Mamm Creek Field Case History
Piceance Basin Colorado

An Unconventional Resource Development
Example of Stray Gas Migration

Isolated Event

Or

More Pervasive Issue of Broader Concern?
Sources and Acknowledgements

• Colorado Oil and Gas Conservation Commission (COGCC)
• (Various Piceance Basin Reports/Data from website at [http://cogcc.state.co.us](http://cogcc.state.co.us))
  • Stuart Ellsworth – Engineering Manager
  • David Andrews – Northwest Area Engineering Supervisor
  • Tom Kerr – Acting Director
  • Crescent Consulting LLC; Reed Energy Consulting LLC; Roge, LLC; EMCPA Study (2011)
  • COGCC Response Memo to Crescent Consulting LLC et al Concl. & Rec. (2011)
• Garfield County Board of Commissioners
  • URS Corp (Phase I Hydrogeologic Characterization - 2006)
  • SS Papadopulos & Associates (Phase II Hydrogeologic Study - 2008)
  • Dr. Geoffrey Thyne, Univ. of Wyo. (Review of Phase II Hydrogeologic Study - 2008)
  • The Walter Environmental Group (Joint Study and Structural Analysis)
• T. Albrecht (unpub. Masters Thesis, CSM)
• S.S. Papadopulos & Associates (Evaluation of Thyne Review - 2008)
• Encana Oil and Gas (USA)
  • Rule Engineering, LLC (West Divide Seep Remediation and Monitoring Results - 2011)
  • Universal Geoscience Consulting Inc. (Review of Thyne Interpretations)
• Bill Barrett Corporation
  • HCItasca Denver, Inc. (Review of Thyne Interpretations)
Mamm Creek Field Play Elements

1. **Reservoir**: Tight Gas Sands (Williams Fork Fm. of Up. Cret. Mesaverde Gp.)
2. **Stimulation**: Requires Hydraulic Fracturing of vertical pay penetrations
3. **Hydrocarbon**: Gas and Gas Condensate prod. from 3000’ to 7000’ depth
4. **Field Area**: 100+ sq. mi. (parts of 4 townships)
5. **Wells**: 2100+ on 10 to 20 acre (bottom hole) spacing from multi-well pads (interspersed with ~ 500 water supply wells – all types)
6. **Surface Geology**: Fractured/jointed* Wasatch Fm. directly overlies WF
7. **Operators**: EnCana, Bill Barrett Corp and ~ 34 others
8. **Major Structure**: Divide Creek Anticline (NW plunge - EMCPA)
9. **Nuisance Gas**: Shallow low pressure gas commonly occurs in Wasatch Fm.
10. **Significant “Event”**: Release to surface of gas and condensate from EnCana Schwartz 2-15B (02) well (Lost Circ. Zones, Wasatch Gas Kick)
11. **Major Issue**: “Claims” and concerns of methane contamination of groundwater supplies [isolated event(s) or more pervasive long-term impacts associated with gas drilling activity?]
Mamm Creek Field – Why the Attention? (Unconventional Resource Play Context)


2. Geologic Conditions result in positive bradenhead pressures on relatively high percentage of completed wells (35%) – requires post-completion monitoring and evaluation for well remediation as needed (> 150 psi)
   a.) COGCC established policy-based areas w/more strict requirements
      1. Revised Cementing Requirements (NTO Policy Areas)
      2. Bradenhead Monitoring (NTO Policy Areas)
      3. Well Remediations in East Mamm Creek Producing Area (EMPCA)
Extent of Piceance Basin, Western Colorado (Colorado Geol. Survey, 2003)

- 7100 sq. mi. basin (brown)
- 100+ sq. mi. Mamm Cr. Area
- Oil and Gas production
  Upper Cretaceous Williams Fork Fm. (> 2100 gas wells)
- Depth to gas is 3000 to 7000 feet across play area
- Wasatch Fm. is primary bedrock aquifer < 600’
  (yields < 10 gpm)
- Alluvial gravels along Colorado River (to north)
  and tribs. provide much greater yields
- 4+ Phases of Water Quality studies conducted in Mamm Creek and surrounding areas

From SPPA (2007)
500 Water Wells (all types – max. depth 600’)
2100 + Gas Wells/Well Pad Locs.

from COGCC, Gintautas
> Formations being hydraulically fractured are deep underground
> Drinking water is shallow in comparison
**Williams Fork Fm.**

Fluvial & Floodplain discontinuous sands/sand lenses – tight, highly “compartmentalized” sand reservoirs require small well spacings to exploit.

**Geologic Section for Western Colorado**

*Mamm Creek Area Geologic Section of Interest (red outline)*

Outcrop: Tertiary Wasatch Fm.
Ground Surface

Base FW (variable) 600’

Vertical Separation TOG to FW 2500 to 7000 feet

Shire Mudst.

Molina Sdst.

Atwell Gulch Mudst.

Mesaverde Top

ORC

Non eco. gas

Prod. Zone Gas

Figure 2.1 Simplified Stratigraphy for Mamm Creek Study Area. No vertical scale. Modified from Carroll (2003) and Johnson and Flores (2003).
Williams Fork non-commercial
"Top of Gas"
Above Commercial Gas

Neutron Density Logs:

"Nuisance"
Shallow Wasatch Gas
API: 05-045-09148

API: 05-045-12515

Top of Gas (Higher Pres.)
Typical S-shaped Directional Williams Fork Completions
(After First Vertical Well)

> Stacked lenticular sand/shale sequence geology requires vertical penetration through gas bearing zones

> Low permeability, small sand bodies require 10 acre density to produce the gas resource

From EPA HF Workshop, Feb. 2011 (Foreman)
S-shaped Directional Wells (pad plan view)

- Plan view of typical pad
- Reach multiple bottom-hole (BH) locations from fewer pads (up to 24, 10-acre wells per pad).
- Typical target: 25’ radius cylinder

From EPA HF Workshop, Feb. 2011 (Foreman)
Mamm Creek study area with major structural elements w/ COGCC special drilling area (EMCPA) outlined in red. & Loc. of Schwartz Well
(From URS 2006 and Review of Phase II Hydrogeologic Study Prepared for Garfield County Thyne, 2008)
East Mamm Creek Producing Area (red outline in previous slide)

Field Measurement of Vertical Joint Face in the fracture/jointed Molina sandstone member of Wasatch Fm. (w/compass bearing)

From Water Group
Photo of an exposed joint face in Molina (like) Sandstone north of the Arbaney(P3) well pad.

(from Walter Group Report)

Sustained Elevated Bradenhead Pressures in 4 of P3 pad wells required pre-completion remediation.

(COGCC)
Joint sets in exposed surface sandstone outcrop of Molina (like) Sandstone Member of Wasatch Fm.
(from Walter Group study)
Joint Strike Measurements from 3 Outcrop Locations near Schwartz Well, West Divide Creek Seep, Water Wells and Well Pad Locations (EMCPA) (mod. from Walter Environmental Group)
Outline of Mamm Creek Producing Area (Black Outline Area, 2005)

- 2100 + Gas Wells
- ~ 66 + Domestic wells (of the 500 WSW)

Locations of Domestic Wtr. Supply Wells

From URS 2005
Location of Domestic and Monitoring Wells in Mamm Creek Study Area with Probable Biogenic and Thermogenic Methane Sources. From Fig. 4.21 (SSPA, 2008)

Various Plots:
- Water Chemistry (ion ratios)
- Carbon & Hydrogen Stable Isotopes of Methane
- Bernard Diagram
- 6 domestic wells > 1 mg/L methane

From SSPA, 2008
Schwartz 2-15B (02) Well and West Divide Creek Gas Seep
General Characteristics and Relationship

- **Well location:** ~3000’ NW of West Divide Seep (swse sec. 2 - T 7 S R 92W)
- **Field:** Mamm Creek (subsequently East Mamm Creek Producing Area, post-NTO)
- **Spud Date:** January 16, 2004 (in Wasatch)
- **Objective Formations:** Williams Fork and Rollins (Rollins not completed)
- **Formation Tops:** Wasatch (at surface), Williams Fork (at 3,217 feet), Rollins (at 6,299 feet) vertical well with total measured depth of 6,535 feet
- **Surface Casing:** 9 5/8” to 706’ depth (water well depths to 450’ in 1 mile. radius)
- **Drilling History:**
  - Jan. 20 Lost Mud Circ. w/gas kick in Wasatch (1589’ depth) – S.I. 1 hr to control kick
  - Jan. 27 Lost Mud Circ. w/gas kick in Williams Fork (4,328’) – Shut In 8 hrs. to control kick
  - Feb. 6 Lost Circ. while running prod. casing – operations shut down for 7 hrs. to regain circ.

From COGCC
Schwartz 2-15B
Wellbore Diagram

Bradenhead Pressure 500 – 661 psig prior to remediation
Wasatch: Surface to 3217’

----9 5/8” casing set at 706’ cemented to surface

Lost Circulation & gas kick 1543’ to 1589’ - Shallow kick extremely unusual

__________Wasatch “G”________________________
Williams Fork Top  3217’

--------- TOC 4050’      TOC < 200’ above Top of Gas (post “fall back”)

Top of Gas 4132’

====== Lost Circulation and gas kick 4328’ while drilling

====== Frac Stage 5: 4458 ‘– 4633’; pp = 1002 psia; grad. = 0.23 psi/ft.

====== Frac Stage 4: 4698’ – 4959’; pp = 1072 psia, grad. = 0.23 psi/ft.

Pressure regime change

====== Frac Stage 3: 5207’ - 5338’; pp = 3033 psia; grad. = 0.57 psi/ft.

====== Frac Stage 2: 5472’ - 5581’; pp = 3282 psia; grad. = 0.60 psi/ft.

====== Frac Stage 1: 5827’ – 5960’; pp = 3497 psia; grad. = 0.60 psi/ft.

7” set at 6514’

Mod From COGCC
Con’t. Schwartz well history

• **Production Casing Primary Cement Job:**
  - Cement initially circulated to surface (25 bbls)
  - Feb. 16,- CBL run shows TOC fallen to 4,050 depth (top of gas at 4,132’ in WF - only **82 feet separation:** TOC to TOG)
    - Temp. survey indicated upward gas migration under Shut-In cond. (cooling at 4,328’)

• **Completion and Post-Completion Bradenhead Pressure Measurements:**
  - EnCana proceeded with frac stimulation of well through March
  - Final frac stage (5) at 4,458’ to 4,633, No BH pres. build-up during frac but build up after frack
  - EnCana also observes BH pres. (515-650 psi) following completion activities and prior to remedial cement operations
  - EnCana submits Sundry Notice to COGCC on Mar. 23 (for remedial cement ops.)
  - COGCC approves Sundry Notice on Mar. 30
  - **April 1 - report of Gas Seep in West Divide Creek 3000’ away**
    - During **Apr. 4 remedial cement job**, flowing BH pres. range 500 to 650 psi
    - Gas sample analytical results (isotopic & compositional) → Williams Fork gas is origin
      - Same for other nearby wells BH gas
    - BH pressure drops **to 0 psi after Remedial Cement Job** and gas flow to creek subsides dramatically w/in 8 days - Benzene levels in Creek drop after 12 days
    - EnCana agrees to 2 mile drilling moratorium while problems are investigated further
    - East Mamm Creek Production Policy area NTO established (revised drilling and completion/cementing)
    - Gas sampling (isotopic & compositional analysis) indicates Bradenhead gas is from Williams Fork (including other nearby wells)
West Divide Creek Seep Elements

- Discovered in April 1, 2004 subsequent to drilling gas kick “events” Jan – Feb 2004 and Mar. 2004 Frac Stimulation in Swartz 2-15B well
- Well and seep in approximate structural alignment as observed joint trends (~3000 feet separation) – (also possible tensional fractures from anticline)
- Methane plus some condensate (BETX compounds) migrated to near-surface groundwater and initially surface water (pre well-remediation)
- Water table range 0 to 10 feet in general area of seep
- GW flow direction to NE (parallel or subparallel to stream)
- Several thousand samples (surface and groundwater) collected
- Active Remediation System – Air Sparging in downgradient area
- Dissolved BTEX (Benzene; MCL = 5 ppb) and Methane monitored
- Maximum plume migration = ~ 500 feet
- Rule Engineering – Environmental Contractor to EnCana
Benzene Concentration

Methane Concentration

West Divide Crk. Seep (near MW-14)
Arrows show up gradient to down gradient well transition
The Issue: Generic Gas Well Completion (either 2- or 3-string casing design) with open annular interval under fractured bedrock conditions (only shows upper hole above TOC):

- Non-target gas (show) zones above production and above TOC capable of flow to borehole open annulus

- Overpressured annulus causes positive bradenhead buildup/gauge pressure; free gas displaces fluid/water column of annulus at 1 ft./0.433 psi build-up pressure: @ 150 psi = 346’ @ 650 psi = 1,501’ (event)

- Management Options: Gas is continuously /intermittently vented (GHG), produced to combustor, compressed and produced to sales (pipeline), shut-in with potential(?) to migrate upward to aquifer
Summary & Conclusions

• Schwartz well gas and condensate escape to surface (Divide Creek Seep)
  • Unique “event” caused by failure of the primary cement job (~4000’ “fall back”) left insufficient TOG to TOC separation
  • “Event” was unrelated to the underground hydraulic fracturing “process” itself
  • Overpressure of open annular interval by Williams Fork gas resulted in effectively an underground blow out with well shut in for several days
  • Gas escaped via pathway of fractured (fault?) or jointed bedrock that intersected borehole wall below surface casing seat to circumvent surface casing & cement of good integrity (problematic well design issue when lost circulation zones compromise circulation of production casing cement to surface)
  • Current production casing cement jobs are designed to isolate all gas producing zones in the Williams Fork Fm. (NTO’s, APD’s w/COA’s) with the requirement of higher TOC but still leaving some open annular for monitoring purposes
CONCLUSIONS con’t.

• Nuisance gas management from the Wasatch Fm. (low vol., low pressure, non-economic.)
  • “Nuisance” gas in the Wasatch Fm. is an independent issue in the greater Mamm Creek area that leads to positive bradenhead pressures on a significant percentage of wells.
  • Bradenhead monitoring and venting is effective mitigation method for potential impacts (evaluate wells for remediation > 150 psi) but it is unclear to what degree any sustained pressure poses a threat of methane migration to drinking water aquifers/supplies over the long term should an open fracture system intersect the open annular borehole wall.
  • Attempts to circulate cement across Wasatch zones are only “marginally effective” at limiting bradenhead build-up pressures.
  • COGCC explores isolation of such zones on a well-by-well basis based on several factors and sustained elevated bradenhead pressures may require targeted cement remediation.
  • Historic venting of bradenhead methane as a future management option needs further analysis given the un-quantified volumes and Global Warming Potential (GWP) of this GHC.
Mamm Creek Field Policy Areas

THANK YOU
Slide #
2. Illustrates too high a cement top concern (choked off gas flow through channeled cement or when cement circulated to surface causing lost cement to LCZ) - possible gas diversion to prevent accurate Bradenhead monitoring
3. Broad conclusion statement specific to Schwartz well “Event”
4. COGCC Evaluation of Bradenhead Pressures (pie diagram)
5. Penoyer Marcellus Summit Poster illustrating gas migration pathways (2) from pervasive fracture system or fault zone when open annular present
6. Microseismic Monitoring Example of Williams Fork Frack Job
7. P3 Pad Remedial Cementing Activity (4 wells) due to Wasatch gas – EMCPA
8. Progression of EnCana Top of Cement vs APD’s through time
9. General Assertions of increasing Methane and Chloride impacts w/ gas development and rebuttal
10. 10–15. COGCC slides indicating Schwartz well was a unique overpressure event that led to Divide Creek seep of WF gas and that Wasatch stray gas is best managed through a variety of options that do not lead to water supply or aquifer impacts from methane or chlorides associated with gas development
COGCC Concern with too high Top of Cement

New Cement Requirements

Current Policy:
- Top of Production Casing Cement
- Mamm Creek Requirement: 500' above TOG

Potential for choked-off gas flow through channeled cement

NEW POLICY:
- Top of Production Casing Cement
- 200' above Mesa/Verde top or Ohio Creek top (if present)
- Adds several hundred feet of cement

Top of Gas (TOG)
- Williams Fork Producing Zone
- Williams Fork Producing Zone
- Production Casing
Conclusion: Insufficient production casing primary cement job w/ subsequent escape of Williams Fork (WF) gas was cause of the high bradenhead pressure – pre-completion TOG to TOC separation (82’) did not meet statewide standard of 200’. High BH pressure lasted several days between final frac stage (5) and until implementation of well remediation. Gas migrated up annulus and then borehole overpressure cause likely escaped through shallow fracture/joint system of Molina Sandstone and possibly Atwell Creek shale to daylight at West Divide Creek (seep).
## COGCC Evaluation of Bradenhead Pressure Data

<table>
<thead>
<tr>
<th>TOTAL WELLS</th>
<th>2867</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null value reported</td>
<td>40 (1%)</td>
</tr>
<tr>
<td>Zero pressure reported</td>
<td>1832 (64%)</td>
</tr>
<tr>
<td>1 psi to 74 psi</td>
<td>762 (27%)</td>
</tr>
<tr>
<td>75 psi to 149 psi</td>
<td>175 (6%)</td>
</tr>
<tr>
<td>150 psi or higher *</td>
<td>57 (2%)</td>
</tr>
</tbody>
</table>

* Based on detailed well-by-well reviews, 12 wells currently recommended for cement remediation, increased monitoring, or testing to evaluate potential remediation.

* Null value reported
* Zero pressure
* 1 psi to 74 psi
* 75 psi to 149 psi
* 150 psi or higher
THE HYDRAULIC FRACTURING PROCESS (HF): REAL CONCERN or MISDIRECTED FOCUS CONCERNING THREATS TO DRINKING WATER SUPPLIES (DWS)

Introduction

This author’s literature review, attendance at various hydraulic fracturing (HF) symposiums, forums, conferences, an EPA sponsored HF workshop on Fate & Transport and discussions with all of gas and regulatory agencies and industry representatives suggest there is a growing, if not already strong consensus among those who have performed objective analyses of the HF process, that the risk posed to potable aquifers or drinking water supplies (DWS) from the deep underground process of HF is now minuscule. Assessments of potential impacts range from “remote” (DOE 90 Day Report) to “do not present a reasonably foreseeable risk of significant adverse environmental impacts” (NYS SGEIS). Furthermore, multiple lines of evidence including the presence of stray gas, the physics of flow, fate and transport modeling and empirical evidence from thousands of frac jobs performed by industry in the last 60+ years without documented impacts to DWS indicate that further public focus on this issue is misdirected and simply unnecessary. It is often a challenge for experts to communicate complex concepts to the public to allay fears and concerns. Terms such as migration, inevitable water saturation, and capillary pressure effects and their underlying conceptual basis while critical to a technical understanding of why 70% to 90% of frac fluids remain unrecovered in flow back, also make it difficult to convey to the public why these residual frac fluids are highly unlikely to subsequently appear in a DWS. Residual frac chemicals are most likely to stick in rock zones of the target shale with no means of escape for periods possibly on a scale approaching that of geologic time. The public can reasonably appreciate the threat of direct impacts by methane gas to DWS and their contamination with other constituents from other mechanisms or processes. Direct impacts by HF fluids have not been documented and, documented pathways for this type of contamination do exist or have occurred, when an unencumbered annulus becomes over pressured. However, in most instances methane occurrence in DWS is still attributable to sources unrelated to gas development. When methane impacts from blown out gas develop, there are often too many roots to a problem: possible injection, water injection, poor cementing practices, etc. Some well designs practises can facilitate stray gas migration when site-specific geologic conditions, as depicted here, are not fully understood. Specifically, should shallow fractured bedrock extend below surface (bio-drainage) or intermediate (3-sting design) casing depths, higher risks for gas migration may be present. This poster illustrates two pathways for stray gas migration that may occur independently of each other, or operate in conjunction, to facilitate gas migration to a DWS when a 3-sting casing design with open annulus becomes over pressured. From a relative threat standpoint, a change in focus from potential hydraulic fracturing fluid impacts to DWS, to the real threat of stray gas migration, presents a need for better regulation and many operational improvements by industry, including frac chemicals disclosure, use of less-toxic (green) frac chemicals and greater transparency of overall operations, are key significant additional environmental gains in this area are likely to occur that further reduce risk in any appreciable manner from its already low state. Further, opponent arguments and concerns regarding impact to DWS from the hydraulic fracturing process appear increasingly without technical merit. In contrast, to frac fluids largely sequestered in the target formation, methane from non-fractured gas bearing zones is abundant and can be released as a phase in addition to dissolved phase, has a pathway that permits several thousand feet of cross-strata migration (open annulus above production casing cement) and a drive mechanism (buoyancy). Furthermore, methane from a deeper source (normal to very low ground pressures gas bearing geologic unit) often leads to overpressuring of casing and annular intervals at shallow depths (i.e. exceed hydrostatic conditions). Overpressuring is undesirable and mitigation/remediation can be problematic and costly or result in continuous venting of this potential GHG over a long period (e.g. (if well). Gas build up (overpressuring) of the annulus can also create the required gradient for stray gas to penetrate fractured bedrock through the open borehole well and move upward and around surface/intermediate casing strings of good integrity to reach a DWS. Earlier overpressure events (e.g. gas kicks) during the drilling and completion phase may also facilitate subsequent movement through shallow fractures from annular overpressuring by establishing a continuous gas phase in the fracture system.

Key Questions:
1. How accurate are these subsurface representations of stray gas migration, relative to frac fluids, and what are the reasonable pathways (shown or not shown)?
2. When an annulus becomes overpressured, can significant amounts of methane gas (enough to impact DWS) penetrate the borehole wall in the dissolved phase or only in the free gas phase (i.e. this requires sufficient overpressuring to drive the water level in the annulus below the intermediate casing seat or further downward than in the case above, so that free gas is opposite the borehole wall)?
3. If venting is the preferred management solution to prevent borehole annulus overpressuring from occurring, over what quantity of methane is being released to the atmosphere by this standard practice?
4. Given that frac fluids have not been documented to impact DWS (few pathways exist), while methane related to stray gas migration has been implicated in several cases (due to documented drive mechanism and a pathway), where are limited resources better spent?

Conclusions

Relative to HF fluids used in frac target gas shales, stray gas from non-targeted (noncommercial) gas bearing zones found above targeted gas is far more abundant, concentrated and mobile with much greater upward migration potential from the deep subsurface due to the buoyancy drive mechanism within an open borehole annulus. A thousand foot deep overpressured, open annular space between top of productive shales and competent surface or intermediate casing/shut-in/open most current well designs accepted by states and the BLM. Should an overpressured annulus develop from these gas sources and an open fractured/limited joint characteristics shallow bedrock that extends below surface or intermediate casing depths, this gas migration pathway to DWS is potentially significant. With the advent of unconventional shale resource plays, their expansive coverage, increased well densities and interacting with rural domestic wells, greater risk over the long term exists from non-annual overpressuring events or when wells are not vented. Migration of shallow source methane gas build up through vertical and lateral wellbores without technical merit. In contrast, to frac fluids largely sequestered in the target formation, methane from non-fractured gas bearing zones is abundant and can be released as a phase in addition to dissolved phase, has a pathway that permits several thousand feet of cross-strata migration (open annulus above production casing cement) and a drive mechanism (buoyancy). Furthermore, methane from a deeper source (normal to very low ground pressures gas bearing geologic unit) often leads to overpressuring of casing and annular intervals at shallow depths (i.e. exceed hydrostatic conditions). Overpressuring is undesirable and mitigation/remediation can be problematic and costly or result in continuous venting of this potential GHG over a long period (e.g. (if well). Gas build up (overpressuring) of the annulus can also create the required gradient for stray gas to penetrate fractured bedrock through the open borehole well and move upward and around surface/intermediate casing strings of good integrity to reach a DWS. Earlier overpressure events (e.g. gas kicks) during the drilling and completion phase may also facilitate subsequent movement through shallow fractures from annular overpressuring by establishing a continuous gas phase in the fracture system.

NOTES
1. 200’ for TOC in Figure 1A applies to maximum height above top of perforations in vertical or slant wells only (CAPP DWS)
2. Positive bioreal pressure range not to exceed 80% x hydrostatic pressure at depth of surface casing + 150 psi in the most pressured gas bearing formation.
3. per PA DEP: 500 psi @ 65% multi. 500 psi @ 75% multi. 500 psi @ 85% multi. 500 psi @ 150% multi.
4. Base of hydrocarbon zone (1000 mg/L, NVPE 300 mg/L, some other states, EPA and BLM (Order of Ranks)
5. Nitrogen spans decades, gas migration through transparent that can sometimes occur. These are related to a mechanically driven circumstance that form annular conductivity. They include micro annular flow between cement shoes and casing borehole wall or matrix permeably channeling when a plug or other cement and migration upward gas jets to occur. This may common in the GOM where shallow overpressured gas is the approach the open annular space. The short time frame may lead to accumulated annular casing pressure (MACP) that stray gas may also require venting.

Below Illustrations Modified From PA DEP and Shell Oil

Potential For Non-Targeted Shallow Gas Emissions. Condition similar to Figure on Left with Surface and Intermediate Casing String Intervals

Evidence that stray gas, its monitoring and its proper management is a concern in PA DEP

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Microseismic Monitoring Shows Frac Containment Within Target Zones

Plan view – frac azimuth is parallel to the maximum horizontal stress

Side view of the same frac treatment

From EPA HF Workshop, Feb. 2011 (Foreman)
P3 Pad activity 2003 – 2006

* Completions Activity
  * Arbaney 3-16C completed June 2003

* Remedial Cementing Activity
  * Procedures approved by COGCC (Jaime Adkins), 2004
  * Arbaney 3-16C, Arbaney 3-15C, Magic 10-1, and Magic 10-2 had elevated bradenhead pressure readings, all remediated Nov/Dec 2004
  * Arbaney 3-15C, Magic 10-1, and Magic 10-2 were remediated prior to completion, and a 3 3/4" liner was run to surface and cemented to protect squeeze holes
  * Magic 10-1A, no bradenhead pressure, no remediation required

Remediation of the Arbaney 3-15C Wellbore Diagram

- Bradenhead (internal surface casing) pressure
- Squeeze #2, 811
- Squeeze #1, 1240
- 3 1/2" production liner, TOC @ surface
- 4 1/2" production casing, TOC @ surface (post-remed)
- Top production Perforation @ 4142'

Remediation of the Arbaney 3-16C Wellbore Diagram

- 3 5/8" surface casing, set @ 910
- TOC @ surface
- Squeeze #1, 1600'
- Squeeze #2, 1500'
- Squeeze #3, 1700'
- Squeeze #4, 1500'
- 4 1/2" production casing, TOC @ surface (post-remed)
- Top production Perforation @ 4174'

Magic 10-1A Wellbore Diagram

- 5 3/4" surface casing, set @ 000'
- TOC @ surface
- 3 1/2" production casing, TOC @ surface
- 4 3/4" production casing, TOC @ surface
- Top production Perforation @ 4350'
- No bradenhead pressure observed
- No remediation performed
Figure 8 – Schlumberger chart showing the progression of top of cement compared to APD values from 2008 through 2010 for all EnCana wells in Piceance Basin. The y-axis represents the height of cement above the State-required TOC in feet.
General Assertions

Methane and chloride concentrations in groundwater (aquifers used for water supply) are increasing over time as the number of gas wells increase (Thyne, 2008). This is based largely on sampling of various water supply wells and a “perceived” trend of increasing methane. Implies increased methane detected in domestic wells is possibly from flow through natural fractures (may be some connectivity with fractures induced from HF) and/or the annulus of gas wells via escape of gas from the target formation (gas kicks during drilling/completion giving rise to over pressuring events) or more broadly, non-target stray gas from zones above the Williams Fork producing zones causing subsequent bradenhead pressure buildup.

**Opposing Arguments:**

1) Background methane value in groundwater used for comparison (1 mg/L) is not accurate or w/o support or technical basis. Many sampling variables affect establishment of an accurate methane baseline. Instances of natural background up to 3 mg/L suggested. Data is incomplete and statistics to support increasing temporal trend of methane and chloride is flawed.

2) There are other sources of Na-CL in the study area other than Williams Fork produced water and they were not acknowledged as alternate hypotheses (e.g. more saline Green River Fm in recharge areas to water supply intervals).

3) Explaining biogenic CH4 as being reduced CO2 gas from the Williams Fork Formation is not the most likely source and is disputed based on isotopic signature.
Schwartz 2-15B (O2) Well
Post-Remediation Observations and Former Moratorium Area

- Following the remedial cement job, bradenhead pressure decreased to zero.
- Gas discharge to West Divide Creek visibly decreased dramatically within 8 days of remediation, and benzene concentrations in West Divide creek decreased within 12 days.
- The post-remediation cement bond log showed good cement to surface.
- EnCana voluntarily agreed to cease drilling and completion operations within a 2-mile radius of the Schwartz 2-15B (O2) Well until new drilling and completion procedures could be developed.
Current Production Casing Cement Procedures

- EnCana currently does not permit wells with production casing cement to surface because of issues related to highly variable lost circulation zones and excess hydrostatic head. However, EnCana’s cement program is designed to circulate cement to 1,500 feet above the top of gas. This is a safety factor to account for a Mamm Creek field requirement to provide cement to 500 feet above the top of gas.

- For comparison, COGCC’s statewide standard (Rule 317.i.) requires production casing cement to 200’ above the shallowest known producing zone.
Mamm Creek Field Notice to Operators

- COGCC engineering staff currently regulate drilling and completion practices in the Mamm Creek field in accordance with COGCC’s rules and regulations.
- More stringent requirements for drilling and completion in the Mamm Creek Field are also required per the Notice to Operators Drilling MesaVerde Group or Deeper Wells in the Mamm Creek Field Area in Garfield County, Well Cementing Procedure and Reporting Requirements, July 23, 2004, Revised February 9, 2007.
- The 2-mile moratorium area was lifted in February 2007, following release of the Notice to Operators.
Mamm Creek Field Notice to Operators

Procedures

- Production casing cement required to 500 feet above top of gas.
- Production casing annular fluid monitoring and reporting for makeup volumes greater than 20 bbls to keep the annulus full.
- Cement bond logs and temperature logs required.
- Sundry Notice Request to Complete.
- Periodic post-cementing Bradenhead pressure monitoring.
- Remedial procedures (venting and/or remedial cement) and reporting for Bradenhead pressures greater than 150 psi.
- Bradenhead monitoring during fracture operations.

Colorado Oil & Gas Conservation Commission
East Mamm Creek Area

Procedures

- Surface casing setting depth must be 15 percent of the total vertical well depth or 500 feet below the total depth of any water well within a one-mile radius.
- Surface casing shoe formation integrity test (FIT) to 13.0 ppg equivalent mud weight.
- Intermediate casing must be set 50 feet below the MesaVerde Group top if the FIT fails.
- Choke pressure monitoring relative to FIT pressure.
- Daily (30 days) and monthly post cementing Bradenhead monitoring for 30 days.

Colorado Oil & Gas Conservation Commission
Mamm Creek Field
Bradenhead Venting – Monitoring and Reporting

- If Bradenhead pressures are reported above 150 psi, and the pressures can be bled down, then COGCC Staff will authorize a 90-day vent to atmosphere after submittal of a venting request on a Sundry Notice, per COGCC Rule 912.

- In order to provide historical comparisons, COGCC Staff has requested EnCana to shut wells in for a period of 7 days to determine if the pressure exceeds 150 psi.

- Depending on pressure measurements and observed flows, COGCC may require remedial cement work to mitigate high Bradenhead pressures.

Colorado Oil & Gas Conservation Commission