LATEST DEVELOPMENTS AND TECHNIQUES IN PRE-MINING METHANE DRAINAGE

Opening of the International Center of Excellence on Coal Mine Methane
Katowice, Poland, June 7-9 2017

Latest Developments in Pre-Mining Drainage

dpi DRILLING PRODUCTS

REI DRILLING DIRECTIONAL UNDERGROUND

"The Majority of Developments in Pre-Mining Drainage Relate to Further Displacement of Conventional Drilling Techniques with Advanced Directional Drilling Solutions"

- Pre-Mining Methane Drainage Considerations
  - Source of Methane Emissions
  - Impact of Reservoir Characteristics
  - Reservoir Simulation
- Developments in Directional Drilling
  - Extended Reach Drills
  - Extended Reach Downhole Equipment
  - MWD/LWD/Geo-Steering
  - Borehole/Well Intercept
  - Torque and Drag Modeling
- Directional Drilling Solutions
  - Impact of Long In-Seam Boreholes
  - Impact of In-Seam Boreholes in Complimentary Systems
  - Application in Friable Coals
  - Coals with Vertical Permeability Barriers and Friable Layers
  - Applications in Tight Coals
  - Recovering CMM form De-Stressed Coals
  - Reducing GC of Overlying Source Seams in Advance of Mining
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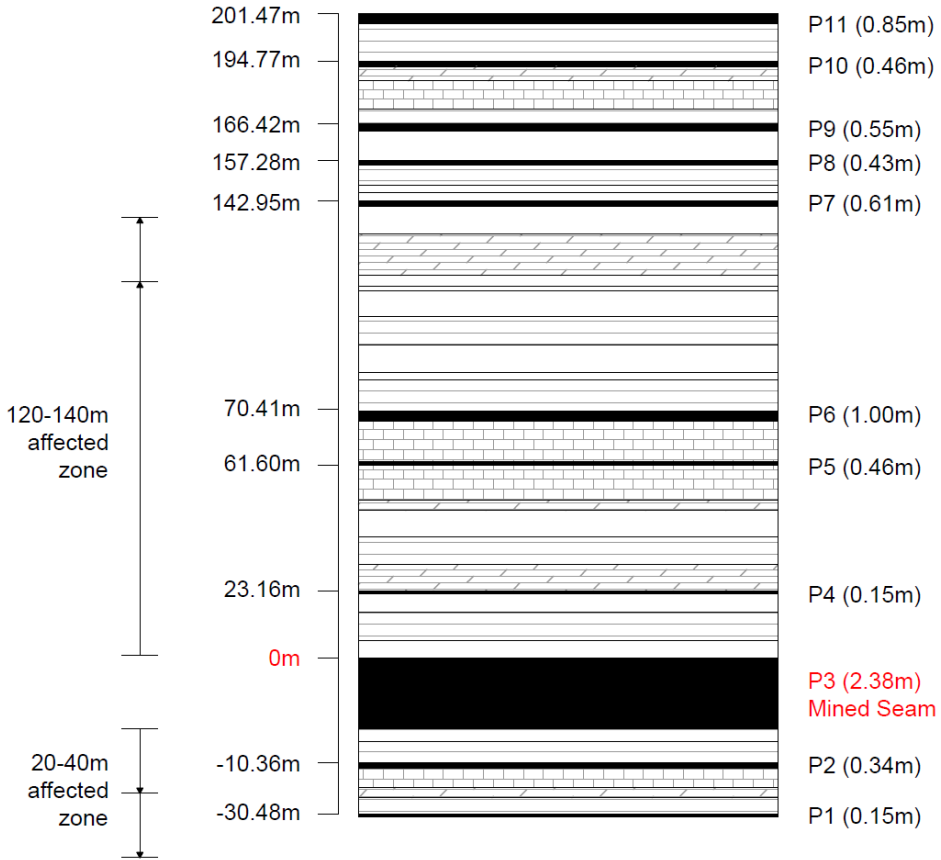
  - Implementing Stand-Alone Systems with Vertical Well Intercepts
  - Combining SIS with Underground In-Seam Drilling
  - Mine Appropriate SIS Approach
- Summary

Pre-Mining Methane Drainage Considerations

Mine Methane Emissions

- Mine Methane Emissions
  - Emissions Distribution
  - Emissions Characteristics
    - Operating Coal Faces
    - Start of Longwall Panels
- Location of Emissions
  - Roof Fractures
  - Floor Fractures
  - Working Seam
  - Behind Shields
  - Gob/Bleeders
  - Belt/Transported Coal
- Source of Methane Emissions
  - Mining Seam
  - Gas Bearing Overlying Strata
  - Gas Bearing Underlying Strata
  - Charged Deep Underlying Gas Sources



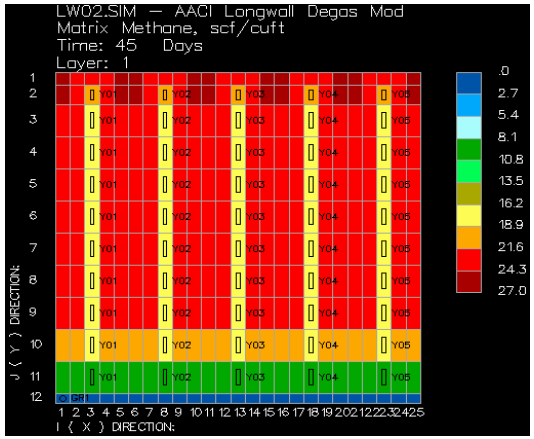
Pre-Mining Methane Drainage Considerations

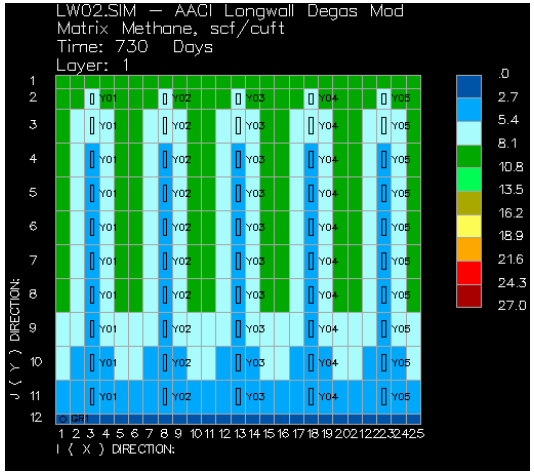
Impact of Reservoir Conditions

Reservoir Properties	Pittsburgh	Pocahontas No. 3	Lower Hartshorne	Blue Creek	Double Seam	USCB
Rank	High Volatile Bituminous	Medium Volatile Bituminous	Low-Medium Volatile Bituminous	Low-Medium Volatile Bituminous	Medium Volatile Bituminous	High -Medium Volatile Bituminous
Depth (m)	250 - 300	180 -390	320 - 610	427 - 640	150 - 350	936
Reservoir Pressure Gradient (kPa/m)	9.48	5.39	9.73	3.39	6.79	7.78
Reservoir Pressure at Depth (kPa)	2,370 – 2,844	969 - 2,100	3,103 - 5,929	1,447 – 2,170	1,018 - 2,376	7,282
Permeability (md)	10 - 15	10 - 27	1.2 - 1.6	12-20	20 - 35	0.5 – 1.0
Thickness (m)	2.0	2.1 - 2.4	1.4 - 4.3	1.5 – 1.9	1.6 - 3.1	1.2 – 8.8
Gas Content (m^3/t dmaf)	5.0 - 7.0	8.0 - 12.9	15.9 - 16.4	12.2 - 16.1	7.8 - 12.8	5 - 10
Langmuir Volume (m^3/t)	22.9	22.4	20.9	20.8	27.16	26.3
Langmuir Pressure (kPa)	2,683	1,165	N/A	1,710	1,419	1,650
Sorption Time (hours)	741	168	37	72 - 96	56.6 - 66.7	360

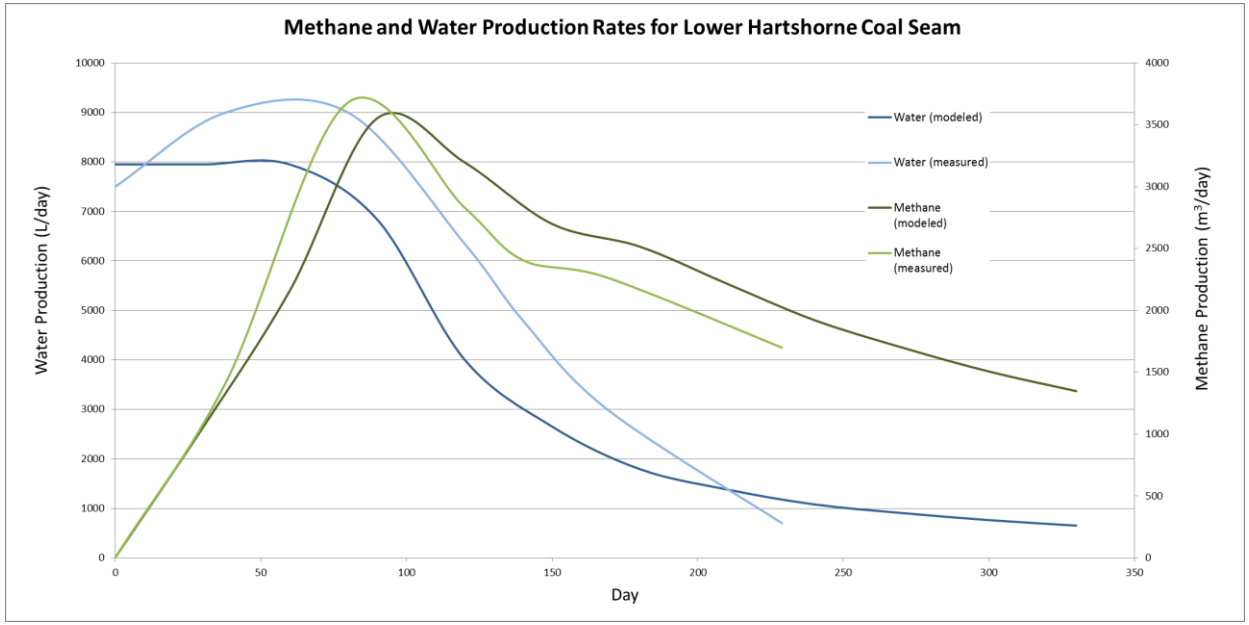
Pre-Mining Methane Drainage Considerations

Reservoir Simulation





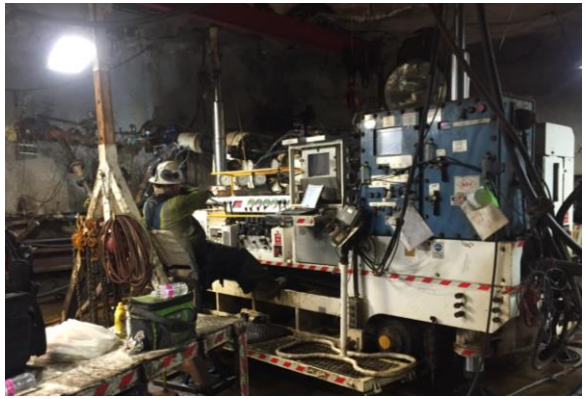
- GC_I = 15 m^3/t, Spacing 20 m



- GC_R = 6 m^3/t , 2 Years

Developments in Directional Drilling

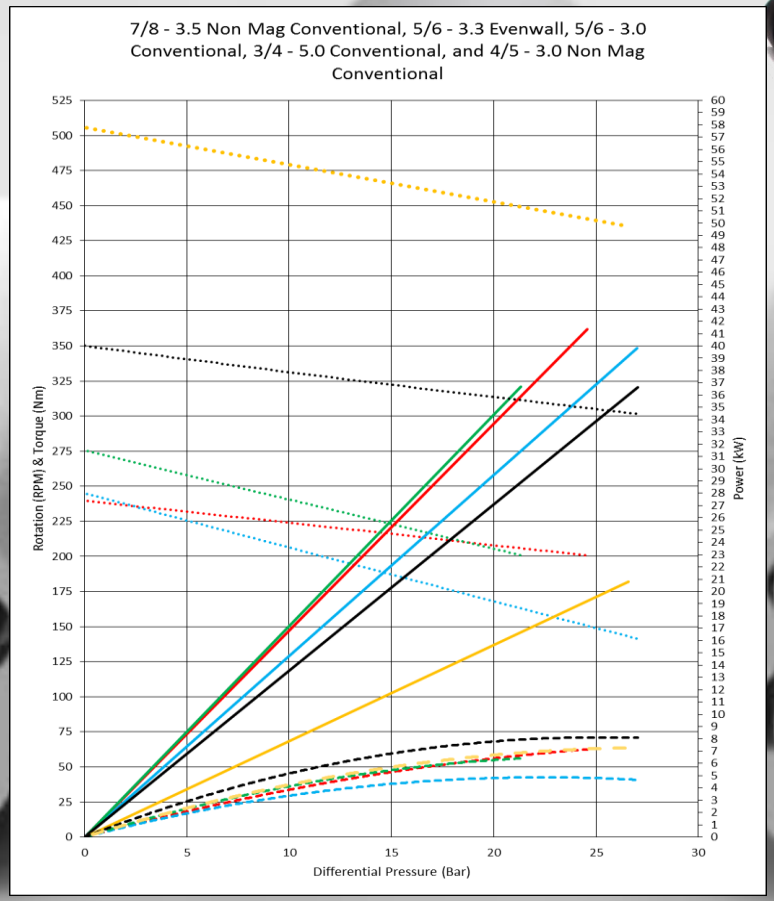
- Extended Reach Drills



- Permissible
  - Performance
    - 200 kN/4,000 NM
    - 1,500 m
- Extended Reach
  - Performance
    - 555 kN/7,500 NM
    - > 2,000 m
- Multi-Purpose
  - Underground
  - Highwall
  - Mine Appropriate SIS

Developments in Directional Drilling

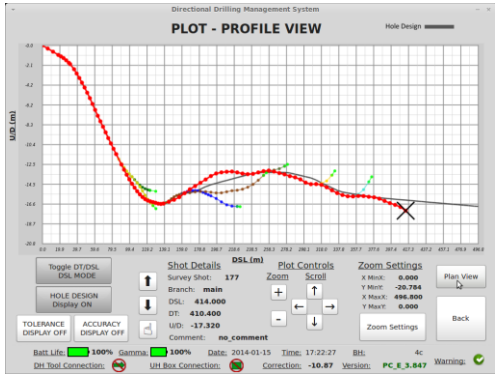
- Extended Reach Downhole Tools and Pumps



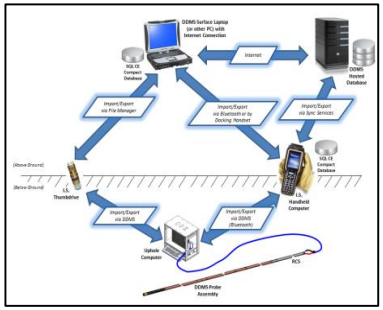
Developments in Directional Drilling

On-Drill Navigation, LWD and Rig Monitoring

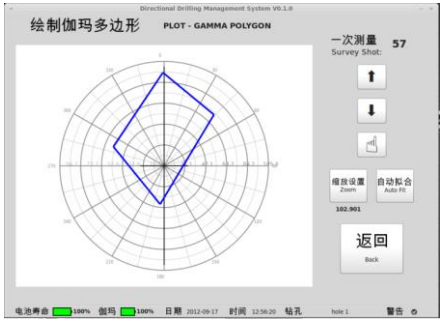
- On-Board Drill to Plan



- Data Management



- On-Board Focused Gamma Polygon Guidance

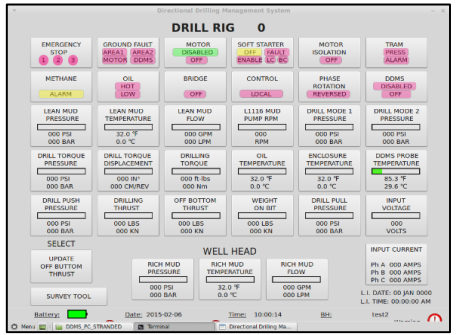


- Roof

- Coal

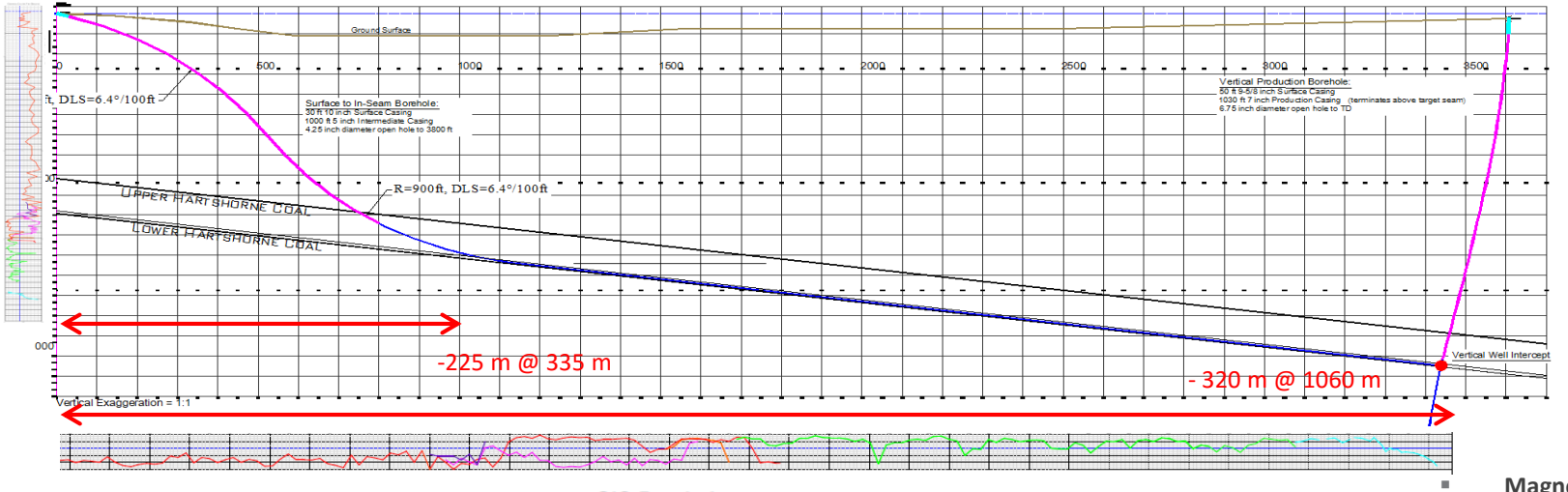
- Floor

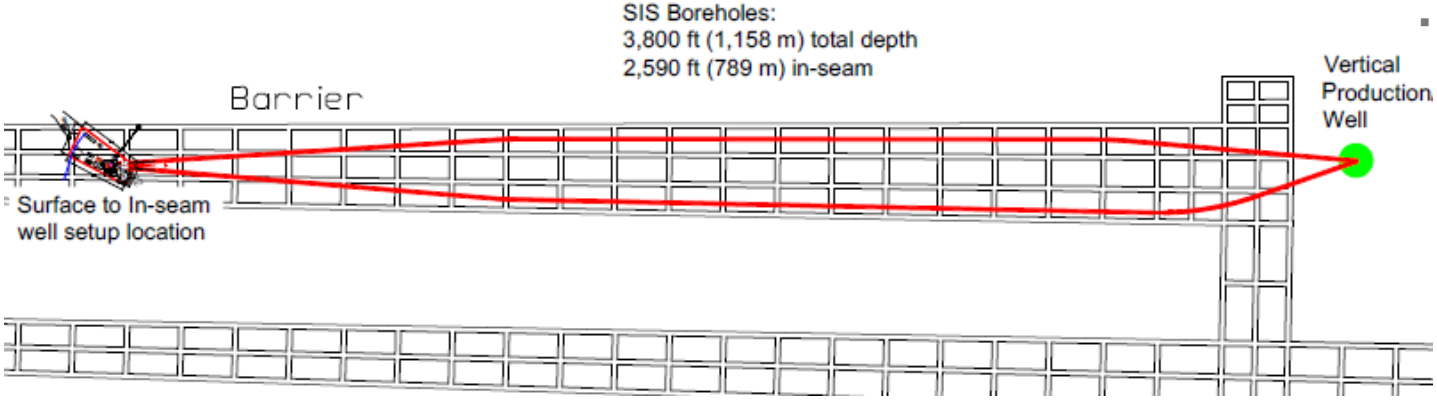
- Drill Monitoring



Developments in Directional Drilling

- Well/Borehole Interception Capabilities



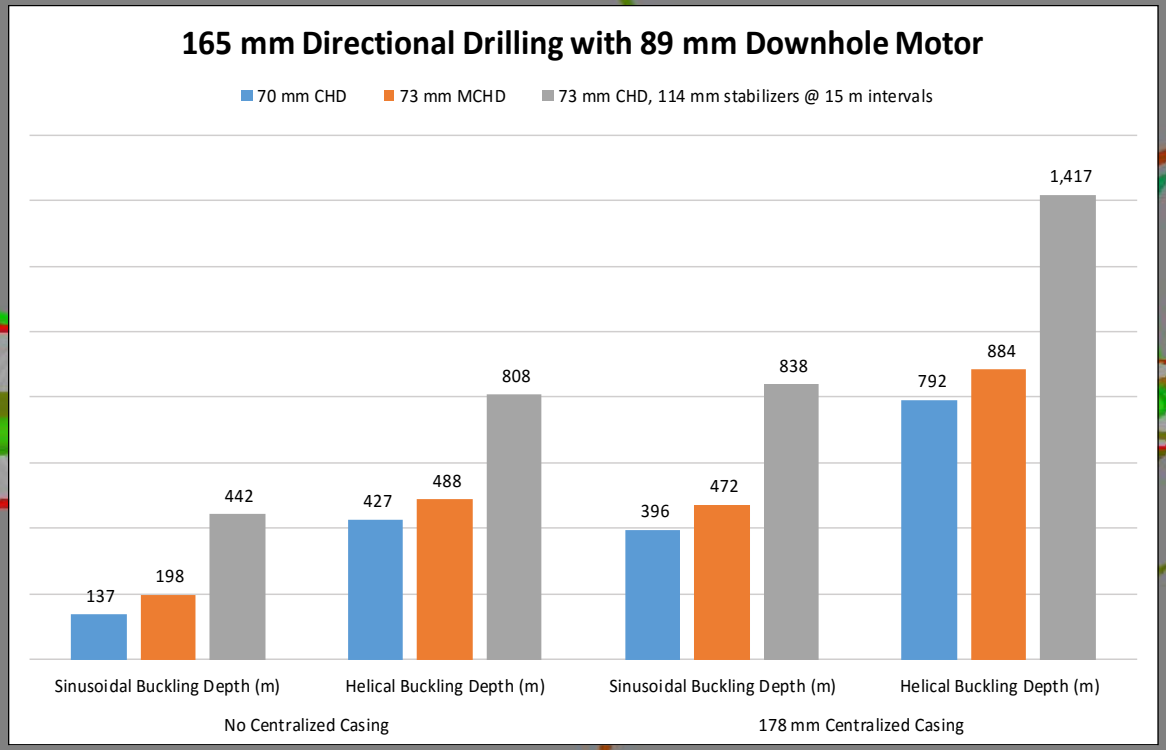


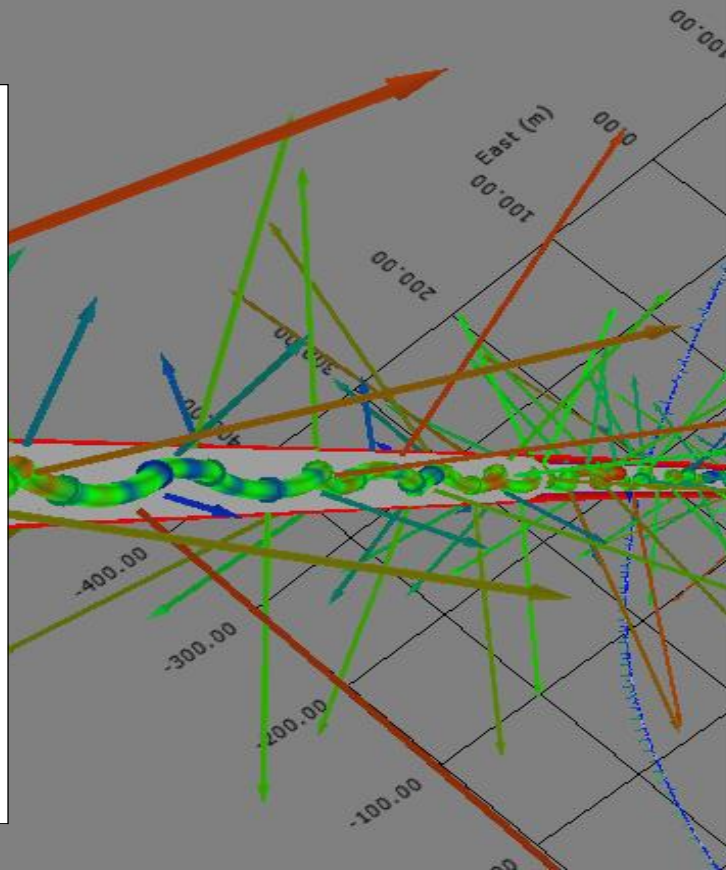
- Magnetic Vector Technology Intercept 150 mm Dia. Vertical Well

Developments in Directional Drilling

Torque and Drag Simulation

- String Model of Drill Steel
- Buckling Limits, Tension - Depth
- Range Chart, Thrust - Depth



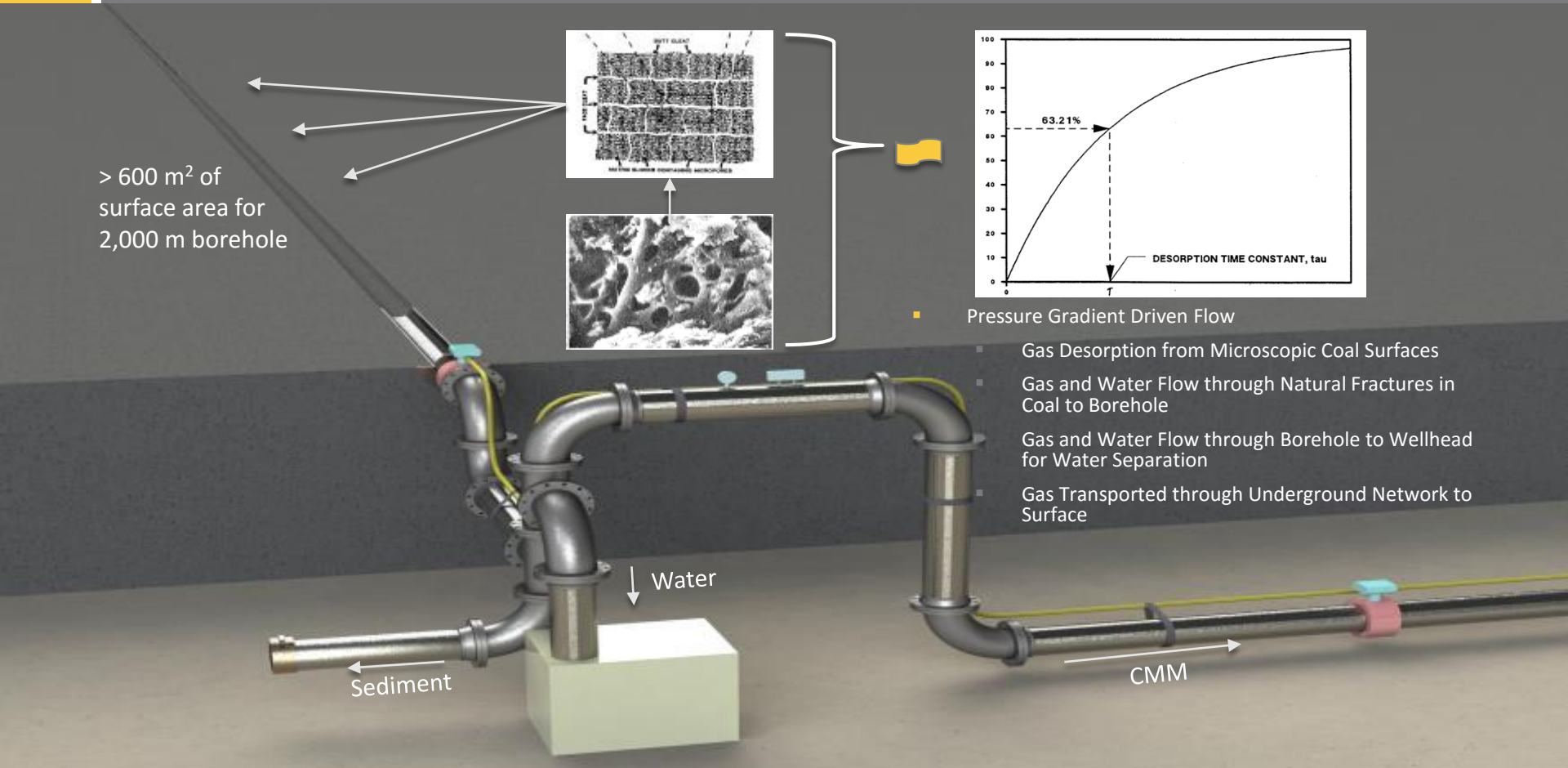


Directional Drilling Solutions

- Impact of Long In-Seam Boreholes

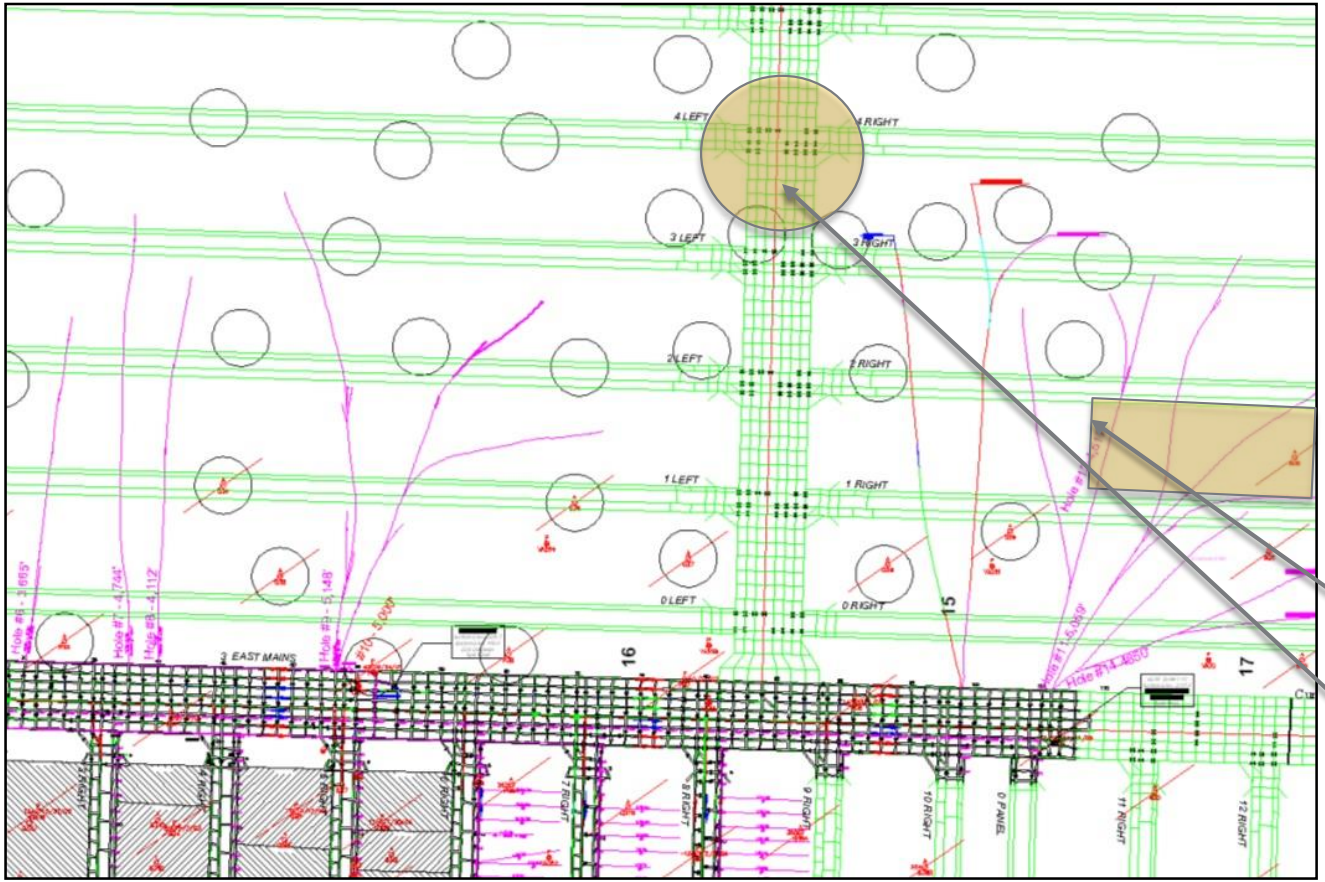
> 600 m^2 of surface area for 2,000 m borehole

- Pressure Gradient Driven Flow
  - Gas Desorption from Microscopic Coal Surfaces
  - Gas and Water Flow through Natural Fractures in Coal to Borehole
  - Gas and Water Flow through Borehole to Wellhead for Water Separation
  - Gas Transported through Underground Network to Surface



Directional Drilling Solutions

- Impact of In-Seam Boreholes on Complementary Systems

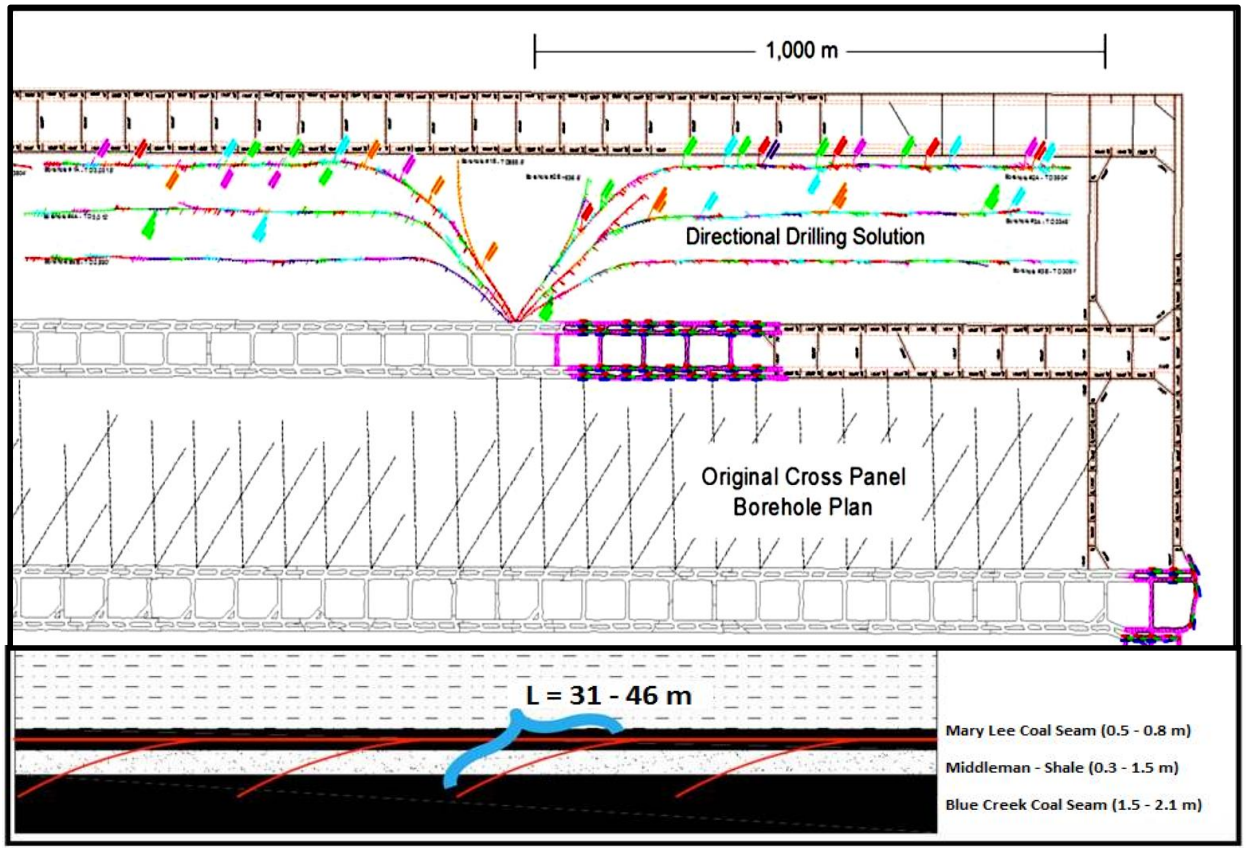


- Complementary Pre-Mining Drainage in High Perm Conditions > 10 md
- > 1600 m Directionally Drilled Boreholes Navigated around Vertical Frac Wells
- In-Seam Borehole Average IP > 40 m^3/min
- Significant Reservoir Pressure Reduction
- Increased Production from Frac Wells
- Record Coal Production Rates after 10 Yrs
- In Place GC Impedes Mains Development Inby of In-Seam Boreholes after 10 Yrs

Directional Drilling Solutions

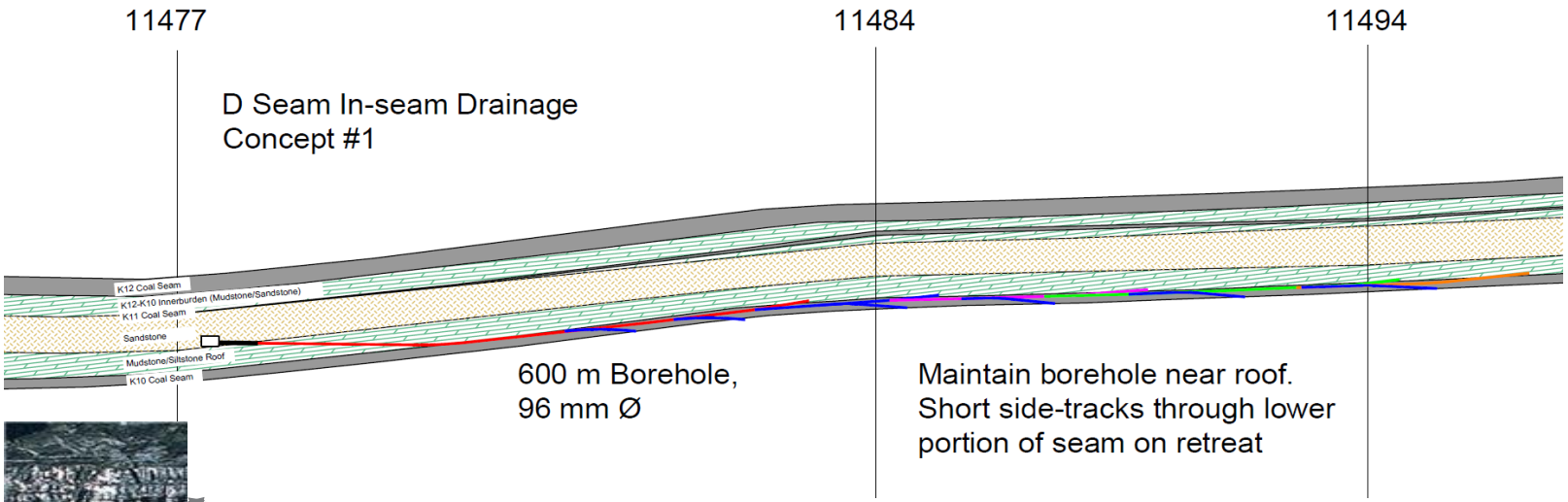
Friable Coals - HG>100

- **Borehole Placement from Adjacent Drillable Horizons**



Directional Drilling Solutions

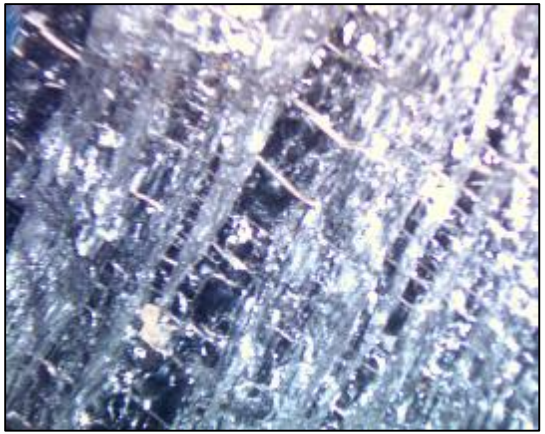
- Coals with Vertical Permeability Barriers and Friable Layers

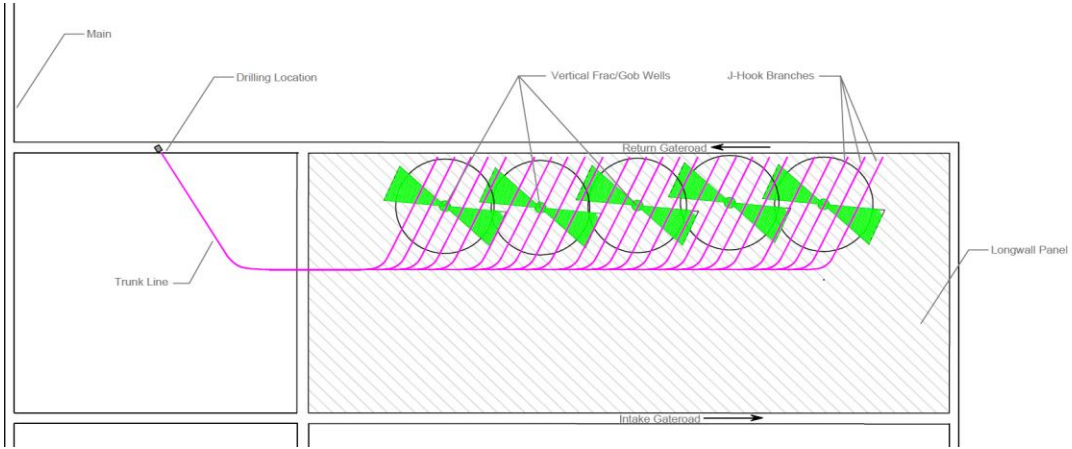


- **Use Competent Coal Layer as a Bridge for Reach**
- **Navigate in Thin Competent Layer with LWD**
- **Develop Side-Tracks Down to Break Through Vertical Permeability Layers**
- **Carefully Contact Lower Friable Layers**

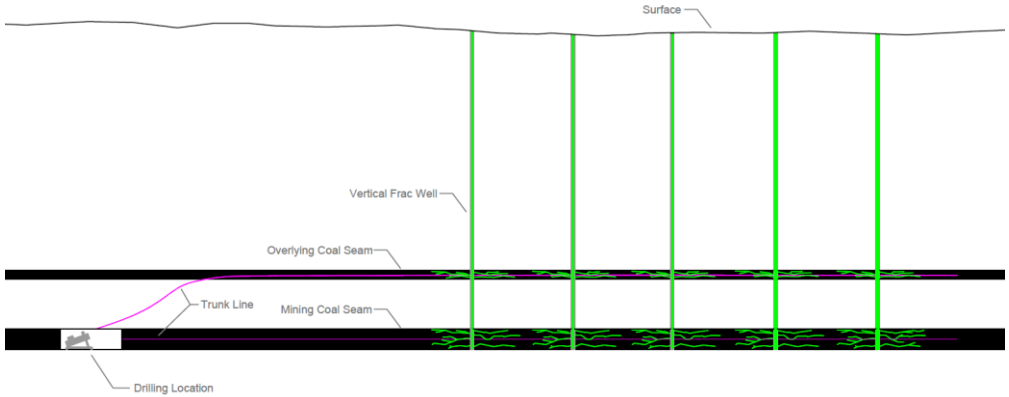
Directional Drilling Solutions

Applications in Tight Coals



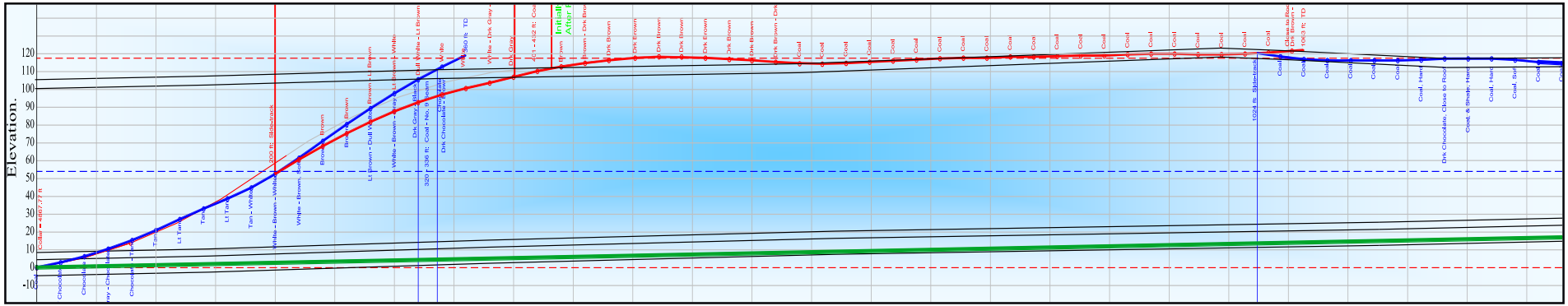


- **Applicable in Tight or Cemented Coals**
- **Where In-seam Gas Production Increases with Mining Related Stress Changes**
- **Intercept Fracs Orthogonally, both Mining and Adjacent Seams**
- **Vertical Wells Serve as Future Gob Wells**
- **CMM Recovered from Surface as Mining Advances**

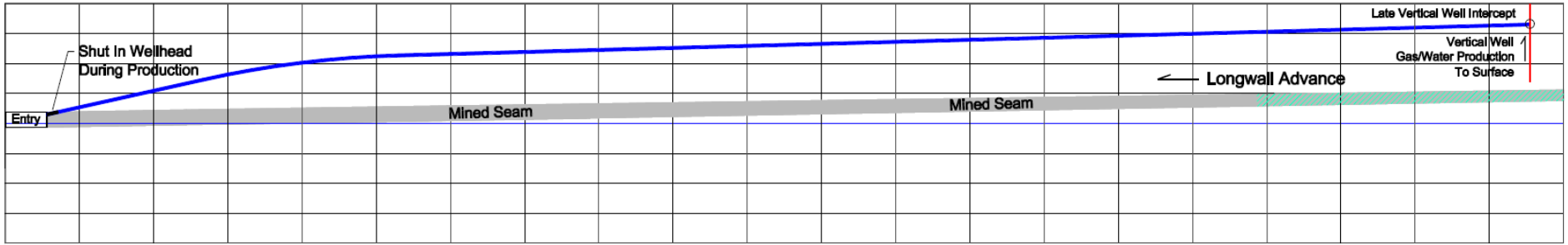


Directional Drilling Solutions

- Reducing GC of Overlying Source Seams



- **Dual Purpose Boreholes**

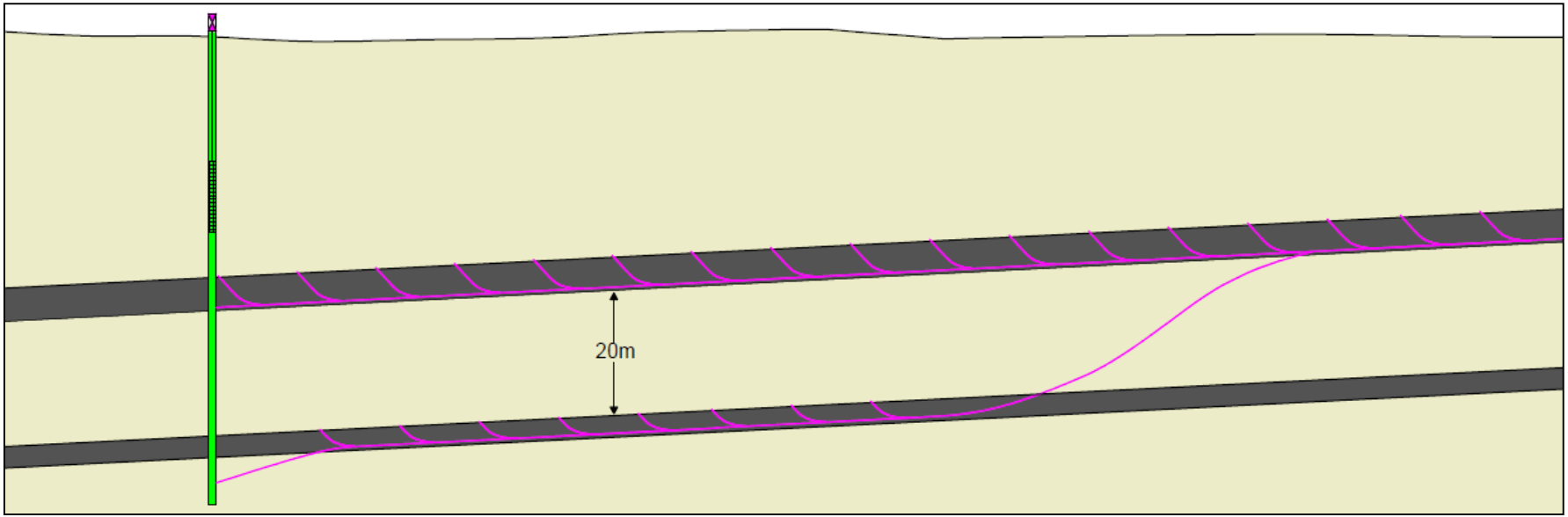


- **Borehole Placement in Overlying Coal or Rock with Vertical Gob Well Interception**

Directional Drilling Solutions

Reducing Gas Contents of Underlying Seams

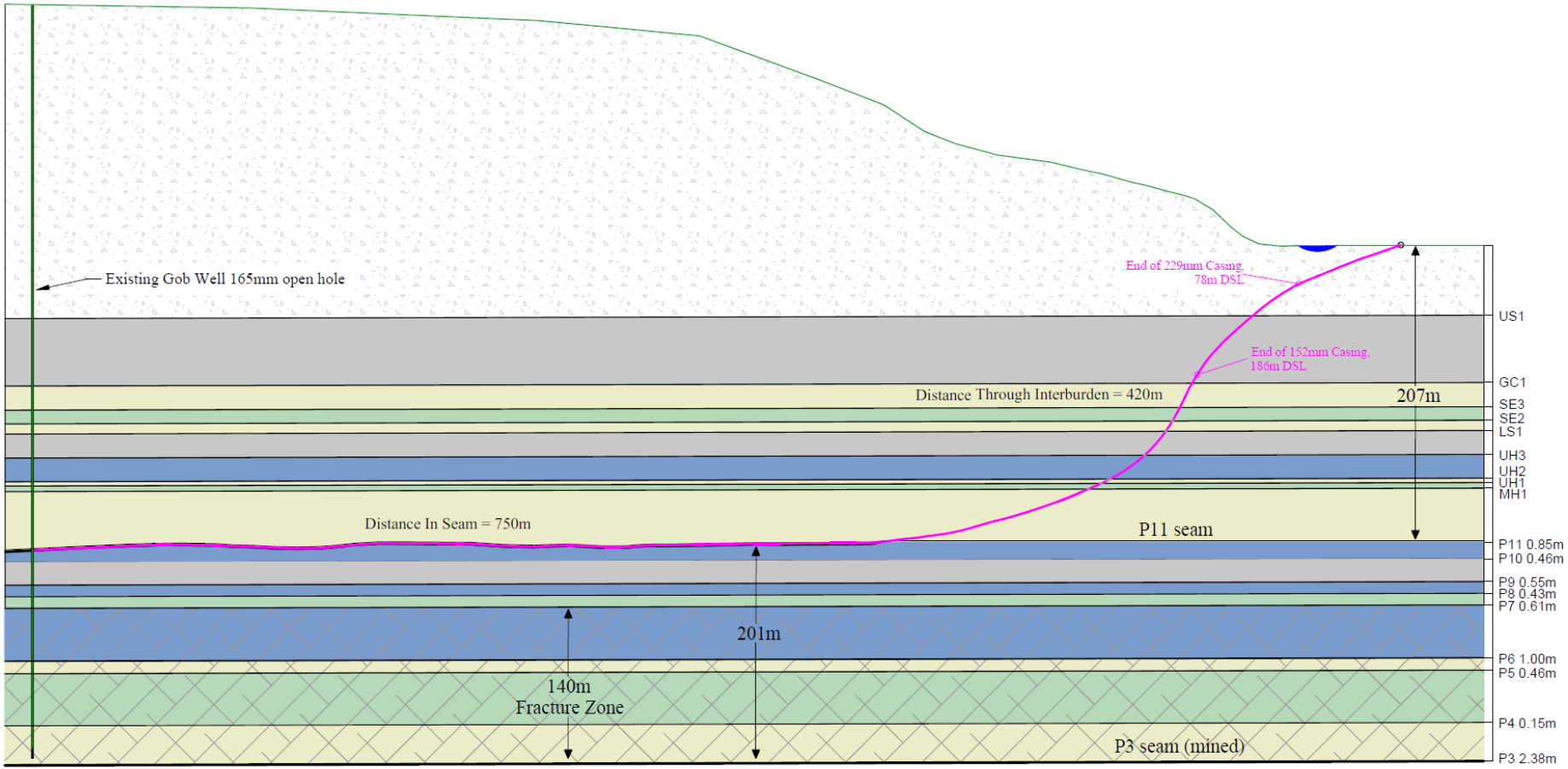
- **Pre-Mining Down-Dip Approach with Late Well Interception**
- **Vertical Well used as a Gob Well once Undermined.**



- **Accumulated Water and CMM from Boreholes Drilled in Underlying Seam Produced from Vertical Well**

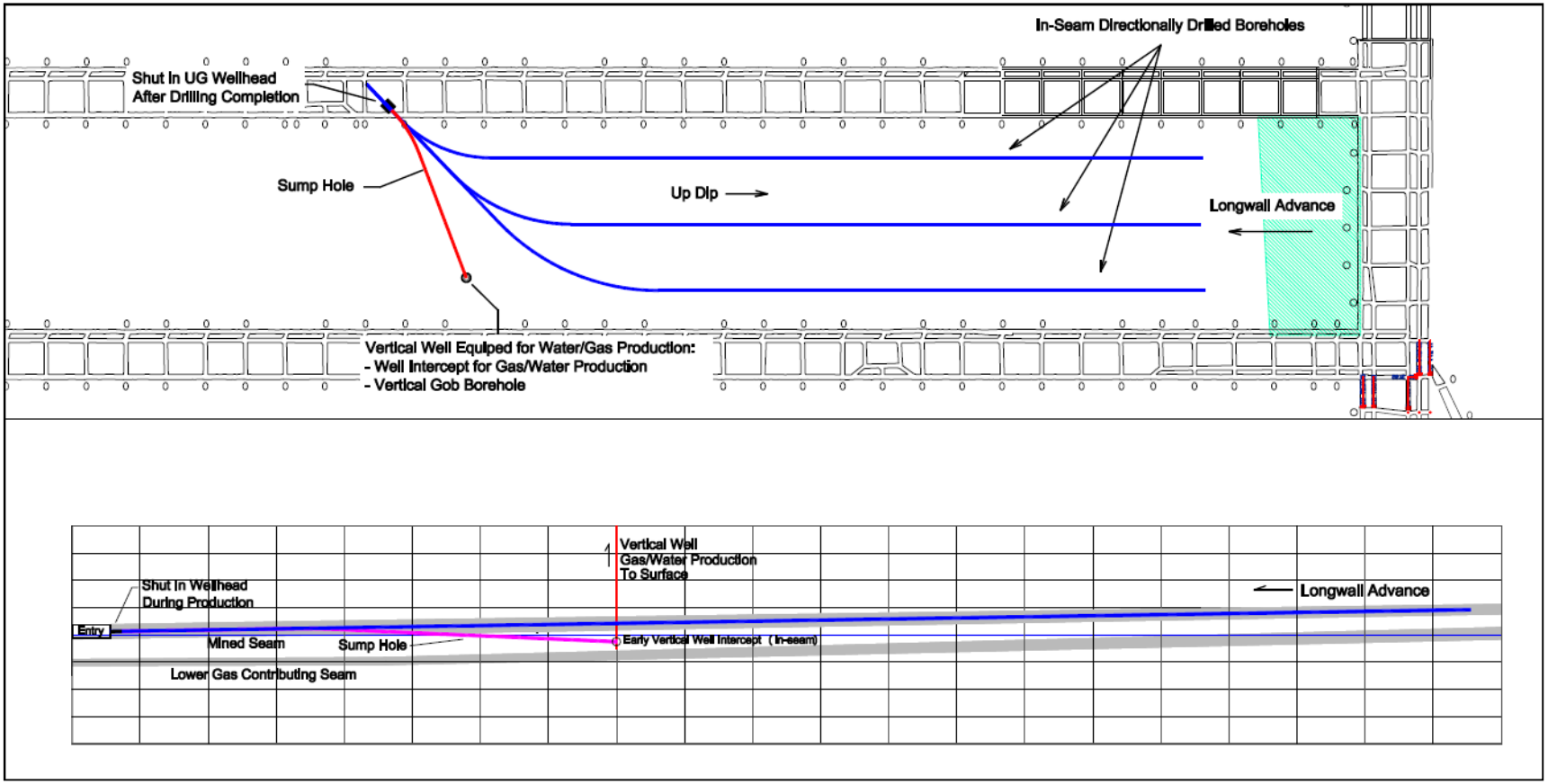
Directional Drilling Solutions

- Producing CMM from De-Stressed Coals



Directional Drilling Solutions

- Implementing Stand-Alone Systems with Vertical Wells

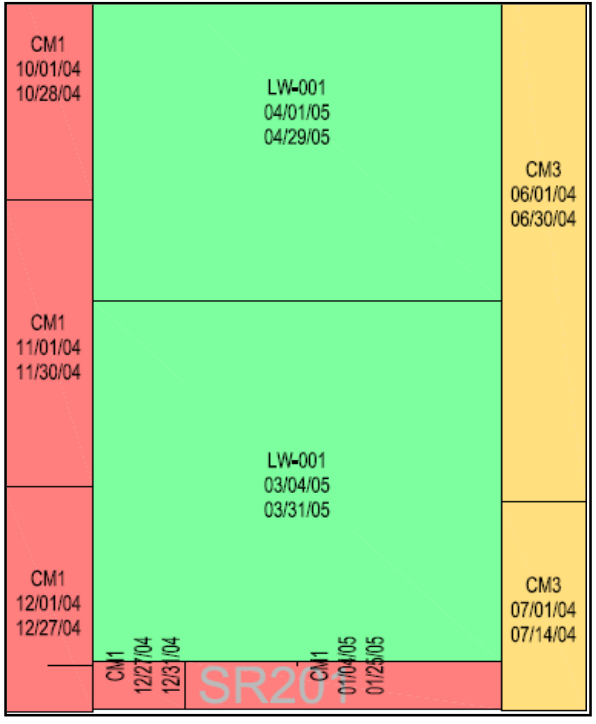


- Gas Production Moved to Surface via Interception with Vertical Well (Post Use Gob Well)

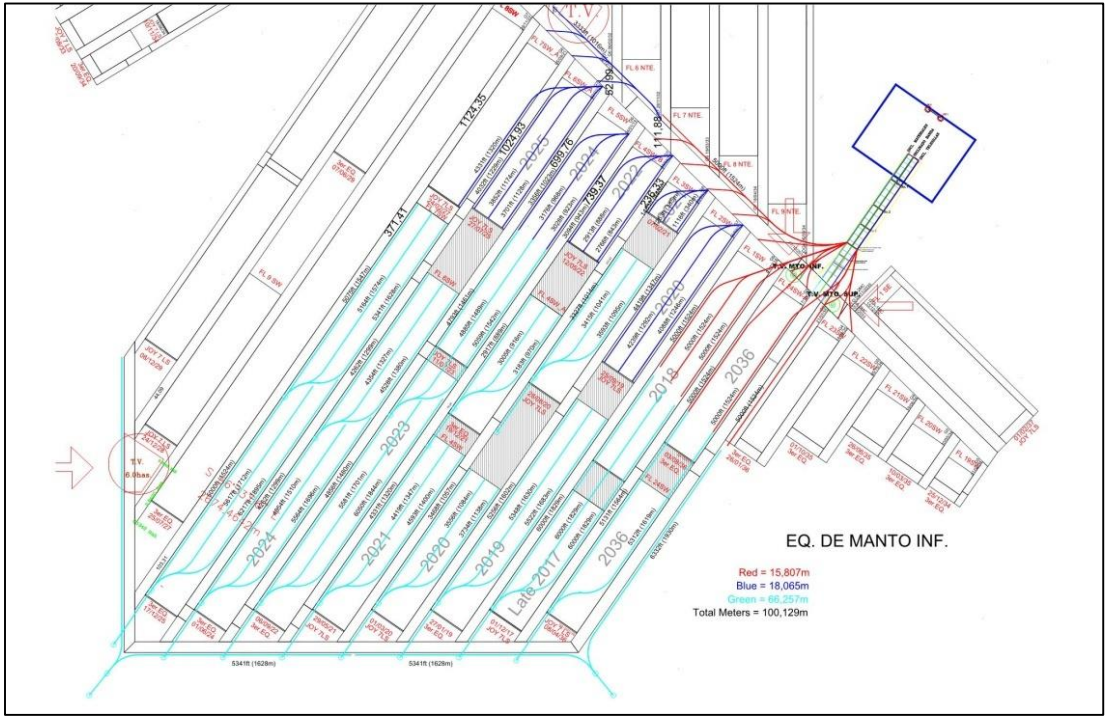
Directional Drilling Solutions

- Combining SIS with Underground In-Seam Drilling

  - Gateroad Development Timing, Start of Longwall (Just in Time)
  - Available Drainage times, Multiple seams, Surface/Underground Approach



- Just in Time Development

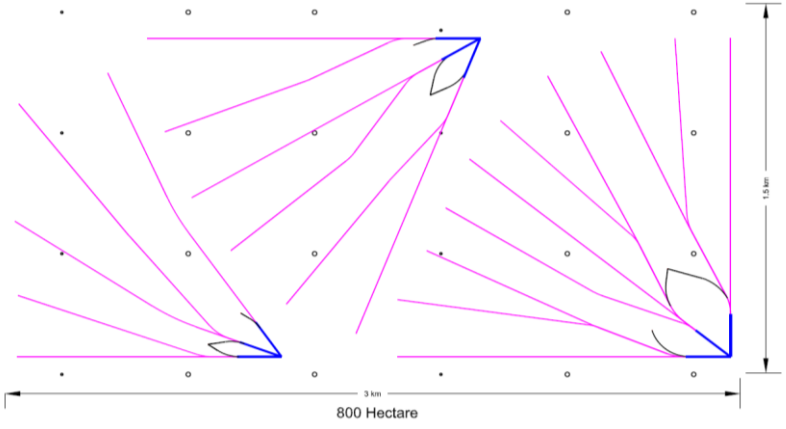


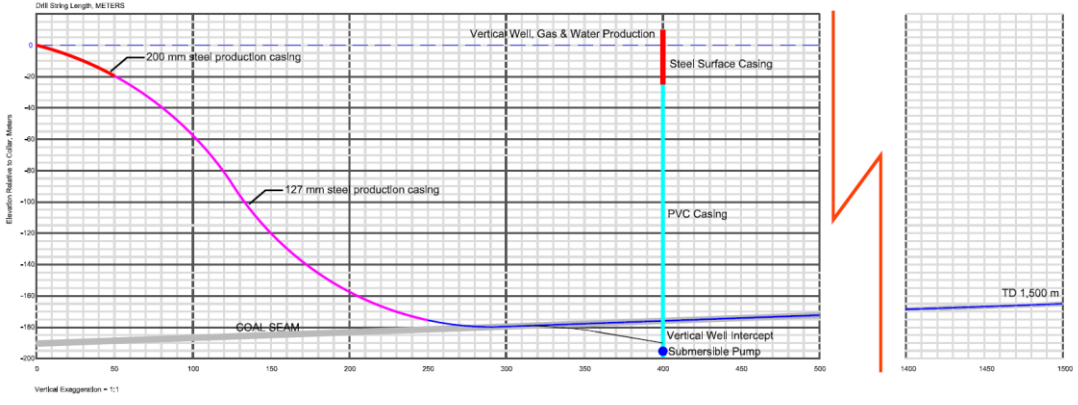
- Underground Directional Drilling Complemented by SIS Approach

Directional Drilling Solutions

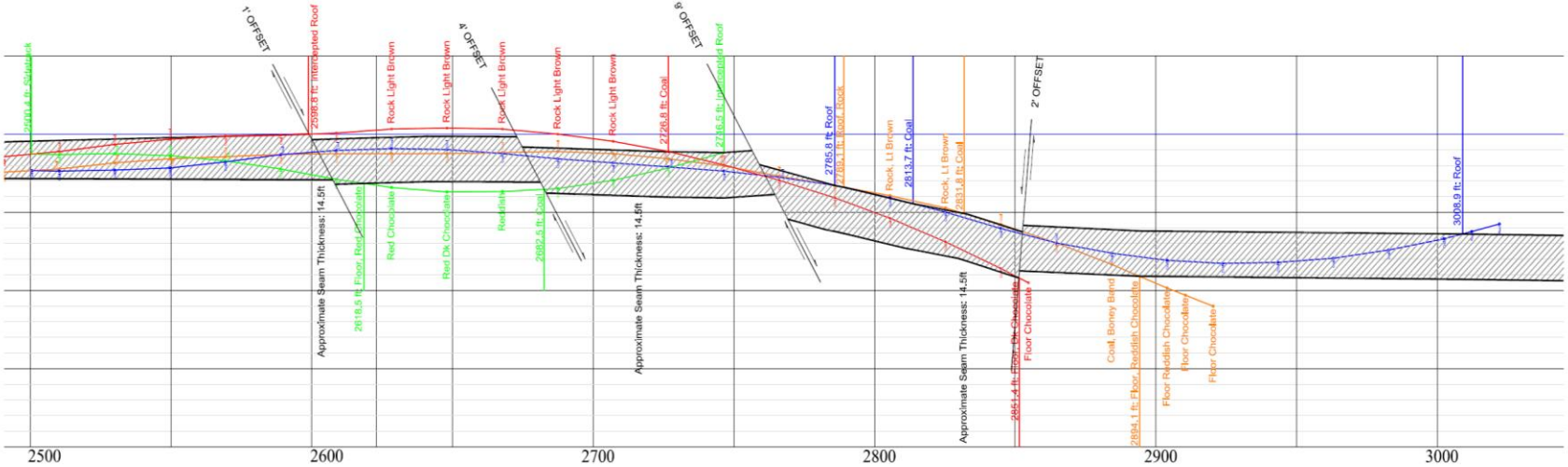
Using a Mine Appropriate SIS Approach

- **Early Vertical Well Intercept Approach**





- **Rapid Surface Casing Installation**

Summary

- Developments in in-seam directional drilling technology provide for longer length, larger diameters, and more accurate placement of boreholes for improved methane drainage efficiency and longer drainage times.
- Developments in reservoir simulation and torque and drag modeling aid in selecting appropriate directional drilling solutions and secondary stimulation or ECMM applications.
- Geo-Steering technology provides the ability to maintain boreholes in-seam or in adjacent seams or strata, or specific coal layers, or hit specific targets, and combine underground and surface systems, particularly through vertical well interception.
- Directional drilling solutions involving complementary surface and underground methane drainage systems can significantly improve gas content reduction and address mine timing and drainage time issues, particularly in tight coals.
- The Majority of Developments in Pre-Mining Drainage Relate to Further Displacement of Conventional Drilling Techniques with Advanced Directional Drilling Solutions.
- Ancillary benefits to employing in-seam directional drilling include the ability to interpret geologic structure and characterize geologic anomalies including normal faults, intrusions (dikes, sand channels, karsts), and seam splits.