A CONCEPTUAL MODEL OF ECOLOGICAL RISK IN A TALLGRASS PRAIRIE ECOSYSTEM

By

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A CONCEPTUAL MODEL OF ECOLOGICAL RISK
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NOMENCLATURE

List of Acronyms

ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
EC5	effective concentration for 5% of the test organisms
EC50	effect concentration for 50% of the test organisms
Eco-SSLs	Ecological Soil Screening Levels
EPA/US EPA	United States Environmental Protection Agency
ERA	Ecological Risk Assessment
g	gram(s)
GIS	Geographical Information System
GPS	Global Positioning System
ha	hectare
HSI	Habitat Suitability Index
ISO	International Standards Organization
LOEC	Lowest-Observed-Effect Concentration
LOEL	Lowest-Observed-Effect Level
mg	milligram(s)
NOEC	No-Observed-Effect Concentration
NOEL	No-Observed-Effect Level
OECD	Organization for Economic Co-operation and Development
RESC	Relevant Ecological Screening Criterion
RBCA	Risk-Based Corrective Action
TPH	Total Petroleum Hydrocarbons
TNC	The Nature Conservancy
TPP	Tallgrass Prairie Preserve

Glossary

Acute Toxicity	A short-term exposure to a contaminant in a medium and usually at concentrations high enough to induce an effect rapidly
ArcView	A computer-based GIS tool produced by the Enviornmental System Research Institute (ESRI) for mapping and analyzing processes and events that are related by their location. This software package facilitates manipulation and analysis of spatially arrayed data
Brine	Saline water
Chronic Toxicity	Long term exposure (weeks, years) to a contaminant in a medium, often includes reproduction or the full life cycle of the organism.
Criteria	Concentrations of contaminants in environmental media that may not be exceeded; legally enforceable and subject to fine or other regulatory action should exceedences occur
Ecological Receptor	Ecosystems, habitats, communities, populations, and individual organisms (except humans) that are exposed directly or indirectly to site stressors
Ecological Risk assessment	A process that involves consideration of the aggregate ecological risk to the target entity caused by the accumulation of risk from multiple stressors
Ecological Soil Screening Levels	Soil concentrations protective of terrestrial organisms; unacceptable adverse effects should not occur to ecological receptors at or below this value
Ecosystem	The biotic community and abiotic environment within a specified location in space and time.

Effect Concentration (EC_x)	The concentration of a chemical in the medium that results in a particular sublethal effect to x% of the test organisms
Endpoint	An explicit expression of the environmental value that is to be protected. An assessment endpoint includes both an ecological entity and specific attributes of that entity. For example, salmon are a valued ecological entity; reproduction and population maintenance of salmon form assessment endpoints.
Lethal Concentration (LC_x)	The concentration of the chemical in the medium that results in mortality to x% of the test organisms
Lowest Observed Adverse Effect Level (LOAEL)	The lowest level of a stressor that causes a statistically significant difference in receptor health from controls.
No Observed Adverse Effect Level (NOAEL)	The highest level of a stressor that does not cause a statistically significant difference in receptor health from the controls
Receptor	The ecological component exposed to the stressor. This term may refer to tissues, organisms, populations, communities, and ecosystems.
Relevant Ecological Screening Criteria	Generic, non-site-specific ecological criteria or guidelines that are determined to be applicable to relevant ecological receptors and habitats, exposure pathways, and site conditions utilized during a Tier 1 evaluation in Risk-Based Corrective Action. These may include chemical concentrations, biological measures, or other relavent generic criteria consistent with the technical policy decisions.

Remediation	Activities conducted to protect human health and the environment. These activities include evaluating risk, making no further action determinations, monitoring, institutional controls, engineering controls, and designing and operating clean-up equipment.
Risk Assessment	An analysis of the potential for adverse effect caused by a chemical(s) of concern from a site to determine the need for remedial action or to the development of target levels where remedial action is required.
Soil Protection Values	A general term used to encompass all soil concentration values derived to protect all or part of the terrestrial system from unacceptable effects due to contamination. It includes screening level values, criteria, and clean-up target levels.
Stressor	Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).
Surface Area Disturbance	Any event or series of events that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment

CHAPTER ONE

DEVELOPMENT OF RELEVANT ECOLOGICAL SCREENING CRITERIA (RESC) FOR THE ECOLOGICAL ASSESSMENT OF PETROLEUM HYDROCARBON CONTAMINATED EXPLORATION AND PRODUCTION SITES

INTRODUCTION

The Nature Conservancy Tallgrass Prairie Preserve (TPP) is a 14,800 ha prairie in the Osage hills of northern Oklahoma (see Figure 1) (Coppedge and Shaw 1998). The Nature Conservancy (TNC) purchased this land in 1989 to create a preserve that protects an array of biodiversity features indigenous to the locale in a setting that utilizes "...ecological processes that are essential to maintaining a naturally functioning tallgrass prairie landscape" (Hamilton 1996). The TPP supports multiple land uses that include recreation, cattle and bison ranching, and oil production. Oil production has occurred on the land now owned by TNC for the last 80 years and has resulted in more than 150 working and derelict oil production facilities. Oil and brine releases have occurred as a result of wellhead releases, pipeline breaks, and leakage from aboveground storage tanks. The impact of these spills on the surrounding prairie environment is unknown and a suitable framework for assessing the ecological risk of the spills is not available. Addressing these two issues forms the focus of this thesis.

Most of the private oil production wells at the TPP produce less than 10 barrels of oil/day (Kerry Sublette, pers comm.). These wells also produce an equivalent amount of saline water (referred to as 'brine'). The oil and brine are stored in separate holding tanks where the brine is eventually reinjected into the formation from which it was withdrawn. Releases of brine, oil, and brine and oil mixtures have occurred.

A variety of remediation measures have been initiated to treat oil and brine releases to soil. Oil spills have been mulched and tilled, amended with fertilizer or gypsum, or, in some cases, allowed to passively remediate. Several researchers are presently working at different spills across the TPP to identify best remediation practices.

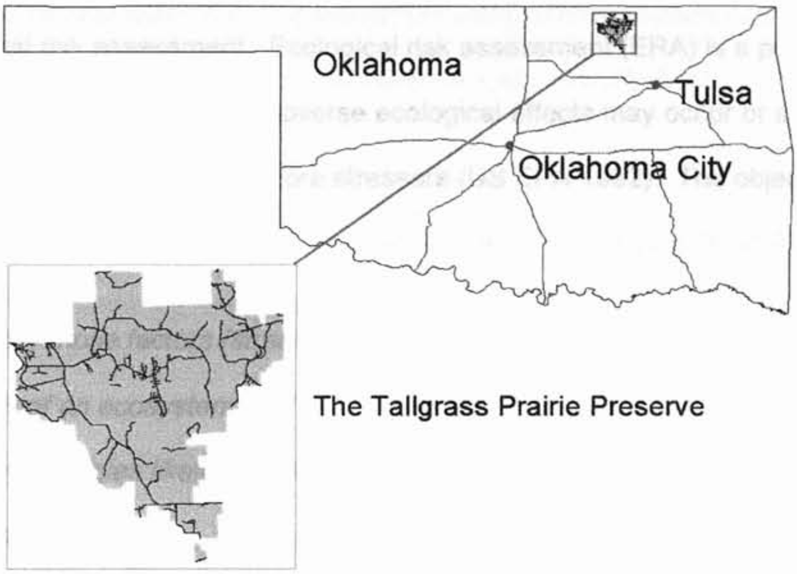

Figure 1. The Nature Conservancy Tallgrass Prairie Preserve is located northwest of Tulsa, Oklahoma.

In considering the impact of spills at the TPP, it is important to understand how oil-contaminated soil can affect the environment. For example, the physical characteristics of the soil, such as water holding capacity or nutrient cycling, may be impaired. The spill may pose a fire hazard or be mobile enough to be transported to groundwater or other areas of the TPP. If the spill covers a sufficiently large area or is frequent enough, habitat continuity may be diminished. Contaminated soil may be toxic to soil invertebrates, mammals, plants, or other ecological receptors. Longer-chain hydrocarbons may be persistent and bioaccumulate in those receptors. The spill may act in a synergistic manner with other environmental stressors in the landscape to cause cumulative effects to specific receptors or ecosystem function as a whole. The spills also may have no measurable impact on the ecosystem.

The measurement of spill-related effects to terrestrial ecological receptors and ecosystem function is a relatively new field in science and policy. One approach to assessing ecological risk to the surrounding prairie environment is to conduct an ecological risk assessment. Ecological risk assessment (ERA) is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (US EPA 1992). The objective of an ERA is to

> *"identify those factors (stressors) that pose the greatest risk to the integrity or health of an ecosystem so that environmental protection efforts can be focused on those strategies likely to yield the greatest reduction in ecosystem risk"* (Wenger et al. 2000).

The U.S. Environmental Protection Agency (US EPA) and the American Society for Testing and Materials (ASTM) have developed guidance documents that prescribe a risk-based approach for ecological assessment (US EPA 1998; ASTM 1999). These documents provide a template to help organize and analyze data, information, assumptions, and uncertainties when evaluating ecological effects (US EPA 1998). Both frameworks have similar approaches to protecting ecological receptors in terrestrial systems through the use of soil protection values. The soil protection values are created from toxicity tests using selected species of plants, soil invertebrates, mammals, or birds. The US EPA refers to their version of soil protection values as "Ecological Soil Screening Levels" (Eco-SSLs) (US EPA 1998). The ASTM guide has adopted a three-tiered process under their Risk-Based Corrective Action (RBCA) framework that was originally developed for human health risk assessment. Tier 1 of ecological RBCA proposes to define "relevant ecological screening criteria" (RESC) as soil protection values. An important research need described in both frameworks is the development of chemical-specific numerical risk-based protection values.

This chapter discusses the development of soil protection values for oil-contaminated soil at the TPP[1]. Chapter Two discusses ecosystem-level effects.

OBJECTIVE OF RESEARCH

The objective of this research is to develop relevant ecological screening criteria for crude oil exposure with plants and invertebrates in soil from the TPP.

METHODS

Description of the TPP

The TPP is located near the southern end of the Flint Hills – the largest extant block of tallgrass prairie in North America (36º50'N, 96º25'W) (Hamilton 1996). Approximately 80% of the preserve is tallgrass prairie vegetation (Hamilton 1996), dominated by big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*) (Coppedge et al. 1998). Average temperatures range from –5°C in January to 34°C in July and approximately 877 mm of precipitation falls annually at the TPP (Coppedge et al. 1998). Each year 20% of the TPP is burned to maintain a functioning tallgrass prairie community. Burns are conducted at different times of the year to mimic presettlement fires (Coppedge and Shaw 1998). Bison were introduced to the TPP in 1993. In the fall of 2000, the Nature Conservancy reported a herd size of 1200 bison (www.tnc.org, Nov, 2001). Herd size is managed by annual round-ups.

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[1] EcoSSLs were not developed in this research project. Methods more closely followed the RESC development process under ASTM protocols.

Description of Test Plots

One release of dewatered crude oil from a pipeline break in early 1999 produced an area of approximately 0.5 ha of contamination spread out over two lobes (North and South lobes), see Figure 2. Each lobe was mulched, tilled and then divided into upslope and downslope areas using a polyethylene divider. Only the downslope side of the lobe was fertilized. Mulching, tilling, and the addition of fertilizer are typical remediation strategies for crude oil spills at the TPP. Soil was collected from the unfertilized side of the lobes to conduct toxicity tests and to perform physical and chemical analysis. An area of the TPP previously uncontaminated with oil or brine was chosen as a reference area. Also, a negative control site that was mulched and tilled, but not fertilized, was created adjacent to the contamination lobes.

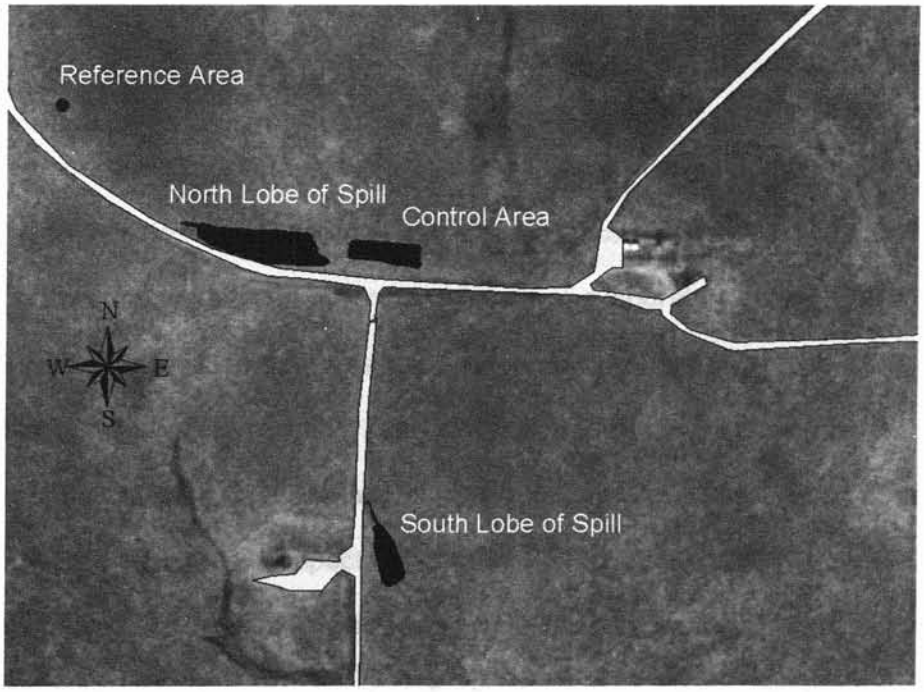

Figure 2. Location of north and south lobes of 1999 spill area. A control area was created adjacent to the north lobe and treated with similar remediation techniques as the spill areas. Reference soil was collected from a point upslope of the spill area in an uncontaminated and undisturbed location.

Toxicity Tests and RESC Development

The general experimental objective of the first portion of the project was to develop a soil-screening value for oil-contaminated soil at the TPP. This involved assessing responses of an array of soil organisms and plants as effects assessment endpoints and measures of total petroleum hydrocarbon in assessing exposure. Toxicity tests were conducted with organisms for which no codified toxicity tests are available (i.e., potworms, springtails), as well as standard soil test organisms (i.e., earthworms), in field soils contaminated with crude oil at different levels. Screening values were estimated from no observed effect concentrations (NOECs) or the value at which 5% of the population is affected (EC5) for sublethal test endpoints such as growth and reproduction.

Toxicity Tests with Eisenia fetida

A single soil organism test has been standardized in both Europe and North America: the lethality test with the earthworm *Eisenia fetida* (ASTM 1997, OECD 1984). Earthworms are easy to culture and handle in a laboratory setting. As a result, a large library of *E. fetida* toxicity data has been produced. Although *E. fetida* is considered a useful indicator of soil quality, they are not true soil dwellers because they do not live in soils but rather in organic matter such as compost. Moreover, *E. fetida* represent only one species in the vast spectrum of soil fauna (Crauau 1999). Therefore, it has been suggested that it is not fully scientifically justified to regard *E. fetida* as a typical representative of the soil community (Rombke et al. 1997). Including alternative soil dwelling organisms in the development of RESC would increase validity and ecological relevance to the conceptual model of ecological risk.

The ASTM protocol E 1676-97 was followed to conduct the *E. fetida* test with the following exceptions. First, field soils were collected from the TPP to be used as a test medium rather than the suggested artificial soil medium (although artificial soils were included as a reference soil). These soils were sieved through a 6-mm screen, then mixed and stored at 4ºC until soil was analyzed for Total Petroleum Hydrocarbon (TPH) content. TPH levels of the soils were analyzed by standard EPA Methods 418.1 (IR) and 8015-B (GC) by Soil Analytical Services, Inc. (SASI), College Station, Texas. Since toxicity organism tests were conducted using field-contaminated soils, a TPH concentration gradient of 13243, 5168, 3733, 2118, 1320, and 1278 mg/kg was used. Second, soils were wetted to a similar consistency using visual observation rather than wetting soils using similar volumes of water. A 24-hour light cycle was used to ensure worms burrowed into the soil. Preliminary experiments with a range-finder test indicated low mortality in these soils, so the 28-day sublethal toxicity test method was followed. Tests were conducted in quadruplicate. Measurements of worm mortality, body-weight, reproduction, and behavior were noted. At the end of the exposure period,worms were rinsed in distilled water, wrapped in hexane-rinsed aluminium foil, and frozen at -20°C.

Toxicity Tests with Enchytraeus albidus

Enchytraeids are a widely distributed annelid species having a broad habitat selection (Augustsson and Rundgren 1998). These Lumbricids are true soil-dwelling organisms and are easily bred under laboratory conditions. *Enchytraeus albidus* offer a reasonable addition to the *E. fetida* test because they live in close association with soils and are native to the TPP. A North American testing guideline has yet to be developed for these "potworms," however a draft guideline has been published by the Organization for Economic Development (OECD 1984). This guideline was followed for the Enchytraeid bioassay, with the following exceptions. Hydrocarbon-contaminated soils were collected from the field site, as described above, rather than using artificial soil. Tests were conducted in replicates of six instead of three. All enchytraeids used in this study were believed to be white potworms, *Enchytraeus albidus*, obtained from our laboratory cultures maintained at 20±2°C. Testing was conducted in environmental chambers with controlled temperature maintained at 20±2°C with a 16:8 light-dark cycle.

Toxicity Tests with Folsomia candida

Collembola are important prey items for many soil-dwelling organisms (Hopkin 1997). They are the most widely distributed and numerous insects in terrestrial ecosystems and have been extensively studied as bioindicators of contaminant exposure (Usher 1977). *Folsomia candida* is a Collembola that inhabits primarily the top horizon of soils with high organic matter content. It is parthenogenic with a high reproductive rate. Because these organisms have different life history strategies and habitat selection than either of the Lumbricids being tested, they are an effective addition to the RESC development.

Collembola bioassays were conducted according to the protocol described by ISO standard 11267 1999-04-01 (ISO 1999), with a few modifications. Bioassays used soil samples collected from TPP and follow the same concentration series and reference soils as described previously, rather than using artificial substrate. Tests were conducted in 100-ml mason jars with 20 g of soil (wet weight) smoothed to the bottom of the jar. Ten 10 to 12-day old *F. candida* were placed in each jar using a fine paintbrush. Tests were conducted in replicates of six rather than three. All *F. candida* were collected from our laboratory culture maintained at 22±2°C. Testing was conducted in controlled environmental conditions at 20°C with a 12:12 light dark cycle. *F. candida* were allowed to acclimate to light and temperature conditions for 24 hours prior to placement in jars. *F. candida* were fed a drop of liquid Brewers yeast on a filter paper disk every four days.

On day 28, all jars were flooded with de-ionized water dyed dark green with food coloring. This improved the visibility of the white *F. candida* against the dark green background to allow for each jar to be digitally photographed. All photographs were then manipulated in Adobe Photoshop using the 'threshold' function. All pixels darker than a pre-determined intensity (50) were converted to black and remaining white spots were counted as individual organisms. Each of the six replicates was photographed three times to account for the *F. candida* bunching together on the surface of the water.

Toxicity Tests with Plant Bioassays

Plant bioassays were conducted according to standard protocols for germination and growth tests (ASTM E 1963-98) using the composite soil samples obtained in the field. Seeds were purchased from a certified distributor (Carolina Biological Supply, CA or Johnston Seed Co., OK) and stored in sealed paper bags at 4±1°C. Seeds were monitored for time to germination, % germination, and height one week after germination. Other observations included: color, diameter of stem, leaf size and number, or any abnormal changes in plant morphology as compared to controls.

At the end of the test, plants were measured for height, stem width, and leaf number and size. Plants were cut at the soil surface and dried at 100°C for dry weight measurement. Radicles (root lengths) were retrieved from the soil, rinsed with de-ionized water, and stored in separate bags for dry-weight measurements.

Data Analysis

Data interpretation was done using Instat (GraphPad Instat V2.05a, copyright 1990-1994) and Excel 2000 (version 9.0.2720, Microsoft® 1983-1999). Standard descriptive statistics, one-way analysis of variance (ANOVA), and linear and non-linear regression techniques were used.

EC50s were estimated for earthworm reproduction, potworm mortality and reproduction, springtail reproduction, and plant germination and biomass by statistical comparison of responses in field-contaminated soils with those in uncontaminated control soils. Earthworm and potworm reproduction data were normalized to cocoons/adult/week and juveniles/adult/week. For plant tests, the percent germination and mean above-ground plant biomass were used as response parameters.

Relationships between physical-chemical parameters, hydrocarbon measures, and bioassay endpoints were evaluated with Pearson product moment-correlation coefficients. EC50s for growth or reproduction were determined by probit analysis and NOECs analyzed by ANOVA with *a posteriori* means comparison using Tukey's Honestly Significant Difference test (α=0.05).

RESULTS

The results of the physical-chemical and hydrocarbon measurements of the soils collected at the TPP are displayed in Table 1. Soil pH values ranged between 5.5 and 7.0. Electrical conductivity was highest in 9N1 soils and lowest in 7N1 soils at 963 and 291 μmhos/cm, respectively. Soil textures were similar, as were available nutrients with sodium as an exception. Sodium levels were highest in soils 9N1 and ES1 at 177.0 and 177.9 ppm, respectively. Increased sodicity was also reflected in the sodium absorption ration (SAR: 9N1 and ES1 exhibit ratios of 5.74 and 9.04 whereas all other soils fell below 2.06). Percent moisture levels were similar between all tilled soils, between 18.2 and 23.0 %. Reference soils were considerably lower, however, at 10.0%. In general, 9N1 and 7N1 appeared to be more saline that other sampled soils. This difference is not sufficient enough to cause a difference in soil dispersion, but its influence on soil plants and invertebrates is unknown.

Table 1. Physical-chemical characteristics of Tallgrass Prairie Soil.

	Soil Sample							
Physical-Chemical Test	Reference	Control	6N1	7N1	8N1	9N1	10N1	ES1
aliphatic (mg/kg)	0	0	1086.3	6184.2	3316.7	1356.3	1918.8	1277.5
aromatic (mg/kg)	0	0	233.8	7058.3	1851.7	761.3	1813.8	0.0
pH (units)	5.5	5.9	5.8	6.2	6.2	7.0	6.6	6.1
EC[1] (umhos/cm)	591	861	870	291	461	963	500	789
Texture	medium-coarse	fine-medium	fine-medium	fine-medium	fine-medium	fine-medium	fine	fine-medium
Na (ppm)	26.9	29.7	74.1	53.7	21.3	177.0	27.8	177.9
K (ppm)	6.5	11.1	8.3	5.6	4.6	5.6	6.5	2.8
Ca (ppm)	33.4	67.9	54.6	37.9	32.3	52.9	40.1	18.4
Mg (ppm)	10.6	17.8	26.2	14.5	12.2	11.7	13.9	6.7
Boron (ppm)	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
TSS[2] (ppm)	390.1	568.3	574.2	192.1	304.3	635.6	330.0	520.7
PAR[3]	0.15	0.18	0.14	0.11	0.10	0.11	0.13	0.08
SAR[4]	1.04	0.82	2.06	1.87	0.81	5.74	0.96	9.04
EPP[5]	4.89	5.23	4.80	4.59	4.47	4.50	4.75	4.28
ESP[6]	0.27	0.30	1.74	1.46	0.26	6.68	0.16	10.70
TOC[7] (%)	1.88	2.31	2.89	2.29	3.46	2.29	3.40	1.70
Buffer Index (units)	6.67	6.80	6.77	7.00	6.83		6.87	6.87
NO_3-N (ppm)	5.17	11.83	27.17	1.83	1.67	1.50	1.67	13.50
P	7.33	7.00	7.67	5.67	5.67	10.00	6.67	7.33
K	135.0	232.0	190.0	215.0	185.3	152.0	203.3	140.7
percent moisture	10.0	18.4	21.8	23.0	22.5	19.6	22.0	18.2

1 = Electrical Conductivity

2 = Total Soluble Salts

3 = Potassium Adsorption Ratio

4 = Sodium Adsorption Ratio

5 = Exchangeable Potassium Percentage

6 = Exchangeable Sodium Percentage

7 = Total Organic Carbon determined by dry combustion using a LECO 2000CN

The TPH concentrations in contaminated soils ranged from 1320 (6N1) mg/kg to 13242.5 (7N1) mg/kg. The aliphatic and aromatic component hydrocarbons are listed in Table 1. ES1 shows no aromatic fraction whereas 7N1 had the highest aromatic fraction at 7058.3 mg/kg oil in soil.

Invertebrate Bioassays

Earthworm survival was 100% in all contaminated and reference soils for the duration of the 28-day reproduction test. Earthworm reproduction was highest in the untilled, uncontaminated reference soils and lowest in the artificial reference soils (Figure 3). No significant difference was observed between control or artificial soil reproduction and reproduction in all TPH-affected soils. However, a significant difference was observed when comparing reference soils and all other test soils except 6N1, the lowest TPH concentration. Mean juvenille production in both reference and 6N1 (1278 mg/kg) soils was above 200 juveniles, whereas juvenile production in other test soils remained below 150. To obtain an EC50, control and artificial soil values were disregarded. Using methods outlined by Stephan (1977), the 28-day EC50 for earthworm reproduction is 2811 mg/kg TPH.

Earthworms were fed using plastic whiffle balls that were split in half and filled with wetted horse manure. These balls contained holes that allowed for easy access of the worms to the food. Cocoons were collected from both the food contained in the whiffle ball and the soil itself. The distribution of cocoons found in food compared to the cocoons found in soil is displayed in Figure 4. A ratio of mean number of cocoons found in soil to mean number of cocoons found in food is also displayed. The soils containing less TPH had higher soil to food ratios than the more contaminated soils. This may indicate a level of reduced exposure with worms in more highly contaminated soils due to the preference for depositing cocoons in food rather that soil.

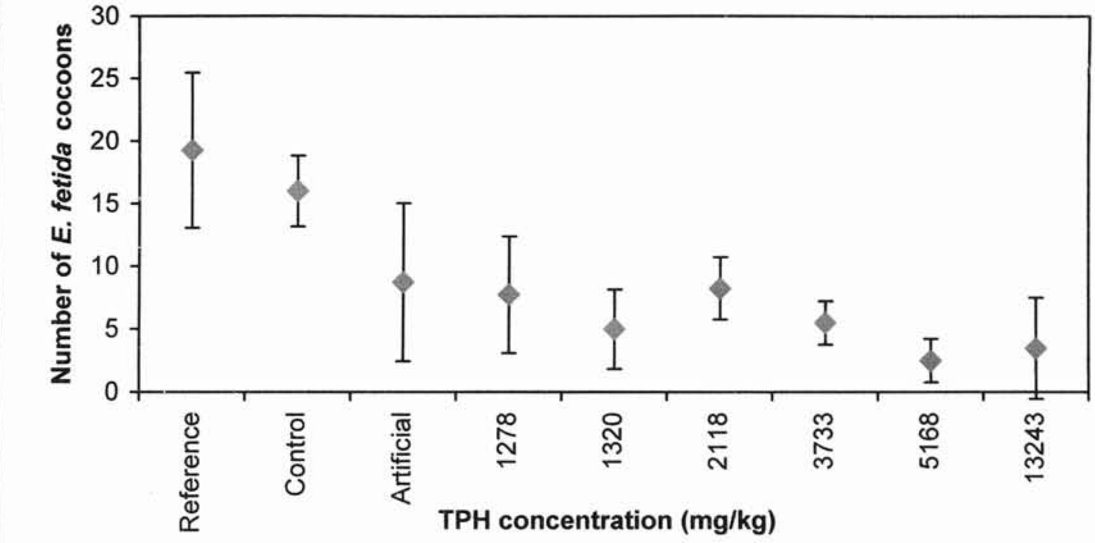

Figure 3. Earthworm cocoon production was displayed above where a significant ($p< 0.0001$) decrease in cocoon production was observed with increased TPH concentration.

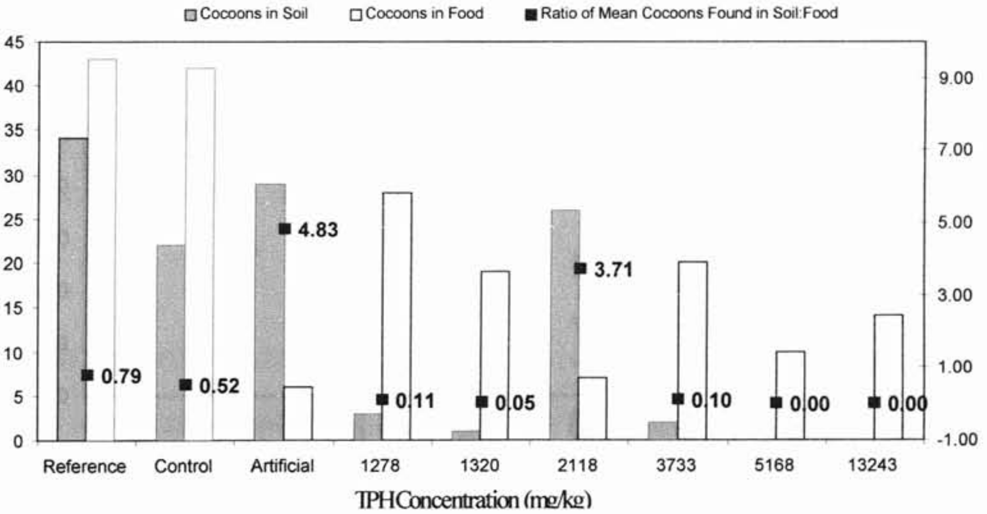

Figure 4. The above graph displays the total number of cocoons collected in test soil, and the total number of cocoons collected in the food ball that was made available throughout the 28-day test. The ratio of mean number of cocoons found in soil to mean number of cocoons found in food is also displayed, where a value less than one indicates more cocoons were found in the food medium than soil.

Tests performed with *Folsomia candida* show no significant difference ($p>0.05$) in reproduction between control and artificial soils and all TPH-affected soils. A significant difference was observed between reference and soils and all other soils except 6N1. These two soils were observed to be less compacted than other test soils. Differences in soil moisture and soil surface roughness may have increased variability between test soils.

Due to low juvenile production in the first round of *Enchytraeus albidus* tests (n=27), a second test was conducted in replicates of six. Both tests and subsequent trials resulted in variable juvenile production at week 6. Test validity criterion require that vessels produce greater than 25 juveniles (Rombke et al. 1997). This criterion was not met in either test. However, when reviewing the survival results alone, no significant difference ($p> 0.05$) was found among test soils in each test trial conducted (Figure 6).

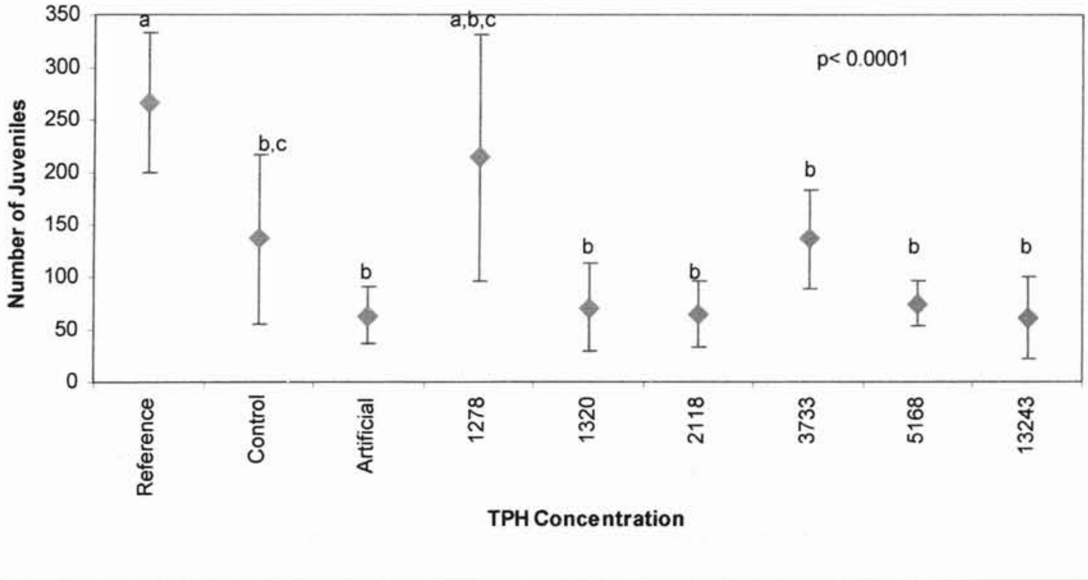

Figure 5. Mean *Folsomia candida* reproduction (n=54 ± SD). Means with the same letter are not significantly different ($p>0.05$).

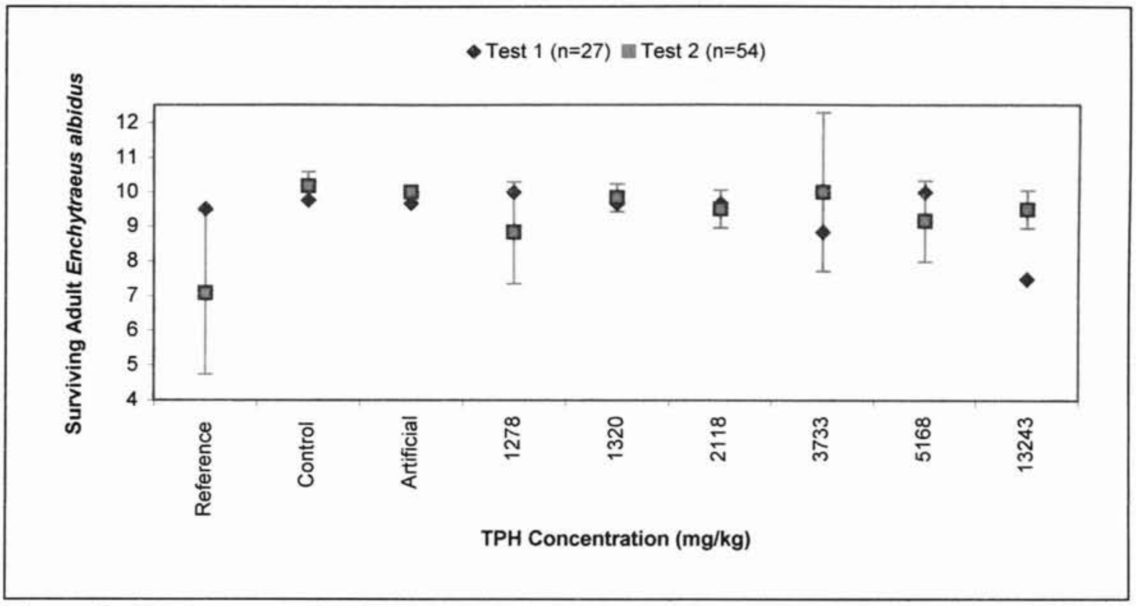

Figure 6. *Enchytraeus albidus* adult survival is displayed for two separate test trials (± SD). Trials were identical except for number of replicates where test one had at least 3 replicates (reference, control and 7N1 all had replicates of four) (p=0.0115) and test two had six replicates.

Plant Bioassays

Germination for lettuce (*Lactuca sativa*) and mustard (*Brassica rapa*) was >60% and >88%, respectively. A concentration-response pattern was not observed for either standard toxicity tests (p>0.05). A significant (p<0.001) increase in above ground biomass was observed in mustard seedlings grown in low-TPH affected soil (6N1) (Figure 7).

Height was determined for mustard at day 14 and day 28 (Figure 8). A significant difference was observed with 6N1 stem height (p < 0.001) and all other test soils. This difference is reflected in above ground biomass, as described above. Stem height was measured successfully on day 28 for lettuce (Figure 9). Height of lettuce seedlings at day 14 was inconclusive due to a lack of differentiation between beginning of leaf buds and end of stem. No significant difference was found between height of seedlings in test soils (p>0.05).

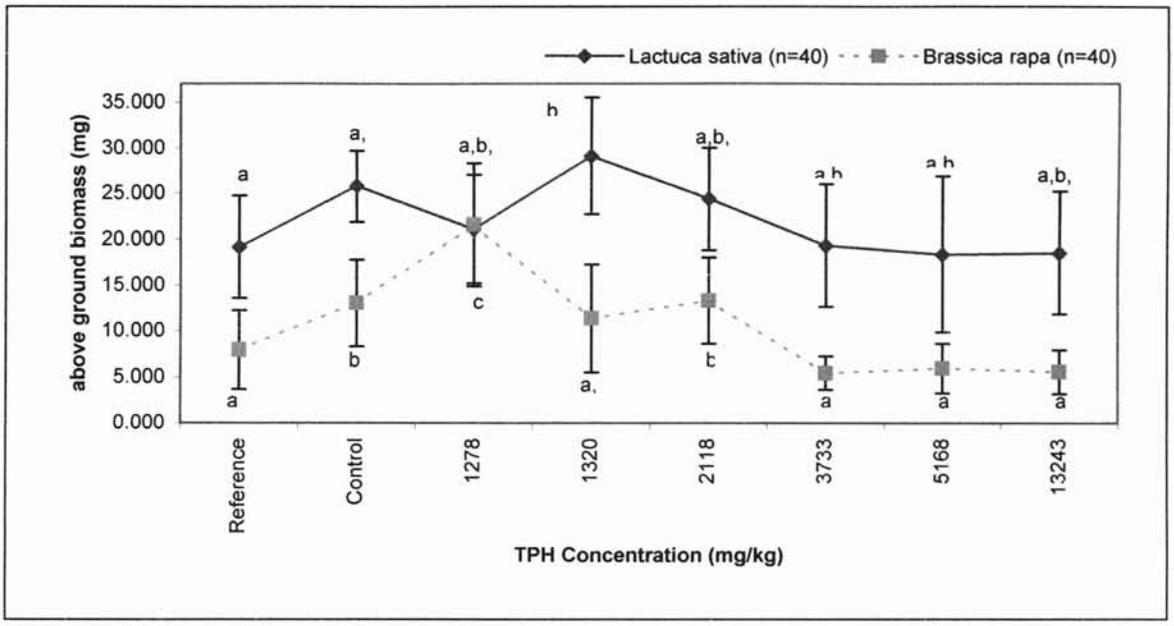

Figure 7. Lettuce (*Lactuca sativa*) and mustard (*Brassica rapa*) above ground dry-weight biomass. Means with the same letter are not significantly different (p>0.05).

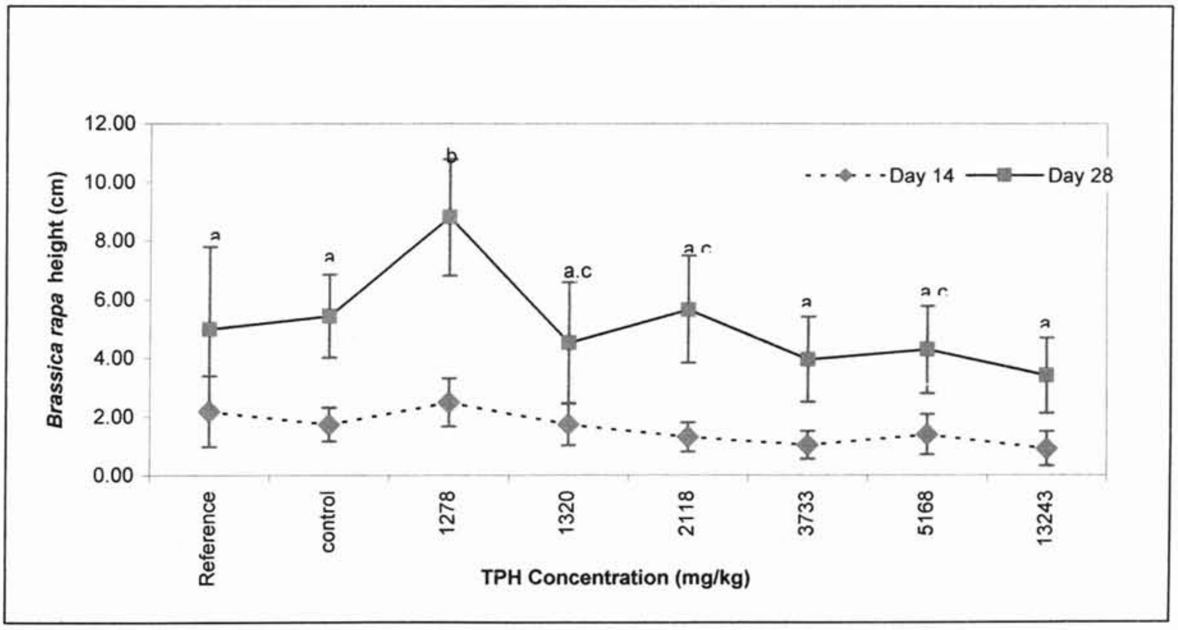

Figure 8. Mustard (*Brassica rapa)* stem height at day 14 and day 28. Means with the same letter are not significantly different (p>0.05).

Germination for big bluestem and little bluestem were both below 5%. Further analysis or comparisons of stem height or plant biomass proved unsuccessful with the limited number of samples.

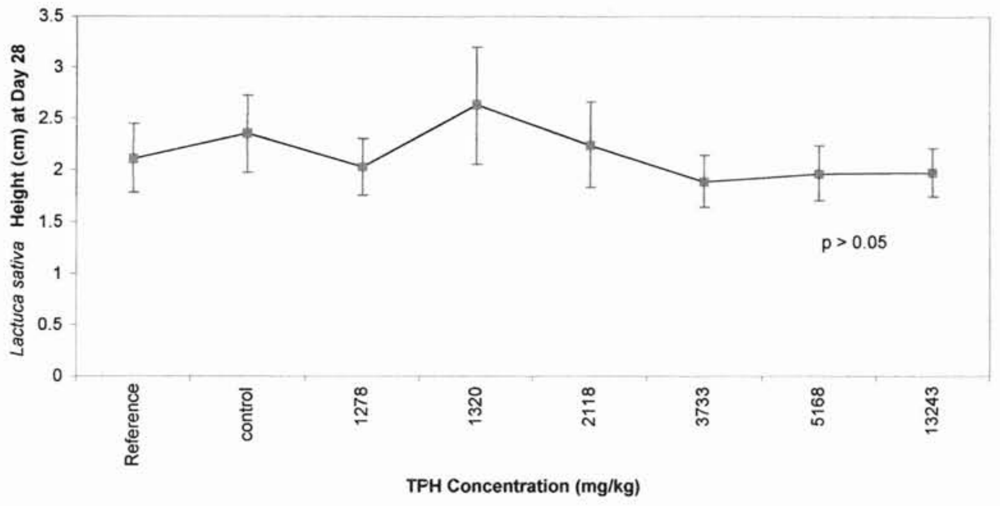

Figure 9. Lettuce (*Lactuca sativa*) stem height at day 28. Stem height was indeterminate on day 14 due to a lack of differentiation between beginning of leaf buds and end of stem.

DISCUSSION

The objective of this assessment was to develop a relevant ecological screening criterion for petroleum-hydrocarbon contaminated sites at the Tallgrass Prairie Preserve (TPP). In total, 13 endpoints from seven soil-organism tests were selected. Of all tests conducted, only *Eisenia fetida* cocoon production was significantly correlated with hydrocarbon measurements (Figure 3).

Results of this study support a criterion for the protection of soil invertebrates based soley on earthworm reproduction. The 28-day *E. fetida* EC50 based on earthworm reproduction was 2811 mg/kg TPH. The tenth percentile of a distribution of effects concentrations is typically used to determine ecotoxicity of petroleum hydrocarbon in soils. Without a suite of effects concentration values, a criteria protective of 90% of the soils species is impossible to obtain. To preserve the protective nature of this calculation the screening value for this study can be set at 10 percent of the earthworm reproduction EC50, or 281 mg/kg TPH. This value is consistent with soil protection values found in current literature (410 mg/kg TPH, Salanitro et al. 1997; 120 mg/kg TPH, Saterbak et al. 1999). Existing numerical standards and screening levels for (TPH) contaminated soils range from tens to thousands mg/kg of soil (Efroymson 2001). Similar plant and soil invertebrate toxicity tests proposed criteria at TPH levels between 4000 and 10000 mg/kg soil for earthworm avoidance and survival and between 2000 and 34000 mg/kg soil for seed germination depending on plant species (Wong et al. 1999). Potential toxicity benchmarks for the protection of soil invertebrate communities are generally lower than those proposed for plant production (Dorn et al. 1998).

In the development of the TPH RESC, standardized tests were adapted for use with TPP field soils. The protocol developed for TPP field soils allowed for microbes, native invertebrates, seeds, small stones and vegetative debris to remain in test soil. Although "relevance" was achieved by testing field soils with native species in addition to non-native test species, clear dose-response relationships were not observed for tests performed with native species.

Invertebrate Bioassays

Mean cocoon production by earthworms in control soils ranged from 1.25-9.5 cocoons/adult/week . These rates are higher than those reported by Saterbak et al. (1999) and Van Gestel et al. (1992) at 1.3 to 2.9 cocoon/adult/week. Variability in cocoon production may have been affected by soil texture or other physical-chemical properties of TPP soils.

The significant correlation between the chemical parameter of soil TPH and the biological endpoint of earthworm cocoon production suggests that fewer analytical tests and toxicity measurements may be necessary to sufficiently define TPP contaminated soils.

Validity criteria for the Enchytraeid reproduction test require the average number of juveniles to be greater than 25 per test vessel and that the coefficient of variation is less than 50% at the end of the test (Rombke et al. 1997). Neither criterion was reached in either of the *Enchytraeus albidus* reproduction trials conducted. In addition, juvenile production was low in artificial soils. This indicates that further method development is necessary before future toxicity tests are performed. Future *Enchytraeus albidus* toxicity tests may be improved by ensuring soil pH is within a biologically appropriate (spell check!) range for this organism.

Tests performed with *Folsomia candida* show no significant difference in reproduction between control and artificial soils and all TPH-affected soils. This species of springtail lives and feeds on the soil surface and therefore experiences reduced dermal and oral uptake of the contaminant when compared to the earthworm species tested. Differences in soil moisture and soil surface roughness may have increased variability between test soils. The protocol developed for TPP field soils should be modified to account for differences in crevices produced in test soil. The availability of these crevices is necessary for egg deposition and protection from moisture deprivation.

Plant Bioassays

An interesting hormetic effect may have been observed with *Brassica rapa* where small additions of oil actually enhanced growth when compared to plants grown in uncontaminated soils. A statistically significant increase ($p<0.001$) occurred in the measured dry-weight biomass of seedlings grown in 1278 mg/kg TPH compared to all other test soils, including control and reference soils (Figure 9). This enhanced effect of crude oil on plant growth has been reported previously in the literature (Salanitro et al. 1997; Wang and Bartha 1990; Baker 1970; Carr 1919). Soybean yield increased 50% in field plots of a sandy soil that contained 7500 mg/kg oil (Carr 1919). Small additions of petroleum also enhanced growth of corn in bioremediated soils (Salanitro et al. 1997). It has been suggested that lipophilic organic contaminants, like petroleum hydrocarbons, partition to the epidermis of the root or to the soil particles and are not drawn into the inner root or xylem because this part of the translocation system is water-based (Simonich and Hites 1995). However, wheat and oat seeds grown in medium- and light-weight crude oils were significantly reduced (20-70% less) (Salanitro et al. 1997). Lower thresholds for toxic effect are common for bioremediated soils and lighter crude oils, likely due to the increased bioavailability or toxicity of polar organic metabolites. Additionally, previous research has shown that lower thresholds for toxic effect of petroleum mixtures in soil occur at concentrations much greater than those of minor individual chemical constituents (Efroymson 2001). These conflicting and confounding effects suggest that until more data is accumulated, phytotoxicity of petroleum hydrocarbons cannot be predicted and varies widely with oil and soil type, concentration, and plant species.

Poor growth in plants grown in high levels (5168 – 13243 mg/kg TPH) of crude oil-contaminated soil may have been due to physical changes in the soil matrix and/or toxic effects of the hydrocarbons. It was observed that containers with high levels of oil contamination required higher volumes of water to maintain an equivalent moisture level with other test soils. Similar effects were found with corn where poor growth was reportedly due to exclusion of air from roots by oil, the depletion of oxygen by increased microbial activity, reduction in availability of water to the plants, and possible toxicity of sulfides and/or manganese during hydrocarbon decomposition (Udo and Fayemi 1975).

Changes to protocol E 1963-98 (ASTM) are recommended for future plant toxicity testing. A large portion of seedling roots emerged through holes in the bottoms of test chambers, thereby reducing exposure to contaminants in the soil. Each chamber contained one or two plants that grew considerably more than the other seedlings, suggesting that plant growth was not independent. Also, the roots of the five plants often entangled, such that the root biomass of individual plants could not be determined. Future tests may be improved by using taller containers, each sown with one seed per container.

In addition to procedural changes, a wider selection of native plant test species may have produced more conclusive results. Both native grass species tested required long (> 2 week) germination times and had slow growth once germinated when compared to the more standard test species, *Brassica rapa* and *Lactuca sativa*. Although assessments using native species improve ecological relevance, the results may be difficult to interpret. A low germination rate and slow rate of growth make these species impractical for use in toxicity testing.

These data show that changes in oil and soil type, and sensitivities of different test species significantly influence toxic effect. Total petroleum hydrocarbon measures have been used as a soil standard to predict acceptable levels of risk from a human health perspective. This is a very general measure of hydrocarbon contamination and does not consider specific chemical composition or the bioavailability of hydrocarbons. These data show that, except for *Eisenia fetida* cocoon production, most toxic effects in test species are poorly correlated to TPH in soil. The development of a chemical measure or technique that assesses the bioavailability of hydrocarbons in soil is a promising approach to normalizing differences in chemical bioavailability among sites due to variations in soil chemical/physical characteristics (Lanno 2001).

The format of this assessment closely follows the protocol outlined for development of an ASTM RBCA RESC, which analogous to the US EPA Eco-SSL process. Although these frameworks for assessing ecological risk are theoretically appealing, these data have shown that it is difficult to produce clear dose-response curves using TPH field-contaminated native soils and native test organisms and that factors other than toxicity due to hydrocarbon exposure may be important in assessing risk. The creation of the TPP site-specific soil protection value was based on earthworm cocoon production, just one of the 13 endpoints reported. The "ecological relevance" of this type of criteria is considered below.

To identify factors that pose risk to an ecosystem, it is important to consider how an ecosystem functions. The measurement of ecosystem function is a heavily debated topic among scientists and policymakers and it is unlikely that a meter-stick will be agreed upon soon (Fairbrother 1998; Wilson 1998). Current parameters measured in ERA studies are far removed from actual ecological risk. This is demonstrated in current ERA strategies that limit assessment to organism-level effects by basing the core of their assessment on comparing constituents to existing screening criteria collected from available online or published databases (ECOTOX, AQUIRE, etc.). To study an ecosystem, observations must be made at the ecosystem level of organization

(Vigerstad and McCarty 2000). The problem with this approach lies in the ability to make quantitative measures at this level of organization. While assessors are relatively comfortable making predictions about chemical concentrations present in a soil, or even risk to individual organisms exposed to that soil, population, community or ecosystem-level assessments are rare and often highly disputed. The state of ecological theory limits the predictions that can be made at these higher levels of organization (Ferson et al. 1996). Trophic interactions are complex and basic assumptions about food web and food chain models are still disputed (Ferson et al. 1996). Without this knowledge, calculating risk across different spatial and temporal scales in ecosystems is difficult. Additionally, ERA is limited in that it is typically focused on a single stressor (Dyer et al. 2000). Cumulative risk from numerous contaminants or other hazards in the landscape may compromise ecological function. Failure to consider all hazards to which a species may be exposed may underestimate actual risk. The ASTM tiered process and the EPA EcoSSL process focus on creating soil protection values from toxicity testing. Other aspects of the ecological impact of a spill, such as cumulative effects and habitat continuity, are not addressed. These discontinuities reveal a gap in the science and policy of ERA. A model that works to bridge that gap will frame the second chapter of this assessment.

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CHAPTER 2

DEMONSTRATION OF THE VALUE OF GIS IN ASSESSING CUMULATIVE ECOLOGICAL RISK

INTRODUCTION

The Tallgrass Prairie Preserve (TPP) contains oil and brine spills as well as production facilities such as roads, pipelines, pumpjacks, and other infrastructure. These disturbances occur across a range of spatial scales that may affect TNC's goal of a functioning, healthy tallgrass prairie ecosystem. To address this concern it is necessary to look beyond the toxicological impacts of oil spills alone. For example, surface area disturbances that are not spill-related can remove vegetation for a period of time. The combination of oil and brine spills and other surface-area disturbances may impact habitat continuity. Habitat may be compromised to a point where patchiness reduces species abundance, which has been shown in a tallgrass prairie community with disturbances as small as pocket gophers mounds that impact plant community structure (Collins 1989). An inventory of existing facilities in the TPP and surface area measurements of the spill sites and surface area disturbances can be used to determine where tallgrass prairie plant species are being disturbed.

The purpose of this assessment is to develop a method for hazard screening for 1) site ranking, 2) prioritization for further investigation, and 3) prioritization for remediation. Information on what facilities are present at the TPP, the land surface areas they encompass and the spatially explicit risk of these facilities on the ecosystem must be obtained. To accomplish this task, a profile of hazards of the TPP was mapped and an ordinal ranking of risk was developed. This method of assessment has allowed for a synoptic approach for predicting local and site-wide risk to the tallgrass prairie ecosystem. It has also helped demonstrate the utility of marrying of GIS and ecological risk assessment to produce a novel and important example of cumulative and ecosystem-wide assessments.

Cumulative risks occur when an ecological receptor is exposed to multiple hazards. In the case of the TPP, species could be threatened by hazards such as contamination of soil by brine or oil, soil compaction, roads, pumping structure, etc. Failure to consider all hazards to which a species may be exposed may underestimate actual risk. Since the particular mix of hazards to which a specific species are exposed varies spatially within an ecosystem, cumulative risks will also vary from one location to another. For this reason, spatial analysis of ecological risks is required to assess risk on an ecosystem level.

Currently, EPA guidance documents that discuss cumulative risk are more theoretical than procedural (US EPA 1999, 1998). The United States government has required cumulative effects to be considered in assessments for over three decades with inception of the National Environmental Policy Act (40 CFR Section 1508.7). In spite of this law and other laws emphasizing the importance of measuring cumulative risks, they are still rarely considered during the decision-making process (Abbruzzese and Leibowitz 1997). Cumulative assessments are impractical for regulators, they can be costly for responsible parties, and uncertainty exists when deciding what endpoints risk assessors should be measuring.

The endpoints measured in this assessment focus on vegetative cover, as justified next. The tallgrass prairie can be valued for the tangible benefits it provides, such as a diverse plant and animal community, valued rangeland for bison and cattle, and oil reserves. The TPP can also be valued for the intangible benefits it provides, such as aesthetics or the preservation of the one of the last intact stands of tallgrass prairie in North America.

The value of each of these ecosystem functions is important and subjective. The decision of what is valuable is not a scientific or technical issue, but must be determined by policymakers (Abbruzzese and Leibowitz 1997). To create a scoring system to measure cumulative effects on the TPP, the goals set by The Nature Conservancy (TNC) were consulted. TNC purchased the TPP in 1989 to create a preserve that will protect an array of biodiversity features indigenous to the locale in a setting that utilizes "...ecological processes that are essential to maintaining a naturally functioning tallgrass prairie landscape" (Hamilton 1996). The focus on tall grasses and other prairie flora is emphasized in TPP literature and web resources (www.tnc.org). The presence of a healthy prairie-plant community is often a good indicator of a healthy prairie animal community (and vice-versa). To utilize this linkage, measuring the presence or absence of prairie plants will provide an appropriate measure of ecosystem health.

A more pragmatic justification for focusing this assessment on plants recognizes the limits of control that TPP managers have over this ecosystem. The TPP is surrounded by a fence; however, the maintenance of many of its small mammal, bird, invertebrate, and microbial communities depends on actions beyond TPP boundaries. TPP managers also cannot directly control other important ecosystem values, such as how aesthetically pleasing the prairie is to each visitor. However, TPP managers can work to maintain coverage of plant communities present in the preserve. They can control the number of roads and facilities constructed on their lands that disturb prairie vegetation. It can be argued that if a healthy plant community exists, the capability of the land to provide habitat for animal communities will follow. Because it is reasonable to limit this investigation of cumulative risks to those activities that are controllable by TPP managers, the presence or absence of plant coverage in the TPP is the focus of this assessment.

The TPP contains a variety of activiites that may influence plant communities. Roads and facilities compact soil and, as a result, prevent plant growth. Tillage of soil often associated with remediation practices uproots plants and limits their growth. Toxicity of contaminants such as oil or the saline water used to extract oil may prevent growth. These sources can be considered "hazards" to vegetative cover and are also quantifiable in surface area and level of toxicity to plants.

LITERATURE REVIEW AND EXISTING MODELS

To help organize the parameters that affect the structures of ecological function, a dynamic and inclusive process of quantifying temporal and spatially explicit ecological risk is needed. Although the processes are still unclear, assessments at the landscape scale have been documented. A number of techniques or observations have been proposed such as, energy flow in units of kg per unit time, production/biomass ratio, and effluent loading in watersheds (Vigerstad and McCarty 2000). Scientists have employed the use of new tools, such as geographical information systems (GIS), in linking organism-level effects to ecosystem-level effects. Graham et al. (1991) developed a "prototype regional ecological assessment" for elevated ozone levels in the Adirondack forest. This group used GIS to link terrestrial and aquatic systems in a regional spatial assessment. Ecosystem level effects from contaminants were also measured in the body burdens of sentinel organisms using measures of dieldrin by Clifford et al. (1996) and metals (Ag, Cd, Cr, Cu) by Birge et al. (2000). Culp et al. (2000) used a weight-of-evidence approach by pooling field and lab measurements and incorporating indicators at different trophic levels to assess ecological risk in an aquatic system. Each of these assessments used a different method to predict ecosystem level effects.

The TPP is a spatially heterogeneous system. The quantification of spatial components can be handled in many ways. Nominal models, weighted (ordinal) models, and quantitative (interval/ratio) models are three approaches used in the quantification of space or to 'simplify reality' (Wadge 1993). Rejeski (1993) discusses weighted models and how some substances, or the characteristics of an organism, may play a disproportionate role in producing risk and need to be accounted for in the model. A recognized ranking scheme that has been peer reviewed is necessary to "debias" this modeling approach (Rejeski 1993). This is true of all modeling approaches.

Ranking schemes have been used previously in ERA. Ecological risk ranking was used in an US EPA Comparative Risk Project for the purposes of conducting an environmental evaluation of 24 distinct ecoregions in US EPA Region 6 (Parrish et al. 1993). The working group assumed that ecological risk existed when environmental threat impaired the ability of an ecoregion to perform basic ecological functions. This risk ranking system was derived from seven basic ecological functions identified in the literature (i.e., vegetative cover, soil type). Results were displayed spatially using a GIS to identify regions of the highest risk. Miller et al. (1998) and Fedra (1998) also discussed the use of GIS mapping techniques in ecological risk assessment. Miller et al. (1998) created "toxicity test scores" from weighting factors when evaluating residual risk from lewisite, nerve agent degradation products, and various metals at a military base. Fedra (1993) described how the process of integrated risk management improved with GIS and that models take on a more intuitive understanding with this tool.

OBJECTIVES OF RESEARCH

The objectives of the proposed research are:

1) develop and inventory of existing hazards such as spills, roads, and other facilities, and to map this data using a Geographical Information System (GIS);

2) combine relevant ecological screening criteria created in another project related to this work with the hazard inventory; and
3) demonstrate how spatially explicit ecological risk can be predicted across the prairie locally and site-wide.

Goal

The goal of this study is to develop a method for hazard screening to enable an assessor to rank a series of sites to be assessed and to prioritize those sites for further investigation and remediation.

Limitations

This project is limited in scope in that it will not assess risk to individual test species. The method employed will assess risk to vegetative cover as a whole and produce a table that can be used as an indicator of threats to that cover. Greater ecological threat to that cover is implied with a higher risk score. TPP managers can display this table to reference areas of hazard concentration. The information may also be used to help focus remediation strategies or as a reference for future ecological risk assessments conducted at the TPP.

METHODS

Study Site

The TPP is located near the southern end of the Flint Hills – the largest extant block of tallgrass prairie in North America (36°50'N, 96°25'W) (Hamilton 1996). Approximately 80% of the preserve is tallgrass prairie vegetation (Hamilton 1996), dominated by big bluestem (*Andropogon gerardii*), indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*) (Coppedge et al.

1998). Bison were introduced to the TPP in 1993. As mentioned above, the Nature Conservancy reported a herd size of 1200 bison in the year 2000 with the intention of expanding that herd to 3300 head in the future (www.tnc.org, Nov, 2001). Herd size is managed by annual round-ups.

Mapping

GIS is a useful tool that can integrate spatial, temporal, and toxicological information in a terrestrial ecosystem. ArcView® is a computer-based GIS tool for mapping and analyzing processes and events that are related by their location. This software package facilitates manipulation and analysis of spatially arrayed data, such as contaminant release location, surface areas and depth, contaminant type and degree of contamination, remediation techniques performed, and other physical parameters (topographical data, temperature data, etc.). This program was used to integrate data from a range of sources (digital ortho-quadrangles, database files, and image files) to assist in calculating risk (hazard?) values.

The TPP was divided into two different levels of resolution, 1600 ha and 400 ha grids, using existing digital ortho-quadrangles (DOQs), obtained from the Oklahoma State University Spatial and Environmental Information Clearinghouse (SEIC) (Figure 10). Preserve boundary information was obtained from existing files in a TPP database where information is collected and maintained by a SEIC employee. Spill data was collected in the field using a Global Positioning System (GPS, GeoExplorer). After collection, the data were corrected using the Oklahoma State University base-station in Pathfinder. All other information was digitized at a scale of 1:1300 m using the 1995 DOQs. Each of the following types of facilities were mapped throughout the TPP:

- All visible gravel and 2-track roads

- storage tanks and pumpjack ('rocker-horse') facilities
- housing and TPP maintenance buildings
- spill areas (crude oil, brine and combination spills)
- Any other bare patches of land that were visible from the 1995 DOQ that removed tallgrass prairie vegetation
- TPP boundaries

The items listed above were mapped because they each remove a discernible amount of vegetation from the TPP landscape, with the exception of the TPP boundary. All features listed above (with the exception of the TPP boundary) are identified as "hazards" and weighted according to their level of disturbance to plant growth.

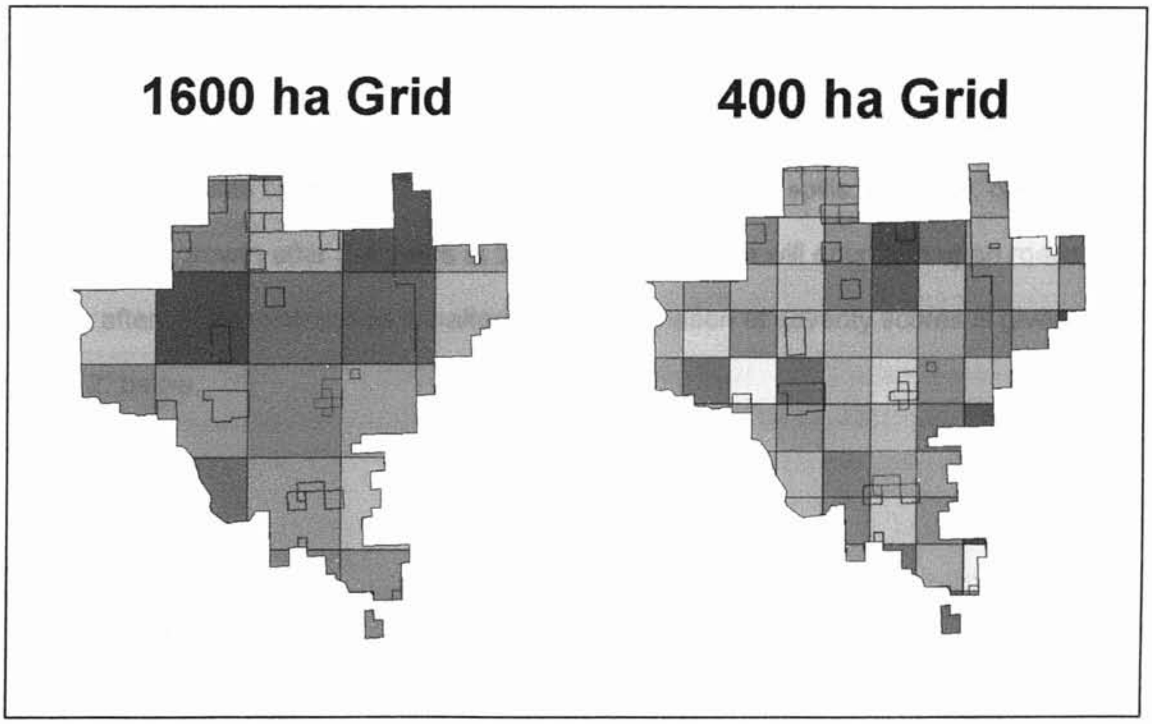

Figure 10. The TPP is divided into two levels of resolution: 21 equal cells, each 1600 hectares in area and 84 equal cells, each 400-hectares in area.

In addition to the risks posed by the quantifiable hazards mentioned above, other occurrences influence TPP vegetation. Invasive species and regular controlled burns also remove vegetation, but will not be quantified in this assessment. The location of invasive plant species is difficult to differentiate from indigenous flora when viewed from a DOQ. Controlled burns are conducted to mimic the response of prairie wildfires and are considered necessary to maintain healthy tallgrass prairie vegetation and are thus not considered hazards (Hamilton 1996).

An ordinal scale was employed to create "severity scores" associated with each of the hazards to measure the type of disturbance imparted to TPP vegetation. For example, some hazards have different vectors of impact to vegetation such as the toxicity of an oil spill to plant growth or the compaction of soil due to roads. The hazard severity scores are related to the permanence in which these hazards disturb the vegetation. A brine spill is given the highest severity score as it has been shown to remove vegetation for the longer amounts of time (Kerry Sublette, pers comm.). Oil spills, however, often sustain plant growth after 3-4 years at the TPP. Vegetation will encroach upon roads shortly after road maintenance is halted. The designation of severity scores is given in Table 2, below.

Table 2. Table of Severity Scores.

Adverse Ecological Effect	Hazard	Hazard Severity Score (ordinal scale)
Soil compaction	Facilities, Roads, Pumpjacks, Tanks, Buildings, all other super structures	2
Toxicity	Oil spill	1
	Brine spill	4
	Combination oil and brine spill	5

Risk Calculation

To calculate risk scores, the percent area covered by each feature in the grid is multiplied by the hazard severity score. For example, if the roads in grid 1 cover 1 ha and the pumpjacks cover 0.5 ha and the grid is 400 ha in total area, the risk value calculation is shown below in Table 3.

Table 3. An example of a Risk Value calcuation.

Example Cell (Total Area 400 ha)	% Surface Area (ha)	Risk Rank (ordinal scale)	Hazard Severity Score (% S.A. * Risk Rank)
Roads	0.25	2	0.5
Pumpjacks	0.125	2	0.25
Facilities	0	2	0
Oil Spills	0	1	0
Brine Spills	0	4	0
Combination Spills	0	5	0
Risk Value (Σ Hazard Severity Scores)			0.75

In this assessment, hazard severity scores are additive for the sake of computation when grids contain more than one hazard type. Although a road is not twice-as damaging as an oil spill, a grid containing roads and an oil spill (2x + 1x) is less hazardous that a grid containing roads and a brine spill (2x + 4x).

Coverage for each hazard in individual grid cells was derived using the clip function in GeoProcessing Wizard, an extension of ArcView. All hazards in the TPP were digitized as polygons and therefore all had surface area. The surface area of each feature was determined using the "ReturnArea" command in the field calculator and then exported to Microsoft Excel for the calculation of risk values. Each hazard theme was digitized into 21 divisions for the 1600 ha grid and then each of those cells was clipped four times for 84 divisions in the 400 ha grid.

RESULTS

Generation of Maps

The TPP was divided into two levels of resolution, 21 1600-ha cells and 84 400-ha cells (Figure 10). This division was operationally most reasonable based on the size and shape of the TPP and followed the goal of reviewing local and site-wide risk levels.

The results of the road, pumpjack, and other facility digitizing are shown in Figures 11 and 12. All gravel roads were digitized with a width wider than visible two-track roads. This difference accommodates the increased presence of vegetation on two-track roads. All visible pumpjacks were digitized regardless of operational status. The total surface area for each type of hazard is shown in Table 4.

Table 4. The total surface area of each hazard in the TPP.

Surface area (ha)				
Roads	Pumpjacks & Facilities	Oil Spills	Brine Spills	Oil-Brine Combination Spills
81.55	9.01	0.94	4.44	0.16

The area of TPP covering each grid was used to normalize risk scores to account for the arbitrary placement of the grid lines.

The risk values are tabulated for each grid resolution in Appendix 1. A concentration of hazards in the northwest portion of the TPP has resulted in high RVs in each grid. The relatively large amount of oil production in this portion of the TPP is shown by these increased values. Figure 13 displays the risk values for both grid resolutions.

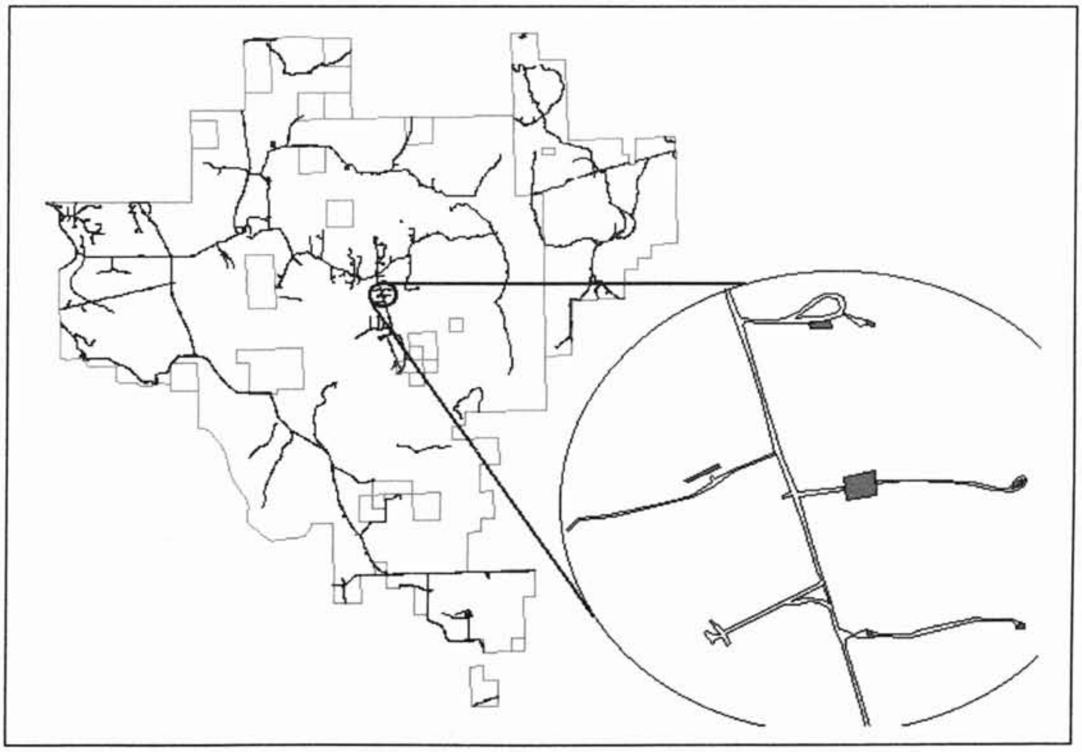

Figure 11. The above diagram shows a close-up view of road and pumpjack/facility layers. The roads are shown in black and pumpjacks and other facilities are shown in purple.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

The risk values created in this assessment show areas of increased threat to the TPP in cells 8, specifically 8a and 8c. These cells are listed as priority one in the 1600 ha map and priority one and two in the 400 ha map. The term priority is used to express grid cells with the highest risk value and therefore areas that may be of highest concern for park managers. This northwest portion of the TPP contains all three types of spills: oil, brine, and oil-brine combinations, and has high road surface areas. All areas that contain brine spills in the prairie are ranked high: grid 8, 10 and 13 are given priority 2,7 and 5 respectively (see Table 5). Cell 3, specifically 3d, is also given high priority;

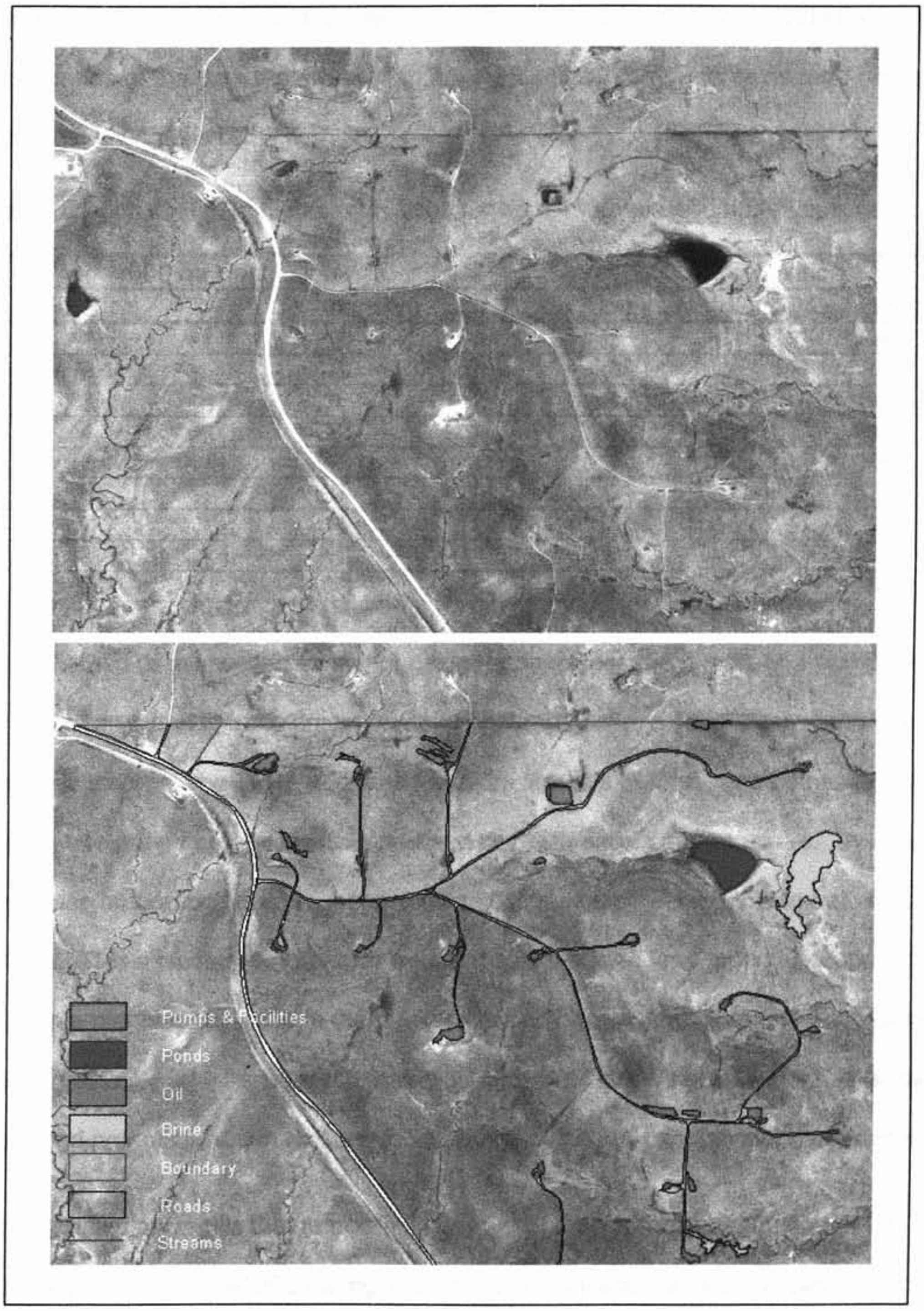

Figure 12. The above DOQ shows the 'before' digitizing view, and the below shows the map produced after digitizing is completed. Roads are shown in black, TPP boundaries in red, oil spills in brown, brine spills in yellow, and pumpjacks and facilities are in purple. This area of the TPP is section 8 and produced the highest RV in the preserve.

however, the small area of the TPP used to normalize RVs is responsible in part for the increased value. Although the majority (94%) of this grid cell falls outside the boundaries of the park the area within the park coincidentally contains road and pump hazards, giving this cell a high RV.

Table 5. Top ten list of high priority sites for both 1600 and 400 ha resolutions.

1600 ha Resolution		400 ha Resolution	
Priority	Cell Identity	Priority	Cell Identity
1	3	1	8a
2	8	2	8c
3	1	3	3d
4	20	4	19d
5	13	5	20b
6	9	6	13d
7	10	7	8b
8	12	8	1d
9	18	9	13a
10	21	10	9b

This method of assessment was not designed to assess the effects of a particular action or object on a specific ecological receptor; instead, it allows for a comparison of potential risk levels across the TPP. Information on the impacts of roads and other oil-related facilities to prairie organisms is limited and costly to collect and measure. By creating a database of threats, future researchers can use it as a screening tool to help focus their efforts. This assessment may also be used as a platform for a proactive approach to land use-planning activities in the tallgrass prairie ecosystem. A regional assessment of the remaining Flint Hills tallgrass prairie stands would show continuity of this landscape type and potentially aid in Nature Conservancy and state park development decisions.

The facilities and spills that temporarily or permanently remove vegetation at the TPP do not support TNC's goal of creating a functioning tallgrass prairie ecosystem. Each of these surface area disturbances can be considered a threat to the goal of the TPP. Some threats may remove the tallgrass prairie vegetation for longer periods of time, such as roads and brine spills. Other hazards may have different vectors of impact, such as the toxicity of oil spills, or the potential risk of a spill from an old pipeline. Regardless of the type of hazard, each disturbance can be ranked and weighted depending on the time that area of land requires to regain plant coverage. The creation of this map will act as a rapid screening tool for tier 1 or first-level assessments. This habitat-based tool can be used to evaluate contaminant-induced changes from oil production and surface area disturbances in this heterogeneously contaminated terrestrial environment.

Cumulative Assessment Conclusion

The second objective of this assessment was to determine what facilities are present at the TPP, how much surface area they encompass, and to calculate the spatially explicit potential risk of these facilities and spills across the landscape. This top-down approach to ecological assessment revealed threats to the TPP landscape that may not have been discovered with the creation of screening criteria alone. Threats such as brine spills, roads, pumpjacks and tillage of oil-spill sites were found to pose toxic effects and/or surface area disturbances not accounted for in the development of a petroleum screening criteria. Areas of highest priority for park managers are displayed in Figure 15. It is recommended that remediation and deactivation efforts be focused in area eight, or the NW portion of the TPP. Four historic brine spills and a concentration of oil production facilities have prevented growth of tall grass species in this area for approximately 70 years.

The use of the GIS database has allowed a more explicit evaluation of the spatial distribution of the cumulative ecological risks from spills and other hazards to vegetation at the TPP. Mapping all disturbed sites and ranking them based on permanence of vegetative removal, regardless of the mode of distubance, removes a toxicological bias that results when screening sites based on RESCs alone. Using this method can aid the park manager's ability to evaluate ecological risks by providing a tool that screens hazards for site ranking and prioritizes these areas for further investigation and remediation.

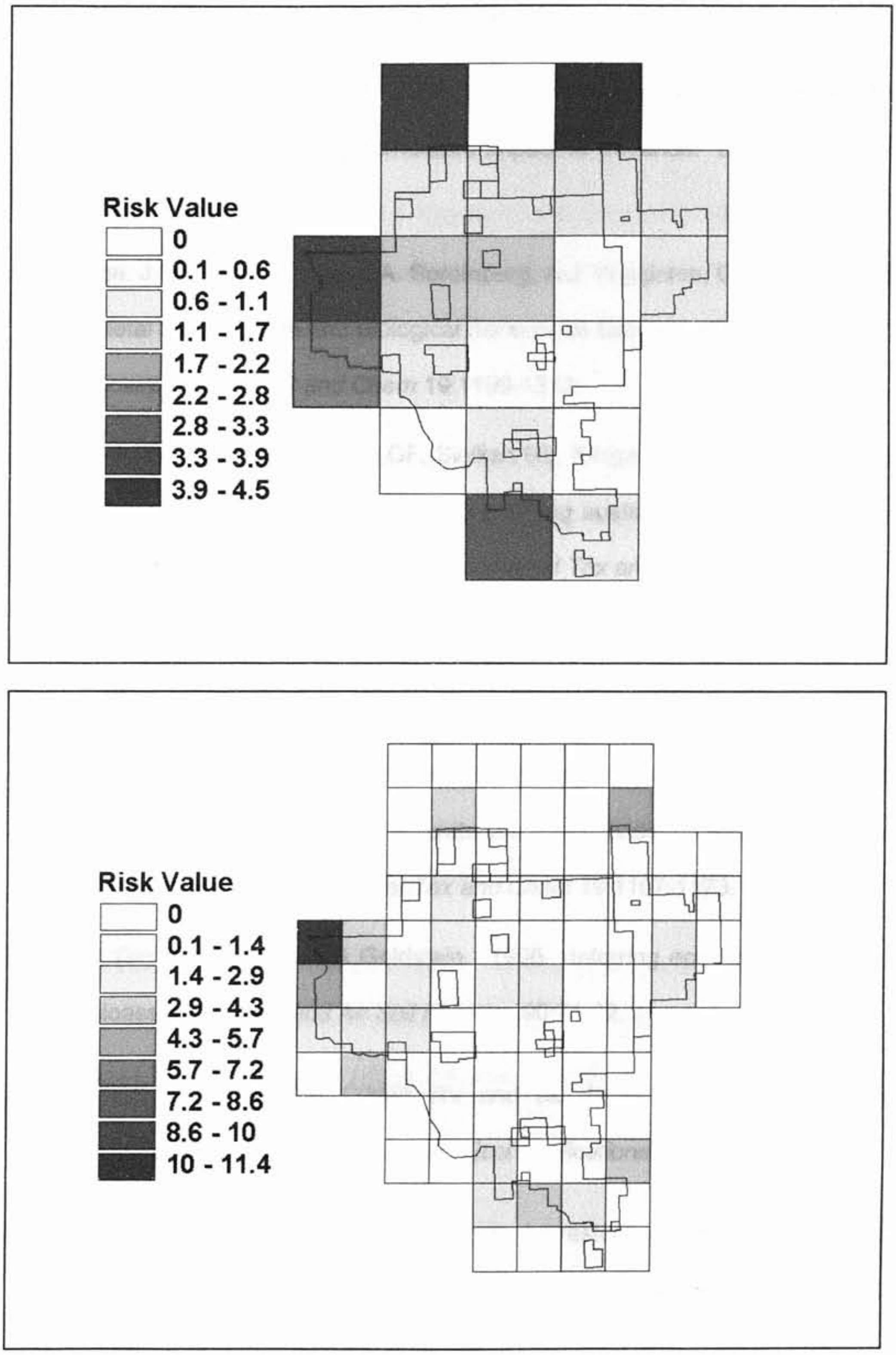

Figure 13. Risk values (RV) are shown for both levels of resolution; 1600 ha, above diagram, and 400 ha, below diagram. Dark red indicates increased RV.

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Appendix 1

Table 1. Risk values for the TPP in 1600 ha and 400 ha resolution.

1600 ha Resolution			400 ha Resolution		
Cell Identity	1600 ha RV	Order of Priority	Cell Identity	400 ha RV	Order of Priority
1	3.43	3	1a	0.000	0
			1b	0.000	0
			1c	0.000	0
			1d	3.431	8
2	0.00	21	2a	0.000	0
			2b	0.000	0
			2c	0.000	0
			2d	0.000	0
3	4.45	1	3a	0.000	0
			3b	0.000	0
			3c	0.000	0
			3d	4.451	3
4	0.80	14	4a	0.000	0
			4b	0.340	45
			4c	0.250	48
			4d	2.161	12
5	1.05	12	5a	0.530	41
			5b	0.000	0
			5c	1.371	23
			5d	1.105	28
6	0.72	15	6a	0.000	0
			6b	1.360	24
			6c	0.104	51
			6d	0.845	34
7	1.08	11	7a	0.000	0
			7b	0.000	0
			7c	1.149	27
			7d	0.967	31
8	3.63	2	8a	11.441	1
			8b	3.868	7
			8c	4.906	2
			8d	1.172	26
9	1.38	6	9a	0.489	42
			9b	2.540	10
			9c	1.860	15
			9d	0.534	40

Table 5. continued.

1600 ha Resolution			400 ha Resolution		
Cell Identity	1600 ha RV	Order of Priority	Cell Identity	400 ha RV	Order of Priority
10	1.19	7	10a	0.156	50
			10b	0.902	33
			10c	1.692	18
			10d	2.019	13
11	0.57	16	11a	1.064	30
			11b	0.654	37
			11c	0.173	49
			11d	0.402	43
12	1.15	8	12a	1.554	19
			12b	0.000	0
			12c	1.525	21
			12d	0.000	0
13	2.62	5	13a	2.913	9
			13b	2.428	11
			13c	0.000	0
			13d	3.945	6
14	0.90	13	14a	1.546	20
			14b	0.000	0
			14c	0.385	44
			14d	1.445	22
15	0.48	18	15a	0.029	54
			15b	1.079	29
			15c	0.814	35
			15d	0.000	0
16	0.35	19	16a	0.041	53
			16b	0.593	39
			16c	0.618	38
			16d	0.000	0
17	0.24	20	17a	0.000	0
			17b	0.328	46
			17c	0.000	0
			17d	0.000	0
18	1.12	9	18a	1.314	25
			18b	0.294	47
			18c	1.767	16
			18d	0.000	0
19	0.57	17	19a	0.042	52
			19b	0.000	0
			19c	0.945	32
			19d	4.211	4

Table 5. continued.

1600 ha Resolution			400 ha Resolution		
Cell Identity	1600 ha RV	Order of Priority	Cell Identity	400 ha RV	Order of Priority
20	3.14	4	20a	1.861	14
			20b	3.981	5
			20c	0.000	0
			20d	0.000	0
21	1.12	10	21a	1.701	17
			21b	0.000	0
			21c	0.731	36
			21d	0.000	0

VITA 2

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