Colorado State University

COLORADO WATER WATCH ANNUAL REPORT

FEBRUARY 2014 - FEBRUARY 2015

CENTER FOR THE NEW ENERGY ECONOMY

CEWS
Center for Energy Water Sustainability

Table of Contents

Executive Summary

BACKGROUND

Dramatic increases in the number of oil and gas extraction wells in Colorado have raised environmental concerns about the potential effects of oil and gas activities, with active debates about the risks of groundwater contamination near the top of the list. Two of the biggest concerns related to potential groundwater contamination are methane gas migration and groundwater contamination by flowback and produced water, either through spills impacting shallow aquifers or casing integrity issues releasing production fluids into deeper, confined aquifers.

The Colorado Oil and Gas Conservation Commission (COGCC) Rule 609 requires up to four baseline samples collected within a half mile radius of a proposed oil and gas well within 12 months prior to drilling, and post-completion sampling between 6 and 12 months after drilling. In addition, additional sampling is required between 5 and 6 years after the last sampling event at the initial sample locations.

The most important goal of monitoring groundwater quality in areas where there is significant oil and gas activity is to determine potential impacts of the industry on groundwater quality by monitoring changes in groundwater quality before, during, and after the construction of oil and gas wells in the area. Rule 609 has significantly improved the visibility the public will have on potential groundwater contamination but a deficiency of the rule is the lack of sampling over time to develop trends that may change seasonally.

COLORADO WATER WATCH

In response to perceived industry and community needs, the Colorado Water Watch (CWW) real-time groundwater monitoring system was developed in a cost-effective manner based on lab-qualified surrogate technologies.

Using a simple in-situ water quality multi-parameter probe, the CWW system monitors groundwater in real-time and collects enough historical data to understand normal water quality conditions (water level, pH, conductivity, dissolved oxygen, oxidation-reduction potential, and temperature). After establishing an initial acceptable baseline, if the groundwater quality changes due to any anthropogenic activities, the surrogate water quality parameters will indicate an event using sophisticated anomaly detection algorithms. The CWW system's anomaly detection algorithms can decide whether field monitoring (grab samples) is necessary to determine whether or not the groundwater disturbance is due to oil and gas activities. If there is any indication that oil and gas activities have contributed to anomaly, the data is turned over to the COGCC who would follow established protocols.

The main purpose of the CWW is to provide transparent information about water quality at oil & gas production sites in Colorado to inform the public about changes that may occur in groundwater sources (from any activity including agriculture and other industries).

EXECUTIVE SUMMARY

The key aspect of the CWW system is that it generates information through data evaluation (qualitative monitoring), not just data collection (quantitative monitoring), which makes the system different from existing monitoring approaches. Information generated by the system will help the industry understand normal background conditions and anomalies of groundwater quality and provide the time needed to sample groundwater for in-depth lab analysis.

HIGHLIGHTS OF 2014-2015

The CWW is intended to be an early warning system that provides risk management and decision-making tools utilizing advanced monitoring and information technologies. It has the ability to enhance other groundwater monitoring networks and approaches for oil and gas regulatory agencies, industry, and communities as well.

The CWW began operation in February 2014 and since the initial monitor installation, five CWW monitoring stations have been established in the Denver-Julesburg Basin. Real-time groundwater data have been collected hourly, transmitted into the CWW database, and analyzed through the event detection software.

There have been a few alarms of events associated with water table fluctuations during the irrigation season at the ARDEC (control) monitoring station, but no oil and gas-related events have been detected at any of the stations.

A seamless integration of real-time data flow, data analysis (event detection) application, event response protocols, and results visualization on a user-friendly website were established in the first year. With a successful first year proof-of-concept, new monitoring stations will be aggressively pursued in 2015 to provide a network with greater resolution and coverage.

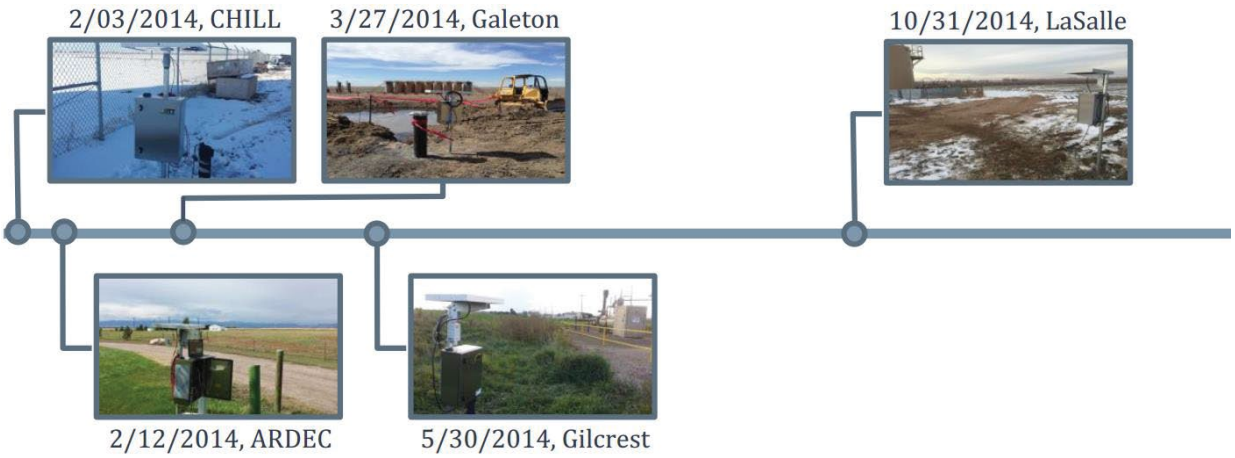
The CWW was successfully launched at the 4th Annual CSU Natural Gas Symposium on September 24, 2014, and has received significant public attention through press coverage and multiple community outreach efforts.

The CWW Team
Center for Energy Water Sustainability
Colorado State University, Fort Collins, CO 80523
February 9, 2015

CWW Monitoring Stations

The first Colorado Water Watch monitoring station was installed on February 3, 2014 at CSU-CHILL, the national weather radar facility in Greeley. The number of stations increased gradually throughout the year and reached a total of five active monitoring stations by the end of 2014.

A multi-parameter *in-situ* probe was installed at the screened level of each monitoring well to measure fresh groundwater and avoid measuring stagnant water in the well. The self-charging cellular data-logger was placed in an enclosed box immediately next to the monitored well.



CURRENT MONITORING STATIONS

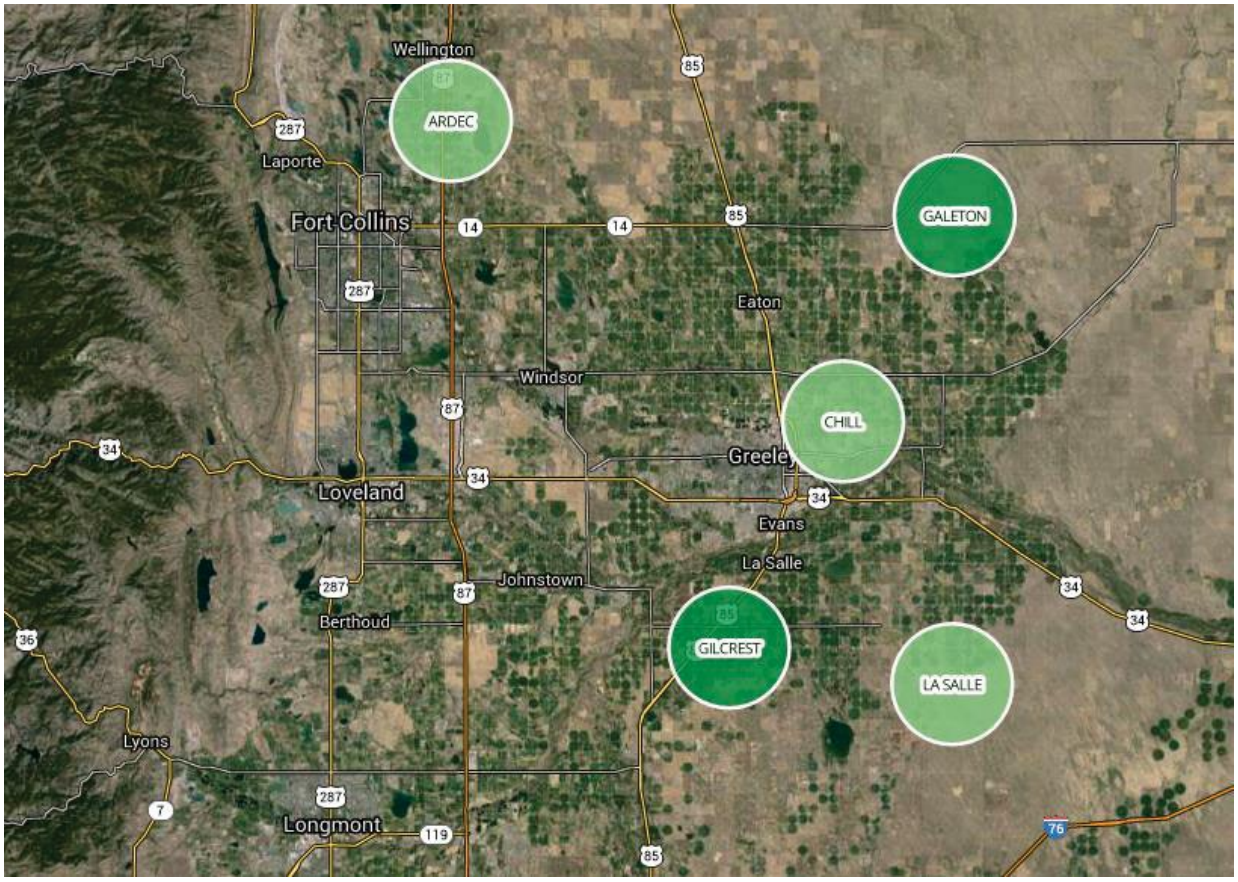
- Four shallow alluvial wells including a control well: no oil & gas activities within a 2-mile radius
- One deep confined aquifer well

MONITOR STATIONS

STATION NAME	TARGET AQUIFER	WELL TYPE	NEARBY OIL & GAS WELLS†	CITY	TOWN SHIP	RANGE
ARDEC (Control)	South Platt Alluvial	Shallow, 25ft	0	Fort Collins	08N	68W
CHILL	South Platt Alluvial	Shallow, 30ft	204	Greeley	06N	65W
Gilcrest	South Platt Alluvial	Shallow, 25ft	323	La Salle	04N	66W
LaSalle	South Platt Alluvial	Shallow, 60ft	223	La Salle	04N	64W
Galeton	Laramie-Fox Hills	Deep-Confined, 375ft	67	Eaton	07N	64W

† Number of active oil & gas production wells within a 2-mi radius of the CWW monitoring station as of Feb 05, 2014.

CWW MONITORING STATIONS



MAP OF CWW MONITORING STATIONS

NEW MONITOR INSTALLATION PLAN FOR 2015

Three additional monitoring sites have been identified and are currently being evaluated. Two additional sites are also being considered and we expect to have five additional monitoring wells by the end of July 2015.

In addition, possible new monitoring sites are continuously explored by the CWW team and Noble Energy. Noble Energy works with their landowners to look for a site feasible for drilling a new monitoring well and the CWW team has been working closely with Department of Agriculture and also with various water districts in Weld County, including West Greeley Conservation District and Central Colorado Water Conservancy District, to look for existing groundwater wells that have potential to be a new CWW monitoring station. In the case of using an existing groundwater well, several conditions are considered: accessibility, well integrity, security, location-nearby active oil & gas wells and domestic wells.

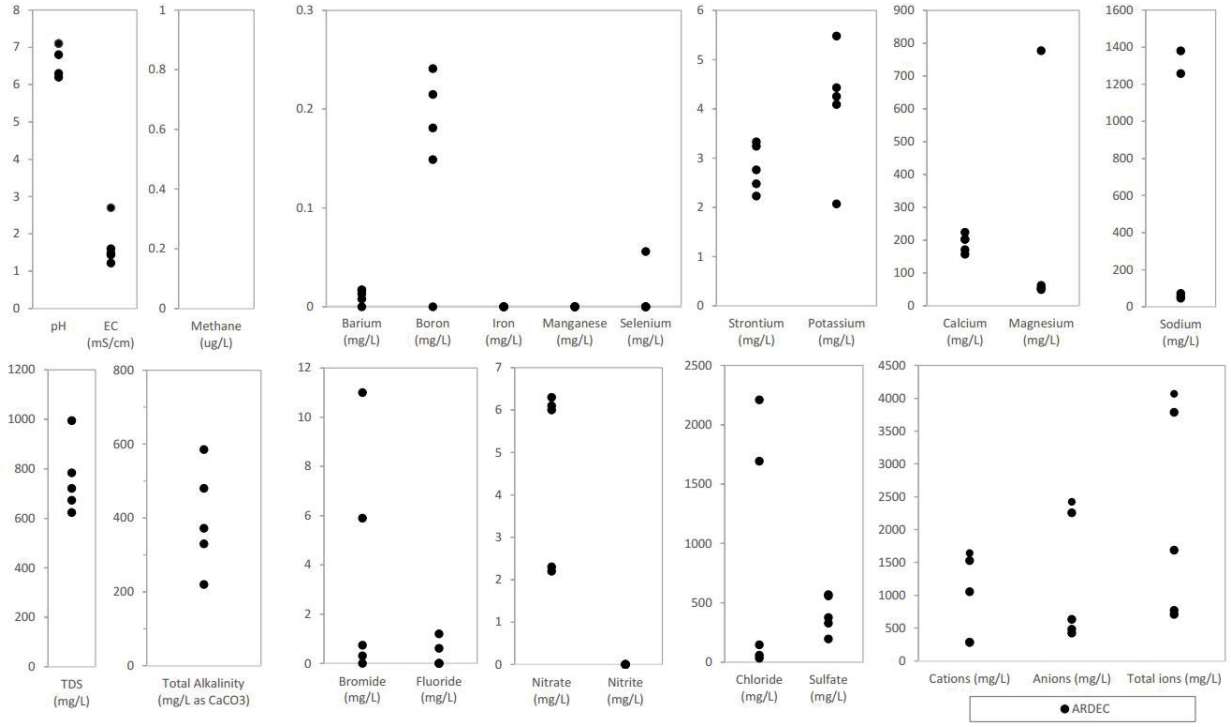
Water Quality Monitoring

Groundwater samples were collected to perform in-depth baseline water quality tests prior to the monitor installation, and monthly sampling was carried out during the first 3-5 months to understand groundwater quality at the CWW monitoring sites. Groundwater quality data have been collected every hour in real-time for about 4-12 months varying by monitoring stations and transferred to the CWW database. The transferred data were then screened through the event detection system in order to analyze event (anomaly) probability at each time step.

BASELINE GROUNDWATER QUALITY

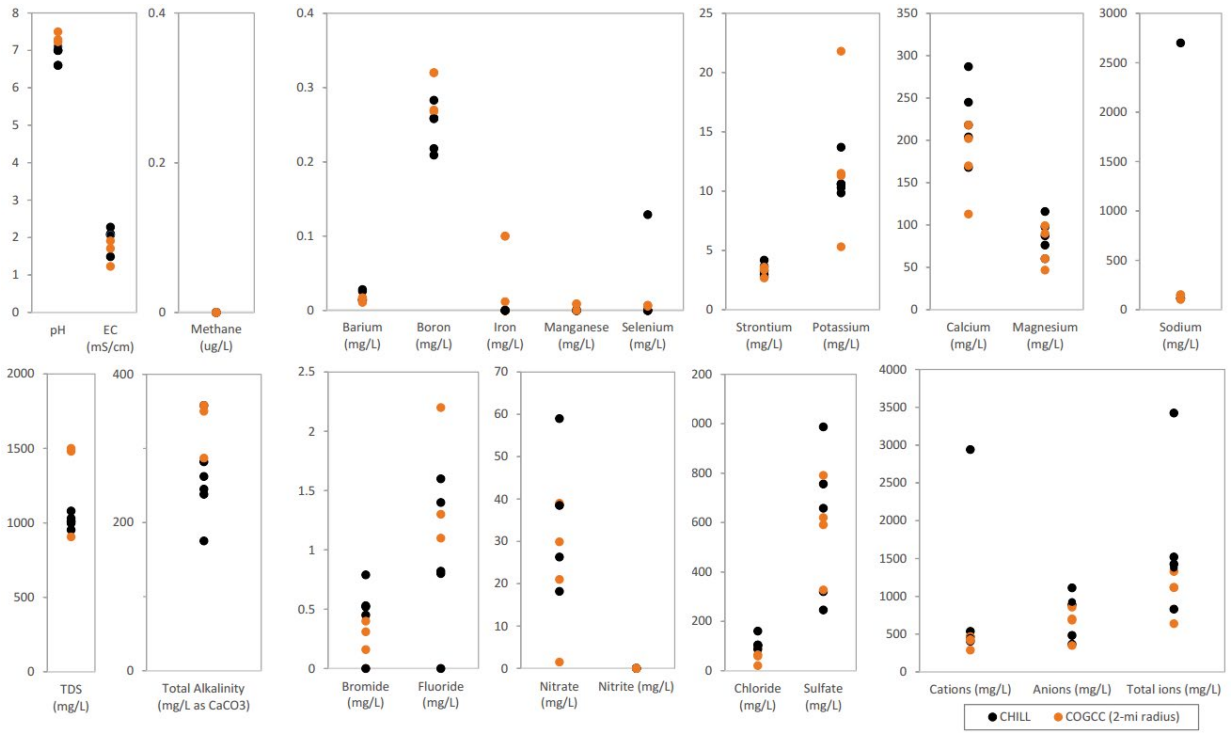
The baseline groundwater quality (measured at an independent, EPA-certified lab) of the CWW stations was compared with available groundwater quality data of nearby groundwater wells in the COGCC database.

ARDEC



- **Data:** Five groundwater samples of ARDEC were collected monthly from February to June 2014. No groundwater quality data around the site was found from the COGCC database.
- **Summary**: ARDEC is surrounded by agricultural area and its groundwater quality varied by season mainly for sodium, chloride and also nitrate. No BTEX or dissolved gases including methane, ethane or propane were found.

CHILL



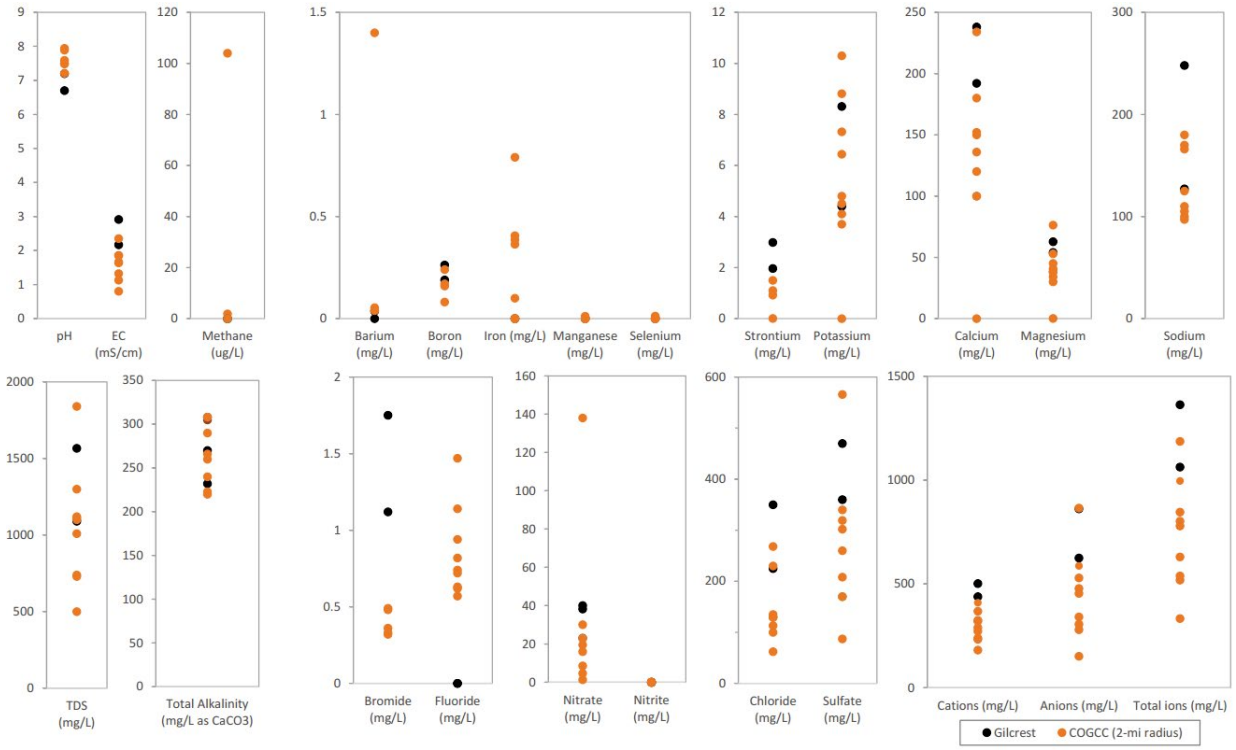
- **Data**: Five groundwater samples of CHILL were collected monthly from February to June 2014, and one additional sample was collected in October 2014. The groundwater quality of CHILL was compared with three sets of groundwater quality data of nearby groundwater wells obtained from the COGCC database.

MAP OF COGCC GROUNDWATER SAMPLING LOCATION

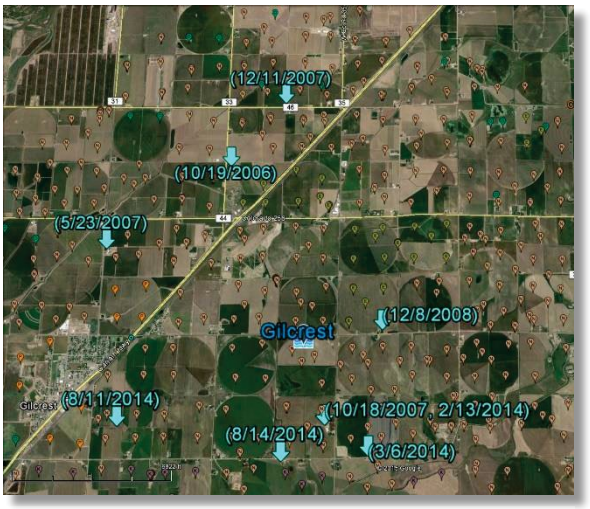
- **Summary:** In general, groundwater quality of CHILL was in the similar range of groundwater quality of nearby groundwater wells located within a 2-mile radius. Sodium concentrations in this area ranged from 104 to 150 mg/L including CHILL and nearby groundwater wells, and the highest sodium concentration (2,701 mg/L) was observed in October from CHILL with the highest nitrate concentration (59 mg/L). This might indicate that the high sodium concentration was from agricultural activities.

No BTEX or dissolved gases including methane, ethane or propane were found from either CHILL or nearby groundwater wells.

GILCREST



- **Data:** Two groundwater samples were collected from Gilcrest in May prior to the monitor installation and also in September 2014. Eight sets of groundwater quality data from nearby groundwater wells were collected from the COGCC database.

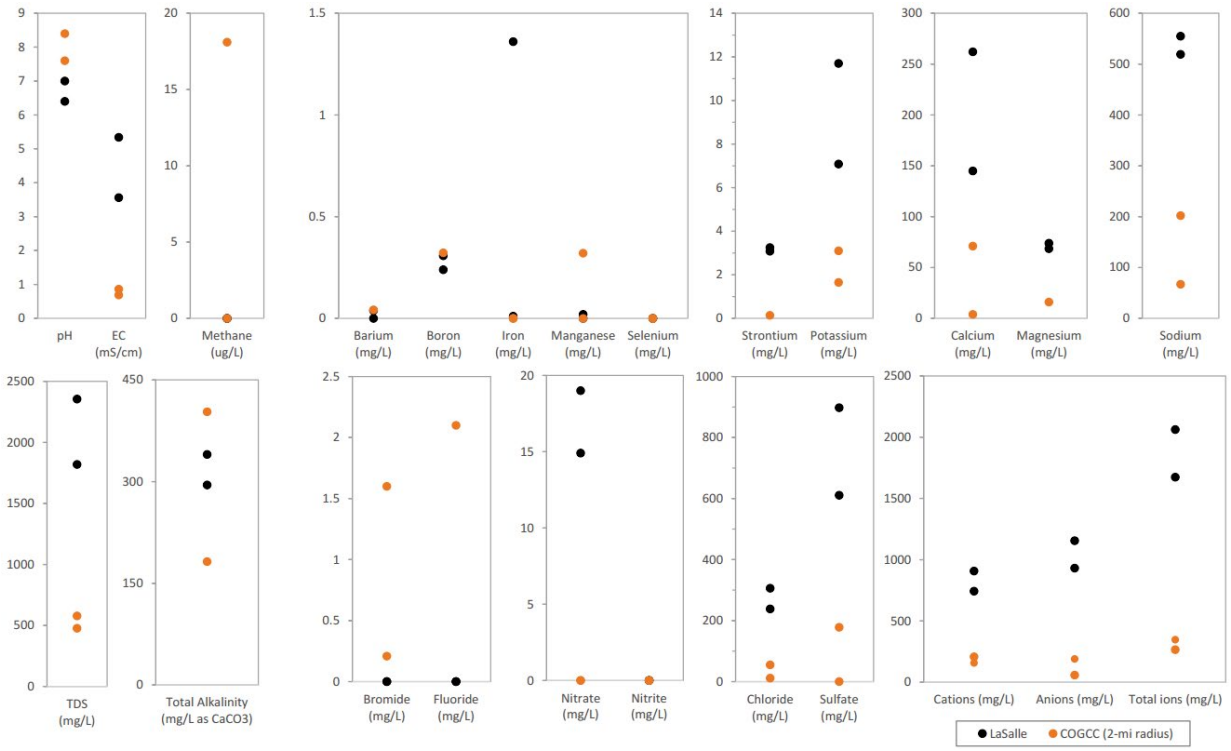


MAP OF COGCC GROUNDWATER SAMPLING LOCATION

- **Summary:** Groundwater quality of Gilcrest was generally similar to that of nearby wells. The highest sodium concentration (248 mg/L) was found with the high nitrate concentration (40 mg/L) from Gilcrest in September. The high nitrate concentration might indicate that the high sodium concentration was from agricultural activities.

No BTEX or dissolved hydrocarbon gases were found in Gilcrest, but a relatively low concentration of dissolved methane (104 µg/L) was found in a nearby groundwater well in October 2007 with no indication of whether the methane was biogenic or thermogenic.

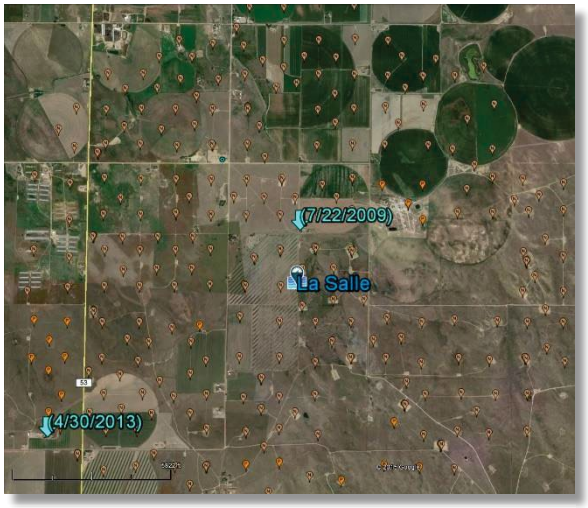
LASALLE



- **Data**: Two groundwater samples were collected from LaSalle in October prior to the monitor installation and also in December 2014. Two sets of groundwater quality data from nearby groundwater wells located within a 2-mile radius of the LaSalle site were collected from the COGCC database.

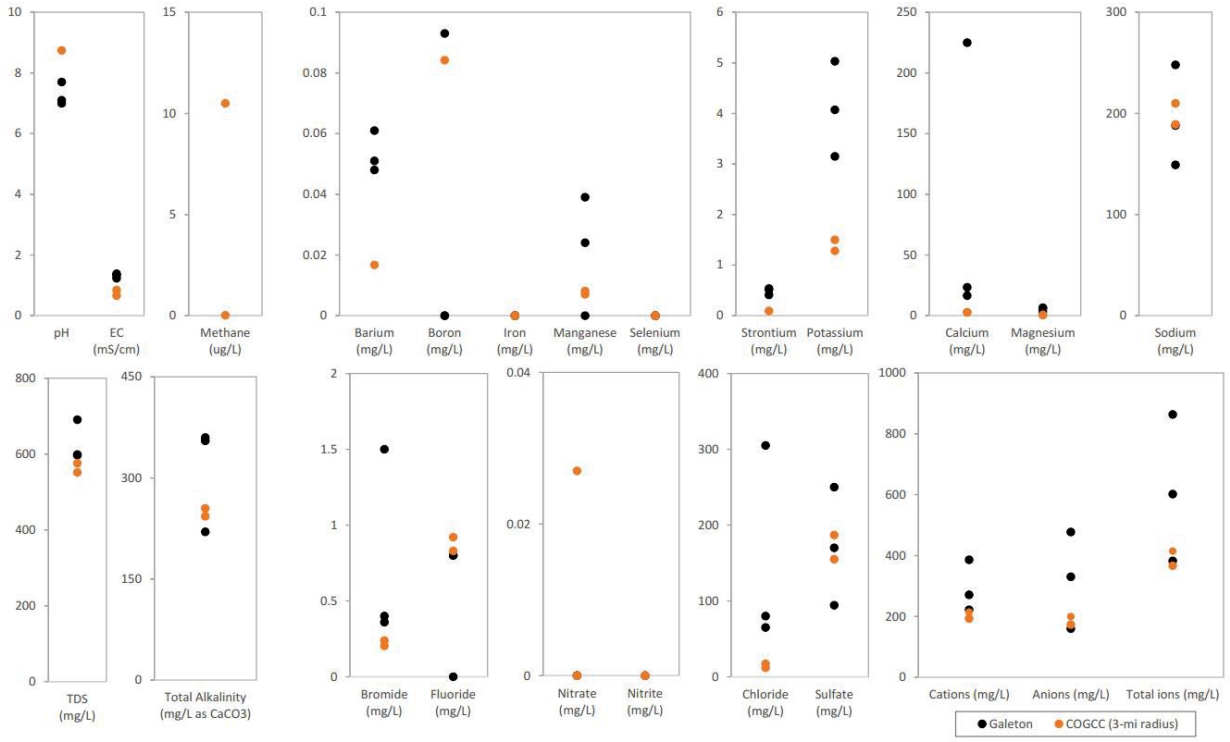
- **Summary:** General ion concentrations, including iron, strontium, potassium, calcium, magnesium, sodium, nitrate, chloride and sulfide, were higher in groundwater samples from the LaSalle well compared to that of nearby groundwater wells.

  No BTEX or dissolved gases including methane, ethane or propane were found from groundwater samples of LaSalle, but a relatively low methane concentration (18 µg/L) was detected from a groundwater sample collected on April 30, 2014 from a nearby groundwater well with no indication of whether the dissolved methane gas was biogenic or thermogenic.



MAP OF COGCC GROUNDWATER SAMPLING LOCATION

GALETON



- **Data:** Three groundwater samples from the Galeton well were collected monthly from March to May 2014. For comparison of groundwater quality between Galeton and nearby ground water wells, there was no groundwater quality data available within a 2-mile radius, therefore two groundwater quality datasets from the Laramie-Fox Hills aquifer wells within a 3-mile radius were obtained from the COGCC database.

MAP OF COGCC GROUNDWATER SAMPLING LOCATION

- **Summary:** Ion concentrations of the confined aquifer well in Galeton were relatively lower compared to that of the alluvial wells (ARDEC, CHILL, LaSalle and Gilcrest), but generally in the same range of that in nearby groundwater wells.

No BTEX or dissolved gases including methane, ethane or propane were found from either Galeton or nearby groundwater wells.

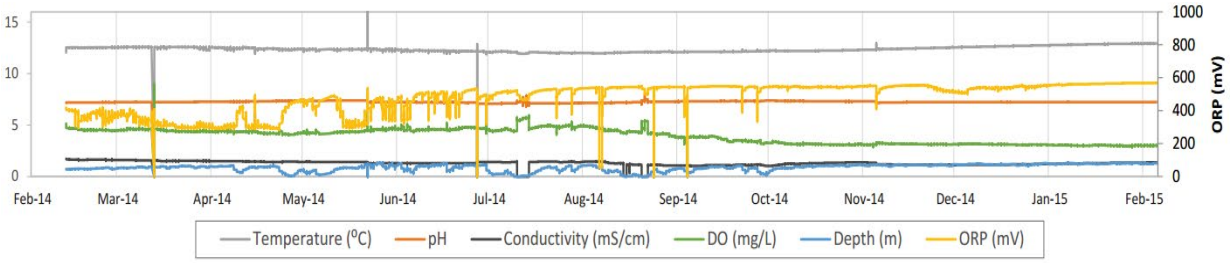
SENSOR DATA AND OIL & GAS WELL DENSITY

Water quality data were collected using multi-parameter probes. Six water quality parameters: water temperature, pH, conductivity, dissolved oxygen (DO), water depth, and oxidation-reduction potential (ORP) were measured every hour in real-time.

ARDEC

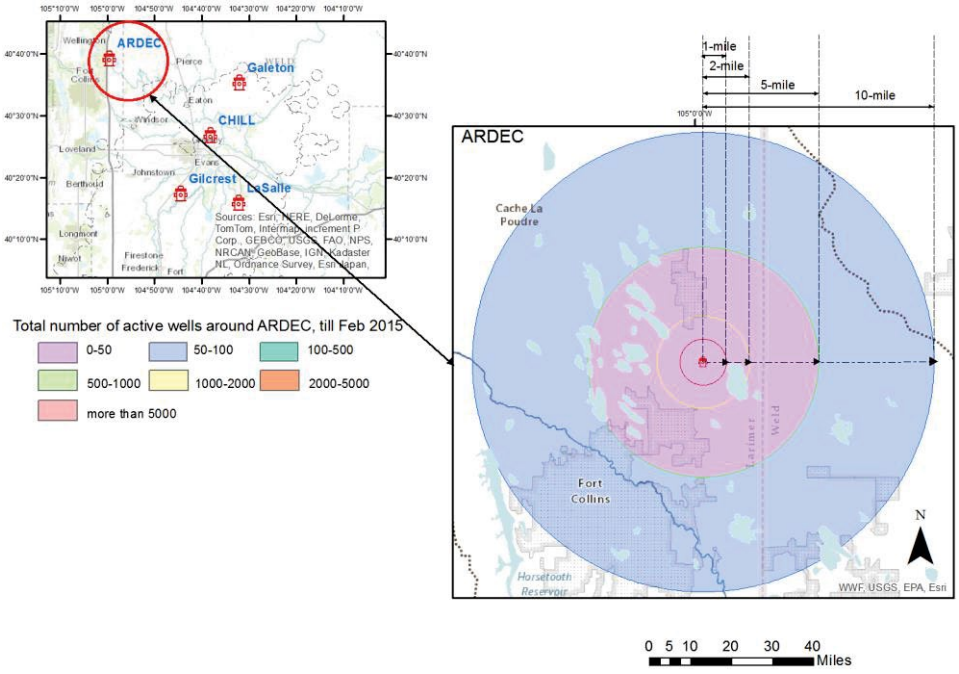
- **Sensor Data Summary**

Sensor data have been collected for about a year from February 2014 at ARDEC. Groundwater depths fluctuated greatly during the irrigation season from April to early October and caused anomalies on other sensors mainly conductivity, ORP and DO. The water quality parameters became relatively steady after the irrigation season.



- **Oil & Gas Well Density**

The density of active oil & gas production wells in the area is the lowest among the five CWW monitoring stations. No active oil & gas wells are located within a 2-mile radius of the site. There are approximately 27 and 84 active oil & gas production wells are located within a 5-mile and a 10-mile radius, respectively.

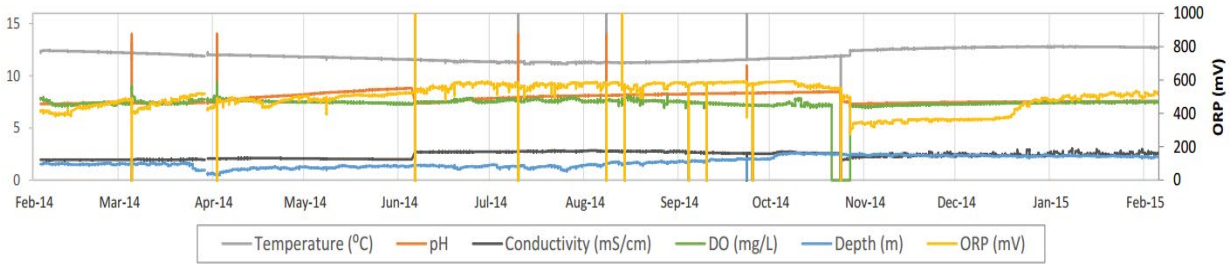


DENSITY MAP OF ACTIVE OIL & GAS PRODUCTION WELLS
(Circle: 1, 2, 5 and 10 mile radius)

CHILL

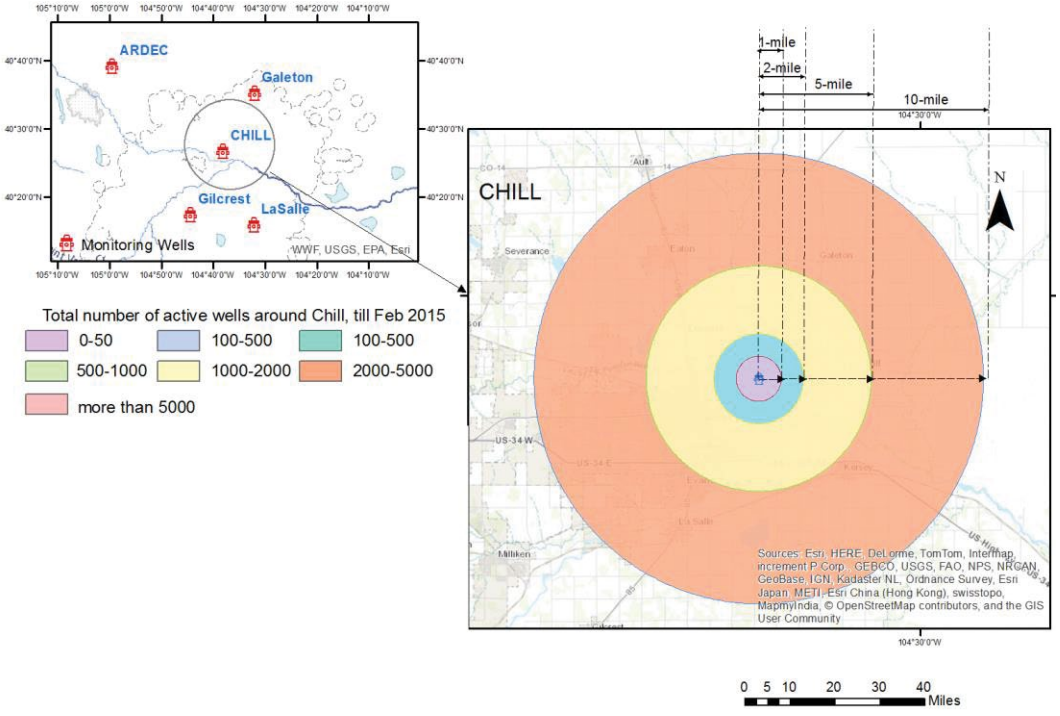
- **Sensor Data Summary**

Sensor data have been collected from February 2014. Water depths at CHILL dropped in the beginning of the irrigation season of April and rose in early October. The DO sensor malfunctioned and was replaced in late October.



- **Oil & Gas Well Density**

The density of active oil & gas production wells in the area is among the highest. There are about 40 wells located within a mile, over 200 wells within 2 miles, approximately 1,100 wells within 5 miles, and over 4,600 wells within 10 miles.

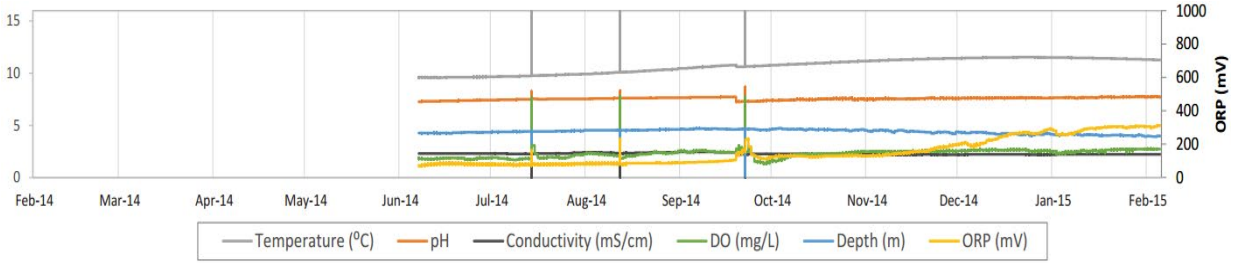


DENSITY MAP OF ACTIVE OIL & GAS PRODUCTION WELLS (Circle: 1, 2, 5 and 10 mile radius)

GILCREST

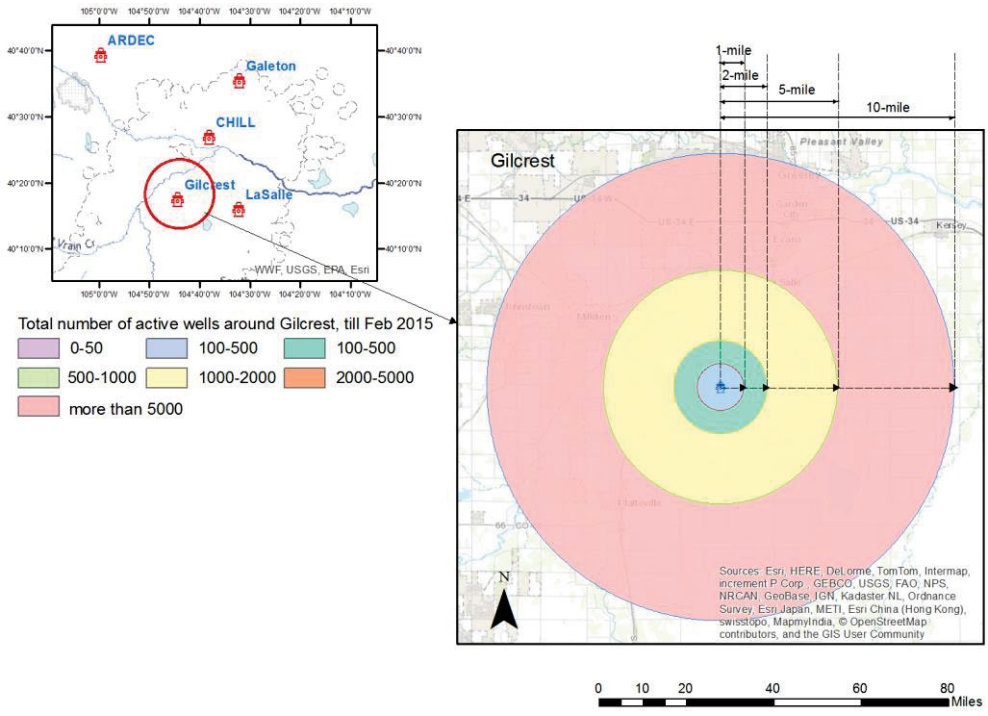
- **Sensor Data Summary**

The monitoring station at Gilcrest was installed on May 30, 2014 but the sensor data have been collected from early June due to an operational issue. Water quality parameters were relatively stable compared to other shallow alluvial wells. The spikes in the sensor data were related to fieldworks (e.g. groundwater sampling).



- **Oil & Gas Well Density**

The density of active oil & gas production wells in the area is the highest. There are about 80 wells within a 1-mile radius, over 320 wells within a 2-mile radius, over 1,950 wells within a 5-mile radius, and over 7,100 wells within a 10-mile radius of the site.

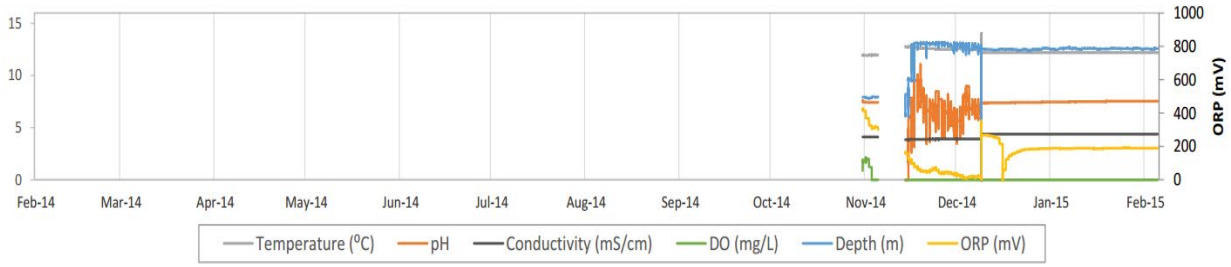


DENSITY MAP OF ACTIVE OIL & GAS PRODUCTION WELLS (Circle: 1, 2, 5 and 10 mile radius)

LASALLE

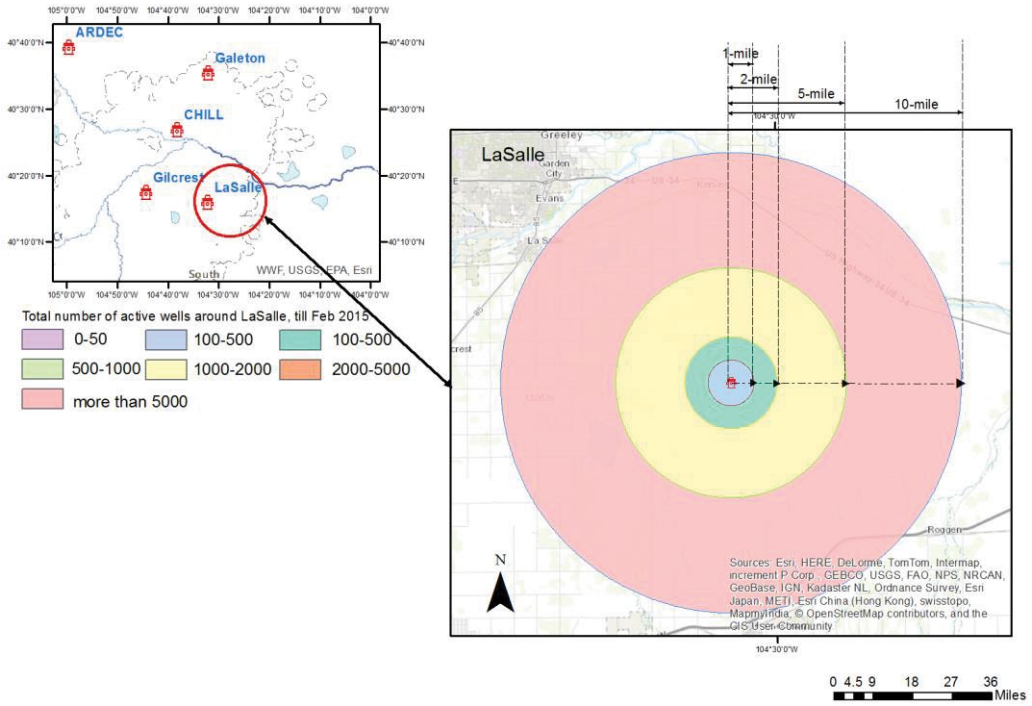
- **Sensor Data Summary**

Sensor malfunction occurred after fieldwork in mid-November and after relocation of the station at the site in early December. The sensor was fixed, and stable water quality parameters have been observed since then.



- **Oil & Gas Well Density**

The density of the active oil & gas production wells around the site is the second highest among the five CWW monitoring sites. There are approximately 55 wells located within a 1-mile radius, over 220 wells within a 2-mile radius, approximately 1,725 wells within a 5-mile radius, and less than 5,280 wells within a 10-mile radius.

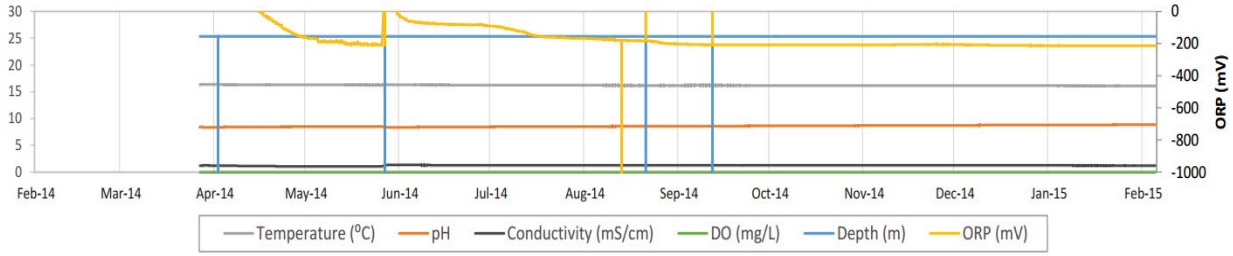


DENSITY MAP OF ACTIVE OIL & GAS PRODUCTION WELLS (Circle: 1, 2, 5 and 10 mile radius)

GALETON

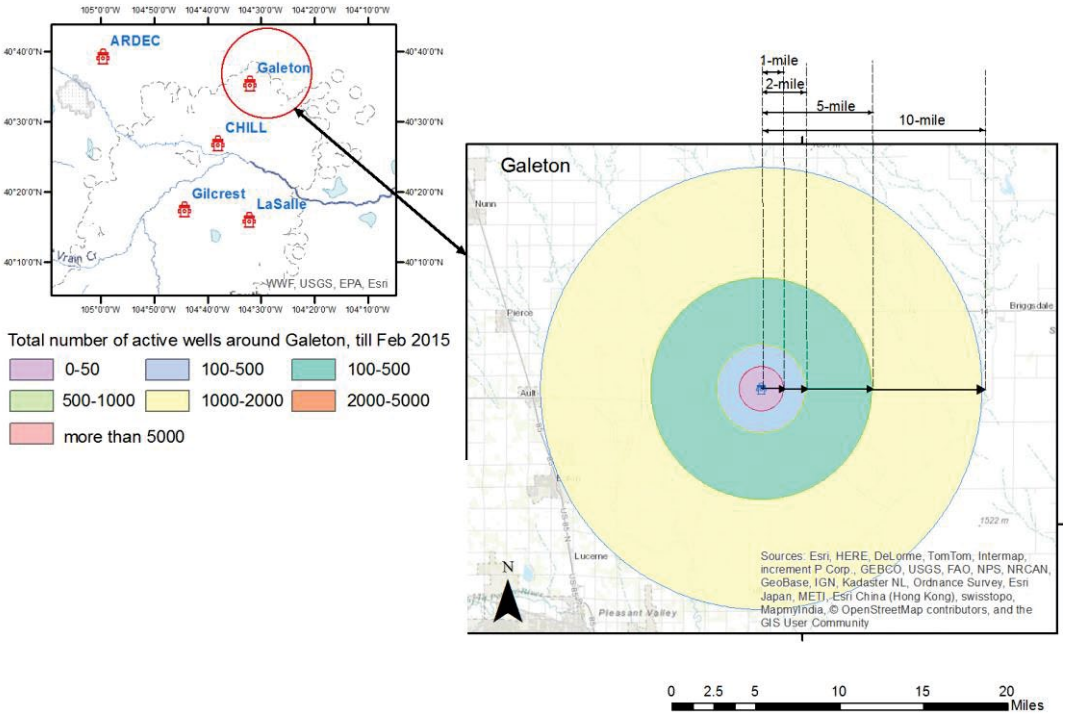
- **Sensor Data Summary**

The well depth of the Galeton site is the deepest (375 ft) and water quality parameters have been very stable. ORP reached an equilibrium state after the latest groundwater sampling in late May.



- **Oil & Gas Well Density**

The density of oil & gas production wells in the area is relatively moderate. There are over 25 active oil & gas production wells within a mile, less than 70 wells within 2 miles, over 320 wells within 5 miles, and over 1,600 wells within 10 miles.



DENSITY MAP OF ACTIVE OIL & GAS PRODUCTION WELLS (Circle: 1, 2, 5 and 10 mile radius)

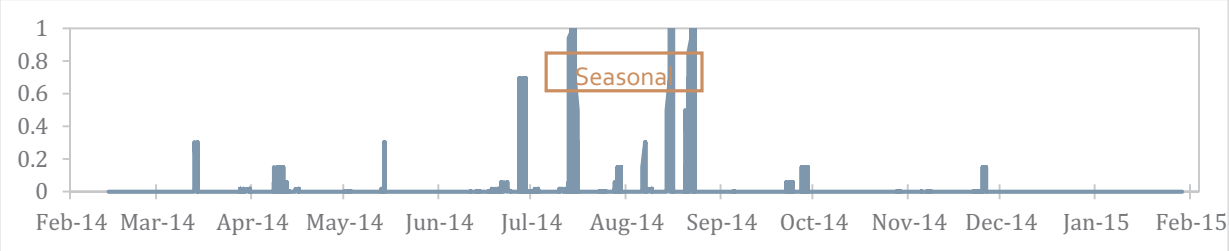
EVENT DETECTION

During the first year of CWW operation, a few events were detected from groundwater quality of the installed monitoring stations after screening the data through the anomaly detection system in real-time.

However, the events were operational (e.g. sensor malfunction) or seasonal changes (e.g. water table drop) and not related to oil & gas operations.

ARDEC

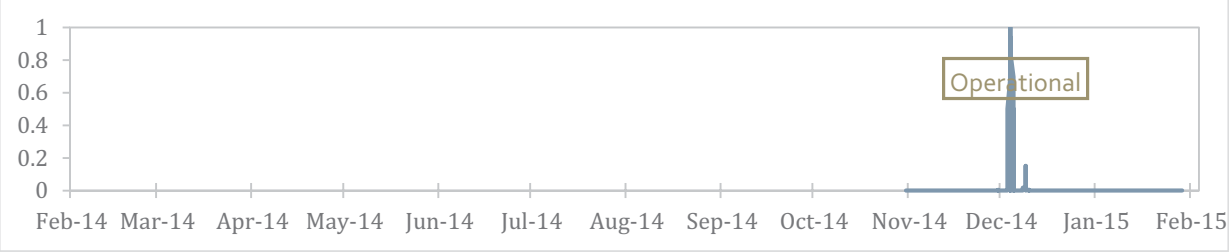
For about a 1-year monitoring period, the greatest number of events was found at ARDEC—the control site where no active oil & gas production wells are located within a 2-mile radius. The most influencing factor on groundwater quality in this area was seasonal changes largely associated with agriculture.



ARDEC EVENT PROBABILITY (1=EVENT)

LASALLE

An operational event occurred while the station at LaSalle was relocated at the site due to a safety issue in December, 2014.



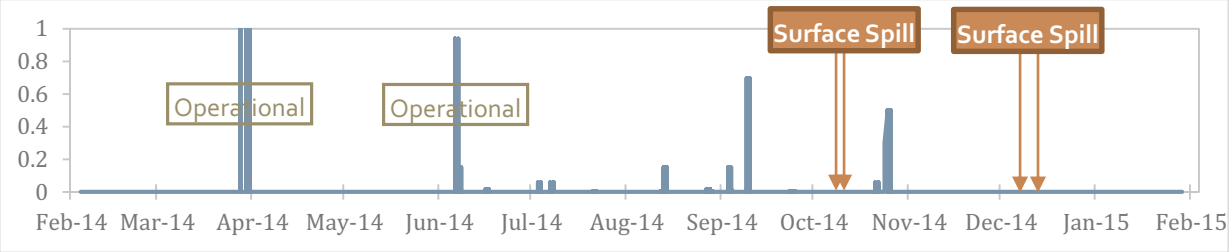
LASALLE EVENT PROBABILITY (1=EVENT)

- **Oil & Gas Operational Incidents**

No oil & gas operational incident that possibly contaminates groundwater was reported around LaSalle after the monitor installation on October 31, 2014.

CHILL

At CHILL, a few operational events were observed related to the field activity (e.g. groundwater sampling) and sensor malfunction for about a 1-year monitoring period.



CHILL EVENT PROBABILITY (1=EVENT)

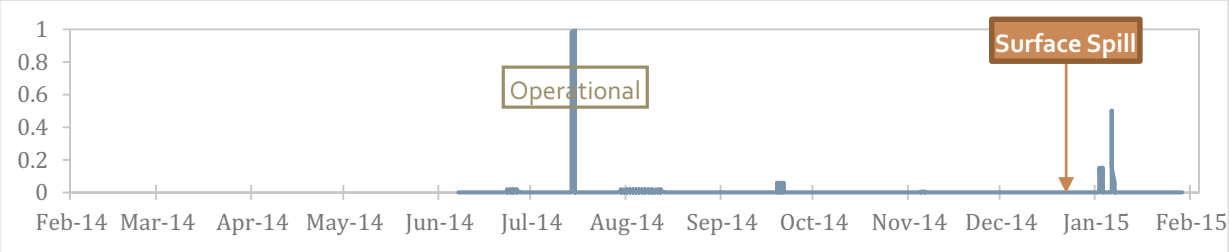
- **Oil & Gas Operational Incidents**

Four spill incidents occurred at tank batteries (10/10, 12/08, 12/15) and a well (10/13) after the monitor installation date of February 3, 2014 at CHILL. The incidents were located in a 2-mile radius and upstream of the monitor, but it contaminated only soils according to the COGCC inspection and no event associated with the incidents was detected by the CWW event detection system.

SPILL INCIDENT MAP NEAR CHILL (A 2-MILE RADIUS) AFTER MONITOR INSTALLATION ON FEB 3, 2014
(Yellow triangles indicate spill incident locations)

GILCREST

An operational event was detected at Gilcrest in July 2014.



GILCREST EVENT PROBABILITY (1=EVENT)

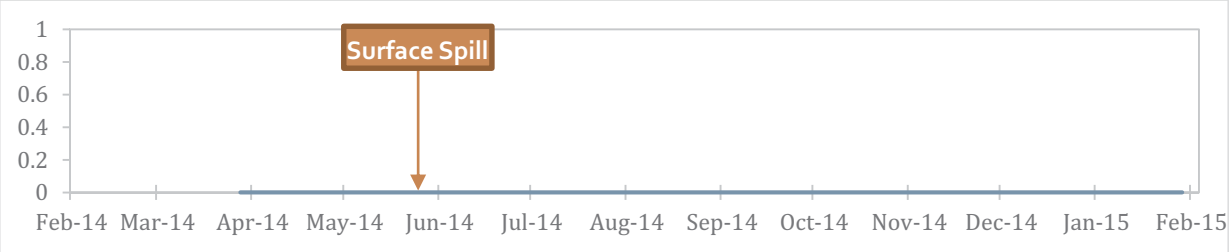
- **Oil & Gas Operational Incidents**

A spill incident at a tank battery occurred on December 23, 2014 within a 2-mile radius of LaSalle after the monitor installation on May 30, 2014. However, the incident didn't affect groundwater quality but contaminated only soils according to the COGCC inspection. The CWW monitoring site did not show an event associated with the spill.

SPILL INCIDENT MAP NEAR GILCREST (A 2-MILE RADIUS) AFTER MONITOR INSTALLATION ON MAY 30, 2014
(The yellow triangle indicates the spill incident location)

GALETON

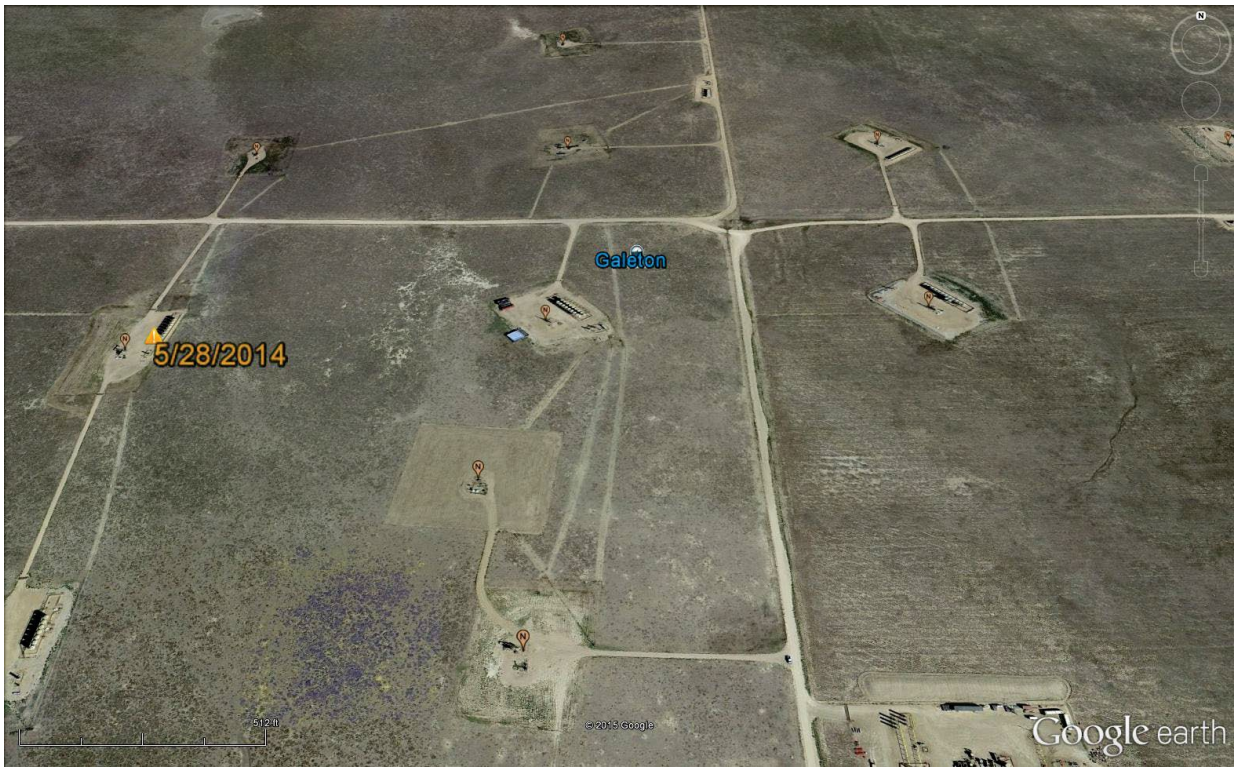
No event was found at Galeton during approximately a 10-month monitoring period from March 27, 2014.



GALETON EVENT PROBABILITY (1=EVENT)

- **Oil & Gas Operational Incidents**

A spill incident at a tank battery was reported on May 28, 2014, 2 months after the monitor installation at Galeton. The Galeton monitoring well is a deep well in the confined Laramie-Fox Hills aquifer so surface spills are not expected to be detected by the CWW monitor, and the incident contaminated only soils according to the COGCC inspection.



SPILL INCIDENT MAP NEAR GALETON (A 2-MILE RADIUS) AFTER MONITOR INSTALLATION ON MAR 27, 2014
(The yellow triangle indicates the spill incident location)

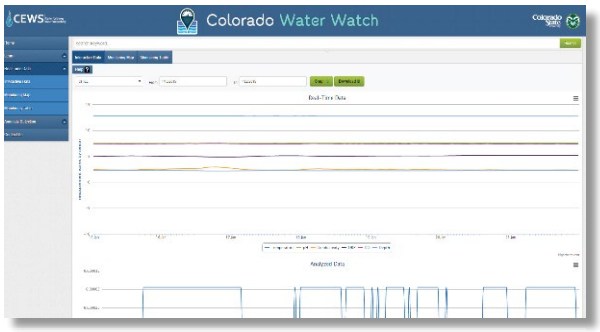
CWW Website

The Colorado Water Watch Website was released on September 24, 2014, and is publicly available at waterwatch.colostate.edu.

The website was developed as a decision making tool for public, industry and government by providing transparency of groundwater quality information gathered from active oil & gas production area in the Denver-Julesburg Basin.

The user-friendly website displays easy-to-understand information of real-time groundwater quality and data screened by an event detection system, which looks for changes in groundwater quality from normal conditions.

Additionally, the website contains various information for the purpose of public education on possible environmental effects of oil & gas activities, primarily hydraulic fracturing.



WATERWATCH.COLOSTATE.EDU

Community Outreach

2014 NATURAL GAS SYMPOSIUM

Colorado Water Watch was successfully launched at the 4th Annual CSU Natural Gas Symposium held at the Grand Hyatt in Denver on September 24, 2014.

The CWW has received a lot of public attention, feedback, and significant recognition and press coverage (see Press Coverage section).

CWW LAUNCH AT THE ANNUAL NATURAL GAS SYMPOSIUM, DENVER, CO SEPTEMBER 24-25, 2014

COMMUNITY OUTREACH EFFORT

The CWW team continues to interact with various groups at different venues to educate people and communicate the availability of real time groundwater monitoring data and the CWW website. The groups include schools, industry, community, and governing boards.

WEST GREELEY CONSERVATION DISTRICT COMMUNITY EVENT, BRIGGSDALE, CO AUGUST 28, 2014

NEW VISTA HIGH SCHOOL, BOULDER, CO SEPTEMBER 10, 2014

Press Coverage

- FOX31 (9/24/2014) "CSU develops monitoring system to test water quality in wells"
- DENVER BUSINESS JOURNAL (9/24/2014) "CSU unveils water monitoring tool for oil and gas sites"
- E&E NEWS (9/24/2014) "Oil and Gas: Tool lets public monitor Colo. groundwater in real time"
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- INNOVATION NEWS (9/24/2014) "Colorado Water Watch to provide real-time info on oil and gas well sites, act as early warning"
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- OIL & GAS 360 (9/24/2014) "Colorado State University Initiates Real-time Water Quality Monitoring in the Wattenberg"
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- NGI (9/25/2014) "Joint Online Water Monitoring Debuts in Colorado"
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- THE DENVER POST (9/28/2014) "Making Colorado water monitoring even better"
- EAGLEFORDTEXAS.COM (11/02/2014) "Website to monitor water quality around drilling sites"
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- SHALE PLAY WATER MANAGEMENT (Nov/Dec 2014) pp.6 "Noteworthy: Colorado Water Watch"

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Peer-Reviewed Publications Related to CWW

Goodwin, S., K. H. Carlson., K. Knox, C. Douglas, L. Rein. 2014. Water intensity assessment of shale gas resources in the Wattenberg Field in Northeastern Colorado. Environmental Science & Technology 48, 5991–5995, dx.doi.org/10.1021/es404675h.

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Son, J., A. Hanif., A. Dhanasekar, K. H. Carlson. Colorado Water Watch: real-time groundwater monitoring for possible contamination from oil and gas activities. Submitted, February 2015.

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