and are not commercial.

v) Single Phase Flow - Single phase flow assumes that only one phase is entering the well bore. Thus for example any gas produced with oil is considered as solution gas and any liquids in a gas test are considered as condensation of gases in the pipe or immediate well bore vicinity.

Method of Construction of Horner plot - Fluid Drill Stem Test

This example is from the Wellington KGS 1-32; DST 1 in the Mississippian from 3664.0 ft to 3690.0 ft dst-fluid.las. The Recovery and Pressure Summary Data will be needed in performing the horner plot and quantitative analysis and is listed as follows,

Recovery Table		
Length (ft)	**Volume (bbl)**	**Description**
55.0	0.27	MCW 40%m 60%w
190.0	0.934	MCW 25%m 75%w
555.0	5.043	MCW 10%m 90%w
_____	_____	
800.0	6.247	Totals

Pressure Summary Table			
Time	**Pressure**	**Temperature**	**Annotation**
(min)	**(psig)**	**(deg F)**	
0.0	1916.58	106.15	Initial Hydrostatic
12.0	68.92	110.06	Open to Flow 1
44.0	239.67	115.88	Shut-in 1
109.0	1047.57	114.85	End Shut-in 1
109.0	257.73	114.46	Open to Flow 2
168.0	414.1	117.63	Shut-in 2
348.0	1049.42	116.7	End Shut-in 2
357.0	1804.33	114.39	Final Hydrostatic

(1) The data necessary for this plot is a set of detailed readings of pressures and times during each shut in period plus the total amount of time spent flowing the well.

(2) Arrange the data in tabular form where,

T = Cumulative flowing time (minutes)
ΔT = Times during shut in that each pressure is read (minutes)
P = Pressure read during shut in time (psig)

Table 3 Tabular Listing of Shut In Data for Horner Plot Calculation

Shut In 1 (Initial)			
Total Flow Time (T) = 32 minutes[a]			
Time (ΔT) (min)	(T+ΔT)/ΔT	Pressure (P) (psig)	Temperature (deg F)
0.0	---	239.67	115.88
4.0	9.00	904.76	115.56
8.0	5.00	950.75	115.24
12.0	3.67	970.32	114.92
16.0	3.00	986.51	114.87
20.0	2.60	1001.44	114.83
24.0	2.33	1008.28	114.78
28.0	2.14	1014.37	114.74
32.0	2.00	1020.47	114.69
36.0	1.89	1026.49	114.64
40.0	1.80	1029.39	114.64
44.0	1.73	1032.30	114.67
48.0	1.67	1035.21	114.71
52.0	1.62	1038.12	114.74
56.0	1.57	1041.03	114.77
60.0	1.53	1043.93	114.81
64.0	1.50	1046.84	114.84

Shut In 2 (Final)			
Total Flow Time (T) = 59 + 32 = 91 minutes[b]			
Time (ΔT) (min)	(T+ΔT)/ΔT	Pressure (P) (psig)	Temperature (deg F)
0.0	---	414.1	117.63
8.0	12.38	905.06	117.44
16.0	6.69	946.13	117.25
24.0	4.79	967.73	117.07
32.0	3.84	985.14	116.89
40.0	3.28	996.56	116.76
48.0	2.90	1006.962	116.63
56.0	2.63	1012.76	116.50
64.0	2.42	1018.56	116.46
72.0	2.26	1022.48	116.46
80.0	2.14	1025.96	116.46
88.0	2.03	1029.44	116.46
96.0	1.95	1032.92	116.46
104.0	1.88	1034.80	116.46
112.0	1.81	1036.54	116.47
120.0	1.76	1038.28	116.506
128.0	1.71	1040.01	116.537
136.0	1.67	1041.46	116.55
144.0	1.63	1042.91	116.58
152.0	1.60	1044.35	116.619
160.0	1.57	1045.80	116.63
168.0	1.54	1047.25	116.66
176.0	1.52	1048.70	116.69

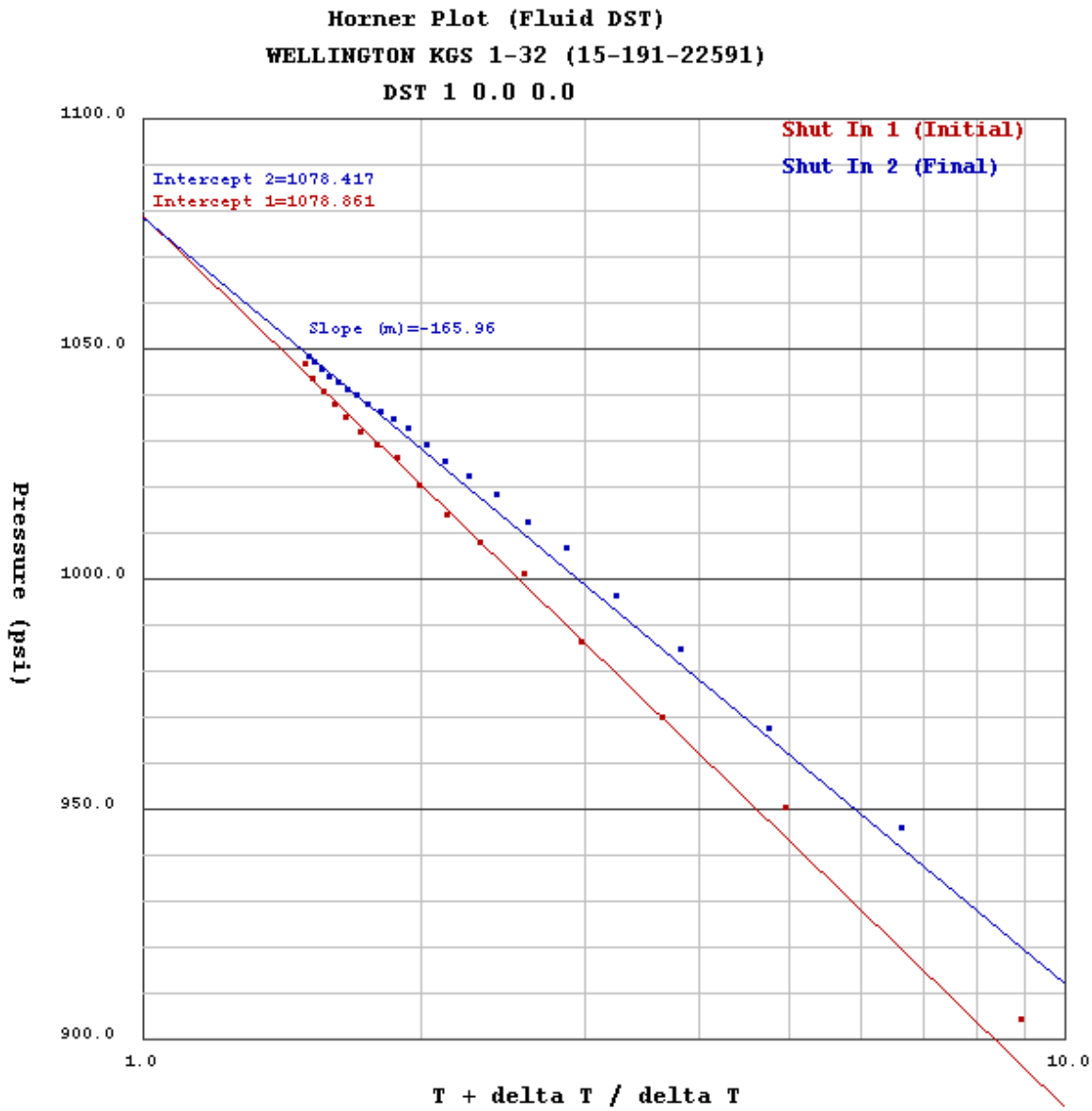
From the Pressure Summary Table
(a) Shut-in 1 Time - Open to Flow 1 Time { 44.0 - 12.0 = 32.0 minutes }
(b) Shut-in 2 Time - Open to Flow 2 Time + Total Flow Time from (a) { 168.0 - 109.0 + 32.0 = 91.0 minutes }

In the table note that the Shut-In 1 (Initial) period was broken down into 4 minute intervals while only 8 minute increments was considered sufficient for the Shut-In 2 (Final) period.

The Pressure Summary Table gives a summary of the DST Pressure-Temperature-Time Readings at specific points. This DST had a 32.0 minute pre flow and a 59.0 minute main flow. Thus 'T' for the Shut-In 1 (Initial) period = 32.0 minutes since there was a total of 32 minutes flow time prior to Shut-In 1 (Initial). T for the Shut-In 2 (Final) period becomes 91 minutes (32 minutes pre flow + 59 minutes main flow since T is the cumulative flow time prior to shut in.

The quantity (T + ΔT)/ΔT is mathematically the same as 1 + (T/ΔT) thus for the Shut In 2 (Final) period example the (T + ΔT)/ΔT for the first increment = (91+8)/8 = 12.38, which is the same as 1 + (91/8) = 1 + 11.38 = 12.38.

(3) The Horner plot is then constructed by plotting $\log_{10}[(T+\Delta T)/\Delta T]$ vs. P for each point.



(4) In figure above both Shut-In Pressure-Time curves have been plotted. In order to determine the static reservoir pressure the linear portion is extrapolated to the left hand margin where the value of the time function (T + ΔT)/ΔT = 1. Since the logarithm of 1 is zero the $\log_{10}[(T + \Delta T)/\Delta T] = 0$ (or infinity) at this point. Thus we are extrapolating the Horner straight line to a 'infinite' shut in time where completely static pressure prevails. In the example here the static pressure ~ 1078.0 psig. Both Shut In intervals extrapolations yield this value. In cases where the

Shut-In 2 (Final) extrapolation is substantially less than the Shut-In 1 (Initial) depletion is indicated. (If the depletion factor 100.0 * Shut-In [(Initial)-(Final))/(Initial)] is greater than 4%, then the indications of depletion can be considered serious or substantial.

(5) The final piece of information which is obtained from the Horner plot is the "slope" (m) of the straight line segment. Numerically this is the difference between the pressure at $\log_{10}[(T + \Delta T)/\Delta T]=0$ and at $\log_{10}[(T + \Delta T)/\Delta T]=1$, where the slope is simply the change in pressure over one complete log cycle. The slope in this example using the Shut-In (Final) slope m=165.96 psi/cycle. The slope is used in the calculations to derive permeability and other reservoir parameters.

Transmissibility (K*h/μ), Permeability Thickness (K*h), Permeability (K)

The well known equation describing pressure build-up characteristics of a well is expressed as

Theoretically, the plot of Pressure Po vs. $\log_{10}[(T+\Delta T)/\Delta T]$ will result in a straight line;
$Po = Pf - m * \log_{10}[(T+\Delta T)/\Delta T]$

where

Pf is the extrapolation of $\log_{10}[(T+\Delta T)/\Delta T]$ to zero or formation pressure and
m is the slope of the line.

m = 162.6 * q * μ * B / (K * h) [psi] / [log cycle]
q = flow rate [STB] / [day]
μ = viscosity [cp]
B = Formation Volume Factor [RB] / [STB]
h = vertical thickness of continuous porosity [ft]
K = average effective permeability [md]

This states that the slope of the buildup is representative of a given fluid having physical properties μ, B flowing at a rate q through a formation having physical properties K * h.

Note: the flow rate (q) is computed by using the total fluid volume in the recovery table and the total flow time computed from the pressure summary table and converting to days, i.e. q = (Total Fluid Volume [bbls] / Total Flow Time [min]) * (60 [min] / [hr]) * (24 [hr] / [day]).

Transmissibility can be found my rearranging the slope as follows,

Transmissibility:	K * h / μ = 162.6 * q * B / m	[md]-[ft]/[cp]
Permeability Thickness:	K * h = (Transmissibility) * μ	[md]-[ft]
Permeability:	K = (Permeability Thickness) / h	[md]

Damage Ratio (DR), Skin factor (S), and related quantities

Damage Ratio (DR) - A numerical value used to predict the flow rate if the damage were removed. In essence the DR becomes a number which when multiplied by the flow rate which existed at the time of the test will yield the flow rate if the damage (or improvement) over the natural condition is removed. This flow rate will be the rate at the same flowing pressure drawdown which existed during the test. From the definition of DR if a zone is neither damaged nor improved then q theoretical is identical to q actual and DR = 1.

$$DR = \frac{P_i - P_{wf}}{m * \log\{[k * T_o / (\phi * \mu * c * r_w^2)]\}} - 2.85$$

where,

P_i	= Initial static reservoir pressure	[psig]
P_{wf}	= Bottom Hole Flowing Pressure (FFP)	[psig]
m	= slope from the Horner plot	[psi] / [log cycle]
K	= Permeability (K)	[md]
T_o	= Flow Time	[min]
φ	= Porosity	
μ	= viscosity	[cp]
c	= compressibility	[vol]/[vol]/[psi]
r_w	= well bore radius	[ft]

If K, φ, μ, c and r_w are not known then the Damage Ratio can be estimated by,

$$EDR = \frac{P_i - P_{wf}}{m * \log\{T_o\}} + 2.65$$

Skin factor (S) - A numerical quantity which attempts to describe the amount of damage or improvement. The numerical value of skin is so defined that a positive value for the skin factor indicates a damaged condition and a negative skin factor indicates improvement over the natural condition. The skin factor is zero when neither skin damage nor improvement are present i.e. no alterations to natural condition.

$$S = 1.1515 * \frac{P_i - P_{wf}}{m} - \log\left[\frac{k * T_o}{\phi * \mu * c * r_w^2}\right] + 5.01$$

where,

P_i	= Initial static reservoir pressure	[psig]
P_{wf}	= Bottom Hole Flowing Pressure (FFP)	[psig]

m	= slope from the Horner plot	[psi] / [log cycle]
K	= Permeability (K)	[md]
T_o	= Flow Time	[min]
φ	= Porosity	
μ	= viscosity	[cp]
c	= compressibility	[vol]/[vol]/[psi]
r_w	= well bore radius	[ft]

If φ, μ, c and r_w are not known then the Skin factor (S), assuming average values of φ=0.15, μ*c=0.00000955 [cp]/[psi] and for simplicity assume r_w=0.333 [ft], can be estimated by,

$$S = 1.1515 * \frac{P_i - P_{wf}}{m} - \log(k * T_o) + 1.80$$

Pressure Drop Across a Damage Zone ΔP_{skin} The additional pressure drop during flow caused by the presence of skin (ΔP_{skin}) may be calculated as follows,

$\Delta P_{skin} = 0.87 * S * m$

where,

S = Skin factor

m = slope from the Horner plot [psi] / [log cycle]

Productivity Index (PI) Productivity Index is a measure of a zone's ability to flow at a particular drawdown (reservoir pressure - flowing pressure). It may be formally defined as the flow rate [STB]/[day] per unit [psi] of pressure differential between the well bore at the formation face and the static reservoir pressure in the zone.

$$PI = 0.00708 \frac{K * h}{\mu * B * (\ln(r_e/r_w) - 0.75 + S)}$$

K	= average effective permeability	[md]
h	= vertical thickness of continuous porosity	[ft]
μ	= viscosity	[cp]
B	= Formation Volume Factor	[RB] / [STB]
r_e	= drainage radius	[ft]
r_w	= well bore radius	[ft]
S	= Skin factor	

Stabilized Production Rate (q_s) Once the stable PI has been derived the stable flow rate at any pressure may be calculated simply by multiplying the chosen drawdown by the PI.

$q_s = PI * (P_i - P_{wf})$

where,

P_i = Initial static reservoir pressure [psig]
P_{wf} = Bottom Hole Flowing Pressure (FFP) [psig]
PI = Productivity Index

Radius of Investigation (RI) The radius of investigation is the radial distance from the well bore which the pressure disturbance from the DST has investigated (in other words "how far out into the zone the DST has looked").

$RI = 2.6408 * \sqrt{(K*T_o / (\phi * \mu * c))}$

where,

K = Permeability (K) [md]
T_o = Flow Time [min]
φ = Porosity
μ = viscosity [cp]
c = compressibility [vol]/[vol]/[psi]

If φ, μ, and c are not known then the Radius of Investigation (RI) is as follows,

For Water: $RI = 6.83 * \sqrt{(K * T_f)}$

For Oil: $RI = 4.63 * \sqrt{(K * T_f)}$

References:
(1) Pressure Build-Up in Wells, by D.R. Horner, 3rd World Petroleum Congress, May 28 - June 6, 1951 , The Hague, the Netherlands
http://www.onepetro.org/mslib/servlet/onepetropreview?id=WPC-4135&soc=WPC
(2) Drill Stem Test Interpretation Seminar, Author & Instructor: H. W. Reid
(3) Recent Developments in the Interpretation and Application of DST Data, by L. F. Maier Journal of Petroleum Technology Volume 14, Number 11, November 1962, pgs 1213-1222 **http://www.onepetro.org/mslib/servlet/onepetropreview?id=00000290**

Horner Plot – Gas DST

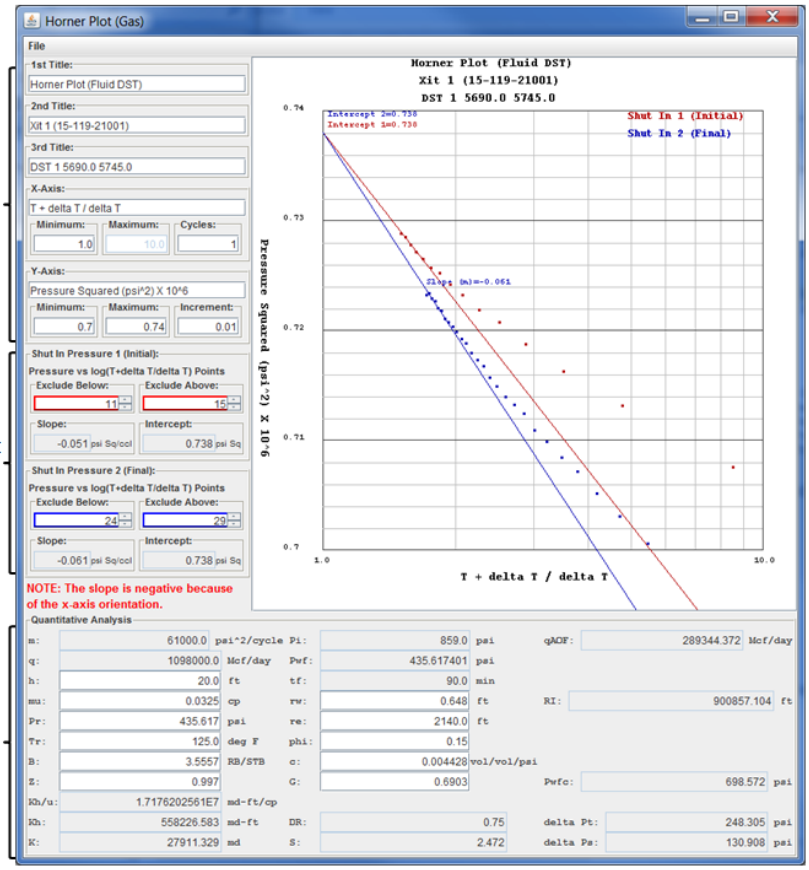
Horner Plot – Gas DST

Click on the "Display Horner Plot" button on the "Shut In Pressure Data" Panel

Plot Parameters. The user can modify the titles to the Horner plot, the Axis Labels and the Axis. The program uses the data to determine initial values.

The spinner text fields allow the user to vary the slope and intercept for both shut in data. This version allows the user to exclude points from both ends of the data set.

Quantitative Analysis Panel allows the user to obtain reservoir parameters based on the results from the Horner plot analysis.



Horner plot a semi log plot of Pressure vs. dimensionless time function (or simply Horner Time) for a fluid DST. For a Gas DST it becomes a semi log plot of Pressure squared vs. Horner Time.

Much of this section is taken from the lecture notes "Modern Concepts in Drill Stem Testing Part 2 Quantitative Analysis"[2] by Hugh W. Read, Author & Instructor.

Conventional Horner Type Pressure Buildup Analysis Conditions Assumed for Analysis Procedure

For a discussion of the theory of pressure buildup interpretation and the derivation of the pertinent equations the reader is referred to the original now classical paper by Horner[(1)].

90% of all quantitative Drill Stem Test analysis is based on Horner's method of analysis which assumes the following ideal conditions:

i) Radial Flow - Radial flow is flow into the well bore equally from all directions in the formation. By and large condition is met by most DST's through linear systems such as fractures; narrow channel sands etc. are obvious exception which may be handled separately.

ii) Homogeneous Reservoir - Homogeneity in a reservoir denotes constant characteristics throughout the length and thickness. Any values calculated from test data then become averages over the length and/or thickness.

iii) "Steady-State" Conditions of Flow - "Steady-state" flow conditions imply a rate and pressure drawdown (which is responsible for the flow) which is constant.

iv) Infinite Reservoir - An infinite reservoir is one in which there are no finite limits or depletion. All DST's in wildcat wells can be considered to test infinite reservoirs, except those testing very small local porosity or fracture developments which in any event deplete rapidly and are not commercial.

v) Single Phase Flow - Single phase flow assumes that only one phase is entering the well bore. Thus for example any gas produced with oil is considered as solution gas and any liquids in a gas test are considered as condensation of gases in the pipe or immediate well bore vicinity.

Method of Construction of Horner plot - Gas Drill Stem Test

This example is from the Xit 1; DST 1 in the Upper Kearny Member from 5690.0 ft to 5745.0 ft dst-gas.las. The Gas Rates and Pressure Summary Data will be needed in performing the plot and quantitative analysis and is listed as follows,

Gas Rates Table				
Flow Period	**Elapsed Time**	**Pressure (psig)**	**Gas Rate (Mcf/day)**	**Choke (in)**
1	10.0	14.0	577000.0	1.0
1	20.0	24.0	817000.0	1.0
1	30.0	28.0	907000.0	1.0
2	10.0	26.0	865000.0	1.0
2	20.0	33.0	1012000.0	1.0
2	30.0	35.0	1057000.0	1.0
2	40.0	36.0	1076000.0	1.0
2	50.0	36.0	1076000.0	1.0
2	60.0	37.0	1098000.0	1.0

Pressure Summary Table			
Time (min)	**Pressure (psig)**	**Temperature (deg F)**	**Annotation**
0.0	2748.7854	122.407204	Initial Hydrostatic
5.5	155.137894	123.1147	Open to Flow 1
36.0	496.501312	121.527901	Shut-in 1
96.0	853.742798	126.989899	End Shut-in 1
97.0	233.796402	126.3834	Open to Flow 2
156.5	435.617401	115.143501	Shut-in 2
280.0	850.436829	125.351997	End Shut-in 2
285.5	2727.0625	126.5923	Final Hydrostatic

See the paper "Recent Developments in the Interpretation and Application of DST Data" by L.F.Maier[(3)]. There were a number of DST papers that seem to use the Pressure squared method. Reid suggests that the linear Horner plot was sufficient. A future version of the DST Tool may allow the user to select between Pressure or Pressure squared in a Horner plot analysis.

(1) The data necessary for this plot is a set of detailed readings of pressures and times during each shut in period plus the total amount of time spent flowing the well.

(2) Arrange the data in tabular form where,

T = Cumulative flowing time (minutes)

ΔT = Times during shut in that each pressure is read (minutes)
P = Pressure read during shut in time (psig)
P^2 = Pressure squared ($psig^2$)

Shut In 1 (Initial)				
Total Flow Time (T) = 30 minutes[a]				
Time (ΔT)	**(T+ΔT)/ΔT**	**Pressure (P)**	**Temperature**	**Pressure squared (P^2)**
(min)		**(psig)**	**(deg F)**	**($psig^2$)**
0.0	---	496.501312	121.527901	246,512.25
4.0	8.50	841.170715	125.614502	707,566.97
8.0	4.75	844.496826	126.780701	713,180.25
12.0	3.50	846.328003	126.656998	716,274.47
16.0	2.88	847.812927	126.512199	718,781.80
20.0	2.50	848.991882	126.430603	720,784.02
24.0	2.25	849.629028	126.429497	721,871.14
28.0	1.07	850.446777	126.441704	723,265.20
32.0	1.94	850.998596	126.487801	724,201.00
36.0	1.83	851.615723	126.541397	725,256.62
40.0	1.75	851.901672	126.6035	725,733.61
44.0	1.68	852.340271	126.679298	726483.48
48.0	1.63	852.739502	126.757896	727,165.51
52.0	1.57	853.130676	126.837502	727,830.80
56.0	1.54	853.542114	126.921898	728,530.53
60.0	1.50	853.742798	126.989899	728,871.99

Shut In 2 (Final)				
Total Flow Time (T) = 59.25 + 30 = 89.25 minutes[b]				
Time (ΔT)	**(T+ΔT)/ΔT**	**Pressure (P)**	**Temperature**	**Pressure squared (P^2)**
(min)		**(psig)**	**(deg F)**	**($psig^2$)**
0.0	---	435.617401	115.143501	189,764.78
4.0	23.31	825.081787	119.8134	680,757.01
8.0	12.16	830.118713	121.163101	689,099.21
12.0	8.44	833.033508	121.227501	693,938.98
16.0	6.68	835.235901	121.179703	697,625.86
20.0	5.46	837.006775	121.144402	700,585.74
24.0	4.72	838.476685	121.177597	703,048.71
28.0	4.19	839.725891	121.214996	705,146.47
32.0	3.79	840.914917	121.298103	707,129.63
36.0	3.48	841.682373	121.412399	708,425.22
40.0	3.23	842.520203	121.562202	709,839.95
44.0	3.03	843.182373	121.730797	710,952.51
48.0	2.86	844.06543	121.915604	712,454.16
52.0	2.72	844.552002	122.107803	713,264.70
56.0	2.59	844.938416	122.306	713,923.60
60.0	2.49	845.54541	122.5158	714,954.80
64.0	2.39	846.011902	122.712097	715,732.92
68.0	2.31	846.609009	122.936401	716,748.49
72.0	2.24	846.955078	123.124702	717,341.24
76.0	2.17	847.331421	123.330902	717,968.13
80.0	2.12	847.858093	123.534203	718,866.58
84.0	2.06	848.078918	123.712997	719,239.69
88.0	2.01	848.460205	123.904503	719,884.37
92.0	1.97	848.756104	124.090897	720,393.54
96.0	1.93	848.997009	124.264297	720,801.00
100.0	1.89	849.177612	124.4431	721,106.67
104.0	1.86	849.583923	124.618301	721,786.18
108.0	1.83	849.724426	124.773598	722,024.08
112.0	1.80	850.115723	124.930603	722,704.01
116.0	1.77	850.256226	125.089798	722,942.07
120.0	1.74	850.521973	125.233299	723,384.27
124.0	1.72	850.436829	125.351997	723,231.18

From the Pressure Summary Table

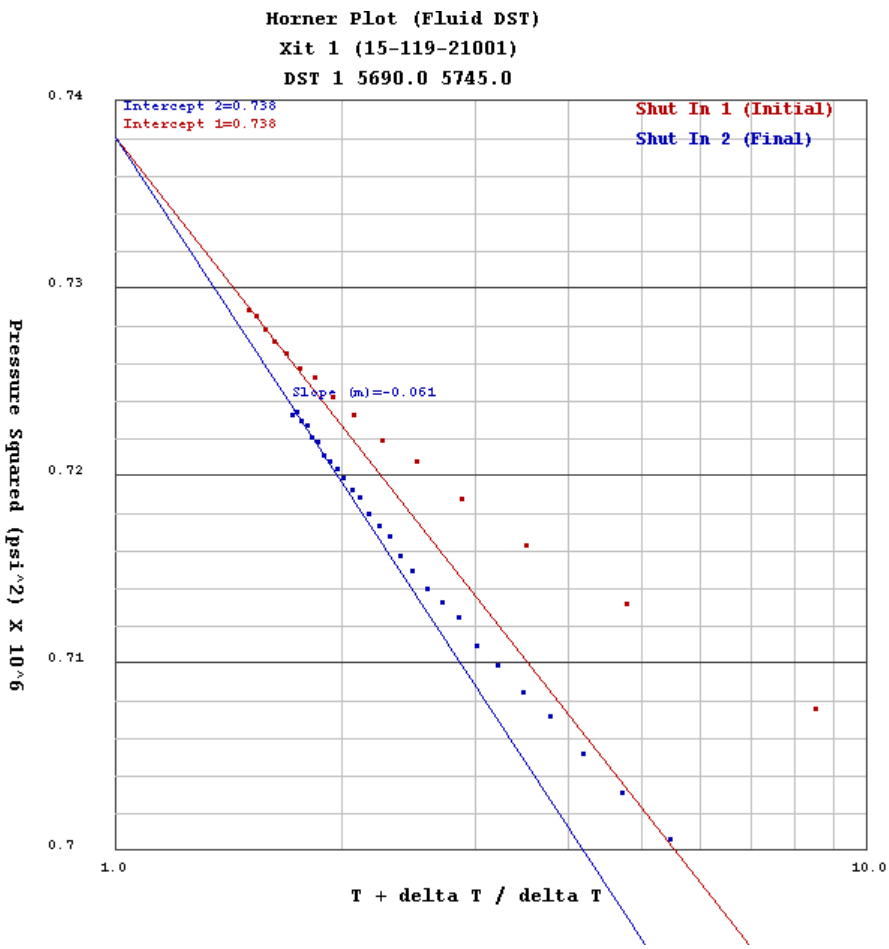
(a) Shut-in 1 Time - Open to Flow 1 Time {38.5 - 8.5 = 30.0 minutes}
(b) Shut-in 2 Time - Open to Flow 2 Time + Total Flow Time from (a) {159.0 - 99.75 + 30.0 = 89.25 minutes}

In the table note that the Shut-In 1 & 2 periods were broken down into 4 minute intervals.

The Pressure Summary Table gives a summary of the DST Pressure-Temperature-Time Readings at specific points. This DST had a 30.0 minute pre-flow and a 59.25 minute main flow. Thus 'T' for the Shut-In 1 (Initial) period = 30.0 minutes since there was a total of 30 minutes flow time prior to Shut In 1 (Initial). T for the Shut-In 2 (Final) period becomes 89.25 minutes 30 minutes pre-flow + 59.25 minutes main-flow since T is the cumulative flow time prior to shut in.

The quantity $(T + \Delta T)/\Delta T$ is mathematically the same as $1 + (T/\Delta T)$ thus for the Shut-In 2 (Final) period example the $(T + \Delta T)/\Delta T$ for the first increment = (89.25+4)/4 = 23.31, which is the same as 1 + (89.25/4) = 1 + 22.31 = 23.31.

(3) The Horner plot is then constructed by plotting $\log_{10}[(T+\Delta T)/\Delta T]$ vs P^2 for each point.



(4) In Figure 2 both Shut-In Pressure-Time curves have been plotted. In order to determine the static reservoir pressure the linear portion is extrapolated to the left hand margin where the value of the time function $(T + \Delta T)/\Delta T = 1$. Since the logarithm of 1 is zero the $\log_{10}[(T + \Delta T)/\Delta T] = 0$ (or infinity) at this point. Thus we are extrapolating the Horner straight line to a 'infinite' shut in time where completely static pressure prevails. In the example here the static pressure squared ~ 738,000.0 $psig^2$ or 859.0 psig. Both Shut In intervals extrapolations yield this value. In cases where the Shut-In 2 (Final) extrapolation is substantially less than the Shut-In 1 (Initial) depletion is indicated. If the depletion factor 100.0 * Shut-In [(Initial)-(Final))/(Initial)] is greater than 4%, then the indications of depletion can be considered serious or substantial.

(5) The final piece of information which is obtained from the Horner plot is the "slope" (m) of the straight line segment. Numerically this is the difference between the pressure at $\log_{10}[(T + \Delta T)/\Delta T]=0$ and at $\log_{10}[(T + \Delta T)/\Delta T]=1$, where the slope is simply the change in pressure over one complete log cycle. The slope in this example using the Shut In (Final) slope m=0.061 psi^2/cycle. The slope is used in the calculations to derive permeability and other reservoir parameters.

Transmissibility (K*h/μ), Permeability Thickness (K*h), Permeability (K)

The pressure build-up equation applicable to gas wells is expressed by

$$P_o^2 = P_f^2 - m_g * \log_{10}[(T+\Delta T)/\Delta T]$$

The build-up plot of Po^2 vs. $\log_{10}[(T+\Delta T)/\Delta T]$ is constructed and extrapolated to $\log_{10}[(T+\Delta T)/\Delta T]$ to zero to obtain Pf^2 and m_g, the slope of the line.

$m_g = 1632 * q_g * \mu * Z * Tf / (K * h)$ [psi^2] / [log cycle]
q_g = flow rate [Mcf] / [day]
μ = viscosity [cp]
Z = Gas Deviation Factor (Compressibility factor)
T_f = Formation Temperature [^oR]; $^oR = {}^oF + 459.67$
h = vertical thickness of continuous porosity [ft]
K = average effective permeability [md]

This states that the slope of the buildup is representative of a given fluid having physical properties μ, Z, Tf flowing at a rate q_g through a formation having physical properties K * h.

Note: the flow rate (q) is computed by using an average of the final gas rates in the gas rates table.

Transmissibility can be found my rearranging the slope as follows,

Transmissibility:	$K * h / \mu = 162.6 * q * B / m$	[md]-[ft]/[cp]
Permeability Thickness:	$K * h = (\text{Transmissibility}) * \mu$	[md]-[ft]
Permeability:	$K = (\text{Permeability Thickness}) / h$	[md]

Damage Ratio (DR), Skin factor (S), and related quantities

Damage Ratio (DR) - A numerical value used to predict the flow rate if the damage were removed. In essence the DR becomes a number which when multiplied by the flow rate which existed at the time of the test will yield the flow rate if the damage (or improvement) over the natural condition is removed. This flow rate will be the rate at the same flowing pressure drawdown which existed during the test. From the definition of DR if a zone is neither damaged nor improved then q theoretical is identical to q actual and DR = 1.

$$DR = \frac{P_i^2 - P_{wf}^2}{m_g * \log\{[k * T_o / (\phi * \mu * c * r_w^2)]\}} - 2.85$$

where,

P_i	= Initial static reservoir pressure	[psig]
P_{wf}	= Bottom Hole Flowing Pressure (FFP)	[psig]
m_g	= slope from the Horner plot	[psi] / [log cycle]
K	= Permeability (K)	[md]
T_o	= Flow Time	[min]
φ	= Porosity	
μ	= viscosity	[cp]
c	= compressibility	[vol]/[vol]/[psi]
r_w	= well bore radius	[ft]

If K, φ, μ, c and r_w are not known then the Damage Ratio can be estimated by,

$$EDR = \frac{P_i - P_{wf}}{m * \log\{T_o\}} + 2.65$$

Skin factor (S) - A numerical quantity which attempts to describe the amount of damage or improvement. The numerical value of skin is so defined that a positive value for the skin factor indicates a damaged condition and a negative skin factor indicates improvement over the natural condition. The skin factor is zero when neither skin damage nor improvement are present i.e. no alterations to natural condition.

$$S = 1.1515 * \frac{P_i^2 - P_{wf}^2}{m_g} - \log\left[\frac{k * T_o}{\phi * \mu * c * r_w^2}\right] + 5.01$$

P_i	= Initial static reservoir pressure	[psig]
P_{wf}	= Bottom Hole Flowing Pressure (FFP)	[psig]
m_g	= slope from the Horner plot	[psi] / [log cycle]

K = Permeability (K) [md]
T_o = Flow Time [min]
φ = Porosity
μ = viscosity [cp]
c = compressibility [vol]/[vol]/[psi]
r_w = well bore radius [ft]

If φ, μ, c and r_w are not known then the Skin factor (S) can be estimated by,

$$S = 1.1515 * \frac{P_i^2 - P_{wf}^2}{m_g} - \log(k * T_o * P_i) + 1.40$$

Pressure Drop Across a Damage Zone ΔP_{skin} The additional pressure drop during flow caused by the presence of skin (ΔP_{skin}) may be calculated as follows,

$\Delta P_{skin} = P_{wf} * \sqrt{(P_{wf}^2 + 0.87 * S * m)}$

where,

S = Skin factor
Pwf = Bottom Hole Flowing Pressure (FFP) [psig]
m = slope from the Horner plot [psi] / [log cycle]

Radius of Investigation (RI) The radius of investigation is the radial distance from the well bore which the pressure disturbance from the DST has investigated (in other words "how far out into the zone the DST has looked").

$RI = 2.6408 * \sqrt{(K*T_o / (\phi * \mu * c))}$

where,

Pi = Initial static reservoir pressure [psig]
K = Permeability (K) [md]
To = Flow Time [min]
φ = Porosity
μ = viscosity [cp]
c = compressibility [vol]/[vol]/[psi]

If φ, μ, and c are not known then the Radius of Investigation (RI) is as follows,

For Gas: $RI = 2.6408 * \sqrt{(K*T_f*P_i)}$

Effects of Turbulence[2] The skin factor and damage ratio values computed from the preceding equations do not take account of the additional pressure drop which is caused by turbulence in gas flow. The turbulence factor is not easy to determine precisely in DST's, however, an approximate empirical relationship between turbulence and permeability has been determined.

Step 1: The flowing pressure corrected for turbulence (P_{wfc}) is computed as follows,

$$P_{wfc} = \sqrt{\left[(P_{wf} + 14.65)^2 + \frac{0.129 * G * T_f * Z * q^2}{K^{4/3} * h^2} * \left[\frac{1}{rw} - \frac{1}{RI}\right]\right]}$$

P_{wf}	= Bottom Hole Flowing Pressure (FFP)	[psig]
G	= Gas Specific Gravity (air = 1)	
T_f	= Formation Temperature	[^oR]; $^oR = {}^oF + 459.67$
Z	= Gas Deviation Factor (Compressibility factor)	
q	= Flow Rate -	[Mcf] / [Day]
K	= Permeability	[md]
h	= thickness	[ft]
r_w	= well bore radius	[ft]
RI	= Radius of Investigation	[ft]

Step 2: The value of (P_{wfc}) is then substituted for (P_{wf}) in the skin factor (S) and damage ratio (DR) equations to determine the true skin factor (S) and damage ratio (DR) to exclude the effects of turbulence.

Step 3: The pressure drop due to turbulence (ΔP_t) may also be of interest and may be calculated simply as,

$$\Delta P_t = - P_{wf} + \sqrt{(P_{wf}^2 + 0.87 * m_g * S)}$$

Absolute Open Flow Capacity (qAOF) A theorectical quantity which describes the maximum flow rate of a gas zone at zero sandface pressure. It is an unattainable rate in practice but from it may be derived the flow rates at any practical flowing pressure.

Houpert equation: $P_i^2 - P_{wf}^2 = a*q + b*q*q$, where

$$a \text{ (Laminar Flow)} = \frac{1424 * T_f * Z}{(K * h / \mu)} * (\ln(r_e/r_w) - 0.75 + S)$$

$$b \text{ (turbulence factor)} = \frac{0.128 * G * T_f * Z}{(K^{4/3} * h^2)} * \ln((1/r_w) - (1/r_e))$$

P_{wf} = 0 by definition

$$qAOF = \frac{-a + \sqrt{(a * a + 4 * b * Pi^2)}}{2 * b}$$

P_i	= Initial static reservoir pressure	[psig]
P_{wf}	= Bottom Hole Flowing Pressure (FFP)	[psig]
K	= Permeability (K)	[md]
h	= vertical thickness of continuous porosity	[ft]
μ	= viscosity	[cp]
Z	= Gas Deviation Factor (Compressibility factor)	
T_f	= Formation Temperature	[^oR]; $^oR = {}^oF + 459.67$
G	= Gas Specific Gravity (air = 1)	
r_e	= drainage radius	[ft]
r_w	= well bore radius	[ft]

If b = 0 then qAOF = P_i^2/ a

References:
(1) Pressure Build-Up in Wells, by D.R. Horner, 3rd World Petroleum Congress, May 28 - June 6, 1951 , The Hague, the Netherlands
http://www.onepetro.org/mslib/servlet/onepetropreview?id=WPC-4135&soc=WPC
(2) Drill Stem Test Interpretation Seminar, Author & Instructor: H. W. Reid
(3) Recent Developments in the Interpretation and Application of DST Data, by L. F. Maier Journal of Petroleum Technology Volume 14, Number 11, November 1962, pgs 1213-1222 **http://www.onepetro.org/mslib/servlet/onepetropreview?id=00000290**

Save DST Test Data in Log ASCII Standard (LAS) version 3.0 File

The LAS (Log ASCII Standard) is rapidly becoming the accepted industry standard for electronic transmission of digital wire-line logs. Earlier digital formats were commonly coded in binary (such as LIS) and so required specialized software to read them. The LAS standard was introduced by the Canadian Well Logging Society (http://www.cwls.org/) in 1989 to standardize the organization of digital log curve information for personal computer users. It did this very successfully and the standard became popular worldwide. Version 1.2 was the first version and was followed in September 1992 by version 2.0 to address some inconsistencies. A more versatile version LAS 3.0 was released in 1999 however at present LAS 2.0 remains the dominant product. LAS 3.0 clarify several of the poorly defined specifications of LAS 2.0 and provide expanded data storage capabilities, but have seen limited implementation.

The GEMINI Tools programs will read either a Log ASCII Standard (LAS) version 2.0 or 3.0 file and version 1.2 but the Well Information Section is backward in data definition and will not be parsed correctly in the GEMINI Tools web apps.

The sections defined for the LAS 2.0 standard are as follows (http://www.cwls.org/wp-content/uploads/2014/09/LAS_20_Update_Jan2014.pdf):

- **"~V"** (also known as "~VERSION INFORMATION SECTION") is a required section; has formatting requirements; must be the first section; identifies the version number and whether data is in "wrapped" or "un-wrapped" mode.
- **"~W"** (also known as "~WELL INFORMATION SECTION") is a required section; has formatting requirements; is preferably the second section; contains information on the well name, location, and start and stop values of the data in this file.
- **"~C"** (also known as ~CURVE INFORMATION SECTION") is a required section; has formatting requirements; contains curve mnemonics and their definitions in the order that they appear in the data section.
- **"~P"** (also known as ~PARAMETER INFORMATION SECTION") is an optional section; has formatting requirements; contains information on parameters or constants relevant to the wellbore such as mud resistivity, wire line engineer, truck number, elevation data, etc.
- **"~O"** (also known as "~OTHER") is an optional section; has no formatting requirements; contains other information or comments.
- **"~A"** (also known as ~ASCII LOG DATA") is a required section; has formatting requirements; is the last section in the file and also referred to as the data section. The index of the data columns is either Depth or Time. The index values always appear in the first column and each column of data must be separated by at least one space (ASCII 32). All values in the ASCII log data section must be floating point or integer (long) values. Other formats such as Text or Exponential values are not supported.

LAS 3.0 (http://www.cwls.org/wp-content/uploads/2014/09/LAS_3_File_Structure.pdf) will be used to save the well data for the GEMINI Tools web apps since it can hold all the well data in one file. You can even think of LAS 2.0 as a subset of LAS 3.0 since the LAS 2.0 is only

concerned with the LOG Data. Note this section includes some of the referenced LAS 3 File Structure PDF; see the above URL for the complete LAS 3.0 File structure.

The **~Version** and **~Well** sections must appear in every LAS 3.0 file as the first and second sections respectively.

Other sections are grouped by data type. Each group consists of two or three sections; a **Parameter Data** section (optional for all but Log data), a **Column Definition** section, and a **Column Data** section, in that order.

For example, core analysis data would have the following three sections:

~Core_Parameter
~Core_Definition
~Core_Data.

At least one group or data type of either the defined LAS 3.0 data types or a user defined type must exist in every LAS 3.0 file.

The **Column Definition** and the **Column Data** sections for each data type are matched sets and must both appear in that order. The corresponding **Parameter Data** section is optional (except for Log data), but if used must appear before the corresponding **Column Definition** Section.

LAS 3.0 defines six specific well related data types and their root Section Title names. They are:

~Ascii or ~Log
~Core
~Inclinometry
~Drilling
~Tops
~Test

Additional data types can be defined by the user and content rules discussed elsewhere in the document may define other section titles.

Stand alone user defined **Parameter Data** sections can be included. Care must be taken to use standalone **Parameter Data** sections only when the data contained does not fit into any of the other defined data types.

When used, the section order of each set of the three sections for each data type must be Parameter, Definition, and then Data.

Blank lines and comment lines can appear within **Column Data** sections, but can only appear BEFORE the first **Column Data** line of that section, or after the LAST **Column Data** line of that section.

The names of each channel can optionally appear above each channel as a comment line immediately before, after or on the section title line of that section if space allows.

Note: Do not use the ~Other section recognized by LAS version 2.0. It is no longer allowed in LAS 3.0. Any data that can be stored in this section must now be stored properly in a user defined **Parameter Data** or **Column Data** section.

The LAS version 3.0 file has the potential to hold all the well data that was collected, i.e. multiple log data files, core data, tops data, DST data, Perforation data, Cuttings Report data, etc. As an example the Wellington KGS 1-32 has log, core, tops, brine data, geologist cuttings/core descriptions as well as DST Test data created from the DST web app. You can view the file at the following URL addresses,

LAS 3.0 Example File: http://www.kgs.ku.edu/Gemini/Tools/documentation/Wellington_KGS_1-32-DST.las

LAS 3.0 in WinZip File : http://www.kgs.ku.edu/Gemini/Tools/documentation/Wellington_KGS_1-32-DST.zip

Standard LAS 3.0 Data Sections for the Wellington_KGS_1-32-DST.las

- ~Version - Version Section
- ~Well - Well Header Information Section
- ~Log - Log Data Section – there are multiple log data (2) sections.
    - ~Log_Parameter
    - ~ Log_Definition
    - ~ Log_Data | Log_Definition, which must be the last section in the LAS File if the Log data is present.
- ~Tops - Formation Top (Stratigraphic Units) Picks Data Section
    - ~Tops_Parameter
    - ~Tops_Definition
    - ~Tops_Data | Tops_Definition
- ~Core – Measured Core Data Section
    - ~Core_Parameter
    - ~Core_Definition
    - ~Perforation_Data | Perforation_Definition
- ~Test – DST Data Section – there are 4 DST Test Data Sections in this file.
    - ~Test_Parameter
    - ~Test_Definition
    - ~Test_Data | Test_Definition

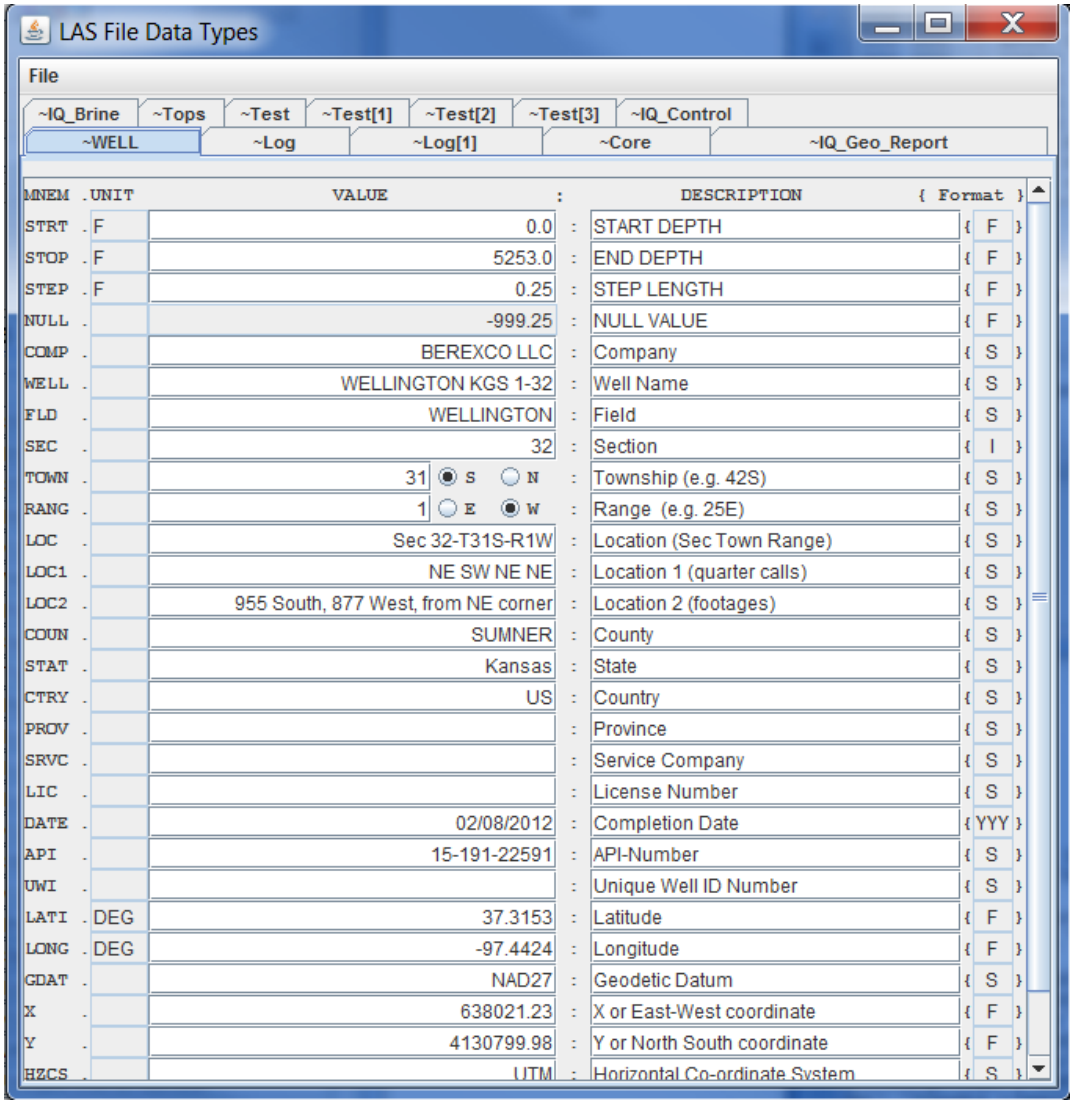
GEMINI Tools Defined LAS 3.0 Data Sections for the Wellington_KGS_1-32-DST.las

- ~IQ_Control - Recreate the Profile Plot Data Section
    - ~IQ_Control_Parameter
    - ~IQ_Control_Definition
    - ~IQ_Control_Data | IQ_Control_Definition
- ~IQ_Brine – This data holds the brine data.
    - ~ IQ_Brine _Parameter
    - ~ IQ_Brine _Definition
    - ~ IQ_Brine_Data | IQ_Brine_Definition
- ~IQ_Geo_Report – This data holds the geologist cuttings report/core description.
    - ~ IQ_Geo_Report_Parameter

- ~ IQ_Geo_Report_Definition
- ~ IQ_Geo_Report_Data | IQ_Geo_Report_Definition

- ~IQ_Las_Parameter - Selected LAS Curves – This Parameter Section was designed to remember the Log Curves selected by the user so the user does not have to map LAS File Curve Mnemonics to KGS Standard Tool Mnemonics when they run this file with other GEMINI Tools.

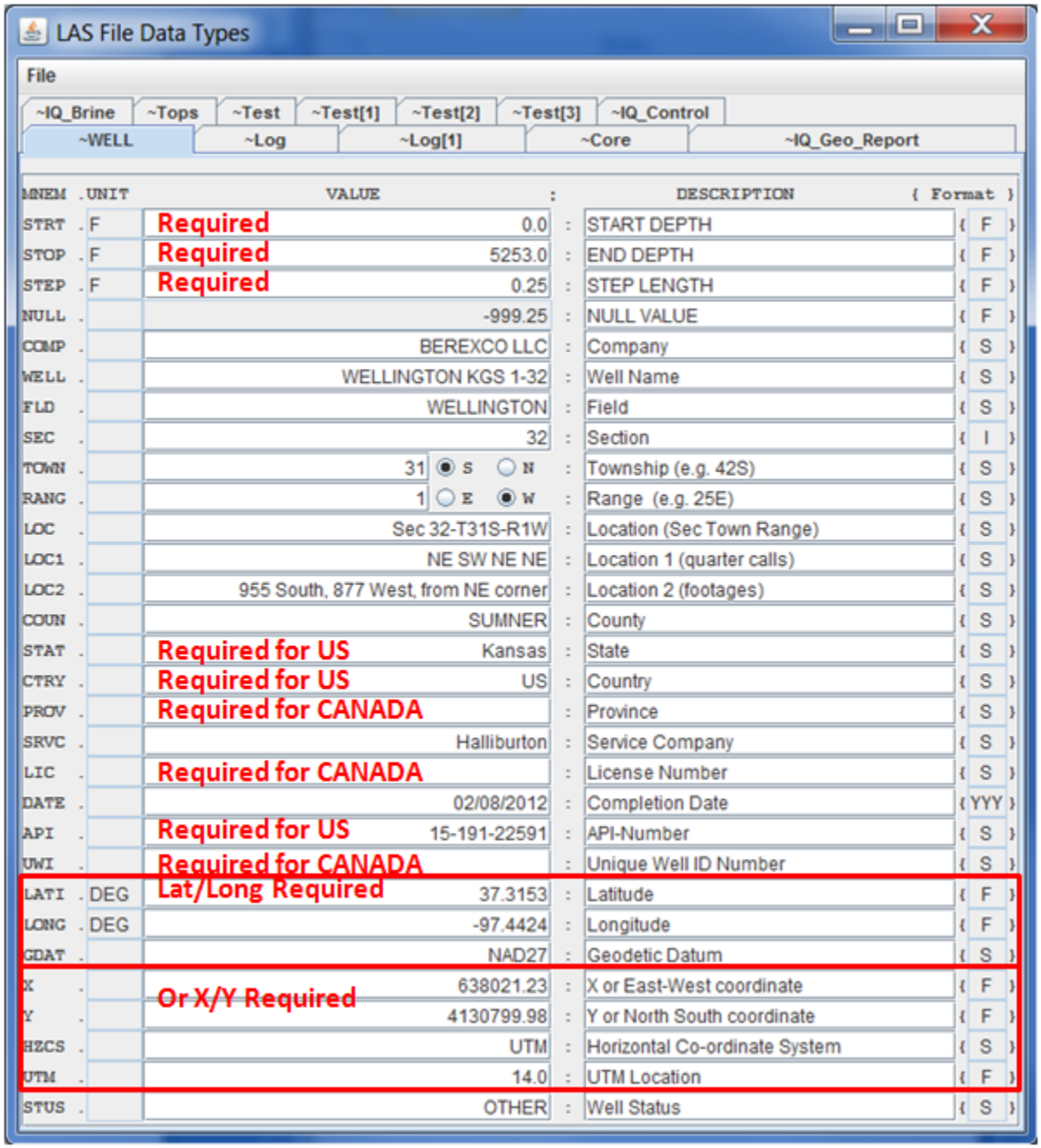
Select the Floppy Disk Image to Open the "LAS File Data Types" Dialog. This dialog allows the user to make changes or additions to the data before it is saved to a Log ASCII Standard (LAS) version 3.0 File.



MNEM	UNIT	VALUE	DESCRIPTION	Format
STRT	F	0.0	START DEPTH	F
STOP	F	5253.0	END DEPTH	F
STEP	F	0.25	STEP LENGTH	F
NULL		-999.25	NULL VALUE	F
COMP		BEREXCO LLC	Company	S
WELL		WELLINGTON KGS 1-32	Well Name	S
FLD		WELLINGTON	Field	S
SEC		32	Section	I
TOWN		31 S N	Township (e.g. 42S)	S
RANG		1 E W	Range (e.g. 25E)	S
LOC		Sec 32-T31S-R1W	Location (Sec Town Range)	S
LOC1		NE SW NE NE	Location 1 (quarter calls)	S
LOC2		955 South, 877 West, from NE corner	Location 2 (footages)	S
COUN		SUMNER	County	S
STAT		Kansas	State	S
CTRY		US	Country	S
PROV			Province	S
SRVC			Service Company	S
LIC			License Number	S
DATE		02/08/2012	Completion Date	YYY
API		15-191-22591	API-Number	S
UWI			Unique Well ID Number	S
LATI	DEG	37.3153	Latitude	F
LONG	DEG	-97.4424	Longitude	F
GDAT		NAD27	Geodetic Datum	S
X		638021.23	X or East-West coordinate	F
Y		4130799.98	Y or North South coordinate	F
HZCS		UTM	Horizontal Co-ordinate System	S

The Tabs at the top identifies the data that will be saved to the Log ASCII Standard (LAS) version 3.0 File. This example saves the well info, log data, core data, brine data, tops data, DST Test data, profile plot control data, and cuttings/core description. The "LAS File Data Types" Dialog allows the user to modify the well header data that is being saved to the LAS version 3.0 file. Also noted in the two images are identified "required" fields for a valid LAS file. The

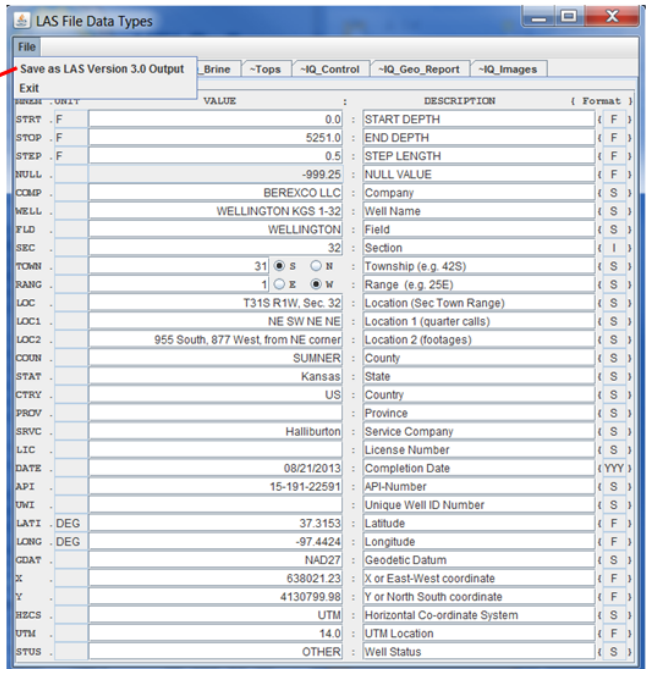
GEMINI Tools Web Apps doesn't care that the LAS file is not valid, just that the data follows the basic rules for the well data sections in the LAS 3.0 file.

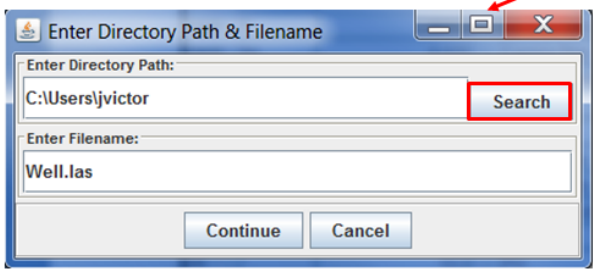


~Log_Parameters

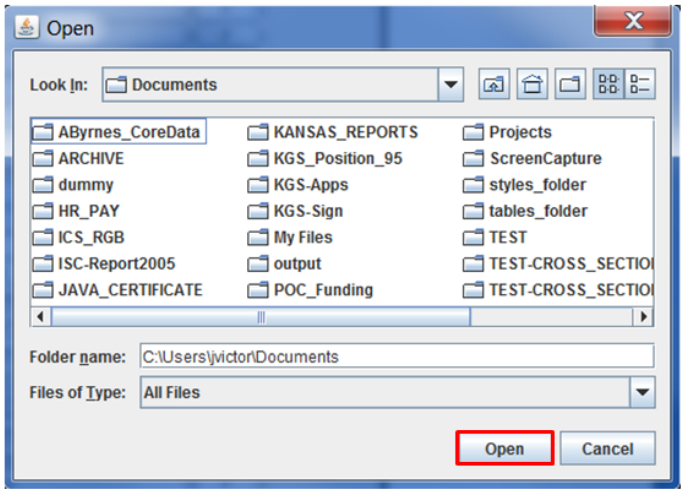
MNEM	.UNIT	VALUE	:	DESCRIPTION	{ Format }	| Association
PDAT .		Required GL	:	Permanent Data	{ S }	
APD .	F	Required 13.0	:	Above Permanent Data	{ F }	
DREF .		Required KB	:	Depth Reference (KB,DF,CB)	{ S }	
EREF .	F	Required 1272.0	:	Elevation of Depth Reference	{ F }	
RUN .		Required 1	:	Run Number	{ F }	
TDL .	F	5240.0	:	Total Depth Logger	{ F }	
TDD .	F	5240.0	:	Total Depth Driller	{ F }	
CSGL .	F	607.0	:	Casing Bottom Logger	{ F }	
CSGD .	F	607.0	:	Casing Bottom Driller	{ F }	
CSGS .	IN	9.625	:	Casing Size	{ F }	
CSGW .	LB		:	Casing Weight	{ F }	
BS .	in	7.875	:	Bit Size	{ F }	
MUD .		Water Based Mud	:	Mud type	{ S }	
MUDS .		Flow Line	:	Mud Source	{ S }	
MUDD .	ppg	9.000001	:	Mud Density	{ F }	
MUDV .	s/qt	48.0	:	Mud Viscosity (Funnel)	{ F }	
FL .	cptm	9.2	:	Fluid Loss	{ F }	
PH .		10.0	:	PH	{ F }	
RM .	OHM-M	0.65	:	Resistivity of Mud	{ F }	
RMT .	degF	58.0	:	Temperature of Mud	{ F }	
RMF .	OHM-M	0.55	:	Resistivity. of Mud Filtrate	{ F }	
RMFT .	degF	58.0	:	Temperature of Mud Filtrate	{ F }	
RMC .	OHM-M	0.75	:	Resistivity of Mud Cake	{ F }	
RMCT .	DEG-F	58.0	:	Temperature of Mud Cake	{ F }	
TMAX .	DEG-F	125.0	:	Maximum Recorded Temp.	{ F }	
TIMC .	DATE		:	Date/Time Circulation Stopped	{ D/M/YYY }	
TIML .	DATE	02/09/2011	:	Date/Time Logger Tagged Bottom	{ M/YYYY }	
UNIT .		10546696	:	Logging Unit Number	{ F }	
BASE .		Liberal, KS	:	Home Base of Logging Unit	{ S }	
ENG .		J. Bosh	:	Recording Engineer	{ S }	
WIT .		L. Watney, KCrisler, G	:	Witnessed By	{ S }	

Select the "File" Menu, Click on the "Save as LAS Version 3.0 Output" Button, which will display the "Enter Directory Path & Filename" Dialog.



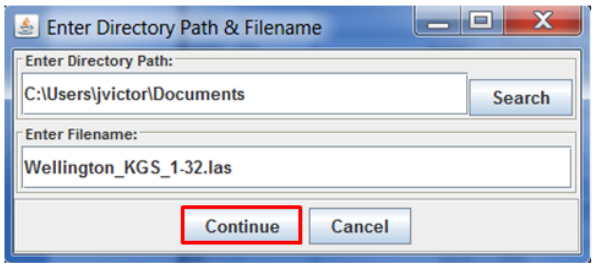


Select the "Search" Button to display the "Open" Dialog to search through the PC for the directory to save the Log ASCII Standard (LAS) version 3.0 File.



Search the PC for the directory that the LAS version 3.0 File will be saved to. Select "Open" Button to transfer the Directory path to the "Enter Directory Path" text field in the "Enter Directory Path & Filename" Dialog.

Change the file name in the ", e.g. "Wellington_KGS_1-32.las, then select the "Continue" Button to save the Wellington KGS 1-32 well data to the LAS version 3.0 file.



Example: Wellington KGS 1-32 - Previous Session

Importing PC Data - Download Well Data to PC – Previous Session

This section loads Drill Stem Test Data saved in a Log ASCII Standard (LAS) version 3.0 file. Download either the ASCII Text Files directly or the Zip files extracting the contents into a directory. The problem with the ASCII Text Files being downloaded directly from a web page is that the web page will alter the contents so it does not retain the basic structure and add HTML text to the file. The preferred method if you have Zip or WinZip is to download the zip files to your PC and extract.

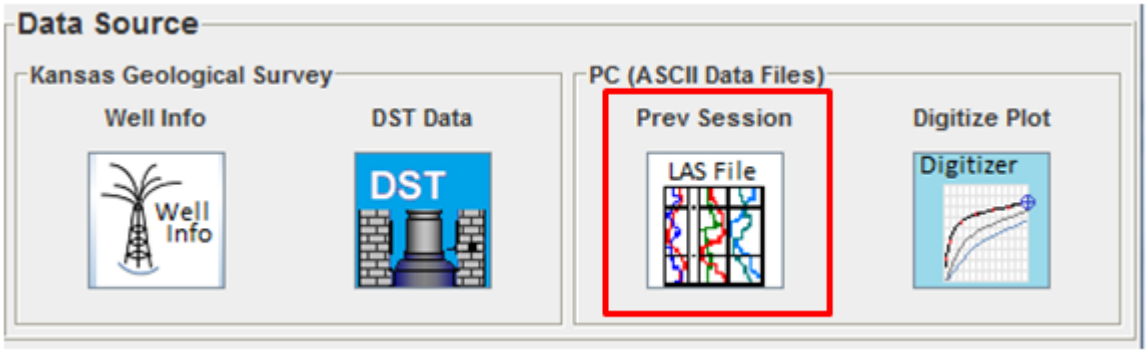
Well Data: Wellington KGS 1-32, Sumner County, Kansas

LAS 3.0 Example File: http://www.kgs.ku.edu/Gemini/Tools/documentation/Wellington_KGS_1-32-DST.las

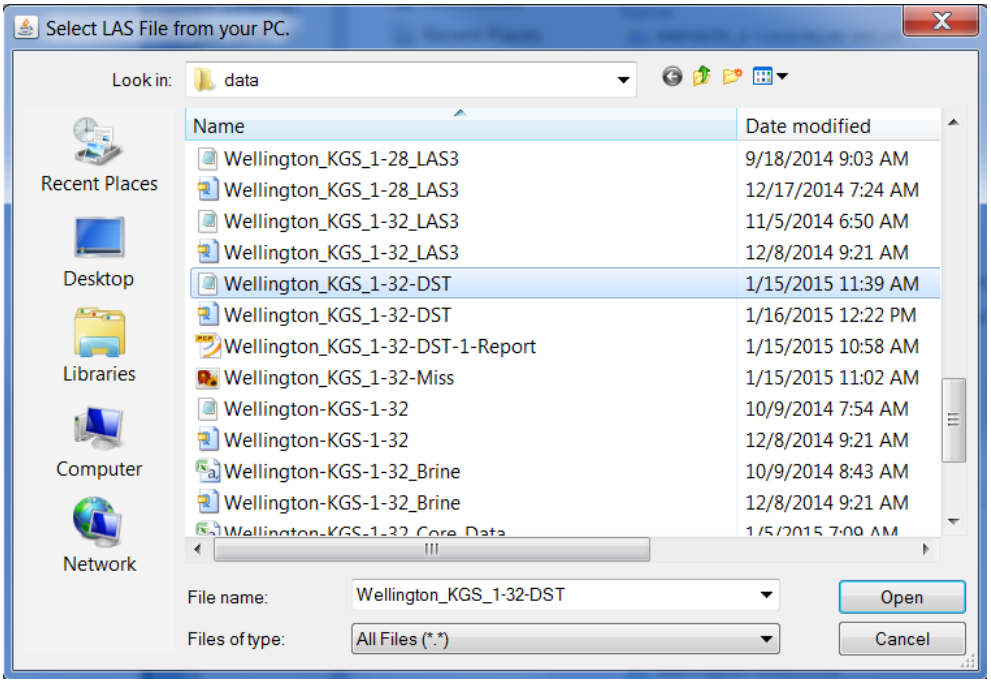
LAS 3.0 in WinZip File : http://www.kgs.ku.edu/Gemini/Tools/documentation/Wellington_KGS_1-32-DST.zip

This file contains, Log Data, Tops Data, Core Data, Brine Data, 4 Drill Stem Tests (DST) and the Geologist Cuttings/Core Description. This program will only load the Well Header Information, i.e. the "~Well" Data Section and the "~Parameters" Data Section and the 4 DST Test Data Sections.

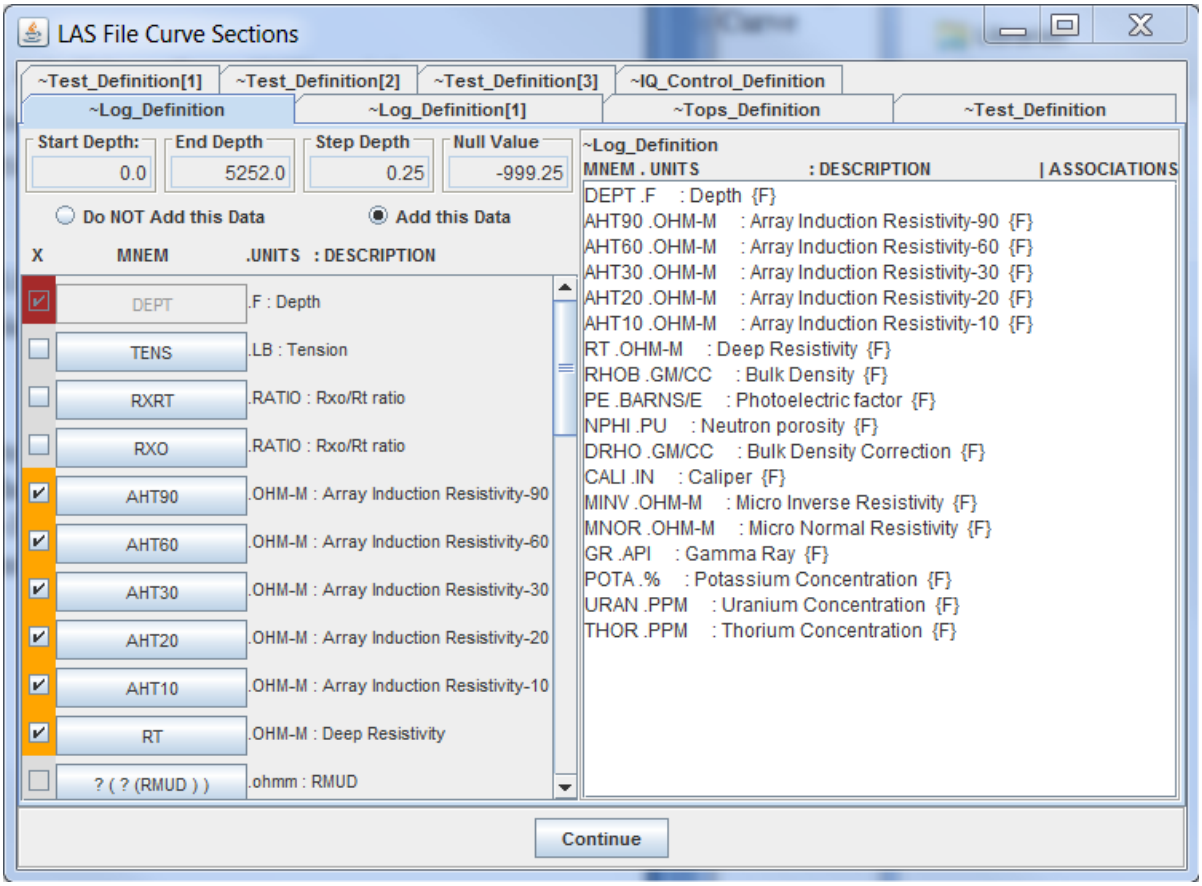
A Note, the user can load either a LAS version 2.0 or version 3.0 file with or without DST Test Data and when the user saves the DST Session they will be able to create a LAS version 3.0 file with the original LAS file data plus the DST Test Section Data.



Left Click on the "Prev Session LAS File" icon image button to display the "Select LAS File from your PC" Dialog. This dialog allows the user to search their PC for the file of interest.



In this example it is the LAS version 3.0 file Wellington-KGS-1-32-DST.las, highlighted below. Select the Open button to display the "LAS File Curve Sections" Dialog.



Notice that some of the check boxes are colored with different colors, which shows that the curves were automatically selected, but also to represent the curve type by color.The Curves are colored by type (data units) as follows,

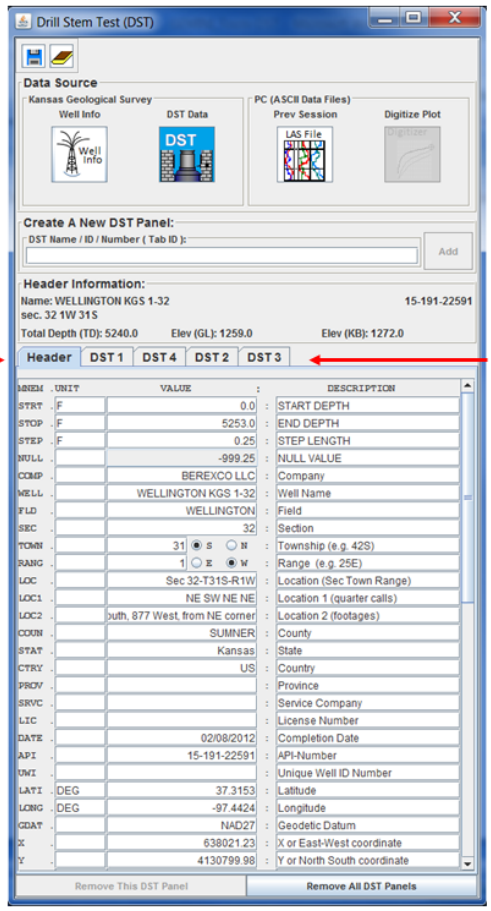
- Orange - OHM-M or Resistivity Logs
- Cyan – PU or porosity Logs, Neutron Porosity, Density Porosity, etc.
- Greenish yellow – BARNS/E or Photoelectric Factor Logs
- Green – GM/CC or Bulk Density Log
- Forest Green – USEC/FT or the Acoustic Transit Time Log
- Red – API, PPM or "%" as Radioactive logs, Gamma Ray, Spectral Gamma Ray, etc.
- Blue – MD or Permeability Logs
- Brown – F, FT or IN or Depth
- Middle yellow – FRAC, or other log curve types.
- Dark Violet – UNI or Unknown Linear Curves
- Medium Violet – UNL or Unknown Logrithum Curves

The color coding of the selected curves were added to also help the user visually recognize that a curve was selected or not.

Select the Continue Button to read and parse the DST Test Data selected into the DST Web App.

Header Tab
Well Header Information Panel all the fields that will be included into the Log ASCII Standard (LAS) version 3.0 File in the "~Well" and "~Parameters" Sections.

As you can observe the contents in the KGS Well Header Database for the Wellington KGS 1-32 well appears in this panel.



DST ...Tabs
Contains the Drill Stem Test Report Data as well as the Shut-In Pressure vs. Time Data.

Each DST Tab has its data loaded into a series of Panels that emulates the Trilobite Drill Stem Test Report.
- **Pressure Summary** – General Information & Pressure Summary Table.
- **Recovery** - Mud & Cushion Information & Recovery Information Table.
- **Gas Rates** – Gas Rates Information & Gas Rates Table.
- **Shut In Pressure Data** – Shut In Pressure-Temperature-Time Data Tables.

Horner Plot Quantitative Analysis Dialog