Flow Modeling Activities:

Team Review with Tom Hunter

July 26, 2010
10:00PM CDT

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Outline of Report

- Problem Statement
- What is known; what is assumed (as of July 27)
- Review of prior work
- Mass flow estimation opportunities during Shut-in efforts
- Review of 4 computational approaches
- Summary & Assessment

What is Known; What must be assumed

- Known: Limited diagnostics for flow estimation
  - BOP Pressure gauge operational and follows trends
  - Pressure gauges in 3-Ram Capping Stack operating
  - No in-flow temperature measurement capability
  - No direct measurements for possible leaks; to-date, no seismic/sonar quantification of leaks
- **Known: ANYTHING ELSE**
- Assumed: Reservoir depletion of order 2000 psi based on shut-in pressure magnitude
- Assumed: Leakage small (can't quantify leak rate)
- **Assumed: ANYTHING ELSE**

History of flow-based estimates of well flow rate prior to Shut-in with 3-Ram Capping Stack

(See notes, next slide)

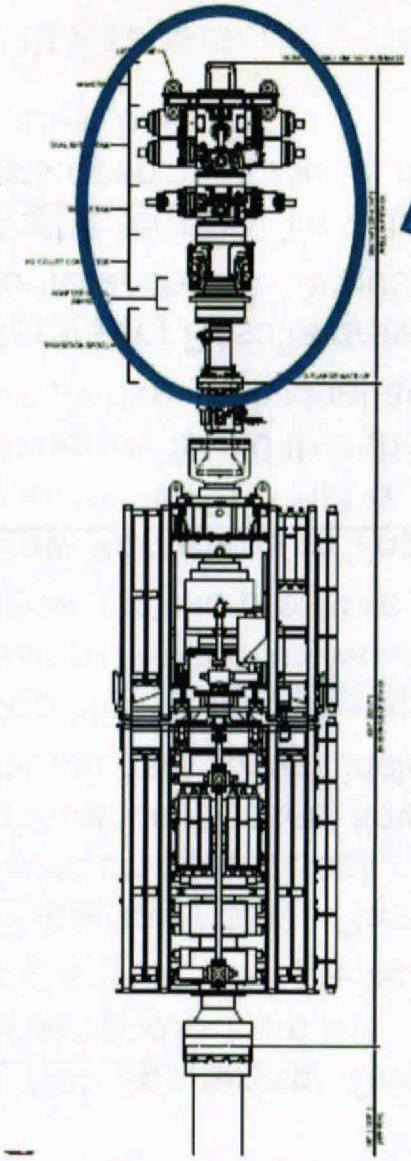
Date	Synopsis	Wellhead flow rate (stock bbl/day)	Summary Document	Notes
5/19/10	4 well scenarios	5000 (specified)	Tri-Lab Pressure Summary	
6/13/10	Video (cut riser)	19,200-46,000	UCSD UW Estimates June 13 (Lasheras)	For Reference/not flow based
6/15/10	Top Hat 4 fixed flow	72,700-83,000 (baseline, 3 Labs) 51,900-104,900 (max range)	4.2 Flows & Pressures	Uncertainty in skirt flow resistance
June & July. Various	Flow Variations	50,000 to > 100,000	None	Various attempts to determine total flow from ship flow changes
7/7/10	Acoustic (fallen riser, no leaks)	18,600-35,700 ($0.12 m^3/s$ to $0.23 m^3/s$)	Preliminary flow rate calculations using acoustic technologies (Camilli)	For Reference/not flow based
7/10/10	Well Integrity	0 (shut-in)	7.2 Well Integrity Report	SIWHP range: 8250 – 8750 psi

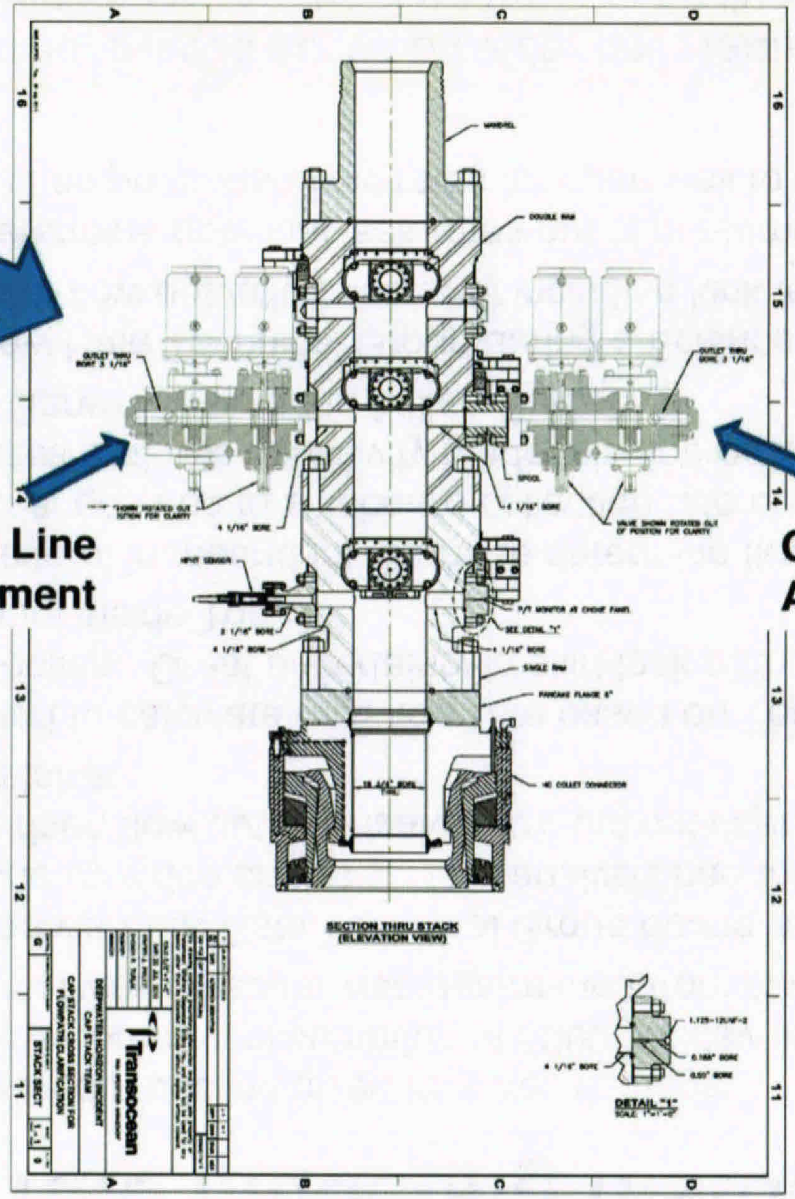
Notes on flow rate modeling history

- **4 Well Scenarios**: Original flow based modeling given four well damage assumptions from BP. All labs made common assumption of 5000 bbl/day flow rate and a fixed BOP pressure. Bottom of well pressure was determined from solution.
- **Video (cut riser):** Results provided via Flow Rate Technical Group during a Science Team conference call. Results done by video analysis. This analysis had three independent cases: flow out fallen riser, flow out kink leaks, flow out cut riser. Only the cut riser results included in the table.
- **Top Hat 4 Fixed Flow**: Tri-Lab effort to calculate total flow rate based on Top Hat 4 leak paths and known surface collection. Great uncertainty in skirt leak path, some uncertainty in pressure measurement inside Top Hat.
- **Flow Variations in Top Hat 4**: Several independent efforts to determine flow rate from known Top Hat & flow rate changes due to shipboard collection rate changes. Generally found that the uncertainties and rate sensitivity made this approach unreliable. Individual attempts by Garwin, Majumdar, Miller, Ratzel .
- **Acoustic:** Results provided via Flow Rate Technical Group during a Science Team conference call. Acoustic analysis of flow out fallen riser, not including kink leaks.
- **Well Integrity**: Tri-Lab effort to determine potential leak rates out of presumed burst disk openings. Model results based on presumed flow rates for open well to define shut-in behavior

Tri-Lab Assessment – None of methods listed above provide "believable" mass flow results – too many model uncertainties and/or data for quantitative analysis

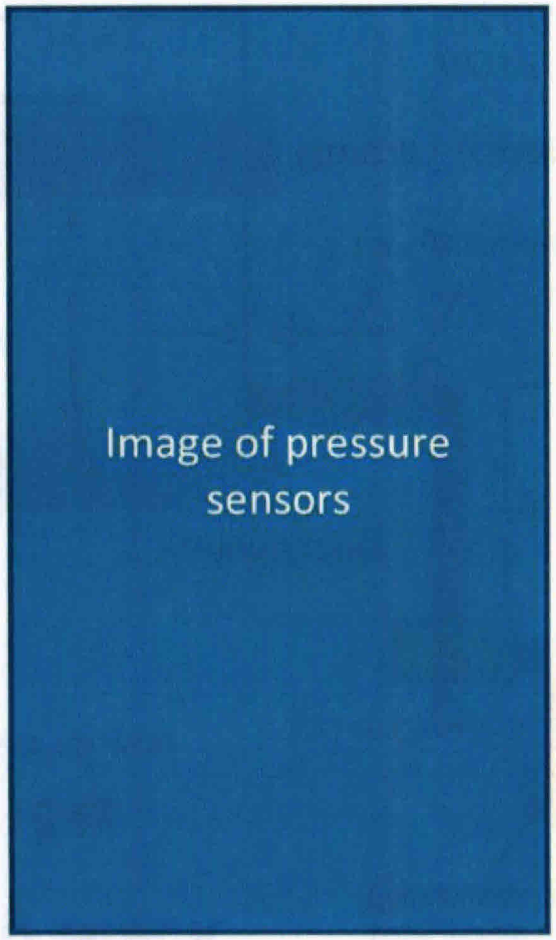
Close-in of the 3-Ram Capping Stack provided opportunities for determining mass flow estimates





Capping Stack Configuration and Pressure Transducer Details

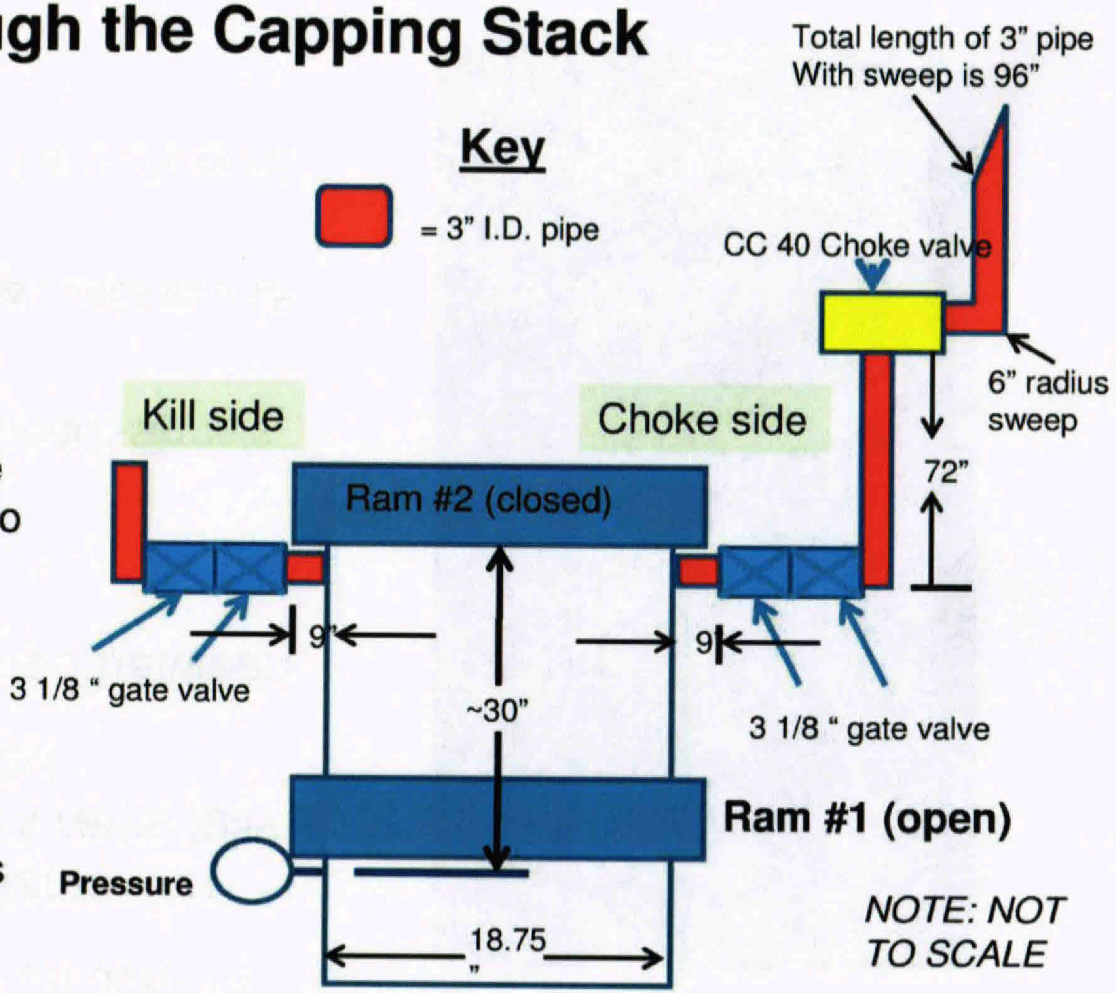
- Bolted onto BOP Manifold on July 13
- Stacking Cap includes 3 Rams. For Shut-in test, top and bottom rams fully open and middle ram closed
- Pressure transducers located between bottom and middle rams
  - ~75 ft above sea floor
  - 2 transducers on single head; signals transmitted acoustically
  - Teledyne Cormon transducer; valid thru 15 kpsi;
  - Transducer accuracy quoted at 0.2% at FS (15psi)
  - **WHAT ELSE?**



Mass Flow Rate estimates are possible from monitoring flow through the Capping Stack Choke and Kill Line

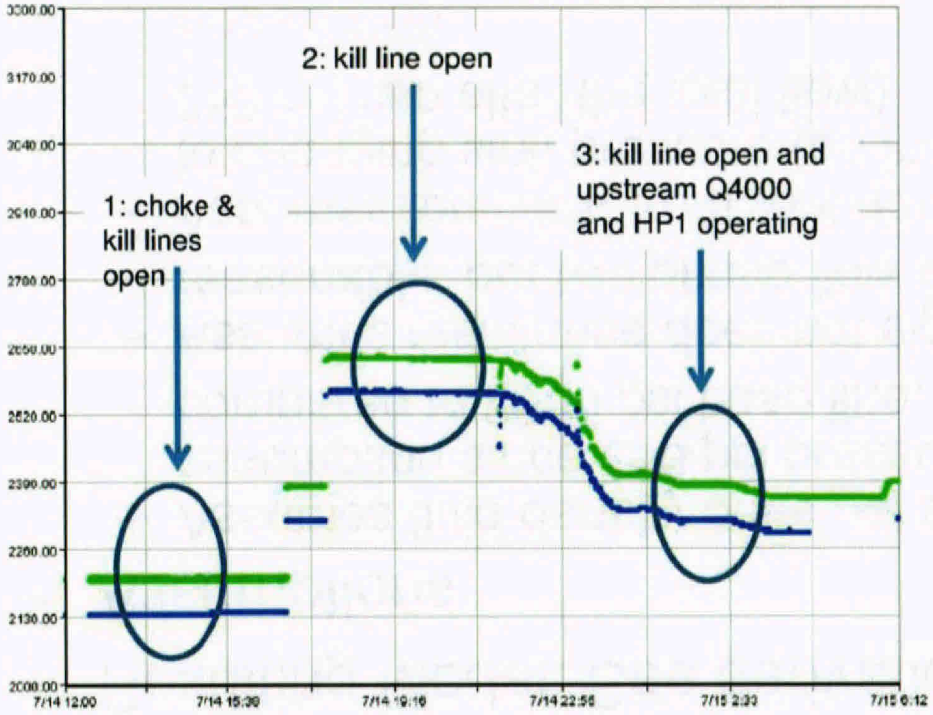
The shut-in test conducted July 14-15 required flow isolation of both lines

1. During final preparations for test on June 14th, a leak in the choke line required test abort; all flow diverted to kill line
2. Over evening/early morning, some of flow collected by HP1 and Q4000 while choke line was being replaced
3. Prior to shut-in, only the choke line remained open
4. Through the shut-in test, pressures were monitored during CC40 Choke valve closure



Top Section of Capping stack.
Pressure gauges mounted to 18-3/4" riser section

Aborted Well Closure on July 14
Different flows through Kill Line during repair



- Well Integrity Test preparations started 7/14 around 1:00PM
- Early in testing sequence to isolate choke line, a leak was uncovered in the choke line that led to test termination.
- Choke line was isolated by closing valves connecting line to capping stack; only kill line remained open
- Over evening and into early morning while repairs were being made, flow to Q4000 and HP1 was resumed

1:Exit Pressure (Pchoke open to sea) ~2178 psi

2: Only kill line open; Pchoke =2600 psi +/-30 psi

3: kill line open with collection upstream; Pchoke =2355 psi +/- 40 psi and recovery from Q4000 and HP1 = 20140 bbl/day+/= 1050 bbl/day

Kill Line Analyses – Method 1
(Ron to check)

- Analysis Method: Use two flow conditions
  - All flow through the Kill Line
  - Some flow through the Kill valve, some diverted earlier to HP1 and Q4000 collection vessels
- Resulting Model: See derivation
- Assumptions
  - Assumes fluid density does not significantly change (reasonable assumption since 250 psi pressure level change is small compared to 2500 psi base line; But not completely negligible.)
  - Assumes resistance does not significantly change (may be reasonable, but two phase flow can be quite touchy)
  - Assumes total flow from well does not significantly change due to changing sink pressure (an increase in the back pressure by 250 psi can alter the total flow)
  - Any others?

POC – Ron Dykhuizen, Sandia

Flow estimates for step change in flow and pressure measurement

(Ron to check)

- Flow through a constant resistance

$$\Delta P_1 = kQ^2$$

- Modify flow rate due to known collection rate change (d)

$$\Delta P_2 = k(Q+\delta)^2$$

- Solve for original flow (Q)

Ron – Please Put in final Eq. here

Note: Required Pressure and collection rate data are obtained from BP and maintained in SharePoint file system

Kill Line Analyses – Method 1 (contd)

(Ron to complete)

- Model Advantages
  - Geometrical effects minimized
  - What else
- Model Limitations/Issues
  - Fill in
- Results
  - Could be a chart and/or tabulations – be sure to add a statement on uncertainties, even if currently a WAG

Kill Line Analyses – Method 2
(Wayne to check/finish)

- Analysis Method: Flow through the Kill Line
  - Model flow restrictions between the pressure gage and exit
  - Use measured Pchoke and known Psea
  - Two cases:
    - Flow only through kill line to exit
    - Some flow through the Kill valve to exit, some diverted earlier to HP1 and Q4000 collection vessels
- Resulting Model: Network Model
- Assumptions

Kill Line Analyses – Method 2 (contd)

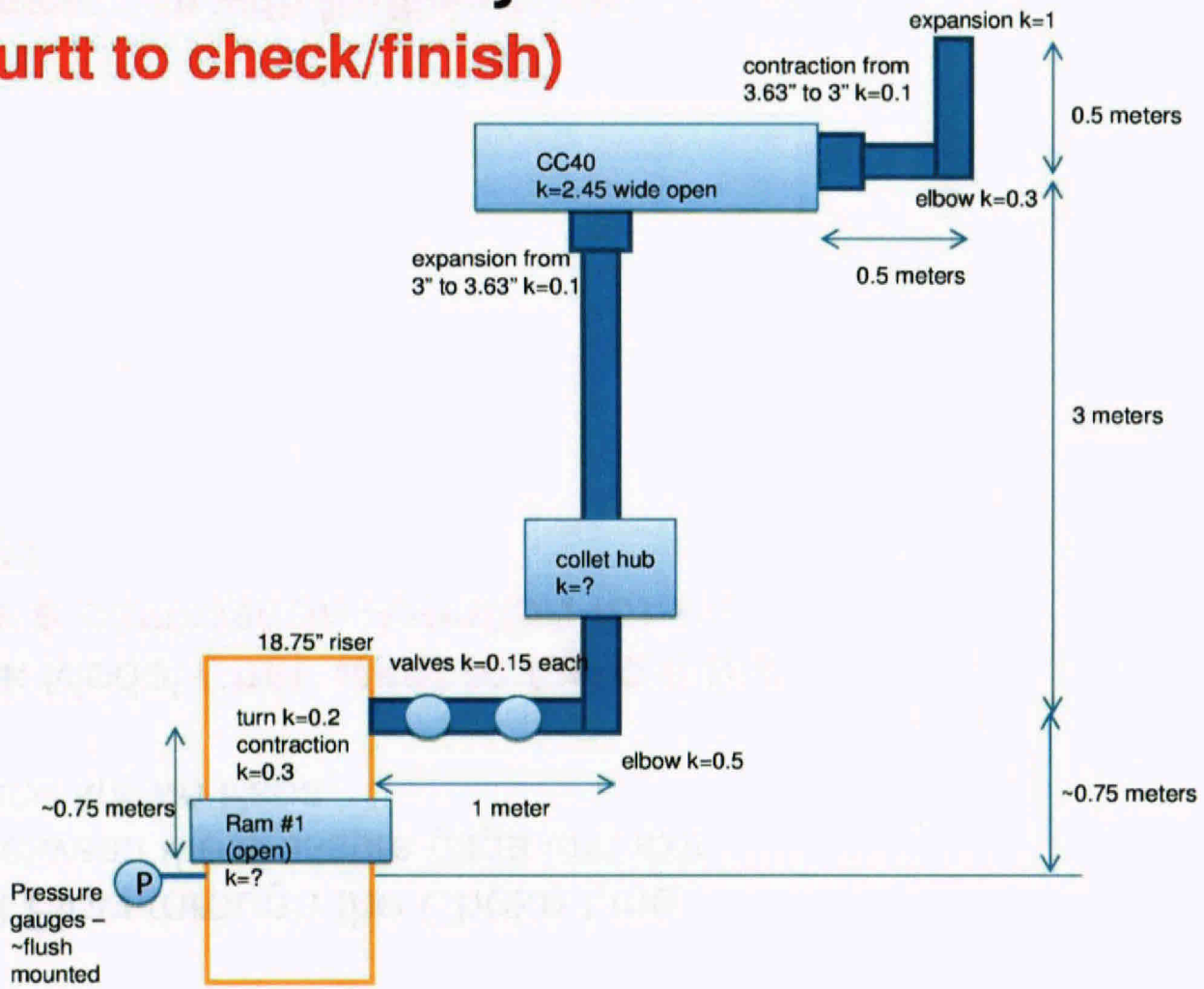
(Wayne to check/finish)

- Model Advantages
  - Simple Geometry
  - What else
- Model Limitations/Issues
  - Fill in
- Results
  - Could be a chart and/or tabulations – be sure to add a statement on uncertainties, even if currently a WAG

Choke Line Analyses – Method 3
Closure Test of July 15
(Curtt to check/finish)

Closure Test of July 15

- Completed repairs to choke line to eliminate leak
- Opened choke line
- Took Q4000 and HP1 collection systems off-line
- Closed valves to kill Line; flow only through choke line
- Closed choke valve in 16 steps (see vgs to follow) to achieve full shut-in; monitored choke pressure



POC – Curtt Ammerman with Multiple modelers – need each to fill in this vg – Art will compile

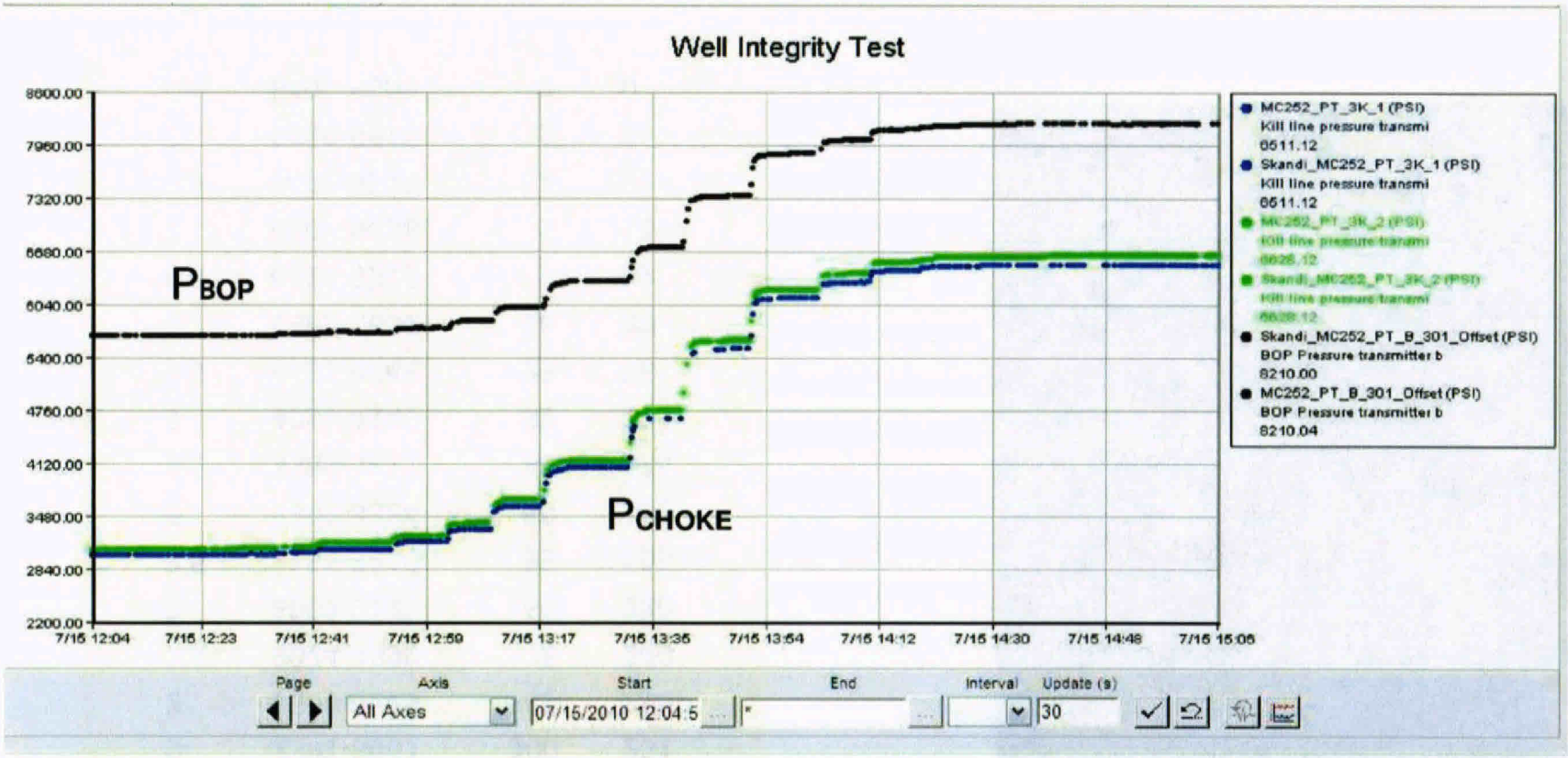
Choke Line Analyses – Method 3

(Curtt to check/finish)

- Analysis Method: Predict Flow through the Choke Line
  - Model flow restrictions between the pressure gage and exit
  - Use measured Pchoke and known Psea
- Resulting Model: Network Model ***(may want to lay-out the network model or show a summation equation for the collection of restrictions***
- Assumptions:

POC – Curtt Ammerman with Multiple modelers – need each to fill in this vg – Art will compile

Results from Well Integrity Shut-in Test of July 15



Pressure records available from SharePoint records

CC40 Choke valve characteristics and choke pressure data for July 15 well integrity shut-in test

# Turns	Pchoke**	% Open	Cv
0	2991-3061	100	251
2	3000-3075	86	250
2.5	3024-3099	78	240
3	3061-3140	69	220
3.5	3155-3230	59	195
4	3309-3384	50	165
4.5	3586-3672	41	133
5	4059-4149	32	103
5.5	4655-4748	23	76
6	5502-5602	16	49
6.5	6113-6220	9	22
7	6301-6408	5	11
7.5	6441-6548	2	5
8	6469-6578	1	2
8.5	6497-6605	0	0

Calibration Curve for CC40 Choke Valve

** Higher readings on **Pchoke** to be used in analysis – compared best with sea pressure at elevation prior to test

Choke Line Analyses – Method 3 (contd)

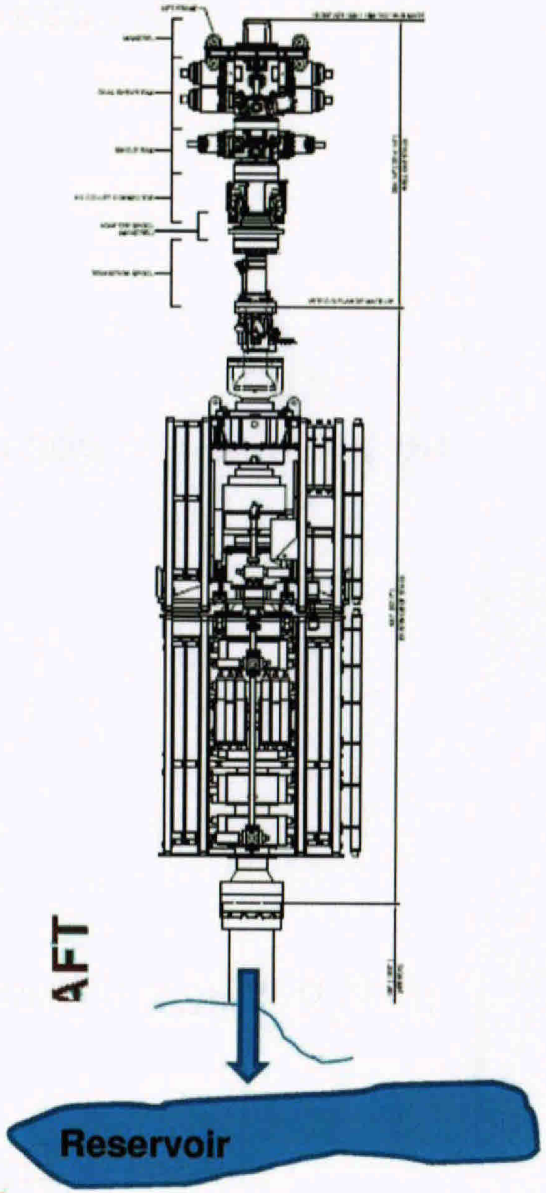
(Curtt to check/finish)

- Model Advantages
  - Analyses does not require knowledge of conditions in BOP and Well section
  - Choke line geometrical effects known;
  - What else
- Model Limitations/Issues
  - Fill in
- Results
  - Could be a chart and/or tabulations – be sure to add a statement on uncertainties, even if currently a WAG

POC – Multiple modelers – need each to fill in this vg – Art will compile

Reservoir-to-Sea Analyses – Method 4

- Analysis Method: Flow through the Well, BOP and Capping Stack to Sea
  - Model flow restrictions between the pressure gage and exit
  - Use measured Pchoke and known Psea
  - Two approaches (both described separately):
    - **BULLET FROM MORROW**
    - **BULLET FROM HAVSTAD**
- Resulting Models (see next 2 vgs)



6/21/2011

POC – C. Morrow & M. Havstad

General Assumptions/BCs for Method 4

- Reservoir Pressure
  - 10050psi (depleted)
  - 11850psi (initial)
- Temperatures
  - 240F (reservoir)
  - 180F (exit of choke line)
- Location of exit flow = Assume ~100' above sea floor (P_{exit} ~2180psi) – **IS THIS RIGHT??**
- Use higher of pressure records during shut-in
- Use choke valve characteristics
- PI for reservoir (set by analyst)

POC – C. Morrow & M. Havstad

Method 4: Model #1 Description
(Morrow to check/finish)

- Model Description ***(could put in network model if have it – in particular, may want to show your BOP network model)***
- Model Assumptions
- Model Uncertainties

Method 4: Model #1 Results

(Morrow to check/finish)

- Charts with a bullet or two at bottom on major take-aways

Method 4: Model #2 Description

(Havstad to check/finish)

- Model Description ***(could put in network model if have it)***
- Model Assumptions
- Model Uncertainties

Method 4: Model #2 Results

(Havstad to check/finish)

- Charts with a bullet or two at bottom on major take-aways

Summary of results from 4 methods for estimating well flow rate

(to be filled in)

Date	Synopsis	Wellhead flow rate (stock bbl/day)	Major Uncertainties	Other Notes
Method 1: Pressure Differential Analyses	Kill Line Studies – uses two flow conditions	TBD	TBD	TBD
Method 2: Flow through Kill Line valve	Computes flow using Pressure at Choke valve and sea pressure through kill line	TBD	TBD	TBD
Method 3: Flow through Choke Line	Computes flow using Pressure at Choke valve and sea pressure through choke line	TBD	TBD	TBD
Method 4: Flow from Reservoir to sea	Uses choke and sea pressure and results from first 3 methods - includes flow through BOP and provides estimate for BOP pressure during close-in			

Flow Rate Calculation Conclusions

- **To Be FILLED IN AFTER RESULTS ASSEMBLED**