APPENDIX S

Pipeline Temperature Effects Study

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Appendix S Pipeline Temperature Effects Study

TransCanada Pipeline, LP (Keystone) has assessed how the proposed 36 inch 900,000 bpd pipeline will affect soil temperatures along the proposed route. The assessment considered the following factors:

(a) Temperature of the proposed pipeline, including variation with time and/or distance along the route.

(b) Heat flux from the proposed pipeline into the surrounding soil, including variation with time.

(c) Expected changes to soil temperature profiles, including variation with time and distance from the pipeline.

(d) At what distance from the pipeline will elevated soil temperature be undetectable?

(e) How many acres of land in total will experience significantly elevated soil temperatures?

(f) How will crops and vegetation be affected by any increased temperature?

(a) **Temperature of the proposed pipeline, including variation with time and/or distance along the route.**

Steady-state temperature profiles were modeled for the Keystone XL Project (Project) for winter and summer operations at 900,000 barrels per day (bbl/d) (**Figure 1**). These profiles are based on assumed oil properties, as well as soil temperatures and thermal conductivities along the pipeline route. The analysis assumes that the pipeline ships 80 percent diluted bitumen and 20 percent synthetic crude.

In general, temperatures of the pipe exterior are higher in the summer months than in the winter months due to the ambient air and soil temperatures. Similarly, temperatures generally increase as volumes increase.

(b) **Heat flux from the proposed pipeline into the surrounding soil, including variation with time.**

A series of heat flux were calculated using a one-dimensional shape factor model that is based on the calculated steady-state pipe temperatures provided in response a) above, and the undisturbed soil temperatures and thermal conductivities at pipeline depth along the route. (**Figure 2)**. These figures are based on a thermal conductivity profile along the Project route.

Although the temperatures of both the soil and the oil in the pipe are higher in summer than in winter, the steady-state heat flux is not expected to vary much throughout the year since it is proportional to the difference between the pipe and soil temperatures, and this difference does not vary much at different times of year (i.e., when soil temperatures are higher, so are flowing temperatures within the pipe).

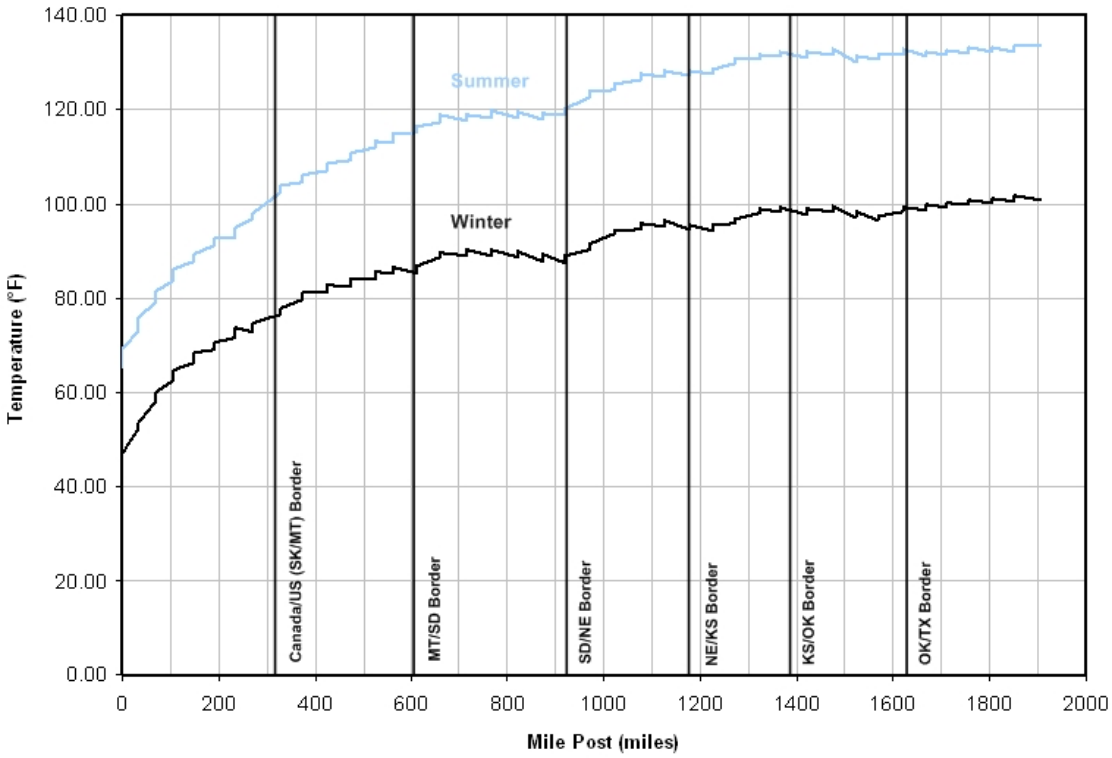


Figure 1

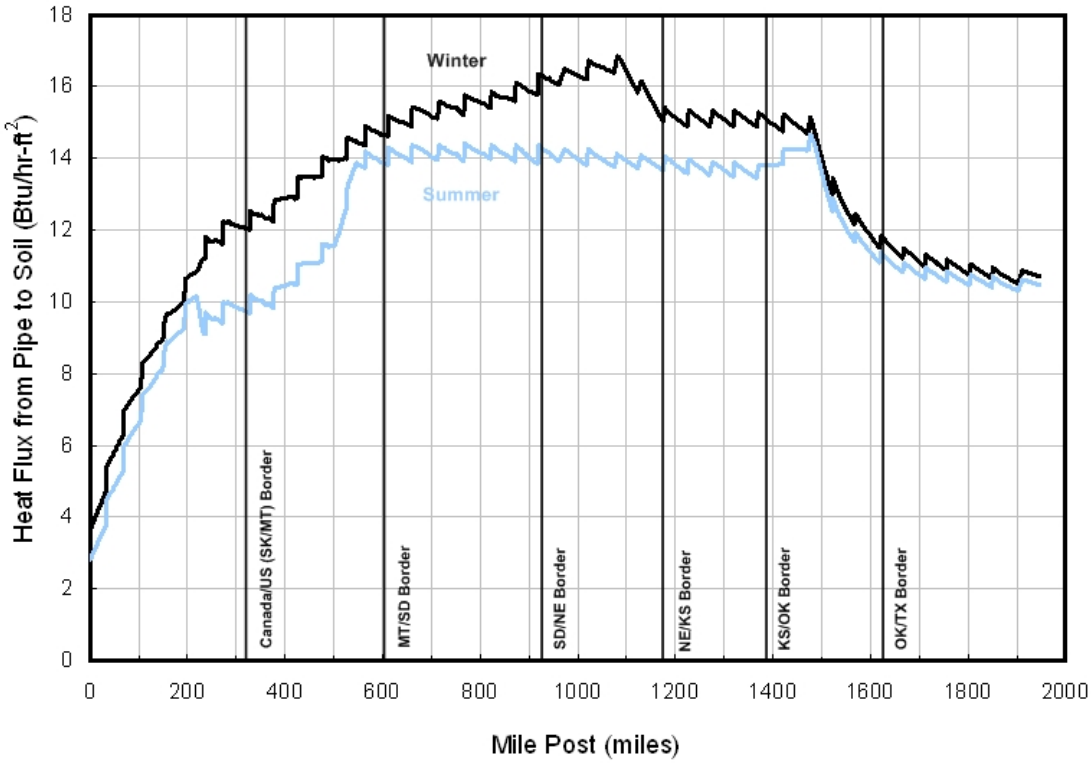


Figure 2

(C) **Expected changes to soil temperature profiles, including variation with time and distance from the pipeline.**

Baseline soil temperatures were developed using long-term climate and soils data from the following locations:

- Near Glasgow, Montana;
- Near Sioux Falls, South Dakota;
- Near Lincoln, Nebraska;
- Near Wichita, Kansas;
- Near Oklahoma City, Oklahoma; and
- Near Houston, Texas.

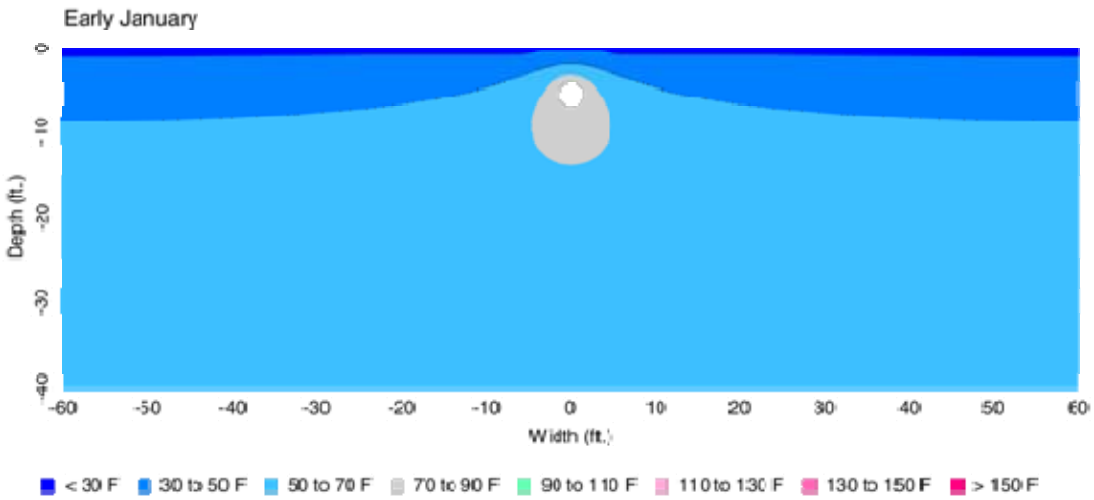
The anticipated, year-after-year, pipeline temperature variations for the 900,000 bbl/d cases provided in the response to part a) above were also utilized.

These areas of the pipeline route were selected for comparative review since an abundance of climate and soils data was publicly available to support the analyses. These temperature data are representative of the temperature profile along the pipeline route:

Temperature Contour for 900,000 bbl/d

Figures 3 through **32** show the temperature profiles around and alongside the pipeline operating at 900,000 bbl/d for selected months. As shown in the figures, the pipeline does have some effect on surrounding soil temperatures, primarily at pipeline depth. Surficial soil temperatures relevant to vegetation are impacted mainly by climate with negligible effect attributable to the operating pipeline. The thermally influenced contour intervals are represented by colored contours, the corresponding temperatures are shown at the bottom of the figures.

Glasgow, Montana Figure 3 to Figure 7:



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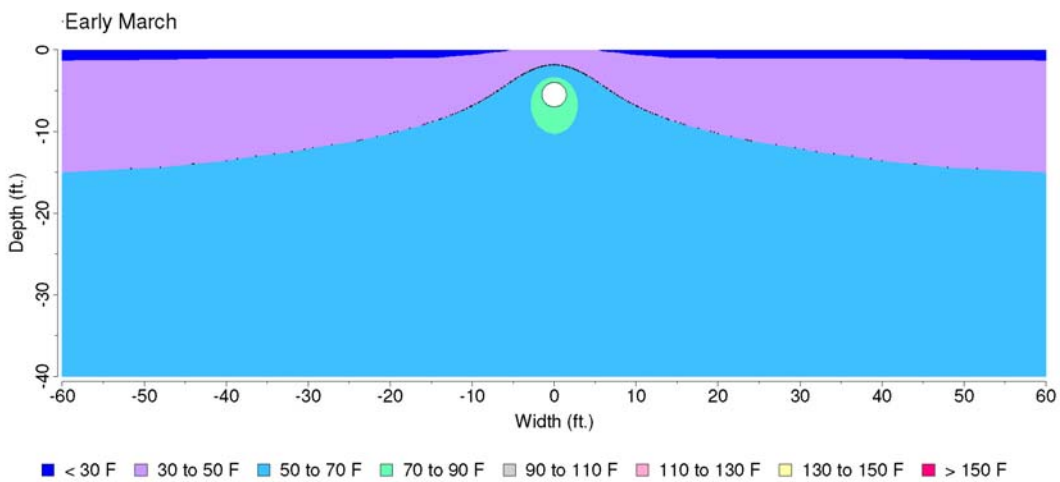

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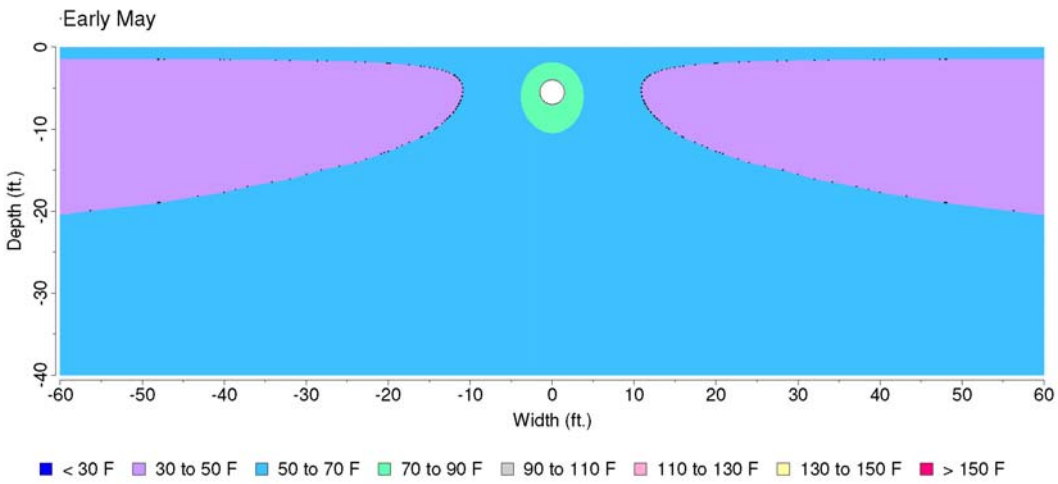

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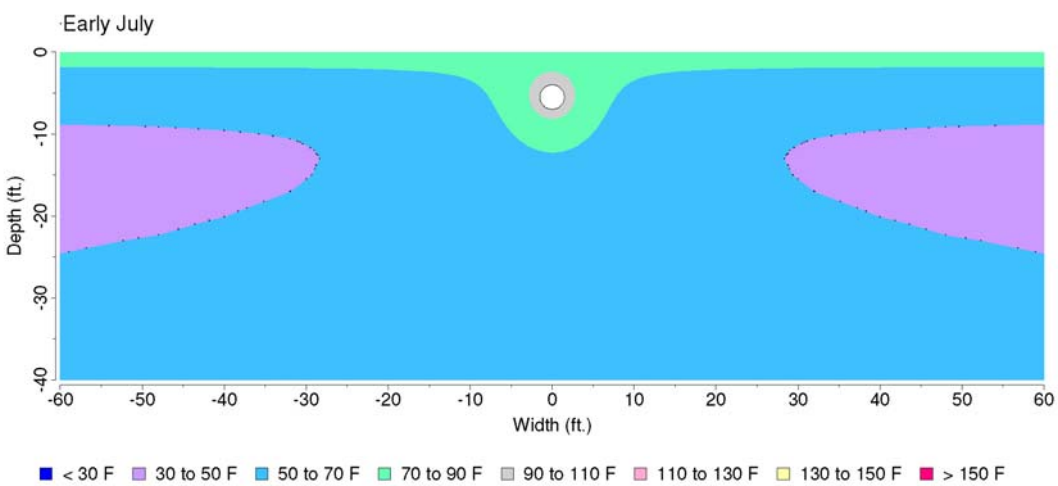

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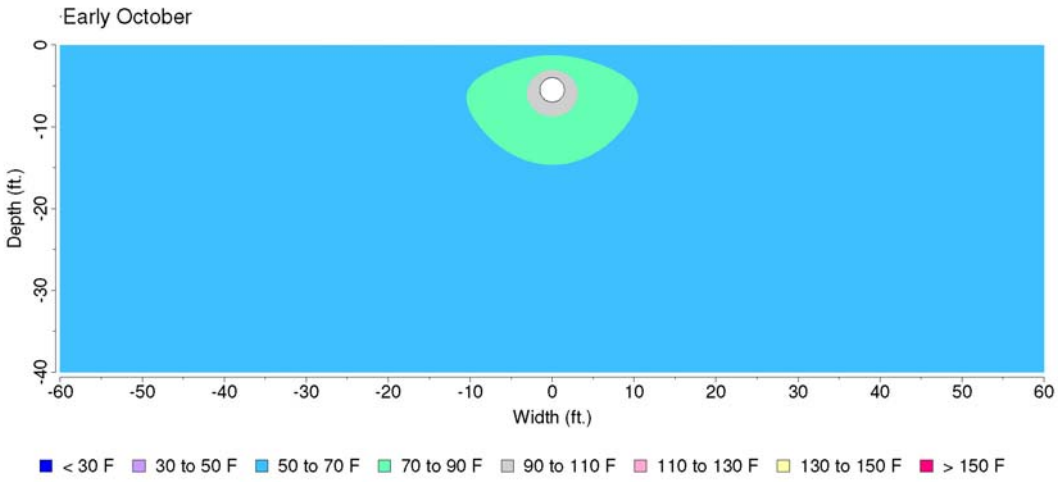
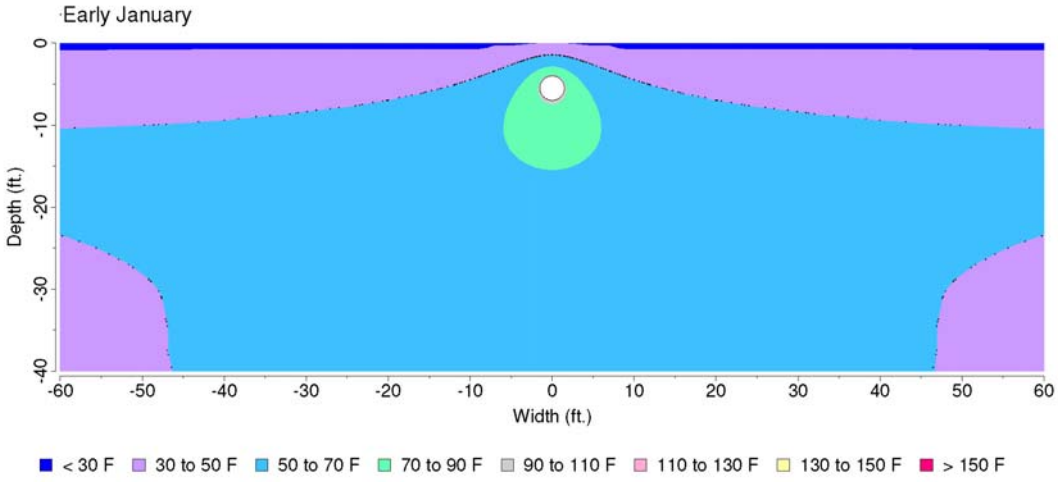


Figure 7

Sioux Falls, South Dakota Figure 8 to Figure 12



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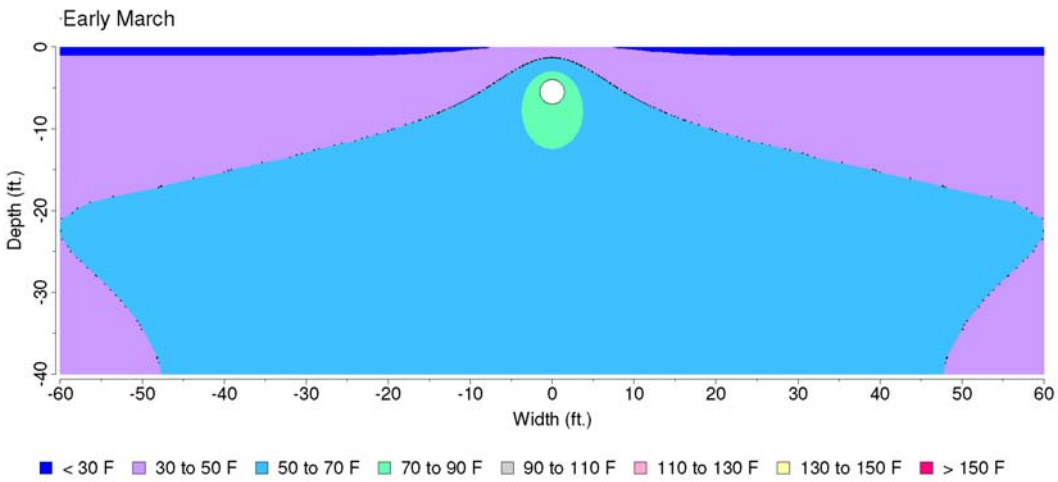

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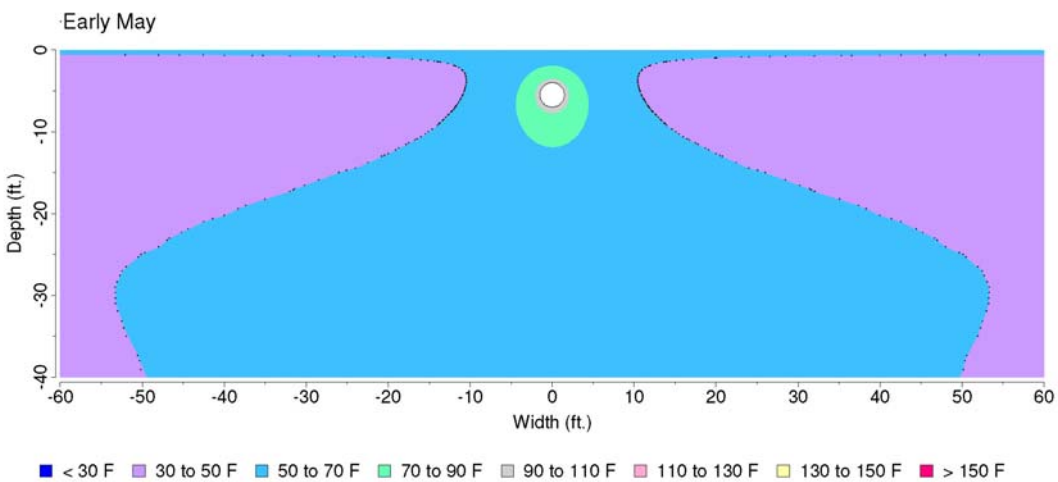

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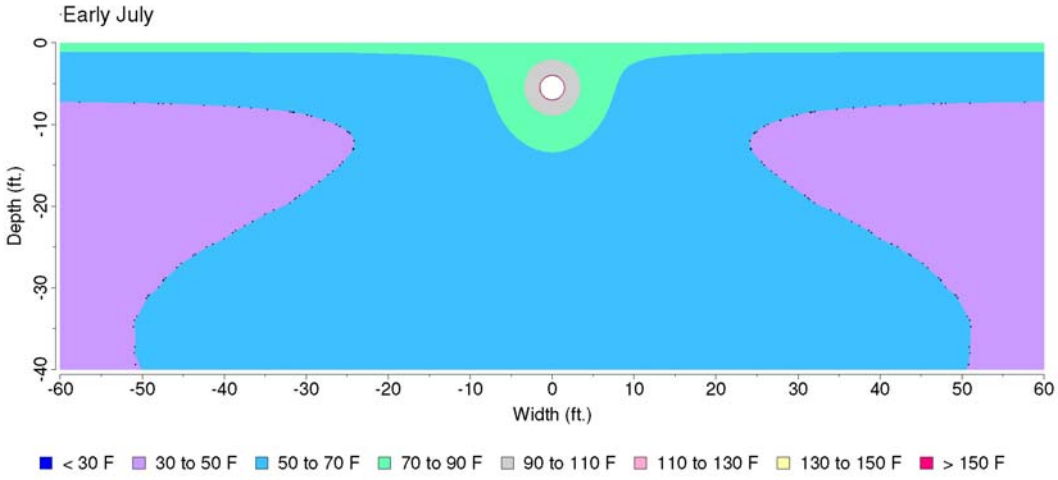

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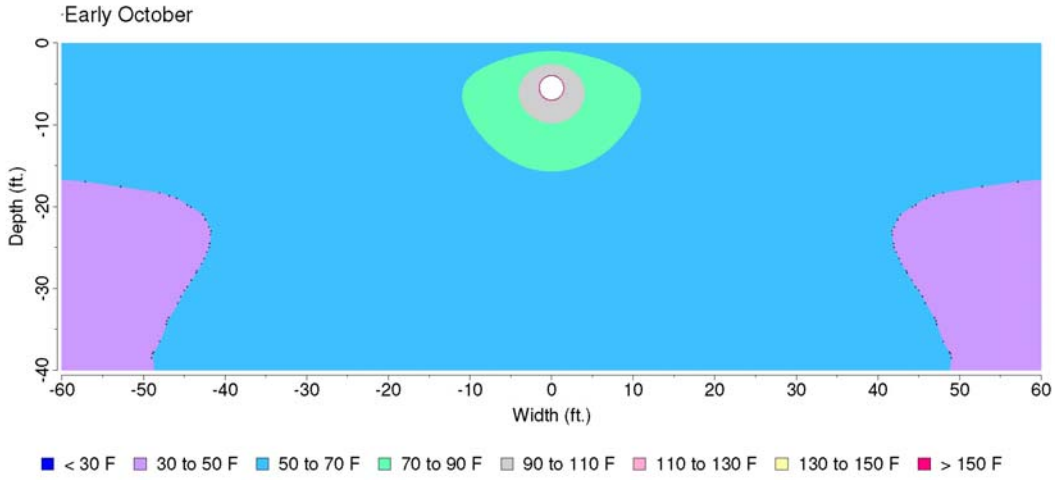
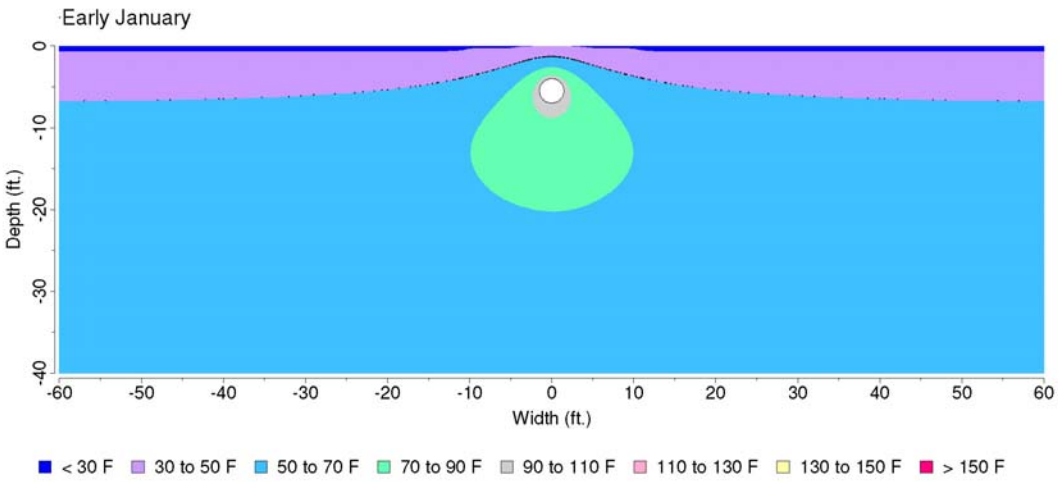


Figure 12

Lincoln, Nebraska Figure 13 to Figure 17



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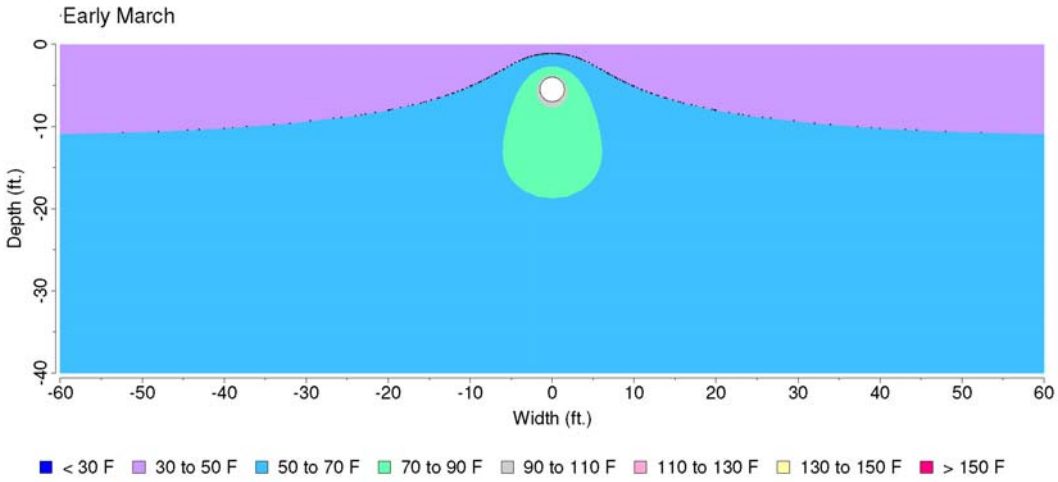

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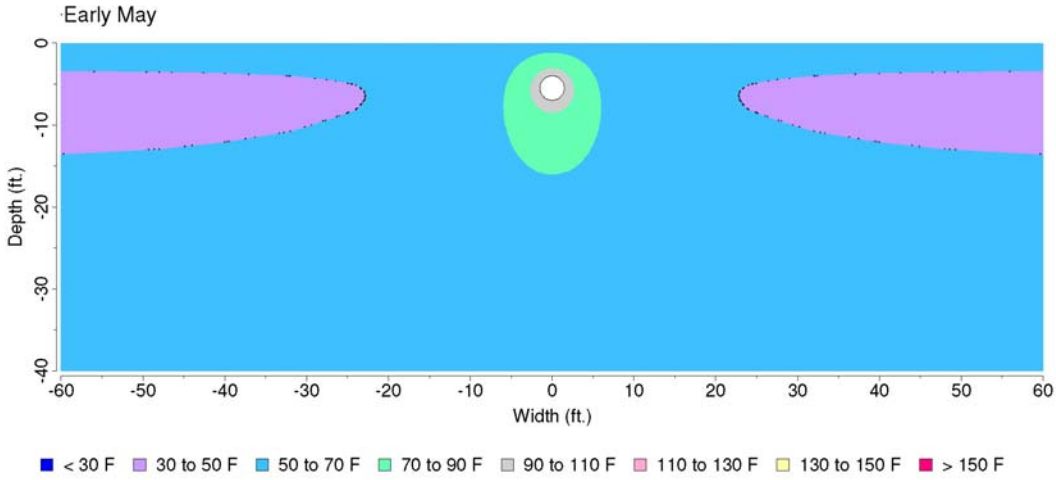

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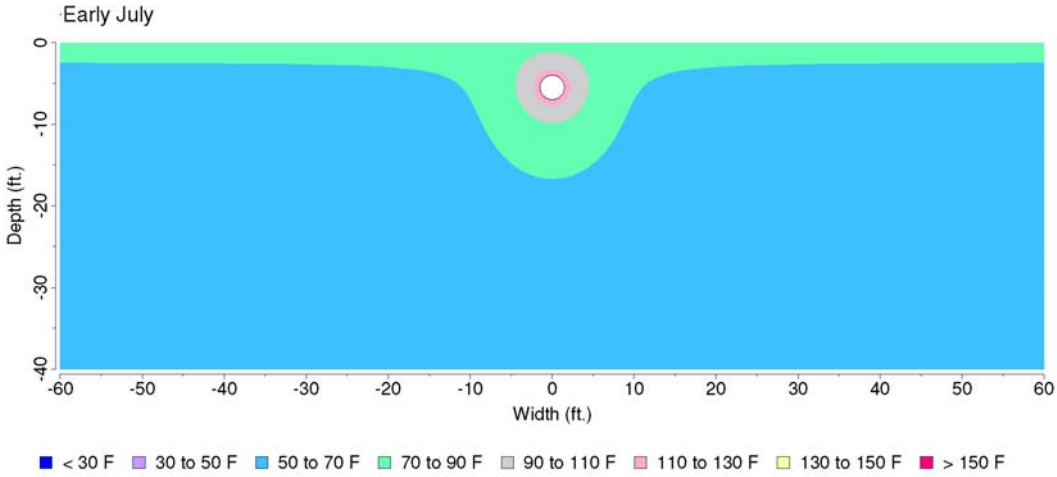

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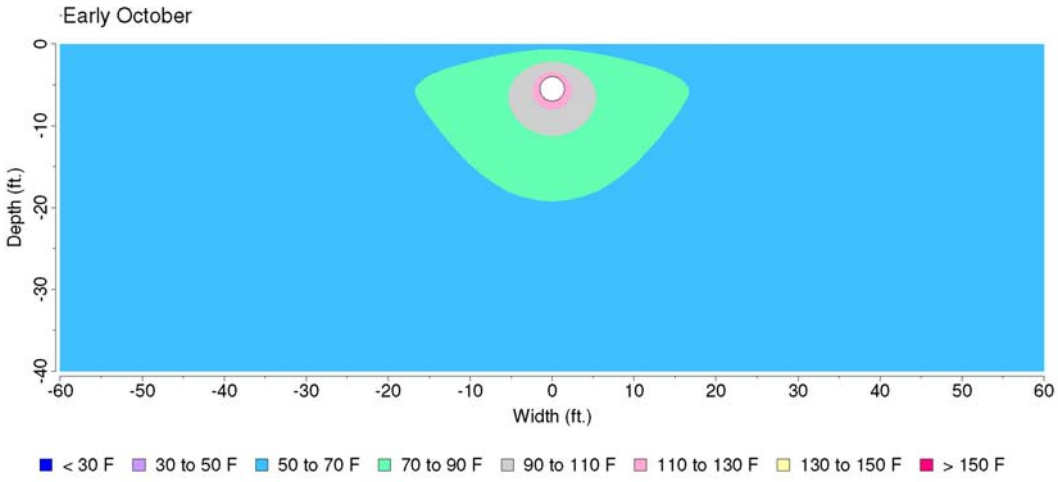
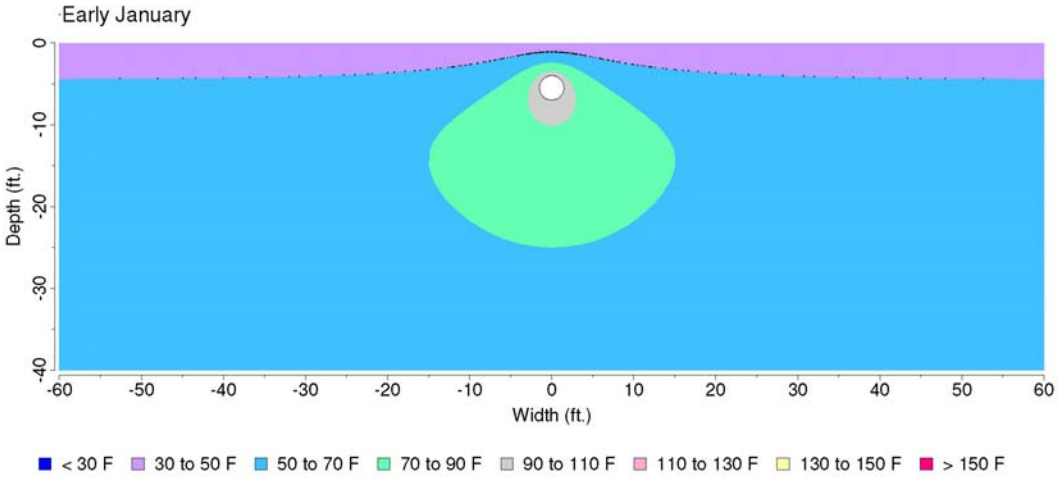


Figure 17

Wichita, Kansas Figure 18 to Figure 22



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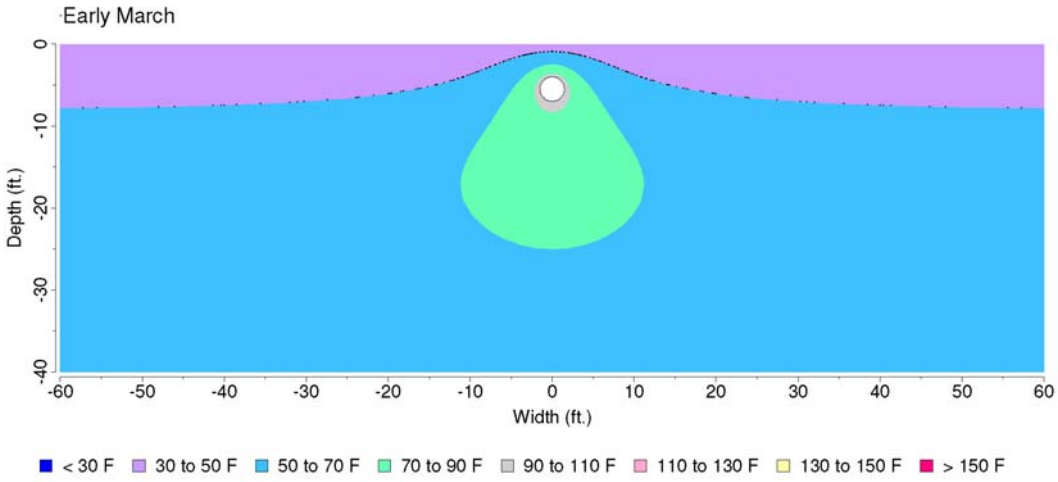

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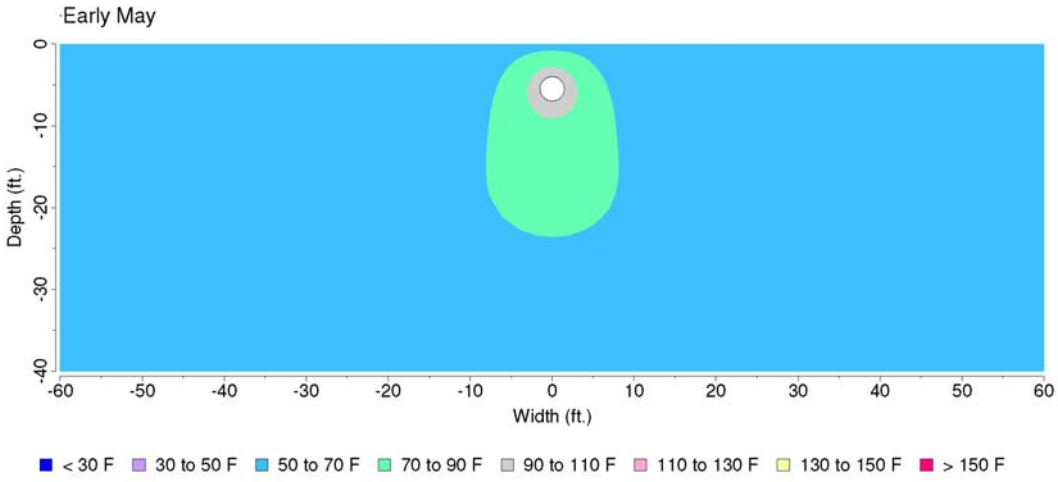

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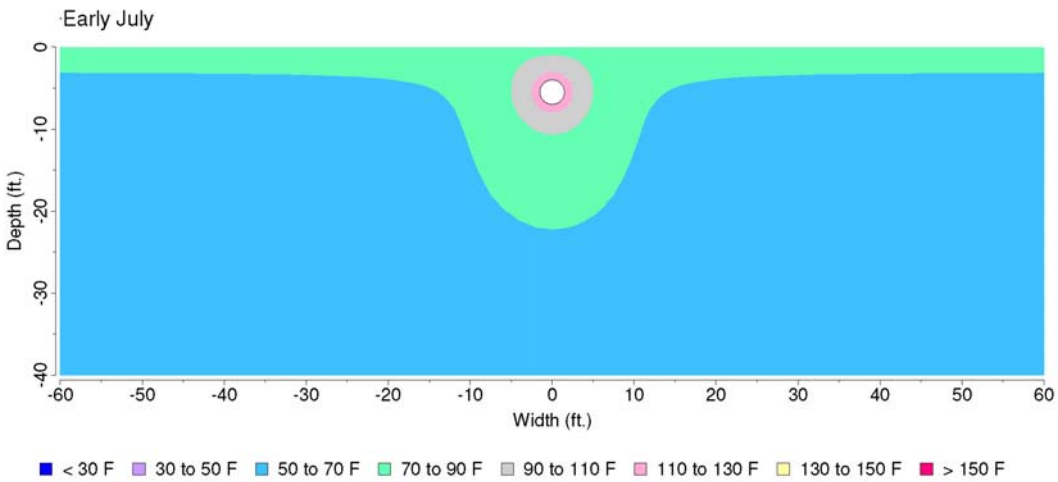

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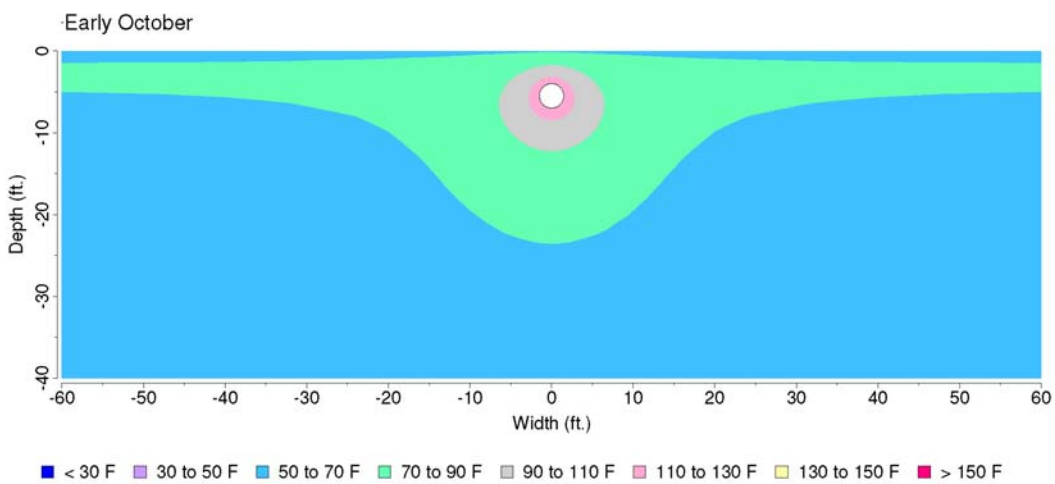
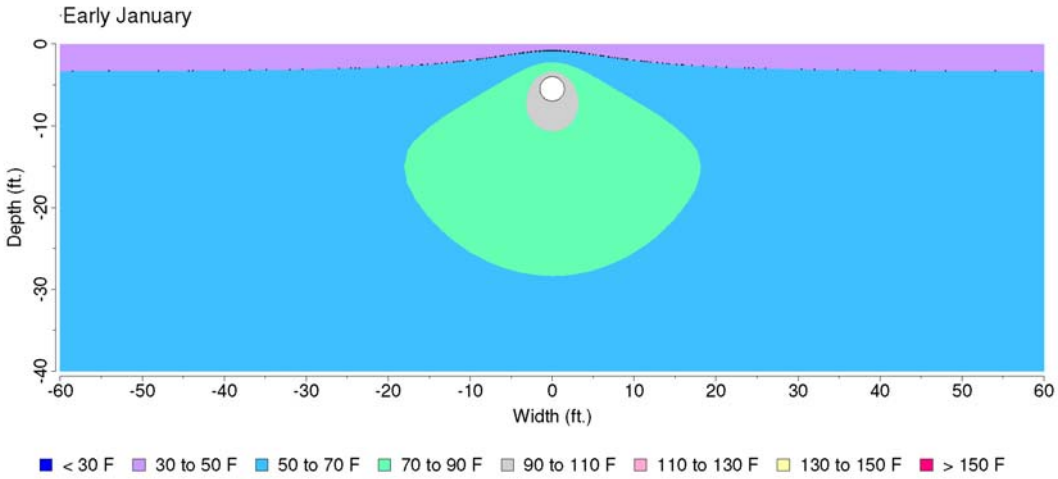


Figure 22

Oklahoma City, Oklahoma Figure 23 to Figure 27



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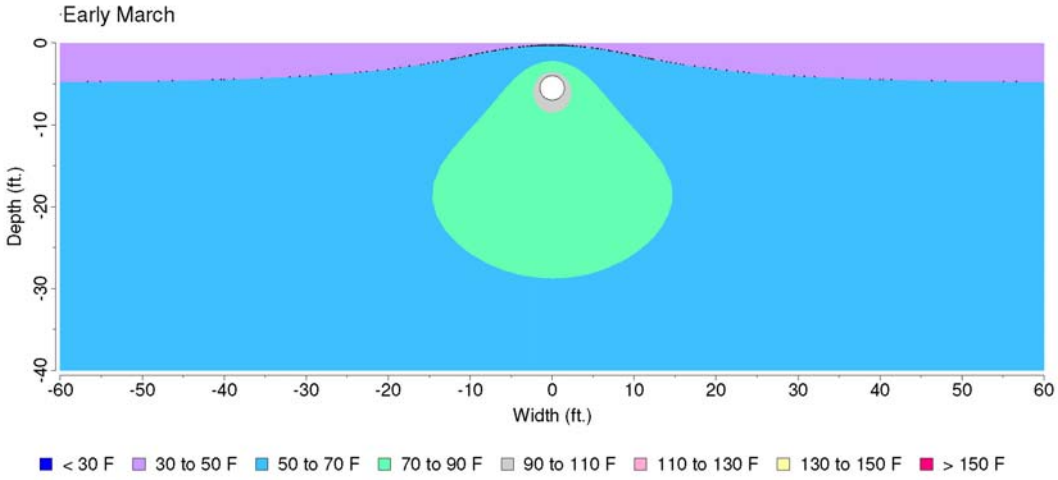

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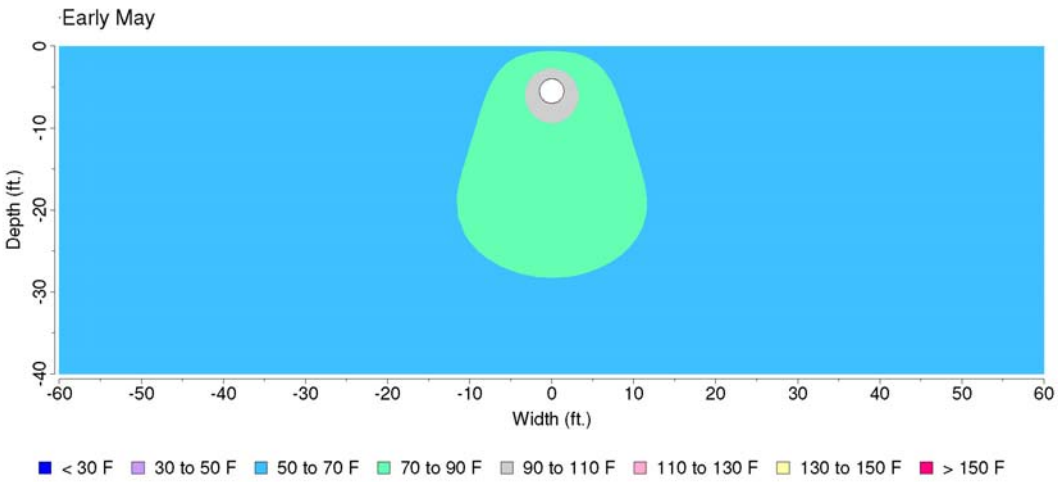

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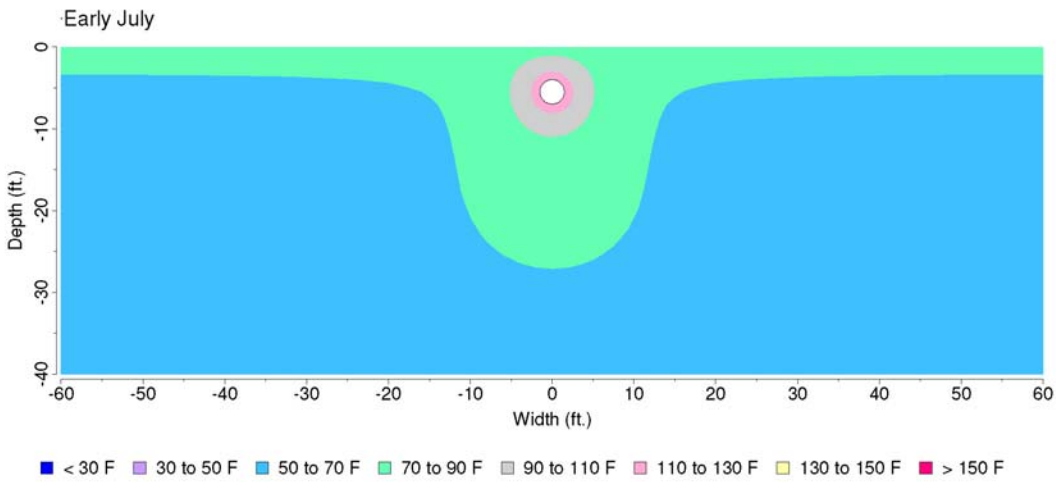

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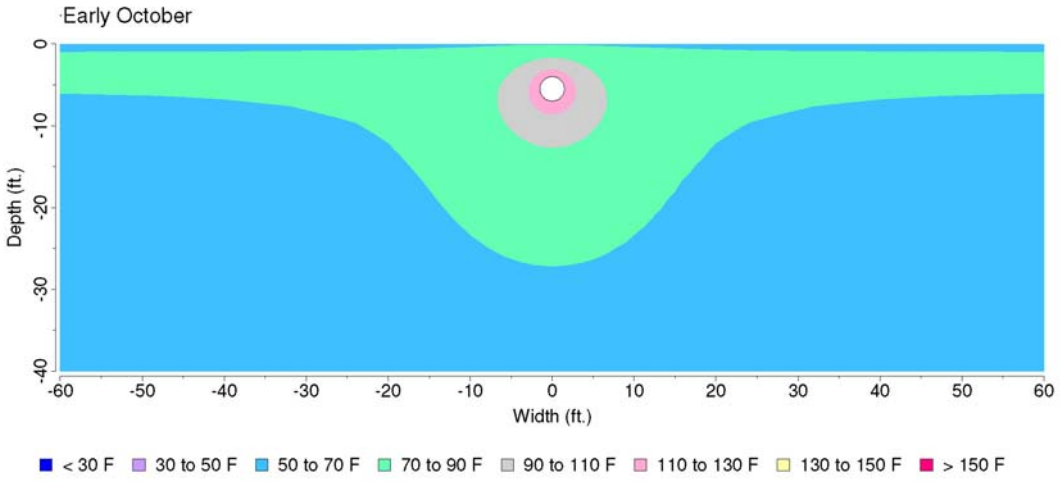
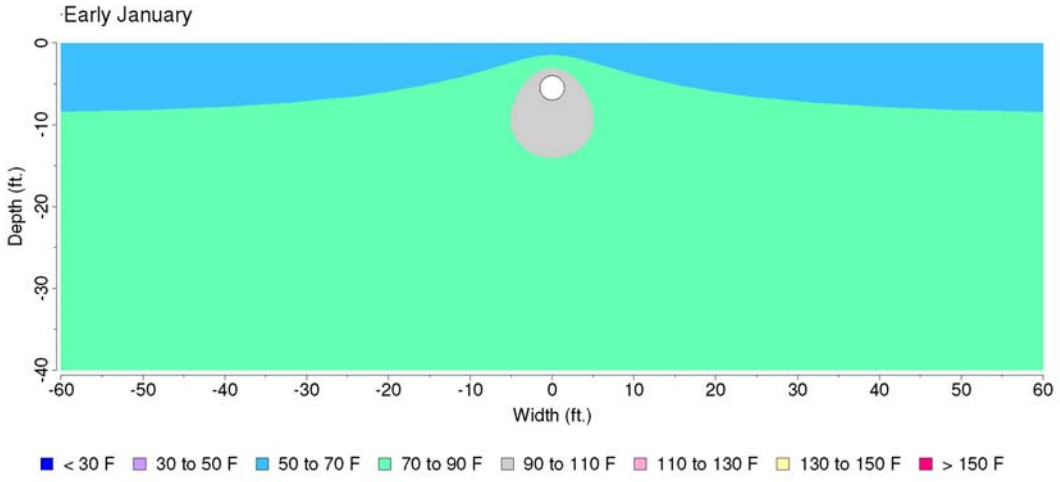


Figure 27

Houston, Texas Figure 28 to Figure 32



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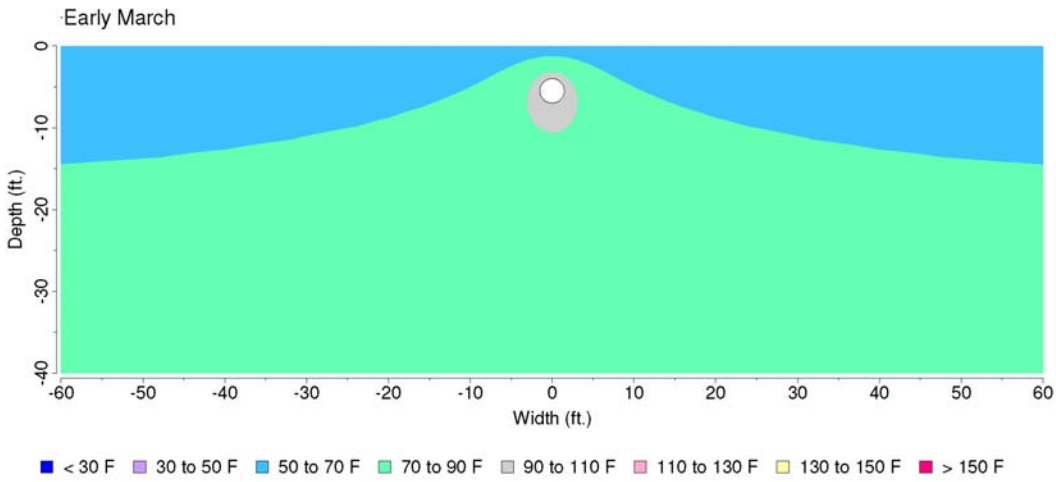

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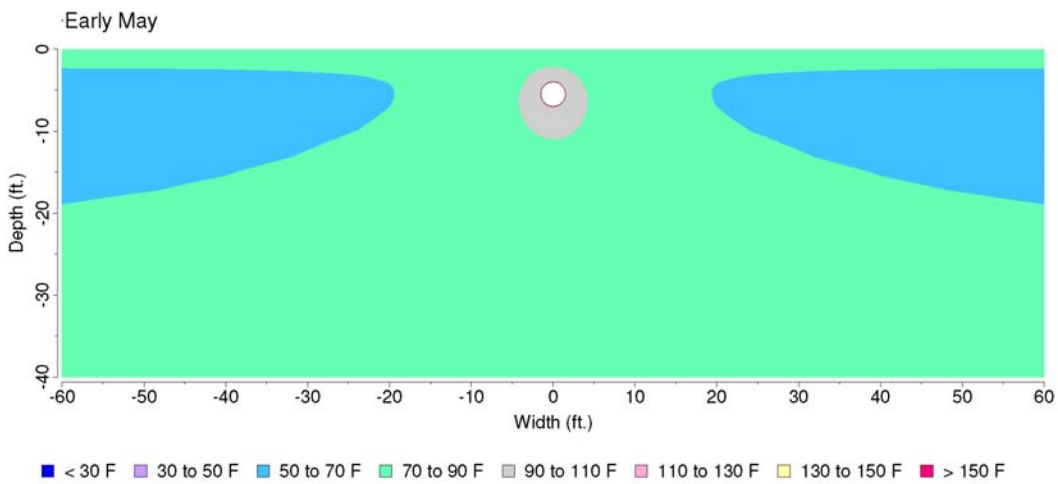

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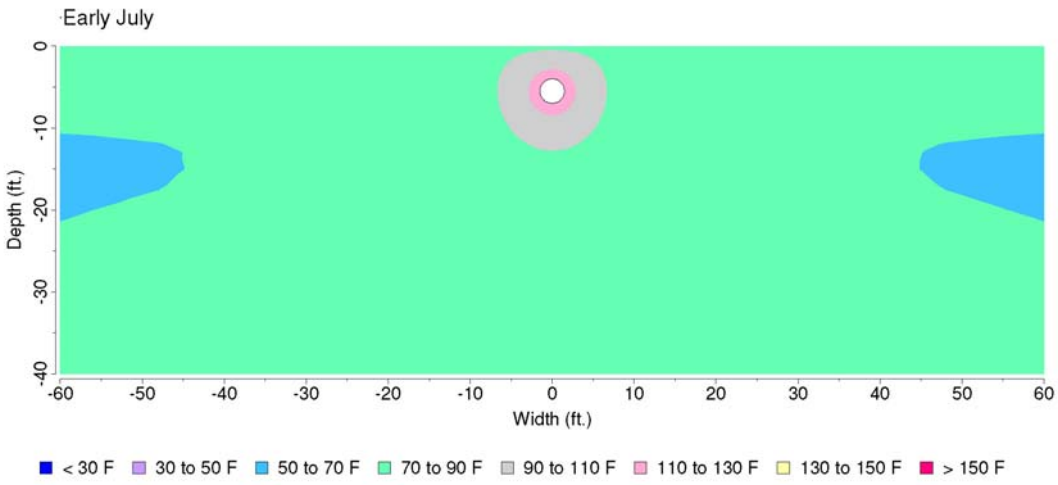

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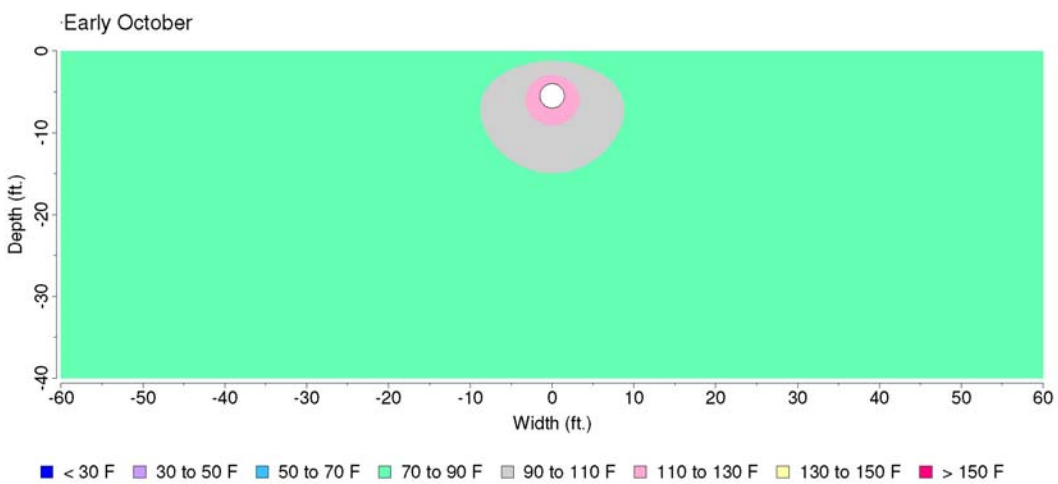


Figure 32

(d) **At what distance from the pipeline will elevated soil temperature be undetectable?**

The analyses shown in part c) above were used to predict the potential effect on soil temperatures at specified distances from the pipe centerline at the surface and at a depth of 6 inches. This largely defines the region of soil of most relevance to vegetation. The effects are summarized in the figures below, which were established for 900,000 bbl/d case. The results indicate that the operating pipeline has negligible effects to these surficial soil temperatures.

Temperature Contour for 900,000 bbl/d

The temperature profiles from the centerline of the pipe at the ground surface and at a depth of six inches below the surface, as affected by the pipeline operating at 900,000 bbl/d, are provided in **Figure 33** to **Figure 44**. These figures show that temperatures above the pipeline and at various distances from it deviate minimally from the background temperature. This demonstrates that there is minimal effect on surficial soil temperatures due to the operating pipeline. This is particularly evident during the growing season, when surficial temperatures are primarily affected by climate.

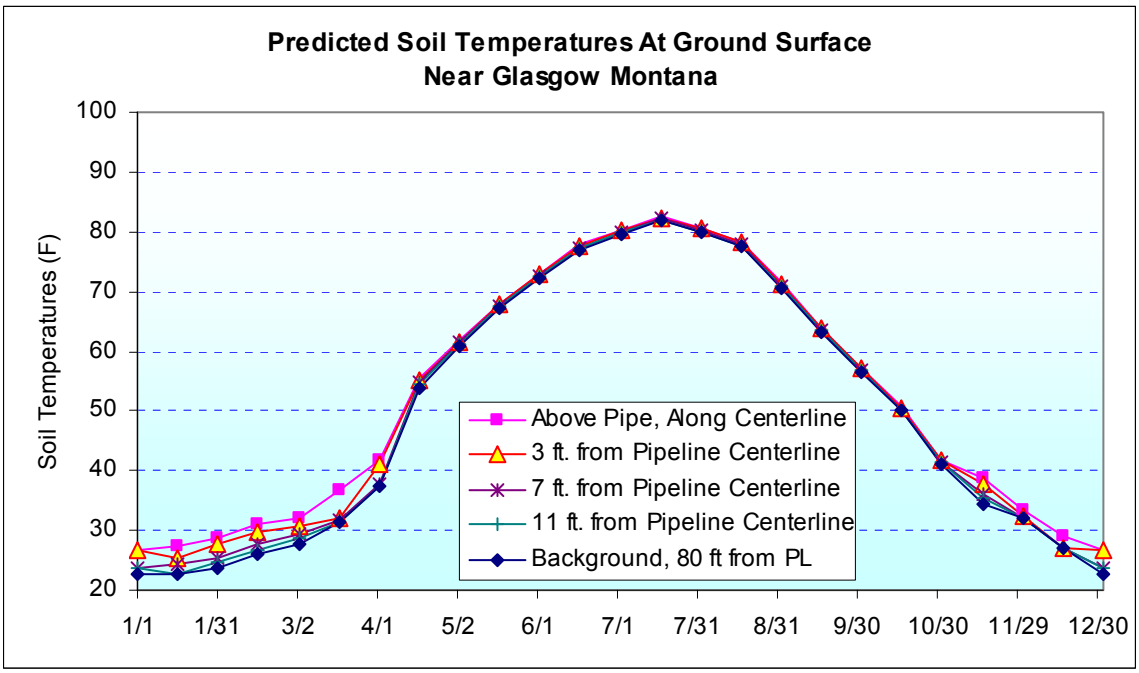
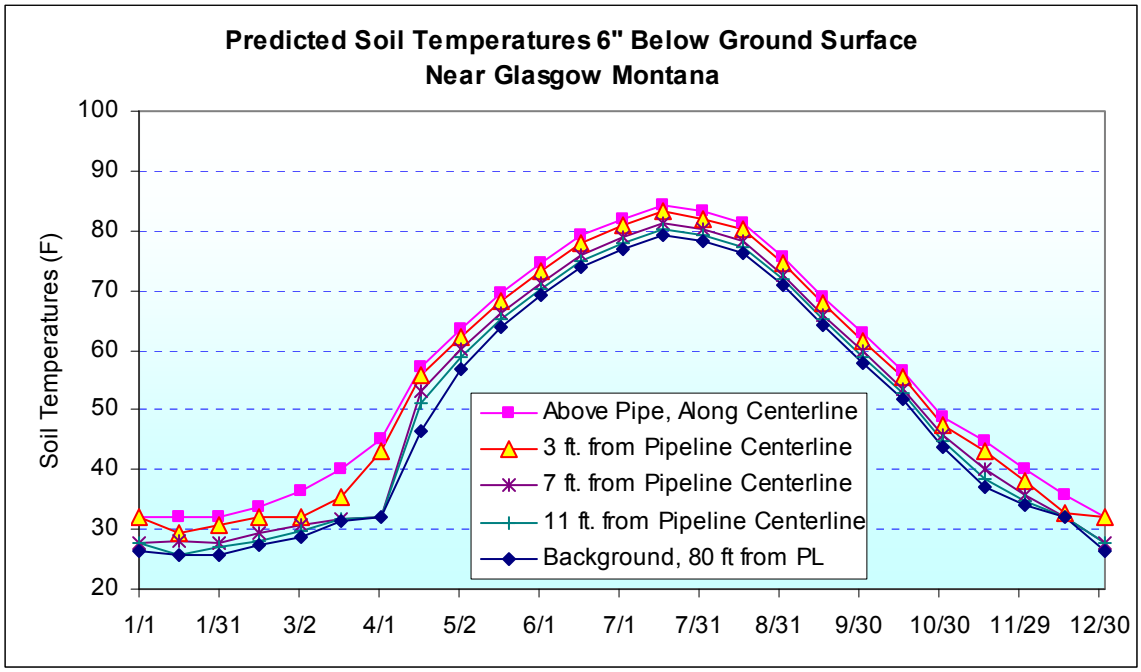


Figure 33



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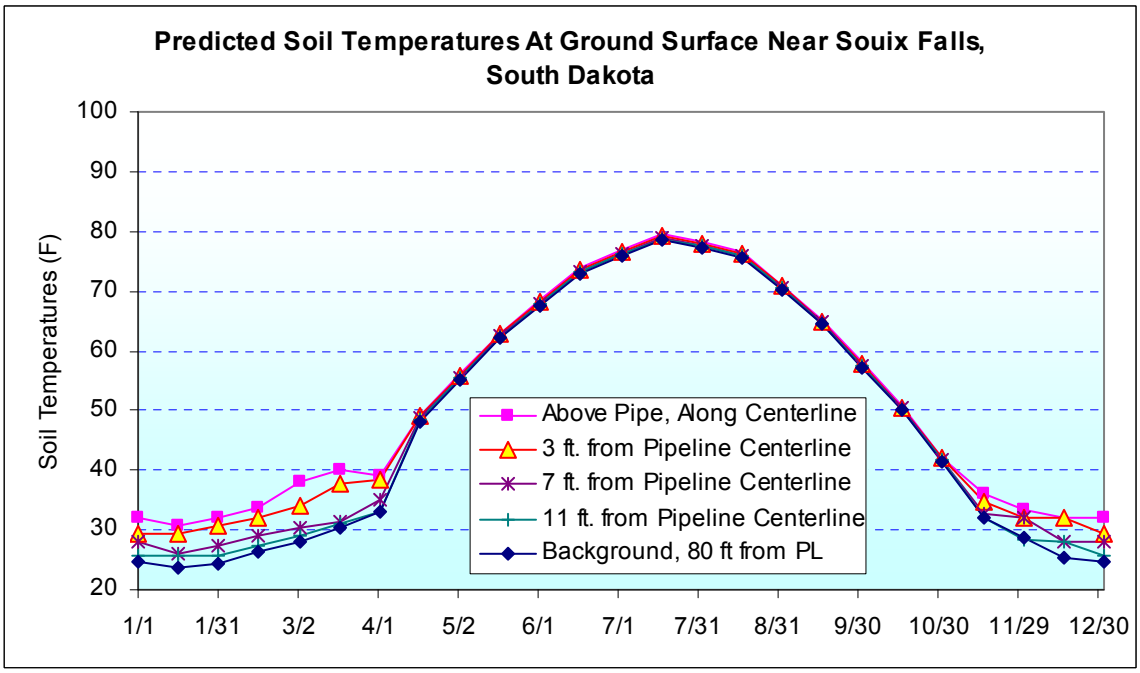

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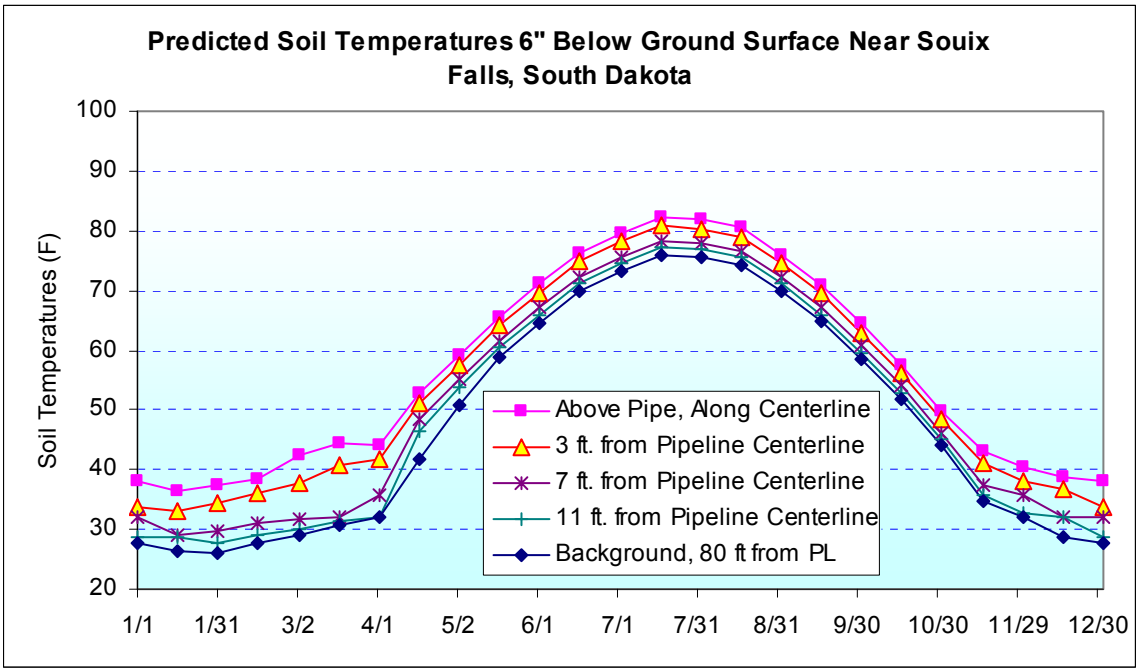

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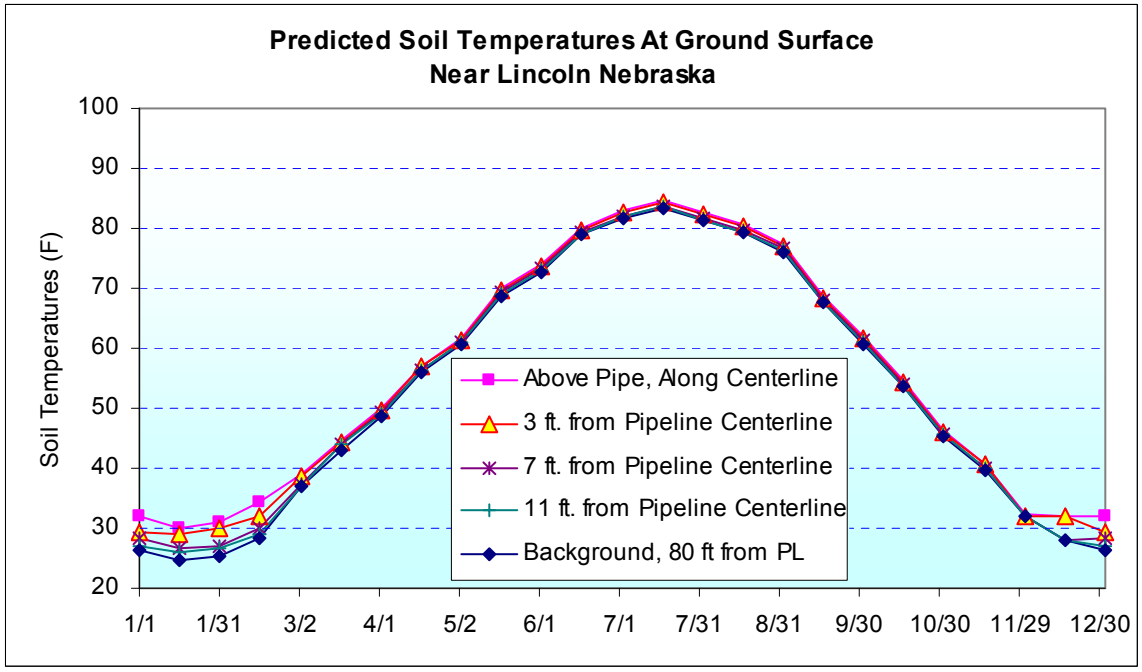

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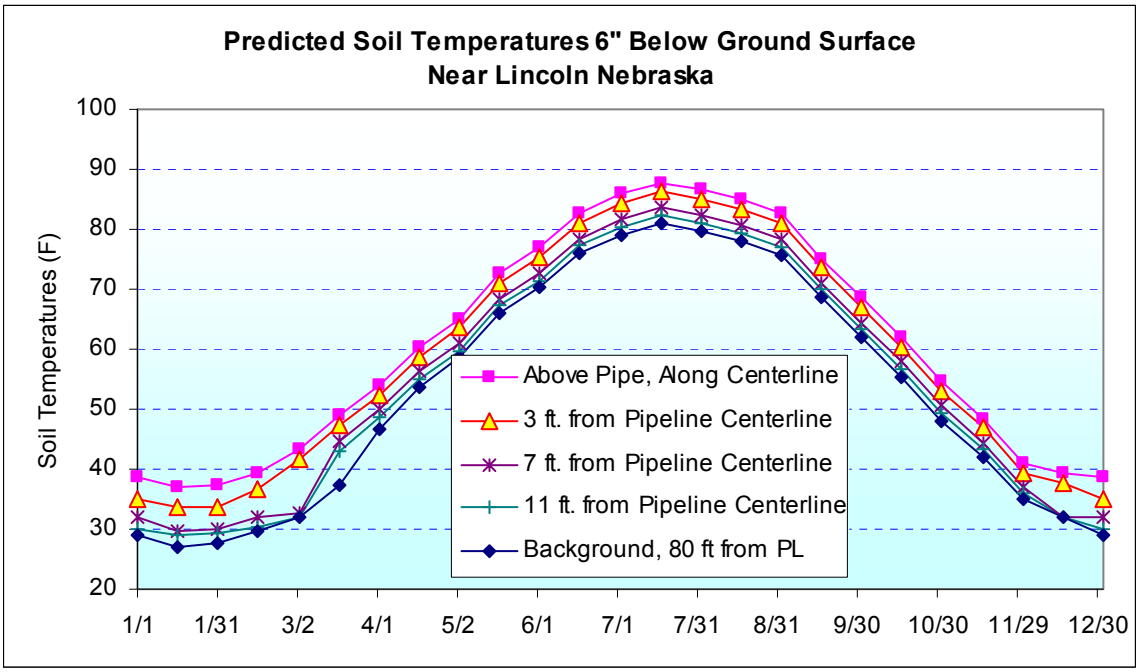

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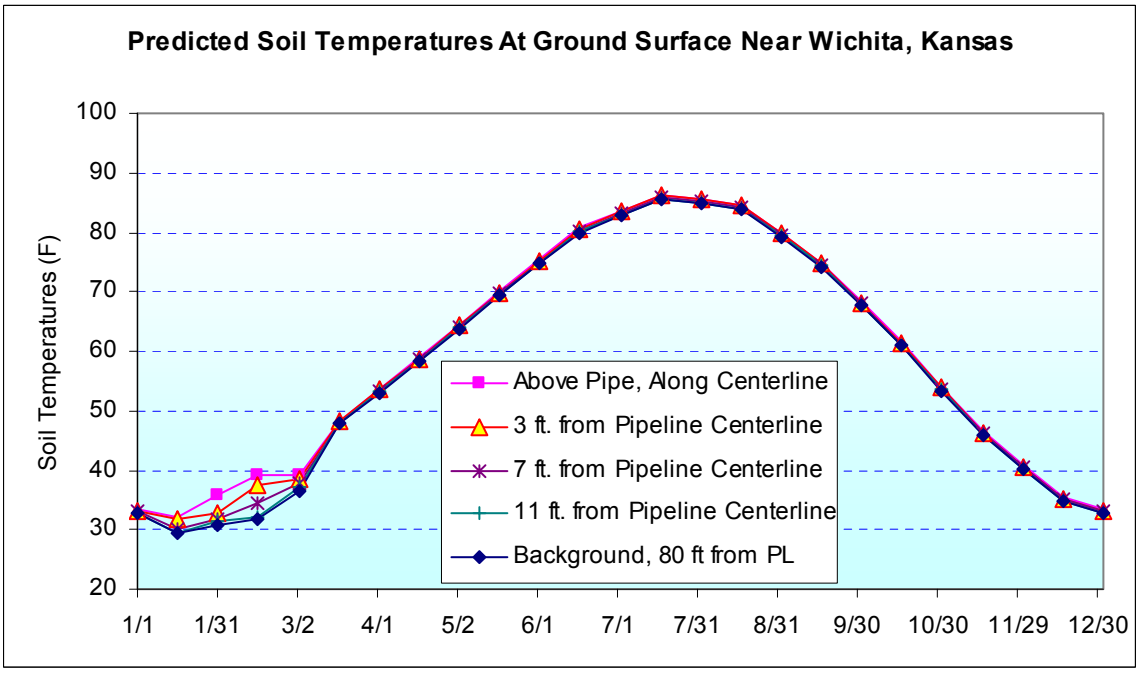

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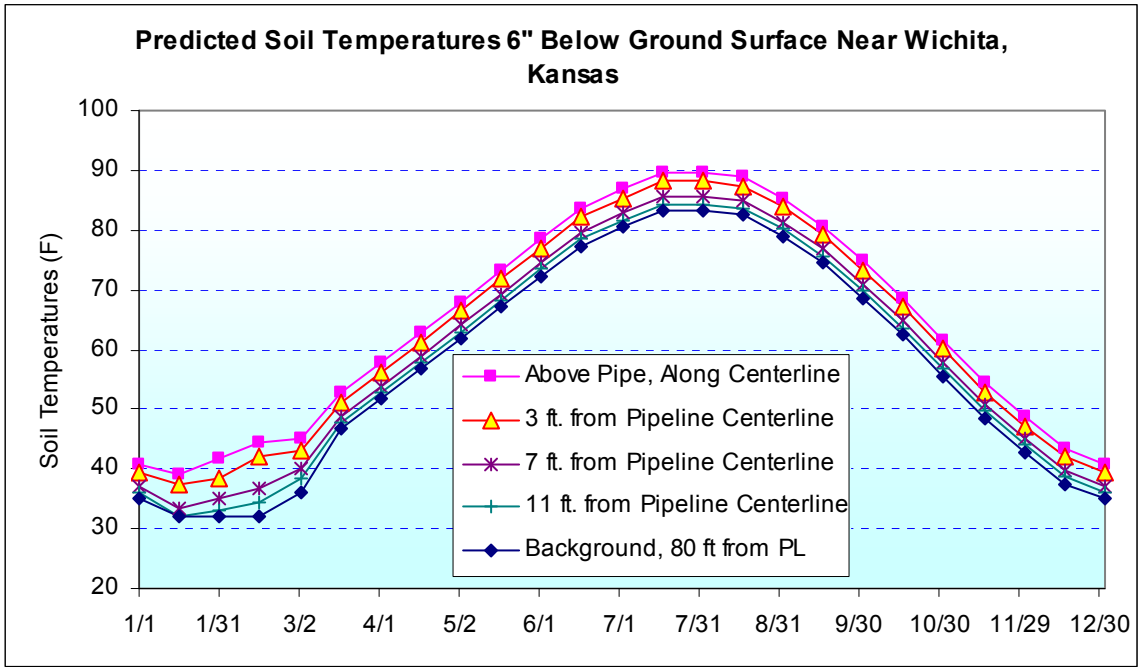

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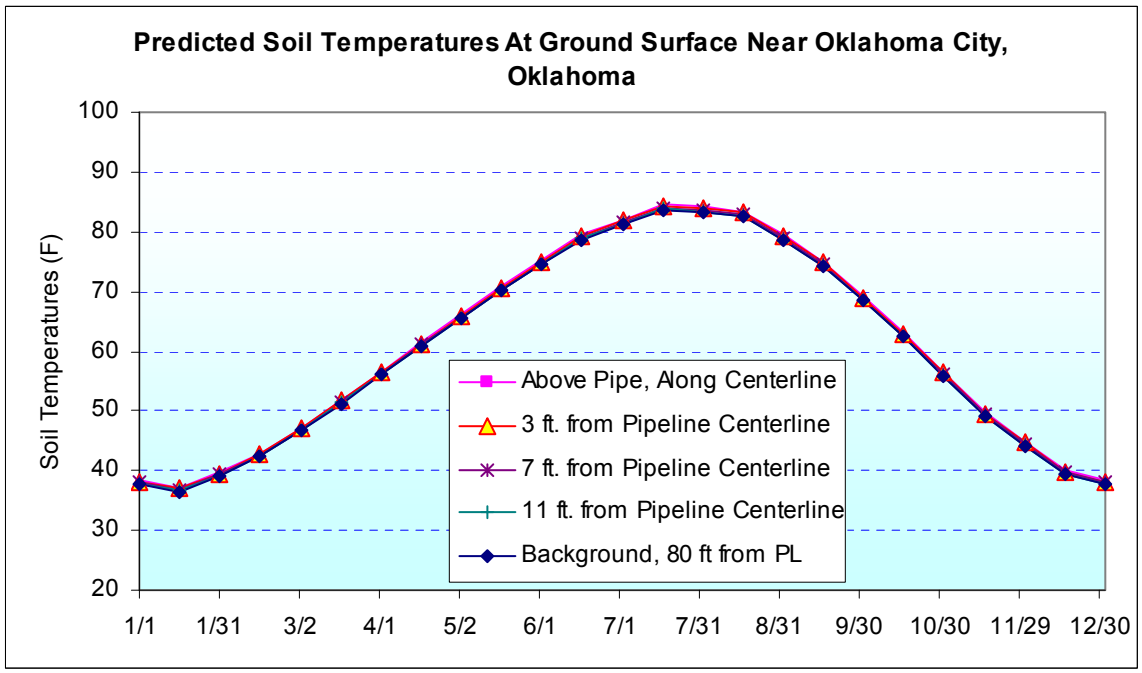

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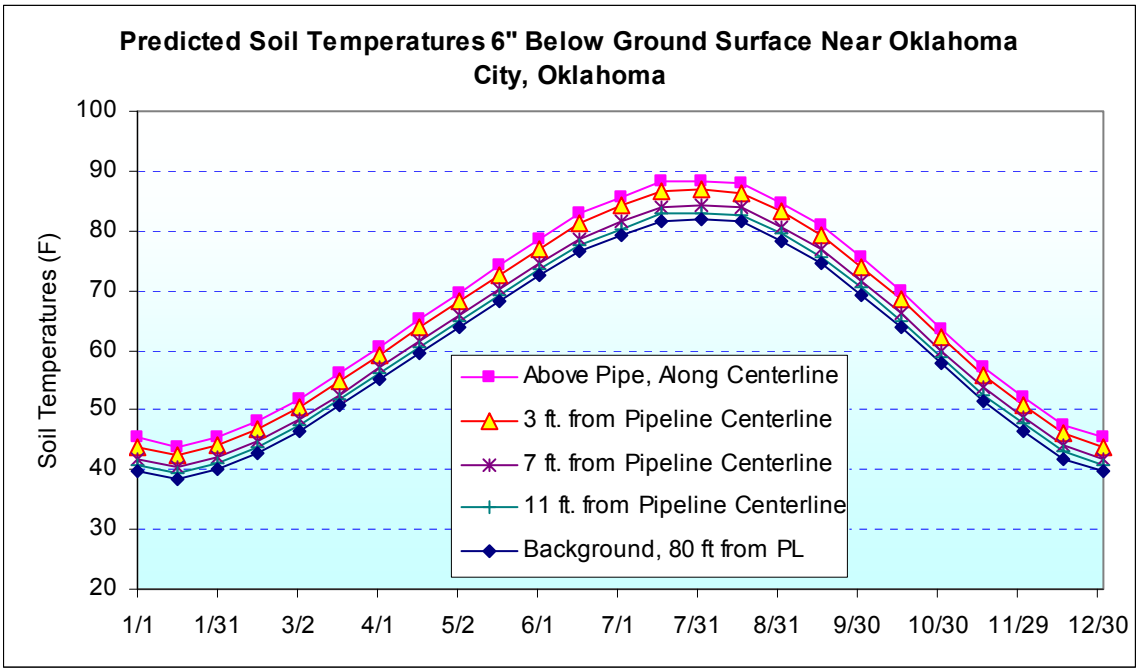

Figure 42

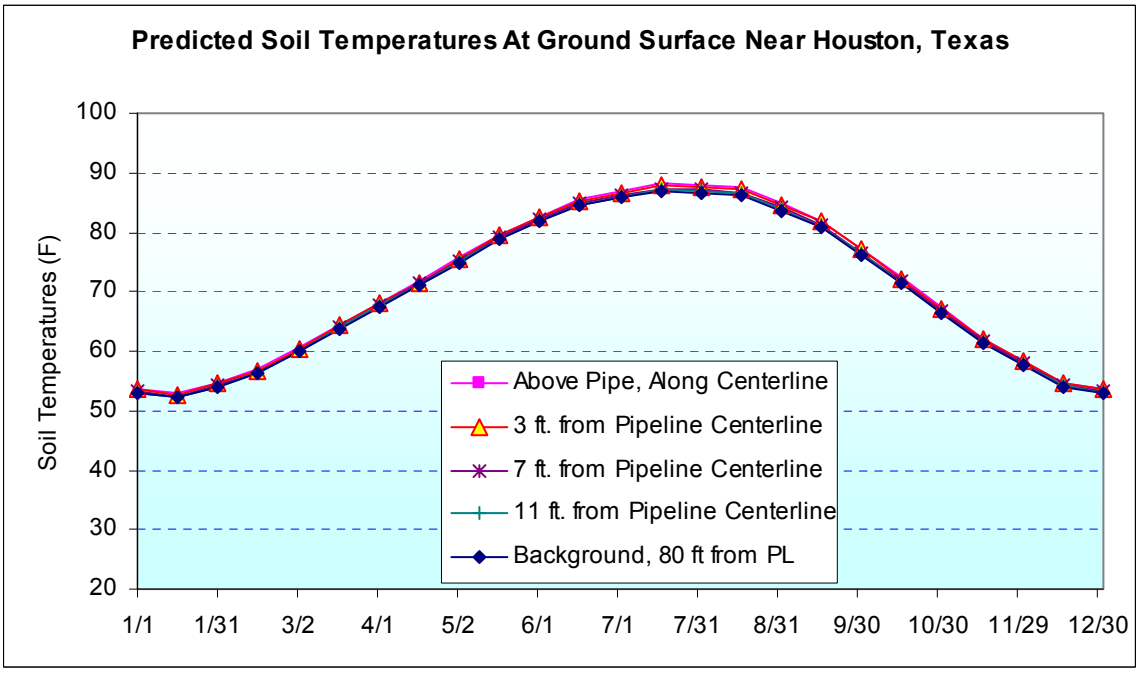

Figure 43

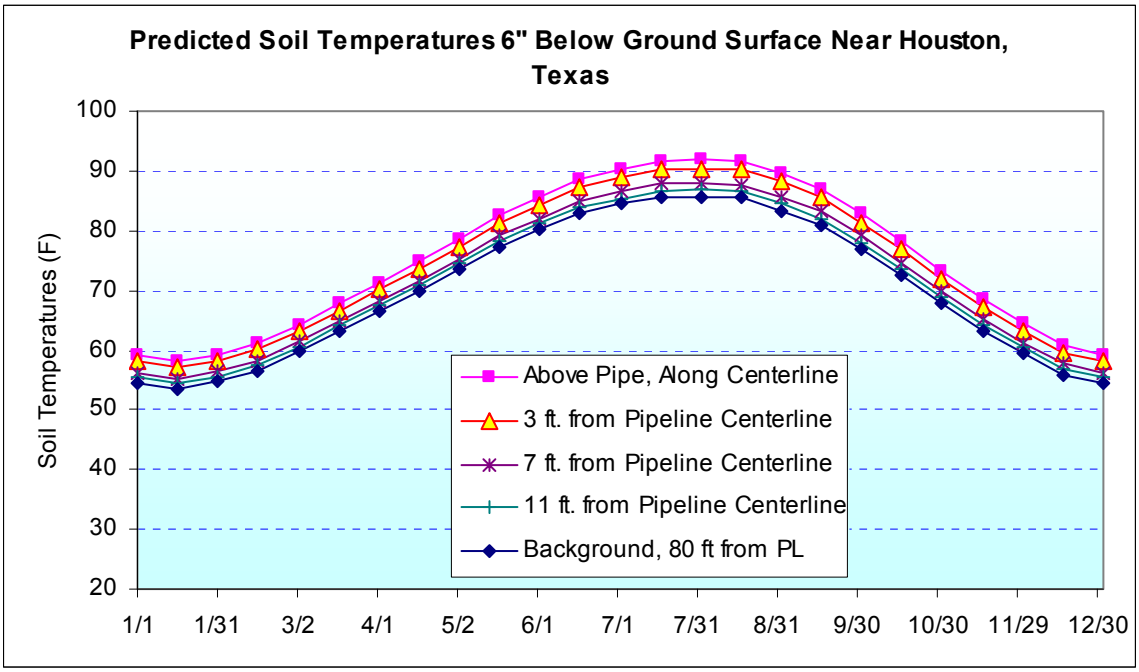

Figure 44

(e) **How many acres of land in total will experience significantly elevated soil temperatures?**

Based on the above data, Keystone does not anticipate that the operation of the pipeline will result in significant effects to surficial soil temperatures, particularly during the growing season.

(f) **How will crops and vegetation be affected by any increased temperature?**

Pipeline operation will modify soil temperatures in an area surrounding the pipe. Temperature profiles indicate that the effects of pipeline-elevated soil temperatures vary seasonally and are minor near the surface where most root zones lie. Potential positive vegetation responses to increased soil temperatures may include accelerated seedling emergence and increased production over the trenchline. Potential negative vegetation responses to increased soil temperature may include decreased water availability and decreased production over the trenchline. To analyze the potential thermal effects of pipeline operation on vegetation, a variety of literature sources and vegetation experts with experience monitoring reclaimed pipelines were consulted. Findings are presented below by issue.

i. Literature review of the effect of elevated soil temperature on vegetation.

Limited information is available regarding the specific thermal effects of pipeline operation on vegetation (see Section ii); however, extensive research has been conducted to assess the effects of elevated soil temperatures in general on vegetation development and production. **Table 1** summarizes typical results and is organized according to common vegetation and crop types that would be crossed by the Project. These data describe common effects of soil temperature on plant growth. Specific vegetation response to soil temperature in each study were also influenced by factors such as soil type, soil moisture, weather, land management practices, or competition with other vegetation species.

Table 1 Effects of Elevated Soil Temperature on Typical Vegetation Crossed by the Keystone XL Pipeline

Vegetation/Crop Type and Experimental Soil Temperature Range	Enhanced Growth Effects	Negative Growth Effects
Big bluestem: Tall-grass prairie species (44° to 95° F)[a]	• Earlier germination and emergence. • Faster growth rate. • Higher net photosynthesis. • Gre ater total biomass. • Strong growth dependence on soil temperature	• No negative effects reported although optimum soil temperatures for greatest biomass production were 77° F.
Various wetland species (41° to 86° F) [b]	• Stem density increased with increasing soil temperature. • Total and annual species richness positively correlated with temperature.	• N one reported although perennial species richness was unresponsive to temperature increases.
Spring Wheat (60° to 105° F)[c]	• Occasional higher soil moisture. • Occasional higher crop yield.	• N one reported.
Corn (50° to 105° F)	• Warmer early-season soil temperatures hasten plant emergence and development. [d] • Optimum germination occurs at soil temperatures of • 85 ° F. [e] • Yield increases with higher soil temperatures at planting (75° to 85° F).[f] • Soil temperatures late in summer less important than air temperature.[f]	• None reported. Effect of high soil temperatures in late summer secondary to effects of high air temperature, low soil moisture, and corresponding drought. [f]
Soybeans (50° to 109° F)	• Optimum soil temperatures for germination is 82° F.[i] • Soybean has competitive advantage over weeds when soil temperatures promote soybean germination. [j]	• None reported. Similar to corn, effect of high soil temperatures in late summer secondary to high air temperature, low soil moisture, and corresponding drought. [j]

a (Delucia et al. 1992); b (Seabloom 1998); c (Dunn et al. pre-published draft); d (Bollero 1996); e (Parsons 2001); f (Riley 1957); i (Tyagi and Tripathi 1983); j (Berglund a Helms 2003).

ii. Literature review of the thermal effect of pipelines on soil temperature and vegetation.

Very few studies have been conducted to assess the thermal impacts of natural gas or crude oil pipeline operation on soil temperature and/or vegetation (Naeth et al. 1993, Fisher et al. 2000, Dunn et al. pre-published draft). Naeth et al. (1993) recorded soil temperatures at various depths over a natural gas pipeline in a Canadian mixed-grass prairie. Elevated winter soil temperatures were recorded below 24 inches, while summer soil temperatures were minimally affected by the pipeline, possibly due to decreased gas flow and increased air temperature. Negative effects on vegetation were not reported.

Fisher et al. (2000) reported increased stature and yield of alfalfa and corn over a natural gas pipeline in central New York. Temperatures fluctuated around the pipeline by season and distance from compressor stations. The ultimate reason for increased production over the pipeline could not be determined but may have been a combination of temperature and water availability.

The most comprehensive assessment of pipeline thermal effects on vegetation was completed on the natural gas Alliance Pipeline (Dunn et al. pre-published draft). Measurements of soil temperature, plant available soil water, and spring wheat and barley yield were completed upstream and downstream of a compressor station on the Alliance Pipeline in 2002, 2003, and 2004. Data collected from four sites downstream of a pump station (0.5 to 52 miles) were compared with a site 0.5 mile upstream of the compressor station at points directly over the trench, 6 and 43 feet away from the trench, and at different soil depths. Temperature varied from 60° F on the upstream side of the compressor station, to 105° F at 0.5 miles downstream of the compressor station. Temperature differences at these coolest and warmest points are shown in **Table 2**.

Table 2 Soil Temperature Differences Measured Over a Natural Gas Pipeline

Distance from Compressor Station	Temperature (° F) Difference over Pipe Compared to 6 feet away from Pipe at 6 to 12 Inch Depth	Temperature (° F) Difference over Pipe Compared to 43 Feet away from Pipe at 6 to 12 Inch Depth
0.5 Miles upstream (coolest point)	1.8 – 3.6	3.6 – 7.2
0.5 Miles downstream (warmest point)	5.4 – 9.0	14.4 – 18.0

Soil temperature difference is similar to what would occur on the Project. No significant differences were noted in plant available soil water or crop yield at any site with the exception that mean plant available soil water was significantly greater over the trench in 2002 than in adjacent areas. Data were collected under the drought conditions that existed in 2002, while precipitation and plant available soil water were normal to above normal in 2003 and 2004, respectively. It was anticipated that soil temperatures above the pipe might lead to increased soil drying, however, this was not documented. Increased soil temperature above the pipeline did not significantly affect plant available soil water or crop yield.

iii. Seasonal pipeline temperature profile and effect on vegetation.

Temperature contours shown in **Figures 3** through **45** indicate natural fluctuations in soil temperatures by season and latitude. Heat from the pipeline typically increases soil temperature 6 inches below the surface between 5° and 8° F above background levels; greater differences occur between January and April, particularly in northern latitudes. Early season temperature differences at northern latitudes are between 10° and 15° F directly over the pipeline compared to background levels. Seasonal differences as a result of pipeline heat are not noticeable in Oklahoma and Texas.

Temperature contours (**Figures 3** to **33**) change dramatically throughout the year as air temperature and soil temperature interact. Although temperature differences are most noticeable in early to mid-spring, the area of maximum temperature difference is restricted to immediately over the pipeline (**Figures 3** and **4** and **8** and **9**). Later spring and summer temperature profiles indicate that average surface temperatures continue through the soil profile in a zone around the pipeline (**Figures 5** and **6** and **10** and **11**). Late fall temperature profiles indicate that pipeline heat has minimal effect on surface conditions (**Figures 7** and **12**). In summary, heat effects from the pipeline would have the greatest impact on surface conditions, and potentially plant growth, in early to mid-spring at northern latitudes.

The roots of most annual crops occur within 1.4 feet of the soil surface at maturity (Merrill et al. 2002). Heat effects from the pipeline are less pronounced within this zone than near the pipe. Also, many crops in northern latitudes are seeded in spring or early summer when heat effects from the pipeline would be minimized by ambient weather conditions. Consequently, root development of spring-seeded plants would occur after pipeline heat effects have substantially dissipated in the rooting zone. The roots of fall-seeded plants, such as winter wheat, would have initiated root growth prior to winter dormancy. The amount of root growth would depend on planting date, soil type, cultivar, and weather (Fowler 2002). Heat effects from the pipeline would be negligible since heat is directed into lower soil profiles in the fall. However, increased early to mid-spring soil temperatures could hasten dormancy emergence in fall-seeded crops such as winter wheat whose roots are already partially developed. Earlier emergence can improve crop yields as shown in **Table 1**.

Elevated soil temperatures could affect other crop physiological functions. Winter wheat requires two cold-affected physiological responses: cold acclimation and vernalization, to achieve dormancy, survive low winter temperatures, and subsequently develop. Cold acclimation and vernalization require a period of fall growth when temperatures are between 30° and 60° F, with 40°F near optimum. If cold acclimation is prevented, plants may be damaged or killed by low winter temperatures. Similarly, if vernalization is prevented, poor heading and flowering will occur in the spring. Eight to ten weeks at the above temperatures is typically required for full cold acclimation and dormancy to be achieved. Vernalization requires approximately 40 days, but can vary from 30 to 60 days depending upon the wheat variety (Fowler 2002).

Based on the pipeline thermal modeling results, surface soil temperatures in September and October (when winter wheat is typically seeded) is primarily a function of air temperature. Optimal winter wheat seeding depth is less than 1 inch (Fowler 2002). Consequently, soil temperatures during initial wheat germination and growth, cold acclimation, and vernalization would be influenced by ambient conditions. Heat generated by the pipeline would not be a factor in cold acclimation and vernalization. Similarly, throughout the winter, heat from the pipeline is directed into the lower soil profiles. Soil surface temperatures and wheat dormancy will be affected by ambient temperatures, not heat from the pipeline.

Although positive effects on vegetation would likely result from elevated soil temperatures in early to mid-spring, potentially negative effects could occur later in the summer if pipeline-influenced soil temperatures promoted soil drying in concert with higher air temperatures. Underground hot-water pipelines (95° F) have been shown to promote germination and early season plant growth, but also deplete available moisture (Rykbost et al. 1975a,b). While it is possible that elevated soil temperature may promote soil drying, it is difficult to separate the effects of soil temperature from the influence of soil structure, soil conductivity, and mycorrhizal function on soil water availability and plant uptake (Killham 1994). Warm soils absorb water faster

than cold soils and therefore soil water may be more readily available to plants in warmer soils than in colder soils (Donohue et al. 1971). Rykbost (1975a, 1975b) found increased crop yields in heated soils with an irrigated water supply. However, most wet soils also evaporate water more quickly than do dry soils, which tend to promote soil cooling (http://www.Newton.dep.anl.gov). Consequently, although soils warmed by the pipeline may absorb more water and promote water infiltration, the greater amount of water moving through the trench could cool the trench soil profile more quickly than the surrounding soil, resulting in slower drying and a neutral impact on plant growth.

In summary, enhanced emergence and initial plant growth may be detected over the pipe centerline in early to mid-spring at northern latitudes since some plants are sensitive to increased soil temperatures during this stage of plant development. Positive or negative effects are unlikely to be measurable later in the growing season since post-emergent plant growth is more influenced by air temperature, day length, and soil moisture than soil temperature. While it is theoretically possible that heat from the pipeline may dehydrate soil moisture directly above the trench, the heated trench may absorb water more rapidly than adjacent soils. The additional water in the trench soil profile would then likely cool the soil more rapidly than in adjacent areas. Ultimately, the thermal effect of the pipeline on plant growth would typically be secondary to other environmental conditions as described in Section iv below.

iv. Land Management Practices Affect Soil Temperature

Although the pipeline will affect nearby soil temperatures, its impact will be confounded by surface land management practices. Crop rotation, grazing practices, and burning treatments influence soil temperature. Crop residues under different tillage systems and pasture utilization affect soil temperature by changing the degree of soil shading. Soil temperatures are often at least 2° F colder at 4-inch depth under cornstalk residue than on essentially bare soil (Mannering http://www.ces.purdue.edu/extmedia/AY/AY-230). Tillage systems were found to significantly affect soil temperature and corn emergence (Drury et al. 1999). Tillage systems also greatly affect soil moisture and soil fertility (Drury et al. 1999, Norwood 1999). Grazing and pasture burning influence soil temperatures by removing vegetation thereby decreasing shade and increasing evaporation. Studies in the tallgrass prairie indicate that burning, or burning and grazing in concert, increase soil temperatures by 20 to 50 percent over unburned and/or ungrazed areas (Knapp et al. 1998). Consequently, although heat generated by the pipeline will affect nearby soils and potentially vegetation, land management practices will greatly influence any measurable effect of the pipeline.

v. Revegetation Monitoring Results on Pipelines

Four years of revegetation monitoring were conducted on the 515-mile Express crude-oil pipeline in Montana and Wyoming. Specific success criteria were defined for native vegetation and Conservation Reserve Program (CRP) fields. Success criterion in native vegetation was defined as achieving 90 percent cover of desirable perennial species compared to adjacent areas within 5 years. Success criteria for CRP fields were defined as stable soils and comparable species composition to adjacent conditions. Following four years of monitoring, revegetation success in native vegetation types had been achieved on approximately 97 percent of the pipeline right-of-way and in all but two CRP fields (WESTECH Environmental Services 1998, 1999, 2000, 2001). After 8 years, all revegetated areas had achieved the success criteria (Larsen, pers. com.).

vi. Summary

Pipeline heat may influence spring growth and production. Positive effects of elevated soil temperature on plant emergence and production have been documented. Negative effects of elevated soil temperature on plant physiology have not been documented at the temperatures that would be generated by the pipeline. The limited number of studies that have been completed on the heat effects of pipelines on vegetation indicate neutral to positive effects. Accordingly, Keystone does not anticipate any significant overall effect to crops and vegetation associated with heat generated by the operating pipeline.

Negative impacts of pipeline construction on post-construction vegetation are typically due to factors other than heat generation including:

- Soil compaction from equipment operation;
- Pipeline trench subsidence;
- Mixed soil horizons/topsoil degradation;
- Poor seed bed preparation; and
- Poorly adapted species used in revegetation.

These types of impacts can be avoided or mitigated through the use of construction, reclamation, and revegetation Best Management Practices (BMPs). Keystone has developed specific construction, reclamation, monitoring, and operational BMPs to insure successful reclamation and revegetation as detailed in the Project Construction, Mitigation, and Reclamation Plan (**Appendix I**). These types of BMPs have been applied by industry partners on thousands of miles of pipelines throughout the United States and Canada and have resulted in successful reclamation of pipeline rights of way that is equivalent to the land capability of adjacent undisturbed areas.

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