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Effects of produced water at some oilfield production sites in southern Illinois

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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SUMMARY

This study is part of a larger U.S. Geological Survey effort to evaluate the character and extent of the surface and subsurface impacts of waters produced in oil and gas exploration and production, to develop better methods to assess the effects, to understand the processes by which contaminants move at these sites, and to find techniques that will allow cost-effective remediation. Specific goals of the study were to evaluate the effectiveness of gamma-spectrometer surveys in assessing NORM contamination at production sites and to evaluate the utility of soil conductivity surveys in delineating saline soils.

During June 1995, reconnaissance investigations at 43 inactive and active oilfield production sites in Hamilton, Franklin, Gallatin, and White Counties in southern Illinois were conducted by the U.S. Geological Survey. Previous studies in southern Illinois had suggested that salt scarring and contamination with radioactive materials were extensive in the area. The purpose of these site visits was to document salt scarring and related soil erosion, to survey for radioactivity, to sample for trace metal contamination, to survey for shallow subsurface brine contamination, and to determine if naturally occurring radioactive materials (NORM, principally radium-226 and radium-228) and trace elements were present in equipment and soils affected by oilfield solid wastes and produced waters. Five of these sites were revisited in June 1996 to expand mapping and sampling, to evaluate changes that occurred, and to study processes that control dispersion of radium and trace elements. Six of the sites had been remediated by the Federal Natural Resource Conservation Service personnel working in collaboration with the local landowners.

The observations of this study show that radium in soils affected by tank sludge and produced waters ranges from background activities to a few thousand pCi/g total radium (radium-226 and radium-228 combined). These radium concentrations locally exceed proposed national standards for radium in soils (5 pCi/g). The volumes of soil exceeding this standard are relatively small (<< 1 m^3) except at one site. Radioactivity levels on oil field equipment and soils also exceeded proposed national standards (25 μR/hr) at 18 of the 43 sites. Laboratory analyses of samples from 2 sites (one in Gallatin County and one in White County) indicate moderate levels of lead (100-450 parts per million, ppm) in soils contaminated by tank sludge. Copper is present in concentrations greater than 100 ppm at 2 sites. Zinc was present in concentrations greater than 100 ppm at 6 sites. Cadmium was detected (1 ppm) at 6 sites. Soils affected by tank sludge had very high concentrations of barium (>>500 ppm) and strontium (>>200 ppm) suggesting the presence of barite, a mineral common in precipitates formed from saline produced waters. Bromine was observed in soil samples at 15 of 21 salt-scar sites. Iodine was detected in soil samples from salt scars at 16 of 21 sites suggesting that this trace element is contributing to inhibited

growth of plants. Five of six water samples from six production sites exceeded total dissolved solid (TDS) limits for drinking waters (500 ppm), but none exceeded limits for use by stock (5,000 ppm). Dissolved radium-226 levels were below levels of concern.

Soil conductivity surveys at three sites show that saline soils occur below the surface salt scars to depths of at least 6 m (the effective limit of the survey instrument). The leading edge of one salt scar along the Gallatin-White County boundary moved downslope about 12 m between June 1995 and June 1996.

Dispersion of radium-bearing soil contaminated by oily tank sludge occurs by physical erosion of the oily soil layer and transport of the particles by slopewash. One-to-two orders of magnitude dilution of the radium by mixing with local soil occurs over a distance of several meters downslope from the distal edge of the radium-rich soil layer. Heavy metals at the same sites follows a dispersion pattern similar to radium.

Field gamma spectrometry proved useful in delineating areas where radium has been added to the natural soil by oilfield solid waste and produced water, although the technique does not meet standards of assessment used in the State of Louisiana which require core sampling of 15 cm intervals and radiochemical analysis in the laboratory. Further work is needed to develop field gamma spectrometry as a substitute for the more expensive coring and laboratory analysis. The ratio of radium-228 to radium-226 may hold promise in evaluating the relative ages of NORM contamination events at a site. Absolute ages of these events can be calculated if the original radium activity ratio can be determined.

INTRODUCTION

These investigations in southern Illinois (Figs. 1-4) are part of a U.S. Geological Survey study of the effects of waters produced from oil and gas operations on soils, shallow bedrock, surface waters, and shallow ground waters. Produced waters in oil and gas fields are often extremely briny (as much as 35 percent total dissolved solids). In addition to high concentrations of sodium, chloride, and other major elements, these produced waters and solids formed from these waters can contain varying amounts of naturally occurring radioactive materials (NORM) and trace elements such as arsenic, selenium, cadmium, chromium, copper, lead, nickel, silver, zinc, mercury, bromine, iodine, fluorine, lithium, and boron. Many of these trace elements can be hazardous to humans and livestock and can inhibit the growth of plants. The effects of produced waters also include salt killing of vegetation, increased soil erosion and siltation of streams, lakes, and reservoirs, and contamination of aquifers and surface water by salt. These effects also can include contamination of soil, sediment, and water by NORM and trace elements, although this contamination is less well documented. The US Environmental Protection Agency (USEPA) estimates that 30 percent of oil and gas production operations in the U.S. may contain levels of NORM in brine and brine solids sufficiently elevated to be of concern (USEPA, 1993a). The USEPA has considered regulations, but has not implemented any. The Conference of Radiation Control Program Directors (CRCPD) has made recommendations for strict NORM standards. As of January 1997, several states have implemented NORM regulations for the oil and gas industry. One oil and gas industry estimate suggests that, if strict regulatory requirements for assessment and cleanup of NORM were put in place in the U.S., 20 percent of oil production and 8 percent of gas production would become uneconomic (Smith and others, 1995).

A 1989 American Petroleum Institute (API) survey of radioactivity in equipment used in active U.S. oil production and gas processing (Otto, 1989) reports 661 readings in Illinois; 140 from Fayette County, 24 from Gallatin County, and 497 readings from unspecified counties (Otto, 1989). All readings were from oil production equipment. Equipment in Fayette County (Fig. 1) showed levels as much as 975 microRoentgen per hour (μR/hr) above background. The average radioactivity across the county was 119 μR/hr above background and the median and 75th percentile values were 50 and 162 μR/hr above background, respectively. In Gallatin County, the maximum reading was 2475 μR/hr, the average was 298 μR/hr, the median was 143 μR/hr, and the 75th percentile was 235 μR/hr. These data suggest that more than 50 percent of oilfield equipment in the two counties may exceed the regulatory standard of 25 μR/hr used for uranium mine tailings reclamation goals and proposed by the CRCPD for defining industrial NORM contamination. High values observed in the API survey in these two counties in Illinois occur mostly on separator tanks, water-storage tanks, and water lines where brine scale and tank sludge accumulate.

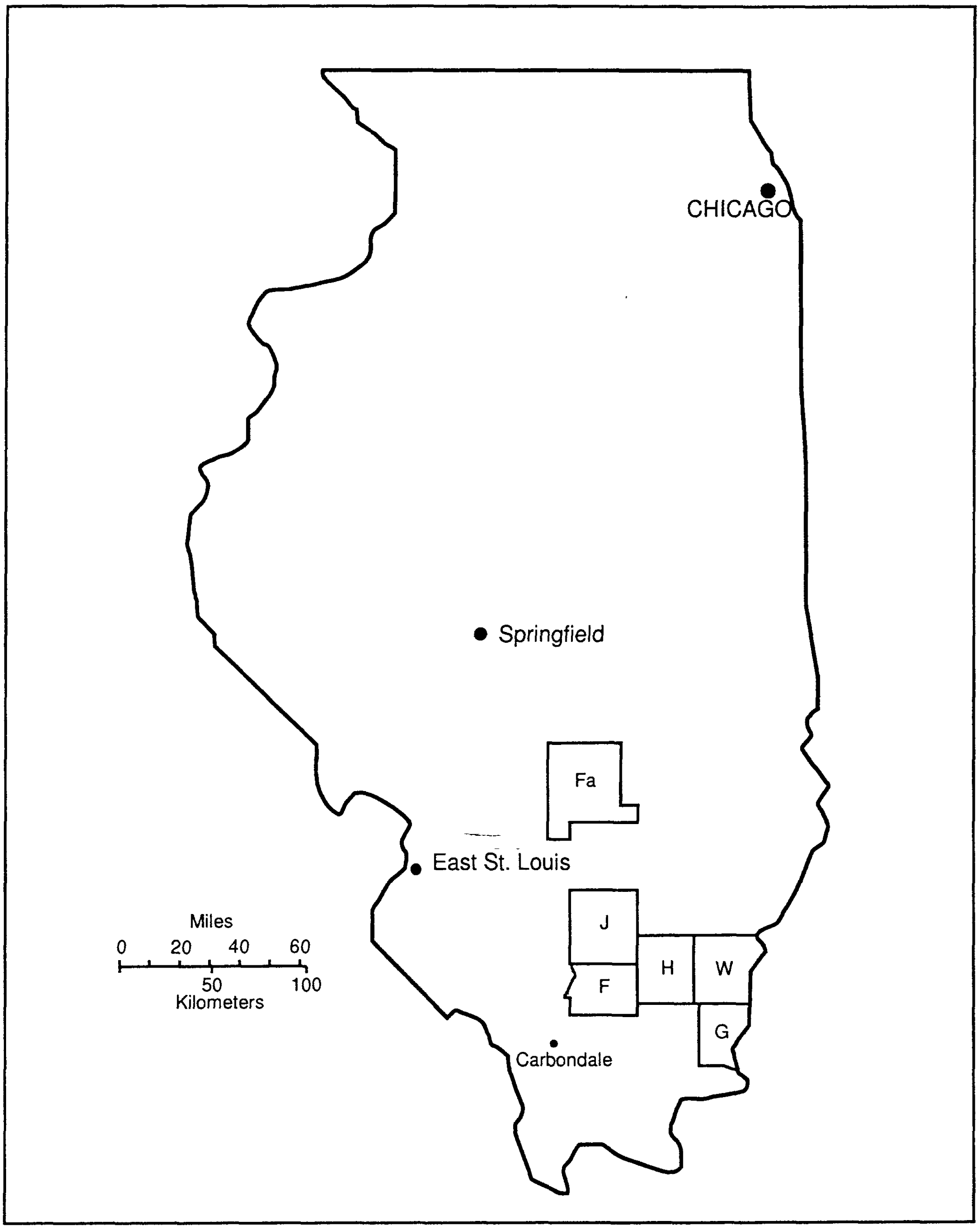


Figure 1- Location map for 4-county study area in southern Illinois, plus other counties mentioned in the text.
Fa- Fayette County; F- Franklin County; H- Hamilton County; G- Gallatin County; J- Jefferson County; W- White County.

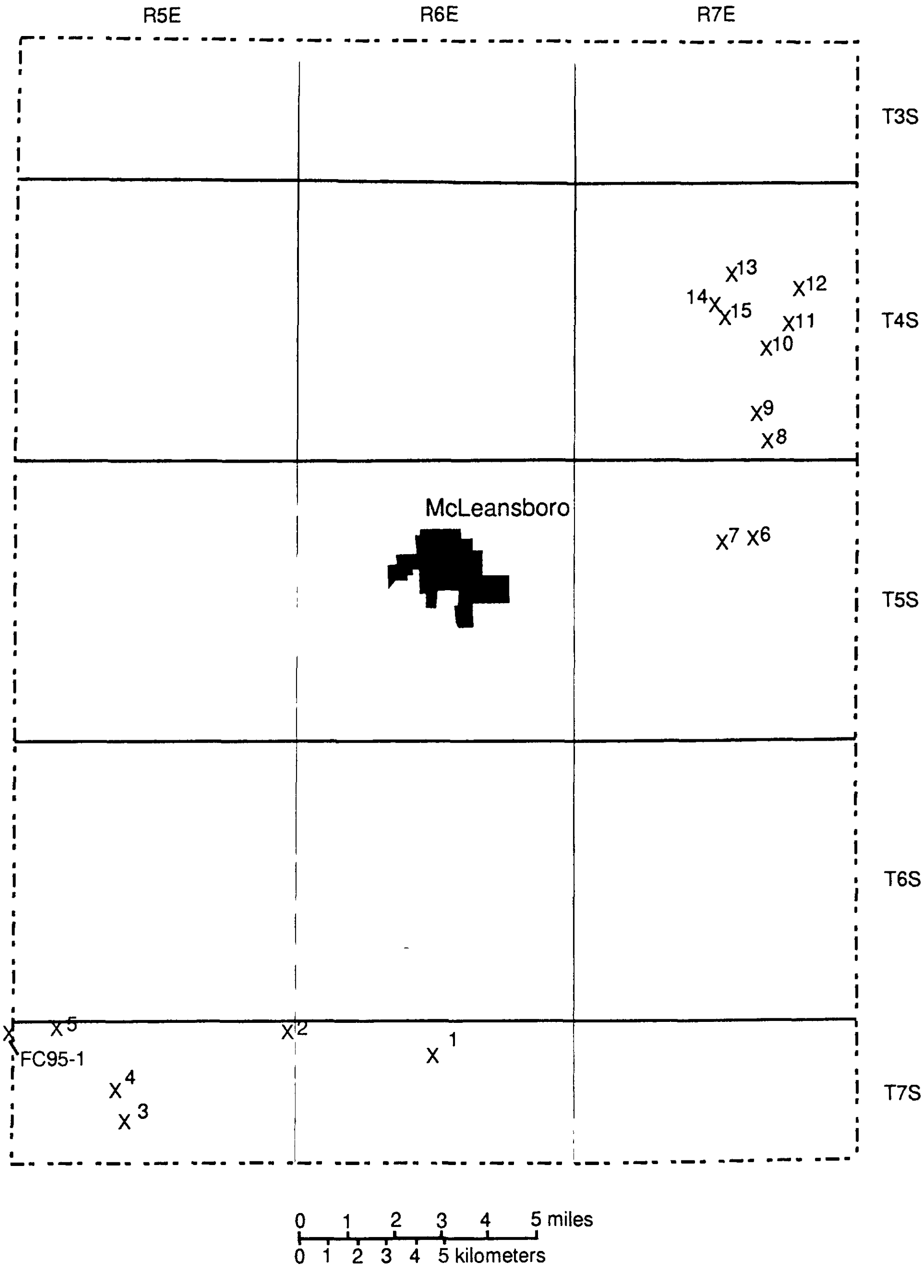


Figure 2- Location map for study sites (HC95 series) in Hamilton County, Illinois. Note that Site FC95-1 in Franklin County also is located on this map along the southwestern edge.

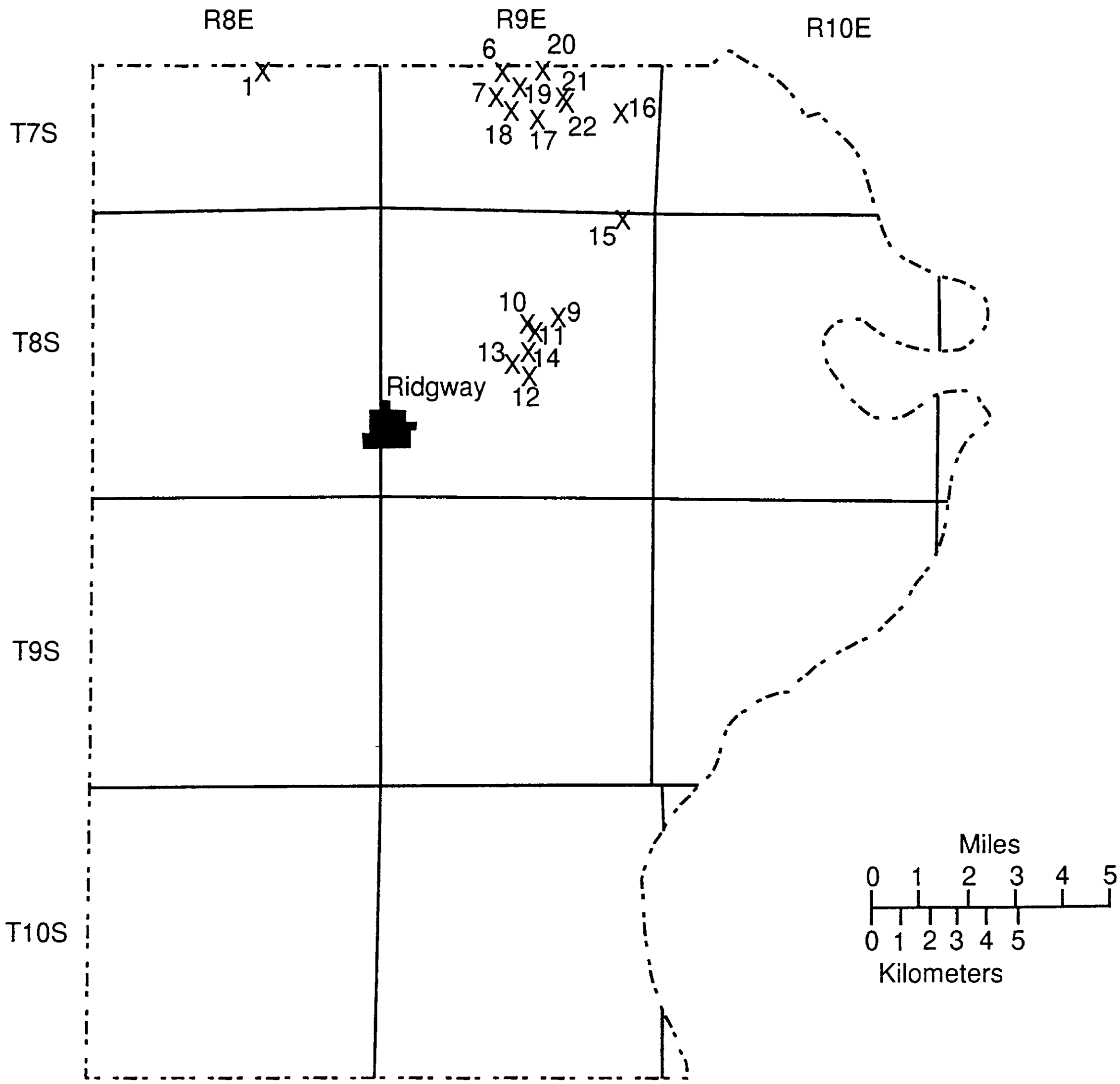


Figure 3- Location map for study sites (GC95 series) in Gallatin County, Illinois.

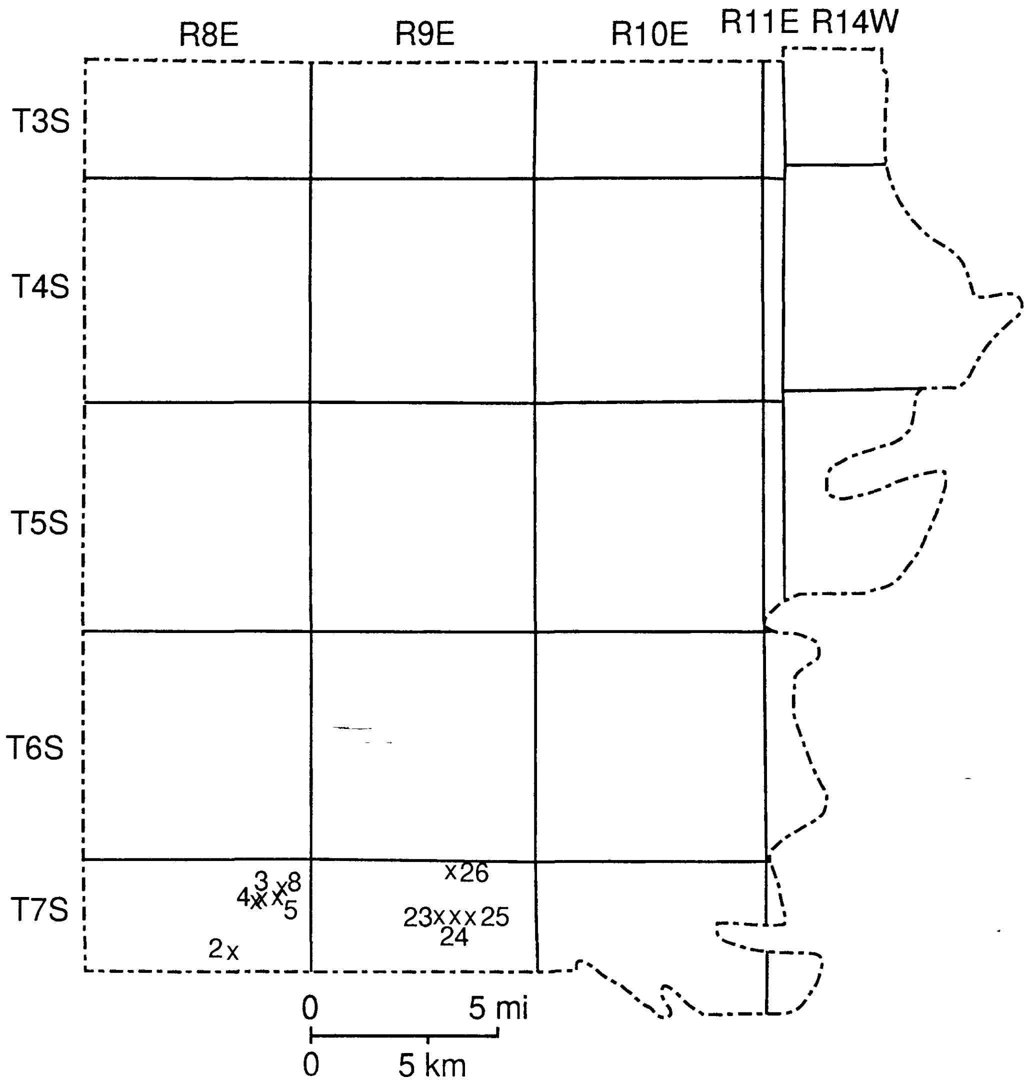


Figure 4- Location map for study sites (GC95 series) in White County, Illinois.

Based on aerial photo studies and followup field visits, the Greater Egypt Regional Planning Commission (1980) estimated that 2150 brine-damaged sites exist in southern and northeastern Hamilton County (Fig. 1). These sites have an estimated average size of 0.77 acres and an average soil loss of 40 tons per acre per year. Brine-damaged lands were subsequently evaluated in Jefferson and Franklin Counties (Fig. 1) (Greater Egypt Regional Planning Commission, 1982). In Franklin County, 508 brine-damaged sites were identified for a total of 390 acres. In Jefferson County, 582 sites totaling 417 acres were identified.

These Greater Egypt Regional Planning Commission field investigations defined three stages of erosion. Sites in the early stages are characterized by advanced sheet and rill erosion, little outwash at the downslope edge, and peripheral expansion of the site along one or more edges. A site in the intermediate stage is characterized by gully development, accumulation of outwash sediment, expansion of the barren area at the outwash edge, and development of sparse vegetation at the upslope periphery and on ridges between gullies due to leaching of salts. A site in the advanced stage is characterized by deep gullying often including complete removal of the upper 0.6-1.5 m of soil, extensive accumulation of outwash sediment at the downslope edge, and recolonization of plants on remaining soil on ridges and islands between gullies and at the periphery. At some old sites, vegetation may be growing throughout the site. A salt-tolerant grass, *Phragmites Australis,* was found partially covering many salt-damaged sites and it probably contributed to underestimation of the size of some sites in aerial photos.

The Natural Resources Conservation Service has worked with local landowners in southern Illinois to stabilize salt-scarred areas, stop further erosion, and possibly return land to productive use. Typically, the affected field is terraced to increase water infiltration and a perforated, PVC-pipe drainage system is installed beneath the field to allow salts to be carried away. The surface is often treated with soil amendments such as limestone, gypsum, and organic matter. These mitigation efforts have often succeeded, but in many fields substantial areas of stunted or no plant growth remain and erosion has returned. Water in the drainage systems is discharged into ditches at the low end of the field. These discharge waters often exceed Federal and State requirements for chloride and salinity.

Based on the reports of brine-damaged soils and elevated radioactivity in oilfield equipment in southern Illinois described above, we consulted with local district conservationists from the Natural Resources Conservation Service in Hamilton and Gallatin Counties to select and investigate some documented brine-affected sites in June 1995. Heavy spring rains fell throughout much of the four county area preceding field activities in 1995 and the ground was nearly saturated at many of the sites. Five sites were revisited in June 1996.

Physiography, climate, and land use

The area of Franklin, Gallatin, Hamilton, and White Counties in southern Illinois is characterized by low rolling uplands, upland plains, glacio-lacustrine plains, and floodplains and terraces along streams and the bigger rivers. The area is drained by the Saline, Wabash, and Skillet Fork Rivers. Relief is low across the area and the elevation ranges from about 340 to 600 feet. The area is underlain mostly by glacial deposits including drift, glacio-lacustrine clays, glacio-fluvial outwash, and loess. The glacial drift is of Illinoian age. The glacio-lacustrine and glacio-fluvial deposits are of Wisconsin age. These glacial deposits vary in thickness and on some upland areas bedrock composed of Pennsylvanian sandstone, siltstone, and shale is exposed. Rainfall ranges from 41 to 45 inches across the area and is about evenly seasonally divided. Agricultural development on the land is extensive with about 70 percent of the land in crops. The major crops are corn, wheat, and soybeans. The agricultural areas are generally poorly drained, but an extensive system of drainage ditches carries away runoff.

SURVEY AND SAMPLING METHODS

Sketch maps were made of most sites to document the cultural features present and the approximate dimensions of the affected area. Distances at sketched localities were estimated by pace. Detailed maps for several sites were created with tape and compass with supplemental distance and direction measurements made by pace and compass from established survey stations. The depth of gullies was measured with a tape.

Each site was surveyed using a handheld Geometrics scintillometer (Model Exploranium, range 1-10,000 counts per second, cps). (Note- Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government). Field calibration of the Geometrics scintillometer used during the survey with a calibrated Ludlum Model 12S μR meter shows a nonlinear relation defined as $x(\mu R/hr) = 2.2 + 0.18492\ y - 1.3428 \times 10^{-5}\ y^2$ where y is the scintillometer reading in counts per second (cps) (J.K. Otton, unpublished data, 1996). "Background" scintillometer readings for sites examined by the U.S. Geological Survey in southern Illinois ("background" here defined as readings on apparently undisturbed soils at the periphery of the site) ranged from 12-30 cps; the most common readings were 20-25 cps. Lower readings typically occurred on water-saturated soils. The 20-25 cps readings equate to 6-7 μR/hr. The median statewide background reading in the American Petroleum Institute survey (Otto, 1989) was 7 μR/hr, comparable to the most common readings taken in the four county area during this study.

Produced water and oil storage tanks, separator tanks, heater/treater tanks, flow lines, pumping wellheads, and injection wellheads were examined by placing the detector flush against the surface of the equipment. Soil surfaces, bedrock exposed in salt scars, and disturbed, oily, and discolored soils also were examined in a similar manner.

Soil and other materials at 29 of the 43 study sites were surveyed in the field with a Scintrex GAD-6 gamma spectrometer. Data from this instrument will hereafter be referred to as "GAD-6 spectrometer data" or a similar expression. This instrument is a four-channel analyzer that records total gamma counts (over an energy range of 0.40-2.8 Mev) and gamma counts for three windows: a potassium window (1.35-1.60 Mev), a uranium window (1.60-1.85 Mev), and a thorium window (2.50-2.75 Mev). The potassium window brackets the 1.46 Mev potassium-40 peak, the uranium window brackets the 1.76 Mev bismuth-214 peak (a uranium-238 decay product), and the thorium window brackets the 2.62 Mev thallium-208 peak (a thorium-232 decay product). The recorded count data for the bismuth-214 and thallium-208 channels are considered to approximate equilibrium activity of radium-226 and radium-228, unless there is suspicion of substantial loss of radon (radon-222 or radon-220) from the material being measured. For oilfield brine solids, the emanation of radon from the solids is typically less than 5 percent (K.K. Nielson, Rogers and Associates Engineering, oral commun., 1995); thus, radon loss is not considered significant. The GAD-6-spectrometer raw count data are more typically converted to equivalent uranium-238 (parts per million eU), and equivalent thorium-232 (parts per million eTh) using equations that account for the counting efficiency of the instrument and background gamma rays from cosmic sources. These equations are developed uniquely for each instrument by calibrating the instrument on concrete pads of known uranium, thorium, and potassium concentrations and by measuring background cosmic radiation at a site remote from sources of uranium, thorium, and potassium, typically at least 100 m from shore in the middle of a lake. The calibration equations for this instrument were developed from readings made at Department of Energy calibration pads at the airport in Grand Junction, Colorado. The cosmic background values used for this instrument were determined at Fairfax Lake, Fairfax County, Virginia (altitude about 100 m). eU and eTh are calculated assuming equilibrium with radium and its decay products. The instrument is further calibrated on a regular basis to make certain that the gamma-counting windows do not drift with time. This is done by using a thorium source and adjusting the thorium count to maximum values using a calibration dial on the instrument. Based on replicate measurements taken at five sites during this study (Table 1), the precision of the eU readings is 12 percent and the precision of the eTh readings is 17 percent.

To obtain Ra-226 activities from GAD-6-spectrometer eU data the eU readings in ppm are multiplied by 0.33. To obtain Ra-228 activities from eTh data the eTh readings are multiplied by 0.11. Total radium activities were obtained by addition of radium-226 and radium-228 activities.

GAD-6-spectrometer readings are of limited usefulness on production equipment because the equations used to convert raw readings to potassium, uranium, thorium, and radium values are designed for planar soil or bedrock surfaces where an ideal

Table 1- GAD-6-spectrometer data for reconnaissance sites in four southern Illinois counties. bg- background.

Location	eU (ppm)	eTh (ppm)	eRa-226 (pCi/g)	eRa-228 (pCi/g)	Ra-228/Ra-226	Total radium (pCi/g)	Comments
Hamilton County							
HC95-1A	4.1	8.7	1.4	1.0	0.71	2.3	
HC95-1B	3.7	8.9	1.2	1.0	0.80	2.2	
HC95-1C	3.2	7.1	1.1	0.8	0.74	1.9	
HC95-1D (bg)	2.3	8.4	0.8	0.9	1.22	1.7	
HC95-2A	2.1	8.4	0.7	0.9	1.33	1.6	
HC95-2B	2.4	7.2	0.8	0.8	1.00	1.6	
HC95-2B rep	2.5	9.6	0.8	1.1	1.28	1.9	
HC95-3A	4.2	9.3	1.4	1.0	0.74	2.4	
HC95-3B	7.9	11	2.6	1.2	0.46	3.9	
HC95-3C	94.5	19	31.5	2.1	0.07	33.6	Over scaly, corroded pipe
HC95-7	39.9	48.6	13.3	5.4	0.41	18.7	Rusty, oily soil/scale
HC95-8	3.5	10.4	1.2	1.2	0.99	2.3	
HC95-9A	3.6	9.3	1.2	1.0	0.86	2.2	
HC95-9B	2.6	8	0.9	0.9	1.03	1.8	
HC95-10	2.6	7.2	0.9	0.8	0.92	1.7	
HC95-11	3.6	9.8	1.2	1.1	0.91	2.3	
HC95-13	4.8	9.5	1.6	1.1	0.66	2.7	
HC95-14A	5.8	9.4	1.9	1.0	0.54	3.0	
HC95-14B	4.4	8.4	1.5	0.9	0.64	2.4	
HC95-15A	4.1	11.3	1.4	1.3	0.92	2.6	
HC95-15B	3.4	12.6	1.1	1.4	1.24	2.5	
Gallatin/White County							
GC95-1A	4.3	9.8	1.4	1.1	0.76	2.5	
GC95-1Arep	3.7	11.4	1.2	1.3	1.03	2.5	
GC95-1B	3	9	1.0	1.0	1.00	2.0	
GC95-1C	3.8	8.2	1.3	0.9	0.72	2.2	
GC95-2	3.9	7.4	1.3	0.8	0.63	2.1	
GC95-2rep	2.8	8.3	0.9	0.9	0.99	1.9	
GC95-2rep	3	6.8	1.0	0.8	0.76	1.8	
GC95-2rep	2.7	8.5	0.9	0.9	1.05	1.8	
GC95-3t	177	268	59.0	29.8	0.50	88.8	On side of tank
GC95-3B	24	37	8.0	4.1	0.51	12.1	Soil at edge of berm near tank
GC95-4	144.3	67.8	48.1	7.5	0.16	55.6	Tank sludge, soil
GC95-5A	10.3	10.8	3.4	1.2	0.35	4.6	Soil between 2 upright tanks
GC95-5B	47.9	48	16.0	5.3	0.33	21.3	Brine-sat. soil adj. to pool of water
GC95-5C	1170	1220	390.0	135.6	0.35	525.6	Bottom of horizontal tank
GC95-6A	20.1	8	6.7	0.9	0.13	7.6	Tank sludge, soil
GC95-6B	2.3	10.4	0.8	1.2	1.51	1.9	
GC95-6C	4.8	7.1	1.6	0.8	0.49	2.4	
GC95-6D	3	7	1.0	0.8	0.78	1.8	
GC95-7	3.1	9.3	1.0	1.0	1.00	2.1	
GC95-8	133.7	112.4	44.6	12.5	0.28	57.1	Scaly, oily soil next to wellhead
GC95-9A	2	6.7	0.7	0.7	1.12	1.4	
GC95-9B	31	10.1	10.3	1.1	0.11	11.5	Soil next to hot H/T tank
GC95-9C	1470	870	490.0	96.7	0.20	586.7	Bottom of H/T tank
GC95-9D	1.5	6.3	0.5	0.7	1.40	1.2	
GC95-13	2.8	5.5	0.9	0.6	0.65	1.5	
GC95-14	13.9	25.8	4.6	2.9	0.62	7.5	Scale and rust inside a cutup tank
GC95-14 rep	11.8	30.8	3.9	3.4	0.87	7.4	Scale and rust inside a cutup tank
GC95-16A	7.3	13.7	2.4	1.5	0.63	4.0	
GC95-16B	5.2	7.2	1.7	0.8	0.46	2.5	
GC95-16C	2	6.9	0.7	0.8	1.15	1.4	
GC95-20	5	10.9	1.7	1.2	0.73	2.9	
GC95-21A	4.6	12	1.5	1.3	0.87	2.9	
GC95-21B	4.7	9.3	1.6	1.0	0.66	2.6	
GC95-21Brep	5	11.2	1.7	1.2	0.75	2.9	
GC95-21C	5.4	9.6	1.8	1.1	0.59	2.9	
GC95-23A	2.9	9.7	1.0	1.1	1.11	2.0	
GC95-23B	4.3	7.3	1.4	0.8	0.57	2.2	
GC95-23C	10.2	10.7	3.4	1.2	0.35	4.6	
GC95-24-EM1	6.9	14.8	2.3	1.6	0.71	3.9	
EM2	3.9	7.8	1.3	0.9	0.67	2.2	
EM3	2.8	8.7	0.9	1.0	1.04	1.9	
EM4	2.5	9.2	0.8	1.0	1.23	1.9	
EM5	3	9.6	1.0	1.1	1.07	2.1	
EM6	3.3	7.9	1.1	0.9	0.80	2.0	
EM7	2.2	8.1	0.7	0.9	1.23	1.6	
EM8	2.3	7.5	0.8	0.8	1.09	1.6	

hemispheric geometry applies. Corrections can be made for simple variations from that hemispheric geometry for an irregular soil or bedrock surface, but the corrections for the source geometries and shielding that apply to radium-bearing sludge layers in tank bottoms or cylindrical pipe scale sources require data that are not readily available (for example, thickness of the pipe scale or tank sludge layer and thickness of the pipe and tank wall (Rogers and Nielson, 1995).

In typical field usage (detector placed against a planar, horizontal soil or rock surface), scintillometers and GAD-6 spectrometers receive most gamma rays from soil within a radius of 30-50 cm depending on the density and composition of the soil and resultant attenuation of the gamma rays. The calculated K, U, Th, Ra-226, and Ra-228 values represent an average for that hemispheric volume of soil. Thus, if a thin surface layer of radium-rich material is underlain by radium-poor materials, the equations used to convert the recorded count from the spectrometer will underestimate the radium content of the surface layer.

Water samples were collected in the field in 1 liter polyethylene bottles. These bottles were prerinsed with sampled water prior to filling. The samples were chilled and transported back to the laboratory for analysis. In the laboratory, an aliquot of the sample was removed and an alkalinity titration using standard sulfuric acid was performed. The bicarbonate concentrations from these titrations are reported, but only provide approximations of the in-situ alkalinity because alkalinity can change with sample storage. The remaining sample was filtered through a 0.45 micron polycarbonate membrane and one aliquot of the filtrate was acidified to a pH less than 2 for cation analysis while a second aliquot of the filtrate was refrigerated prior to analysis for anions. Cations were determined with standard flame atomic absorption spectrophotometry. The method of additions was utilized to compensate for matrix interferences. Anions were measured by ion chromatography following the method of Fishman and Pyen (1979). Field pH and field conductivity measurements were made using standard techniques.

Soil samples were collected from the surface layer (10 cm) with a plastic scoop and placed in HUBCO sample sacks. Samples were transported to the laboratory where they were split using standard techniques. The soil samples were analyzed, as received, by non-destructive, energy dispersive, X-ray fluorescence for a limited suite of trace elements (iron, copper, lead, zinc, cadmium, zirconium, barium, strontium, bromine, iodine). Because of possible hazards associated with handling of dry, radium-bearing soil samples, the samples were not pulverized and homogenized prior to analysis, and the results should therefore be considered semi-quantitative. The reported concentrations in whole soil samples provide no information on the solubility or mobility of the measured elements and, thus, do not necessarily indicate a hazard to crops, humans, or the environment.

Radium-226 in water samples was determined by the radon emanation technique (Broecker, 1965). An aliquot of the sample was placed in a radon bubbler and helium passed through it to remove all radon. The flask was then sealed to allow in-growth of radon-222 from the radium-226 in the sample. After a known time interval, the radon was again removed from the flask and transferred to a counting cell coated with silver-activated zinc sulfide and placed on a photomultiplier tube to measure radon and daughter product activity. The efficiency of the radon collection, transfer, and counting procedures was calibrated using National Institute of Standards and Technology (NIST) radium standards.

The radium-226 and radium-228 activity of soil samples was measured using gamma-ray spectroscopy in two different laboratories. To discriminate these data from the GAD-6-spectrometer data, these data will be referred to as "laboratory-based radiochemical data". In laboratory 1, aliquots of samples were sealed in 10 ml polyethylene vials and placed in the well of a high-purity germanium detector which was calibrated with similar quantities of radium-containing barium-sulfate precipitate prepared by adding $Ba(NO3)_2$ to NIST radium-226 and radium-228 standards and then adding H_2SO_4 to quantitatively precipitate $Ba(Ra)SO_4$ (Michel et al., 1981). The $Ba(Ra)SO_4$ precipitate standards were stored to allow equilibration of daughter products of radium-226 and radium-228 before using the standards to calibrate the detector. $BaSO_4$ was chosen as the matrix to calibrate the detector because most of the high-activity samples in this study contain radium in a $BaSO_4$ precipitate, which is common in oil-field brine scales.

Other soil samples were analyzed by gamma-ray spectrometry in a second laboratory (laboratory 2). The samples were sealed in plastic containers and held for 3 weeks prior to counting to permit attainment of radioactive equilibrium between radium-226 and its short-lived daughters. The samples were counted for several hours on a low-energy photon (LEP) detector. Gamma-ray energies ranging from 30 keV to 400 keV were recorded for the analyses. Detector efficiencies were calibrated versus gamma-ray energies using a NIST-traceable source. Several efficiency calibration plots were obtained to correspond to the appropriate sample geometry. Photopeak count rates (in counts per minute), detector efficiency values, and published gamma-ray branching ratios (i.e. gamma-ray emissions/ total disintegrations) were used to calculate the absolute activities of the radionuclides (disintegrations per minute). Radium-228 activities are reported here using the photopeaks derived from its immediate decay product, actinium-228.

Six samples were analyzed by both laboratories. Radium-226 activities reported by laboratory 2 were consistently higher for five of the six samples ranging in activity from 17 to 2190 pCi/g. The difference ranged from 0.23-26%. Radium-228 activities reported by the two laboratories for five of the six samples did not vary systematically, but the difference ranged from 1 to 36%. In one sample, the radium-226 and radium-228 activities were low and laboratory 1 reported a few tenths of a pCi/g whereas laboratory 2 reported not detected.

This laboratory-based gamma-spectrometry technique differs from the field gamma (GAD-6) spectrometry in that a high-resolution Ge(Li) crystal is used rather than a NaI(Tl) crystal. The Ge(Li) crystal volume is much higher than the NaI(Tl) crystal volume. This allows for greater precision. The samples are much smaller and perhaps less representative of the soil at the site.

Soil conductivity measurements were made at Site FC95-1, GC95-6, and GC95-24 using an EM-31 Geonics Limited instrument (McNeill, 1980a, 1980b). Measurements were made in four orientations: 1) vertical dipole mode parallel to traverse line; 2) vertical dipole mode perpendicular to traverse line; 3) horizontal dipole mode parallel to traverse line; and 4) horizontal dipole mode perpendicular to the traverse line. In the vertical dipole mode, the instrument has an effective depth of exploration of about 6 m whereas in the horizontal dipole mode, the effective depth of exploration is about 3 m. Measurements parallel and perpendicular to the traverse line permit the operator to determine if cultural features such as pipelines may be present that may affect the conductivity readings. Readings more than 10-20 percent different from one another suggest that such features are present.

DATA FROM SITES STUDIED

In evaluating the chemical data below it must be remembered that the State of Illinois Department of Nuclear Safety has not written regulations for NORM radioactivity and radium for the oil and gas exploration and production industry. The proposed CRCPD regulations of 25 μR/hr on equipment and 5 pCi/g in soils provide a basis of comparison that may or may not be adopted by the State. The USEPA's present standard for radium in water is 5 pCi/L. No Federal or State standards exist for lead or other toxic trace elements at oil and gas exploration and production sites.

Hamilton County

Sixteen oil production sites were visited in Hamilton County in 1995. Personnel from local Natural Resources Conservation Service offices in McLeansboro, Illinois assisted in site selection and field measurements. These sites were not revisited in 1996.

Site HC95-1 (Larry Launius farm)

Site HC95-1 (Fig. 2, Fig. 5) is located in a wheat field in SE/4, NE/4, SE/4, sec 4, T7S, R6E in southern Hamilton County. A paved road and an adjacent ditch run along the southern edge of the field. A trackway, a ditch, and a strip of trees runs along the eastern edge of the field. The field was fallow at the time of the visit with wheat stubble covering most of the surface. The soil was damp everywhere and water saturated in low spots. The heavy spring rains had prevented planting. The northern and western parts of the field slope towards the low, almost flat southeastern third.

The 1982 orthophotoquad in the Hamilton County soil survey (sheet 56, Currie, 1986) shows a brine pond and a farm pond in the north-central and northern part, respectively, of the wheat field. Their former locations are noted in Figure 5. In this photo, several stands of vegetation, probably *Phragmites*, occur in the low parts of the field and just upslope from the brine pond.

The brine pond and associated salt scar and the farm pond have been reclaimed by plowing, terracing, and placing a drainage field underneath the salt-scarred areas. The lower edge of the terraced area is marked by a berm and adjacent ditch within the field (Fig. 5). Water from the drainage system flows into the ditch at the southeast corner of the field (Fig. 5). Surface runoff is carried away from the field by a sump and pipe that passes under the trackway and flows into a ditch along the east edge of the field (not shown in Fig. 5).

A barren strip of salt-scarred soil occurs along the upslope edge of the terrace at its northeast end and a patch of barren soil occurs on the downslope side of the terrace near the first scar. These areas show some minor rill development and can be classified in the early stages of erosion. These two areas are close to or overly the apparent position of the brine pond. Downslope from these two barren patches the field is low and wet and sparse *Phragmites* are growing in the field. The field was surveyed with a scintillometer and gamma-spectrometer measurements were taken at 4 sites; two on the salt-scarred soil areas (A and B, Fig. 5), one in the low spot downslope from the terrace (C, Fig. 5), and one near the road as a reference site (Site D, Fig. 5). Water from the drainage pipe at the southeast corner of the field was sampled. Soil samples were taken at two of the GAD-6-spectrometer sites (A and C). All of the scintillometer readings varied within a narrow range of 12-16 cps (4-5 μR/hr). GAD-6-spectrometer readings showed total radium activities that range from 1.70 pCi/g at the reference site near the paved road to 2.33 pCi/g on the salt scar (HC95-1A-D, Table 1).

The two soil samples from this site (Fig. 5) showed concentrations of iron, heavy metals, zirconium, strontium, and barium near median values for this study (HC95-1A,B, Table 2). Both samples had measurable bromine and the sample in the low area southeast of the terrace (C, Fig. 5) had 15-25 ppm iodine. These two samples had nearly identical laboratory-based total radium activities of 2.3 and 2.2 pCi/g (HC95-1A,1B, Table 3). The total radium activity for HC95-1A was essentially the same as the GAD-6-spectrometer reading of 2.33, whereas the second sample (HC95-1B) was somewhat higher than the corresponding GAD-6-spectrometer reading of 1.86 pCi/g.

Water flowing out of the drainage pipe at the southeast corner of the field had a field pH of 7.3, a temperature of 16.3^{o}C, and a laboratory conductivity of 4600 mmhos/cm. Total dissolved solids (TDS) in this sample was about 1900 ppm (HC95-1W, Table 4). Radium-226 activity in this water sample was 0.09±0.01 pCi/L.

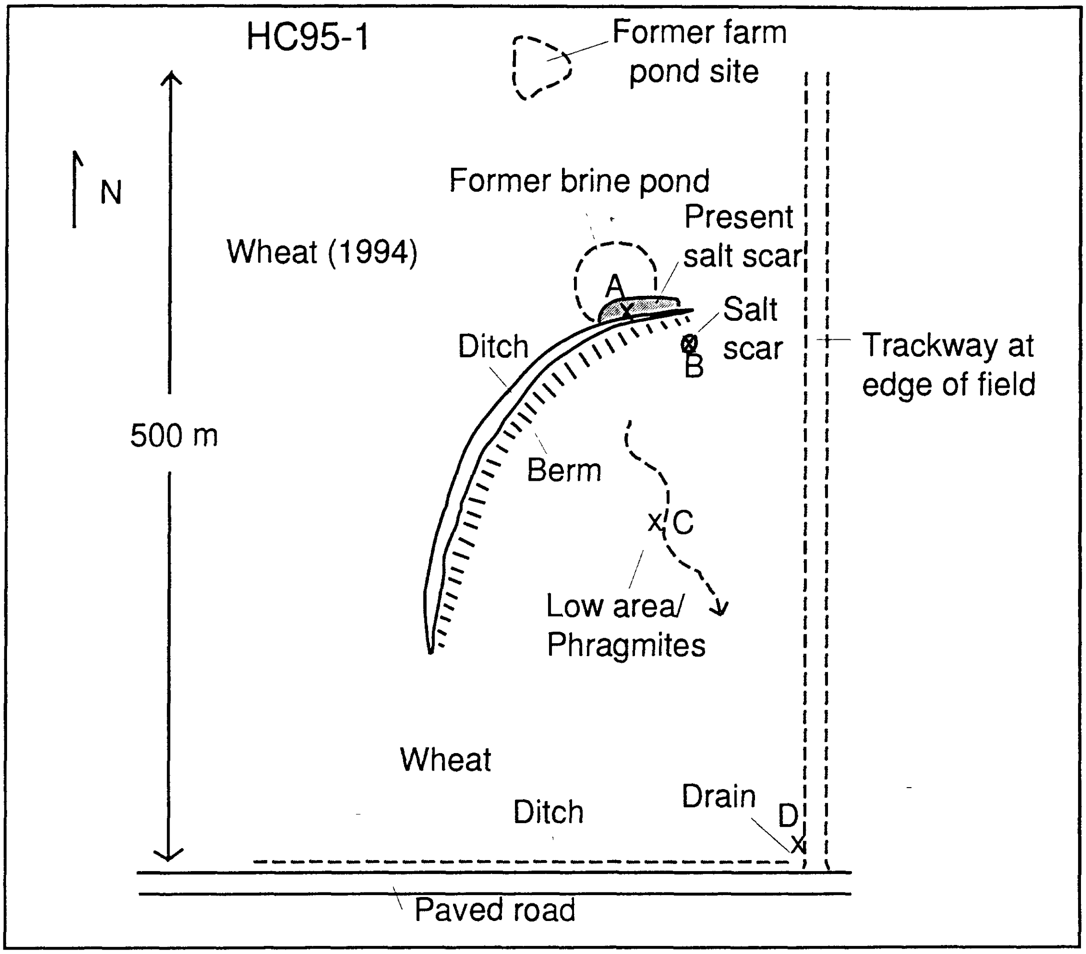


Figure 5- Sketch map of study Site HC95-1 (Larry Launius farm) in a wheat field in southern Hamilton County (SE/4, NE/4, SE/4, sec 4, T7S, R6E). Not to scale. A-D- gamma spectrometer stations. Location of former farm pond site based on aerial photo.

Table 2- Trace element data for soil and other samples from sites in southern Illinois.
Samples were analyzed by X-ray fluorescence; George Desborough, U.S. Geological Survey, analyst.

Sample	Fe (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Cd (ppm)	Zr (ppm)	Sr (ppm)	Ba (ppm)	Br (ppm)	I (ppm)
Hamilton County										
HC95-1A	2.5	<20	<40	60	<1	455	135	445	10,20	-
HC95-1B	2.0	<20	<40	45	<1	425	105	510	1,5	15,25
HC95-2	1.5	<20	<40	40	<1	435	230	490	50,60	-
HC95-3	17.2	145	<40	195	1	215	570	3040	-	1,5
HC95-6	1.7	<20	<40	45	<1	470	130	630	1,5	15,30
HC95-7A	2.0	<20	<40	120	<1	420	120	400	-	15,20
HC95-7B	6.6	<20	<40	45	<1	85	260	1945	5,10	-
HC95-14A	3.1	<20	40	60	1	290	95	450	-	-
HC95-14B	2.6	30	<40	45	<1	340	125	660	15,20	10,20
Franklin County										
Sample	Fe (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Cd (ppm)	Zr (ppm)	Sr (ppm)	Ba (ppm)	Br (ppm)	I (ppm)
FC95-1A	2.2	<20	<40	50	<1	370	140	450	1,5	10,20
FC95-1B	1.3	<20	<40	45	<1	345	150	590	1,5	-
Gallatin and White Counties										
Sample	Fe (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Cd (ppm)	Zr (ppm)	Sr (ppm)	Ba (ppm)	Br (ppm)	I (ppm)
GC95-1A	3.9	20	<40	80	<1	370	110	505	5,10	1,5
GC95-1B	2.1	<20	40	40	<1	445	95	460	15	-
GC95-2A	2.2	20	<40	<20	<1	315	115	370	15	-
GC95-2B,<.25mm	1.2	25	<40	45	<1	485	130	540	15,20	-
GC95-2B,>.25mm	1.2	<20	<40	45	<1	475	135	3900	20,30	-
GC95-3	3.9	60	<40	105	<1	335	660	>1.5%	1,5	-
GC95-4	17.7	95	85	385	1	130	3280	>1.5%	-	-
GC95-5	2.7	<20	40	80	1	310	260	2670	1,5	1,15
GC95-6*	3.2	<20	<40	70	<1	410	170	520	-	-
GC95-6A	4.8	30	165	95	<1	205	895	380	-	-
GC95-6D	1.6	<20	<40	40	<1	410	135	555	10,50	-
GC95-9	1.1	<20	<40	35	<1	265	115	365	-	1,5
GC95-11,<.25mm	14.0	50	<40	<20	<1	50	120	90	10,15	-
GC95-11,.25-.50mm	17.0	95	<40	<20	<1	45	65	90	15,25	-
GC95-13	0.8	<20	<40	25	<1	320	145	520	-	10,15
GC95-14	16.2	50	85	<20	<1	20	1460	105	-	5,15
GC95-16	17.8	45	<40	50	<1	495	200	225	-	5,25
GC95-21A	2.8	20	<40	80	<1	385	170	465	10,15	5,30
GC95-21B	2.3	<20	<40	50	<1	550	160	580	15,30	10,15
GC95-23	2.7	<20	<40	45	<1	400	155	490	5,10	5,10
GC95-24A	1.8	<20	<40	65	<1	520	145	595	15,25	-
GC95-24B	1.7	35	<40	65	1	490	110	515	5,10	5,15
GC95-24C	3.0	<20	<40	30	<1	415	100	555	10,15	-
GC95-24D	1.5	<20	<40	45	<1	545	150	575	40,60	10,15
GC95-25a	11.3	210	450	525	<1	275	8800	>2%	-	-
GC95-25b	3.4	60	140	355	<1	430	2050	>1%	10,20	-
GC95-25c	2.4	30	65	125	<1	460	500	4030	10,35	-
GC95-25d	2.7	40	50	110	<1	445	300	1800	10,15	5,30
GC95-25e	3.2	20	65	95	<1	395	355	2220	10,15	-
GC95-25f	3.4	<20	<40	125	1	455	530	3880	-	30,50
GC95-25g	2.1	<20	<40	100	<1	410	275	1950	10,20	20,30
GC95-25h	3.3	<20	40	145	<1	430	190	1300	5,15	15,35
GC95-25i	2.4	<20	45	110	<1	475	275	1880	5,15	-
Median (all values)	2.7	<20	<40	55	<1	397.5	152.5	555	5,15	<1

Table 3- Water chemistry data for samples from sites in southern Illinois.
Field data and laboratory data are reported. Lab analyst- Cyndi Rice, U.S. Geological Survey.

	Hamilton County			Gallatin County		
	HC95-1W	HC95-13W	GC95-2W	GC95-5W	GC95-21W	GC95-24W
Parameters						
Field temp (C)	16.3	25.7	24.5	30.5	23.5	27.8
Field pH	7.3	8	6.2	8.2	6.5	8.2
Lab pH	7.55	7.05	6.55	9.7	6.95	8.3
Field conductivity	ND	3250	280	950	ND	ND
Lab conductivity	4600	3700	290	1500	970	7700
Cations						
Ca (ppm)	24	70	21	47	78	310
K (ppm)	2.5	2.8	0.03	0.15	0.55	17
Mg (ppm)	92	17	11	9.1	51	122
Na (ppm)	440	500	18	180	66	930
Sr (ppm)	2	11.8	0.4	0.9	0.5	1.7
Ra-226 (pCi/L)	0.09±0.01	0.11±0.04	0.10±0.03	0.17±0.04	0.11±0.01	0.43±0.06
Anions						
HCO3 (ppm)	140	39	82	22	300	94
CO3 (ppm)				7.87		
Cl (ppm)	800	720	20	230	120	
SO4 (ppm)	420	40	35	220	52	120
TDS (ppm)	1921	1401	187	717	668	3400

Table 4- Laboratory-based radiochemical data for soil samples from reconnaissance sites in southern Illinois counties. Samples analyzed by gamma spectrometry in two different labs. *Six samples were analyzed by both labs.*

Sample number	Lab	Ra-226 (dpm/g)	Ra-226 (pCi/g)	Ra-228 (dpm/g)	Ra-228 (pCi/g)	Ra-228/Ra-226	Total Ra (pCi/g)
				Hamilton County			
HC95-1A	2	3.2	1.5	1.9	0.9	0.59	2.3
HC95-1B	2	2.6	1.2	2.3	1.0	0.88	2.2
HC95-3	2	728.0	330.9	20.0	9.1	0.03	340.0
HC95-7A	1	2.6	1.2	3.2	1.5	1.23	2.7
HC95-7B	2	154.0	70.0	31.0	14.1	0.20	84.1
HC95-14A	2	5.0	2.3	2.1	1.0	0.42	3.2
HC95-14B	2	4.1	1.9	2.7	1.2	0.66	3.1
				Franklin County			
Sample number	Lab	Ra-226 (dpm/g)	Ra-226 (pCi/g)	Ra-228 (dpm/g)	Ra-228 (pCi/g)	Ra-228/Ra-226	Total Ra (pCi/g)
FC95-1A	2	1.8	0.8	1.9	0.9	1.06	1.7
FC95-1B	2	2.1	1.0	1.9	0.9	0.90	1.8
				White and Gallatin Counties			
Sample number	Lab	Ra-226 (dpm/g)	Ra-226 (pCi/g)	Ra-228 (dpm/g)	Ra-228 (pCi/g)	Ra-228/Ra-226	Total Ra (pCi/g)
GC95-1A	2	2.6	1.2	2.6	1.2	1.00	2.4
GC95-1B	2	2.4	1.1	1.7	0.8	0.71	1.9
GC95-2A	1	2.1	1.0	1.4	0.6	0.66	1.6
GC95-2B	1	2.0	0.9	2.7	1.2	1.34	2.1
GC95-3	1	47.3	21.5	17.2	7.8	0.36	29.3
GC95-4	1	461.0	209.5	40.6	18.5	0.09	228.0
GC95-4	2	481.0	218.6	30.0	13.6	0.06	232.3
GC95-5	1	37.7	17.1	20.3	9.2	0.54	26.4
GC95-5	2	46.0	20.9	20.0	9.1	0.43	30.0
GC95-9	1	2.9	1.3	1.4	0.6	0.48	2.0
GC95-11	1	4.3	1.9	1.0	0.5	0.23	2.4
GC95-13	1	1.2	0.5	1.4	0.7	1.24	1.2
GC95-14	1	22.6	10.3	9.2	4.2	0.41	14.4
GC95-16	1	0.8	0.3	0.4	0.2	0.57	0.5
GC95-16	2	0.1	0.0	ND	ND	ND	0.1
GC95-21A	1	20.6	9.4	2.1	0.9	0.10	10.3
GC95-21B	1	3.7	1.7	3.2	1.5	0.87	3.2
GC95-23	1	4.6	2.1	2.0	0.9	0.43	3.0
GC95-24A	1	3.1	1.4	3.7	1.7	1.17	3.1
GC95-24B	1	3.4	1.6	3.0	1.4	0.87	2.9
GC95-24C	1	3.1	1.4	2.9	1.3	0.93	2.7
GC95-25A	1	3825.0	1738.6	344.0	156.4	0.09	1895.0
GC95-25A	2	4811.0	2186.8	425.0	193.2	0.09	2380.0
GC95-25B	1	1222.0	555.5	143.0	65.0	0.12	620.5
GC95-25B	2	1225.0	556.8	118.0	53.6	0.10	610.5
GC95-25C	1	202.0	91.8	27.6	12.5	0.14	104.4
GC95-25C	2	246.0	111.8	28.0	12.7	0.11	124.5
GC95-25D	2	88.0	40.0	8.6	3.9	0.10	43.9
GC95-25E	2	121.0	55.0	20.0	9.1	0.17	64.1
GC95-25F	2	316.0	143.6	31.0	14.1	0.10	157.7
GC95-25G	2	71.0	32.3	23.0	10.5	0.32	42.7
GC95-25H	2	29.0	13.2	9.4	4.3	0.32	17.5
GC95-25I	2	65.0	29.5	12.4	5.6	0.19	35.2

1- Gamma-spectrometry, Thomas Kraemer, analyst, U.S. Geological Survey, Reston, Virginia
2- Gamma-spectrometry, James Budahn, analyst, U.S. Geological Survey, Lakewood, Colorado

Site HC95-2 (Burnett lease)

The Burnett lease (Figs. 2 and 6) is located in a field in S/2, NE/4, NE/4, NE/4, sec 1, T7S, R5E in southwestern Hamilton County. The site has been partly reclaimed; however, salt scarring and erosion have denuded an irregular area about 60 m by 30 m that covers the site of a reclaimed brine pond. Till and loess are exposed in the salt scar and locally salt efflorescence

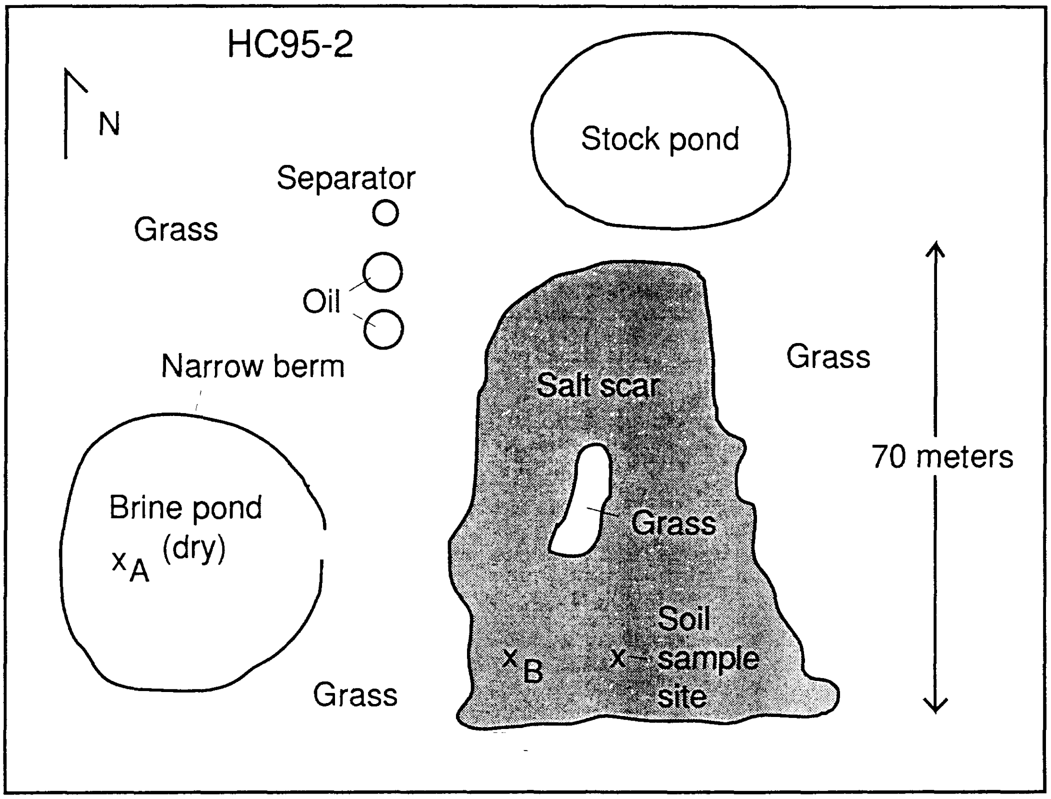


Figure 6- Sketch map of study site HC95-2 in southwestern Hamilton County (S/2, NE/4, NE/4, NE/4, sec 1, T7S, R5E). Not to scale. A-B- GAD-6 spectrometer stations.

occurs on the surface. This site is in the intermediate stage of erosion. An old brine pond site (dry) lies to the west of the scarred area and a stock pond lies to the north. Three tanks are located off the northwestern corner of the scarred area. Radioactivity of the soils and the tanks at the site varies little from background (20 cps, 6 μR/hr). GAD-6-spectrometer readings on the dry brine pond surface and exposed soil in the salt scar indicate 1.60 and 1.75 pCi/g total radium activity, respectively (HC95-2A,B, Table 1). A single soil sample taken from the south-central part of the salt scar had bromine levels of 50-80 ppm, about 5-6 times the median value for the study (HC95-2, Table 2). All other elements were near median values.

Site HC 95-3

This site is in a heavily forested area adjacent to an old, partly overgrown, dirt road in SW/4, sec 9, T7S, R5E in southwestern Hamilton County (Figs. 2 and. 7). This road was built to access oil exploration and production sites. The road runs near the crest of a broad ridge. Background radioactivity along the road ranges from 20-30 cps (6-8 μR/hr). An area of weeds and brambles with several pieces of old pipe and some old equipment separate the road from a salt scar that extends approximately 50 m downhill to the south and 70 m parallel to the road. Erosion has exposed a layer of loess at the head of the scar near the road. Thin-bedded sandstone and shale are exposed in the middle and lower parts of the salt scar. This hillslope is in an advanced stage of erosion.

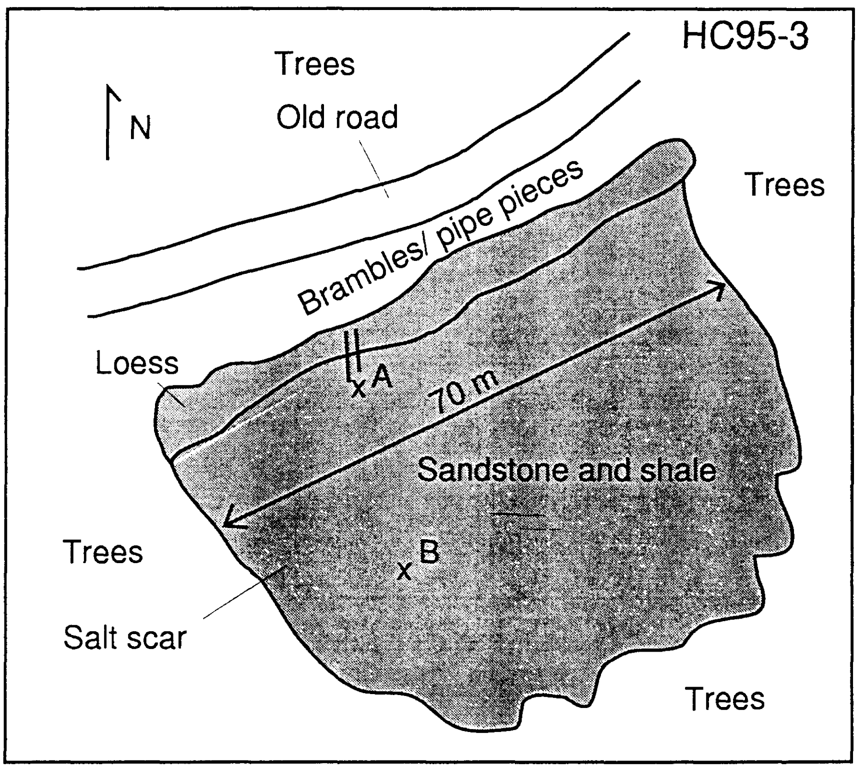


Figure 7- Sketch map of study site HC95-3 in southwestern Hamilton County (SW/4, sec 9, T7S, R5E). Not to scale. North is approximately located. A-B- gamma spectrometer stations.

Scintillometer readings on the sandstone and shale range from 10-20 cps (4-6 μR/hr). A few pieces of pipe are scattered about on the salt scar surface. Pipe in the brambles near the road measures as much as 150 cps (30 μR/hr). Two pieces of pipe near the head of the salt scar near Site A (Fig. 7) read about 40 cps

(10 µR/hr). A single piece of pipe low on the salt scar near Site B reads 400 cps (74 µR/hr).

GAD-6-spectrometer readings were made at two localities on the exposed sandstone bedrock in salt scar (A and B, Fig. 7). These readings were 2.4 pCi/g and 3.8 pCi/g total radium (HC95-3A,B, Table 1). The spectrometer was placed over the exposed piece of radioactive corroded pipe (near B, Fig. 7). This reading was 33.6 pCi/g total radium (HC95-3C, Table 1; a minimum activity for the scale in the pipe). A sample of the scale was collected for laboratory analysis. It contained 17.2 percent iron, 145 ppm copper, 195 ppm zinc, 1 ppm cadmium, 570 ppm strontium, and 3040 ppm barium (HC95-3, Table 2). All of these values are well above the median values for the study. The scale sample had a laboratory-based total radium activity of 340 pCi/g (HC95-3, Table 3) and a very low Ra-228/Ra-226 value of 0.03 suggesting that the initial activity ratio was very low or that several half-lives of radium-228 ($t_{1/2}$=5.8 years) had passed since the scale formed. Judging from the apparent age of the equipment on the site, the latter is probably true. Note that the laboratory determination of radium-226 activity in the collected pipe scale is approximately 10 times the activity estimated in the field by placing the GAD-6-spectrometer on the pipe.

Site HC95-4

A tank battery is located in SW/4, NW/4, sec 9, T7S, R5E in southwestern Hamilton County (Fig. 2). A small oil spill has occurred at the site. Scintillometer readings ranged from 20-30 cps (6-8 µR/hr) on equipment and nearby soils (at or slightly above background). No significant salt scarring was observed.

Site HC95-5

A tank battery and an associated salt scar and injection well occur in NE/4, NE/4, sec T7S, R5E in southwestern Hamilton County (Fig. 2). The salt scarred area is in the early stages of erosion. No anomalous radioactivity was observed at this site.

Site HC95-6

An active tank battery surrounded by a berm occurs in SE/4, SE/4, sec 10, T5S, R7E (Fig. 2) in eastern Hamilton County. Seven tanks are on the site, a shed, and a pit next to the shed. Soil around the tanks is oil saturated. The northern edge and the northwestern corner of the bermed area contained ponded water at the time of this survey. A salt scar extends beyond the bermed area to the north and northwest. Erosion is in the early stages on the scarred surface. Background radioactivity at the site was 14-15 cps (5 µR/hr). No anomalous radioactivity was observed on any of the soils or the equipment. A sample of the sediment at the edge of the pond in the northwest corner of the bermed area contained levels of trace elements close to median values for the study, except that 15-30 ppm iodine was present (HC95-6, Table 2).

Site HC95-7 (West Thackberry unit tank farm)

This site includes a bermed tank battery (4 oil tanks, a separator tank, and a wooden water storage tank), 2 injection wells, and 2 salt scars (Figs. 2 and 8). The site is located in SW/4, SW/4, sec 10, T5S, R7E in eastern Hamilton County. Along the west edge of the site is a paved road. Along the north edge of the site is a dirt road. The site slopes to the south and a salt scar extends from the bermed tank battery area to the east, south, and west. A ditch marks the southern boundary of the salt scar. A ditch containing a stand of *Phragmites* and an oil-stained pool lies along the north edge of the dirt road. A second smaller salt scar occurs east of the main salt scar. The scarred areas are in the early to intermediate stages of erosion.

Background scintillometer readings were about 15 cps (5 μR/hr). Most of the tanks and the shed were at background. The wooden tank read 25 cps (7 μR/hr). Soil at the southern edge of the small salt scar at the east side of the site read 70-80 cps (15-17 μR/hr). The northern part of this smaller salt scar had a 10-12 cm thick layer of oily, rusty-weathering soil (tank sludge?) on the surface that read from 50-180 cps (11-35 μR/hr). A GAD-6-spectrometer reading (A, Fig. 8) on this layer gave a total radium

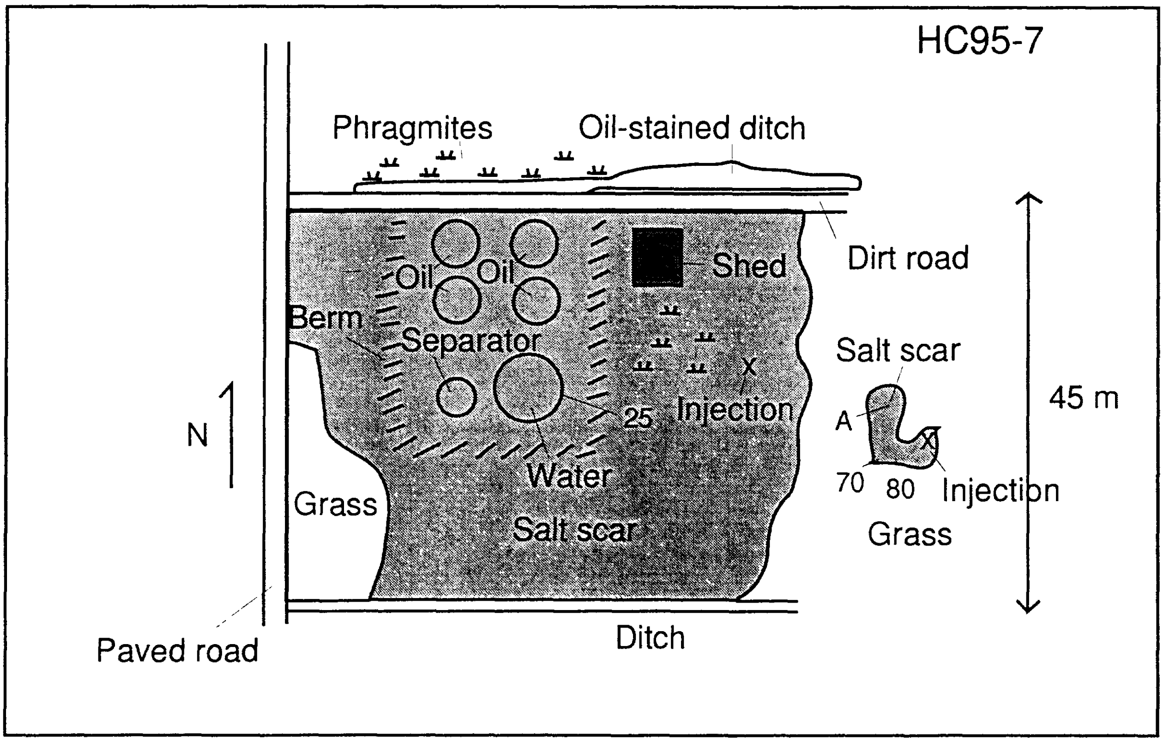


Figure 8- Sketch map of study site HC95-7 in eastern Hamilton County (SW/4, SW/4, sec 10, T5S, R7E). Not to scale. Water tank is made of wood. A- gamma-spectrometer station.

activity of 18.7 pCi/g (HC95-7, Table 1). Trace elements in a sample of sediment from the marshy area south of the shed were near median values for the study except for zinc (120 ppm) and iodine (15-20 ppm) (HC95-7A, Table 2) and 2.65 pCi/g total radium (HC95-7A, Table 3). A sample of the sludge-contaminated soil from the site A (Fig. 8) had iron, strontium, and barium concentrations above median values for this study (HC95-7B, Table 2). The laboratory-based radium activity was 84.1 pCi/g (HC95-7B, Table 3). This radium activity is high compared to the GAD-6-spectrometer measurement at the same site (18.7 pCi/g) and indicates that the radium is concentrated in the collected surface layer.

HC95-8

This site is located in NW/4, SW/4, sec 35, T4S, R7E in northeastern Hamilton County (Fig. 2). A bermed tank battery with 7 tanks, a nearby pumping unit, and an irregular salt-scarred area occur on site. A wet, marshy area with small *Phragmites* has formed in the salt scar near the bermed area. The scarred area is generally in the early stages of erosion. A small pile of pipe lay next to the berm. Ponded water stood within the bermed area at the time of the visit. All scintillometer readings on the equipment, pipe, and the salt-scarred soils ranged 20-30 cps (6-8 μR/hr), the local background value. A GAD-6-spectrometer measurement near the pipe stack and the berm yielded a total radium activity of 2.32 pCi/g (HC95-8, Table 1).

HC95-9

This site consists of an old tank battery, equipment, pipe, a shed, an injection well, two unreclaimed pits, and a salt scar with a substantial growth of *Phragmites* in its southern end. Erosion is in the early stages at this site. The site is located in SE/4, SE/4, SE/4, sec 27, T4S, R7E, just southwest of the intersection of county roads 1610N and 1600E in northeastern Hamilton County (Fig. 2). Background scintillometer readings on soil at the site were 20-25 cps (6-7 μR/hr). Most of the old equipment and soils at the site were at background levels. A scintillometer reading adjacent to one of the pits was 45-50 cps (10-11 μR/hr). A GAD-6-spectrometer reading at that site yielded 2.23 pCi/g total radium (HC95-9A, Table 1). A reading in the salt scar at the edge of the *Phragmites* to the south of the pits and shed was 1.76 pCi/g total radium activity (HC95-9B, Table 1).

HC95-10

This site is located in NW/4, NW/4, SW/4, sec 23, T4S, R7E in northeastern Hamilton County (Fig. 2) and consists of two oil tanks and a separator tank and a salt scar immediately south of the tanks. Erosion is in the early stages in the salt-scarred area. A paved section line road is at the western edge of the site and a dirt access road is at the northern edge of the site.

The surface of the salt scar had been covered with mulch. A field planted with soybeans extends to the south and southeast of the site. The three tanks and the salt scar were all at background (20-25 cps, 6-7 μR/hr). A GAD-6-spectrometer reading from the north edge of the salt scar near the tanks gave a reading of 1.67 pCi/g total radium activity (HC95-10, Table 1).

HC95-11

This site includes a bermed tank battery (7 tanks), a pumping unit north of the tank battery, and a shed and injection well east of the tank battery, located along the north edge of sec 23, T4S, R7E just south of county road 1800 N about midway between the section corners (Fig. 2). A substantial salt scar extends east and south of the bermed area. Erosion is in the early to intermediate stages at this site.

Scintillometer count over the site ranges 20-30 cps (6-8 μR/hr) (background to slightly above background level). A GAD-6-spectrometer reading on soil near the southeast corner of the bermed area resulted in a total radium activity of 2.29 pCi/g (HC95-11, Table 1).

HC95-12

This site is located in SE/4, NE/4, sec 14, T4S, R7E in northeastern Hamilton County (Figs. 2 and 9). A row of trees

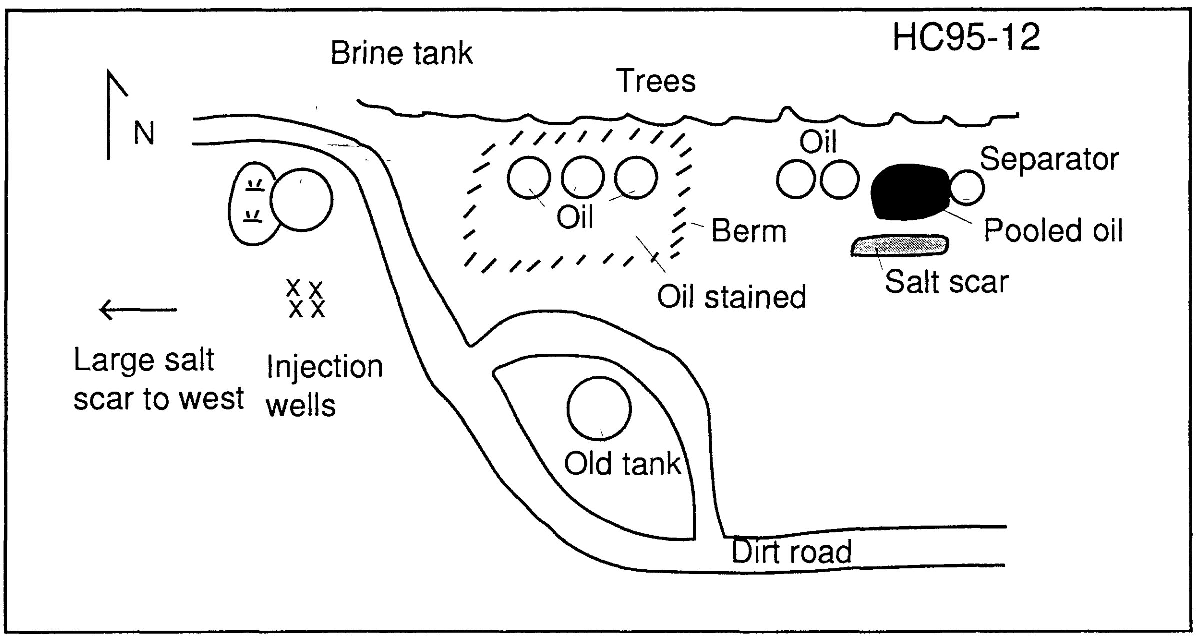


Figure 9- Sketch map of study site HC95-12 in eastern Hamilton County (SE/4, NE/4, sec 14, T4S, R7E). Not to scale. B- brine water tank; S- separator tank; I- injection well cluster. Smaller tanks are about 2 m across.

marking the south edge of an adjacent field lies just to the north of the site. The site includes a bermed tank battery (3 tanks) with three isolated, unbermed older tanks to the east (two oil tanks and a separator), one isolated oil tank to the south, and a brine tank, a cluster of old injection wells, and a large salt scar (not shown on Fig. 9) to the west. This large salt scar is in the intermediate stages of erosion. The soil surface within the bermed area is oil stained and an oil-filled pool lies between a separator tank and the two oil tanks to the east. A small salt scar is just south of this oil-filled pool. The access road goes through the site.

Scintillometer readings indicated that most of the soils and equipment at the site were at background levels (20 cps, 6 μR/hr), however the separator to the east read 30 cps (8 μR/hr) near the base and the pipe and soils near the injection wells read 25-30 cps (7-8 μR/hr).

HC95-13

This site occurs at the south edge of the SW/4 of sec 10, T4S, R7E (Figs. 2 and 10). A dirt road lies along the south edge of the site. The site includes a tank battery (4 large oil tanks and 2 separator tanks) and a large salt scar with patches of grass that extends north from the tank battery. The salt scar contains patches of grass. A ditch marks the north edge of the site and separates the scarred area from fields to the north. The ditch was filled with milky water and bright green algae. A pipe exits the west edge of the bermed area and water was dripping from the pipe into a small pool during the field visit. Gas was flaring from the end of an exposed pipe in the salt scar. The soil exposed in the salt scar was clayey. Lush *Phragmites* was growing to the west and east of the scarred area.

A GAD-6-spectrometer reading in the salt scar (A, Fig. 10) yielded 2.66 pCi/g total radium (HC95-13, Table 1). Water in the small pool at the west end of the tank battery was at a temperature of 25.7 °C, with a pH of 8.0, and a field conductivity of 3250 μS/cm (HC95-13W, Table 4). TDS in this sample was 1401 ppm. Radium-226 activity in the water sample was 0.11± 0.04 pCi/L.

HC95-14

This site includes several tanks with a large salt scar located in NE/4, SE/4, sec 16, T4S, R7E in northeastern Hamilton County (Figs. 2 and 11). A road lies along the western edge of the site. The entire salt scar is surrounded to the south, east, and north by lush *Phragmites* with a maximum height of 3.5 m. This site is in the early stage of erosion. A single large tank enclosed by a berm is located on the northwest corner of the site. An area of oil-soaked soil extends from the southeast corner of the berm eastward. Some oil lay on the soil surface around the base of the *Phragmites*. Six tanks (4 vertical and 2 horizontal) lie to the south of the bermed tank.

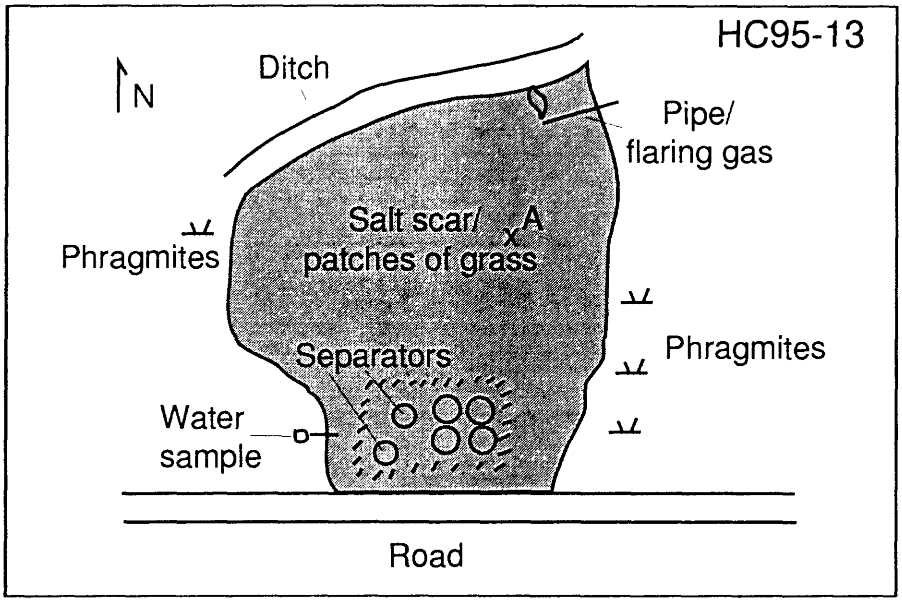


Figure 10- Sketch map of study site HC95-13 in eastern Hamilton County (south edge of the SW/4 of sec 10, T4S, R7E). Not to scale. Site is about 30 m north to south.

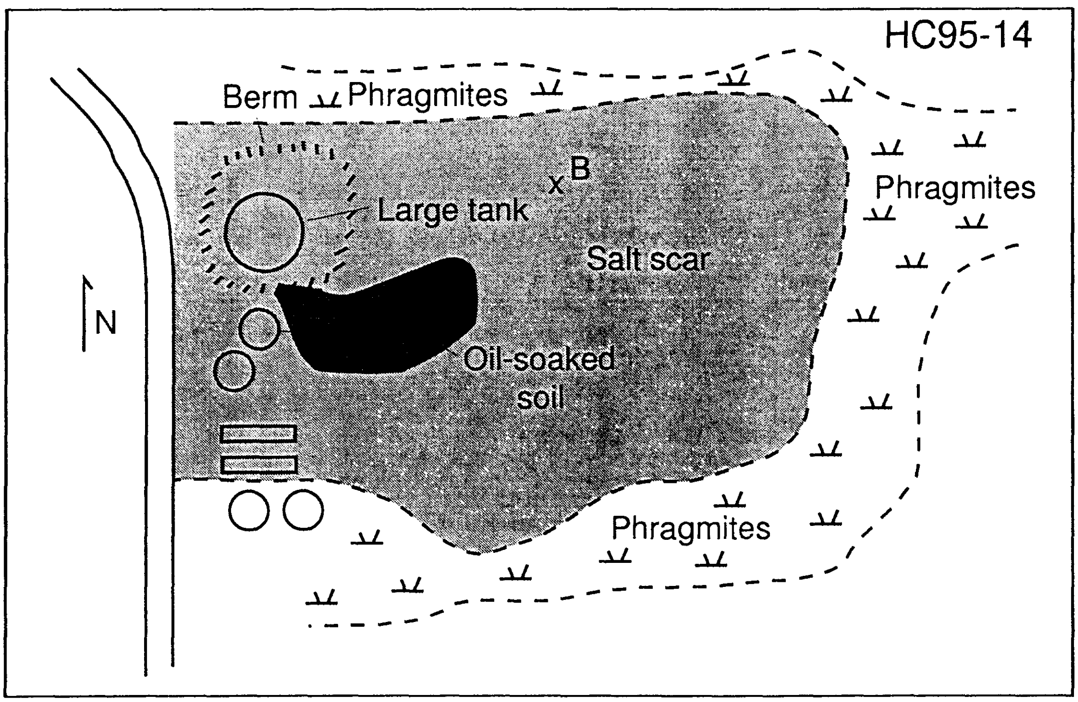


Figure 11- Sketch map of study site HC95-14 in eastern Hamilton County (NE/4, SE/4, sec 16, T4S, R7E). Not to scale. Site is about 80 m east to west.

Background scintillometer readings for the site were about 20 cps (6 μR/hr). Most of the soil and equipment on the site was at or slightly above background. One tank just south of the bermed area read 60 cps (13 μR/hr) at its base (Fig. 11). The east end of the oil-soaked soil read 32 cps (8 μR/hr) (A, Fig. 11). A GAD-6-spectrometer reading at that site yielded a total radium activity of 2.98 pCi/g (HC95-14A, Table 1), whereas a reading in the salt scar to the northeast of the oil-soaked area (B, Fig. 11) was 2.40 pCi/g (HC95-14B, Table 1). A soil sample from site A (oil-stained) had 40 ppm lead and 1 ppm cadmium (HC95-14A, Table 2), other elements were near median values for the study. A soil sample from site B (brine-affected, but not oil-stained) contained values close to the median for most elements except copper (30 ppm) and iodine (10-20 ppm) (HC95-14B, Table 2). The laboratory-based radium activity in soil samples from these two sites was essentially identical (3.2 and 3.1 pCi/g; HC95-14A,B; Table 3) and slightly above the respective GAD-6-spectrometer readings.

HC95-15

This site is located in SW/4, SW/4, sec 15, T4S, R7E in northeastern Hamilton County (Figs. 2 and 12). It consists of a bermed tank battery comprised of two oil storage tanks and a separator tank. An older separator tank lies outside the bermed area to the east (not shown in Fig. 12). The soil in the interior of the bermed area is oil soaked. A small salt scar lies immediately to the north of the tank battery; however, a larger scar about 75 m long north-to-south has formed off the northeast corner of the bermed area. A gully as deep as 1.5 m is at the head of this larger scarred area. These scarred areas are in the intermediate stage of erosion. Soils and equipment across the entire site give background scintillometer readings. A GAD-6-spectrometer reading on the small salt scar just north of the tank battery (A, Fig. 12) yielded 2.62 pCi/g total radium (HC95-15A, Table 1). Another reading on the lower part of the larger salt scar (B, Fig. 12) yielded 2.53 pCi/g total radium (HC95-15B, Table 1).

HC95-16

A large tank farm is located in E/2, NE/4, sec 21, T4S, R7E in northeastern Hamilton County (Fig. 2). This farm includes three separate tank batteries, two of which were composed of 4 oil storage tanks and one separator tank and one of which had three oil storage tanks and one separator tank. Minor oil spills were present near some of the tanks. No anomalous gamma activity was present at any of the tanks or on adjacent soils. No salt scarring was observed.

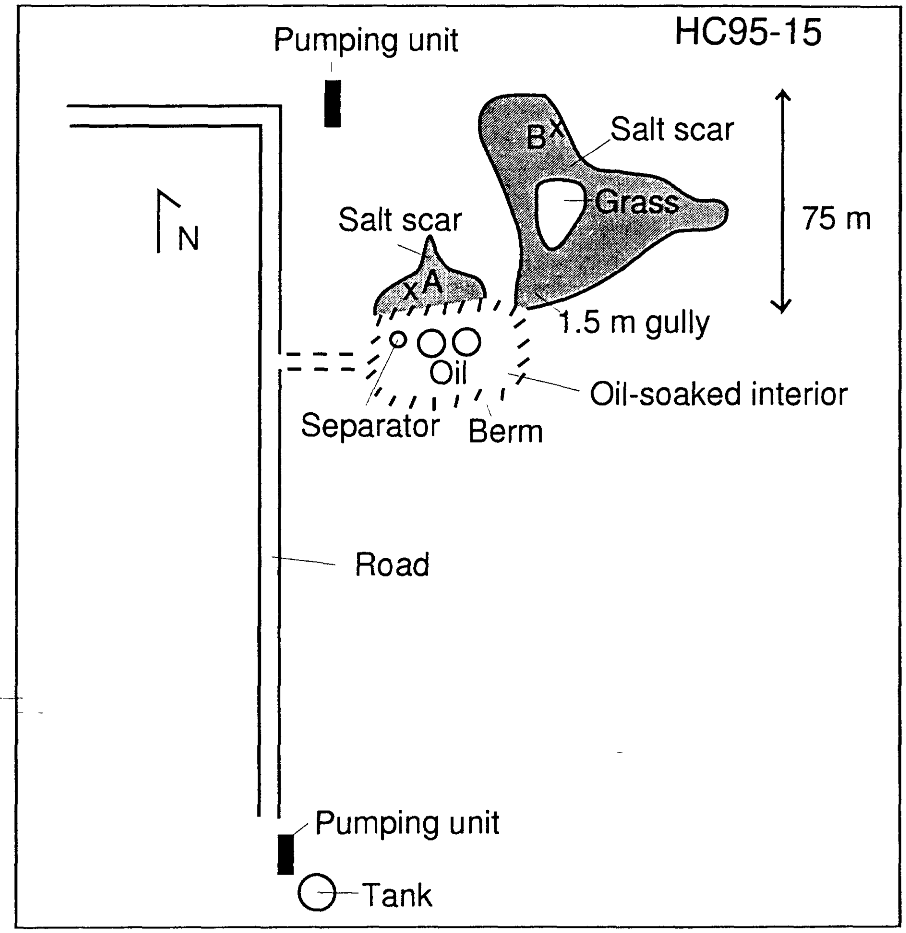


Figure 12- Sketch map of study site HC95-15 in eastern Hamilton County (SW/4, SW/4, sec 15, T4S, R7E). Not to scale. A-B-GAD-6-spectrometer survey sites.

Franklin County

One older production site was visited in 1995 in Franklin County along the Hamilton County boundary. This site was not revisited in 1996.

Site FC95-1

This site is just west of a section line road that follows the boundary between Hamilton County to the east and Franklin County to the west (Figs. 2 and 13). An old brine pit (not shown in Fig. 13) occurs along the road adjacent to a former tank battery site. Northwest of and downslope from the brine pit is a salt scar in an advanced stage of erosion. It is surrounded by a field covered by grasses, sparse sumac, and cedar. Oak forest lies to the west and north. GAD-6-spectrometer measurements and conductivity soundings were made along three traverse lines. An additional gamma-spectrometer reading was made in the scar on a zone of salt efflorescence (A, Fig. 13).

The salt scar heads in two gullies, which are as much as 1.5 m deep. These two gullies drain into a flatter area at the low end of the salt scar where outwash sediment is accumulating. Surface runoff from the site drains northwest off the scar along an old road surface and eventually enters a pond a few hundred meters to the northwest.

GAD-6-spectrometer readings show that total radium activities range from 1.60 to 2.46 pCi/g (Table 5). Highest activities are along the middle reaches of the narrow gully on the northeast side of the salt scar (Stations 20/0 and 30/0, Fig. 13). Lowest Ra-228/Ra-226 values also were measured at those two stations.

Soil conductivity readings (Table 6) are highest (100-230 mmhos/cm) at stations 30/0, 40/0, 50/10, 50/20, and 60/15 (Fig. 13). The low readings at 50/40 (25-35 mmhos/cm) probably represent local background levels for these soils. Conductivity readings for shallow soundings are lower than the deeper readings suggesting that salts have been partly flushed from the near surface, but that salt remains in the deeper subsurface.

A soil sample from station 30/0 (Fig. 13) showed values close to the median for all elements except iodine (10-20 ppm) (FC95-1A, Table 2). Trace element concentrations in a soil sample from station 50/10 (Fig. 13; FC95-1B, Table 2) were all close to median values. Laboratory-based gamma spectrometry of soil samples from these two stations indicated that radium activities were essentially identical (1.7 and 1.8 pCi/g, FC95-1A,B, Table 3). The deeper-viewing GAD-6-spectrometer readings at these soil sample sites were 2.34 and 1.70 pCi/g, respectively.

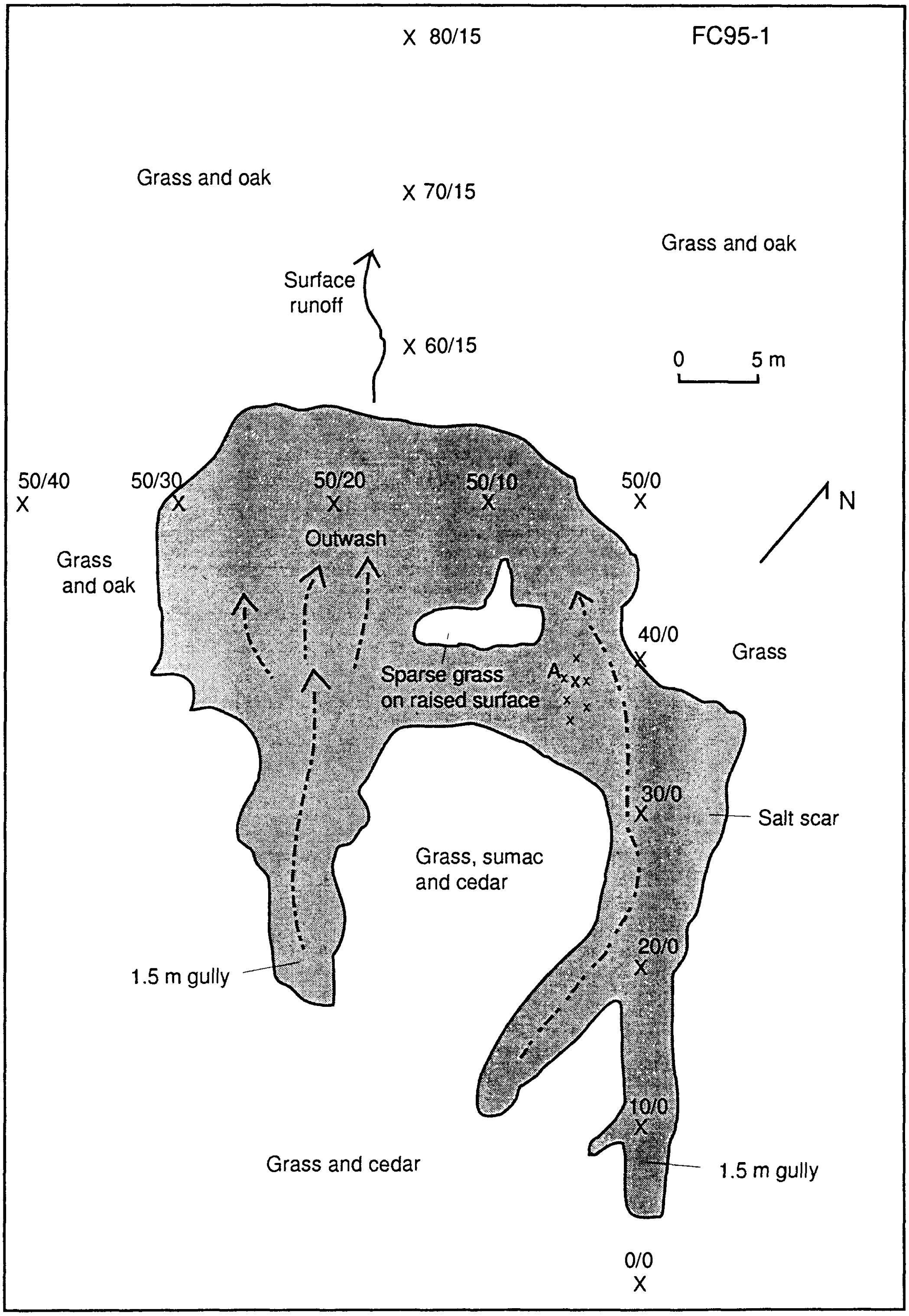


Figure 13- Detailed map of a salt scar at Site FC95-1 in Franklin County adjacent at the Hamilton County boundary. Gamma-spectrometer and conductivity surveys were made along the 3 traverse lines.

Table 5- GAD-6-spectrometer data for site FC95-1 in Franklin County, Illinois. See Fig. 13 for locations.

Grid (m)	Grid (m)	eU (ppm)	eTh (ppm)	eRa-226 (pCi/g)	eRa-228 (pCi/g)	Ra-228/Ra-226	Total Ra (pCi/g)
0	0	2.4	8.9	0.80	0.99	1.24	1.79
10	0	2.7	9.3	0.90	1.03	1.15	1.93
20	0	4.1	9.8	1.37	1.09	0.80	2.46
30	0	4.6	7.3	1.53	0.81	0.53	2.34
40	0	3.2	9.3	1.07	1.03	0.97	2.10
50	0	2.2	7.8	0.73	0.87	1.18	1.60
50	10	2.9	6.6	0.97	0.73	0.76	1.70
50	20	3.2	7.7	1.07	0.86	0.80	1.92
50	30	3.4	10.1	1.13	1.12	0.99	2.26
60	15	3.2	9.9	1.07	1.10	1.03	2.17
70	15	3	9.3	1.00	1.03	1.03	2.03
80	14	3.3	8.6	1.10	0.96	0.87	2.06
A		2.3	9	0.77	1.00	1.30	1.77

Table 6- Soil conductivity data for site FC95-1 in Franklin County, Illinois. See Fig. 13 for locations.

		Conductivity values (mmho/m)			
Grid point (m)	Grid point (m)	Vertical dipole	Perpendicular	Horizontal dipole	Perpendicular
0	0	44	39	43	34
10	0	63	67	36	45
20	0	89	81	59	55
30	0	230	190	155	190
40	0	135	111	120	120
50	0	85	86	65	64
50	10	151	150	145	160
50	20	218	218	185	180
50	30	70	68	58	56
50	40	35	35	25	26
60	15	105	95	100	82
70	15	51	49	40	38
80	15	37	36	31	28

Gallatin and White Counties

Twenty-six sites were visited in Gallatin and White Counties. Most of these sites are near the boundary between the two counties. During the survey, soils were generally nearly water saturated and many fields and most ditches contained standing water. Sites in these two counties were designated GC95-1 to GC95-26 (Figs. 3 and 4). Personnel from the Natural Resource Conservation Service offices in Ridgway, Gallatin County, Illinois assisted in the site selection and field survey in 1995. At that time, both White and Gallatin Counties were under the jurisdiction of the Ridgway office. Five sites were revisited in June 1996: GC95-4, GC95-6, GC95-8, GC95-25, and GC95-26.

GC95-1 (Gallatin County)

This site includes a bermed tank battery, a pumping unit, an injection well, and a narrow salt scar that extends downslope from the tank battery through a cornfield to a broad ditch (Figs. 3 and 14). The scarred area is in the early stage of erosion. The site

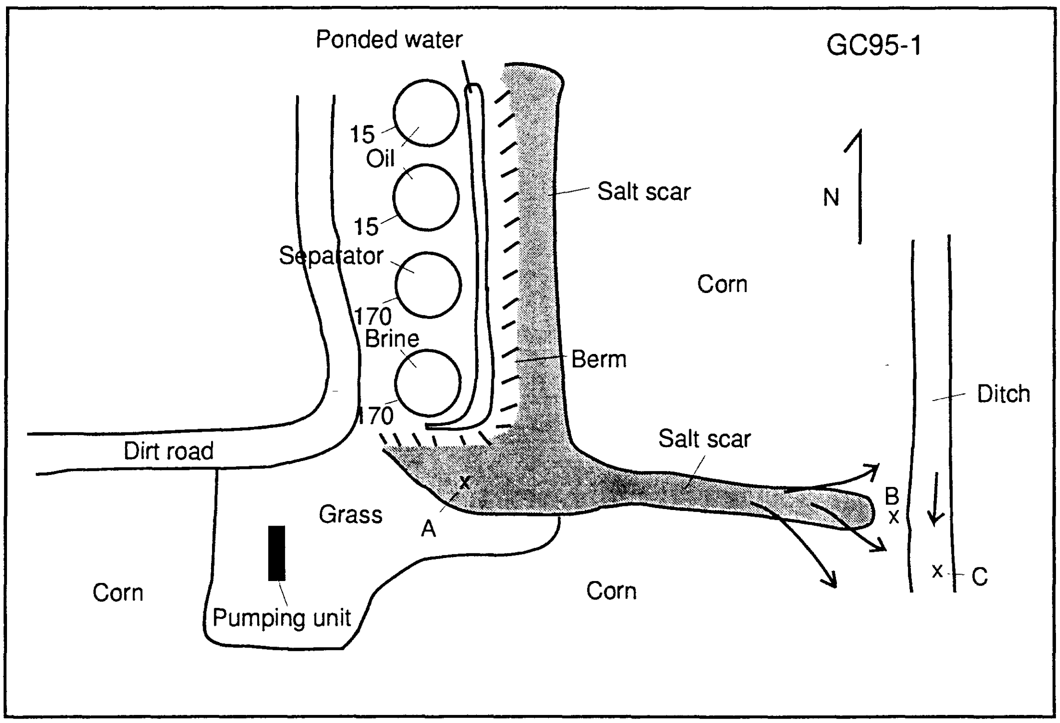


Figure 14- Sketch map of study site GC95-1 (Clyde Bryant farm) in Gallatin County. Not to scale. The approximate distance across the width of the sketch is 50 m. The injection well lies adjacent to the dirt road a few tens of meters south of the area covered by the sketch. Arrows at east end of salt scar suggest direction of surface drainage towards the ditch. A-C- gamma-spectrometer stations.

is located in NE/4, NW/4, sec 22, T7S, R8E, a few tens of meters south of the private residence of the landowner. The two oil tanks read 15 cps (5 μR/hr), slightly below the local background level of 20 cps (6 μR/hr), whereas the bases of the brine storage and separator tanks read 170 cps (33 μR/hr). The injection wellhead (not shown in Fig. 14) was at background levels. Scintillometer readings on the soil exposed in the salt scar at site A (Fig. 14) just below the berm of the tank farm were above background level (55-60 cps, 12-13 μR/hr). Readings at sites along the narrow salt scar leading to the ditch and in the ditch were slightly anomalous (20-35 cps, 6-9 μR/hr) and decreased with increasing distance from the tank battery. GAD-6-spectrometer readings (GC95-1A,B,C, Table 1) show that total radium activities are slightly lower at the two distant sites (B=2.00 pCi/g, C=2.18 pCi/g) compared to the nearest site (A=2.51 pCi/g).

A surface grab sample of the soil in the salt scar adjacent to the berm contained somewhat elevated concentrations of copper (20 ppm), zinc (80 ppm), iron (3.9 percent), and iodine (1-5 ppm) compared to median values (GC95-1A, Table 2). This surface grab sample also had a laboratory-based total radium activity of 2.4 pCi/g (GC95-1A, Table 3). A soil sample from the ditch (C, Fig. 14) contained somewhat elevated lead concentrations (40 ppm) (GC95-1B, Table 2). This sample had a laboratory-based total radium activity of 1.9 pCi/g (GC95-1B, Table 3), a value close to the GAD-6-spectrometer reading at the site.

GC95-2 (White County)

This site is in N/2, NE/4, SE/4, sec 15, T7S, R8E (Fig. 4, Fig. 15). It consists of a bermed tank battery (3 tanks) and a salt scar about 25 m long to the east of the battery, both of which lie at the northern edge of a soybean field just south of a county road. The west end of the salt scar overlies a reclaimed brine pit. This salt scar is in the early stage of erosion. The field slopes very gently to the east and drains into a ditch along its eastern edge. The field is poorly drained and is underlain by a PVC pipe drainage system that was put in to improve drainage, not to remediate salt scarring. At the time of the survey, soybeans planted earlier in the season had not sprouted in the lower, poorly drained part of the field. Gullies have formed in the east side of the field and part of the drainage pipe system has been washed out.

Local scintillometer background readings on the soil were about 20 cps, (6 μR/hr). The base of one tank was slightly anomalous (30 cps, 8 μR/hr) and the salt scar was slightly anomalous (20-30 cps, 6-8 μR/hr). Replicate GAD-6-spectrometer readings made in the middle of the salt scar over the old brine pit averaged about 1.9 pCi/g total radium (GC95-2, Table 1). A grab sample of surface soil from the same site (GC95-2B, Table 3) had a total laboratory-based radium activity of 2.11 pCi/g. This sample was split into two size fractions (< 0.25 mm and >0.25 mm) for trace element analysis (GC95-2B, Table 2). These two

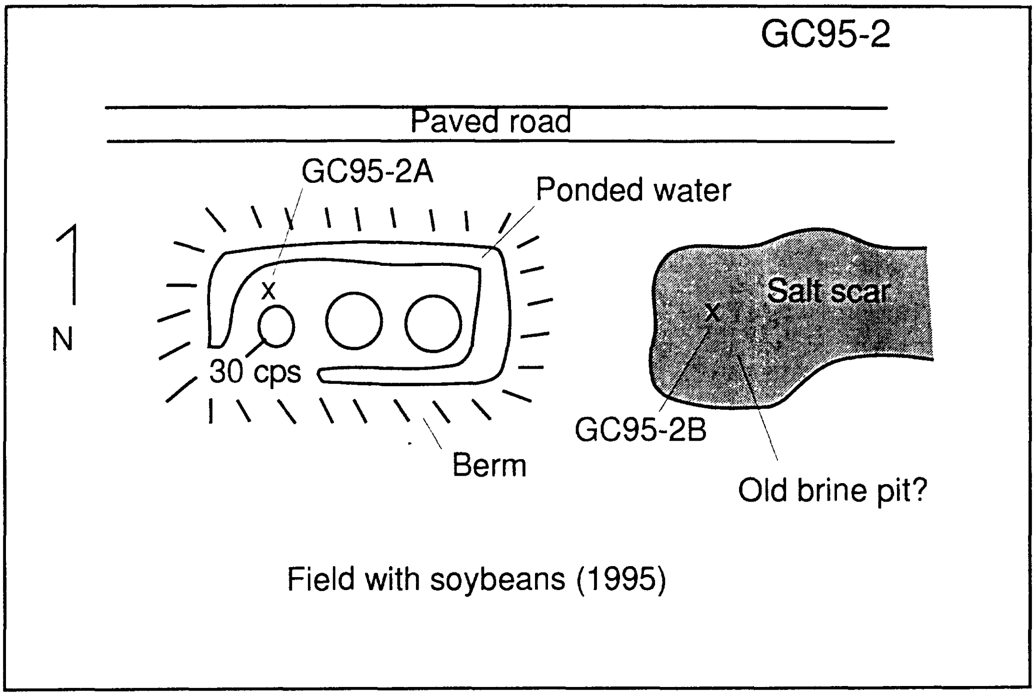


Figure 15- Sketch map of study site GC95-2 in White County. Not to scale. The larger circular tanks are about 2 m in diameter.

fractions were generally similar in trace-element content except that the larger size fraction contained 3900 ppm barium versus 540 ppm and slightly more bromine (20-30 ppm versus 15-20 ppm). This larger fraction may contain traces of barite. The bromine concentrations in both fractions were above median values for the study. A soil sample from the west end of the bermed area had a total laboratory-based radium activity of 1.60 pCi/g (GC95-2A, Table 3). Trace element concentrations in this sample were close to median values (GC95-2A, Table 2).

A water sample from the gully yielded a field pH of 6.2, a conductivity of 280 mmhos/m, and a temperature of 24.5°C. TDS in this sample was 187 ppm. Radium-226 activity in the water sample was 0.10± 0.03 pCi/L (GC95-2W, Table 4).

GC95-3 (White County)

This site consists of a bermed tank battery just south of a paved county road in SW/4, NW/4, NE/4, sec 11, T7S, R8E (Figs. 4 and 16). Three tanks are present at the site. No salt scarring was observed. Water was ponded in the southwest corner of the bermed area during the survey. Water drains from the site directly into a ditch along the south edge of the adjacent paved road. The center tank read 260 cps (49 μR/hr) and the eastern tank read 820 cps (145 μR/hr) compared to a background level of 20 cps (6 μR/hr). GAD-6-spectrometer readings on the base of the hotter tank yielded about 89 pCi/g total radium (GC95-3t, Table 1; a minimum activity for the sludge in the bottom of the tank), whereas the water-saturated soil within the berm along its northern edge (B, Fig. 16) yielded 11.4 pCi/g total radium (GC95-3B, Table 1). A soil sample taken at a point between the two radioactive tanks (Fig. 16) had a total laboratory-based radium activity of 29.3 pCi/g (GC95-3, Table 3). This same sample contained elevated (with respect to median values) levels of iron (3.9 percent), copper (60 ppm), zinc (105 ppm), and strontium (660 ppm), and high levels of barium (>1.5 percent) (GC95-3, Table 2).

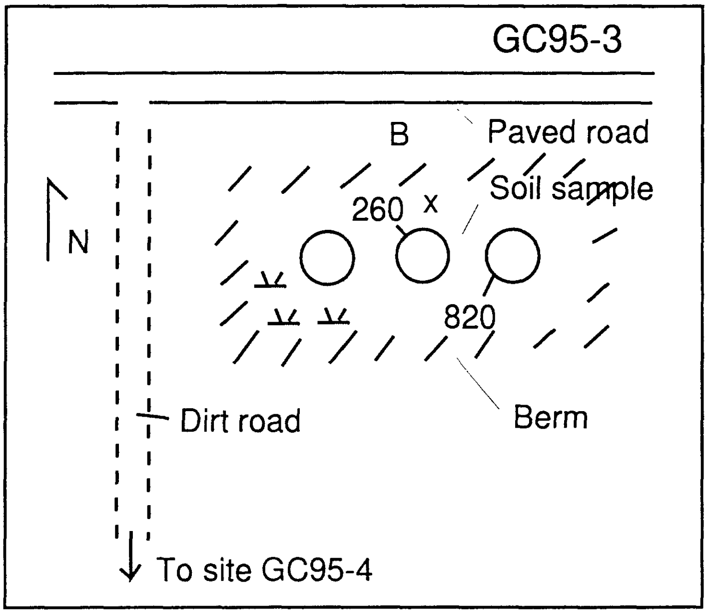


Figure 16- Sketch map of study site GC95-3 in White County. Not to scale. The circular tanks are approximately 2 m in diameter.

GC95-4 (White County)

Just to the southwest of Site GC95-3 is another site consisting of two small bermed tank batteries and an injection well (Figs. 4 and 17). This site is located in SE/4, NE/4, NW/4, sec 11, T7S, R8E. A diversion ditch separates this site from a cornfield downslope to the west. A small wetland dominated by *Phragmites* lies just south of the injection well and extends westward to the head of the diversion ditch. The cornfield contains some areas of barren soil, but it is uncertain whether these areas are related to the tank battery and injection well. The injection wellhead and the base of the oil tank adjacent to it were slightly below background (15 cps, 5 μR/hr). The three water tanks were anomalous in activity level with the central tank measuring 520 cps (92 μR/hr) at its base and the western tank measuring 440 cps (81 μR/hr) at its base.

The land surface rises to the north of this tank battery and a thin layer of oily scale was present on the barren, sloped surface. This material and the associated soil is eroding and moving back down into the bermed area forming a small fan of sediment (Fig. 17). The oily scaly soil on the hillslope gave a maximum reading of 720 cps (128 μR/hr), whereas the sediment in the fan ranged from 200-420 cps (39-77 μR/hr). A GAD-6-spectrometer reading on the oily scale layer (A, Fig. 17) yielded 56 pCi/g total radium (GC95-4, Table 1). A grab sample of the surface material from the GAD-6-spectrometer site yielded 228 pCi/g total radium in the laboratory-based analysis (GC95-4, Table 3). The higher total radium activity in the grab sample compared

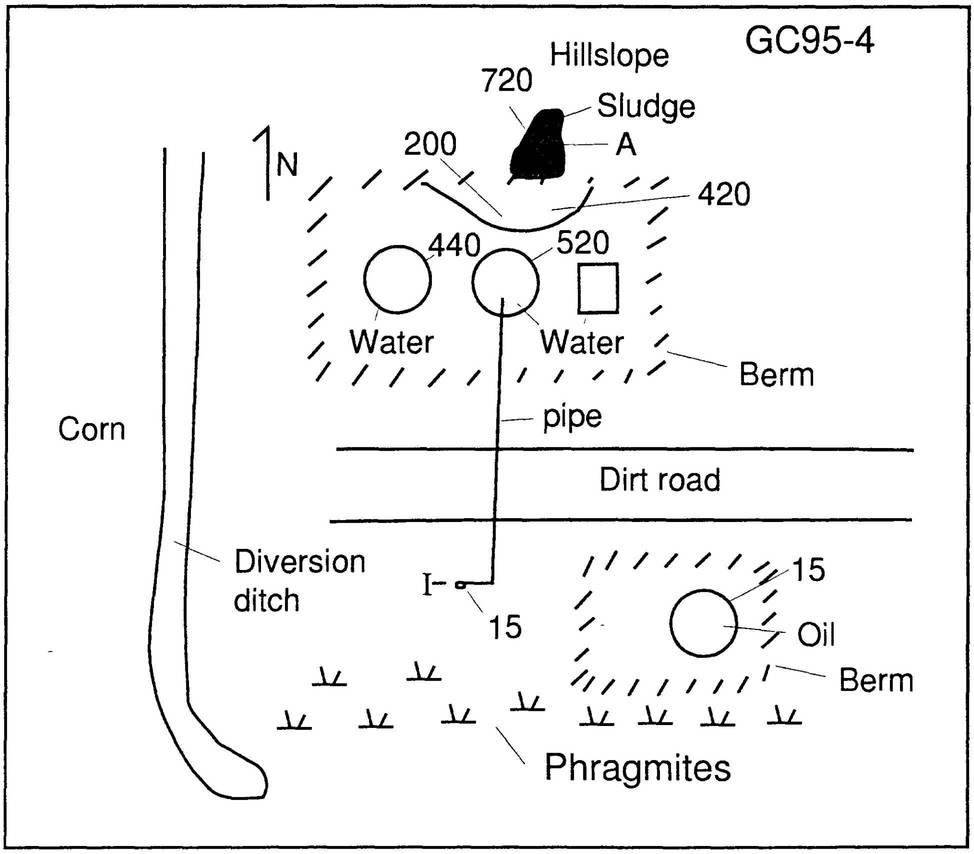


Figure 17- Sketch map of study site GC95-4 in White County. Not to scale. The circular tanks are approximately 2 m in diameter. Exposed soil and tank sludge on the hillslope north of the bermed area has washed down forming a small delta of radium-rich sediment.

to the GAD-6-spectrometer reading at the site suggests that most of the radium is contained within the surface layer. This sample also contained very high levels of iron (17.7 percent), strontium (3280 ppm), and barium (>1.5 percent) and elevated levels of copper (95 ppm), lead (85 ppm) and zinc (385 ppm) when compared to median values for the study (GC95-4, Table 2). Cadmium was detected at 1 ppm.

GC95-5 (White County)

A tank farm is located in NE/4, NE/4, sec 11, T7S, R8E on the southeast corner of the intersection of two county roads (Fig. 4, no map was made of this site). Eight tanks are on the site. Minor salt scarring occurs around the site. Four of the tanks are at background levels, however three water storage tanks along the north edge of the site are moderately (400-620 cps, 74-110 μR/hr) to highly radioactive (2700 cps (400 μR/hr) at one end of a horizontal tank). A GAD-6-spectrometer reading taken on the soil between two of the tanks yielded 4.6 pCi/g total radium activity (GC95-5A, Table 1); however, a GAD-6-spectrometer reading on soil adjacent to the end of the most radioactive tank yielded 21 pCi/g total radium (GC95-5B, Table 1) and a GAD-6 reading from the underside of the south end of this hottest tank yielded 525 pCi/g total radium (GC95-5C, Table 1, a minimum activity for sludge in the tank). A sample of the soil from the end of the most radioactive tank contained elevated (compared to median values from this study) levels of lead (40 ppm) and zinc (80 ppm) and detectable cadmium (GC95-5, Table 2). The soil sample also contained elevated levels of strontium (260 ppm), barium (2670 ppm) and iodine (1-15 ppm). The same sample had a laboratory-based total radium activity of 28.2 pCi/g (average of analyses from two different labs). This lab-based radium activity is higher than the corresponding GAD-6-spectrometer reading for the site, but much lower than the minimum total radium activity for sludge inside the tank. The GAD-6-spectrometer reading may have been influenced by the water saturation of the soil at the site, but it is surprising that the gamma activity from the tank itself didn't compensate for the water effects.

A field pH of 8.2, a temperature of 30.5^{o}C, and a field conductivity of 950 mmhos/m was measured in water in the small pool formed by brine dripping from the valve at the end of this most radioactive tank. TDS were 717 ppm. The radium-226 activity in this sample was 0.17± 0.02 pCi/L.

GC95-6 (Gallatin County)

A substantial salt scar is just south of the White County line southeast of the intersection of State Highway 141 with County Road 850 E (Figs. 3 and 18) in NW/4, NW/4, NE/4, sec 21, T7S, R9E. A tank battery, no trace of which now remains, was located near the crest of the hill between the salt scar and Highway 141 (Buck Buchanan, Natural Resources Conservation Service, oral commun., 1995). Another salt scar occurs in a field

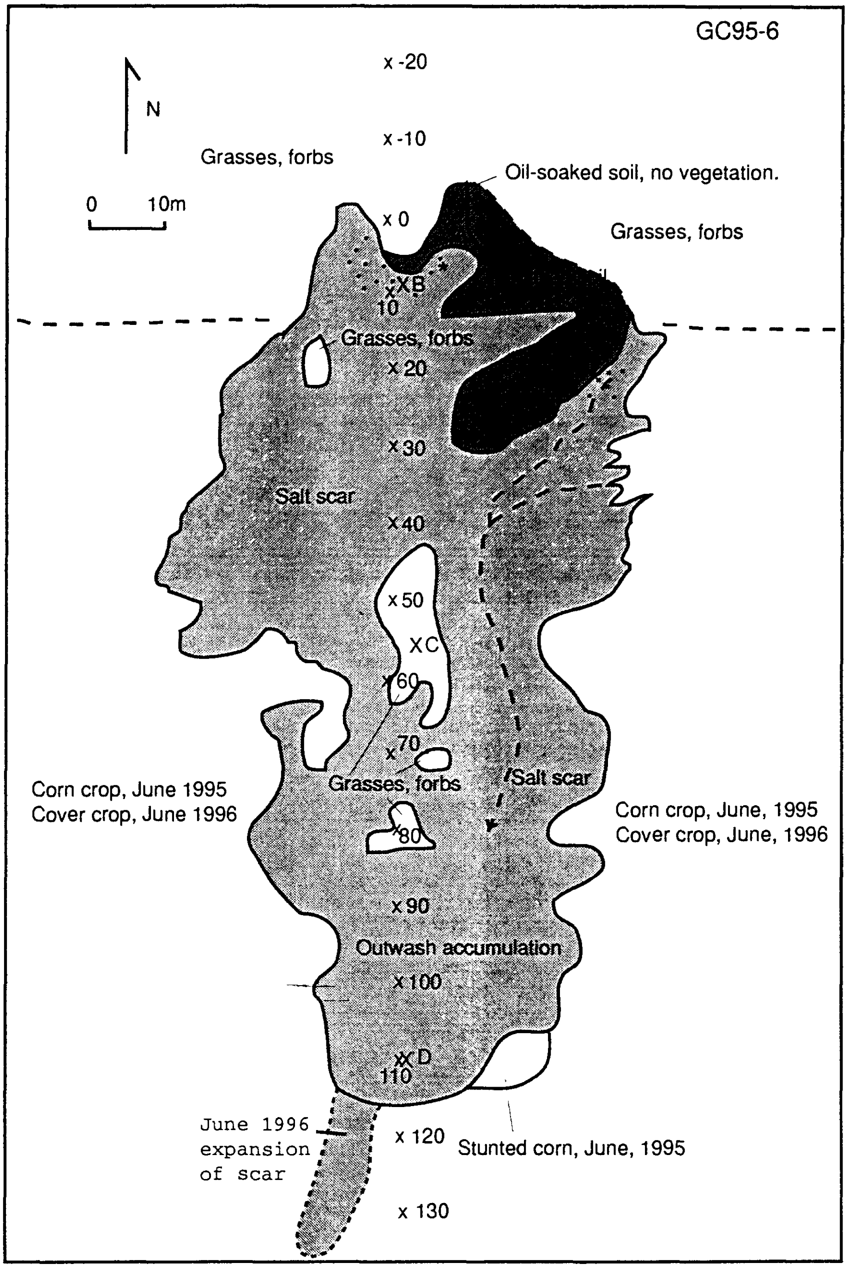


Figure 18- Detailed map of a salt scar at Site GC95-6 in Gallatin County near the White County boundary. dots- areas of salt efflorescence at the soil surface; x- conductivity measurement stations (numbered -20 to 130); X- gamma-spectrometer stations (A,B,C,D); *- soil sample sites, Stations A and D are also soil sample sites; short dash line- rills and shallow gullies in the salt scar.

northeast of the highway intersection (not shown in Fig. 18). It was probably formed by leakage from this same tank battery.

The scar slopes downhill to the south into a cultivated field. In June 1995, the salt scar was about 118 m long (N-S) and 60 m wide (E-W) and headed in a series of gullies along its northern and northeastern edge. This scarred area is in the intermediate stage of erosion. At the leading (southern) edge of the salt scar, corn was stunted during the 1995 field survey. In June 1996, a narrow tongue of the leading edge of the salt scar had migrated about 12 m further downslope. A thin layer of grayish brown, resistant oily soil and scale occurs at the head of the scar and extends into adjacent grassy areas. Exposures are insufficient to tell whether this layer is a surface feature or if it represents a resistant layer that extends into the subsurface north of the scar. Salt efflorescence is present in some of the gully heads adjacent to the edges of the oily soil layer.

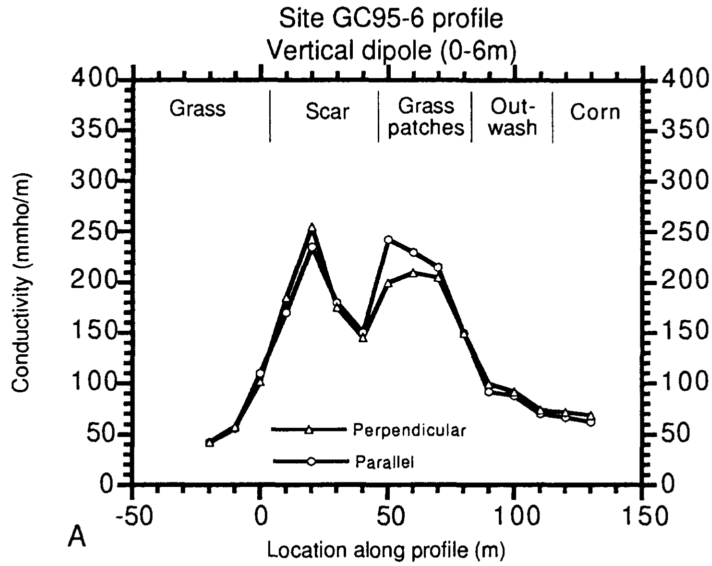
GAD-6-spectrometer data for the site indicate that the areas underlain by weathered oily soil contain about 7.6 pCi/g total radium, whereas the rest of the salt scar averages about 2 pCi/g total radium (GC95-6A-D, Table 1). The Ra-228/Ra-226 value is very low (0.13) on the oily soil, and is higher but variable (0.49-1.51) over the rest of the salt scar. A sample of the oily soil layer (A, Fig. 18) contains elevated iron (4.8 percent) and copper (30 ppm), lead (165 ppm), and zinc (95 ppm) with respect to median values for the study. Strontium also seems elevated (895 ppm) in this sample, but barium (380 ppm) does not (GC95-6A, Table 2). A sample of the soil with salt efflorescence taken just below and south of the oily soil layer (* locality, Fig. 18) contains concentrations of trace elements near median values (GC95-6*, Table 2). A sample of sediment from the outwash area near the south end of the salt scar (D, Fig. 18) contains levels of trace elements close to median values for the study except for bromine (10-50 ppm) (GC95-6D, Table 2).

A soil conductivity survey down the axis of the salt scar (Figs. 19A,B, Table 7) shows that conductivity readings in the 6 m sounding (Fig. 19A) rise from stations -20 m to 0 m in the grassy area just north of the north edge of the salt scar and peak at the 20 m station in the upper part of the salt scar. The conductivity readings drop beneath stations 30 m and 40 m (still below the salt scar), then rise again through stations 50 m, 60 m, and 70 m beneath patches of grass in the salt scar. Conductivities then drop again beneath the outwash area from 150 mmhos/m to about 70 mmhos/m (stations 80 m to 100 m) and level off at 50-60 mmho/m at stations 110 m-130 m (into the corn).

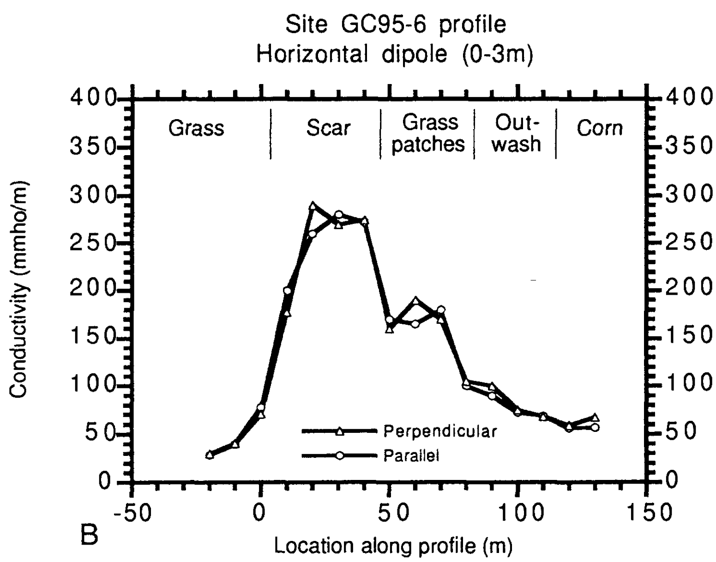
In the 3 m sounding (Fig. 19B), conductivity readings in the northernmost 3 stations also rise from stations -20 m to 0 m, then form a broad peak with no lower values through stations 20 m to 40 m across the width of the upper part of the salt scar. South of this broad peak, values drop sharply, but level out at about 170 mmhos/m through stations 50-70 m, then drop sharply again to about 100 mmhos/m at station 80 m. Stations 50 m to 80 m are characterized by grassy patches on the surface of the salt scar. Across the outwash accumulation area (stations 90 m to 110 m)

Table 7- Soil conductivity data for site GC95-6 in Gallatin County, Illinois. See Fig. 18 for locations.

		Conductivity values (mmho/m)		
Location (m)	Vertical dipole	Perpendicular	Horizontal dipole	Perpendicular
-20	42	42	29	30
-10	56	58	40	41
0	110	102	78	71
10	170	185	200	178
20	235	255	260	290
30	180	175	280	270
40	150	145	272	275
50	242	200	170	160
60	230	210	165	190
70	215	205	180	170
80	150	150	100	105
90	92	100	90	100
100	88	92	72	75
110	70	74	69	68
120	67	72	56	59
130	62	69	57	67



A



B

Figure 19 - Soil conductivity measurements made along a profile down the axis of the salt scar at Site GC95-6 in Gallatin County, Illinois. For survey station locations, see Fig. 18. A - Conductivity readings with the EM-31 in the vertical dipole position. Readings with the instrument parallel to and perpendicular to the traverse line are both shown. B - Conductivity readings with the EM-31 in the horizontal dipole position. Readings with the instrument parallel to and perpendicular to the traverse line are both shown.

values gradually drop to about 60 mmhos/m, then level out at 50-70 mmhos/m in the corn.

The 3 m soundings are lower than the 6 m soundings for most of the profile except for stations 10 m to 40 m. At these stations, salt effloresces at the surface. Along most of the profile salt may have been flushed from the near surface soils by the heavy spring rains. In the area of stations 10 m to 40 m, a small body of saline soil may remain near the surface, protected from flushing by the oily surface layer present to the north and beneath the grass to the northeast (Fig. 18).

Conductivity values (3 m and 6 m) in the corn crop area south of the scar remain at levels above those at the north end of the profile (29-40 mmho/m to the north, 57-69 mmho/m to the south). This may reflect movement of modest amounts of salt into these areas or higher water table or both.

GC95-7 (Gallatin County)

This site consists of a large, flat salt scar about 110 m by 40 m that occupies most of a field in SW/4, NE/4, SW/4, sec 21, T7S, R9E (Fig. 3). The area is in the early stages of erosion. The western edge and the southwestern part of the field were covered with standing water during the field survey. *Phragmites* was growing in one patch. Scintillometer readings of 15 cps (5 μR/hr) occurred where the soil was relatively dry; readings were 6-8 cps (3-4 μR/hr) near the water-saturated areas. A single GAD-6-spectrometer reading yielded 2.07 pCi/g total radium (GC95-7, Table 1).

GC95-8 (White County)

This site is surrounded by trees and is located at the end of an oiled dirt road in SW/4, SW/4, sec 1, T7S, R8E (Fig. 4). It includes an active pumping unit in a small open area with much oil-stained soil immediately around the wellhead. Some disturbed, oily soil with scale lies at the northeastern edge of the open area surrounding the pumping unit. A reclaimed pit area lies to the east of and topographically below the pumping unit. This irregular area is about 30 m east to west and about 25 m north to south. The surface is moderately vegetated. A small brine pit is located at the western edge of the reclaimed area and a stream flows along its eastern and southeastern edge. The bottom of the stream channel is a few meters below the surface of the reclaimed area. The edge of the reclaimed area is beginning to erode adjacent to the stream.

GAD-6-spectrometer measurements during the 1995 field survey on scaly, oily soil next to the wellhead yielded a total radium activity of 57.1 pCi/g (GC95-8, Table 1). The reclaimed area has oil oozing to the surface locally and the surface reads 50-60 cps (11-13 μR/hr, about twice the local background level). The area of oily, scaly soil at the northeastern edge of the open area around the pumping unit read 300 cps (57 μR/hr, maximum).

GC95-9 (Gallatin County)

This site consists of a small, bermed tank battery (3 tanks), a salt scar, and an abandoned brine pit in SE/4, NW/4, NE/4, sec 15, T8S, R9E (Figs. 3 and 20). The site lies in a winter

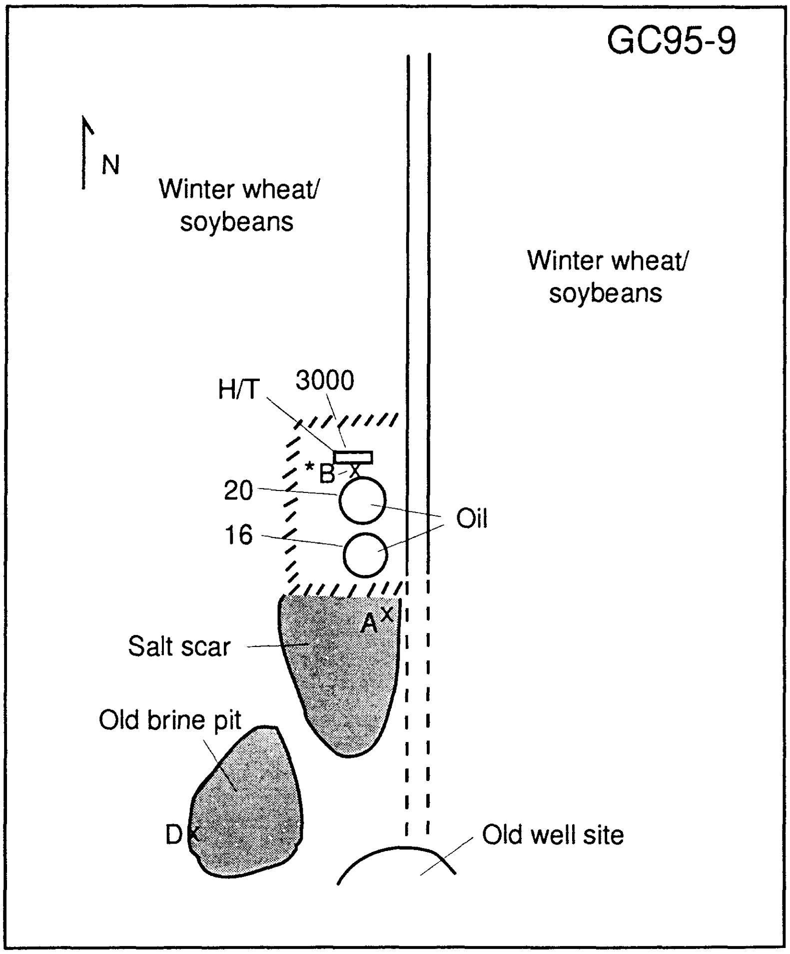


Figure 20- Sketch map of study site GC95-9 in Gallatin County, Illinois. Not to scale. The circular tanks are approximately 2m in diameter.

wheat/soybean field near the end of an access road that connects to a county road. An old well site lies at the southern end of this access road beyond the tank battery. A wetland occupies the abandoned brine pit site and junk equipment has been discarded in the pit. The salt scars are in the early stages of erosion.

Background scintillometer readings were about 22 cps (6 μR/hr). Two oil tanks read 20 and 16 cps (6 and 5 μR/hr); however, the bottom of a heater/treater tank read 3000 cps (436 μR/hr). A GAD-6-spectrometer reading on the salt scar just south of the berm (A, Fig. 20) yielded 1.5 pCi/g total radium (GC95-9A,

Table 1). A reading on soil between the H/T tank and an oil tank (B, Fig. 20) gave 11.5 pCi/g total radium (GC95-9B, Table 1). A reading on the bottom of the H/T tank gave 587 pCi/g total radium (GC95-9C, Table 1; a minimum activity for sludge in the tank). A GAD-6-spectrometer reading at the west edge of the old pit area (D, Fig. 20) gave 1.20 pCi/g total radium (GC95-9B, Table 1). A soil sample from the bermed area adjacent to the heater/treater tank (* locality, Fig. 20) contained trace element concentrations close to median values, except for traces of iodine (1-5 ppm). Laboratory-based gamma spectrometry indicated that the total radium activity for this soil sample was 1.96 pCi/g (GC95-9, Table 3).

GC95-10 (Gallatin County)

This site consists of 5 tanks (two separator and three oil tanks) in a field between a north-south county road and a wheat field to the east in SW/4, NW/4, NW/4, sec 15, T8S, R9E (Fig. 3). A ditch separates the roadside field from the wheat field. No salt scarring was present at the site, however, soil on the east side of the two easterly tanks was oil-soaked. Background scintillometer readings on soil at the site were 10-12 cps (4 μR/hr). Three oil tanks read 10 cps (4 μR/hr). One separator read about 10 cps (4 μR/hr), the other about 25 cps (7 μR/hr).

GC95-11 (Gallatin County)

This site occupies the northwestern corner of the intersection of two dirt roads in SE/4, SW/4, NW/4, sec 15, T8S, R9E (Fig. 3). It includes a bermed tank battery (five tanks), an injection well, an adjacent pumping unit, remnants of an old brine pit, and 3 pumping units at some distance to the north and east. Water in the brine pit had a surface layer of oily scum. This site is in the early stages of erosion.

Background scintillometer readings on soils at the site were 12-14 cps (4-5 μR/hr). No anomalous readings were observed on any of this equipment or nearby soils. Oily soil around the adjacent pumping unit read 10-18 cps (4-5 μR/hr). A sample of material thought to be highly corroded tank bottom fragments with sludge was collected for laboratory measurements and had a total radium activity of 2.39 pCi/g (GC95-11, Table 3). This sample was split into two size fractions (<0.25 mm and 0.25-0.50 mm) and analyzed for trace metals (GC95-11, Table 2). These splits had a high iron content (14 and 17 percent), elevated copper (50 and 95 ppm), and some bromine (10-15 and 15-25 ppm). Barium concentrations (90 ppm in both splits) are below that expected for tank sludge or scale in this area and also below that for soil samples from other sites (Table 2). This sample is probably a mixture of soil and corroded tank floor.

GC95-12 (Gallatin County)

This site is located in SE/4, SW/4, NW/4, sec 22, T8S, R9E (Fig. 3). It consists of a tank battery with 1 separator and 2 oil tanks, an old brine pit in a treed area to the north, and an active pumping unit and adjacent small pit and pipe stack to the northwest. Water in the pit adjacent to the pumping unit was at a depth of 1.5 m below the surface. An area of oil-soaked soil lies north of the tank battery. Background scintillometer readings on soils in a nearby field were 10 cps (4 μR/hr). The tanks and the soils in the old brine pit ranged 10-20 cps (4-6 μR/hr). The pumping unit, adjacent pit, and pipe stack were at or below 10 cps (4 μR/hr).

GC95-13 (Gallatin County)

A large tank battery and tank storage site with 16 tanks contained within a bermed area are located in NE/4, NE/4, sec 21, T8S, R9E (Fig. 3). An old pit site and an operating pumping unit are located to the east of the bermed area. A small salt scar in the early stages of erosion occurs at the east edge of the bermed area. Background scintillometer readings were about 15 cps (5 μR/hr). One tank yielded a maximum reading of 25 cps (7 μR/hr) and another about 60 cps (13 μR/hr). Scintillometer readings on the surface of the salt scar were slightly above background level. A GAD-6-spectrometer reading on saturated ground at the west edge of the ponded pit gave 1.5 pCi/g total radium (GC95-13, Table 1). A soil sample from the salt scar about 0.5 m from an outlet through the east edge of the berm yielded a laboratory-based total radium activity of 1.18 pCi/g (GC95-13, Table 3). This same soil sample contained trace element concentrations close to median values for this study (GC95-13, Table 2) except for low iron (0.8 percent) and zinc (25 ppm) and elevated iodine (10-15 ppm).

GC95-14 (Gallatin County)

Old tanks and other equipment are in a field on the northeast corner of a county road intersection in SE/4, SW/4, SW/4, sec 15, T8S, R9E (Fig. 3). This site has been used for tank storage and recycling. At the time of the survey, a heater/treater tank, cut in half, was laying on its side on the property. This half tank was partly filled with corroded tank wall fragments and scale. A scintillometer placed on this material gave readings that ranged from 50-90 cps (11-19 μR/hr) (local background levels were 20-25 cps, 6-7 μR/hr). A GAD-6-spectrometer placed on the material in the tank gave a reading of 6.9 pCi/g total radium (GC95-14, Table 1). A grab sample of the scale analyzed by laboratory-based gamma spectrometry yielded 14.5 pCi/g total radium (GC95-14, Table 3). This same sample had high iron concentrations (16.2 percent), elevated copper (50 ppm) and lead (85 ppm), anomalously low zirconium (20 ppm) and barium (105 ppm) and elevated strontium (1460 ppm) and iodine (5-15 ppm) compared to median values in this study (GC95-14, Table 2). Other tanks, an injection well, and a workover rig in a field to the east gave background scintillometer readings.

GC95-15 (Gallatin County)

The site is located in NW/4, NW/4, NW/4, sec 1, T8S, R9E just southeast of the Asbury Methodist Church (Fig. 3). A pumping unit and two produced water storage units on the site were at background (20 cps, 6 µR/hr).

GC95-16 (Gallatin County)

This large site is located in SW/4, SW/4, SW/4, sec 24, T7S, R9E (Figs. 3 and 21). The site lies north of a paved road and includes three isolated tanks, a bermed tank battery (six large tanks), a partly filled brine pit with some wetland vegetation growing in it, and an old tank lying on its side, all aligned north-south. Salt scars in the early stages of erosion flank these features to the west, north, and south. Thin piles of rusty-weathering material lie on the ground surface south of the tank lying on its side. The soil inside the bermed area was saturated with oil. An irregular salt scar about 150 m long lies

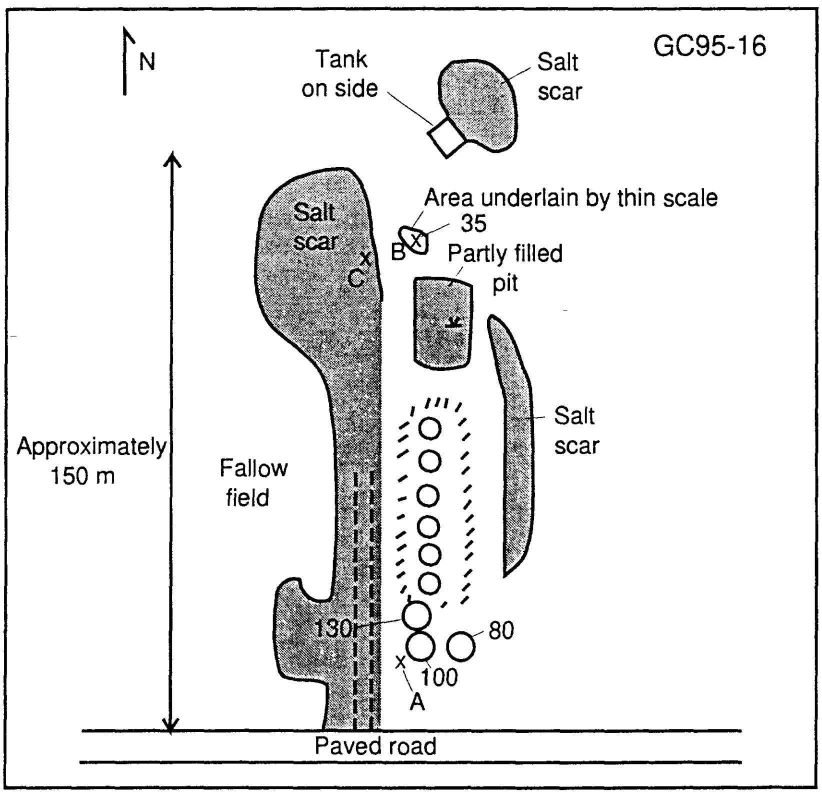


Figure 21- Sketch map of study site GC95-16 in Gallatin County, Illinois. Not to scale. Eastern edge of the large salt scar is poorly defined.

to the west of this equipment, and another shorter salt scar lies to the east. Background scintillometer readings on soils were 15-20 cps (6 μR/hr). During the field survey, the ground was nearly water saturated everywhere.

The three tanks south of the bermed area read 80, 100, and 130 cps (17, 21, 26 μR/hr). A GAD-6-spectrometer reading on soil near one of these tanks (A, Fig. 21) yielded 4.0 pCi/g total radium (GC95-16A, Table 1). A reading from the middle of the thin layers of rusty-weathering material (B, Fig. 21) yielded 2.5 pCi/g total radium (GC95-16B, Table 1). A reading on soil in the northern part of the long salt scar on the west side of the site (C, Fig. 21) gave 1.4 pCi/g total radium (GC95-16C, Table 1). A grab sample of the rusty-weathering material from site B (Fig. 21) had 0.54 pCi/g total radium based on laboratory gamma spectrometry (GC95-16, Table 3). This sample contained high concentrations of iron (17.8 percent), elevated copper (45 ppm) and strontium (200 ppm) and low barium (225 ppm) compared to median values for soil samples from other sites in this study. Iodine was found (5-25 ppm) (GC95-16, Table 2). This material probably represents a mixture of corroded tank wall fragments and soil.

GC95-17 (Gallatin County)

This tank battery is located in NE/4, NE/4, NW/4, sec 27, T7S, R9E (Fig. 3). It includes 4 oil-storage tanks, 2 separators, a small H/T unit, and a brine storage tank enclosed within a berm. Oil was spilled on the soil surface inside the berm. Background readings were 20 cps (6 μR/hr). Maximum readings on the equipment were 40 cps (10 μR/hr).

GC95-18 (Gallatin County)

This bermed tank battery site is located in SW/4, SE/4, SE/4, sec 21, T7S, R9E (Fig. 3). The site includes 3 oil tanks and a separator tank. Minor salt scarring in the early stages of erosion is present on the east and south edge of the bermed area. Background readings were 20 cps (6 μR/hr). Two of the oil tanks were at background, one read 55 cps (12 μR/hr). The separator read 240 cps (46 μR/hr).

GC95-19 (Gallatin County)

A tank battery at this site, located in S/2, SE/4, NE/4, sec 21, T7S, R9E includes three oil tanks and a separator surrounded by a berm (Fig. 3). A minor salt scar in the early stages of erosion occurs at the east edge of the berm. Two of the oil tanks were empty and gave background (20 cps, 6 μR/hr) readings. The third oil tank read 120 cps (24 μR/hr). The separator read 270 cps (51 μR/hr).

GC95-20 (Gallatin County)

A large tank battery is located in SE/4, NE/4, NW/4, sec 22, T7S, R9E (Figs. 3 and 22). A dirt road runs along the east edge of the tank battery and an access road runs along the south edge. The battery includes 8 tanks aligned east-west surrounded by a berm. An active pump shed and pumping unit are just north of the east end of the bermed area. Ponded water is at the west end of the bermed area. Background scintillometer readings were about 22 cps (6 μR/hr). Readings from most of the tanks ranged 20-30 cps (6-8 μR/hr); however, readings from two tanks were at 300 and 180 cps (57 and 35 μR/hr) and a separator tank was 55 cps (12 μR/hr). A GAD-6-spectrometer reading inside the berm along its southeastern edge (A, Fig. 22) gave 2.7 pCi/g total radium (GC95-20, Table 1). A recent produced-water spill had killed vegetation along the access road south of the east end of the bermed area (Fig. 22).

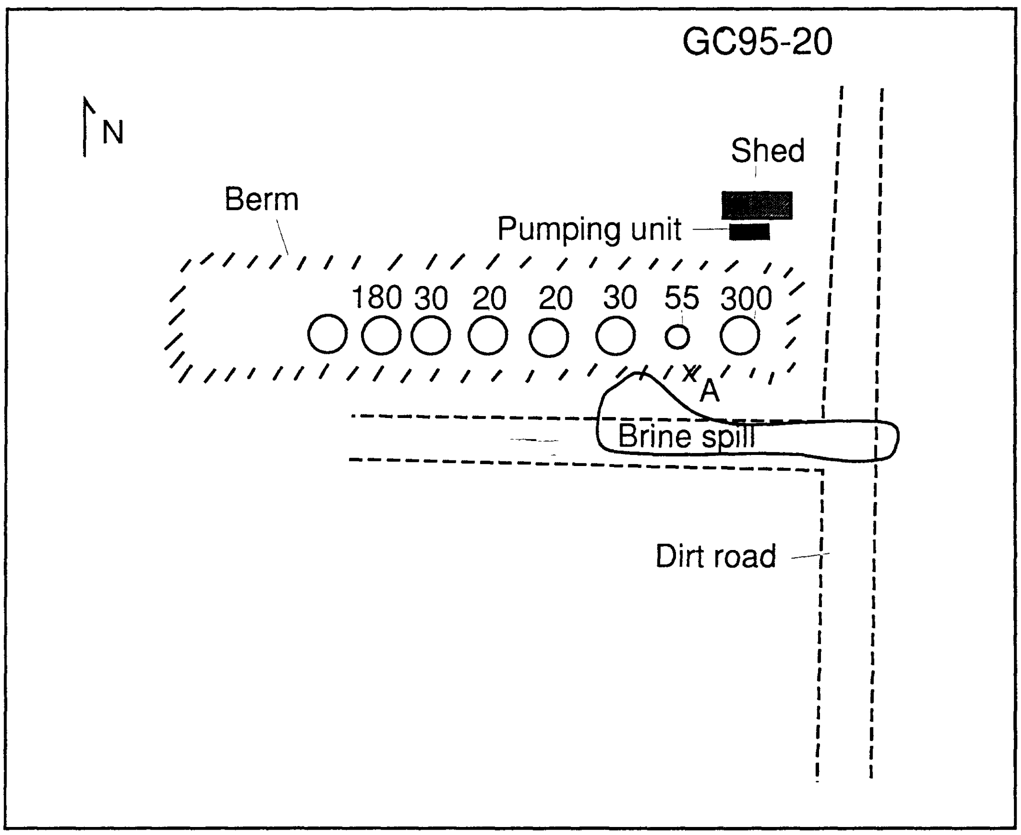


Figure 22- Sketch map of study site GC95-20 in Gallatin County, Illinois. Not to scale. The larger circular tanks are approximately 2 m in diameter.

GC95-21 (Gallatin County)

This site consists of a tank battery and associated reclaimed salt-scar complex (Figs. 3 and 23) in SE/4, NE/4, SE/4, sec 22, T7S, R9E. A fenced horse pasture lies to the west of the tank battery. The battery consists of two oil tanks, a separator, and a brine-storage tank. The site slopes to the east and an arcuate berm about 20 m long lies on the east side of the battery. Water ponded behind the berm during the field survey was grayish-brown and had a film of oil on the surface. Dirt access roads lie at the east and south edges of the reclaimed field. East of the north-south access road is a fallow field, a broad ditch, and corn field. A salt scar occurs along the broad ditch. An outlet pipe, which drains saline water flowing into the drainage tile system under the reclaimed site, empties water into the ditch to the southeast. The reclamation was partly successful, irregular salt scars persist in the midst of the fescue and switch grass. Erosion in the scarred areas is in the early stages.

Background scintillometer readings were 16-18 cps (5 μR/hr) on wet soil and 22-25 cps (6-7 μR/hr) on dry soils. The oil tanks read 35 and 40 cps (9 and 10 μR/hr). The brine tank read 500 cps (90 μR/hr). The separator tank yielded a maximum reading of about 1750 cps (285 μR/hr) about 30 cm above the base of the tank. The soil on the berm read 35-45 cps (9-11 μR/hr).

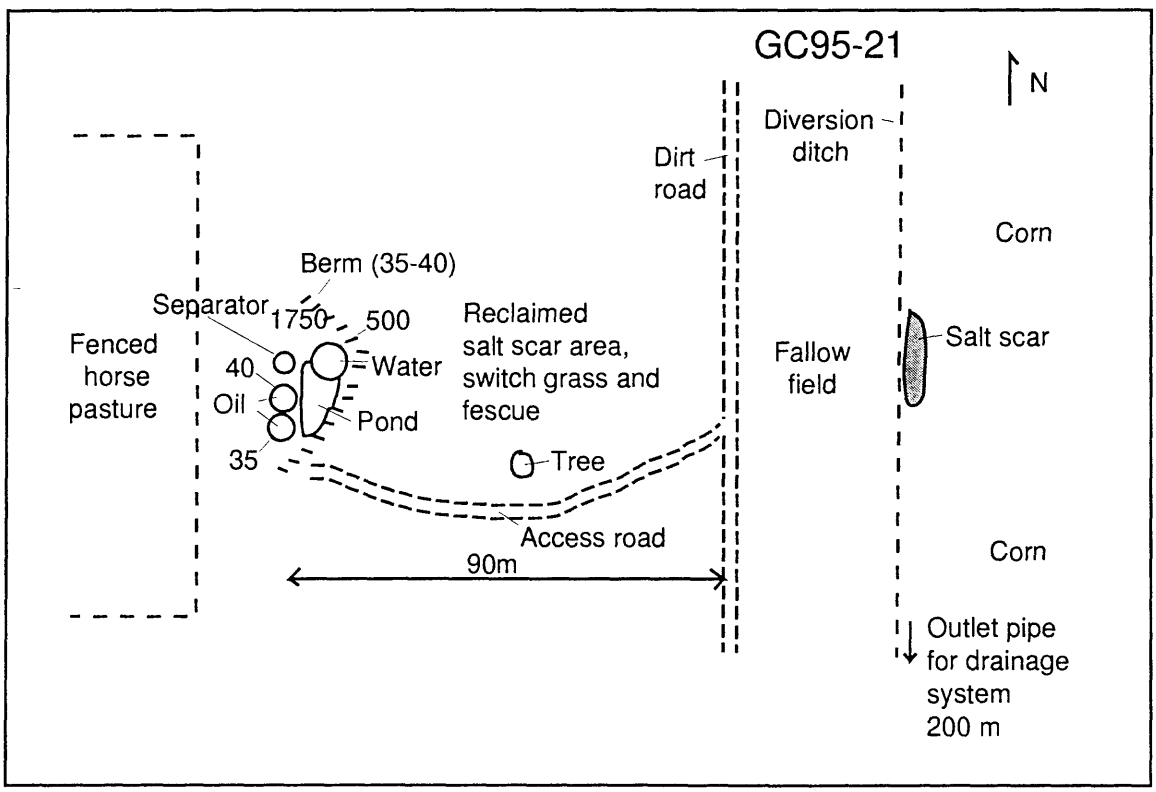


Figure 23- Sketch map of study site GC95-21 in Gallatin County, Illinois. Not to scale.

A GAD-6-spectrometer reading on the berm gave 2.9 pCi/g total radium (GC95-21, Table 1). A grab sample of the soil in the berm had 10.3 pCi/g total radium (GC95-21A, Table 3). This sample had trace element levels close to median values (GC95-21A, Table 2), except that copper and zinc were slightly elevated and iodine was 5-30 ppm. Replicate GAD-6-spectrometer readings from the salt scar 5 m east of the berm were 2.60 and 2.91 pCi/g total radium (average 2.76 pCi/g) (GC95-21B, Table 1). A grab soil sample from this site had 3.15 pCi/g total radium by laboratory-based gamma spectrometry (GC95-21B, Table 3). This same sample was similar to the sample from the berm in trace element composition except that bromine (15-30 ppm) concentrations were slightly higher (GC95-21B, Table 2). Iodine concentrations are elevated. A GAD-6-spectrometer reading from the salt scar about 40 m east of the berm yielded 2.9 pCi/g total radium (GC95-21C, Table 1).

Water from the discharge pipe along the diversion ditch was slightly acidic (field pH- 6.5) and somewhat conductive (970 micromhos/cm) (GC95-21W, Table 4). TDS was 668 ppm and dissolved radium-226 activity was 0.11± 0.01 pCi/L.

GC95-22 (Gallatin County)

This site, located at the southern edge of SW/4, SE/4, NE/4, sec 22, T7S, R9E, includes a pumping unit with adjacent salt scar and oil-soaked soil (Fig. 3). The scarred area is in the early stages of erosion. Maximum readings on the affected soils were 22 cps (6 μR/hr) compared to a background level of 15 cps (5 μR/hr).

GC95-23 (White County)

A salt scar is located at the middle of the west edge of W/2, SE/4, sec 10, T7S, R9E, just east of a highway intersection (Figs. 4 and 24). The scar is surrounded by a corn field and occupies a low area in the field. The surface drains to the east although the topographic gradient is very low. The scarred area is in the intermediate stage of erosion. Fescue has been established on part of the scar surface during reclamation efforts. The scar is about 40 years old and has not migrated (Buck Buchanan, Natural Resources Conservation Service, oral commun., 1995). Corn in parts of the field to the north of the scar is stunted. A short, oiled dirt road leads up to the edge of the salt scar from the road intersection. No scintillometer readings were recorded at this site.

The oiled road surface had a total radium activity of 4.6 pCi/g based on a GAD-6-spectrometer reading (GC95-23C, Table 1). A low spot on the salt scar near its southern limit had 2.1 pCi/g total radium activity (GC95-23A, Table 1), whereas a spot near the oiled road had 2.2 pCi/g total radium activity (GC95-23B, Table 1). A grab sample of the soil from the latter site yielded 2.98 pCi/g total radium by laboratory-based gamma spectrometry (GC95-23, Table 3). This sample includes fragments of material washed from the surface of the oiled road. This sample contained concentrations of most trace elements close to median values except for iodine (5-10 ppm) (GC95-23, Table 2).

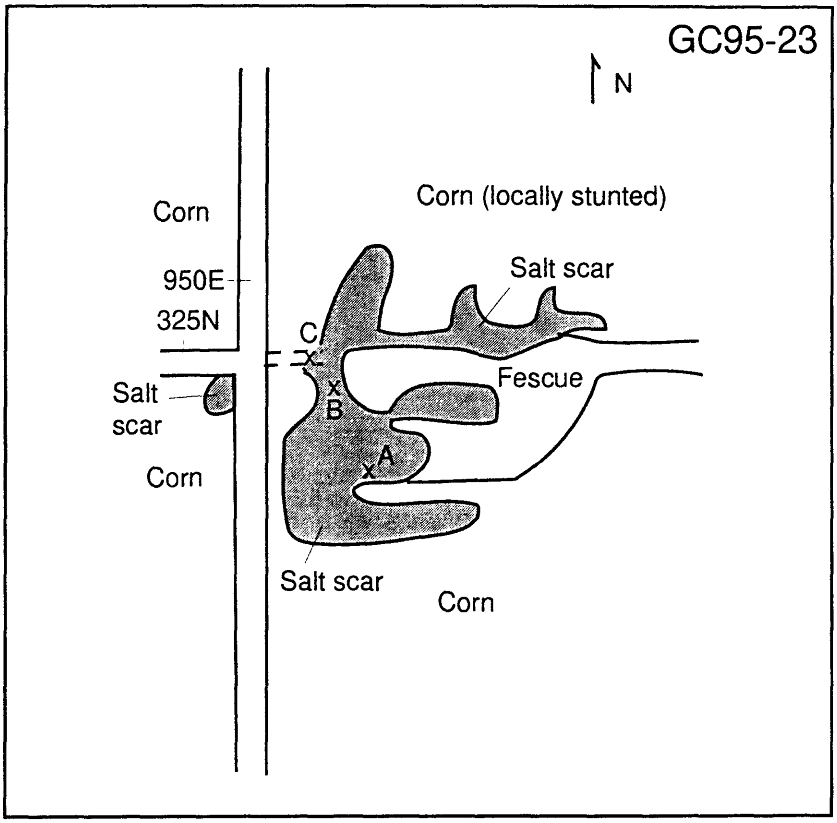


Figure 24- Sketch map of study site GC95-23 in White County, Illinois. Not to scale. The north-south dimension of the salt scar is about 30 m. A-C- Gamma-spectrometer stations.

GC95-24 (White County)

This large site, located in the center of E/2, SE/4, sec 10, T7S, R9E, includes a tank battery, an area delineated by ditches that includes an oil seep, a salt scar, and a tall stand of *Phragmites*, and several irregular salt scars and areas of stunted crops which extend eastward into section 11 (Figs. 4 and 25). The scarred areas are in the early to intermediate stages of erosion. The southwest part of the ditched area is elevated more than a meter above the surface of the surrounding field. The fields were planted in soybeans at the time of the field survey. Water draining off the southwest corner of the ditched area follows a drainageway to the southwest and south. Along this topographic low the soybeans are stunted or absent.

This site was mapped and surveyed in detail to document the extensive salt scarring, the size and nature of the ditched area, the oil seep, and the geochemistry, radiochemistry and soil conductivity of the brine-affected soils. This site was unusual in that reclamation efforts involved an attempt to contain a salt scar and oil seep area by ditching the affected area.

The soil within the bermed area is heavily oil stained. An overflow pipe at the southeast corner of the bermed area drains water into a ditch adjacent to the arcuate access road. The adjacent county road has been treated with oil to control dust. The tanks were surveyed with a scintillometer. Four GAD-6-spectrometer and conductivity traverses were run across the site. A water sample was collected from a pool in the drainageway just

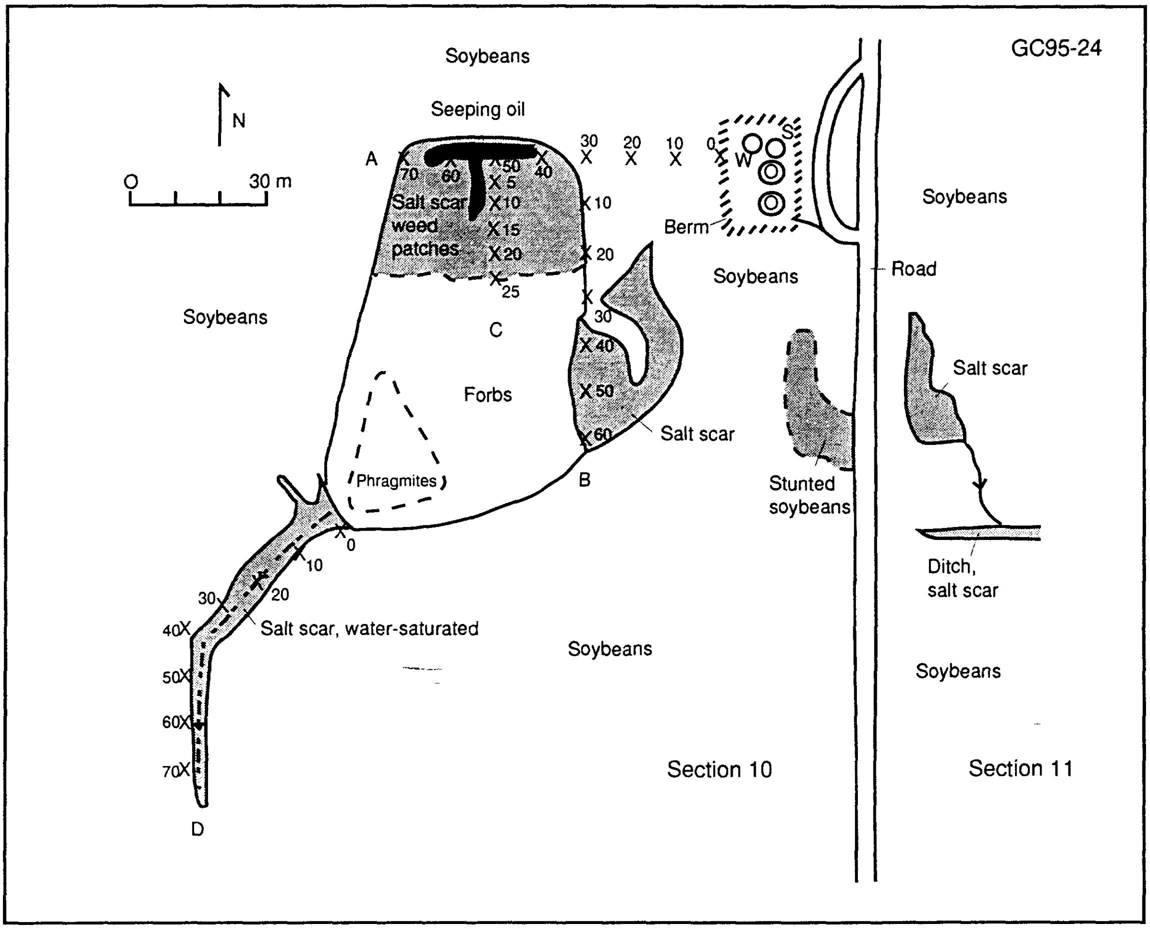


Figure 25- Detailed map of a tank battery, reclaimed area and adjacent features at Site GC95-24 in White County, Illinois. A-D- Gamma-spectrometer profiles.

southwest of the ditched area (adjacent to 0 m station, profile D, Fig. 25).

Two oil tanks read 20 cps (6 μR/hr), whereas the separator tank read 50 cps (11 μR/hr) and the brine storage tank read 740 cps (130 μR/hr). GAD-6-spectrometer readings in four profiles (Figs. 25 and 26A-D, Table 8) showed total radium activities within a relatively narrow range of 1.63-2.38 pCi/g for most of the site. Readings from the oil-saturated area at the north end of the ditched area (Stations 40, 50, 60, 70, Fig. 23) ranged from 2.44-5.72 pCi/g (Fig. 26A). For profile A, there is an inverse relation between total radium and Ra-228/Ra-226 (Fig. 26A), however, that relation does not apply for the other profiles.

Conductivity data along four profiles (Figs. 27 and 28A-D, Table 9) show that readings in and near the salt-scarred areas generally range from 70-210 mmho/m. Readings elsewhere range 20-60 mmho/m (in the range of literature values for silty and clayey sandy loam soils, McNeill, 1980b). Readings from the shallower soundings are generally lower than the deeper soundings, probably indicating the effects of periodic saturation of the shallow soil with precipitation and flushing of some salt from the shallow subsurface. At a few sites, the shallow soundings gave readings that are higher than the deeper soundings (conductivity profile B, 30/20m and conductivity profile C, 30m). These two sites are adjacent. The parallel and perpendicular readings at these sites were strongly divergent, suggesting some interference from linear conductive material such as a buried pipe. The area delineated by ditches is underlain by a saline soil (conductivity profile A, 30m

Table 8- GAD-6-spectrometer data for profiles A-D at Site GC95-24, White County, Illinois. See Fig. 25 for locations.

Grid point (mW)	Grid point (mS)	eU (ppm)	eTh (ppm)	eRa-226 (pCi/g)	eRa-228 (pCi/g)	Ra-228/Ra-226	Total radium (pCi/g)
				Profile A			
0	0	4.1	8.2	1.37	0.91	0.67	2.28
10	0	3.1	9.1	1.03	1.01	0.98	2.04
20	0	3.3	9	1.10	1.00	0.91	2.10
30	0	3.6	9.5	1.20	1.06	0.88	2.26
40	0	6.1	11.4	2.03	1.27	0.62	3.30
50	0	6.2	11	2.07	1.22	0.59	3.29
60	0	12.5	14	4.17	1.56	0.37	5.72
70	0	3.8	10.6	1.27	1.18	0.93	2.44
				Profile B			
30	0	3.6	9.5	1.20	1.06	0.88	2.26
30	10	2.8	9.8	0.93	1.09	1.17	2.02
30	20	3.7	7.9	1.23	0.88	0.71	2.11
30	30	3.3	9.5	1.10	1.06	0.96	2.16
30	40	3.9	8.3	1.30	0.92	0.71	2.22
30	50	2.8	8.4	0.93	0.93	1.00	1.87
30	60	3	7.7	1.00	0.86	0.86	1.86
				Profile C			
50	0	6.2	11	2.07	1.22	0.59	3.29
50	5	4	9.4	1.33	1.04	0.78	2.38
50	10	3.8	9.4	1.27	1.04	0.82	2.31
50	15	3.8	7.7	1.27	0.86	0.68	2.12
50	20	4.2	7.9	1.40	0.88	0.63	2.28
50	25	3.9	8	1.30	0.89	0.68	2.19
				Profile D			
EM10	0	2.1	8.4	0.70	0.93	1.33	1.63
EM11	10	2.5	9.6	0.83	1.07	1.28	1.90
EM12	20	3.7	7.7	1.23	0.86	0.69	2.09
EM13	30	2.7	8.9	0.90	0.99	1.10	1.89
EM14	40	2.4	8.8	0.80	0.98	1.22	1.78
EM15	50	3	6.5	1.00	0.72	0.72	1.72
EM16	60	2.9	6.5	0.97	0.72	0.75	1.69
EM17	70	3.2	7	1.07	0.78	0.73	1.84
				Replicates			
EM17	70	2	7.1	0.67	0.79	1.18	1.46
50	20	3.7	7.7	1.23	0.86	0.69	2.09

Table 9- Soil conductivity data for profiles A-D at site GC95-24 in White County, Illinois. See Fig. 25 for locations.

		Conductivity values (mmho/m)			
Grid point (m)	Grid point (m)	Vertical dipole	Perpendicular	Horizontal dipole	Perpendicular
Profile A					
10		60	68	30	29
20		55	59	35	35
30		118	130	82	98
40		205	195	148	157
50		158	135	160	130
60		128	123	102	110
70		68	79	60	80
80		38	38	23	23
Profile B					
30	0	130	115	100	83
30	10	122	108	78	72
30	20	40	85	75	105
30	30	128	129	92	90
30	40	130	130	135	138
30	50	108	102	90	82
30	60	118	110	112	100
Profile C					
0		200	150	60	35
10		108	112	35	40
20		80	80	55	55
30		65	60	107	85
40		125	128	89	92
50		140	140	100	95
60		140	138	115	110
70		140	142	120	128
80		130	130	115	112
Profile D					
0	0	110	100	107	90
10	0	115	109	99	87
20	0	112	105	89	82
30	0	107	105	82	82
40	0	80	80	61	65
50	0	75	70	50	49
60	0	60	58	55	42
70	0	49	45	38	36

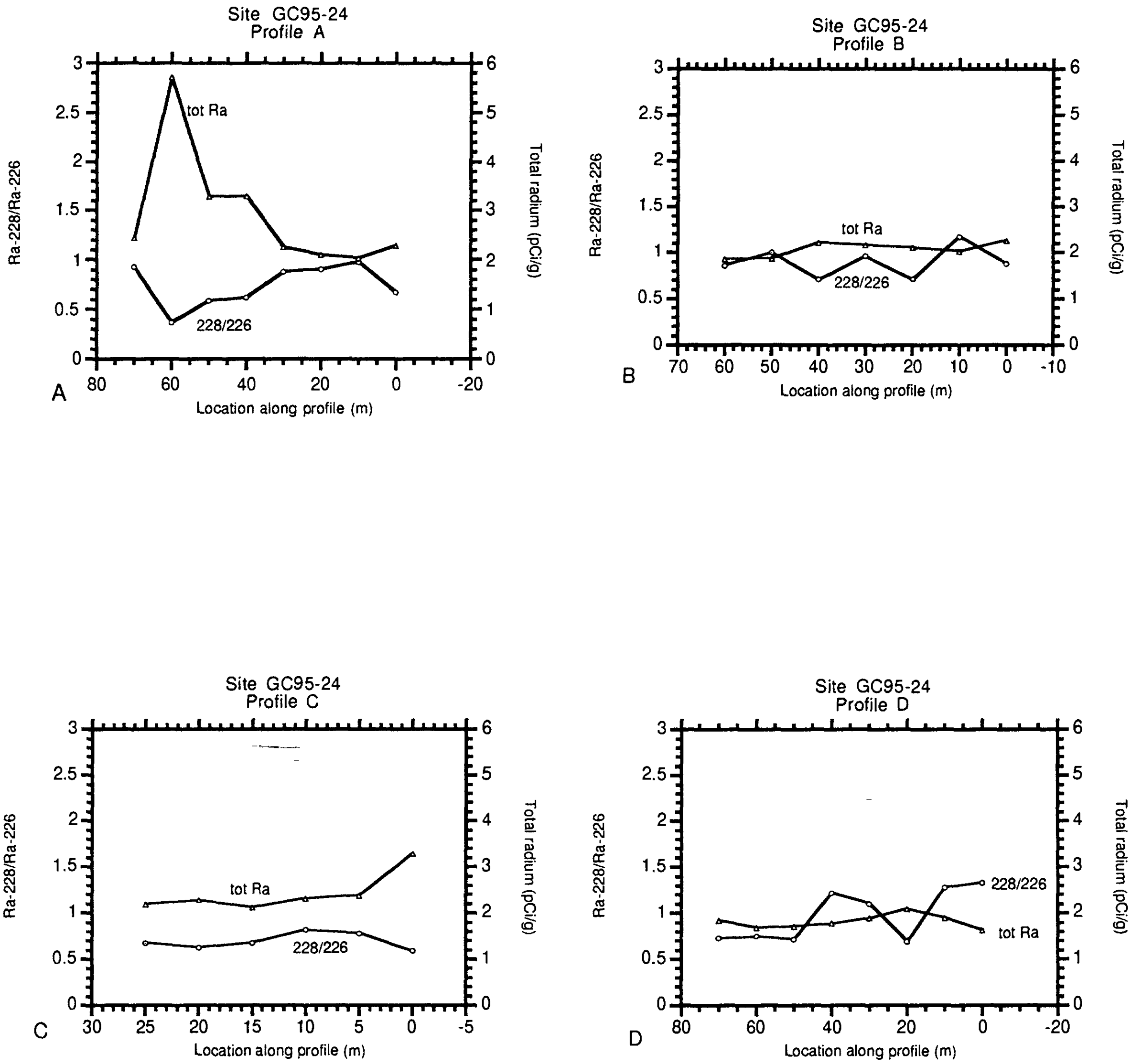


Figure 26A-D- Plots of gamma-spectrometer data along profiles A-D, Site GC95-24, White County, Illinois (see Fig. 25).

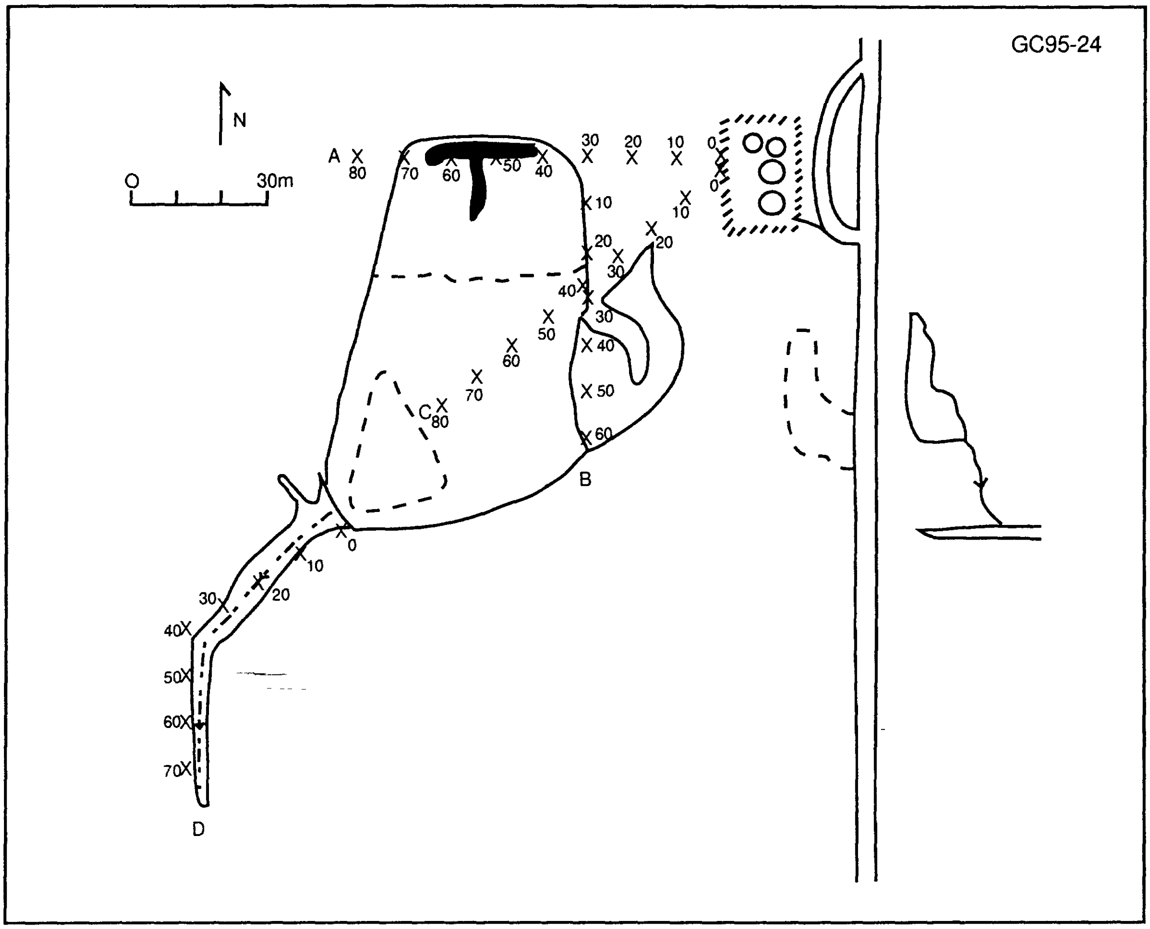


Figure 27- Detailed map of area in Fig. 25 showing conductivity survey stations along 4 profiles (A-D), Site GC95-24, White County, Illinois.

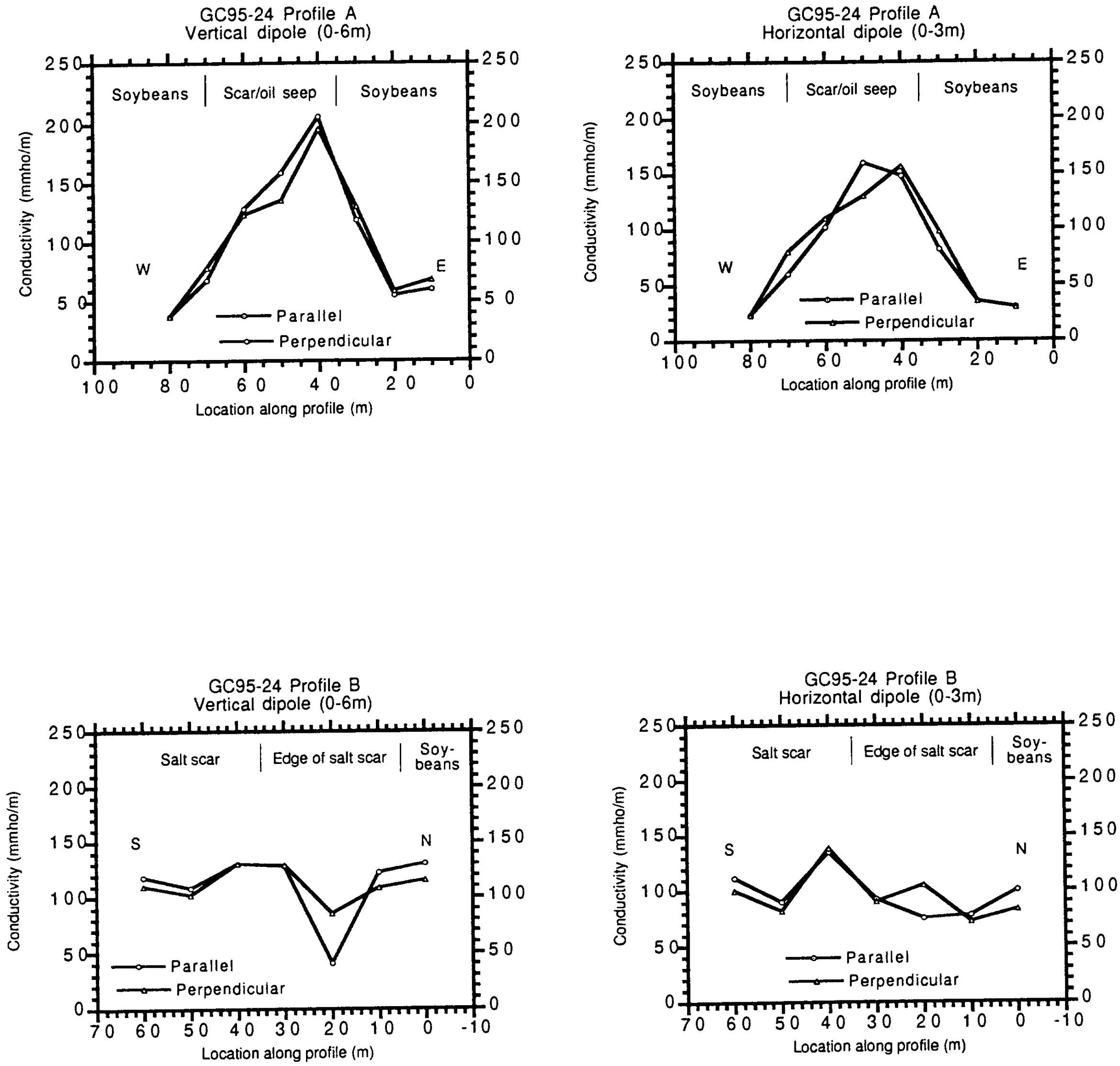


Figure 28A-D- Plots of conductivity measurements along profiles A-B, Site GC95-24, White County, Illinois (see Fig. 27).

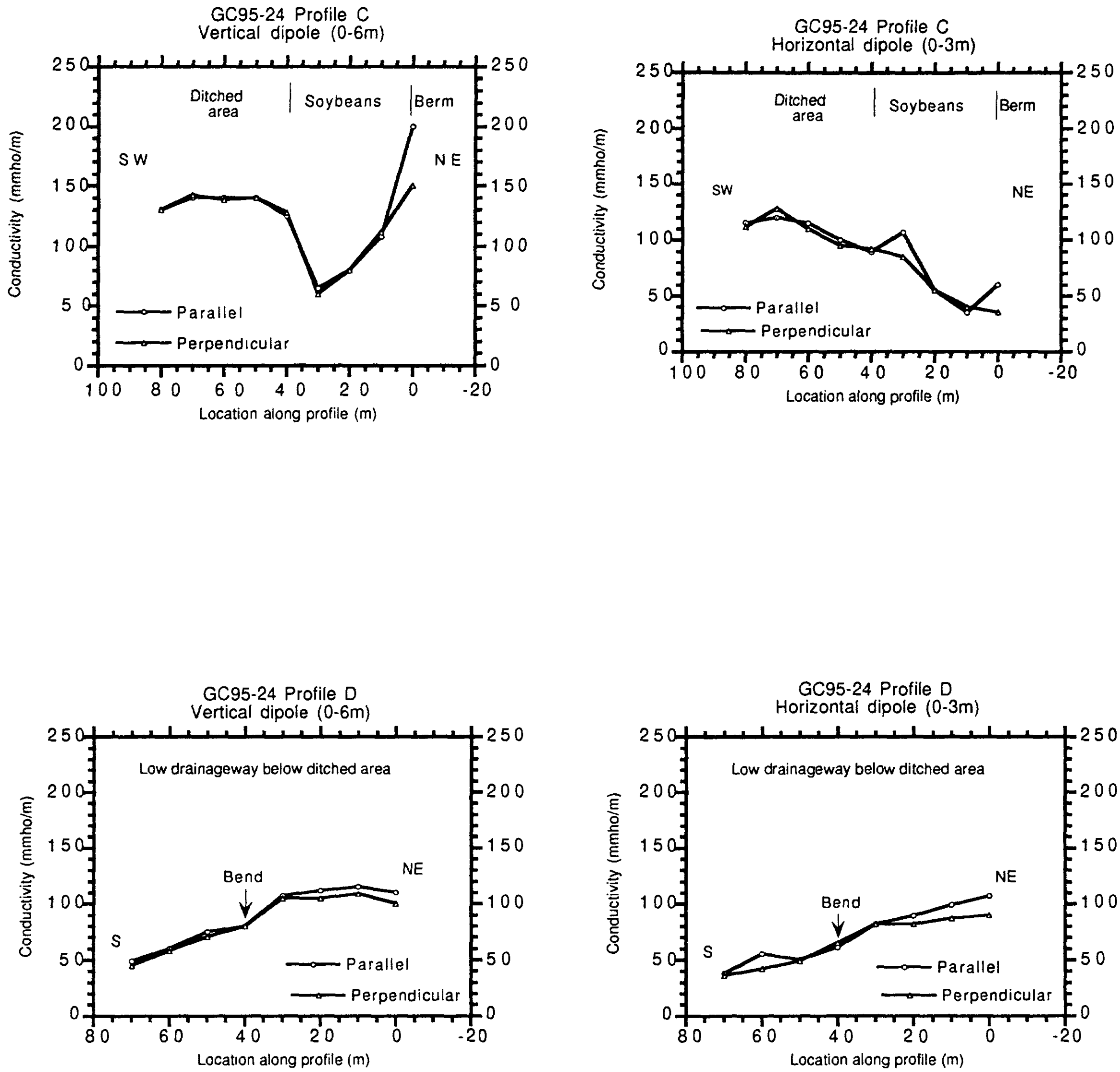


Figure 29A-D- Plots of conductivity measurements along profiles C-D, Site GC95-24, White County, Illinois (see Fig. 27).

to 70m; conductivity profile C, stations 40m to 80m) that probably extends downslope to the southwest (conductivity profile D, stations 0m to 30m). Higher vertical dipole readings along conductivity profile C immediately southwest of the bermed tank battery (stations 0m to 20m) suggest that saline soil in the deeper subsurface extends southwest from the edge of the berm.

The water sample had a Ra-226 activity of 0.43±0.05 pCi/L, the highest observed in this study. Field pH reading was 8.2; field temperature was 27.8°C; the field conductivity measurement was not reliable because of instrument problems; however, a laboratory conductivity reading was 7700 micromhos/cm (GC95-24W, Table 4), also the highest observed in this study. TDS as measured in the laboratory was about 3400 ppm.

Four soil samples were collected at this site (GC95-24A-D, Table 2). Sample GC95-24A was collected just below the end of the outlet pipe at the southeast corner of the bermed tank battery (Fig. 25). Trace element concentrations were close to median values except that bromine were somewhat higher (15-25 ppm). Sample GC95-24B was collected next to the oil seep at the 50 m station along Profile A (Fig. 25). This sample contained elevated copper (35 ppm), cadmium (1 ppm), and iodine (5-15 ppm). Sample GC95-24C was collected in the topographic low just off the southwest corner of the ditched area (adjacent to the water-sample locality). Trace element concentrations were close to median values. Sample GC95-24D was collected from the salt scar within the ditched area at the 15 m station along Profile C (Fig. 25). Most trace element concentrations were close to median values except that bromine and iodine concentrations were significantly elevated at 40-60 ppm and 10-15 ppm, respectively.

GC95-25 (White County)

This site lies near the crest of a hill in SW/4, NE/4, SW/4, sec 11, T7S, R9E (Figs. 4, 30, and 31). This site was visited in June 1995 and June 1996. The site includes a bermed tank battery with 2 oil tanks and a separator tank, a bermed water tank, a pump house, 2 small sheds, an old pumping unit platform (removed after the 1995 visit), a brine pond, and an old water tank now used for storage (T, Fig. 30). At the time of the 1995 survey, a salt scar in the early stages of erosion was east of the pump house and extended a few tens of meters downslope to the east. Another salt scar in the early stages of erosion occurs in the cornfield below the pond. We can't tell whether this scar has formed as a result of overflow from the brine pond or subsurface seepage from bottom of the pond. Prior to the 1995 survey, oil had spilled from an overflow pipe from the tank next to the pump house downslope into the brine pond and beyond into an adjacent field (Fig. 31-recent oil spill, and Fig. 30-oil-soaked salt scar). Prior to the 1996 survey, the oil-soaked soil in Fig. 31 was removed, a road put through the middle of the site, and berms installed around the tank battery and the isolated oil tank. The central part of the site is partly enclosed by a steel post fence, a segment of which was removed between our two visits.

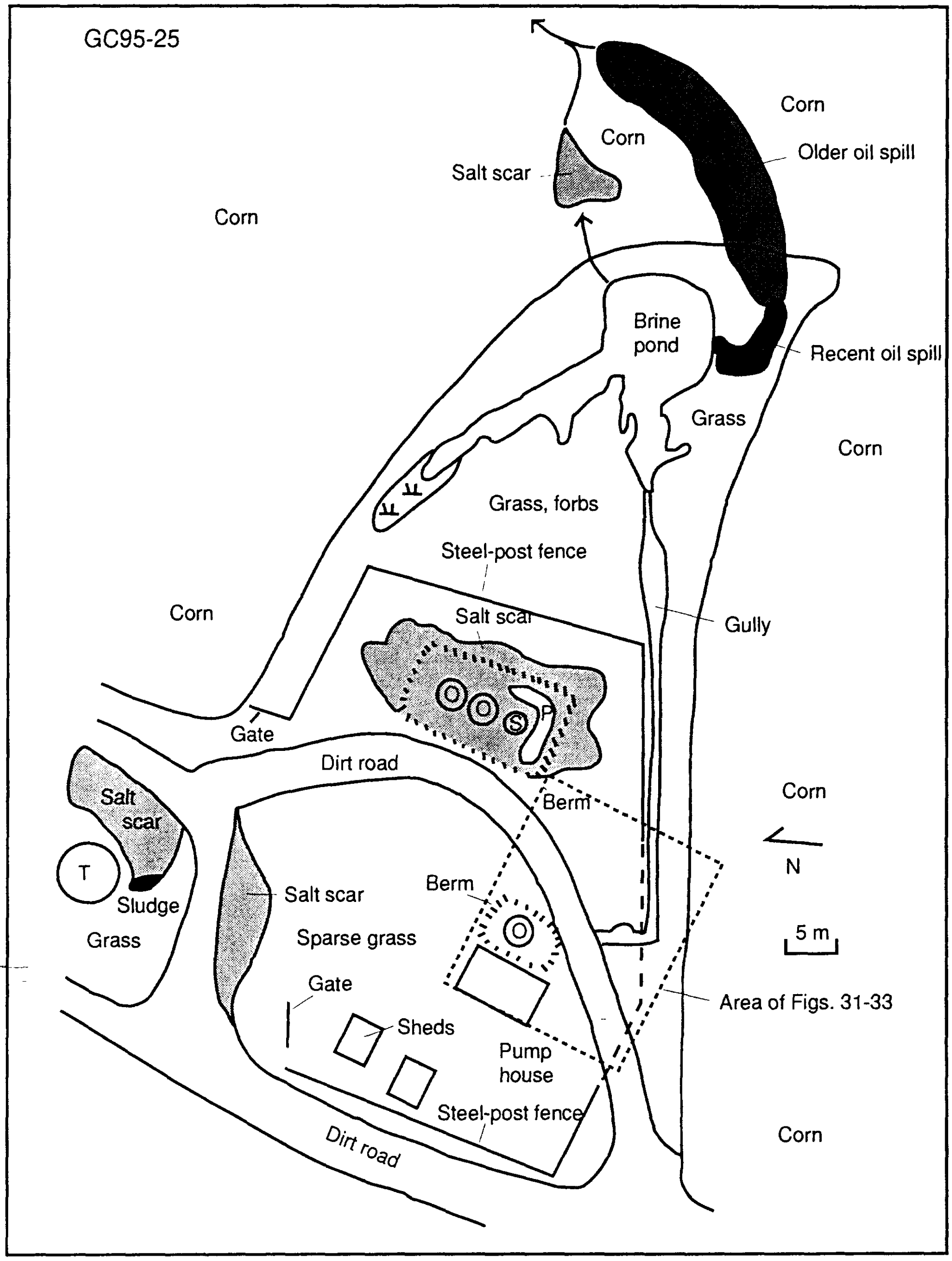


Figure 30- Detailed map of buildings, roads, tank batteries, brine pond, and other features at Site GC95-25, White County, Illinois, June, 1996. The road between the pump house and the three-tank battery to the east was not present in June of 1995. The berm around the tank adjacent to the pump house was built between June of 1995 and June of 1996. O- oil tank; P- ponded water; S- separator tank; T- older tank, now used for storage.

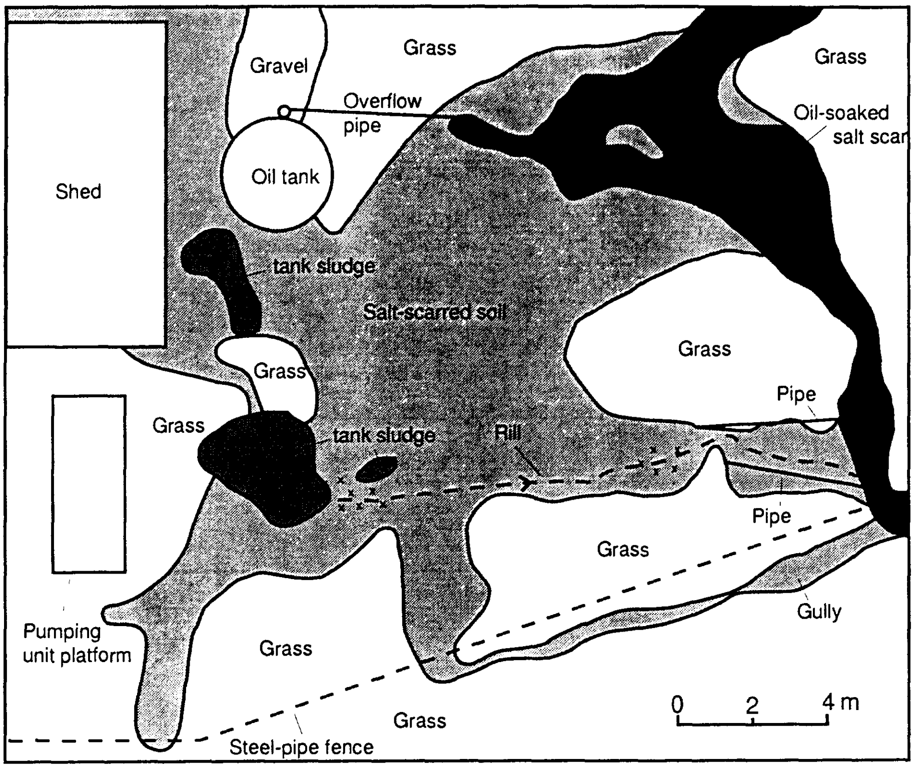


Figure 31- Detailed map of salt scar and related features east of the pumphouse and old pumping unit platform at Site GC95-25, White County, Illinois, June, 1995. This site was disturbed between June of 1995 and June of 1996 by the building of a berm around the tank and the construction of a road across the site. See Fig. 30 for location. x- salt efflorescence.

In 1995, part of the site near the pump shed was mapped in detail (Fig. 31) and surveyed with a scintillometer. Gamma-spectrometer readings were taken along selected profiles during the 1995 survey. Several soil samples were taken along dispersion pathways from areas of NORM-bearing soils during both visits. Results of the 1995 soil sampling are reported here. The entire site was mapped during the 1996 survey (Fig. 30).

Background scintillometer readings for the site were about 20 cps (6 μR/hr). Scintillometer readings in the detailed map area (Fig. 32) range from 35 to 5000 cps (10 to 600 μR/hr). Three areas underlain by brown, oily, scaly soil southeast of the shed read greater than 1000 cps (175 μR/hr, shaded areas, Fig. 32). This material is interpreted as tank bottom sludge discarded on the soil surface.

Three GAD-6-spectrometer profiles were run within the area of Figure 31 in 1995 (Profiles A,B,C, Fig. 33, Table 10). Along profile A (Fig. 34A), total radium activity in the soil in the salt scar ranged from 20-80 pCi/g, with the highest activity at a location near the area of brown, oily, scaly soil. In the grassy area to the east, the total radium activity fell to the 2.5-3.5 pCi/g range. Along profile B (Fig. 34B), the highest total radium activity (34 pCi/g) was near the shed. Total radium activities decrease steadily away from the shed to the south to about 4 pCi/g. In contrast to profile A, the grassy area did not show low radium activity compared to the salt scar; however, the grass was sparse and the grass probably represented revegetation of a former salt-scarred, NORM-contaminated area. Profile C (Fig. 34C) showed

Table 10- GAD-6-spectrometer data for profiles A-C at Site GC95-25, White County, Illinois. See Fig. 33 for locations of profiles. Site [4,4]-radium levels too high for GAD-6 measurement.

				Profile A			
Location (mN)	Location (mE)	eU (ppm)	eTh (ppm)	eRa-226 (pCi/g)	eRa-228 (pCi/g)	Ra-228/Ra-226	Total radium (pCi/g)
0	0	70.4	62.8	23.47	6.98	0.30	30.44
0	2	198.1	132	66.03	14.67	0.22	80.70
0	4	66.9	50.4	22.30	5.60	0.25	27.90
0	6	47.5	34.3	15.83	3.81	0.24	19.64
0	8	79.2	64.6	26.40	7.18	0.27	33.58
0	10	21.6	20.9	7.20	2.32	0.32	9.52
0	12	4.8	14.9	1.60	1.66	1.03	3.26
0	14	7.2	10.4	2.40	1.16	0.48	3.56
0	16	5.4	13.7	1.80	1.52	0.85	3.32
0	18	6	11	2.00	1.22	0.61	3.22
0	20	4.5	10.1	1.50	1.12	0.75	2.62
				Profile B			
10	0	8.2	14.1	2.73	1.57	0.57	4.30
8	0	24.8	20.8	8.27	2.31	0.28	10.58
6	0	45.8	34.5	15.27	3.83	0.25	19.10
4	0	71.1	38.4	23.70	4.27	0.18	27.97
2	0	85.2	50.2	28.40	5.58	0.20	33.98
				Profile C			
4	4	ND	ND				
4	6	234.4	134.1	78.13	14.90	0.19	93.03
4	8	111.8	94.1	37.27	10.46	0.28	47.72
4	10	100.1	77	33.37	8.56	0.26	41.92
4	12	92.7	74	30.90	8.22	0.27	39.12
4	14	42.3	32.3	14.10	3.59	0.25	17.69
4	16	32.2	30.9	10.73	3.43	0.32	14.17
4	18	51.3	43	17.10	4.78	0.28	21.88

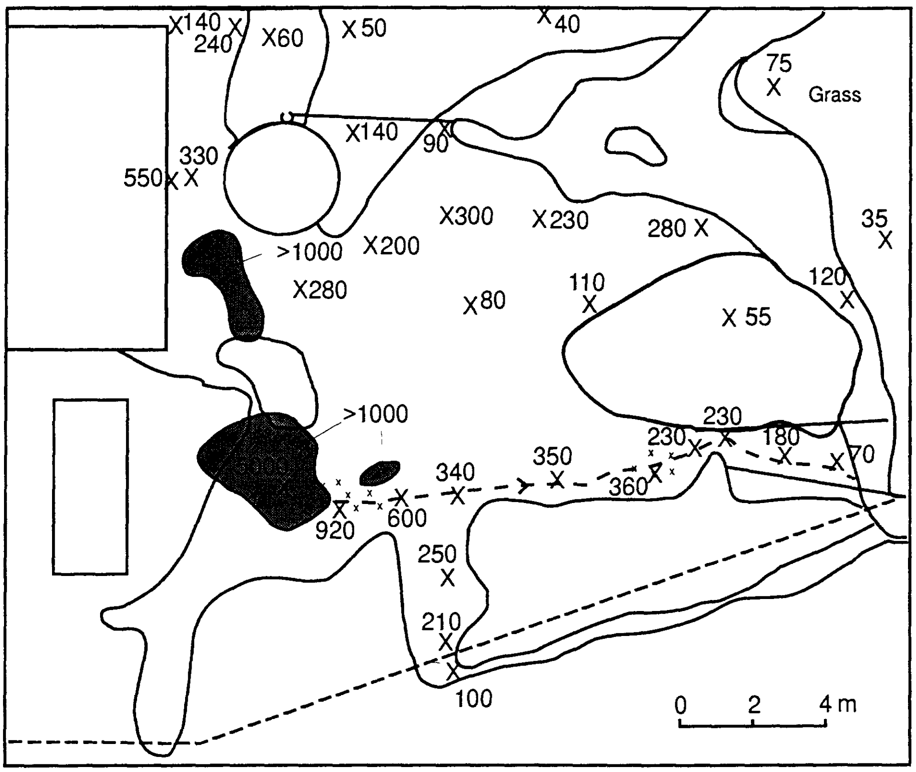


Figure 32- Detailed map of part of Site GC95-25 showing scintillometer readings (cps) from the site. Background readings near the site were about 20 cps.

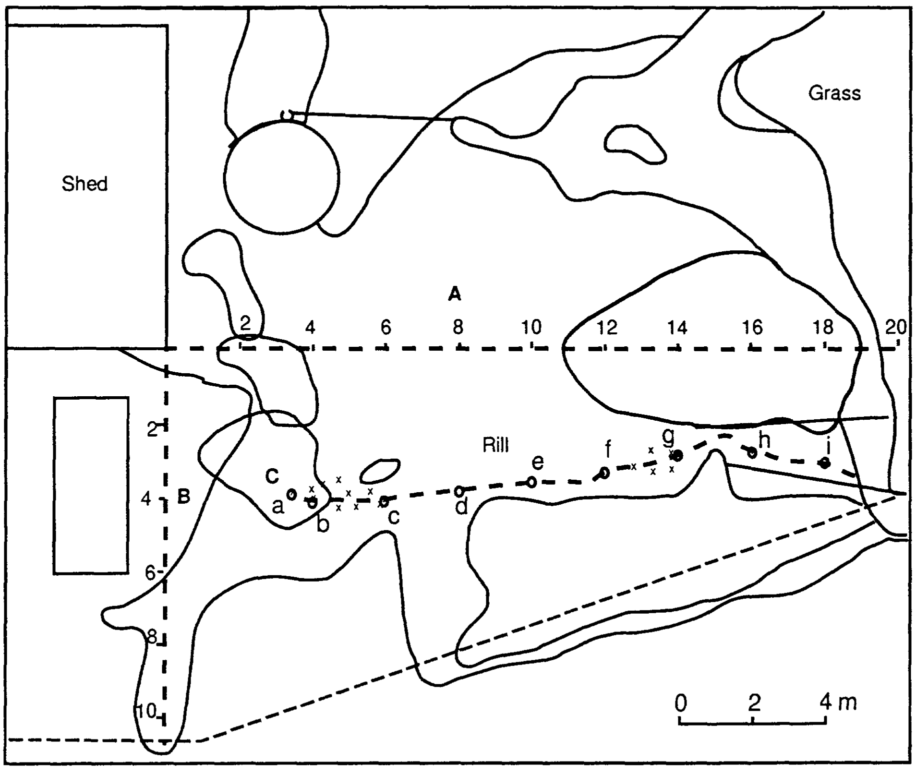


Figure 33- Detailed map of part of Site GC95-25, White County, Illinois, showing locations for gamma-spectrometer profiles A-C. See Table 10 for the data for all three profiles and Figs. 34A-C for a plot of the data. Small circles along Profile C are sediment sample locations and gamma-spectrometer stations, no gamma-spectrometer readings were made at the two most westerly sites in oily scaly patch.

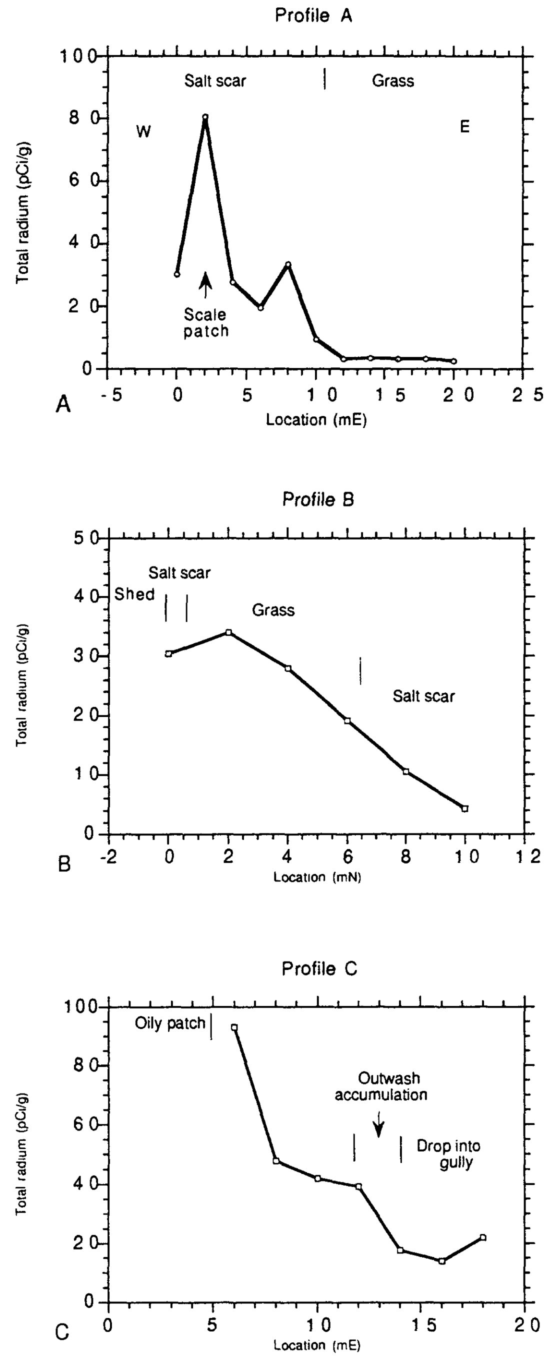


Figure 34A-C- Plots of total radium data from gamma-spectrometer surveys along profiles A-C, Site GC95-25, White County, Illinois (see Fig. 33 for locations of the three profiles). Distances for sites in profile C are given with respect to their grid locations.

that radium activity decreases sharply along the rill with increasing distance from the oily soil patch from about 90 pCi/g within 50 cm to about 20 pCi/g about 14 m away.

In 1995, as part of this site study, dispersion of radium and trace elements along the rill (from the large patch of tank sludge-affected soil eastward to where the rill joins another channel) was characterized using radium and trace element analyses of samples collected along the rill (small circles labeled a-i in Fig. 33). The rill showed geomorphic features that seemed to affect dispersion of radium and trace elements. From the lower edge of the oily patch to an area of outwash accumulation and salt efflorescence about 8 m to the east, the rill had a gentle, concave upwards slope, which decreased near the salty area. Downslope, east of the zone of salt and outwash accumulation, the rill channel narrowed initially, then became deeper and wider forming a gully several tens of centimeters below the surface of the surrounding topography. Near the head of the gully, the channel gradient abruptly shallowed once again and sediment had accumulated. The gully continued for a few meters to the east where it joins another channel contaminated by the oil spill. During the construction of the road and tank berm and subsequent erosion on the site between the two surveys, the patches of oily and scaly soil were buried by sediment eroding from the newly built tank berm and the rill and gully areas were covered by the road or recontoured.

Data for soil samples were collected along profile C are found in Tables 2 and 4 (GC95-25a-i). Sample GC95-25a was taken at the most radioactive spot within the oily, scaly patch. Sample GC95-25b was taken from the downslope fringe of the oily, scaly patch. Salt efflorescence occurred at the surface where this sample was taken. Sample GC95-25c was taken about 1.75 m downslope at the low end of the area of salt efflorescence. Samples GC95-25d-i were taken at 2 m intervals below these other samples. The gradient of the rill nearly flattens below GC95-25e and between GC95-25f and GC95-25g is a zone of sediment accumulation and salt efflorescence. Below GC95-25g the channel narrows and deepens forming a gully, the gradient steepens and drops several tens of centimeters below the elevation of sample GC95-25g. Sample GC95-25h was taken where the gradient abruptly shallows once again and sediment has accumulated and GC95-25i was taken just above the junction with the channel contaminated with oil.

The most radioactive sample, GC95-25a (5000 cps (600 μR/hr), 2380 pCi/g total radium), contains elevated concentrations of iron (11.3 percent), copper (210 ppm), lead (450 ppm), zinc (525 ppm), strontium (8800 ppm), and barium (>2 percent) (Table 2). No cadmium, bromine, or iodine were detected and the zirconium concentration appears lower than median values for soils from other southern Illinois sites sampled (Table 2). The high strontium and barium concentrations suggest that barite is a component of the sample. This sample reacts moderately with 1M hydrochloric acid (R. Zielinski, U.S. Geological Survey, oral commun., 1996) indicating that it contains some calcite.

Sample GC95-25b, from the edge of the oily, scaly soil layer, contained a much greater proportion of the underlying natural soil. The total radium activity of this sample was 610 pCi/g, a drop of 74 percent compared to sample 25a (Table 3). Likewise iron, copper, lead, and strontium showed a drop of 70 to 80 percent compared to sample GC95-25a. The barium concentration also decreased markedly, but the percentage of decrease is not known. Zinc decreased by only 32 percent. Zirconium increased to a concentration that is close to the median for soils in the area and bromine is detectable (10-20 ppm). Sample GC95-25b reacted more strongly to 1M hydrochloric acid (R. Zielinski, U.S. Geological Survey, oral commun., 1996) than GC95-25a suggesting that the native soils are calcareous.

Samples collected farther down the rill, taken at 2 m intervals, show continued decreases in radium, barium, and strontium (GC95-25 c,d), but concentrations increased slightly in sample GC95-25f near the head of the zone of outwash accumulation. Concentration values decrease again farther downslope into the gully, but increase slightly in sample GC95-25i at the lowest part of the gully.

Profiles for radium, barium, and strontium parallel one another closely (Fig. 35A,B,C). Zirconium, generally found in the dense mineral zircon, parallels barium and strontium (Fig. 35D) except that zirconium levels are low in the tank sludge-affected sites (a,b). Iron, copper, lead, and zinc concentrations are all high in the tank sludge-affected soils and decrease rapidly down the rill where iron and zinc seem to follow one another fairly closely (Fig. 35E-H). For copper and lead, the concentrations in the lower part of the profile are close enough to their detection limits that the data may not be reliable enough to see a pattern.

Bromine (Table 2) was not detectable in the sludge (GC95-2a) nor in sample GC95-2f, but generally was above median values in the upper part of the rill. In the gully, values dropped to median values. Iodine (Table 2) is detected only once in the first five localities (GC95-25a-e) but then increased to highest concentrations seen in the study (20-50 ppm) in the two samples in the lower efflorescent salt zone (GC95-25f,g).

A comparison of the GAD-6-gamma spectrometer data to laboratory-based radium analyses for the same sites along Profile C (c-i, Fig. 36) shows that the two values diverge the most in the zone of sediment accumulation (e,f,g), suggesting that radium is concentrated in the surface layer. At sample site d, the two values differ by less than the error of the measurement, suggesting that there is no preferential radium accumulation in the surface layer. At the last three sites, c, h, and i, the surface layer is somewhat more enriched in radium than the volume of soil below the surface.

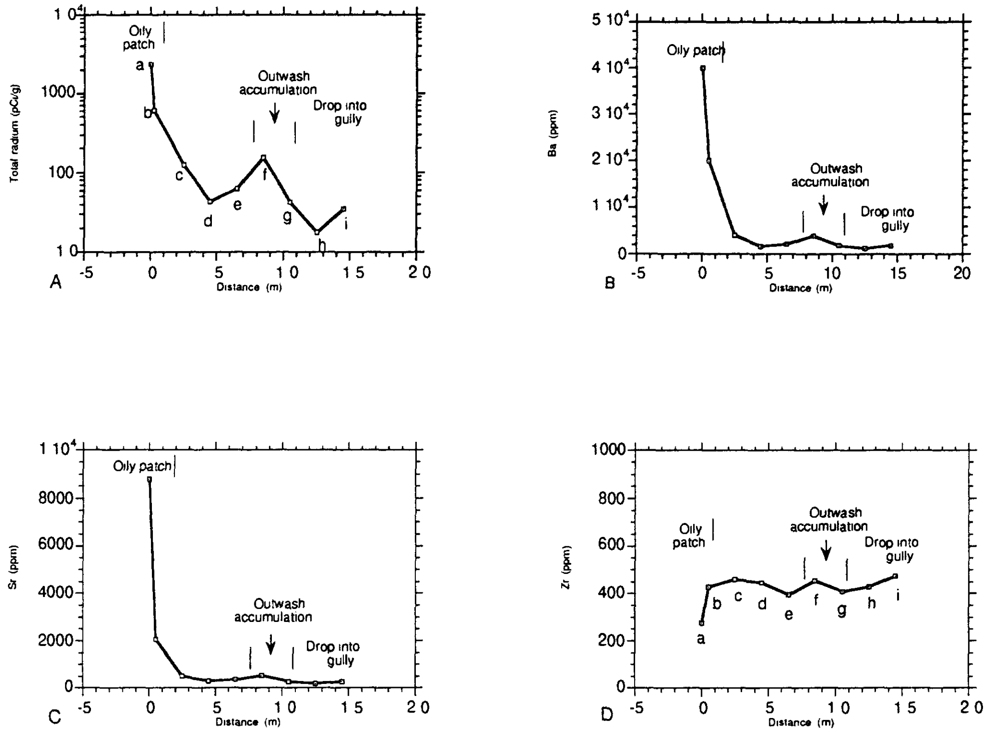


Figure 35A- Total radium data derived from laboratory-based gamma-spectrometry for samples collected along the rill, Site GC95-25, White County, Illinois (for sample locations, see profile C in Fig. 33). Distances are given with 0 m for the most westerly sample site.

35B- Ba data for samples collected along the rill (for sample locations, see profile C in Fig. 33).

35C- Sr data for samples collected along the rill (for sample locations, see profile C in Fig. 33).

35D- Zr data for samples collected along the rill (for sample locations, see profile C in Fig. 33).

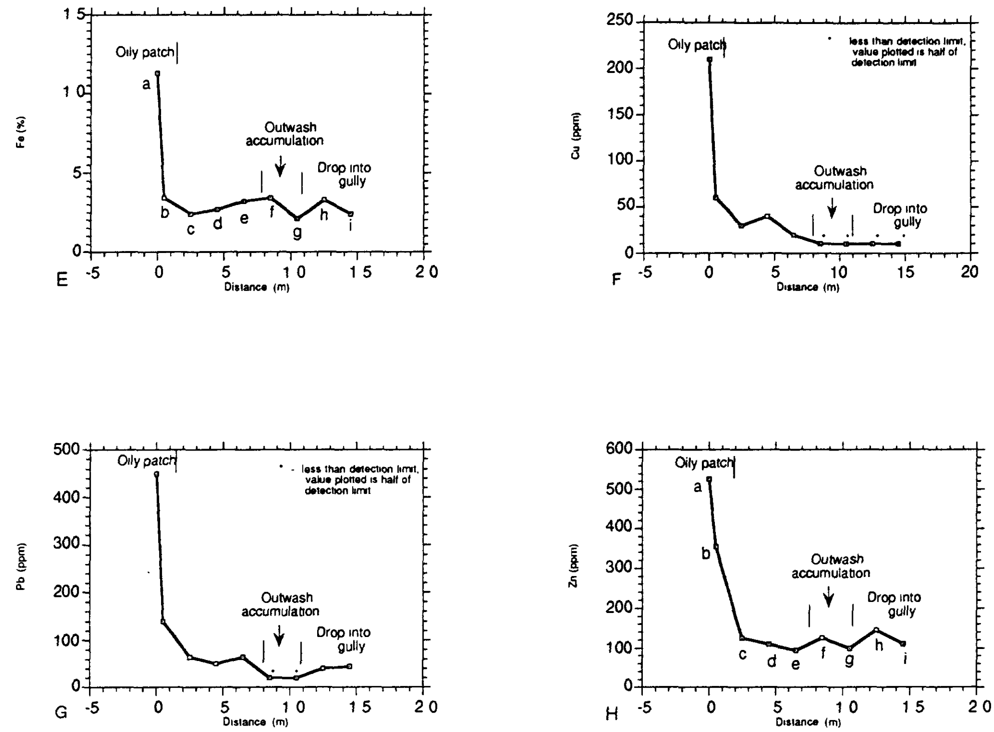


Figure 35E- Fe data for samples collected along the rill, Site GC95-25, White County, Illinois (for sample locations, see profile C in Fig. 33).

35F- Cu data for samples collected along the rill (for sample locations, see profile C in Fig. 33).

35G- Pb data for samples collected along the rill (for sample locations, see profile C in Fig. 33).

35H- Zn data for samples collected along the rill (for sample locations, see profile C in Fig. 33).

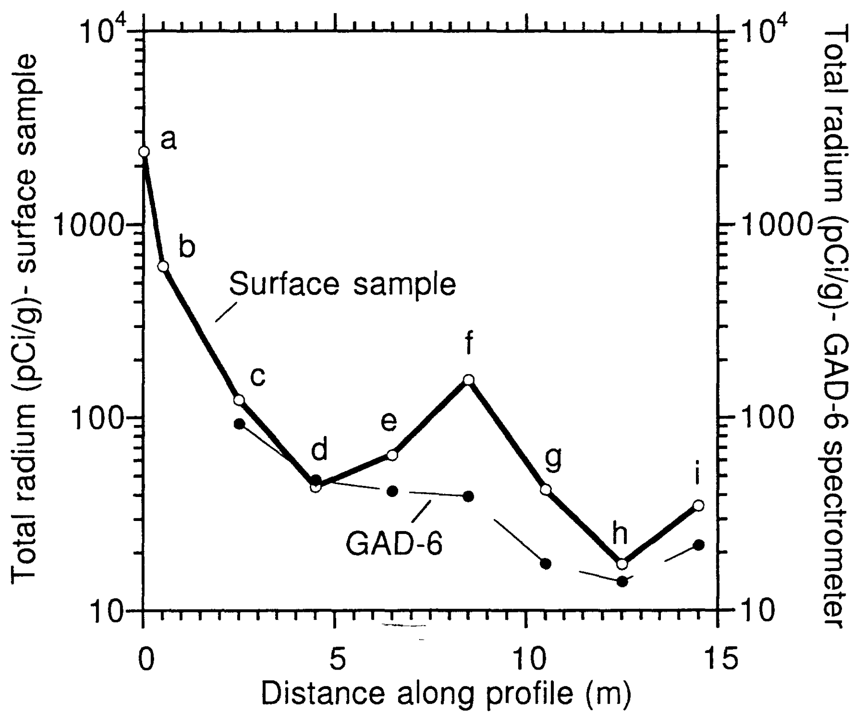


Figure 36- A plot of total radium versus distance along profile C for the GAD-6 spectrometer sites and the laboratory-based spectrometer analyses of surface samples from the same sites, Site GC95-26, White County, Illinois. a-i- samples analyzed by laboratory-based gamma spectrometry. Soil sample sites a and b were not GAD-6 survey sites.

GC95-26 (White County)

This site is located mostly in SE/4, SW/4, NE/4, sec 3, T7S, R9E and includes 3 tank batteries and 4 small brine pits (Figs. 4 and 37). An area 85 m long by 35-50 m wide in the advanced stages of erosion occurs downslope and east of Tank Battery 1. Gullies 2-3 m deep exit the east end of this eroded area and join a south-trending ditch a few tens of meters east of the area shown in Figure 36. This site was visited briefly in 1995 then mapped in detail and surveyed with a scintillometer in 1996.
Background radioactivity across the site ranges from 30-35 cps (8-9 μR/hr). Areas of high radioactivity include an area of spilled tank sludge about 25 m long along the road at the south end of the site. Scintillometer readings vary from 100-7700 cps (20-630 μR/hr) (Fig. 38). A second area of high radioactivity includes the separator tank (maximum scintillometer reading of 1600 cps, 260 μR/hr), a thick mass of oily sludge (maximum scintillometer reading of 2850 cps, 420 μR/hr), and adjacent soils (range 80-200 cps, 17-40 μR/hr) within the bermed area at the north end of Tank Battery 1 (Fig. 38). The base of the water tank at Tank Battery 3 has a maximum scintillometer reading of 550 cps (100 μR/hr). The adjacent salt scar ranges from about 70 cps (15 μR/hr) near the tank to 40 cps (10 μR/hr) at the low end of the scar (Fig. 38). Modestly elevated radioactivity (35-70 cps, 9-15 μR/hr) was measured on the tanks and soils in Tank Battery 2. An area of oily sludge just below the berm of Tank Battery 2 ranges from 100-150 cps (20-30 μR/hr) (Fig. 38).

In the deeply eroded, salt-scarred area below Tank Battery 1, radioactivity drops to background levels within 5 m of the edge of the berm around the tank battery. The entire deeply eroded area, including the area of outwash accumulation and the horizon of salt efflorescence (Fig. 38), has radioactivity readings at background levels.

The brines that have killed vegetation and have allowed the deeply eroded area to form appear to have come from produced water overflow and the small pit at Tank Battery 1 and from overflow and the two pits at Tank Battery 2. Depth of the gullies in the deeply eroded area is as much as 3.5 m (Fig. 37). A laterally continuous zone of salt efflorescence is exposed along a particular horizon in the middle part of the deeply eroded area and probably represents erosional exposure of a less permeable layer in the soil profile above which brine seeps to the surface.

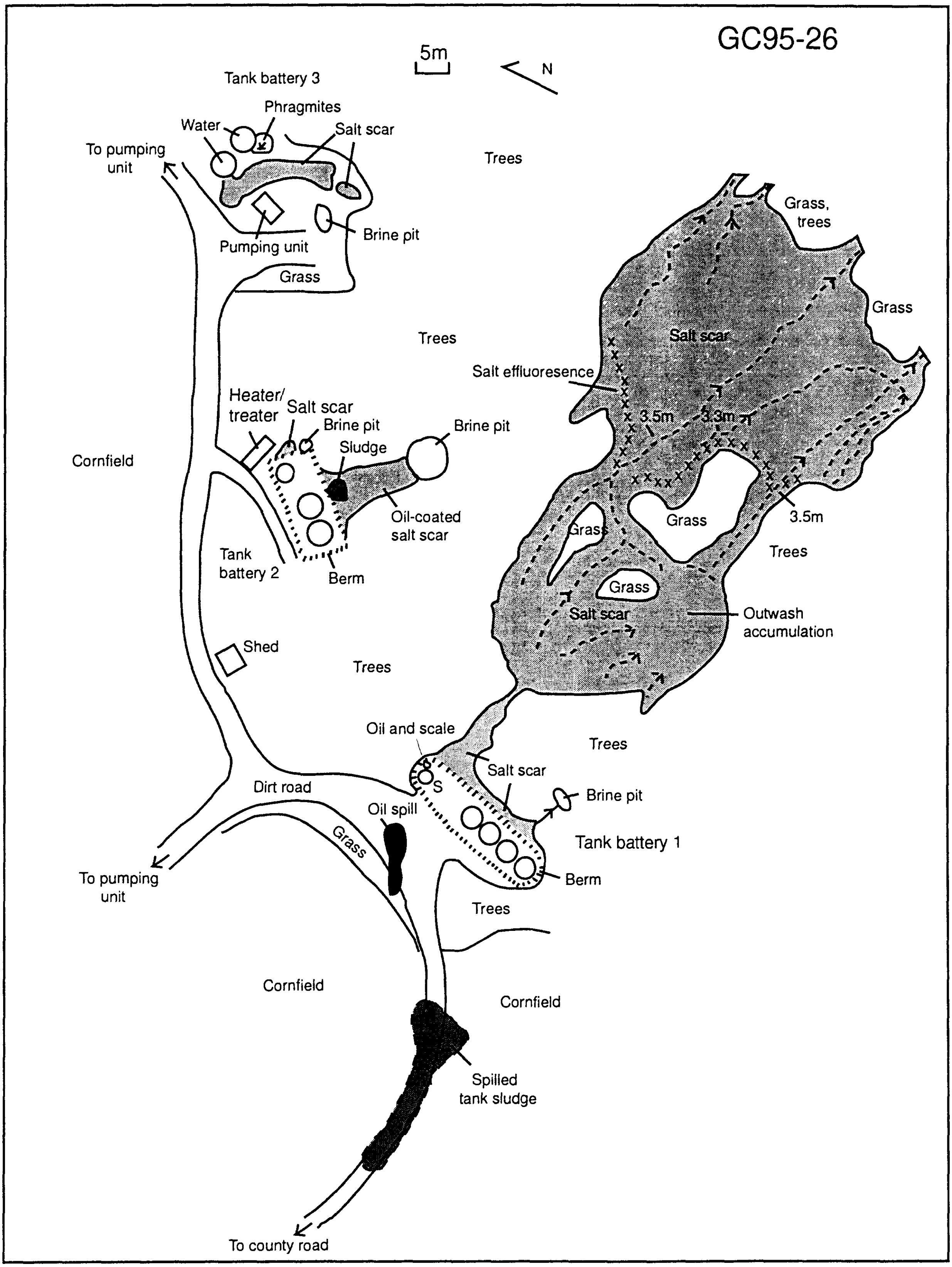


Figure 37- Detailed map of tanks batteries, salt scars, and related features at Site GC95-26, White County, Illinois. S-separator tank.

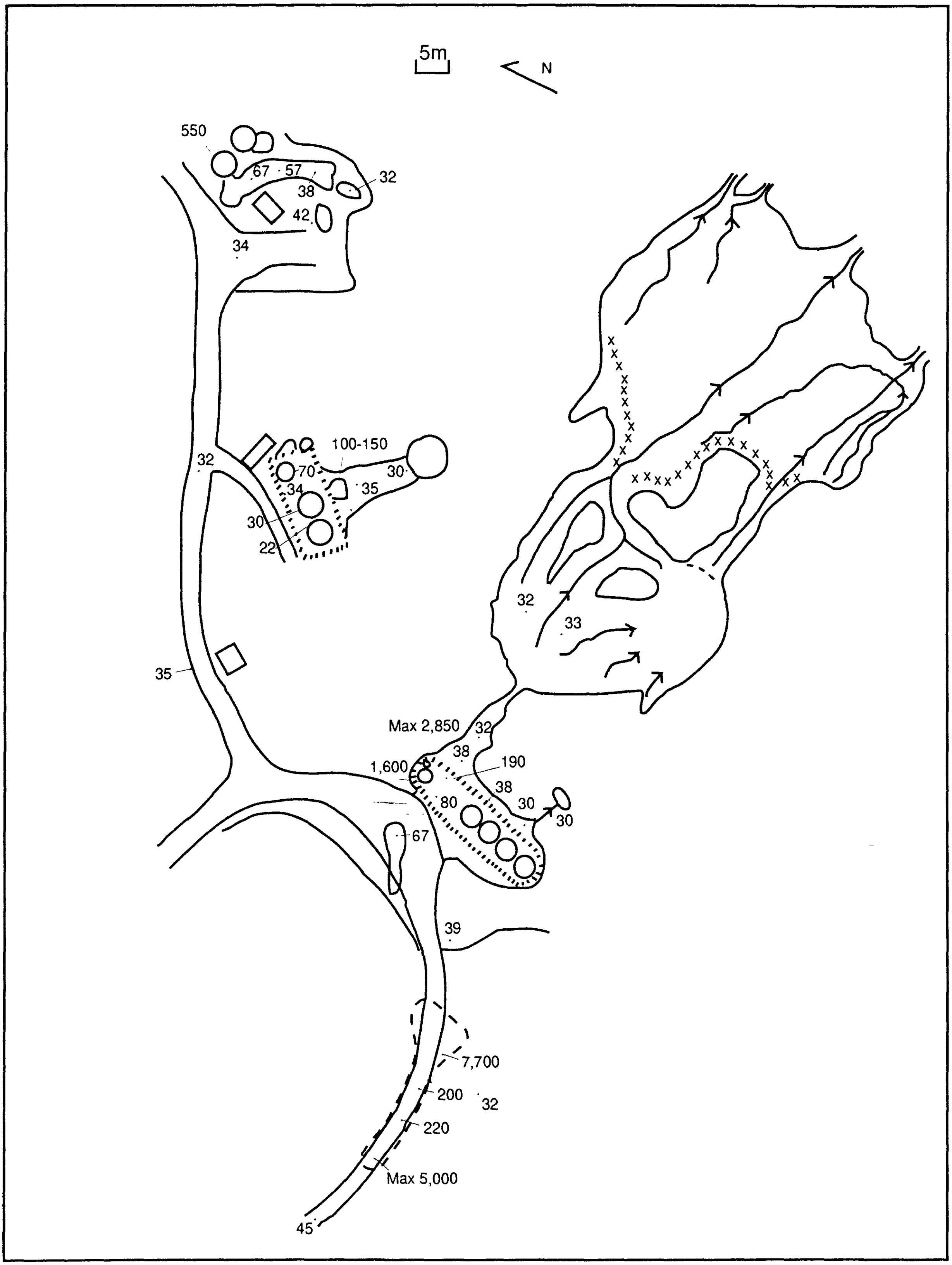


Figure 38- Scintillometer readings on soils, equipment, and spilled material at Site GC95-26, White County, Illinois.

DISCUSSION AND CONCLUSIONS

Erosion and salinity

Produced waters have caused variable amounts of salt scarring and erosion at most oil and gas production sites visited during field surveys in southern Illinois in 1995-96. Of the 43 sites in the four counties, three sites had no erosion or vegetation kill associated with them and one site was a tank storage and reclamation site with no brine or oil production or storage. Of the remaining 39 sites, 26 (67 percent of scarred sites) were judged to be in the early stages of erosion based on the criteria of the Greater Egypt Regional Planning and Development Commission (1982). Eight sites (21 percent of scarred sites) were judged to be in the intermediate stages of erosion. Five sites (13 percent of scarred sites) were judged to be in the advanced stages of erosion. For comparison, the Greater Egypt Regional Planning and Development Commission (1982) showed that 62 percent of Jefferson and Franklin County sites were in the early stages of erosion, 23 percent in the intermediate stages, and 16 percent in the advanced stages of erosion.

Six of the 42 sites visited during the field survey had been reclaimed. Each of the reclaimed sites has had some continued erosion after reclamation. At 3 of the sites, parts of the site were in the early stages of erosion and at 3 others, parts of the site were in the intermediate stages of erosion. One site (HC95-1) had development of sparse *Phragmites* in the lower part of the reclaimed area suggesting that slightly saline soils were persisting.

All of the soils at visited sites were silt loams or, more rarely, silty clay loams. The local slope was the most obvious contributor to erosion on salt scars. The degree of erosion observed at those unreclaimed sites that had salt scars was compared to the slope reported for the mapped soil unit in the published soil surveys (Currie, 1986; Wallace and Fehrenbacher, 1969; Martin, 1996). Table 11 shows that with increased slope there is a tendency for an increased degree of erosion (reclaimed sites were eliminated in this comparison). The size and age of the salt scar also influenced the degree of erosion with larger and older sites tending to be more eroded.

Phragmites was noted at nine sites; six in Hamilton County (HC95-1,7,8,9,13,14); two in White County (GC95-4,24); and one in Gallatin County (GC95-7). This plant typically occurred in shallow, depressional zones at the margins of salt-scarred areas and injection well sites, and in ditches along dirt roads adjacent to salt scars. Elsewhere across the world *Phragmites* is especially common in alkaline and brackish (slightly saline) environments in temperate areas (Haslam 1971, 1972; Tucker, 1990) and has become very invasive in the upper Midwest over the past few decades. New populations of *Phragmites* often establish themselves where soils are disturbed by human activities and

Table 11- Comparison of slope and degree of erosion at 33 selected oil and gas exploration and production sites in southern Illinois (reclaimed and unscarred sites eliminated).

Slope (percent)	Early	Intermediate	Advanced
11+	0	0	2
5-10	1	2	1
2-5	12	4	0
0-2	10	1	0

salinity and sedimentation rates have increased (McNabb and Batterson, 1991). It does not compete well with other wetland species where waters are fresh, but its higher salt and shallower water level tolerances allow it to invade many disturbed, wet, saline sites in preference to other wetland plants. Water depths greater than 5 cm and salinities greater than 22,000 ppm prevent germination. Salinities greater than 10,000 ppm reduce germination (Kim and others, 1985; Tucker, 1990). Salinity tolerances for established *Phragmites* stands in a study in New York State were about 29,000 ppm (Hocking and others, 1983). The wet, disturbed, moderately saline soils and increased sedimentation at these nine southern Illinois oilfield sites favor growth of *Phragmites*. *Phragmites* may be used as an indicator plant in this area to show where saline soils occur. *Phragmites* may take up salts. If so, growing and harvesting *Phragmites* may provide a means of desalinizing soils.

Conductivity surveys at three sites (FC-1, GC95-6, GC95-24) suggest that saline soils extending to depths of at least 6 m underlie the surface salt scars. Highest readings are typically in the middle and upper middle parts of the salt scar. Erosion at sloped sites may migrate upslope from the areas of highest initial salinity by headward erosion and downslope by migration of salt. Soil conductivity readings above normal extend downslope from the lower edge of the surface salt scar a few meters (FC95-1) to a few tens of meters (GC95-6, GC95-24) suggesting that the salt scars are tending to migrate downslope. A season to season comparison at site GC95-6 showed apparent downslope migration of about 12 m (the increase in barren soil); however, the crop from 1995 (corn) was different than the cover crop in 1996, thus the apparent migration of the salt scar may only reflect greater sensitivity of the cover crop to salt.

Oily surface soil layers, whether formed by an oil spill or by discarded tank sludge, are typically more resistant to weathering than the surrounding soil horizons; thus, at sites that are in intermediate to advanced stages of erosion, these oil-saturated soil layers often form resistant ledges. These ledges commonly slow headward erosion. At Site GC95-6 a zone of salt efflorescence was found just downslope from an oily soil layer. The oily surface horizon may serve to prevent infiltration of precipitation and flushing of salt from the near-surface soil layers.

Radioactivity

During this study, sites in White County showed elevated radioactivity in oilfield equipment and soils more commonly than sites in the other counties. Seven sites in White County were judged to have high radioactivity (>50 μR/hr on equipment, or >30 pCi/g radium in sludge, scale, or soils, or both), whereas 1 site was judged to have moderate radioactivity (>25 μR/hr, but <50 μR/hr radioactivity in equipment, or >5 pCi/g, but <30 pCi/g radium in sludge, scale, or soils, or both) and 1 site was judged to have low radioactivity (<25 μR/hr radioactivity on equipment and <5 pCi/g radium in sludge, scale, or soils, or both). In Gallatin County, 2 sites were high in radioactivity levels, 6 were moderate, and 9 were low. In Hamilton and Franklin Counties combined, 1 site was high, 1 was moderate, and 15 were low.

Table 12- Ranking of radioactivity at some oilfield sites in southern Illinois

County	High	Moderate	Low
White	7	1	1
Hamilton/ Franklin	1	1	15
Gallatin	2	6	9

The criterion used here to differentiate high, moderate, and low are related to NORM standards either in use in some States or proposed for other States for radioactivity in equipment (in μR/hr) and radium in solids (in pCi/g). The upper limit of "low" radioactivity for equipment, 25 μR/hr, is a value proposed for use by States by the Conference of Radiation Control Program Directors (E. Kray, Radiation Control Division, Colorado Department of Public Health and Environment, written commun., 1995). The lower limit of "high" radioactivity, 50 μR/hr, is a value used in Georgia, Louisiana, New Mexico, Oklahoma, South Carolina, and Texas (Peter Gray and Associates, 1996). Thus, "low" radioactivity sites described here would be of no regulatory concern for NORM contamination under any proposal or existing statute; whereas sites herein designated as "high" may be of concern under any of the proposed or existing statutes. NORM regulations have not been established for the State of Illinois (Peter Gray and Associates, 1996).

In the API survey (Otto, 1989), the median radioactivity observed at 24 Gallatin County sites was 143 μR/hr above background and the maximum was 2475 μR/hr, meaning that substantially more than 50 percent of the sites were greater than 25 μR/hr above background. In this study, 47 percent of Gallatin County sites were above 25 μR/hr including background. Neither of the two surveys followed random selection procedures thus neither survey results likely accurately represents radioactivity at Gallatin County sites. As noted in the API survey, separators, heater/treaters, water storage tanks, and water flow lines consistently produced the highest radioactivity in equipment in this survey.

Radium

Material interpreted as oily tank bottom sludge discarded on soils consistently yields the highest radium activities in laboratory-based spectrometer analyses of soil samples and GAD-6 gamma-spectrometer readings on soils. The strong association between high radium values and high barium and strontium concentrations in the same samples suggests that radiobarite is the dominant mineral host for radium. X-ray diffraction studies of some of these samples confirm the presence of barite (R.A. Zielinski, U.S. Geological Survey, written commun., 1996). Radium-bearing tank sludge was discarded on the surface at Sites GC95-4,5,25. Radium-bearing pipe scale was observed at Site HC95-3. Rusty-stained radium-bearing soil was found around the wellhead at Site GC95-8 and adjacent to an injection well at HC95-7. This may represent material (for example, formation sand cemented with barite) brought up the hole during reworking of the wells. Each tank or pipe with above-background radioactivity likely contains radium-bearing sludge.

Radium-226 activities in the six water samples (Table 4) were low in spite of elevated TDS in all but one sample. Four water samples were collected from ditches or pipes at the low end of salt-scarred fields. The water sample at GC95-5 came from a leaky, very radioactive heater/treater tank. Most of the radium originally in the water has been coprecipitated with the mineral species in the sludge in the tank, probably barite.

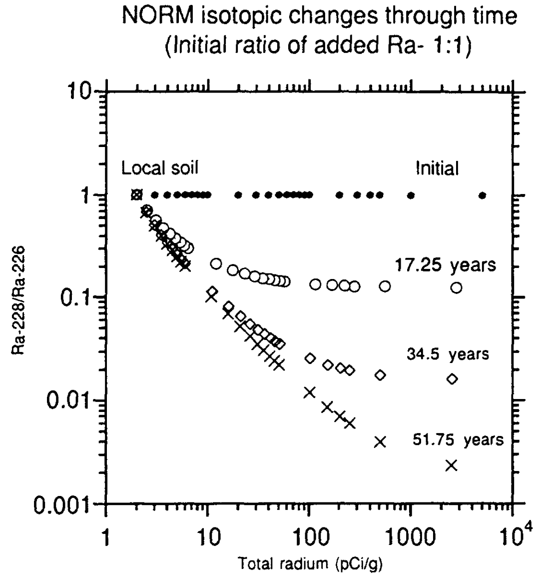
During this study Ra-226 and Ra-228 data were gathered by the GAD-6-spectrometer at the field sites and laboratory-based gamma spectrometry on collected soil samples. The Ra-228/Ra-226 activity ratio, when plotted against a variable such as total radium, may provide some insights into the history of NORM additions to soils at a site. The ratio in the sample is influenced by 1) ratio of Ra-228 and Ra-226 in the native soil at the site; 2) the relative proportions of native soil and the added radium-bearing material (sludge or scale) in the soil sample or in the soil volume "seen" by the GAD-6 spectrometer; 3) the initial ratio and the original total activity of Ra-228 and Ra-226 in the added material; and 4) the amount of time since the radium-bearing material was added. Radium-226 has a half-life of 1620 years whereas radium-228 has a half-life of 5.75 years. Thus, over a period of a few decades the amount of radium-228 will drop significantly if the radium-228 is not supported by the decay of thorium-232.

In most native soils, the radium-228 is replaced continuously by the decay of thorium-232 that is also present in the soil however, in almost all brines, the amount of dissolved thorium is extremely small compared to the amount of dissolved radium-228. Thus in the brine and in radium-bearing solids formed from the brine, this radium-228 decays away without being replaced. Where the radium-228 is added to a soil or adsorbed from the brine by the soil, it will decay away and the Ra-228/Ra-226 value will drop by approximately half every 5.75 years.

Figure 39A shows a hypothetical plot of Ra-228/Ra-226 versus total radium for soil samples of varying total radium where the original soil had a radium activity ratio of 1:1 and a total radium content of 2 pCi/g, and the added radium also had a radium activity ratio of 1:1. Such a circumstance might occur where radium-bearing tank sludge which has accumulated in a tank battery over a period of a few years is discarded on the nearby soil surface during cleaning of the tanks. The total initial radium values after radium addition range from 2 pCi/g (no added radium) to 5000 pCi/g (solid circles, Figure 39A). These initial values were then "aged" for 3 (17.25 years), 6 (34.5 years), and 9 (51.75 years) half-lives of radium-228 and the ratio and total radium values replotted (open circles, diamonds, and "x"s, Figure 39A).

Figure 39A suggests that data for samples from such a hypothetical site should plot on a curve whose steepness is dependent on its age. Note that the older the sample the steeper the curve in the low total radium part of the graph. Moreover, the greater the amount of added radium, the better defined the curve may be. The arrows in Figure 39B show the path that a given sample takes on the graph as the sample ages. This becomes significant if there is more than one radium contaminant event at a site. Assuming the same initial radium activity ratio for both events, samples from the younger event should plot along a curve above samples from the older event if they are separated spatially at the site. If the soil at a locality on the site contains radium from more than one event, more complex radium-activity ratio/total-radium patterns will likely be present. Mapping of the soils at the site can assist selection of sample sites and interpretation of the gamma-spectrometer data.

If the initial radium activity ratio for the brine or solids derived from the brine can be determined, then an apparent age can also be calculated. For an active site, this could be done by sampling the produced water or by sampling radium-bearing solids and measuring the radium-226 and radium-228 activities. For older sites, especially abandoned ones, this may not be possible.



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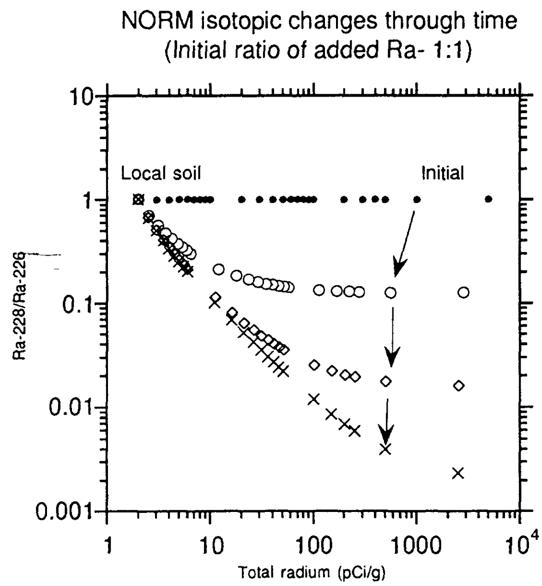

Figure 39- Plots of the calculated changes in total radium and the radium-228/radium-226 value through time. The initial hypothetical soil contains 2 pCi/g total radium and an initial radium-228/radium-226 value of 1. The added radium also has an initial radium-228/radium-226 value of 1. A- Plots for 3 1/2 lives (17.25 years); 6 1/2 lives (34.5 years); and 9 1/2 lives (51.75 years). B- Plot with arrows showing the time pathway for a sample with an initial total radium content of 1000 pCi/g.

Figures 40A and 40B show plots of the activity ratio versus total radium for eight sites in this study. All the sites are plotted using the same ranges of values on the x- and y-axes so that the sites may be compared readily. Site HC95-3 (Fig. 40A) has a sufficiently large range of radium activity to suggest the shape of the curve. This curve corresponds approximately to the 34.5 year curve in Figure 39A, however we don't know what the original Ra-228/Ra-226 value of the added radium is. If that initial ratio was 2:1 then this site would be approximately 6 years older. If that initial ratio were 0.6:1 then the site would be approximately 6 years younger. However, the data overall are sparse and the site could be more complex than that suggested here.

Site FC95-1 (Fig. 40A) has a limited range of ratio and total radium values. There is some suggestion that the curve may be steeper than that in HC95-3, but the data are inadequate. Although the apparent age of the site based on physical appearance seems old, the age of this site cannot be evaluated by the radium data. Data from Site GC95-5 (Fig. 40A) were taken on soil between two upright oil tanks, on saline soil adjacent to a brine pool at the end of a "hot" heater/treater tank, and on the bottom of the "hot" heater/treater tank itself. Note that the ratios are relatively constant (0.33-0.35) over a wide range of total radium values. The average of these three values (0.34) is probably close to the activity ratio for brine at this site. If so, it would be below the usual range of activity ratios of 0.6 to 2.0 (Kraemer and Reid, 1984). The sample site with the lowest total radium value (4.63 pCi/g) has a ratio value that doesn't seem to reflect the influence of the native soils at the site which probably have a ratio of 1.0-1.2 based on data from this study. The soil at this site may have had radium-bearing brine move through it and exchange radium with radium in the native soil. If so, then the radium activity ratio would closely resemble the ratio seen in the other two GAD-6-spectrometer sites which are clearly strongly influenced by radium in precipitates from the brine.

At Site GC95-6 (Fig. 40A), the spread on the total radium data are not quite enough to define the curve, although it suggests a site with radium contamination in the 30-40 year range. This site also has the physical appearance of an older site. At Site GC95-9 (Fig. 40B) the data do not suggest a fit to a single curve. The three lower total radium sites were on soils and these three values begin to define a curve. The high total radium site (Ra-228/Ra-226=0.2) was on the base of a heater/ treater tank. This would suggest that the material in the tank is more recently deposited than the radium added to the soil. The absolute age of radium added to the soil and the radium in the tank cannot be known without knowing the radium activity ratio in the brine.

Radium data at Site GC95-21 (Fig. 40B) have a limited range of total radium values which limits the ability to interpret the data. However, the single lab-based analysis with about 10 pCi/g total radium gives a steep appearance to the data suggesting an

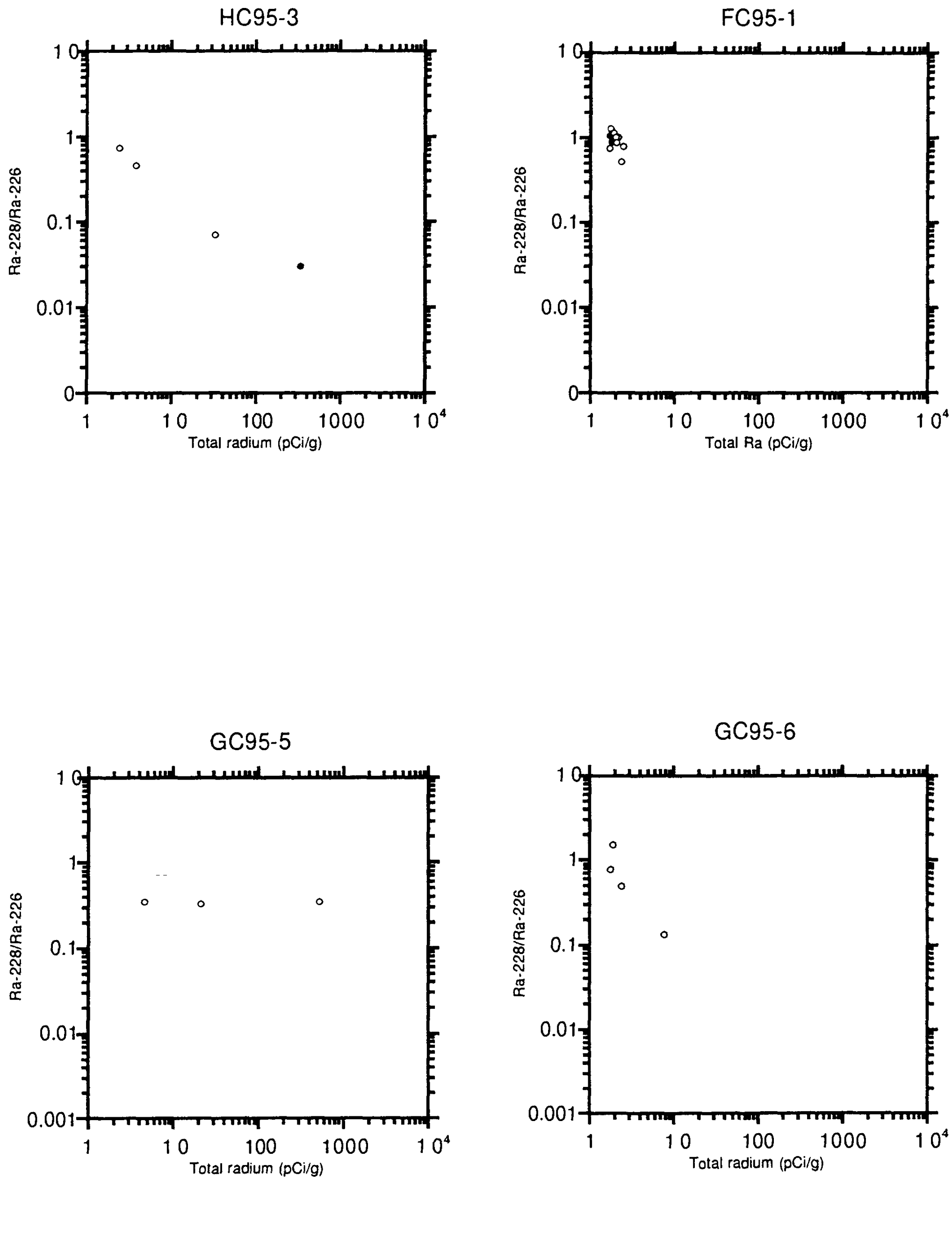

Figure 40A- Plots of GAD-6-spectrometer and laboratory-based spectrometer data for Sites HC95-3, FC95-1, GC95-5, and GC95-6 from this study. Open circles represent GAD-6-spectrometer data. Solid circles represent laboratory-based spectrometer data.

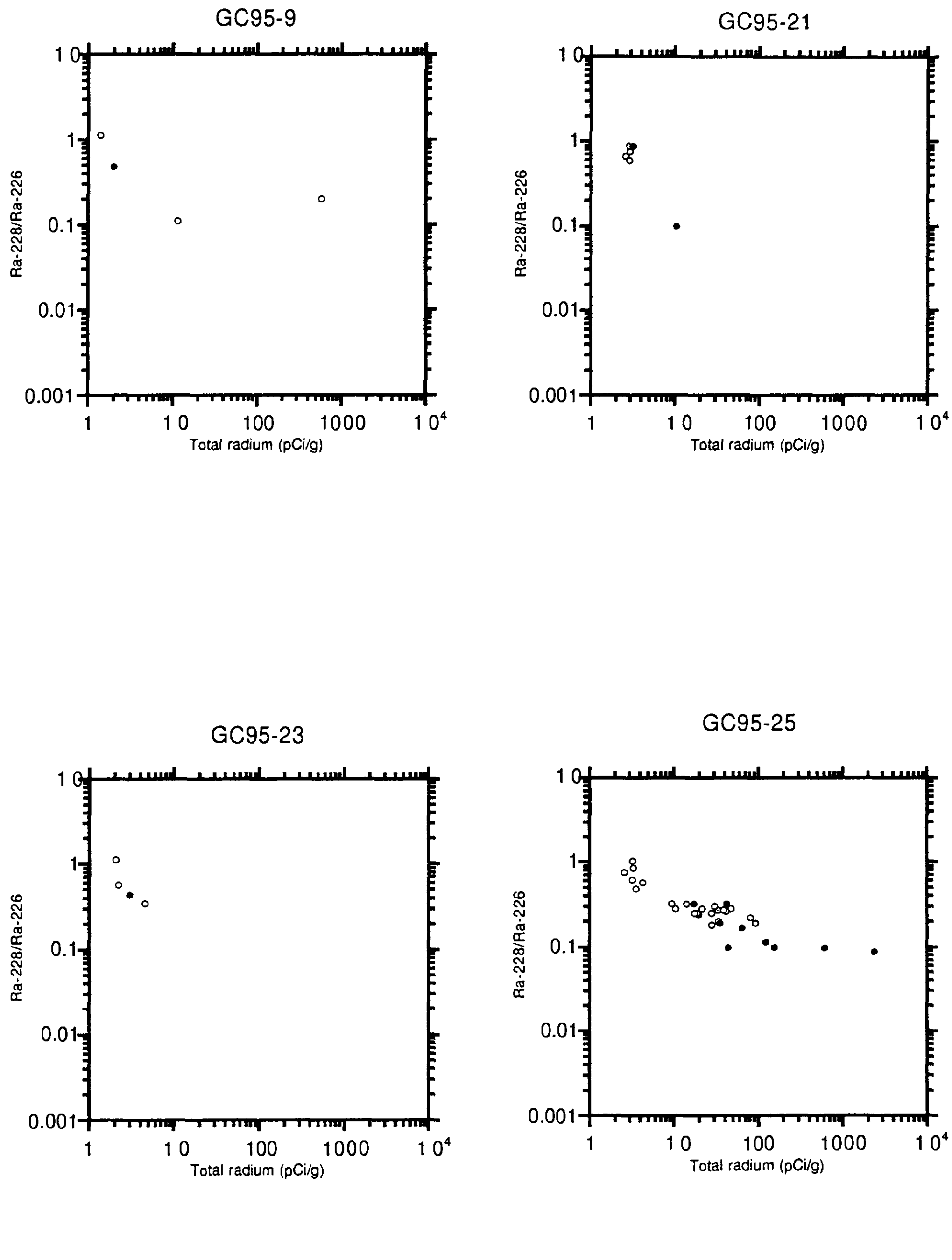

Figure 40B- Plots of GAD-6-spectrometer and laboratory-based spectrometer data for Sites GC95-9, GC95-21, GC95-23, and GC95-25 from this study. Open circles represent GAD-6-spectrometer data. Solid circles represent laboratory-based spectrometer data.

old radium addition event perhaps greater than 40 years. Further analyses are needed to confirm this speculation. Site GC95-23 (Fig. 40B) shows a limited range of total radium and radium activity ratio values. No material with high radioactivity was observed at this site, in spite of thorough examination. This site is at least forty years old (Buck Buchanan, Natural Resources Conservation Service, oral commun., 1995). The limited range of radium data preclude any estimate of the age.

Site GC95-25 (Fig. 40B) was surveyed along three profiles and showed a broad range of radium activity. There is considerable variability away from an ideal curve like those portrayed in Fig. 39A suggesting a complex history of radium addition for the site. A closer look at the data (Fig. 41) shows that GAD-6-spectrometer data along Profiles A and B ("X", Fig. 41) appear to define a curve that levels out at an activity ratio of about 0.2 at higher total radium values. The GAD-6-spectrometer data for Profile C

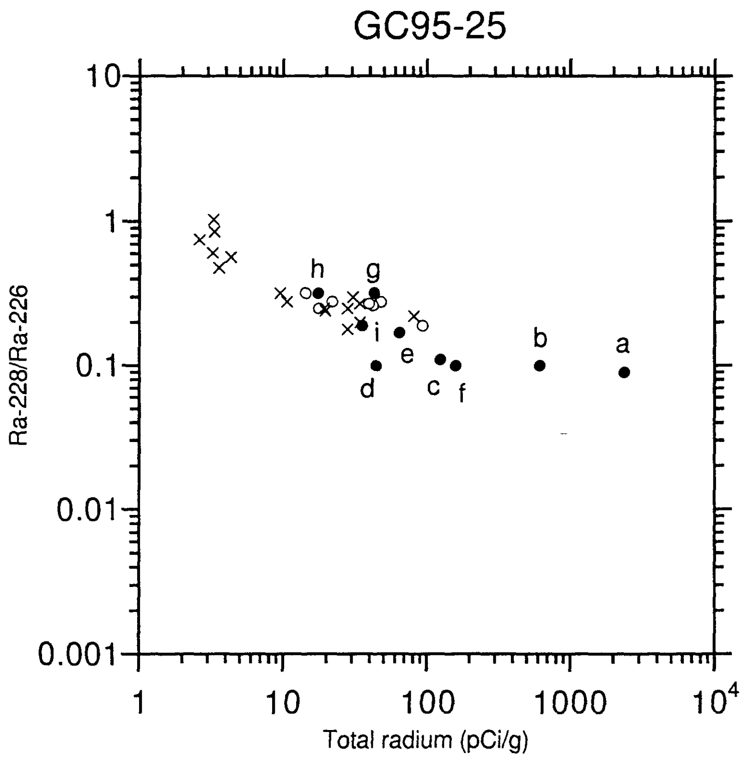

Figure 41- Plot of GAD-6-spectrometer and laboratory-based spectrometer data for Site GC95-25 from this study. X represents GAD-6 spectrometer data from Profiles A and B. Open circles represent GAD-6-spectrometer data from Profile C. Solid circles represent laboratory-based spectrometer data where the letters a-h are the respective soil sample locations along Profile C.

(open circles, Fig. 40) fall in positions that correspond to the higher total radium portion of the curve for Profiles A and B. In contrast, the laboratory-based data (solid circles, Fig. 40), which are all taken from Profile C (the tank sludge hot spot and material dispersed downslope from it), plot on a curve that has lowest activity ratio values of about 0.1 and that has signatures resembling those of the curve defined by the GAD-6-spectrometer data at lower total radium values.

This data seems best interpreted as the result of at least two episodes of radium contamination. A somewhat younger episode may be suggested for the GAD-6-spectrometer data along Profiles A and B (assuming that all the radium at this site has a common radium source with a fixed initial radium activity ratio). The GAD-6-spectrometer data along Profile C falls along this same curve only because it measures gamma activity from radium in the surface layer which has radium dispersed from the tank sludge spot <u>and</u> it measures gamma activity from radium in the larger volume of soil contaminated by radium with a different activity ratio. Note that the radium activity ratio and the total radium values for soil samples along Profile C that are the most distant from the sludge hotspot (g and h, Fig. 41) are most like the GAD-6-spectrometer data for Profiles A and B. The samples with the highest proportion of radium from tank sludge (a and b, Fig. 41) have the lowest activity ratio values. We suggest that the tank sludge represents an older radium contamination event that occurred when tank bottom material was removed from a tank and discarded on site. In adjacent areas, radium has been added to the soil in at least one later event.

Where radium-bearing tank sludge has been discarded on road surfaces, radium-bearing dust may form an inhalation hazard. This has occurred along the access road into Site GC95-26 (Fig. 37). Tires grind the tank sludge and mix it with the dust on the road surface. The typical brown, oily appearance of the material changes to match that of the rest of the dust on the road surface although the radioactivity remains. This is beginning to occur at Site GC95-26 and has occurred at other sites visited in the Wildhorse oilfield in Osage County, northeastern Oklahoma (Otton and others, 1997).

Trace elements

Iron concentrations in samples of soil and waste from the study sites in southern Illinois range from 0.8 to 17.8 percent. Samples with greater than 5 percent iron are mixtures of 1) soil and tank sludge; 2) scale, corroded pipe, and soil; or 3) corroded tank wall and scale. Soils on salt scars, in ponded areas within tank battery berms, or in ditches, ponds, and wetlands receiving surface produced water runoff range from 0.8 to 3.9 percent. No samples of soils were collected that were unaffected by produced waters or oilfield solids thus no data allow us to establish what the background concentrations of iron are for soils in southern Illinois.

Copper concentrations range from less than 20 ppm (the detection limit) to 210 ppm. Copper concentration in 25 of 44 samples were less than the detection limit. Elevated copper concentrations occur in sludge-affected soils (notably at GC95-25) and in mixtures of corroded tank wall or pipe and scale. Elevated copper levels were found in soils affected by oil contamination without scale.

Lead was detected in 13 of 44 samples (detection limit-40 ppm) with a maximum concentration of 450 ppm in the patch of tank sludge at Site GC95-25. Seven of the 13 detectable lead values were at Site GC95-25 in the patch of tank sludge and in the rill downslope from the patch (GC95-25A-I, Table 2). The other detectable lead occurred in soil samples containing tank sludge (GC95-4, GC95-6B); oil (HC95-14A); in a ditch downslope from a tank battery (GC95-1B); in soil adjacent to a pool of brine leaking from an active heater/treater tank (GC95-5), or in a sample of scale and corroded tank wall fragments (GC95-14). Oil and gas production operations are presently largely exempt from Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response Compensation and Liability Act (CERCLA) regulations; thus, no limits are presently placed on toxic trace element levels in sludges and scales or in soils affected by sludge, scale, or produced waters. However, for lead, USEPA has set a preliminary remediation goal of 400 ppm for CERCLA sites and RCRA corrective action facilities (USEPA, 1994). Soil screening levels for other trace elements are under consideration by USEPA, but are not presently (1997) ready for publication. It is the intent of the USEPA that screening levels trigger further remedial investigation or feasibility studies.

Zinc was detected in all but 4 samples. The samples lacking detectable zinc include tank wall, scale and little or no soil (GC95-11, GC95-14) and soil from a reclaimed brine pit site (GC95-2). Highest values (>100 ppm) were associated with sludge-contaminated soils or alluvium, weathered pipe scale and soil, and wetland sediments.

Cadmium was detected in 6 samples: in a sample dominated by scale and pipe fragments (HC95-3); in two samples of salt-scarred soil with oil contamination (HC95-14A, GC95-24B); in one sample containing a high proportion of sludge (GC95-4); in a sample downslope from a patch of tank sludge (GC95-25F); and in a sample of soil adjacent to a pool of water leaking from a heater/treater tank (GC95-5).

Zirconium, a common, generally insoluble component of minor minerals in soils, ranged from 310 to 550 ppm in soil samples from scars, ditches, pond edges, and bermed areas. Soil samples affected by sludge ranged from 85 to 495 ppm zirconium. The two samples composed mostly of corroded tank wall and scale contained 20 and 50 ppm zirconium. The one sample composed of a mixture of pipe scale, corroded pipe wall, and soil contained 215 ppm zirconium. The zirconium concentration can provide a rough estimate of the proportion of soil (zirconium-rich) to other material (zirconium-poor pipe scale, corroded tank or pipe wall fragments, tank sludge).

Barium, and strontium are high in sludge-contaminated soil samples suggesting that barite and/or celestite are present in the tank sludge. Barium concentrations in soil samples from salt scars, wetlands, and pond edges range from 380 to 660 ppm whereas strontium concentrations range from 95 to 230 ppm. Barium concentrations are generally greater than strontium in these samples by a ratio of 3:1 to 5:1. In sludge- or scale-contaminated soils, however, strontium concentrations are as high as 8800 ppm and barium concentrations locally exceed 2 percent. Strontium concentrations are about equal to or exceed barium in 4 samples (GC95-6B, GC95-11, GC95-14, GC95-16). In these samples, each of which contain scale or sludge, the dominant mineral precipitate may be calcite rather than barite. Strontium substitutes freely for calcium in calcite but barium does not.

Both soil samples from sites affected by freshly spilled crude oil contained detectable concentrations of cadmium (1 ppm, HC95-14A, GC95-24B), copper (30 ppm in HC95-14B, 35 ppm in GC95-24B), and one of these contained detectable lead (40 ppm, HC95-14A). This suggests that trace metals in samples affected by oily sludge may, in part, come from the oil component in addition to the mineral precipitates.

Water quality

TDS concentrations of water in pools and ditches draining five of six sampled sites in the four counties (Table 4, HC95-1, HC95-13, GC95-2, GC95-5, GC95-21, GC95-24) exceed drinking water limits (500 ppm) in spite of wet conditions during the survey. TDS may be higher during drier periods. Concentrations of radium-226 in the water samples from the six sites range 0.09-0.44 pCi/L radium-226. Radium-228 was not measured. The current USEPA radionuclide standard for radium-226 and radium-228 combined in drinking water is 5 pCi/L. It seems unlikely that these waters exceed current radium standards even during dry periods. New, proposed maximum contaminant levels for radium-226 and radium-228 in public water supplies are 20 pCi/L each (USEPA, 1991).

The presence of dissolved trace metals toxic to plants may limit the success of remedial efforts designed to remove salts from contaminated soils and ground waters in southern Illinois. For example, traces of soluble iodine (0.5-1 ppm) in soil pore waters inhibits the growth of plants (Gough, Shacklette, and Case, 1979). Iodine was detected in 21 of 44 soil samples with maximum concentrations between 30 and 50 ppm. The analytical methods used do not allow the determination of the amount of iodine that is soluble and, therefore, available to plants, but the concentrations observed do suggest that at many sites iodine is present and may be available. The presence of substantial amounts of bromine and iodine in many of these soil samples suggest that other trace elements not analyzed for, such as boron and lithium, may be present in these soils or in the soil pore water. Boron concentrations in produced waters range from a few to several hundred ppm (Collins, 1975) and boron is toxic to many plants at levels of 1-3 ppm dissolved boron in soil pore water (Gough, Shacklette, and Case, 1979). The possible synergistic effects of iodine, boron, and other elements on plant toxicity in brine-affected soil needs to be investigated.

Dispersion of radium at oilfield sites

Understanding the dispersion pathways and dispersion mechanisms for radium at oil and gas exploration and production sites is important in evaluating the risk models that have been developed for determining human health effects of radium exposure at NORM-contaminated sites. Parameters used in existing models are based on data developed for uranium mill tailings and phosphogypsum waste pile sites, yet the characteristics of NORM-contaminated materials at oil and gas exploration and production sites are less well studied. For NORM placed on or near the surface, the exposure pathways include: 1) direct gamma radiation from the ground to an onsite worker, visitor, or resident; 2) inhalation of suspended radium-bearing dust by an onsite worker, visitor, or resident; 3) dissolution and downward movement of radium into a potable aquifer with subsequent ingestion from a well onsite; 4) dissolution of radium from waste or soil in surface runoff and movement into a surface water supply; 5) surface erosion and runoff of radium-bearing particulates into a surface water supply; 6) uptake by plants or animals and subsequent human ingestion; 7) inhalation of suspended radium-bearing dust by an offsite resident; and 8) movement of radon through soil into an onsite inhabited structure (USEPA, 1993b). This study includes some data relevant to some of these transport pathways.

The results of the preliminary dispersion study along Profile C at Site GC95-25 suggest lateral transport of radium-bearing particulates along the rill. The geochemical and mineralogical data suggest that radium in the source (the patch of oily tank sludge) is associated with barite. As this oily material ages and weathers it can be transported downslope by slope wash processes. Mixing with and dilution by low-radium soil matter occurs over very short distances. In Profile C at Site GC95-25, the total radium activity in the rill below the patch of oily, contaminated soil decreases more than one order of magnitude over the first 2.25 m and about two orders of magnitude over a distance of 12.5 m (Fig. 29A).

As barite is heavy relative to other soil-forming minerals, it responds to decreases in the gradient of the rill by dropping out more readily during surface runoff events than other transported soil mineral grains. Thus radium, barium, and strontium concentrations, all trace elements associated with the barite, increase in the zone of outwash accumulation (Sample GC95-25f). These same trace elements drop off as the rill drops into the gully, but then increase in a zone of sediment accumulation in the bottom of the gully (Sample GC95-25i). The zirconium concentration also peaks in Sample GC95-25f then drops and increases again to values higher than GC95-25f in the lowest part of the gully. Zirconium typically occurs in heavy minerals in soils, principally zircon, thus one would expect zirconium to behave similarly to barium. These data suggest that radium-bearing mineral grains could be expected to accumulate in low-gradient areas downslope from the source.

Vertical dispersion of radium at Site GC95-25 is more difficult to evaluate. More than one radium contaminant event seems to have occurred (see discussion of radium-228/radium-226 values for this site above). A comparison of total radium for the GAD-6 spectrometer and total radium for the laboratory-based analyses of the surface samples (Fig. 36) along Profile C shows that the surface sample results are generally higher except at sample site d where the analyses are within analytical error of one another at about 46 pCi/g. Based on the lack of contrast between the two values at site d, the radium appears to be relatively uniformly dispersed through the soil volume sampled by the GAD-6 spectrometer. At the other sites radium is concentrated to varying degrees in the surface layer as noted above. The radium-228/radium-226 value at site d more closely resembles the signature for the sludge-dominated sample (a, Fig. 36) suggesting that most of the radium at this site is derived from dispersion from the sludge patch rather than from the younger event. Further studies are necessary to determine the mechanisms of downward dispersion at Site d on Profile C and elsewhere on the site.

Use of field gamma-spectrometer surveys in assessing NORM

As of late 1996, seven states have passed rules regulating NORM at oil and gas exploration and production sites; however, only one state, Louisiana, has issued regulations defining how to assess radium contamination at a site (Nuclear Energy Division, Louisiana Department of Environmental Quality, 1989, 1995; Radiation Protection Division, Louisiana Department of Environmental Quality, 1992). A preliminary site survey using a μR meter with a grid spacing no greater than 10 m must be performed (if hot spots are present the grid spacing must be 3 m). Soil sampling is required for any area with survey readings greater than twice background or any area which has an average reading greater than 1.5 times background over an area of 1000 square feet or more. The sample site must be mapped and one or more 100 square meter grids (typically 10 m by 10 m) must be laid out. A minimum of five samples per 100 square meter area must be taken and the top 15 cm layer and the next 15 cm layer must be sampled separately. Sample locations must be noted on the map. The samples must be submitted to a qualified laboratory for analysis. The samples must be analyzed separately and the results averaged for the same depth interval and same 100 square meter area. The criteria for soil contamination by radium are 5 pCi/g of radium-226 or radium-228 above background in the first 15 cm layer averaged over a 100 square-mater area and 15 pCi/g of radium-226 or radium-228 above background averaged over a 100 square-meter area in any 15 cm layer thereafter. No single non-composited sample may exceed 60 pCi/g of soil.

This procedure is time consuming and costly. In addition to labor for required surveying and sampling, analytical expenses are as much as $200 per sample for both radium-226 and radium-228.

Confirmatory analyses are required after removal of the radium-bearing material prior to release of the land. In some cases in Louisiana, such as a pipe-cleaning operation, the Nuclear Energy Division must perform the confirmatory work.

Field gamma spectrometry may offer an alternative to the Louisiana procedures for screening, assessment sampling, or confirmatory work. The initial instrument costs are relatively high (about $10,000) and the instrument must be calibrated periodically, but these costs would be rapidly recovered after a few site assessments. The instrument records gamma activity from a hemispheric volume of soil about 30-50 cm in radius depending on soil characteristics, thus it does not gather the same type of data specified in the Louisiana regulations. However, simple protocols could be developed that would achieve the same result. Addition of downhole-probe capabilities (not used in this study) would add to the utility of field gamma spectrometry. Data may be rapidly acquired (typically 5 minutes per site after the grid is setup, less if the activity is higher, more if greater precision is required). Use of the instrument also would permit rapid establishment of "background" radium-226 and radium-228 activity in nearby soils.

Use of the EM-31 conductivity meter in assessing soil salinity

Soil conductivity data were collected at three sites during this study. At the 3 sites conductivity readings greater than 3 times background (90-120 mmhos/m) were usually contained within the visible salt scar. However, at FC95-1, 0-3 m values of 150-180 mmhos/m occurred below grass/forb patches within the salt scar. It is likely that the soil within the rooting zone of the plants has a much lower conductivity than that indicated by the 0-3 m sounding. Conductivity measurements on 1:1 soil-water pastes using a field conductivity meter may assist in detecting shallow low salinity zones not discriminated by the 0-3 m soundings. Values 1-3 times background were common beyond the downslope edge of salt scars. Careful evaluation of close-spaced soil conductivity readings beyond the downslope edge of a salt scar may suggest future migration directions for the salt scar. Differences between the 0-3 m and 0-6 m conductivity readings can suggest if salt has been flushed from the surface but remains in the deeper subsurface or if salt is concentrated in surface layers.

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