

## ENGINEERING TECHNICAL NOTE

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### DESIGN CONSIDERATION FOR WELLS PRODUCING GAS IN MONTANA

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Water wells are installed under NRCS conservation programs as a source of water for prescribed grazing systems and irrigation efficiency improvements. Water wells completed in Montana have the potential to produce significant amounts of gas along with water. These gases include methane (combustible), carbon dioxide and nitrogen (asphyxiating), and hydrogen sulfide (toxic). These gases are usually dissolved in the water and have the potential to create hazardous conditions if the well and water distribution system are not designed and installed properly. This technical note identifies geographic areas prone to hazardous gas production and presents various design measures to mitigate the hazards.

### HAZARDOUS CONDITIONS CREATED BY WELL GASES

Gas accumulation in well pits, pump houses, and water storage tanks can be fatal to humans. Fatalities generally occur by compounding the toxic effect of hydrogen sulfide with the asphyxiating effect of oxygen displacement by other gases such as, carbon dioxide, and nitrogen. Gas accumulations can also be combustible and create the conditions for an explosion or flash fire triggered by electrical appurtenances, static electricity, or friction. Two or more of these hazards may be present at the same time and place. See Appendix 1 for a detailed discussion of individual gases.

One or more of the following conditions may be caused by gas emissions from wells and/or well water:

#### Asphyxiating Atmospheres

Atmospheres with less than 19.5% oxygen are considered to be deficient in oxygen content. Atmospheres with less than 12% oxygen will cause immediate loss of consciousness and death under continuous exposure. Additions of nitrogen, carbon dioxide, methane, or other gases to the atmosphere in a frost pit, pump house, storage tank, or other confined space can produce an asphyxiating atmosphere.

#### Flammable/Explosive Atmospheres

The presence of methane, hydrogen sulfide, and other combustible gases can create a combustible or explosive atmosphere. Combustible atmospheres can cause flash fires and ignite nearby structures or burn equipment in frost pits or pump houses, and cause personal injury. Flash fires can also generate oxygen deficient atmospheres by consuming the available oxygen. Explosive atmospheres can cause explosions that destroy structures and equipment and cause personal injury.

#### Toxic Atmospheres

Hydrogen sulfide is a poisonous and combustible gas. It is also caustic to eyes and airway and corrosive to most metals including copper, brass, bronze, and steel. It is odorous so its presence is

easily detected, but determination of hazardous concentrations requires using a meter. As little as one breath at high concentrations can be fatal.

## **AREAS UNDERLAIN BY FORMATIONS LIKELY TO PRODUCE GASES**

Certain formations in Montana produce one or more gases from water wells. These formations include the Tongue River Member of the Fort Union Formation, Hell Creek-Fox Hills, Judith River, Eagle, Fall River, Kootenai, and possibly other formations. Confined aquifers in these formations are likely to produce gases. Gases likely to be encountered will vary among the aquifers and between areas. See Appendix 2 for a detailed discussion of aquifers likely to be used for stockwater in Montana. See Appendix 3 for maps showing areas with the potential to have gas prone wells. Maps are available for Park, Meagher, Cascade, Teton, Pondera, and Glacier Counties, and all counties to the east. Counties located to the west of these counties are not likely to have gas prone wells but caution is advised throughout Montana.

## **SOURCE OF WELL GAS**

Most gas produced by a well will likely come from gas that is held in solution by confining pressure. If the confining pressure is reduced by drilling a well into the aquifer, then gas will be released from solution and fill the well bore. Gas production can vary with atmospheric pressure and water production. Gas emission will be highest when pumping rates are high and when atmospheric pressure is low.

In some cases, porous rocks will contain pressurized gas without water. This gas may migrate up the annulus (space between casing and rock walls of drill hole) to the surface if the annulus is not properly sealed or enter the casing if the casing is perforated above the water table. Gases migrating through the annulus can accumulate in frost pits and pump houses or travel along poorly compacted pipe trenches. Gas escaping from the annulus of the well may be difficult to detect without a meter as it is likely to be diffuse seepage from the soil. Extreme cases may show dead or dying vegetation in the vicinity of the well head caused by gas displacing oxygen in the soil or altering the soil chemistry.

A special case of gas wells are “Breathing Wells” developed in large, high porosity, alluvial deposits. When wells are completed in large, high porosity alluvial deposits and the casing is perforated above the water table, air can be drawn into and expelled from the alluvium depending on atmospheric pressure gradients. Air expelled from the alluvium can be deficient in oxygen content creating hazardous atmospheres in pump houses, frost pits, basements, and other closed spaces that surround well heads. The wells may produce an audible noise during exhaust or intake events.

Conditions may change with time so that a well that was free of gas may start discharging gas through the well or annulus. For this reason, caution should be used around all frost pits, storage tanks, covered stock tanks, and/or pump houses associated with well heads.

## **DETECTION AND SAMPLING OF GAS IN WATER WELLS**

There are few visual clues to the presence of these gases other than bubbles in the well water. The only gas that has an olfactory clue is hydrogen sulfide, but large concentrations reduce the sensitivity of the olfactory receptors so smell cannot be relied upon to detect hazardous concentrations. However, gases can be detected by using portable meters designed to measure atmospheric gas concentration of methane, carbon dioxide, hydrogen sulfide, and oxygen.

Wells producing water that has a high methane content may also have a large dissolved iron content that precipitates when exposed to air. Iron deposits as shown in Fig. 1 may be an indicator of methane in the water.



**Figure 1. Methane rich water depositing iron oxide upon exposure to air.**

### **Field Sampling of Well Gas**

Field sampling of gases produced with pumped or flowing water is easily done, but it requires the use of a simple apparatus as described below. Care must be taken to avoid contamination of the sample. Sampling of gases from the casing head vent requires care to avoid contaminated gas in the vent pipe. Casing gas should be sampled from a valve provided on top of the casing. Special Tedlar or similar sample bags are used to contain the sample.

Sampling apparatus would include a 5 gallon bucket or tub, a length of hose to deliver water from the well to the bucket, a funnel or modified plastic bottle converted into a gas collector, a length of 1/8" tubing with a short tee, and a Tedlar sample bag. To collect a sample, the bucket is allowed to fill with water. The discharge hose is held near the bottom of the bucket so that the produced gas forms bubbles that rise to the surface. The funnel or modified plastic bottle is held over the rising chain of bubbles so the gas can enter the tubing attached to the apex and flow into the sample bag. The tubing and collector need to be flushed with the gas to remove contamination and flow through the tubing needs to be adjusted so that a headspace is formed in the apex to prevent water being forced into the sample bag.

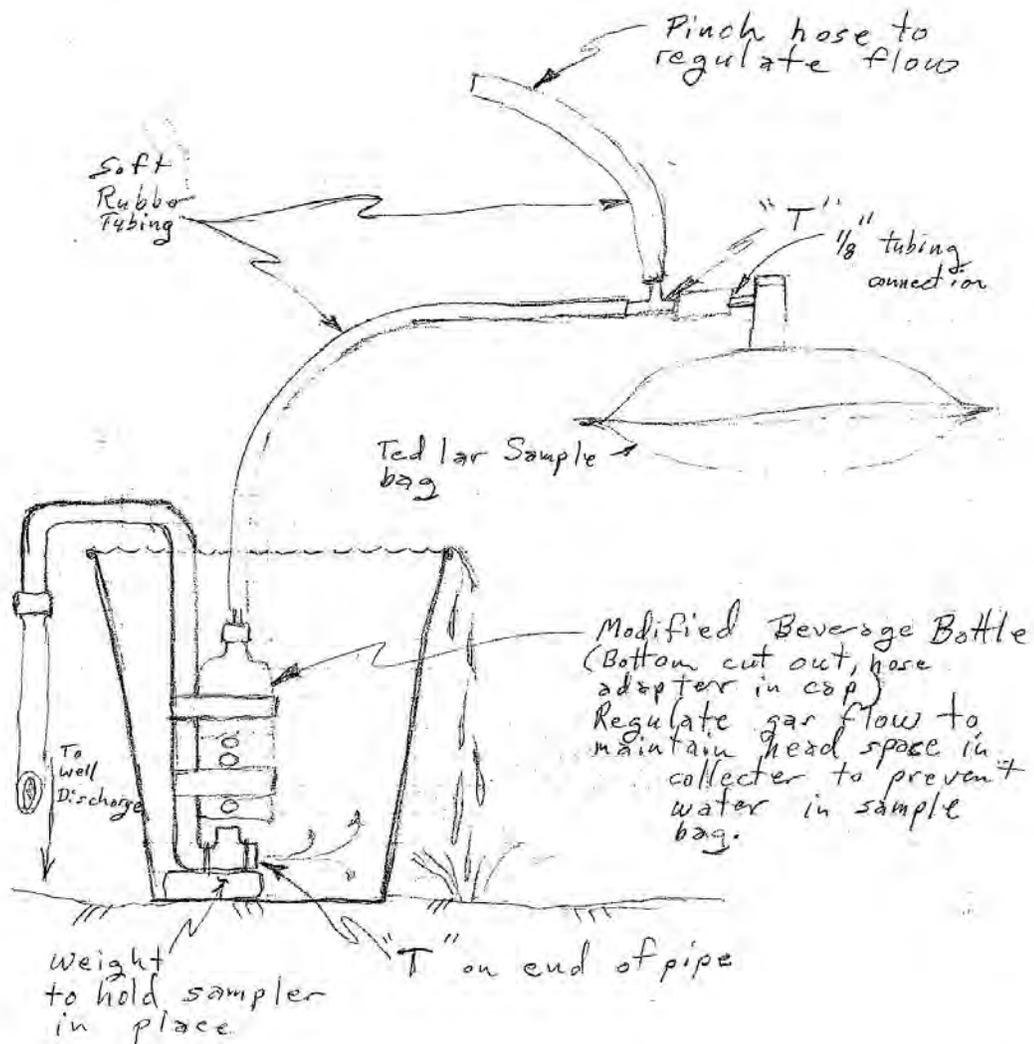


Figure 2. Sketch of gas sampling apparatus

## OTHER CONSIDERATIONS

Conventional submersible pumps may not be effective in producing water from wells with a large amount of dissolved gas. When gas is dissolved in water, the gas will come out of solution when the water is agitated or if the pressure is reduced. Both of these things happen when water enters a submersible pump. The gas forms bubbles that can cause the pump to "air lock" when the impellers are filled with gas and unable to expel the gas from the bowls. This can be alleviated to some degree by placing the foot valve about 20 feet above the pump, but this is not effective for wells producing large amounts of gas. "Air locked" pumps commonly need to be pulled from the well and re-installed before they will resume pumping. Another technique is to place a shroud around the pump intake that raises the effective intake higher than the top of the pump. This shroud allows bubbles formed below the pump to bypass the intake. Specially designed submersible pumps for gassy wells are available. These pumps generally use a progressing cavity device (Moyno pumps). They are not subject to air locking.

# HAZARD MITIGATION

## Avoidance

The simplest method of gas mitigation is to eliminate frost pits and/or pump houses. Most valves, switches, pressure tanks and other appurtenances found in frost pits now have direct burial or in-the-casing equivalents that can be used instead of a frost pit or well house. Storage tanks and covered stock tanks can be constructed to prevent entry by persons.

## Isolation

If a frost pit or well house is unavoidable, then frost pits and pump houses should be placed a minimum of 50 feet from the well head to minimize the potential for gas transfer along the well casing and pipeline trench into the confined spaces of the frost pit or pump house. Excavations between the well head and the frost pit and/or pump house require thorough compaction to eliminate preferential flow paths through the soil. The bottom of frost pits and pipe entry/exit holes should be sealed with concrete. Threaded pipe fittings should be sealed with gas rated (yellow) Teflon tape or joint compound. The electrical systems associated with gassy wells must be designed for combustible atmospheres. This includes junction boxes, switches, and pump and ventilation motors and their controls.

## Ventilation

Ventilation can be used to mitigate the hazards associated with gas producing wells. Ventilation applies to both the production side of the project (frost pits or well houses) and the storage side (storage tanks). Natural ventilation (wind, convection) will likely be suitable for operational conditions but forced (fan, compressed air) ventilation will be required for entry into any enclosed space.

Water delivered to a storage tank should discharge above the maximum water surface (top of tank) in order to de-gasify the water at the lowest possible (atmospheric) pressure. Some form of sprinkler head on the delivery line can improve de-gassing of the stored water and promote oxidation and precipitation of dissolved iron and manganese, if present. For pipeline systems requiring reverse flow in the delivery pipe, a one-way valve can be installed inside the base of the tank on a "tee" connected to the delivery line. Livestock have been reported to not drink water until the gas has been removed from the water.

To reduce the risk of explosion, minimize the gaseous headspace in the storage tanks by limiting the drawdown before the pump turns on. Add a 6-inch diameter PVC ventilation pipe on the end of the storage tank (opposite the lid). This will act as the inlet for fresh air. Add a natural ventilation fan on the lid of each storage tank. The fan will pull in the fresh air through the 6-inch PVC inlet and cross ventilate the headspace.

Additional mitigation in frost pits should include ventilation fans to replace hazardous gases with normal atmospheric air. This system should include an intake near the bottom of the structure and a discharge above the ground surface. Ventilation systems must be capable of displacing much more air than is being released by the well. Ventilation times must allow for three times the volume of the space plus the volume of gas produced by the well during the ventilation period (10 to 15 minutes recommended). Care must be taken in order to avoid re-circulation of displaced gases.

For flowing wells that require pumps, gases accumulating in the top of the casing may force the water surface in the well down to below the pump intake. For artesian wells using flowing well pitless adaptors, a vent located below the spool may be required. For flowing wells using regular pitless adaptors, the vent can open a few feet below the pitless adaptor. Vent valves must be installed below the frost line and vent to the atmosphere above the ground surface.

## **Warnings**

Hazard control and accident prevention are dependent upon the awareness, concern, and prudence of personnel involved in the operation, maintenance, and use of the system. The landowner should be provided with appropriate safety information in the Operation and Maintenance Plan. Design provisions for safety should be referenced so they are recognized and maintained. Safety equipment, warning signs, and management suggestions should also be referenced in the Plan.

A discussion on the steps and precautions that should be considered if storage tank entry is required (e.g., close curb stops, de-energize water level sensors, drain tanks, power ventilate the tanks or utilize hazardous gas sensors, partner, etc.), reference OSHA confined space entry standard.

Add a warning sign for explosive, asphyxiating, and toxic gas at the well head, and entry points for frost pit(s), and storage tanks.

## APPENDIX 1

### GASES FOUND IN WELL WATER

#### Hydrogen Sulfide

Hydrogen sulfide is a toxic gas. It is the most dangerous of well gases. It is colorless and smells like rotten eggs in small concentrations but rapidly paralyzes the sense of smell in large concentrations so odor cannot be relied upon for detecting hazardous conditions. It is heavier than air and tends to collect in low, confined and poorly-ventilated areas. It is produced by the anaerobic bacterial oxidation of organic material in the presence of dissolved sulfates. The bacteria use the sulfate ion as a source for metabolic oxygen. The process yields hydrogen sulfide that is dissolved in the water until confining pressure is released or until the water is disturbed.

Hydrogen sulfide is corrosive to most metals, including iron, zinc, copper, and brass. Black flake corrosion on copper pipes is an indication of chronic exposure to concentrations of hydrogen sulfide. Iron or carbon steel pipes show intense rusting of exposed surfaces and pipe joints.

Hydrogen sulfide is flammable and high concentrations in the atmosphere can be explosive. Burning hydrogen sulfide generates sulfuric acid which is also toxic and highly corrosive.

Hydrogen sulfide is toxic. The primary route of exposure is through the lungs and other mucus membranes (nose, mouth, and eyes). Hydrogen sulfide is rapidly absorbed through the lungs and affects oxygen utilization and the central nervous system. It also irritates the eyes and airway.

Chronic exposure to low levels may also be harmful and reduce tolerance to higher levels of the gas. Exposure to high concentrations causes shock, convulsions, respiratory paralysis, extremely rapid unconsciousness, coma, and death. As little as one breath can be fatal.

#### BEFORE ENTERING AREAS WHERE HYDROGEN SULFIDE MAY BE PRESENT:

1. Air must be tested for the presence and concentration of hydrogen sulfide using air monitoring equipment, such as hydrogen sulfide detector tubes or a multi-gas meter that detects the gas. Testing should also determine if fire/explosion precautions are necessary.
2. If the gas is present, the space/area must be ventilated continually to remove the gas.
3. If the gas cannot be removed, the person entering the space/area must use appropriate respiratory protection and any other necessary personal protective equipment, rescue and communication equipment. OSHA's Confined Spaces standard contains specific requirements for identifying, monitoring and entering confined spaces.

A level of hydrogen sulfide gas at or above 100 ppm is immediately dangerous to life and health. Entry into this atmospheric concentration can only be made using: 1) A full-face piece pressure demand self-contained breathing apparatus (SCBA) with a minimum service life of thirty minutes; or 2) A combination full-face piece pressure demand supplied-air respirator with an auxiliary self-contained air supply.

If hydrogen sulfide levels are below 100 ppm, an air-purifying respirator may be used, assuming the filter cartridge/canister is appropriate for hydrogen sulfide. A full-face piece respirator will prevent eye irritation. If air concentrations are elevated, eye irritation may become a serious issue. If a half mask respirator is used, tight fitting goggles must also be used. Workers in areas containing hydrogen sulfide must be monitored for signs of overexposure. NEVER attempt a rescue in an area that may contain hydrogen sulfide without using appropriate respiratory protection and without being trained to perform such a rescue.

Concentrations up to 10 ppm can be tolerated but with significant irritation to the eyes, nose, and throat. Concentrations greater than 10 ppm should be considered hazardous to health and greater than 50 ppm should be considered hazardous to life.

## **Methane**

Methane is a flammable gas that is colorless, odorless, and lighter than air. It is produced naturally by thermogenic or biogenic processes. Thermogenic processes require elevated temperatures that are not ordinarily encountered at the depth of most stockwater wells. However, methane can migrate through rocks for long distances, both vertically and horizontally. Biogenic methane production requires an anoxic environment and involves the reduction of carbon dioxide by primitive, bacteria like, Archaea. This is a two-stage process. In the first stage bacteria metabolize organic matter utilizing oxygen from dissolved sulfate ions and other sources, and generate hydrogen sulfide and carbon dioxide. In the second stage Archaea then reduce the carbon dioxide to methane. This source of methane is common in the Cretaceous and Early Tertiary sedimentary systems of eastern Montana. Formations known to contain biogenic methane include the Tongue River Member of the Fort Union Formation, the Hell Creek-Fox Hills (small, local areas), Judith River Formation, Eagle Formation (almost everywhere this formation is present), and the Kootenai Formation. Because biogenic methane generation is an anoxic process, methane is not produced near outcrops and therefore is not generally encountered in shallow aquifers or aquifers that are unconfined. Methane most commonly occurs in aquifers where they are distant from their recharge areas, and are confined.

The primary hazards from methane are explosions and fires. Excessive accumulations of methane can generate oxygen deficient atmospheres. Some wells produce enough methane to burn continuously, but others cannot support a continuous flame. Most methane discharges come from aquifers developed by the well but methane can migrate to the surface through the annulus (space between the casing and wall of the drilled hole) from overlying beds. This type of discharge can be difficult to control and vent. Fires can be hazardous to structures close to the well and will likely damage electrical wiring and plastic pipes. Flash fires can cause injury to people and other animals. Explosions can destroy structures and injure people and animals. Sources of ignition include sparks from electrical equipment, static electricity and lightning, open flames, friction heat, and sparks from percussion events.

The Occupational Safety and Health Administration (OSHA) has no permissible exposure limit for methane, but the National Institute for Occupational Safety and Health's (NIOSH) maximum recommended safe methane concentration for workers during an 8-hour period is 1,000 ppm (0.1 percent). Methane is considered an asphyxiant at extremely high concentrations and can displace oxygen in the blood (Table 1).

**Table 1. Methane Exposure Levels and Effects**

<b>Exposure Level (ppm)</b>	<b>Effect or Symptom</b>
1000	NIOSH 8-hours TLV*
50,000 to 150,000	Potentially explosive
500,000	Asphyxiation

\* TLV = Threshold Limit Value

Hazards can be mitigated by eliminating enclosed spaces such as frost pits and pump houses. If these types of spaces are unavoidable, the proper venting and barriers between source (well) and pit can be used. Spark-proof electrical devices and grounding straps can also reduce the probability of fire. It is recommended that the annulus space of wells be grouted with cement grout instead of bentonite type grouts. Bentonite grouts can dry out and crack, allowing gas to migrate through the grout to the surface. If methane is present, then Teflon tape rated for natural gas pipes is required for threaded pipe joints.

Fires in frost pits have been reported at wells completed in the Judith River Formation and pump house explosions have been reported that were associated with other Cretaceous formations. Well fires have destroyed drill rigs and caused bodily injury at wells completed in the Tongue River Member.

## **Carbon Dioxide**

Carbon dioxide is a colorless, odorless gas. It is heavier than air and collects in low, poorly-ventilated places. Carbon dioxide is considered to be a simple asphyxiate but at high concentrations it produces some symptoms suggesting toxicity. Carbon dioxide can be produced by bacterial oxidation of organic material in rock formations. Carbon is provided by the organic material deposited at the time of sedimentation and oxygen comes from recharge water containing dissolved oxygen or sulfate salts or from air circulating through near surface aquifers. Carbon dioxide can also be found associated with springs and wells originating from limestone formations and from geothermal features (hot springs, fumaroles). Carbon dioxide can also be produced by decaying organic material under atmospheric conditions such as decomposing lumber in a frost pit or other enclosed spaces with poor ventilation.

The primary hazard associated with carbon dioxide is simple asphyxiation due to increased carbon dioxide displacing oxygen in the atmosphere. Carbon dioxide is heavier than air so it tends to accumulate in low areas with poor ventilation such as frost pits. Carbon dioxide concentrations have also been noted in some caves and old mines. It is odorless and colorless so it is difficult to detect. The only reliable form of detection is by using one of various kinds of gas detectors. This gas has been observed in wells completed in the Tongue River Member of the Fort Union Formation, and has been reported in other formations, likely at relatively shallow depths.

## **Other Gases**

There is a slight potential for other gases to be encountered in Montana water wells. These include nitrogen, and radon. Nitrogen can be a residual gas left after the oxygen has been consumed by organic processes. Nitrogen has been found in some deep, oil field wells. Nitrogen makes up about 78% of the normal atmosphere and oxygen is about 21%. If nitrogen content increases, then oxygen content will decrease, generating an oxygen deficient atmosphere which is a hazardous condition.

Radon is a radioactive gas that is the product of the radioactive decay of uranium and thorium. It is a heavy, radioactive, inert gas. It is odorless, colorless, and tasteless so is non-detectable without a radon gas detector or one of the various test kits. Radon and its chain of decay products are all radiation emitters that constitute a lung cancer hazard. Radon is primarily found in Cretaceous and Tertiary, granites and rhyolites and their erosion products and thus is most likely to be encountered in southwestern Montana, especially in and near the Boulder Batholith.

## **Oxygen Deficient Atmospheres**

Atmosphere that contains less than 19.5% oxygen is considered to be oxygen deficient. Oxygen deficiency can be caused by consumption of the oxygen by combustion, organic activity, or oxidation of metals. It can also be caused by introduction of other gases such as carbon dioxide, nitrogen, or other gases that do not metabolize in the human biological system. Atmospheres containing 12% or less oxygen will cause immediate loss of consciousness and death if exposure is continued.

## **APPENDIX 2**

### **DISCUSSION OF INDIVIDUAL AQUIFERS**

#### **1. Alluvium (Quaternary and Tertiary, Map Symbols: Qal, Qaf, Qgr, QTgr, Tgr)**

Alluvium is composed of relatively recently (<6,000,000 years old) deposited sand and gravel with more or less silt and clay. This material is unconsolidated and generally has high permeability and porosity if silt and clay content is low. These aquifers are distributed throughout the state and are usually found under flood plains of modern streams and some older terraces. These aquifers are usually unconfined. Some older terraces may be perched aquifers and other terraces may be drained due to a high topographic position. These aquifers may include weathered parts of the underlying bedrock. Potentiometric surfaces in these aquifers are subject to rapid fluctuations in elevation due to wet and/or dry periods.

The water in these aquifers is unconfined and exposed to the atmosphere, allowing gases to escape into the atmosphere or be oxidized by atmospheric oxygen. They are generally limited in areal extent and their thickness rarely exceeds 50 feet. They are not likely to have hazardous gas emissions as most are small and unconfined. Water quality is generally adequate for livestock purposes but sulfate content can exceed safe limits for livestock, especially if the bedrock is one of the Cretaceous marine shales.

#### **2. Till (Quaternary and Tertiary, Map Symbols: Qgd)**

Till is generally a poor aquifer but local sand and gravel lenses within the till, weathered bedrock under the till, and alluvium deposits covered by the till can produce adequate volumes of water for livestock. Water quality from wells associated with till is highly variable and can be very toxic from sulfate and metal cations leached from the till. Till and associated deposits are not known to produce hazardous gases.

#### **3. Aquifers in the Paleocene Fort Union Formation**

The Fort Union Formation is generally composed of three members; Tullock, Lebo, and Tongue River, with additional members restricted to the eastern part of the state. Over much of central and eastern Montana, various members of the Fort Union Formation are exposed at the surface and provide the shallowest available groundwater resource. The quality of groundwater from the Fort Union is generally adequate for all classes of livestock except for local areas where sulfates and sodium may be excessive. The Tongue River member is noted for its sub-bituminous coal beds in the Powder River Basin (generally the area bounded by the Powder River, the Yellowstone River, the Bighorn River and the Wyoming-Montana State Boundary) and the Bull Mountain Basin (area between the Musselshell River and the Yellowstone River in Musselshell and Yellowstone Counties). The Tongue River Member (the upper member) is a known source of coal bed methane in the Powder River Basin and the Bull Mountain Basin. Any well completed in a coal bed in these areas should be considered a potential source of methane. In local areas near outcrops along the upper part of Hanging Woman Creek in southeastern Big Horn County, and in other areas with similar geologic features, this member may produce large volumes of carbon dioxide instead. Fort Union coals in the Williston Basin are lignite type coals, are not known to produce methane, but can produce carbon dioxide and nitrogen gases.

#### **4. Aquifers in the Cretaceous Hell Creek-Fox Hills and Lance Formations**

The Hell Creek-Fox Hills aquifer is an important groundwater resource in much of eastern Montana. The Lance is a lateral equivalent of the Hell Creek that is recognized in south central Montana, mostly in western Rosebud, Treasure, Big Horn, Yellowstone, and Musselshell Counties.

Where exposed at the surface, there is little likelihood for gassy wells. If wells are completed in these Cretaceous sediments, but the Fort Union Formation is the surface geologic unit, then the wells should be tested for methane and/or carbon dioxide and nitrogen, especially if they are flowing wells. These formations are not known for producing hydrogen sulfide. Water quality in these formations is almost always good for livestock consumption.

## **5. Aquifers in the Cretaceous Judith River Formation**

The Judith River is a known gas-prone aquifer. It is likely to produce methane gas where it is confined and more than two miles from the outcrop. The potential gas emission hazard will increase with increasing distance from the outcrop. Hydrogen sulfide and carbon dioxide/nitrogen emissions are not known from this aquifer. The overlying Bearpaw Shale has a high concentration of sulfate so the Judith River aquifer commonly has high sulfate content and its waters should always be tested for sulfate content to be sure it is safe for livestock.

## **6. Aquifers in the Cretaceous Eagle Formation**

This formation is a major methane gas-producing formation in several gas fields in northern and north-central Montana. All wells completed in the Eagle and more than two miles from the outcrop should be considered hazardous. Wells that have methane-rich waters may have a high dissolved iron concentration. This dissolved iron will precipitate when exposed to air or by bacterial action. The precipitated iron can restrict water flow in pipes and fittings and will be very difficult to remove. The Eagle is generally deeply buried. Where the formation is exposed, the water may be high in sulfates due to high sulfate content of surrounding shales. Where deeply buried, water in the aquifer is likely to have less sulfate, but such water may have a high potential for methane production.

## **7. Aquifers in the Cretaceous Fall River Sandstone and Kootenai Formations**

The Kootenai Formation is the basal formation of the Cretaceous and it is overlain by the Fall River Sandstone. The Kootenai Formation produces oil in central Montana (Cat Creek Anticline). The Fall River Sandstone is a producer of gas and oil in the Powder River Basin. In the Porcupine Dome area of northern Rosebud County, hydrogen sulfide has been reported from the Kootenai. For most of Montana, the Fall River-Kootenai interval is too deep or too saline for economical water wells. In those areas where it is likely to be utilized, it is near the outcrop and not likely to be gas prone. The Porcupine Dome and the area along the north flank of the Pryor Uplift are the major areas where gases are a potential hazard in the Fall River-Kootenai aquifers. These formations should have water quality adequate for livestock in areas near their outcrops but deeper portions of the aquifer may have brines not suitable for livestock use.

## **8. Formations of Jurassic Age and Older**

Aquifers found in formations older than Cretaceous are seldom utilized for stockwater. They generally are found at great depths and contain brines unsuitable for livestock use or are exposed at the surface in mountainous areas where there is adequate surface water.

## REFERENCES

Alberta Agriculture and Rural Development, Methane Safety  
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OSHA Hydrogen Sulfide (H<sub>2</sub>S) Fact Sheet  
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Occupational Safety and Health Administration  
U. S. Department of Labor

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[http://ehstoday.com/safety/confined-spaces/ehs\\_imp\\_32784](http://ehstoday.com/safety/confined-spaces/ehs_imp_32784)

<http://www.osha.gov/SLTC/etools/shipyard/shiprepair/confinedspace/oxygendeficient.html>

Carbon Dioxide Material Safety Data Sheet

Cliff Balster, Consulting Geologist, personal communication

Larry Bond, Licensed Montana Water Well Contractor, personal communication

Stephen Hansen, Licensed Montana Water Well Contractor, personal communication

Elizabeth Meredith, Geologist, Montana Bureau of Mines and Geology, personal communication

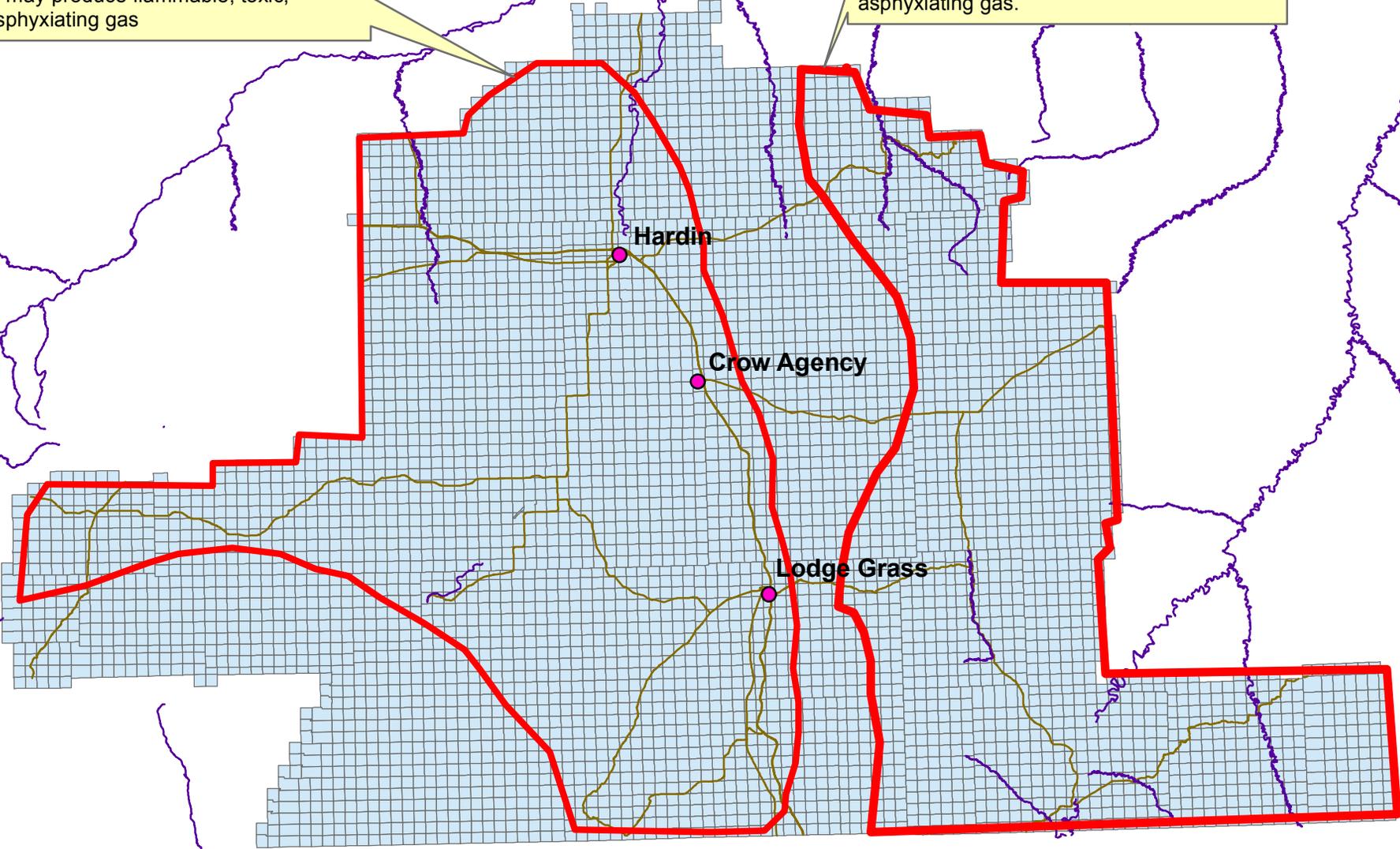
## **APPENDIX 3**

### **MAPS SHOWING AREAS OF POTENTIAL TOXIC, ASPHYXIATING, OR FLAMMABLE GAS EMISSIONS FROM STOCKWATER WELLS**

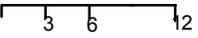
1. Big Horn
2. Blaine
3. Carbon
4. Carter
5. Cascade
6. Chouteau
7. Custer
8. Daniels
9. Dawson
10. Fallon
11. Fergus
12. Garfield
13. Glacier
14. Golden Valley
15. Hill
16. Judith Basin
17. Liberty
18. McCone
19. Meagher
20. Musselshell
21. Park
22. Petroleum
23. Phillips
24. Pondera
25. Powder River
26. Prairie
27. Richland
28. Roosevelt
29. Rosebud
30. Sheridan
31. Stillwater
32. Sweetgrass
33. Teton
34. Toole
35. Treasure
36. Valley
37. Wheatland
38. Wibaux
39. Yellowstone

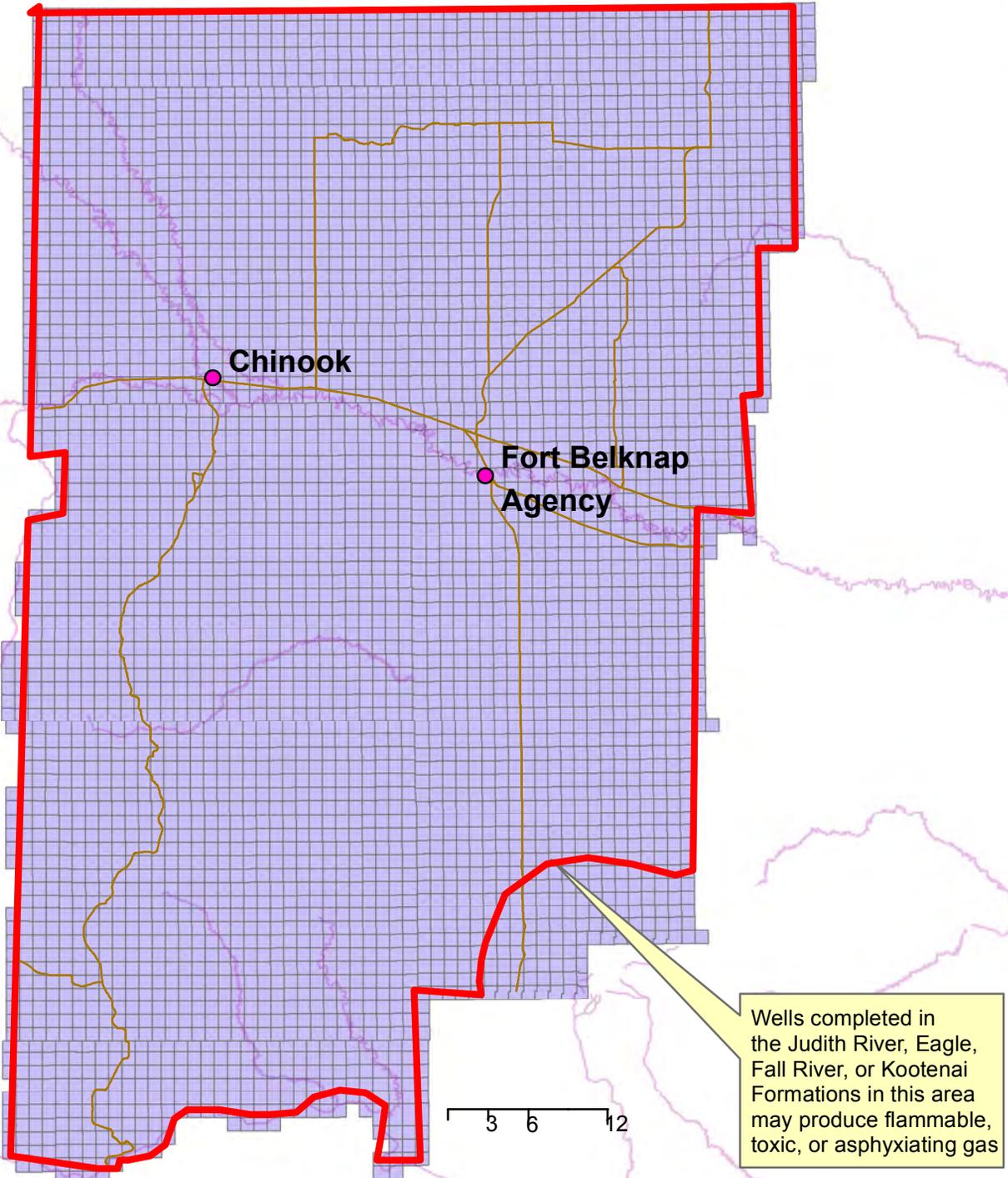
Wells completed in the Judith River, Eagle, Fall River, or Kootenai Sandstones, in this area may produce flammable, toxic, or asphyxiating gas

Wells completed in the Fort Union Formation in this area may produce flammable or asphyxiating gas.

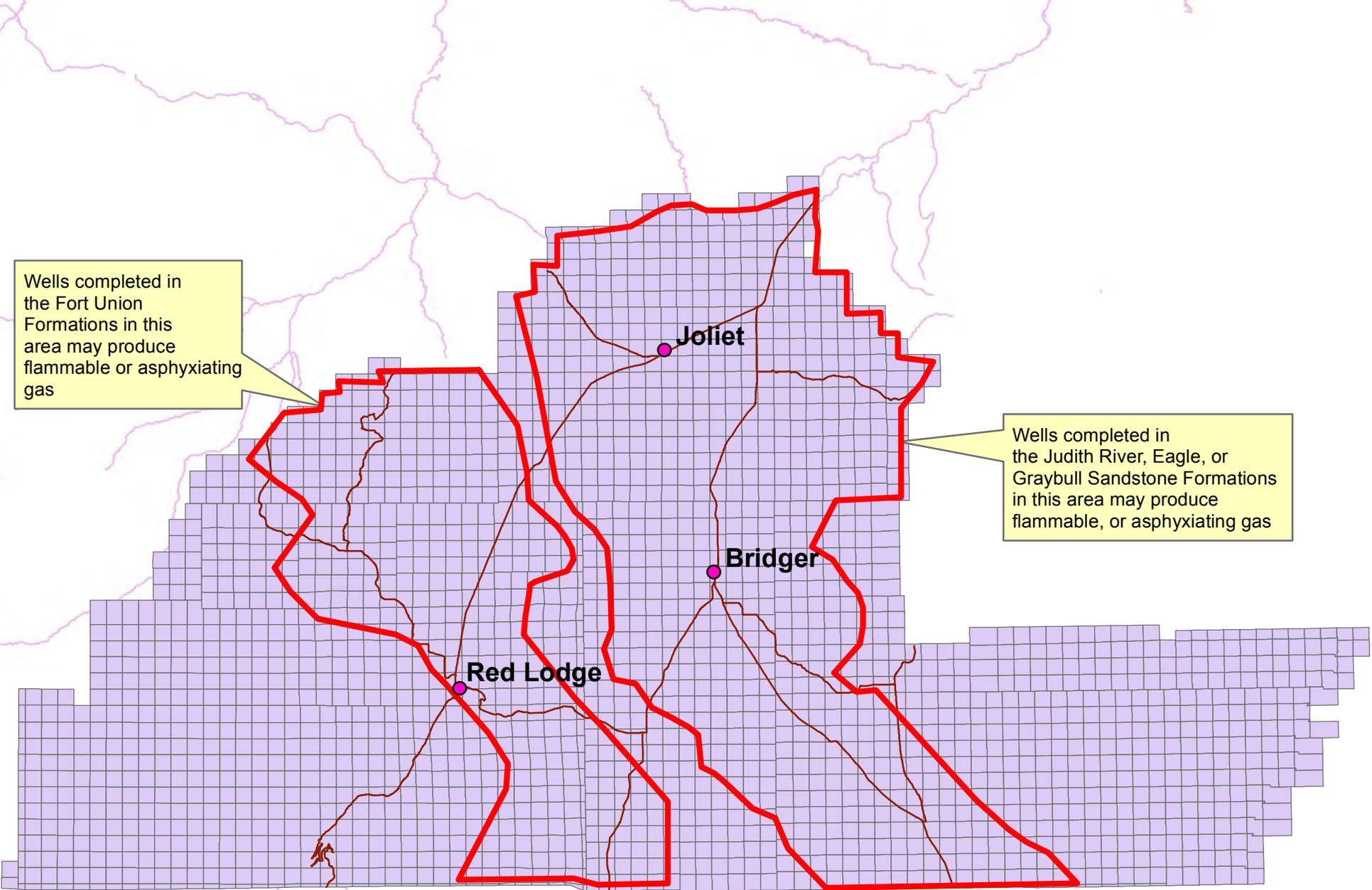


Areas of potential flammable, toxic, or asphyxiating gas emissions from stockwater wells in Bighorn County





Areas of potential flammable, toxic, or asphyxiating gas emissions from stockwater wells in Blaine County



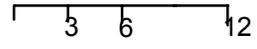
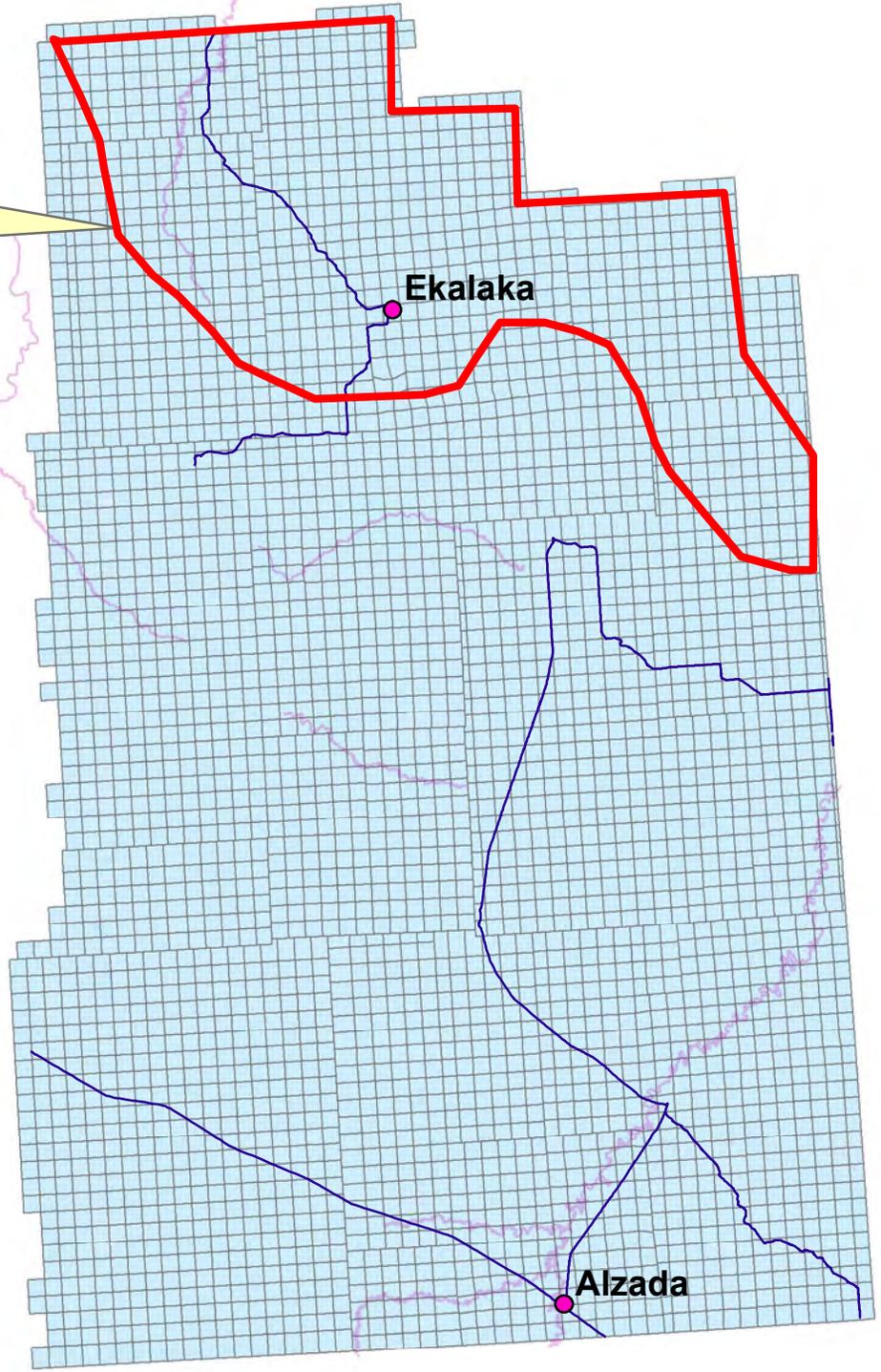
Wells completed in the Fort Union Formations in this area may produce flammable or asphyxiating gas

Wells completed in the Judith River, Eagle, or Graybull Sandstone Formations in this area may produce flammable, or asphyxiating gas

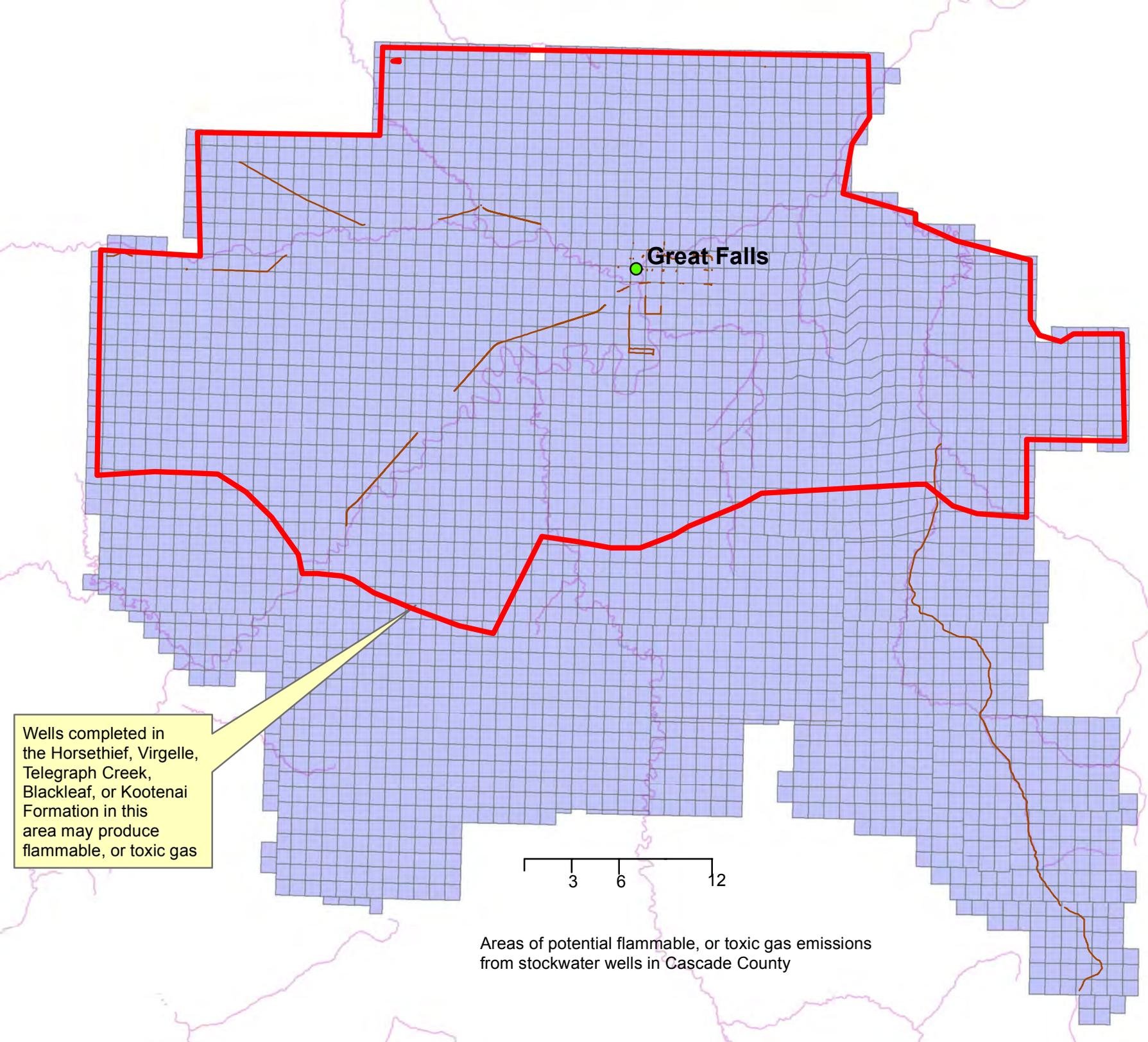
Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Carbon County

3 6 12

Wells completed in the Fort Union Formation in this area may produce flammable or asphyxiating gas



Areas of potential toxic, asphyxiating, or flammable gas emissions from stockwater wells in Carter County

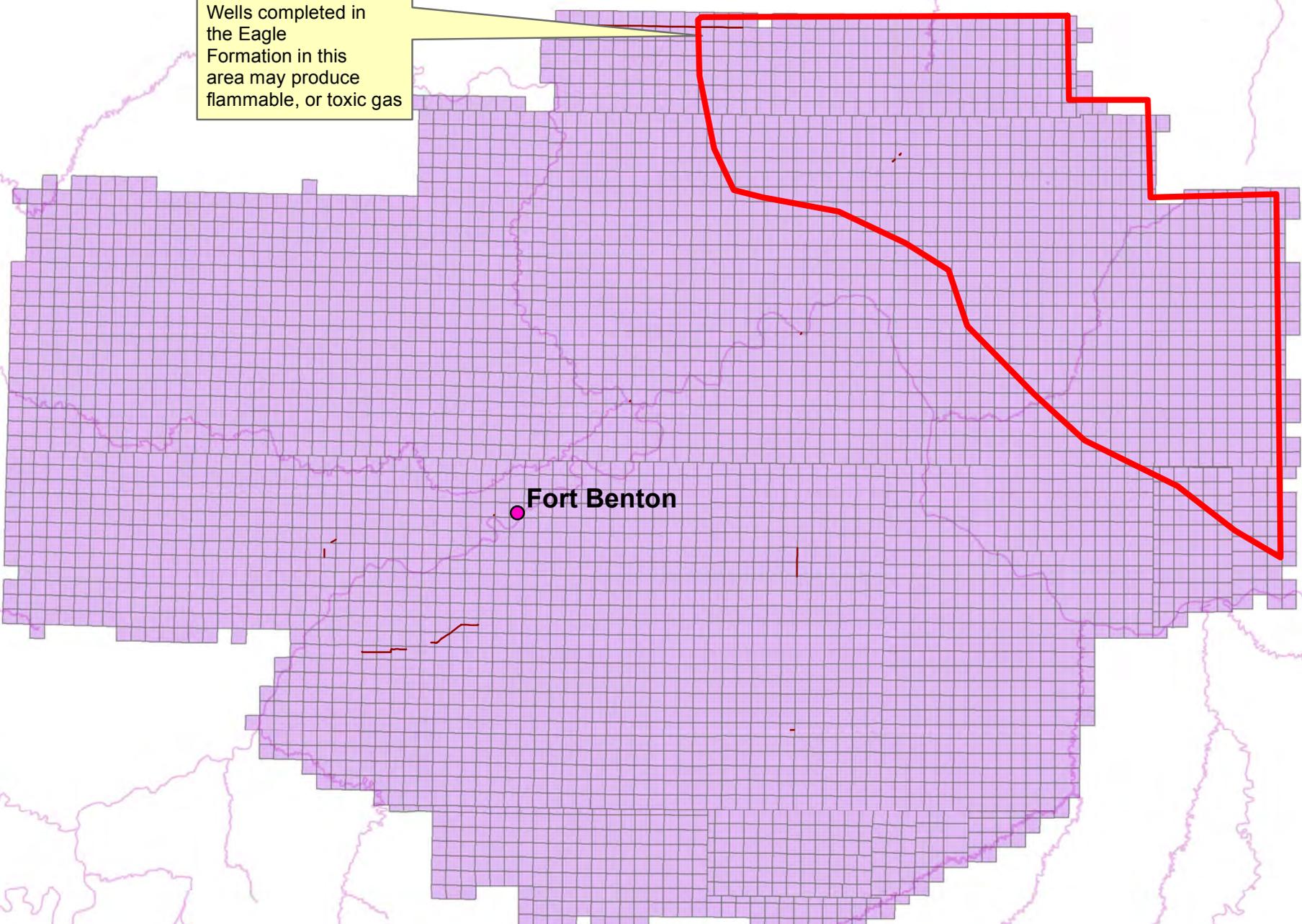


Wells completed in the Horsethief, Virgelle, Telegraph Creek, Blackleaf, or Kootenai Formation in this area may produce flammable, or toxic gas

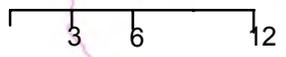
3 6 12

Areas of potential flammable, or toxic gas emissions from stockwater wells in Cascade County

Wells completed in the Eagle Formation in this area may produce flammable, or toxic gas



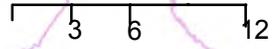
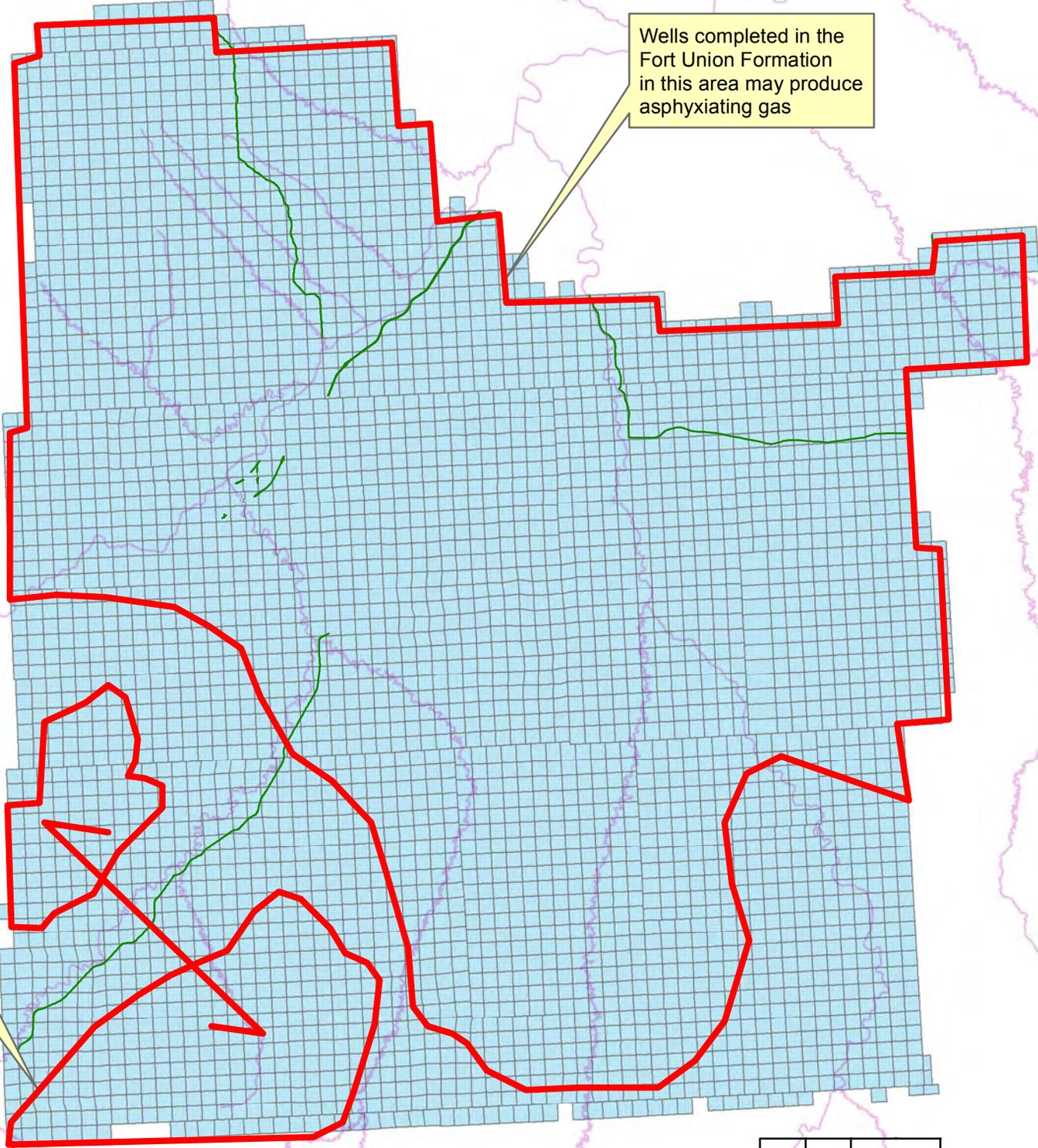
Fort Benton



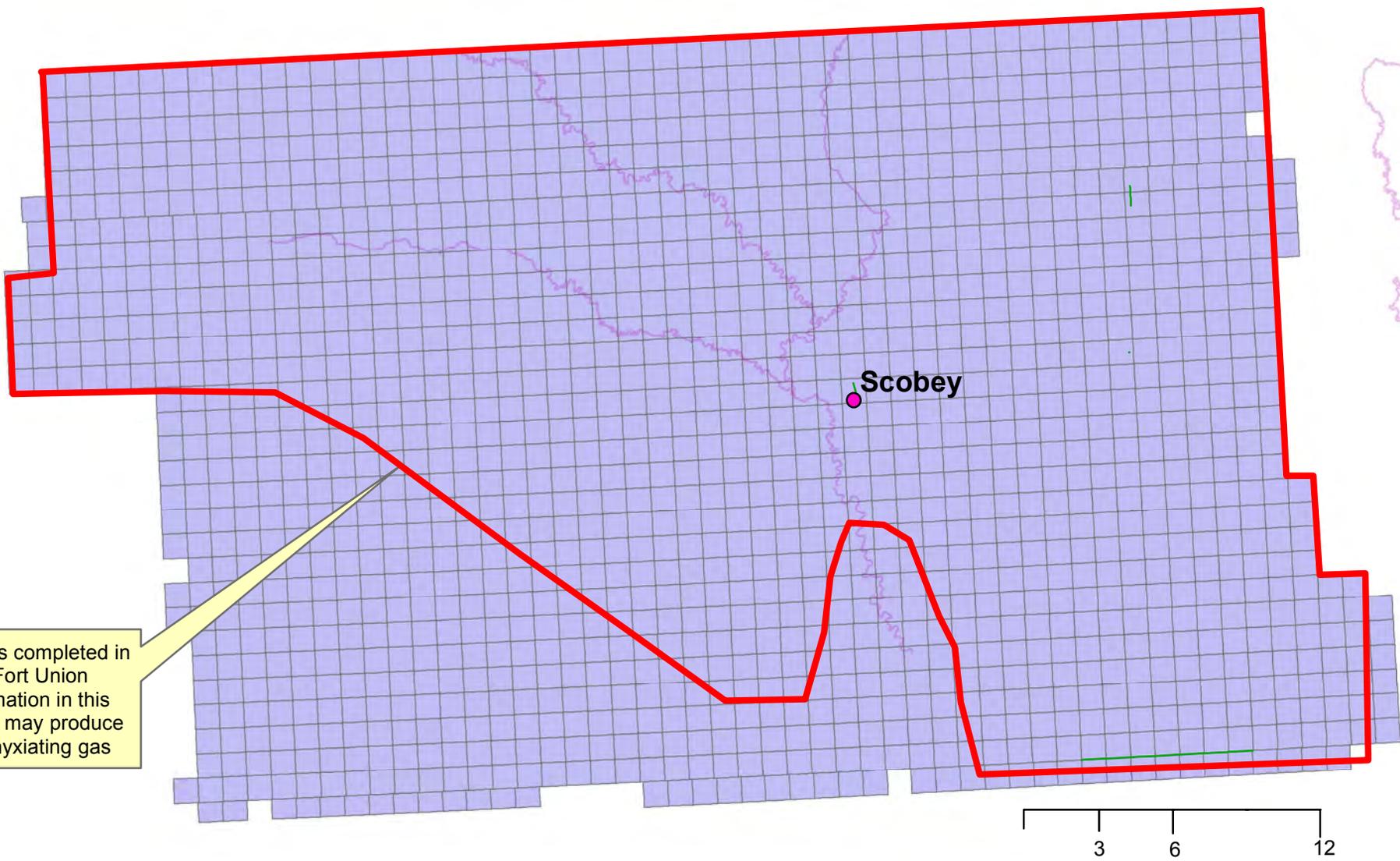
Areas of potential flammable, or toxic gas emissions from stockwater wells in Chouteau County

Wells completed in the Fort Union Formation in these areas may produce flammable or asphyxiating gas

Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

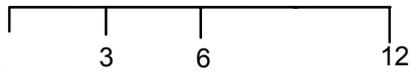


Areas of potential asphyxiating, or flammable gas emissions from stockwater wells in Custer County



Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

Scobey

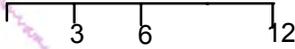


Areas of potential asphyxiating gas emissions from stockwater wells in Daniels County

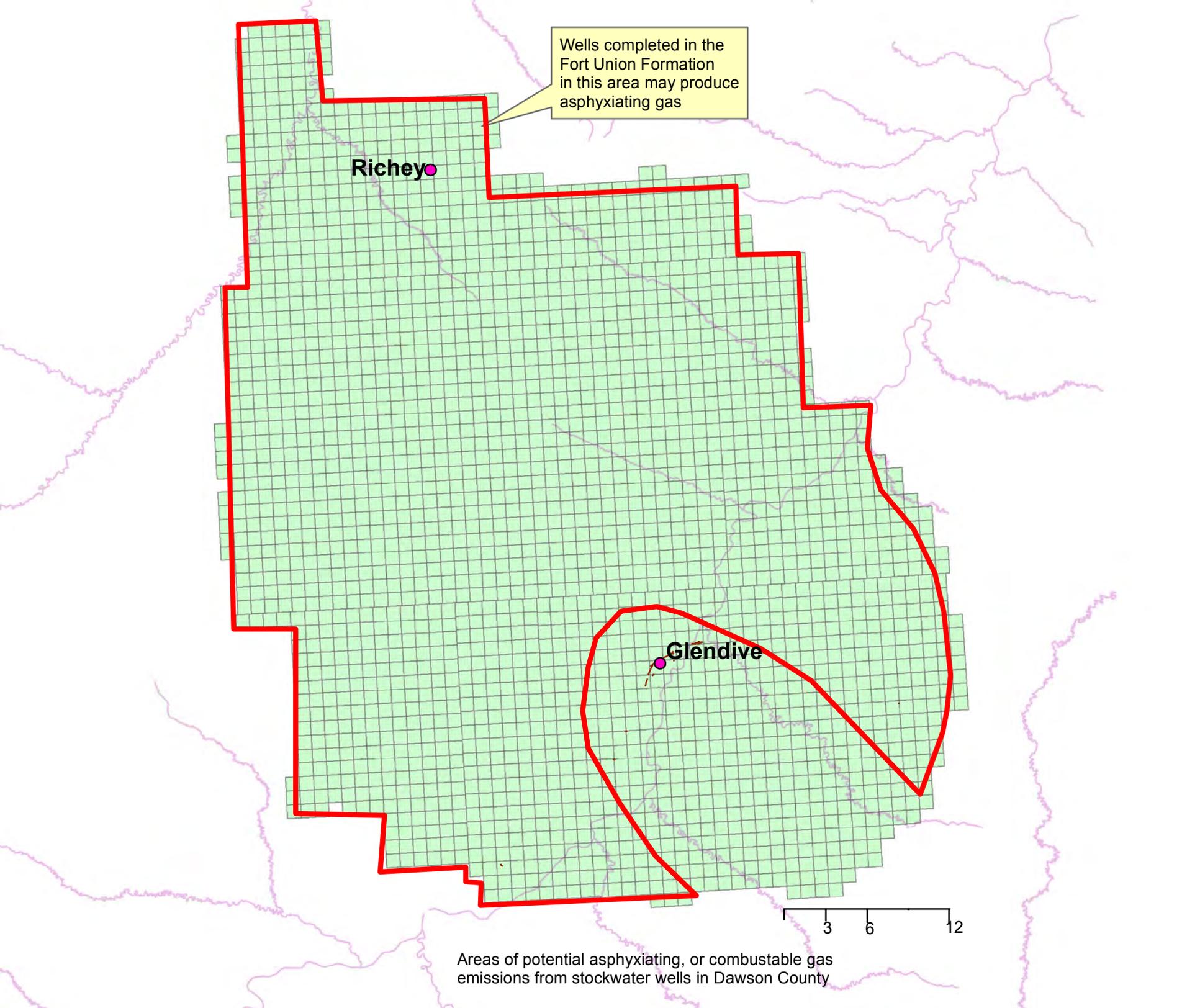
Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

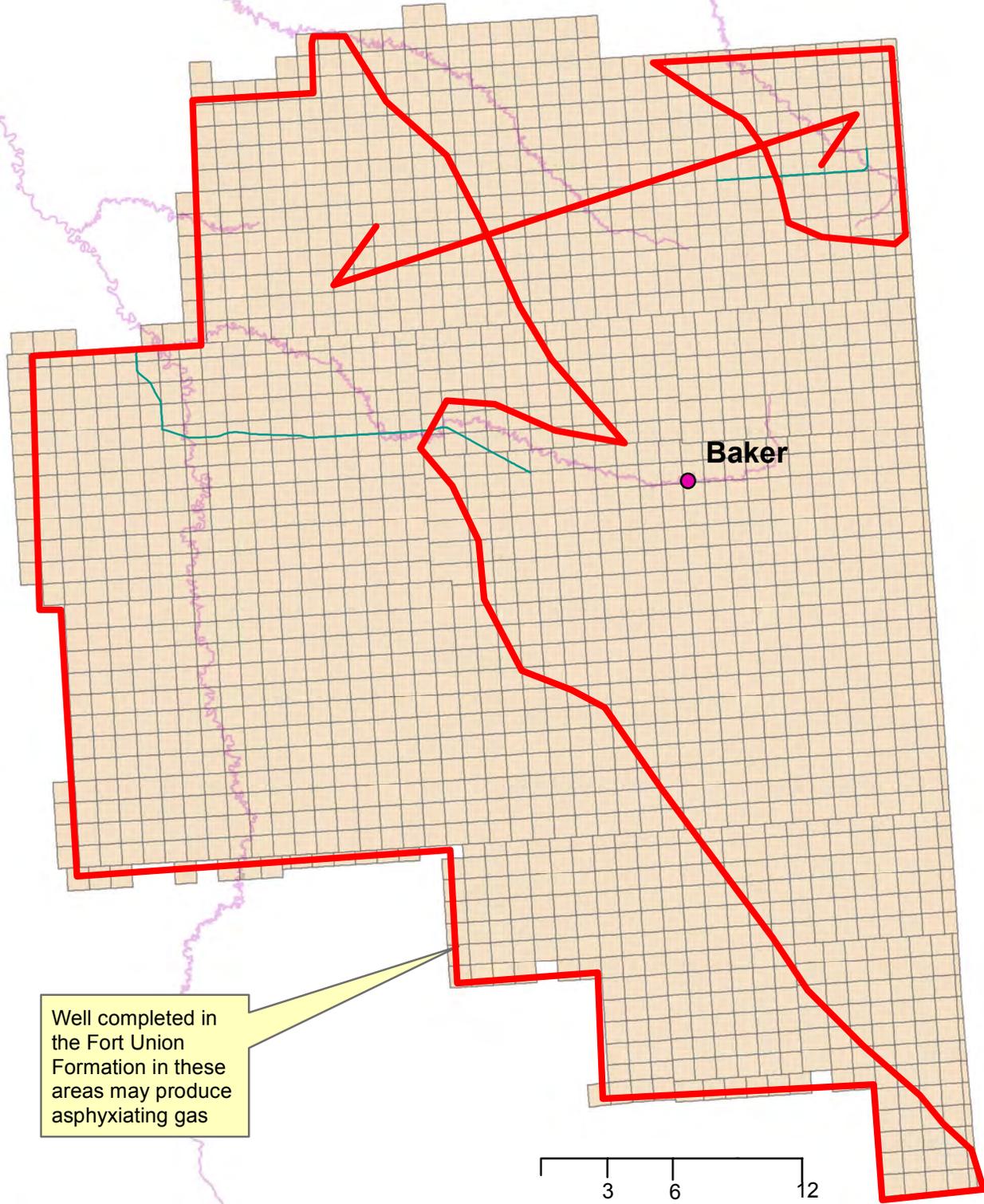
Richey

Glendive

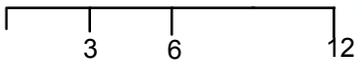


Areas of potential asphyxiating, or combustible gas emissions from stockwater wells in Dawson County

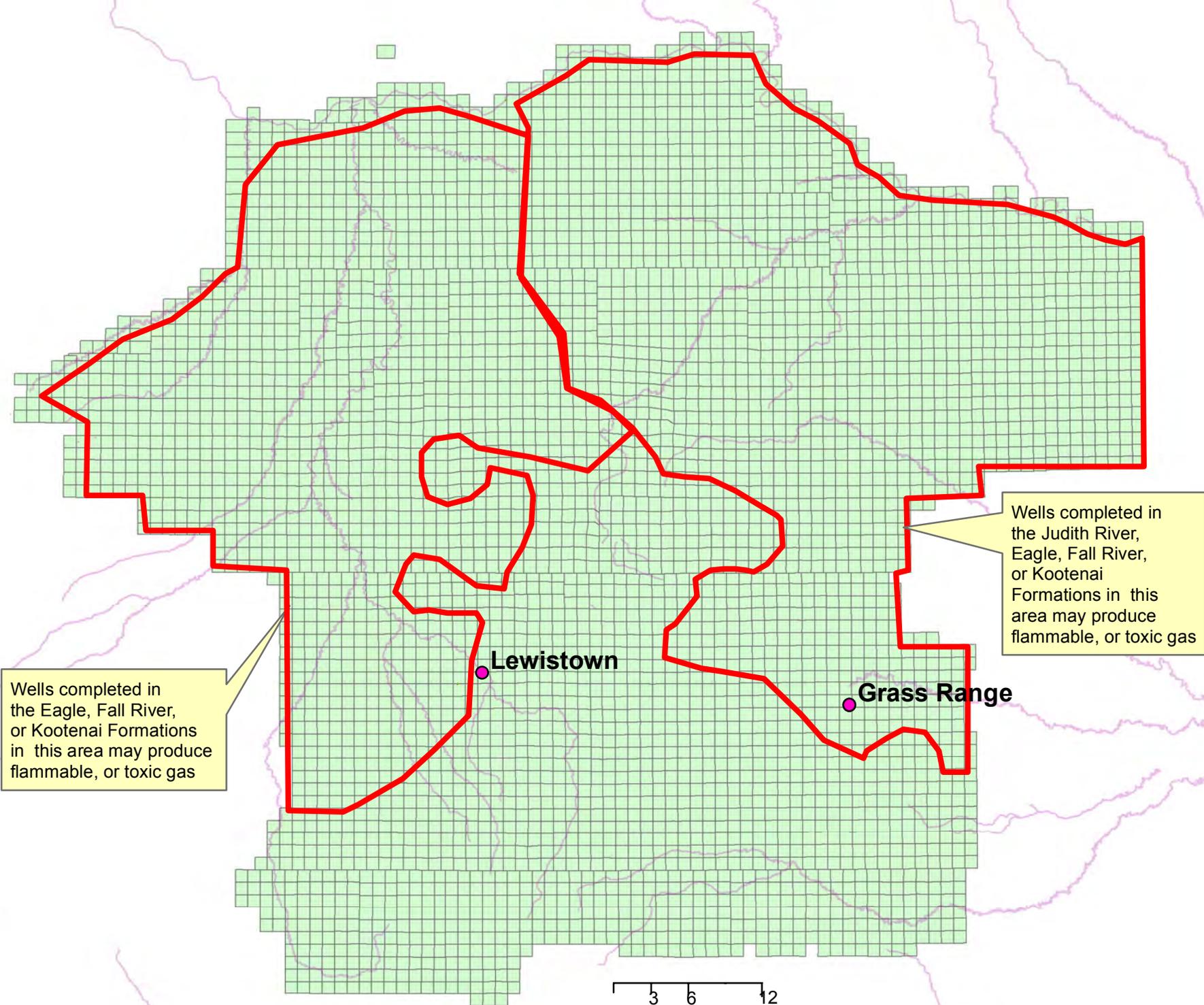




Well completed in the Fort Union Formation in these areas may produce asphyxiating gas



Areas of potential asphyxiating gas emissions from stockwater wells in Fallon County



Wells completed in the Eagle, Fall River, or Kootenai Formations in this area may produce flammable, or toxic gas

Wells completed in the Judith River, Eagle, Fall River, or Kootenai Formations in this area may produce flammable, or toxic gas

**Lewistown**

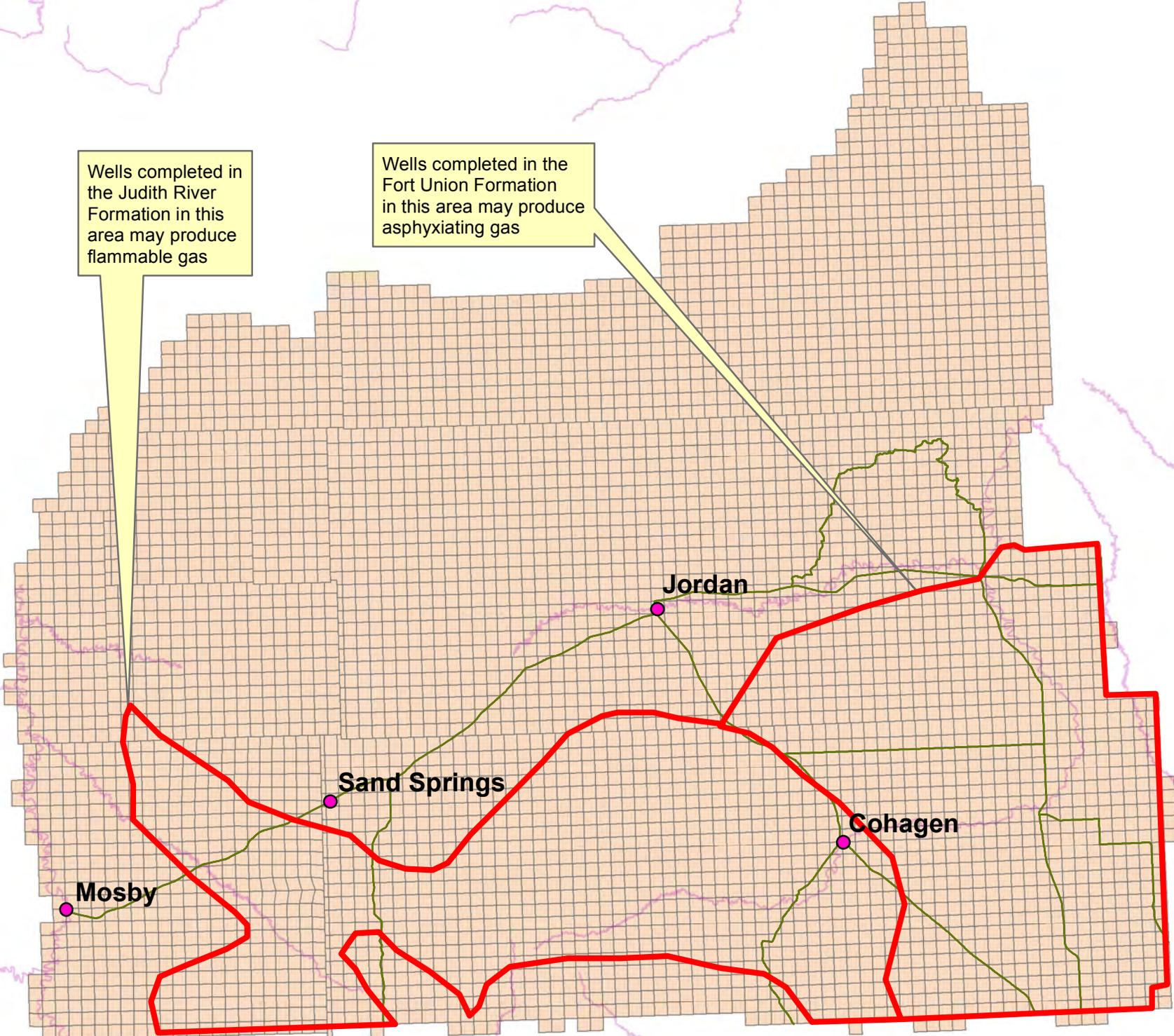
**Grass Range**

3 6 12

Areas of potential toxic, or flammable gas emissions from stockwater wells in Fergus County

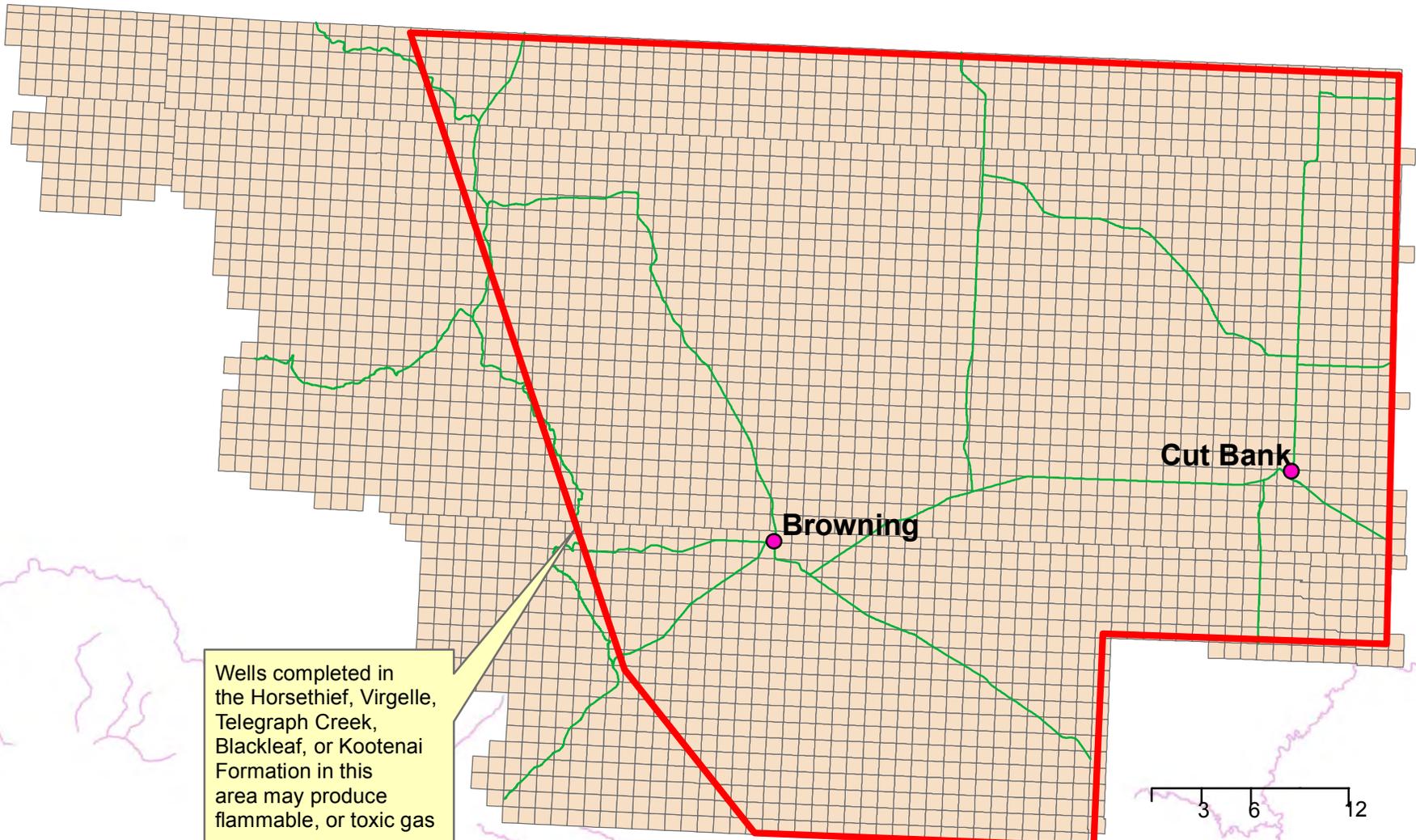
Wells completed in the Judith River Formation in this area may produce flammable gas

Wells completed in the Fort Union Formation in this area may produce asphyxiating gas



3 6 12

Areas of potential asphyxiating or flammable gas emissions from stockwater wells in Garfield County



Wells completed in the Horsethief, Virgelle, Telegraph Creek, Blackleaf, or Kootenai Formation in this area may produce flammable, or toxic gas

Areas of potential flammable, or toxic gas emissions from stockwater wells in Glacier County

Wells completed in the Judith River, Eagle, or Kootenai Formations in this area may produce flammable, or toxic gas

Wells completed in the Judith River, Eagle, or Kootenai Formations in this area may produce flammable, or toxic gas

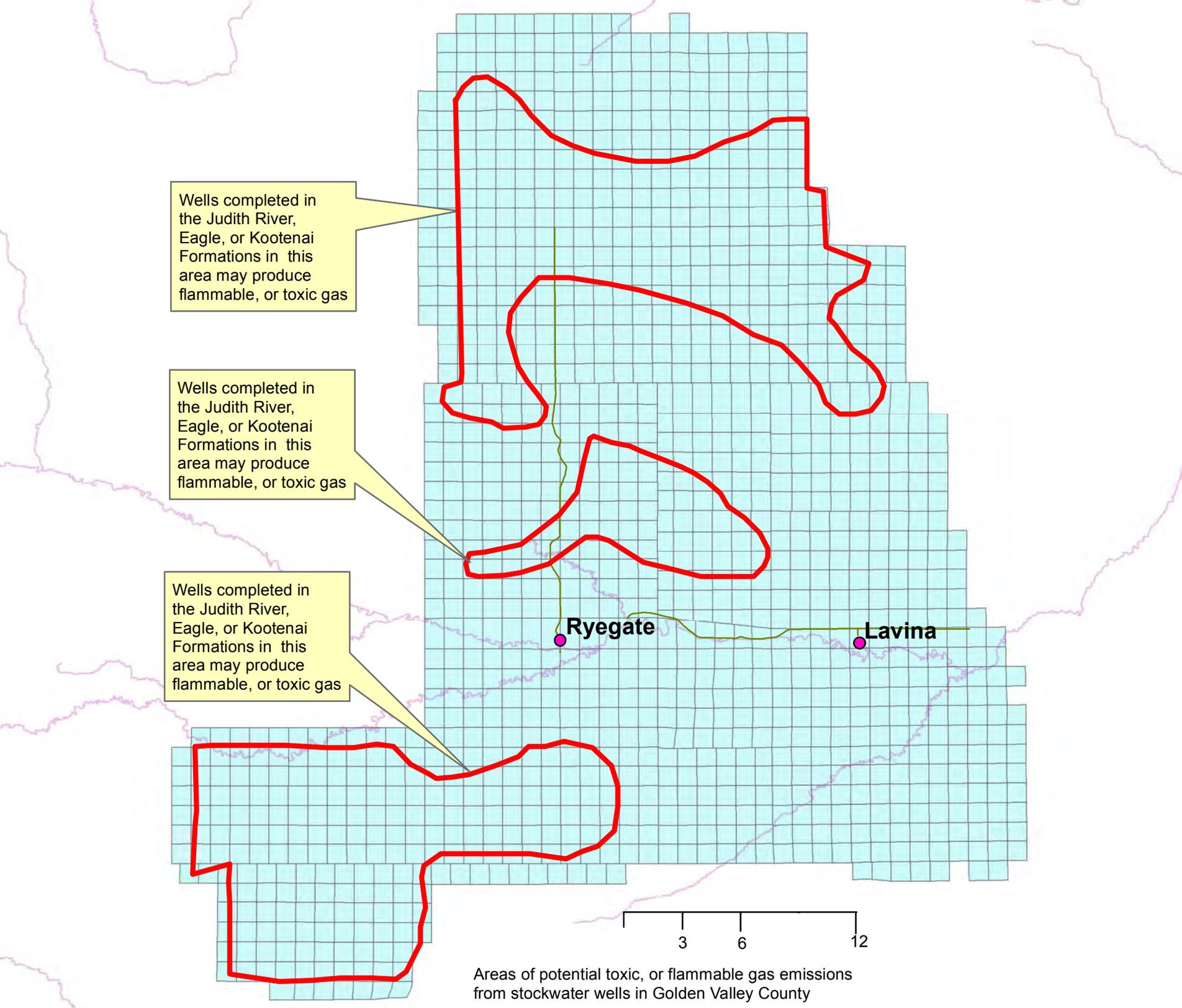
Wells completed in the Judith River, Eagle, or Kootenai Formations in this area may produce flammable, or toxic gas

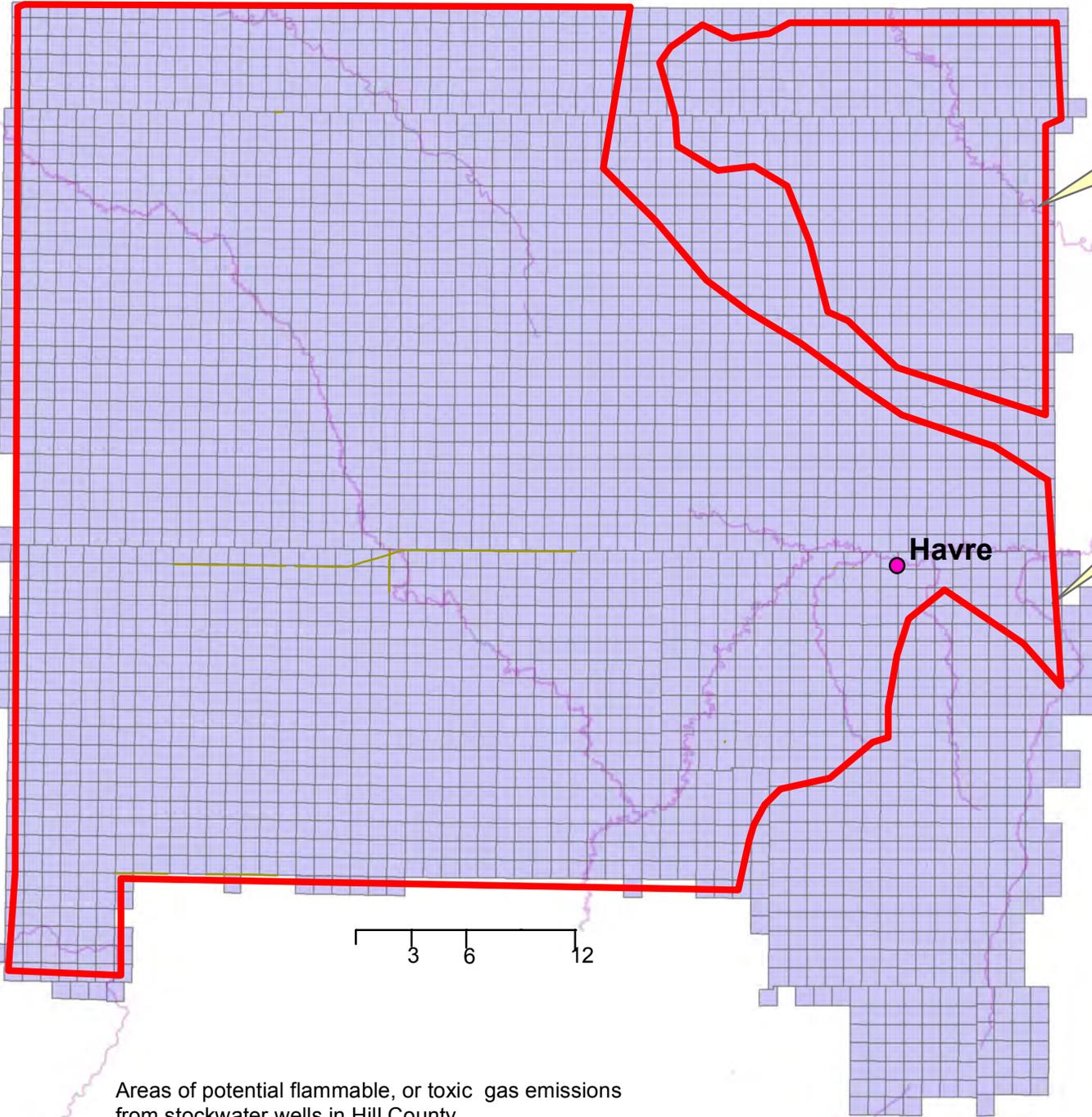
Ryegate

Lavina



Areas of potential toxic, or flammable gas emissions from stockwater wells in Golden Valley County

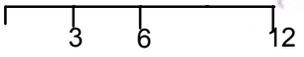




Wells completed in the Judith River Formation in this area may produce flammable, or toxic gas

Wells completed in the Eagle Formation in this area may produce flammable, or toxic gas

Havre



Areas of potential flammable, or toxic gas emissions from stockwater wells in Hill County

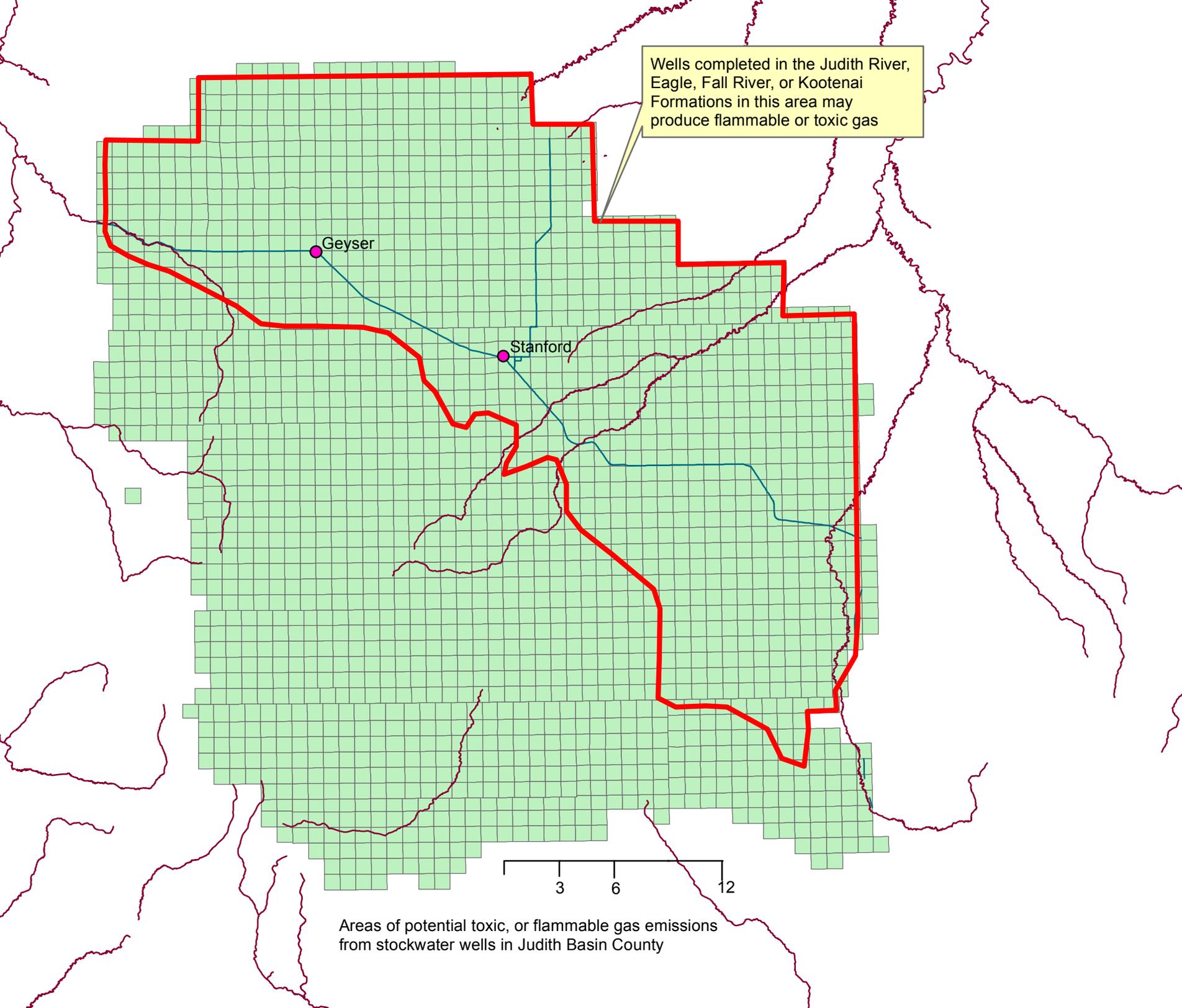
Wells completed in the Judith River, Eagle, Fall River, or Kootenai Formations in this area may produce flammable or toxic gas

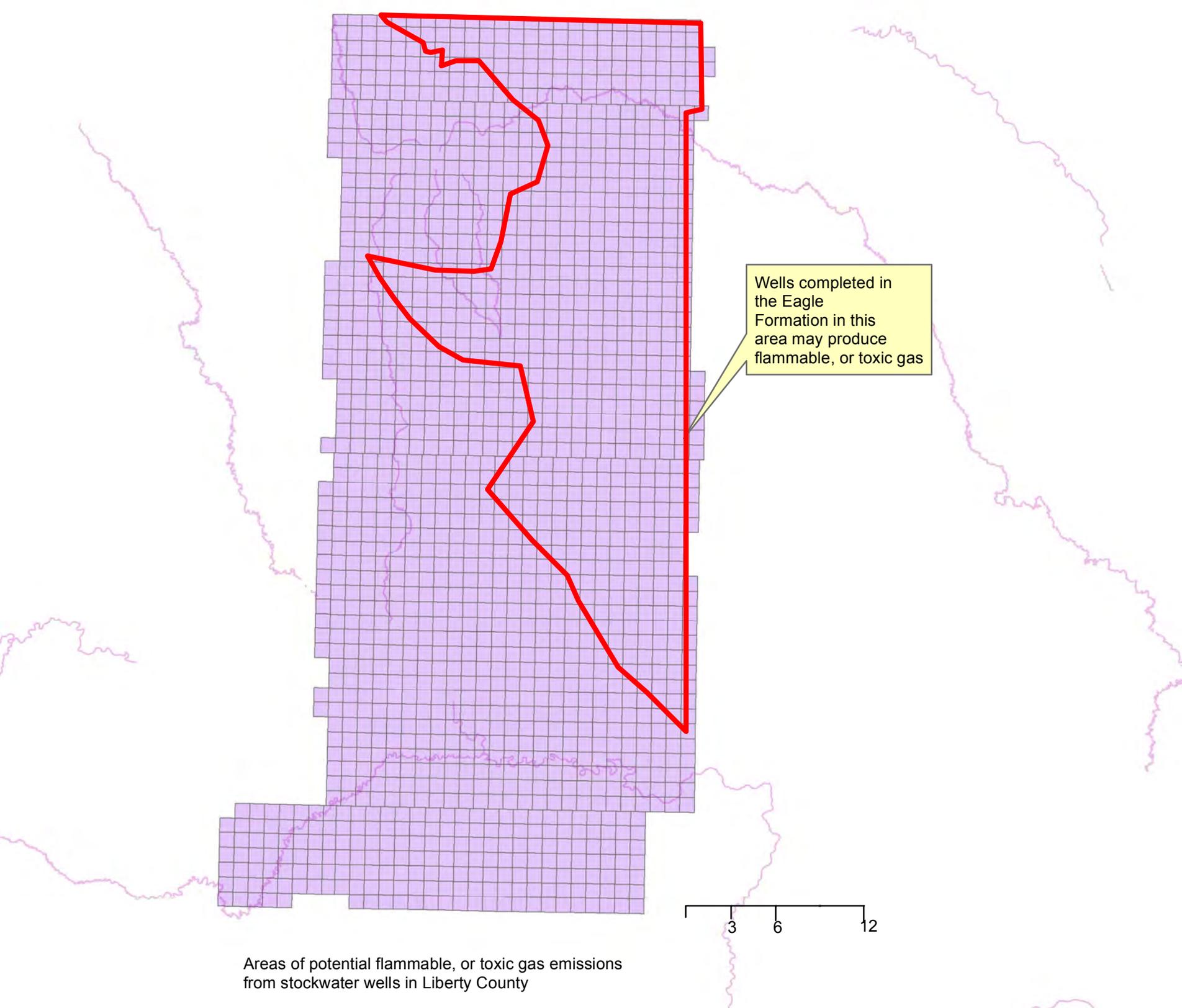
Geyser

Stanford

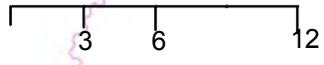
3 6 12

Areas of potential toxic, or flammable gas emissions from stockwater wells in Judith Basin County





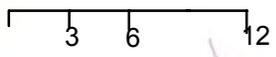
Wells completed in the Eagle Formation in this area may produce flammable, or toxic gas



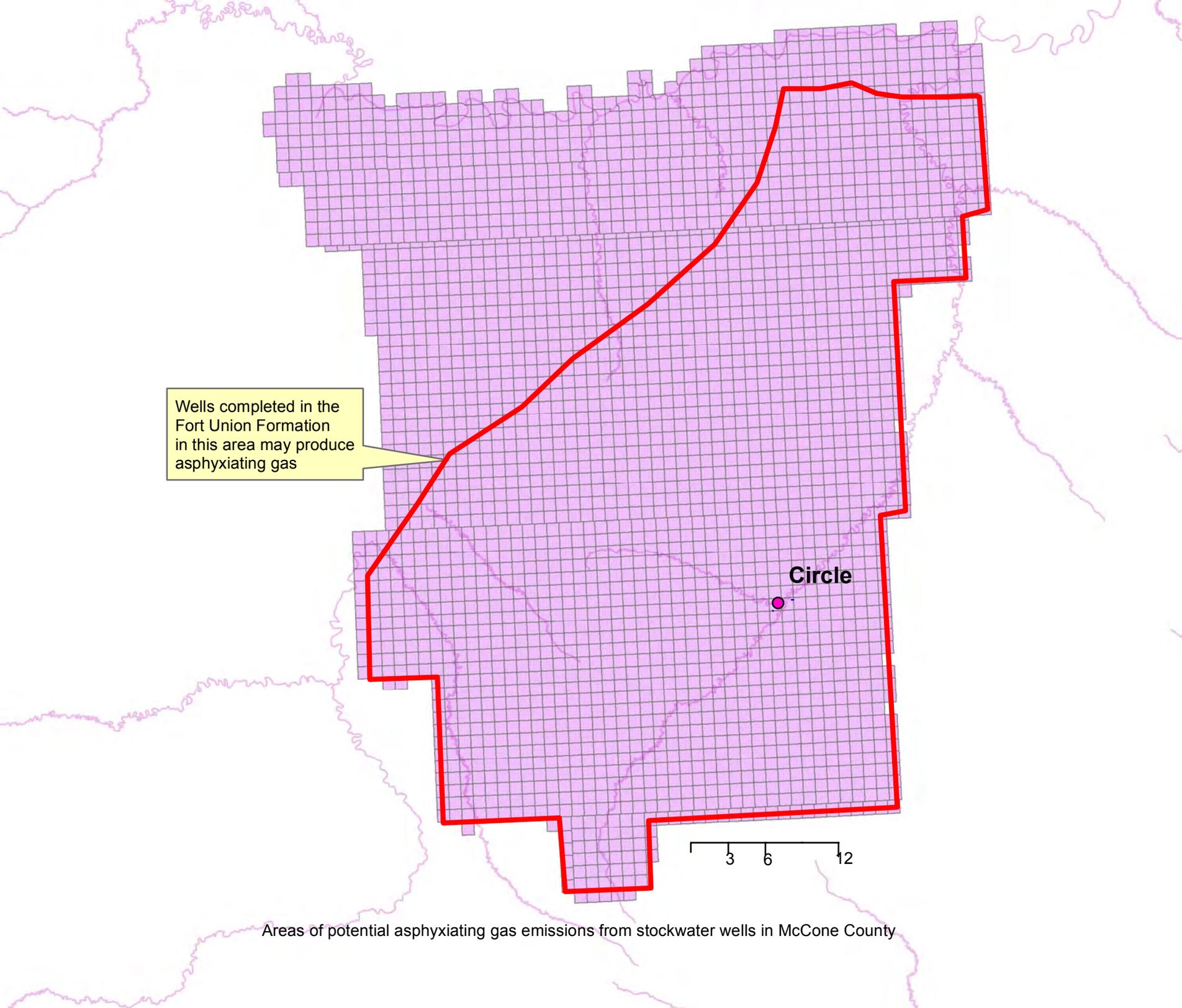
Areas of potential flammable, or toxic gas emissions from stockwater wells in Liberty County

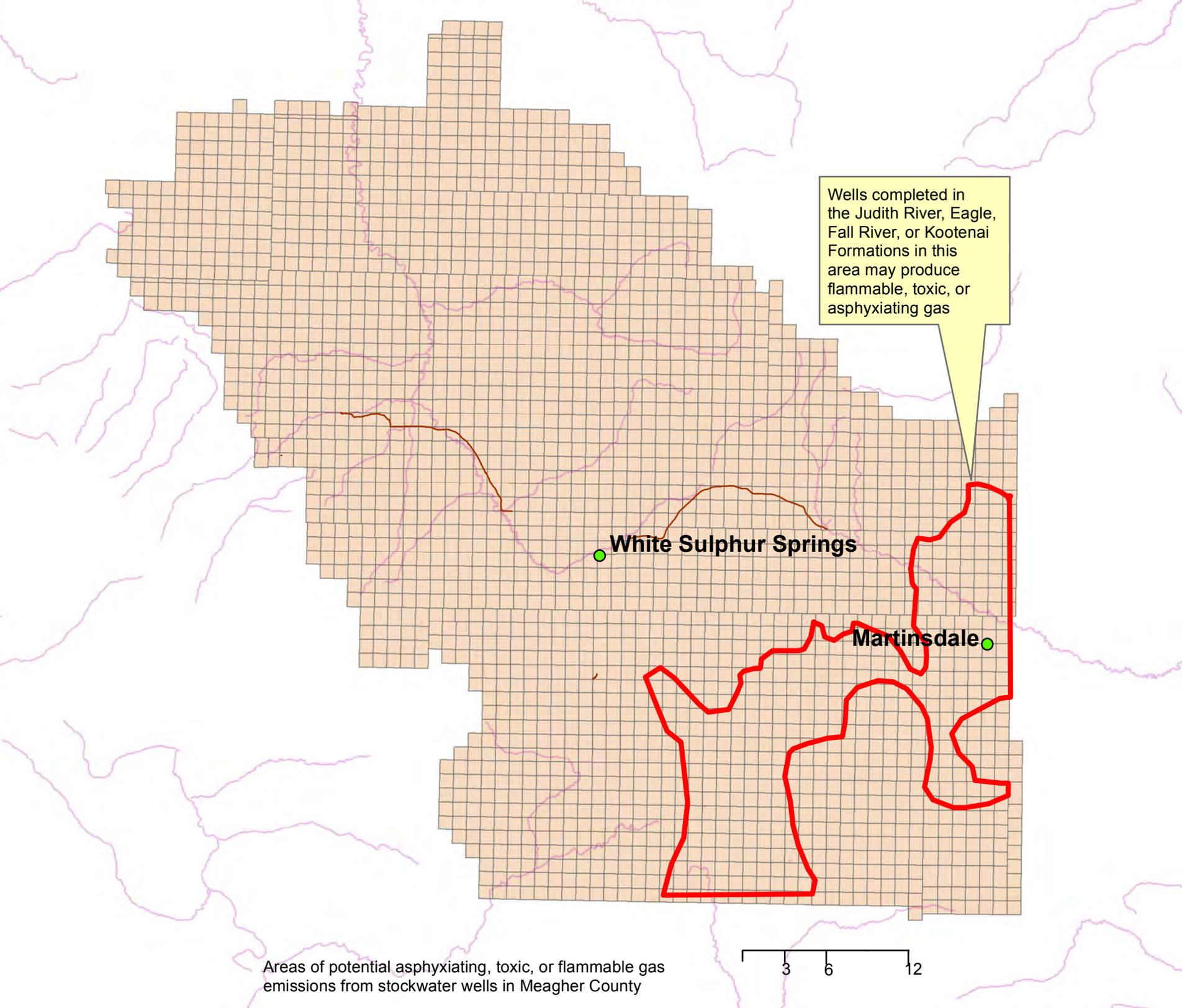
Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

Circle



Areas of potential asphyxiating gas emissions from stockwater wells in McCone County



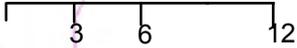


Wells completed in the Judith River, Eagle, Fall River, or Kootenai Formations in this area may produce flammable, toxic, or asphyxiating gas

**White Sulphur Springs**

**Martinsdale**

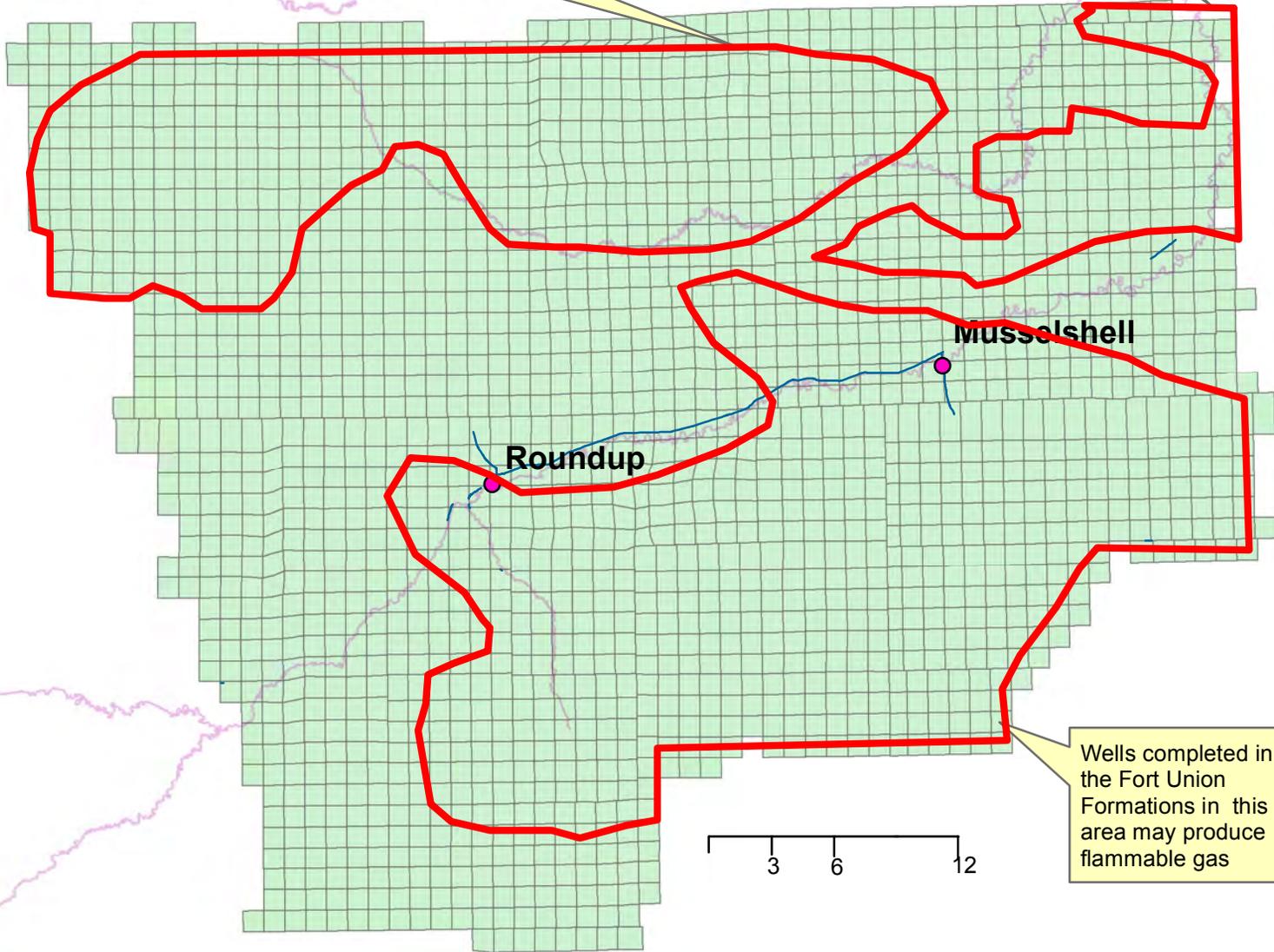
Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Meagher County



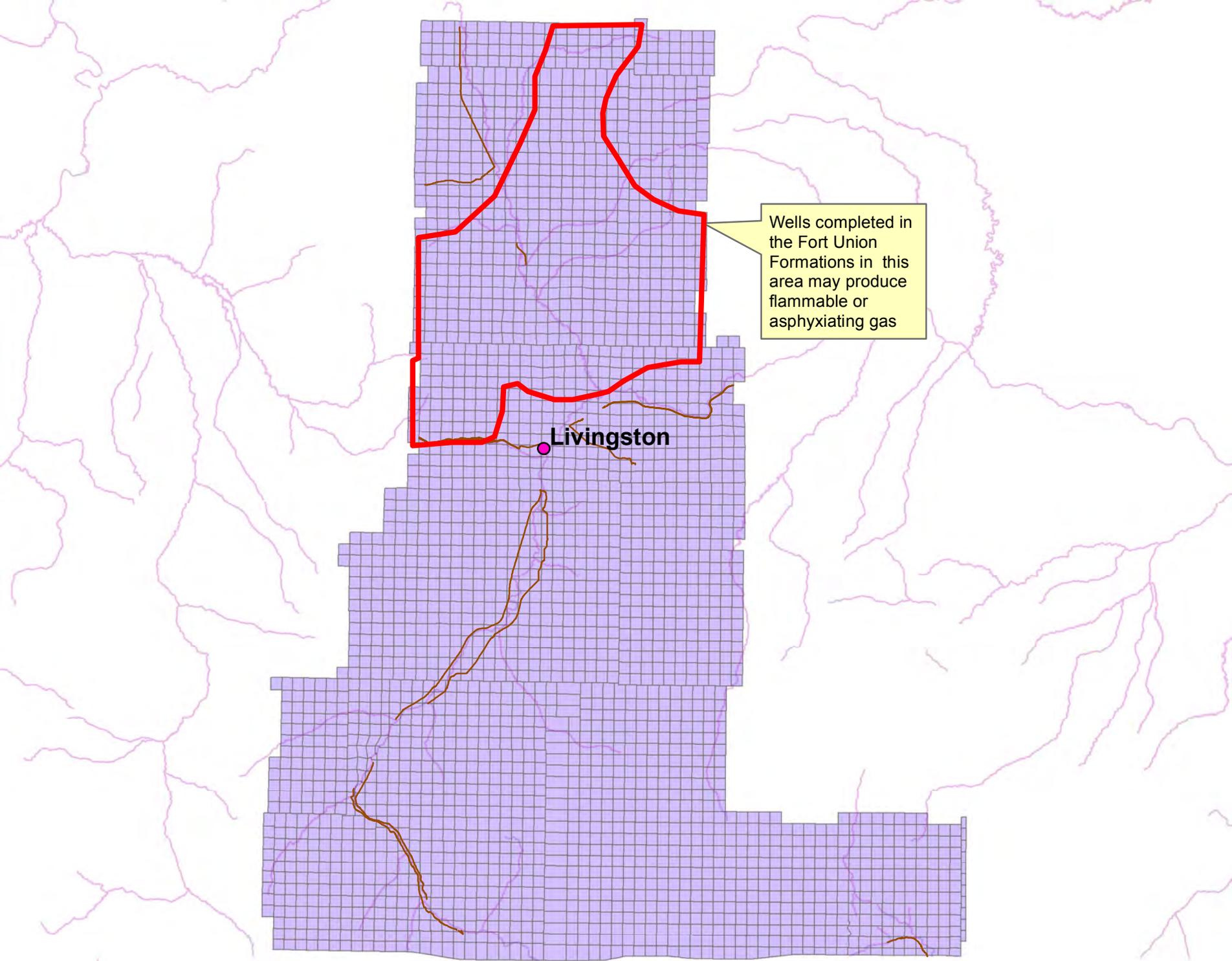
Wells completed in the Judith River, Eagle, Fall River, or Kootenai Formations in this area may produce asphyxiating, toxic, or flammable gas

Wells completed in the Judith River or Eagle Formations in this area may produce flammable gas

Wells completed in the Fort Union Formations in this area may produce flammable gas



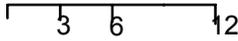
Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Musselshell County



Wells completed in the Fort Union Formations in this area may produce flammable or asphyxiating gas

Livingston

Areas of potential asphyxiating, or flammable gas emissions from stockwater wells in Park County



Wells completed in the Judith River or Eagle Formations in this area may produce flammable, or toxic gas

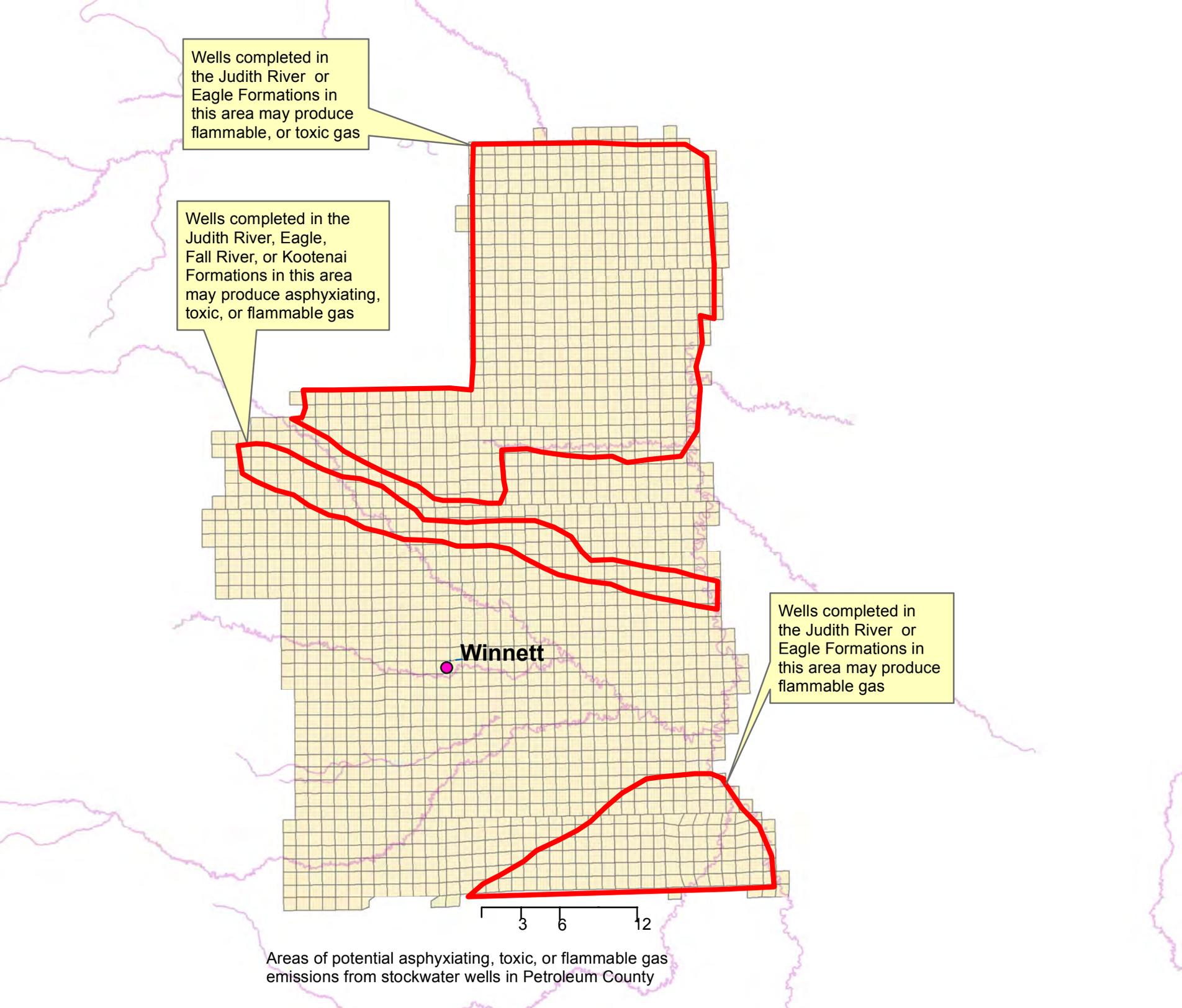
Wells completed in the Judith River, Eagle, Fall River, or Kootenai Formations in this area may produce asphyxiating, toxic, or flammable gas

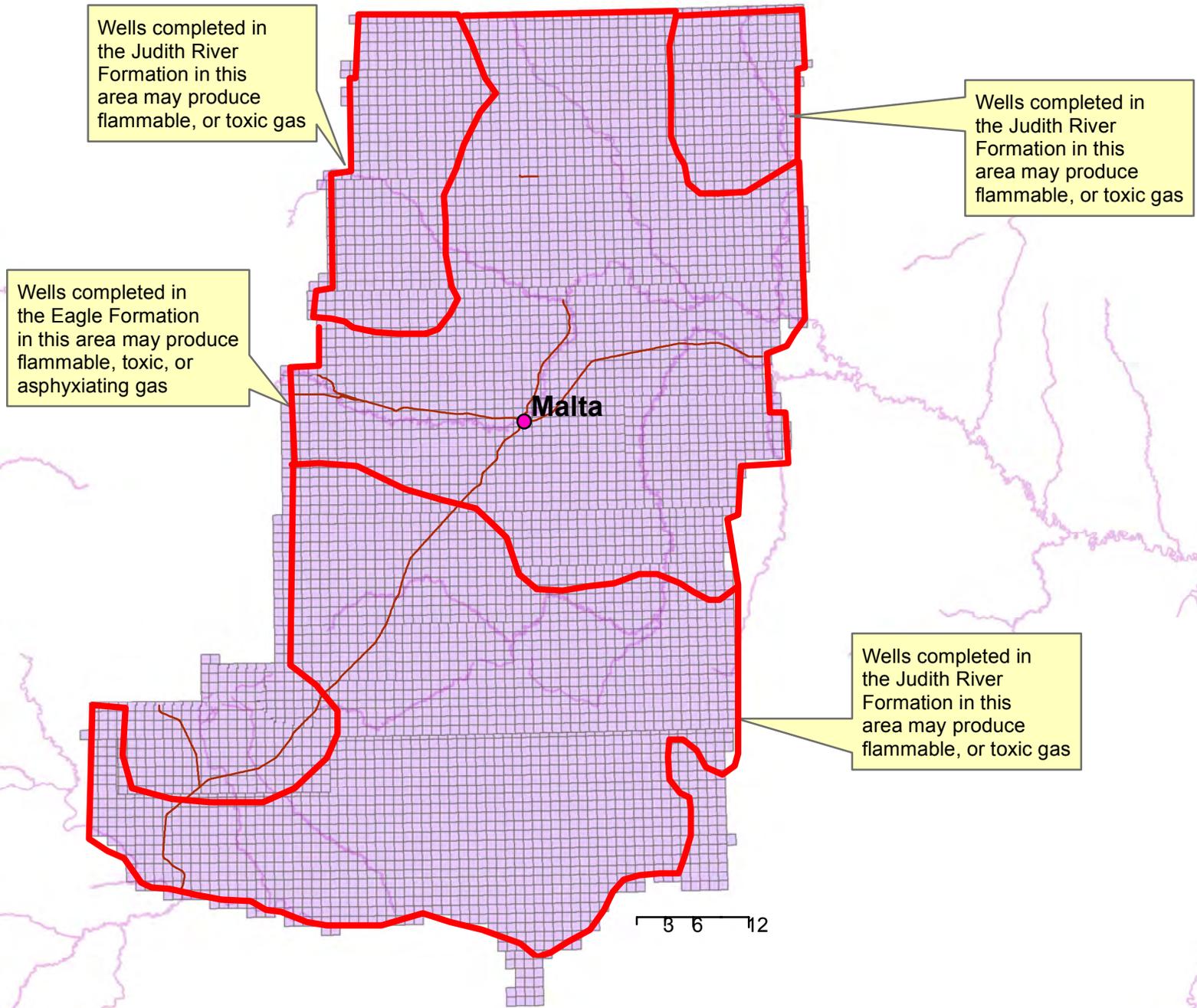
Wells completed in the Judith River or Eagle Formations in this area may produce flammable gas

**Winnett**

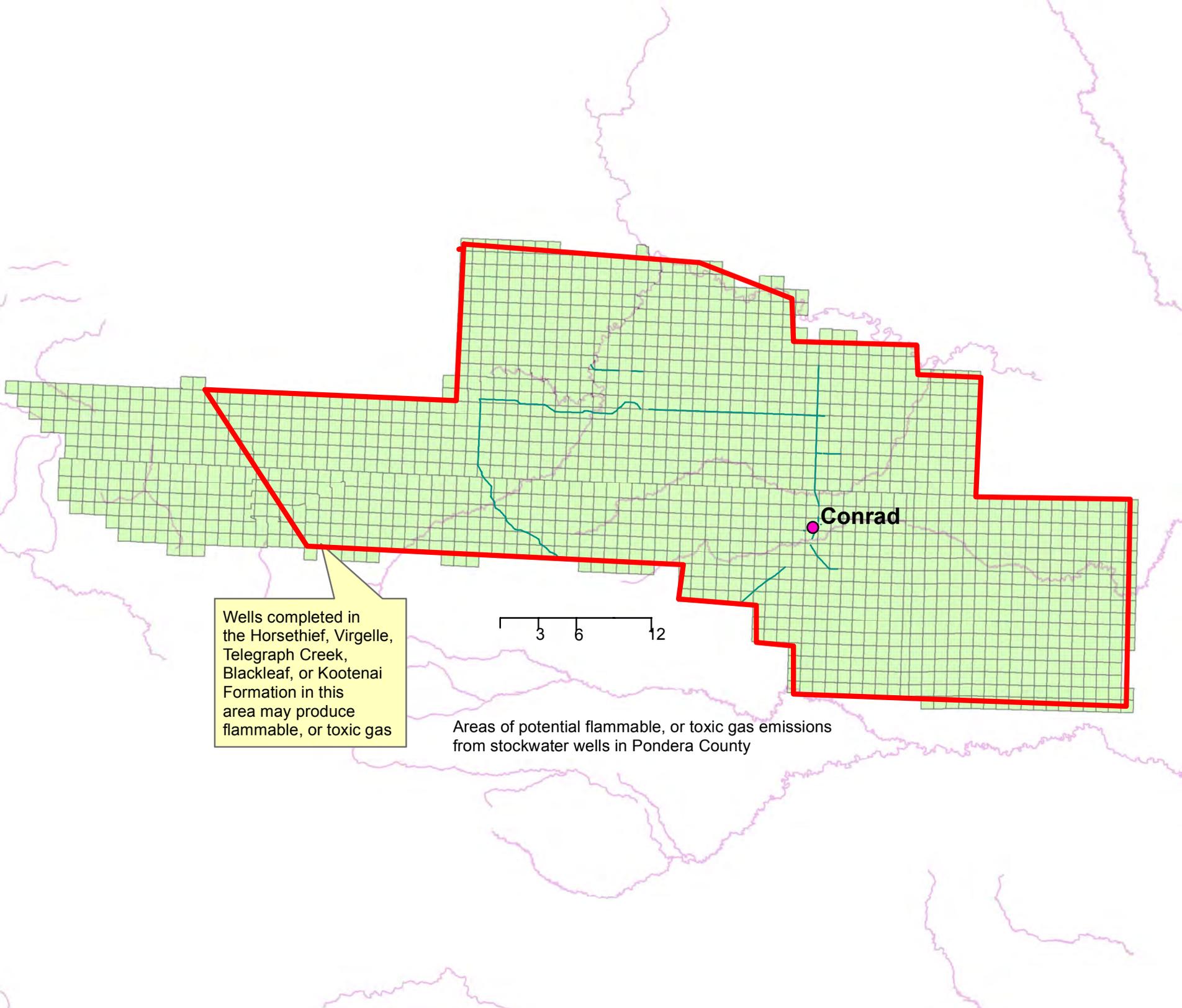
3 6 12

Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Petroleum County





Areas of potential flammable, toxic, or asphyxiating gas emissions from stockwater wells in Phillips County



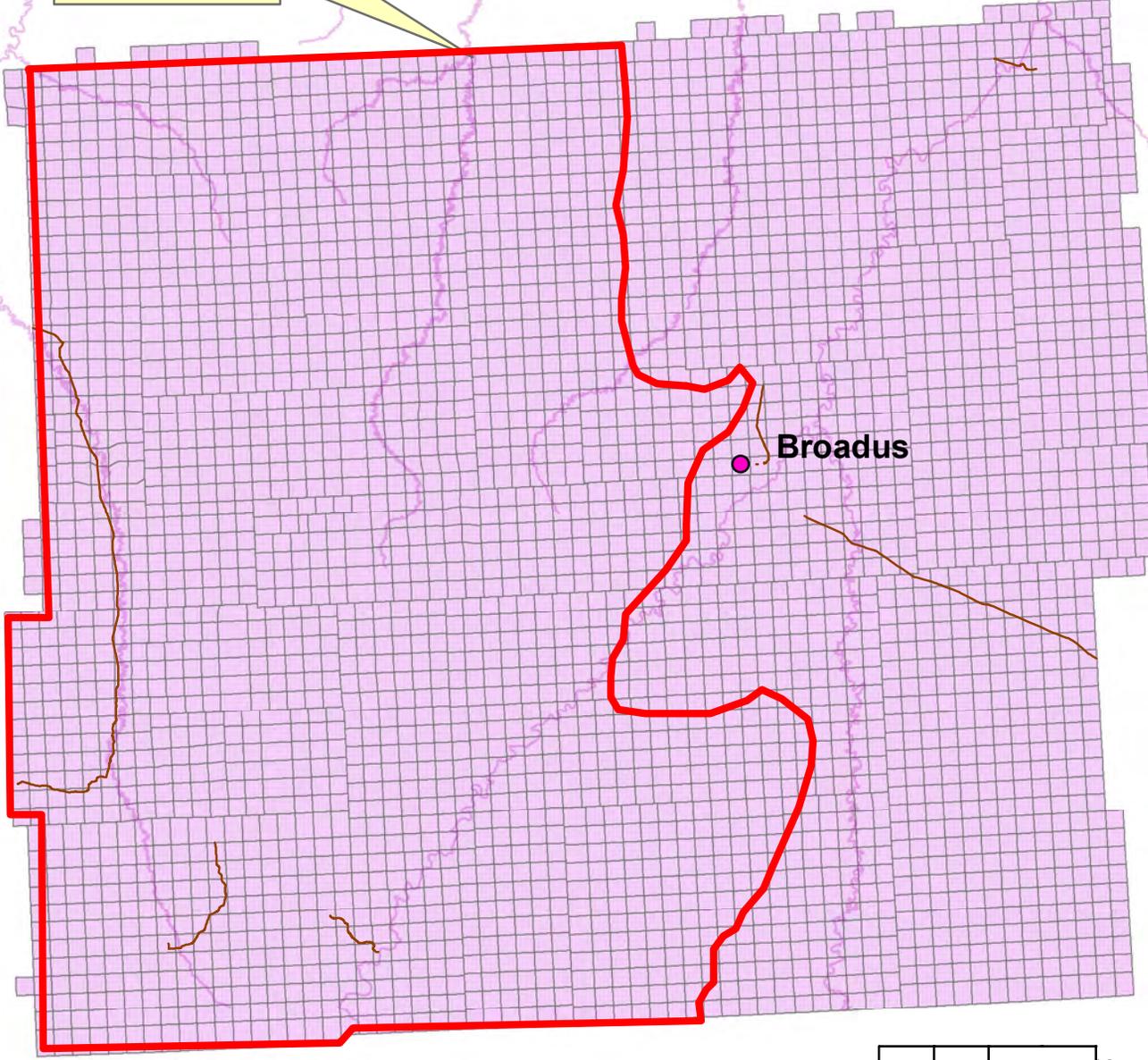
Wells completed in the Horsethief, Virgelle, Telegraph Creek, Blackleaf, or Kootenai Formation in this area may produce flammable, or toxic gas

3 6 12

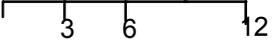
Areas of potential flammable, or toxic gas emissions from stockwater wells in Pondera County

Conrad

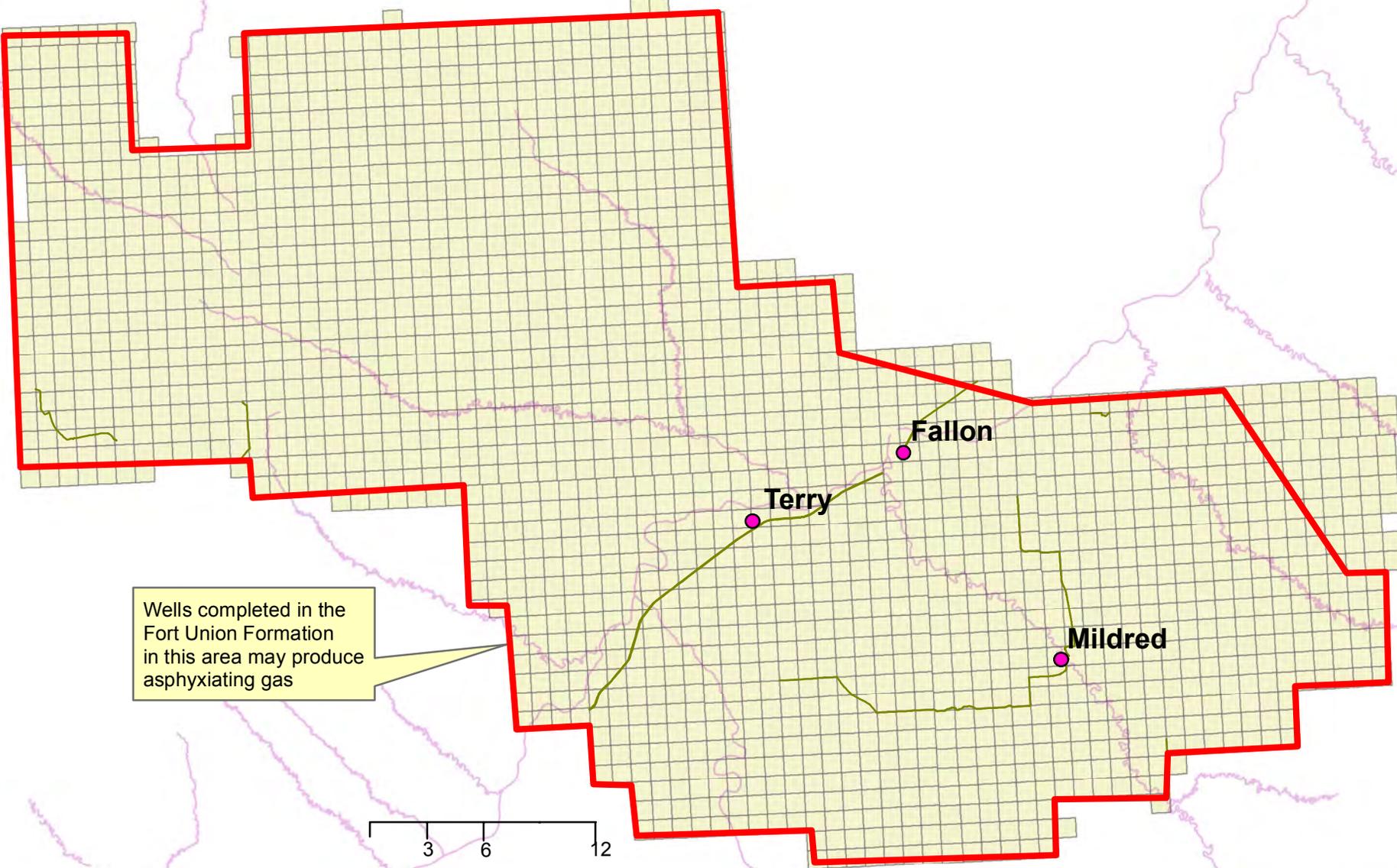
Wells completed in the Fort Union Formation in these areas may produce flammable or asphyxiating gas



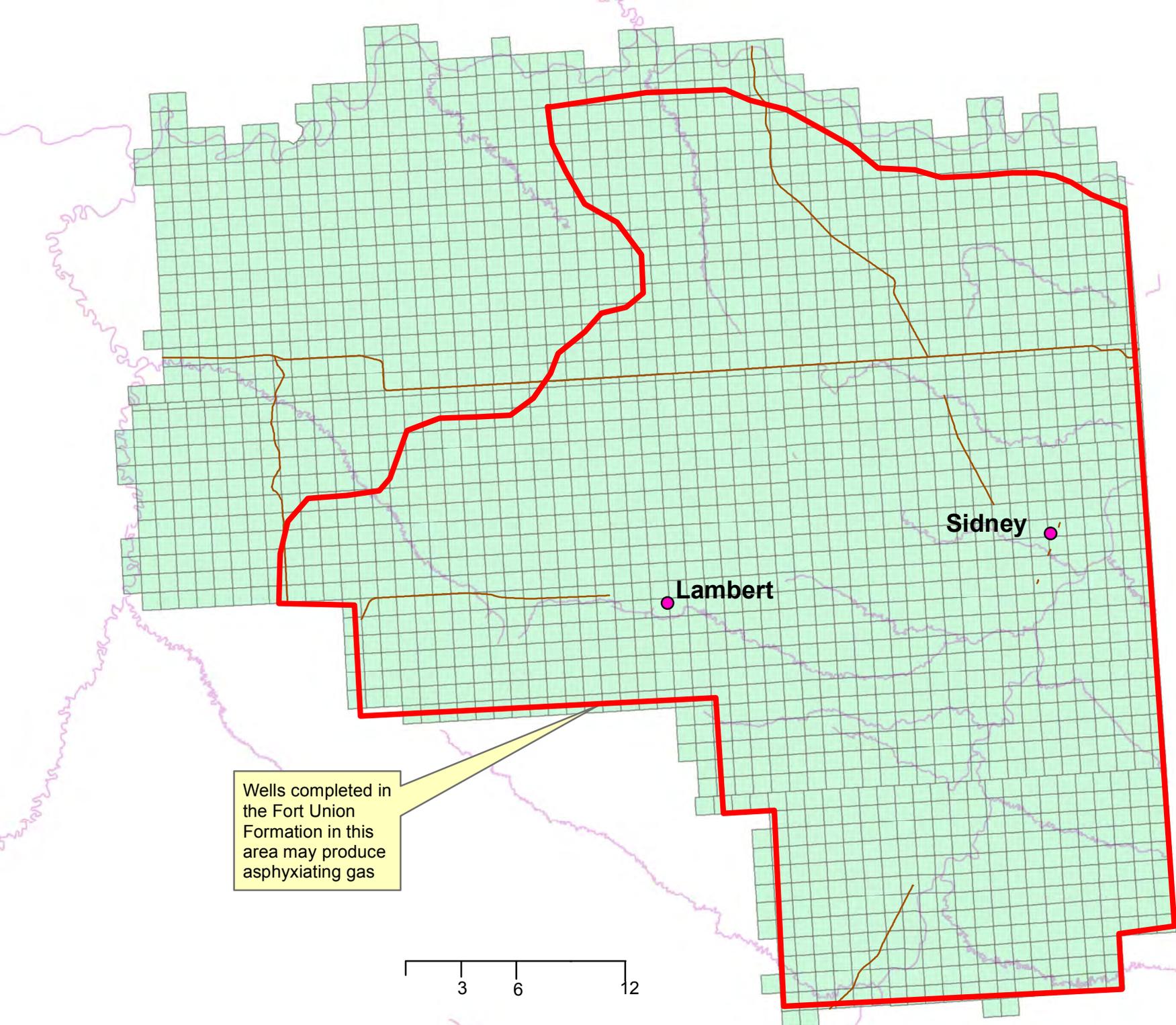
Broadus



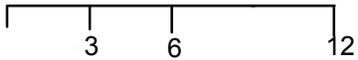
Areas of potential asphyxiating, or flammable gas emissions from stockwater wells in Powder River County



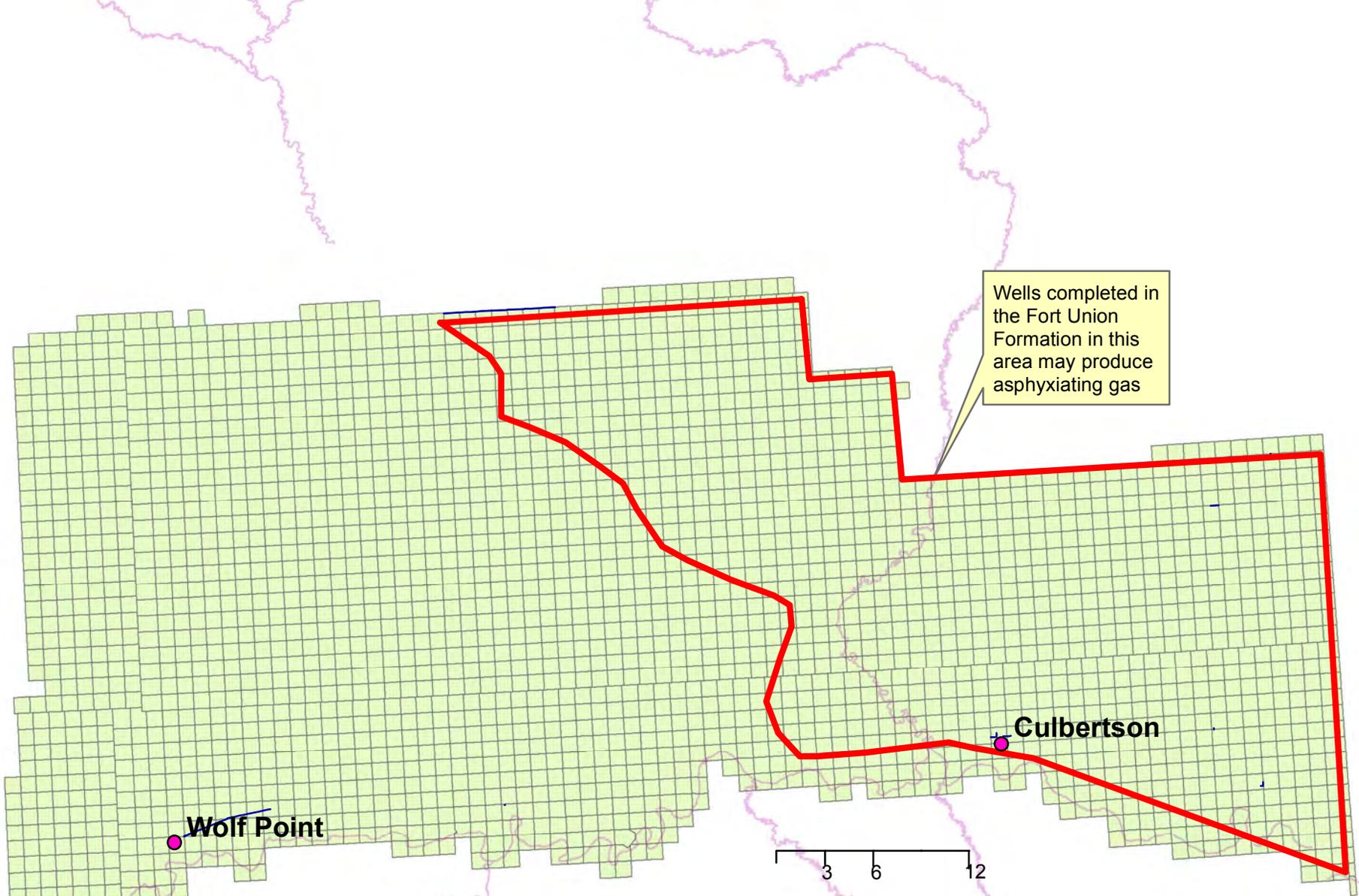
Areas of potential asphyxiating gas emissions from stockwater wells in Prairie County



Wells completed in the Fort Union Formation in this area may produce asphyxiating gas



Areas of potential asphyxiating gas emissions from stockwater wells in Richland County



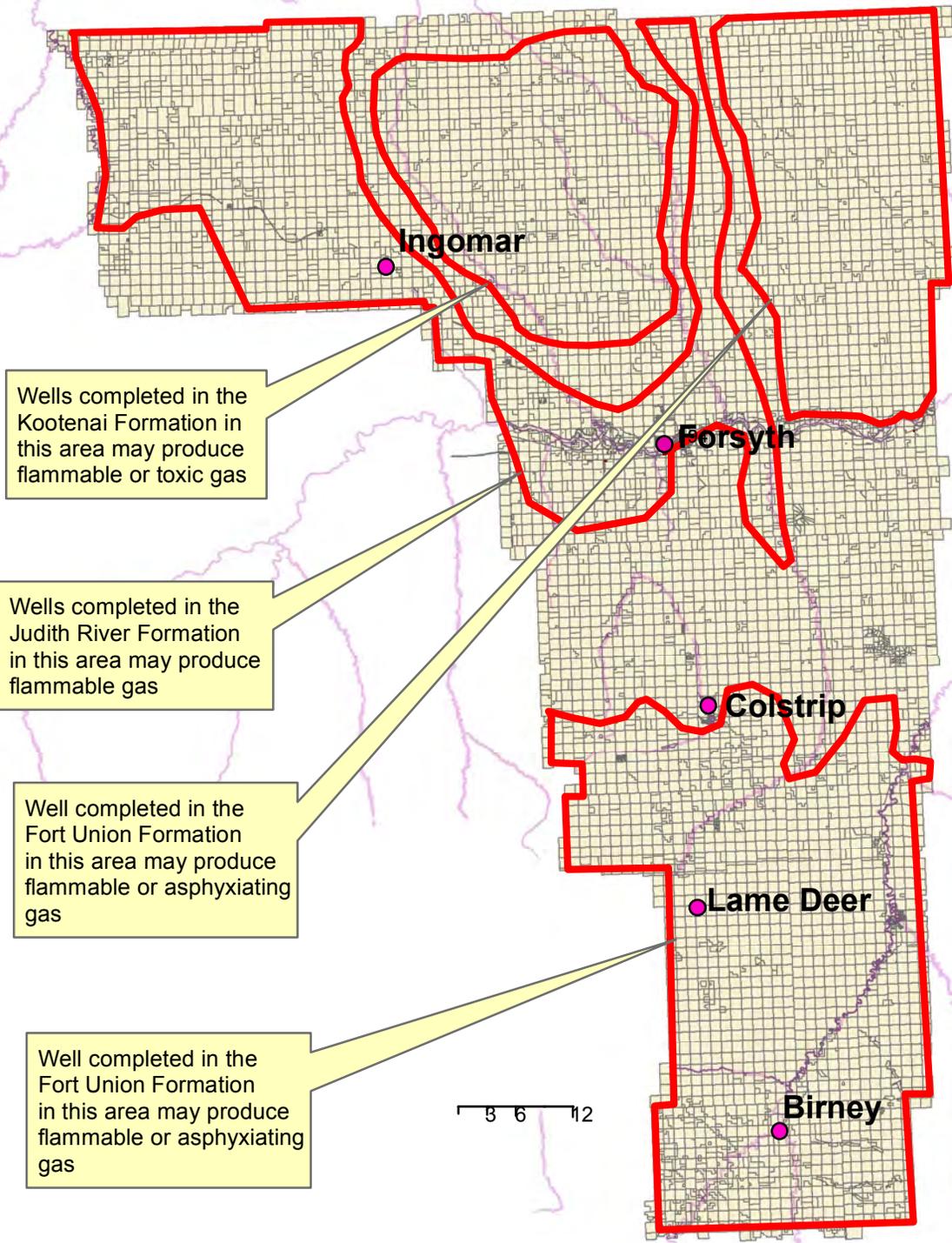
Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

**Wolf Point**

**Culbertson**

3 6 12

Areas of potential asphyxiating gas emissions from stockwater wells in Roosevelt County



**Ingomar**

Wells completed in the Kootenai Formation in this area may produce flammable or toxic gas

**Forsyth**

Wells completed in the Judith River Formation in this area may produce flammable gas

**Colstrip**

Well completed in the Fort Union Formation in this area may produce flammable or asphyxiating gas

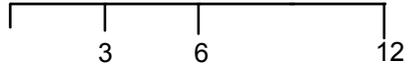
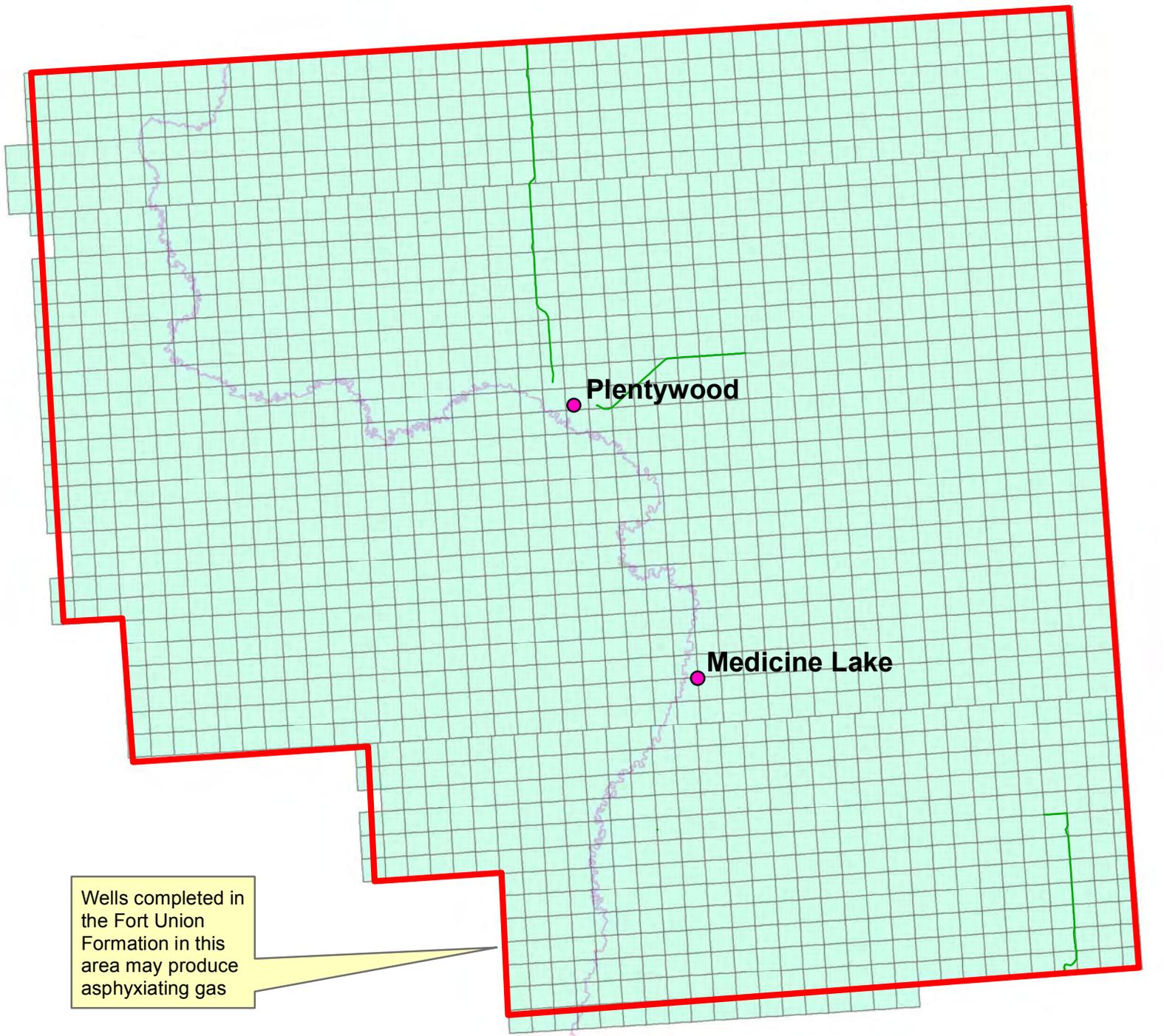
**Lame Deer**

Well completed in the Fort Union Formation in this area may produce flammable or asphyxiating gas

**Birney**

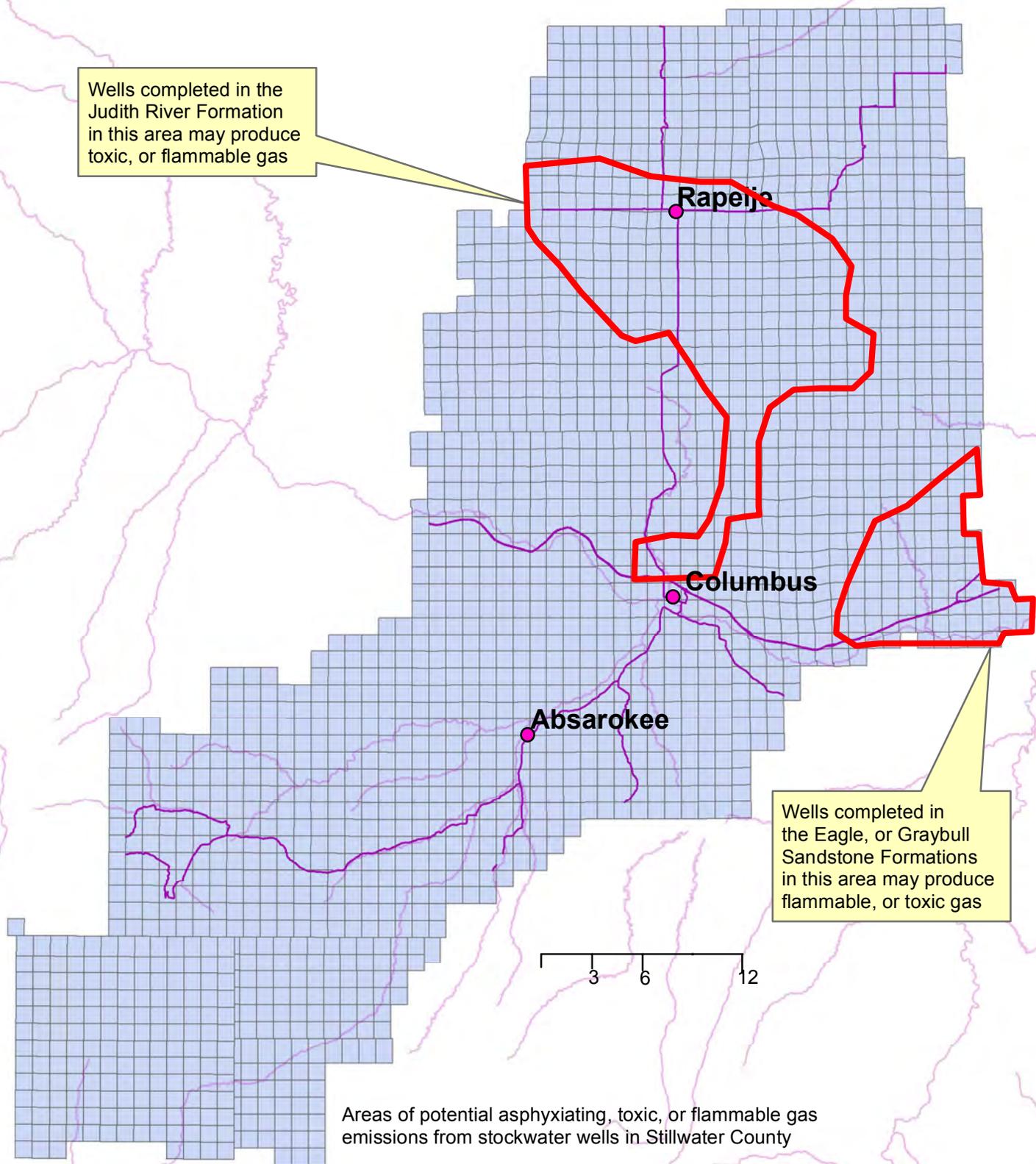
0 6 12

Areas of potential toxic, asphyxiating, or flammable gas emissions from stockwater wells in Rosebud County



Areas of potential asphyxiating gas emissions from stockwater wells in Sheridan County

Wells completed in the Judith River Formation in this area may produce toxic, or flammable gas

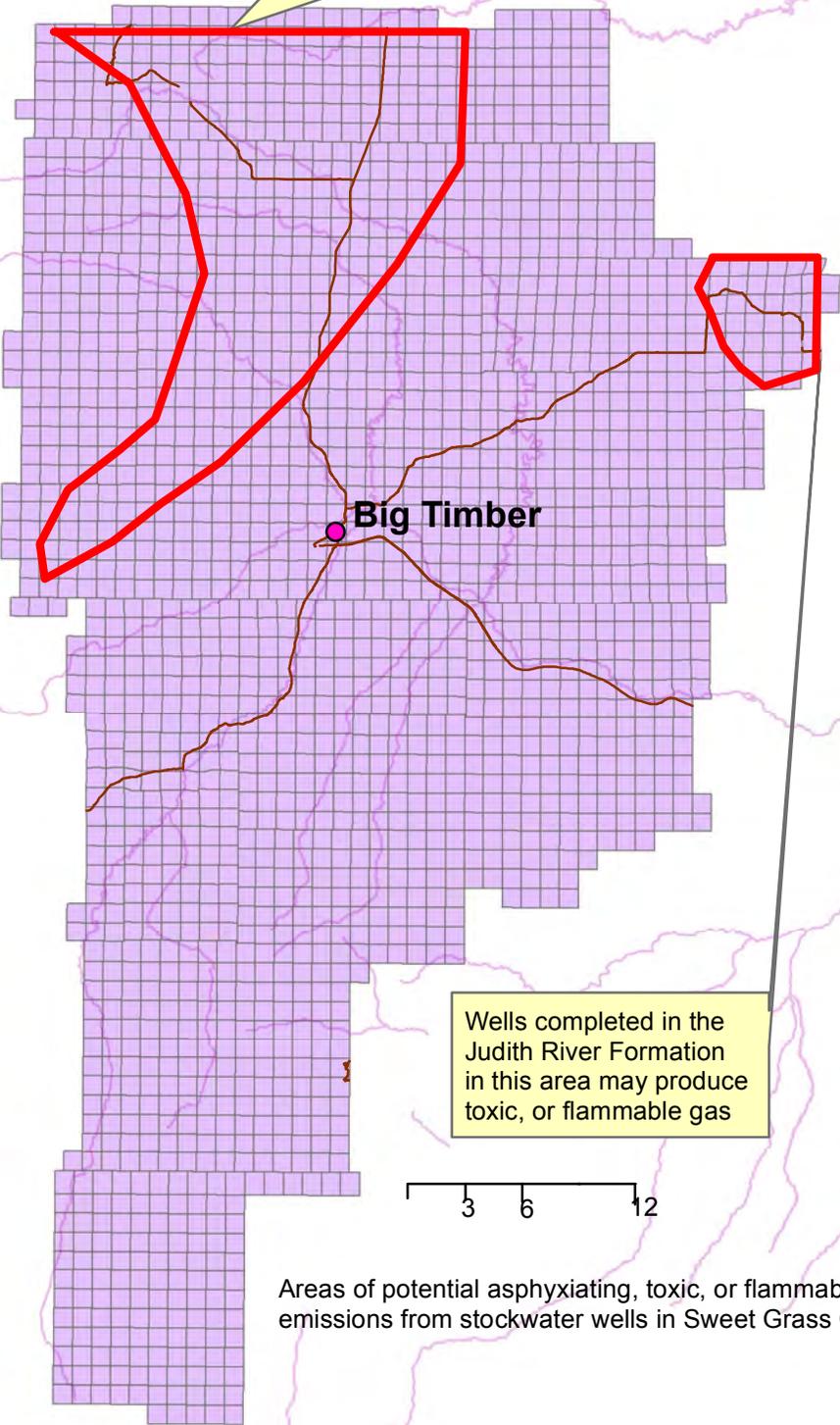


Wells completed in the Eagle, or Graybull Sandstone Formations in this area may produce flammable, or toxic gas

3 6 12

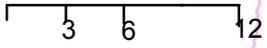
Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Stillwater County

Wells completed in the Fort Union Formation in this area may produce flammable or asphyxiating gas

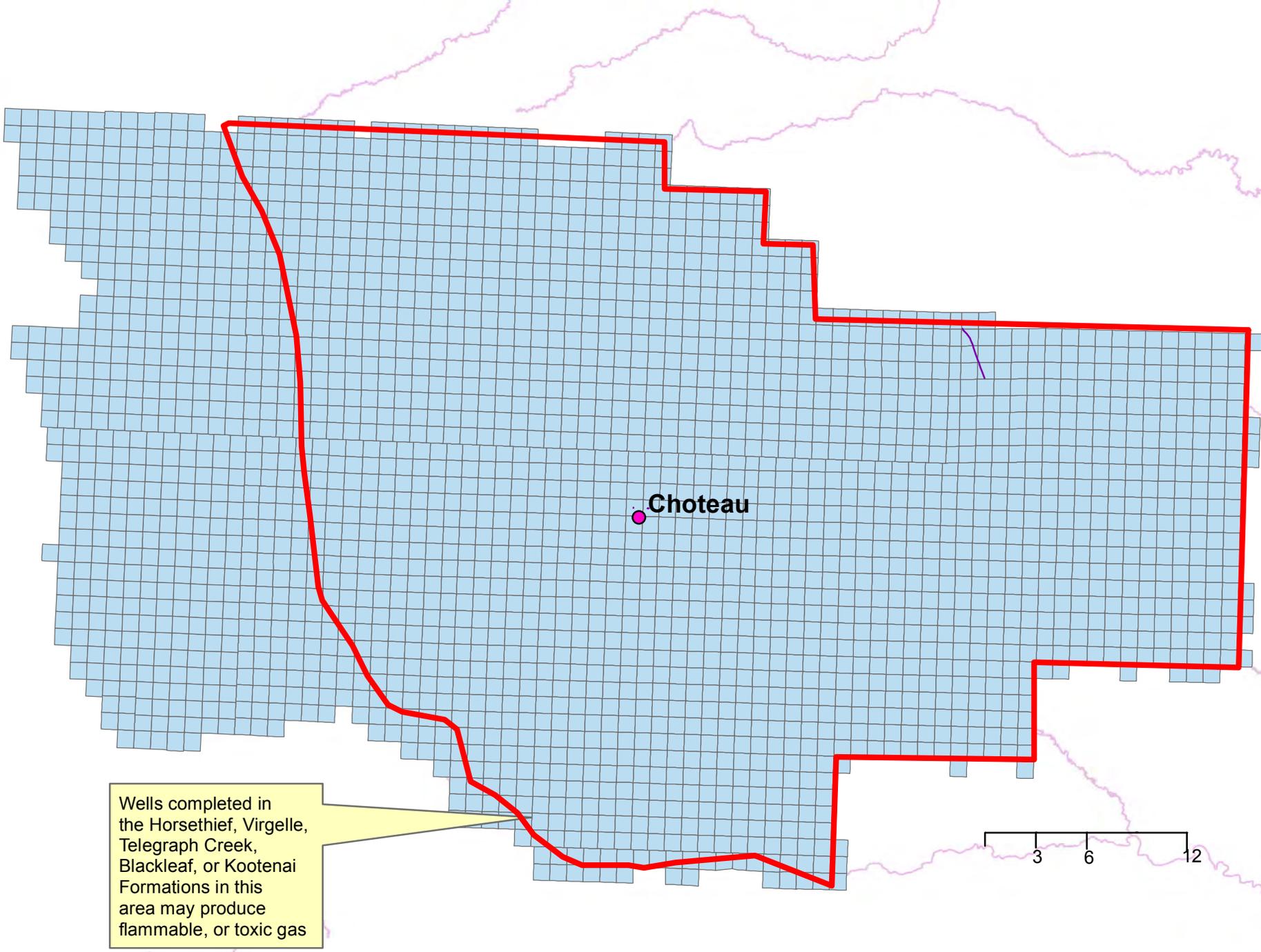


**Big Timber**

Wells completed in the Judith River Formation in this area may produce toxic, or flammable gas



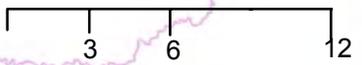
Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Sweet Grass County



Wells completed in the Horsethief, Virgelle, Telegraph Creek, Blackleaf, or Kootenai Formations in this area may produce flammable, or toxic gas

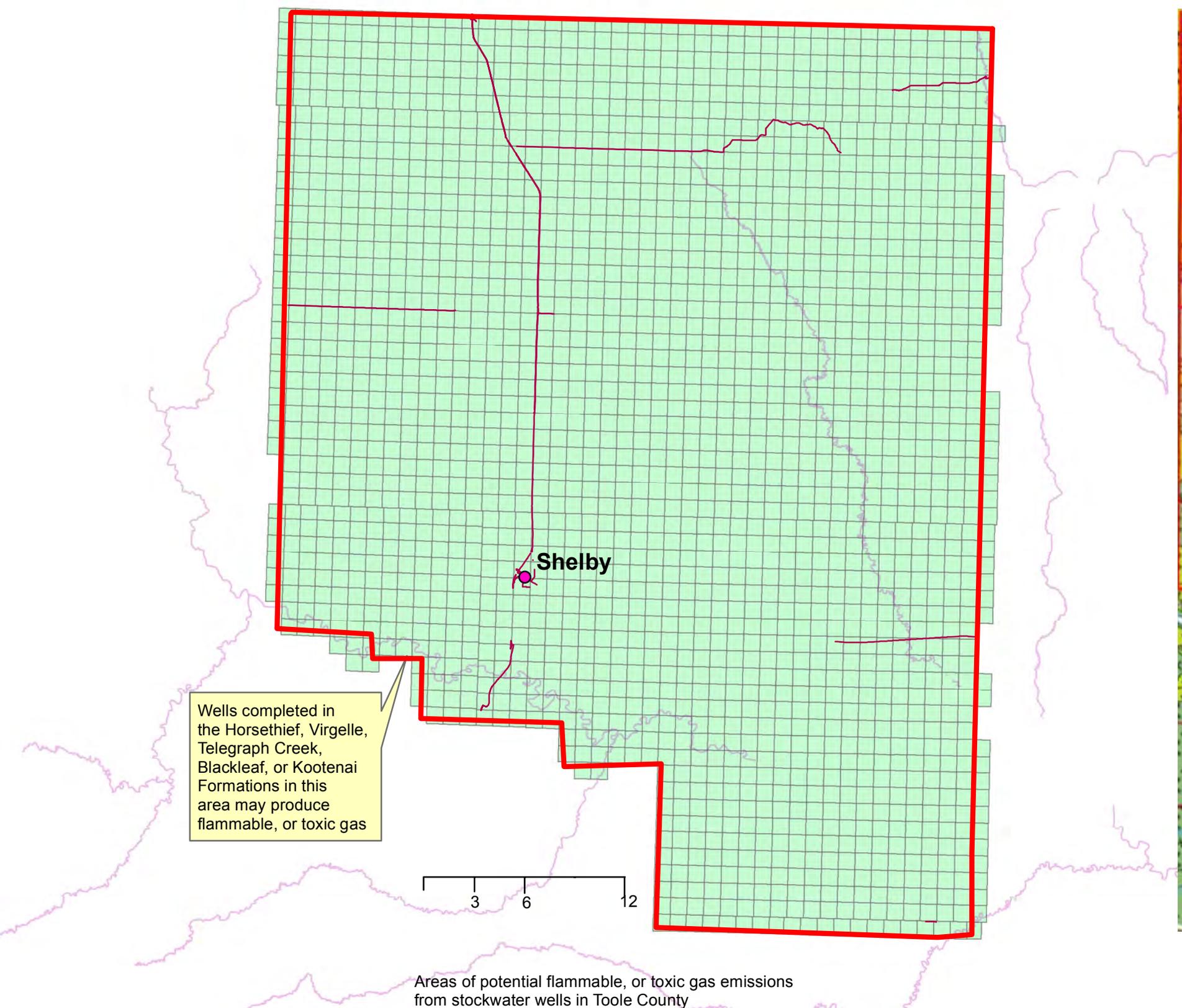
Areas of potential flammable, or toxic gas emissions from stockwater wells in Teton County

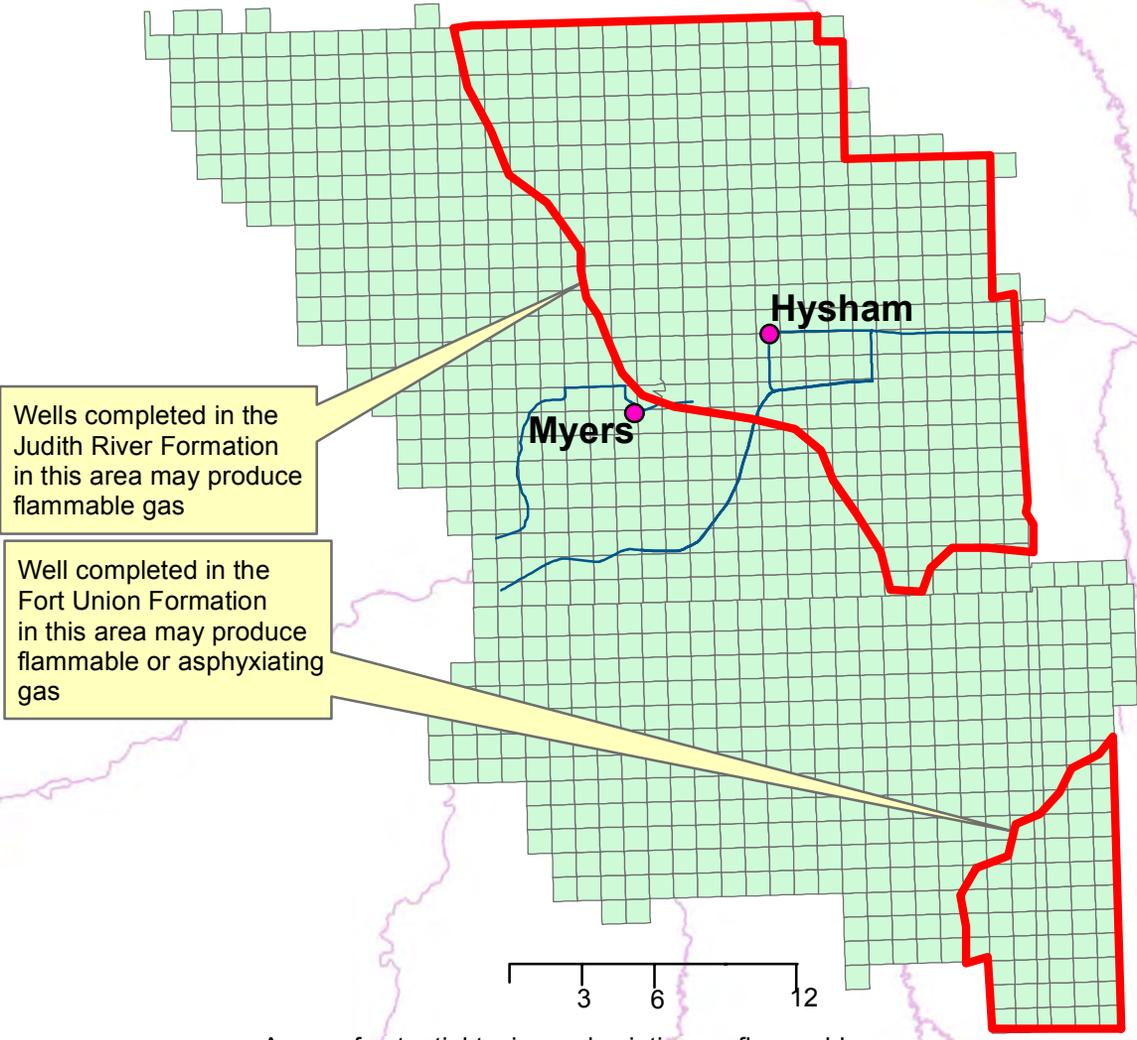
Wells completed in the Horsethief, Virgelle, Telegraph Creek, Blackleaf, or Kootenai Formations in this area may produce flammable, or toxic gas



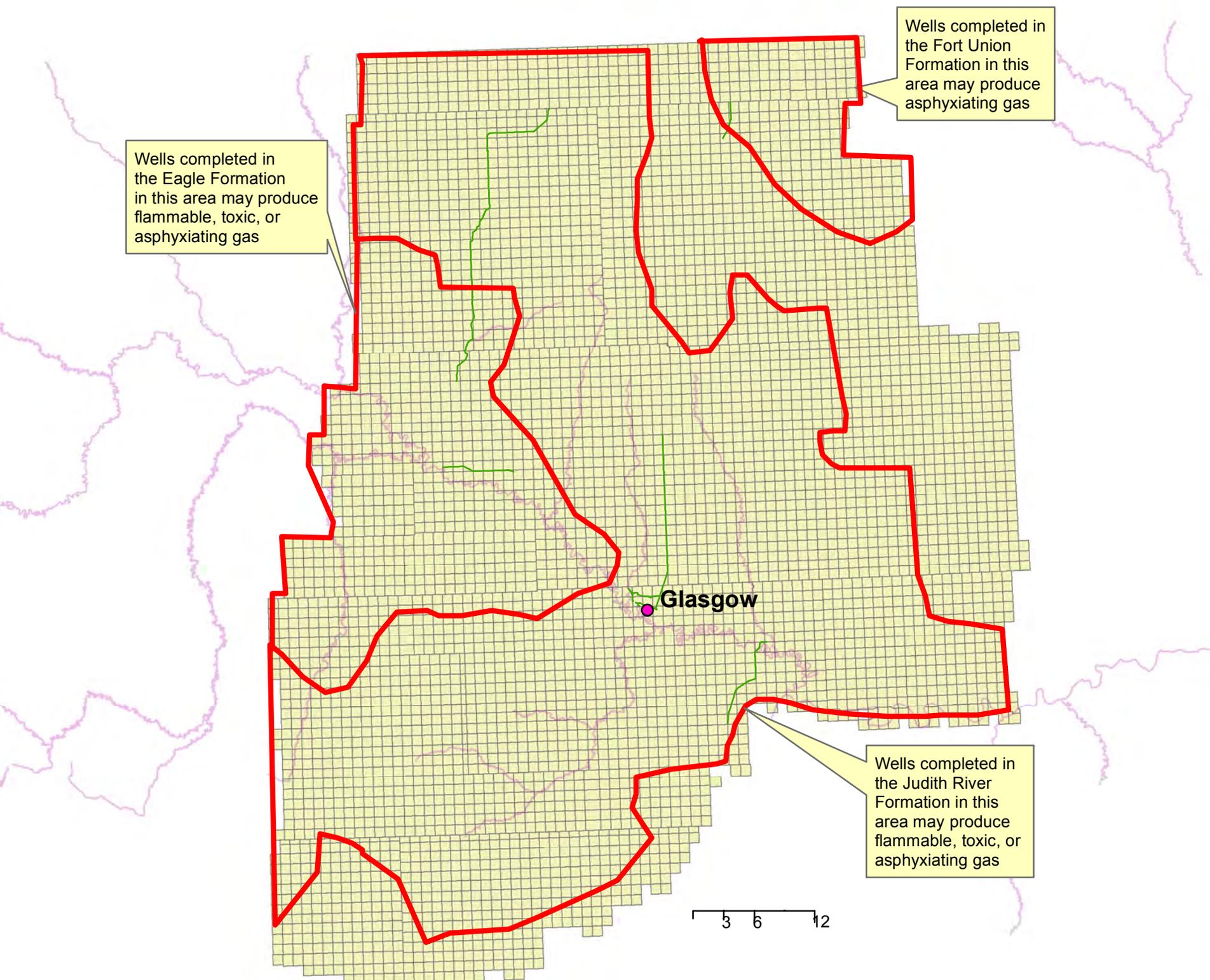
Shelby

Areas of potential flammable, or toxic gas emissions from stockwater wells in Toole County





Areas of potential toxic, asphyxiating, or flammable gas emissions from stockwater wells in Treasure County



Wells completed in the Eagle Formation in this area may produce flammable, toxic, or asphyxiating gas

Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

Glasgow

Wells completed in the Judith River Formation in this area may produce flammable, toxic, or asphyxiating gas

3 6 12

Areas of potential flammable, toxic, or asphyxiating gas emissions from stockwater wells in Valley County

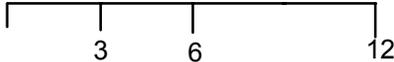
Wells completed in the Eagle Formation in this area may produce flammable, or toxic gas

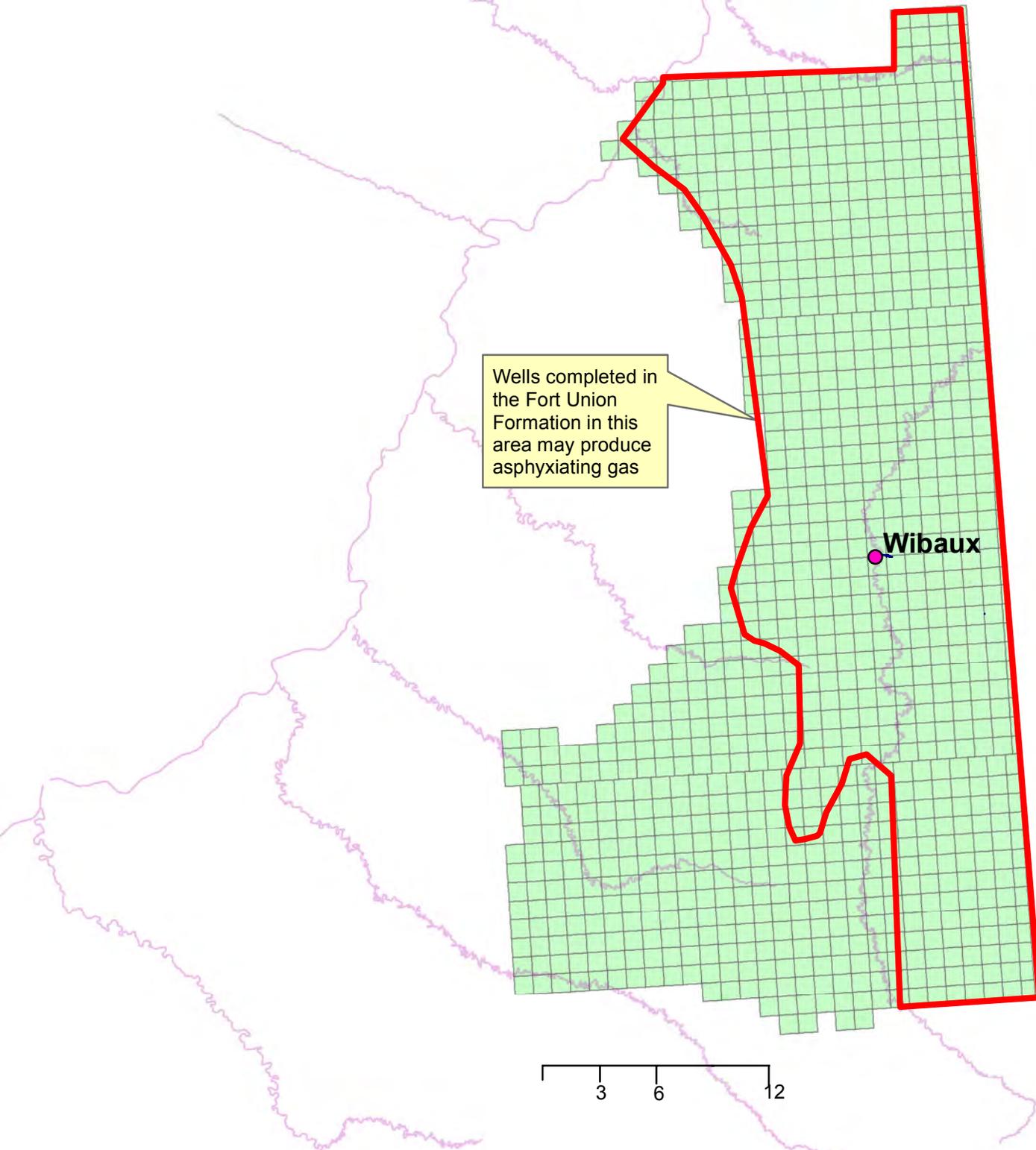
**Two Dot**

**Harlowton**

Wells completed in the Eagle Formation in this area may produce flammable, or toxic gas

Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Wheatland County





Wells completed in the Fort Union Formation in this area may produce asphyxiating gas

Wibaux

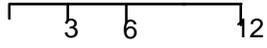
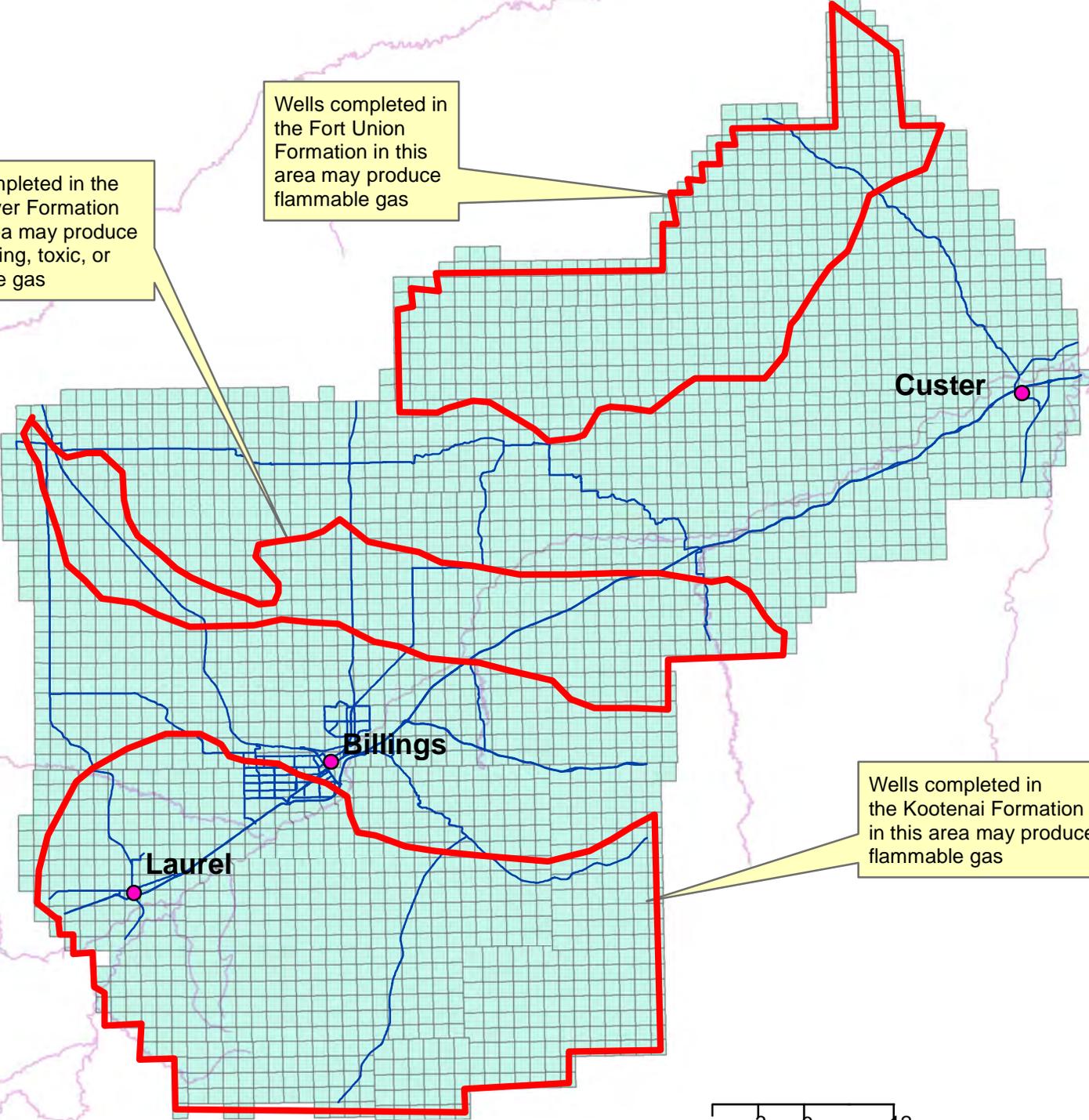
3 6 12

Areas of potential asphyxiating gas emissions from stockwater wells in Wibaux County

Wells completed in the Judith River Formation in this area may produce asphyxiating, toxic, or flammable gas

Wells completed in the Fort Union Formation in this area may produce flammable gas

Wells completed in the Kootenai Formation in this area may produce flammable gas



Areas of potential asphyxiating, toxic, or flammable gas emissions from stockwater wells in Yellowstone County