Smart Production Monitoring Enabled by Virtual Well Metering

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- Safety Moment
- What is VMS?
- Wood Experience with VMS
- Differences Between VMS and Multiphase Meters
- VMS Calculation Overview
- Data Filtering
- VMS Lite
- Tuning – How and Why
- Field Examples
- Conclusions

Safety and Flexibility

- Going to Site is sometimes critical to project success because design does not always match actual.
- Be prepared for things that can go wrong before you go to site.

What is VMS?

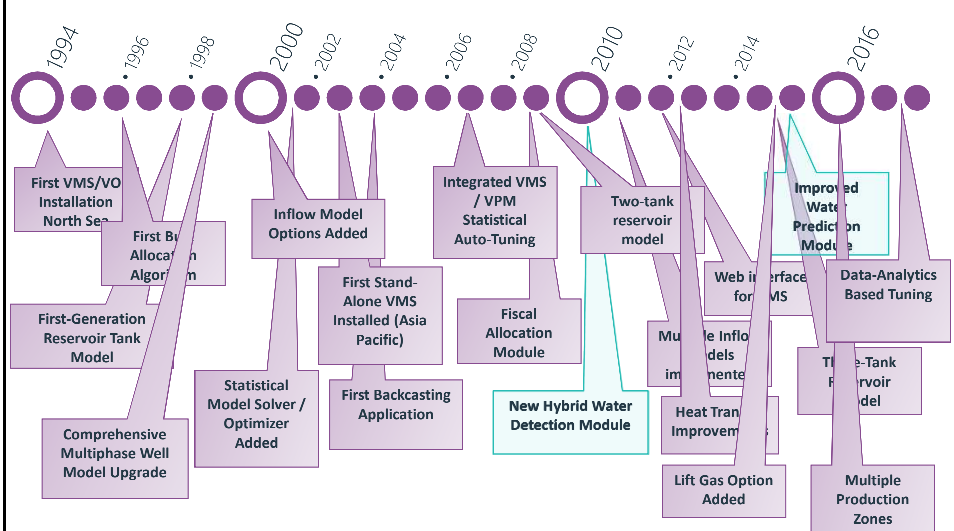
Virtual Metering System (VMS)

VMS – Inferential Metering System Calculates flowrates (G/O/W) using typical instrumentation data around well, e.g. Ps & Ts before & after the choke.

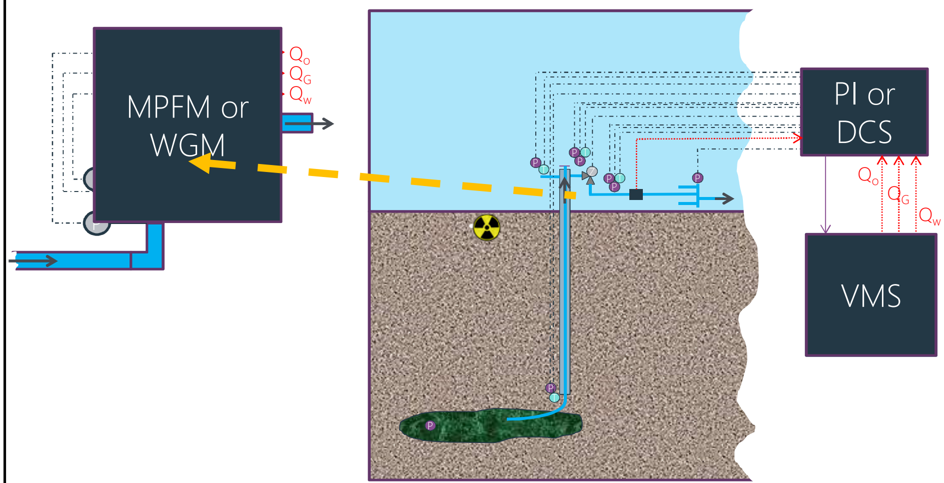
Wood Experience with VMS

- Over 25 years of installing and maintaining online, real-time dynamic modeling technology for upstream production operations (Virtuoso®)
- 150+ custom installations in 20+ different countries for over 30 different companies
- Virtual Metering Technology deployed in 50+ Platforms, 75+ Reservoirs, nearly 1000 Wells – thousands of well-years of VMS performance experience
- Globally installed and most still being maintained
- First system delivered in 1994 – ran until the platform was Decommissioned in October 2018.

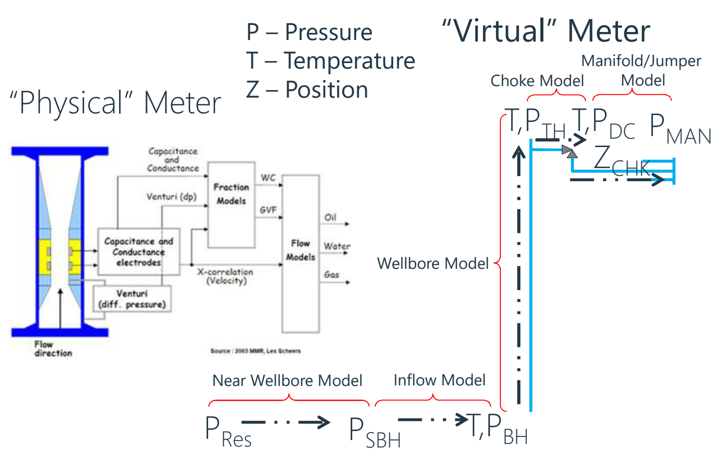
VMS Evolution and Applications



Wellhead Metering



VMS and Physical Meter Models



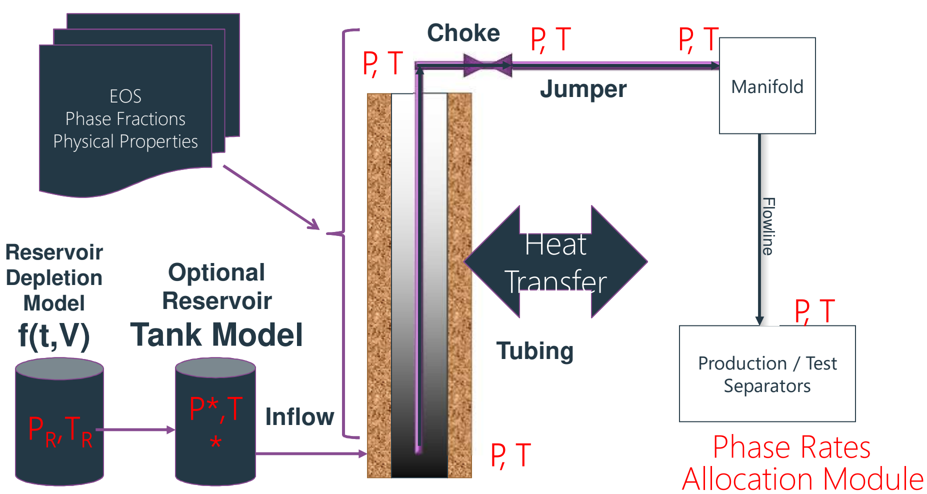
dP in millibars - .010 bar <<<< dP in hundreds of bars

VMS Methods

- Very robust, software/model-based solution for calculating wellhead flow rates from conventional well instrumentation
  - Uses all available instrumentation (P,T,Z) from perforation to manifold
  - Nine standard methods* combined statistically to determine best flow rate estimate
  - Uses first-principles of heat, mass, & momentum transfer, coupled with thermodynamics engine for phase behavior and physical property calculation

- A smart meter and well surveillance tool which is remotely readable and configurable

How VMS Works - VMS Models

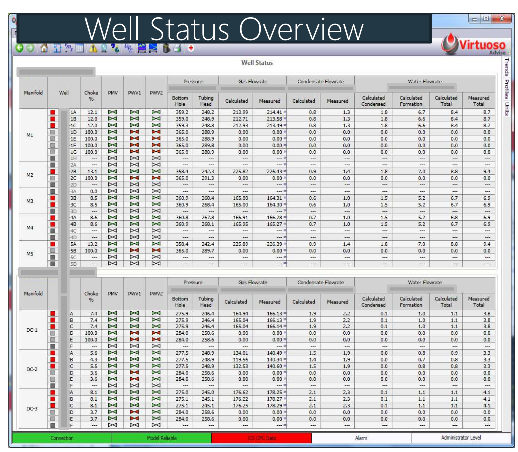


VMS Calculation Procedure

- Best Estimated = Weighted Average
- Overall Uncertainty has two components:
  - Error propagation due to instrumentation
  - Model Uncertainty

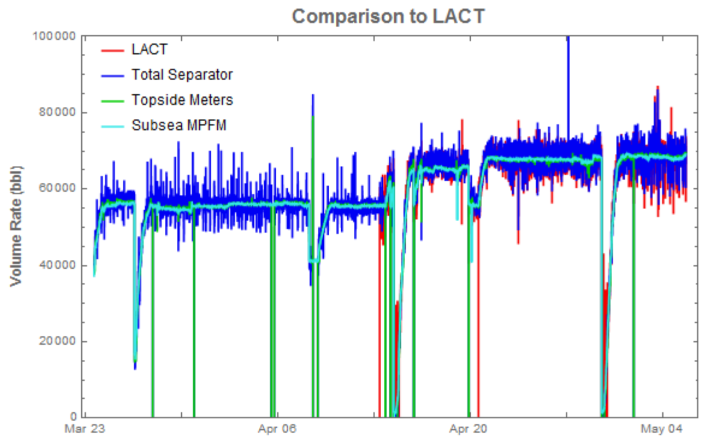
Benefits of VMS

- Has been used in lieu of subsea multiphase meters.
- Has been used for surveillance and an insurance policy for subsea metering
- Can be used / installed retrospectively (brown field applications)
- Very robust – uptime of 99.9%+
- improved decision making
- Increased accuracy of estimating remaining recoverable hydrocarbons
- Enhanced real-time well and reservoir surveillance and management (watch the physics)
- Cost of VMS usually order of magnitude less than MPFM
- Can be Tuned Based on LACT Meters
- Production allocation & cumulative production to facilitate history matching
- Can be used to Find Meter Factors for Multiphase Meters



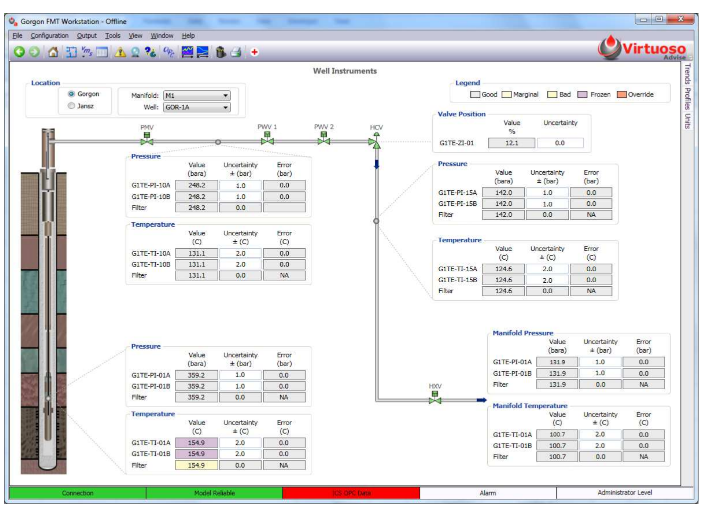
Multiphase Meter Tuning

- Volume rates for all meters at stock tank conditions

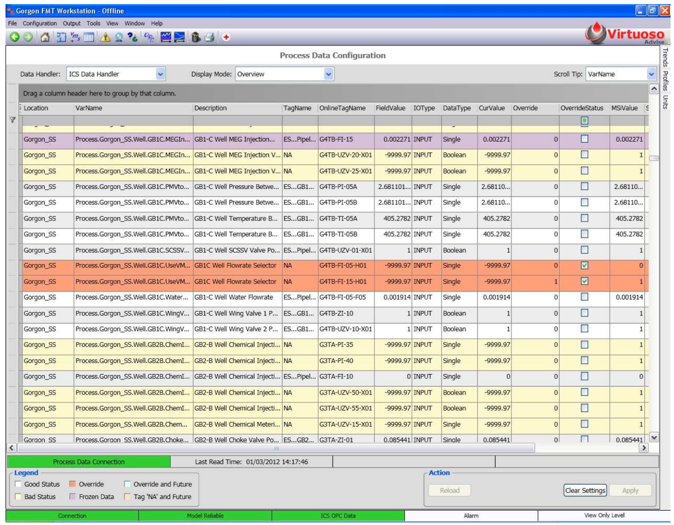


Location	Gain
Train 1	1.0531
Train 2	1.0838
A Topside	1.0024
B Topside	1.0246
C Topside	1.0017
D Topside	1.0046
Riser A	0.9492
Riser B	0.9448
Riser C	0.9744
Riser D	0.9363
RiserE	0.9600

Sensor Status Summary



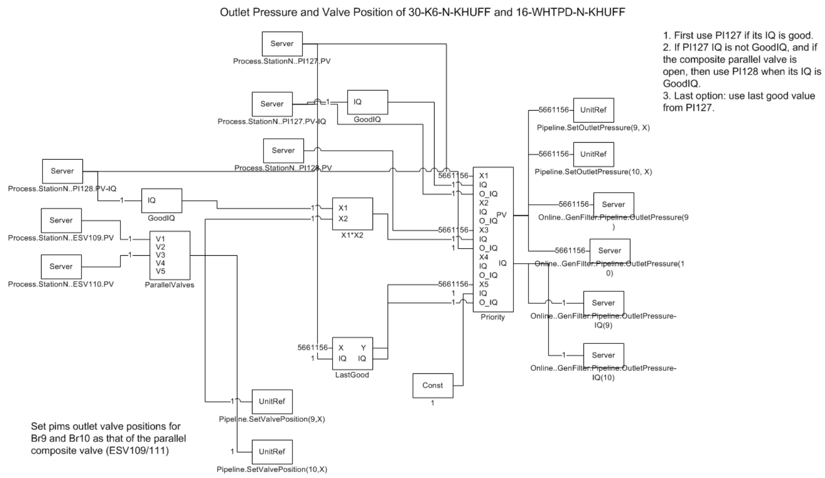
Data Filtering



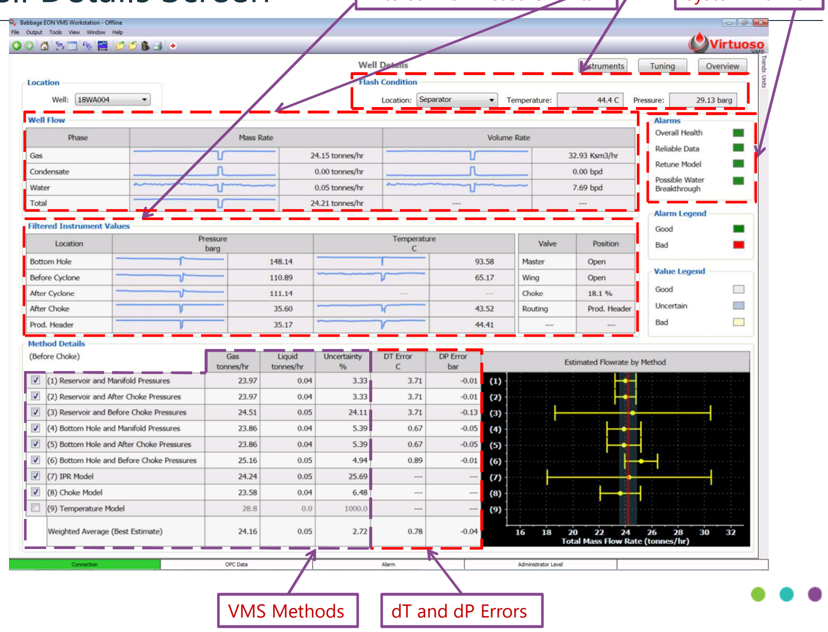
Field Data Filtering and Reconciliation in VMS

- Data Treatment Methods
  - Gross error detection and isolation using statistical tests, global tests, nodal tests, measurements tests, unbiased estimate techniques
  - Data filtering and reconciliation algorithms
- Outlier Removal and Best Filter Definition
  - Deliver a dataset which closer to the true process state than raw data

Chameleon™ Filters



Well Details Screen

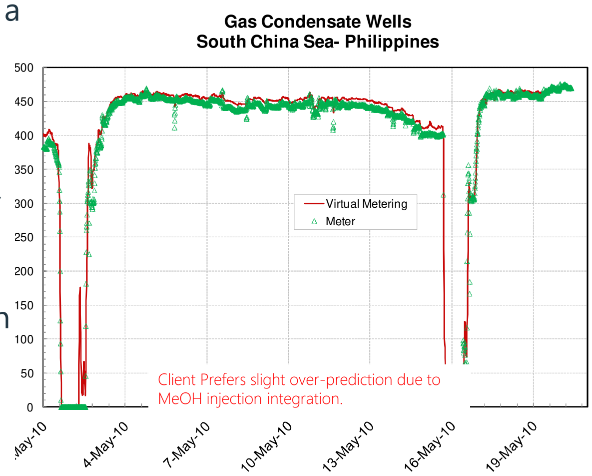


VMS – Accuracy and Field Performance

Accuracy depends on a range of issues:

- Fluid type
- Instrumentation & Accuracy
- Ability to accurately Tune

Out of the box (design data)
~ ±10-15% Gas & Liquid Rates

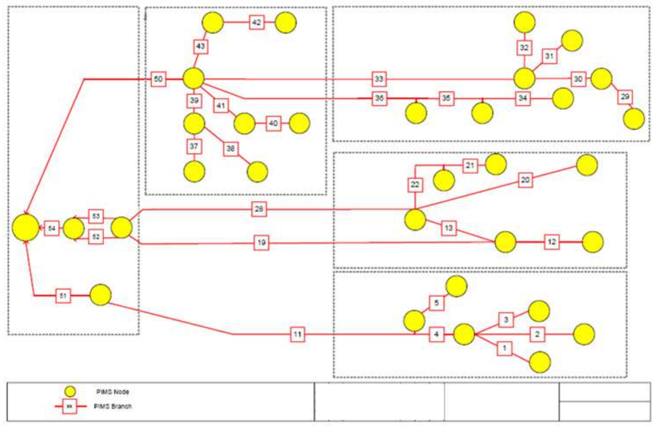


Tuned
~ ±1-5% Gas & Liquid Rates

VMS Lite vs Regular VMS

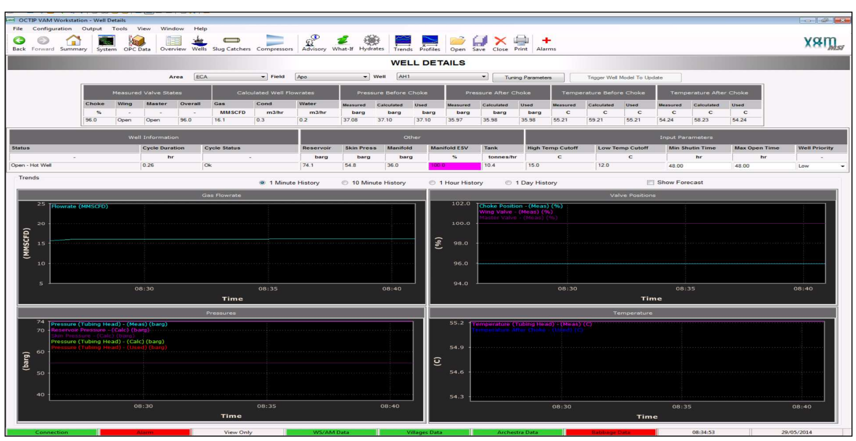
- VMS Lite uses 2 methods instead of 9.
- VMS Lite Typically Used when No Bottom Hole Pressure Measurement
- Used in Cases where Data Analytics Required to Estimate Flowrate from Each Well
  - In one case – no well tests for 5 to 15 years.
  - 1 Fiscal Meter for 20 Wells Located 40 km Away
  - Reservoir Engineers Only have Field Wide View Models not well by well view
  - Need Ability to Simulate 6 months of Data in 5 seconds for Funtional Evulation for Data Analyic Fitting Methods

Example Application of VMS-Lite



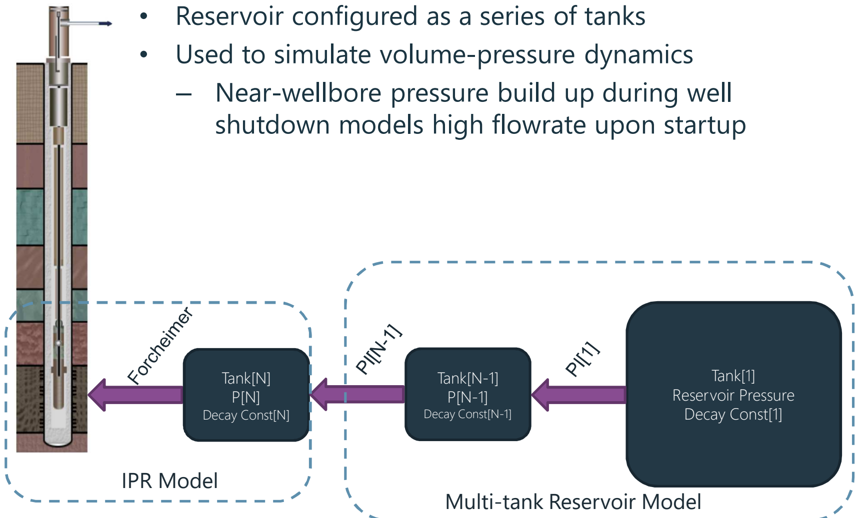
Three Fiscal Meters
Three Allocation Meters
100 Wells

VMS-Lite Example Screen

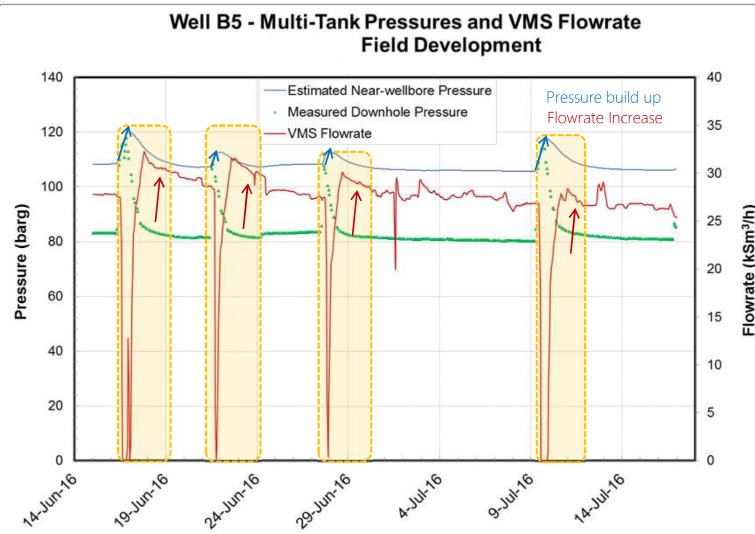


Multi-Tank Implementation

- Reservoir configured as a series of tanks
- Used to simulate volume-pressure dynamics
  - Near-wellbore pressure build up during well shutdown models high flowrate upon startup

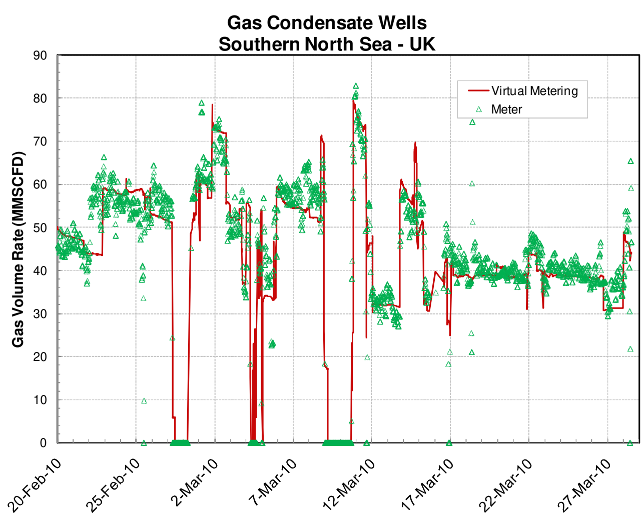


Multi-Tank Implementation

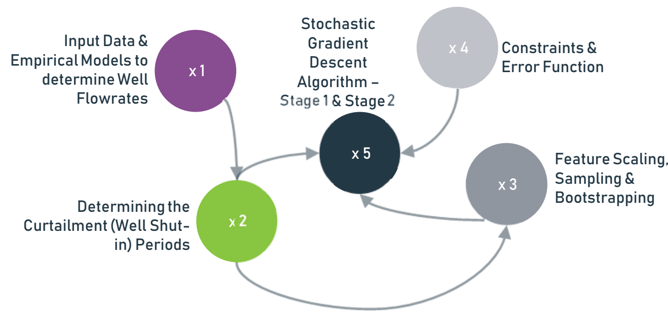


Fitting VMS-Lite Using Data Analytics

- Minimize the error for the following predictions
- Cumulative Flowrate of all wells compared to total (by difference)
- Flowing Well Head Temperature
- Pipeline Pressure Drop
- Shut-in Pressure Buildup



VMS LITE PYTHON MODEL IN A NUTSHELL



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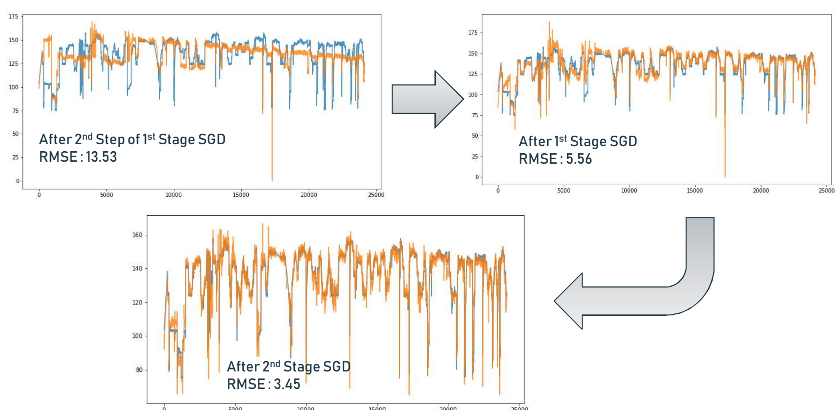
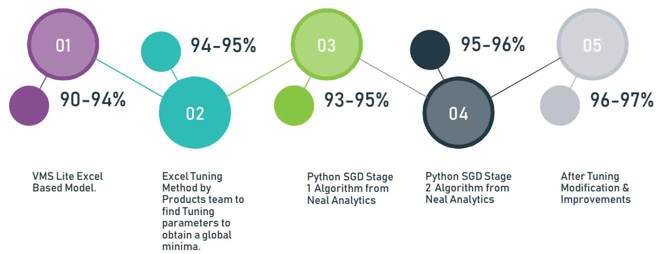
A presentation by Wood.

RESULTS – STOCHASTIC GRADIENT DESCENT



INCREASE IN ACCURACY



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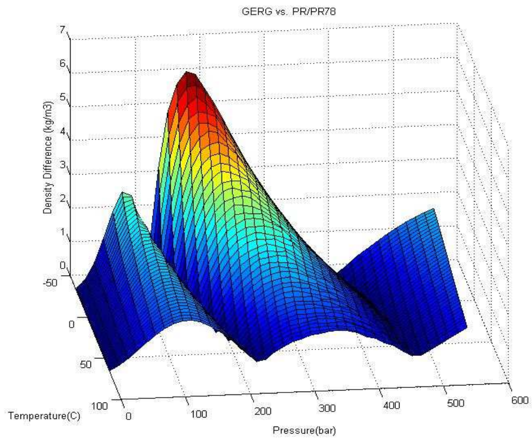
A presentation by Wood.

Tuning of Regular VMS

- Closing the asset mass balance - at separators (single phase meters) and custody transfer points
- Reprocessing and Analysis:
  - Choke characteristics change over time
    - Positioner calibration
    - Erosion
    - Blocking of holes
    - Choke change-out
  - Reservoir characteristics – pressure and inflow performance.
  - Small changes to composition/loading/water which change the density amount of head
  - Properties of tubing (roughness) tend to increase slightly over time
  - Hydrocarbon Viscosity/Density

GERG VS. PR



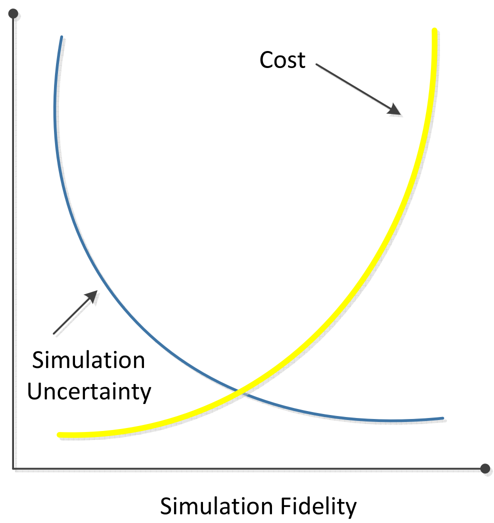
Sometimes Operates Outside the Envelope

- Client performed backyard experiments to clarify downcomer flow regimes and behavior

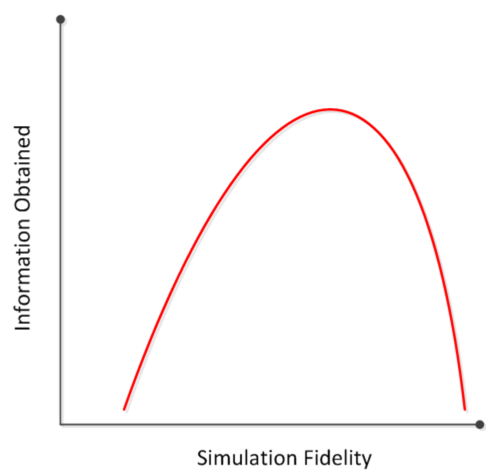
Liquid Down

Gas Bubbles

Practical Trade-offs in Industrial Setting



Pick the Optimum Fidelity to Maximize Information Obtained



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Field Application Examples

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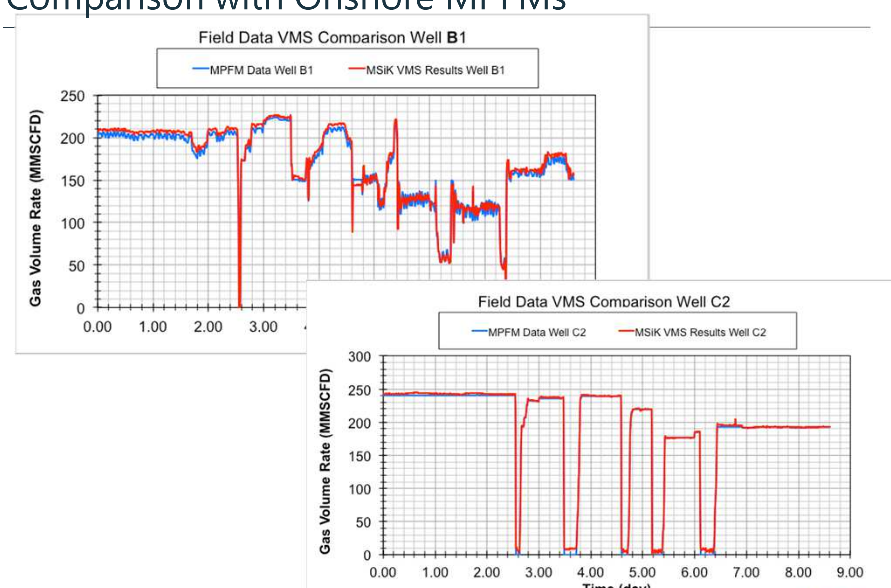
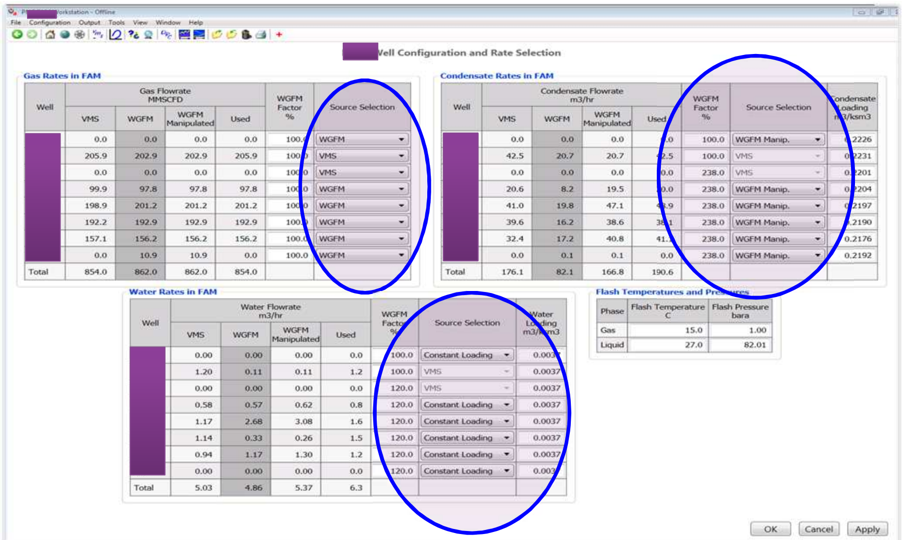
Comparison with Onshore MPFMs



Six Months Later …



Gas Rates in FAM

Well	Gas Flowrate MMSCFD VMS	WGFM	WGFM Manipulated	Used	WGFM Factor %	Source Selection
[redacted]	0.0	0.0	0.0	0.0	100.0	WGFM
	205.9	202.9	202.9	205.9	100.0	VMS
	0.0	0.0	0.0	0.0	100.0	VMS
	99.9	97.8	97.8	97.8	100.0	WGFM
	198.9	201.2	201.2	201.2	100.0	WGFM
	192.2	192.9	192.9	192.9	100.0	WGFM
	157.1	156.2	156.2	156.2	100.0	WGFM
	0.0	10.9	10.9	0.0	100.0	WGFM
Total	854.0	862.0	862.0	854.0		

Condensate Rates in FAM

Well	Condensate Flowrate m3/hr VMS	WGFM	WGFM Manipulated	Used	WGFM Factor %	Source Selection	Condensate Loading m3/ksm3
[redacted]	0.0	0.0	0.0	0.0	100.0	WGFM Manip.	0.2226
	42.5	20.7	20.7	42.5	100.0	VMS	0.2231
	0.0	0.0	0.0	0.0	238.0	VMS	0.2201
	20.6	8.2	19.5	20.0	238.0	WGFM Manip.	0.2204
	41.0	19.8	47.1	48.9	238.0	WGFM Manip.	0.2197
	39.6	16.2	38.6	38.1	238.0	WGFM Manip.	0.2190
	32.4	17.2	40.8	41.1	238.0	WGFM Manip.	0.2176
	0.0	0.1	0.1	0.0	238.0	WGFM Manip.	0.2192
Total	176.1	82.1	166.8	190.6			

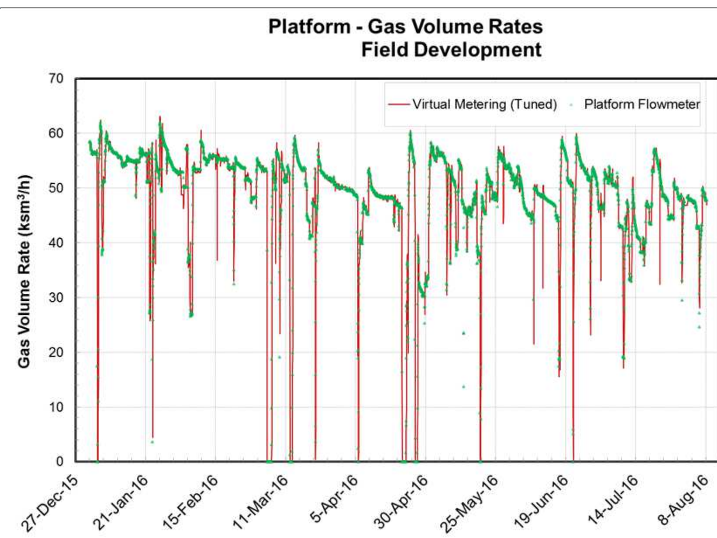
Water Rates in FAM

Well	Water Flowrate m3/hr VMS	WGFM	WGFM Manipulated	Used	WGFM Factor %	Source Selection	Water Loading m3/ksm3
[redacted]	0.00	0.00	0.00	0.0	100.0	Constant Loading	0.0037
	1.20	0.11	0.11	1.2	100.0	VMS	0.0037
	0.00	0.00	0.00	0.0	120.0	VMS	0.0037
	0.58	0.57	0.62	0.8	120.0	Constant Loading	0.0037
	1.17	2.68	3.08	1.6	120.0	Constant Loading	0.0037
	1.14	0.33	0.26	1.5	120.0	Constant Loading	0.0037
	0.94	1.17	1.30	1.2	120.0	Constant Loading	0.0037
	0.00	0.00	0.00	0.0	120.0	Constant Loading	0.0037
Total	5.03	4.86	5.37	6.3			

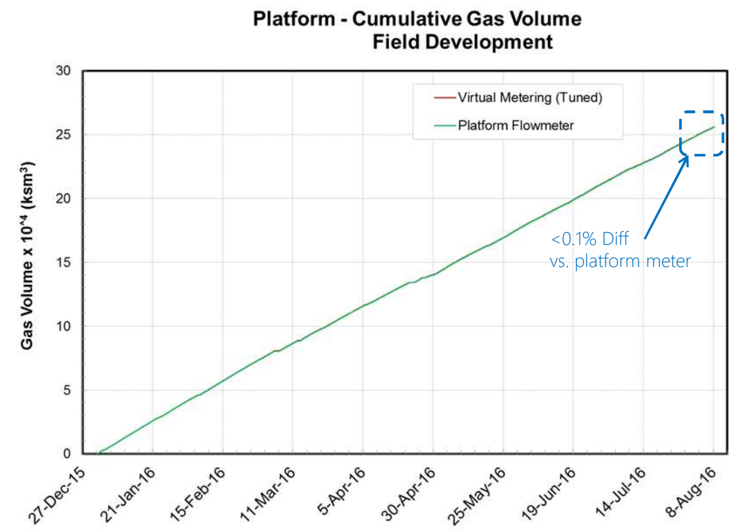
Flash Temperatures and Pressures

Phase	Flash Temperature C	Flash Pressure bara
Gas	15.0	1.00
Liquid	27.0	82.01

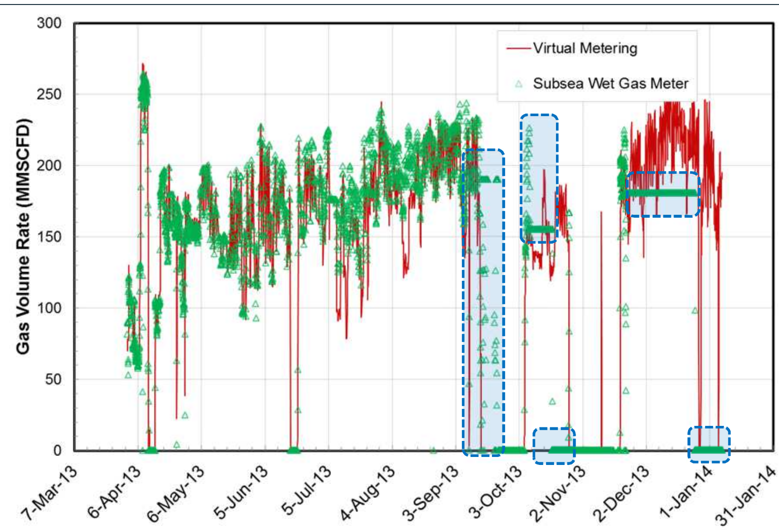
VMS vs Platform Flowmeter



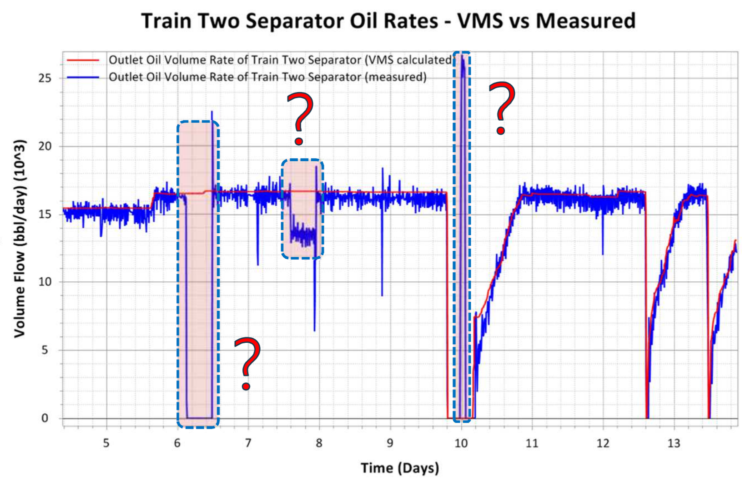
VMS vs Platform Flowmeter



Subsea Wet Gas Meter Failures

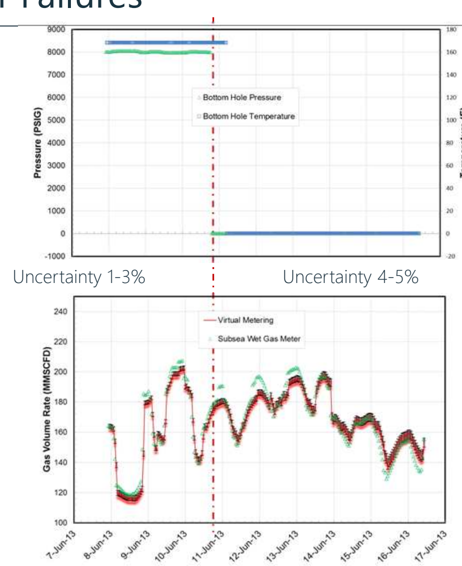


Single-Phase Flowmeter Failures



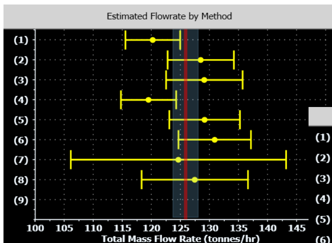
Bottom Hole Sensor Failures

On 11th June Bottom hole sensors failed.

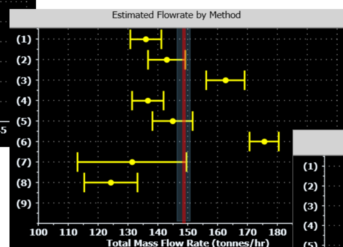


VMS Automatically detected, and excluded results with slight increase in uncertainty

VMS Method Alignment with VWDS

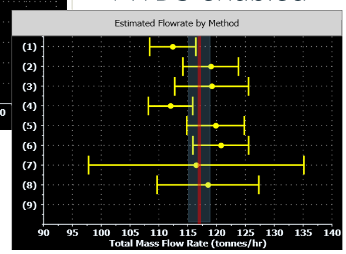


0 BBL/MMSCF



8 BBL/MMSCF, VWDS disabled

8 BBL/MMSCF, VWDS enabled



Conclusions

- Virtual metering technologies can provide significant reduction in cost as well as additional data that well tests and MPFMs do not provide
- Viable alternative technology to using physical metering and well test facilities
- Field proven technology which uses standard models developed by researchers and field data
- Online VMS technology can be used together with existing multiphase flow meters (MPFMs) to diagnose breakdown or fault of a given MPFM
- VMS technology is well suited for real-time offshore and onshore well performance monitoring, automated diagnostics, and improved reservoir management

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Well Status

Prod Instruments | Prod Details | Prod Tuning
Inj Instruments | Inj Details | Inj Tuning

Production Well Status

Manifold	Well	Choke %	PMV	PWV	Pressure psig			Calculated		
					Bottom Hole L	Bottom Hole U	Tubing Head	Oil Flowrate bopd	Gas MMSCFD	Water Flowrate bwpd
SS-MFLD	D	6.4			13120.4	13013.2	8646.4	2799.5	3.84	460.7
	H	6.0			14083.6	13999.4	10220.1	5096.8	19.17	0.0
SS-ILS-P01	A	0.5			13563.6	13500.9	4204.6	0.0	0.00	0.0
	B	21.2			11729.5	11632.9	7105.1	13290.3	18.20	0.0
SS-ILS-P02	C	5.1			10321.9	10223.1	6331.7	4609.9	7.02	0.0
Total		---	---	---	---	---	---	25803.9	48.26	460.8

Injection Well Status

Well	Choke %	IMV	IWV	Pressure psig			Predicted Sandface		Calc Water Flowrate bwpd
				Bottom Hole	Downstream Choke	Upstream Choke	Pressure psig	Temperature F	
E	14.5			8106.8	6032.0	6583.5	15566.3	75.4	5257.6
G	0.0			16785.0	986.1	986.1	24252.1	-459.7	0.0
								Total	5262.8
								Total Measured	6059.6

Predicted Export Rate	5621.4 bwpd
Measured Discharge Rate	6059.6 bpd
Measured Export Pressure	4658.7 psig

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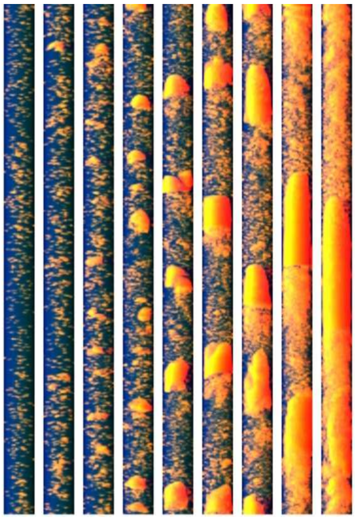
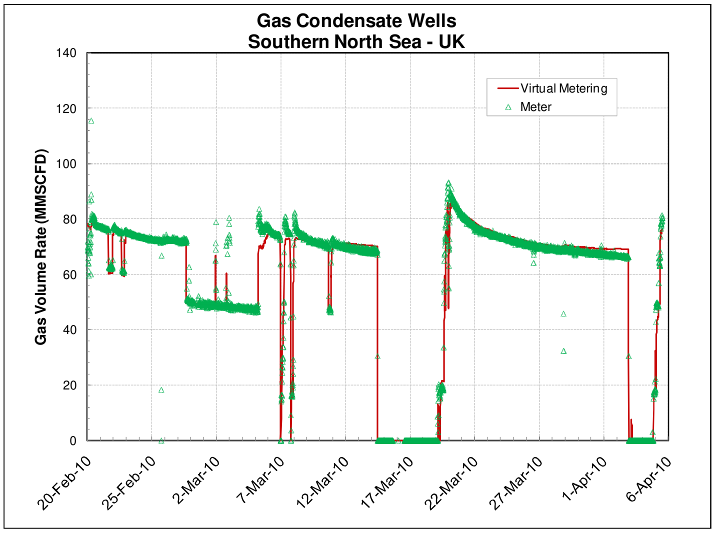
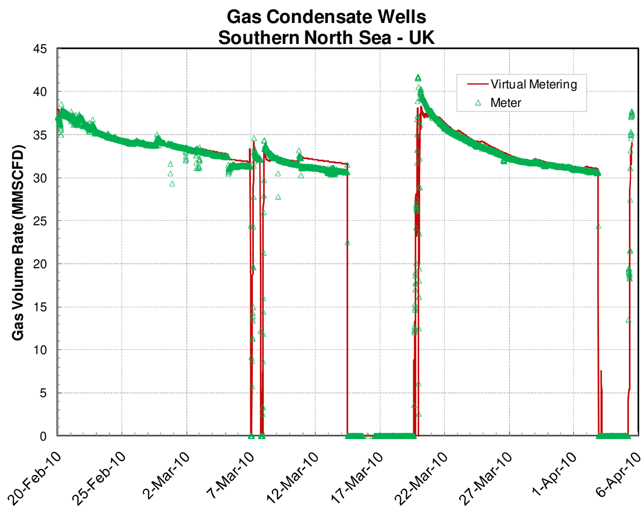
Tuning Parameters (continued)

- Predictions are based on physics
- Main tuning parameters:
  - Fluid GOR / Watercut
  - Flow path roughness
  - Interfacial surface tension
  - Fluid viscosity
  - IPR relationships
  - Reservoir depletion curves (and actual PBH-Static / TRes)
  - Cv curves, valve position
  - Other frictional losses (eg due to obstructions)
  - Thermodynamics (eg wellbore OHTC / Thermal mass)
  - Field data filtering / measurement drift
  - Model uncertainty filtering
- Often teaches you something about your system that you did not know






Gas Condensate Wells
Southern North Sea - UK
Gas Volume Rate (MMSCFD)
45
40
35
30
25
20
15
10
5
0
Virtual Metering
Meter
20-Feb-10
25-Feb-10
2-Mar-10
7-Mar-10
12-Mar-10
17-Mar-10
22-Mar-10
27-Mar-10
1-Apr-10
6-Apr-10