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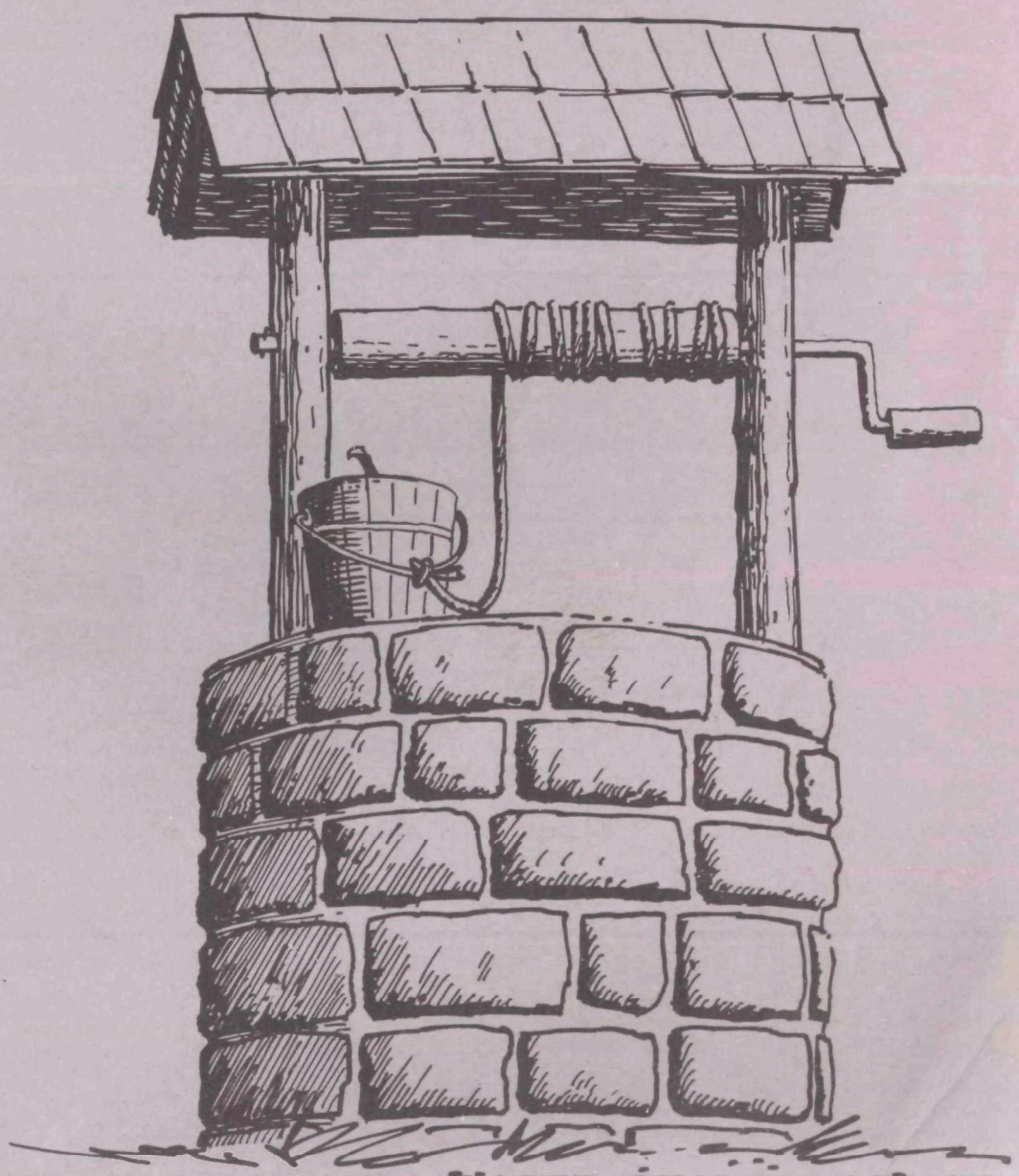
INFILTRATION RATES AND GROUNDWATER QUALITY BENEATH CATTLE FEEDLOTS, TEXAS HIGH PLAINS



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INFILTRATION RATES AND GROUNDWATER QUALITY BENEATH CATTLE FEEDLOTS, TEXAS HIGH PLAINS

by

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Lubbock, Texas 79409

for the

WATER QUALITY OFFICE

ENVIRONMENTAL PROTECTION AGENCY

Project #16060EGS
Contract # 14-12-804

January, 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 65 cents
Stock Number 5501-0125

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ABSTRACT

Detailed field and laboratory studies of five feedlots were conducted to determine field seepage rates and distributive geometry of infiltrated runoff. Practical field seepage rates at these sites ranged from 2 to 20 feet/year. Dispersal rates of ions in the groundwater zone varied from 45 to 400 feet/year.

Nitrogen (NO_3, NO_2, NH_4, Org-N) and common chemical parameters (Ca, Mg, Na, K, Cl, SO_4, TDS, pH, and conductance) were determined in cores and groundwater samples; based on groundwater analyses from 80 Texas High Plains feedlots, rates of concentration of NO_3-N and Cl in groundwater beneath feedlots range from 0.07 to 0.4 p.p.m. per year, and average 0.17 p.p.m. per year.

Laboratory determined constant head vertical permeability of cores from 22 feedlot sites revealed a range in values of 10^{-2} to 10^{-6} cm/sec for Ogallala sediments, 10^{-4} to 10^{-7} cm/sec for near-surface material of floodplains and feedpen-runoff surfaces, and values of 10^{-6} to 10^{-8} cm/sec for playa clay.

Factors related to runoff-infiltration were correlated with groundwater quality, and it was determined that local surficial material and regional soils patterns are closely related to quality of groundwater beneath feedlots. Direct correlation of water quality does not exist with feedpen-runoff slope, cattle load, and surface-area ratios of drainage basin to collection system.

This report is submitted in fulfillment of Project Number 16060EGS, Contract Number 14-12-804, under the (partial) sponsorship of the Water Quality Office, Environmental Protection Agency.

Key Words: Nitrates, groundwater quality, Ogallala Formation, core chemistry, permeability, High Plains geologic environment.

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CONCLUSIONS

1. Concentration values of ammoniacal, organic and nitrite nitrogens, calcium, magnesium, sodium, potassium, and chloride in collected cattle-feedlot runoff exceed "normal" values for groundwater in the Ogallala Formation. Nitrate-nitrogen in collected feedlot runoff may be found to be less concentrated than in Ogallala groundwater. The occurrence of high values of nitrate-nitrogen in Ogallala groundwater in the vicinity of a feedlot is not always prima facie evidence of a feedlot source.

2. Nitrite-nitrogen, ammoniacal and organic nitrogen occur in high concentrations in collected feedlot runoff. These ions usually are partially removed at the surface or retained in the unsaturated subsurface environment and do not concentrate in the saturated zone in proportion (quantitatively) to their surface occurrence. Removal of ammonia, organic and nitrite-nitrogen is a result of nitrification-denitrification reactions as well as volatilization of ammonia. Nitrogen retention is in part accountable to clay mineral adsorption and to bacterial fixation.

3. Surficial silt-clay mixtures of feedpens and/or runoff surfaces exhibit secondary cementation in the form of root fillings, vug and pore fillings, and veinlets. Below this developed hardpan, soil densities are noticeably less and permeability values are larger.

4. The ubiquitous Texas High Plains "caprock" caliche is often porous and permeable below runoff collection systems. Secondary solution of caliche is evidenced by vugs, secondary cementation of fractures and solution vugs, and by silt-clay-fillings in the solution vugs and voids.

5. The unsaturated zone of the Ogallala Formation is slow-to-rapidly permeable. Laboratory determined constant head vertical permeability values in the unsaturated zone range from 10^{-2} to 10^{-6} cm/second. Laboratory determined permeability values of playa sediments are usually less than 10^{-6} cm/second. Permeability values of feedpen and runoff surface material range from 10^{-4} to 10^{-7} cm/second. Minimum permeability of the surficial mantle and minimum permeability values of the Ogallala sediments determine practical infiltration rates.

6. Regional soils patterns and the localized surficial sediments of playas are related to groundwater quality beneath cattle feedlots. Total infiltration and infiltration rates are greater in the sandy soil zones than in the hardland

zones of the High Plains. The "ponding" part of playas that contain the usual clay layer are an effective barrier against infiltration of feedlot runoff.

7. Concentration in groundwater of dissolved solids derived from High Plains cattle feedlots is restricted to the vicinity of the point-source (feedlot). This is accountable to the low total volume of infiltrate, plus dilution of the infiltrate in the groundwater zone. Low total volume of infiltrate is, in large part, due to (A) low rainfall, high runoff-evaporation rates, (B) low permeability factors associated with the feedlots, and (C) secondary precipitation in the unsaturated zone. Around feedlots a significant dilution factor is the usually large flow rate (natural and induced) in the Ogallala relative to permeability rates between the watertable and the surface. Groundwater dispersal rates determined under existing field conditions show average values ranging from 45 to 400 feet per year. Actual dispersal rates are greatly dependent upon distribution and pumping rate of producing wells at the site. Where a feedlot operation uses large volumes of groundwater, significant quantities of infiltrate that reach the saturated zone are recovered by pumping.

8. Practical seepage rates determined under existing field environments range from 2 to 20 feet/year. Rates of concentration of NO_3-N in the Ogallala Formation of the High Plains approximate 0.07 to 0.3 p.p.m. NO_3-N/year. Approximate values for rate of concentration of chloride are 0.07 to 0.4 p.p.m. Cl/year. Average values for rates of concentration of chloride and nitrate-nitrogen are about 0.17 p.p.m. per year. Average rates of increase in conductance values for groundwater beneath High Plains feedlots are 40-100 micromhos/cm per year.

9. There are several feedlots in this study that have contributed NO_3-N to levels approaching or exceeding recommended limits (10 p.p.m. NO_3-N). Some of the lots that have degraded water quality approaching recommended limits are expected to exceed such limits in the future. On the other hand, some sites in the High Plains will probably never significantly degrade groundwater quality, the reasons being slow infiltration rates relative to groundwater dispersal rates, recycling of infiltrated runoff, subsurface impermeability at the site, and rapid dispersal of surface runoff. No regional degradation of the Ogallala groundwater is expected in the foreseeable future, only degradation in specific localized areas.

RECOMMENDATIONS

1. Ion-balance studies are needed of nitrogen and other common ions associated with feedlot runoff. As already known, the concentration of some ions, for example Ca, K, NO_2, NH_4, Org-N, are not quantitatively correlative from ponded runoff to the unsaturated zone to the groundwater zone. Imbalances of nitrogen are in part attributable to nitrification-denitrification reactions and volatilization of ammonia; Ca and K reductions are attributable to cation exchange reactions between plants-soils-bacteria and to chemical precipitation by oxidation reactions and evaporation. Natural processes operate to cause such desirable imbalances; thus, techniques need to be investigated to enhance these desirable results.

2. An investigation is required to determine optimal relationships of seepage to return flow (pumping) under field conditions. Some feedlots for all practical purposes should show buildup of runoff in the groundwater zone yet the buildup does not occur; quantitative relationships of seepage to return flow need to be evaluated. Slow seepage rates may be acceptable for feedlots that use large volumes of groundwater.

3. Shallow-hole exploration (20-40 feet) of playas is needed to better determine the geology and its relation to control of seepage. New (pre-feedlot) and old playas should be included to evaluate the effects of colloid-filtrate plugging.

4. Periodic evaluation of groundwater quality beneath selected sites used in this study should be made on an annual basis. It is recommended that water supply wells in the vicinity of all feedlots be sampled annually for specific ion content in groundwater.

5. In selecting future feedlot sites to minimize degradation of groundwater it seems significant to pay attention to the geographic location, type of "runoff system" and liquid-waste handling procedures, composition and structure of near-surface earth materials at the site, and pre-existing water quality beneath the site.

Ideally, it would seem preferable to locate sites outside areas with very sandy soil zones. This in fact has been the trend in feedlot location, though probably unintentional. The "migration" of feedlots has been northward on the Plains to areas with less sandy soil than exists in the south, southwest part of the Plains.

The best "runoff system" should be a situation where long-term ponding does not occur. Water that is ponded should be in an essentially impermeably bottomed reservoir. Many High Plains playas serve this purpose if the natural clay liner is not breached and the storage capacity of the impermeable (clay) part of the playa is not exceeded. If the natural clay liner of a playa is breached, the side-slopes of the excavation as well as the bottom should be restored to its original density. Clay layers in playas are lense-shaped bodies that are thin toward the edges of the "ponding" part of the playa; therefore, the "ponding" area of a playa adjoins what can be relatively permeable material. Long-term induced head due to "ponding", even in poorly permeable zones, may eventually cause movement of liquid waste to the groundwater zone. Handling procedures for liquid waste may be of considerable significance in reducing potential pollution hazards. Spreading of liquid waste increases the ultimate destruction and rate of conversion of nitrogens to tolerable levels as well as serving to decrease concentrations in localized areas.

Permeability data taken from cores of the subsurface unsaturated zone (Ogallala Formation) and from near-surface soil zones of feedlots indicate that the least permeable zones are consistently at or near the surface. This is a result of several factors some of which are inherently due to the geologic development of the Ogallala and some due to secondary precipitation of dissolved solids in soil zones of feedlot runoff surfaces. Runoff slopes in time usually decrease in permeability.

There are places in the High Plains where naturally occurring nitrate-nitrogen and other ions are in high concentration. Obviously, in these geographic areas small additions of undesirable chemical compounds to the groundwater zone can degrade water quality to an intolerable limit for household or municipal use. The intolerable limit one speaks of is dependent upon the intended usage of the water. Certainly many industrial and agricultural applications of water have much higher tolerable limits in terms of nitrate-nitrogen and other ionic concentrations than water for household usage.

INTRODUCTION

Increasing concern within the last decade over possible concentration of nitrate and other ions in the saturated zone beneath commercial cattle feedlots has warranted numerous studies where feedlots proliferate. Fortuitously interrelated factors of climate, soil, and groundwater, resulting in high-yield feedgrain production, have led to development of over one hundred major cattle feeding operations in the High Plains of Texas. Commercial cattle feedlots have been in existence in the Texas High Plains for 35 years, but increasing concern due to asymtotic development within the 1960's led to initiation of this and other studies.

The initial objectives of this study included (1) quantitative estimates and distributive geometry of nitrogen (NO_3, NO_2, NH_4, Org-N) and other chemical parameters (Ca, Mg, Na, K, Cl, SO_4, pH, conductance) in groundwater below some major feedlot operations, and (2) determination of relative rates of movement of infiltrates from surface to the groundwater zone under field conditions existing in the High Plains. Initiation of the original project by the EPA led to incorporation of additional objectives supported by the Texas Water Development Board, Texas Cattle Feeders Association, North Plains Water District (Texas), and Texas Tech University. The principal objectives incorporated into the total project, by support of the aforementioned agencies, were to (3) determine the significance of subsurface distribution of dissolved solids from feedlot runoff to the groundwater zone (Ogallala aquifer), and to (4) evaluate what total geologic environment(s) in the High Plains is (are) least conducive to infiltration of feedlot runoff to the groundwater zone. Discussion, presentation of data, and conclusions relative to objectives 1 and 2 are, primarily, herein reported. A separate publication[1] relative to objectives 3 and 4 is in preparation.

Study Sites

Eighty commercial cattle feedlots (locations, Figure 1) were investigated to varying degrees for the total research program. The 80 feedlots ranged from new to 35 years in established age (distribution, Figure 2) with a one-time cattle capacity of over one million head (load vs years established, Figure 3).

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[1]To be published by International Center for Arid and Semi-Arid Land Studies, Texas Tech University, Lubbock, Texas.

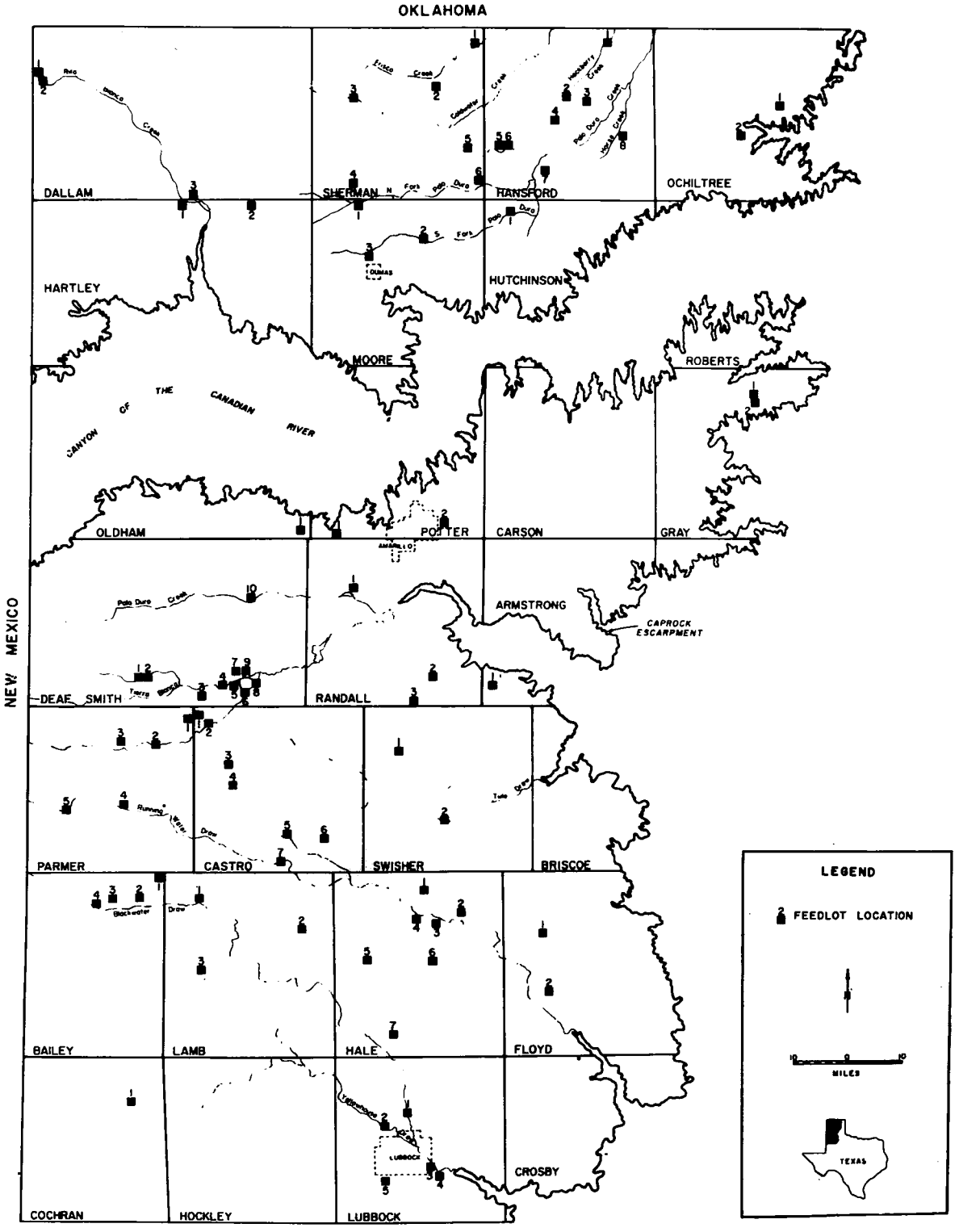
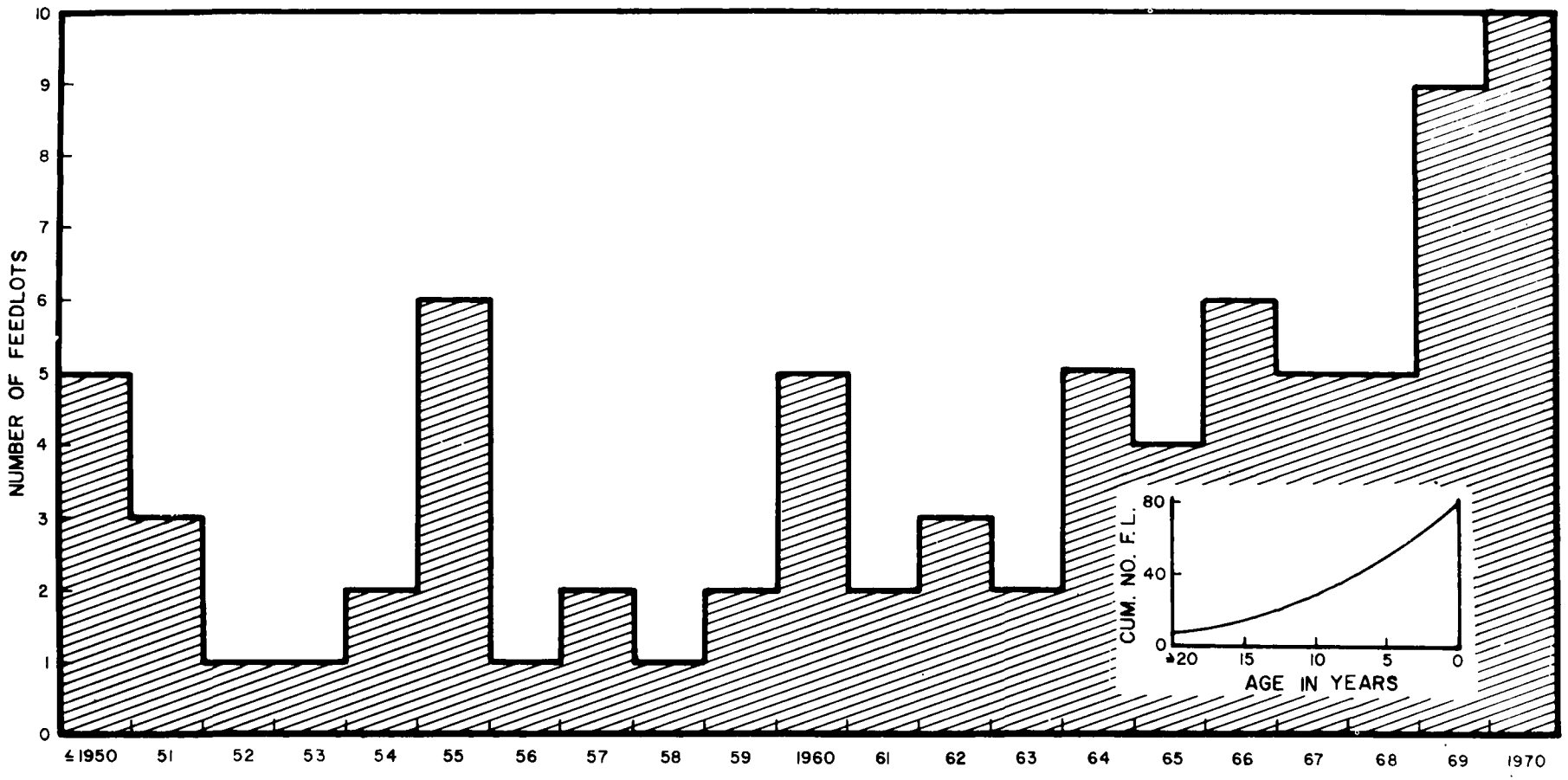


FIGURE 1--LOCATION OF CATTLE FEEDLOTS INVESTIGATED IN STUDY, TEXAS HIGH PLAINS



YEAR FEEDLOTS ESTABLISHED

FIGURE 2--AGE DISTRIBUTION OF FEEDLOTS IN STUDY

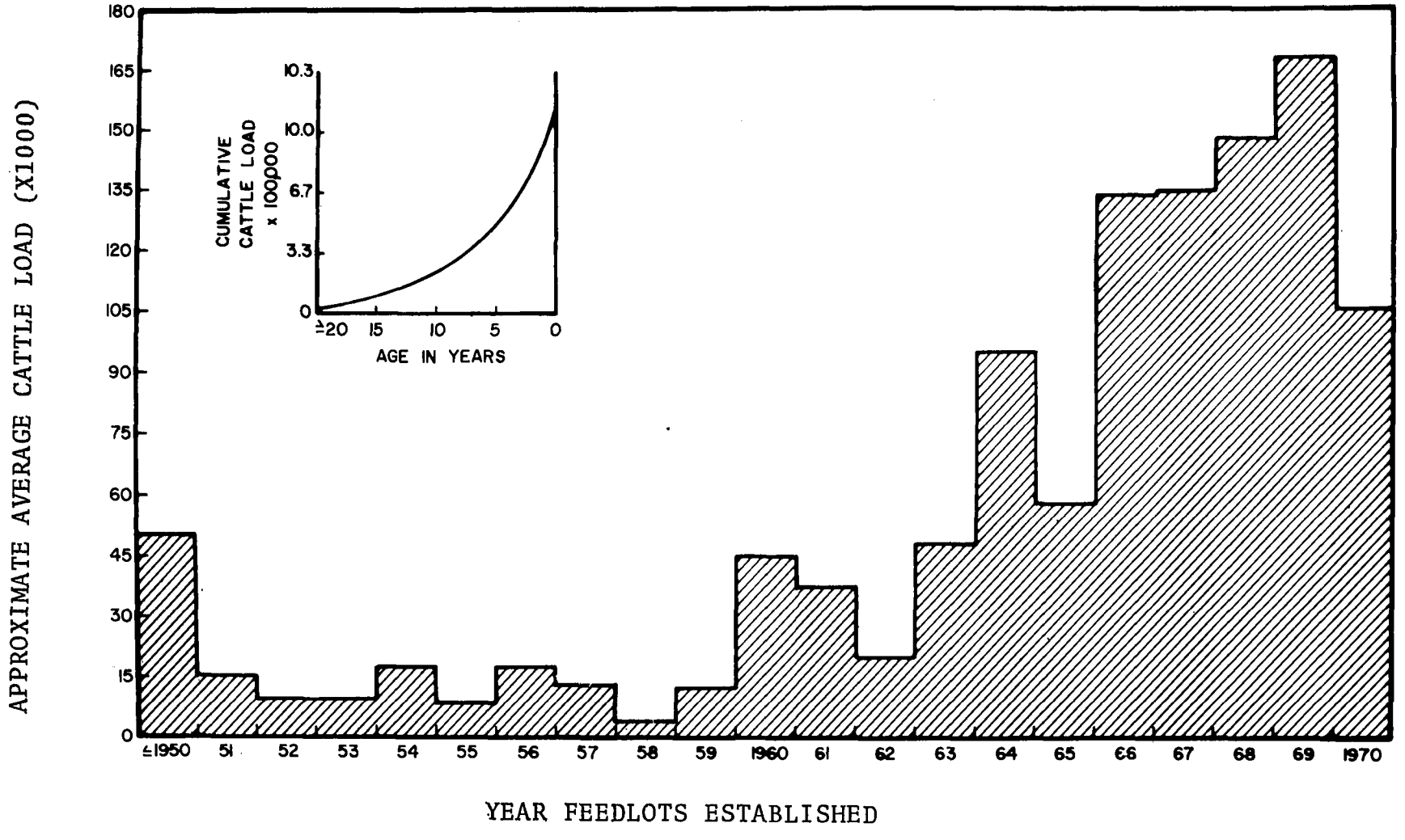


FIGURE 3--APPROXIMATE AVERAGE CATTLE LOAD vs YEAR FEEDLOT ESTABLISHED

Twenty-two feedlots were drilled and/or cored to investigate subsurface geology and chemistry of part of the unsaturated zone. Five representative feedlots, each of which lies south of the Canadian River, are herein described in detail.

Socio-economic implications inherent in such a volatile topic as feedlots and potential groundwater pollution prohibit detailed locations. The specific site locations are of but academic interest; geologic environments and their relation to the Texas High Plains geologic framework are the significant factors. Accordingly, we have designated the sites under the generality of field sites I thru V.

Field Methods

Holes were drilled with a commercially-owned mud-rotary rig and with a mud-rotary rig of the Texas Water Development Board. All coring was completed with the TWDB rig. Drilled holes were reamed 12 3/4 inches in diameter to a depth of 50 feet and then completed to TD with an 8 3/4-inch bit. All drilled holes were set with slotted, 6-inch plastic casing and cemented to a depth of 50 feet. One-foot extensions of casing above ground level were capped with a commercial well seal. Holes drilled and cored with the Water Development Board rig were completed to TD with an 8 3/4-inch bit, and set with slotted, 5-inch plastic casing, cemented to a depth of 20-40 feet, and capped with a commercial well seal. Holes were completed below the watertable but not necessarily to the base of the Ogallala Formation. Gamma and spontaneous potential-resistivity logs were run by the U. S. Geological Survey, Lubbock, Texas, on all drilled holes reported in this phase of the project.

Four-inch diameter, two-foot long rotary cores of the Ogallala Formation were taken with a double-walled core barrel with a custom-designed sheet-metal liner to retain the core upon removal from the barrel. Four-inch diameter push barrels were used for cores of soil zones. Core samples collected in the field for chemical analysis were retained below groundwater temperatures with dry ice. The metal liners were sealed with paraffin, the push cores sealed with plastic wrapping and paraffin, and then shipped to the TWDB Materials Testing Laboratory, Austin, Texas, for determination of plasticity index, void ratio, porosity, permeability, size analysis, and moisture content. Field and laboratory descriptions of lithology were made according to the Unified Soil Classification System.

Laboratory Methods

Laboratory core analyses included determination of (1) in situ unit weight and moisture content, (2) Atterberg Limits, (3) shrinkage factors, (4) grain size analysis by sieving and hydrometer, (5) specific gravity, and (6) vertical constant head permeability. In addition to the above laboratory tests, void ratio, porosity, and degree of saturation were calculated.

Details of techniques used to determine each of the aforementioned parameters are available from the following sources. The in situ unit weight and moisture content test procedure used is "Suspended Weight in Air and Water", as described in U. S. Bureau of Reclamation Earth Manual, Designation E-10, Part E, page 454.

The test procedure for determining Atterberg Limits was the one-point hand method for liquid limit (LL), as described in the Texas Highway Department Soil Manual, Test Method Tex-104-E. The plastic limit (PL) and plasticity index (PI) were measured according to ASTM Test Specification D-424; shrinkage factors are described in ASTM Test Specification D-427.

The grain-size analysis procedure used is described in ASTM Test Specification D-422. All soils samples in which 5% or more of the material passed the No. 200 sieve were graded by both sieving and hydrometer analysis.

The procedure used to determine the specific gravity of soil is described in ASTM Test Specification D-854. Fifty-gram samples were treated in a 500 ml flask; a vacuum pump was used to remove entrapped air.

Constant head permeability tests were run on an undisturbed core, trimmed to obtain parallel ends and uniform diameter. The sample was then placed in a permeameter and saturated under constant head. When uniform flow was obtained, the quantity of water flow during a measured time was determined. Permeability was calculated as shown.

$$K=\frac{QL}{thA}$$

K = coefficient of permeability
Q = quantity of flow
L = core length
t = time elapsed
h = total head loss
A = core cross-sectional area

Water-quality parameters determined include the nitrogen family (NO_3, NO_2, NH_4, Org-N), common ions (Cl, Ca, Mg, Na, K, SO_4), pH and conductance.

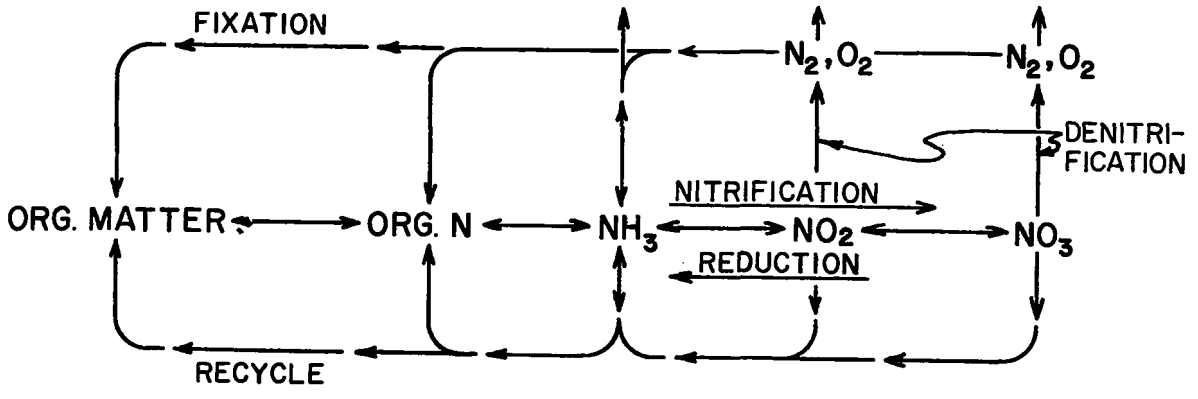
Water-quality determinations were made using Orion specific ion probes, a Technicon nitrogen autoanalyzer, and wet chemistry techniques; conductivity and pH values were measured by meters. The wet chemistry analyses were performed in accordance with procedures specified in Standard Methods for Examination of Water and Wastewater. Duplication of analytical techniques was employed in the examination of many samples in order to provide a basis for correlation of results obtained by different techniques.

Aliquots for core chemistry were taken by soaking and mechanically mixing equal weights of sediment and distilled water. The core extracts were analyzed in the same manner as the water samples.

Nitrogen Cycle

A review of the nitrogen cycle is presented as prelude to the discussion of feedlots and water quality. Nitrogen in nature occurs as molecular nitrogen (N_2); as organic nitrogen in urea, proteins, amino acids, and protein derivatives; inorganic nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), and ammonium (NH_4) ions; and as other less (quantitatively) important intermediate products.

All animals and plants contain nitrogen, and nitrogen also exists in the earth's atmosphere, lithosphere, and hydrosphere. Inorganic physico-chemical reactions and inorganic-organic reactions associated with plant-animal metabolic activity serve as the "catalyst" whereby nitrogen in various forms is cycled in nature. As a generality, the biological (inorganic-organic) phase of the nitrogen cycle is graphically represented.



In the cycle, organic nitrogen is converted into inorganic ammonia, nitrite, nitrate and to molecular nitrogen. Decomposition of organic matter results in formation of organic nitrogen and other products. Subsequently, organic nitrogen is used as an energy source by bacteria and is converted to ammonia. Large quantities of ammonia escape to the atmosphere as a gas; other molecules of ammonia are oxidized under aerobic conditions, as a bacterial energy source, to nitrite and nitrate. Nitrite and nitrate may further be converted to nitrogen gas.

Shortcuts and reversals exist in the aforementioned oxidative process (See diagram). Under anaerobic conditions, nitrate may be converted to nitrite and to nitrogen gas. To close the cycle, some organisms are capable of assimilating nitrogen into cellular matter.

Significant differences in factors affecting the nitrogen cycle exist between the environment of feedlots and that of many freshwater systems. These factors are the organic-inorganic load, predominance of bacterial activity over the activity of algae, changing aerobic-anaerobic environments, and the removal of runoff to the subsurface environment.

A Texas High Plains feedlot surface is an environment of alternate wetting-drying, the organic and inorganic load exceeds the capacity for degradation, the surface is aerobic (sometimes anaerobic at depth), and bacterial activity is high. The runoff collection-system is heavily laden with organic-inorganic matter, oxygen-deficient conditions often exist at depth, and bacterial activity is high. In the unsaturated subsurface, seepage results in removal of liquid from the anaerobic conditions. The denitrification and reduction of nitrate by bacteria account for relatively low concentrations of nitrate in feedlot-runoff collection ponds. On the contrary, nitrification (oxidation) of organic nitrogen, nitrite and ammonia to nitrate account in part for the accumulation of nitrate in the unsaturated zone and groundwater zone beneath feedlots.

DISCUSSION OF STUDY AREA

Observations on the relationships of cattle feedlot sites to geomorphological-geological features and groundwater quality in the Southern High Plains are presented, followed by descriptions of representative field sites. Outlining the geologic setting of High Plains cattle feedlots provides the framework for evaluating relative rates of movement of nitrate and other ions from the surface to the watertable, and natural rates of dispersal in the groundwater zone under existing field conditions.

Geomorphology-Geology

The High Plains is in the "Panhandle" of Texas and is the southernmost extension of the Great Plains which borders the east side of the Rocky Mountains. The High Plains is bounded on the east and west by an erosional escarpment and merges southward into the Edwards Plateau.

Only one major stream, the Canadian River, transgresses the southern High Plains, but tributary drainage to the Red, Colorado, and Brazos rivers originates in the region. Drainage relative to cattle feedlots is localized principally within the stream systems and in the ubiquitous closed-drainage playas that occur in the region. Semiarid climatic conditions of low rainfall (±20 inches), large daily fluctuations in temperature (±40°), and high-wind conditions (5-35 mph) result in low values for long-term runoff and in periods of rapid drying.

Most feedlots in the High Plains are located on stream drainage systems or playa systems. Approximately 40% of the feedlots considered in this study are located on streams, 45% on playas, and 15% have no relation to the aforementioned geomorphic features. These statistics are applicable to all feedlots in the Texas High Plains. Of course, good drainage is an economic asset and in most instances such benefits are readily obtainable by proper geographic location.

High Plains streams have gradients ranging from about 10 feet/mile to less than 5 feet/mile. Feedlot playas considered in this study have a relief of from 5 to 45 feet of closed contours. Feedpens located adjacent to stream channels and playas in Armstrong, Bailey, Castro, Lamb, Lubbock, Parmer and parts of Deaf Smith counties (Figure 1) have drainage slopes ranging from 2% to 5%; feedpens in Floyd, Hale, Gray, Potter, Oldham and Moore counties have slopes ranging between 0.2% and 2%. Few feedpen slopes of the High Plains exceed 5% in value.

The Ogallala Formation, the principal aquifer, surfaces the Texas High Plains, along with a thin intermittent veneer of unconsolidated Pleistocene sediments. The Ogallala is breached to the underlying Cretaceous System in some large playas (non feedlot) and to the Triassic and Permian systems along the Canadian River.

Soils distribution in the High Plains (Figure 4) (1, 2, 3) has a significant relation to infiltration of surface water, thus a relationship to infiltration of cattle feedlot runoff. Rates of infiltration and total accumulation of dissolved solids in groundwater are, in general, higher in "sandy soils" and areas of "sand dunes" than in the tighter soil zones. Total dissolved solids (TDS) and specific-ion maps[2] (chloride, nitrate) of areas in the southern High Plains where no feedlots are located, indicate this relationship. A contributing factor for the sandy soils, groundwater quality relationship is the relatively rapid entrapment of surface water by loose surficial material (sand) which prevents ready runoff, evaporation, and even evapotranspiration due to low plant density. One should add that the significance of soils distribution in terms of potential degradation of large volumes of groundwater is diminished when one considers the low total number of feedlots (±20 in 1970) in the sandy soil zones of the High Plains.

Most surface materials on stream and playa feedlot slopes consist of dense, fine-grained, semi-consolidated soils underlain by caliche. Feedlots located on Texas High Plains streams have feedpens situated on slopes consisting of caliche and thin soils, but in many the stream bottoms have breached the caliche. Feedlots in headwater areas and tributaries of streams have the usual caliche zone beneath the stream channel. Poorly permeable, thin zones of clayey silt were found in stream channels that breach the caliche; at most sites these zones were underlain by thin layers of fine- to coarse-grained sand and/or gravel. The clayey silt and sand-gravel valley fill overlies the Ogallala Formation.

Vertical constant head permeability values determined for the clay-silt sediments of channels are 10^{-4} to 10^{-6} cm/second.[3] The underlying sand zones usually have vertical permeability values of 10^{-4} cm/sec, or larger. Most sediments that occupy the floodplain of the channel consist of a near-surface zone

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[2]Derived from published and unpublished data of Texas Water Development Board and High Plains Water District, and by chemical analyses in Geoscience Department Water Quality Lab, Texas Tech University. In preparation for publication.

[3]1×10^{-6} cm/sec equals 1.034 ft/year.

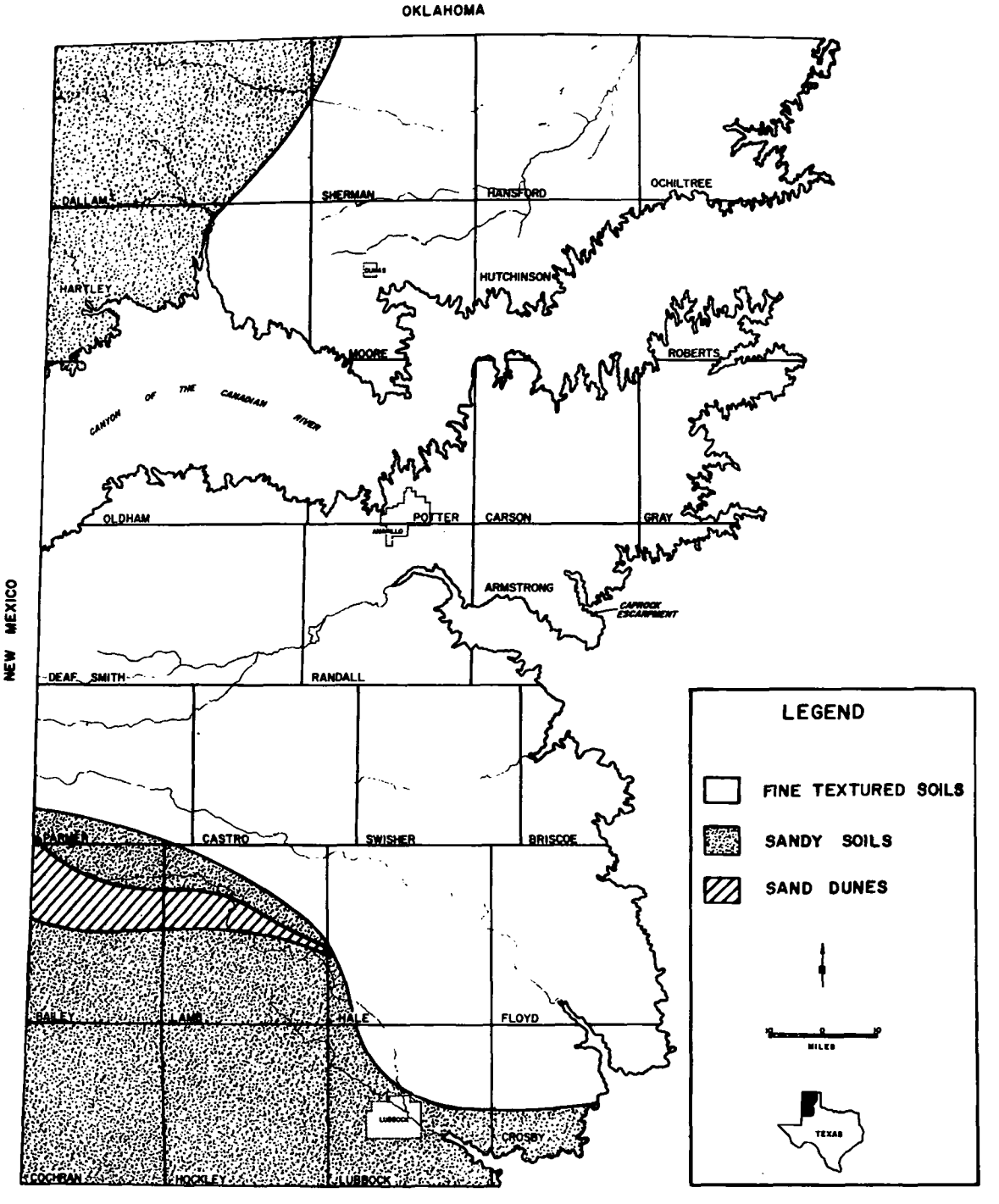


FIGURE 4--GENERALIZED SOIL TEXTURE MAP, TEXAS HIGH PLAINS

(After Carter, 1931; Lotspeich & Coover, 1962; Lehman, Stewart & Mathers, 1970)

of clay and clay-silt that is slowly permeable to impervious. Vertical constant head permeability values determined for floodplain sediments in this study range from 10^{-7} cm/sec to larger permeability values.

The "pond" of playas is surfaced by layers of clay, which is underlain by layers of "lake-fill" sand and/or lenses of clay-silt-sand. Playa "fills" up to 40 feet in thickness were measured, and all are underlain by the Ogallala Formation. Vertical permeability values of playa lake clay are 10^{-6} to 10^{-8} cm/sec or lower in value (impermeable). Lithification of medium and coarse-grained clastic zones is noticeably absent beneath the "standing water area" in all types of collection systems.

Surficial silt-clay mixtures surfacing feedpens and/or runoff slopes exhibit secondary cementation in the form of root fillings, vug and pore fillings, and veinlets. Below this developed hardpan, soil densities are noticeably less. Permeability values typical of the hardpan surface of feedpens and drainage slopes range from 10^{-4} to 10^{-7} cm/second.

Caliche below playa and stream channel collection systems is porous and permeable. Secondary solution of caliche is evidenced by vugs, secondary cementation of fractures and solution vugs, and by silt-clay filling in solution vugs and voids.

The Ogallala Formation underlies the surficial material at all feedlots considered in this study. In terms of infiltration, most laboratory determined permeability values in the unsaturated zone range from 10^{-2} cm/sec to 10^{-6} cm/sec; the larger permeability values of Ogallala sediments will permit rapid percolation of water. However, minimum permeability of near-surface material and minimum permeability values of Ogallala sediments determine actual vertical transmissibility rates.

Groundwater

Groundwater in the study area is ubiquitous within the Ogallala Formation. Depth-to-water ranges from a minimum of 10 feet (parts of Tierra Blanca Draw) to depths of 250-300 feet. Saturated thicknesses range from 30 feet to 300 feet in areas investigated. Concentration of water-quality parameters in this study varies significantly in the Ogallala aquifer within short distances (few hundred feet), regionally from north to south, and in some geographic localities from west to east.

In the High Plains, nitrite, ammoniacal and organic nitrogen, sodium, potassium, calcium, chloride, and total-dissolved-solids (TDS) are definitive parameters for collected feedlot runoff. Most feedlot runoff (ponded) ranges from less than one hundred to several hundred p.p.m. of ammoniacal and organic nitrogen, chloride, sodium, calcium, potassium, and up to several thousand p.p.m. of TDS. These chemical parameters invariably are more concentrated in collected runoff than in Ogallala groundwater. Nitrite and nitrate-nitrogen concentrations in feedlot runoff (ponded) range from less than 10 p.p.m. to several tens-of-parts-per-million. Nitrite-nitrogen is consistently more concentrated in feedlot runoff than in groundwater, but this relation is not always true for nitrate-nitrogen.

There are areas in the southern High Plains, particularly in sandy soil zones, where naturally occurring NO_3-N is higher in "normal" Ogallala groundwater than in water beneath feedlots that show evidence of "seeping" to the watertable. Thus, in order to relate groundwater quality to cattle feedlot runoff one must first establish the quality of water in the Ogallala aquifer in the vicinity of a feedlot site prior to time of establishment of the site in question.

Ionic concentrations in feedlot runoff are often difficult to correlate with concentrations of specific ions in groundwater derived from feedlot runoff. This is particularly true for potassium. Rarely is there correlation of high potassium concentrations in feedlot runoff with low potassium concentrations consistent in Ogallala groundwater. This is in part accountable by plant use of potassium, adsorption by clay minerals, and use of potassium by organisms. Nitrite-nitrogen, ammoniacal nitrogen and organic nitrogen infiltrated from feedlot runoff also are not easily correlated with the occurrence of these ions in groundwater. Such imbalances are attributable to inorganic oxidation-reduction reactions and/or to metabolic processes of organisms. Chloride and conductivity values, and sometimes NO_3-N, show the most consistent correlation.

As noted previously, secondary precipitation of dissolved solids is readily noticeable in the few feet of near-surface material of feedlots and in parts of the unsaturated zone of the Ogallala Formation. This is another cause of the often observed common cation-anion imbalance between the chemistry of cattle feedlot runoff and groundwater.

INFILTRATION - GROUNDWATER QUALITY RELATIONSHIPS

Theoretical consideration aside, particular attention was given to field evaluation of factors that control seepage and seepage rates. Cattle loading history in terms of years and number of cattle was developed for 80 feedlot sites. Other data for the sites include determining thickness of the saturated and the unsaturated zones; feedpen slopes; drainage basin, feedpen, collection system area-volume relations; and type of collection system. Other practical matters of rainfall rates and periodicity, and balance studies of amount and rate of runoff-evaporation-infiltration were not determined directly. Distribution of nitrogen (NO_3, NO_2, NH_4, Org-N) and common chemical parameters (Ca, Mg, Na, K, Cl, SO_4, pH, conductance) in groundwater beneath the 80 feedlots and their vicinity were determined. Also, near-surface cores were taken from 22 feedlot sites (feedpens and collection ponds) in the High Plains.

From a regional viewpoint, concentration of nitrate and other dissolved solids in groundwater as a result of runoff from feedlots is related to soils patterns. The southern part of the southern High Plains and the western part of the North Plains has a sandy soil cover (Figure 4, page 15), and the feedlot water-quality data developed for this study show higher infiltrate concentrations in groundwater beneath the sandy soil zones than in the hardland region. As noted previously, this observation concerning soil-infiltration relationships is confirmed, independent of this study, by Texas Water Development Board annual observation well records and by specific ion (NO_3, Cl) distribution maps of the southern High Plains.

Local sediment distribution is significant also. Surface sediments in High Plains playas are, almost invariably, essentially impermeable ($<10^{-6}$ cm/sec). Also, secondary deposition in feedpens and on runoff slopes develops a near-surface hardpan that retards infiltration. The unsaturated portion of the Ogallala at few sites considered in this study is sufficiently impervious to prevent some seepage of ponded feedlot runoff if it penetrates the surfacing mantle; therefore, permeability of near-surface material is often the essential controlling factor in infiltration.

No direct correlation between drainage slopes and groundwater quality in the High Plains is apparent. As indicated previously, few slopes exceed about 5 percent, and within these limits other overriding factors evidently are more significant. The prime significance of feedlot slopes is to prevent ponding which increases the probability of seepage.

Ratios of collection-system area to area of drainage-basin are in general unrelated directly to groundwater quality. Possible exceptions to this observation are large ratios of drainage-basin area to runoff-collection area of feedlots located on stream channels, and small ratios of drainage basin to runoff-collection area of feedlots located on playa systems. In many large drainage basins with through-flowing streams into which feedlots empty, there has not been any significant buildup of infiltrates beneath the feedlots. Perhaps other unknown factors affect this relationship.

According to Lehman, Stewart and Mathers (3), playa collection systems that are small (volume) in relation to drainage basin areas influence infiltration of impounded water. Computation of drainage-basin area to playa-area ratios and their correlation to groundwater quality do not confirm this. However, a study by Hauser (4) and permeability determinations in this current study leads the writer to agree with Lehman and others. One must conclude that small ratios of drainage basin to playa volume are of some importance in preventing collection and infiltration of runoff in the "overflow" parts of the playas bordered by sandy soils. Hence, the pumping of excess water out of playa collection systems is a justifiable practice.

Cattle load and surface-area of feedpens may have some significance to seepage and seepage rates, but they do not appear to be independently related to groundwater quality beneath Texas High Plains cattle feedlots. Perhaps the interaction with other factors may mask their correlation with groundwater quality. A summary of the relationship of this and other factors to quality of groundwater are enumerated in Table I.

TABLE I

RELATION OF FEEDLOT RUNOFF SEEPAGE FACTORS TO GROUNDWATER QUALITY, TEXAS HIGH PLAINS

Factors	Relation
Geographic Location	Significant; related to soils distribution, geomorphic and geologic control.
Age of lot	Significance interdependent on other factors. Related, but old feedlots do not mean pollution.
Feedlot cattle load	Not considered significant for commercial feedlots.
Feedpen surface	Surficial material of most feedpens is poorly permeable due to compaction and cementation.
Feedpen gradient	Not correlative with groundwater quality.
Stream gradient	No relation to groundwater quality.
Drainage area vs Feedpen area	Rarely significant; Only with very large ratios in streams and small ratios in playas.
Type of collection system	Significant; playa and non-ponding system away from stream most desirable.
System capacity vs Drainage area	Not always significant. Local geology important.
Collection-pond surficial material	Important; playa clay impermeable.
Subsurface lithology	Minimum permeability significant in Ogallala.
Caliche "caprock"	Significance is questionable due to unpredictable permeability.
Depth to water	Significant in some geographic locations.
Saturated thickness beneath lot	Importance dependent in part on transmissibility of Ogallala Formation.

FIELD INFILTRATION RATES AND DISPERSAL RATES IN GROUNDWATER

Infiltration and groundwater dispersal rates of feedlot runoff are evaluated within the detailed geologic framework of five selected field sites. In addition, concentration of NO_3-N, chloride, and conductance values in groundwater are correlated with the ages of 80 feedlots (Locations, Figure 1, p. 6) to further determine field rates of infiltration that exist in the Texas High Plains. The field sites, designated I through V, are located in the central part of the southern High Plains.

Field Site I. Distribution of observation wells at Site I is shown in Figure 5. This feedlot is eleven years old and has a one-time capacity of 7,000 head of cattle. Runoff from this feedlot collects in a large shallow playa that contains an open borehole which has been in existence for two years; surface runoff moves by gravity flow into the groundwater zone.

The Ogallala Formation crops out at the surface in the feedpens. The playa contains 20-25 feet of sediment consisting of a near-surface clay and, underlying this, alternating lenses of clay-silt and nodular caliche; a profile of subsurface lithology of the Ogallala Formation at Field Site I is shown in Figure 6, page 23.

Thirteen cores were taken for permeability determinations, but most of the section is so loosely consolidated and friable that in situ permeability determinations were not always possible. Constant head permeability values determined at this site in the Ogallala range from 1.45×10^{-5} cm/sec to 5.5×10^{-3} cm/second. Certainly 10^{-5} cm/sec is near the minimum permeability of the Ogallala at this site. The clay layer of the playa is very slowly permeable to impermeable (10^{-7} cm/sec). Various hydrologic parameters of subsurface material are shown in Figure 7, page 23.

Core chemistry (Table II) beneath the collection pond indicates runoff has not infiltrated to the groundwater zone. Water-quality data (Table III, p. 25) from well installations (Well #5, #6, Figure 5) also indicate that seepage has not occurred beneath the feedpens to the groundwater zone.

Laboratory determined minimum permeability values for the Ogallala at this site are about 15 feet/year. Depth-to-water beneath the feedpens is 120-130 feet, which theoretically would permit seepage to the watertable within about 8-9 years. Since runoff has not reached the watertable due to seepage,

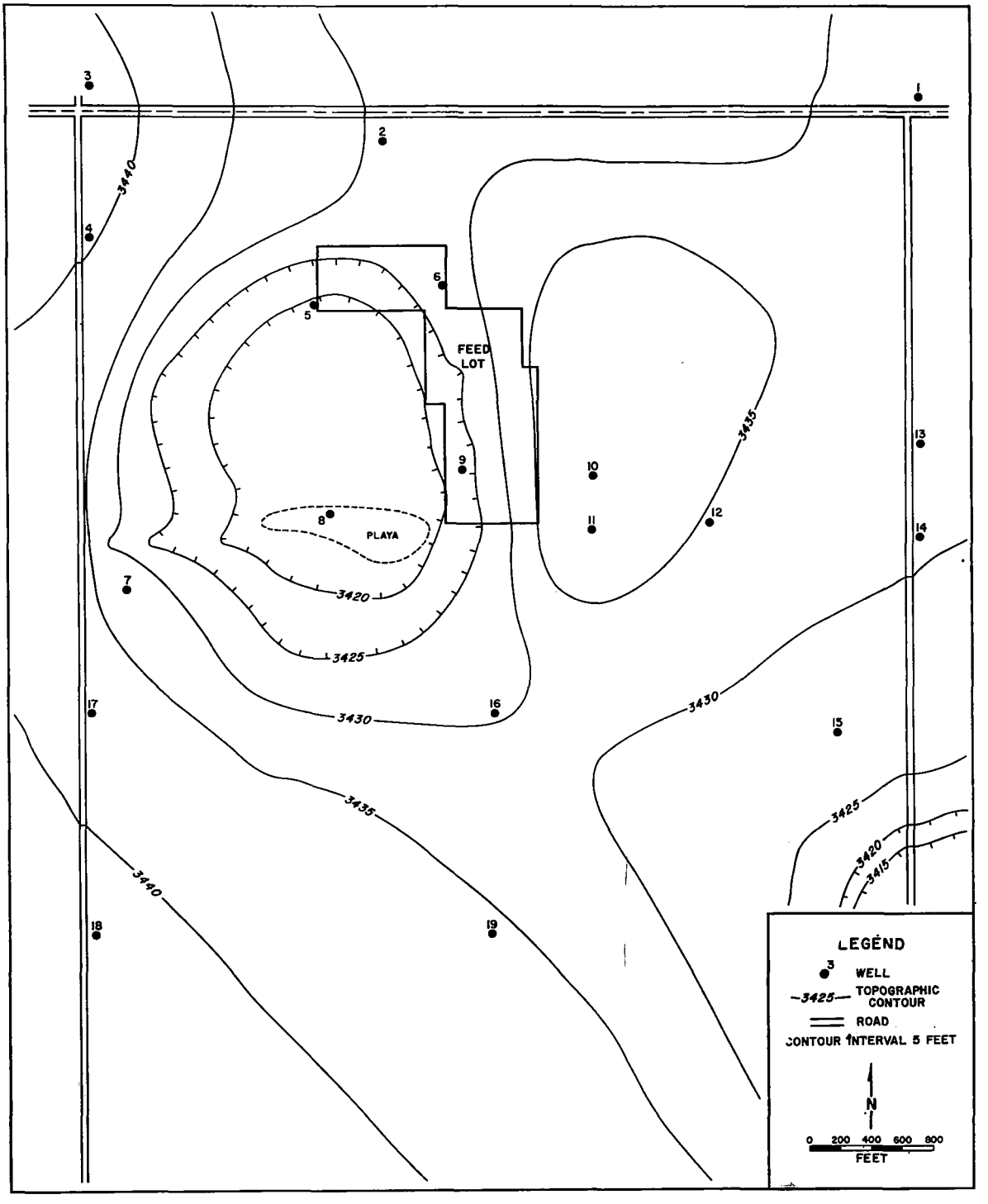


FIGURE 5--DISTRIBUTION OF OBSERVATION WELLS, FIELD SITE I

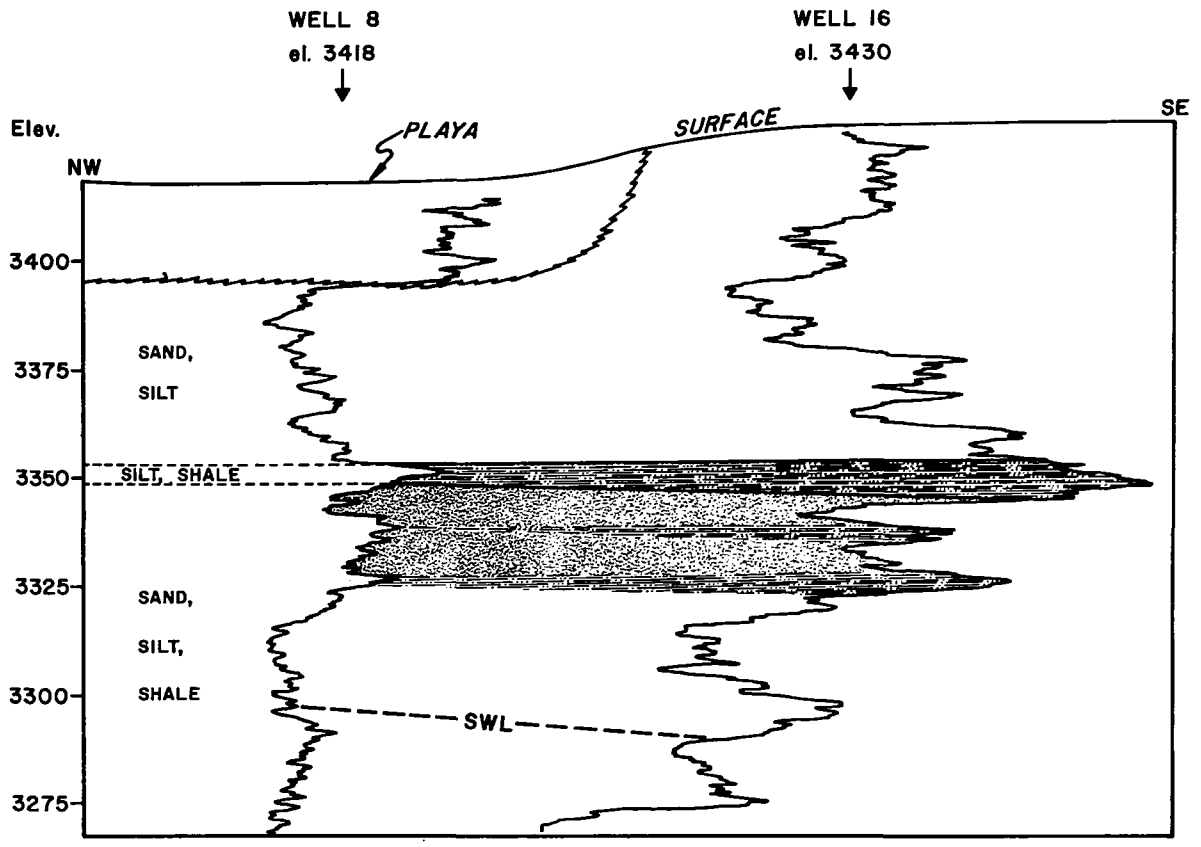


FIGURE 6--GAMMA LOG PROFILES, FIELD SITE I

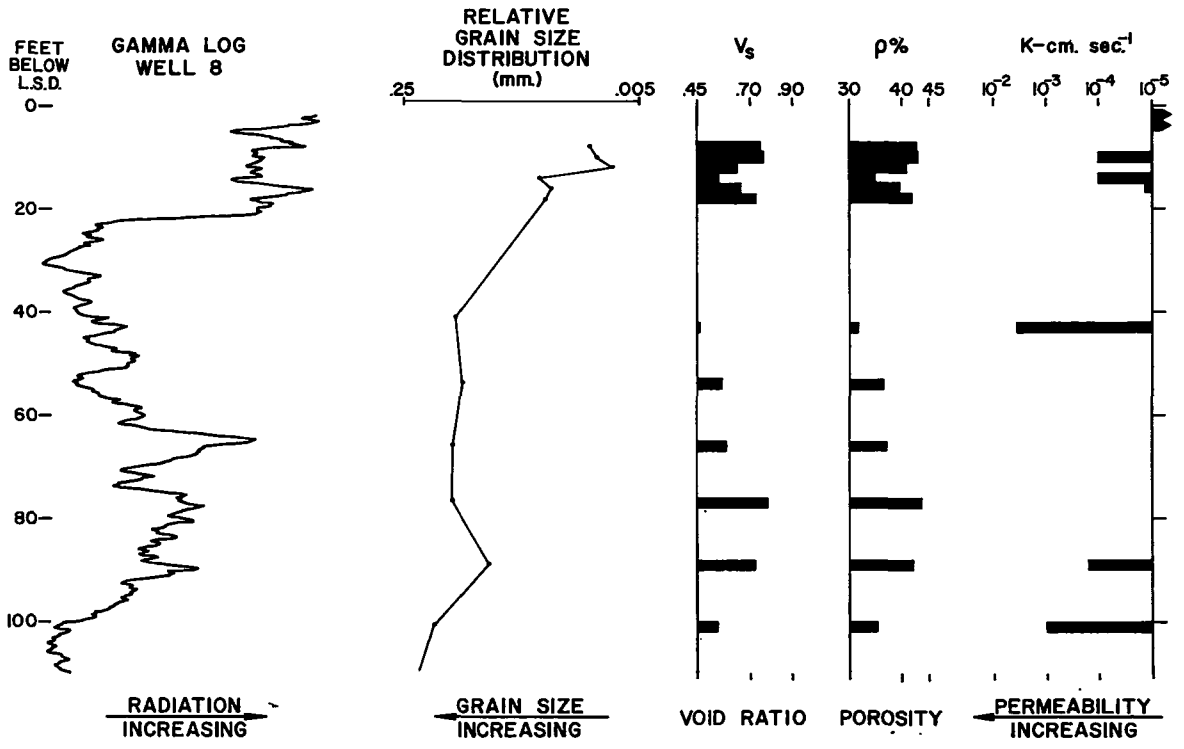


FIGURE 7--SUBSURFACE HYDROLOGIC PARAMETERS, FIELD SITE I

TABLE II--CORE CHEMISTRY, WELL #8, FIELD SITE I

FEET BELOW L.S.D.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	CL	SO_4	TDS	pH	% MOIST
0	6.64	0.003	0	0.84	38	6	20	28	214	8.03	13
9	1.33	0.003	0	0.84	44	4	20	20	78	8.10	15
17	1.33	0.003	0	0.56	42	8	20	16	448	8.13	13
44	0.44	0.003	0	0.56	38	8	20	12	68	8.22	17
67	0.88	0.003	0	0.56	45	6	26	13	192	8.01	17
90	0.81	0.003	0	0.56	30	9	12	11	120	8.30	13

ALL CHEMICAL CONCENTRATION VALUES REPORTED AS DRY WEIGHT; ALL IONS IN P.P.M.

at Field Site I during its 11 years of existence, the conclusion is that near-surface permeabilities are the controlling factor in the extended seepage time.

The saturated zone of the Ogallala Formation is 180 feet in thickness. The Triassic immediately underlying the Ogallala is an aquiclude, as is usual in the High Plains. Flow direction in the Ogallala is normally toward the east but the presence of the open borehole has resulted in a mound on the watertable. The mound is recognizable for a radius of approximately 800 feet in a southeast direction from Well #9. The present difference in head from epicenter to the southeast edge of the mound is on the order of 10 feet. This well is pumped intermittently; therefore, the geometry of the mound varies with time.

Groundwater chemistry (Table III, page 25) was determined from sampling of 19 observation wells. The real indicators of runoff reaching the groundwater zone at this site are the high NO_2-N and NH_4-N values of Well #9. Distribution of "above-normal" NO_3-N in groundwater (Figure 8) corresponds to the geometry of the groundwater mound described previously.

Rate of dispersal of runoff-derived groundwater has averaged 400 feet/year. This field rate is reported under conditions of periodic rainfall-injection and on a recovery-as-needed basis.

Scalf, Hauser, McMillion, Dunlap and Keeley (5), and Schneider, Jones and Wiese (6) report from short-term induced injection-recovery studies of NO_3 movement in the Ogallala Formation that rates of movement under injection exceed the 400 feet/year value. Also, these investigators revealed that recovery

TABLE III--GROUNDWATER CHEMISTRY, FIELD SITE I

WELL NO.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	NA	K	CL	SO_4	COND.	pH
1	1.3	0.000	0.00	0.00	42	41	31	8	70	60	735	7.3
2	1.1	0.009	*	*	18	48	33	10	34	140	647	7.5
3	1.4	0.001	*	0.22	53	29	34	9	22	7	855	7.3
4	1.0	0.003	*	0.42	83	30	29	9	64	26	685	7.8
5	2.1	0.000	*	*	56	52	78	7	110	100	765	7.3
6	1.3	0.100	0.00	0.00	44	45	20	8	46	40	680	7.2
7	1.0	0.003	*	*	42	63	28	8	23	*	660	7.4
8	0.9	0.600	0.00	3.60	48	47	16	8	54	40	600	7.5
9	7.9	6.300	11.77	7.00	58	41	45	42	71	40	735	7.3
10	4.4	0.006	0.28	0.00	68	78	20	11	170	40	1040	7.1
11	2.4	*	*	*	40	79	29	11	64	*	660	7.3
12	0.8	0.006	*	*	40	39	27	7	25	40	690	7.3
13	0.8	0.003	*	0.14	78	30	36	10	52	21	680	7.8
14	0.8	0.003	*	0.28	17	26	*	*	40	20	640	7.8
15	0.6	0.015	*	*	44	74	25	11	28	*	640	7.3
16	0.5	*	*	*	36	47	31	10	23	*	490	7.4
17	0.7	*	*	*	40	44	41	10	25	*	640	7.3
18	0.5	*	*	*	44	45	25	10	32	*	645	7.3
19	3.5	0.003	*	0.28	80	27	*	*	52	25	558	7.9

ALL VALUES IN P.P.M. EXCEPT CONDUCTANCE AND pH. CONDUCTANCE IN MICROMHOS

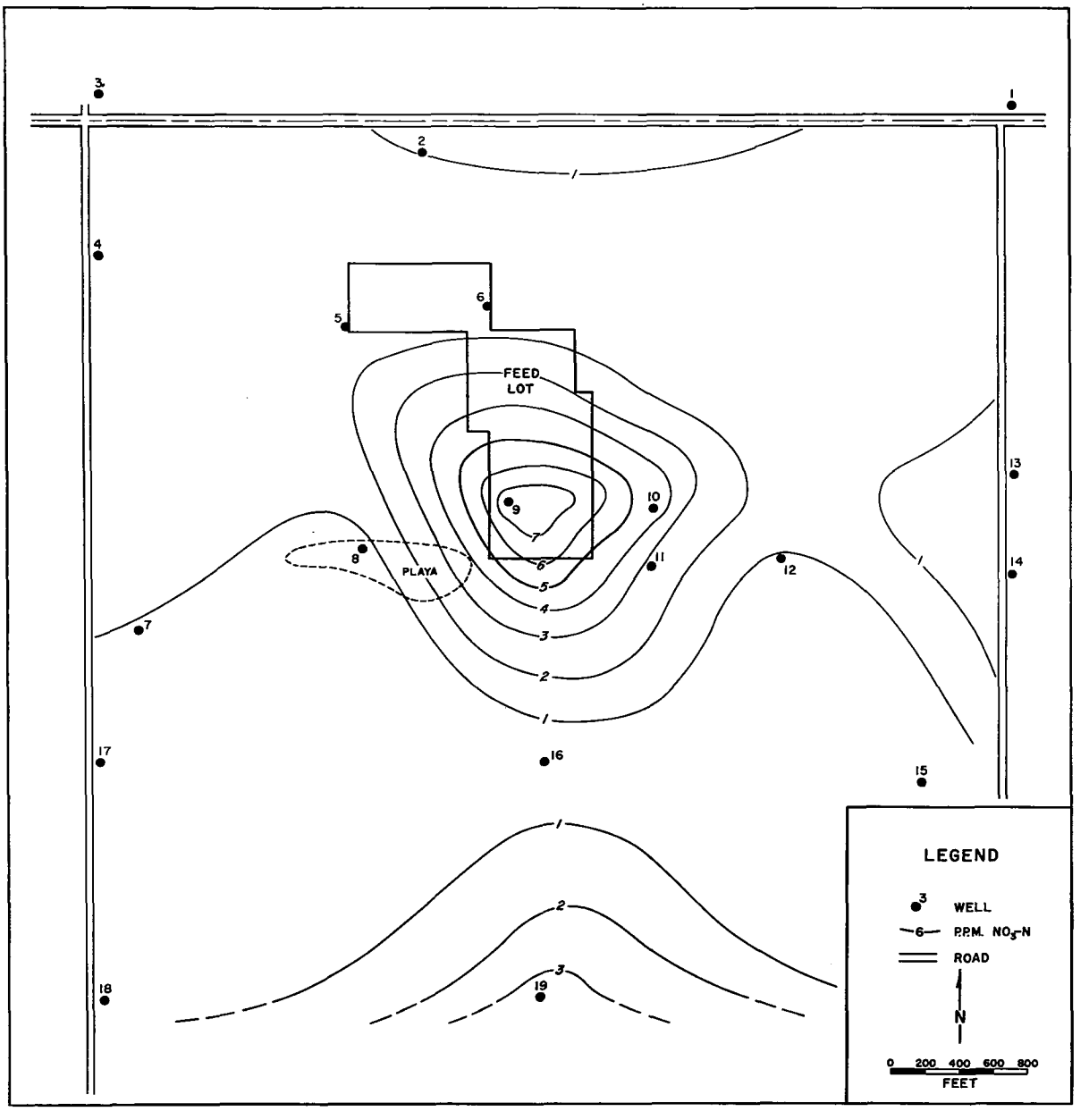


FIGURE 8--DISTRIBUTION OF NO_3-N IN GROUNDWATER, FIELD SITE I

of injected NO_3 is related closely to volume of water recovered during pumping. Even though very high concentrations of dissolved solids in runoff have flowed to the groundwater zone at this site, high concentrates do not exist at great distances from the borehole. This relationship is due essentially to volume recovery of high TDS concentrates near the bore hole, and due to dilution away from the point source of injection.

Field Site II. Location of observation wells of Field Site II are shown in Figure 9. Site II is a 19-year feedlot with a one-time cattle capacity of 8,000 head. A playa collects runoff from the feedlot and, in periods of high rainfall, runoff flows southwestward down an intermittent drainage channel. Water stands in the playa except for relatively long dry periods. Drainage slope of the feedpen is approximately one percent.

The Ogallala Formation crops out at the surface. The feedpen surface is soil covered, and below this lies a caliche "caprock." The caliche is breached in the deepest part of the playa. The playa fill consists of 5 feet of dense, impermeable clay below which lies 15 feet of clay-silt and secondary nodular caliche. The lake fill overlies fine-grain, clean sand of the Ogallala Formation that typically underlies the small playas in the High Plains (Figure 10). Constant head permeability values of the unsaturated zone range between 1.0×10^{-4} cm/sec to 4.7×10^{-3} cm/sec (Figure 11). Playa lake clay permeability is 10^{-7} cm/sec, or less.

Surface material is the only impediment to seepage of feedlot runoff at this locality. Seepage occurs at this site as indicated by core chemistry (Table IV) and degreee of saturation (66-87%) above the watertable.

Field Site II has been in existence for 19 years; depth to the watertable at this location averages 115 feet. Theoretically, average rates of seepage have exceeded 6.0 feet/year. As stated, the minimum permeability of the Ogallala is 1.0×10^{-4} to 4.7×10^{-3} cm/sec (exceeds 100 ft/yr). In practical terms, average field seepage rates are controlled by near-surface seepage rates; the actual rate is indeterminable.

An average 200 foot saturated zone occurs within the Ogallala Formation in this area; the underlying Triassic serves as an aquiclude. As is typical in the High Plains, groundwater flow is to the southeast.

Groundwater-quality parameters (Table V) for this site were established from 14 observation wells. Nitrate-nitrogen values in groundwater range from 0.8 to 7.9 parts per million.

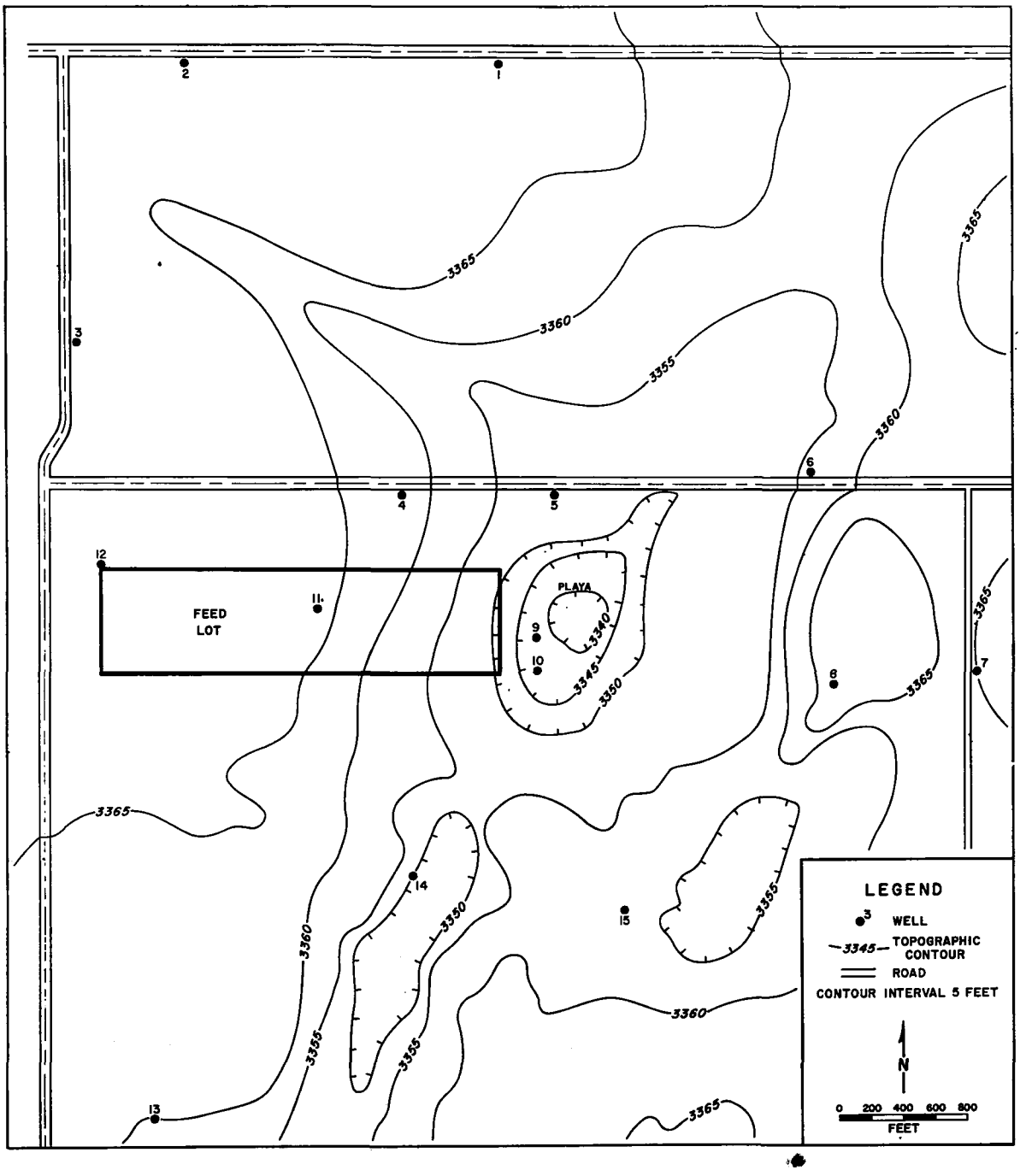


FIGURE 9--DISTRIBUTION OF OBSERVATION WELLS, FIELD SITE II

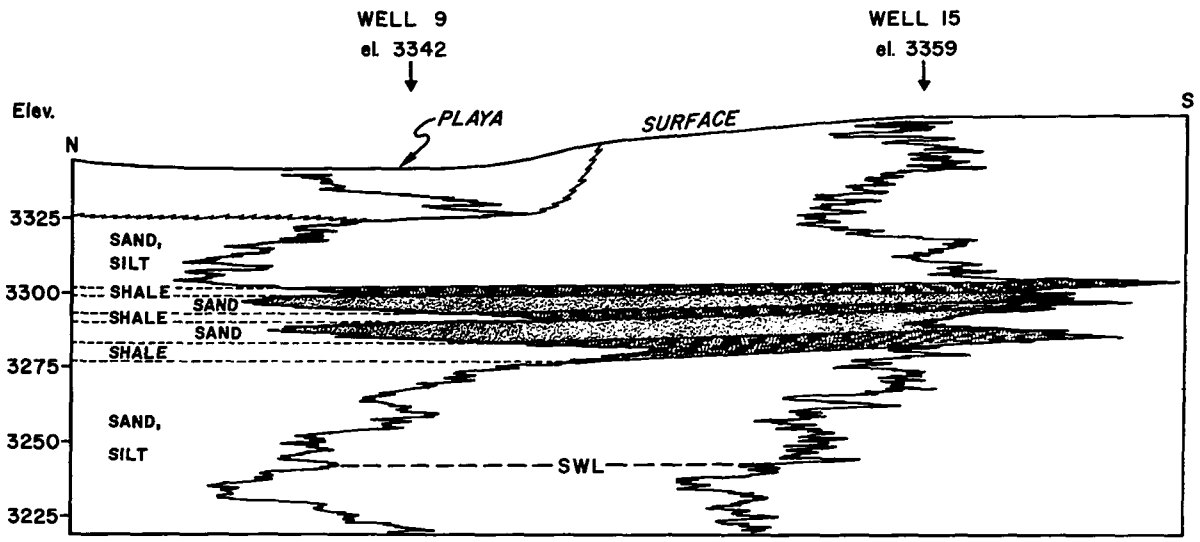


FIGURE 10--GAMMA LOG PROFILES, FIELD SITE II

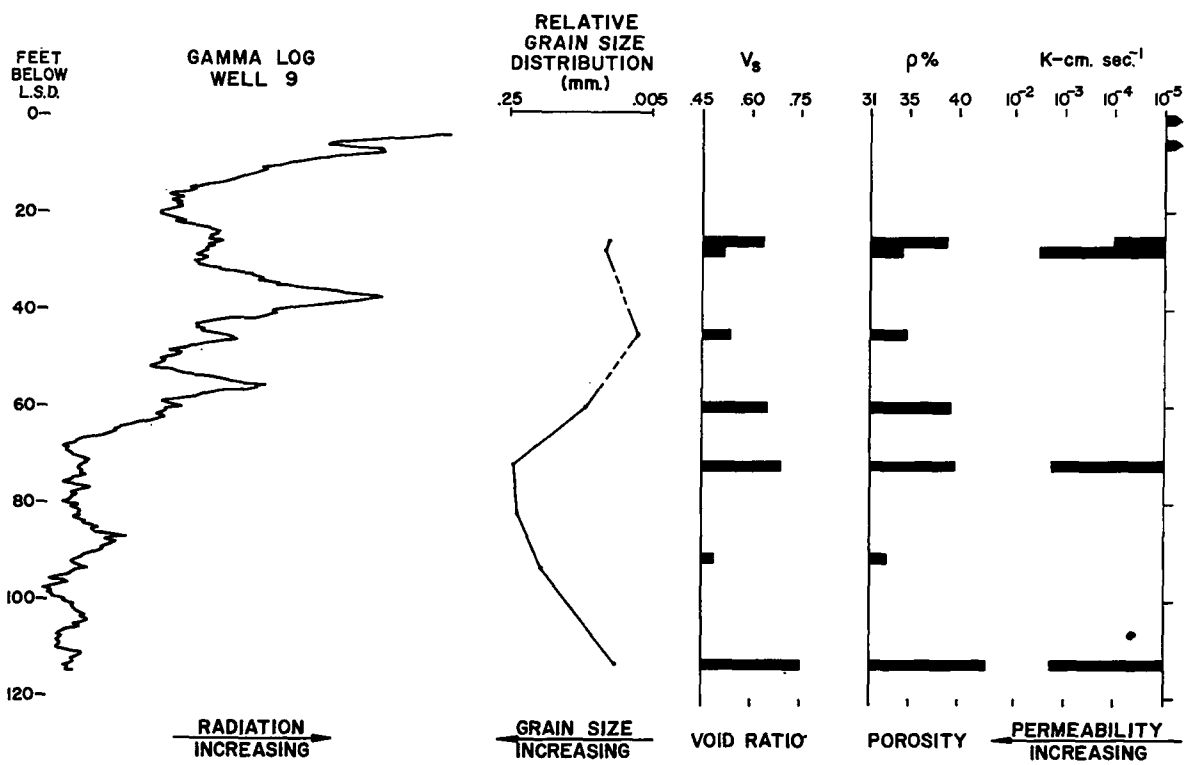


FIGURE 11--SUBSURFACE HYDROLOGIC PARAMETERS, FIELD SITE II

TABLE IV--CORE CHEMISTRY, WELL #9, FIELD SITE II

FEET BELOW L.S.D.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	NA	K	CL	SO_4	TDS	pH	% MOIST
0.0	374.20	5.39	114.60	10556.80	*	*	*	*	*	*	14700	*	8.4
2.5	152.80	3.32	0	3476.00	*	*	*	*	*	*	*	*	25.7
4.5	76.20	2.40	9.40	531.50	108	41	*	*	383	*	1764	*	25.5
6.5	67.72	0.95	37.54	227.60	68	29	42	86	220	25	1176	7.3	16.1
9.5	65.69	*	20.23	123.70	44	34	30	71	170	25	1000	7.4	13.5
12.0	43.54	2.44	8.94	301.40	72	22	38	78	220	25	1176	7.3	21.7
18.0	72.57	1.69	8.94	130.30	84	46	30	43	188	25	1118	7.3	21.7
25.0	14.64	1.49	0	1.29	60	34	28	38	142	25	942	7.4	22.4
46.0	26.68	1.88	0	184.27	120	46	30	36	262	75	647	7.3	14.8
61.0	0	0.69	0	128.50	84	39	12	28	167	25	559	7.4	13.6
73.0	0	1.07	0	15.74	64	32	32	26	156	75	471	7.2	17.4
83.0	13.94	1.23	0	35.58	60	36	32	26	149	25	529	7.3	18.5
94.0	13.36	1.51	0	149.41	128	46	14	32	230	25	647	7.2	15.0
114.0	0	1.06	0	32.65	68	68	12	34	230	25	588	7.3	17.3

ALL CHEMICAL CONCENTRATION VALUES REPORTED AS DRY WEIGHT: ALL IONS IN P.P.M.

Nitrate-nitrogen values beneath this site are below the maximum value for the immediate area; therefore, NO_3-N independently is not prima facie evidence of seepage. However, Ca, Mg, Cl, and conductance values (Well #10, Table V) show that seepage is detectable in groundwater below the feedlot site. The relatively high chloride (Well #10) is not detectable for more than 800-900 feet away from the epicenter of the playa collection system (Figure 12). Assuming that runoff could have reached the groundwater zone within the first year the site was in operation, the minimum rate of dispersal in groundwater has been approximately 45 feet/year. Permeability values of the Ogallala indicate that minimum seepage time would be 2-3 years; therefore, minimum dispersal rates would be on the order of 55 feet/year.

Field Site III. Location of observation wells of Field Site III are shown in Figure 13. This site is four years old with a one-time cattle capacity of 4,000 head. The operation is located on a stream, the stream channel serving as the collection system for runoff. Runoff collects in a low, dredged-out area of the channel, with the system overflowing during periods of high rainfall. Drainage slope in the feedpens is 3-4%, and the stream channel has a gradient of less than ten degrees.

TABLE V--GROUNDWATER CHEMISTRY, FIELD SITE II

Well No.	NO_3-N	NO_2-N	Am-N	Org-N	Ca	Mg	Na	K	Cl	SO_4	COND.	pH
1	4.2	*	0.00	0.00	46	46	21	10	53	40	647	7.4
2	4.2	*	*	*	46	45	37	10	52	40	650	7.4
3	7.9	*	0.00	0.00	46	45	40	11	53	40	588	7.4
4	7.1	0.060	0.00	0.00	46	44	21	10	64	40	647	7.3
5	5.0	0.009	0.00	0.00	46	46	21	10	45	40	676	7.4
6	3.3	0.006	0.00	0.00	54	46	28	13	59	40	618	7.3
7	2.8	0.015	0.00	0.00	45	51	32	9	52	40	627	7.2
8	4.7	0.031	0.00	0.00	54	35	33	11	50	40	599	7.3
9	*	*	*	*	*	*	*	*	*	*	*	*
10	5.0	0.020	0.00	0.00	74	85	24	10	89	50	1029	7.3
11	2.5	0.400	0.00	0.00	40	41	41	10	53	40	620	7.3
12	2.5	0.009	*	*	40	51	22	10	53	40	735	7.4
13	1.3	0.006	0.00	0.00	54	28	80	11	60	40	559	7.2
14	1.8	*	*	*	22	44	10	10	26	*	620	7.7
15	0.8	0.000	0.00	0.70	40	55	82	8	37	100	794	7.2

All values in P.P.M. except conductance and pH. Conductance in micromhos
[9]Core Hole

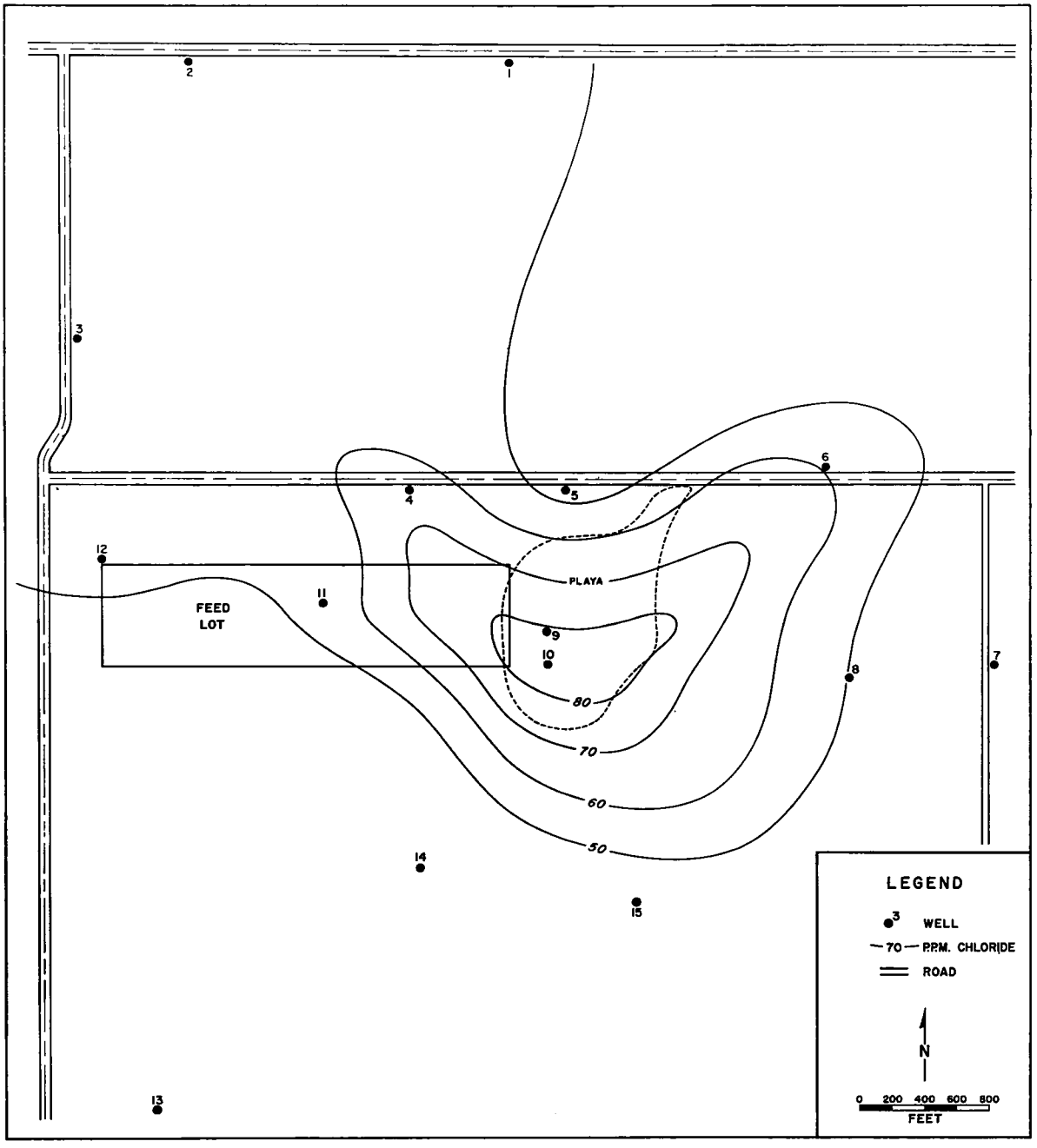


FIGURE 12--DISTRIBUTION OF CHLORIDE IN GROUNDWATER, FIELD SITE II

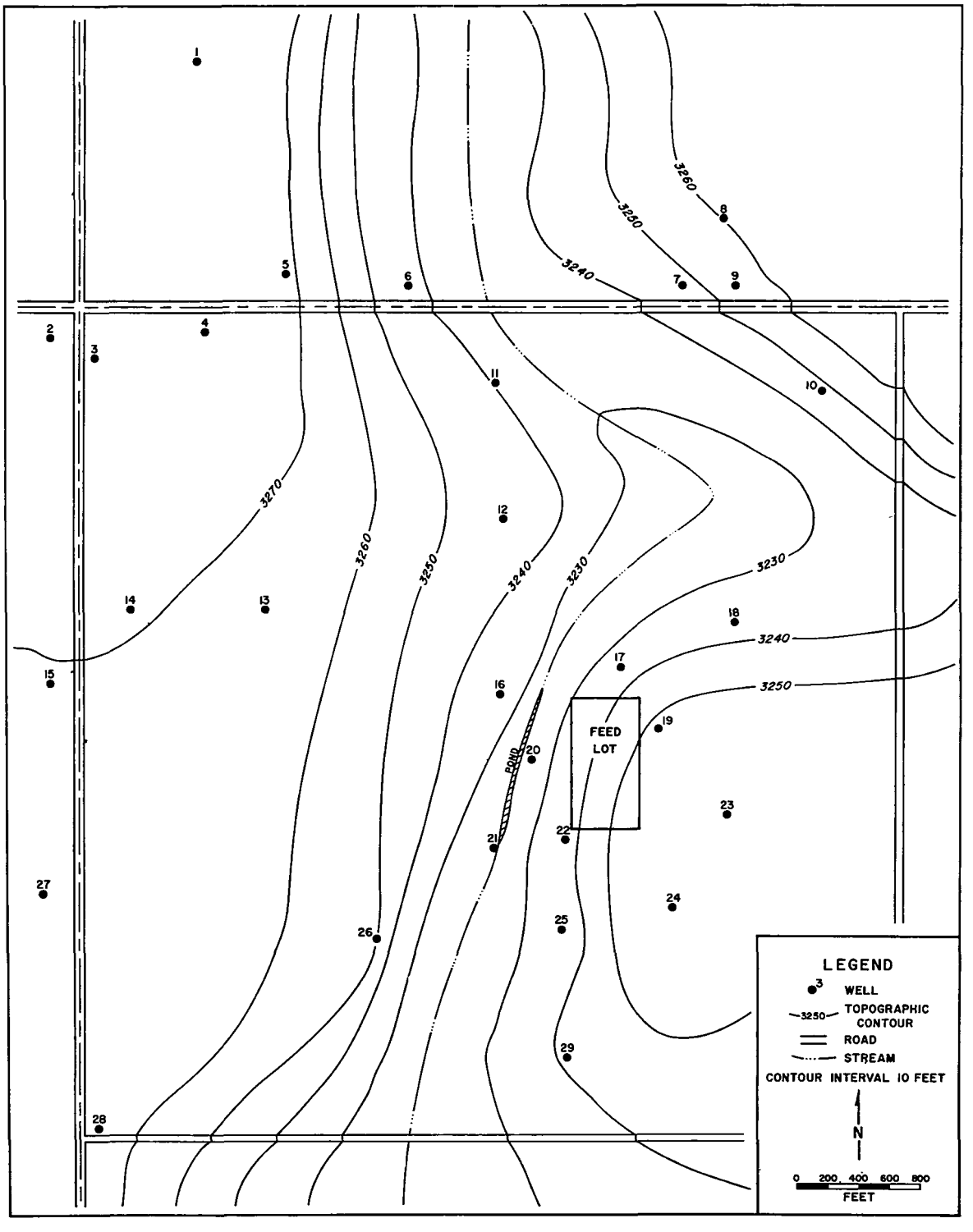
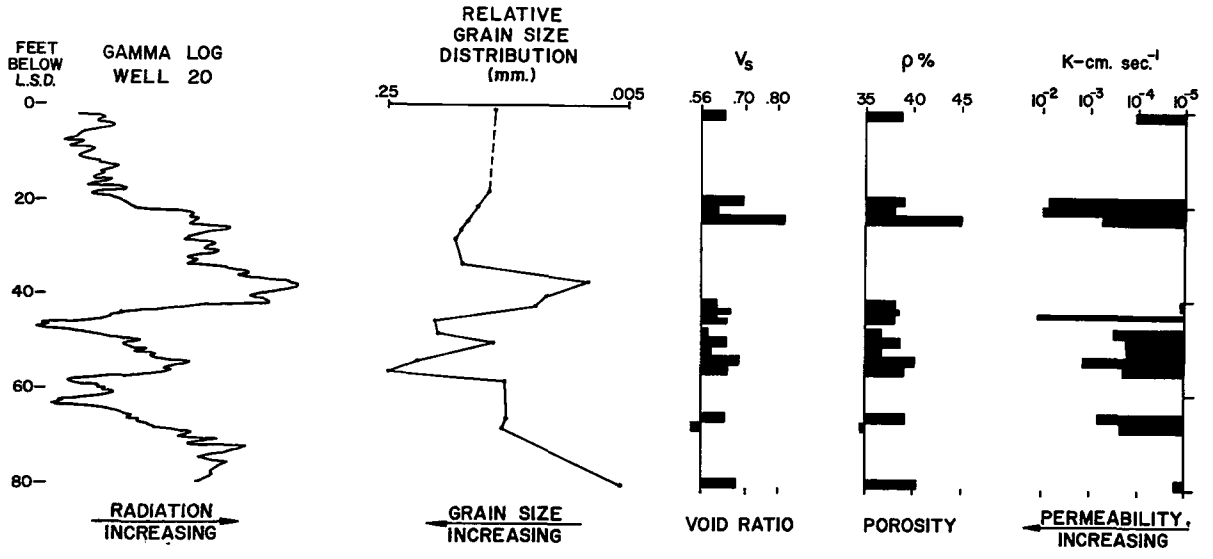


FIGURE 13--DISTRIBUTION OF OBSERVATION WELLS, FIELD SITE III

The Ogallala Formation crops out at the surface, with less than 10' of Pleistocene "cover sand" and soil overlying the Ogallala caliche "caprock." The caliche is within the feed-pens but is breached in the low part of the stream channel. Subsurface lithology (Figure 14) consists of zones of clay, silt, clay-silt mixtures, and zones of fine to medium-grain sand typical of the upper part of the Ogallala Formation.

Constant head permeability values in the unsaturated zone of the Ogallala at the site range from 1.9 X 10^{-5} cm/sec to 1.39 X 10^{-2} cm/sec (Figure 14). There are no essentially impervious stratigraphic units detectable between the surface and watertable.

FIGURE 15--SUBSURFACE HYDROLOGIC PARAMETERS, FIELD SITE III



Percentage saturation values of effective pore space of 75-85% in several cores indicate that seepage does take place. Also, core chemistry (Table VI) indicates a NO_3-N profile of 170 p.p.m. near the surface to 11 p.p.m. at a depth of 80 feet.

The rate of initial seepage probably is less than horizontal flow rates in the saturated zone, as evidenced by the lack of a groundwater mound beneath the collection pond. The depth of water at this 4-year-old site ranges from 60-90 feet. Seepage has reached the groundwater zone; therefore, the minimum average field seepage rate is on the order of 15-23 feet/year. Minimum permeability values determined in the laboratory are 20 feet/year.

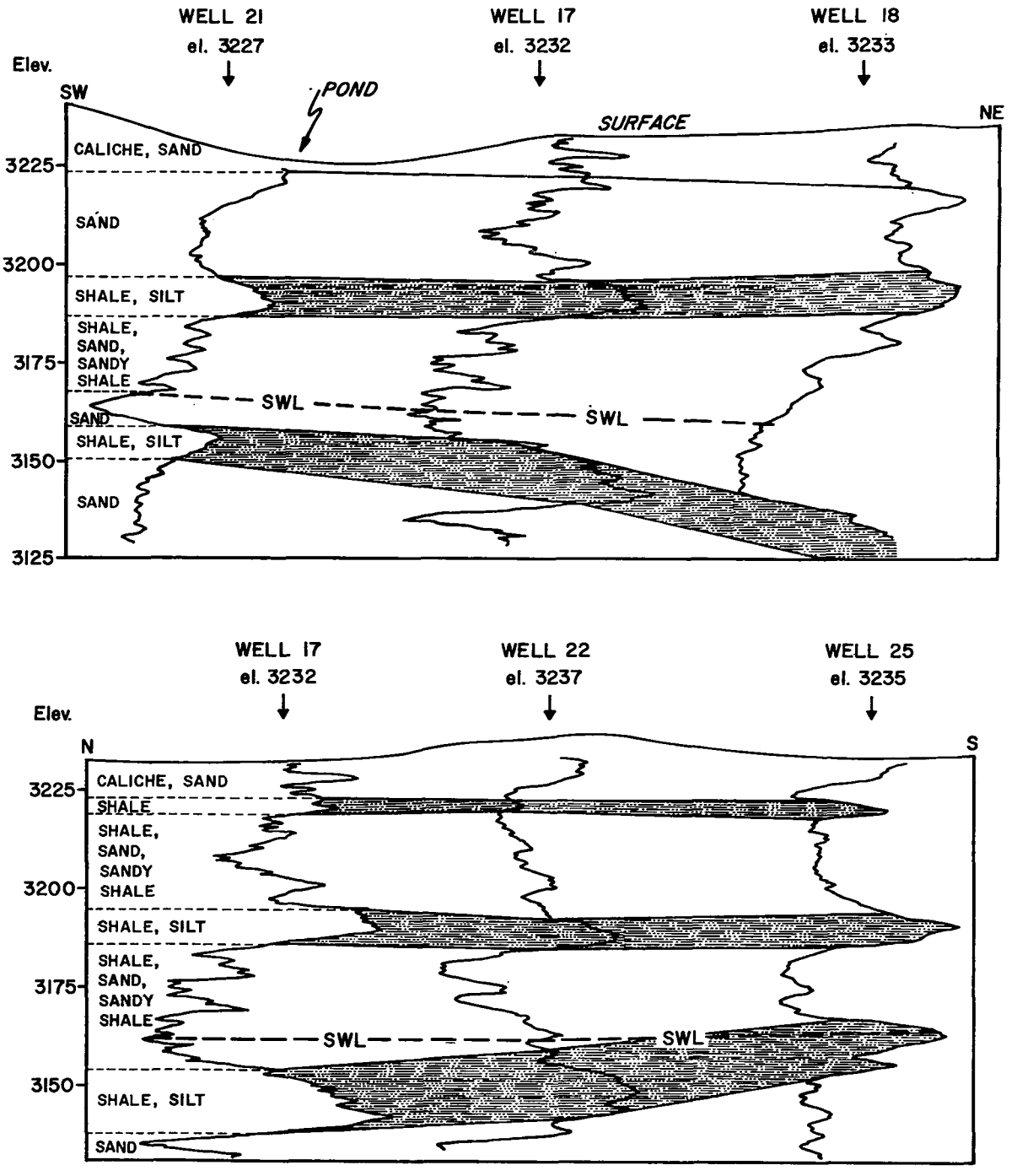


FIGURE 14--GAMMA LOG PROFILES, FIELD SITE III

TABLE VI--CORE CHEMISTRY, WELL #20, FIELD SITE III

FEET BELOW L.S.D.	NO_3-N	NO_2-N	ORG-N	K	CL	% MOIST
2	170	0.80	585	400	567	14.3
6	68	0.92	85	60	549	15.2
18	22	0.44	102	40	461	14.7
21	22	0.92	94	40	461	18.3
28	22	0.96	23	40	372	19.8
36	45	0.52	46	40	390	16.8
37	45	0.48	95	120	355	18.1
45	50	0.52	51	40	390	14.9
54	11	0.76	16	40	319	16.3
68	44	0.88	45	60	337	17.0
80	11	0.96	212	120	408	10.1

ALL CHEMICAL CONCENTRATION VALUES REPORTED AS DRY WEIGHT; ALL IONS IN P.P.M.

The saturated zone in the vicinity of Site III is within the Ogallala Formation and the underlying Cretaceous limestone. Saturated thickness is 100 feet and, within this zone, flow direction is to the east.

Water-quality parameters determined from samples from 28 observation wells in the area are shown in Table VII. NO_3-N values in the vicinity range from 0.7 to 16.7 parts per million. "Normal" background NO_3-N values approximate a range of 0.7 to 7.1 parts per million. This is the range in values in the area west of the feedlot and up-dip on the watertable.

Abnormally high NO_3-N values (distribution, Figure 16) exist near the feedlot and below the floodplain that exists north of the feedlot. The floodplain has been under cultivation and fertilization for many years and some of the NO_3-N in the groundwater is attributed to this practice. With groundwater flow to the east, if the feedlot were the principal source of NO_3-N, the influent nitrogen would be expected to have reached Well #23 (Location, Figure 13) before or by the time water was degraded in wells numbered 22, 24, and 25. Wells #23 and #24 are more apt to represent distance of movement, which is on the order of a few hundred feet, with an average rate of 100 feet/year.

TABLE VII--GROUNDWATER CHEMISTRY, FIELD SITE III

WELL NO.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	NA	K	CL	SO_4	COND.	pH
1	1.4	*	*	*	65	27	54	9	45	*	705	7.4
2	7.1	0.160	0.28	2.23	94	77	78	16	25	75	1323	7.2
3	2.6	0.009	*	0.84	88	44	*	*	150	86	692	7.6
4	4.2	0.100	0.28	1.02	50	50	59	13	85	100	882	7.4
5	5.5	0.020	0.00	0.83	60	50	62	13	113	50	941	7.3
6	1.4	0.006	0.84	0.00	70	58	67	17	117	150	1058	7.3
7	15.7	0.600	0.00	0.10	58	39	59	14	46	40	765	7.4
8	15.7	0.530	0.00	0.10	50	36	56	13	32	40	647	7.2
9	15.1	0.030	0.56	2.14	50	51	65	12	50	52	882	7.3
10	7.9	0.130	*	1.52	50	57	57	21	64	80	613	7.3
11	5.6	0.009	0.00	0.00	54	25	64	17	60	40	1058	7.2
12	4.0	0.003	0.00	0.10	58	26	57	16	67	40	735	7.3
13	5.8	*	0.00	*	60	54	78	18	124	40	941	7.3
14	5.0	*	0.00	0.00	82	22	72	22	142	80	853	7.4
15	3.9	0.010	0.84	1.51	54	51	56	13	103	50	882	7.4
16	6.7	0.009	0.00	0.00	54	25	59	17	82	40	824	7.2
17	14.9	0.020	0.00	0.48	50	52	65	13	71	100	1100	7.4
18	16.7	0.060	*	0.10	51	55	65	12	58	*	1040	7.3
19	13.5	0.240	0.56	0.00	64	62	57	15	57	40	647	7.1
20	*	*	*	*	*	*	*	*	*	*	*	*
21	11.7	0.009	0.00	0.10	53	28	60	17	50	*	824	7.4
22	11.7	0.009	0.00	0.10	50	52	63	16	59	75	824	7.3
23	0.9	0.000	0.00	*	48	35	60	15	69	85	618	7.4
24	5.0	0.070	*	0.81	50	69	62	24	92	80	658	7.2
25	10.8	0.012	0.00	0.10	48	44	58	12	57	100	706	7.3
26	5.0	0.010	0.00	0.44	58	56	64	14	30	100	1069	7.4
27	0.7	0.003	0.28	*	76	60	74	17	138	100	1058	7.2
28	3.9	0.010	0.84	*	90	77	78	15	138	125	1176	7.2
29	3.4	0.004	0.00	0.00	44	49	64	12	59	280	730	7.4

ALL VALUES IN P.P.M. EXCEPT CONDUCTANCE AND pH. CONDUCTANCE IN MICROMHOS

[20] CORE HOLE

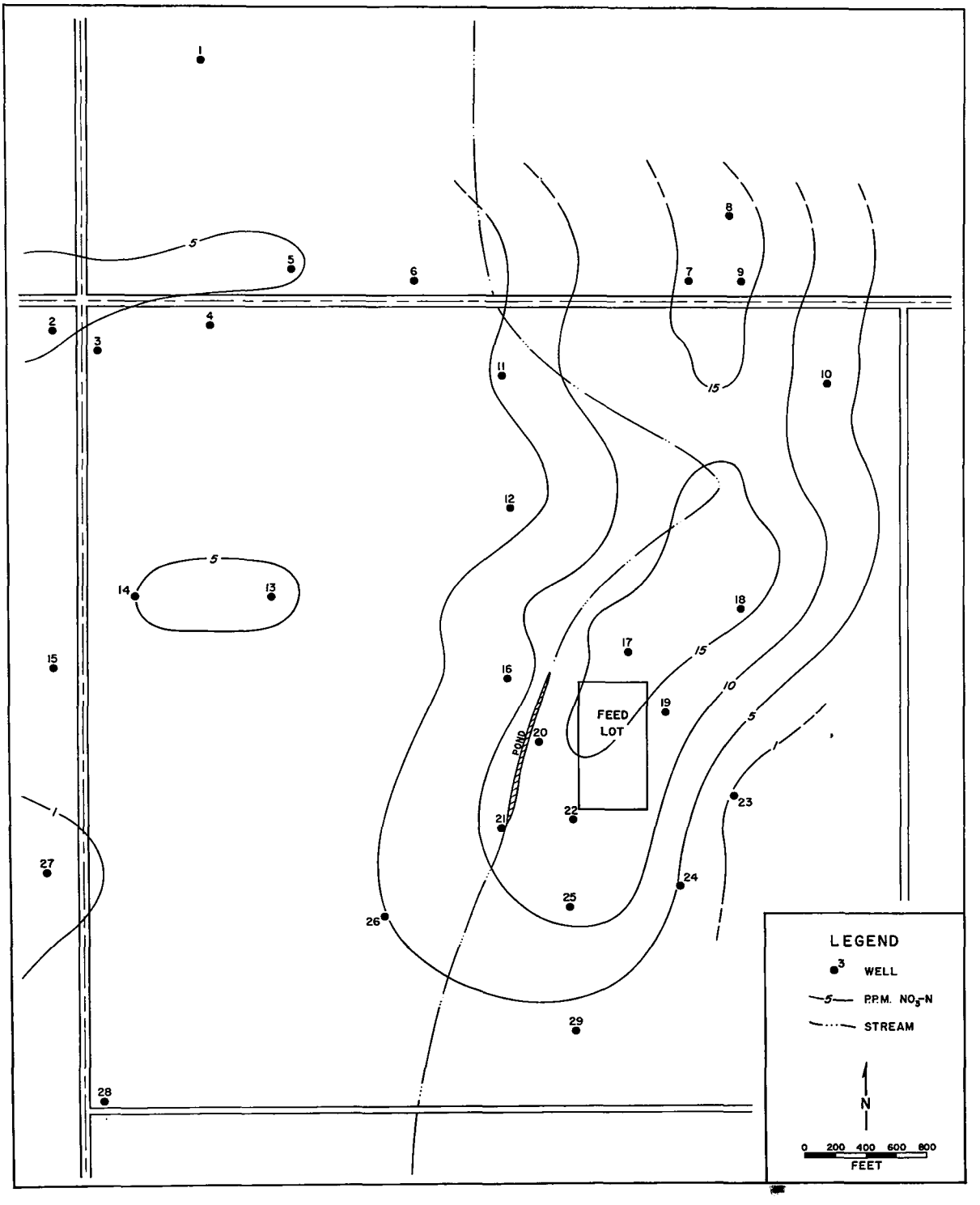


FIGURE 16--DISTRIBUTION OF NO_3-N IN GROUNDWATER, FIELD SITE III

Field Site IV. Field Site IV observation wells are shown in Figure 17. This location has been in use for 16 years with a one-time capacity of 4,500 cattle. Runoff from this site collects in a playa.

The Ogallala Formation crops out at the surface. Playa sediments are 10 feet in thickness, including a 4-foot upper clay layer. The clay layer of the playa is relatively impermeable at the cored location (Well #7). Typical subsurface lithologies of the Ogallala are depicted in Figure 18.

Nine cores were taken in the Ogallala Formation beneath the pond, and representative analyses indicate a constant head permeability range in value of 5.27×10^{-5} cm/sec to 1.03×10^{-3} cm/sec (Figure 19).

Core chemistry (Table VIII) indicates that NO_3 has penetrated to a depth of at least 46 feet, and other ions show a decreasing trend to the watertable. Calcium, potassium, and conductivity values decrease sharply below 11 feet. Based on NO_3-N, the field seepage rate has been no more than 3-4 feet/year.

TABLE VIII--CORE CHEMISTRY, WELL #7, FIELD SITE IV

FEET BELOW L.S.D.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	NA	K	CL	SO_4	TDS	pH	% MOIST
2.5	0.00	1.40	0.00	113	*	*	*	*	*	*	*	*	14.2
6	12.45	1.59	0.00	33	84	26	68	30	230	80	1058	7.3	9.3
11	13.04	1.25	0.00	67	88	26	38	44	242	40	1000	7.4	13.4
30	*	*	*	*	34	13	60	27	117	40	647	7.4	*
46	13.33	1.18	0.00	0	32	34	8	22	78	80	588	7.4	15.3
57	0.00	1.68	0.00	171	28	36	11	17	78	40	529	7.3	18.9
68	0.00	1.29	0.00	32	24	18	18	14	69	40	412	7.4	15.0
88	0.00	1.13	0.00	65	16	16	33	10	53	40	647	7.4	15.2
110	0.00	1.04	0.00	32	24	16	32	10	62	80	382	7.5	15.2

ALL CHEMICAL CONCENTRATION VALUES REPORTED AS DRY WEIGHT; ALL IONS IN P.P.M.

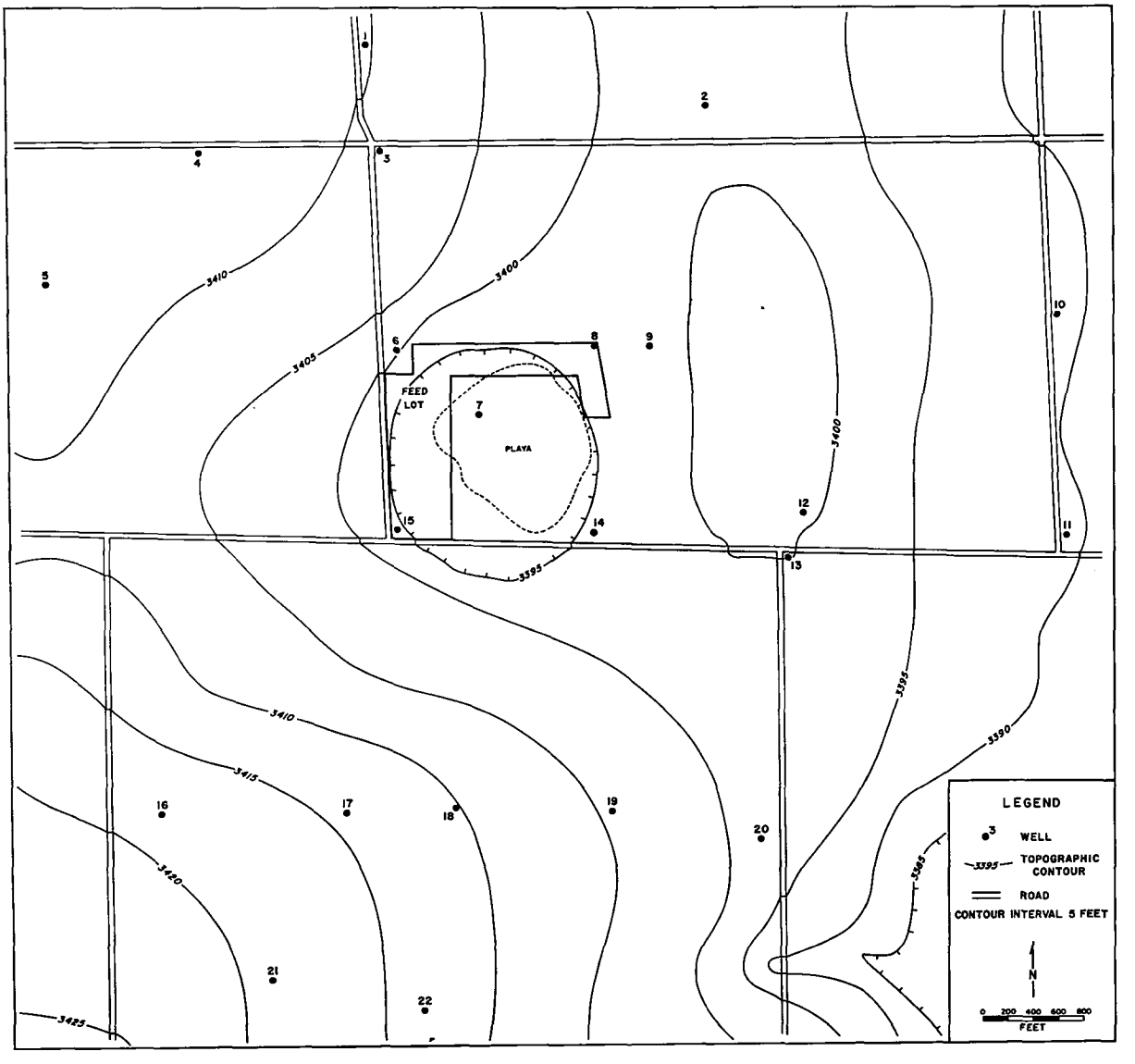


FIGURE 17--DISTRIBUTION OF OBSERVATION WELLS, FIELD SITE IV

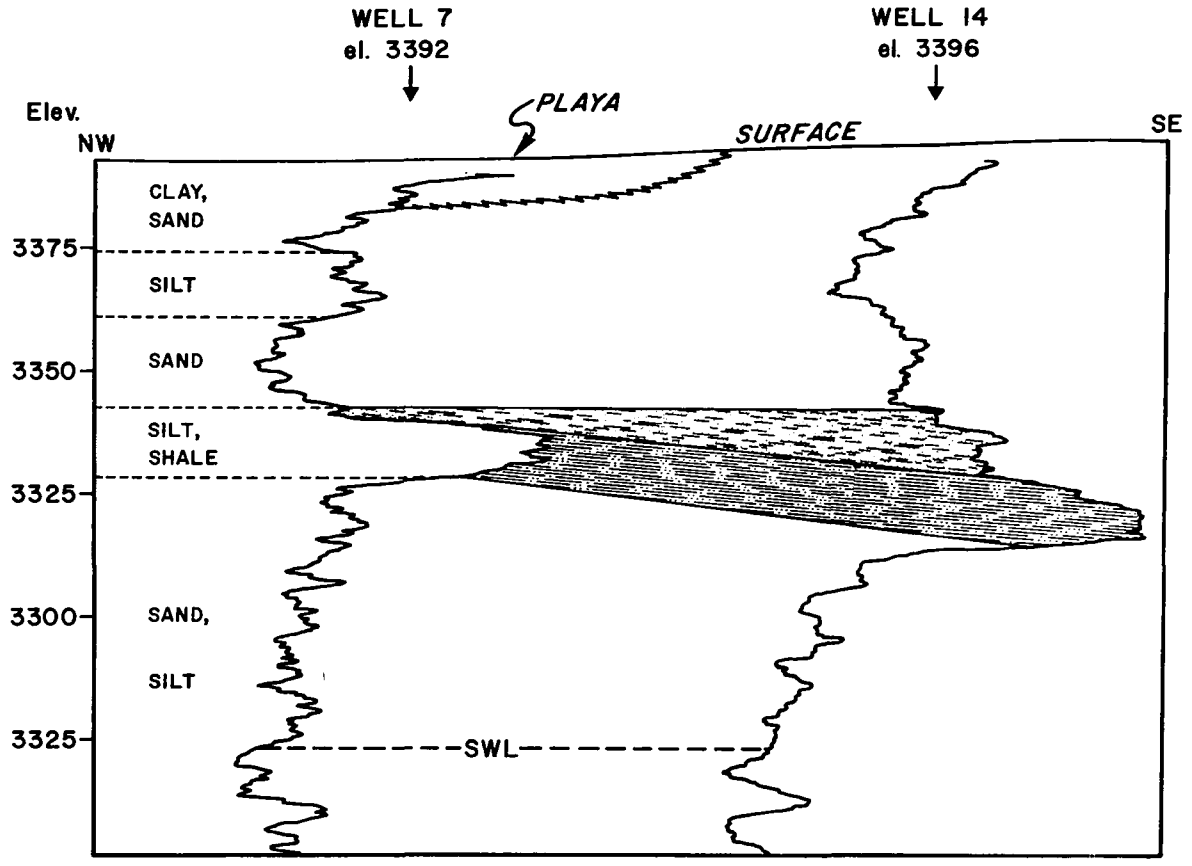


FIGURE 18--GAMMA LOG PROFILES, FIELD SITE IV

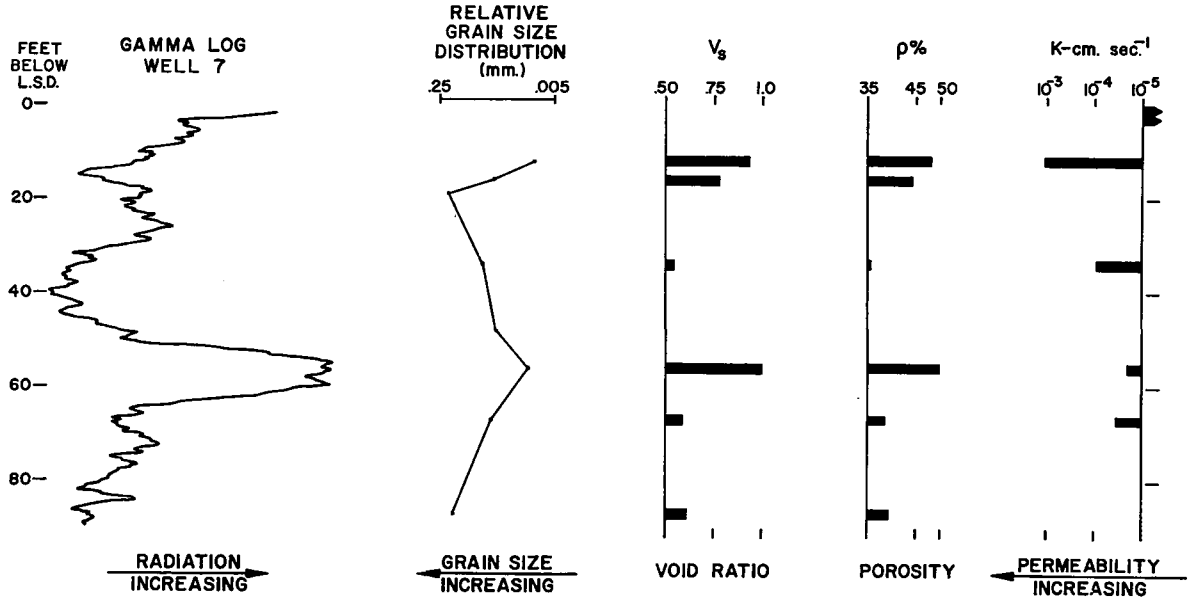


FIGURE 19--SUBSURFACE HYDROLOGIC PARAMETERS, FIELD SITE IV

The saturated zone of the Ogallala Formation is 200 feet in thickness. Within this zone, 21 wells were used to collect water samples for chemical analyses (Table IX). In terms of NO_3-N, the range in normal background NO_3-N is 0.7 p.p.m. to 4.7 parts per million. Seepage has not reached the groundwater at this site.

Field Site V. The surface layout of Site V is shown in Figure 20. This site has been in operation for 35 years and has a one-time capacity of 17,000 head of cattle. The capacity was 4,000 cattle in the 1940's, 7-10,000 head in the 1950's, and 15-17,000 head of cattle in the 1960's. Runoff collects in a playa, and the playa water in turn is pumped outside the basin for purposes of irrigation. Feedpen drainage slopes average 1-2 percent.

The Ogallala Formation crops out in the feedpens. A caliche layer exists near the surface, and below this is a typical Ogallala section (Figure 21). The playa is filled with sediment to a depth of about 20 feet.

Constant head permeability values within the Ogallala range from essentially non-pervious to 3.2×10^{-3} cm/sec (Figure 22). The geologic section at this site is less permeable than any of the other sites described in the report.

Core chemistry (Well #9, Table X, p. 46) indicates that perhaps NO_3 has not reached the water table beneath the pond; however, groundwater chemistry (Table XI, Wells 4, 5, 9, 11, 13) indicates some seepage of NO_3 has occurred. The depth to water is 110-115 feet; thus, the 35-year-old-site exhibits an average minimum field rate of infiltration of about 3 feet/year. This falls within the range of laboratory determined permeability values for the site.

The saturated zone at the site is within the Ogallala Formation, and groundwater chemistry was determined from 16 observation wells penetrating this zone. NO_3-N values (distribution, Figure 23) range from 0.8 to 8.4 parts per million; NO_3-N values exceeding 5 p.p.m. are above normal at the site. Rate of dispersal of NO_3-N in groundwater has been less than 100 ft/year.

Other Sites

A minimum of five and a maximum of 25 groundwater samples from beneath each of 75 additional feedlots were chemically analyzed. Distributive groundwater geometry of NO_3-N (and other ions) derived from feedlot runoff was determinable from about 15 to 20 of these sites. The maximum detectable distance of

TABLE IX--GROUNDWATER CHEMISTRY, FIELD SITE IV

WELL NO.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	NA	K	CL	SO_4	COND.	pH
1	0.8	*	*	*	44	39	32	10	27	*	720	7.3
2	1.4	*	*	*	34	55	31	11	44	140	700	7.4
3	2.3	*	*	*	45	48	37	9	34	*	550	7.6
4	2.5	0.120	0	0	44	39	31	9	57	40	647	7.2
5	2.8	0.300	0	0	48	38	33	9	46	40	588	7.4
6	1.7	0.006	0	0	50	55	29	11	39	40	647	7.2
7	1.60	0.030	0	2.0	54	57	11	11	43	20	663	7.6
8	2.1	0.006	0	0	46	34	36	9	41	40	647	7.2
9	1.9	*	*	*	43	37	35	11	39	*	740	7.8
10	0.7	*	*	*	38	57	35	10	21	*	540	7.5
11	3.5	0.200	1.96	0	56	38	41	8	39	40	588	7.2
12	1.4	*	*	*	45	35	54	9	64	*	640	7.3
13	3.6	0.060	0	0	40	36	50	8	50	40	588	7.4
14	1.43	0.010	0	4.87	64	52	21	8	41	20	595	7.5
15	2.1	0.006	*	*	50	55	30	10	43	*	676	*
16	4.1	0.006	*	*	43	47	35	11	47	*	650	7.5
17	2.5	0.560	0.28	0	46	40	41	9	53	40	559	7.4
18	4.7	0.240	0	0	42	45	31	9	50	40	559	7.4
20	4.2	0.160	0	0	40	43	34	7	57	40	588	7.4
21	2.1	0.760	0	0	44	35	33	9	43	40	588	7.4
22	1.7	*	1.96	0	48	34	40	8	43	40	559	7.3

ALL VALUES IN P.P.M. EXCEPT CONDUCTANCE AND pH. CONDUCTANCE IN MICROMHOS X 10^3

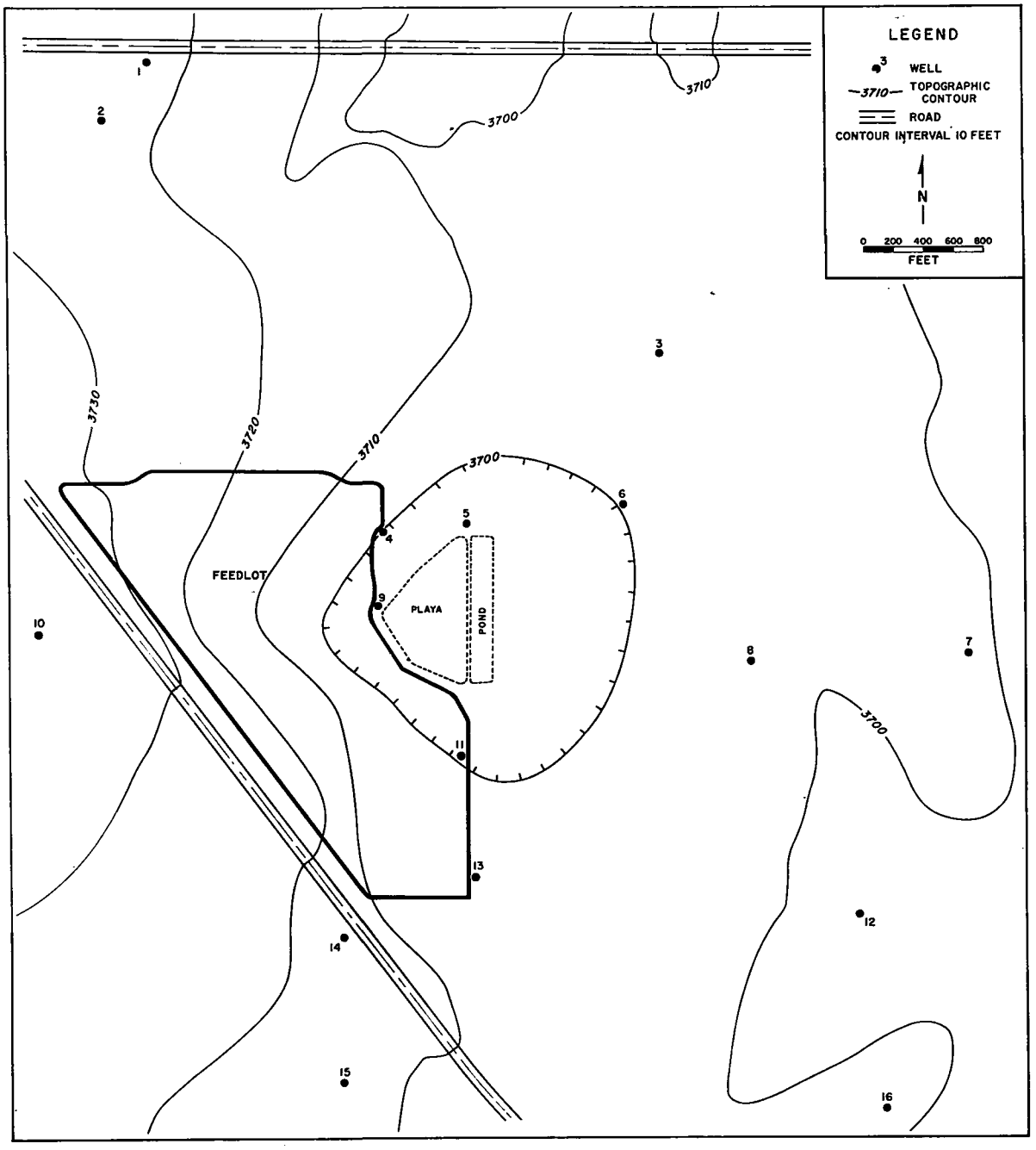


FIGURE 20--DISTRIBUTION OF OBSERVATION WELLS, FIELD SITE V

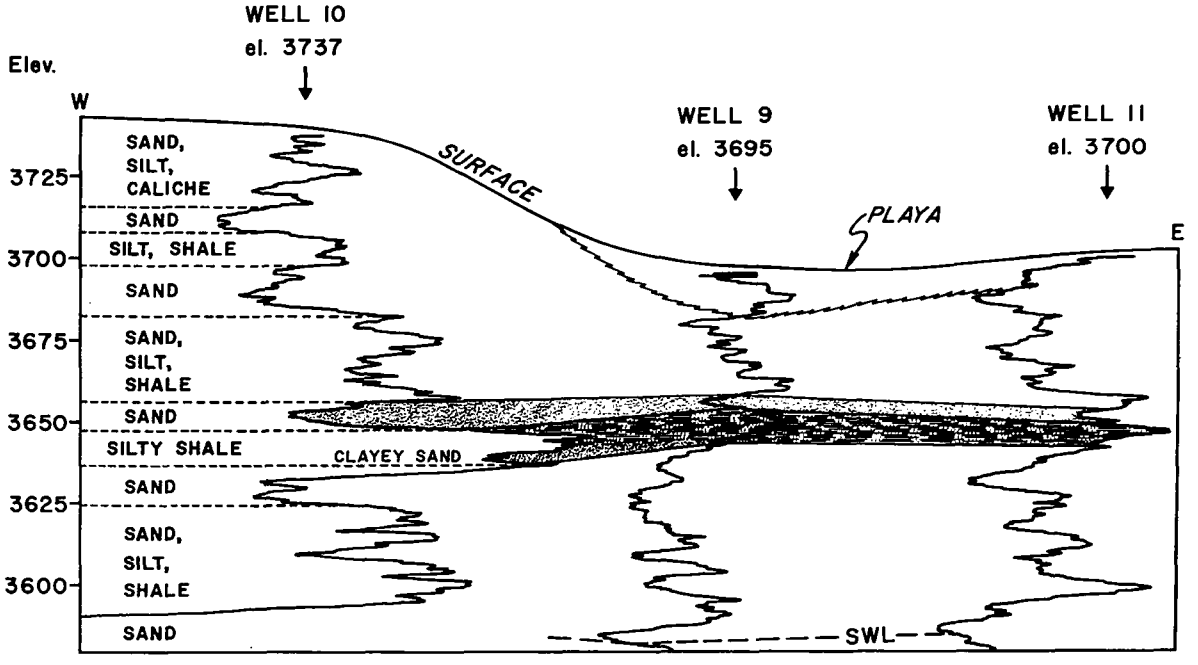


FIGURE 21--GAMMA LOG PROFILES, FIELD SITE V

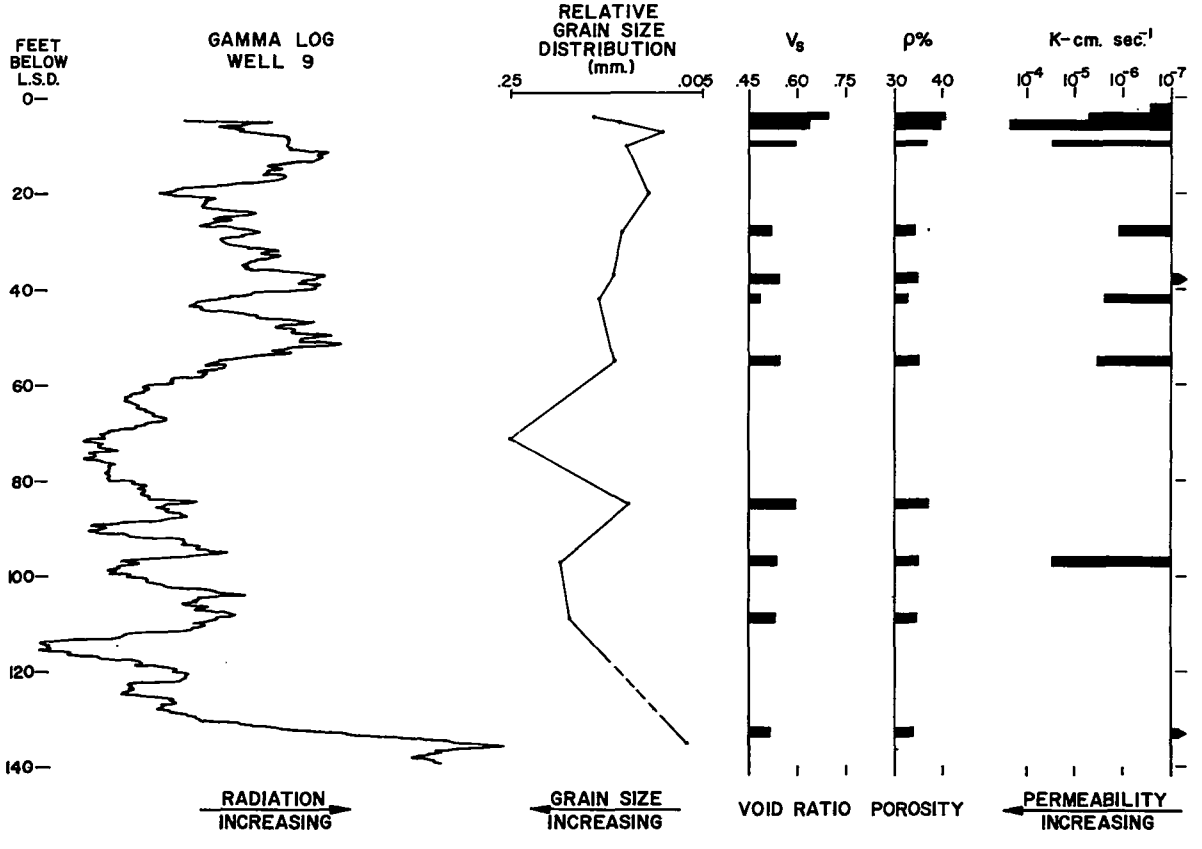


FIGURE 22--SUBSURFACE HYDROLOGIC PARAMETERS, FIELD SITE V

TABLE X--CORE CHEMISTRY, WELL #9, FIELD SITE V

FEET BELOW L.S.D.	NO_3-N	NO_2-N	AM-N	ORG-N	CA	MG	NA	K	CL	SO_4	TDS	pH	% MOIST
3.5	24.16	0.99	0.00	13.98	54	26	25	11	106	40	412	7.4	6.6
9	11.97	1.15	0.00	46.30	52	16	13	7	96	40	588	7.4	5.7
17	0.00	0.80	7.80	22.68	40	24	38	9	71	80	529	7.4	*
22	0.00	1.00	0.00	78.41	40	27	50	18	115	40	529	7.5	11.8
29	0.00	1.04	0.00	65.00	34	21	48	9	124	60	588	7.2	15.2
35	25.31	0.98	0.00	5.35	36	22	50	10	113	60	588	7.1	14.2
43	0.00	1.03	0.00	46.12	36	18	31	11	99	40	529	7.2	11.1
58	12.49	1.06	0.31	17.11	50	23	24	13	82	160	559	7.2	9.6
72	73.62	0.61	0.00	0.00	38	19	12	9	64	80	441	7.3	8.0
84	12.59	1.16	0.00	17.47	48	19	18	10	64	120	471	7.2	10 3
98	12.81	1.09	0.00	97.33	30	10	13	6	57	60	324	7.3	11.9
110	0.00	1.13	0.33	47.84	26	13	15	7	60	60	353	7.3	14.8

ALL CHEMICAL CONCENTRATION VALUES REPORTED AS DRY WEIGHT; ALL IONS IN P.P.M.

travel of NO_3-N in the groundwater zone was on the order of 1500 feet. It is concluded, dissolved solids concentrated in Ogallala groundwater from point-sources such as cattle feedlots usually are restricted to the vicinity of the site.

To determine relative field rates of seepage on a regional basis, several chemical parameters were evaluated in terms of ages of feedlots. The values used to derive the graph shown in Figure 24 represent maximum values of NO_3-N in groundwater beneath each of 80 feedlots. Each feedlot used represents 5 to 25 groundwater analyses, and the high and low maxima for each year represent 5 to 70 determinations of NO_3-N. The dashed line shows the base level for NO_3-N beneath Texas High Plains feedlots. This base level has not been corrected for "normal" background levels in the Ogal lala before establishment of the feedlots; therefore, the base level for feedlot NO_3-N contribution is less than shown. The base line shows a general increasing trend in NO_3-N concentration with age. The upper (solid) line of Figure 24

TABLE XI--GROUNDWATER CHEMISTRY, FIELD SITE V

WELL NO.	NO_3-N	NO_2-N	AM-N	CA	MG	NA	K	CL	SO_4	COND.	pH
1	1.4	*	*	56	52	59	9	78	145	880	7.3
2	2.3	*	*	64	37	39	12	195	40	1150	7.2
3	2.4	*	*	80	36	72	13	124	40	882	7.2
4	5.7	*	*	54	60	60	15	72	140	890	7.3
5	5.0	*	*	64	61	60	10	85	150	790	7.5
6	3.6	0.000	0	67	59	64	12	85	*	706	7.6
7	1.4	*	*	65	37	65	14	125	*	995	7.4
8	1.0	0.003	0	64	62	57	15	85	*	706	*
9	6.4	0.003	0	65	60	59	16	95	*	805	7.3
10	1.0	0.003	0	56	52	58	8	85	40	735	7.4
11	8.4	0.012	0	65	52	57	11	50	*	794	7.5
12	1.0	*	0	60	33	44	10	82	40	706	7.2
13	5.2	0.099	0	74	80	52	15	174	134	1215	7.4
14	2.7	*	0	68	29	85	11	124	40	1000	7.2
15	0.8	*	0	92	47	52	16	195	40	941	7.2
16	4.17	*	0	68	40	52	10	103	40	735	7.2

ALL VALUES IN P.P.M. EXCEPT CONDUCTANCE AND pH. CONDUCTANCE IN MICROMHOS

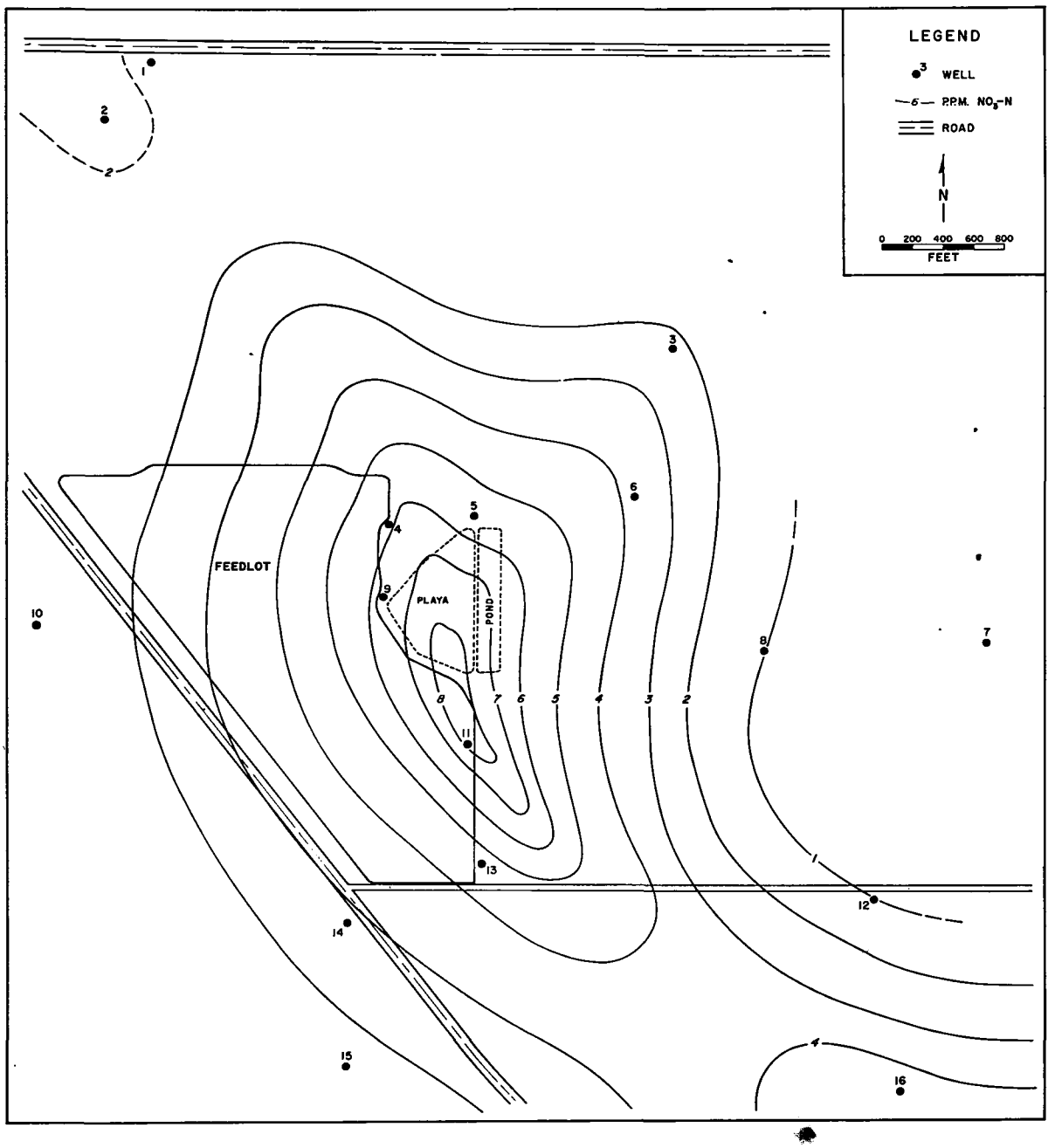


FIGURE 23--DISTRIBUTION OF NO_3-N IN GROUNDWATER, FIELD SITE V

represents the highest maximum level of NO_3-N found in all lots for each year shown. As with the base line, it has not been corrected for "normal" background NO_3-N. The upper line tends toward considerable variation in age concentration relationships and indicates that, disregarding age, some lots contribute NO_3-N to the groundwater zone of the High Plains.

The average slope of the NO_3-N base line (dashed) is about 0.17 p.p.m. NO_3-N per year. The maximum slope value is 0.3 p.p.m. NO_3-N per year. These approximated rates represent point-sources beneath all feedlots in the study and have no significance for a specific geographic location. In conclusion, these values approximate a regional rate of concentration of NO_3-N in Ogallala groundwater from cattle feedlots.

Additional profiles are shown for chloride (Figure 25) and conductivity values (Figure 26) beneath the 80 feedlots. The profiles show slopes of 0.07-0.40 p.p.m. Cl/year and an increase in conductivity of 40-100 micromhos/cm/year, respectively. These data also reflect field infiltration rates as described for NO_3-N.

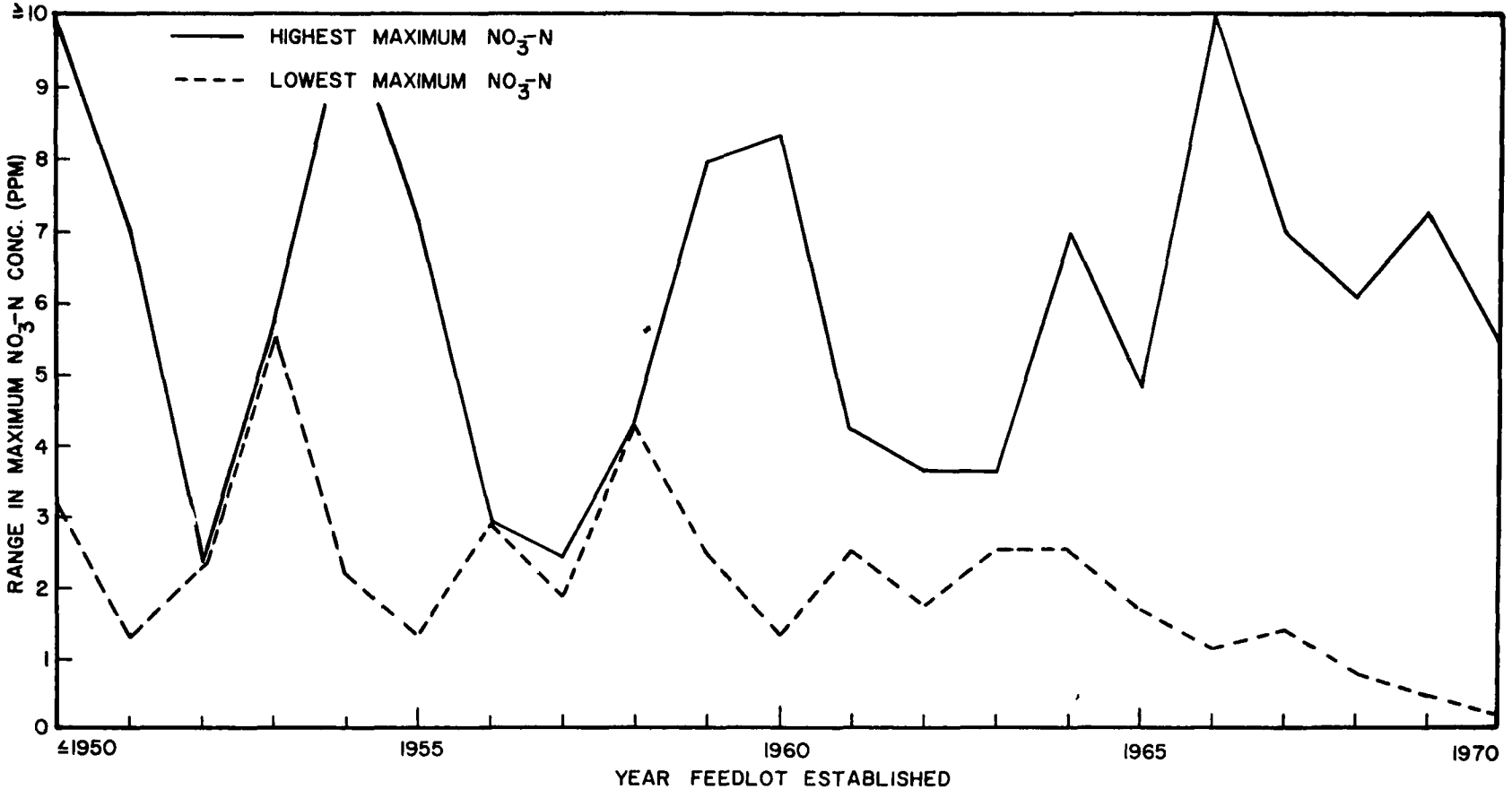


FIGURE 24--AGE OF FEEDLOTS INVESTIGATED vs RANGE IN MAXIMUM NO_3-N CONCENTRATION IN GROUNDWATER

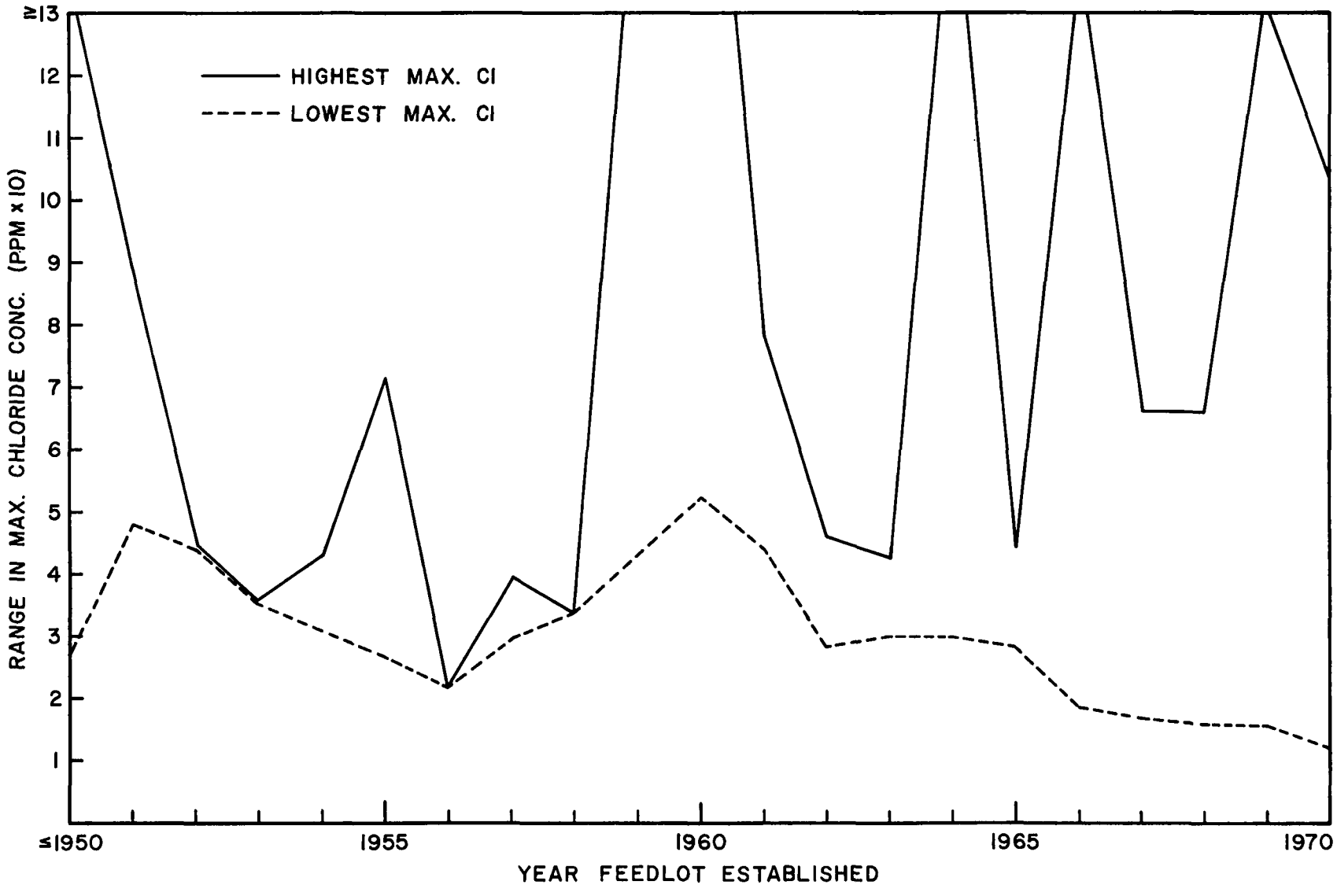


FIGURE 25--AGE OF FEEDLOTS INVESTIGATED vs. RANGE IN MAXIMUM CHLORIDE CONCENTRATION OF GROUNDWATER

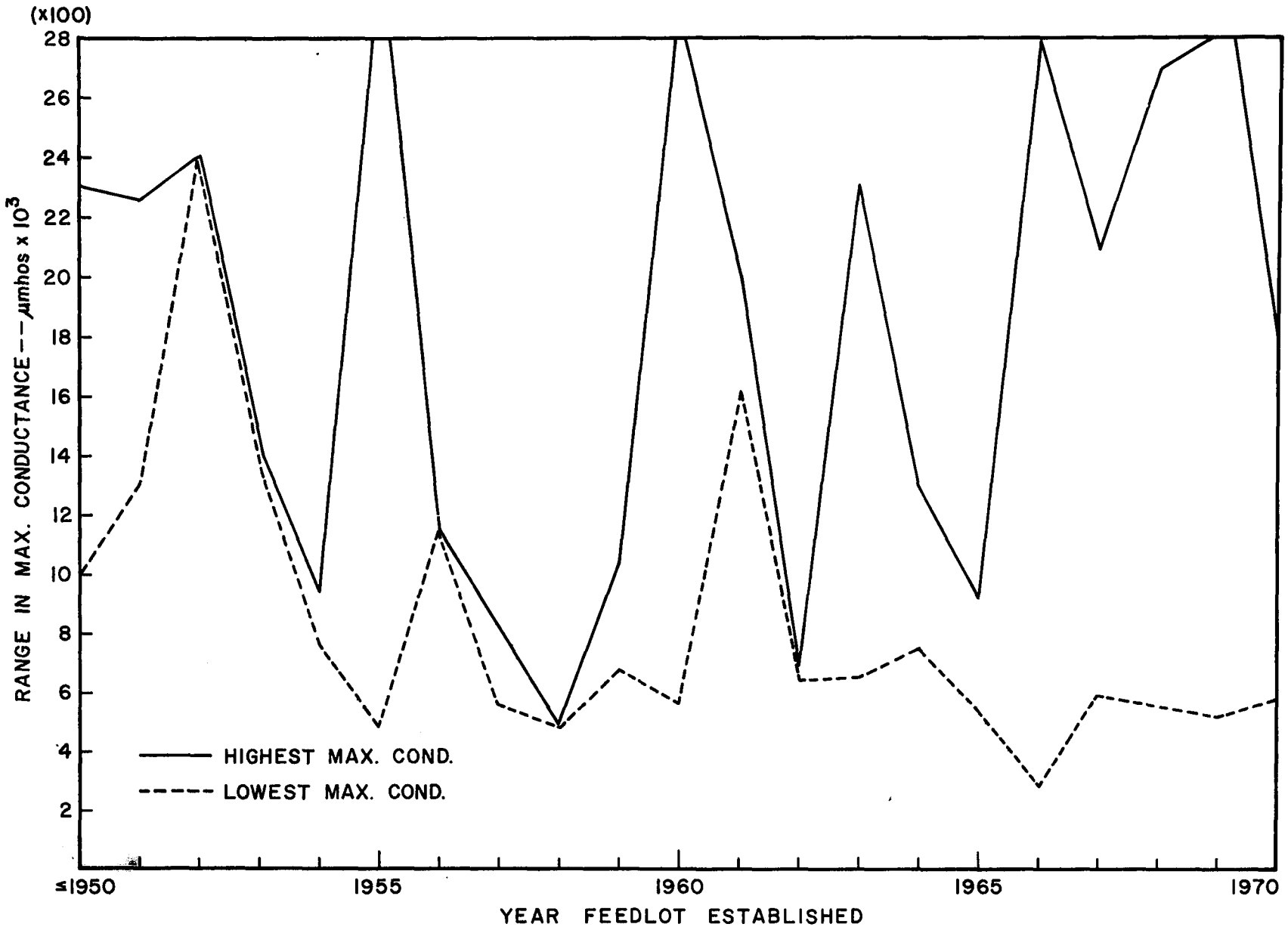


FIGURE 26--AGE OF FEEDLOTS INVESTIGATED vs RANGE IN MAXIMUM CONDUCTANCE OF GROUNDWATER

ACKNOWLEDGMENTS

William D. Miller, Professor and Chairman, Geosciences Department, Texas Tech University, served as principal investigator and assumes sole responsibility for the scientific accuracy of the results herein reported.

Special acknowledgment is due the feedlot owners and managers of the Texas High Plains who generously allowed us full use of their facilities, often for many days at a time. Their generosity is especially gratifying due to the public outcry over potential pollution by feedlots.

The Projects Division and Materials Testing Laboratory of the Texas Water Development Board were major contributors to the total project. The core-drill crew from the Projects Division, TWDB, included James W. Sansom, Jr., Geologists and Crew Chief; Keith Keppel and Leon Byrd, Geologists; Lewis Barnes, Chief Driller, Hugo Walker and Lynn Jorgensen, Assistant Drillers. Materials Testing Laboratory personnel who contributed to the field work and who performed laboratory investigations of cores are Messrs. Paul Pasemann, Ronnie Weddell, Joe Gates, Steve Gifford, all Engineering Technicians, and Mike Howard, Technician, Structure Section.

Messrs. G. S. Sawyer, Projects Division Director, J. E. Hunt, Chief, Materials Testing Lab, and James O. Rodgers, Engineer, were instrumental in the planning phase of the project. Appreciation is also extended to Mr. C. R. Baskin, Chief Engineer, Mr. Seth Burnitt, Water Quality, and Mr. R. C. Peckham, Head, Ground Water division, Texas Water Development Board, for their assistance with planning and implementation of portions of the project.

Recognition is given for financial support of the project to the Texas Cattle Feeders Association, Mr. Lloyd Bergsma, Executive Director, and the TCFA Board of Directors, Mr. Bob Carter, President.

The North Plains Water District (Texas), J. W. Buchanan, Manager, contributed financial support, and SP-logging equipment for logging in the North Plains.

Messrs. Dennis Bell, Chief Research Assistant, and John Buchanan, David Normand and Bill Watson, Student Research Assistants, Geoscience Department, Texas Tech University, contributed to the field and laboratory investigations.

Mr. Clyde Wilson, Acting Project Chief, Bill Sandeen, Physical Science Technologist, and Jim Smith, Hydrologist, U. S. Geological Survey, Lubbock, Texas, performed the well logging reported in this study.

The initiation and major support of the project by the Environmental Protection Agency, Ada, Oklahoma, and the support by the Project Director, Mr. Marion R. Scalf, are gratefully appreciated.

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1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM

5 Organization
Geosciences Department
Texas Tech University

6 Title
INFILTRATION RATES AND GROUNDWATER QUALITY BENEATH CATTLE FEEDLOTS, TEXAS HIGH PLAINS

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16 Project Designation
EPA Project #16060EGS

21 Note

22 Citation

23 Descriptors (Starred First)
Groundwater, nitrates*, feedlot runoff*, infiltration*

25 Identifiers (Starred First)
nitrates*, feedlot runoff, infiltration

27 Abstract Detailed field and laboratory studies of five feedlots were conducted to determine field seepage rates and distributive geometry of infiltrated runoff. Practical field seepage rates at these sites ranged from 2 to 20 feet/year.

Nitrogen (NO_3, NO_2, NH_4, Org-N) and common chemical parameters (Ca, Mg, Na, K, Cl, SO_4, TDS, pH, and conductance) were determined in cores and groundwater samples; based on groundwater analyses from 80 Texas High Plains feedlots, rates of concentration of NO_3-N and Cl in groundwater beneath feedlots range from 0.07 to 0.4 p.p.m. per year, and average 0.17 p.p.m. per year.

Laboratory determined constant head vertical permeability of cores from 22 feedlot sites revealed a range in values of 10^{-2} to 10^{-6} cm/sec for Ogallala sediments, 10^{-4} to 10^{-7} cm/sec for near-surface material of floodplains and feedpen-runoff surfaces, and values of 10^{-6} to 10^{-8} cm/sec for playa clay.

Factors related to runoff-infiltration were correlated with groundwater quality, and it was determined that local surficial material and regional soils patterns are closely related to quality of groundwater beneath feedlots. Direct correlation of water quality does not exist with feedpen-runoff slope, cattle load, and surface-area ratios of drainage basin to collection system.

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