MINUTES OF THE REGULAR CITY COUNCIL MEETING
CITY OF COLLEGE STATION
DECEMBER 18, 2014

STATE OF TEXAS §
§
COUNTY OF BRAZOS §

**Present:**

Nancy Berry, Mayor

**Council:**

Blanche Brick
Steve Aldrich
Karl Mooney
John Nichols
Julie Schultz, via videoconference
James Benham

**City Staff:**

Kelly Templin, City Manager
Carla Robinson, City Attorney
Chuck Gilman, Deputy City Manager
Sherry Mashburn, City Secretary
Tanya McNutt, Deputy City Secretary

**Call to Order and Announce a Quorum is Present**

With a quorum present, the Regular Meeting of the College Station City Council was called to order by Mayor Berry at 7:37 p.m. on Thursday, December 18, 2014 in the Council Chambers of the City of College Station City Hall, 1101 Texas Avenue, College Station, Texas 77840.

1. **Pledge of Allegiance, Invocation, consider absence request.**

**Recognition of The Board of the Brazos Valley Groundwater Conservation District voted to award Apache Corp with a "Conservationist of the Year"**

Dave Coleman, Director of Water Services, introduced Alan Day, General Manager of the Brazos Valley Groundwater Conservation District, who presented the "2014 Groundwater Conservationist" award to the Apache Corporation.

**Citizen Comments**

Ben Roper, 5449 Prairie Dawn Court, came before Council to honor the service and sacrifice of Pvt. Robert L. Frantz.

Marty Allday, 2211 Norfolk #410, representing the Texas Chapter of Consumer Energy Alliance, read a prepared statement to the Council, attached.

Richard Woodward, 1001 Pershing Drive, spoke on behalf of Citizens for Safe Fracking. He presented a memorandum to Council, attached.

**CONSENT AGENDA**

2a. **Presentation, possible action, and discussion of minutes for:**
- **November 24, 2014 Workshop**
- **November 24, 2014 Regular Council Meeting**

2b. **Presentation, possible action, and discussion regarding approval of a contract between the City of College Station and National Field Services, Inc., in the amount of $305,419.86 for Annual Electric Substation Maintenance Labor Contract #15-039, which includes $254,516.55 in scheduled work and potential additional/miscellaneous repairs as specified in the bid, and an additional 20% not to exceed cost of $50,903.31 as a contingency for unforeseen emergency work.**

2c. **Presentation, possible action, and discussion on a construction contract with Gaeke Construction, in the amount of $242,868.50 for site work, electrical, water and wastewater utilities installation, and construction of a restroom facility at the Wolf Pen Creek Park Festival Site. Project Number WP 1401.**

2d. **Presentation, possible action, and discussion regarding the approval for purchase of new grounds maintenance equipment for the Parks and Recreation Department in the amount of $89,172.68.**

2e. **Presentation, possible action, and discussion regarding Ordinance 2014-3620, amending Chapter 11 of the City Code of Ordinances, by adding to Section 2(D)(3) a new rate class for commercial sewer customers who are not on the City's water supply.**

2f. **Presentation, possible action, and discussion regarding an annual purchase agreement for dewatering chemical (polymer) with Fort Bend Services, Inc. not to exceed $100,100.**

2g. **Presentation, possible action, and discussion regarding the purchase of mobile data terminals (MDTs) from Avinext for the not to exceed amount of $99,553.35.**

2h. **Presentation, possible action, and discussion on approving the Affordable Care Act mandated Transitional Reinsurance Fee due on January 15, 2015. The amount for this expenditures is $87,192.**

2i. **Presentation, possible action, and discussion on rejecting RFP 15-003 and approving projected health plan expenditures for the period of January 1, 2015 through December 31, 2015 and Resolution 12-18-14-2i, authorizing the City Manager to execute and approve all required contracts and subsequent expenditures related to the Employee Benefits Agreements. The projected amount for both the renewals and total projected expenditures is $8,326,981.**

2j. **Presentation, possible action, and discussion regarding approval of a 3-year agreement with Suddenlink for the purchase of their Internet Services in the amount of $50,400.**

2k. **Presentation, possible action, and discussion on a construction contract (Contract No. 14-422) with Angel Brothers Enterprises in the amount of $1,400,962.80 for the construction of the Rock Prairie Road Rehabilitation Project.**

2l. **Presentation, possible action, and discussion regarding Ordinance 2014-3621, amending Chapter 10, "Traffic Code," of the Code of Ordinances of the City of College Station, Texas, to prohibit u-turns on northbound Texas Avenue between University Drive and Cooner Street.**

2m. **Presentation, possible action, and discussion on a Memorandum of Understanding (MOU) between the Bryan/College Station Metropolitan Planning Organization (BCS MPO), the City of Bryan, the City of College Station, Brazos County, Texas A&M University and the Texas Department of Transportation regarding the Bryan/College Station Regional Bicycle and Pedestrian Infrastructure Coordination Program.**

2n. **Presentation, possible action, and discussion of proposed changes to the City's housing assistance programs funds with grants from the U. S. Department of Housing and Urban Development.**

**MOTION:** Upon a motion made by Councilmember Nichols and a second by Councilmember Benham, the City Council voted seven (7) for and none (0) opposed, to approve the Consent Agenda. The motion carried unanimously.

**REGULAR AGENDA**

1. **Public Hearing, presentation, possible action, and discussion regarding Ordinance 2014-3622, amending Chapter 12, "Unified Development Ordinance," Section 12-4.2, "Official Zoning Map," of the Code of Ordinances of the City of College Station, Texas by changing the zoning district boundaries from M-2 Heavy Industrial and GS General Suburban to PDD Planned Development District for approximately 36.86 acres being 36.86 acres in the Crawford Burnett League, A-7, College Station, Brazos County, Texas, and being the same called 14.58 acre tract of land conveyed to Cherokee Limited, recorded in Volume 323, Page 735, and the called 7.76 acre tract conveyed to Navajo Ltd.; as recorded in Vol. 337, Page 500, of the Brazos County Deed Records and the two tracts conveyed to Palomares Construction Co. called 12.58 acres, Tract 1, as recorded in Vol. 2508, Page 234, and all of called 2 acres, called Tract 2, as recorded in Vol. 2507, Page 180, of the Brazos County Official Records, located at 1800 Wellborn Road, and more generally located between Wellborn Road and Jones-Butler Road, north of Harvey Mitchell Parkway.**

Jennifer Prochazka, Planning and Development, reported that this request is to rezone the property from M-2 Heavy Industrial and General Suburban to Planned Development District for a multi-family residential development with modifications to development standards.

The Planning and Zoning Commission considered this item at their December 4, 2014 meeting and unanimously recommended approval with three conditions:

- Impacts of any floodplain alterations be contained within the subject property;
- Maximum density of 850 bedrooms permitted with this project; and
- Number of residents should not exceed the number of bedrooms in the project.

Staff also recommends approval with the above stated conditions.

At approximately 8:09 p.m., Mayor Berry opened the Public Hearing.

Veronica Morgan, Mitchell and Morgan Engineers, 3204 Earl Rudder Freeway, provided a short presentation on the project.

Jerome Rektorik, Planning and Zoning Commission, reported on the P&Z's discussion on this item and their recommended conditions.

There being no further comments, the Public Hearing was closed at 8:21 p.m.

**MOTION:** Upon a motion made by Councilmember Benham and a second by Councilmember Mooney, the City Council voted six (6) for and one (1) opposed, with Councilmember Brick voting against, to adopt Ordinance 2014-3622, amending Chapter 12, "Unified Development Ordinance," Section 12-4.2, "Official Zoning Map," of the Code of Ordinances of the City of College Station, Texas by changing the zoning district boundaries from M-2 Heavy Industrial and GS General Suburban to PDD Planned Development District for approximately 36.86 acres being 36.86 acres in the Crawford Burnett League, A-7, College Station, Brazos County, Texas, and being the same called 14.58 acre tract of land conveyed to Cherokee Limited, recorded in Volume 323, Page 735, and the called 7.76 acre tract conveyed to Navajo Ltd.; as recorded in Vol. 337, Page 500, of the Brazos County Deed Records and the two tracts conveyed to Palomares Construction Co. called 12.58 acres, Tract 1, as recorded in Vol. 2508, Page 234, and all of called 2 acres, called Tract 2, as recorded in Vol. 2507, Page 180, of the Brazos County Official Records, located at 1800 Wellborn Road, and more generally located between Wellborn Road and Jones-Butler Road, north of Harvey Mitchell Parkway. The motion carried.

**2. Public Hearing, presentation, possible action, and discussion regarding Ordinance 2014-3623, amending Chapter 12, "Unified Development Ordinance," Section 12-4.2, "Official Zoning Map," of the Code of Ordinances of the City of College Station, Texas by changing the zoning district boundaries from PDD Planned Development District and R Rural to PDD Planned Development District to amend the concept plan layout and uses for approximately 19.125 acres in the Samuel Davidson League, Abstract No. 13, College Station, Brazos County, Texas, being a remainder of a called 22.418 acre tract described as Tract One in a deed to Creek Meadows Partners, LP, as described in Volume 7633, Page 239; and 15.37 acres in the Samuel Davidson League, Abstract No. 13, College Station, Texas, being a portion of the remainder of a called 171.043 acre tract described as Tract One by a deed to Creek Meadows Partners, LP, recorded in Volume 7068, Page 220, of the Official Deed Records of Brazos County, Texas, located at 3850 Greens Prairie Road West, and more generally located near the entrance of Creek Meadows Subdivision at the intersection of Greens Prairie Road West and Creek Meadows Boulevard North.**

Jennifer Prochazka, Planning and Development, reported that Creek Meadows began development in the ETJ and is vested to the uses proposed at that time. This rezoning request would allow approximately 19 acres north of Greens Prairie Road West to develop as single-family (currently vested for multi-family), approximately 15.4 acres south of Greens Prairie Road West to develop as townhomes (currently vested to and zoned for duplexes). The density exchange will result in an overall reduction of 127 potential dwelling units in Sections 1C and 1A.

The Planning and Zoning Commission considered this item at their November 20, 2014 meeting and voted unanimously to recommend approval of the amendment with the condition that a uniform six-foot fence with design elements be constructed at the time of subdivision development on the northern and eastern property lines of the portion of the subject property located north of Greens Prairie Road West. Staff recommends approval as well.

At approximately 8:56 p.m., Mayor Berry opened the Public Hearing.

Lisa Cantrell, 15097 Turnberry, lives adjacent to the subject property. There are eight units in the Turnberry HOA. They have concerns about drainage from this property.

Veronica Morgan, Mitchell and Morgan Engineers, 3204 Earl Rudder Freeway, provided a short presentation on the project. The applicant has agreed to the fence.

There being no further comments, the Public Hearing was closed at 8:59 p.m.

**MOTION:** Upon a motion by Councilmember Mooney and a second by Councilmember Benham, the City Council voted seven (7) for and none (0) opposed, to adopt Ordinance 2014-3623, amending Chapter 12, "Unified Development Ordinance," Section 12-4.2, "Official Zoning Map," of the Code of Ordinances of the City of College Station, Texas by changing the zoning district boundaries from PDD Planned Development District and R Rural to PDD Planned Development District to amend the concept plan layout and uses for approximately 19.125 acres in the Samuel Davidson League, Abstract No. 13, College Station, Brazos County, Texas, being a remainder of a called 22.418 acre tract described as Tract One in a deed to Creek Meadows Partners, LP, as described in Volume 7633, Page 239; and 15.37 acres in the Samuel Davidson League, Abstract No. 13, College Station, Texas, being a portion of the remainder of a called 171.043 acre tract described as Tract One by a deed to Creek Meadows Partners, LP, recorded in Volume 7068, Page 220, of the Official Deed Records of Brazos County, Texas, located at 3850 Greens Prairie Road West, and more generally located near the entrance of Creek Meadows Subdivision at the intersection of Greens Prairie Road West and Creek Meadows Boulevard North. The motion to amend carried unanimously.

**3. Public Hearing, presentation, possible action, and discussion regarding Ordinance 2014-3624, amending Chapter 12, "Unified Development Ordinance," related to the creation and amendment of multi-family residential and mixed-use zoning districts.**

Jennifer Prochazka, Planning and Development, reported that Staff has worked with a sub-committee of the Planning and Zoning Commission to develop the concepts and language for the proposed "MF Multi-Family" and "MU Mixed-Use" districts based on direction in the Comprehensive Plan and input from stakeholder groups. The City's existing multifamily districts, "R-4 Multi-Family" and "R-6 High Density Multi-Family," are proposed to be "retired" with the amendment. Retired districts remain active for those properties with the zoning designations, but may not be requested to be applied to other properties in the future.

At approximately 9:07 p.m., Mayor Berry opened the Public Hearing.

There being no comments, the Public Hearing was closed at 9:07 p.m.

**MOTION:** Upon a motion made by Councilmember Nichols and a second by Councilmember Benham, the City Council voted seven (7) for and none (0) opposed, to adopt Ordinance 2014-3624, amending Chapter 12, "Unified Development Ordinance," related to the creation and amendment of multi-family residential and mixed-use zoning districts. The motion carried unanimously.

**4. Public Hearing, presentation, possible action, and discussion regarding Ordinance 2014-3625, amending Chapter 12, "Unified Development Ordinance," Section 12-4.2, "Official Zoning Map," of the Code of Ordinances of the City of College Station, Texas, by changing the zoning district boundaries from R Rural to GS General Suburban for approximately 1 acre being Lots 8, 9, and 10, Block 2, Needham Estates as recorded in volume 276, page 301 of the Official Records of Brazos County, Texas, generally located at 2468 Barron Road, more generally located at the northwest corner of Renee Lane and Barron Road.**

Jessica Bullock, Planning and Development, reported that this request is to rezone the property from Rural to General Suburban.

The Planning and Zoning Commission considered this item at their November 20, 2014 meeting and voted 5-0 to recommend approval of the rezoning. Staff also recommends approval.

At approximately 9:10 p.m., Mayor Berry opened the Public Hearing.

There being no comments, the Public Hearing was closed at 9:10 p.m.

**MOTION:** Upon a motion made by Councilmember Aldrich and a second by Councilmember Benham, the City Council voted seven (7) for and none (0) opposed, to adopt Ordinance 2014-3625, amending Chapter 12, "Unified Development Ordinance," Section 12-4.2, "Official Zoning Map," of the Code of Ordinances of the City of College Station, Texas, by changing the zoning district boundaries from R Rural to GS General Suburban for approximately 1 acre being Lots 8, 9, and 10, Block 2, Needham Estates as recorded in volume 276, page 301 of the Official Records of Brazos County, Texas, generally located at 2468 Barron Road, more generally located at the northwest corner of Renee Lane and Barron Road. The motion carried unanimously.

**5. Public Hearing, presentation, possible action and discussion of Ordinance 2014-3626, amending Chapter 10, "Traffic Code", Section 4 "Administrative Adjudication of Parking Violations", E "Parking Regulations of Certain Described Areas", (1) "Traffic Schedule XIV - No Parking Here to Corner or No Parking Anytime to remove stopping, standing, and parking along Regal Row and Castlebrook Drive.**

Donald Harmon, director of Public Works, reported that citizens contacted the City of College Station concerned about the loading and unloading of College Station Middle School students along Regal Row and Castlebrook Drive. A primary concern was the ability to see pedestrians crossing the street at the intersection of Regal Row and Castlebrook Drive. An additional concern was the ability for emergency vehicles to respond to emergencies along Regal Row during school pick-up and drop-off periods. Based upon the observations of the fire department, police department, and traffic engineering, the City presented a no stopping, standing, or parking ordinance to the residents along Regal Row and Castlebrook Drive. At the public meeting on November 24, 2014, organized by the Williams Court Homeowner's Association, 15 residents were in support of this ordinance. There were zero residents in attendance that opposed this ordinance. Based upon the need for emergency vehicle access and the need to see pedestrians at the intersection of Regal Row and Castlebrook Drive for their safety, the traffic management team recommends approving this ordinance.

Staff also recommends approval of the ordinance amendment.

At approximately 9:12 p.m., Mayor Berry opened the Public Hearing.

There being no comments, the Public Hearing was closed at 9:12 p.m.

**MOTION:** Upon a motion made by Councilmember Benham and a second by Councilmember Mooney, the City Council voted seven (7) for and none (0) opposed, to adopt Ordinance 2014-3626, amending Chapter 10, "Traffic Code", Section 4 "Administrative Adjudication of Parking Violations", E "Parking Regulations of Certain Described Areas", (1) "Traffic Schedule XIV - No Parking Here to Corner or No Parking Anytime to remove stopping, standing, and parking along Regal Row and Castlebrook Drive. The motion carried unanimously.

**6. Presentation, possible action, and discussion regarding appointments to the Capital Improvement Program 2015 Bond Citizen Advisory Committee.**

Aubrey Nettles, Assistant to the City Manager, reported that the Capital Improvement Program Citizen Advisory Committee will help identify and prioritize potential capital improvement projects that will be undertaken by the City through a voter approved bond issue to be placed on the November 2015 ballot. The committee will have 23 members, who will compose three sub-committees: facilities, transportation, and parks.

Appointments were as follows:

*Chair:* Penrod Thornton
*Co-chair:* William Smith
*Facilities:* Gary Ives, William Lartigue, Jr., Kevin McGinnis, Jeffrey Raisor, Rene Ramirez, Thomas Taylor; James Watson
*Transportation:* James Batenhorst, Tedi Ellison, Mark Green, Linda Harvell, Brittan Johnson, Ronald Kaiser, Beverly Kuhn
*Parks:* Marc Chalupka, Jon Denton, Sherry Ellison, Don Hellriegel, Keith Roberts, Chris Scotti, Dan Stribling

7. **Presentation, possible action, and discussion regarding the appointment of Councilmember to boards and commissions.**

This item was postponed to the first January meeting.

8. **Adjournment.**

**MOTION:** There being no further business, Mayor Berry adjourned the Regular Meeting of the City Council at 9:35 p.m. on Thursday, December 18, 2014.

Nancy Berry, Mayor

ATTEST:

Sherry Mashburn, City Secretary

CITY OF COLLEGE STATION
*Home of Texas A&M University®*

**College Station City Council Regular Agenda**
**Sign In Sheet**
**Thursday, December 18, 2014 at 7:00 p.m.**
**City Hall Council Chamber**



| | Name | Address | Email or Phone No. |
|---|---|---|---|
| 1. | Kerry Pillow | 3204 Earl Rudder Fwy S | 979-260-6963 |
| 2. | Veronica Morgan | 3204 Earl Rudder Fwy S | 979-260-6963 |
| 3. | JASON DOORNBOS | 455 EPPS BRIDGE PKWY | 706-543-1901 |
| 4. | Lisa Cantrell | 15097 Turnberry, CS 77845 | lpcantrell@gmail.com. |
| 5. | Adrian D Vigel | 2218 Rain Tree DR., CS 77845 | |
| 6. | Gwen Rougas | 3417 Regal Row CS 77845 | gwenrougas@gmail.com |
| 7. | CLINT [illegible] | 1700 [illegible] | [illegible] |
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| 15. | | | |

*****Note this not a Hear Visitors form*** To speak on a particular item please file out the Citizen Speakers Form next to sign in sheet.**

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# CITIZEN COMMENT SIGN-UP FORM

**Regular Meeting Date:** 12/18/14
MM / DD / YY

*** Please PRINT all information ***

**Name:** Ben Roper **Phone:** 979-777-0382

**Address:** 5449 Prairie Dawn Ct, College Station

**Email:** broper0001@hotmail.com **Comments:** [ ] WRITTEN [X] ORAL

**Comments are presented for:** [X] HEAR VISITORS [ ] AGENDA ITEM # ______

**FOR WRITTEN COMMENTS, PLEASE WRITE BELOW:**

[ ] COMMENTS CONTINUED ON ATTACHED DOCUMENT OF _____ PAGE(S)

## FOR ORAL COMMENTS:

1. YOU MUST SIGN UP PRIOR TO THE SCHEDULED MEETING
*(At the City Secretary's Office during regular business hours, or from 5:00 p.m. to 6:45 p.m. the day of the meeting.);*
2. YOU WILL HAVE ONE OPPORTUNITY TO SPEAK; AND
3. YOU MUST OBSERVE THE 3-MINUTE TIME LIMIT. *(Time cannot be transferred to another speaker.)*

Inquiries from speakers about matters not listed on the agenda will either be directed to the Staff or placed on a future agenda for Council consideration. **See reverse side for additional rules**.

## MAIL, FAX OR EMAIL COMPLETED FORM TO:

City of College Station
City Secretary's Office – City Hall
1101 Texas Avenue, College Station, Texas 77840
Fax: 979-764-6377
Email: smashburn@cstx.gov

OFFICE USE ONLY:
(# in which received)
1

# RULES FOR PUBLIC COMMENTS AT CITY COUNCIL MEETINGS

CITY OF COLLEGE STATION
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**Public Comments:** The City Council welcomes written and oral comments from the public at regular meetings. Individuals wishing to speak must sign in at the City Secretary's Office at City Hall during regular business hours, or from 5:00 p.m. to 6:45 p.m. the day of the meeting. Speakers who have not registered by 6:45 p.m. may be allowed to speak after first registering with the City Secretary before the Hear Visitors period is finished or the agenda item has been finished. Speakers will have one opportunity to speak during the time period, and they must observe the three-minute time limit. Time cannot be transferred. When a speaker yields the floor, he/she waives their remaining time, but that remaining time does not get added to another speaker's time.

**Written Comments / Handouts / PowerPoint:** Individuals may use the comment sheets provided in the City Secretary's Office at City Hall. Comment sheets submitted to the City Secretary by 6:45 p.m. on the day of the Council meeting will be copied and distributed to the Council Members. An individual who wishes to submit other written material should submit 10 copies to the City Secretary for distribution to Council Members and senior staff. Individuals wishing to provide a PowerPoint presentation must submit the presentation to the City Secretary's office no later than noon the day of the meeting. This will allow staff time to review any type of video or PowerPoint to determine appropriateness for display at a public meeting, and to give the IT department enough time to check the files or CDs to make sure that there are no viruses prior to loading on the City computers.

**Hear Visitors Period:** The Hear Visitors section is set aside during Regular Meetings in order to give the public the opportunity to speak on City-related matters **not** covered by the agenda. However, no formal action will be taken on any matters not listed on the agenda. The response of the Council to any comment under this heading is limited to making a statement of specific factual information in response to the inquiry, or reciting existing policy in response to the inquiry. Any deliberation of the issue is limited to a proposal to place it on the agenda for a later meeting.

**Consent and Regular Agenda Items:** At the discretion of the Mayor, individuals may be allowed to speak on either a Consent or Regular Agenda item. Individuals who wish to address the Council on either a Consent or Regular agenda item shall register with the City Secretary during regular business hours, or from 5:00-6:45 p.m. the day of the meeting. Speakers who have not registered by 6:45 p.m. may be allowed to speak after first registering with the City Secretary. Speakers will have one opportunity to speak during the time period, and they must observe the three-minute time limit. Time cannot be transferred. When a speaker yields the floor, he/she waives their remaining time, but that remaining time does not get added to another speaker's time. Comments on the agenda items must be made when the agenda item comes before the Council.

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**Rules for Speakers:**

1. Members of the public may address the City Council at the following times during a meeting:
   - During Hear Visitors Period, if such a period is on the agenda for the meeting.
   - During a public hearing on an agenda item.
   - During Consent and Regular Agenda items with the permission of the presiding officer.
   - During Work Study Agenda items with the permission of the presiding officer.

2. Speakers must state their name and address for the record.
3. Speakers must address all comments and questions to the presiding officer.
4. Speakers must limit their comments to three minutes.
5. Speakers may not employ tactics of defamation, intimidation, personal affronts, profanity, or threats of violence.

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# CITIZEN COMMENT SIGN-UP FORM

**Regular Meeting Date:** 12/18/14
MM / DD / YY

*** Please PRINT all information ***

**Name:** Marty Allday **Phone:** 713 201 5434

**Address:** 2211 Norfolk, #410, Houston, Tx 77098

**Email:** mallday@consumerenergyalliance.org **Comments:** ☑ WRITTEN ☑ ORAL

**Comments are presented for:** ☑ HEAR VISITORS ☐ AGENDA ITEM # ______

**FOR WRITTEN COMMENTS, PLEASE WRITE BELOW:**

☐ COMMENTS CONTINUED ON ATTACHED DOCUMENT OF ______ PAGE(S)

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3. Speakers must address all comments and questions to the presiding officer.
4. Speakers must limit their comments to three minutes.
5. Speakers may not employ tactics of defamation, intimidation, personal affronts, profanity, or threats of violence.

CONSUMER ENERGY ALLIANCE
THE VOICE OF THE ENERGY CONSUMER

2211 Norfolk Street, Suite 410
Houston, Texas 77098
P 713 337 8800

**Remarks by Marty Allday**
**Executive Director of Consumer Energy Alliance-Texas (CEA-TX)**
**City Council of College Station, Texas Regular Meeting**
**Thursday, December 18, 2014**

My name is Marty Allday, and I am here representing the Texas Chapter of Consumer Energy Alliance, or CEA. CEA's business address is 2211 Norfolk, Suite 410, Houston, TX 77098. CEA is a nationwide association of energy consumers who advocate in support of balanced energy policies that facilitate affordable, reliable energy. We are active in 20 states and represent over 250 company and association members and more than 400,000 individual members, including more than 30,000 here in Texas. I serve as the Executive Director of CEA-Texas.

CEA represents the Voice of the Energy Consumer. We give a voice to energy consumers both large and small, ranging from large petrochemical facilities along the Gulf Coast to small and medium-sized businesses, all of whom depend on balanced energy policies to meet payrolls, hire new employees, and grow the local economy, and some of whom count energy companies among their most significant customers.

We represent bakers, electricians, and candlestick makers in small communities across Texas and America that, until recently, were dependent on maintaining purchase orders from a limited customer base just to stay alive, but thanks to the shale boom are now seeing dramatic growth that is benefitting their businesses. We represent the shopkeeper who reports a boost in sales in the wake of new service companies relocating to her small town.

We also represent the parent driving car pool who is grateful this year (thanks to lower fuel costs) to have an estimated extra $500 to spend on Christmas presents or put away in college savings account in the hopes of sending their child perhaps to Texas A&M, where the child might hope to earn an engineering degree that will allow them to work in a career in energy earning wages that rank among the highest in the nation.

On a larger scale, shale oil and natural gas development is leading to a rebirth of American manufacturing from coast to coast, and especially along the Gulf Coast, where petrochemical manufacturing firms are returning to the US to be near North America's renewed energy abundance. Old plants are being expanded and new plants are being built, bringing tremendous benefits to the nonresidential construction sector. None of this would be happening — none of it would be possible — were it not for the shale revolution.

The City of College Station is to be commended for facing the challenge of modernizing your city ordinances to keep pace with the State of Texas' resurgent role as a global leader in energy production. In doing so, CEA would urge you to move cautiously and also take into consideration the broader economic renaissance that many Texas communities are enjoying because of shale development. Shale energy is THE economic driver for Texas and an energy resource for the entire county, and can help bring jobs and new tax revenues to fund schools and infrastructure in this community. We understand that managing energy development in an urban environment presents some challenges that may seem new to many, yet we also know that industry can meet high standards that address health, safety, and environmental concerns AND deliver to the community of College Station the significant and well-documented benefits that come along with energy development. We hope that is your view as well.

CITY OF COLLEGE STATION
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# CITIZEN COMMENT SIGN-UP FORM

**Regular Meeting Date:** 12/18/14
MM / DD / YY

*** Please PRINT all information ***

**Name:** Richard Woodward **Phone:** 979-703-6470

**Address:** 1001 Pershing Dr.

**Email:** rtwoodward@gmail.com **Comments:** ☑ WRITTEN ☑ ORAL

**Comments are presented for:** ☑ HEAR VISITORS ☐ AGENDA ITEM # ______

**FOR WRITTEN COMMENTS, PLEASE WRITE BELOW:**

☐ COMMENTS CONTINUED ON ATTACHED DOCUMENT OF ____ PAGE(S)

## FOR ORAL COMMENTS:

1. YOU MUST SIGN UP PRIOR TO THE SCHEDULED MEETING *(At the City Secretary's Office during regular business hours, or from 5:00 p.m. to 6:45 p.m. the day of the meeting.);*
2. YOU WILL HAVE ONE OPPORTUNITY TO SPEAK; AND
3. YOU MUST OBSERVE THE 3-MINUTE TIME LIMIT. *(Time cannot be transferred to another speaker.)*

Inquiries from speakers about matters not listed on the agenda will either be directed to the Staff or placed on a future agenda for Council consideration. **See reverse side for additional rules**.

## MAIL, FAX OR EMAIL COMPLETED FORM TO:

City of College Station
City Secretary's Office – City Hall
1101 Texas Avenue, College Station, Texas 77840
Fax: 979-764-6377
Email: smashburn@cstx.gov

OFFICE USE ONLY:
(# in which received)
3

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# RULES FOR PUBLIC COMMENTS AT CITY COUNCIL MEETINGS

**Public Comments:** The City Council welcomes written and oral comments from the public at regular meetings. Individuals wishing to speak must sign in at the City Secretary's Office at City Hall during regular business hours, or from 5:00 p.m. to 6:45 p.m. the day of the meeting. Speakers who have not registered by 6:45 p.m. may be allowed to speak after first registering with the City Secretary before the Hear Visitors period is finished or the agenda item has been finished. Speakers will have one opportunity to speak during the time period, and they must observe the three-minute time limit. Time cannot be transferred. When a speaker yields the floor, he/she waives their remaining time, but that remaining time does not get added to another speaker's time.

**Written Comments / Handouts / PowerPoint**: Individuals may use the comment sheets provided in the City Secretary's Office at City Hall. Comment sheets submitted to the City Secretary by 6:45 p.m. on the day of the Council meeting will be copied and distributed to the Council Members. An individual who wishes to submit other written material should submit 10 copies to the City Secretary for distribution to Council Members and senior staff. Individuals wishing to provide a PowerPoint presentation must submit the presentation to the City Secretary's office no later than noon the day of the meeting. This will allow staff time to review any type of video or PowerPoint to determine appropriateness for display at a public meeting, and to give the IT department enough time to check the files or CDs to make sure that there are no viruses prior to loading on the City computers.

**Hear Visitors Period**: The Hear Visitors section is set aside during Regular Meetings in order to give the public the opportunity to speak on City-related matters **not** covered by the agenda. However, no formal action will be taken on any matters not listed on the agenda. The response of the Council to any comment under this heading is limited to making a statement of specific factual information in response to the inquiry, or reciting existing policy in response to the inquiry. Any deliberation of the issue is limited to a proposal to place it on the agenda for a later meeting.

**Consent and Regular Agenda Items:** At the discretion of the Mayor, individuals may be allowed to speak on either a Consent or Regular Agenda item. Individuals who wish to address the Council on either a Consent or Regular agenda item shall register with the City Secretary during regular business hours, or from 5:00-6:45 p.m. the day of the meeting. Speakers who have not registered by 6:45 p.m. may be allowed to speak after first registering with the City Secretary. Speakers will have one opportunity to speak during the time period, and they must observe the three-minute time limit. Time cannot be transferred. When a speaker yields the floor, he/she waives their remaining time, but that remaining time does not get added to another speaker's time. Comments on the agenda items must be made when the agenda item comes before the Council.

**Public Hearings:** Registering to speak at a Public Hearing is the same as for a regular agenda item. After a Public Hearing is closed, there shall be no additional public comments. If Council needs additional information from the general public, some limited comments may be allowed at the discretion of the Mayor.

**Rules for Speakers:**

1. Members of the public may address the City Council at the following times during a meeting:
   - During Hear Visitors Period, if such a period is on the agenda for the meeting.
   - During a public hearing on an agenda item.
   - During Consent and Regular Agenda items with the permission of the presiding officer.
   - During Work Study Agenda items with the permission of the presiding officer.

2. Speakers must state their name and address for the record.
3. Speakers must address all comments and questions to the presiding officer.
4. Speakers must limit their comments to three minutes.
5. Speakers may not employ tactics of defamation, intimidation, personal affronts, profanity, or threats of violence.

**MEMORANDUM**

TO: City of College Station Staff and Council

FROM: College Station Citizens for Safe Fracking

DATE: December 18, 2014

SUBJECT: Revisions to College Station oil and gas ordinance

College Station Citizens for Safe Fracking is concerned about the quality of life in our city and the potential adverse impacts of oil and gas development within the city. We request that Council members and staff revise the relevant proposed ordinance to protect the health and welfare of the city's residents. In the attached findings, we provide evidence supporting a strong ordinance in regards to air quality, setbacks, and noise. While there are numerous minor changes that we believe should be made in the ordinance, we believe two are of overriding importance:

- Establish setback provisions of 1,500 feet from residences, schools, health care facilities, playgrounds, and places of worship;
- Require continuous on-site fence-line monitoring of air quality and noise levels to ensure the health and safety of nearby residences per state and Federal standards.

It is important to recognize that while hydraulic fracturing in some form has been around for many years, the type of hydraulic fracturing used for tight gas and shale gas wells that is prevalent today is a new phenomenon, particularly in our area. This form of hydraulic fracturing uses massive amounts of water and chemicals and creates enormous streams of waste.

Because this process is so new, the scientific understanding of how the process creates risks to human health and safety is still in its early stages. The evidence that does exist is troubling, indicating a wide range of serious consequences including detrimental impacts on health, air quality and water quality. Hence, we urge the city to take a precautionary approach, instituting restrictions designed to mitigate, to the extent practicable, adverse impacts resulting from all aspects of extraction and transmission of hydrocarbons. Should scientific evidence and/or engineering expertise evolve in such a way that convinces the Council that drilling can be safely done within the city, standards might be relaxed in the future. It is much more difficult and costly to make changes in the other direction.

Further, we urge that regulations adopted with explicit recognition of the potentially affected parties in a way that empowers citizens to monitor and enforce the provisions of the relevant ordinance. Hence, air quality and noise standards should be set at the fence line. Referring citizens to the Texas Commission on Environmental Quality is not a substitute for responsible local governance of environmental risks. Numerous conflicts in Texas have developed because of lack of data on air quality. Therefore, objective data would provide assurances to oil or gas operators, city officials, and citizens regarding air quality standards.

College Station has the reputation of an attractive place to live, bolstered by low traffic, clean air, and a healthy environment. We urge the city to be proactive by taking every feasible step to maintain the quality of life residents enjoy and have come to expect.

Clear rules regarding location of oil and gas extraction will provide transparency needed for College Station citizens and oil and gas firms interested in obtaining mineral resources in ways that do not endanger public health and safety. A strong ordinance should aim to do three things: improve the social license of oil and gas firms to operate; shield city officials from frivolous complaints and unscrupulous oil and gas firms; and protect the health and safety of College Station residents. This memorandum outlines provisions that will help accomplish these three goals.

# Scientific Understanding of Health Impacts of Hydraulic Fracturing

**Summary**
Mounting scientific evidence indicates that hydraulic fracturing is associated with a wide range of risks, even if the literature is in early stages. A 2010 TCEQ memorandum revealed that benzene levels above the long term health based comparison value (> 1.4 ppb) had been detected at 21 monitoring sites in 12 different areas. McKenzie et al. (2012) concluded that "Residents living ≤½ mile from wells are at greater risk for health effects from NGD [natural gas development] than are residents living >½ mile from wells", and rapid growing number of studies detecting similarly high ambient air pollutant concentrations than those the McKenzie et al. conclusions were based upon have since been published. While definitive epidemiological evidence connecting hydraulic fracturing with health risks is still lacking, there is sufficient evidence to conclude there is a high probability of significant health risks and, therefore, sufficient evidence to justify a protective regulation of these activities. A recent review of the peer-reviewed literature completed by Physicians Scientists & Engineers for Healthy Energy found only 15 original public health studies on these issues, all published since 2011, and all but two of those studies found potential risks or adverse health outcomes, further vetted by other public health experts through an additional approximately 30 publications.

**Selected quotes**
"Shale gas is developed using high-volume, horizontal, hydraulic fracturing (HVHF). HVHF includes the drilling and hydraulic fracturing events as well as the ancillary infrastructure required for the entire process. Data suggest that this process poses substantial risk to public health. However, the science and epidemiology is incomplete and more research is needed to adequately understand the public health dimensions of shale gas development and HVHF."
Physicians, Scientists, and Engineers for Healthy Energy 2012. "Public Health Dimensions of Shale Gas Development."

"…more than half of the articles on health risks and outcomes have been published since 2013."
Letter from Seth B. Shonkoff, PhD, MPH to Nirav R. Shah, Commissioner, New York State Department of Health

"There is evidence that shale and tight gas development is associated with pollution that is known to increase public health risks. Additionally, there is much more that we don't know. Scientific investigations are hampered by limitations on monitoring, reporting, and disclosure requirements of compounds and processes associated with oil and gas development."
Seth B. Shonkoff http://www.psehealthyenergy.org/data/PSE_Press_Release_4.10_.14_Final_.pdf

*The following quotes are taken from a story about a recent OSHA presentation at a conference in Houston, "Feds warn of danger from well-site chemicals" Mike Soraghan, EnergyWire, December 4, 2014*

- "Everybody we talked to said they'd experienced lightheadedness or weakness in the knees, or it had happened to someone they knew," said Todd Jordan, director of the Occupational Safety and Health Administration's Health Response Team. "That's something that can't be dismissed."
- "Public health officials have said they'd like to know more about the effect of the volatile compounds on people who live and work near oil and gas wells. But worker safety researchers said they don't even have enough data for work sites, much less broader exposures."

**Sources**

TCEQ Interoffice Memo Jan . 27, 2010, "Health Effects Review of Barnett Shale Formation Area Monitoring Projects" and Sadlier & Honeycutt, "TCEQ Barnett Shale Update" 2010
http://www.tceq.state.tx.us/assets/public/implementation/barnett_shale/2010.01.27-healthEffects-BarnettShale.pdf

**Peer-Reviewed Sources**

A list of articles on this topic is included in the Appendix of the report, "Towards an understanding of the environmental and public health impacts of shale gas development: an analysis of the peer-reviewed scientific literature, 2009-2014," which is attached to this memorandum.

# Precedents for Air Quality Provisions in Texas

**Summary**
We reviewed provisions in the oil and gas ordinances of Dallas, Southlake, and Flower Mound to identify precedent regulation of air emissions that provide a means of protecting city residents from harmful airborne pollutants. For the most part, air quality standards are set by the TCEQ and are, therefore, not under the jurisdiction of the city. However, all three cities have requirements that the operator provide on-site monitoring to ensure that air quality standards are satisfied. Given the potential for severe short term violations and the fact that air pollutants disperse quickly, we believe that continuous on-site monitoring should be required for all operators within the city. Dallas and Southlake also require baseline air quality testing prior to drilling.

**Southlake** (http://www.cityofsouthlake.com/index.aspx?NID=905)
***Air Quality Testing*** To ensure that the overall air quality impact to the City is minimized and that future air impact from operations do not exceed regulatory criteria on or off the drill site the City will direct the following air quality activities

1 Baseline Air testing Prior to any disturbance of the drill site the City will conduct a Baseline Air Survey over a 48 hour period At a minimum the sampling will include evaluation on benzene, toluene, ethylbenzene, xylenes, ozone, nitrogen oxides, sulfur dioxides, and formaldehyde The operator may conduct independent sampling during the evaluation period or be present during testing if desired

2 Continuous Air Monitoring: Continuous air monitoring is required immediately following the commencement of fracturing and must be maintained until all wells are abandoned. Two monitors will be placed at the site to allow a general evaluation of the possible upwind and downwind portions of the drill site The location of the continuous monitoring equipment will be discussed with the operator representative prior to installation The system may include either a static auto gas chromatograph fence line monitoring system or equivalent as approved by City Council or delegated City staff. At a minimum monitoring will include evaluation of benzene, toluene, ethylbenzene, xylenes, ozone, nitrogen oxides, sulfur dioxides, and formaldehyde Alteration to the monitoring approach to accommodate specific compounds may be considered by the City as appropriate The data will be made available to the public via either a dedicated website or direct incorporation with the Texas Commission on Environmental Quality air monitoring network as applicable

(tt) Thermal Oxidizer: A thermal oxidizer shall be required at times deemed necessary by the city inspector or consultant

(zz) Hydrogen Sulfide If a gas or oil field in the city is identified as a Hydrogen Sulfide field or if a well is producing Hydrogen Sulfide, $H_2S$, gas the operator shall immediately cease operation of that well or facility

**Dallas** (http://www.ci.dallas.tx.us/cso/resolutions/2013/12-11-13/13-2139.PDF)
(p. 28-32) Permit applications. … shall provide the following information on a form furnished by the city:..

(19) an air quality management and monitoring plan that includes:

(A) measures and equipment the operator will use to ensure that all site activities and equipment on the operation site comply with applicable emissions limits, applicable laws relating to emissions and best management practices of the Environmental Protection Agency and the Texas Commission on Environmental Quality;
(B) monitoring techniques the operator will use to measure for and ensure compliance with applicable emissions limits and all applicable laws relating to emissions; and
(C) a categorization of Environmental Protection Agency Tier (Tier 0 to 4) of all diesel equipment that will be used on the operation site during each phase of the drilling and production use;

(p. 51) (f) Environmental requirements…

(2) Air quality
(A) Gases vented or burned.
(i) Except as permitted by the Texas Railroad Commission and the fire marshal, the operator shall not vent gases into the atmosphere or burn gases by open flame.
(ii) At no time may a well flow or vent directly into the atmosphere without first directing the flow through separation equipment or into a portable tank.
(iii) If venting or burning of gases is permitted, the vent or open flame must be located at least 300 feet from any structure that is necessary to the everyday operation of wells.
(B) Reduced emissions.
(i) Internal combustion engines and compressors, whether stationary or mounted on wheels, must be equipped with an exhaust muffler or comparable device that suppresses noise and disruptive vibrations and prevents the escape of gases, fumes, ignited carbon, or soot.
(ii) After fracturing or re-fracturing is completed. the operator must employ appropriate equipment and processes as soon as practicable to minimize natural gas and associate vapor releases into the environment.
(iii) All salable gas must be directed to a sales line as soon as practicable or shut in and conserved.
(iv) All wells that have a sales line must employ reduced-emission completion techniques unless the gas inspector determines that reduced-emission completion techniques are not feasible or would endanger the safety of personnel or the public.
(v) Vapor recovery equipment is required in accordance with state and federal rules and regulations.

(C) Emissions compliance.
(i) If an operation site receives two or more notices of violation for emissions or air quality violations during any 12 month period, as determined by the Texas Commission on Environmental quality or the Environmental Protection Agency, within 30 days after receiving the second notice, the operator shall submit to the gas inspector an emissions compliance plan.
(ii) The emissions compliance plan must include:
(aa) 24-hour monitoring techniques the operator will use to demonstrate that the operation site complies with applicable emissions limits and all applicable laws relating to emissions;
(bb) activities and equipment the operator will immediately employ to ensure that the operation site complies with applicable emissions limits and all applicable laws related to emissions; and
(cc) quarterly reporting to the gas inspector for a period of 12 months of documented compliance.

(3) Baseline assessments.

(i) Before gas drilling activities begin on an operation site, the operator shall perform a baseline test air quality on the operation site.

(ii) The baseline air quality test must be collected and analyzed by a qualified third party using proper sampling and laboratory protocol from an Environmental Protection Agency or a Texas Commission on Environmental Quality approved laboratory

(iii) The minimum baseline air quality results must include benzene, toluene, ethylbenzene, xylenes, ozone, hydrocarbons (e.g. methane, ethane, propane), nitrogen oxides, volatile organic compounds, sulfur dioxide, naphthalenes, acroleins, and formaldehyde.

(iv) The baseline air quality test results must be provided to the gas inspector within 30 days after the baseline testing is conducted.

(v) The operator is responsible for the cost and fees associated with baseline testing of air quality.

**Flower Mound** (http://www.flower-mound.com/index.aspx?NID=308 )
(p. 37)
(h) Emissions requirements for oil and gas well permits; emissions compliance plan. Gas well sites and production facilities shall comply with all state and federal emissions and air quality regulations for exhaust emissions, fugitive emissions, greenhouse gas emissions and all other applicable emissions control and air quality standards for natural gas drilling and production. In the event there are two (2) or more notices of violation during any twelve (12) month period, as determined by the Texas Commission on Environmental Quality or the United States Environmental Protection Agency, within thirty (30) days of the second notice of violation, the operator shall submit to the town an emissions compliance plan. An emissions compliance plan shall include, but is not limited to, twenty-four (24) hour on-site emissions monitoring and subsequent periodic reporting to the town council for a period of twelve (12) months of documented compliance, and the installation of appropriate equipment to meet the requirements of the emissions compliance plan, which may include but is not limited to vapor recovery units or other emissions control technology, to ensure that any emissions are within applicable state and federal regulations. Thereafter the operator shall employ best management practices to eliminate any emissions in violation of any state and federal regulations.

## Summary of Scholarly Support for Drilling Operation Setbacks

Setbacks between oil or gas wells and other land uses, such as houses, schools, health care providers, and places of worship, are a key provision in municipal ordinances in home-rule cities in Texas. The purpose of the setback distance is "to provide a mechanism to protect health, safety, and welfare of residents, the rights of property owners, to safeguard environmental quality and promote efficient gas extraction" (Fry 2013). Setback distances allow municipal policy makers to address several issues associated with shale gas drilling including human health, safety, and welfare. Fry (2013) determined that setbacks in Texas municipalities were determined by political compromise among residents, mineral owners and lessee, and oil and gas industry firms and lobbyists.

Only one study, conducted by a real estate consulting firm, showed evidence that gas drilling negatively affects property values up to 1,500 feet. This study informed the establishment of the 1,500 foot setback distance in Flower Mount (Fry 2013).

Unfortunately, the ideal or "safe" distance between oil and gas drilling and associated activities and residences, schools, playgrounds, health care facilities, and places of worship is unknown. However, dispersion models indicated setback distances for nuisances related to animal feeding operations, wastewater plants (e.g., Schauberger et al., 2002; Yu and Guo, 2011), wastewater treatment plants (e.g., Stellacci et al. 2010), and solid waste incinerators (e.g., Tavares et al. 2011). Such dispersion modeling could be used in a similar fashion to establish appropriate setbacks for shale gas drilling. Accurate dispersion modeling, however, requires either direct air quality emissions measurements needed as inputs to the modeling or at least worst case scenario estimates. Such data could also be used to standardize setback distances. To the extent that hydraulic fracturing is introduced in College Station, these data should be gathered to provide a strong objective and scientific foundation for controlling these risks over time.

The city of Fort Worth did use dispersion modeling after the fact to assess their setback provisions. Two air toxins, acrolein and formaldehyde were found in higher concentrations than the TCEQ protective health limits. Despite this finding, the city concluded that the 600 ft. set back was acceptable on the basis of political compromise.

In addition to setbacks, the strictest ordinances list permissible quantities of contaminants, and require pre-drilling baseline measurements and continuous monitoring of air quality

There have been some studies on the impact of unconventional hydraulic fracturing on property values. In Flower Mound, a study showed that residential property values within 1000 ft. of wellheads decreased between 3% and 14%, (when the well was in full view from the property) (Integra Realty Resources, 2010). Muehlenbachs, et al. (2014) evaluated property value data from mostly rural Pennsylvania and find evidence that properties less than 1.5 km from unconventional well site suffer a price loss of 3.4% when they are groundwater dependent, but increase because of the potential for royalties. They go on, however to note, "Very near the well (within 1 km [3280 feet]), we see much larger negative impacts and insignificant positive impacts." Based on this analysis, there is economic support for a protective set back provision in College Station.

**References:**

Fry, Matthew, Urban gas drilling and distance ordinances in the Texas Barnett Shale, Energy Policy, 62, 2013, 79-89.

IntegraRealtyResources. 2010. Flower Mound well site impacts study, file number: 116-2010-0511. Available at http://www.flower-mound.com/DocumentCenter/ View/1456.

Muehlenbachs, Lucija, Elisheba Spiller, and Christopher Timmins. 2014. The Housing Market Impacts of Shale Gas Development. NBER Working Paper No. 19796 (http://www.nber.org/papers/w19796)

Schauberger, G.,Piringer,M.,Petz,E.,2002.Calculating direction-dependent separation distance by a dispersion model to avoid livestock odour annoyance. Biosystems Engineering 82(1),25–37.

Stellacci, P., Liberti, L., Notarnicola, M., Haas, C.N., 2010. Hygienic sustainability of site location of waste water treatment plants: a case study. I. Estimating odour emission impact. Desalination 253, 51–56.

Tavares, G., Zsigraiová, Z., Semiao, V., 2011. Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. Waste Management 31(9–10), 1960–1974.

Yu, Z. M., Guo, H. Q., 2011. Determination of setback distances for livestock operations using a new Livestock Odor Dispersion Model (LODM). Journal of the Air & Waste Management Association 61 (12), 1369–1381.

# Legal Precedents for Set-Back Provisions in Texas

## Summary

We reviewed several ordinances that contained protective setback provisions. In the three reviewed, set back provisions required a buffer of at least 1,000 feet from residences. This compared with the College Station draft in which only a 600 foot buffer was provided for, and 1,000 for some other protected uses. In Dallas and Flower Mound, both of which require 1,500 foot set-backs, a specific process is provided for a well developer to request a shorter set-back provision, provided that the developer can show that the well will not pose a hazard to the public.

| City | Set back distance for residences | Includes provisions specifically for requesting shorter set backs |
|---|---|---|
| College Station (11/24 draft) | 600 feet | none found |
| Dallas | 1,500 feet | Yes |
| Flower Mound | 1,500 feet | Yes |
| Southlake | 1,000 feet | none found |

## Dallas (http://www.ci.dallas.tx.us/cso/resolutions/2013/12-11-13/13-2139.PDF)

Section E. F. ii

aa) Except as otherwise provided in this provision, a gas drilling and production use must be spaced at least 1,500 feet from a protected use (except trailers or mobile homes placed on the operation site as temporary residences for workers).

bb) City council may reduce the minimum 1,500 foot spacing requirement from a protected use by not more than 500 feet with a favorable vote of two-thirds of all members of the city council if city council finds that the reduction will not harm the public health, safety, or welfare.

Section 2.A

(iii) PROTECTED USE means institutional and community service uses (except cemetery or mausoleum); lodging uses; office uses; recreation uses (except when the operation site is on a public park, playground, or golf course); residential uses; and retail and personal service uses (except commercial motor vehicle parking or commercial parking lot or garage). Parking areas and areas used exclusively for drainage detention are not part of a protected use.

## Flower Mound (http://www.flower-mound.com/index.aspx?NID=308 )

**(ordinance 29-11)**

p. 34

(1) It shall be unlawful to drill, redrill, deepen, re-enter, activate or convert any oil or natural gas well, for which the closest edge of construction or surface disturbance is located

a. Within one thousand five hundred feet (1,500') from an public park; or

b. Within one thousand five hundred feet (1,500') from any residence; or

c. Within one thousand five hundred feet (1,500') from the property line upon which any religious institution, public building, hospital building or school is located or for which a building permit has been issued on or before the date of the application for a drilling permit is filed with the oil and gas inspector; or

d. Within one thousand five hundred feet (1,500') from any habitable structure; or

...

i. All distances shall be measured from the closest edge of construction or surface disturbance in a straight line, without regard to intervening structures, or objects to the closest exterior point of any object, structure, or recorded property, lot or tract line, listed in subparagraphs (a) through (h) above

(2) The distances set out in subsection (1), "Wells setbacks for oil and gas well permits," may be reduced and documented as variances to the requested permit prior to issuance at the discretion of the oil and gas board of appeals pursuant to section 34-432, "Appeals," of this article but said distances shall never be reduce to less than;

a. Twenty-five percent (25%) of the distances set out in subsection (2) "Wells setbacks for oil and gas well permits,"; or

b. No variance shall be permitted for any existing storage tank or source of potential ignition, pursuant to section 34-422(d)(1)(f) of this article, or any public street, road, highway or right-of-way line, pursuant to section 34-422(d)(1)(g) of this article.

**Southlake** (http://www.cityofsouthlake.com/index.aspx?NID=905)

**Ordinance NO 880B**

Sec. 95242 Onsite operation requirements

a It shall be unlawful to drill a well or to redrill deepen reenter activate or convert any abandoned well the center of which at the surface of the ground is located within 500 feet from any City owned public park or within1000 feet from any habitable structure or property line of any occupied public or private school

b All distance in a above shall be measured from the proposed well bore in a straight line without regard to intervening structures or objects to the closest exterior point of the habitable structure

# Legal Precedents for Noise Provisions in Texas

**Summary**

Provisions regarding noise vary somewhat across the three city ordinances that we reviewed. Noise problems are among the most common complaints associated with drilling and hydraulic fracturing, hence it is important that the related ordinances be proactive. All of the provisions we reviewed restricted noise based on deviations from ambient levels when measured at a distance relative to the nearest habitable structure. The provisions of Southlake and Dallas use a measure relative to ambient noise levels; Flower Mound's standard is set at 56 dB during the night. All three cities place restrictions on low frequency noises (see table in each of the ordinances).

**Southlake** (http://www.cityofsouthlake.com/index.aspx?NID=905)

(1) No well shall be drilled, redrilled or any equipment operated at any location within the city in such a manner so as to create any noise which causes the exterior noise level when measured at the either the property line of the tract upon which the nearest habitable structure is located or 100 feet from the nearest habitable structure as measured to the closest exterior point of the habitable structure whichever is closer to the well to exceed the ambient noise level

a. By more than ten decibels during fracturing operations and

b. By more than five decibels during daytime hours or more than three decibels during nighttime hours for all activities not addressed in paragraph a above

c. An operator shall not drill or re drill a well or operate any equipment in such a manner so as to create pure tones where one third octave band sound pressure level in the land with the tone exceeds the arithmetic average of the sound pressure levels of two contiguous one third octave bands by five 5 dB for center frequencies of 500 hertz and above and by eight 8 dB for center frequencies between 160 and 400 hertz and by fifteen 15 dB for center frequencies less than or equal to 125 hertz

d. An operator shall not drill or redrill a well or operate any equipment in such a manner so as to create low frequency outdoor noise levels that exceed the following decibel levels

16 hertz octave band 65 dB
32 hertz octave band 65 dB
64 hertz octave band 65 dB

(2) The operator shall be responsible for establishing and reporting to the city the pre drilling ambient noise level prior to the issuance of a well permit. Once the drilling is complete the operator shall be required to establish a new ambient noise level prior to the installation of any new noise generating equipment. In lieu of the foregoing the city may elect to perform the required noise testing and establish the ambient noise level.

(3) Adjustments to the noise standards as set forth above in subsection d1of this Section may be permitted in accordance with the following

| Permitted Increase Duration of Increase | |
|---|---|
| dBA | Minutes* |
| 5 | 15 |
| 10 | 5 |
| 15 | 1 |
| 20 | less than 1 |

* Cumulative minutes during any one hour period####$

(4) No workover or reworking operations shall be permitted during nighttime hours

(5) If the proposed gas well is within1000 feet of any habitable structure the operator must comply with these additional noise abatement measures:

a. Exterior noise levels including pure tone and low frequency data shall be continuously monitored to ensure compliance. This data shall also include an audio recording to help identify the source of sound level spikes throughout the logging period The continuous noise monitoring equipment shall be capable of wireless transmission of real time noise and audio data. Access to this real time data shall be made available to the inspector. The cost of all such monitoring shall be borne by the operator. The noise readings shall also be submitted to the inspector on a weekly basis in an electronic format or other format specified by the inspector. The weekly report shall state whether the drill site is in compliance with the noise requirements. If the report states that the drill site is not in compliance with the noise standards then the report shall state the measures that are being taken to return the drill site to compliance and the timeframes for implementing these remedial measures.

b. At a minimum the operator shall install noise reduction blankets on the drill site boundaries facing any habitable structure within1000 feet. The height of boundary blankets shall at a minimum be 30 feet. The height may be increased at the discretion of the inspector in response to topographic necessity. In addition to the boundary barriers the operator must at a minimum install additional noise reduction blankets to mitigate noise generated from the rig substructure the rig floor area brake drum housings mud pumps diesel motors and generators. The blankets shall be constructed of a fire retardant material approved by the fire department

(6) Acoustical blankets sound walls mufflers or other alternative methods as approved by the inspector may be used to ensure compliance with this Article All soundproofing shall comply with accepted industry standards and subject to approval by the fire marshal Noise mitigation measures will be evaluated on a case by case basis The inspector may require the operator to use noise reduction blankets that meet a standard of STC 30 or greater if necessary

(7) The sound level meter used in conducting noise evaluations shall meet the American National Standard Institute standard for sound meters or an instrument and the associated recording and analyzing equipment which will provide equivalent data

(8 ) A citation may be issued for the failure to immediately correct the violation upon notice of violation by the city or the inspector

(9) During nighttime operations the operation of vehicle audible backup alarms are prohibited If the operator uses any equipment during nighttime operations which are required to have backup alarms the operator shall provide and use only approved non auditory signaling systems such as spotters or flagmen Deliveries of pipe casing and heavy loads shall be limited to daytime hours except for emergency situations. The derrick man and driller shall communicate only by walkie-talkie or other no disruptive means when the derrick man is in the derrick. Horns may not be used to signal for connection or to summon crew except that a horn may be used for emergency purposes only. The operator shall conduct onsite meetings to inform all personnel of nighttime operations noise control requirements

(10) The operator shall file a noise management plan which shall detail how the equipment used in the drilling completion transportation or production of a well complies with the maximum permissible ambient noise levels of this Article The noise management plan

must be approved by the director of planning and development services and must comply with the following requirements:

a Identify operation noise impacts and

b Provide documentation if applicable establishing the ambient noise level prior to and after the installation of the noise generation equipment verifying compliance with this Section and

c Detail how the impacts will be mitigated In determining noise mitigation specific site characteristics shall be considered including but not limited to the following:

1 The location type nature and proximity of adjacent development and
2 Seasonal and prevailing weather patterns including wind directions and
3 Vegetative cover on or adjacent to the site and
4 Topography and
5 Operation and site noise management measures which may include but not be limited to use of critical grade mufflers on generators and motors use of structural noise curtains walls or enclosures and best management practices by limiting or eliminating noisier operations such as tripping deliveries of pipe casing and heavy loads use of horns for communication and operation of vehicle audible backup alarms during nighttime hours.

Violation of the noise management plan shall be a violation of this Article

**Flower Mound** (http://www.flower-mound.com/index.aspx?NID=308 )
(p. 37)
Nighttime defined as 7:00 p.m. – 7:00 a.m.

(i) Noise Restrictions for oil and gas well permits (page 37)

(1) No drilling, producing, or other operations shall produce a sound level greater than:

a. Seventy (70) decibels using the "A weighting filter" ("db(a)") when measured at a distance of three hundred feet (300') from the drilling, producing, or operating equipment in question during the daytime.

b. Fifty-six (56) db(a) when measured to the nearest residence, public building, or habitable structure from the drilling, producing, or operating equipment in question during the nighttime.

c. Seventy (70) dB(a) during apply to formation fracturing when measured at a distance of three hundred feet (300') from the production equipment in question during the daytime.

(2) No person shall operate or permit to be operated in connection with the operation of a producing well(s) any compression facility which creates a sound level that exceeds the ambient noise level by more than three (3) db(a) when measured at the nearest property line, residence, habitable structure, or public building, whichever is closer. In addition, if a residence, habitable structure or public building for which an application for a building permit has been submitted on or before the date the application for a building permit for the compression facility is proposed, the sound level shall not exceed the ambient noise level by more than three (3) dB(a) when measured at the proposed residence, habitable structure or public building. Upon approval by the town, the compression facility shall be totally enclosed and designed to meet architectural standards complementary of the surrounding area

(3) Low frequency noise standards. No drilling, production, or other operations shall produce a low frequency sound level that exceeds the following decibel levels:
16Hz octave band: 65 decibels
32Hz octave band: 65 decibels
64Hz octave band: 65 decibels

(4) Sound level measurements shall conform to the following guidance

a. Sound level meters shall conform, as a minimum to the requirements of the American National Standards Institute.

b. sound level measurements shall be taken four feet (4') above ground level

c. sound levels shall be determined by averaging minute-by-minute measurements made over minimum fifteen (15) minute sample duration, if practicable. Sound level measurements shall be taken under the conditions that are representative of the noise experienced by the complainant (e.g. at night, morning, evening, or during special weather conditions).

3. In all sound level measurements, the existing ambient noise level from all other sources in the encompassing environment at the time and place of such sound level measurement shall be considered to determine the contribution to the sound level by the oil and gas operation(s)

(5) The noise management plan, as approved by the oil and gas inspector. shall detail how the equipment used in the drilling, completion, transportation. or production of a well complies with the maximum permissible noise levels of this article. The noise management plan must:

a. Identify operation noise impacts;

b. Provide documentation, if applicable, establishing the ambient noise level for both daytime and nighttime hours prior to construction of any wellhead compressor or compression facility and after the installation of the noise generation equipment verifying compliance with this section. The operator shall be required to submit noise compliance reports at least

c. Detail how the impacts will be mitigated. In determining noise mitigation, specific site characteristics shall be considered. including but not limited to the following:

1. Nature and proximity of adjacent development, location, and type;
2. Seasonal and prevailing weather patterns, including wind directions;
3. Vegetative cover on or adjacent to the site;
4. Topography;
5. Operation and site noise management measures which may include but not be limited to: use of critical grade mufflers on generators and motors: use of structural noise curtains, walls, or enclosures; and best management practices by limiting or eliminating noisier operations. such as tripping, deliveries of pipe, casing and heavy loads. use of horns for communication. and operation of vehicle audible back-up alarms at night.

d. Identify the location of noise blankets. sound walls or other applicable noise mitigation effects around the pad side. Noise mitigation shall be required for all drilling, hydraulic fracturing and production operations.

**Dallas** (http://www.ci.dallas.tx.us/cso/resolutions/2013/12-11-13/13-2139.PDF)
(p. 10)
(ii) To reduce noise, all compressors must be fully enclosed in a building.
(v) To reduce noise and emissions. electric motors must be used on the gas pipeline compressor station unless the operator submits a report to the gas inspector and the gas inspector finds that electric motors cannot be used.

(p. 61) Section 51A-I22O4(l). "Noise."

Noise.
(1) Conflicts. Except as otherwise provided in this subsection, the noise regulations in Section 51A-6.102 apply.
(2) Pre-drilling noise levels.

(A) Before the gas well permit may be issued, the operator shall establish and report to the gas inspector the continuous 72-hour pre-drilling ambient noise levels.

(B) The 72-hour time span must include at least one, 24-hour reading during either a Saturday or Sunday. The timeframe for this noise study must be designed to avoid the influence of wind interference on the noise study.

(C) The operator shall submit a proposed ambient noise level study plan to the gas inspector for approval before conducting the noise study. The proposed noise level study plan must contain a proposed testing schedule and other details as required by the gas inspector.

(D) The gas inspector shall determine if subsequent noise studies are needed to reevaluate ambient noise conditions.

(E) The operator is responsible for all costs and fees associated with establishing and reporting the continuous 72-hour pre-drilling ambient noise levels.

(3) Noise levels. An operator may not drill, re-drill, or operate any equipment in such a manner so as to create noise that causes the exterior noise level, when measured at the nearest property line of the tract upon which the nearest protected use or habitable structure is located, or at a point that is 100 feet from the nearest protected use or habitable structure, whichever is closer to the well, to:

(A) exceed the ambient noise level by more than:

(i) 10 dB during fracturing operations;

(ii) five dB during daytime hours that do not include fracturing operations; and

(iii) three dB during all other hours

(B) create pure tones where one-third octave band sound-pressure level in the band with the tone exceeds the arithmetic average of the sound-pressure levels of two contiguous one-third octave bands by:

(i) five dB for center frequencies of 500 hertz and above;

(ii) eight dB for center frequencies between 160 and 400 hertz; and

(iii) 15dB for center frequencies less than or equal to125 hertz; or

(C) create low-frequency outdoor noise levels that exceed the following dB levels:

(i) 16 hertz octave band: 65 dB;

(ii) 32 hertz octave band: 65 dB; and

(iii) 64 hertz octave band: 65 dB.

(4) Adjustments

(A) Adjustments to the noise regulations in this subsection are permitted intermittently as follows:

| Permitted Increases (dBA) | Duration of Increase in minutes (cumulative during any 1 hour period)* |
|---|---|
| 5 | 15 |
| 10 | 5 |
| 15 | 1 |
| 20 | less than 1 |

(B) The time period of monitoring will be continuous over a minimum of one hour and will use the A-weighting network reported in decibel units. Data must be recorded and reported as Lea. which means an average measure of continuous noise that has the equivalent acoustic energy of the fluctuating signal over the same period.

(5) Continuous monitoring.

(A) If a proposed gas well is within 1,500 feet of a protected use measured from the gas well in a straight line, without regard for intervening structures or objects, to the closest protected use, the operator shall comply with the following additional noise abatement measures:

(i) Exterior noise levels, including pure tone and low frequency data, must be continuously monitored to ensure compliance. The continuous noise level monitoring data must also include an audio recording to help identify the source of sound 1evel spikes throughout the logging period.

(ii) The continuous noise monitoring equipment must be capable of wireless transmission of real-time noise and audio data. Access to this real-time data must be made available to the gas inspector

(iii) The noise readings must also be submitted to the gas inspector on a weekly basis in an electronic format or other format specified by the gas inspector. The weekly report must contain all noise data, including pure tone and low frequency readings. The report must state whether the operation site is in compliance with the noise requirements in this subsection and Section 51A-6.102.

(B) If the report indicates that the operation site is not in compliance with the noise regulations in this subsection or Section 51A-6.102, the report must state the measures that are being taken to bring the operation site into compliance and the time frame for implementing these remedial measures.

(C) The operator is responsible for all costs and fees associated with all continuous noise monitoring.

(D) Continuous monitoring must occur at:

(i) the protected use property line or 100 feet from the nearest protected use. whichever is closer to the noise source: or

(ii) a location approved by the gas inspector

*[the noise section continues for another page]*

## Trucks and Traffic Issues Related to Hydraulic Fracturing

**Summary**
All three phases of a gas well – drilling, fracturing, and maintenance – require hundreds of trips of trucks weighing up to 80,000 to 100,000 lbs., taking a serious toll on the roads that were not designed for such heavy usage. ("Our Look At Road Damages From Heavy Truck Traffic," at http://www.marcellus-shale.us/road_damage.htm). The resulting road damage costs tens of millions of dollars to fix. For example, the Texas Department of Transportation committed $40 million to repair roads damages from hydraulic fracturing. (Bloomberg Businessweek, May 15, 2012 at http://www.businessweek.com/news/2012-05-15/taxpayers-pay-as-fracking-trucks-overwhelm-rural-cow-paths). Furthermore, because the trucks and train cars carry explosive, because highly volatile hydrocarbons, hydraulic fracturing increases the risk of serious vehicular accidents (NY Times, Business Section, B5. December 10, 2014).

College Station's proposed new ordinance for governing hydraulic oil and gas extraction activities within the city recognize the road damage and traffic issues arising from fracturing. However, compared with the ordinances that were passed in Dallas, Southlake, and Flower Mound, TX, the College Station ordinance seemed to lack certain safeguards.

- Will the operator be required to submit a traffic impact analysis that includes specifying the turning movements on the maps showing the proposed transportation route within the City?
- What are the provisions for enforcing the Road Maintenance Agreement? If a hazardous road condition is created, who will be responsible to respond immediately? Will there be pre-, post-, and periodic assessment of the road conditions that will be part of the Permittee's proposed transportation route?
- While the draft ordinance requires that drill site access roads be constructed of crushed rock, gravel or ore in sufficient quantity and compacted to a sufficient degree to support all surface operations and traffic, questions arise as to the procedures by which the sufficiency is determined.
- While the draft ordinance states that produced water or fluids shall not be used for dust abatement, why not explicitly prohibit the use of brine water, sulfur water, and water in mixture with any type of hydrocarbon and require a mud shaker for truck traffic?

### Examples of Other Ordinances on Trucking and Traffic:

**Southlake**

(1) Southlake (S/L ) (O/N880-A) 9.5-231: A statement of intent to enter into a road repair agreement shall be submitted in conjunction with the application for specific use permit or seismic survey permit;

(2) S/L (O/N880-A) 9.5-234(b)(4) A map showing the proposed transportation route identifying all public and private roads routes intended for use within the territorial limits of the city which transportation route must be consistent with the requirements of the specific use permit.

(3) S/L (O/N880-A) 9.5-234(b)(36) A dust mitigation plan detailing measures to be implemented to mitigate and suppress dust generated at the drill site and the private vehicle access route including a mud shaker for vehicles exiting the site or if a specific use permit has already been approved for the drill site a copy of the dust mitigation plan previously approved.

(4) S/L (O/N880-A) 9.5-234(b)(47): A traffic impact analysis study which includes but is not limited to proposed truck routes types and weights of trucks and vehicles accessing the drill site hours of the day that truck and vehicle traffic will be entering and leaving the site days of the week that truck and vehicle traffic will be entering and leaving the site, turning movements associated with truck and vehicle traffic, proposed access points and proposed traffic control devices.

(5) S/L (O/N880-A) 9.5-242(f): The operator shall construct all facilities located off the pad site and used for parking loading unloading driveways and other vehicular access areas of concrete unless an alternative material is approved by the city council as a condition of a specific use permit or an approved variance The operator shall maintain the surface for such facilities and drive approach in good condition and repair and meet the minimum requirements set forth in the fire code approved by the city council as amended The pad site is not required to be constructed of concrete or asphalt

(6) S/L (O/N880-A) 9.5-242(yy) Heavy vehicles access to all operational wells shall be limited to state or federal highways within the city and to those routes otherwise designated in Article IV chapter 118 of this Code governing the transportation of heavy vehicles on city streets unless another route is expressly approved under the specific use permit.

(7) S/L (O/N880-A) 9.5-243(g) The operator shall immediately notify the city of any substantial accumulations of dirt dust mud or other debris deposited on city thoroughfares by vehicles involved in the well drilling or servicing or pipeline installation process The operator shall be responsible for removing accumulations of dirt dust mud or other debris from the city thoroughfares on a daily basis If for safety or other reasons the city elects to perform the removal the cost of such removal shall be assessed against and paid by the operator.

**Dallas**

(8) DALLAS (D/S) 51A-12.202(b)(37) a transportation plan that includes:

(A) traffic impact analysis, including the proposed truck routes, the types and weights of trucks and vehicle accessing the operational sites; hours of the day that truck and vehicle traffic will be entering and leaving the operation site; days of the week that truck and vehicle traffic will be entering and leaving the operation site; turning movements associated with the truck and vehicle traffic; proposed access points; and proposed traffic control devices;

(B) map consistent with any SUP (seismic survey permit) requirements showing the truck routes approved by the gas inspector and identifying all public-rights-of-way, private streets and routes intended for use within the city;

(C) videotape of the approved truck routes, showing in adequate detail the physical conditions of the rights-of-way and

(D) road repair agreement approved as to form by the city attorney and the operator;

(9) D/S 51A12.203(h) <u>Road repair security instrument</u>. Before issuance of a gas well permit, the operator shall give the gas inspector a road repair performance bond or an irrevocable letter of credit approved as to form by city attorney. The road repair security instrument is in addition to the performance bond or the letter of credit required by 51A-12.203(g).

(10) D/S 51A-12.204(f)(7): Erosion control practices. Berms that are at least one foot high and two feet wide, or equivalent erosion devices, must be installed to prevent lot-to-lot drainage. Any

damages to adjacent properties from sedimentation or erosion must be repaired immediately.

(11) D/S 51A-12.204(j)(6): Truck traffic. Except as otherwise provided in this paragraph, truck deliveries and removal of equipment and materials associated with drilling, fracturing, or production. well servicing, site preparation, or other related work conducted on the operation site may only occur during daytime hours. In cases of fires, blowouts, explosions, other emergencies, or where the delivery of equipment is necessary to prevent the cessation of drilling or production, truck deliveries and removal of equipment may occur 24 hours a day.

(12) [D/S 51A-12.204(p)]: Rights-of-Way. For the purpose of this subsection, rights of way means those rights-of-way located along the truck routes shown on the operator's approved transportation plan and incorporated by reference into the gas well permit.

(1) Periodic inspection: The operators shall periodically inspect the rights-of way to determine if damage has occurred,

(2) City notifying operator. If the department of public works determines that the rights-of-way have been damaged, the gas inspector shall notify the operator in writing of the damage.

(3) Repairs. The operator shall repair the damage to the rights-of-way within10 days after discovering or receiving notice of the damage. Repairs must be made in accordance with the current standards of the department of public works. At least two days before making the repairs, the operator shall notify the department of public works of the operator's intent to begin repairs. The operator shall have all necessary permits before repairing the rights-of-way.

(4) City making repairs and invoicing operator.

(A) If the operator fails to make repairs within 10 days after discovering or receiving notice of the damage, the director of public works may make the necessary repairs and invoice the operator The operator shall pay the amount due within 30 days after the invoice date.

(B) If the director of public works determines that the damages to the rights-of-way affect the immediate health and safety of the public, the director of public works may make the repairs without first requesting that the operator make the repairs. The director of public works shall invoice and the operator shall pay the amount due within 30 days after the invoice date.

(C) If required by state law, the director of public works shall employ a competitive bidding process before making the repairs to the rights-of-way.

(5) Final inspection. After the gas inspector approves the abandonment and restoration of the operation site, the operator shall notify the director of public works and request an inspection of the right-of-way. After inspection, the director of public works shall notify the operator of any needed repairs. Repairs must be made in accordance with this article.

PSE Healthy Energy
Physicians Scientists & Engineers

# Towards an understanding of the environmental and public health impacts of shale gas development: an analysis of the peer-reviewed scientific literature, 2009-2014

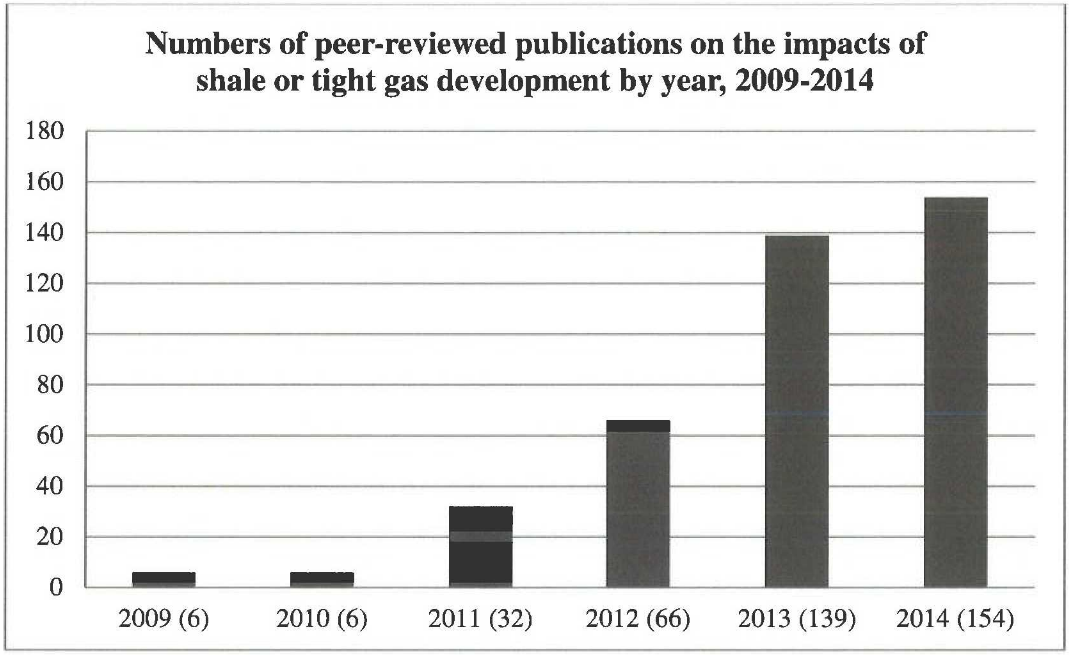
## Introduction

Conversations on the negative environmental and public health impacts of shale gas development continue to play out in the media, in policy discussions, and among the general public. But what does the science actually say? While research continues to lag behind the rapid scaling of shale gas development, there has been a surge of peer-reviewed scientific papers published in recent years. In fact, of all the available scientific peer-reviewed literature on the impacts of shale gas development, approximately 73% has been published since January 1, 2013. What this tells us is that the scientific community is only now beginning to understand the impacts of this industry on the environment and human populations. Hazards and risks have been identified, but many data gaps still remain. Importantly, there remains a dearth of quantitative epidemiology that assesses associations between risk factors and human health outcomes among populations.

Still, there is now a lot more known about the impacts of shale gas development than when New York's *de facto* moratorium went into effect. This analysis is intended to provide an overview of what is currently known about the potential impacts of shale gas development on human health and the environment. We include only the published peer-reviewed literature available on the subject. Specifically, this analysis uses studies relevant to near-term and long-term population health in communities experiencing shale gas development.

As the industry continues to expand in other parts of the country, New York has been in a unique position to learn from experiences and research in places like Pennsylvania, Texas, and Colorado. Clearly, this is a complex, polarizing issue and one that likely requires more than simply empirical evidence to create sound policy decisions. Yet, New York should pay close attention to the actual experiences and evidence arising out of other parts of the country that have opened their borders to shale gas development.

There are limitations to this analysis and it provides just a snapshot of what we know scientifically about the public health hazards, risks, and impacts associated with shale gas development. Furthermore, this document is preliminary and has not yet been subjected to external peer review. Nonetheless, it should provide readers with a general sense of the existing body of scientific literature on shale gas development.




## Methods

*Database assemblage and review*

This analysis was conducted using the PSE Study Citation Database (available at: http://psehealthyenergy.org/site/view/1180). This near exhaustive collection of peer-reviewed literature on shale gas development was broken into 12 topics that attempt to organize the studies in a useful and coherent fashion. These topics include air quality, climate, community, ecology, economics, general (comment/review), health, regulation, seismicity, waste/fluids, water quality, and water usage. This collection was assembled over several years using a number of different search strategies, including the following:

- Systematic searches in scientific databases across multiple disciplines: PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://www.webofknowledge.com), and ScienceDirect (http://www.sciencedirect.com)
- Searches in existing collections of scientific literature on shale gas development, such as the Marcellus Shale Initiative Publications Database at Bucknell University (http://www.bucknell.edu/script/environmentalcenter/marcellus), complemented by Google (http://www.google.com) and Google Scholar (http://scholar.google.com)
- Manual searches (hand-searches) of references included in all peer-reviewed studies that pertained directly to shale gas development.

For bibliographic databases, we used a combination of Medical Subject Headings

(MeSH)-based and keyword strategies, which included the following terms, as well as relevant combinations:

> shale gas, shale, hydraulic fracturing, fracking, drilling, natural gas, air pollution, methane, water pollution, public health, water contamination, fugitive emissions, air quality, climate, seismicity, waste, fluids, economics, ecology, water usage, regulation, community, epidemiology, Marcellus, Barnett, Denver-Julesberg Basin, unconventional gas development, and environmental pathways.

This database and subsequent analysis excluded technical papers on shale gas development not applicable to determining potential environmental and public health impacts. Examples include papers on optimal drilling strategies, reservoir evaluations, estimation algorithms of absorption capacity, patent analysis, and fracture models designed to inform stimulation techniques. Because this collection is limited to papers subjected to external peer-review in the scientific community, it does not include government reports, environmental impact statements, policy briefs, white papers, law review articles, or other grey literature. This database also does not include studies on coalbed methane, coal seam gas, tar sands or other forms of fossil fuel extraction (offshore drilling, etc.).

We have tried to include all literature that meets our criteria in our collection of the peer-reviewed science, however, it is possible that some papers may have gone undetected. Thus, we refer to the collection as *near* exhaustive. We are sure, however, that the most seminal studies on the public health dimensions of shale gas development in leading scientific journals are included. The PSE Healthy Energy database has been used and reviewed by academics and experts throughout the U.S. and internationally and has been subjected to public and professional scrutiny before and after this analysis. It represents the most comprehensive public collection of peer-reviewed scientific literature on shale gas development in the world and has been accessed by thousands of people. Many of the publications in this database can be found in a review paper, published in the peer-reviewed journal, *Environmental Health Perspectives*, authored by Shonkoff et al. (2014) (http://ehp.niehs.nih.gov/wp-content/uploads/advpub/2014/4/ehp.1307866.pdf).

*Scope of analysis & inclusion/exclusion criteria*

There has been great confusion about environmental dimensions of shale gas development or "fracking" because of the lack of uniform, well-defined terminology and boundaries of analysis. The public and the media use the term fracking as an umbrella term to refer to the entirety of shale gas development, including processes ranging from land clearing to well stimulation, to waste disposal. On the other hand, the oil and gas industry and many in the scientific community generally use the term as shorthand for one particular type of well stimulation method used to enhance the production of oil and natural gas – hydraulic fracturing.

The PSE Healthy Energy database and this analysis are both concerned with shale gas development in its entirety, enabled by hydraulic fracturing, and not just the moment of hydraulic fracturing well stimulation, which should have a limited role in sound policy discussions. If we are to understand the social, environmental, and public health dimensions of shale gas development we must look beyond only the moment of well stimulation, especially when the scientific literature indicates other aspects of the overall process warrant concern. Thus, this project can be viewed as an analysis of the scientific literature on hydraulic fracturing *and* its associated operations and ancillary infrastructure.

The focus of this analysis is, first and foremost, on the primary research on shale gas development published to date. To that extent we have only included papers that evaluate the association between shale gas development and environmental and public health impacts. As such, not all publications in the PSE Healthy Energy database were used in this analysis. We have not included the following topics in this analysis: climate, community, ecology, economics, general, regulation, seismicity, waste/fluids, and water usage. We have also not included all of the papers within the three topics we did include (health, water quality, and air quality). For instance, with the exception of public health papers, for which there has been very little primary research, we have excluded commentaries and review articles. We have also excluded those papers that provide baseline data or address research methods that do not assess impacts. We have also excluded letters to the editor of scientific journals that critique a particular study or the subsequent response of the author(s).

We have restricted the studies included in this analysis to those published between 2009 and 2014. The main reason for doing so is that scientific literature on shale gas development did not appear until around that time. There are some studies in the database on conventional forms of oil and natural gas development that are relevant to shale gas, but to maintain greater consistency we have decided to exclude those prior to 2009 from the analysis. For instance, we excluded a study published in *The Lancet* that examined the association between testicular cancer and employment in agriculture and oil and gas development published in 1986 (Sewell *et al.* 1986). Relatedly, some of the studies included in this analysis may be broader than shale gas development and could potentially include other forms of both conventional and unconventional oil and gas development. This is true for some of the top-down, field based air pollutant emissions studies that gauge leakage rates and emission factors in Western oil and gas fields. Where studies are not specifically related to shale gas development we included them only when the findings are recent and substantially relevant.

Again, it is important to note that scientists are only beginning to understand the environmental and public health impacts of these rapidly expanding industrial practices. Our analysis represents a survey of the existing science to date in an attempt to determine the direction in which consensus is headed and to achieve a deeper understanding of the environmental and public health impacts of this form of energy development. What we know at this time is based on modeling and field-based studies on unconventional oil and gas development (primarily from shale) in parts of the United States, such as Texas, Colorado, and Pennsylvania, where the extraction of natural gas from shale formations has only relatively recently been scaled.

*Categorical framework*

We have created categories for each topic in an attempt to identify and group studies in ways that are both useful and intuitive. Clearly, there are limitations to this approach and many studies are nuanced or incommensurable in ways that may be inappropriate for this type of analysis. This is especially true for some topics, such as air and water quality. Further, some studies may properly be included in multiple topics and in a few cases we have done so. For instance, some studies may contain data that are relevant to both air quality and public health (Bunch et al. 2014; Colborn et al. 2014; Macey et al. 2014).

Nonetheless, in order to glean some kind of scientific overview or growing scientific consensus on the environmental public health dimensions of shale gas development that may be useful to policy determinations we strived to create the most simple and accurate approach possible. Please refer to the tables included in the appendix for citations and categorization of studies.

| Topics | Categories |
|---|---|
| Health | • Indication of potential risks of or actual adverse health outcomes<br>• No indication of significant risks of or actual adverse health outcomes |
| Water Quality | • Indication of potential, positive association, or actual incidence of water contamination<br>• Indication of minimal potential, negative association, or rare incidence of water contamination |
| Air Quality | • Indication of elevated air pollution emissions and/or atmospheric concentrations<br>• No indication of significantly elevated air pollutant emissions and/or concentrations |

*Health*

Health outcome studies and epidemiologic investigations continue to be particularly limited and most of the peer-reviewed papers to date are commentaries and reviews. We have also separately analyzed peer-reviewed scientific commentaries because original research is still so limited for public health ("all papers"). Although commentaries should essentially be acknowledged as opinions, they are the opinions of experts formed from the available literature and have also been subjected to peer-review.

Included in this topic are papers that consider the question of public health in the context of shale gas development. Of course, research findings in other categories such as air quality and water quality are relevant to public health, but here we only include those studies that *directly* consider the health of individuals and human populations. We considered this topic and its related categories in both the context of original research and commentaries and reviews. We only consider research to be original if it measures health outcomes or complaints (i.e., not health research that attempts to determine perceptions or methods for future research agendas). The vast majority of these papers indicate the need for additional study, particularly large-scale, quantitative epidemiologic research.

*Water Quality*

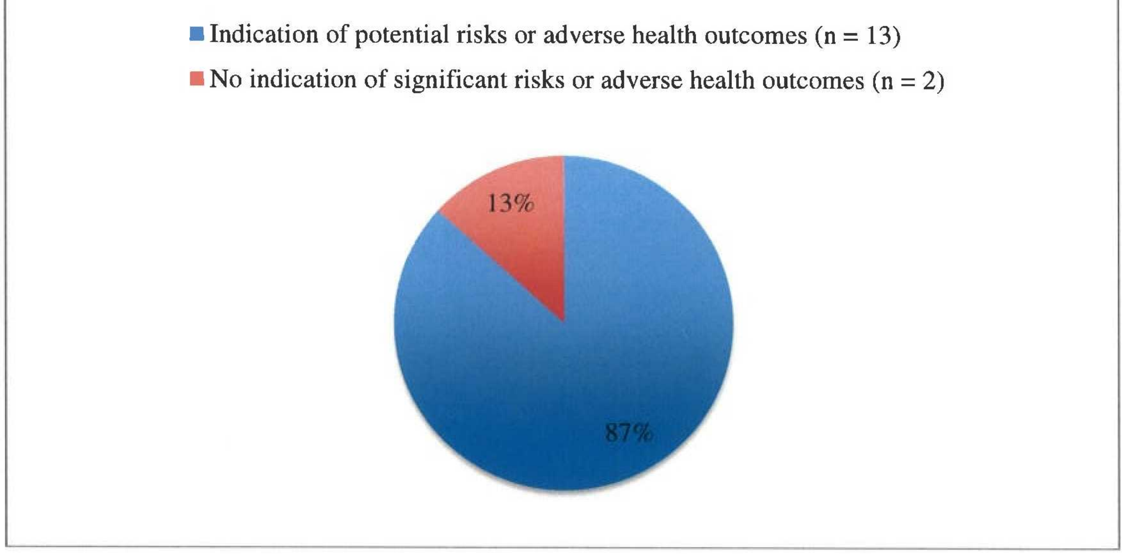
Papers on water quality are more nuanced in that some rely on empirical field measurements, while others explore mechanisms for contamination or use modeled data to determine water quality risks. Further, some of these studies explore only one aspect of shale gas development, such as the well stimulation process enabled by hydraulic fracturing. Thus, these studies do not indicate whether or not shale gas development as a whole is associated with water contamination and are therefore limited in their utility for gauging water quality impacts. Nonetheless, we have included all original research, including modeling studies. We have excluded studies that explore only evaluative methodology or baseline assessments as well papers that simply comment on or review previous studies. Here we are only concerned with actual findings in the field or modeling studies that specifically address the risk or occurrence of water contamination.

*Air Quality*

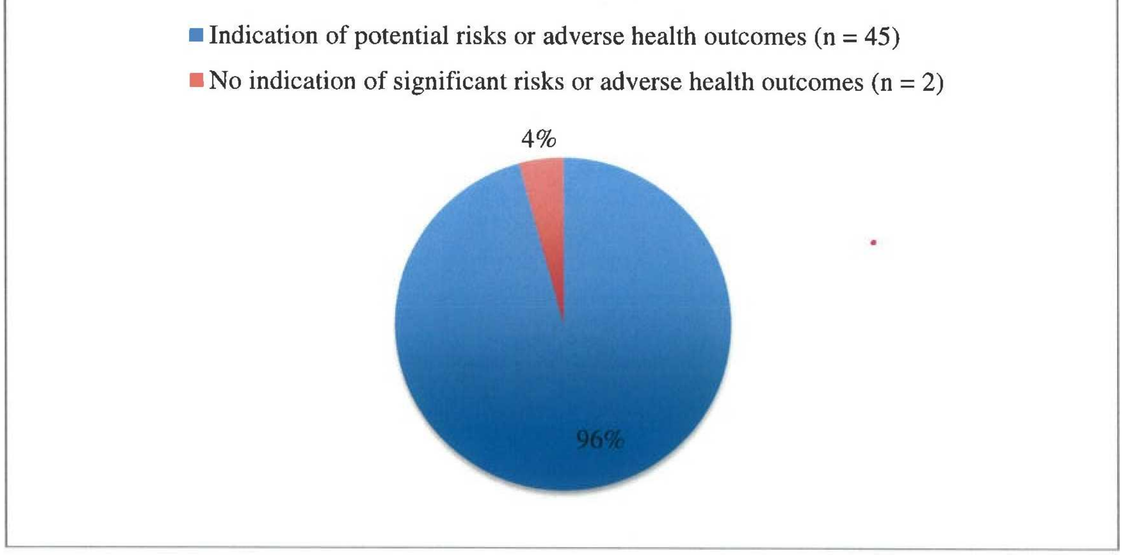
Air quality is a more complex, subjective measure that beckons comparison to other forms of energy development or industrial processes. Yet, a review and analysis of the air quality data is still useful and certainly relevant to health outcomes. Although methane is a precursor to tropospheric ozone we have excluded studies that focus exclusively on methane emissions from this topic. However, studies that address methane *and* non-methane volatile organic compound (VOC) emissions have been included, given the health-damaging dimensions of a number of VOCs (i.e., benzene, toluene, ethylbenzene, xylene, etc.) and the role of VOCs in the production of tropospheric ozone, a strong respiratory irritant. Studies that have explored the health implications of air pollution emissions, atmospheric concentrations, and exposure levels are included in both this category and the public health category. The studies listed under this topic are those that specifically address air emissions and air quality from well stimulation-enabled oil and gas development (i.e., unconventional oil and gas development) at either a local or regional scale. These include local and regional measurements of non-methane volatile organic compounds and tropospheric ozone. We only include original research for this topic, as measurement studies constitute the majority of air emission and air quality studies.

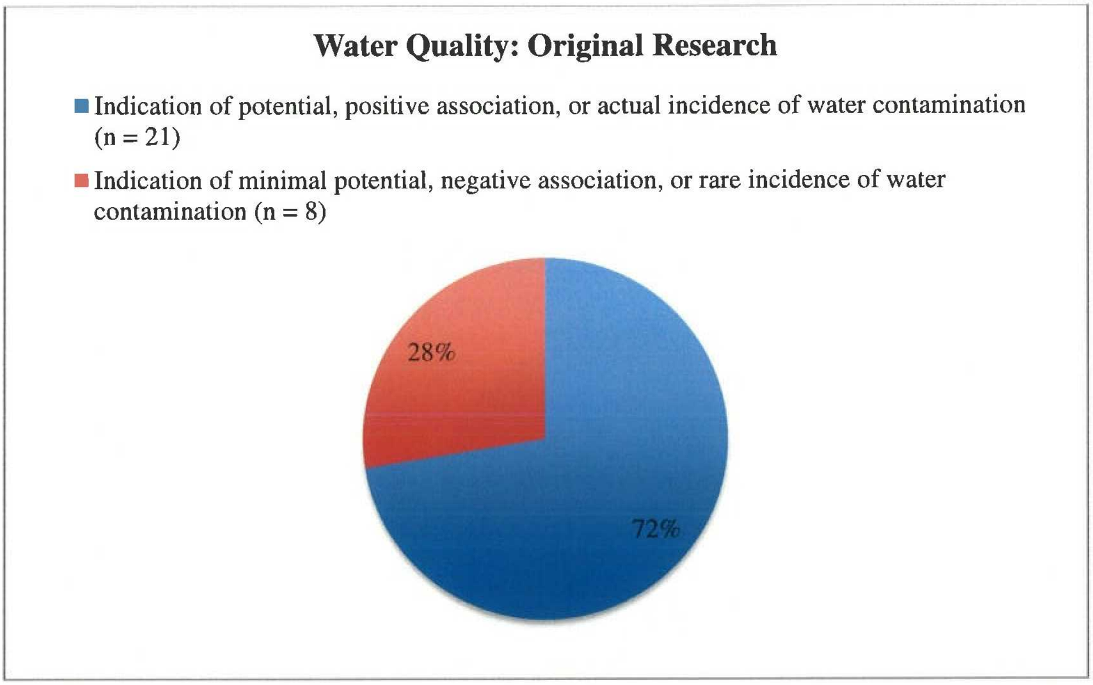
## Results

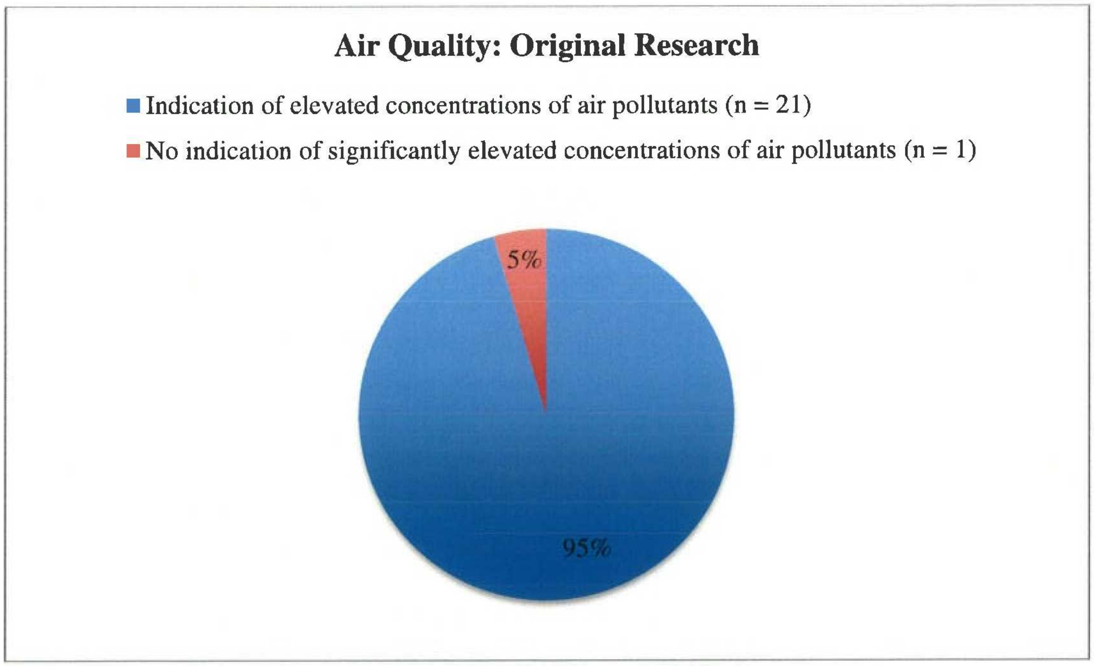
### Health: Original Research




### Health: All Papers




Water Quality: Original Research
Indication of potential, positive association, or actual incidence of water contamination (n = 21)
Indication of minimal potential, negative association, or rare incidence of water contamination (n = 8)
28%
72%


Air Quality: Original Research
Indication of elevated concentrations of air pollutants (n = 21)
No indication of significantly elevated concentrations of air pollutants (n = 1)
5%
95%

## Limitations

This project aims to provide an overview of existing scientific studies and findings based on the world's experience with shale gas development. While our database is, to our best estimation, exhaustive, our literature search may not have captured all relevant scientific literature. Additionally, differences in geography may render some studies less relevant when interpreted across geographic and geological space. While the majority of the studies included in this analysis are directly relevant to shale gas development, some may include data from other types of well stimulation-enabled oil and gas reservoirs, such as that from tight sands. However, because many of the processes are, for practical purposes, sufficiently similar (e.g., drilling, hydraulic fracturing, generation and disposal of waste), we have included them in this analysis.

Despite the inherent limitations in this type of analysis, our literature review provides a general idea of the weight of the scientific evidence of possible impacts that could ensue in New York State should it open its borders to shale gas development. It is important to note that this analysis only concerns itself with current empirical evidence and does not take into account developments that could potentially influence environmental and public health outcomes in positive or negative ways under different regulatory regimes. For instance, technological improvements may mitigate some existing problems, but as development continues, well pad intensities increase, and novel geologies and practices are encountered, impacts may increase.

Finally, all forms of energy production and industrial processing have environmental impacts. This report is only focused on reviewing and presenting the available science on some of the most salient environmental and public health concerns associated with shale gas development. We make no claims about the level of impacts that should be tolerated by society – these are ultimately questions of societal values.

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# Appendix

## Health: Original Research (n = 15)

- *Indication of potential risks or adverse health outcomes (n = 13)*


1. Bamberger M, Oswald RE. 2012. Impacts of Gas Drilling on Human and Animal Health. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 22:51–77; doi:10.2190/NS.22.1.e.
2. Colborn T, Kwiatkowski C, Schultz K, Bachran M. 2011. Natural Gas Operations from a Public Health Perspective. Human and Ecological Risk Assessment: An International Journal 17:1039–1056; doi:10.1080/10807039.2011.605662.
3. Colborn T, Schultz K, Herrick L, Kwiatkowski C. 2014. An Exploratory Study of Air Quality near Natural Gas Operations. Human and Ecological Risk Assessment: An International Journal 0:null; doi:10.1080/10807039.2012.749447.
4. Esswein EJ, Breitenstein M, Snawder J, Kiefer M, Sieber WK. 2013. Occupational exposures to respirable crystalline silica during hydraulic fracturing. J Occup Environ Hyg 10:347–356; doi:10.1080/15459624.2013.788352.
5. Esswein EJ, Snawder J, King B, Breitenstein M, Alexander-Scott M, Kiefer M. 2014. Evaluation of Some Potential Chemical Exposure Risks During Flowback Operations in Unconventional Oil and Gas Extraction: Preliminary Results. Journal of Occupational and Environmental Hygiene 11:D174–D184; doi:10.1080/15459624.2014.933960.
6. Ferrar KJ, Kriesky J, Christen CL, Marshall LP, Malone SL, Sharma RK, et al. 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. International Journal of Occupational and Environmental Health 19:104–112; doi:10.1179/2049396713Y.0000000024.
7. Kassotis CD, Tillitt DE, Davis JW, Hormann AM, Nagel SC. 2013. Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region. Endocrinology 155:897–907; doi:10.1210/en.2013-1697.
8. Macey GP, Breech R, Chernaik M, Cox C, Larson D, Thomas D, et al. 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 13:82; doi:10.1186/1476-069X-13-82.
9. McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, Adgate JL. 2014. Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado. Environmental Health Perspectives 122; doi:10.1289/ehp.1306722.
10. McKenzie LM, Witter RZ, Newman LS, Adgate JL. 2012. Human health risk assessment of air emissions from development of unconventional natural gas resources. Sci. Total Environ. 424:79–87; doi:10.1016/j.scitotenv.2012.02.018.
11. Rabinowitz PM, Slizovskiy IB, Lamers V, Trufan SJ, Holford TR, Dziura JD, et al. 2014. Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. Environmental Health Perspectives; doi:10.1289/ehp.1307732.
12. Saberi P, Propert KJ, Powers M, Emmett E, Green-McKenzie J. 2014. Field Survey of Health Perception and Complaints of Pennsylvania Residents in the Marcellus Shale Region. Int J Environ Res Public Health 11:6517–6527; doi:10.3390/ijerph110606517.
13. Steinzor N, Subra W, Sumi L. 2013. Investigating Links between Shale Gas Development and Health Impacts Through a Community Survey Project in Pennsylvania. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 23:55–83; doi:10.2190/NS.23.1.e.


- *No indication of significant risks or adverse health outcomes (n = 2)*


1. Bunch AG, Perry CS, Abraham L, Wikoff DS, Tachovsky JA, Hixon JG, et al. 2014. Evaluation

of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Science of The Total Environment 468–469:832–842; doi:10.1016/j.scitotenv.2013.08.080.
2. Fryzek J, Pastula S, Jiang X, Garabrant DH. 2013. Childhood cancer incidence in pennsylvania counties in relation to living in counties with hydraulic fracturing sites. J. Occup. Environ. Med. 55:796–801; doi:10.1097/JOM.0b013e318289ee02.

**Health: All Papers (n = 47)**

- *Indication of potential risks or adverse health outcomes (n = 45)*

1. Adgate JL, Goldstein BD, McKenzie LM. 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol. 48:8307–8320; doi:10.1021/es404621d.
2. Bamberger M, Oswald RE. 2012. Impacts of Gas Drilling on Human and Animal Health. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 22:51–77; doi:10.2190/NS.22.1.e.
3. Bamberger M, Oswald RE. 2014. Unconventional oil and gas extraction and animal health. Environ. Sci.: Processes Impacts; doi:10.1039/C4EM00150H.
4. Chalupka S. 2012. Occupational silica exposure in hydraulic fracturing. Workplace Health Saf 60:460; doi:10.3928/21650799-20120926-70.
5. Colborn T, Kwiatkowski C, Schultz K, Bachran M. 2011. Natural Gas Operations from a Public Health Perspective. Human and Ecological Risk Assessment: An International Journal 17:1039–1056; doi:10.1080/10807039.2011.605662.
6. Colborn T, Schultz K, Herrick L, Kwiatkowski C. 2014. An Exploratory Study of Air Quality near Natural Gas Operations. Human and Ecological Risk Assessment: An International Journal 0:null; doi:10.1080/10807039.2012.749447.
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9. Esswein EJ, Breitenstein M, Snawder J, Kiefer M, Sieber WK. 2013. Occupational exposures to respirable crystalline silica during hydraulic fracturing. J Occup Environ Hyg 10:347–356; doi:10.1080/15459624.2013.788352.
10. Esswein EJ, Snawder J, King B, Breitenstein M, Alexander-Scott M, Kiefer M. 2014. Evaluation of Some Potential Chemical Exposure Risks During Flowback Operations in Unconventional Oil and Gas Extraction: Preliminary Results. Journal of Occupational and Environmental Hygiene 11:D174–D184; doi:10.1080/15459624.2014.933960.
11. Ferrar KJ, Kriesky J, Christen CL, Marshall LP, Malone SL, Sharma RK, et al. 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. International Journal of Occupational and Environmental Health 19:104–112; doi:10.1179/2049396713Y.0000000024.
12. Finkel M, Hays J, Law A. 2013a. The Shale Gas Boom and the Need for Rational Policy. American Journal of Public Health e1–e3; doi:10.2105/AJPH.2013.301285.
13. Finkel ML, Hays J. 2013. The implications of unconventional drilling for natural gas: a global public health concern. Public Health 127:889–893; doi:10.1016/j.puhe.2013.07.005.
14. Finkel ML, Hays J, Law A. 2013b. Modern Natural Gas Development and Harm to Health: The Need for Proactive Public Health Policies. ISRN Public Health; doi:http://dx.doi.org/10.1155/2013/408658.
15. Finkel ML, Law A. 2011. The rush to drill for natural gas: a public health cautionary tale. Am J

Public Health 101:784–785; doi:10.2105/AJPH.2010.300089.
16. Goldstein BD. 2014. The importance of public health agency independence: marcellus shale gas drilling in pennsylvania. Am J Public Health 104:e13–15; doi:10.2105/AJPH.2013.301755.
17. Goldstein BD, Kriesky J, Pavliakova B. 2012. Missing from the Table: Role of the Environmental Public Health Community in Governmental Advisory Commissions Related to Marcellus Shale Drilling. Environ Health Perspect 120:483–486; doi:10.1289/ehp.1104594.
18. Hill M. 2014. Shale gas regulation in the UK and health implications of fracking. The Lancet 383:2211–2212; doi:10.1016/S0140-6736(14)60888-6.
19. Kaktins NM. 2011. Drilling the Marcellus shale for natural gas: environmental health issues for nursing. Pa Nurse 66: 4–8; quiz 8–9.
20. Kassotis CD, Tillitt DE, Davis JW, Hormann AM, Nagel SC. 2013. Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region. Endocrinology 155:897–907; doi:10.1210/en.2013-1697.
21. Korfmacher KS, Elam S, Gray KM, Haynes E, Hughes MH. 2014. Unconventional natural gas development and public health: toward a community-informed research agenda. Reviews on Environmental Health; doi:10.1515/reveh-2014-0049.
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23. Kovats S, Depledge M, Haines A, Fleming LE, Wilkinson P, Shonkoff SB, et al. 2014. The health implications of fracking. The Lancet 383:757–758; doi:10.1016/S0140-6736(13)62700-2.
24. Lauver LS. 2012. Environmental health advocacy: an overview of natural gas drilling in northeast Pennsylvania and implications for pediatric nursing. J Pediatr Nurs 27:383–389; doi:10.1016/j.pedn.2011.07.012.
25. Law A, Hays J, Shonkoff SB, Finkel ML. 2014. Public Health England's draft report on shale gas extraction. BMJ 348:g2728–g2728; doi:10.1136/bmj.g2728.
26. Macey GP, Breech R, Chernaik M, Cox C, Larson D, Thomas D, et al. 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 13:82; doi:10.1186/1476-069X-13-82.
27. Mackie P, Johnman C, Sim F. 2013. Hydraulic fracturing: a new public health problem 138 years in the making? Public Health 127:887–888; doi:10.1016/j.puhe.2013.09.009.
28. Mash R, Minnaar J, Mash B. 2014. Health and fracking: Should the medical profession be concerned? S. Afr. Med. J. 104: 332–335.
29. McDermott-Levy BR, Kaktins N, Sattler B. 2013. Fracking, the Environment, and Health. AJN, American Journal of Nursing 113:45–51; doi:10.1097/01.NAJ.0000431272.83277.f4.
30. McDermott-Levy R, Kaktins N. 2012. Preserving health in the Marcellus region. Pa Nurse 67: 4–10; quiz 11–12.
31. McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, Adgate JL. 2014. Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado. Environmental Health Perspectives 122; doi:10.1289/ehp.1306722.
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34. Perry SL. 2013. Using Ethnography to Monitor the Community Health Implications of Onshore Unconventional Oil and Gas Developments: Examples from Pennsylvania's Marcellus Shale. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 23:33–53; doi:10.2190/NS.23.1.d.
35. Rabinowitz PM, Slizovskiy IB, Lamers V, Trufan SJ, Holford TR, Dziura JD, et al. 2014.

Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. Environmental Health Perspectives; doi:10.1289/ehp.1307732.
36. Rafferty MA, Limonik E. 2013. Is shale gas drilling an energy solution or public health crisis? Public Health Nurs 30:454–462; doi:10.1111/phn.12036.
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- *No indication of significant risks or adverse health outcomes (n = 2)*

1. Bunch AG, Perry CS, Abraham L, Wikoff DS, Tachovsky JA, Hixon JG, et al. 2014. Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Science of The Total Environment 468–469:832–842; doi:10.1016/j.scitotenv.2013.08.080.
2. Fryzek J, Pastula S, Jiang X, Garabrant DH. 2013. Childhood cancer incidence in pennsylvania counties in relation to living in counties with hydraulic fracturing sites. J. Occup. Environ. Med. 55:796–801; doi:10.1097/JOM.0b013e318289ee02.

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**Water Quality: Original Research (n = 29)**

- *Indication of potential, positive association, or actual incidence of water contamination (n = 21)*


1. Darrah TH, Vengosh A, Jackson RB, Warner NR, Poreda RJ. 2014. Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales. PNAS 201322107; doi:10.1073/pnas.1322107111.
2. Davies RJ, Almond S, Ward RS, Jackson RB, Adams C, Worrall F, et al. 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology 56:239–254; doi:10.1016/j.marpetgeo.2014.03.001.
3. Ferrar KJ, Michanowicz DR, Christen CL, Mulcahy N, Malone SL, Sharma RK. 2013. Assessment of effluent contaminants from three facilities discharging Marcellus Shale wastewater to surface waters in Pennsylvania. Environ. Sci. Technol. 47:3472–3481; doi:10.1021/es301411q.
4. Fontenot BE, Hunt LR, Hildenbrand ZL, Carlton Jr. DD, Oka H, Walton JL, et al. 2013. An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation. Environ. Sci. Technol. 47:10032–10040; doi:10.1021/es4011724.
5. Gassiat C, Gleeson T, Lefebvre R, McKenzie J. 2013. Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential contamination of shallow aquifers over long time scales. Water Resour. Res. 49:8310–8327; doi:10.1002/2013WR014287.
6. Gross SA, Avens HJ, Banducci AM, Sahmel J, Panko JM, Tvermoes BE. 2013. Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. J Air Waste Manag Assoc 63: 424–432.
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10. Jackson RB, Vengosh A, Darrah TH, Warner NR, Down A, Poreda RJ, et al. 2013. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. PNAS 110:11250–11255; doi:10.1073/pnas.1221635110.
11. Kassotis CD, Tillitt DE, Davis JW, Hormann AM, Nagel SC. 2013. Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region. Endocrinology 155:897–907; doi:10.1210/en.2013-1697.
12. Myers T. 2012. Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers. Ground Water 50:872–882; doi:10.1111/j.1745-6584.2012.00933.x.
13. Olmstead SM, Muehlenbachs LA, Shih J-S, Chu Z, Krupnick AJ. 2013. Shale gas development impacts on surface water quality in Pennsylvania. Proc. Natl. Acad. Sci. U.S.A. 110:4962–4967; doi:10.1073/pnas.1213871110.
14. Osborn SG, Vengosh A, Warner NR, Jackson RB. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. PNAS 108:8172–8176; doi:10.1073/pnas.1100682108.
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Sci. Technol.; doi:10.1021/es5028184.
17. Rozell DJ, Reaven SJ. 2012. Water pollution risk associated with natural gas extraction from the Marcellus Shale. Risk Anal. 32:1382–1393; doi:10.1111/j.1539-6924.2011.01757.x.
18. Trexler R, Solomon C, Brislawn CJ, Wright JR, Rosenberger A, McClure EE, et al. 2014. Assessing impacts of unconventional natural gas extraction on microbial communities in headwater stream ecosystems in Northwestern Pennsylvania. Front. Microbiol 5:522; doi:10.3389/fmicb.2014.00522.
19. Warner NR, Christie CA, Jackson RB, Vengosh A. 2013a. Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania. Environ. Sci. Technol.; doi:10.1021/es402165b.
20. Warner NR, Darrah TH, Jackson RB, Millot R, Kloppmann W, Vengosh A. 2014. New Tracers Identify Hydraulic Fracturing Fluids and Accidental Releases from Oil and Gas Operations. Environ. Sci. Technol.; doi:10.1021/es5032135.
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- *Indication of minimal potential, negative association, or rare incidence of water contamination (n = 8)*

1. Brantley SL, Yoxtheimer D, Arjmand S, Grieve P, Vidic R, Pollak J, et al. 2014. Water resource impacts during unconventional shale gas development: The Pennsylvania experience. International Journal of Coal Geology; doi:10.1016/j.coal.2013.12.017.
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3. Flewelling SA, Sharma M. 2014. Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine. Groundwater 52:9–19; doi:10.1111/gwat.12095.
4. Flewelling SA, Tymchak MP, Warpinski N. 2013. Hydraulic fracture height limits and fault interactions in tight oil and gas formations. Geophysical Research Letters 40:3602–3606; doi:10.1002/grl.50707.
5. Li H, Carlson KH. 2014. Distribution and Origin of Groundwater Methane in the Wattenberg Oil and Gas Field of Northern Colorado. Environ. Sci. Technol. 48:1484–1491; doi:10.1021/es404668b.
6. Molofsky LJ, Connor JA, Wylie AS, Wagner T, Farhat SK. 2013. Evaluation of methane sources in groundwater in northeastern pennsylvania. Ground Water 51:333–349; doi:http://onlinelibrary.wiley.com/doi/10.1111/gwat.12056/abstract.
7. Pelak AJ, Sharma S. 2014. Surface water geochemical and isotopic variations in an area of accelerating Marcellus Shale gas development. Environmental Pollution 195:91–100; doi:10.1016/j.envpol.2014.08.016.
8. Warner NR, Kresse TM, Hays PD, Down A, Karr JD, Jackson RB, et al. 2013b. Geochemical and isotopic variations in shallow groundwater in areas of the Fayetteville Shale development, north-central Arkansas. Applied Geochemistry 35:207–220; doi:10.1016/j.apgeochem.2013.04.013.

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## Air Quality: Original Research (n = 22)

- *Indication of elevated concentrations of air pollutants (n = 21)*


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# Environmental Public Health Dimensions of Shale and Tight Gas Development

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BACKGROUND: The United States has experienced a boom in natural gas production due to recent technological innovations that have enabled this resource to be produced from shale formations.

OBJECTIVES: We reviewed the body of evidence related to exposure pathways in order to evaluate the potential environmental public health impacts of shale gas development. We highlight what is currently known and identify data gaps and research limitations by addressing matters of toxicity, exposure pathways, air quality, and water quality.

DISCUSSION: There is evidence of potential environmental public health risks associated with shale gas development. Several studies suggest that shale gas development contributes to ambient air concentrations of pollutants known to be associated with increased risk of morbidity and mortality. Similarly, an increasing body of studies suggest that water contamination risks exist through a variety of environmental pathways, most notably during wastewater transport and disposal, and via poor zonal isolation of gases and fluids due to structural integrity impairment of cement in gas wells.

CONCLUSION: Despite a growing body of evidence, data gaps persist. Most important, there is a need for more epidemiological studies to assess associations between risk factors, such as air and water pollution, and health outcomes among populations living in close proximity to shale gas operations.

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## Introduction

Technological innovations in drilling and well-stimulation techniques have led to the production of natural gas from previously inaccessible geological formations, such as shale. Proponents of modern gas development argue that it has created a unique economic and political opportunity. Some in the public health community, however, have concerns about the potential for the extraction process to negatively impact the environment and human health (Finkel et al. 2013; Goldstein et al. 2012; Saberi 2013; Witter et al. 2013).

Producing natural gas from shale and tight gas formations in an economically feasible manner frequently requires a new constellation of existing technologies: high-volume, slickwater, hydraulic fracturing from clustered, multiwell pads using long directionally drilled laterals. This method can involve drilling a well vertically thousands of feet below the surface and then directionally (horizontally) for up to 2 miles. An average of 2–5 million gallons of fluid consisting of water, proppant (often crystalline silica), and chemicals (some of which are known carcinogens or otherwise toxic) are injected into the well at a pressure high enough to fracture the shale rock [U.S. Environmental Protection Agency (EPA) 2010a]. Chemicals often referred to as slickwater are added to the fracturing fluid to decrease its friction. The fracturing fluid creates and expands cracks in the shale. When the pressure is released, the cracks are held open by the sand, allowing the tightly held gases to flow into the cracks and up the production casing. The gas is then collected, processed, and sent through transmission pipelines to market. In 2012, shale gas constituted nearly 40% of U.S. gas production, up from 2% in 2000 (Hughes 2013).

Natural gas has a variety of attractive attributes. In the current market, it is a relatively inexpensive and abundant fuel. When combusted for electricity generation, it emits fewer health-damaging contaminants and approximately 50% less carbon dioxide emissions compared with burning coal (U.S. Energy Information Administration 2013). Yet, emerging scientific evidence suggests that there may be health risks associated with the development of shale gas.

In this review we discuss the body of scientific literature relevant to the environmental public health impacts of shale gas production. We highlight what is currently known and identify data gaps and research limitations.

## Methods

*Scope of review.* For this review, we focused primarily on literature directly pertinent to the human health dimensions of shale and tight gas development. "Tight gas" refers to natural gas produced from reservoir rocks of low permeability, such as shale or sandstone. Shale gas and other forms of tight gas are referred to as "unconventional" because of their atypical reservoirs, which require new production techniques. However, we cite some studies that did not directly evaluate unconventional natural gas operations, but that are nonetheless relevant to various aspects of the overall process [e.g., particulate matter (PM) pollution, ozone]. In the case of ozone, for instance, we analyzed top-down studies that measured tropospheric concentrations rather than studies that supplied bottom-up measurements (e.g., leakage rates). Publications included in our review are predominantly sourced from the peer-reviewed scientific literature but include, where appropriate, government reports and other gray literature. Although the production chain of gas development is far reaching, we focused on the processes that begin with trucking the water, sand, chemicals, and other materials to the well pad, and end with the disposal of wastewater. Evidence suggests that these processes present the greatest risks to environmental public health and therefore have received the most attention in the scientific literature (Korfmacher et al. 2013; McKenzie et al. 2012; Rozell and Reaven 2012; Witter et al. 2013).

*Terminology.* Terminology is important when discussing modern forms of natural gas development. In part because of a lack of well-defined, uniform terminology, there has been confusion regarding which processes constitute this type of development. The terms, "hydraulic fracturing" or "fracking" are regularly used in the popular media as umbrella terms to describe the entire process of obtaining shale gas, as well as other forms of unconventional natural gas development, from land clearing and well spudding to transmission of natural gas to market. However, taken literally, "hydraulic fracturing" refers only to well-stimulation processes and excludes other potentially more health and environmentally

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impactful processes, including but not limited to well drilling, fracturing-fluid production, wastewater disposal, transportation of materials, and the processing, compression, and transmission of gas and liquids.

Many of the studies we cite in this review may also apply to other forms of oil and gas development that use well-stimulation techniques, including matrix acid stimulation, acid fracturing, and steam injection. However, these other techniques are beyond the focus of this review. The term "unconventional oil and gas development" can also refer to bitumen/tar sands extraction and processing, and other types of fossil fuel development that employ novel engineering and production techniques to obtain fuels from unconventional resources (e.g., coalbed methane) that are beyond the scope of our review. Because most of the environmental public health–relevant scientific literature on modern oil and gas production has focused on the development of natural gas from shale formations, we use the term "shale gas development." However, here we discuss, where appropriate, scientific literature on other forms of unconventional or tight gas development that include the most prominent and relevant features of shale gas development, such as high-volume, horizontal hydraulic fracturing.

*Identification of relevant studies.* The literature directly relevant to the environmental public health dimensions of shale gas development is still limited. For this reason, we adopted a broad search strategy comprising the following:

- Systematic searches in three peer-reviewed science databases across multiple disciplines: PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://www.webofknowledge.com), and ScienceDirect (http://www.sciencedirect.com)
- Searches in existing collections of scientific literature on this subject, such as the Marcellus Shale Initiative Publications Database at Bucknell University (http://www.bucknell.edu/script/environmentalcenter/marcellus), complemented by Google (http://www.google.com) and Google Scholar (http://scholar.google.com)
- Manual searches (hand-searches) of references included in all peer-reviewed studies that pertained directly to shale gas development.

For bibliographic databases, we used a combination of Medical Subject Headings (MeSH)-based and keyword strategies, which included the following terms, as well as relevant combinations:

shale gas, shale, hydraulic fracturing, fracking, drilling, natural gas production, Marcellus, Barnett, Denver-Julesberg Basin, air pollution, methane, water pollution, public health, water contamination, fugitive emissions, air quality, epidemiology, unconventional gas development, and environmental pathways.

This search identified a total of 211 peer-reviewed publications that pertain directly to shale gas development. [This database, the PSE STUDY CITATION DATABASE on Shale Gas & Tight Oil Development, is available online (http://psehealthyenergy.org/site/view/1180), and we will continue to update it with relevant literature.] Of these 211 publications, only 33 presented original data that met our inclusion criteria and that we considered relevant as primary literature.

*Inclusion/exclusion criteria.* From the studies identified through 1 February 2014, we excluded nonrelevant technical papers and studies related to economics, climate change, sociology, regulation, seismicity, water usage, social stress, and quality of life considerations. Although we excluded commentaries from the results of our review, a few are cited in order to provide documentation of particular considerations among the public health community. We included studies with direct pertinence to the environmental public health and environmental exposure pathways (i.e., air and water) associated with shale and tight gas development. In this regard, we supplemented the shale gas literature with studies that evaluated particular environmental pathways and health outcomes. For instance, we included studies directly related to the health impacts of tropospheric ozone, fine particulate air pollution, and endocrine-disrupting chemicals (EDCs). We excluded the vast majority of non–peer-reviewed scientific literature, but environmental impact statements and other government reports are cited where appropriate.

## Results

***The environmental public health framework and possible exposure pathways.*** The environmental exposure pathway framework is often used to describe associations between pollutant sources and health effects via emissions, environmental concentrations of pollutants, pollutant exposure pathways (e.g., mouth, nose, ears, eyes, skin), and dose (i.e., micrograms of pollutant ingested per day) (Figure 1) (Agency for Toxic Substances and Disease Registry 2005).

Potential sources of health-relevant environmental pollution are present throughout many phases of shale gas development. These sources include shale gas production and processing activities (i.e., drilling, hydraulic fracturing, hydrocarbon processing and production, and wastewater disposal);.the transmission and distribution of the gas to market (i.e., transmission lines and distribution pipes); and the transportation of water, sand, chemicals, and wastewater before, during, and after hydraulic fracturing.

## Hydraulic Fracturing Fluids: Chemical Toxicology and Exposure Pathways

Shale gas development uses fracturing fluids that contain organic and inorganic chemicals known to be health damaging (Aminto and Olson 2012; U.S. House of Representatives, Committee on Energy and Commerce 2011). Fracturing fluids can move through the environment and come into contact with humans in a number of ways, including surface leaks, spills, releases from holding tanks, poor well construction, leaks and accidents during transportation of fluids, flowback and produced water to and from the well pad, and run-off during blowouts, storms, and flooding events (Rozell and Reaven 2012). Further, the mixing of these compounds under conditions of high pressure—and often high heat—may synergistically create additional potentially toxic compounds (Kortenkamp et al. 2007; Teuschler and Hertzberg 1995; Wilkinson et al. 2000). Compounds found in these mixtures may pose risks to the environment and to public health through numerous environmental pathways, including water, air, and soil (Leenheer et al. 1982).

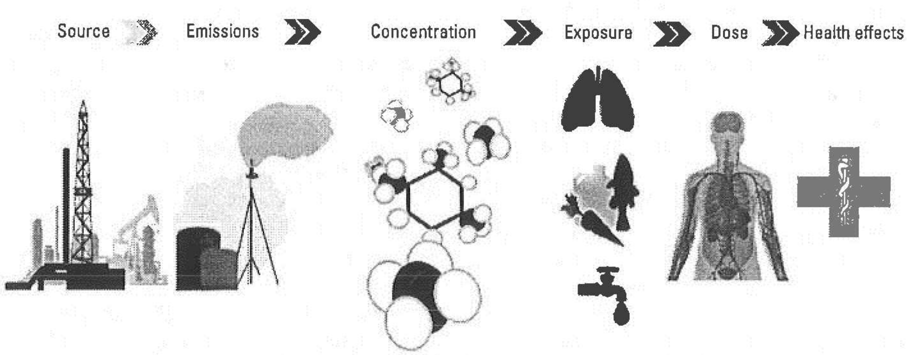


**Figure 1.** The environmental exposure pathway provides an analytical framework to describe, in broad terms, the connections between pollutant sources and human health outcomes. This framework begins with the emission source, in this case a well pad and associated infrastructure, which emit a variety of contaminants into the air, water, and soil. The concentrations of pollutants in the air, water, and soil that result from these emissions influence the magnitude of human exposures through organs such as the nose, mouth, and skin. Once the level of exposure is identified, it is then possible to estimate the dose, or how much of the pollutant is ingested in a given period of time. The dose, in turn, determines the health outcome.

Chemicals are used in drilling and fracturing processes as corrosion inhibitors, biocides, surfactants, friction reducers, gels, and scale inhibitors, among others (Aminto and Olson 2012; New York State Department of Environmental Conservation 2011; Southwest Energy 2012). These chemicals include methanol, ethylene glycol, naphthalene, xylene, toluene, ethylbenzene, formaldehyde, and sulfuric acid, some of which are known to be toxic, carcinogenic, or associated with reproductive harm (Colborn et al. 2011; New York State Department of Environmental Conservation 2011). Many of these compounds are considered hazardous water pollutants and are regulated in other industries (Clean Water Act of 1972; Safe Drinking Water Act of 1974; U.S. House of Representatives 2011).

Many of the chemical compounds used in the fracturing process lack scientifically based maximum contaminant levels, making it more difficult to quantify their public health risks (Colborn et al. 2011). Moreover, uncertainty about the chemical makeup of fracturing fluids persists because of the limitations on required chemical disclosure, driven by the Energy Policy Act of 2005. For instance, in many states, companies are not mandated to disclose information about the quantities, concentrations, or identities of chemicals used in the process on the principle that trade secrets might be revealed (Centner 2013; Centner and O'Connell 2014; Maule et al. 2013).

Some companies make efforts to be more transparent in the disclosure of chemicals used in the process. FracFocus (http://www.fracfocus.org) was developed as an online, voluntary chemical disclosure registry, and some agencies (e.g., Bureau of Land Management) have suggested that it be used as a regulatory compliance tool (Konschnik et al. 2013). However, the registry has been criticized because of uncertainty surrounding the timing, substance, and omissions of the disclosed data on the website (Konschnik et al. 2013).

Because of the limited information that is available, researchers have sought to acquire more information on the chemical makeup of fracturing fluids through other means. For example, using material safety data sheets, Colborn et al. (2011) identified 353 of 632 chemicals contained in 944 products used for natural gas operations in Colorado, and they examined available information on each product. Their study represents one of the first attempts to conduct a chemical hazard assessment by identifying some of the compounds in fracturing fluids.

It should be noted that the scope of the study by Colborn et al. (2011) is limited in that they did not measure exposure, dose, or health outcomes across populations. The researchers identified Chemical Abstract Service (CAS) numbers for the chemicals and used these in systematic searches of databases such as TOXNET (http://toxnet.nlm.nih.gov). On the basis of search results, the researchers classified the compounds into 12 health-effects categories. At certain concentrations or doses, > 75% of the chemicals they identified are known to negatively impact the skin, eyes, and other sensory organs; the respiratory system; the gastrointestinal system; and the liver. Fifty-two percent of the chemicals have the potential to negatively affect the nervous system, and 37% are candidate EDCs (Colborn et al. 2011).

EDCs present unique hazards, particularly during fetal and early childhood growth and development (Diamanti-Kandarakis et al. 2009). They can affect the reproductive system and epigenetic mechanisms that may lead to pathology decades after exposure (Zoeller et al. 2012). EDCs have challenged traditional concepts in toxicology because effects at higher doses do not always predict effects at low doses (Vandenberg et al. 2012). In other words, the dose does not always make the poison.

Kassotis et al. (2014) measured estrogen and androgen receptor activity in surface and groundwater samples in Colorado using reporter gene assays in human cell lines. Water samples collected from the more intensive areas of natural gas development exhibited statistically significantly more estrogenic, antiestrogenic, or antiandrogenic activity than references sites with either no operations or fewer operations (Kassotis et al. 2014). The concentrations of chemicals detected were in high enough concentrations to interfere with the response of human cells to male sex hormones and estrogen. This study by Kassotis et al. (2014) indicated that EDCs are a potential health concern in natural gas operations, and suggested that chemicals used in the process should be screened for EDC activity.

## Air Quality

Air pollutant emission sources from shale gas development can be grouped into two main categories: *a*) emissions from drilling, processing, well completions, servicing, and other gas production activities; and *b*) emissions from transportation of water, sand, chemicals, and equipment to and from the well pad.

***Air pollution: drilling, well stimulation, gas production, processing, and servicing.*** The literature suggests that shale gas development processes emit hazardous air pollutants including—but not limited to—BTEX compounds (benzene, toluene, ethylbenzene, and xylene), formaldehyde, hydrogen sulfide, acrylonitrile, methylene chloride, sulfuric oxide, nitrogen oxides ($NO_x$), volatile organic compounds (VOCs), trimethylbenzenes, aliphatic hydrocarbons, diesel PM, and radon gas (McKenzie et al. 2012; Pétron et al. 2012; Roy et al. 2013). These emissions can result in elevated air pollution concentrations that exceed U.S. EPA guidelines for both carcinogenic and noncarcinogenic health risks (McKenzie et al. 2012; Meteorological Solutions Inc. 2011).

McKenzie et al. (2012) used U.S. EPA guidance to estimate chronic and subchronic non-cancer hazard indices (HIs) and cancer risks from exposure to hydrocarbons for residents living > 0.5 mile and ≤ 0.5 mile from wells in Colorado. The authors found that residents living ≤ 0.5 mile from wells were at a greater risk for health effects from exposure to natural gas development than those living > 0.5 mile from wells. Notably, they found a subchronic non-cancer HI of 5 for those living ≤ 0.5 mile compared with an HI of 0.2 for those living > 0.5 mile from wells, which was driven primarily from exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons (McKenzie et al. 2012). Unfortunately, baseline air quality data prior to the study were not available. However, the statistically significant spatial associations between air quality and shale gas development indicate that air quality may be negatively impacted and health risks may increase during various stages of shale gas development.

Bunch et al. (2013), however, found that shale gas production activities did not result in community-wide exposures to concentrations of VOCs at levels that would pose a health concern. They compared VOC concentration data from seven air monitors at six locations in the Barnett Shale region in Texas with federal and state health-based air comparison values (HBACVs) in order to determine possible acute and chronic health effects; none of the concentrations exceeded acute HBACVs (Bunch et al. 2013). Air quality data included in their study were generated from monitors focused on regional atmospheric concentrations of pollutants (Bunch et al. 2013). Conversely, McKenzie et al. (2012) included samples at the community level in close proximity to gas development. Finer geographically scaled samples often capture local atmospheric concentrations that are more relevant to human exposure. This may be a primary reason why health hazard estimates differed between the two studies.

Roy et al. (2013) estimated emissions of $NO_x$, VOCs, and PM for an air emissions inventory for the development of natural gas in the Marcellus Shale region for 2009 and 2020. They predicted that, in 2020, shale gas development activities would contribute 6–20% (mean, 12%) of the $NO_x$ emissions and 6–31% (mean, 12%) of anthropgenic VOC emissions in Pennsylvania. However, these estimates were based on assumptions of improvements in gas production, completion, and processing infrastructure. If source-level emissions remain the same as in 2009, Marcellus VOC emissions were predicted to constitute approximately 34% (19–62%) of the regional anthropogenic VOC emissions in 2020 (Roy et al. 2013). Increases in emissions of VOCs and NOx, which are precursors of tropospheric ozone formation, could complicate ozone management in the region and potetentially offset ozone precursor emission reductions in other sectors at a time when several regions in Pennsylvania struggle to be within ozone attainment (Roy et al. 2013).

In another study focused on hydrocarbon emissions, Colborn et al. (2014) assessed air quality in western Colorado using weekly air samples collected before, during, and after drilling and hydraulic fracturing on a new natural gas well pad. They found numerous chemicals in the air samples that are associated with natural gas development operations, most notably methane, ethane, propane, and other alkanes. Many non-methane hydrocarbons (NMHCs), which were observed during the initial drilling phase, are associated with multiple health effects. Notably, 30 of the NMHCs they observed in the field were EDCs. In addition to the direct air pollution associated with natural gas drilling and processing (e.g., NMHCs, VOCs) outlined above, there are also indirect pollution concerns, such as the secondary atmospheric formation of tropospheric (ground-level) ozone (Colborn et al. 2014).

Studies have indicated that shale gas development is associated with the production of secondary pollutants such as tropospheric (ground-level) ozone, which is formed through the interaction of methane, VOCs, and $NO_x$ in the presence of sunlight (Jerrett et al. 2009; U.S. EPA 2013). Tropospheric ozone is a strong respiratory irritant associated with increased respiratory and cardiovascular morbidity and mortality (Jerrett et al. 2009; United Nations Environment Programme 2011). Although toxicological data suggest that pure methane is not by itself health damaging (excluding its role as an asphyxiant and an explosive), it is a precursor to global tropospheric ozone (Smith et al. 2009).

Pétron et al. (2012) analyzed data collected at the National Oceanic and Atmospheric Administration (NOAA) Boulder Atmospheric Observatory (http://www.esrl.noaa.gov/psd/technology/bao) and filtered by wind sector, which indicated a high alkane and benzene signature from the direction of the Denver-Julesburg Basin, an area of considerable oil and gas development. The researchers found that an estimated 4% (range, 2.3–7.7%) of all natural gas (composed mostly of methane) produced was being accidentally leaked or purposefully vented to the atmosphere (Pétron et al. 2012). Karion et al. (2013) observed significant methane leaks in the Uintah Basin shale gas field, with an estimated 6.2–11.7% of total gas production leaking into the atmosphere.

In a national methane emissions study that combined ground and aerial sampling of methane with computer modeling, Miller et al. (2013) found that atmospheric levels of methane due to oil and gas extraction could be 4.9 ± 2.6 times greater than current estimates from the Emissions Database for Global Atmospheric Research (EDGAR) (http://edgar.jrc.ec.europa.eu/index.php) and the U.S. EPA. Although it is difficult to distinguish the sources of methane between oil and gas production and gas production, transmission, and storage, Peischl et al. (2013) estimated that 17% of gross methane production from oil and gas activities in the Los Angeles Basin are leaked or vented to the atmosphere.

Some studies have modeled ozone impacts associated with shale gas operations. Kemball-Cook et al. (2010) modeled ozone precursor emissions (VOCs and $NO_x$) in the Haynesville Shale play that lies beneath the northeast Texas/northwest Louisiana border. Photochemical modeling for 2012 showed increases in 8-hr ozone design values of up to 5 ppb, which, along with the amount of projected emissions, give cause for concern about future atmospheric concentrations of ozone in Texas and Louisiana (Kemball-Cook et al. 2010). Olaguer (2012) used the Houston Advanced Research Center (HARC) neighborhood air quality model to simulate ozone formation near a hypothetical natural gas–processing facility, using estimates based on both regular and nonroutine (e.g. flaring) emissions. This model predicted that under average conditions, using regular emissions associated with compressor engines may significantly increase ambient ozone in the Barnett Shale formation (> 3ppb at 2 km downwind from the facility) (Olaguer 2012).

Substantial air quality impacts from oil and natural gas operations in Wyoming, Colorado, Utah, and Texas have also been directly measured (Carter and Seinfeld 2012; Edwards et al. 2013; U.S. Department of Energy 2011). Schnell et al. (2009) studied air quality in the rural Upper Green River Basin (UGRB) of Wyoming near the Jonah-Pinedale Anticline natural gas field in February 2008. They observed high photochemical ozone concentrations in the UGRB in the winter, reporting readings of up to 140 ppb, just less than double the U.S. EPA ozone concentration limit of 75 ppb (U.S. EPA 2012a). Before 2005, typical wintertime ozone concentrations in this area were 30–40 ppb (Pinto 2009). This increase in ozone concentration during this time period could be associated with the increase in $NO_x$ and VOC emissions from oil and gas development activities in the area (Schnell et al. 2009). In a study conducted for the Wyoming Department of Environmental Quality, Meteorological Solutions Inc. (2011) found that the 8-hr ozone concentrations in the UGRB in 2011 exceeded the U.S. EPA ozone 8-hr standard for 13 days (Meteorological Solutions Inc. 2011) and exceeded the U.S. EPA scientists-recommended limit of 65 ppb for 25 days (Weinhold 2008).

In Utah there were 68 days in the winter of 2010 when ozone levels exceeded the U.S. EPA ozone standard of 75 ppb, and in 2011 there were readings more than double the U.S. EPA standard (Utah Department of Environmental Quality 2013). Results of experiments conducted by the U.S. EPA and NOAA indicated that ozone precursor emissions (VOCs and $NO_x$, primarily) from oil and gas development in the Uintah Basin in Utah were a primary factor in the increased ozone level (Utah Department of Environmental Quality 2013).

Crystalline silica sand, used as a proppant (to "prop" open cracks in the target formation to allow gas to flow up the well), is delivered by trucks to the drilling site. Transporting this sand in trucks and trains and mixing it into fracturing fluids with sand movers, conveyer belts, and blender hoppers at the well site release silica dust into the air, where well-pad workers can be exposed (Esswein et al. 2013). Workers experience the most direct exposure; however, silica dust may also be an air contaminant of concern to nearby residents. The etiological association between respiratory exposure to silica dust and the development of silicosis is well known [Centers for Disease Control and Prevention (CDC) 1992, 2002]. Silicosis is a progressive lung disease in which tissue in the lungs reacts to silica particles, and can result in inflammation and scarring, which decreases the ability of the lungs to take in oxygen (CDC 1992, 2002). Respiratory exposure to silica is also associated with other diseases such as chronic obstructive pulmonary disease, tuberculosis, kidney disease, autoimmune conditions, and lung cancer (CDC 2002).

In cooperation with industry partners, Esswein et al. (2013) collected full-shift air samples at 11 sites in five states to determine levels of worker exposure. Of 111 air samples, 51.4% showed silica exposures greater than the calculated Occupational Safety and Health Administration permissible exposure level and 68.5% showed exposures greater than the National Institute for Occupational Safety and Health recommended exposure limit of 0.05 $mg/m^3$ (Esswein et al. 2013). Further, these researchers noted that the type of respirators worn by workers were not sufficiently protective in some cases, given the magnitude of silica concentrations (Esswein et al. 2013).

*Air pollution: transportation.* Each well requires on average between 2 and 5 million gallons of water per hydraulic fracturing event (U.S. EPA 2010a). Water is generally not pumped directly to wells but is instead transported by diesel trucks, each of which has an approximate capacity of 3,000 gallons (U.S. EPA 2011b). It has been estimated that approximately 2,300 trips by heavy-duty trucks are required for each horizontal well during early stages of shale gas development (New York State Department of Environmental Conservation 2011). With thousands of such wells concentrated in high-development regions, levels of truck traffic and diesel-associated air pollution will increase in these areas.

The pollutant of primary health concern emitted from the transportation component of shale gas development is fine diesel PM. Diesel PM is a well-understood health-damaging pollutant that contributes to cardiovascular illnesses, respiratory diseases (e.g., lung cancer) (Garshick et al. 2008), atherosclerosis, and premature death (Pope 2002; Pope et al. 2004). For example, a study from the California Air Resources Board (Tran et al. 2008) indicated that there is an expected 10% (uncertainty interval: 3%, 20%) increase in the number of premature deaths per 10-$\mu g/m^3$ increase in $PM_{2.5}$ (PM ≤ 2.5 μm in aerodynamic diameter) exposure. Particulates can also contain concentrated associated products of incomplete combustion, and when particle diameter is < 2.5 μm, they can act as a delivery system to the alveoli of the human lung (Smith et al. 2009). In addition to diesel PM, as previously mentioned, $NO_x$ and VOCs—other pollutants prevalent in diesel emissions—react in the presence of sunlight and high temperatures to produce tropospheric (ground-level) ozone.

## Water Quality

Rozell and Reaven (2012) conducted a risk assessment that identified five main pathways of water contamination in the shale gas production process: *a*) transportation spills of fracturing fluid or produced water; *b*) well casing leaks; *c*) leaks through fractured rock; *d*) drilling site discharge; and *e*) wastewater disposal. They found that wastewater disposal carries a potential risk of water contamination several orders of magnitude larger than that of the other pathways (Rozell and Reaven 2012).

Other studies have suggested that structural impairment of cement used to prevent transzonal gas migration in the wellbore is the most common mechanism through which groundwater can become contaminated (Vidic et al. 2013). Indeed, state environmental regulators at the Pennsylvania Department of Environmental Protection found that oil and gas development was responsible for polluting water supplies for at least 161 residences in Pennsylvania between 2008 and 2012, primarily due to cement structural integrity in wells and wellbores (Legere 2013). For the purpose of this review, we focused primarily on well casing leaks, drilling site discharge, and wastewater disposal because these are generally regarded as the most viable means of water contamination (Rozell and Reaven 2012; Vidic et al. 2013).

*Flowback and produced water.* Estimates of the proportion of fracturing fluid that returns to the surface as flowback and produced waters range from 9% to 80%, with most estimates around 35% (Horn 2009; New York State Department of Environmental Conservation 2011; U.S. EPA 2010a). These wastewaters contain the chemicals used in the fracturing fluid as well as compounds found deep in geological strata, such as salts, chlorides, heavy metals (e.g., cadmium, lead, arsenic), organic chemicals (e.g., BTEX compounds), bromide, and—depending on the geology—naturally occurring radioactive materials (e.g., radium-226). Many of these naturally occurring compounds are associated with human health effects when exposure is sufficiently elevated (Balaba and Smart 2012; Colborn et al. 2011; Haluszczak et al. 2013). A proportion of flowback and produced waters are treated and released as effluent or for other beneficial uses, such as irrigation for agriculture. However, many of the chemicals persist in high quantities because treatment facilities are unable to screen for and eliminate the complex array of compounds and products of synergistic interactions among them (Ferrar et al. 2013; Hladik et al. 2014; Lutz et al. 2013).

Flowback and produced water are sometimes treated at facilities and then discharged into surface waters (Ferrar et al. 2013). Warner et al. (2013a) examined water quality and isotopic compositions of discharged effluents, surface waters, and stream sediments associated with a Marcellus wastewater treatment facility site. Their findings suggest that insufficiently treated flowback and produced water that contained elevated concentrations of contaminants associated with shale gas development entered local water supplies, even after treatment. They also found elevated levels of chloride and bromide downstream, along with radium-226 levels in stream sediments at the point of discharge, that were approximately 200 times greater than upstream and background sediments and well above regulatory standards (Warner et al. 2013a). These types of water emissions may increase the health risks of residents who rely on these surface and hydrologically contiguous groundwater sources for drinking water (Wilson and VanBriesen 2012) and sources of food (i.e., fish protein) (Papoulias and Velasco 2013).

In a meta-analysis of chemical and physical characterizations of produced waters from shale gas, Alley et al. (2011) found that most of the produced waters generated by shale gas development were classified as saline (> 30,000 mg/L) or hypersaline (> 40,000 mg/L). These authors pointed out that treatment of this produced water for beneficial use often involves reverse osmosis, a practice that may generate a waste stream too large to justify the activity. Alley et al. (2011) also found that prior to treatment, produced waters can exceed toxicity thresholds of contaminants of concern, including—but not limited to—phosphates, cadmium, aluminum, barium, chloride, strontium, radium-226, bromine, lithium, and magnesium. Toxicity thresholds used in their meta-analysis were $LC_{50}$ values (concentration lethal to 50%) for *Ceriodaphnia dubia* Richard, *Daphnia magna* Straus, and *Pimephales promelas* Rafinesque, and water-use criteria from the Food and Agricultural Organization of the United Nations guidelines for agricultural uses and the U.S. EPA Water Quality Criteria for surface discharge (Alley et al. 2011).

The results of Alley et al. (2011) agree with other reports that samples of fracturing fluids, drilling muds, and flowback and produced waters in wastewater–surface containment ponds contain chemicals that, at elevated doses or certain concentrations, have been associated with health effects ranging from skin and eye irritation to neurological and nervous system damage, cancer, and endocrine disruption (Colborn et al. 2011). Moreover, between July 2009 and June 2010, 192.5 million gallons of produced water was reported in Pennsylvania alone, with no certainty as to the location and type of disposal to be employed (Pennsylvania Department of Environmental Protection 2010).

The handling and disposal of flowback and produced water also hold implications for air quality because of volatile compounds, such as BTEX compounds, that are often mixed with the fluids. This may be particularly relevant when wastewater is stored in surface containment ponds and misted into the air to promote evaporation (Colborn et al. 2011).

*Gas and fluid migration.* Subsurface gas and fluid migration is most commonly associated with impaired structural integrity of well cement and, to a lesser extent, well casings. Failures in well barriers may allow intrusion of gases and fluids from producing formations below the casing shoe or from shallower gas- and fluid-bearing formations intersected by the wellbore to lower-pressure annuli. This may result in annular gas flow or sustained casing pressure and thus become a pathway for gas migration to the surface, a known mechanism of emissions of gases to the air and migration of gases and fluids to groundwater (Brufatto et al. 2003; Watson and Bachu 2009). Methane and other hydrocarbons can also migrate along improperly plugged wells, through an inadequately sealed annulus, or between geological zones as a result of cement failures in the wellbore (Vidic et al. 2013).

Leaking oil and gas wells have been recognized as a potential mechanism of subsurface migration of methane and heavier *n*-alkanes and other non-methane VOCs into groundwater and the atmosphere, contributing risks to drinking water and air quality (Bourgoyne et al. 2000; Brufatto et al. 2003; Chilingar and Endres 2005; Watson and Bachu 2009). Cement failures in onshore and offshore wells, reported to occur in 2–50% of all wells, provide pathways for gas migration to occur in the wellbore (Bourgoyne et al. 2000; Brufatto et al. 2003; Watson and Bachu 2009).

Because methane has a low solubility (26 mg/L at 1 atm, 20°C) (Vidic et al. 2013) and is relatively unreactive compared with longer-chain and unsaturated hydrocarbons (Jackson et al. 2011), it is typically regarded as nontoxic and is not regulated in the United States as a solute in water wells. However, there are no peer-reviewed studies on the health effects of chronic exposure to lower concentrations of methane in drinking water or indoor or outdoor air (Jackson et al. 2011). Further, if there is a pathway for methane migration, there could be a pathway for associated health-damaging gases coproduced with methane.

Some attention has been paid to the flammability of methane, the risk of explosions, and the risk of asphyxiation (primarily in high indoor concentrations). For example, in 2007 in Geauga County near Cleveland, Ohio, methane contaminated a water well and a home exploded; the Ohio Department of Natural Resources blamed a faulty concrete casing in a nearby gas well (Ohio Department of Natural Resources 2008). Similarly, in Pavillion, Wyoming, high concentrations of methane found in drinking water wells were attributed to gas production activities (DiGiulio et al. 2011). In addition, the U.S. EPA concluded that methane from geological layers not targeted for gas production migrated up the wellbore to an aquifer as a result of well cement failures in Parker County, Texas (U.S. EPA 2010b).

In certain regions, methane can naturally occur in aquifers, and there are conflicting scientific opinions about whether its presence is caused or exacerbated by shale gas development (Davies 2011; Saba and Orzechowski 2011; Schon 2011). However, there are convincing findings that shed light on the likelihood that shale gas development is associated with high methane levels in drinking water wells. Osborn et al. (2011) found that communities in Pennsylvania that had active shale gas development (one or more gas wells within 1 km) had statistically significantly higher concentrations of methane in their water wells compared with nonextraction sites (no shale gas wells within 1 km). The chemical signature of the methane found in drinking water wells in the active area indicated that the methane came from a high-pressure, deep-earth source (thermogenic methane). Alternatively, the methane from nonactive sites had signatures of shallow earth origins (biogenic methane). This suggests that shale gas production processes were the source of the methane contamination (Osborn et al. 2011).

Building on previous work by Osborn et al. (2011), Jackson et al. (2013) analyzed 141 drinking water wells across northeastern Pennsylvania. The researchers found methane in 82% of the samples (115 of 141 wells), with average concentrations six times higher for homes that were < 1 km from natural gas wells (59 of 141). These data, based on isotopic signatures and gas ratios, suggest that a subset of homeowners living < 1 km from shale gas wells had drinking water that was contaminated with stray gases associated with gas development activities (Jackson et al. 2013).

There is evidence that, in some locations, pathways exist between deep underlying formations and shallow drinking water aquifers (Vengosh et al. 2013). A modeling study by Myers (2012) suggested that pathways would allow for the transport of contaminants from the fractured shale to aquifers. Warner et al. (2012) found evidence of possible migration of Marcellus brine through naturally occurring pathways, based on strong geochemical fingerprints in salinized groundwater samples.

Both of these studies (Myers 2012; Warner et al. 2012) suggest that migration through fractured rock can serve as a subsurface contamination pathway to underground sources of drinking water. They also highlight the significance of the specific geographic configuration because some shallow drinking water resources are at more risk for contamination than others. In a study of the Fayetteville Shale in Arkansas, Warner et al. (2013b) suggested that methane contamination of shallow groundwater may not be a problem in certain shale formations. This difference may be attributed to geological variations across geographic space, including the presence of intermediate gas-bearing formations that are found overlying parts of some shale plays (e.g., Marcellus) but not others (e.g., Fayetteville).

In addition, Fontenot et al. (2013) evaluated water quality in private drinking water wells near natural gas operations in the Barnett Shale formation in Texas and found higher levels of arsenic, selenium, strontium, and total dissolved solids in wells located within 3 km of active gas wells. The authors used historical data from the region as a baseline to determine the contamination rates before the expansion of natural gas operations. Although heavy metals were present at low levels in aquifers in the region, concentrations were significantly higher in areas of active development (Fontenot et al. 2013). The authors were able to link contamination to natural gas activities; however, the specific factor responsible for contamination (e.g., well casing failures, mobilization of natural constituents, hydrogeochemical changes from lowering the water table) was not determined (Fontenot et al. 2013).

Researchers have been challenged in their ability to link associations between water contamination and unconventional natural gas development to any particular part of the process. After complaints about the taste and odor of well water from residents of Pavillion, Wyoming, the U.S. EPA initiated a groundwater investigation (DiGiulio et al. 2011). The observed water wells were located in an area known as the Pavillion gas field, which contained 169 gas production wells and 33 containment ponds used for storage/disposal of drilling wastes and produced and flowback waters from unconventional natural gas development of a sandstone formation.

From 2009 to 2011 the U.S. EPA conducted four sampling events meant to determine the presence (not extent) of groundwater contamination in the formation. In that study, DiGiulio et al. (2011) detected elevated concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) in sampling wells at concentrations of 246, 617, 67, and 750 μg/L, respectively. Trimethylbenzenes and diesel range organics were detected at concentrations up to 105 and 4,050 μg/L, respectively, and total purgeable hydrocarbons were detected in the groundwater samples near the containment ponds (DiGiulio et al. 2011). Although these initial data indicated groundwater impacts that seem likely to be associated with unconventional gas production practices (U.S. EPA 2011a), the results of the study by DiGiulio et al. (2011) have been contested, and it is still unclear which part of the gas development process (if any) is responsible for the contamination. Further, there are geological differences between sandstone and shale, and fracturing is often conducted closer to the surface in sandstone formations. However, the findings suggest an association between water contamination and production activities that have also been identified in shale gas development (DiGiulio et al. 2011).

*Site discharge and improper waste disposal.* Fracturing fluids and produced waters can also contaminate underground sources of drinking water during waste management and disposal. Flowback and produced waters are often contained in evaporation ponds, pits, and tanks, in some cases in very close proximity to residences (Bamberger and Oswald 2012; Rozell and Reaven 2012). These containment ponds are often, but not always, lined to protect against leakage; however, case studies have documented reported ruptures to these liners that may have led to water and soil contamination and contributed to fish and livestock deaths (Bamberger and Oswald 2012). An analysis of waste obtained from reserve pits indicated the potential for exposure to technologically enhanced naturally occurring radioactive material and potential health effects from individual radionuclides (Rich and Crosby 2013).

Groundwater contamination can also result from surface spills at active well sites. Gross et al. (2013) analyzed data from the Colorado Oil and Gas Conservation Commission (http://cogcc.state.co.us) and noted 77 reported surface spills (associated with < 0.5% of active wells) impacting groundwater in Weld County, Colorado. The groundwater samples were analyzed for BTEX components. Most notably, benzene measurements exceeded the U.S. EPA National Drinking Water maximum contaminant level of 5 ppb in 90% of the samples (Gross et al. 2013). Because baseline-sampling measurements were not available, the background BTEX concentrations remain unclear. However, natural groundwater concentrations are typically low near deposits of crude oil, coal, and natural gas (Gross et al. 2013).

## Discussion

*Future research needs.* There is a growing body of scientific literature on the environmental public health dimensions of shale gas development; however, a number of important data gaps persist. Measurements of emissions and atmospheric concentrations should be conducted among diverse geographies, both indoors and outdoors, to help to estimate the types and magnitude of population exposures to pollutants associated with shale gas development. In addition, studies that take into account personal exposures and time–activity patterns of individuals would be helpful in assessing epidemiologically meaningful exposures. These studies could include the use of personal monitors and sampling of household drinking water in conjunction with health records to look at disease outcomes.

Perhaps the most important information gap is the lack of epidemiological studies. There is a need to assess the strength of the association between risk factors, such as air pollution and water contamination, and health outcomes among populations living in close proximity to shale gas develoment activities compared with those populations living in areas without these activities. Although lacking in definitive proof of cause and effect, self-reporting health surveys and environmental testing have suggested possible adverse health outcomes from shale gas development in Pennsylvania (Steinzor et al. 2013). Of particular interest are the epidemiological studies on vulnerable populations, including pregnant women, young children, the elderly, and those with compromised immune systems, who live, work, and play in close proximity to shale gas development. Because workers are likely to be the first and the most exposed demographic from shale gas development, further occupational health studies are also needed.

There have been some efforts in epidemiology and risk assessment, including a recent retrospective cohort study by that examined associations between maternal residential proximity to natural gas development and a number of birth outcomes. The authors found no positive association between density and proximity of wells within a 10-mile radius of maternal residence and prevalence of oral clefts, preterm birth, or term low birth weight. However, the researchers did observe a positive association between density and proximity of pregnant mothers to shale gas development and the prevalence of congenital heart defects and possibly neural tube defects in their newborns (McKenzie et al. 2014).

There have been some other epidemiological efforts as well, including a study funded by America's Natural Gas Alliance that evaluated associations between childhood cancer incidence in Pennsylvania and hydraulic fracturing sites (Fryzek et al. 2013). The authors included 29,000 hydraulically fractured wells drilled between 1990 and 2009 in their analysis and obtained data on childhood cancers from the Pennsylvania cancer registry for this time period. However, shale gas development did not begin in Pennsylvania until 2006, when four wells of this type were drilled. In fact, only 726, or 2.5% of the 29,000 wells in their database, were relevant to directionally drilled shale gas wells. Unfortunately, this exposure misclassification and the disregard for the extended latency periods of many childhood cancers render this study inconclusive as to the effect of shale gas development on childhood cancer rates. The study by Fryzek et al. (2013) demonstrates the need for more epidemiological assessments that pay attention to the latency periods of environmentally mediated diseases.

Epidemiological investigations are challenged by the difficult task of identifying specific risk factors and the uncertainty in exposure classification because compounds used in shale gas development are often not disclosed. In these cases of uncertainty, a comprehensive water monitoring and—under certain circumstances, a biomonitoring program—that uses both targeted and nontargeted strategies would be useful. Useful data could be generated by targeted testing for specific compounds known to be associated with shale gas development in drinking water supplies and in the blood and urine of a representative sample of individuals living in close proximity to shale gas development. Nontargeted techniques, including time-of-flight mass spectrophotometers (TOF-MS), may also be helpful. Rather than monitoring for individual chemicals, TOF-MS has been important for the progress of biomonitoring in recent years by allowing researchers to monitor for tens of thousands of organic compounds at a time. This enables researchers to circumvent policy issues that do not require companies to disclose the compounds they employ in their activities, such as is the case in many regions throughout the United States.

Even with full disclosure of the chemicals added to fracturing fluid, the ability to link chemicals to specific health outcomes remains difficult. Fracturing fluids and flowback and produced wastewaters are complex mixtures of chemicals with individual and possibly cumulative and synergistic properties. Many health outcomes are not specific to chemicals associated with shale gas development (e.g., headaches can be caused by a number of factors, rashes can be nonspecific, and asthma can be induced through a number of pathways), complicating the task of assessing associations between exposures and health outcomes. In turn, more exposure assessments and water and air monitoring should be undertaken to investigate the full suite of compounds emitted to the environment from these activities.

The chemicals contained in fracturing fluids are often not publicly disclosed because of trade secret laws and exemptions under the Energy Policy Act of 2005 that further confound environmental public health research. Moreover, the U.S. EPA is precluded from regulating hydraulic fracturing under the Safe Drinking Water Act (1974), and Congress expressly exempted hydraulic fracturing from the Underground Injection Control program (U.S. EPA 2012b). The nondisclosure of these chemicals creates research barriers because it is difficult to monitor for unknown compounds.

*Limitations.* In this review, we focused on the peer-reviewed scientific literature on the environmental public health dimensions of shale gas development. Although we used a broad search strategy, some publications and other relevant data could have been missed in our literature searches. However, we consider this to be a substantive summary of the currently available literature. Results of future studies will clarify the scientific understanding of the environmental public health concerns of shale gas development.

## Conclusion

We reviewed the body of evidence of potential environmental public health dimensions of shale gas development. Scientific modeling and field investigations have helped to illuminate the emerging environmental issues with which shale gas production may be associated. Several studies have suggested that shale gas development contributes to pollutants in ambient air at concentrations known to be associated with increased risk of morbidity and mortality (Colborn et al. 2014; Kemball-Cook et al. 2010; McKenzie et al. 2012, 2014). Similarly, some evidence supports theories of water contamination risks through a variety of pathways, most notably during wastewater transport and disposal and through failed cement in wells with poor structural integrity (Vengosh et al. 2013; Vidic et al. 2013; Warner et al. 2013a). The existing peer-reviewed scientific data suggest that there are potential risks that could possibly influence public health. More research is needed to clarify the magnitude of these concerns. Because shale gas development activities have accelerated dramatically over the past decade, the need for well-designed empirical studies becomes increasingly apparent.

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# Urban gas drilling and distance ordinances in the Texas Barnett Shale

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## HIGHLIGHTS

- Urban shale gas drilling is expanding across the globe.
- Municipal distance regulations address many concerns associated with urban drilling.
- In Texas, setbacks have no empirical basis, but are political compromises.
- Advanced monitoring methods could be used to standardize setback distances.

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## ABSTRACT

Newly accessible shale deposits and other unconventional sources of natural gas have dramatically increased global gas reserves and are regarded as major future energy sources. Shale gas drilling began in Texas and is expanding throughout the U.S. and globally. In Texas and other regions, large population centers overlie these deposits. As a result, city residents increasingly come into contact with extraction activities. The proximity of drilling activities to residential areas raises a number of concerns, including noise, dust and emissions hazards, public safety, diminished quality of life, and effects on neighborhood aesthetics and property values. Cities in Texas address these concerns through setback ordinances that regulate the distance between gas wells and residences, schools, floodplains, etc. Although the state of Texas permits drilling 200 ft (61 m) from residences, many municipalities in the Dallas–Fort Worth Metroplex (DFW) have established longer setback distances. This paper analyzes the purpose and basis for setback distances among 26 municipalities in DFW. Findings show that there is no uniform setback distance, distances have increased over time, and, rather than technically-based, setbacks are political compromises. For policy makers confronted with urban shale gas drilling, deriving setback distances from advanced emissions monitoring could decrease setback distance ambiguity.



## 1. Introduction

Access to shale and other unconventional sources of natural gas has dramatically increased global gas reserves and shale gas is regarded as a major future energy source (EIA, 2011). In the United States, for example, shale gas is projected to comprise 49% of national natural gas production by 2035 (up from 23% in 2010), almost single-handedly increasing total natural gas supply by 27% (EIA, 2012). The combined use of hydraulic fracturing or 'fracking' with horizontal drilling initiated the commercial production of shale gas in the early 2000s. Fracking uses a mixture of water, sand, and chemicals injected at high pressure to free gas and oil from tight shale deposits while horizontal drilling enables producers to tap larger areas within stratified shale layers. With these new technologies, large shale and unconventional sources of natural gas and oil throughout the world are being targeted for production (Fig. 1).

In many of these areas, including the United States, England, Turkey, India, Poland, and China, large population centers overlie shale deposits (EIA, 2011, 2012). For example, the Barnett Shale in the U.S. state of Texas underlies much of the Dallas–Fort Worth Metroplex (DFW). From 1999 to 2010, DFW had one of the highest urban population growth rates in the U.S. (23.4%; U.S. Census Bureau, 2011); at the same time, over 14,420 gas wells were drilled into the Barnett Shale (Railroad Commission of Texas, 2011). Today, DFW's 6.7 million residents make it the fourth most populous metropolitan area in the country. The city is also ground zero for urban shale gas drilling. Although the state of Texas prevents drilling within 200 ft (61 m) of residences, municipalities in DFW have established longer setback distances. Setback distances allow municipal policy makers to address several issues associated with shale gas drilling including human health and safety, environmental degradation, and effects on property values. Consequently, setbacks condense several debates about the impacts of shale gas drilling into one 'technical' policy.

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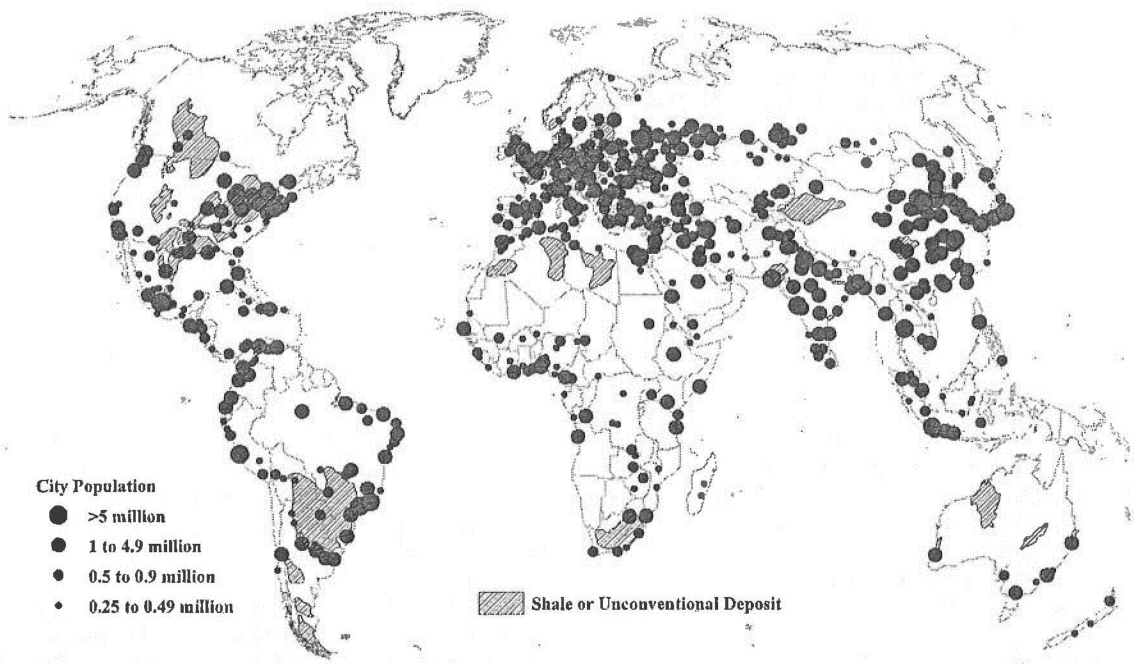


**Fig. 1.** In many countries, cities (gray bubbles) overlie current and potential commercially-viable shale and other unconventional deposits (red) [Modified from (EIA, 2011)]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The goal of this paper is to provide information on the geography and legal landscape of urban shale gas drilling. I examine setback distance regulations among 26 municipalities in Denton County, located in the north of DFW, by reviewing gas drilling ordinance documents. Specifically, I ask three basic questions: (1) what are the setback distances in Denton County? (2) What is their intent/purpose? And (3) how are setback distances justified? A better understanding of drilling regulations in DFW and, in particular, how municipal governments regulate the placement of gas wells, will provide valuable insight for policy makers whose cities overlie shale deposits.

The paper begins with a brief review of urban drilling, municipal regulations, and regulatory takings lawsuits. This is followed by the methods and results, which show that municipal setback ordinances in Denton County are not based on measured emissions or noise. In the discussion, setbacks are shown to be negotiated and highly politicized compromises among political, economic, environmental, public welfare, and legal interests. It is proposed that setback distances can be standardized. The paper concludes with a summary of the findings and future research questions.

## 2. Cities and shale gas

### 2.1. Urban residents and drilling

Generally, urban residential and commercial areas have not been regarded as compatible with oil and gas production activities (Laurie, 1965). However, the presence of oil and gas drilling in urban areas is not new. The City of Los Angeles, California, was one of the first cities to experience the impacts of unrestrained oil development within its limits (Smutz, 1965). With over 70 oilfields in the Los Angeles Basin (Chilingar and Endres, 2005), the area has produced oil since the late 1890s, but it was not until the mid-1930s that the city first established zoning for urban drilling and again in the 1950s when the city further regulated drilling activities (Smutz, 1965). Although the migration of explosive methane gas to the surface was a real concern for city planners in Los Angeles during this period (Enders et al., 1991), controversy over oil drilling in residential areas primarily centered on noise, traffic, and neighborhood aesthetics (Branch, 1972). In addition to these ‘nuisances,’ contemporary shale gas drilling poses additional concerns for urban residents.

Today, public concerns about shale gas drilling center on the chemical compounds used in fracking fluids, including the potential for contamination of ground and surface water, the potential for negative health effects from hazardous air emissions, and the safe disposal of flowback fluids (Rahm, 2011; Howarth and Ingraffea, 2011). Non-disclosure of the chemical ingredients used in fracking fluids has resulted in limited research data on the potential health impacts and environmental effects of hydraulic fracturing (Thompson, 2012; although see Oswald and Bamberger, 2012; Osborn et al., 2011). However, beginning in 2010, several U.S. states, including Texas, enacted legislation forcing companies to reveal most of the chemical ingredients used in their fracking fluids (Rahm, 2011; Thompson, 2012).

Recent empirical research on shale gas extraction demonstrates other negative public perceptions of shale gas drilling. For example, Fry et al. (2012) present survey results showing that one-third of DFW residents believe shale gas drilling is the greatest threat to their water supply. Theodori (2012) finds that the duration of drilling activities affects how residents feel about shale gas drilling in general, with the most negative perceptions of the gas industry occurring among residents living in places where shale gas drilling is less established. As well, Anderson and Theodori (2009) and Wynveen (2011) use key informant interview data to measure perceived impacts associated with shale gas development in Texas. Among a number of positive and negative social impacts, both studies show that the placement of gas wells near homes is a major concern for residents.

### 2.2. Shale gas in Texas

Early expansion of shale gas production in Texas was restricted primarily to the Barnett Shale. This deposit accounted for as much as 66% of U.S. shale gas production in the 2000s (EIA, 2011). In 2009, 35 shale plays (or geologic fields) across the U.S. produced 20.6 trillion $ft^3$ (583.3 billion $m^3$) of natural gas (EIA, 2011). In Texas, seven shale plays currently produce natural gas (Fig. 2). The Barnett and Haynesville/Bossier are two of the largest gas producing plays in the U.S. (EIA, 2011); together with the Eagle Ford, they are the largest natural gas producing shale plays in the state (Railroad Commission of Texas, 2012). In terms of area, proven reserves, number of gas wells, and total production, the Barnett is the largest of the three; it is also where hydraulic fracturing was first used in 1997 and where horizontal drilling began in the early 2000s.

Productive Barnett Shale is found at depths of 2.0–2.6 km with shale thickness varying from 30 to 180 m. It takes approximately 20–80 days to drill to these depths and hydraulically fracture the deposit. Although Texas law allows drilling operators to use as much of the surface as necessary (Railroad Commission of Texas, 2013), average well size in the Barnett Shale is approximately 90,000 $ft^2$ (8361 $m^2$; Barnett Shale Energy Education Council, 2013). Noise, vibrations, and traffic are most noticeable during active drilling, fracking, and flowback (when frack fluid returns to the surface). After this stage, the well head, storage tanks, fencing, and sometimes compressor tanks remain at the gravel-surfaced site. However, drilling activity can resume at any time because multiple wells can be bored in different directions at the same site and wells also can be re-fracked.

### 2.3. Drilling ordinances and setbacks in DFW

In the DFW area, the placement of Barnett Shale gas wells is influenced by physical geology and such 'above-ground' factors as political economy, knowledge, market conditions, technical progress, and legal regulations (e.g., Bridge and Wood, 2010; Labban, 2010; Bradshaw, 2010). Legal regulations are of particular importance because they codify the boundaries of the material environment and provide legal definitions of space (Blomley, 2005). However, the power to legally define space is constantly contested by different governing authorities (Blandy and Wang, 2013). For example, the power to determine where shale gas wells can be located, i.e., the legally-defined space that gas wells can occupy on the surface, is contested among federal, state, and municipal governments.

Although the U.S. Environmental Protection Agency is investigating fracking and its impacts on air and drinking water (EPA (United States Environmental Protection Agency), 2011), federal regulatory power over shale gas extraction is limited (Rahm, 2011). Nevertheless, in terms of well placement, the federal government can regulate drilling activities if they threaten the stability of public work projects. For example, the U.S. Army Corps of Engineers uses Section 408 of Title 33 of the United States Code, which makes it unlawful to destroy or impair the usefulness of works built by the U.S. government, to prohibit drilling and fracking within 3000 ft (914.4 m) of dams and other critical structures (Town of Flower Mound, 2011). Ultimately, however, states and municipalities wield the majority of regulatory power over shale gas drilling.

In Texas, the Railroad Commission of Texas (RRC) is responsible for virtually all activities associated with oil and gas including exploration, extraction, production, and transport, although the Texas Commission on Environmental Quality (TCEQ) regulates air quality. To Rahm (2011, p. 2978), the "fundamental anti-regulatory disposition" of Texas' state government gives substantial leeway to the oil and gas industry. For example, the RRC allows drilling as close as 200 ft (61.4 m) from residences. Many municipalities deem this to be too close and have responded by establishing longer setback distances.

Under Texas law, municipalities are vested with substantial political and legal autonomy to govern local activities and interests (Riley, 2007). Municipal regulatory power over drilling has its roots in state statutes implemented in the mid-1970s that aimed to protect surface owners from the effects of oil and gas exploration or drilling operations on their property (Miller, 2003). To facilitate mineral development, the state divides property into two estates: surface and mineral. Essentially, the RRC governs the mineral estate while

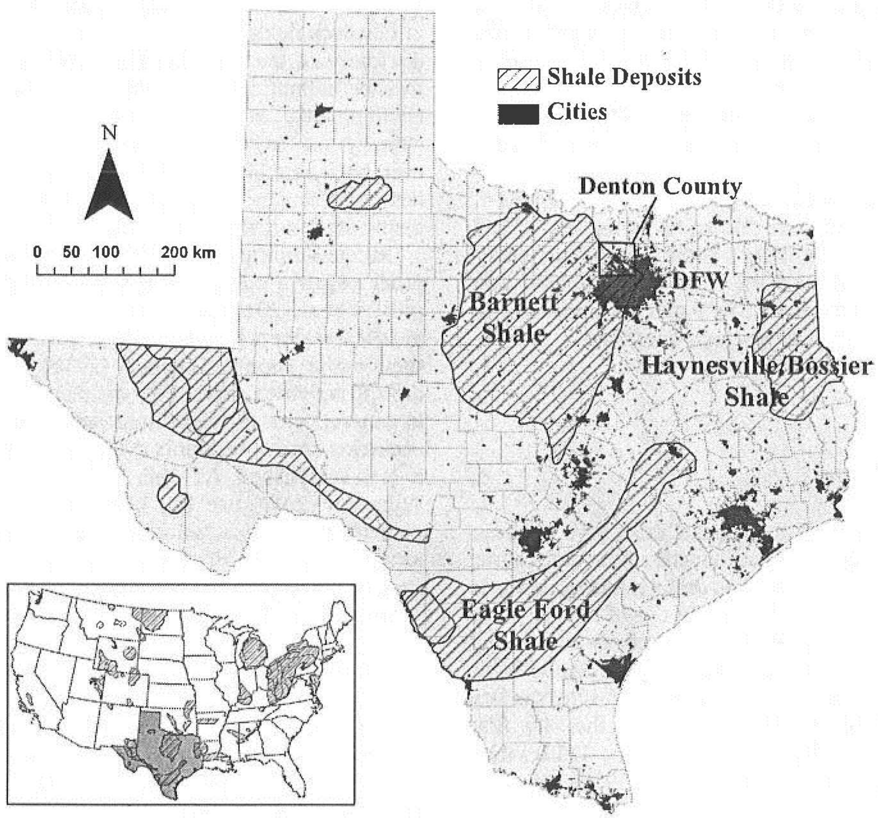


**Fig. 2.** Map of commercially-viable shale deposits and urban areas in Texas.

municipalities have authority over surface estates within their jurisdiction (Riley, 2007). Therefore, in terms of gas well distribution in Texas, municipal policies play an important role in the placement of gas wells. However, as Riley (2007, p. 7) points out, "vertically severing the estate interests of the same parcel of land creates unique problems, particularly when a mineral estate holder seeks to access or use the surface to develop the underlying reserves."

## 3. Regulatory takings

Legal scholarship provides insight into the adjudication of legal disputes between mineral and surface owners and the extent of municipal police powers. Both of these issues are relevant to discussions about gas drilling regulations. In 1971, the Texas Supreme Court ruled in *Getty Oil Co. v. Jones* that the mineral estate is dominant for oil and gas interests because the owner or lessee of the mineral rights must be able to use the surface estate to explore and extract oil or gas, otherwise the value of those minerals would be worthless (*Getty Oil Co. v. Jones*, 470 S.W.2d. 618, 621 [Tex. 1971] in Riley, 2007, p. 5). But the mineral estate's dominance is not absolute because the rights of the surface owner must always be given due regard by the mineral owner (Riley, 2007). Moreover, in a 1943 decision regarding the police powers of municipal zoning ordinances, the Texas Supreme Court held that the state and municipalities have the authority to regulate the use of all private property (i.e., surface and mineral) so that it does not endanger the lives and personal safety of people (*Ellis v. City of W. Univ. Place*, 175 S.W.2d. 396–398 [Tex. 1943] in Riley, 2007, p. 7). Therefore, cities in Texas have the power to restrict the mineral rights of private property owners with zoning ordinances enacted to protect the health, safety, and general welfare of its citizens. However, if an ordinance is not substantially related to public health, safety, or general welfare, or if it is unreasonable or arbitrary, it could be deemed an unconstitutional regulatory taking of private property (*City of Coll. Station v. Turtle Rock Corp.*, 680 S. W.2d 802, 805 [Tex. 1984] in Riley (2007, n104)).

Regulatory takings occur when a government regulation "denies the landowner all economically viable use of the property or totally destroys the value of the property" (*Lucas v. South Carolina Coastal Council*, 505 U.S. at 935 [1992] in Welch (2012, p. 2)). In other words, through its regulation or ordinance, the government exercises its power of *eminent domain* yet does so without fairly compensating the private property owner. In the pivotal 1978 case *Penn Central Transp. Co. v. City of New York* the U.S. Supreme Court established three other factors besides rendering the property valueless to determine if a regulatory takings had occurred, including: (1) the character of the government action, (2) the economic impact of the regulation upon the claimant, and (3) the extent to which the regulation interferes with investment-backed expectations (*Penn Central Transp. Co. v. City of New York*, 438 U.S. 104 [1978] in Welch (2012, p. 3)). In *Mayhew v. Town of Sunnyvale* in 1998, the Texas Supreme Court summarized these factors as "the historical nature of the land," the timing of the restriction relative to the acquisition of the property, and "if the restriction could have been reasonably expected" as other aspects to be taken into consideration for regulatory takings claims (*Mayhew v. Town of Sunnyvale*, 964 S. W.2d at 937–38 [Tex. 1998] in Cady (2009, p. 12)).

However, despite a long and complex history of regulatory takings claims (see e.g., Welch, 2012) and a few instances when shale gas operators were denied drilling permits in municipal areas (see e.g., Arlington Heights Neighborhood Association, 2008), to date no regulatory takings claims involving urban shale gas drilling have risen to the level of the Texas Supreme Court. Indeed, Riley (2007, p. 7) believes that a properly enacted drilling ordinance would be a substantial hurdle for a regulatory takings claim and an "extraordinary burden" for a party to challenge. Yet Welch (2012) argues that Texas municipalities' shale gas drilling ordinances have entered "uncharted territory" because there are few prior precedents on which to base regulatory standards. Therefore, among contemporary municipal gas drilling ordinances it remains unclear what constitutes a regulatory takings. Ultimately, a municipality's authority to regulate drilling only goes as far as the municipality's justification for the ordinance as reasonably protecting "public health, morals, safety, and general welfare" (*Lombardo v. City of Dallas*, 73 S.W.2d 475, 481 [Tex. 1934] quoted in Riley (2007, p. 7)).

## 4. Methods

In this study, I compare gas well distance ordinances in 26 municipalities in Denton County, Texas, in order to provide some clarity to the "uncharted territory" of these ordinances, as discussed by Welch (2012). Three sources of data were used: (1) gas well permit, and latitude and longitude data from the Railroad Commission of Texas (RRC); (2) municipal ordinance documents; and (3) archival material, including town and city council meeting minutes, legal notes, and other municipal information. First, setback distances and gas wells were mapped using ArcGIS 9: ArcMap 9.3 (ESRI, 2008). Spatial data for municipal boundaries and county features were obtained from the North Central Texas Council for Governments (NCTCOG, http://www.nctcog.org) and the Texas Natural Resources Information System (TNRIS, www.tnris.org). Attributes of the RRC data provided information on well counts, permitting and spud dates, well type (e.g., horizontal or vertical), etc. Second, municipal ordinances were downloaded from municipal government and legal publishing websites (see Appendix A). For this study, I restricted my analysis to statements pertaining to distance regulations and setbacks, monitoring of noise and emissions, and the underlying purposes of regulations. Third, in order to understand the legislative intent and the justification for setback ordinances, I examined archival information from city council meetings, municipal impact studies, and legal advice and scholarship on gas drilling regulations.

## 5. Results: Municipalities and gas drilling ordinances in Denton County, Texas

### 5.1. Ordinances and setback distances

Fig. 3 demonstrates the rapid increase in shale gas drilling in Denton County municipalities. Passage of municipal gas well or drilling ordinances accompanied the rise in drilling activity. Fort Worth passed the first gas well ordinance in Denton County in 2001 (Fort Worth is the county seat for Tarrant County, but the city extends into Denton County). Today, a total of 26 municipalities located over the Barnett Shale in the south and western portion of the county have drilling ordinances (Fig. 4). Most ordinances begin with a purpose statement and term definitions. From there, the structure of each ordinance varies. In general, regulation statements within ordinances include those pertaining to permit requirements, processing permits, standards and conditions for production, variance procedures, security, safety and emergency preparations, fire prevention, liability insurance, bonds, appeals, revocation and transfer of permits, clean-up and maintenance, and re-working of a gas well. Moreover, all ordinances contain setback or separation distances for roads, water wells, public parks, schools, churches, and residences.

Among the municipalities in Denton County, setback distances from residences range from 300 to 1500 ft (91.4 to 457.2 m), mean = 830 ft (253 m), mode = 1000 ft (304.8 m), and median = 900 ft

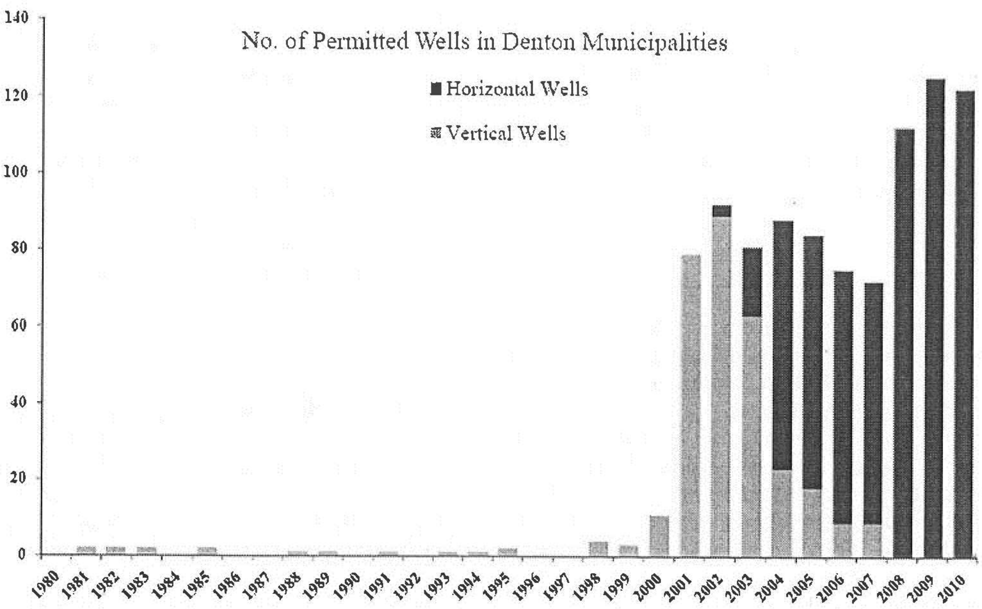


**Fig. 3.** Permit dates for 962 wells located within towns and cities in Denton County, Texas.

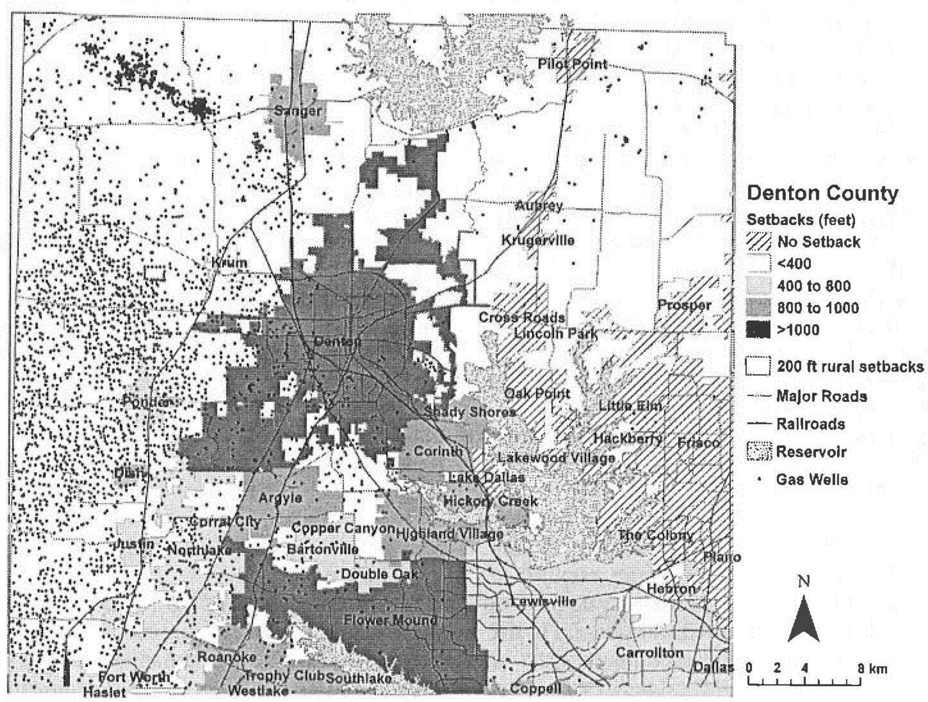


**Fig. 4.** Map of Denton County, municipalities, and setback distances.

(274.2 m) (Fig. 4). With surface owners' and city council approval, waivers or variances permit gas drilling closer to residences. Variance setback distances typically differ between residences whose owners control the mineral interests and those whose owners do not, with shorter distances for the former. In rural areas outside of municipal territories, the RRC regulated setback distance of 200 ft (61 m) applies. The City of Fort Worth has the highest number of gas wells, although most of these are not located in Denton County. The Town of Flower Mound has the longest setback distance, 1500 ft (457.2 m), which is the longest in the state. And the Town of Krum has the shortest setback length, 300 ft (91.4 m; Fig. 4 and Table 1).

At least 12 municipal drilling ordinances have been rewritten and/or amended. In addition to other changes, updated ordinances often change their setback distances. For example, the City of Fort Worth increased their setback distance from 300 to 600 ft (91.4 to 182.9 m) when they changed their ordinance in 2009. The Town of Flower Mound adopted a drilling ordinance in 2003 and passed amendments in 2005 and 2007. In 2011, the town established a new ordinance that increased setbacks from 1000 to 1500 ft (304.8 to 457.2 m). After 2011, the City of Denton, and the Towns of Ponder and Argyle also rewrote their drilling ordinances and increased setback distances from 1000 to 1200 ft (304.8 to 365.8 m), 300 to 600 ft (91.4 to 182.9 m), and 600 to 800 ft (182.9 to 243.8 m), respectively. In 2013, Dallas was also in the process of rewriting their gas well ordinance. It is notable that no municipality in Denton decreased the length of their setback distance and, of the 12 municipalities that changed their setbacks, all increased their lengths.

**Table 1**
Municipalities in Denton County, Texas, including characteristics, drilling ordinance dates, setback lengths, and gas well count.
*Sources*: http://www.rrc.state.tx.us/; http://www.dfwmaps.com/clearinghouse/, 2011; Texas State Library and Archives Comission; https://www.tsl.state.tx.us/ref/abouttx/population2.html; and for municipal ordinances see Appendix A.

| Municipality | Pop 2011 | Total area/area in county (km²) | No. permitted wells, 2010 | First horizontal drill (Year) | Original ordinance (Year) | Residential setback (ft/m) | Min. setback w/ variance (ft/m) |
|---|---|---|---|---|---|---|---|
| Argyle | 3,403 | 29.5 | 26 | 2005 | n.d. | 800/243.8 | 400/121.9 |
| Bartonville | 1,523 | 16.6 | 28 | 2005 | n.d. | 600/182.9 | 250/76.2 |
| Carrollton | 122,640 | 96.1/52.6 | 1 | n.d. | 2007 | 600/182.9 | 150/45.7 |
| Coppell | 39,462 | 38.1/4.1 | 2 | n.d. | 2009 | 1000/304.8 | 300/91.4 |
| Copper Canyon | 1,382 | 11.9 | 21 | 2006 | 2006 | 1000/304.8 | 300/91.4 |
| Corinth | 20,662 | 20.2 | 3 | 2005 | 2005 | 1000/304.8 | < 1000/304.8 |
| Dallas[a] | 1,223,229 | 999.2/7.0 | 6 | n.d. | 2007 | 600/182.9 | n.d. |
| Denton | 117,187 | 231.3 | 227 | 2003 | 2002 | 1200/365.8 | 250/76.2 |
| Dish | 208 | 2.8 | n.d. | n.d. | 2006 | 1000/304.8 | 500/152.4 |
| Double Oak | 2,970 | 6.3 | 6 | 2008 | 2005 | 500/152.4 | < 500/152.4 |
| Flower Mound | 67,019 | 115.3 | 109 | 2004 | 2003 | 1500/457.2 | 1125/342.9 |
| Fort Worth | 758,738 | 903.4/43.5 | 1010 | 2003 | 2001 | 600/182.9 | 300/91.4 |
| Haslet | 1,553 | 21.2/0.8 | 604 | 2002 | 2004 | 600/182.9 | 200/61.0 |
| Hickory Creek | 3,364 | 11.9 | 4 | 2008 | n.d. | 1000/304.8 | < 1000/304.8 |
| Highland Village | 15,602 | 16.6 | 0 | | 2006 | 1000/304.8 | 600/182.9 |
| Justin | 3,360 | 5.7 | 123 | 2003 | 2000 | 600/182.9 | 200/61.0 |
| Krum | 4,310 | 5.7 | 28 | 2005 | n.d. | 300/91.4 | 200/61.0 |
| Lewisville | 98,737 | 110.1 | 38 | 2007 | n.d. | 500/152.4 | 300/91.4 |
| Northlake | 1,788 | 43.3 | 69 | 2003 | 2006 | 600/182.9 | 300/91.4 |
| Ponder[b] | 1,446 | 8.3 | 77 | 2003 | 2002 | 600/182.9 | 300/91.4 |
| Roanoke | 6,179 | 14.0 | 15 | 2004 | 2005 | 1000/304.8 | 500/152.4 |
| Sanger | 7,168 | 19.7 | 56 | n.d. | n.d. | 1000/304.8 | 300/91.4 |
| Shady Shores | 2,709 | 7.5 | 0 | | 2003 | 1000/304.8 | 500/152.4 |
| Southlake | 27,189 | 58.3/8.0 | 14 | after 2010 | n.d. | 1000/304.8 | none |
| Trophy Club | 8,311 | 10.4 | 42 | 2004 | 2003 | 1000/304.8 | 250/76.2 |
| Westlake | 1,009 | 17.9 | 1 | after 2010 | 2009 | 1000/304.8 | 300/91.4 |

[a] Dallas currently has a moritorium on drilling as they amend their ordinance.
[b] Ponder passed a new ordinance, but it is not yet available online.

### *5.2. The purpose of setbacks*

The legal boilerplate language in ordinance purpose statements is nearly identical among 21 of Denton County's 26 municipal gas well ordinances. Fort Worth's Ordinance 14880 from December 2001 has served as the template for other ordinance purpose statements:

The exploration, development, and production of gas in the City is an activity which necessitates reasonable regulation to ensure that all property owners, mineral and otherwise, have the right to peaceably enjoy their property and its benefits and revenues. It is hereby declared to be the purpose of this Ordinance to establish reasonable and uniform limitations, safeguards and regulations for present and future operations related to the exploring, drilling, developing, producing, transporting and storing of gas and other substances produced in association with gas within the City to protect the health, safety and general welfare of the public, minimize the potential impact to property and mineral rights owners, protect the quality of the environment and encourage the orderly production of available mineral resources.

From this statement, the 'purpose' of setback distances can be understood as a mechanism to protect the health, safety, and welfare of residents; the rights of property owners; safeguard environmental quality; and promote efficient gas extraction.

### *5.3. Noise and emissions*

The justification for specific setback distances is not apparent in municipal gas well ordinance documents. Although noise and atmospheric emissions are regulated, neither seems to factor into the designation of particular distances. For example, noise standards regulate the noise level of drilling rigs and compression tanks. Some noise regulations distinguish between drilling, fracturing, and production; others, require different maximum decibel levels for day and night (see Table 2). In most cases, noise levels cannot exceed an established decibel (dB) level as measured at a certain distance from the gas well. For example, in Bartonville, drilling cannot exceed 60 dB measured at 300 ft (91.4 m) from the wellhead or the closest protected use. However, the difference between the distance for measuring noise and Bartonville's setback distance of 600 ft (182.9 m), suggests that noise level is not the determining factor, nor justification for the setback length. In other municipalities, such as Coppel, Corinth, Southlake, and Westlake, noise levels are measured at the setback length of 1000 ft (304.8 m), and in Fort Worth and Haslet, noise is measured at the 600 ft (182.9 m) setback distance. However, these distances serve as points to monitor noise, rather than demarcating a threshold for unsafe noise levels.

The TCEQ (Texas Commission on Environmental Quality) regulates atmospheric emissions and contaminants from oil and gas production. The primary chemical of concern for TCEQ is the volatile organic compound benzene, but they also measure levels of toluene, ethylbenzene, xylenes, C1–C13 hydrocarbons (e.g., methanes, ethanes, pentanes, propanes), trimethylbenzenes, carbon disulfide, etc. (TCEQ (Texas Commission on Environmental Quality) AutoGC data). TCEQ began monitoring emissions from shale gas drilling in the Barnett Shale region in 2009. Although TCEQ has five stationary canister monitors in Denton County (TCEQ (Texas Commission on Environmental Quality) AutoGC data), the full spatial distribution and concentration of emissions from gas wells in the county remains unclear.

Despite TCEQ's regulatory power, half of the municipal ordinances in Denton County contain air emissions statements

**Table 2**
Summaries of Denton County municipal noise and emission standards, 2013. (see Appendix A for sources).

| Municipality | Noise standards (dB/dist) | Emissions standards summarized |
|---|---|---|
| Argyle | 80/300 ft | Compliance with state and federal standards |
| Bartonville | 60/300 ft (Compressors 40/300 ft) | Measure contaminates at or beyond setback; list contaminates, tolerable levels |
| Carrollton | 78 drill, 85 frac, 65 prod/300 ft | |
| Coppell | Ambient +5 day, +3 night, +10 frac, +3 prod/1000 ft | |
| Copper Canyon | 78 day,56 night,85 frac/300 ft | |
| Corinth | Ambient +5 day, +3 night, +10 frac, +3 prod/1000 ft | Measure contaminates at or beyond setback; list contaminates, tolerable levels |
| Dallas | | |
| Denton | 65/1000 to 1100 ft | |
| Dish | 78/300 ft | |
| Double Oak | 40, 45 frac/300 ft | |
| Flower Mound | day 70/300 ft; night 56/nearest residence; frac 70/300 ft | Compliance with state and federal standards; hires independent firm to monitor |
| Fort Worth | Ambient +5 day, +3 night,+10 frac, +3 prod/600 ft | Permit includes 'Reduced Emission Completion' statement |
| Haslet | Ambient +5 day, +3 night, +10 frac, +3 prod/600 ft | Permit includes 'Reduced Emission Completion' statement |
| Hickory Creek | 70/100 ft | |
| Highland Village | 70 drill, 80 frac/300 ft | |
| Justin | | |
| Krum | Below levels detrimental to health, safety or welfare | |
| Lewisville | 78/300 ft | Control/reduction plan required for permit; compliance with state and federal law |
| Northlake | 70/300 ft | |
| Ponder | 85 drill, 90 frac/300 ft | Must make efforts to minimize harmful emissions |
| Roanoke | 78 drill, 85 frac/300 ft | |
| Sanger | 70/100 ft | Air pollution control devices required for permit |
| Shady Shores | 90/300 ft | |
| Southlake | Ambient +10 frac, +5 day, +3 night/1000 ft | Baseline air testing; continuous air monitoring; field inspection monitoring |
| Trophy Club | | |
| Westlake | Ambient +10 frac, +5 day, +3 night/1000 ft | Air quality control measures required for permit |

(note that all municipal ordinances have a venting/emissions clause that is not specific to contaminants; as well, most ordinances include an excessive dust clause). Among the ordinances with emissions statements, some mention that drillers must comply with state and federal law; others require that drillers include a 'Reduced Emissions Completion' statement or air quality control measures in their permit application; and a few simply encourage drillers to make efforts to minimize contaminants (see Table 2). The strictest measures list permissible quantities of contaminants, and require pre-drilling baseline measurements and continuous monitoring of air quality. In terms of setback distances, Bartonville and Corinth, for example, use residence setback distances to measure air contaminant levels. However, as with noise levels, the setback distances only serve as points to monitor emissions and the spatial distributions of emissions are not criteria used to determine the length of setback distances.

### 5.4. *Legal consultations and task forces*

The establishment of drilling ordinances also relies on lengthy consultations with industry and municipal lawyers, public hearings, and, in some cases, the advice of advisory panels or task forces. For example, in Carrollton, the city spent nine months conducting "research, consultation with industry experts and oil and gas attorneys, and site visits" before voting to model their ordinance on Fort Worth's (Carrolton Public Hearing, 2007, p. 209). Minutes from a 2005 Flower Mound town council meeting demonstrate that their first setback distance of 1000 ft (304.8 m) was based on a margin of safety established by the RRC. In the meeting, a staff lawyer noted that during the only blowout of a gas well in the Barnett Shale, the RRC evacuated a 1000-ft (304.8 m) area; therefore, the town's staff "felt they could justify the 1000-ft setback" (Flower Mound Town Council Work Session, February 17 2005).

Some city councils also appoint 'Gas Drilling Task Forces' to gather data and make recommendations. In 2006, for example, the Fort Worth City Council appointed an 18-member task force to investigate citizen concerns about gas drilling. Similarly, the Town of Flower Mound organized a 'Gas Drilling Advisory Panel' prior to adopting their 2011 ordinance. In the City of Denton, before adopting a new ordinance in January 2013, a drilling moratorium was imposed while the city's 'Gas Drilling Task Force' held meetings and public hearings, and conducted background research on gas drilling. In an attempt to represent the best interests of citizens, the energy industry, and the City, the Task Force was made up of individuals with "specialized knowledge in the environment, gas, engineering, and legal industries" (City of Denton, 2013).

### 5.5. *Municipal studies*

Both Fort Worth and Flower Mound contracted private firms to collect ambient air samples from stationary monitors in areas near gas wells. The City of Fort Worth Natural Gas Air Quality Study also incorporated dispersion models that were used to assess whether or not the city's 600-ft (182.9 m) setback distance was adequate to protect public health (Eastern Research Group, 2011). Point sources collected near and at fence line, and estimates of emissions were used to construct the models. Although the modeling analysis indicated that the 600-ft (182.9 m) setback distance was adequate, it also "found some areas beyond the setbacks to have estimated acrolein and formaldehyde concentrations greater than protective health-based screening levels published by TCEQ" (Eastern Research Group, 2011, p. xiii–xiv). Therefore, the study recommends more detailed and longer-term monitoring of these two contaminants. Although the 8 monitoring stations that collected ambient air pollution levels over 2 months at sites near well pads did not test for acrolein, the data also suggested that 600 ft (182.9 m) was an adequate distance for the city's setback (Eastern Research Group, 2011).

In addition to their emissions study, the Town of Flower Mound measured the effects of gas drilling on cancer rates and property values in 2009–2010. While the air emissions and cancer rates studies were related because exposure to benzene is associated with leukemia and non-Hodgkin's lymphoma, all three studies had the potential to offer justification for residential setback distances. For the town's air quality monitoring program, an independent firm was hired to collect and analyze air samples in 2010. Later, TCEQ installed a permanent monitoring station. As well, Flower Mound conducts independent monthly air quality tests and provides access to air quality monitors via the internet (Town of Flower Mound, 2013). To date, benzene and other contaminant levels have remained within TCEQ's safety margins. In 2010, the Texas Department of State Health Services conducted the cancer rate study in Flower Mound. The study found the incidence of leukemia within normal ranges, while high breast cancer rates were attributed to population growth, not gas wells (TDSHS (Texas Department of State Health Services), 2010). Thus, neither the cancer study nor the air emissions study directly contributed to Flower Mound's decision to establish setback lengths of 1500 ft.

In 2009, Flower Mound contracted Integra Realty Resources to "develop an opinion of the impact, if any, of the proximity of improved residential properties as a result of their proximity to gas well sites" (Integra Realty Resources, 2010, p. 2). The study found measurable impacts on property values when residential properties are located adjacent to well sites, and as distance from the well increases, property values also increase. Specifically, residential properties within 1000 ft (304.8 m) of wellheads experience decreases of −3 to −14% from their total value (Integra Realty Resources, 2010). Moreover, Integra's study found that property values only decrease for houses with a full view of the drill pad. Finally, Integra found that the impact on housing prices dissipates between 1000 and 1500 ft (304.8 and 457.2 m). This finding provided justification for the town to increase its setback distance to 1500 ft (457.2 m).

## 6. Discussion

### 6.1. Space politicized

Although the setback distance is expressed as a length, it actually demarcates an area: the distance is the radius for a circular buffer around the drilling rig or pad site. The purpose of this buffer space is to protect public health, safety, and welfare; safeguard environmental quality; promote efficient gas extraction; and minimally impact the rights of property owners. However, with the exception of Flower Mound's setback distance of 1500 ft (457.2 m), which is based on results from a study on the effects of shale gas drilling on residential property values, the spaces created by other municipal setback distance ordinances appear to have no 'technical' bases, i.e., they are not derived from empirical or data-driven analysis. Nor are they outcomes of a historical event, i.e., they do not demarcate a known blast radius or spatial dispersion of emissions during a large flare event. As a result, nearly all municipal setbacks are outcomes of negotiations among city council members and interested parties. In other words, setback distances in Denton County demarcate a highly politicized and negotiated space.

Negotiated setback distances are not unique to urban shale gas drilling. For example, Watson et al. (2012) report similar variability among municipal wind turbine setback distances in Canadian municipalities. In their study, the only consistency among the factors used to determine setbacks was the "breadth of political influence," which precludes any chance for a single, one-size-fit-all setback distance (Watson et al., 2012, p. 789). Indeed, competing priorities among the economic, environmental, and political goals of energy development can be nearly irreconcilable for municipal policy makers (Breukers and Wolsink, 2007). For example, Smutz (1965) referred to the years of negotiations among Los Angeles policy makers and oil drillers as the "hard experience" and Branch (1972) "the long struggle". To date, the setback distance negotiations in Denton County's municipalities also demonstrate a struggle between a number of competing priorities and interest groups.

Purpose statements and other language within ordinances reveal some of the opposing goals of setback distances and highlight some of the interests involved, including economic, environmental and human health, and public welfare interests. Among economic interests, setback distances protect those of the gas industry, mineral owners, surface owners, and the municipality itself. Setback lengths should not overly restrict the areas where the gas industry can legally set up drilling rigs. Nor should setbacks be so long that they prohibit mineral owners from exploiting their resources for revenue. Indeed, this is clearly stated within ordinance purpose statements. Likewise, protecting the rights of surface property owners is also written into ordinance purpose statements. In addition, ad valorem taxes on drilling activities are assessed and collected by Denton County and distributed to municipalities. Although the amount of money from these taxes is small relative to annual budgets, they can fund a variety of municipal projects (McGraw, 2008). As well, some municipalities, including Denton and Fort Worth, receive monthly royalty payments from gas wells located on city-owned mineral properties.

Safeguarding environmental quality and human health also appear in gas well ordinances. For example, the emissions standards in Table 2 clearly aim to protect public health. As well, all drilling ordinances contain statements regarding the proximity of gas wells to water wells or potable water sources and flood plains. Noise regulations also address human health and public welfare. As well, in terms of public welfare, most ordinances address community aesthetics by requiring drillers to clean-up and sometimes landscape around drill sites after production activities end, for example. As outcomes of negotiations among these competing interests, setback distances represent compromises to alleviate the tension between promoting energy development and minimizing negative impacts from energy production (Watson et al., 2012).

Drilling ordinance and setback distance negotiations also must wade through the tensions and uncertainties surrounding shale gas drilling, including the heated debate between drilling's proponents and its skeptics. This debate is best seen in the popular documentaries Gasland (2010) and The Sky is Pink (2012), and the gas industry's response to the *Gasland* documentary (see e.g., ANGA, 2013). For example, The Sky is Pink (2012) suggests the shale gas industry purposively contradicts scientific findings about negative impacts from hydraulic fracturing in order to foster a debate that perpetuates the public's uncertainty about who to trust. Thompson (2012) shows how the dearth of peer-reviewed, empirical studies on the potential environmental and health effects from shale gas drilling also likely contributes to the uncertainties surrounding this activity. In the absence of scientific data, discourses (e.g., pro- and anti-drilling narratives) can serve as influential references that inform peoples' knowledge and beliefs about environmental issues (see e.g., Hajer, 1995; Hajer and Versteeg, 2005). Discourses that inform public perceptions can also play important roles in the formation of policies, especially at the municipal level (Robbins, 2006). In the case of shale gas drilling, some of the competing discourses include job creation and economic gain on the one hand, versus negative environmental and health effects on the other. Yet, to date, it remains unclear how discourses such as these might influence the final votes of municipal policy makers.

Nevertheless, the competition between interest groups does appear during municipal drilling ordinance negotiations. For example, the City of Denton's 2012 drilling task force was comprised of five voting members: two shale gas industry representatives, and three community residents, one of whom was a retired petroleum engineer (City of Denton, 2013). Several residents complained that the composition of the task force was too industry friendly because the petroleum engineer "sided too often with the industry, resulting in 3–2 votes to kill stricter rules for noise, well casings, public notification and other industry activities" (Brown, 2012). On the other hand, the fact that 12 municipalities in Denton County increased their setback distances suggests that the health, environmental, and/or public welfare interests of the community trumped those of the gas industry. Finally, setback distances not only represent a compromise between economic gains and community impacts, but they are also heavily laden with legal prudence.

### 6.2. Legal prudence

To Welch (2012), setback distances mediate the tensions between municipalities and mineral owners. Municipalities use their police powers to protect community rights, while mineral owners rely on state government support via the RRC to minimize regulations in order to exploit their minerals for maximum revenue. To Blandy and Wang (2013), the legal constitution of a particular site and its form necessarily involves consideration of the contestation of power among governing authorities. In the Barnett Shale region, municipalities use their power to regulate the space around gas wells. In turn, the state government uses its power to contest that of municipal governments. For example, some members of the state government regard setbacks as major regulatory road blocks for the oil and gas industry in Texas. As a result, Texas House Bill (HB) 1496 was brought to the state legislature in March 2013. Though the bill did not pass, its intent was to limit municipal regulatory power over oil and gas drilling (Taylor, 2013). Thus for municipal policy makers, one form of legal prudence involves contesting the power of the state government as it attempts to direct the decision-making of local authorities (Blandy and Wang, 2013).

However, setback distances also represent the distance that municipal staff lawyers feel they can legally justify in a regulatory takings lawsuit. For example, filing a regulatory takings claim against a municipality is the primary recourse for mineral owners denied access to their mineral property by a municipal setback ordinance. In Denton County, Flower Mound's 1500 ft (457.2 m) setback distance is the most vulnerable to a takings lawsuit simply because it is the longest. Indeed, as long as setback distances remain shorter than Flower Mound's, other municipalities in the region limit their vulnerability to a takings lawsuit. However, Cady (2009, p. 12) feels that even a completely restrictive drilling ordinance would probably not constitute a regulatory takings. In his opinion, as outlined in *Penn Central Transp. Co. v. City of New York*, the court would likely evaluate the property as a whole, i.e., both mineral *and* surface. In that case, the surface estate would almost certainly retain some value even if the mineral estate did not; and if *Lucas v. South Carolina Coastal Council* is applied "even a nominal value remaining in a property will render a takings claim unsuccessful" (Cady, 2009, p. 12). Moreover, according to *Mayhew v. Town of Sunnyvale*, reasonable expectation of a restriction would also render a takings claim unsuccessful. And mineral owners and leasees in Denton County would either be aware of existing gas drilling ordinances or should reasonably expect some type of regulation in a municipality overlying a shale deposit (Cady, 2009). It also would be problematic for most shale gas drillers to establish that a drill rig "fits within the nature and character of a residential neighborhood" (Cady 2009, p. 12). Nevertheless, without technical basis, politically-negotiated municipal setback distances in Denton County could be considered ambiguous or even 'arbitrary,' which would expose municipalities to a regulatory takings lawsuit (e.g., Riley, 2007). Therefore, standardizing or developing a 'technical' basis for setback distances should be a priority for municipal policy makers.

### 6.3. Standardizing setbacks

Despite the use of dispersion models to estimate odor-based setbacks around concentrated animal feeding operations (e.g., Schauberger et al., 2002; Yu and Guo, 2011), wastewater treatment plants (e.g., Stellacci et al., 2010), and solid waste incinerators (e.g., Tavares et al., 2011), few dispersion models based on noise or emissions from shale gas drilling, for example, have been used as the basis to standardize gas drilling setback distances. Although a number of ambient, stationary monitoring devices have been used in the DFW area to measure emissions for gas drilling, producing models from this data is problematic due to the relatively short time frame of monitoring in the region, small number of canisters collecting emissions data, and inherent problems with the placement and immobility of stationary monitors, including the inability to detect episodic events (e.g., Olaguer, 2012; Vardoulakis et al., 2005; Mukerjee et al., 2004). For example, although Fort Worth's emissions study "was conducted with methods developed by EPA and widely used in air toxics monitoring programs nationwide" (Eastern Research Group, 2011, p. 5–3), it also only utilized 8 stationary canisters over a relatively short time period, which seems inadequate given the scale of drilling activity in the municipality. Indeed, the unprecedented scale of urban drilling in DFW would seem to require an equally unprecedented degree of emissions monitoring. Application of advanced emissions monitoring methods to construct more accurate dispersion models is one way municipalities could better understand emissions. This data could also be used to standardize setback distances.

An increasing variety of cost effective, mobile, and real-time monitoring systems could be used to improve shale gas emissions models (see e.g., Marć et al., 2012). For example, Huang et al. (2010) utilized a portable mass spectrometer to detect 0.2 parts-per-billion (ppb) of benzene in ambient air, which is well below the parts-per-million (ppm) permissible levels. As well, Guven and Olaguer (2011) were able to produce visualizations of episodic emissions events from industrial facilities by back tracing from monitoring stations and emissions inventories. Combining mobile monitoring with these types of new monitoring technologies could greatly enhance real-time monitoring of shale gas emissions. For example, the Benzene and other Toxics Benzene Exposure (BEE-TEX) Study utilizes remote sensing, Computer-Aided Tomography, ambient breathing zone measurements using both stationary and mobile techniques, meteorological data (e.g., SOnic Detection And Ranging [SODAR] and LIght Detection and Ranging or Laser Imaging Detection and Ranging [LIDaR]), inverse plume modeling, personal exposure monitoring, and dispersion, atmospheric transformation, and human exposure modeling to measure benzene, toluene, ethylbenzene, and xylenes (Olaguer, 2009). By measuring both human exposure to and source attribution of the air toxics, BEE-TEX is the type of monitoring and modeling program that could be employed among shale-drilling municipalities (Olaguer, 2012). In sum, accurate dispersion models developed from advanced and multi-method monitoring packages in the DFW region, where urban drilling is widespread, could provide the template for standardized and empirically-based setback distance regulations. This information would also greatly aid municipal policy makers in other regions of the world confronted with shale gas drilling.

## 7. Conclusion

This study is a first attempt at understanding sub-regional regulatory policies and shale gas drilling. The findings show that there is no uniform setback distance among Denton County municipalities. Moreover, municipal setback lengths have increased over time. The variability among setback distances demonstrates that rigorous, empirical research was not utilized to determine or demarcate 'safe' or 'healthy' distances, i.e., setbacks are not 'technical'. Instead, setback distances are highly politicized compromises between residents' concerns about the proximity of gas wells to their homes, mineral owners' rights to profit from gas drilling, and the city council's fear of legal lawsuits for a regulatory takings. Therefore, political negotiations among council members, municipal lawyers, staff, citizens, mineral owners, and drilling companies ultimately determine setbacks. Furthermore, setbacks are at the core of an "uneasy tension" between municipal and state governments, surface and mineral owners, and pro- and anti-drilling proponents.

Because of its anti-regulatory zeal and openness to oil and gas production activities (Rahm, 2011), the state of Texas could be considered unique from other regions where large shale gas deposits are present. However, the examples of municipal government regulatory policies presented in this study provide useful information for other municipal policy makers confronted with shale gas drilling and production activities. Indeed, because there is no technical basis to setback distances, it is important for policy makers to fund advanced methods for monitoring shale gas emissions. This information is severally lacking and would provide the necessary data to construct dispersion models of emissions, particularly benzene, from which 'safe' and 'healthy' setback distances could be derived. Rigorously determined safety distances would also remove much of the political arbitrariness that plagues current setback distances.

Finally, for Texas and other regions, a better understanding of the influences on city council member's decisions about gas drilling ordinances is a logical next step for a more complete explanation of the spatial arrangement and basis of current setback distances. Therefore, important research questions about setbacks and municipal regulations that need to be asked include: who (including municipal policy makers, interest groups, legal advisors, etc.) and what discourses influence drilling ordinances and setback distances? What are the distance ordinances outside of DFW? And, how do Denton's municipal ordinances compare to drilling ordinances in other shale regions?

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## Appendix A. Denton County municipalities and web links for gas drilling ordinances

Argyle, http://z2.franklinlegal.net/franklin/Z2Browser2.html?showset=argyleset

Bartonville, http://z2.franklinlegal.net/franklin/Z2Browser2.html?showset=bartonvilleset

Carrollton, http://www.cityofcarrollton.com/Modules/ShowDocument.aspx?documentid=1364

Coppell, http://coppelltx.c2crm.com/departments/departments-n-z/planning/oil-and-gas-drilling.html

Copper Canyon, index.asp?Type=B_BASIC&SEC=%7bB85D0EAE-6432-4CFD-A8FE-748C2862412F%7d

Corinth: http://cityofcorinth.com/ or http://www.amlegal.com/nxt/gateway.dll/Texas/corinth_tx/titlexibusinessregulations/chapter114gasdrilling?f=templates$fn=altmain-nf.htm$q=[and%3Agas%20well]%20$x=server$3.0#LPHit1

Dallas, http://www.dallascityhall.com/html/codes.html

Denton, http://www.cityofdenton.com/

Dish, http://townofdish.com/index.php?id=EKC4LS3O4

Double Oak: http://double-oak.com/public-works/city-ordinances/?doing_wp_cron=1361741616.0177209377288818359375

Flower Mound, http://www.flower-mound.com/ or http://library.municode.com/index.aspx?clientId=13329&stateId=43&stateName=Texas

Fort Worth, http://fortworthtexas.gov/uploadedFiles/Gas_Wells/gasdrilling_ordinance.pdf

Haslet, http://www.haslet.org/government/ or http://z2.franklinlegal.net/franklin/Z2Browser2.html?showset=hasletset

Hickory Creek, http://www.hickorycreek-tx.gov/ or http://z2.franklinlegal.net/franklin/Z2Browser2.html?showset=hickorycreekset

Highland Village, http://www.highlandvillage.org/index.aspx?nid=122 or http://z2.franklinlegal.net/franklin/Z2Browser2.html?showset=highlandvillageset

Justin, index.asp?Type=B_BASIC&SEC=%7b31309FCF-82B1-4F58-A5AB-FCBF0F2B3990%7d or http://library.municode.com/index.aspx?clientId=13599

Krum, http://www.ci.krum.tx.us/index.php?id=MTEzNjQxNzAyOA5

Lewisville, http://www.cityoflewisville.com/index.aspx?page=103 or http://library.municode.com/HTML/19957/level3/PTIICOOR_CH7LIBURE_ARTXVIIIOIGADRPR.html

Northlake, http://www.town.northlake.tx.us/ or http://z2codes.franklinlegal.net/franklin/Z2Browser2.html?showset=northlakeset

Ponder, http://www.pondertx.com/index.php?id=MTEzNjQxNzAyOA5 or http://www.pondertx.com/objects/Code_of_Ordinances2.pdf

Roanoke, http://roanoketexas.com/ or http://library.municode.com/index.aspx?clientId=13617&stateId=43&stateName=Texas

Sanger, http://sangertexas.org/?page_id=3432 or http://z2codes.franklinlegal.net/franklin/Z2Browser2.html?showset=sangerset

Shady Shores, http://www.nctcog.org/trans/air/ShadyShores.pdf

Southlake, http://www.cityofsouthlake.com/index.aspx?nid=248 or http://library.municode.com/index.aspx?clientID=12906&stateID=43&statename=Texas%29

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# Human health risk assessment of air emissions from development of unconventional natural gas resources☆,☆☆

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ABSTRACT

*Background:* Technological advances (e.g. directional drilling, hydraulic fracturing), have led to increases in unconventional natural gas development (NGD), raising questions about health impacts.
*Objectives:* We estimated health risks for exposures to air emissions from a NGD project in Garfield County, Colorado with the objective of supporting risk prevention recommendations in a health impact assessment (HIA).
*Methods:* We used EPA guidance to estimate chronic and subchronic non-cancer hazard indices and cancer risks from exposure to hydrocarbons for two populations: (1) residents living >½ mile from wells and (2) residents living ≤½ mile from wells.
*Results:* Residents living ≤½ mile from wells are at greater risk for health effects from NGD than are residents living >½ mile from wells. Subchronic exposures to air pollutants during well completion activities present the greatest potential for health effects. The subchronic non-cancer hazard index (HI) of 5 for residents ≤½ mile from wells was driven primarily by exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons. Chronic HIs were 1 and 0.4. for residents ≤½ mile from wells and >½ mile from wells, respectively. Cumulative cancer risks were 10 in a million and 6 in a million for residents living ≤½ mile and >½ mile from wells, respectively, with benzene as the major contributor to the risk.
*Conclusions:* Risk assessment can be used in HIAs to direct health risk prevention strategies. Risk management approaches should focus on reducing exposures to emissions during well completions. These preliminary results indicate that health effects resulting from air emissions during unconventional NGD warrant further study. Prospective studies should focus on health effects associated with air pollution.



## 1. Introduction

The United States (US) holds large reserves of unconventional natural gas resources in coalbeds, shale, and tight sands. Technological advances, such as directional drilling and hydraulic fracturing, have led to a rapid increase in the development of these resources. For example, shale gas production had an average annual growth rate of 48% over the 2006 to 2010 period and is projected to grow almost fourfold from 2009 to 2035 (US EIA, 2011). The number of unconventional natural gas wells in the US rose from 18,485 in 2004 to 25,145 in 2007 and is expected to continue increasing through at least 2020 (Vidas and Hugman, 2008). With this expansion, it is becoming increasingly common for unconventional natural gas development (NGD) to occur near where people live, work, and play. People living near these development sites are raising public health concerns, as rapid NGD exposes more people to various potential stressors (COGCC, 2009a).

The process of unconventional NGD is typically divided into two phases: well development and production (US EPA, 2010a; US DOE, 2009). Well development involves pad preparation, well drilling, and well completion. The well completion process has three primary stages: 1) completion transitions (concrete well plugs are installed in wells to separate fracturing stages and then drilled out to release gas for production); 2) hydraulic fracturing ("fracking": the high pressure injection of water, chemicals, and propants into the drilled well to release the natural gas); and 3) flowback, the return of fracking and geologic fluids, liquid hydrocarbons ("condensate") and natural gas to the surface (US EPA, 2010a; US DOE, 2009). Once development is

*Abbreviations:* BTEX, benzene, toluene, ethylbenzene, and xylenes; COGCC, Colorardo Oil and Gas Conservation Commission; HAP, hazardous air pollutant; HI, hazard index; HIA, health impact assessment; HQ, hazard quotient; NATA, National Air Toxics Assessment; NGD, natural gas development.

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complete, the "salable" gas is collected, processed, and distributed. While methane is the primary constituent of natural gas, it contains many other chemicals, including alkanes, benzene, and other aromatic hydrocarbons (TERC, 2009).

As shown by ambient air studies in Colorado, Texas, and Wyoming, the NGD process results in direct and fugitive air emissions of a complex mixture of pollutants from the natural gas resource itself as well as diesel engines, tanks containing produced water, and on site materials used in production, such as drilling muds and fracking fluids (CDPHE, 2009; Frazier, 2009; Walther, 2011; Zielinska et al., 2011). The specific contribution of each of these potential NGD sources has yet to be ascertained and pollutants such as petroleum hydrocarbons are likely to be emitted from several of these NGD sources. This complex mixture of chemicals and resultant secondary air pollutants, such as ozone, can be transported to nearby residences and population centers (Walther, 2011; GCPH, 2010).

Multiple studies on inhalation exposure to petroleum hydrocarbons in occupational settings as well as residences near refineries, oil spills and petrol stations indicate an increased risk of eye irritation and headaches, asthma symptoms, acute childhood leukemia, acute myelogenous leukemia, and multiple myeloma (Glass et al., 2003; Kirkeleit et al., 2008; Brosselin et al., 2009; Kim et al., 2009; White et al., 2009). Many of the petroleum hydrocarbons observed in these studies are present in and around NGD sites (TERC, 2009). Some, such as benzene, ethylbenzene, toluene, and xylene (BTEX) have robust exposure and toxicity knowledge bases, while toxicity information for others, such as heptane, octane, and diethylbenzene, is more limited. Assessments in Colorado have concluded that ambient benzene levels demonstrate an increased potential risk of developing cancer as well as chronic and acute non-cancer health effects in areas of Garfield County Colorado where NGD is the only major industry other than agriculture (CDPHE, 2007; Coons and Walker, 2008; CDPHE, 2010). Health effects associated with benzene include acute and chronic nonlymphocytic leukemia, acute myeloid leukemia, chronic lymphocytic leukemia, anemia, and other blood disorders and immunological effects. (ATSDR, 2007a, IRIS, 2011). In addition, maternal exposure to ambient levels of benzene recently has been associated with an increase in birth prevalence of neural tube defects (Lupo et al., 2011). Health effects of xylene exposure include eye, nose, and throat irritation, difficulty in breathing, impaired lung function, and nervous system impairment (ATSDR, 2007b). In addition, inhalation of xylenes, benzene, and alkanes can adversely affect the nervous system (Carpenter et al., 1978; Nilsen et al., 1988; Galvin and Marashi, 1999; ATSDR, 2007a; ATSDR, 2007b).

Previous assessments are limited in that they were not able to distinguish between risks from ambient air pollution and specific NGD stages, such as well completions or risks between residents living near wells and residents living further from wells. We were able to isolate risks to residents living near wells during the flowback stage of well completions by using air quality data collected at the perimeter of the wells while flowback was occurring.

Battlement Mesa (population ~5000) located in rural Garfield County, Colorado is one community experiencing the rapid expansion of NGD in an unconventional tight sand resource. A NGD operator has proposed developing 200 gas wells on 9 well pads located as close as 500 ft from residences. Colorado Oil and Gas Commission (COGCC) rules allow natural gas wells to be placed as close as 150 ft from residences (COGCC, 2009b). Because of community concerns, as described elsewhere, we conducted a health impact assessment (HIA) to assess how the project may impact public health (Witter et al., 2011), working with a range of stakeholders to identify the potential public health risks and benefits.

In this article, we illustrate how a risk assessment was used to support elements of the HIA process and inform risk prevention recommendations by estimating chronic and subchronic non-cancer hazard indices (HIs) and lifetime excess cancer risks due to NGD air emissions.

## 2. Methods

We used standard United States Environmental Protection Agency (EPA) methodology to estimate non-cancer HIs and excess lifetime cancer risks for exposures to hydrocarbons (US EPA, 1989; US EPA, 2004) using residential exposure scenarios developed for the NGD project. We used air toxics data collected in Garfield County from January 2008 to November 2010 as part of a special study of short term exposures as well as on-going ambient air monitoring program data to estimate subchronic and chronic exposures and health risks (Frazier, 2009; GCPH, 2009; GCPH, 2010; GCPH, 2011; Antero, 2010).

### *2.1. Sample collection and analysis*

All samples were collected and analyzed according to published EPA methods. Analyses were conducted by EPA certified laboratories. The Garfield County Department of Public Health (GCPH) and Olsson Associates, Inc. (Olsson) collected ambient air samples into evacuated SUMMA® passivated stainless-steel canisters over 24-hour intervals. The GCPH collected the samples from a fixed monitoring station and along the perimeters of four well pads and shipped samples to Eastern Research Group for analysis of 78 hydrocarbons using EPA's compendium method TO-12, Method for the Determination of Non-Methane Organic Compounds in Ambient Air Using Cyrogenic Pre-concentration and Direct Flame Ionization Detection (US EPA, 1999). Olsson collected samples along the perimeter of one well pad and shipped samples to Atmospheric Analysis and Consulting, Inc. for analysis of 56 hydrocarbons (a subset of the 78 hydrocarbons determined by Eastern Research Group) using method TO-12. Per method TO-12, a fixed volume of sample was cryogenically concentrated and then desorbed onto a gas chromatography column equipped with a flame ionization detector. Chemicals were identified by retention time and reported in a concentration of parts per billion carbon (ppbC). The ppbC values were converted to micrograms per cubic meter ($\mu g/m^3$) at 01.325 kPa and 298.15 K.

Two different sets of samples were collected from rural (population < 50,000) areas in western Garfield County over varying time periods. The main economy, aside from the NGD industry, of western Garfield County is agricultural. There is no other major industry.

#### *2.1.1. NGD area samples*

The GCPH collected ambient air samples every six days between January 2008 and November 2010 (163 samples) from a fixed monitoring station located in the midst of rural home sites and ranches and NGD, during both well development and production. The site is located on top of a small hill and 4 miles upwind of other potential emission sources, such as a major highway (Interstate-70) and the town of Silt, CO (GCPH, 2009; GCPH, 2010; GCPH, 2011).

#### *2.1.2. Well completion samples*

The GCPH collected 16 ambient air samples at each cardinal direction along 4 well pad perimeters (130 to 500 ft from the well pad center) in rural Garfield County during well completion activities. The samples were collected on the perimeter of 4 well pads being developed by 4 different natural gas operators in summer 2008 (Frazier, 2009). The GCPH worked closely with the NGD operators to ensure these air samples were collected during the period while at least one well was on uncontrolled (emissions not controlled) flowback into collection tanks vented directly to the air. The number of wells on each pad and other activities occurring on the pad were not documented. Samples were collected over 24 to 27-hour intervals, and samples included emissions from both uncontrolled flowback and diesel engines (i.e., from. trucks and generators supporting completion activities). In addition, the GCPH collected a background sample 0.33 to 1 mile from each well pad (Frazier, 2009). The highest hydrocarbon levels corresponded to samples collected directly downwind of the tanks (Frazier, 2009; Antero, 2010). The lowest hydrocarbon levels corresponded either to background samples or samples collected upwind of the flowback tanks (Frazier, 2009; Antero, 2010).

Antero Resources Inc., a natural gas operator, contracted Olsson to collect eight 24-hour integrated ambient air samples at each cardinal direction at 350 and 500 ft from the well pad center during well completion activities conducted on one of their well pads in summer 2010 (Antero, 2010). Of the 12 wells on this pad, 8 were producing salable natural gas; 1 had been drilled but not completed; 2 were being hydraulically fractured during daytime hours, with ensuing uncontrolled flowback during nighttime hours; and 1 was on uncontrolled flowback during nighttime hours.

All five well pads are located in areas with active gas production, approximately 1 mile from Interstate-70.

### 2.2. Data assessment

We evaluated outliers and compared distributions of chemical concentrations from NGD area and well completion samples using Q–Q plots and the Mann–Whitney *U* test, respectively, in EPA's ProUCL version 4.00.05 software (US EPA, 2010b). The Mann–Whitney *U* test was used because the measurement data were not normally distributed. Distributions were considered as significantly different at an alpha of 0.05. Per EPA guidance, we assigned the exposure concentration as either the 95% upper confidence limit (UCL) of the mean concentration for compounds found in 10 or more samples or the maximum detected concentration for compounds found in more than 1 but fewer than 10 samples. This latter category included three compounds: 1,3-butadiene, 2,2,4-trimethylpentane, and styrene in the well completion samples. EPA's ProUCL software was used to select appropriate methods based on sample distributions and detection frequency for computing 95% UCLs of the mean concentration (US EPA, 2010b).

### 2.3. Exposure assessment

Risks were estimated for two populations: (1) residents >½ mile from wells; and (2) residents ≤½ mile from wells. We defined residents ≤½ mile from wells as living near wells, based on residents reporting odor complaints attributed to gas wells in the summer of 2010 (COGCC, 2011).

Exposure scenarios were developed for chronic non-cancer HIs and cancer risks. For both populations, we assumed a 30-year project duration based on an estimated 5-year well development period for all well pads, followed by 20 to 30 years of production. We assumed a resident lives, works, and otherwise remains within the town 24 h/day, 350 days/year and that lifetime of a resident is 70 years, based on standard EPA reasonable maximum exposure (RME) defaults (US EPA, 1989).

#### 2.3.1. Residents >½ mile from well pads

As illustrated in Fig. 1, data from the NGD area samples were used to estimate chronic and subchronic risks for residents >½ mile from well development and production throughout the project. The exposure concentrations for this population were the 95% UCL on the mean concentration and median concentration from the 163 NGD samples.

#### 2.3.2. Residents ≤½ mile from well pads

To evaluate subchronic non-cancer HIs from well completion emissions, we estimated that a resident lives ≤½ mile from two well pads resulting a 20-month exposure duration based on 2 weeks per well for completion and 20 wells per pad, assuming some overlap in between activities. The subchronic exposure concentrations for this population were the 95% UCL on the mean concentration and the median concentration from the 24 well completion samples. To evaluate chronic risks to residents ≤½ mile from wells throughout the NGD project, we calculated a time-weighted exposure concentration ($C_{S+c}$) to account for exposure to emissions from well completions for 20-months followed by 340 months of exposure to emissions from the NGD area using the following formula:

$$C_{S+c} = (C_c \times ED_c/ED) + (C_S \times ED_S/ED)$$

where:

$C_c$ Chronic exposure point concentration (μg/m$^3$) based on the 95% UCL of the mean concentration or median concentration from the 163 NGD area samples

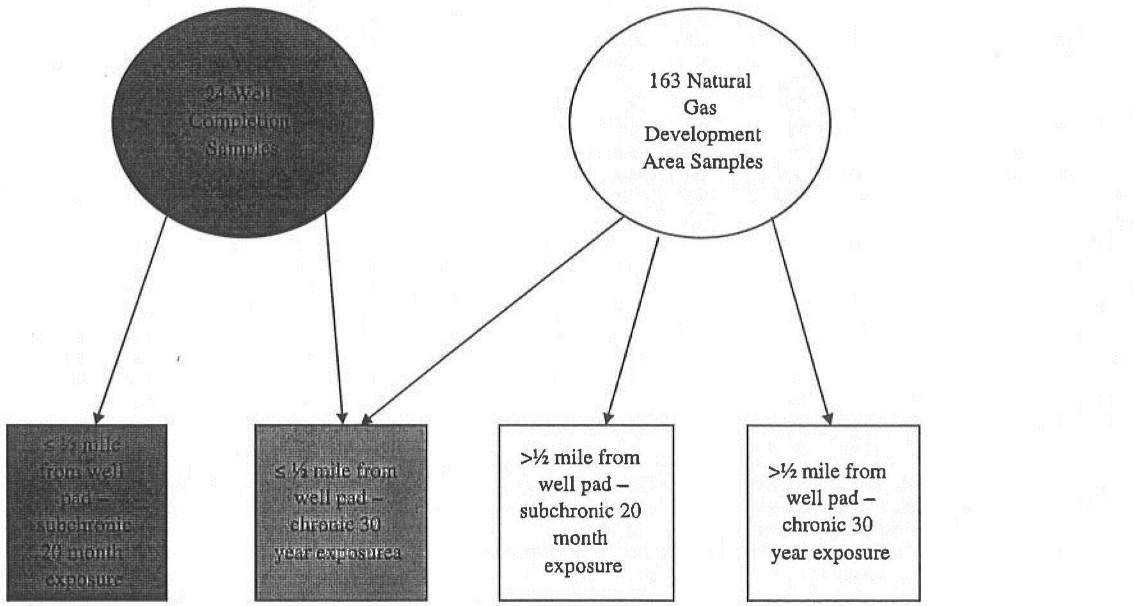


**Fig. 1.** Relationship between completion samples and natural gas development area samples and residents living ≤½ mile and >½ mile from wells. [a]Time weighted average based on 20-month contribution from well completion samples and 340-month contribution from natural gas development samples.

$ED_c$ Chronic exposure duration
$C_S$ Subchronic exposure point concentration (μg/m$^3$) based on the 95% UCL of the mean concentration or median concentration from the 24 well completion samples
$ED_S$ Subchronic exposure duration
ED Total exposure duration

### 2.4. Toxicity assessment and risk characterization

For non-carcinogens, we expressed inhalation toxicity measurements as a reference concentration (RfC in units of μg/m$^3$ air). We used chronic RfCs to evaluate long-term exposures of 30 years and subchronic RfCs to evaluate subchronic exposures of 20-months. If a subchronic RfC was not available, we used the chronic RfC. We obtained RfCs from (in order of preference) EPA's Integrated Risk Information System (IRIS) (US EPA, 2011), California Environmental Protection Agency (CalEPA) (CalEPA, 2003), EPA's Provisional Peer-Reviewed Toxicity Values (ORNL, 2009), and Health Effects Assessment Summary Tables (US EPA, 1997). We used surrogate RfCs according to EPA guidance for $C_5$ to $C_{18}$ aliphatic and $C_6$ to $C_{18}$ aromatic hydrocarbons which did not have a chemical-specific toxicity value (US EPA, 2009a). We derived semi-quantitative hazards, in terms of the hazard quotient (HQ), defined as the ratio between an estimated exposure concentration and RfC. We summed HQs for individual compounds to estimate the total cumulative HI. We then separated HQs specific to neurological, respiratory, hematological, and developmental effects and calculated a cumulative HI for each of these specific effects.

For carcinogens, we expressed inhalation toxicity measurements as inhalation unit risk (IUR) in units of risk per μg/m$^3$. We used IURs from EPA's IRIS (US EPA, 2011) when available or the CalEPA (CalEPA, 2003). The lifetime cancer risk for each compound was derived by multiplying estimated exposure concentration by the IUR. We summed cancer risks for individual compounds to estimate the cumulative cancer risk. Risks are expressed as excess cancers per 1 million population based on exposure over 30 years.

Toxicity values (i.e., RfCs or IURs) or a surrogate toxicity value were available for 45 out of 78 hydrocarbons measured. We performed a quantitative risk assessment for these hydrocarbons. The remaining 33 hydrocarbons were considered qualitatively in the risk assessment.

## 3. Results

### 3.1. Data assessment

Evaluation of potential outliers revealed no sampling, analytical, or other anomalies were associated with the outliers. In addition, removal of potential outliers from the NGD area samples did not change the final HIs and cancer risks. Potential outliers in the well completion samples were associated with samples collected downwind from flowback tanks and are representative of emissions during flowback. Therefore, no data was removed from either data set.

Descriptive statistics for concentrations of the hydrocarbons used in the quantitative risk assessment are presented in Table 1. A list of the hydrocarbons detected in the samples that were considered qualitatively in the risk assessment because toxicity values were not available is presented in Table 2. Descriptive statistics for all hydrocarbons are available in Supplemental Table 1. Two thirds more hydrocarbons were detected at a frequency of 100% in the well completion samples (38 hydrocarbons) than in the NGD area samples (23 hydrocarbons). Generally, the highest alkane and aromatic hydrocarbon median concentrations were observed in the well completion samples, while the highest median concentrations of several alkenes were observed in the NGD area samples. Median concentrations of benzene, ethylbenzene, toluene, and m-xylene/p-xlyene were 2.7, 4.5, 4.3, and 9 times higher in the well completion samples than in the NGD area samples, respectively. Wilcoxon–Mann–Whitney test results indicate that

**Table 1**
Descriptive statistics for hydrocarbon concentrations with toxicity values in 24-hour integrated samples collected in NGD area and samples collected during well completions.

| Hydrocarbon (μg/m$^3$) | NGD area sample results[a] | | | | | | | Well completion sample results[b] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % > MDL | Med | SD | 95% UCL[c] | Min | Max | No. | % > MDL | Med | SD | 95% UCL[c] | Min | Max |
| 1,2,3-Trimethylbenzene | 163 | 39 | 0.11 | 0.095 | 0.099 | 0.022 | 0.85 | 24 | 83 | 0.84 | 2.3 | 3.2 | 0.055 | 12 |
| 1,2,4-Trimethylbenzene | 163 | 96 | 0.18 | 0.34 | 0.31 | 0.063 | 3.1 | 24 | 100 | 1.7 | 17 | 21 | 0.44 | 83 |
| 1,3,5-Trimethylbenzene | 163 | 83 | 0.12 | 0.13 | 0.175 | 0.024 | 1.2 | 24 | 100 | 1.3 | 16 | 19.5 | 0.33 | 78 |
| 1,3-Butadiene | 163 | 7 | 0.11 | 0.020 | 0.0465 | 0.025 | 0.15 | 16 | 56 | 0.11 | 0.021 | NC | 0.068 | 0.17 |
| Benzene | 163 | 100 | 0.95 | 1.3 | 1.7 | 0.096 | 14 | 24 | 100 | 2.6 | 14 | 20 | 0.94 | 69 |
| Cyclohexane | 163 | 100 | 2.1 | 8.3 | 6.2 | 0.11 | 105 | 24 | 100 | 5.3 | 43 | 58 | 2.21 | 200 |
| Ethylbenzene | 163 | 95 | 0.17 | 0.73 | 0.415 | 0.056 | 8.1 | 24 | 100 | 0.77 | 47 | 54 | 0.25 | 230 |
| Isopropylbenzene | 163 | 38 | 0.15 | 0.053 | 0.074 | 0.020 | 0.33 | 24 | 67 | 0.33 | 1.0 | 1.0 | 0.0 | 4.8 |
| Methylcyclohexane | 163 | 100 | 3.7 | 4.0 | 6.3 | 0.15 | 24 | 24 | 100 | 14 | 149 | 190 | 3.1 | 720 |
| m-Xylene/p-Xylene | 163 | 100 | 0.87 | 1.2 | 1.3 | 0.16 | 9.9 | 24 | 100 | 7.8 | 194 | 240 | 2.0 | 880 |
| n-Hexane | 163 | 100 | 4.0 | 4.2 | 6.7 | 0.13 | 25 | 24 | 100 | 7.7 | 57 | 80 | 1.7 | 255 |
| n-Nonane | 163 | 99 | 0.44 | 0.49 | 0.66 | 0.064 | 3.1 | 24 | 100 | 3.6 | 61 | 76 | 1.2 | 300 |
| n-Pentane | 163 | 100 | 9.1 | 9.8 | 14 | 0.23 | 62 | 24 | 100 | 11 | 156 | 210 | 3.9 | 550 |
| n-Propylbenzene | 163 | 66 | 0.10 | 0.068 | 0.10 | 0.032 | 0.71 | 24 | 88 | 0.64 | 2.4 | 3.3 | 0.098 | 12 |
| o-Xylene | 163 | 97 | 0.22 | 0.33 | 0.33 | 0.064 | 3.6 | 24 | 100 | 1.2 | 40 | 48.5 | 0.38 | 190 |
| Propylene | 163 | 100 | 0.34 | 0.23 | 0.40 | 0.11 | 2.5 | 24 | 100 | 0.41 | 0.34 | 0.60 | 0.16 | 1.9 |
| Styrene | 163 | 15 | 0.15 | 0.26 | 0.13 | 0.017 | 3.4 | 24 | 21 | 0.13 | 1.2 | NC | 0.23 | 5.9 |
| Toluene | 163 | 100 | 1.8 | 6.2 | 4.8 | 0.11 | 79 | 24 | 100 | 7.8 | 67 | 92 | 2.7 | 320 |
| Aliphatic hydrocarbons $C_5$–$C_8$[d] | 163 | NC | 29 | NA | 44 | 1.7 | 220 | 24 | NC | 56 | NA | 780 | 24 | 2700 |
| Aliphatic hydrocarbons $C_9$–$C_{18}$[e] | 163 | NC | 1.3 | NA | 14 | 0.18 | 400 | 24 | NC | 7.9 | NA | 100 | 1.4 | 390 |
| Aromatic hydrocarbons $C_9$–$C_{18}$[f] | 163 | NC | 0.57 | NA | 0.695 | 0.17 | 5.6 | 24 | NC | 3.7 | NA | 27 | 0.71 | 120 |

Abbreviations: Max, maximum detected concentration; Med, median; Min, minimum detected concentration; NGD, natural gas development; NC, not calculated; No., number of samples; SD, standard deviation; % > MDL, percent greater than method detection limit; μg/m$^3$ micrograms per cubic meter; 95% UCL 95% upper confidence limit on the mean.
[a] Samples collected at one site every 6 six days between 2008 and 2010.
[b] Samples collected at four separate sites in summer 2008 and one site in summer 2010.
[c] Calculated using EPA's ProUCL version 4.00.05 software (US EPA, 2010b).
[d] Sum of 2,2,2-trimethylpentane, 2,2,4-trimethylpentane, 2,2-dimethylbutane, 2,3,4-trimethylpentane, 2,3-dimethylbutane, 2,3-dimethylpentane, 2,4-dimethylpentane, 2-methylheptane, 2-methylhexane, 2-methylpentane, 3-methylheptane, 3-methylhexane, 3-methylpentane, cyclopentane, isopentane, methylcyclopentane, n-heptane, n-octane.
[e] Sum of n-decane, n-dodecane, n-tridecane, n-undecane.
[f] Sum of m-diethylbenzene, m-ethyltoluene, o-ethyltoluene, p-diethylbenzene, p-ethyltoluene.

**Table 2**
Detection frequencies of hydrocarbons without toxicity values detected in NGD area or well completion samples.

| Hydrocarbon | NGD area sample[a] detection frequency (%) | Well completion sample[b] detection frequency (%) |
|---|---|---|
| 1-Dodecene | 36 | 81 |
| 1-Heptene | 94 | 100 |
| 1-Hexene | 63 | 79 |
| 1-Nonene | 52 | 94 |
| 1-Octene | 29 | 75 |
| 1-Pentene | 98 | 79 |
| 1-Tridecene | 7 | 38 |
| 1-Undecene | 28 | 81 |
| 2-Ethyl-1-butene | 1 | 0 |
| 2-Methyl-1-butene | 29 | 44 |
| 2-Methyl-1-pentene | 1 | 6 |
| 2-Methyl-2-butene | 36 | 69 |
| 3-Methyl-1-butene | 6 | 6 |
| 4-Methyl-1-pentene | 16 | 69 |
| Acetylene | 100 | 92 |
| a-Pinene | 63 | 100 |
| b-Pinene | 10 | 44 |
| cis-2-Butene | 58 | 75 |
| cis-2-Hexene | 13 | 81 |
| cis-2-Pentene | 38 | 54 |
| Cyclopentene | 44 | 94 |
| Ethane | 100 | 100 |
| Ethylene | 100 | 100 |
| Isobutane | 100 | 100 |
| Isobutene/1-Butene | 73 | 44 |
| Isoprene | 71 | 96 |
| n-Butane | 98 | 100 |
| Propane | 100 | 100 |
| Propyne | 1 | 0 |
| trans-2-Butene | 80 | 75 |
| trans-2-Hexene | 1 | 6 |
| trans-2-Pentene | 55 | 83 |

Abbreviations: NGD, natural gas development.
[a] Samples collected at one site every 6 six days between 2008 and 2010.
[b] Samples collected at four separate sites in summer 2008 and one site in summer 2010.

concentrations of hydrocarbons from well completion samples were significantly higher than concentrations from NGD area samples ($p<0.05$) with the exception of 1,2,3-trimethylbenzene, n-pentane, 1,3-butadiene, isopropylbenzene, n-propylbenzene, propylene, and styrene (Supplemental Table 2).

### 3.2. Non-cancer hazard indices

Table 3 presents chronic and subchronic RfCs used in calculating non-cancer HIs, as well critical effects and other effects. Chronic non-cancer HQ and HI estimates based on ambient air concentrations are presented in Table 4. The total chronic HIs based on the 95% UCL of the mean concentration were 0.4 for residents >½ mile from wells and 1 for residents ≤½ mile from wells. Most of the chronic non-cancer hazard is attributed to neurological effects with neurological HIs of 0.3 for residents >½ mile from wells and 0.9 for residents ≤½ mile from wells.

Total subchronic non-cancer HQs and HI estimates are presented in Table 5. The total subchronic HIs based on the 95% UCL of the mean concentration were 0.2 for residents >½ mile from wells and 5 for residents ≤½ mile from wells. The subchronic non-cancer hazard for residents >½ mile from wells is attributed mostly to respiratory effects (HI = 0.2), while the subchronic hazard for residents ≤½ mile from wells is attributed to neurological (HI = 4), respiratory (HI = 2), hematologic (HI = 3), and developmental (HI = 1) effects.

For residents >½ mile from wells, aliphatic hydrocarbons (51%), trimethylbenzenes (22%), and benzene (14%) are primary contributors to the chronic non-cancer HI. For residents ≤½ mile from wells, trimethylbenzenes (45%), aliphatic hydrocarbons (32%), and xylenes (17%) are primary contributors to the chronic non-cancer HI, and trimethylbenzenes (46%), aliphatic hydrocarbons (21%) and xylenes (15%) also are primary contributors to the subchronic HI.

### 3.3. Cancer risks

Cancer risk estimates calculated based on measured ambient air concentrations are presented in Table 6. The cumulative cancer risks based on the 95% UCL of the mean concentration were 6 in a million for residents >½ from wells and 10 in a million for residents ≤½ mile from wells. Benzene (84%) and 1,3-butadiene (9%) were the primary contributors to cumulative cancer risk for residents >½ mile from wells. Benzene (67%) and ethylbenzene (27%) were the primary contributors to cumulative cancer risk for residents ≤½ mile from wells.

## 4. Discussion

Our results show that the non-cancer HI from air emissions due to natural gas development is greater for residents living closer to wells. Our greatest HI corresponds to the relatively short-term (i.e., subchronic), but high emission, well completion period. This HI is driven principally by exposure to trimethylbenzenes, aliphatic hydrocarbons, and xylenes, all of which have neurological and/or respiratory effects. We also calculated higher cancer risks for residents living nearer to wells as compared to residents residing further from wells. Benzene is the major contributor to lifetime excess cancer risk for both scenarios. It also is notable that these increased risk metrics are seen in an air shed that has elevated ambient levels of several measured air toxics, such as benzene (CDPHE, 2009; GCPH, 2010).

### 4.1. Representation of exposures from NGD

It is likely that NGD is the major source of the hydrocarbons observed in the NGD area samples used in this risk assessment. The NGD area monitoring site is located in the midst of multi-acre rural home sites and ranches. Natural gas is the only industry in the area other than agriculture. Furthermore, the site is at least 4 miles upwind from any other major emission source, including Interstate 70 and the town of Silt, Colorado. Interestingly, levels of benzene, m,p-xylene, and 1,3,5-trimethylbenzene measured at this rural monitoring site in 2009 were higher than levels measured at 27 out of 37 EPA air toxics monitoring sites where SNMOCs were measured, including urban sites such as Elizabeth, NJ, Dearborn, MI, and Tulsa, OK (GCPH, 2010; US EPA, 2009b). In addition, the 2007 Garfield County emission inventory attributes the bulk of benzene, xylene, toluene, and ethylbenzene emissions in the county to NGD, with NGD point and non-point sources contributing five times more benzene than any other emission source, including on-road vehicles, wildfires, and wood burning. The emission inventory also indicates that NGD sources (e.g. condensate tanks, drill rigs, venting during completions, fugitive emissions from wells and pipes, and compressor engines) contributed ten times more VOC emissions than any source, other than biogenic sources (e.g. plants, animals, marshes, and the earth) (CDPHE, 2009).

Emissions from flowback operations, which may include emissions from various sources on the pads such as wells and diesel engines, are likely the major source of the hydrocarbons observed in the well completion samples. These samples were collected very near (130 to 500 ft from the center) well pads during uncontrolled flowback into tanks venting directly to the air. As for the NGD area samples, no sources other than those associated with NGD were in the vicinity of the sampling locations.

Subchronic health effects, such as headaches and throat and eye irritation reported by residents during well completion activities

**Table 3**
Chronic and subchronic reference concentrations, critical effects, and major effects for hydrocarbons in quantitative risk assessment.

| Hydrocarbon | Chronic | | Subchronic | | Critical effect/ target organ | Other effects |
|---|---|---|---|---|---|---|
| | RfC (μg/m³) | Source | RfC (μg/m³) | Source | | |
| 1,2,3-Trimethylbenzene | 5.00E+00 | PPTRV | 5.00E+01 | PPTRV | Neurological | Respiratory, hematological |
| 1,3,5-Trimethylbenzene | 6.00E+00 | PPTRV | 1.00E+01 | PPTRV | Neurological | Hematological |
| Isopropylbenzene | 4.00E+02 | IRIS | 9.00E+01 | HEAST | Renal | Neurological, respiratory |
| n-Hexane | 7.00E+02 | IRIS | 2.00E+03 | PPTRV | Neurological | – |
| n-Nonane | 2.00E+02 | PPTRV | 2.00E+03 | PPTRV | Neurological | Respiratory |
| n-Pentane | 1.00E+03 | PPTRV | 1.00E+04 | PPTRV | Neurological | – |
| Styrene | 1.00E+03 | IRIS | 3.00E+03 | HEAST | Neurological | – |
| Toluene | 5.00E+03 | IRIS | 5.00E+03 | PPTRV | Neurological | Developmental, respiratory |
| Xylenes, total | 1.00E+02 | IRIS | 4.00E+02 | PPTRV | Neurological | Developmental, respiratory |
| n-propylbenzene | 1.00E+03 | PPTRV | 1.00E+03 | Chronic RfC PPTRV | Developmental | Neurological |
| 1,2,4-Trimethylbenzene | 7.00E+00 | PPTRV | 7.00E+01 | PPTRV | Decrease in blood clotting time | Neurological, respiratory |
| 1,3-Butadiene | 2.00E+00 | IRIS | 2.00E+00 | Chronic RfC IRIS | Reproductive | Neurological, respiratory |
| Propylene | 3.00E+03 | CalEPA | 1.00E+03 | Chronic RfC CalEPA | Respiratory | – |
| Benzene | 3.00E+01 | ATSDR | 8.00E+01 | PPTRV | Decreased lymphocyte count | Neurological, developmental, reproductive |
| Ethylbenzene | 1.00E+03 | ATSDR | 9.00E+03 | PPTRV | Auditory | Neurological, respiratory, renal |
| Cyclohexane | 6.00E+03 | IRIS | 1.80E+04 | PPTRV | Developmental | Neurological |
| Methylcyclohexane | 3.00E+03 | HEAST | 3.00E+03 | HEAST | Renal | – |
| Aliphatic hydrocarbons $C_5$–$C_8$[a] | 6E+02 | PPTRV | 2.7E+04 | PPTRV | Neurological | – |
| Aliphatic hydrocarbons $C_9$–$C_{18}$ | 1E+02 | PPTRV | 1E+02 | PPTRV | Respiratory | – |
| Aromatic hydrocarbons $C_9$–$C_{18}$[b] | 1E+02 | PPTRV | 1E+03 | PPRTV | Decreased maternal body weight | Respiratory |

Abbreviations: 95%UCL, 95% upper confidence limit; CalEPA, California Environmental Protection Agency; HEAST, EPA Health Effects Assessment Summary Tables 1997; HQ, hazard quotient; IRIS, Integrated Risk Information System; Max, maximum; PPTRV, EPA Provisional Peer-Reviewed Toxicity Value; RfC, reference concentration; μg/m³, micrograms per cubic meter. Data from CalEPA 2011; IRIS (US EPA, 2011); ORNL 2011.
[a] Based on PPTRV for commercial hexane.
[b] Based on PPTRV for high flash naphtha.

occurring in Garfield County, are consistent with known health effects of many of the hydrocarbons evaluated in this analysis (COGCC, 2011; Witter et al., 2011). Inhalation of trimethylbenzenes and xylenes can irritate the respiratory system and mucous membranes with effects ranging from eye, nose, and throat irritation to difficulty in breathing and impaired lung function (ATSDR, 2007a;

**Table 4**
Chronic hazard quotients and hazard indices for residents living >½ mile from wells and residents living ≤½ mile from wells.

| Hydrocarbon | >½ mile | | ≤½ mile | |
|---|---|---|---|---|
| | Chronic HQ based on median concentration | Chronic HQ based on 95% UCL of mean concentration | Chronic HQ based on median concentration | Chronic HQ based on 95% UCL of mean concentration |
| 1,2,3-Trimethylbenzene | 2.09E−02 | 1.90E−02 | 2.87E−02 | 5.21E−02 |
| 1,2,4-Trimethylbenzene | 2.51E−02 | 4.22E−02 | 3.64E−02 | 2.01E−01 |
| 1,3,5-Trimethylbenzene | 1.96E−02 | 2.80E−02 | 3.00E−02 | 1.99E−01 |
| 1,3-Butadiene | 5.05E−02 | 2.23E−02 | 5.05E−02 | 2.25E−02 |
| Benzene | 3.03E−02 | 5.40E−02 | 3.32E−02 | 8.70E−02 |
| Cyclohexane | 3.40E−04 | 9.98E−04 | 3.67E−04 | 1.46E−03 |
| Ethylbenzene | 1.63E−04 | 3.98E−04 | 1.95E−04 | 3.23E−03 |
| Isopropylbenzene | 3.68E−04 | 1.78E−04 | 3.90E−04 | 3.05E−04 |
| Methylcyclohexane | 1.18E−03 | 2.00E−03 | 1.36E−03 | 5.32E−03 |
| n-Hexane | 5.49E−03 | 9.23E−03 | 5.76E−03 | 1.47E−02 |
| n-Nonane | 2.11E−03 | 3.14E−03 | 2.95E−03 | 2.31E−02 |
| n-Pentane | 8.71E−03 | 1.32E−02 | 8.79E−03 | 2.39E−02 |
| n-propylbenzene | 9.95E−05 | 9.59E−05 | 1.28E−04 | 2.64E−04 |
| Propylene | 1.09E−04 | 1.27E−04 | 1.10E−04 | 1.30E−04 |
| Styrene | 1.43E−04 | 1.25E−04 | 1.42E−04 | 4.32E−04 |
| Toluene | 3.40E−04 | 9.28E−04 | 4.06E−04 | 1.86E−03 |
| Xylenes, total | 1.16E−02 | 1.57E−02 | 1.54E−02 | 1.71E−01 |
| Aliphatic hydrocarbons $C_5$–$C_8$ | 4.63E−02 | 7.02E−02 | 4.87E−02 | 1.36E−01 |
| Aliphatic hydrocarbons $C_9$–$C_{18}$ | 1.22E−02 | 1.35E−01 | 1.58E−02 | 1.83E−01 |
| Aromatic hydrocarbons $C_9$–$C_{18}$ | 5.44E−03 | 6.67E−03 | 7.12E−03 | 2.04E−02 |
| Total Hazard Index | 2E−01 | 4E−01 | 3E−01 | 1E+00 |
| Neuorological Effects Hazard Index[a] | 2E−01 | 3E−01 | 3E−01 | 9E−01 |
| Respiratory Effects Hazard Index[b] | 1E−01 | 2E−02 | 2E−02 | 7E−01 |
| Hematogical Effects Hazard Index[c] | 1E−01 | 1E−01 | 1E−01 | 5E−01 |
| Developmental Effects Hazard Index[d] | 4E−02 | 7E−02 | 5E−02 | 3E−01 |

Abbreviations: 95%UCL, 95% upper confidence limit; HQ, hazard quotient.
[a] Sum of HQs for hydrocarbons with neurological effects: 1,2,3-Trimethylbenzene, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene, 1,3-butadiene, benzene, cyclohexane, ethylbenzene, isopropylbenzene, n-hexane, n-nonane, n-pentane, n-propylbenzene, styrene, toluene, xylenes, aliphatic $C_5$–$C_8$ hydrocarbons.
[b] Sum of HQs for hydrocarbons with respiratory effects: 1,2,3-Trimethylbenzene, 1,2,4-Trimethylbenzene, 1,3-butadiene, ethylbenzene, isopropylbenzene, n-nonane, propylene, toluene, xylenes, aliphatic $C_9$–$C_{18}$ hydrocarbons, aromatic $C_9$–$C_{18}$ hydrocarbons.
[c] Sum of HQs for hydrocarbons with hematological effects: 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene.
[d] Sum of HQs for hydrocarbons with developmental effects: benzene, cyclohexane, toluene, and xylenes.

**Table 5**
Subchronic hazard quotients and hazard indices residents living >½ mile from wells and residents living ≤½ mile from wells.

| Hydrocarbon (μg/m³) | >½ mile | | ≤½ mile | |
|---|---|---|---|---|
| | Subchronic HQ based on median concentration | Subchronic HQ based on 95% UCL of mean concentration | Subchronic HQ based on median concentration | Subchronic HQ based on 95% UCL of mean concentration |
| 1,2,3-Trimethylbenzene | 2.09E−03 | 1.90E−03 | 1.67E−02 | 6.40E−02 |
| 1,2,4-Trimethylbenzene | 2.51E−03 | 4.22E−03 | 2.38E−02 | 3.02E−01 |
| 1,3,5-Trimethylbenzene | 1.18E−02 | 1.68E−02 | 1.29E−01 | 1.95E+00 |
| 1,3-Butadiene | 5.04E−02 | 2.23E−02 | 5.25E−02 | 8.30E−02 |
| Benzene | 1.14E−02 | 2.02E−02 | 3.25E−02 | 2.55E−01 |
| Cyclohexane | 1.13E−04 | 3.33E−04 | 2.93E−04 | 3.24E−03 |
| Ethylbenzene | 1.81E−05 | 4.42E−05 | 8.56E−05 | 5.96E−03 |
| Isopropylbenzene | 1.63E−03 | 7.92E−04 | 3.62E−03 | 1.14E−02 |
| Methylcyclohexane | 1.18E−03 | 2.01E−03 | 4.67E−03 | 6.47E−02 |
| n-Hexane | 1.92E−03 | 3.23E−03 | 3.86E−03 | 3.98E−02 |
| n-Nonane | 2.11E−04 | 3.14E−04 | 1.80E−03 | 3.78E−02 |
| n-Pentane | 8.71E−04 | 1.32E−03 | 1.05E−03 | 2.13E−02 |
| n-propylbenzene | 9.95E−05 | 9.57E−05 | 6.36E−04 | 3.26E−03 |
| Propylene | 1.43E−04 | 3.80E−04 | 4.12E−04 | 6.02E−04 |
| Styrene | 5.68E−04 | 4.16E−05 | 4.00E−06 | 1.97E−03 |
| Toluene | 4.18E−05 | 9.28E−04 | 2.46E−04 | 1.84E−02 |
| Xylenes, total | 2.91E−03 | 3.93E−03 | 2.05E−02 | 7.21E−01 |
| Aliphatic hydrocarbons $C_5$–$C_8$ | 1.07E−03 | 1.63E−03 | 2.07E−03 | 2.89E−02 |
| Aliphatic hydrocarbons $C_9$–$C_{18}$ | 1.3E−02 | 1.41E−01 | 7.9E−02 | 1.03E−00 |
| Aromatic hydrocarbons $C_9$–$C_{18}$ | 6.00E−04 | 6.95E−04 | 3.7E−03 | 2.64E−02 |
| Total Hazard Index | 1E−01 | 2E−01 | 4E−01 | 5E+00 |
| Neuorological Effects Hazard Index[a] | 9E−02 | 8E−02 | 3E−01 | 4E+00 |
| Respiratory Effects Hazard Index[b] | 7E−02 | 2E−01 | 2E−01 | 2E+00 |
| Hematogical Effects Hazard Index[c] | 3E−02 | 4E−02 | 2E−01 | 3E+00 |
| Developmental Effects Hazard Index[d] | 1E−02 | 3E−02 | 5E−02 | 1E+00 |

Abbreviations: 95%UCL, 95% upper confidence limit; HQ, hazard quotient.
[a] Sum of HQs for hydrocarbons with neurological effects: 1,2,3-Trimethylbenzene, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene, 1,3-butadiene, benzene, cyclohexane, ethylbenzene, isopropylbenzene, n-hexane, n-nonane, n-pentane, n-propylbenzene, styrene, toluene, xylenes, aliphatic $C_5$–$C_8$ hydrocarbons.
[b] Sum of HQs for hydrocarbons with respiratory effects: 1,2,3-Trimethylbenzene, 1,2,4-Trimethylbenzene, 1,3-butadiene, ethylbenzene, isopropylbenzene, n-nonane, propylene, toluene, xylenes, aliphatic $C_9$–$C_{18}$ hydrocarbons, aromatic $C_9$–$C_{18}$ hydrocarbons.
[c] Sum of HQs for hydrocarbons with hematological effects: 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene.
[d] Sum of HQs for hydrocarbons with developmental effects: benzene, cyclohexane, toluene, and xylenes.

ATSDR, 2007b; US EPA, 1994). Inhalation of trimethylbenzenes, xylenes, benzene, and alkanes can adversely affect the nervous system with effects ranging from dizziness, headaches, fatigue at lower exposures to numbness in the limbs, incoordination, tremors, temporary limb paralysis, and unconsciousness at higher exposures (Carpenter et al., 1978; Nilsen et al., 1988; US EPA, 1994; Galvin and Marashi, 1999; ATSDR, 2007a; ATSDR, 2007b).

### 4.2. Risk assessment as a tool for health impact assessment

HIA is a policy tool used internationally that is being increasingly used in the United States to assess multiple complex hazards and exposures in communities. Comparison of risks between residents based on proximity to wells illustrates how the risk assessment process can be used to support the HIA process. An important component of the HIA process is to identify where and when public health is most likely to be impacted and to recommend mitigations to reduce or eliminate the potential impact (Collins and Koplan, 2009). This risk assessment indicates that public health most likely would be impacted by well completion activities, particularly for residents living nearest the wells. Based on this information, suggested risk prevention strategies in the HIA are directed at minimizing exposures for those living closet to the well pads, especially during well completion activities when emissions are the highest. The HIA includes recommendations to (1) control and monitor emissions during completion transitions and flowback; (2) capture and reduce emissions through use of low or no emission flowback tanks; and (3) establish and maintain communications regarding well pad activities with the community (Witter et al., 2011).

### 4.3. Comparisons to other risk estimates

This risk assessment is one of the first studies in the peer-reviewed literature to provide a scientific perspective to the potential health risks associated with development of unconventional natural

**Table 6**
Excess cancer risks for residents living >½ mile from wells and residents living ≤½ mile from wells.

| Hydrocarbon | WOE | | Unit Risk (μg/m³) | Source | >½ mile | | ≤½ mile | |
|---|---|---|---|---|---|---|---|---|
| | IRIS | IARC | | | Cancer risk based on median concentration | Cancer risk based on 95% UCL of mean concentration | Cancer risk based on median concentration | Cancer risk based on 95% UCL of mean concentration |
| 1,3-Butadiene | B2 | 1 | 3.00E−05 | IRIS | 1.30E−06 | 5.73E−07 | 1.30E−06 | 6.54E−07 |
| Benzene | A | 1 | 7.80E−06 | IRIS | 3.03E−06 | 5.40E−06 | 3.33E−06 | 8.74E−06 |
| Ethylbenzene | NC | 2B | 2.50E−06 | CalEPA | 1.75E−07 | 4.26E−07 | 2.09E−07 | 3.48E−06 |
| Styrene | NC | 2B | 5.00E−07 | CEP | 3.10E−08 | 2.70E−08 | 3.00E−08 | 9.30E−08 |
| Cumulative cancer risk | | | | | 5E−06 | 6E−06 | 5E−06 | 1E−05 |

Abbreviations: 95%UCL, 95% upper confidence limit; CalEPA, California Environmental Protection Agency; CEP, (Caldwell et al., 1998); IARC, International Agency for Research on Cancer; IRIS, Integrated Risk Information System; Max, maximum; NC, not calculated; WOE, weight of evidence; μg/m³, micrograms per cubic meter. Data from CalEPA 2011; IRIS (US EPA, 2011).

gas resources. Our results for chronic non-cancer HIs and cancer risks for residents > than ½ mile from wells are similar to those reported for NGD areas in the relatively few previous risk assessments in the non-peer reviewed literature that have addressed this issue (CDPHE, 2010; Coons and Walker, 2008; CDPHE, 2007; Walther, 2011). Our risk assessment differs from these previous risk assessments in that it is the first to separately examine residential populations nearer versus further from wells and to report health impact of emissions resulting from well completions. It also adds information on exposure to air emissions from development of these resources. These data show that it is important to include air pollution in the national dialogue on unconventional NGD that, to date, has largely focused on water exposures to hydraulic fracturing chemicals.

### 4.4. Limitations

As with all risk assessments, scientific limitations may lead to an over- or underestimation of the actual risks. Factors that may lead to overestimation of risk include use of: 1) 95% UCL on the mean exposure concentrations; 2) maximum detected values for 1,3-butadiene, 2,2,4-trimethylpentane, and styrene because of a low number of detectable measurements; 3) default RME exposure assumptions, such as an exposure time of 24 h per day and exposure frequency of 350 days per year; and 4) upper bound cancer risk and non-cancer toxicity values for some of our major risk drivers. The benzene IUR, for example, is based on the high end of a range of maximum likelihood values and includes uncertainty factors to account for limitations in the epidemiological studies for the dose–response and exposure data (US EPA, 2011). Similiarly, the xylene chronic RfC is adjusted by a factor of 300 to account for uncertainties in extrapolating from animal studies, variability of sensitivity in humans, and extrapolating from subchronic studies (US EPA, 2011). Our use of chronic RfCs values when subchronic RfCs were not available may also have overestimated 1,3-butadiene, n-propylbenzene, and propylene subchronic HQs. None of these three chemicals, however, were primary contributors to the subchronic HI, so their overall effect on the HI is relatively small.

Several factors may have lead to an underestimation of risk in our study results. We were not able to completely characterize exposures because several criteria or hazardous air pollutants directly associated with the NGD process via emissions from wells or equipment used to develop wells, including formaldehyde, acetaldehyde, crotonaldehyde, naphthalene, particulate matter, and polycyclic aromatic hydrocarbons, were not measured. No toxicity values appropriate for quantitative risk assessment were available for assessing the risk to several alkenes and low molecular weight alkanes (particularly $<C_5$ aliphatic hydrocarbons). While at low concentrations the toxicity of alkanes and alkenes is generally considered to be minimal (Sandmeyer, 1981), the maximum concentrations of several low molecular weight alkanes measured in the well completion samples exceeded the 200–1000 $\mu g/m^3$ range of the RfCs for the three alkanes with toxicity values: n-hexane, n-pentane, and n-nonane (US EPA, 2011; ORNL, 2009). We did not consider health effects from acute (i.e., less than 1 h) exposures to peak hydrocarbon emissions because there were no appropriate measurements. Previous risk assessments have estimated an acute HQ of 6 from benzene in grab samples collected when residents noticed odors they attributed to NGD (CDPHE, 2007). We did not include ozone or other potentially relevant exposure pathways such as ingestion of water and inhalation of dust in this risk assessment because of a lack of available data. Elevated concentrations of ozone precursors (specifically, VOCs and nitrogen oxides) have been observed in Garfield County's NGD area and the 8-h average ozone concentration has periodically approached the 75 ppb National Ambient Air Quality Standard (NAAQS) (CDPHE, 2009; GCPH, 2010).

This risk assessment also was limited by the spatial and temporal scope of available monitoring data. For the estimated chronic exposure, we used 3 years of monitoring data to estimate exposures over a 30 year exposure period and a relatively small database of 24 samples collected at varying distances up to 500 ft from a well head (which also were used to estimate shorter-term non-cancer hazard index). Our estimated 20-month subchronic exposure was limited to samples collected in the summer, which may have not have captured temporal variation in well completion emissions. Our ½ mile cut point for defining the two different exposed populations in our exposure scenarios was based on complaint reports from residents living within ½ mile of existing NGD, which were the only data available. The actual distance at which residents may experience greater exposures from air emissions may be less than or greater than a ½ mile, depending on dispersion and local topography and meteorology. This lack of spatially and temporally appropriate data increases the uncertainty associated with the results.

Lastly, this risk assessment was limited in that appropriate data were not available for apportionment to specific sources within NGD (e.g. diesel emissions, the natural gas resource itself, emissions from tanks, etc.). This increases the uncertainty in the potential effectiveness of risk mitigation options.

These limitations and uncertainties in our risk assessment highlight the preliminary nature of our results. However, there is more certainty in the comparison of the risks between the populations and in the comparison of subchronic to chronic exposures because the limitations and uncertainties similarly affected the risk estimates.

### 4.5. Next steps

Further studies are warranted, in order to reduce the uncertainties in the health effects of exposures to NGD air emissions, to better direct efforts to prevent exposures, and thus address the limitations of this risk assessment. Next steps should include the modeling of short- and longer-term exposures as well as collection of area, residential, and personal exposure data, particularly for peak short-term emissions. Furthermore, studies should examine the toxicity of hydrocarbons, such as alkanes, including health effects of mixtures of HAPs and other air pollutants associated with NGD. Emissions from specific emission sources should be characterized and include development of dispersion profiles of HAPs. This emissions data, when coupled with information on local meteorological conditions and topography, can help provide guidance on minimum distances needed to protect occupant health in nearby homes, schools, and businesses. Studies that incorporate all relevant pathways and exposure scenarios, including occupational exposures, are needed to better understand the impacts of NGD of unconventional resources, such as tight sands and shale, on public health. Prospective medical monitoring and surveillance for potential air pollution-related health effects is needed for populations living in areas near the development of unconventional natural gas resources.

## 5. Conclusions

Risk assessment can be used as a tool in HIAs to identify where and when public health is most likely to be impacted and to inform risk prevention strategies directed towards efficient reduction of negative health impacts. These preliminary results indicate that health effects resulting from air emissions during development of unconventional natural gas resources are most likely to occur in residents living nearest to the well pads and warrant further study. Risk prevention efforts should be directed towards reducing air emission exposures for persons living and working near wells during well completions.

Supplementary materials related to this article can be found online at doi:10.1016/j.scitotenv.2012.02.018.

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# RULES FOR PUBLIC COMMENTS AT CITY COUNCIL MEETINGS

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**Public Comments:** The City Council welcomes written and oral comments from the public at regular meetings. Individuals wishing to speak must sign in at the City Secretary's Office at City Hall during regular business hours, or from 5:00 p.m. to 6:45 p.m. the day of the meeting. Speakers who have not registered by 6:45 p.m. may be allowed to speak after first registering with the City Secretary before the Hear Visitors period is finished or the agenda item has been finished. Speakers will have one opportunity to speak during the time period, and they must observe the three-minute time limit. Time cannot be transferred. When a speaker yields the floor, he/she waives their remaining time, but that remaining time does not get added to another speaker's time.

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**Hear Visitors Period**: The Hear Visitors section is set aside during Regular Meetings in order to give the public the opportunity to speak on City-related matters **not** covered by the agenda. However, no formal action will be taken on any matters not listed on the agenda. The response of the Council to any comment under this heading is limited to making a statement of specific factual information in response to the inquiry, or reciting existing policy in response to the inquiry. Any deliberation of the issue is limited to a proposal to place it on the agenda for a later meeting.

**Consent and Regular Agenda Items:** At the discretion of the Mayor, individuals may be allowed to speak on either a Consent or Regular Agenda item. Individuals who wish to address the Council on either a Consent or Regular agenda item shall register with the City Secretary during regular business hours, or from 5:00-6:45 p.m. the day of the meeting. Speakers who have not registered by 6:45 p.m. may be allowed to speak after first registering with the City Secretary. Speakers will have one opportunity to speak during the time period, and they must observe the three-minute time limit. Time cannot be transferred. When a speaker yields the floor, he/she waives their remaining time, but that remaining time does not get added to another speaker's time. Comments on the agenda items must be made when the agenda item comes before the Council.

**Public Hearings:** Registering to speak at a Public Hearing is the same as for a regular agenda item. After a Public Hearing is closed, there shall be no additional public comments. If Council needs additional information from the general public, some limited comments may be allowed at the discretion of the Mayor.

**Rules for Speakers:**

1. Members of the public may address the City Council at the following times during a meeting:
   - During Hear Visitors Period, if such a period is on the agenda for the meeting.
   - During a public hearing on an agenda item.
   - During Consent and Regular Agenda items with the permission of the presiding officer.
   - During Work Study Agenda items with the permission of the presiding officer.

2. Speakers must state their name and address for the record.
3. Speakers must address all comments and questions to the presiding officer.
4. Speakers must limit their comments to three minutes.
5. Speakers may not employ tactics of defamation, intimidation, personal affronts, profanity, or threats of violence.

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- 1 co-chair
- 21 members

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| | GUERRA, Joe | | | | | | | | | |
| | HARVELL, Linda | | | | | | | | | |
| | HELLRIEGEL, Don | ✓ | ✓✓ | ✓ | | | | | | |
| | HIGGINSON, David | | | | | | | | | |
| | JOHNSON, Brittan | | | | | | | | | |
| | KAISER, Ronald | | | | | | | | | |
| | LIGHTFOOT, Robert | | | | | | | | | |
| | MARTINEZ, Elizabeth | | | | | | | | | |
| | McALLISTER, Jonathan | | | | | | | | | |
| | ROBERTS Keith | | | | | | | | | |
| | RUESINK, David | | | | | | | | | |
| | SCOTTI, Chris | | | | | | | | | |
| Co-chair | SMITH, William** | ✓ | | ✓ | | ✓ | ✓ | ✓ | | |
| Chair | THORNTON, Penrod | | | | ✓ | ✓ | ✓ | ✓ | | |
| | WATSON, James | | | | | | | | | |

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| FIX, Joseph | | | | | | | | | |
| GROM, John | | | | | | | | | |
| HELLRIEGEL, Don | | | | | | | | | |
| HIGGINSON, David | | | | | | | | | |
| IVES, Gary | ✓ | | | | | | | | |
| KOHEL, Russell | | | | | | | | | |
| LARTIGUE, Jr., William | | | | ✓ | | | | | |
| McGINNIS, Kevin | | | | | | | ✓ | | |
| RAISOR, Jeffrey | | | | | | ✓ | | | |
| RAMIREZ, Rene | | | ✓ | | | | | | |
| RUESINK, David | | | | | | | | | |
| SCOTTI, Chris | | | | | | | | | |
| STRIBLING, Danny | | | | | | | | | |
| TAYLOR, Thomas | | | | | ✓ | | | | |
| THORNTON, Penrod | | | | | | | | | |
| WATSON, James | | ✓ | | | | | | | |

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| BATENHORST, James | | | | | ✓ | | | | |
| BOCHNER, Brian | | | | | | | | | |
| CANNADAY, Rory | | | | | | | | | |
| COOPERSMITH, Jonathan | | | | | | | [illegible] | | |
| ELLISON, Tedi | | ✓ | | | | | | | |
| GREEN, Mark | | | | | | ✓ | | | |
| GUERRA, Joe | | | | | | | | | |
| HARVELL, Linda | ✓ | | | | | | | | |
| JOHNSON, Brittan | | | | | | | ✓ | | |
| KAISER, Ronald | | | ✓ | | | | | | |
| KUHN, Beverly | | | | ✓ | | | | | |
| LIGHTFOOT, Robert | | | | | | | | | |
| MARTINEZ, Elizabeth | | | | | | | | | |
| ROBERTS, Keith | | | | | | | | | |
| SMITH, William | | | | | | | | | |
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| COTHRAN, Marian | | | | | | | | | |
| CROCKETT, Jerry | | | | | | | | | |
| DENTON, Jon | | | | ✓ | | | | | |
| DUCHMASCLO, Frank | | | | | | | | | |
| ELLISON, Sherry | | | | | ✓ | | | | |
| MARKOWICH, Gerald | | | | | | | | | |
| McALLISTER, Jonathan | | | | | | | | | |
| VAN DER BOOM, Patricia | | | | | | | | | |
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Brick: Don Hellwig
Aldrich: Marc Chalupa
Mooney: Dan Stribling
Schultz: Chris Scott [illegible] [illegible]
Benham: Keith Robert

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