PRELIMINARY EVALUATION OF METHANE SEEPAGE MITIGATION ALTERNATIVES

SAN JUAN BASIN, COLORADO

May 2006

Prepared for:

COLORADO OIL AND GAS CONSERVATION COMMISSION
Denver, Colorado

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1.0 INTRODUCTION

This Preliminary Evaluation of Methane Seepage Mitigation Alternatives (Evaluation) was prepared for the Colorado Oil & Gas Conservation Commission (COGCC). This document was prepared by LT Environmental, Inc. (LTE) with the assistance of various state and federal regulatory agencies; members of the oil and gas industry; environmental engineering and consulting firms; and resources from other industries that may provide insight into possible mitigation of methane seepage.

1.1 Purpose and Scope

The purpose of this Evaluation is to identify potential mitigation methods for addressing impacts from methane gas seeps present in the San Juan Basin (SJB). The objective is to provide some possible methane mitigation alternatives which will support the overall objectives of:

- Protecting Public Health, Safety, and Welfare;
- Protecting Biota;
- Protecting Property Values;
- Preserving and Recovering Mineral Resources; and
- Reducing Emissions of Methane Gas to the Atmosphere.

The scope of work includes an initial compilation of potentially applicable characterization and mitigation methods using existing published literature, including information from the radon gas and landfill gas mitigation industries; "brainstorming" of ideas from various technical experts; and interviews with regulatory and oil and gas industry personnel who have already implemented various mitigation methods.

It is important to recognize that this document is not an engineering feasibility study but rather a compilation of possible methods which, when investigated further, may or may not be appropriate for technical or economic reasons. In addition, there is the potential that none of these measures will prevent the methane seepage from continuing. If that should be the case, then the focus of the methane mitigation might need to be limited to protecting public health, safety, and welfare and to reducing the ecological impacts.

First, 10 methods designed to determine the extent of methane impacts and to characterize seeps over time are evaluated. Next, a preliminary evaluation of each potential mitigation method is presented and the factors that affect its viability are identified. Consideration is given to the following:

- Applicability;
- Advantages and Disadvantages;

- Implementation Costs including assessment, installation and operational requirements; and

- Other Considerations.

1.2 Organization of Report

This report is divided into six sections, including this introduction. Section 2.0 describes some background information used to establish the criteria for selecting the methods presented. Section 3.0 describes the criteria used in evaluating each method. Section 4.0 contains recommended use of the report. Section 5.0 contains the limitations of the report. LTE has cited in Section 6.0 all sources used in the preparation of this report. Citations are noted throughout the individual specification sheets. Table 1 is a chart summarizing the characterization and mitigation methods identified in this document. The chart summarizes the various evaluation criteria for easy comparison of the different mitigation alternatives.

Attachment 1 contains 31 individual specification sheets, one for each of the identified mitigation methods. Each sheet identifies one of the mitigation technologies or approaches and discusses its applicability; provides a summary description; lists the objectives the method may meet; discusses the advantages and disadvantages of the methods; provides an estimated range of costs (where practical); and provides other considerations. Each sheet contains a sketch, diagram, or photograph of the mitigation method. Specification sheets S-1 through S-10 discuss the various characterization methods. Specification sheets S-11 through S-31 discuss the mitigation technologies compiled by LTE.

2.0 BACKGROUND

Three factors should be reviewed when selecting mitigation alternatives for impacts to public health, safety, and welfare and the environment. These include:

- Identifying the source of the impact;

- Identifying the receptors that may be affected; and

- Characterizing the migration pathways and the extent of the impact.

Once these three factors have been evaluated, it is possible to consider methods to mitigate the perceived or actual impacts.

2.1 Source

For consideration in this document, there are two end member types of methane gas: thermogenic and biogenic methane. Thermogenic methane is formed by the “cracking” of organic matter buried deep beneath the earth’s surface under the influence of heat. Biogenic methane is produced by methanogenic bacteria under anaerobic conditions. Methanogenic bacteria can produce biogenic methane either by fermentation of organic matter or by reduction of carbon dioxide. Based on analytical data from gas samples collected at various locations along the perimeter of the SJB, the majority of the gas present in the seeps is thermogenic gas.

This evaluation focuses on the thermogenic gas seeps located along the Fruitland Formation (Kf) outcrop and/or other unidentified sources along the perimeter of the SJB. The technologies discussed also could be applied to mitigation of impacts from high concentrations of biogenic gas. While rare, there are other potential sources of methane seepage, such as thermogenic methane from buried leaking natural gas pipelines and improperly completed or abandoned production wells, or biogenic gas leaking from septic tanks, septic leach fields, landfills, or water wells.

2.2 Receptors

Identifying the potential receptors of seeping methane gas is probably the single most important factor in selecting mitigation options. For example, a building into which methane gas has seeped and created a hazardous atmosphere within the structure might be considered a more sensitive receptor than vegetation in a hay field that is being killed by methane seepage. Judging the degree to which a receptor is impacted is important in establishing the level of effort in mitigating the methane seepage.

There are five primary receptors identified in this report: water, land, structures, atmosphere, and mineral owner/mineral resource.

- Water receptors can be water supply wells, groundwater, and surface water. Aquatic life may also be considered a receptor to impacts from methane seeps in surface waters.

- Land receptors include the vegetation affected by methane seepage; the farmers, ranchers, or foresters who rely on the vegetation as a cash crop or as feed; and wildlife that rely on the vegetation for habitat and food. In addition, land or surface water could also be considered receptors if they were to be impacted by erosion from land that is devoid of vegetation because of methane seepage.

- Structures are considered receptors to the extent that the methane seepage has the potential to enter the structure and create a hazardous, potentially explosive atmosphere, thereby endangering human health, safety, and welfare. These structures can include houses, modular homes, garages, water well pump houses, subsurface cisterns, storage sheds, barns, or any other temporary or permanent structure.

- Methane is a greenhouse gas; therefore, the atmosphere is considered a receptor and potential long term impacts to the atmosphere from uncontrolled seepage should be considered.

- Mineral owners loss of revenue and the potential loss of a mineral resource.

It is important to recognize that methane gas is not considered a toxic human health hazard (NIOSH; IDPH). Methane is not considered a carcinogen and does not cause adverse health effects from the ingestion, inhalation, or adsorption. However, if methane accumulates in a confined or poorly ventilated space, then an explosion hazard can be created, and because oxygen is displaced, an asphyxiation hazard may also be created.

2.3 Characterization

Prior to developing a mitigation approach, an assessment to characterize the extent of the impact should be conducted. This process includes confirming the source, identifying potential receptors, understanding the migration of the gas through natural and/or manmade pathways, and establishing the extent of the seepage both vertically and horizontally, if possible.

LTE has compiled a list of characterization methods that have been used in assessing methane seepage in the SJB. Each method is presented in Table 1 and has been summarized in individual specification sheets included in Attachment 1.

3.0 EVALUATION CRITIEIA

Table 1 provides a summary of the various methods presented in the individual specification sheets in Attachment 1. Each method was evaluated based on a number of broad categories. In addition, a determination as to what type of media would be mitigated by the method is presented. Finally, the table indicates which of the objectives described in Section 1.1 could be met by implementation of the method. This section provides a brief description of each of the evaluation criteria.

Applicability As defined in Section 2.2, there are five potential receptors which may be impacted by the methane seepage: water, land, structures, atmosphere, and mineral owner/mineral resource.

In many cases, mitigation methods may address more than one type of impact. LTE has developed a color coding system to identify which methods may be applicable to mitigate specific types of impact. The applicability codes are listed below:

Applicability Color Code

Characterization	**C**
Water Impacts	●
Land Impacts	●
Structure Impacts	●
Mineral Resource Recovery	●
Atmospheric Impacts	●

Method Is the method listed a proven methane mitigation technology or approach? This is an important criterion in that some of the listed methods have not been applied to methane impacts and will require additional investigation to determine whether the method is applicable and/or effective.

Aesthetics This criterion is categorized in this document by evaluating whether a method is Invasive, Moderately Invasive, or Non-Invasive.

Assessment An assessment is an evaluation of the nature and extent of the methane impact. In addition, a determination of the potential pathways and receptors at a particular site may be needed so that the most appropriate mitigation methods can be selected and implemented. Therefore, we asked the question: Is an assessment necessary to implement the method to address the site-specific situation properly? For this report, LTE divided this criterion into two categories: Recommended or Required.

Pilot Test A pilot test is a small scale implementation of a full scale mitigation design. As with an assessment, a Pilot Test provides site-specific information about the applicability of a selected mitigation solution. In addition, a Pilot Test will provide the information that will be used to design the most appropriate full scale system. Two categories were defined: Not Necessary and Recommended.

Installation Complexity Installation of a mitigation measure can be as simple as installing passive vents or a methane detection system in or around a structure, to extremely complex, such as developing a mitigation bank or installing gas production wells to capture the methane. This criterion has been divided into three broad categories: Low, Medium, and High.

Methane Recovery Some mitigation alternatives are designed to recover the methane and produce it or consume it by chemical oxidation, either of which may reduce methane emissions to the atmosphere. In addition, if the methane can be collected, then the mineral resource is not lost. Those alternatives with the potential to recover methane are noted in Table 1.

Operation and Maintenance (O&M) Effort Some of the listed methods require ongoing O&M to implement the mitigation measure effectively. This can include operator labor, power supply, and routine maintenance and monitoring requirements. The level of O&M anticipated for the listed methods is divided into four categories: None, Low, Medium, and High.

Cost An estimate of the total costs to implement each of the listed methods is presented. These costs are gross estimates. In some instances, several boxes are checked because the application of the method and therefore the costs are size dependent. Site-specific detailed costs will be required to implement the listed methods properly. Some costs could not be determined without further investigation. The costs were divided into five categories (in $1000’s): 0 to 10, 10 to 50, 50 to 100, 100 to 150, and greater than 150.

Meets Objective Five objectives for implementation of methane mitigation measures were identified in Section 1.1, and include:

1) Protecting Public Health, Safety, and Welfare;

2) Protecting Biota;

3) Protecting Property Values;

4) Preserving and Recovering Mineral Resources; and

5) Reducing Emissions of Methane to the Atmosphere.

An initial estimation about which of these objectives are met by the listed methods is presented on Table 1. In many cases, mitigation technologies may address more than one objective.

4.0 RECOMMENDATIONS

COGCC and LTE recommend that this Evaluation be a starting point for further investigation as to the applicability of the listed methods. This is a “living document” that should be changed as more information becomes available with an ultimate goal of providing interested parties a list of possible options to consider if mitigation of methane is deemed to be viable in the SJB or elsewhere.

Methods identified in this report may not apply at all sites or situations, or may be proven to be ineffective. Site-specific evaluation should be completed to determine which technology or approach is most likely to be effective. In addition, any mitigation method will require site-specific design considerations to increase the potential for success.

Multiple mitigation methods may be applicable to any one gas seep. In many cases, a combined approach may be useful to address the mitigation. There may also be more than one receptor at a site, each requiring a different method of mitigation. Nearly all mitigation measures require some level of monitoring to ensure that the mitigation measure is performing to the design standards and to determine whether changing site conditions warrant a change in mitigation method.

Methane mitigation is a relatively new approach in the SJB. In many cases, the technologies identified within this report have not been tested. LTE recommends that the use of pilot-scale tests be implemented where appropriate to determine the technical and economic feasibility of the mitigation measure prior to implementation of a full scale system.

5.0 LIMITATIONS

COGCC and LTE understand that the methods identified are not applicable to all technical or economic situations and that some may be controversial. The technologies identified in this Evaluation have been compiled through a variety of sources. This document was not designed to be an exhaustive list of all potential mitigation methods. As this information is spread across the professional community and various methods are implemented, it is likely that new approaches will be added to the list of mitigation options, while others may be removed.

Since methane mitigation relies so heavily on site-specific considerations, it is difficult to effectively estimate the cost for implementation. LTE has generated estimated costs for various technologies, as practical. Please note that some technologies cannot be costed at this stage of the evaluation and that those costs generated are likely to change once site-specific considerations are incorporated into the design. In addition, the costs from some alternatives are dependent on the size of the system implemented and/or the area requiring mitigation. Costs for recovering methane cannot be calculated at this time because they are dependent on the volume of gas recovered; the type of equipment needed for recovery, reuse, or flaring; and various other factors.

The technologies included in this Preliminary Evaluation of Methane Seepage Mitigation Alternatives (Evaluation) require proper assessment of the impact followed by competent design by qualified scientists and engineers.

6.0 REFERENCES

The following references have been footnoted from the specification sheets presented in Attachment 1.

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TABLE 1

TABLE 1

METHANE CHARACTERIZATION AND MITIGATION COMPARISON

METHANE MITIGATION ALTERNATIVES EVALUATION
SAN JUAN BASIN, COLORADO

METHODOLOGY	APPLICABILITY	METHODOLOGY		AESTHETICS			ASSESSMENT		PILOT TEST		INSTALLATION COMPLEXITY			O&M EFFORT				COST (IN $1,000's)					METHANE RECOVERY	MEETS OBJECTIVE	PAGE # OF SPEC. SHEET
		Unproven	Proven	Non-Invasive	Moderate	Invasive	Recommended	Required	Not Necessary	Recommended	Low	Medium	High	None	Low	Medium	High	0-10	10-50	50-100	100-150	>150			
Pedestrian Survey	C		×	×							×			×				×	×	×				1	S-1
Permanent Soil Vapor Tube	C		×		×							×			×			×	×					1	S-2
Flux Chamber Monitoring	C		×			×						×	×			×	×	×	×					1	S-3
Infrared Imagery and Field Verification	C		×	×									×	×					×					1	S-4
Temporary Monitoring Probe	C		×	×							×			×				×	×					1	S-5
Detailed Mapping	C		×	×								×		×				×	×					1	S-6
Monitoring Wells/Piezometers	C		×			×						×	×		×			×	×	×				1	S-7
Mobile Surveys	C		×	×	×								×	×				×	×					1	S-8
IR Gas Leak Imaging	C	×		×									×									×		1	S-9
Seismic Monitoring	C	×			×								×				×	×	×	×				1	S-10
Passive Sub-Slab Depressurization	● (black)		×		×		×		×		×			×				×	×					1,3	S-11
Active Sub-Slab Depressurization	● (black)		×		×			×		×		×			×			×	×					1,3	S-12
Residential Methane Detection System	● (black)		×		×		×		×		×				×			×						1,3	S-13
Commercial Methane Detection System	● (black)		×			×	×		×			×				×			×					1,3	S-13
Passive Structural Ventilation	● (black)		×		×		×		×		×			×				×	×					1,3	S-14
Active Structural Ventilation	● (black)		×			×	×			×			×			×			×	×				1,3	S-14
Passive Soil Vapor Extraction (SVE)	● (black) ● (green) ● (red) ● (magenta)		×		×		×		×			×		×				×					×	1,2,3,4,5	S-15
Active Soil Vapor Extraction (SVE)	● (black) ● (green) ● (red) ● (magenta)		×			×		×		×		×					×		×	×			×	1,2,3,4,5	S-15
Positive Pressure Diversion	● (black)	×				×	×			×			×		×			×	×					1,3	S-16
Crawlspace/Subfloor Sealing	● (black)		×	×			×		×			×		×				×						1,3	S-17
Gas Collector/Reverse French Drain System	● (black) ● (green) ● (red) ● (magenta)		×		×	×		×	×			×	×	×					×	×	×		×	1,2,3,4,5	S-18
Source/Pathway Removal	● (black) ● (blue) ● (green) ● (red) ● (magenta)		×		×		×		×				×	×						???			×	1,2,3,4,5	S-19
Air Stripping	● (blue)		×		×	×	×			×			×			×		×						1,3	S-20
Institutional Controls	● (black) ● (blue) ● (green)		×	×				×	×		×			×						???				1,3	S-21
Interceptor Wells	● (black) ● (blue) ● (green) ● (red) ● (magenta)	×				×	×			×			×			×				×			×	1,2,3,4,5	S-22
Slant Recovery Wells	● (black) ● (blue) ● (green) ● (red) ● (magenta)	×				×		×		×			×		×							×	×	1,2,3,4,5	S-23
Production On/Near Outcrop	● (black) ● (blue) ● (green) ● (red) ● (magenta)	×				×		×		×			×				×				×	×	×	1,2,3,4,5	S-24
Water Injection	● (black) ● (blue) ● (green) ● (magenta)	×			×	×		×		×			×				×			???				1,2,3,5	S-25
Ozone Injection	● (blue) ● (magenta)		×		×		×		×			×				×		×	×					1,3,5	S-26
Horizontal Venting Wells	● (black) ● (blue) ● (green) ● (red) ● (magenta)	×				×	×			×			×			×						×	×	1,2,3,4,5	S-27
Passive/Active Aeration	● (blue)		×		×	×	×		×			×	×				×	×	×					1,3	S-28
Mitigation Bank/Credit	● (black) ● (blue) ● (green) ● (red) ● (magenta)	×		×			×		×				×	×						???				1,2,3,4,5	S-29
Mitigation Fund	● (black) ● (blue) ● (green) ● (red) ● (magenta)	×		×			×		×		×			×						???				1,2,3,4,5	S-30
Surface Water Body Liner	● (blue)		×			×	×		×			×		×					×	×	×	×		1,2,3	S-31

NOTES:

C - Characterization Technology

Applicability Codes:

● (black) - Structural Impacts
● (blue) - Water Impacts
● (green) - Land Impacts
● (red) - Mineral Resource Recovery
● (magenta) - Atmospheric Impacts

Objectives Codes:

1 - Protecting Pubic Health, Safety, and Welfare
2 - Protecting Biota
3 - Protecting Property Values
4 - Preserving and Recovering Mineral Resources
5 - Reducing Emissions of Methane Gas to the Atmosphere

ATTACHMENT 1

SPECIFICATION SHEETS

CHARACTERIZATION METHOD
PEDESTRIAN SURVEYS

Applicability
For use in monitoring large areas with the potential to contain methane seeps, to identify new seep areas, and to monitor changes over time. Delineation of methane seepage can provide for protecting public health, safety, and welfare.

Description
This technology consists of a methane seep survey performed on foot across large areas. The field crew walks across as much of the outcrop as possible looking for areas of dead vegetation and measuring the concentration of methane in various locations.[1] This type of survey can also be made around manmade structures that have the potential to leak methane gas.

Methane concentrations can be collected using a slide hammer to install temporary soil vapor probes or using a funnel assembly to capture gas seeping at the ground surface. A field meter is connected to the soil vapor probe or funnel assembly to measure methane concentration.

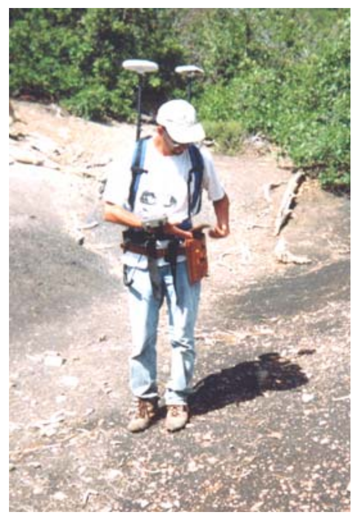
A global positioning system (GPS) is used to mark locations where measurements are collected and to record methane concentrations.

Advantages
- Allows for the field crew to physically observe large portions of the study area.

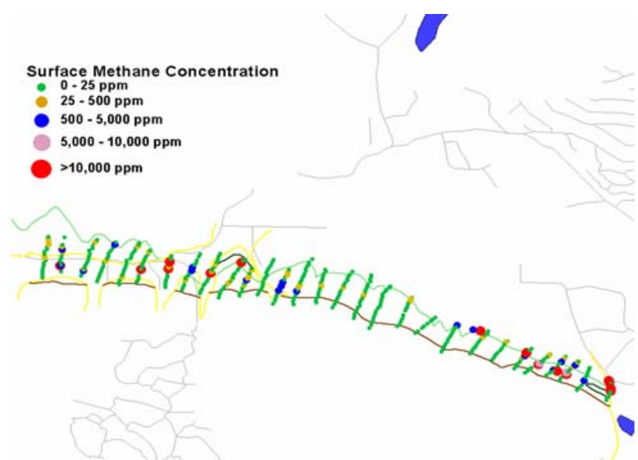
Disadvantages
- Choice of where measurements are collected is largely arbitrary.
- Difficult to quantify extent of impact to vegetation and extent of methane seepage.
- Very labor intensive due to steep terrain and heavy vegetation.
- Difficult to identify areas with dead vegetation from the ground, high likelihood that dead vegetation and seep areas will be overlooked.
- Surface measurements often experience accuracy issues due to air exchange at the ground surface.
- Limited by vegetation conditions and other causes of vegetation mortality.

Estimated Cost
Costs range from $1,500 to $3,000 per square mile of study area including labor, materials, and reporting costs but is dependent on level of detail.

Other Considerations
- Permission to access private land may not be obtained.
- Recurrent surveys are recommended to monitor changes over time.
- Survey areas generally extend across multiple parcel boundaries requiring significant property access coordination prior to field work.
- Installation of multiple transects across the outcrop using temporary or permanent monitoring probes may be beneficial.[2]
- Surveys should be performed and evaluated by qualified personnel.



(LTE, 1998)



(Stonebrooke, 1996)

CHARACTERIZATION METHOD
PERMANENT SOIL VAPOR TUBE

Applicability
For use in defining extent of a specific methane gas seep. Delineation of methane seepage can provide for protecting public health, safety, and welfare.

Description
The soil vapor tube consists of polyethylene tubing installed into the subsurface to a depth of approximately three feet below ground surface (bgs). The bottom six inches of the tubing is perforated to allow seeping methane gas to enter the tube.[3]

Typically, the soil vapor tube is completed at the surface with a polyvinyl chloride surface casing and cap and set in concrete.

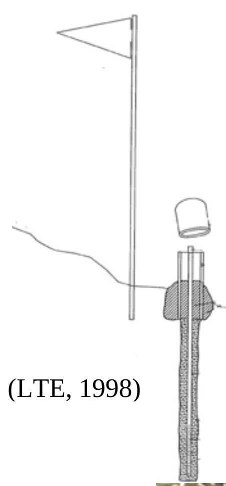
The soil vapor tubes can be used to measure methane concentrations and flow rate as part of a monitoring network on a reoccurring schedule. Methane concentrations can be measured using a field meter.

Advantages
- Limits interference and dilution from surface air exchange.
- Provides a tangible network of monitoring points for long-term monitoring programs.
- Rugged surface completion provides long-term integrity of sampling point.
- Allows for a simplified monitoring technique with limited field judgment required.

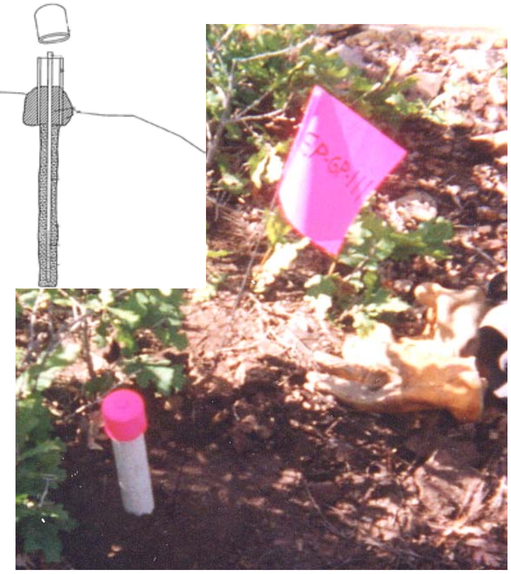
Disadvantages
- Extremely limited aerial coverage.
- Fixed-point monitoring device limits ability to characterize dynamic seep activity.[5]
- Placement of the monitoring point into the monitoring network requires substantial field judgment to provide adequate monitoring of a seep area.
- Surface completion considered unsightly by some.
- Surface completion requires periodic maintenance to maintain integrity following weathering and erosional events.
- Large network of fixed-point monitoring devices are required to adequately assess extent of gas seep and changes over time.
- Near surface monitoring devices often experience accuracy issues due to dispersion and dilution between source of seeping gas and ground surface.[4]

Estimated Cost
Typically cost $50-$75 per soil vapor tube to install including materials, provided large number of soil vapor tubes are installed. Annual monitoring costs depend on the number of points installed and frequency of measurement.

Other Considerations
- Recurrent measurements from tubes are recommended to monitor changes over time.
- Need to establish a consistent protocol for sampling and recording data in order to not bias results (i.e. recording maximum value measured, minimum value, constant value, purging prior to sampling, etc.).
- Grid sampling method may be appropriate when developing monitoring network.
- Design of soil vapor tube network, installation, and data interpretation should be performed by qualified personnel.
- Statistical analysis recommended to interpret data.
- Permission to access private land may not be obtained.



(LTE, 1998)



(LTE, 1998)

CHARACTERIZATION METHOD
FLUX CHAMBER MONITORING

Applicability
For use in monitoring changes in gas seepage rates over time at known seep locations. Characterization of methane seepage activity can provide for protecting public health, safety, and welfare.

Description
The flux chamber, also known as a pyramid, is constructed of a pyramid-shaped collection device equipped with a flow meter at the top to measure the flux or flow rate of methane gas.[3]

The flux chamber is set over a gas seep and the pyramid funnels the gas into the flow meter. A datalogger is used to record flow rates on a specified interval.

Advantages
- Allows for long term monitoring with relatively precise measurements of gas flow over time.
- Limited interference with surface operations.
- Monitoring technique is not labor-intensive.
- Allows for a simplified monitoring technique with limited field judgment required.

Disadvantages
- Fixed-point monitoring device limits ability to characterize dynamic seep activity.
- Electronic equipment and flow meters requires frequent maintenance to maintain integrity following weathering and erosional events.
- Near surface monitoring devices often experience accuracy issues due to dispersion and dilution between source of seeping gas and ground surface.[4]
- Considered unsightly by some.

Estimated Cost
Typically cost $5,000 to $7,000 to install. Operation and Maintenance (O&M) activities cost approximately $3,000 per year per unit.

Other Considerations
- Hard-wired power supply is preferred over battery power or solar panels.
- Largest possible radius of capture recommended to increase reliability of data.
- Design, installation, and maintenance of flux chamber should be performed by qualified personnel.
- Permission to access private land may not be obtained.

(LTE, 2002)

(LTE, 2002)

CHARACTERIZATION METHOD
INFRARED IMAGERY EVALUATION AND FIELD VERIFICATION

Applicability

For use in monitoring large areas with the potential to contain methane seeps to identify new seep areas, and to monitor changes over time. Delineation of methane seepage can provide for protecting public health, safety, and welfare.

Description

This method is performed in three stages. The first stage is to conduct low altitude, high-resolution aerial reconnaissance and image capture using a digital infrared (IR) camera. The IR camera is capable of identifying areas of dead and stressed vegetation.[5]

The second stage is to evaluate all of the images and identify areas containing dead and/or stressed vegetation or other chromatic anomalies. The stressed and dead vegetation is used as an indirect indication that methane may be seeping from the ground. These "suspect areas" are identified with polygons in a Geographic Information System (GIS) and used to focus field investigation in areas with the highest potential to contain methane seeps.

The third stage consists of the field verification of suspect areas. A field crew equipped with a GPS and slide-hammer advance temporary soil vapor probes in the suspect areas to determine the presence or absence of methane. Field verification is generally not performed to the level of detail as a detailed mapping event.

Advantages

- Subsurface measurements limit interference and dilution from surface air exchange.
- Allows for a monitoring program to assess a dynamic change in methane seep conditions.
- Provides an efficient means to monitor a large study area and focus laborious field efforts in areas more likely to exhibit methane seepage.
- Provides a systematic method to identify seep areas as opposed to random identification through pedestrian survey.
- Generates a comprehensive photo-record of the vegetative conditions over a large area.

Disadvantages

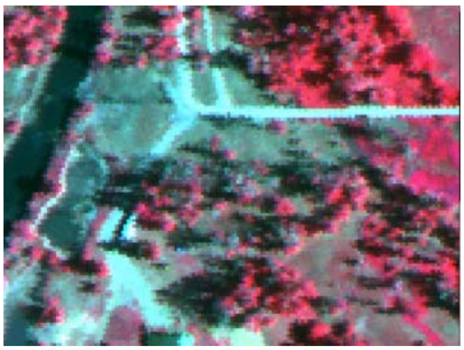
- Field methods require experienced personnel to make field judgments as to where delineation points are obtained.
- Near surface measurements often experience accuracy issues due to dispersion and dilution between source of seeping gas and ground surface.
- Non-vegetated areas with methane seepage are difficult to identify.
- Geo-rectification of IR images provides less accurate basemap as compared to Digital Ortho Quadrangle images.
- IR imagery evaluation requires interpretation by trained personnel.
- Imagery is susceptible to interference from shadows, moisture content, rock exposures, etc.
- Imagery can not differentiate between vegetation mortality due to methane or vegetation mortality due to other causes.

Estimated Cost

Cost is approximately $3,000 per square mile of study area including labor, materials, interpretation, and reporting costs.

Other Considerations

- Recurrent surveys are recommended to monitor changes over time.
- Seep areas generally extend across multiple parcel boundaries requiring significant property access coordination prior to field verification.
- Important to recognize that while the method focuses on vegetation as the indicator for mapping features, it is not uncommon to identify dead or stressed vegetation unrelated to methane seepage.
- IR imagery capture and image interpretation requires specialized equipment and skills. Activities should be performed by qualified personnel.
- Permission to access private land may not be obtained.



CHARACTERIZATION METHOD
TEMPORARY MONITORING PROBE

Applicability
For use in defining extent of known or suspected methane gas seeps. Delineation of methane seepage can provide for protecting public health, safety, and welfare.

Description
The temporary soil vapor tube consists of polyethylene tubing installed into the subsurface to a depth of approximately three feet below ground surface (bgs) using a slide hammer to bore a small diameter hole. The bottom six inches of the tubing is perforated to allow seeping methane gas to enter the tube.[5]

Once the gas measurement is collected, the tubing is removed from the borehole and the borehole is backfilled with native material.

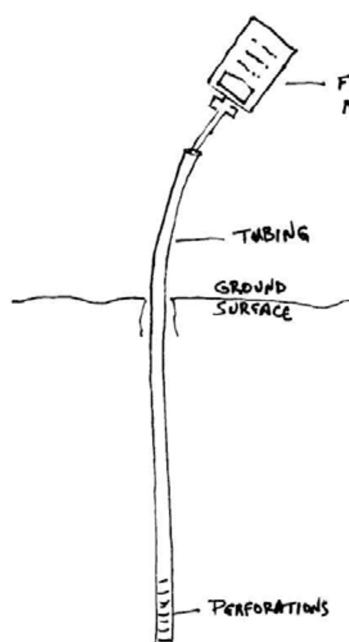
Advantages
- Limits interference and dilution from surface air exchange.
- Allows for a monitoring program to assess a dynamic change in methane seep conditions.
- Quickly installed and removed with very little impact to the land and aesthetics of the area.
- Reduced materials costs and maintenance as compared to permanent monitoring probes.

Disadvantages
- Requires many points to be obtained /installed to be useful.
- Requires field judgment by qualified personnel to assess data in real-time to advance delineation borings to define extent.
- Near surface monitoring devices often experience accuracy issues due to dispersion and dilution between source of seeping gas and ground surface.

Estimated Cost
Typically cost $1-$4 per soil vapor tube to install, provided large number of soil vapor tubes are installed.

Other Considerations
- Recurrent measurements are recommended to monitor changes over time.
- Need to establish a consistent protocol for sampling and recording data in order to not bias results. (i.e. recording maximum value measured, minimum value, constant value, purging prior to sampling, etc.).
- Grid sampling method may be appropriate when developing monitoring network.
- Assessment and interpretation of data should be performed by qualified personnel.
- Permission to access private land may not be obtained.

(LTE, 1998)



(LTE, 2006)

CHARACTERIZATION METHOD
DETAILED MAPPING

Applicability
For use in defining the extent of known or suspected methane gas seeps and monitor changes in seep conditions over time, primarily focused in prominent active seep areas. Delineation of methane seepage can provide for protecting public health, safety, and welfare.

Description
Detailed seep mapping is typically performed by a field team of two people equipped with a GPS slide-hammer, and methane field meter.

The field crew maps areas of dead vegetation, dead trees, visible seeps in surface water bodies, and other pertinent features using the GPS.[5]

Subsurface measurements of methane, carbon monoxide, oxygen, and hydrogen sulfide are made using the slide-hammer, temporary soil vapor probes, and field meter in dead/stressed vegetation areas.

Measurements of gas concentration are collected as practical to define the extent of the gas seep.

Data are plotted on an aerial photograph using a GIS for evaluation.

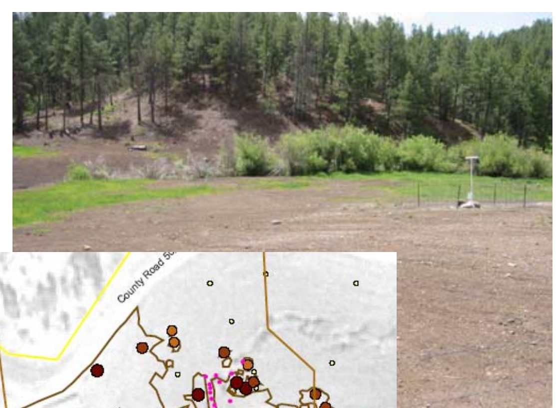
Subsequent monitoring events allow for comparisons over time.

Advantages
- Generates large amounts of data for interpretation.
- Subsurface measurements limit interference and dilution from surface air exchange.
- Allows for a monitoring program to assess dynamic changes in methane seep conditions.

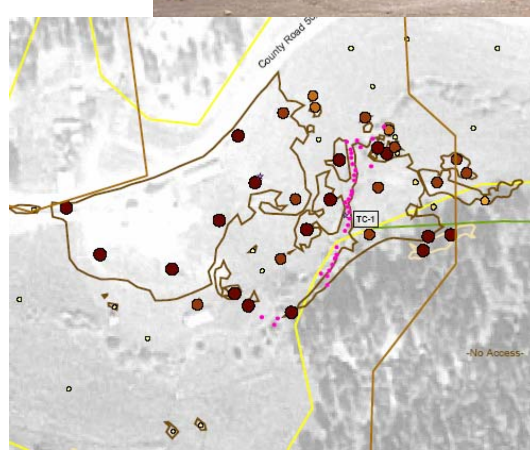
Disadvantages
- Field methods require experienced personnel to make field judgments as to where delineation points are installed.
- Near surface measurements often experience accuracy issues due to dispersion and dilution between source of seeping gas and ground surface.
- Difficult to reproduce results from event to event with a high level of precision.
- Not efficient monitoring method over very large contiguous areas (> 1 square mile)

Estimated Cost
Costs range from $5,000 to $7,000 per square half-mile of mapping area including labor, materials, and reporting costs.

Other Considerations
- Recurrent mapping events are recommended to monitor changes over time.
- Seep areas generally extend across multiple parcel boundaries requiring significant property access coordination.
- Important to recognize that while the method focuses on vegetation as the indicator for mapping features, it is not uncommon to identify dead or stressed vegetation unrelated to methane seepage.
- It may be appropriate to modify the method to establish a grid system of sampling across the entire extent of the seep area.
- Detailed mapping activities should be performed and evaluated by qualified personnel.
- Maintaining consistent personnel and method for subsequent events is important to collect and to interpret data effectively.
- Understanding common causes of vegetation mortality in the region is useful.
- Permission to access private land may not be obtained.



(LTE, 2005)



(LTE, 2005)

CHARACTERIZATION METHOD
MONITORING WELLS/PIEZOMETERS

Applicability
For use in understanding the hydrogeologic conditions affecting seep activity.

Description
Monitoring wells consist of vertical pipe/well installed into the subsurface for the purpose of monitoring reservoir pressures and/or groundwater quality.

The monitoring well construction can be designed in a variety of ways depending on the type of aquifer, geology, and intended use of the well. A slotted section of pipe is used to allow for the infiltration of water and/or gas from the desired interval.

The COGCC currently operates several monitoring wells screened across certain coal seams in the Fruitland Formation to monitor wellhead and buttonhole pressure near the outcrop over time in an attempt to understand the relationship between down-basin production and near outcrop hydrogeologic conditions.[7]

Monitoring wells can be equipped with transducers to provide long term data collection of downhole pressure and/or other types of probes for water quality parameters.

Piezometers are similar to monitoring wells, but are generally used for measuring the potentiometric head of the groundwater. They are typically smaller in diameter than wells and have a shorter well screen interval (often less than 2 feet). Piezometers may also be equipped with long term water level transducers and dataloggers, but not usually water quality probes.

Advantages
- Provides long term data gathering device that can monitor subsurface conditions.
- Relatively little interference with surface use activities once installed.
- Limited O&M requirements.
- Large volume of data generated if using electronic measurement.

Disadvantages
- Generally requires a network of wells to be useful in understanding hydrogeologic conditions over a large area.
- Data interpretation requires significant understanding of complex hydrogeologic principles, reservoir engineering, physics, and chemistry.
- Generally causes impacts to surface area.

Estimated Cost
Typical cost ranges from $45,000 to $60,000 per monitoring well/piezometer, including high-tech monitoring transducers, surface completions, and dataloggers.[8]

Shallow monitoring wells less than 30 feet deep range in cost from $1,000 to $1,500 per well/piezometer not including transducers and dataloggers.

Other Considerations
- Recurrent measurements from wells are recommended (either electronically or manually) to monitor changes over time.
- Prior to installation, it is recommended to establish design criteria such as number of wells, location, depth, screened interval, construction materials, surface completion consideration, drill rig requirements, and data needs. This should be performed by qualified personnel.
- Drilling activities for deep wells involve significant surface disturbance at the well site. Some reclamation of the surface may be needed.
- Property access may be difficult on private lands. Road access sufficient to get the drilling rig to the site may also be difficult.

(Applied Hydrology & Associates, 2002)

CHARACTERIZATION METHOD
MOBILE SURVEYS

Applicability
For use in monitoring large areas with the potential to contain methane seeps, to identify new seep areas, and to monitor changes over time.

Description
This method uses an infrared (IR) gas analyzer mounted in a land vehicle or helicopter. The carrier is equipped with an air scoop on the front that funnels air into the gas analyzer. The carrier can access roads and trails or fly at low altitude within the study area. The IR gas analyzer is capable of detecting methane at very low concentrations. Areas with detections indicate the potential for methane seeps to be present nearby. An integrated GPS keeps track of the location where each measurement is collected.[9]

Advantages
- Rugged and mountable on multiple types of carriers.
- Highly reliable.
- 3-channel multi-gas capability eliminates false positives.
- Useful in very large study areas, especially in areas with no prior knowledge of methane seeps.
- High degree of accuracy and precision in detecting methane concentration and hydrocarbon differentiation.
- Not intrusive to landowners if driven on public roads or conducted with helicopter.
- Increases amount of coverage achieved per hour or day compared to pedestrian surveys.

Disadvantages
- Limited to areas with vehicle access, except when helicopter is carrier.
- Limited capability in defining the extent of the seep or assessing the location of the source.
- Not designed to be man-portable.
- Limited capability in assessing changes in magnitude of the methane seep due to dilution and dispersion at the ground surface.

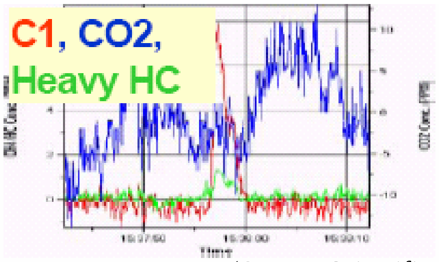
Estimated Cost

Cost is approximately $1,500 to $2,000 per day including labor, materials, and reporting costs. Area covered during one day time period is only limited by accessibility to roads and speed at which vehicle can move.[10] Costs increase if using helicopter as the carrier.

Other Considerations
- Recurrent surveys are recommended to monitor changes over time.
- Integrated GPS provides accurate location measurements
- Seep areas generally extend across multiple parcel boundaries requiring significant property access if accessing private lands.
- Has been used successfully to detect methane seeps in the Raton Basin, Colorado.
- Permission to access private land may not be obtained.

(Apogee Scientific, 2001)

(Apogee Scientific, 2001)



(Apogee Scientific, 2001)

CHARACTERIZATION METHOD
IR GAS LEAK IMAGING

Applicability
Primarily designed for leak detection at chemical plants and pipelines, but may be applicable to methane gas seep assessment. Delineation of methane seepage can provide for protecting public health, safety, and welfare.

Description
The technology uses an IR camera to view scene of interest. An IR laser is used to illuminate the scene and an image is created by backscatter of laser light.[11]

The wavelength of IR laser is tuned to particular gas adsorption rates and can be used to observe leaking methane gas.

Leaking gas is viewed by the camera and can be seen in grayscale as a black or grey cloud.

Advantages
- Allows visual identification of methane gas ordinarily not seen in the visible light spectrum.
- Not intrusive to landowners or the subsurface.
- Capable of detecting multiple types of gases.

Disadvantages
- Limited resolution, incapable of detecting gases at low concentrations (<5,000 ppm).

Estimated Cost
Unit not in commercial production. Estimated cost is approximately $150,000 for the camera.

Other Considerations
- Recurrent surveys are recommended to monitor changes over time.
- Unit not in production at this time.
- The technology was a preliminary "concept" and will require design refinements and improvements in available technologies before it can become commercially viable.[12]

Gas leak at valve in visible light

(Laser Imaging Systems, 2005)

Gas leak at valve using IR imaging

(Laser Imaging Systems, 2005)

CHARACTERIZATION METHODOLOGY
SEISMIC MONITORING

Applicability
For use in monitoring seep activity and to provide warning prior to episodes of increased seepage. Warning system can provide for public safety.

Description
A scientific study for the San Juan Basin (SJB) has been published which associates much of the methane seepage with deep seismic activity.[19]

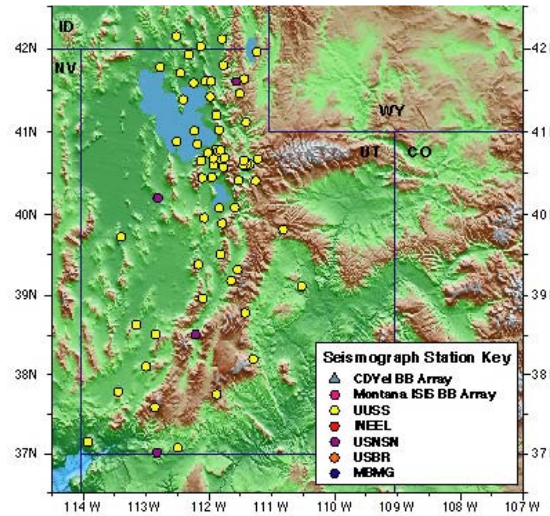
A seismic array could be used to monitor seismic activity in the area. The seismic monitoring would consist of an array of seismometers across the region. The seismographs would be linked to a central processing location for interpretation. Once significant seismic activity is noted, a warning can be posted informing people of the potential for increased methane seepage.

Advantages
- Provides a sensitive system to monitor what may be subtle changes in seepage activity.
- Can help focus mitigation efforts on risks to sensitive receptors.

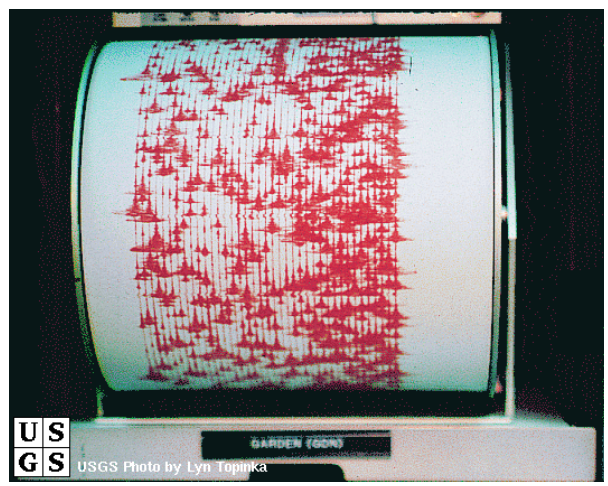
Disadvantages
- Requires specialized skills to interpret data.
- Will not quantify changes in seepage extent or magnitude.
- Requires extensive operation and maintenance for accuracy.
- Will require a network of sensors to be effective.
- Equipment and protective housing may be considered unsightly.

Estimated Cost
Commercial seismographs can cost more than $5,000 per station with annual operating costs exceeding that amount.

Other Considerations
- Continuous monitoring will be required in order to be effective.
- May want to link warning system to governmental agency website for public access.
- The relationship between seismic activity and methane seepage is not agreed upon by all scientists studying the gas seeps in the SJB.



(University of Utah, 2006)

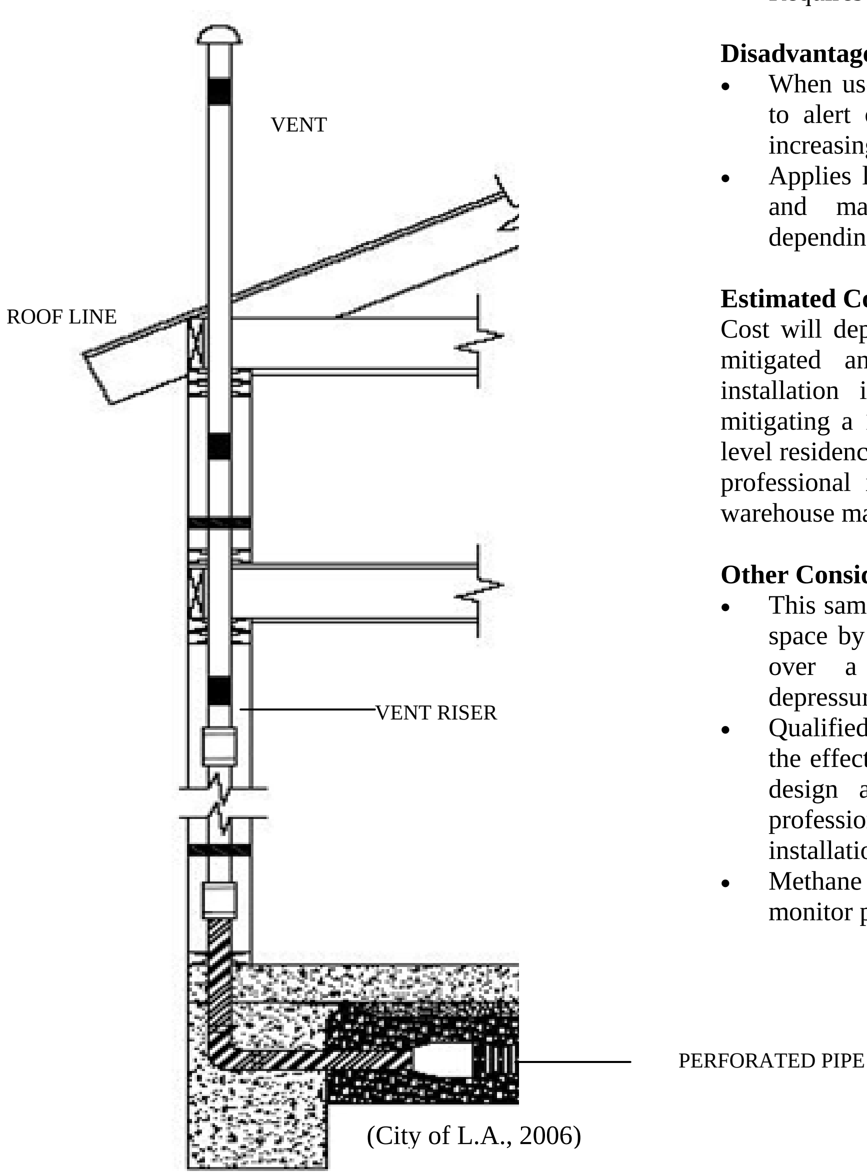


(USGS, 2006)

MITIGATION METHODOLOGY
PASSIVE SUB-SLAB DEPRESSURIZATION (SSD)

Applicability
Used to mitigate methane impacts within structures by passively drawing methane-containing soil gas from beneath an existing concrete slab or foundation before it enters the structure.[14] Passive depressurization is generally the preferred method for new construction, while active depressurization is the preferred method with existing structures.

Description
The technique consists of installing horizontal perforated piping in gravel bedding below a concrete slab prior to slab installation. The perforated pipe is connected to non-perforated riser pipe and vented to the atmosphere. The concrete slab is generally sealed from subsurface soil gas using an impervious membrane, such as plastic sheeting. Thermal stack effect and roofline wind effect create a slight negative pressure, or vacuum, beneath the slab, causing soil gasses to be ventilated to the atmosphere. Installing a wind turbine on the stack will increase this effect.



(City of L.A., 2006)

Advantages
- The approach does not rely on electricity to deter methane from entering a structure.
- Can be effective in preventing methane from building up within and below structures.
- Requires minimal maintenance.

Disadvantages
- When used alone, there is no alarm system to alert occupants of a malfunction or of increasing methane concentrations.
- Applies less vacuum than an active system and may not be aggressive enough depending on concentrations present.

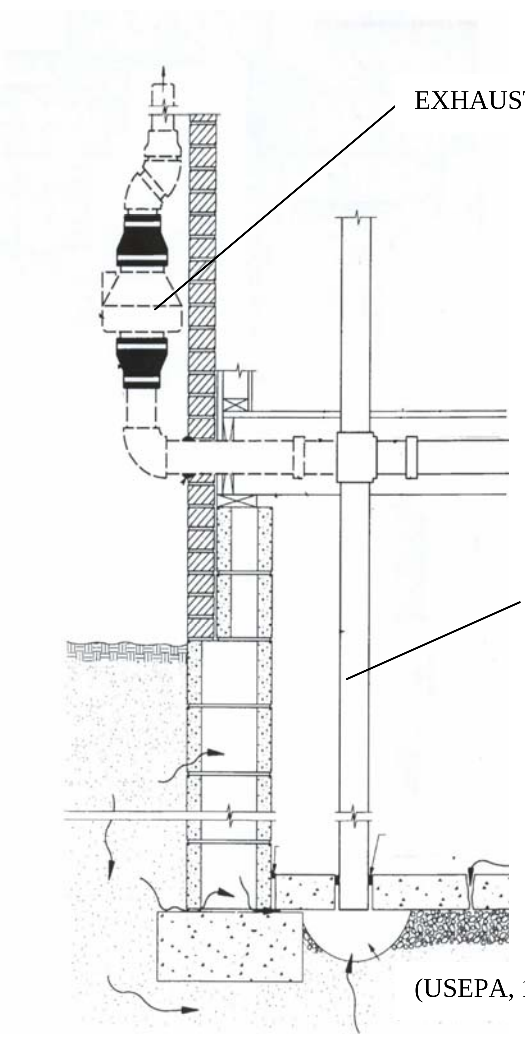
Estimated Cost
Cost will depend on the size of the area being mitigated and whether or not professional installation is required. Material costs for mitigating a 1,000 square foot slab on a single level residence will be approximately $900 while professional installation in a moderately sized warehouse may range up to $5,000.

Other Considerations
- This same concept can be applied to a crawl space by laying an impermeable membrane over a dirt crawl space floor and depressurizing beneath the membrane.
- Qualified personnel should be used to assess the effectiveness of ventilation as well as to design a ventilation system. Qualified professionals should be used to complete all installation activities.
- Methane detection system recommended to monitor performance of system.

MITIGATION METHODOLOGY
ACTIVE SUB-SLAB DEPRESSURIZATION (SSD)

Applicability
Used to mitigate methane impacts beneath structures by actively drawing methane-containing soil gas from beneath an existing concrete slab or foundation before it enters the structure [14]. Active depressurization is generally the preferred method with *existing* structures, while passive depressurization is the preferred method with new construction.

Description
The technique consists of extending extraction piping below a concrete slab, connecting the piping to an exhaust fan, and discharging the fan to atmosphere. Fan activation can be based on a timer or a methane detector. Fan operation creates a negative pressure, or vacuum, beneath the slab, thereby removing the methane before it enters through cracks in the concrete and into the structure.



(USEPA, 1993)

Advantages
- Offers a pro-active approach that can deter methane from entering a structure.
- Can be effective in preventing methane from building up within and below structures.

Disadvantages
- When used alone, there is no alarm system to alert occupants of a malfunction or of increasing methane concentrations within a structure.
- May create preferential pathways for the movement of methane toward the collection points.
- Often considered unsightly especially when installed in a finished area.

Estimated Cost
Cost will depend on the size of the area being mitigated. Professional installation of an active SSD system in a residential location would cost approximately $2,000-$2,500 while installation in a 10,000 square foot warehouse may cost over $8,000. Estimated cost includes concrete coring, inlet, in-line centrifugal fan(s), and exhaust piping to reach above the eave.

Other Considerations
- Sizing of the fan(s) and spacing between the suction points should be determined through a pilot test prior to system design.
- This same concept can be applied to a crawl space by laying an impermeable membrane over a dirt crawl space floor and depressurizing beneath the membrane.
- Care must be taken to ensure that proper explosion-proof electrical equipment is installed.
- Qualified personnel should be used to assess the need for depressurization as well as to design a depressurization system. Qualified professionals should be used to complete all installation activities.
- Methane detection system recommended to monitor performance of system.

Maintenance
Fans should be checked monthly for functionality and piping should be kept free of obstructions. Periodic methane detection should take place to ensure that the depressurization system is efficiently removing the methane.

MITIGATION METHOD
RESIDENTIAL AND COMMERCIAL METHANE DETECTION SYSTEM

Applicability
For use with known or potential methane impacts within structures: houses, garages, water well/pump houses, commercial buildings, industrial buildings, and other permanent or temporary structures. To be used when a site assessment has detected methane within a structure or when a potential for impact exists.

Description
Methane gas sensors are designed to detect combustible gas in an enclosed area, such as a house or basement. Standard equipment will generate an audible alarm at a pre-calibrated or pre-programmed percent (%) of the Lower Explosive Limit (LEL) for methane. Sensor technologies include infrared, catalytic bead, or solid state offering various levels of accuracy and required maintenance.

Depending on the level of response required, most systems can be configured to operate external equipment, including closure of a relay to trigger an emergency phone call, an alarm strobe, and/or operation of ventilation blowers.

Commercial grade units generally include %LEL digital display and data logging capabilities, along with the ability to mount the sensor remotely or local to the control panel.[13] Residential methane detectors can be interlocked with multiple units and are similar in appearance to a residential smoke detector.

Advantages
- Can alert occupants of rising levels of methane before dangerous concentrations are reached.
- Offers the ability to activate additional external methane mitigation devices.

Disadvantages
- Level of required maintenance and calibration generally increases with level of accuracy and reliability.
- Sensor units are susceptible to degradation, especially in harsh environments such as temperature extremes and humidity.
- Often considered unsightly depending upon location.

Estimated Cost
Depending on required configuration, stand-alone residential unit using solid state technology will cost approximately $100-200 plus installation and the cost of added external devices.

Commercial units require a control panel and separate sensors totaling approximately $1,400 for a two-sensor system. Additional installation and external device costs will apply raising the total system cost for a 10,000 square foot warehouse to approximately $25,000.

Other Considerations
- Manufacturers generally recommend one unit per 900 square feet.
- A simple plug-in device with an audible alarm can be installed by an individual homeowner.
- Stand alone units can be custom calibrated from the manufacturer to alarm at any desired %LEL for methane.

Maintenance
- Residential units generally require periodic functionality testing, but no calibration.
- Commercial/industrial units require monthly to quarterly calibration.

(Scott Instruments, 2005)

MITIGATION METHODOLOGY
PASSIVE or ACTIVE STRUCTURAL VENTILATION

Applicability

Used to mitigate methane impacts within structures by extracting methane vapors that have entered a structure. The decision to use active over passive ventilation should be based on methane volume, methane concentration, and the volume of air that must be exchanged to reduce hazard.

Description

Passive ventilation consists of installing slotted vents or screens on the walls or ceiling of a structure to encourage airflow in an impacted area allowing methane to vent to the atmosphere. Active ventilation applies an electric powered blower (such as a centrifugal fan) to remove methane-impacted air and/or supply fresh air into the structure. Ventilation conduit can be used to distribute ambient air or to collect impacted air from multiple areas. Blowers can be turned on and off manually, using timers, or using a relay in a methane detection system.

Advantages

- Allows methane to be ventilated to atmosphere prior to reaching dangerous concentrations within a structure.
- The passive approach does not rely on electricity to induce airflow.

Disadvantages

- Additional ventilation often results in higher structural heating and cooling costs.
- In some cases, operating an extraction blower may actually induce methane-containing soil vapors to enter a structure more aggressively.
- Active ventilation relies on electricity and requires relatively high maintenance.

Estimated Cost

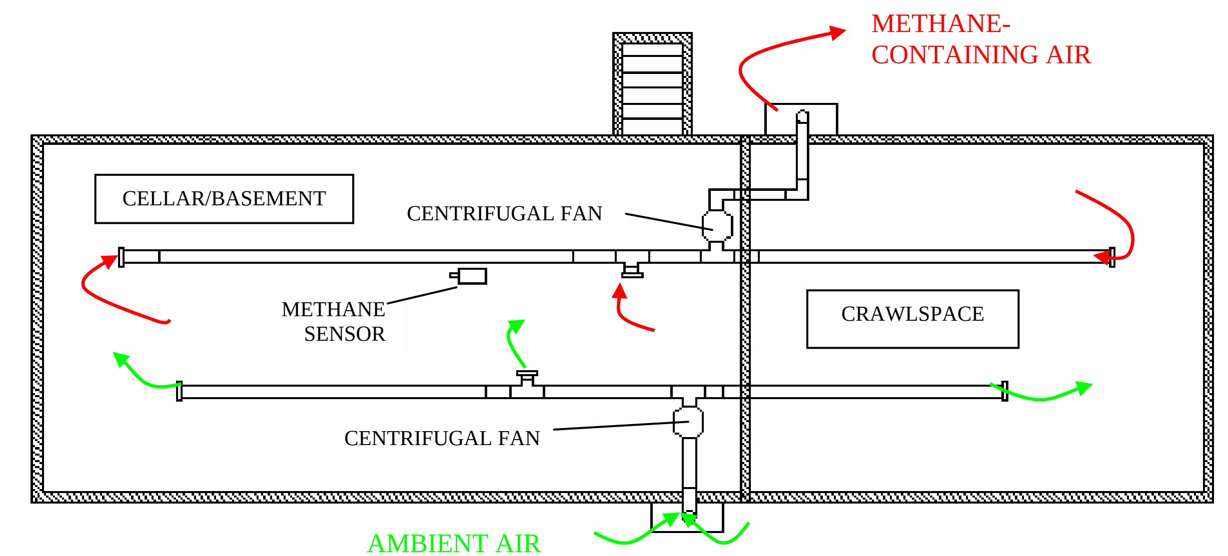
Cost will depend on the total cubic feet of the area being mitigated. Installation of passive vents in a residential crawl space may cost only several hundred dollars, while installation of an active ventilation system in a warehouse will cost approximately $4,000 for a moderately sized system.

Other Considerations

- Methane detection system recommended to monitor performance of system.
- Qualified personnel should be used to assess the need for ventilation as well as to design a ventilation system. Qualified professionals should be used to complete all installation activities.
- When using active ventilation, consideration should be given to the type of equipment used due to the explosive characteristics of methane.
- Heat tracing and insulating water pipes in basements and crawl spaces may be required.

Maintenance

Functionality tests and sensor calibration, if applicable, should be performed at least monthly. All piping must be kept free of obstructions and should be periodically checked for leaks.



MITIGATION METHODOLOGY
PASSIVE or ACTIVE SOIL VAPOR EXTRACTION (SVE)

Applicability
Used to mitigate methane impacts to agricultural and natural vegetation as well as within structures by allowing soil vapors to escape through wells or vertical piping. Recovered gas can be put to beneficial use.

Description
Passive SVE consists of installing vertical, perforated wells below grade, extending a ventilation stack above grade, and attaching a rain cap or wind powered ventilation turbine at the top of the stack.

Active SVE employs an electric powered vacuum blower that manifolds to multiple wells and operates either on a continual or timed basis. Both designs can be modified to cover greater areas by installing horizontal, perforated piping below grade. For an enhanced effect, horizontal piping should be bedded in pea gravel and the area above the piping can be sealed with an impervious membrane, such as plastic sheeting.

Advantages
- This approach can be effective in creating a preferential pathway for methane to escape the subsurface, thereby decreasing the area of the methane seep.
- The passive approach does not rely on electricity to deter methane from impacting a structure or vegetation.
- Can be effective in preventing methane from building up within and below structures.

Disadvantages
- Venting gas to atmosphere does not benefit recovery of resource or reduce atmospheric gas emissions.
- Active SVE relies on electricity.
- Installation requires significant invasive procedures.

Estimated Cost
Cost will depend on the size of the area being mitigated. Installation of a single, passive SVE well to ten feet below grade will cost approximately $1,000. A small, active SVE system operating four vertical SVE wells and housed in a shed may cost $5,000 not including design. A large, active SVE system that manifolds to multiple wells could cost over $80,000.

Other Considerations
- System can be equipped to recover methane gas for beneficial use or flaring. Recovery of gas will require evaluation of additional issues such as mineral rights, gas storage, combustible gas safety, compression, transmission, flaring, and/or additional equipment needs.
- Qualified personnel should be used to assess the need for SVE as well as to design an SVE system. Drilling of SVE wells should be done by an experienced drilling company. All other installation should be completed by professionals.
- When using active SVE, explosion proof (XP) equipment and installation procedures must be employed due to the explosive characteristics of methane.
- The decision to use active over passive should be based on methane volume, methane concentration, and the extent of the impact.
- Methane detection system recommended to monitor performance of system when used to mitigate structures.

Maintenance
Passive SVE systems require little to no maintenance. Active SVE systems require greasing of blowers, collection of various parameters, and operational check-ups.

(LTE, 2004)

MITIGATION METHODOLOGY
POSITIVE PRESSURE DIVERSION

Applicability
Used to mitigate methane impacts within structures by actively blowing air into an area in order to restrict the ability of the methane to enter.

Description
Using an electrically operated blower, ambient air is forced into a structure. In addition, the structure is sealed to prevent the air from escaping. The result is to create a slight positive pressure within the structure, which limits or eliminates the movement of methane from the subsurface into the area.

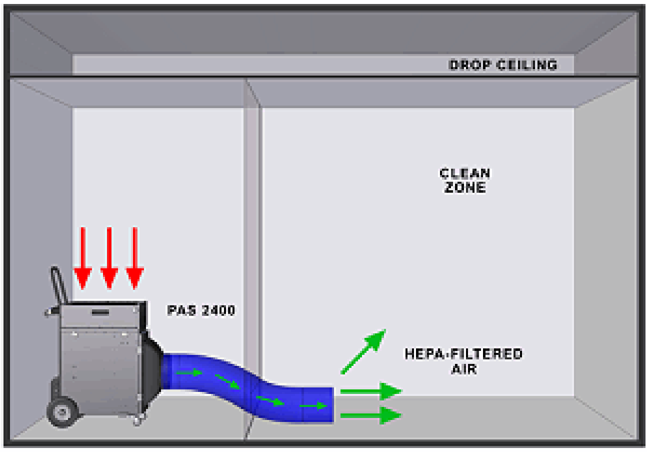
Advantages
- Discourages methane from ever entering a structure.

Disadvantages
- It may be difficult and impractical to seal a preexisting structure tight enough to keep the pressure from escaping.
- This technology has not been proven for long-term applications for methane in a typical structure.
- Sealing a building, such as a house, may have other detrimental environmental effects.
- Pressure created by the blower is reliant upon electricity.
- When used alone, there is no alarm system to alert occupants of a malfunction or of increasing methane concentrations within a structure.

Estimated Cost
Cost will depend on the size of the area being mitigated. Installation of positive pressure blower in a 1,500 square foot structure may cost $500, but sealing the house may cost $10,000 to $15,000, and likely more for larger spaces.

Other Considerations
- Methane detection system recommended to monitor performance of system.
- Qualified personnel should be used to assess the need for methane mitigation as well as to design a positive pressure diversion system. Qualified professionals should be used to complete all installation activities.

Maintenance
Blowers should be evaluated monthly for operational efficiency. The sealing of the structure should also be verified periodically.



(Abatement Technologies, 2006)

(Fantraxx, 2006)

MITIGATION METHOD
CRAWLSPACE/SUBFLOOR SEALING

Applicability
For use where possible methane impacts are within structures: houses, garages, water well/pump houses, commercial buildings, industrial buildings, and other permanent and temporary structures. To be used when a site assessment has detected methane within a structure, or when property owners suspect possible impacts.

Description
Sealing an existing crawlspace or sub-floor requires the installation of an impervious membrane separating the soil gasses from the living space. The membrane can consist of plastic sheeting or a spray-on seamless membrane.[16] In either application, all penetrations must be properly sealed and care must be taken not to puncture the membrane. Depending on accessibility and stage of construction, this method can be used in combination with other methods, such as sub-slab depressurization, active/passive ventilation, and/or detection.

Advantages
- Can be effective in keeping methane gas from exiting the soil and entering into a structure.
- Requires very little maintenance to keep the seal intact.
- Low tech method that does not rely on electricity.

Disadvantages
- Membranes are subject to damage in traffic areas.
- Plastic sheeting can prove difficult to seal to walls and around posts or pipes and in crawl spaces.
- Spray-on membranes create a better seal around penetrations but generally cost more and are difficult to apply in the confines of a crawlspace.
- Not very effective for existing construction applications.

Estimated Cost
Cost will depend on the size of the area being mitigated. 2,000 square feet of 4 mils plastic sheeting can be purchased for approximately $130.00. Additional materials, such as tape, glue, clamps, etc., are also necessary. Spray-on membrane material averages approximately $3/square foot and does not include the application labor. Total estimated cost ranges from $200 for a residential slab to $30,000 for a moderately sized warehouse.

Other Considerations
- Methane detection system recommended to monitor performance of system.
- Qualified personnel should be used to assess the need for sealing as well as to design and install the appropriate sealing method.
- In high methane volume conditions, technologies, such as sub-slab depressurization, would be necessary.

Maintenance
Little to no maintenance required. In sealed areas with pedestrian or other traffic, periodic inspections of the sealant material should be performed.

(LBI Technologies, Inc., 2006)

MITIGATION METHODOLOGY
GAS COLLECTOR/REVERSE FRENCH DRAIN SYSTEM

Applicability
For use in collecting seeping methane gas to reduce impacts to vegetation. Can be used to increase resource recovery and reduce atmospheric gas emissions if gas is recovered.

Description
This system consists of a narrow trench or rectangular shallow excavation containing a gravel fill material and a network of slotted pipe positioned over an active seep area.

The slotted pipe is manifolded to one or more surface vents. The trench or excavation, gravel fill, and piping are covered with an impermeable barrier such as plastic. The impermeable barrier is then covered with the native soil.

Seeping gas is captured by the slotted pipe and impermeable barrier and diverted through the pipe network toward the vent.

Once collected the gas could be vented to the atmosphere or put to beneficial use.

Advantages
- Can be used to monitor seep trends with the installation of a flow meter and datalogger on the vent stack.
- Gas can be collected for beneficial use if desired ultimately reducing atmospheric gas emissions.
- Very limited above ground infrastructure required thereby limiting impacts to existing surface use, after installation.

Disadvantages
- Generally requires a very large system in order to be effective.
- Installation activities are extremely disruptive to existing surface uses.
- Not effectively installed in areas where digging is difficult (rocks and trees) or where much of the surface area is covered by existing structures.
- May not entirely remove impacts from seep.

Estimated Cost
Costs vary greatly based on design considerations and location of installation. One collector measuring 300 feet long by 400 feet wide has been installed in an alluvial valley at the rim of the San Juan Basin at a cost of more than $90,000.[4]

Other Considerations
- Methane detection system recommended to monitor performance of system when used to mitigate structures.
- System can be equipped to recover methane gas for beneficial use or flaring. Recovery of gas will require evaluation of additional issues such as mineral rights, gas storage, combustible gas safety, compression, transmission, flaring, and/or additional equipment needs.
- Equipping collector with a bioreactor may be useful in destroying methane, ultimately reducing atmospheric gas emissions.

(BP, 1998)

(BP, 1998)

MITIGATION METHODOLOGY
SOURCE/PATHWAY REMOVAL

Applicability
May be used as a mitigation measure to minimize or eliminate impacts whenever the source of the methane or pathway for seepage can be defined and can be reasonably addressed.

Description
If the conduit of methane can be defined, measures can be taken to redirect or cap off the flow. Measures include the proper abandonment of wells, the installation of trench dams, or the redirection of natural or manmade conduits.

Although rare, water wells and abandoned production wells have been documented as pathways of methane impacts to structures, land, and water. Professional abandonment of these wells can effectively cut off a preferential pathway for methane escaping the subsurface. Depending on the volume of methane escaping, sealing a well may cut off the flow entirely, or it may cause the methane to seek new pathways in the area.[15]

Natural fractures and utility corridors have also been known to create preferential pathways contributing to methane impacts. Defining these conduits through assessment can provide the information necessary to evaluate the effectiveness of redirecting or sealing these pathways.

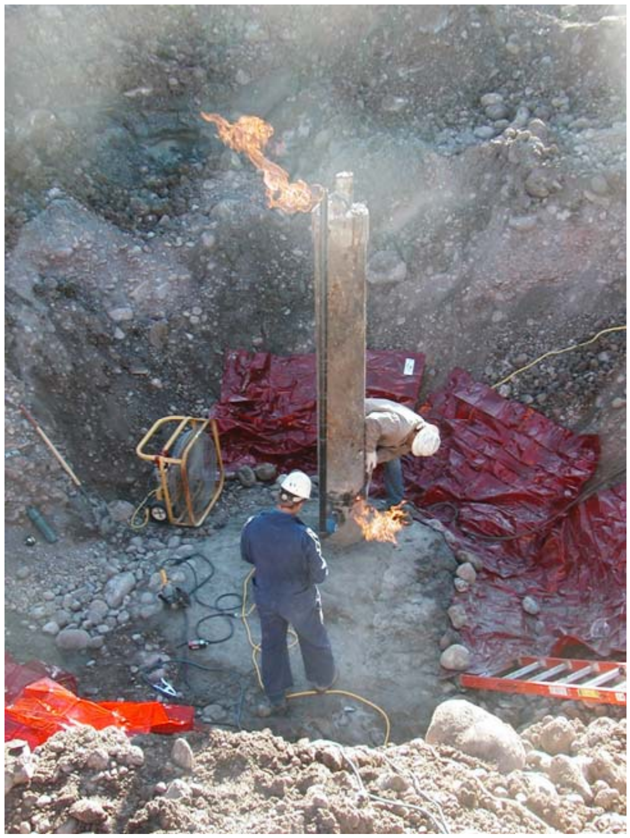
Advantages
- Redirection of methane can be effective in keeping the gas from ever entering a structure or impacting land or water.
- Abandoning methane-releasing wells helps reduce the release of greenhouse gasses into the atmosphere.

Disadvantages
- Plugging or redirecting methane sources may only cause the methane to seek new pathways in the immediate vicinity.
- Methane sources can be difficult and costly to define.
- Plugging or redirecting natural pathways may be cost prohibitive or even impossible.
- When used alone, there is no alarm system to alert occupants of a breach or of increasing methane concentrations.

Estimated Cost
Costs associated with this technology are based on the nature of the source. Abandoning a water well may cost as little as $2,000, while redirecting a naturally occurring pathway may cost over $50,000.

Other Considerations
- Relocating a structure or agricultural field may prove more cost effective than removing the source of the methane.
- Depending on the volume of the gases being released, beneficial use for the methane may be considered.
- Methane detection system recommended to monitor performance if used to mitigate a structure.

Maintenance
Generally, creating a trench dam or abandoning a well will require no future maintenance. However, due to the possibility of methane finding new preferential pathways, ongoing monitoring of the impacted area is recommended.



(LTE, 2005)

MITIGATION METHODOLOGY
AIR STRIPPING

Applicability
May be used as a mitigation measure to minimize or eliminate dissolved methane impacts to potable water supplies and surface water.

Description
Air stripping, like aeration, utilizes the introduction of oxygen into water to transfer the methane out of the water. (Many manufacturers refer to air stripping as aeration, and the two technologies are often used interchangeably due to the similarities.) Rather than spraying water out of nozzles, air stripping uses submerged diffusers to distribute air through the water.

This methodology can be applied to everything from residential water supplies to ponds. As with aeration, a residential water supply would be pumped into a cistern using the existing water well pump. Submerged air diffusers release air bubbles supplied by an air compressor or electric pump, through microporous bubblers and into the water.

Air stripping technology can also be applied to treating methane impacts on a larger scale, such as in ponds. Many manufacturers offer complete air stripping systems utilizing windmills, electricity, and/or compressed air for improving water quality in ponds. These systems can be implemented to reduce methane impacts in water.

Advantages
- Effective at reducing dissolved methane concentrations in water.
- Enables the use of methane-containing well water.

Disadvantages
- Water storage using a tank presents additional problems, such as biological growth. The introduction of oxygen through air stripping tends to contribute to this issue.
- Is not a proven method for effectively reducing extremely high concentrations of methane to a safe level.
- Does not address the cause of methane in water.

Estimated Cost
Costs are dependent upon the existing infrastructure. Mitigating methane from a residential water supply that has an existing well pump would require the addition of a cistern, additional piping, air supply, diffusers, and a secondary pump totaling approximately $1,500. Mitigating methane impacts to a small pond may cost over $5,000.

Other Considerations
- May be necessary to vent or treat off-gas.
- The introduction of chemicals, such as chlorine, can be used to control biological growth in the holding tank.
- Depending on geographical location, the cistern may need to be heated, housed in a heated shed, or buried to prevent freezing.
- Qualified personnel should be used to assess the effectiveness of air stripping as well as to design a system. Qualified professionals should be used to complete all installation activities.
- Explosion proof electrical devices and location of the tank should be assessed by a professional due to the explosive nature of methane.

Maintenance
- Weekly chemical treatment of biological growth in the cistern may be required.
- Diffusers may be susceptible to carbonate buildup requiring cleaning.
- Water quality should be monitored at least quarterly.

(Vertex Water Features, 2006)

MITIGATION METHODOLOGY
INSTITUTIONAL CONTROLS

Applicability
Used to prevent exposure to methane in known seep areas by restricting access or establishing mandatory construction requirements.

Institutional controls can also be used to establish assessment requirements and establish criteria for when methane mitigation is required.

It can be used to establish performance criteria and construction standards for mitigation technology for impacts to structures and water supplies.

Description
This approach could be designed in a manner similar to the regulations already established in Los Angeles, California, an area with extensive methane seep activity.[17]

The ordinance is enforced by the city or county building department and is based on known areas of methane seeps and a buffer zone around seep areas.

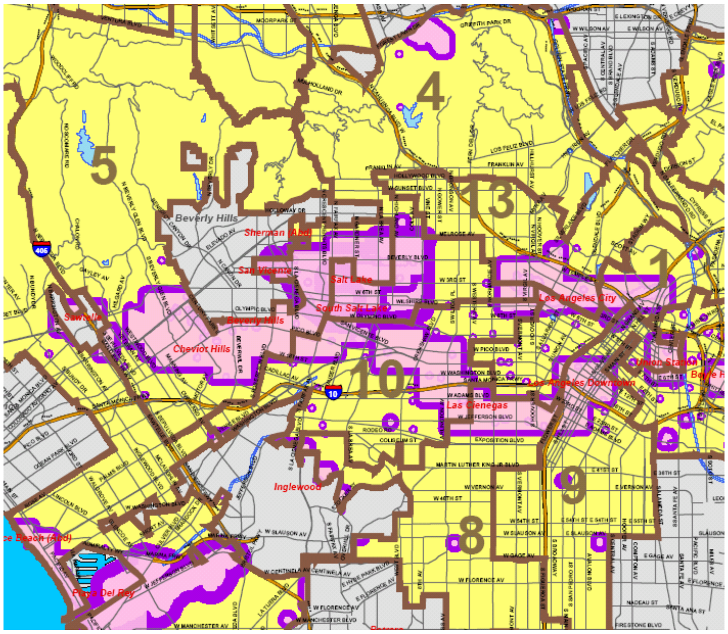
The regulations describe how soil gas testing is to be conducted and what construction measures are required based on the concentration of methane gas present.

Advantages
- This approach can reduce potential hazards to structures from man-made or naturally occurring phenomenon.
- Provides the regulatory framework necessary for regulators to enforce construction safety standards in hazardous areas.

Disadvantages
- Rural counties such as La Plata and Archuleta may not have resources to implement and maintain regulatory program.

Estimated Cost
Costs are difficult to estimate without specific standards and protocols established.

Other Considerations
- The regulations established in Los Angeles County may be useful as a model or template for the development of a program in the San Juan Basin.
- Need to do a comprehensive assessment to establish hazard zone and buffer zone.



(City of LA, 2002)

MITIGATION METHODOLOGY
INTERCEPTOR WELLS

Applicability
Used to mitigate methane impacts to agricultural and natural vegetation and to increase recovery of lost resource. Successful implementation would also likely mitigate impacts to structures and water. Recovered gas can be put to beneficial use.

Description
The mitigation technology involves drilling vertical production wells in close proximity to, but slightly down-dip of the outcrop to intercept methane prior to seeping at the outcrop.[18]

The wells could extract methane gas actively or passively. To increase recovery of lost resource, the collected gas would have to be transported via pipeline.

Advantages

- This approach may be effective in creating a preferential controlled pathway for methane at the outcrop.
- The passive approach does not rely on electricity to deter methane from impacting a structure or vegetation.

Disadvantages

- Would likely require a large number of wells to be effective.
- Difficult to measure performance.
- Recovery may be limited without active dewatering of interceptor wells.
- Active dewatering may produce an undesirable initial increase in seepage at the outcrop.
- Success of implementation strongly linked to permeability, subsurface structural controls, and preferential pathways which are difficult to characterize.
- Access to properties for purpose of installing interceptor wells may be difficult.
- Will require large infrastructure to capture and transport gas and produced water if dewatered.
- Active local dewatering could introduce oxygen into subsurface increasing the potential combustibility of the coals.

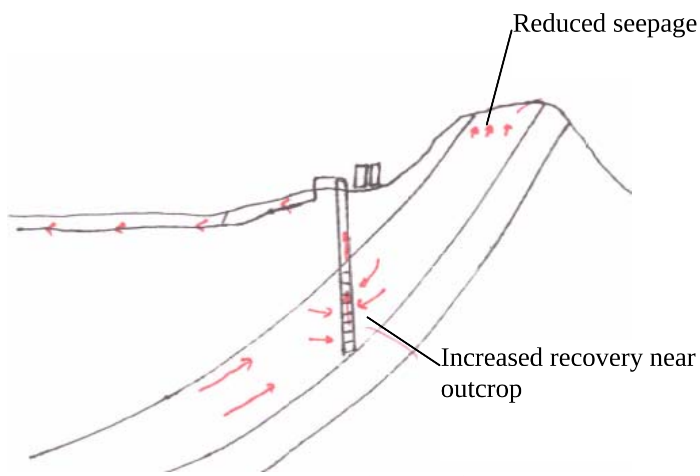
Estimated Cost
Costs are difficult to estimate and are heavily dependent on design and infrastructure requirements. Southern Ute Indian Tribe (SUIT) has attempted similar approach with a test using nine wells costing $50,000 each.[18]

Other Considerations

- System can be equipped to recover methane gas for beneficial use or flaring. Recovery of gas will require evaluation of additional issues such as mineral rights, gas storage, combustible gas safety, compression, transmission, flaring, and/or additional equipment needs.
- Methane detection system recommended to monitor performance of system when used to mitigate structures.
- SUIT has attempted this technology using passive well to create a pathway for gas. SUIT has had difficulty measuring performance of the 9 wells.
- This technology will likely have limited effectiveness in areas with very shallow groundwater table (i.e. Pine River or Texas Creek valleys).
- Pilot testing should be performed prior to full-scale implementation. Design and installation should be performed by qualified personnel.

Maintenance
Passive well systems require little to no maintenance but may limit effectiveness.

Active interceptor well system will require significant maintenance similar to the standard CBM production well network.



(LTE, 2006)

MITIGATION METHOD
SLANT RECOVERY WELLS

Applicability

Used to mitigate methane impacts to agricultural and natural vegetation and to increase recovery of mineral resource. Successful implementation may also mitigate impacts to structures and surface water and reduce gas emissions to the atmosphere.

Description

This mitigation methodology involves drilling extraction wells parallel to the dip of the formation within seeping coal beds at the outcrop.[18]

The wells could extract methane gas actively or passively. To increase recovery of mineral resource, the gas collected would have to be transported via pipeline.

Advantages

- This approach can be effective in controlling the location of gas migration by creating a preferential pathway for methane to escape the subsurface through the wells rather than along some other pathway.
- The passive approach does not rely on electricity to prevent methane from impacting a structure or vegetation.

Disadvantages

- Would likely require a large number of wells to be effective.
- Difficult to measure performance.
- Success of implementation strongly linked to permeability, subsurface structural controls, and preferential pathways which are difficult to characterize.
- Access to properties for purpose of installing slant wells may be difficult.
- Topography may also limit access.
- Will require large infrastructure to capture and transport gas.
- Difficult well installation to set wells in desired zones.
- Active local dewatering could introduce oxygen into subsurface increasing the potential combustibility of the coals.

Estimated Cost

Costs are difficult to estimate and are heavily dependent on design and infrastructure requirements. A similar approach in one coal seam has been attempted in the SJB. 6 slant wells are spaced along an approximate 0.25 mile line of outcrop. This project cost more than $750,000.[18]

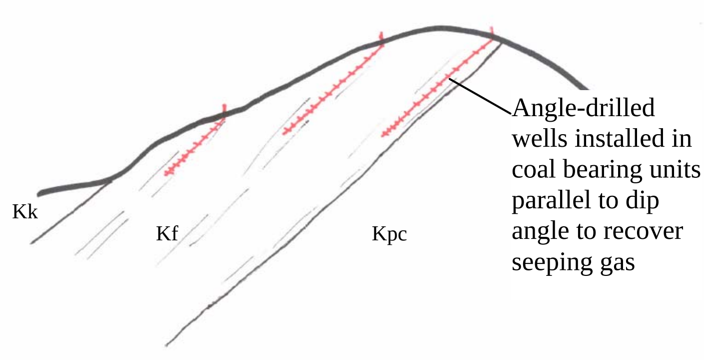
Other Considerations

- System can be equipped to recover methane gas for beneficial use, flaring, or chemical oxidation. Recovery of gas will require evaluation of additional issues such as mineral rights, gas storage, combustible gas safety, compression, transmission, flaring, dehydration, and/or additional equipment needs.
- Methane detection system recommended to monitor performance of system when used to mitigate structures.
- This technology has been attempted but has shown only limited effectiveness. Performance of the 6 wells has been difficult to measure.
- This technology may have limited effectiveness in areas with very shallow groundwater table.
- Will require many wells given the main gas producing horizons in the Fruitland Formation (Kf).
- Increases oxygen in the subsurface and may increase potential for coal fires.
- Increased radius of influence may be accomplished with active extraction.
- Pilot testing is recommended prior to implementation of this technology. Design and installation of system should be performed by qualified personnel.

Maintenance

Passive well systems require little to no maintenance.

Active extraction will require greasing of blowers, and operational check-ups.



(LTE, 2006)

MITIGATION METHODOLOGY
PRODUCTION ON/NEAR OUTCROP

Applicability
For use in collecting seeping methane gas to reduce impacts to structures, vegetation, water, and increase resource recovery.

Description
This methodology consists of installing additional CBM production wells near or on the outcrop.

Currently, the COGCC has established a 1.5 mile buffer zone from the outcrop in which drilling of CBM wells is not permitted. This technology would require a variance from the buffer zone order and place production wells near the outcrop to dewater the Fruitland Formation (Kf) and recover methane gas.

Once collected, the gas would be transported via pipeline for sale.

Advantages
- Gas can be collected for beneficial use if desired ultimately reducing atmospheric gas emissions.
- Would increase efficiency of reservoir recovery.

Disadvantages
- Generally requires a large network of wells in order to be effective.
- Will require land surface disturbances for well pad and pipeline construction.
- Cost recovery may be slow.

Estimated Cost
Cost for a CBM well is approximately $100,000 to $300,000. Pipeline system ranges in cost from $500,000 to $1,000,000 per mile.[20]

Other Considerations
- Recovery of gas will require evaluation of additional issues such as mineral rights, gas storage, combustible gas safety, compression, transmission, and/or additional equipment needs.
- Some scientists argue that the source of some methane seeps are not from the Kf. Therefore, producing gas on the outcrop may not reduce seepage.[19]
- Pilot testing should be performed prior to full-scale implementation. Design and installation should be performed by qualified personnel.
- It is possible that production on or near the outcrop might not be economically feasible as compared to present production areas. One method of balancing this issue may be to establish mitigation credits to make up for potential losses.

(Progressive cavity pump well, 2006)

(LTE, 2002)

MITIGATION METHODOLOGY
WATER INJECTION

Applicability
For use in reducing impacts to structures, land, air, and water.

Description
This methodology is based the idea of preventing or reducing the desorption of methane gas by injecting water into under-pressured coal seams.

Wells could be installed into under-pressured coal zones. Water, presumably derived from down basin CBM production, would be injected into the under-pressured coals at the gas seep areas with the intention of increasing pressure and reducing or preventing desorption of gas.[21]

Advantages
- If effective, this mitigation technology would not only help with mitigating seeps but also provide a disposal method for produced water, a common problem in CBM development.
- Can be used to reduce atmospheric gas emissions.

Disadvantages
- Will require significant energy resources to transport water to injection points and create enough pressure to inject.
- Injection efficiency strongly influenced by permeability of the injection zone which is highly variable across the outcrop. Variable permeability will produce variable levels of success.
- Source of injectate water may prove difficult, downbasin production water has poor water quality as compared to near-outcrop water. Injecting water that degrades existing subsurface water quality is not desirable.
- Technique will likely require sustained operation in order to be effective.
- May not completely remove seepage at the outcrop.

Estimated Cost
The cost to implement this technology is unknown at this time. Site-specific design criteria strongly influence cost such as: water source, water quality, injection pressure requirements, and others.

Other Considerations
- This technology assumes that the seeping gas is coming from coal zones. Work in the Pine River area has shown that the major coal zones of the Fruitland Formation are already over-pressured and the gas is coming from the transition zone and/or deeper formations. If under-pressured coal seems are not identified in the seep area, this technology will not be effective.
- Chemical content of the injectate water will be a crucial element of the success of this technology. High levels of iron sulfide in the injectate water will likely increase the production of hydrogen sulfide gas, potentially creating a more serious condition.[4]
- Precipitate from the water may form within the injection zone limiting injection efficiency.
- Methane detection system recommended to monitor performance of system if used to mitigate a structure.

(Kansas Geological Survey, 2004)

MITIGATION METHODOLOGY
OZONE INJECTION

Applicability
May be used as a mitigation measure to minimize or eliminate dissolved methane impacts to water.

Description
Ozone is a powerful oxidizer that can be used to destroy certain organic compounds such as dissolved methane in water. In addition to its oxidizing effect, injecting ozone into a collection of water utilizes the air stripping effect to further reduce methane concentrations.

Ozone is produced using an ozone generator, by passing air through a high voltage cell and subjecting it to electricity to convert the oxygen to ozone.[10] The ozone is then forced through diffusers into the water to distribute the molecules and contribute to the air stripping effect.

Unlike other aeration or air stripping technologies that are susceptible to biological growth within a holding tank, ozone also acts as a biocide preventing the growth of slime-forming bacteria.

Ozone dissolved in pure water has a half-life of only 30-minutes before reverting to oxygen.

Advantages
- Effective at reducing dissolved methane concentrations in water.
- Enables the use of methane-containing well water.
- Reduces or eliminates biological growth within well water supplies.
- Destruction of methane gas reduces atmospheric gas emissions.

Disadvantages
- Does not address the cause of methane in water.
- Ozone is a hazardous substance that should not be ingested or breathed. Additional controls may be necessary.
- Can not be used on chlorinated water systems as ozone reacts with chlorine to produce the hazardous compound chloroform.
- Ozone generator relies on electricity.

Estimated Cost
Costs are dependent upon the existing infrastructure. Mitigating methane from a residential water supply that has an existing well pump would require the addition of a cistern, additional piping, ozone generator, diffusers, and a secondary pump totaling approximately $3,000. Mitigating methane impacts to a small pond may cost over $10,000.

Other Considerations
- Depending on geographical location, the cistern may need to be heated, housed in a heated shed, or buried to prevent freezing.
- Qualified personnel should be used to assess the effectiveness of ozone injection as well as to design a treatment system. Qualified professionals should be used to complete all installation activities.
- Ozone is not compatible with many common construction materials. Proper research should be completed to determine installation products.

Maintenance
- Water quality should be monitored at least quarterly.
- Frequency of air filter replacement will depend on operating environment.

(Keeton Industries, 2006)

MITIGATION METHODOLOGY
HORIZONTAL VENTING WELLS

Applicability
For use in collecting seeping methane gas to reduce impacts to structures, vegetation, water, air, and resource recovery.

Description
This system consists of slotted pipes that are installed in the Fruitland Formation (Kf) but installed horizontally parallel to the strike rather than vertically.[21]

The slotted pipe is manifolded to one or more surface vents. This technology is similar to the trench and cover horizontal vents but is installed using a horizontal drill rig.

Seeping gas is then captured by the slotted pipe and diverted through the pipe network toward the vent.

Once collected, the gas could be vented to the atmosphere, flared, or put to beneficial use.

Advantages
- This method limits surface disturbances as compared to trenching horizontal recovery systems.
- Can be used to monitor seep trends with the installation of a flow meter and datalogger on the vent stack(s).
- Gas can be collected for beneficial use if desired ultimately reducing atmospheric gas emissions.

Disadvantages
- Generally requires a very large system in order to be effective.
- May require multiple "lines" of horizontal pipes in order to increase capture efficiency across the outcrop.
- Installation activities are costly due to high-tech equipment requirements.
- May not entirely remove impacts from seep area.

Estimated Cost
From a study of horizontal drilling activity in Utah, costs range from $100 per foot to $200 per foot.[22] Costs vary greatly based on design considerations, depth, length, and location of installation.

Other Considerations
- System can be equipped to recover methane gas for beneficial use or flaring. Recovery of gas will require evaluation of additional issues such as mineral rights, gas storage, combustible gas safety, compression, transmission, flaring, and/or additional equipment needs.
- Pilot testing should be performed prior to full-scale implementation. Design and installation should be performed by qualified personnel.
- Methane detection system recommended to monitor performance of system when used to mitigate structures.

(Delft Hydraulics, 2006)

MITIGATION METHODOLOGY
PASSIVE/ACTIVE AERATION

Applicability
May be used as a mitigation measure to minimize or eliminate dissolved methane impacts to water. Specifically, aeration has been a proven technology for surface ponds and potable residential water supplies.

Description
"Aeration may be defined as the process by which a gaseous phase, such as air and water are brought in contact with each other for the purpose of transferring volatile substances to or from the water. These volatile substances may include, but not limited to ammonia, carbon dioxide, hydrogen sulfide, nitrogen, methane,… and other volatile organic compounds (VOCs), as well as various unidentified organic compounds responsible for taste and odor."[23]

Passive aeration of a well water supply consists of using the existing well pump to fill a plastic or concrete cistern or holding tank. Rather than filling the tank using a typical water line, the water is forced through spray nozzles located in the headspace of the cistern. The spraying effect allows the methane to escape from the water and vent to atmosphere through ventilation ports in the top of the cistern.[24]

Active aeration utilizes the same concept as passive aeration, with the added feature of re-circulating the water. Using the pump that delivers the water from the cistern to the endpoint, or using an added sump pump, standing water in the cistern is re-circulated on a timed basis. Agitation of the surface of the water alone is relatively effective at removing methane, but reintroducing the water through additional spray nozzles heightens the effectiveness.[24]

This concept can be applied to treating methane impacts on a larger scale. Many manufacturers offer complete aeration systems utilizing windmills, electricity, and/or compressed air for improving water quality in ponds.[25] These systems can be implemented to reduce methane impacts in water.

Advantages
- Relatively low-tech and low-cost.
- Effective at reducing methane concentrations in water from 26-30 parts per million (ppm) to 3-5 ppm.

Disadvantages
- Water storage using a tank presents additional problems, such as biological growth. The introduction of oxygen through aeration tends to contribute to this issue.
- Is not a proven method for effectively reducing extremely high concentrations of methane to a safe level.
- Does not address the cause of methane in water.

Estimated Cost
Costs are dependent upon the existing infrastructure. Mitigating methane from a residential water supply that has an existing well pump would require the addition of a cistern, additional piping, spray nozzles, and a secondary pump totaling approximately $600. Mitigating methane impacts to a small pond may costs over $5,000.

Other Considerations
- The introduction of chemicals, such as chlorine, can be used to control biological growth in the holding tank.
- Depending on geographical location, the cistern may need to be heated, housed in a heated shed, or buried to prevent freezing.
- Explosion proof electrical devices and location of the tank should be assessed by a professional due to the explosive nature of methane.

Maintenance
- Weekly chemical treatment of biological growth in the cistern may be required.
- Spray nozzles should be inspected weekly and cleaned on an as-needed basis due to buildup of calcium and other carbonates.
- Water quality should be monitored at least quarterly.

(Airmaster Aerator, 2006)

MITIGATION METHODOLOGY
MITIGATION BANK/CREDITS

Applicability
May be used to offset impacts to structures, land, vegetation, and surface waters via compensatory obligation, construction of like habitats, or purchase/sale of mitigation credits.

Description
This methodology is simply conceptual at this stage of the evaluation. The use of mitigation banks is very common in the wetlands mitigation arena. In wetlands mitigation, a mitigation bank is a wetland, stream, or other aquatic resource area that has been restored, established, enhanced, or (in certain circumstances) preserved for the purpose of providing compensation for unavoidable impacts to aquatic resources permitted under Section 404 or a similar state or local wetland regulation.[27]

This approach may be viable in mitigating impacts from methane seeps. As impacts from methane seepage occurs, the established mitigation bank can offset the impacts by having land available for construction as a wildlife preserve, construct new forests, wetlands, or other habitats.

One other method of implementation could be to mitigate a specific seep area directly on the outcrop using an engineered mitigation alternative rather than establishing a wildlife preserve or manufactured habitat. In turn, the developer could build credits toward mitigating seep areas that cannot be readily mitigated.

The approach could also be used to buy and sell mitigation credits. The developer of a mitigation measure or bank that is more extensive than required could sell mitigation credits.

Advantages
- Reduce uncertainty over whether the compensatory mitigation will be successful in offsetting observed impacts.
- Provide more cost-effective compensatory mitigation opportunities.
- Enable the efficient use of limited agency resources in the review and compliance monitoring of compensatory mitigation projects because of consolidation.
- Low tech method with long life and low maintenance.

Disadvantages
- May not repair damage created.
- May not remove hazards to existing structures.
- Will require independent party to manage the bank/credits.
- May not mitigate loss of resource to the atmosphere.
- May not meet objectives of impacted landowners.

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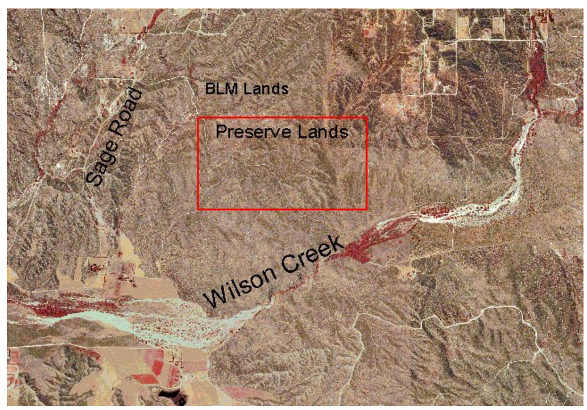
Estimated Cost
Costs associated with this technology are difficult to assess at this time. Additional evaluation of the potential mitigation strategy would be required to yield cost estimates.

Other Considerations
- Will require legislative development and regulatory oversight.
- Establishing wildlife protection areas in mitigation banks may be useful.
- A weighted ratio requirement (i.e. 5 acres of mitigation banks required to offset 1 acre of methane impact) may be useful.



(USACE)

MITIGATION METHODOLOGY
MITIGATION FUND

Applicability
May be used to provide a financial resource to offset impacts to structures, land, vegetation, and surface waters through monetary compensation.

Description
This methodology is conceptual at this stage of the evaluation. The fund could be established in a manner similar to the Environmental Response Fund (ERF) that receives money through taxes, fees, or royalties of oil & gas production in the San Juan Basin.

The fund would then be available to finance mitigation efforts. The fund may be used to provide financial compensation to impacted parties or used to fund the pilot-testing or full-scale implementation of an engineered mitigation alternative.

Advantages
- Spreads costs among multiple parties.
- Provide assurance to those with the potential to be impacted by methane seepage that their interests will be protected.
- Low tech method with long life and low maintenance.

Disadvantages
- May not achieve any of the objectives unless money from the fund is used to implement one or more of the mitigation alternatives.
- Will require independent party to manage the fund.
- May be difficult to establish criteria for disbursement.
- May not meet objectives of all affected parties.
- Methodology may promote abuse among potential recipients.

Estimated Cost
Costs associated with this technology are difficult to assess at this time. Additional evaluation of the potential mitigation strategy would be required to yield cost estimates.

Other Considerations
- May require legislative development and regulatory oversight.
- The use of an insurance policy may be applicable to reduce costs.

MITIGATION METHODOLOGY
SURFACE WATER BODY LINER/SEALING

Applicability
For use where possible methane impacts are within surface water bodies.

Description
This methodology incorporates the use of a barrier or liner to prevent the seepage of methane into surface water bodies.

The surface water body would be drained or diverted to facilitate the installation of a liner or barrier layer. Piping could be added around the perimeter of the liner to collect and control the gas emission.

Once installed, the barrier would divert methane gas around the surface water body preventing impacts to the water and wildlife habitats.

Advantages
- Can be effective in keeping methane gas from impacting surface water bodies.
- Requires very little maintenance to keep the seal intact.
- Low tech method that does not rely on electricity.
- Provides a method to reduce impacts to wildlife habitats.

Disadvantages
- May be difficult to divert large streams/rivers.
- Will cause significant surface disturbance to implement.
- May require enhancements or a long period of time to reestablish aquatic and biologic habitat once installed.

Estimated Cost
Cost is dependent on the size of the surface water body requiring mitigation. Lining small ponds may range in cost from \$10,000 to \$50,000.

Diverting large streams and lakes may cost more than \$500,000.

(Everliner, 2006)