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Investigation Of Stressed And Dying Vegetation At Evans Ranch, Weld County, Colorado

Final Report

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Risk Assessment - Toxicology - Ecological Studies
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1.0 Introduction

The site is located in Weld County at the intersection of County Rd. 18 and 19. Several natural gas pipelines occur adjacent to the site. On August 29, 2009, Mr. Robert Chesson of Colorado Oil and Gas Conservation Commission (COGCC) and a subcontractor, Dr. Carolyn Fordham of Terra Technologies Environmental Services, LLC, visited the site and interviewed the land owner. Figure 1 shows the locations observed throughout the affected property. A neighboring prairie dog colony was found to be abandoned. Red cedars along the fence line were highly stressed as indicated by red/brown leaves. A tree in the yard southwest of the intersection was chlorotic, and nearly all growth was dead or dying. Nearby, a large bed of iris was stressed and the leaves dying back. In the northeast corner of the property nearest the pipelines, all vegetation, including grass and a rosebush, were dead. Many trees in the yard south of the pipeline and west of Road 19 had lost their crowns. Vegetation directly on top of the pipeline was stressed and dead from the corner of Road 18 and 19 westward several hundred feet. Natural gas could be smelled at the corner. It was noted during the site visit that a patch of onions near Road 19 was also stressed. The purpose of this investigation was to determine, if possible, if natural gas was the cause of the phytotoxicity.

Figure 1. Site Location Showing Sample Locations and Sample Numbers

2.0 Site Characteristics and Ecological Setting

The site setting is located in Weld County and has been described as exhibiting phytotoxicity to 'select' species (i.e., red cedar, iris and others) while others (cottonwood) remain unharmed. However, in the past many large cottonwoods along the road died. A soil gas survey to identify and evaluate possible methane gas impact on the Evans property was conducted by the COGCC on November 5, 2007, but results were negative.

The affected species are very different in their rooting and growth characteristics. Red cedar is an evergreen which has a singular tap root system, while cottonwoods tend to develop significant surface-located 'root flair' systems. If natural gas is the source of the phytotoxicity, it is possible that the red cedar trees have tapped into water yielding fissures that also act as the conduits for gas or methane transport. The shallower vadose zones where cottonwood roots reside may be more aerated. Cottonwoods also have a more elaborate root structure that allows for a certain amount of root disturbance without having lethal effect, whereas cedar has a singular root.

Iris have a bulb and a shallow root system, and yet were observed to be stressed. It is possible, therefore, that root characteristics do not determine susceptibility to whatever is causing stress. In addition, iris are salt-sensitive, and heavy fertilization can cause salt toxicity. Iris are also sensitive to fluorine, and phosphorus fertilizers are not recommended. Excess manganese should be avoided.

Natural gas is suspected to be the primary stressor. Natural gas or methane concentrations may not be consistent throughout the soil, but follow pathways of least resistance such as utility lines. The nearby natural gas pipelines are very low pressure, however, and thus the only force for movement would be diffusion.

Other stressors may be present. Drought conditions have been common across Colorado for several years. Magnesium chloride is used on dirt roads as the dust suppressant in the summer. It is also used for ice control on paved roads in the winter. Trees can absorb soil magnesium chloride and accumulate it in leaves. Magnesium chloride is toxic to plants; foliar chloride is more closely tied to toxicity than magnesium, weakening or killing leaves which can lead to death of the tree (Goodrich and Jacobi, 2008). The symptoms appear as death or browning along the edges of deciduous leaves, or tip burn on conifer needles. As exposure continues, tissue death spreads towards the middle of the leaf or the base of the conifer needle. Early loss of leaves can occur. Typically, effects are more severe on older needles closest to the trunk, and sometimes the new needles or current season needles are unaffected. Drought, winter burn, herbicides, and dehydration can also appear as tip or marginal burning on tree leaves, and chloride toxicity can be made worse by drought stress (Goodrich and Jacobi, 2008).

3.0 Literature Review of Phytotoxicity of Natural Gas (Methane)

This section summarizes available literature describing the toxicology of natural gas to vegetation. The term phytotoxicity refers to toxic effects on vegetation. Both laboratory and field-derived studies were reviewed. The phytotoxicological effects documented within these studies are consistently similar, but dependent upon factors such as soil type, plant species, depth to groundwater, and persistence of the gas source (e.g. leak).

3.1 Natural Gas

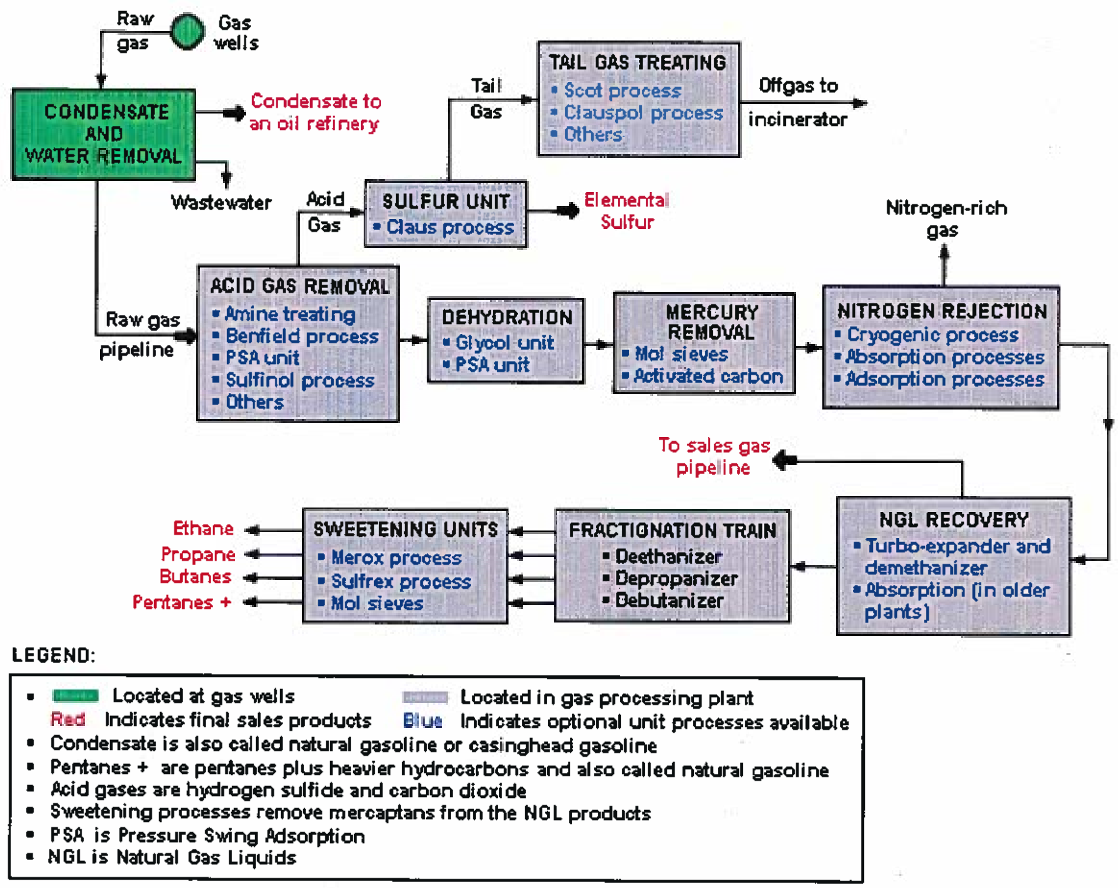
Natural gas is a gas consisting primarily of methane. It is found associated with fossil fuels, in coal beds, and is created by methanogenic organisms that break down organic material in settings such as marshes, bogs and landfills. Before natural gas can be used as a fuel, it must undergo processing to remove most all material other than methane. The by-products (Table 1) include ethane, propane, butanes, pentanes and higher molecular weight hydrocarbons, elemental sulfur and trace amounts of oxygen, helium and nitrogen. The process by which these by-products are removed is shown in Figure 2.

Table 1. Components of Natural Gas

Component	Typical Analysis (mole %)	Range (mole %)
Methane	95.2	87.0 - 96.0
Ethane	2.5	1.5 - 5.1
Propane	0.2	0.1 - 1.5
iso - Butane	0.03	0.01 - 0.3
Normal - Butane	0.03	0.01 - 0.3
iso - Pentane	0.01	trace - 0.14
Normal - Pentane	0.01	trace - 0.04
Hexanes plus	0.01	trace - 0.06
Nitrogen	1.3	0.7 - 5.6
Carbon Dioxide	0.7	0.1 - 1.0
Oxygen	0.02	0.01 - 0.1
Hydrogen	trace	trace - 0.02

Source: http://www.naturalgas.org/overview/background.asp

Figure 2. Schematic Flow Diagram of a Typical Natural Gas Processing Plant



Source: http://en.wikipedia.org/wiki/Natural_gas_processing

3.2 Effects of Natural Gas on Soil and Vegetation

Studies describing the toxicological effects to vegetation date back to the 1920's. The most recent efforts no longer focus upon the toxicology, but rather upon the development of remote-sensing detection methods based upon vegetation impacts (NETL, 2004; Nooman, 2007). The following provides a summary of the general soil impacts, phytotoxicological effects, recovery times, recovery methods and methods to detect natural gas impacts.

In general, natural gas displaces the soil air and the oxygen shortage causes changes in vegetation survival and growth. Natural gas leaks are often accompanied by elevated carbon dioxide concentrations due to bacterial methane oxidation. A step-wise summary of soil changes that occur in response to a natural gas leak are summarized as follows:

- Normal soil atmosphere is displaced resulting in a decrease in soil oxygen (Schumacher, 1996). The critical oxygen level below which root growth stops is 15 to $20x10^{-8}$ g/sq cm/min (Smith, 1978; Visser et al., 1971).
- Soil oxygen may decrease further due to methanotrophic bacteria that oxidize methane thereby generating carbon dioxide and water (Hanson and Hanson, 1996). Bacterial oxygen depletion can range from 1.8 to 4.7% (as percentage of total soil air).
- Methane oxidation yields carbon dioxide as an end product. The energy liberated in the oxidation process may be used for the synthesis of bacterial cell material (Brown et al., 1964). The break-down process is:
    - CH_4 → Methane CH_3OH → methanol HCOH → formaldehyde HCOOH → formic acid CO_2 carbon dioxide
- The resulting anaerobic soil conditions change the pH and cause a drop of the redox potential (Eh) (Schumacher, 1996, Adams and Ellis, 1960).
- The low redox potential reduces the pH of alkaline soils and increases the pH of acid soils. These affected pH changes can mobilize trace elements such as manganese and ferric iron, and for near-surface carbonates (Schumacher, 1996).

Normal soil contains about 17 to 19% oxygen. Soil within the presence of natural gas leaks can plummet to almost 0% with carbon dioxide content at about 6 to 8% (Hoeks, 1972a and 1972b). The distribution of damaged soil around a gas leak showed that when methane was supplied for seven weeks to soil at a rate of 0.18 cu cm/min., an anaerobic zone existed over 10 m from the leak. After the leak was repaired, oxygen returned to the soil in the following times and amounts (Table 2):

Table 2. Soil Oxygen Concentration (Volume %) as Related to Distance from Leak and Time from Leak Repair. (Hoeks, 1972a)

Time from Leak Repair (Days)	Distance from Leak (meters)			
	0.5	1.0	4.0	8.0
0	0	1	6	16
25	10	11	12	16
50	12	13	13	16
75	15.5	16	16	18.5
100	18	17	17	19

The after-effects of gas leakage may persist for a considerable period. First, the lack of soil oxygen may cause plant injury and second, toxic components may be left in the soil as reduced inorganic substances (e.g., Fe^{2+}, Mn^{2+}, and S^{2-}) or organic acids (butyric, propionic) as well as the organic chemicals formaldehyde and methanol, which are also toxic to plants (Smith, 1978).

Most plants need oxygen for respiration of the roots and for proper uptake of water and nutrients (Drew, 1983). Soil oxygen shortage leads to reduced root and shoot growth. The reaction of plants to oxygen shortage depends upon duration and species. The process is exacerbated when bacterial oxygen depletion occurs from the methane decay process. High soil carbon dioxide disrupts root respiration and can cause acidification of ground water. Field studies have shown a decrease in leaf 'greenness' as well as decreases in shoot and root growth (Nooman, 2007). The pH changes in the soil can cause mobilization of possibly phytotoxic elements such as manganese and aluminum. Adams and Ellis (1960) suggest that the increased manganese found in gas-saturated soil could reach toxic levels for plant growth. Godwin et al. (1990) showed that up to a distance of 9 m from a leaking gas well, manganese increased 5 to 10-fold, approaching toxic levels. It is not known if methane gas affects the plants. It has been assumed that the secondary effects (loss of soil atmosphere, pH change, mobilization of metals) are the toxic contributors.

Typical characteristics observed in vegetation exposed to natural gas include yellowing of leaves (chlorosis), early fall of leaves, restricted growth, failure of reproduction, and change in vegetation diversity and cover. Pysek and Pysek (1989) tested 35 plant species and nearly all showed a moderate to strong reduction in growth. Many did not flower or reproduce. Vegetation stress and mortality are standard observations used by NTEL to identify pipeline leaks (NTEL, 2007).

3.3 Determining Cause of Phytotoxicity

Methods by which to test the nature and extent of possible leak impacts include the measurement of soil pH/Eh. As per the literature review, it appears that effects to soil pH could be measurable even after the source is removed. It is also possible to use remote-sensing tools such as those described by NTEL and others, if aerial images are available that bracket the time when the leak began. Determining that natural gas is present and other factors (e.g., pests, road salts) are not the cause of stress is also helpful.

It is known that natural gas in soil affects vegetation health which may be detected through analysis of reflectance spectra. Gas leaks can cause changes in vegetation reflectance as early as two weeks after gas leakage starts (Nooman, 2007). The reflectance of healthy vegetation in the visible light spectrum is characterized by absorption features caused by plant pigments such as chlorophyll and carotenoids, while the near infrared (NIR) and shortwave infrared (SWIR) are characterized by four major water absorption features (Nooman, 2007). A typical feature of healthy vegetation is the high reflectance in the NIR between 800 and 1100 nm which is dependent on the internal leaf structure and leaf area. Nooman observed that a 'decrease in leaf area' is the clearest indication that plants are affected by gas leakage.

Other methods have relied upon measuring 'changes in mineralogy' using magnetism, electricity and radioactivity (Schumacher, 1996; Smith and Rowe, 1997; Ellwood and Burkart, 1996; Aldana et al., 2003) while Wagner et al. (2002) describe a microbial prospecting method that could separate methane-oxidizing bacteria from higher hydrocarbon oxidizing bacteria.

3.4 Remediation of Natural Gas in Soil

Remedy of natural gas leaks has been described by Hoeks (1972b) as being best accomplished by physical means. Hoeks (1972b) suggested that auger holes be drilled around plants in the vicinity of leaks; one 70-cm deep, 25-cm diameter hole can remove 5 to 50 liters of gas per hour. He emphasized that replanting should wait until soil oxygen is above 12 to 14% in areas where plant mortality has occurred. Once the anaerobic conditions have been controlled, it has been observed that the setting can now contain an abundance of carbon-containing material which can act like a fertilizer to the setting so long as other toxic constituents are at a minimum (Adams and Ellis, 1960).

4.0 Methods For Current Phytotoxicity Study

The landowner was interviewed. It was determined that adverse effects appeared recently, within the last 4-8 weeks. Iris were full grown but not blooming, and red cedar had growth from this season, which supports a time-frame of July-August. A strong odor of methane could be smelled at the corner, suggesting a current release. Additional pressure testing of the Machii-Ross natural gas gathering pipeline identified several leaks on the line at the location of the intersection of WCR 18 and WCR 19. The leaks were repaired in late September 2009 and the line tested to approximately 60 pound per square inch (PSI), which is around five times the normal gathering line operating pressure, and the line returned to operation.

Methane readings were taken in prairie dog burrows (6-12 inches from burrow entrance), throughout the yard, and inside the house with a four way gas meter (Figure 1). No methane was detected. Methane was detected at the north corner of CR 18 & CR 19. Five soil samples were collected for nutrient analysis by the Soil Testing Laboratory, CSU, Ft. Collins, CO. Soil locations were recorded by GPS. The objective of this sample collection was to compare areas obviously impacted by natural gas leaks to areas with stressed vegetation and to an onsite control. Nutrients, salt content, and physical measurements (i.e., pH) were performed. The samples were as follows:

Sample	Location
1	By dying red cedar
2	In iris bed
3	Reference area in far southwest corner of yard
4	By large dead cottonwood stump along road near prairie dog town
5	At corner above pipeline

Two plant samples from stressed vegetation (lilac, red cedar) were collected and sent to the Plant Diagnostics Clinic, CSU, Ft. Collins, CO. The objective of these data was to determine if a cause of stress could be determined (i.e., fungus, pests).

5.0 Results of Current Phytotoxicity Study

The soil results are reported in Table 3 and in Figure 3. It would be expected that if soil conditions were responsible for plant stress, that a trend would be observed for one of the measured parameters (i.e., lower or higher at affected areas than at the reference). The area identified as a reference sample in the southwest corner of the yard provides a "baseline" conditions location. There is no consistent trend in most of the measured soil parameters with respect to observed adverse effects. The following observations were made:

- Soil pH is slightly lower than reference at affected areas from the center of the yard (samples 1 and 2), but is higher than reference in affected areas outside the yard (samples 4 and 5). Thus, soil pH does not show a trend with respect to phytotoxicity. This suggests natural gas is not the primary stressor (see previous section 3.2. Soil pH would decrease if methane gas were the primary stressor).

- Salts and sodium adsorption ratio (SAR) are similar at the affected iris bed as the unaffected reference site, yet irises are stressed. This suggests that salts are not the stressor at least for these iris. Salts are higher at other locations; but all are less than 2 mmhos/cm (<2 dS/m). Plants are typically unaffected between 0 and 2 mmhos/cm (Cardon et al., 2007). SAR is the relative concentration of sodium to calcium and magnesium. A SAR near 5 or higher indicates that sodium sensitive plants are at risk. Salts in soils do not appear to be the cause of vegetative stress.

- Organic matter (OM) is higher at the stressed red cedar in the center of the yard than at the unaffected reference location. Organic matter is lower at other affected areas than the reference. Organic matter does not appear to show a trend in relation to stress.

- Most metals show no trend. Copper (Cu) is above reference for the center yard samples, but outside the yard copper concentrations are lower than reference. Iron (Fe) is above reference for the center yard samples and the cottonwood stump, but the iron concentrations from the corner where gas is leaking are lower than reference. Zinc (Zn) at the stressed red cedar is similar to reference, but all other locations are lower.

- Nitrogen (N), phosphorus (P), and potassium (K) vary, with some impacted locations higher than reference and some lower.

Only manganese (Mn) is above reference at all locations. Manganese is expected to be higher in areas with natural gas. However, the concentrations measured are not expected to be toxic to plants. The metals are well below USGS background (Table 3); note that this is likely an artifact of the sampling method used by CSU Soil Testing laboratory, which measures a bioavailable form with an ammonium bicarbonate-DTPA extraction as compared to the standard EPA acid extraction used by USGS.

Plant samples sent to the CSU Plant Diagnostics Clinic were evaluated microscopically. The lilac bush was determined to have powdery mildew. This mildew is endemic in Colorado. A fungicide should be applied (sulfur dust, funginex). The leaves should be raked and removed in fall to reduce spores. There are no pathogens on the stressed red cedar.

Table 3. Summary of Analytical Results for Soil.

Lab ID No.	Sample No. and Description	pH	Salts (Mmhos /cm)	Lime (%)	Texture Estimate	SAR	Organic Matter %	Nitrate (ppm)	Phosphorus (ppm)	Potassium (ppm)	Zinc (ppm)	Iron (ppm)	Manganese (ppm)	Copper (ppm)
H184a	1 - Stressed Red Cedar	6.3	1.6	Low	Sandy Loam	0.7	4.5	83	87.2	581	15.2	***14.8***	8.2	3.4
H185b	2 - Iris Bed	6.3	0.5	Low	Sandy Loam	0.2	2.8	3	37.4	445	10	***46.7***	5	3.4
H186c	3 - Reference Evans Yard SW	6.9	0.5	Low	Sandy Loam	0.1	3.5	6	21.2	309	12.2	***21.8***	2.5	2.9
H187d	4 - Cottonwood Stump by road	7.8	0.7	Low	Sandy Loam	0.4	1.8	6	15.6	218	1.2	***70.8***	10.2	1.9
H188e	5 - Corner Across Street	7.3	1.4	High	Sandy Loam	0.6	3.4	22	26.5	526	5	***13.3***	9	3
	Background[1]	--	--	--	--	--	--	NA	0.019	2	28	2	223	15

Footnotes

Date Received: 8/31/2009

Date Reported: 9/10/2009

County: Jefferson

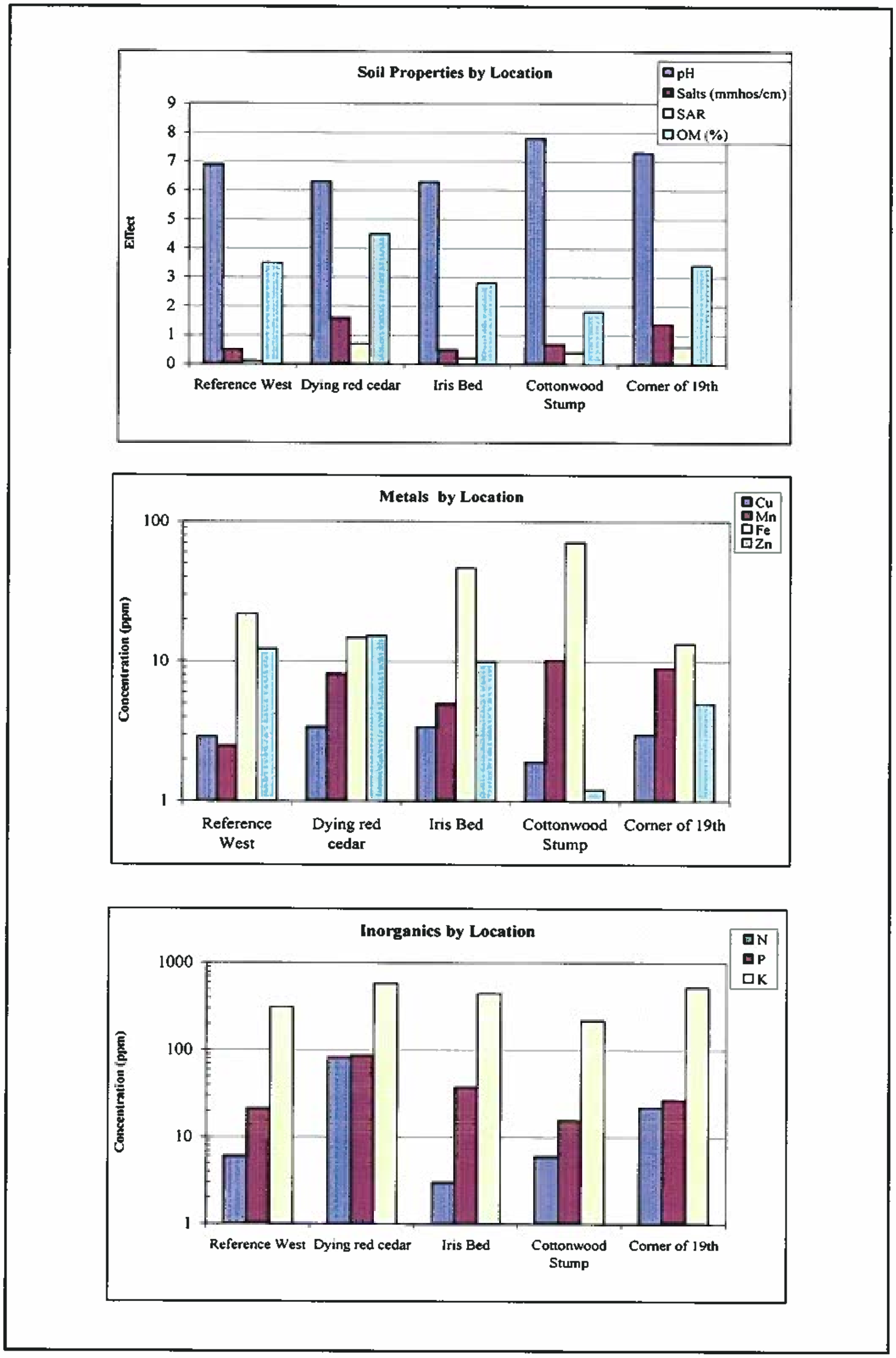
Chain of Custody: CC02584

Analysis completed by: CSU Cooperative Extension Service and Experiment Station; Soil, Water & Plant Testing Laboratory.

NA - Not available

1 - Average of total metals for three values for Weld County, CO. Source: Shacklette, H.T. and J.G. Boemgen. 1984. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. U.S. Geological Survey Professional Paper 1270. Washington, D.C. data online: http://tin.er.usgs.gov/ussoils/ussoils.xls

Figure 3. Measured Soil Properties, Metals, and Inorganics by Sample Location



6.0 Conclusions

The types of stress seen include dead vegetation, crown loss, grey foliage, and browning foliage. The grey foliage on the lilacs is definitively diagnosed as due to mildew. There is no conclusive diagnosis for the other stressed plants.

The dead vegetation in the northeastern corner of the yard resembles the opposite (north) corner which may be due to natural gas leaks previously discussed. Soil gas surveys in the yard; however, are generally negative or showing low concentrations. There is no obvious reason for plant mortality in the central yard, with the exception of the lilac, which has mildew.

Drought stress can take a similar appearance to plant stress due to natural gas and cannot be eliminated as a cause or contributing factor. Soils in the iris bed were observed to be very dry during the site visit.

One other potential source of stress not evaluated is magnesium chloride, used for dust suppression and ice prevention. Recent road construction was conducted. This could have led to disturbance of plant roots along the road, or it is possible that magnesium chloride was applied frequently during construction in order to keep dust to a minimum. The effects of magnesium chloride are similar to that of natural gas. They are not necessarily correlated with soil salt concentrations, but are more closely correlated with chloride concentrations in leaves. It is possible that magnesium chloride and dust blew onto the plant leaves producing toxicity. Magnesium chloride could also run off of the road into the patch of onions. Excess chloride concentrations are linked to decreased growth and browning of leaves. Different plant species exhibit widely different tolerances to salt concentrations, and tolerance to sodium chloride or calcium chloride does not correlate with tolerance to magnesium chloride (Kobayashi et al., 2004).

Goodrich et al. (2009) report high concentrations of soil magnesium and chloride (400–500 ppm), high foliar chloride (2,000–16,000 ppm), as well as high incidence of foliar damage along straight road segments for 3 to 6 meters (m) adjacent to treated roads. In addition, in drainages where water runs off treated roads, high concentrations of magnesium and chloride and foliar damage were measured at distances of 3 and 98 m from the road. Injury appears as browning, with progression towards the base, which are symptoms observed in the trees in the center yard. While the overall soil salts did not appear high (Table 3), leaves were not tested for chloride content. On dirt roads, most magnesium chloride damage occurs within 20 feet of the road (Goodrich and Jacobi, 2008). This could explain why trees closer to Road 19 are affected and those on the western side of the yard remain relatively healthy.

Recommendations are as follows:

- Treat lilacs for mildew by applying fungicide and raking leaves.
- Continue being alert for and monitoring natural gas leaks.
- Water plants regularly to prevent drought stress.
- If it is noticed that magnesium chloride is being applied to the road, spraying the trees with water after exposure might wash the salt off and protect the needles and leaves.
- Plant tissue chloride, magnesium, and boron could be measured and compared to reference samples if effects continue next growing season.

- Samples of remaining affected plants could be submitted for pathogen analysis at a cost of $10/sample.

- A copy of the recommendations for soil management from CSU is attached.

7.0 References

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Attachment 1. CSU Report.

Customer Name:	**Carolyn L Fordham**	**Colorado State University**
		Soil, Water and Plant Testing Laboratory
Lab Number:	H184a-H188e	Room A319, NESB
Sample ID Number:	1 dead red oak, 2 Evans, 3 reference Evans, 4 Evans 5 Evans	PHONE: 970-491-5061 / FAX: 491-2930
Date:	9/14/2009	

pH	Adequate for plant growth in all sites. An ideal pH is about 6.5; however, most Colorado soils have pH's greater than 7.0.
E. C. OR SALTS (Electrical Conductivity)	Low in all sites; salts are not a problem.
Lime Estimate	Low indicates less than 1% $CaCO_3$. Medium indicates 1 to 2% $CaCO_3$. High indicates greater than 2% $CaCO_3$.
Texture Estimate	Sandy soils drain at fast rates. Clay soils drain at slow rates. Sandy clay loams or clay loam soils drain at moderate rates.
SAR (Sodium adsorption ratio)	Low in all sites; sodium is not a problem.
O. M. (Organic Matter)	High in all sites; no additional organic matter is needed.
NO_3-N (Nitrate-Nitrogen)	High in # 1; no additional N is needed. Low in all other sites; add 3 lb. N per 1000 sq. ft.
P (Available Phosphorus)	High in # 1; no additional P_2O_5 is needed. Moderate on #2, #3, and #5; add 3 lb. P_2O_5 per 1000 sq. ft. Low in # 4; add 4 lb. P_2O_5 per 1000 sq. ft.
K (Available Potassium)	High in all sites; no additional K_2O is needed.
Zn (Available Zinc)	High in all sites; no additional Zn is needed.
Fe (Available Iron)	High in all sites; no additional Fe is needed.
Mn (Available Manganese)	High in all sites; no additional Mn is needed.
Cu (Available Copper)	High in all sites; no additional Cu is needed.
Additional Comments:	

APPROVED ____________________

TITLE Extension Soil Testing Specialist