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Recommended Practice for Safe Well Positioning, Separation, and Surveying

Jonathan Dale Lightfoot

OXY

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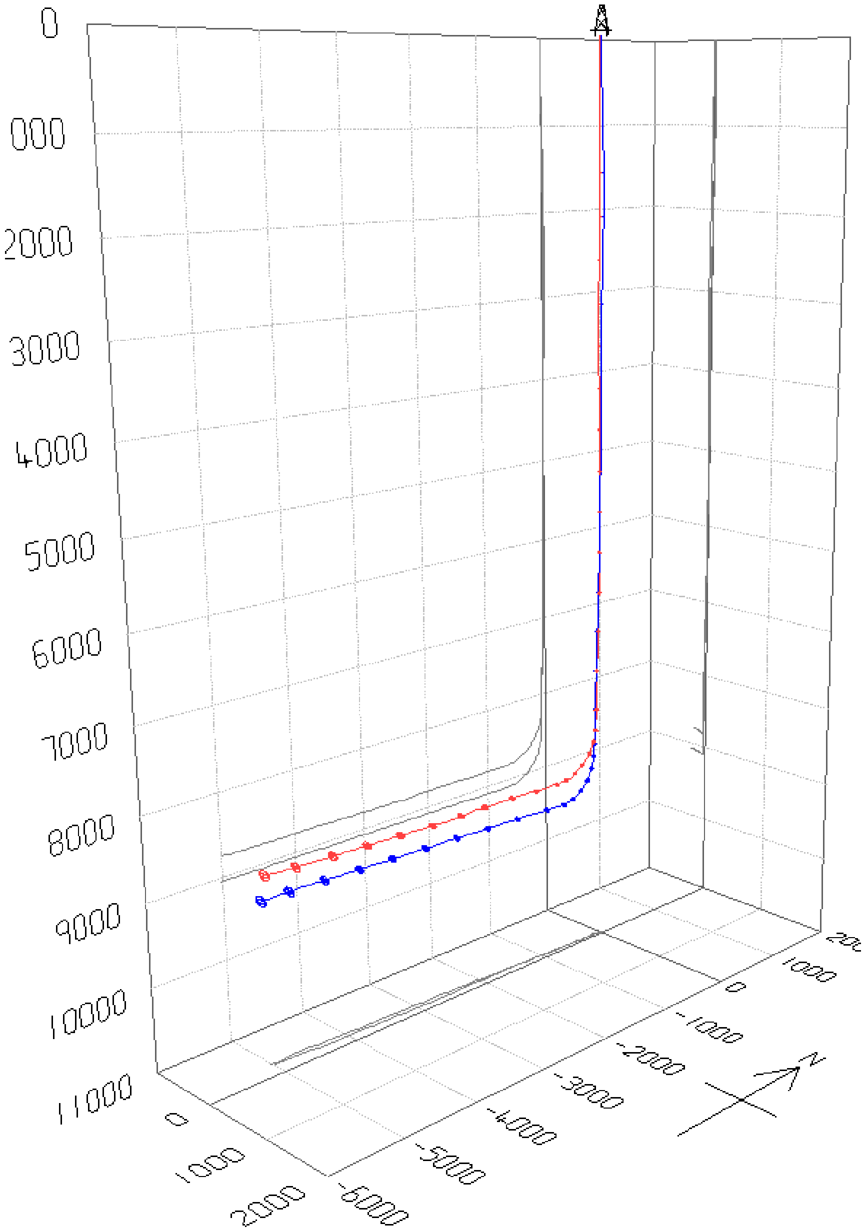
Presentation Outline

- **Safe Separation**
- **Applications**
- **Industry Collaboration**
- **Management Principles**
- **Position Uncertainty Models (PUMs)**
- **Offset Well Environment**
- **Case Studies**
  - **Offset Operator Close Approach**
  - **Lateral Undulations**
  - **Key Performance Indicators**
  - **Steerable Motor Curve**
  - **Lateral Tortuosity**
- **Key Takeaways**



Safe Separation

The Wellbore Positioning Technical Section (WPTS) Rule

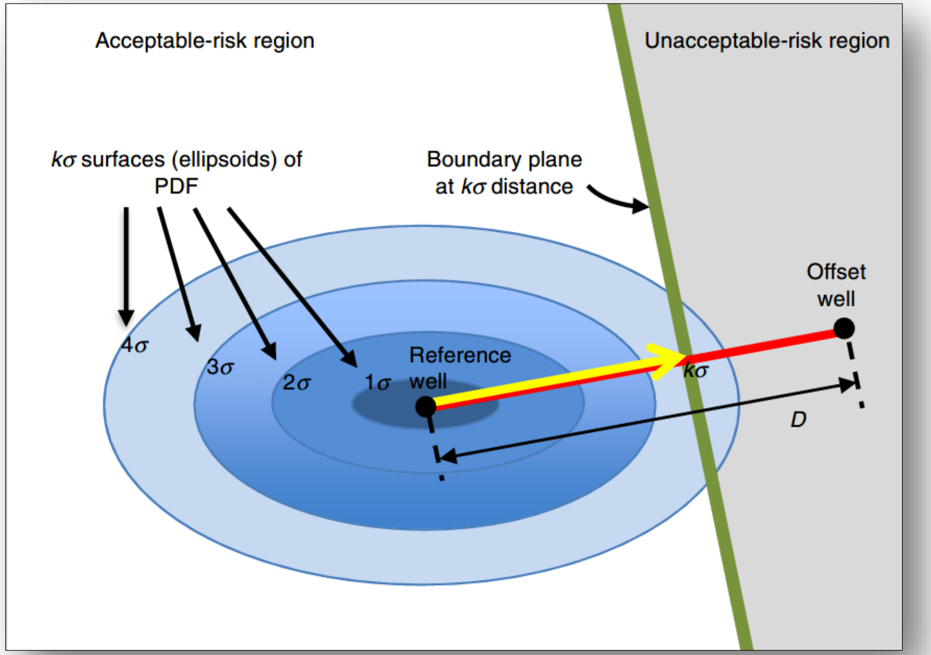
Separation Factor = Ratio of Separation Distance and Uncertainty

$$\frac{\text{Numerator}}{\text{Denominator}} = \frac{\text{Distance}}{\text{Uncertainty}}$$

$$SF = \frac{D - R_r - R_o - S_m}{k\sqrt{\sigma_s^2 + \sigma_{pa}^2}}$$

$$\sqrt{\sigma_r^2 + \sigma_o^2}$$

$$k\sqrt{\sigma_s^2 + \sigma_{pa}^2}$$



WPTS Separation Rule Illustration (SPE-187073-PA)

Applications

Serves as the primary technical reference for proven engineering practice in the broad wellbore construction application of:

- **Oil and Gas**
- **Geothermal**
- **Carbon Sequestration**
- **Coalbed Methane (CBM)**
- **Horizontal Directional Drilling (HDD), trenchless boring**
- **Mineral Ventilation and Extraction**
- **Scientific Coring**
- **All other subsurface borehole construction applications**

Industry Collaboration

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- **Industry Steering Committee on Wellbore Survey Accuracy**
  - Produces, maintains, and publishes standards for the industry
  - Promotes a collaborative understanding of issues associated with wellbore surveying
  - Formed in 1999, ISCWSA has been around for 29 Years [SPE 67616-PA]
  - 57 General Meetings
- **SPE Wellbore Positioning Technical Section (WPTS)**

ISCWSA

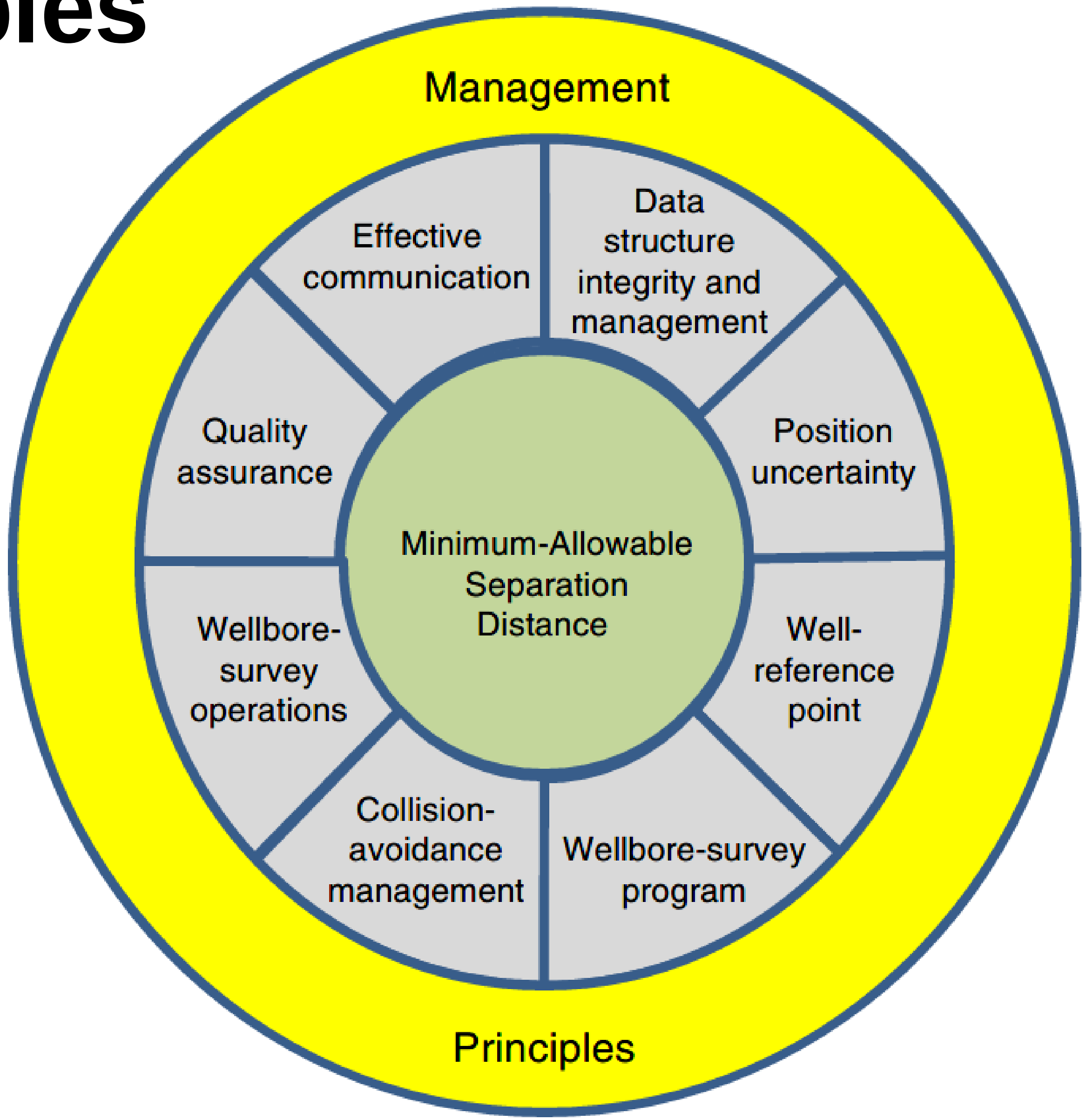
Industry Collaboration

WPTS has Six (6) Primary Sub-Committees

1. Collision Avoidance
2. Error Model Maintenance
3. Well Intercept
4. Operator's Wellbore Survey Group
5. Quality Assurance / Quality Control
6. Education

Management Principles

- **Minimum Allowable Separation Distance (MASD)**
- **Maintain a Safe Separation Distance Between Wells Being Drilled and Subsurface Hazards**
- **8 Core MASD Elements**



The eight collision-avoidance elements supporting the MASD

MASD Management Principles (SPE-187073-PA)

Allowable Deviation from Plan for SF=1

Any given SF value represents a specific probability of the reference well crossing the offset well. The distance D at which a particular SF value occurs is situation specific. For any point on a reference well, the critical value $SF = 1$ defines a minimum allowable separation distance (MASD) from the specified offset well along D :

$$SF = \frac{D - R_r - R_o - S_m}{k\sqrt{\sigma_s^2 + \sigma_{pa}^2}}$$

$$SF = \frac{D - R_r - R_o - 0.3}{3.5\sqrt{\sigma_s^2 + 0.25}}$$

$$D_{MASD} = k\sqrt{\sigma_s^2 + \sigma_{pa}^2} + R_r + R_o + S_m$$

Allowable Deviation from Plan for SF=1

$$D_{MASD} = k\sqrt{\sigma_s^2 + \sigma_{pa}^2} + R_r + R_o + S_m$$

If the distance D falls below D_{MASD}, then $SF < 1$. The difference between the planned distance D_{plan} and the D_{MASD} is the allowable deviation from the plan D_{ADP} :

$$D_{ADP} = D_{plan} - D_{MASD}$$

SPE-187073-MS

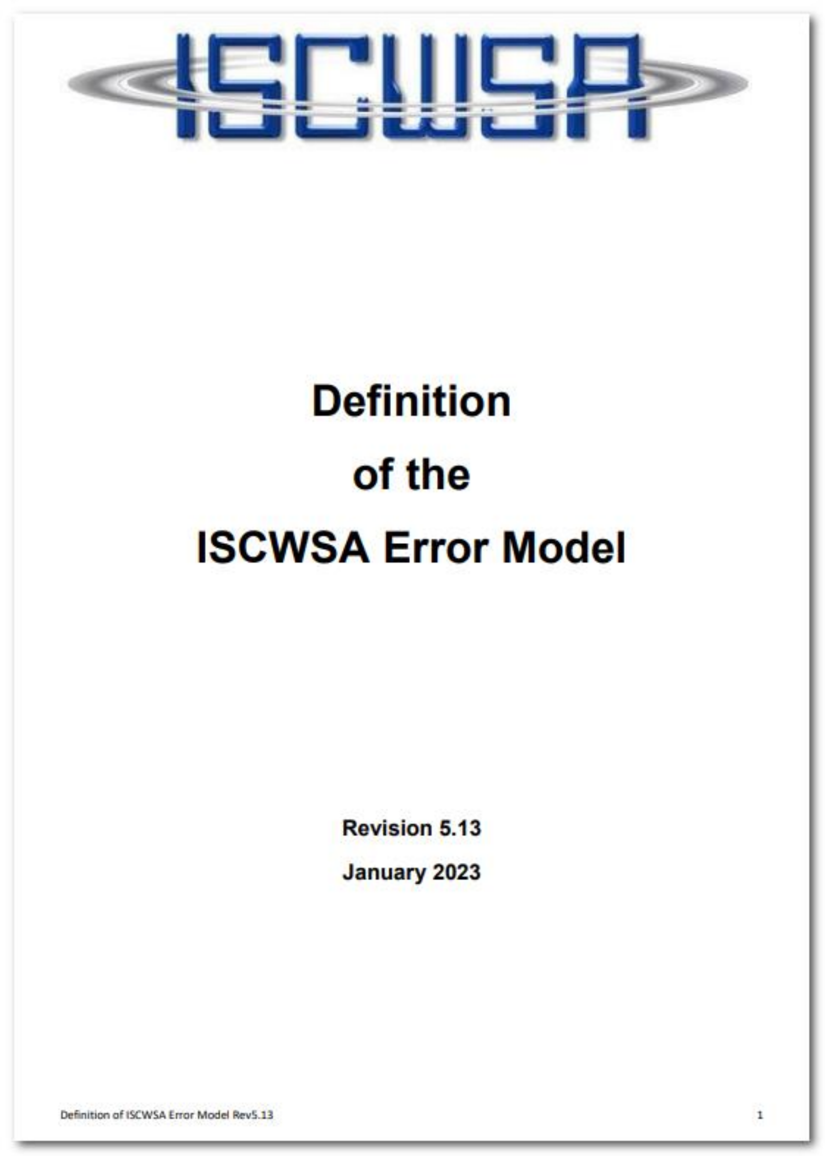
Well Collision Avoidance - Separation Rule

S.J.Sawaryn, Consultant, H. Wilson, Baker Hughes a GE Company, J. Bang, Gyrodata Inc., E. Nyrnes, Statoil ASA, A. Sentance, Dynamic Graphics Inc., B. Poedjono and R. Lowdon, Schlumberger, I. Mitchell and J. Codling, Halliburton, P.J. Clark, Chevron Energy Technology, W.T. Allen, BP

MASD Management Principles (SPE-187073-PA)

Position Uncertainty Models (PUM)

- ISCWSA & OWSG Revisions
- PUM Categories
- Magnetic Reference Classification
- Generic Models (Set A & B)
- PUM Example – MWD + SRGM
- MWD Corrections



ISCWSA

Definition

of the

ISCWSA Error Model

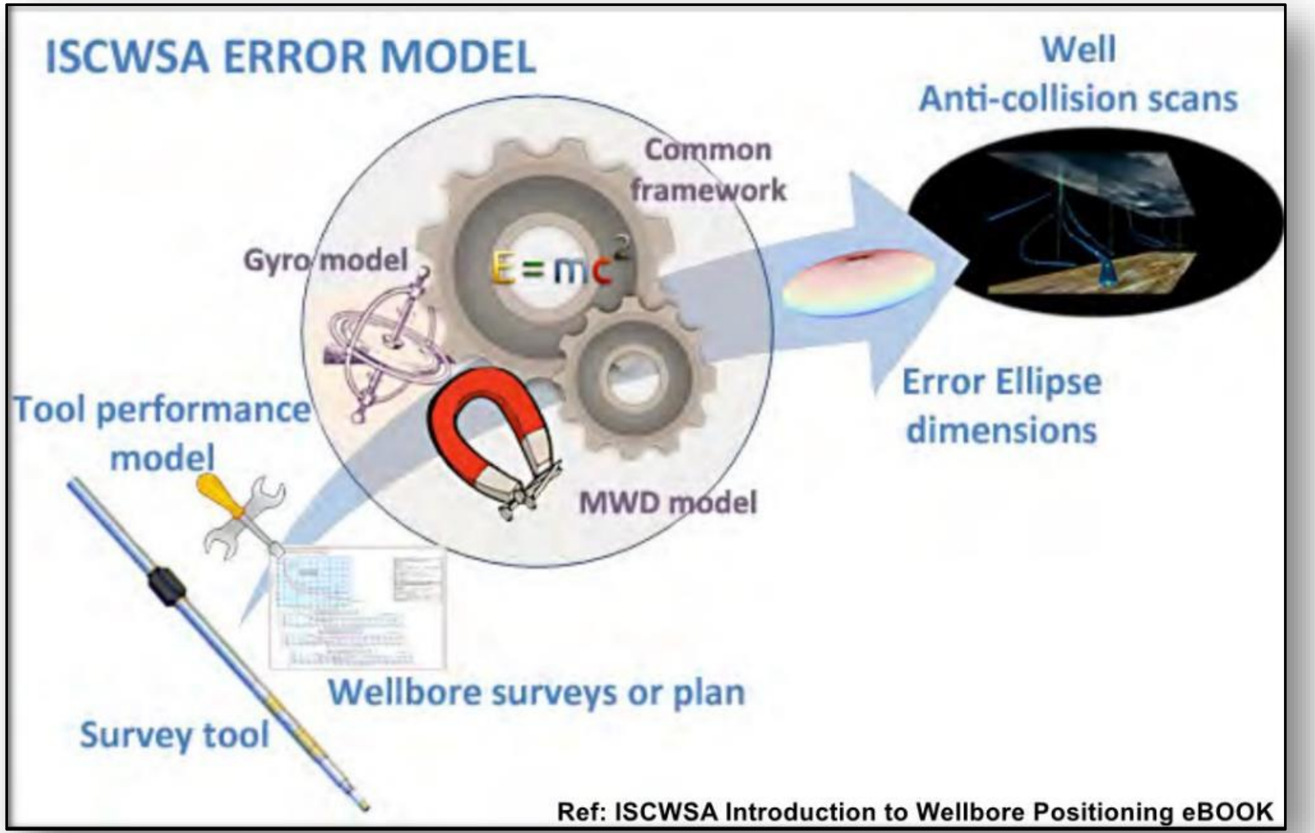
Revision 5.13

January 2023

Definition of ISCWSA Error Model Rev5.13 1

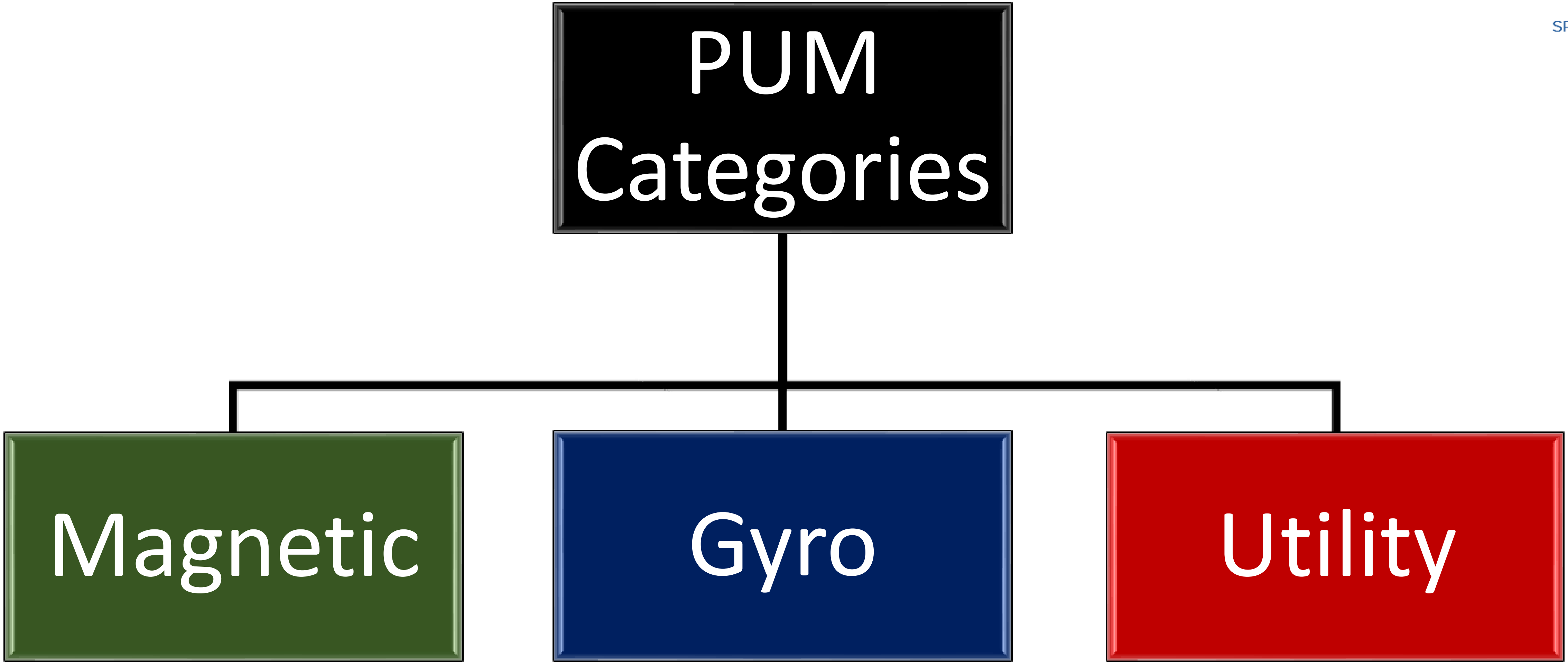
PUM Sets – Established by OWSG

- **PUM, often referred to as Error Models or Instrument Performance Models, Revision 5.13 (Current)**
- **Set A: Standard**
- **Set B: Extended**
- **Set C: Vendor-supplied**
- **Set D: Gyro software validation**
- **Set E: Prototypes in development**

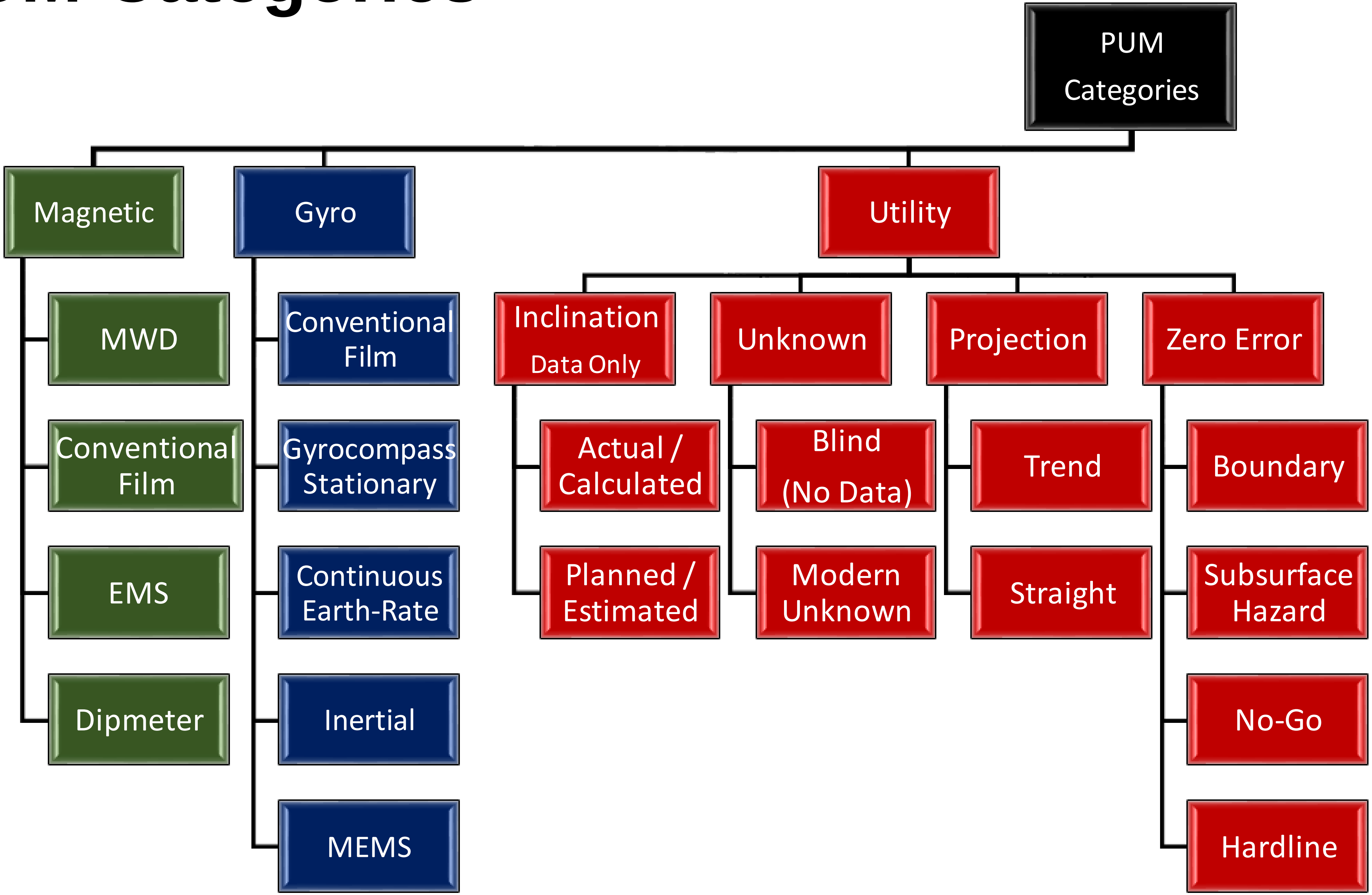


Grindrod, S. J., Clark, P. J., Lightfoot, J. D., Bergstrom, N.. , and L. S. Grant. "**OWSG Standard Survey Tool Error Model Set for Improved Quality and Implementation in Directional Survey Management**." Paper presented at the IADC/SPE Drilling Conference and Exhibition, Fort Worth, Texas, USA, March 2016. doi: https://doi.org/10.2118/178843-MS

PUM Primary Categories



PUM Categories



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Position Uncertainty Models (PUM)

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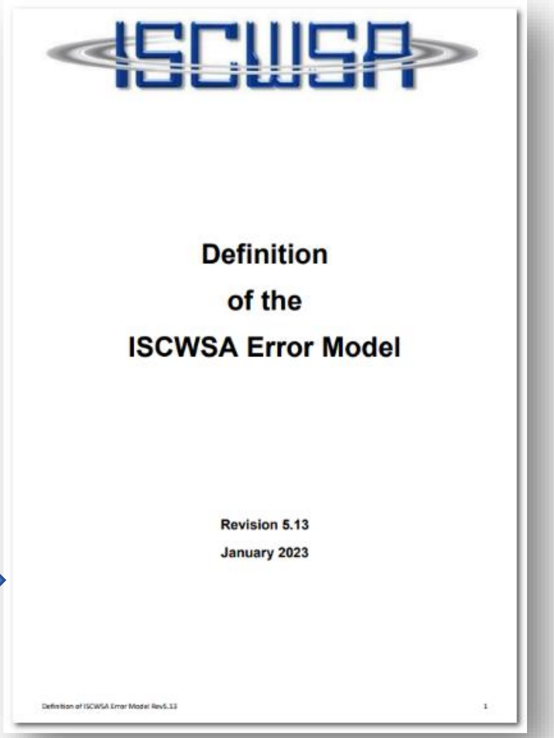
Revision	Date	Description
Rev 0	**Dec 2000**	As per SPE 67616 together with various typographical corrections [1]
Rev 1	**March 2005**	Changed to the gyro style misalignment with 4 terms and calculation options [2]
Rev 2	**Feb 2007**	Changes to the parameter values for the depth scale and stretch terms [2]
Rev 3	**Oct 2009**	Replacement of all toolface dependent terms
Rev 4 & OWSG Rev 2	**Mar 2019**	Introduction of AMIL term and changes to misalignment magnitudes. Random magnetic reference values introduced to the main MWD model. OWSG includes Conventional, Gyro and Utility PUMs. Included Low Resolution and High Resolution Magnetic Reference Models for MWD and EMS. [3]
Rev 5	**Oct 2020**	Introduction of the XCL term, changes to misalignments and sag, breakout of magnetic reference terms and clarification of the surface tie-on. [4]
Rev 5.13	**Jan 2023**	**Minor updates to Rev 5 [4] – Latest Revision**


ISCWSA

Definition
of the
ISCWSA Error Model

Revision 5.13
January 2023

Document Links

1. https://doi.org/10.2118/67616-PA
2. https://doi.org/10.2118/105558-MS
3. https://doi.org/10.2118/178843-MS
4. https://www.iscwsa.net/media/files/files/64bd61c2/definition-of-iscwsa-error-model-v5-13.pdf

Magnetic Reference PUM Classification

Category	Abbreviation	Example Geomagnetic Models	Wavelength from 40,000 km Coverage	Update Frequency
Low Resolution	LRGM	GRF, WMM, CGRF	≤ 4000 km	Less than Annual
Standard Resolution	SRGM	MVSD, Pre-BGGM2019	≤ 300 km	Annual
High Resolution	HRGM	HDGM, MVHD, BGGM2019+, HDGM-RT	≤ 55 km	Annual
In-Field Referencing	IFR1	IFR, IFR1, Ground shot plus secular variation correction	≤ 2 km	Annual
In-Field Referencing with Realtime Disturbance Field Correction	IFR2	IFR2, IIFR	≤ 2 km plus local realtime (≤ 1 min) sampling	Annual

Multiplier	Category
1.21	LRGM
1.00	SRGM
0.82	HRGM

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PUM Toolcodes Rev 5-1

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A default set of conservative PUM tool-codes for use when tool specific models are not available.

- ISCWSA_Generic_Toolcodes SetA Rev5-1

  (updated Sept 23, 2022)

- ISCWSA_Generic_Toolcodes SetB Rev5-1

  (updated Sept 23, 2022)

- **Header / Reference Info**
- **Weighting Functions**
- **Technical Reference / Source**
- **Code & Term Description**
- **Type, Magnitude & Units**
- **Correlation Coefficients & Comments**
- **Formulas (Inclination & Azimuth)**

	OWSG Prefix	Short Name	Long Name
1	A001Mc	MWD+SRGM	OWSG MWD + SRGM
3	A002Mc	MWD+SRGM+SAG	OWSG MWD + SRGM + Sag Correction
5	A003Mc	MWD+SRGM+AX	OWSG MWD + SRGM + Axial Correction
7	A004Mc	MWD+SRGM+AX+SAG	OWSG MWD + SRGM + Axial Correction + Sag Correction
9	A005Mc	MWD+IFR1	OWSG MWD + IFR1
11	A006Mc	MWD+IFR1+AX	OWSG MWD + IFR1 + Axial Corr
13	A007Mc	MWD+IFR1+AX+SAG	OWSG MWD + IFR1 + Axial Corr + Sag Correction
15	A008Mc		
17	A009Mc		
19	A010Mc		
21	A011Mc		
23	A012Mc		
25	A013Mc		
27	A014Mc		
29	A015Mc		
31	A016Mc		
33	A017Mc		
35	A018Mb		
37	A019Gb		
39	A020Gb		
41	A021Gc		
43	A022Gb		
45	A023Gb		
47	A024Mb		
49	A025Mb		
51	A026Ua		
53	A027Ub		
55	A028Ub		
57	A029Ub		
59	A030Ua		

	OWSG Prefix	Short Name	Long Name
1	B001Mc	MWD+HRGM	OWSG MWD + HRGM
3	B002Mc	MWD+HRGM+AX	OWSG MWD + HRGM + Axial Correction
5	B003Mc	MWD+HRGM+AX+SAG	OWSG MWD + HRGM + Axial Correction + Sag Correction
7	B004Mc	MWD+HRGM+SAG	OWSG MWD + HRGM + Sag Correction
9	B005Mc	MWD+HRGM+SAG+MS	OWSG MWD + HRGM + Sag + Multi-Station Correction
11	B006Mc	MWD+LRGM	OWSG MWD + LRGM
13	B007Mc	MWD+LRGM+AX	OWSG MWD + LRGM + Axial Correction
15	B008Mc	MWD+LRGM+AX+SAG	OWSG MWD + LRGM + Axial Correction + Sag Correction
17	B009Mc	MWD+LRGM+SAG	OWSG MWD + LRGM + Sag Correction
19	B010Mc	EMS+IFR1+AX+SAG	OWSG EMS + IFR1 + Axial Corr + Sag Correction
21	B011Mc	EMS+IFR1+SAG	OWSG EMS + IFR1 + Sag Correction
23	B012Mc	EMS+IFR1+SAG+MS	OWSG EMS + IFR1 + Sag + Multi-Station Correction
25	B013Mc	EMS+HRGM	OWSG EMS + HRGM
27	B014Mc	EMS+HRGM+AX	OWSG EMS + HRGM + Axial Correction
29	B015Mc	EMS+HRGM+AX+SAG	OWSG EMS + HRGM + Axial Correction + Sag Correction
31	B016Mc	EMS+HRGM+SAG	OWSG EMS + HRGM + Sag Correction
33	B017Mc	EMS+LRGM	OWSG EMS + LRGM
35	B018Md	EMS+LRGM+AX	OWSG EMS + LRGM + Axial Correction
37	B019Md	EMS+LRGM+AX+SAG	OWSG EMS + LRGM + Axial Correction + Sag Correction
39	B020Mc	EMS+LRGM+SAG	OWSG EMS + LRGM + Sag Correction
41	B021Ga	FINDS	OWSG BHI Ferranti FINDS
42	B022Ua	BLIND+TREND	OWSG BLIND+TREND

Set B Extended

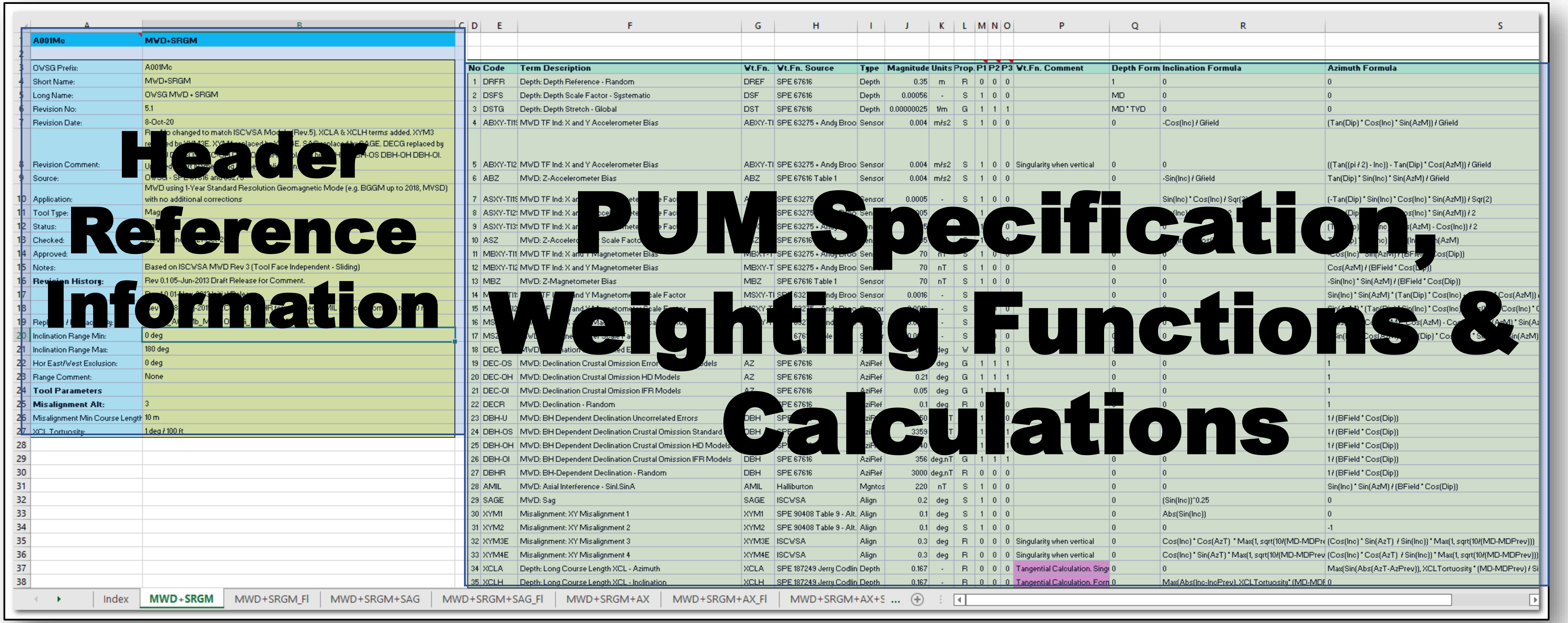
https://www.iscwsa.net/error-model-documentation/

Example: A001Mc MWD+SRGM

https://www.iscwsa.net/error-model-documentation/

[ISCWSA_Generic_Toolcodes_SetA Rev5-1](#) (updated 23/9/22)

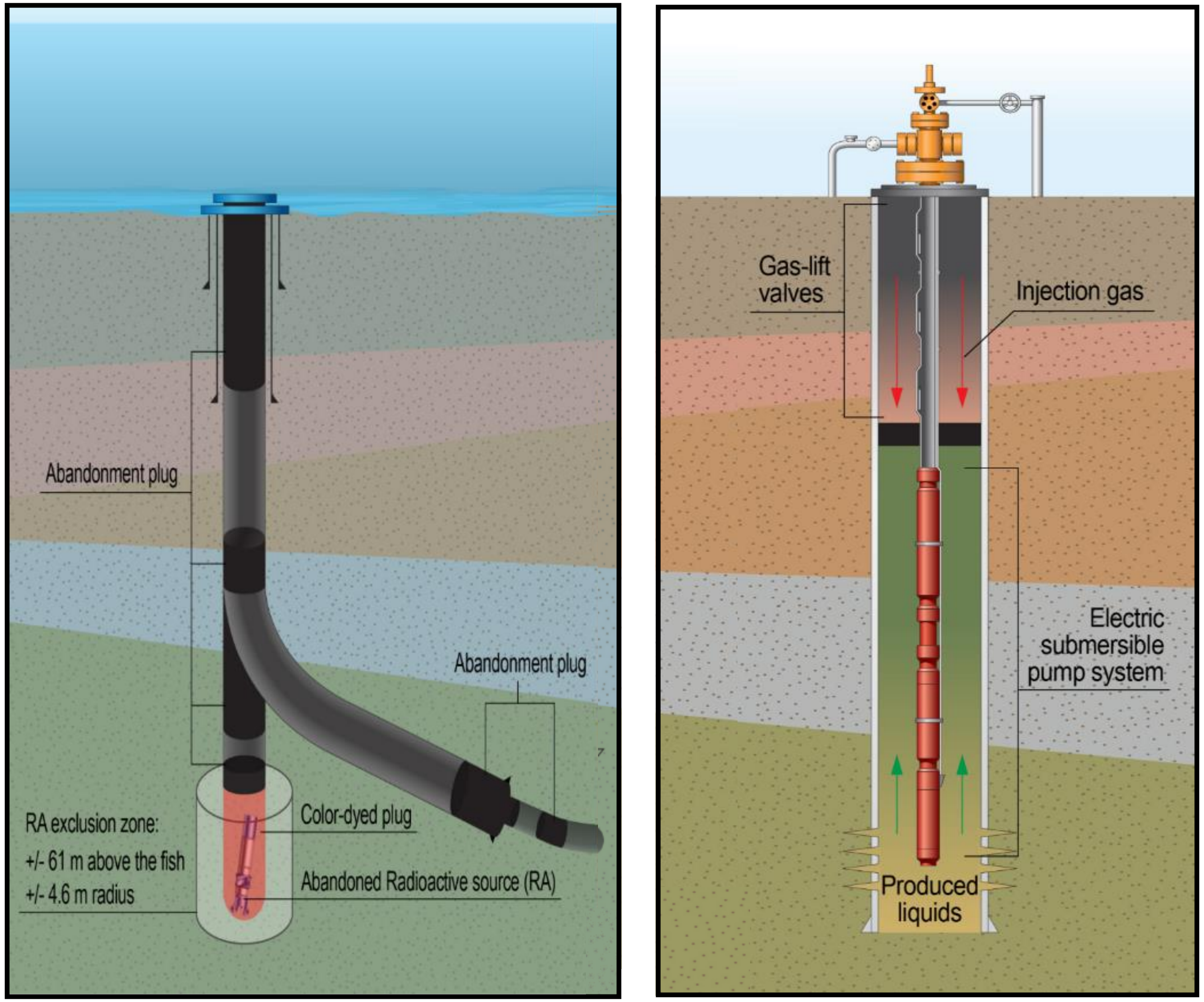
Excel Workbook Tab: MWD+SRGM



MWD PUM Survey Corrections

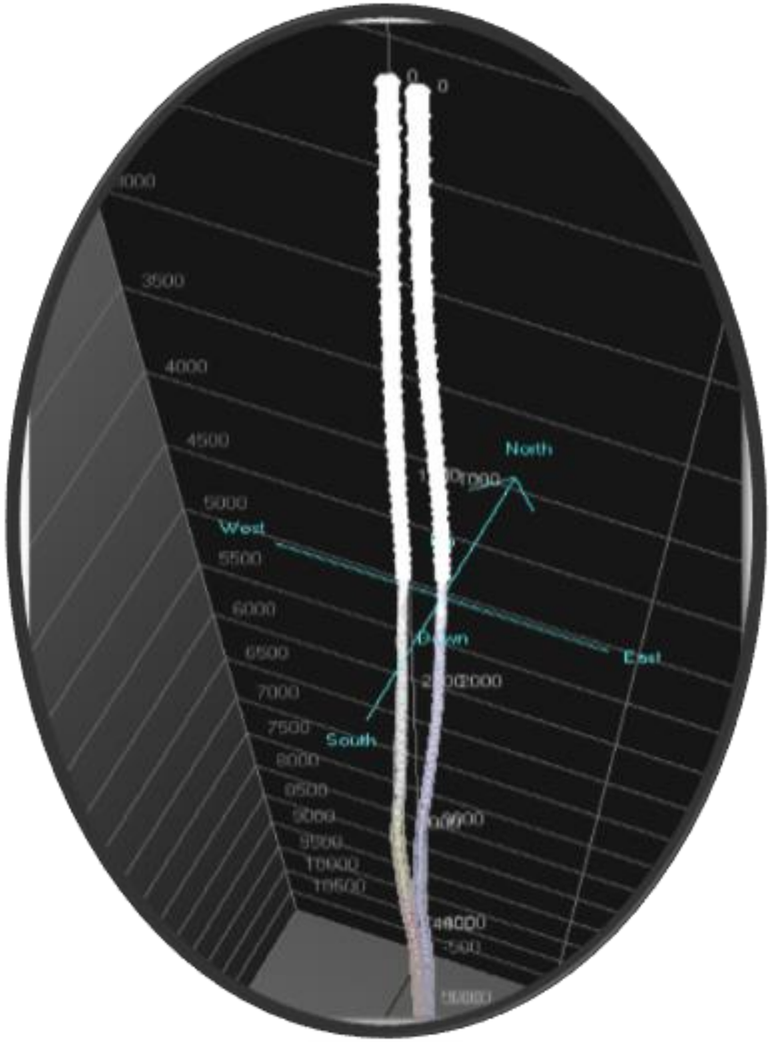
- **Axial (AX)**
- **Sag**
- **Multi-Station Analysis (MSA or MS)**
- **Axial + Sag**
- **Multi-Station + Sag**
- **Depth Corrections**
- **Advanced MWD Corrections**
  - **Ground Shot (GS) IFR**
  - **Advanced Multi-Station (AMSA)**
    - **All BHA's for a Wellbore**
    - **All BHA's for all wellbores on a well (Includes Sidetracks / By-Pass Wellbores)**
    - **All BHA's for all wellbores on a Site/Location/Pad**

Offset Well Environment



MASD Management Principles (SPE-187073-PA)

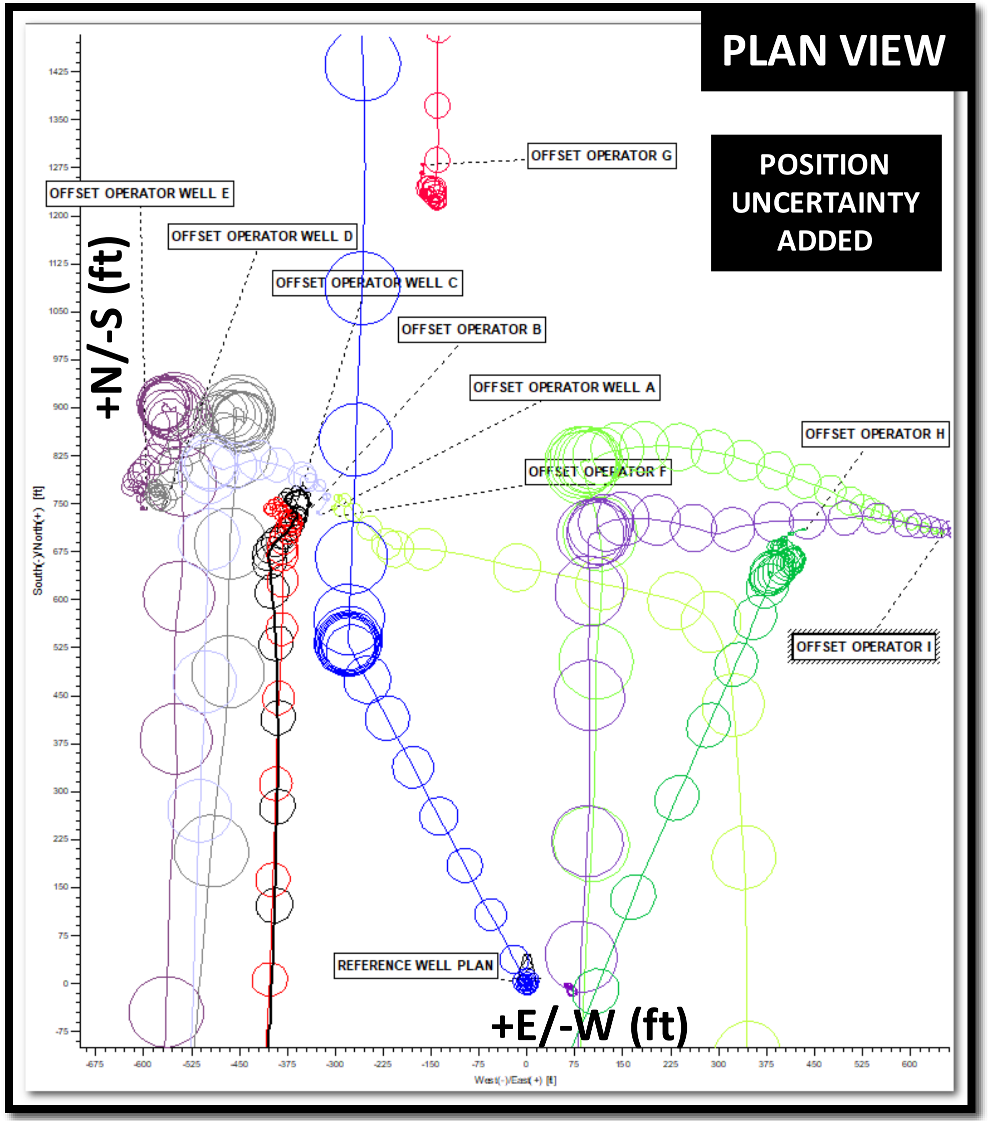
- Offset Well Environment
  - Status
  - Completion Type
  - Wellbore Fluids
  - Lifting Mechanism
- Artificial Lift
  - Rod Pump
  - Progressive Cavity
  - Hydraulic Pump
  - Gas Lift (GL)
  - Electric Submersible Pump (ESP)
  - Hybrid Lift System
    - GL & ESP
    - ESP & Natural Flow

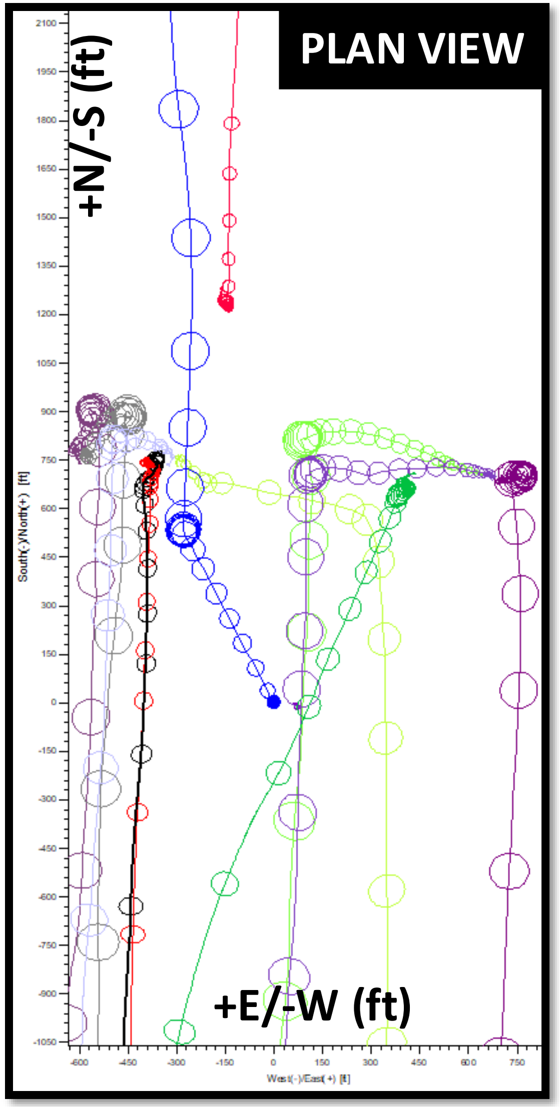


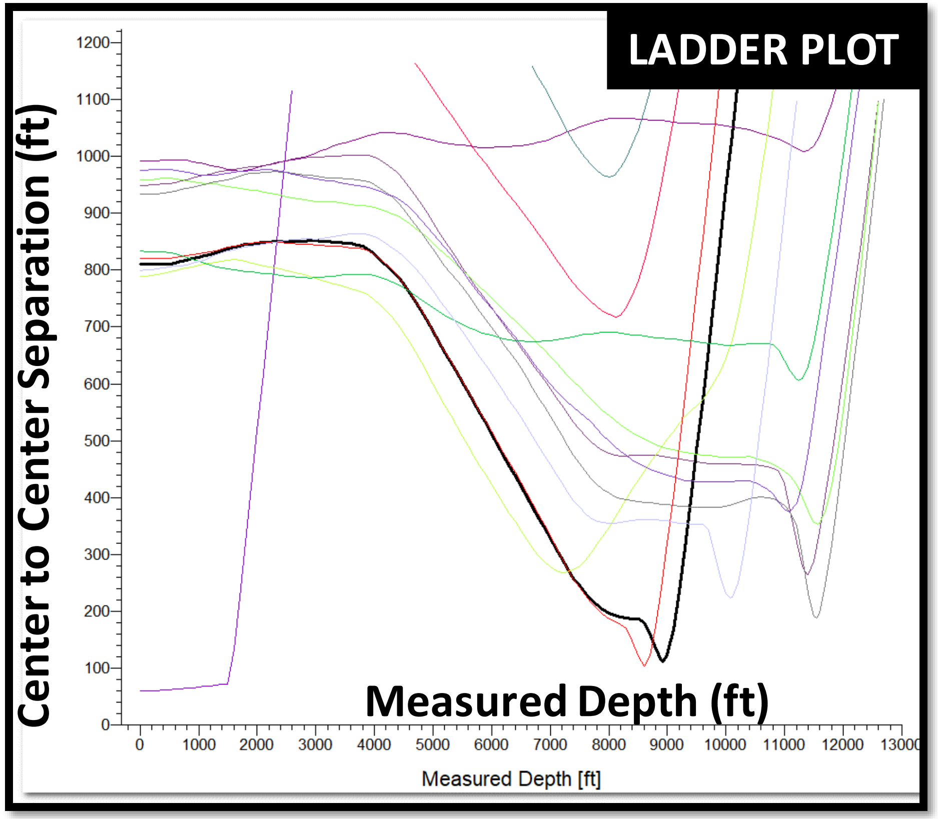
Case Study

Offset Operator Close Approach

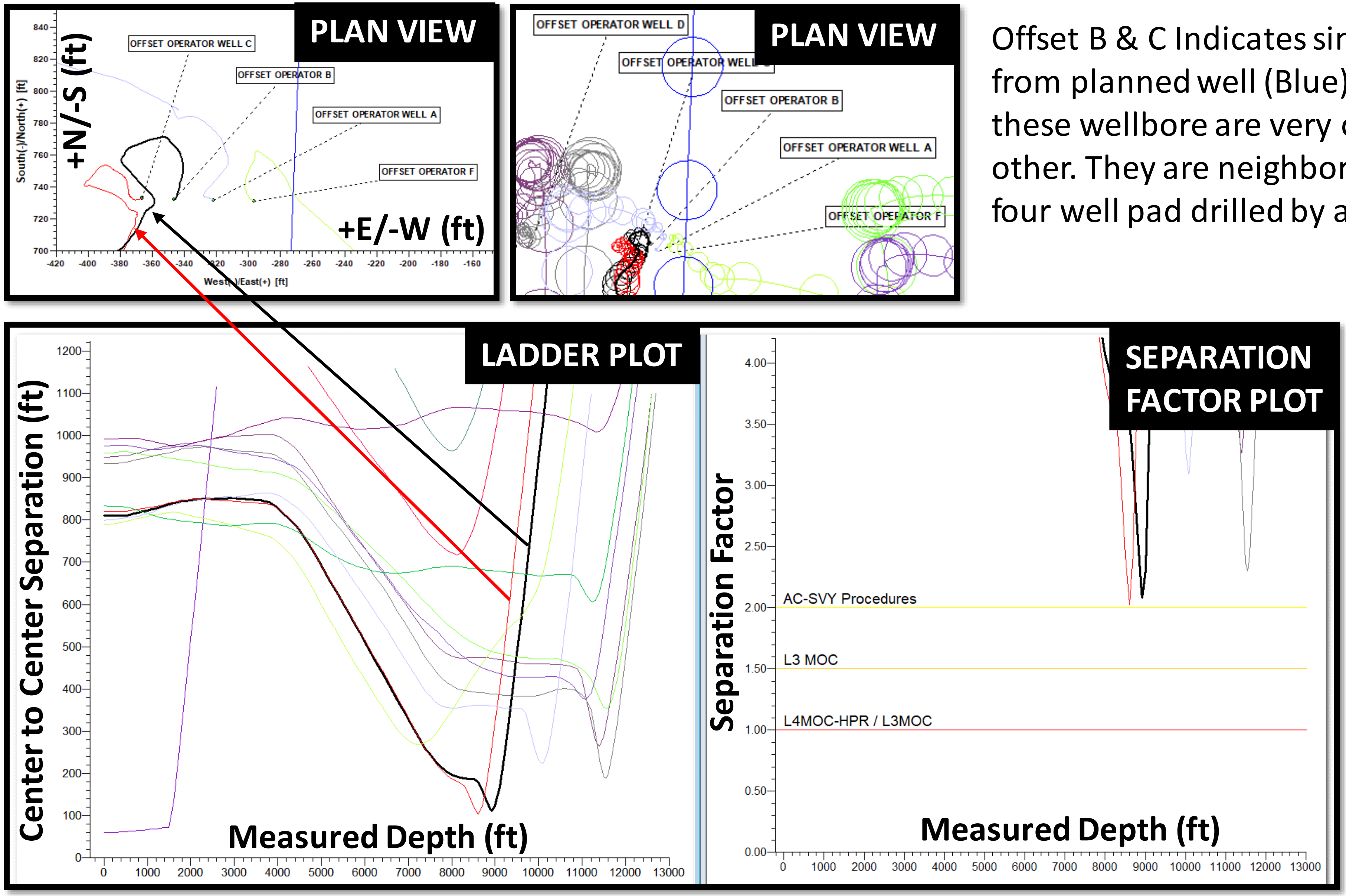
Safe Separation Plots – Ladder & Separation Factor



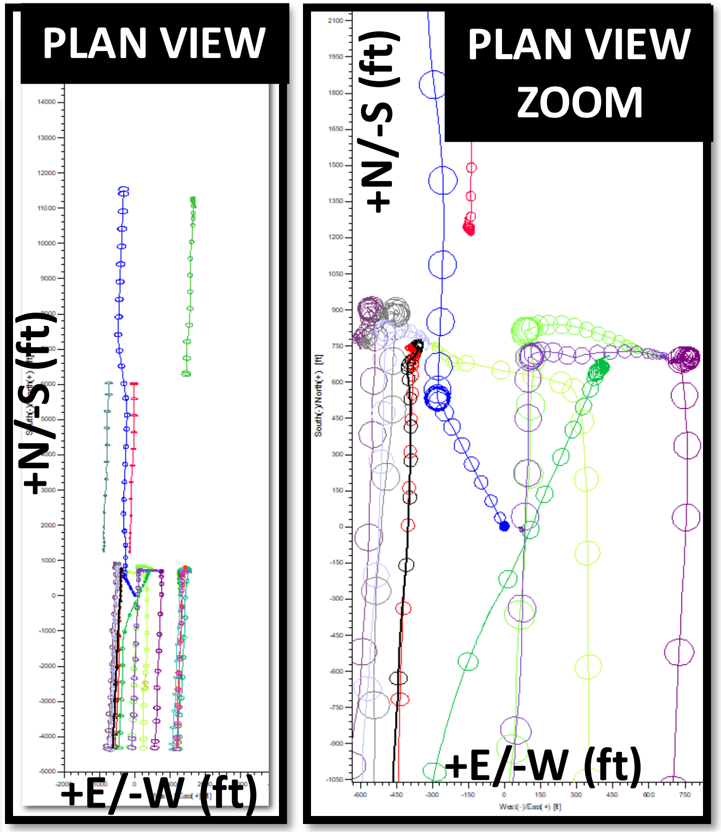




Safe Separation Plots – Ladder & Separation Factor



Offset B & C Indicates similar distance from planned well (Blue) which means these wellbore are very close from each other. They are neighboring slots on a four well pad drilled by another Operator.



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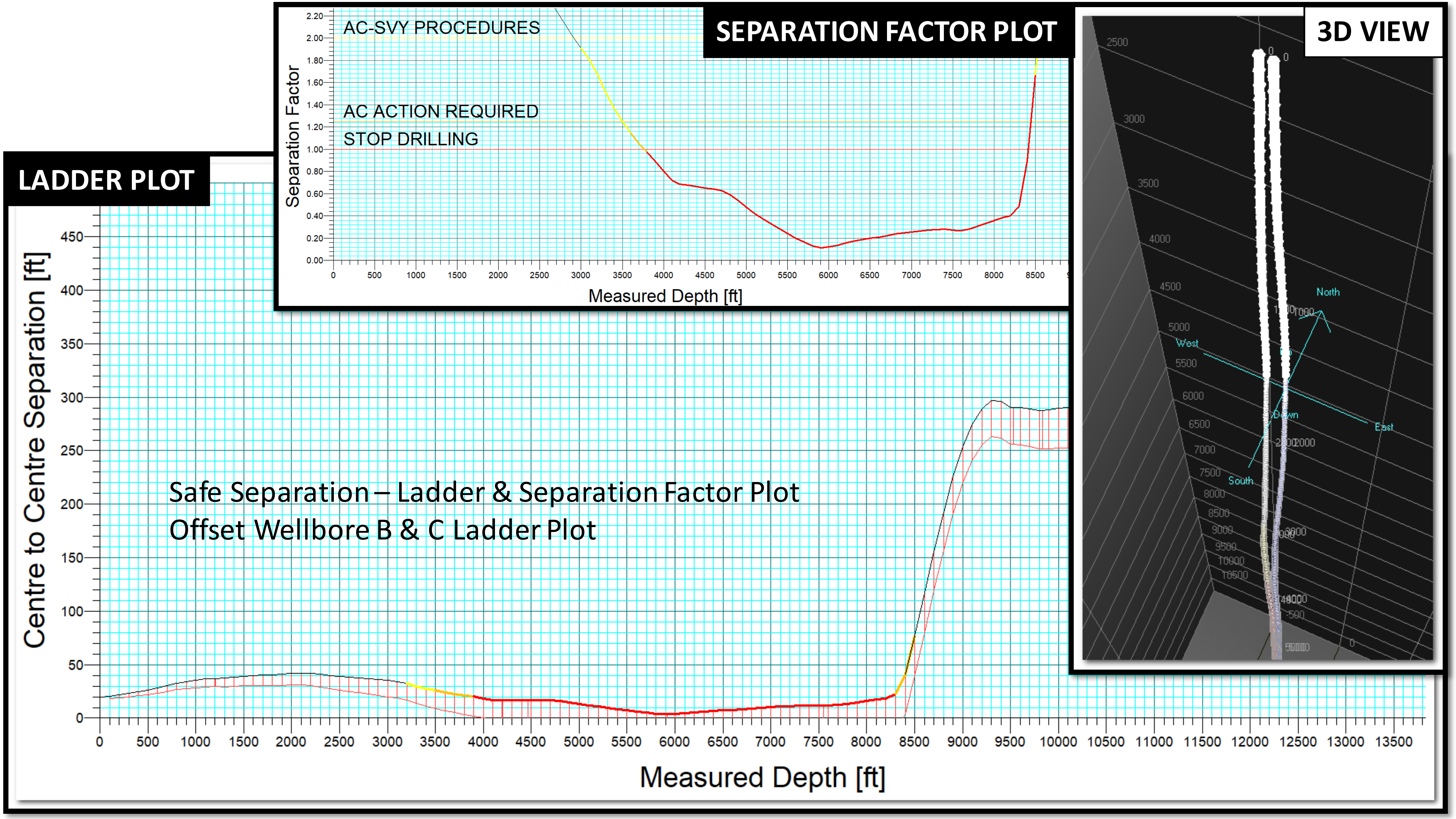
Safe Separation Plots – Ladder & Separation Factor



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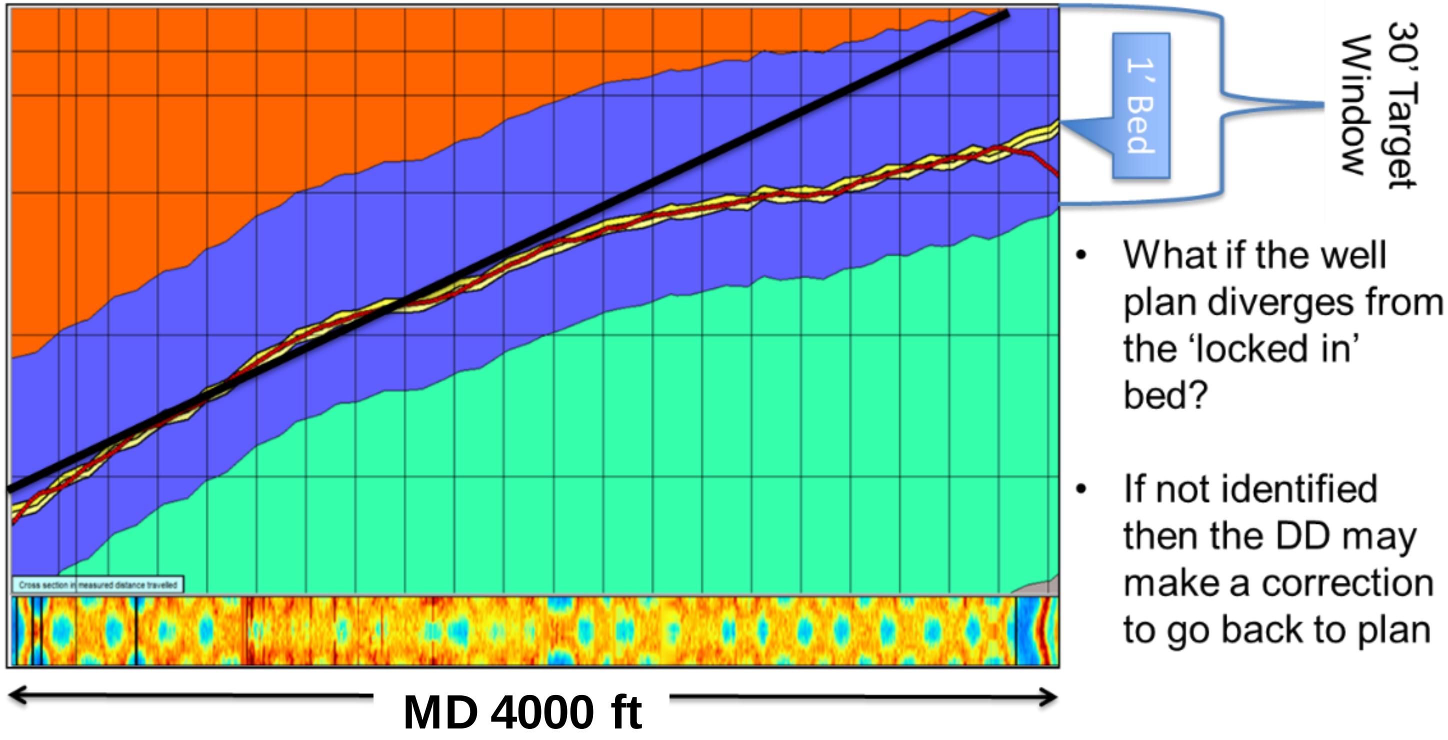
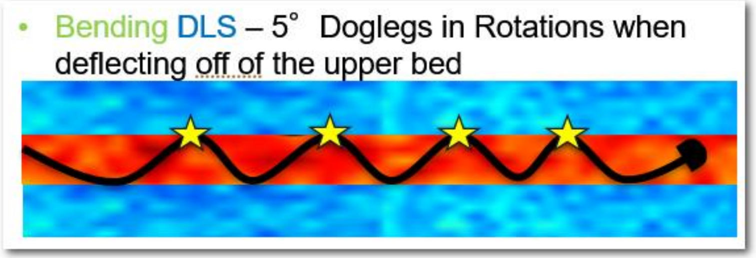
Case Study

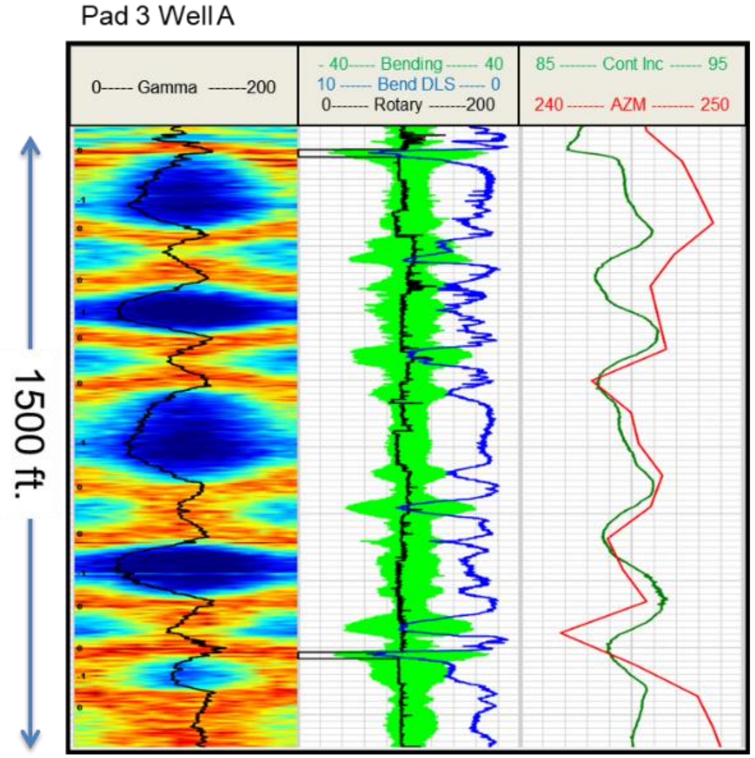
Lateral Undulations
Key Performance Indicators
Steerable Motor Curve
Lateral Tortuosity

Lateral Undulation Period - TVD Accuracy



- What if the well plan diverges from the 'locked in' bed?
- If not identified then the DD may make a correction to go back to plan

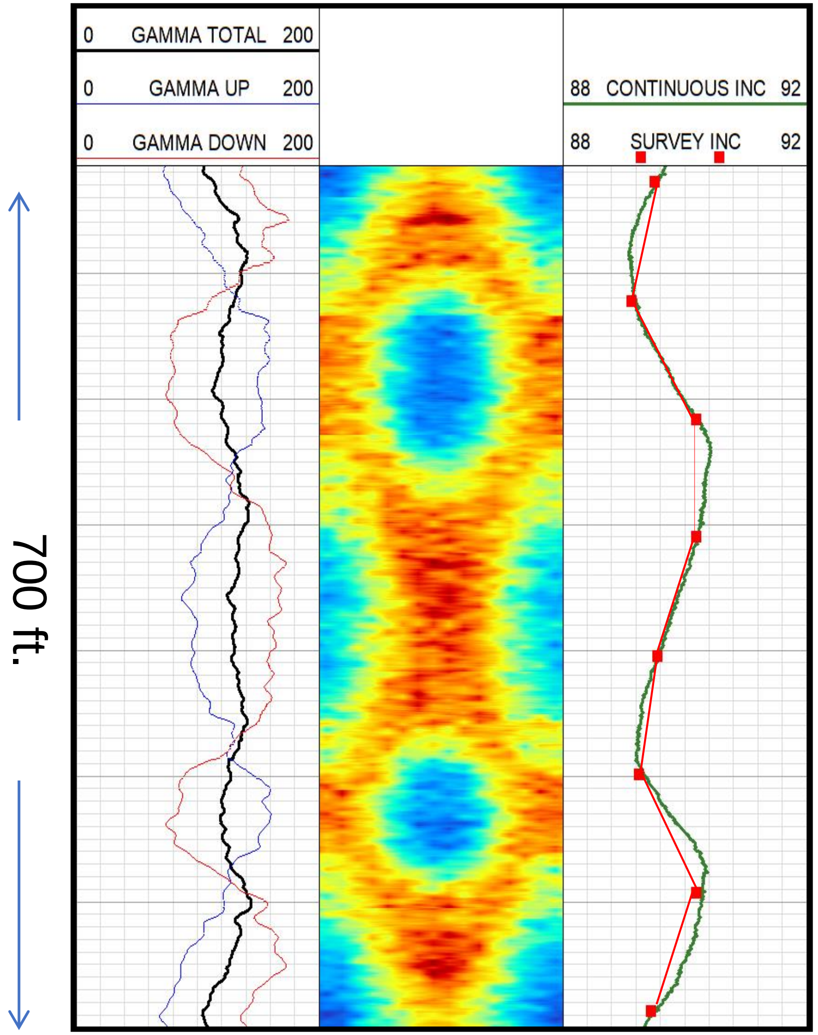




Viens, Christopher , Clark, Tyler , Lightfoot, Jonathan , and Carlos Mercado. "**Real-Time Downhole Data Resolves Lithology Related Drilling Behavior."** Paper presented at the IADC/SPE Drilling Conference and Exhibition, Fort Worth, Texas, USA, March 2018. doi: https://doi.org/10.2118/189697-MS

Lateral Undulation Period - TVD Accuracy

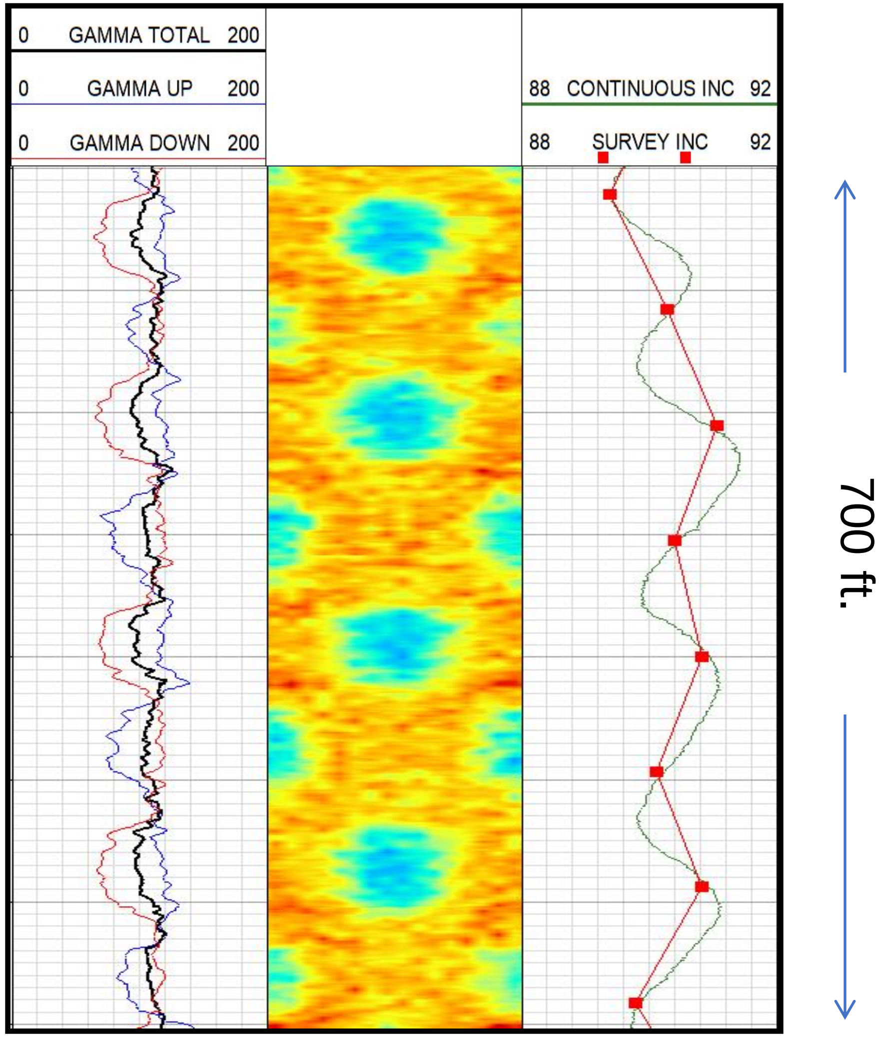
Pad 2 Well A



Left: 90' surveys adequate to due large period of oscillation

Right: 90' surveys inadequate to short oscillation period

Pad 1 Well A



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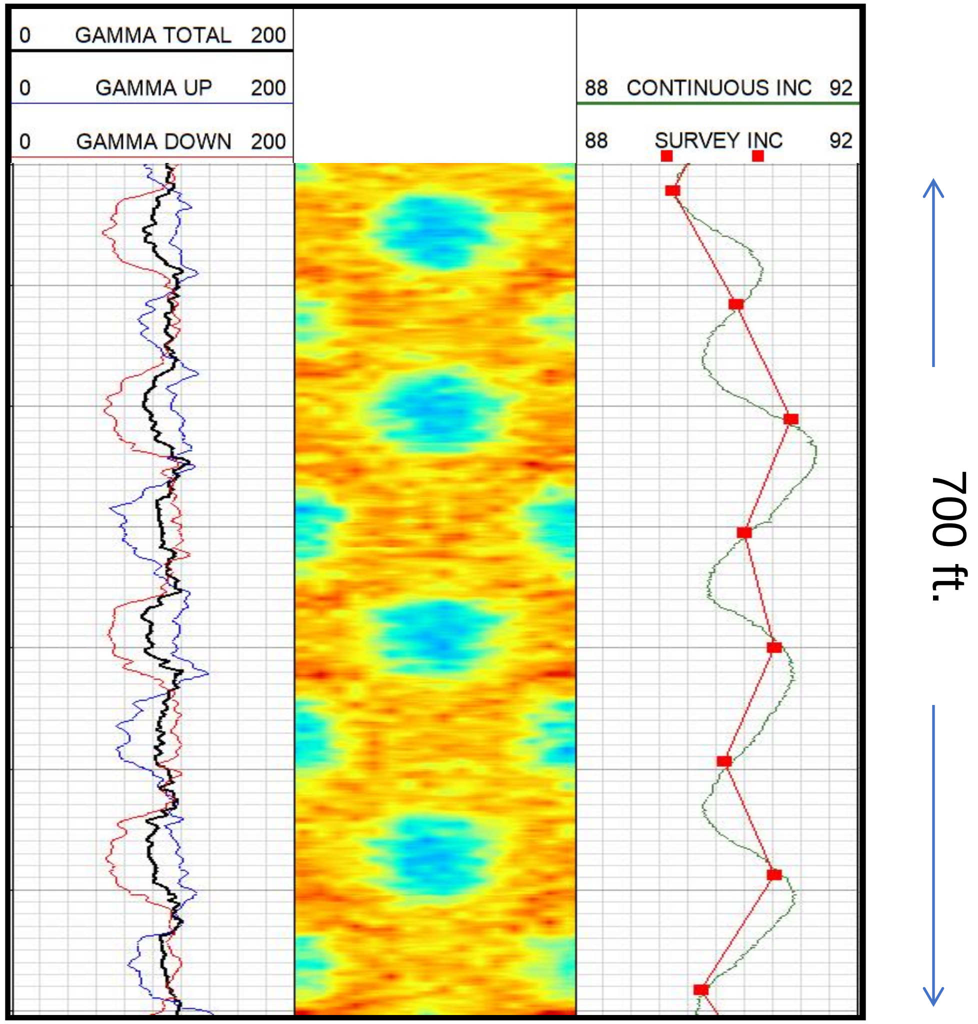
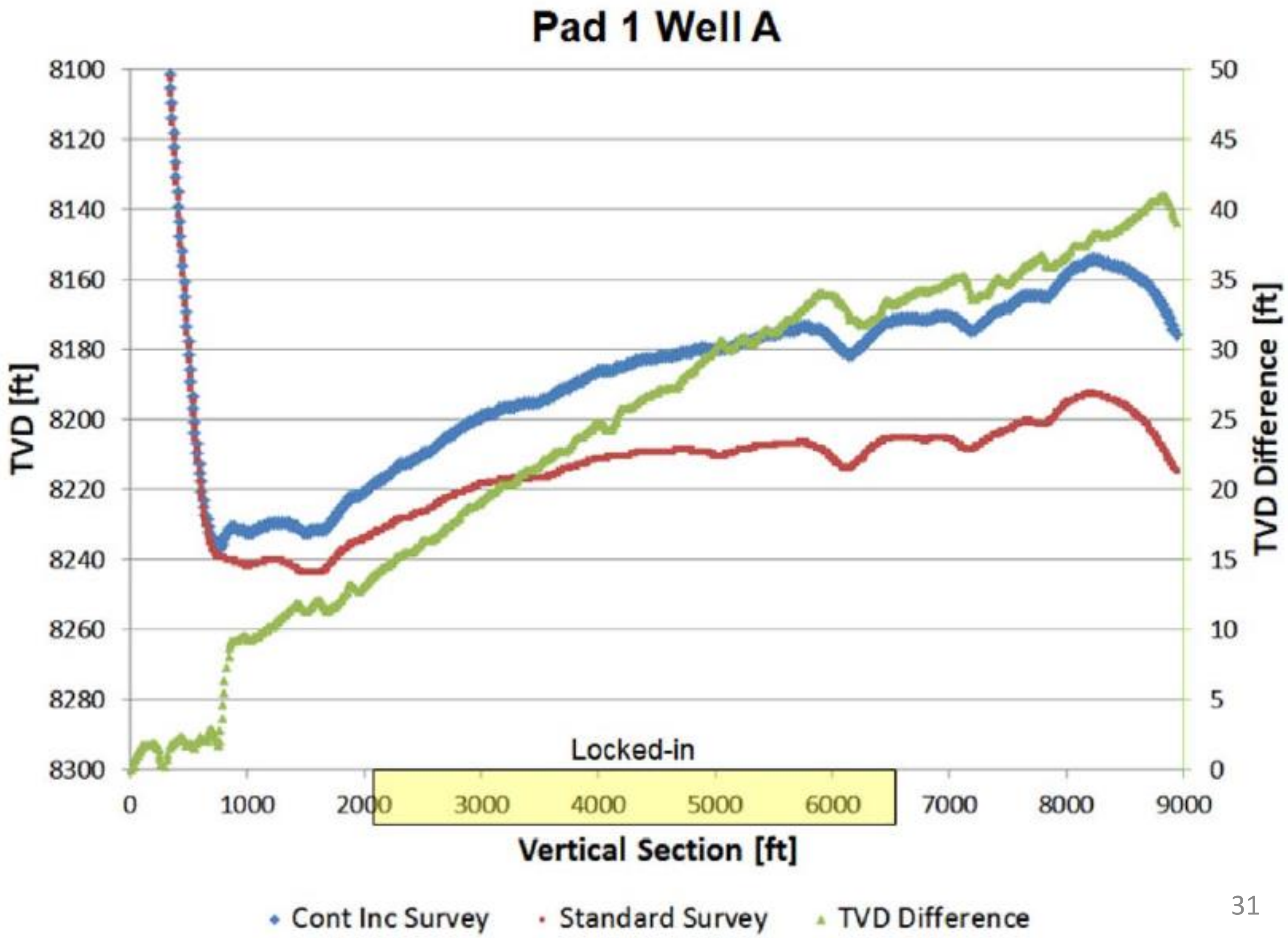
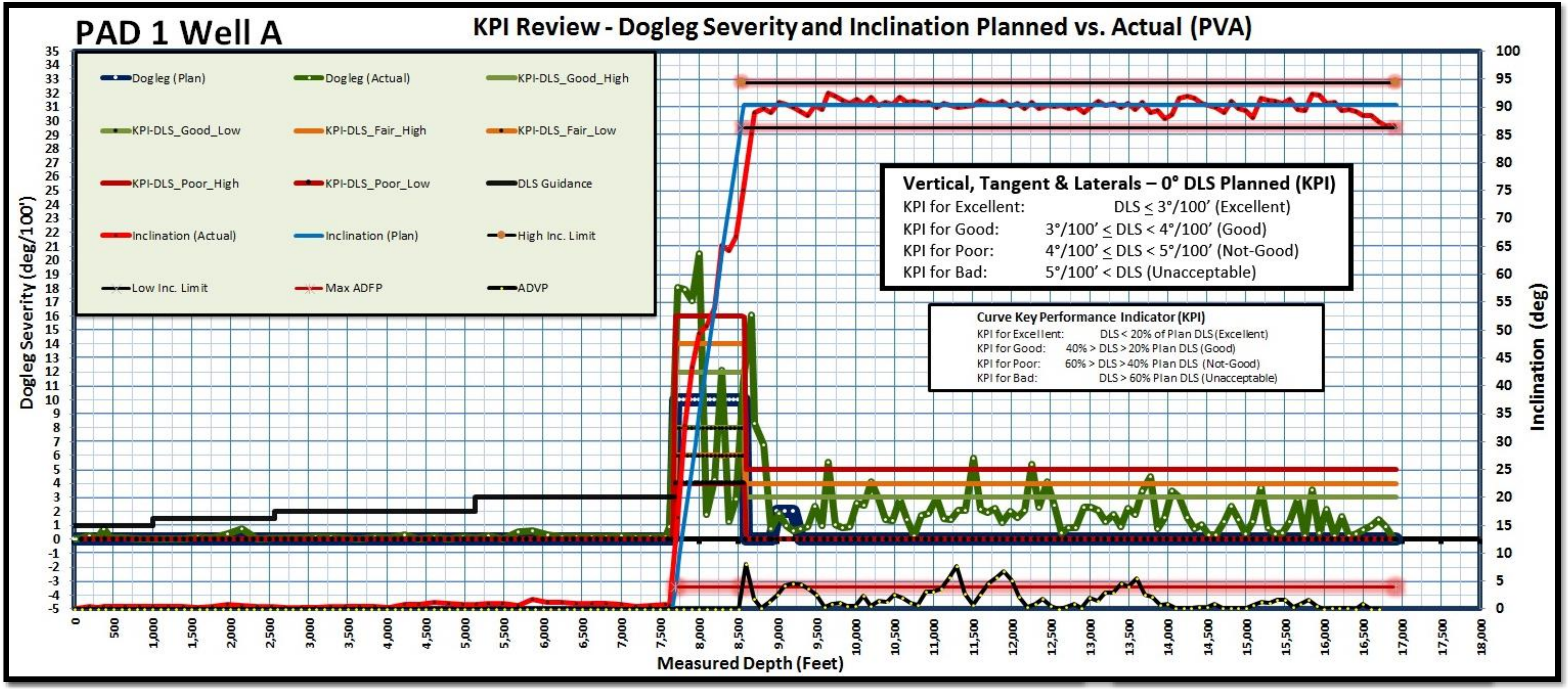
Lateral Undulation Period - TVD Accuracy

Pad 1 Well A

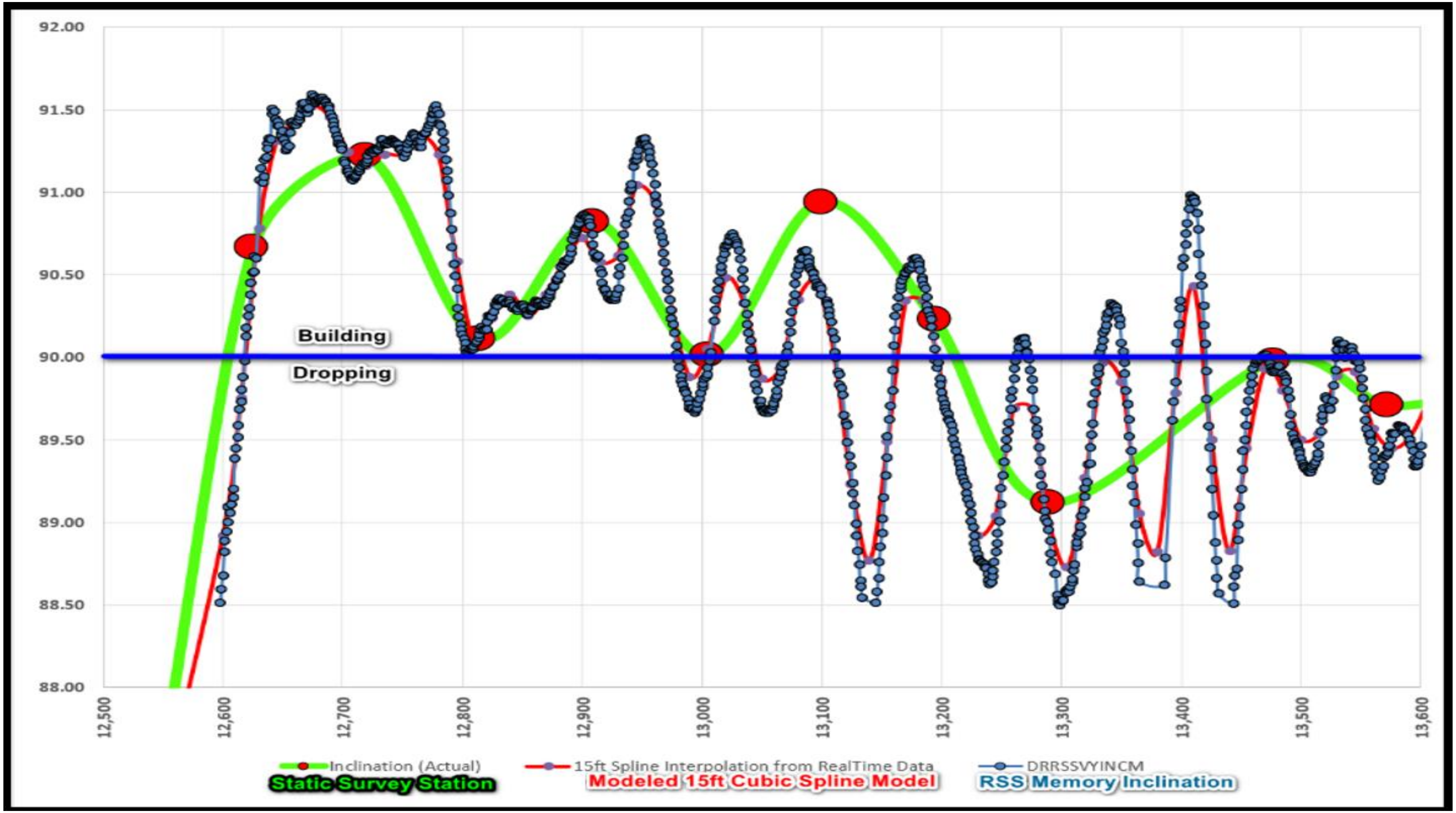




Directional Drilling Key Performance Indicators



Lateral Undulation Period – RSS Example



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Slide / Rotate Effect – Curve TVD Accuracy

Starting Survey = 10,000 ft MD

Inclination 30° & Azimuth 45°

- **Case A: Slide 30 ft then Rotate 70 ft @ 10°/100'**
- **Case B: Rotate 70 ft then Slide 30 ft @ 10°/100'**

Final Inclination 40° & Final Azimuth 45°

Case A: Survey at 10,030' & at 10,100'

- *DLS 16.7°/100 ft & TVD 9,082.6 ft*

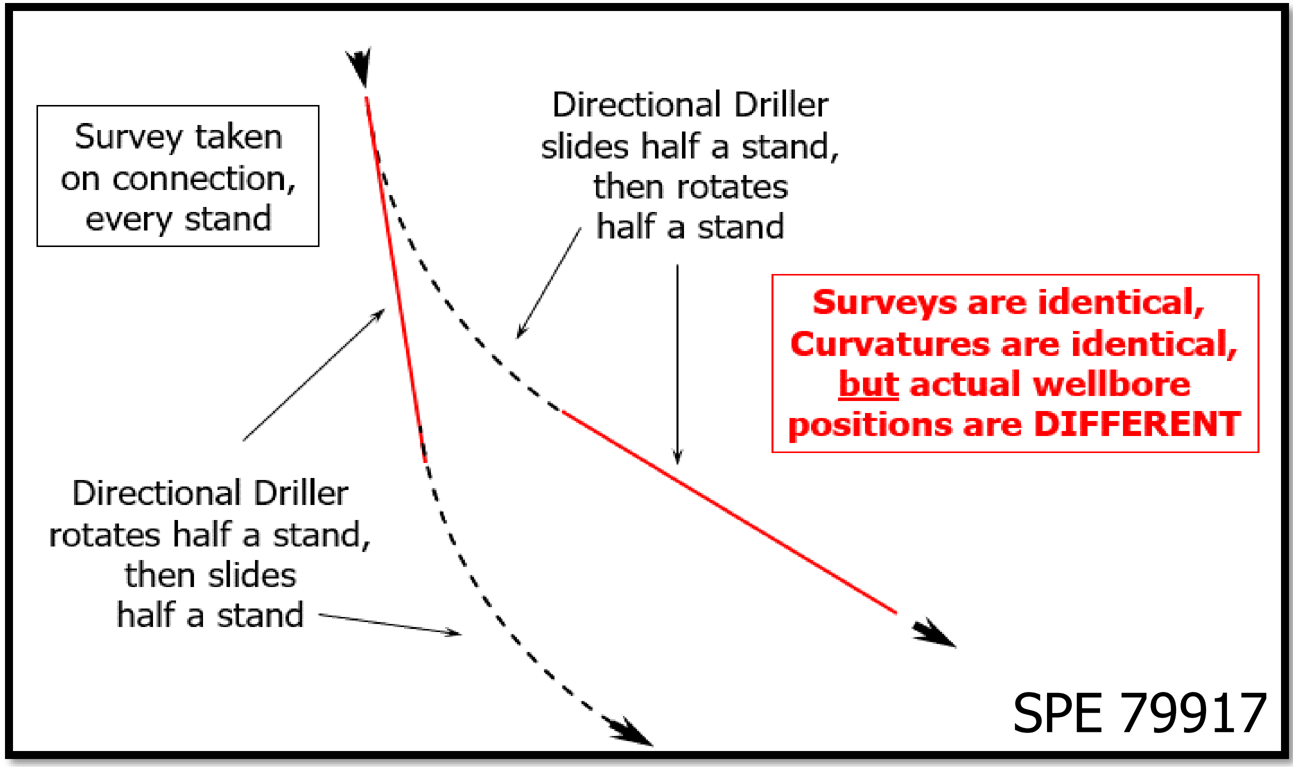
Case B: Survey at 10,070' & at 10,100'

- *DLS 16.67°/100 ft & TVD 9,085.9 ft*

Case C: Survey only at 10,100'

- *DLS 5°/100 ft & TVD 9,084 ft*

Case A vs. Case B have a TVD difference 3.29 ft over only 100 ft of MD (1-Stand)

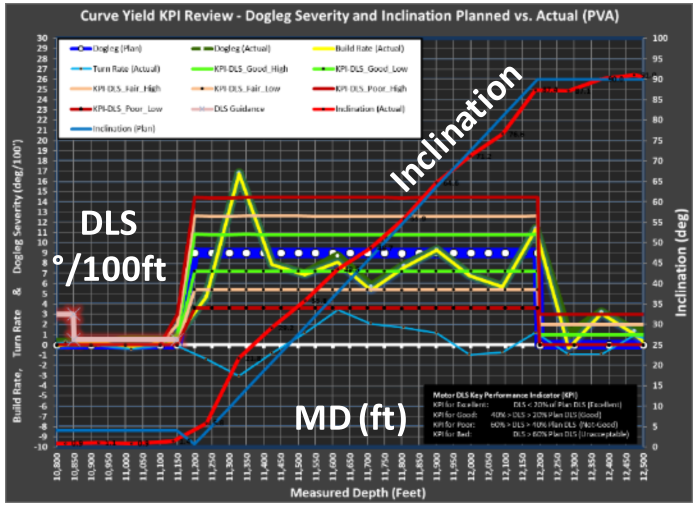


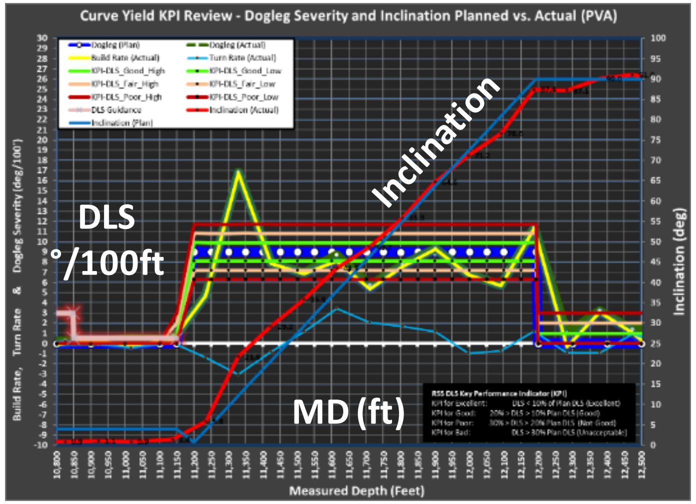
SPE 79917

Directional Drilling Key Performance Indicators

Directional Drilling Dogleg Severity Control Key Performance Indicators				
Directional Tools & Hole Section Type	Excellent	Good	Not-Good	Unacceptable RCRA Required
Vertical Intervals	DLS ≤ 2	2 < DLS ≤ 3	3 < DLS ≤ 4	4 < DLS
Tangent Intervals	DLS ≤ 2	2 < DLS ≤ 3	3 < DLS ≤ 4	4 < DLS
Lateral Intervals	DLS ≤ 2	2 < DLS ≤ 3	3 < DLS ≤ 4	4 < DLS
Directional Motor Steering Interval	DLS < +/- 20% of Planned DLS	Between 20-40% of Planned DLS	Between 40-60% of Planned DLS	DLS > +/- 60% of Planned DLS
Directional RSS Steering Interval	DLS < +/- 10% of Planned DLS	Between 10-20% of Planned DLS	Between 20-30% of Planned DLS	DLS < +/- 30% of Planned DLS

Offset Operator Motor Curve





Motor Curve KPI Chart 20-40-60%

RSS Curve KPI Chart 10-20-30%

Slide / Rotate Effect – Curve TVD Accuracy

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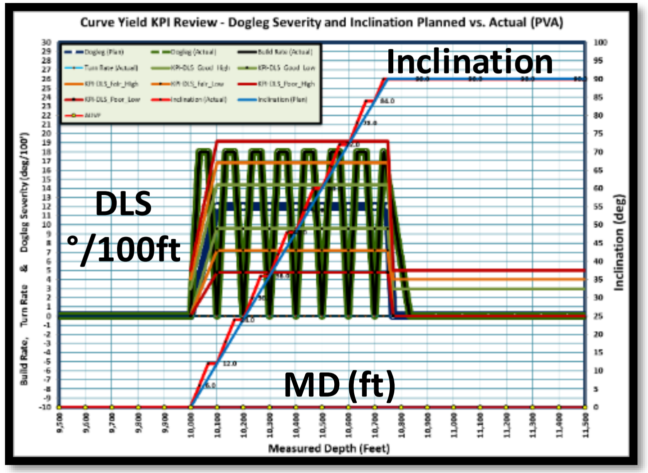
Case A: Slide 33 ft, Rotate 33 ft and Slide 33 ft from 0° to 90° Inc.

Case A Directional Survey

MD	Inclination (Actual)	Azimuth (Actual)	Course Length	TVD	Vertical Section	+N / - S	+E / -W	Colosure Distance	@ AZM	Dogleg (Actual)	Build Rate (Actual)	Turn Rate (Actual)
0.00	0.00	45.00	******	0.00	0.00	0.00	0.00	0.00		0.00	*****	*****
10,000.00	0.00	45.00	10000.00	10000.00	0.00	0.00	0.00	0.00	45.00	0.00	0.00	0.00
10,033.33	6.00	45.00	33.33	10033.27	1.26	1.23	1.23	1.75	45.00	18.00	18.00	0.00
10,066.67	12.00	45.00	33.33	10066.18	5.03	4.92	4.92	6.96	45.00	18.00	18.00	0.00
10,100.00	12.00	45.00	33.33	10098.78	10.05	9.82	9.82	13.89	45.00	0.00	0.00	0.00
10,133.33	18.00	45.00	33.33	10130.97	16.29	15.92	15.92	22.51	45.00	18.00	18.00	0.00
10,166.67	24.00	45.00	33.33	10162.07	24.92	24.36	24.36	34.45	45.00	18.00	18.00	0.00
10,200.00	24.00	45.00	33.33	10192.52	34.73	33.95	33.95	48.01	45.00	0.00	0.00	0.00
10,233.33	30.00	45.00	33.33	10222.21	45.67	[illegible]	44.64	[illegible]	[illegible]	18.00	18.00	0.00
[illegible]	36.00	45.00	33.33	10250.15	58.80	57.47	57.47	[illegible]	45.00	[illegible]	[illegible]	0.00
[illegible]	[illegible]	45.00	33.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00
[illegible]	42.00	45.00	33.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.00	18.00	0.00
[illegible]	[illegible]	45.00	33.33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.00	[illegible]	0.00
10,400.00	48.00	45.00	33.33	10348.87	123.11	120.33	120.33	170.17	45.00	0.00	0.00	0.00
10,433.33	54.00	45.00	33.33	10369.84	141.84	138.64	138.64	196.06	45.00	18.00	18.00	0.00
10,466.66	60.00	45.00	33.33	10387.99	162.06	158.40	158.40	224.01	45.00	18.00	18.00	0.00
10,500.00	60.00	45.00	33.33	10404.66	182.94	178.81	178.81	252.87	45.00	0.00	0.00	0.00
10,533.33	66.00	45.00	33.33	10419.78	204.42	199.80	199.80	282.56	45.00	18.00	18.00	0.00
10,566.66	72.00	45.00	33.33	10431.72	226.92	221.79	221.79	313.67	45.00	18.00	18.00	0.00
10,599.99	72.00	45.00	33.33	10442.02	249.86	244.21	244.21	345.37	45.00	0.00	0.00	0.00
10,633.33	78.00	45.00	33.33	10450.64	273.14	266.97	266.97	377.55	45.00	18.00	18.00	0.00
10,666.66	84.00	45.00	33.33	10455.86	296.94	290.24	290.24	410.46	45.00	18.00	18.00	0.00
10,699.99	84.00	45.00	33.33	10459.34	320.93	313.68	313.68	443.61	45.00	0.00	0.00	0.00
10,733.33	90.00	45.00	33.33	10461.08	345.00	337.20	337.20	476.88	45.00	18.00	18.00	0.00

SIMULATED EXAMPLE

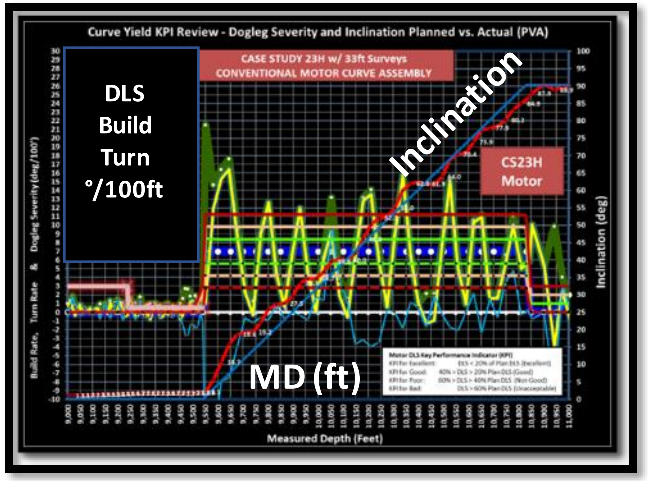


Case B: Survey Every 100 ft from 0° to 90° Inc. (16 ft TVD Delta)

Case B Directional Survey

MD (Plan)	Inclination (Plan)	Azimuth (Plan)	Course Length	TVD	Vertical Section	+N / - S	+E / -W	Closure	@ AZM	Dogleg (Plan)	Build Rate	Turn Rate
0.00	0.00	0.00	*******	0.00	0.00	0.00	0.00	0.00		0.00	*****	*****
10,000.00	0.00	45.00	10000.00	[illegible]		[illegible]	0.00	[illegible]		0.00	0.00	0.45
[illegible]	[illegible]	[illegible]	100.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	100.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00
[illegible]	[illegible]	45.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00
10,400.00	48.00	45.00	100.00	10354.83	114.29	111.71	111.71	157.98	45.00	12.00	12.00	0.00
10,500.00	60.00	45.00	100.00	10413.50	172.71	168.81	168.81	238.73	45.00	12.00	12.00	0.00
10,600.00	72.00	45.00	100.00	10454.10	238.68	233.29	233.29	329.92	45.00	12.00	12.00	0.00
10,700.00	84.00	45.00	100.00	10474.85	309.32	302.33	302.33	427.56	45.00	12.00	12.00	0.00
10,750.00	90.00	45.00	50.00	10477.46	345.42	337.62	337.62	477.46	45.00	12.00	12.00	0.00

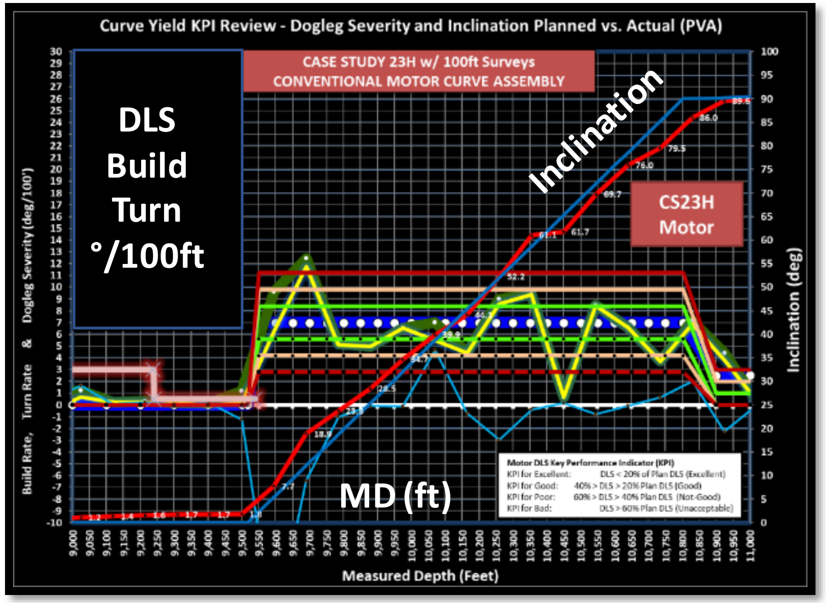
ACTUAL EXAMPLE



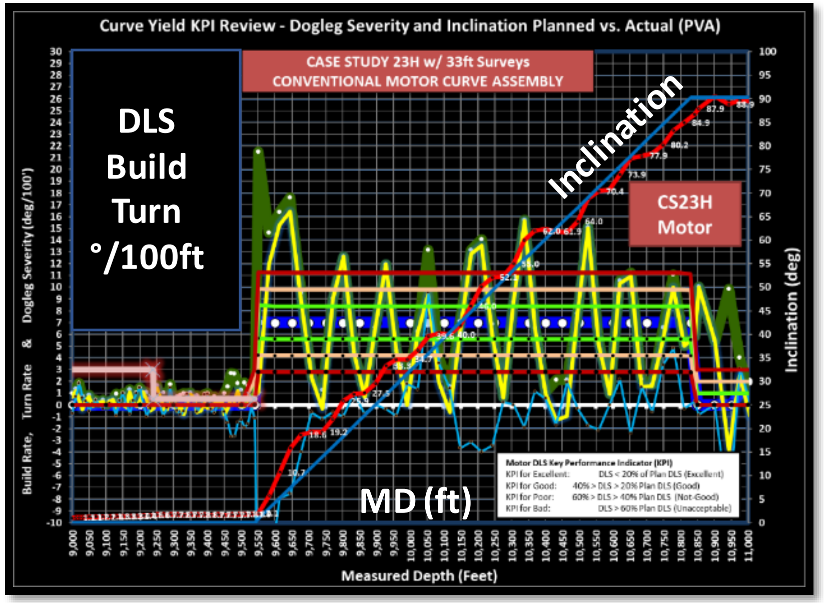
Case Study - Steerable Motor Curve

- Survey Frequency is Important for Medium Radius Curves
- If slide % is less, consider surveying twice a stand or every joint
- When sliding 90 to 100%; survey is less prone to landing TVD error

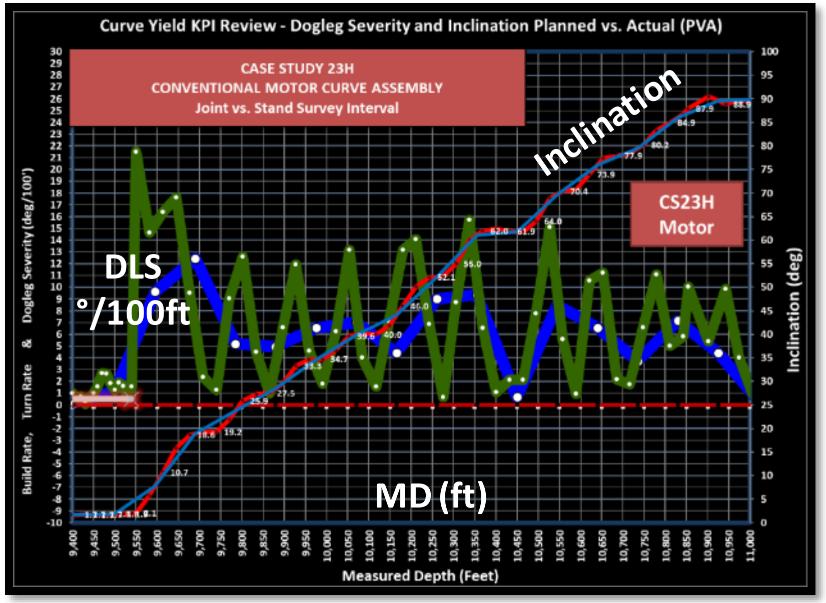
96 FT SURVEYS



32 FT SURVEYS

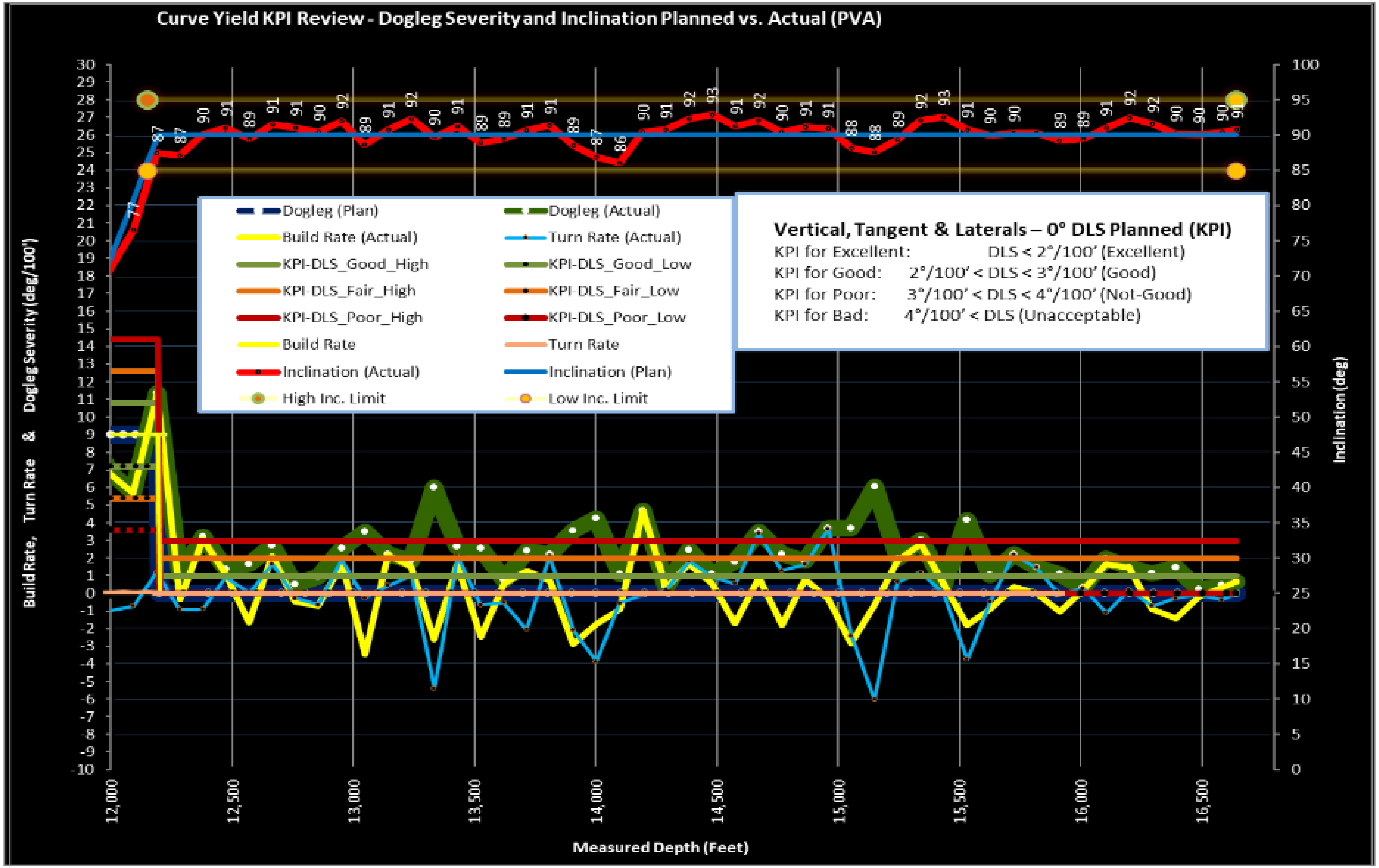


DLS COMPARISON



SPE DISTINGUISHED LECTURER

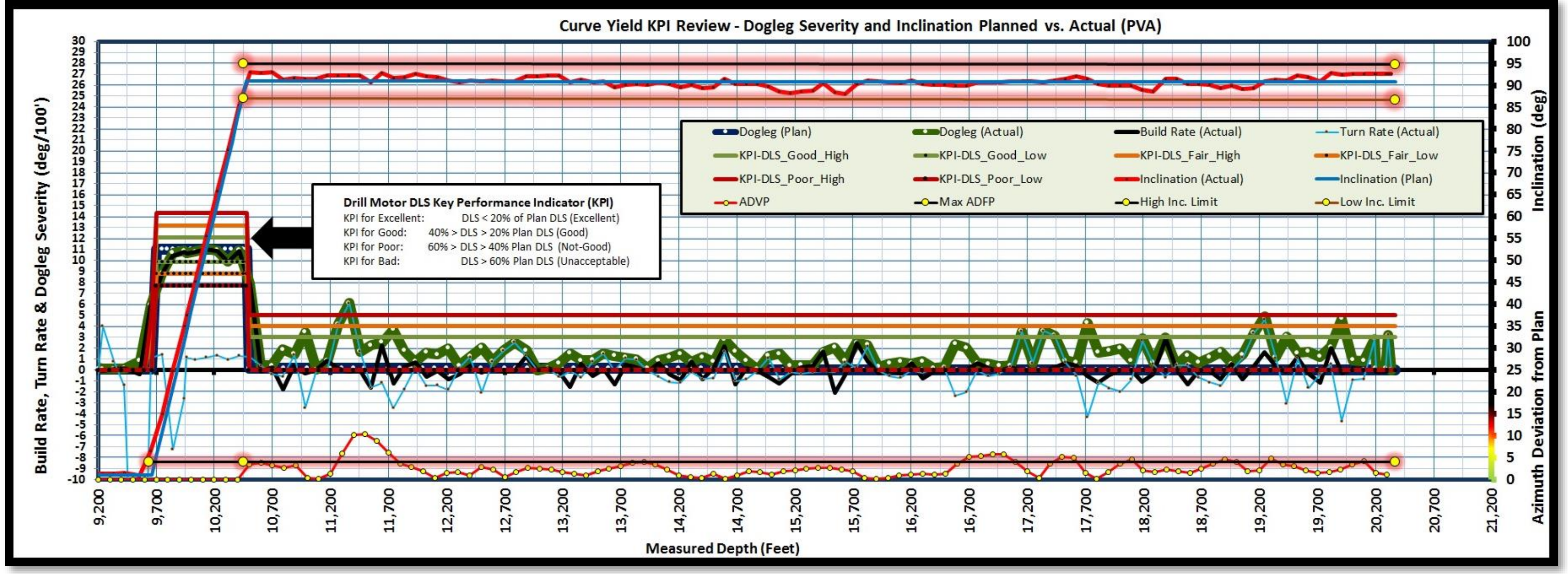
Lateral Tortuosity KPI – Case Study



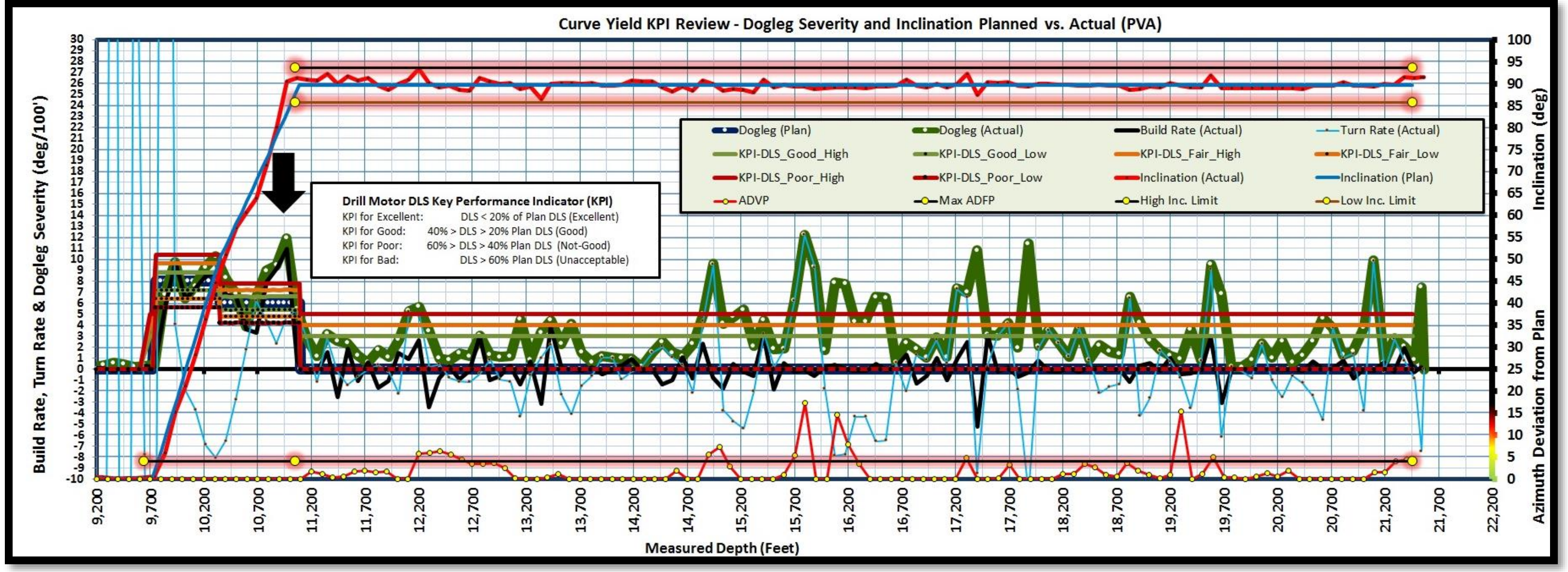
Lateral DLS Build & Turn Rate KPI Chart With Inclination +/- Allowable Deviation from Plan

Surface to TD DLS KPI Chart with Artificial Lift DLS Guidance for Surface & Intermediate

Case Study – RSS Low Tortuosity



Case Study – RSS High Tortuosity



SPE DISTINGUISHED LECTURER

Curve Lateral Tortuosity KPI RSS Examples

Key Takeaways

- As demonstrated in these case studies, Safe Separation collision avoidance methods are designed to safely separate wellbores while also improving wellbore position accuracy.
- The survey interval should be considered during both the drilling planning and execution phases.
- Key performance indicators aid in achieving the objectives and expectations of directional wells.
- Wellbore Surveying and Positioning Practices
  - Provides a primary source of technical information for all subsurface borehole construction applications.
  - Contributes to the modernization of the wellbore construction industry by promoting safe separation procedures.
  - All participants in wellbore construction should support the collaborative effort of a committed group of industry volunteers. The desired outcome is industry-wide adoption.

See the WPTS for more information: https://connect.spe.org/wellborepositioning

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