MBMG 237-A

IMPACTS OF OIL FIELD WASTES ON SOIL AND GROUND WATER IN RICHLAND COUNTY, MONTANA

PART I – OVERVIEW

By

Jon C. Reiten

Hydrogeologist

Montana Bureau of Mines and Geology

Billings, Montana 59101

Final Report for

RIT Grant

RIT-87-8513

1991

IMPACTS OF OIL FIELD WASTES ON SOIL AND GROUND WATER IN RICHLAND COUNTY, MONTANA

PART I - OVERVIEW
Table of Contents

PART I - OVERVIEW - Figures

PART I - OVERVIEW - Tables

IMPACTS OF OIL FIELD WASTES ON SOIL AND GROUND WATER IN RICHLAND COUNTY, MONTANA

PART I - OVERVIEW

INTRODUCTION

The resurgence of oil field development in the Williston Basin of eastern Montana during the late 1970's and early 1980's coincided with a time of greater environmental awareness and concern among the local residents. Consequently, regulators and oil company staff were being asked to consider the toxicity of the oil field wastes, the methods of waste disposal and potential damages to soil and water resources.

This research project was initially designed to determine:

1. The basic water quality of the "lost" formation fluids
2. The rate of movement of brine plumes
3. The dispersion and dilution effects of the shallow groundwater system
4. The projected size of the plume by the time it is diluted enough for: (a) stock use, (b) human use and (c) how long of a time will be required to reach those conditions
5. The feasibility of soil reclamation techniques, both technically and economically and determine the time frame for revegetation

More than a dozen sites were initially evaluated before final sites were selected for study. Types of sites evaluated included former evaporation pits, injection wells, mud disposal sites, and reserve pits. Most of these sites were originally brought to the attention of the Montana Bureau of Mines and Geology (MBMG) by members of the Northeast Montana Land and Mineral Owners Association.

Four sites were selected for further hydrogeologic and soils studies (Figure 1). Hydrogeologic research focused on the Hunter site and the Iverson site. Soil research was conducted at these sites plus the Propp site and the Watt site.

Waste drilling mud had been buried at the two sites selected for more detailed hydrogeologic investigations. The Hunter site, located 3 miles northwest of Fairview, Montana about 300 feet above the Yellowstone River valley, consists of centralized disposal pits that were used for off-site disposal of waste drilling mud. The centralized facility had been developed without prior geologic investigation or state authorization. Subsequent test drilling indicated a minimum of 35 feet of sand and gravel underlying the site implying a strong potential for vertical leaching of contaminants. The Iverson site, located 3 miles north of Sidney, Montana in the Yellowstone River valley, consists of a reserve pit that was reclaimed by trenching in 1982. Previous hydrogeologic investigations at this site identified a brine plume originating at the reserve pit (Dewey, 1984).

Soil studies were conducted at all four research sites. The only contaminated soil at the Iverson site was a small area directly overlying the reserve pit, so no more than a cursory

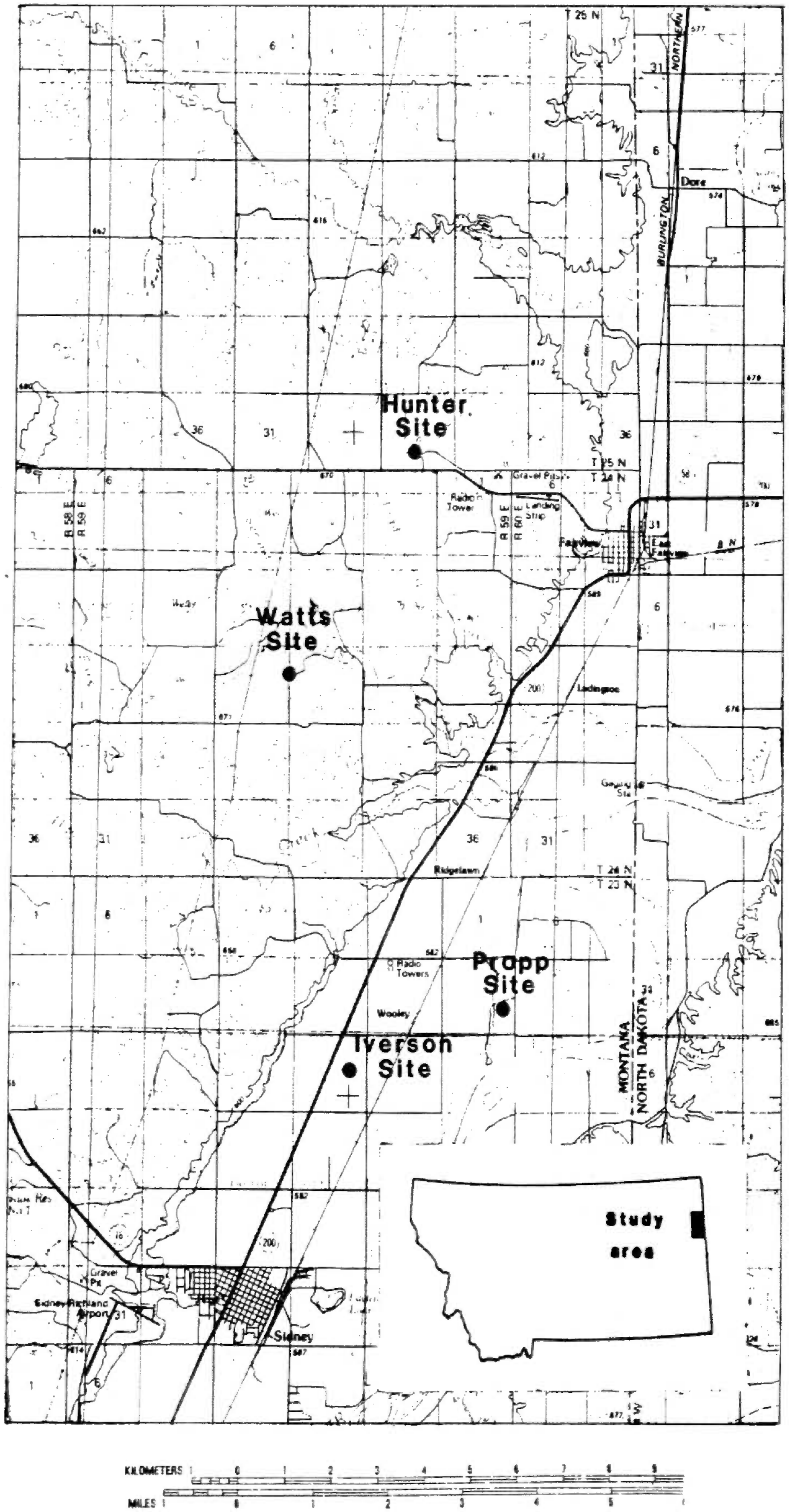

Figure 1. Location of study sites.

evaluation was conducted. Soil contamination at the Hunter site was more extensive and consequently research was more intensified. Soil testing and reclamation were conducted at the Propp site where reserve pit leachate has damaged soils on more than 1 acre of bottom land. Soil testing at the Watt site identified about 5 acres of damaged soils. It appears that the soil damage was caused by disposal of reserve pit wastes in an area prone to saline seeps.

The study was divided into 4 sections that are presented as separate parts of this report. Part I is an overview. Part II investigates contaminant movement in both the unsaturated and saturated zone at the Hunter site and is entitled "Contaminant Movement Below Oil Field Drilling Mud Disposal Sites Near Fairview, Montana". Part III evaluates hydrogeology of the Iverson site and is entitled "Hydrogeological Conditions and Ground Water Quality at an Oil Well Reserve Pit, Richland County, Montana". Part IV evaluates soil reclamation techniques at several locations in Richland County and is entitled "Reclamation of Soils Damaged by Oil Field Wastes, Richland County, Montana".

BACKGROUND

Montana's crude oil production for 1943 to 1987 is summarized in Figure 2. The Williston Basin produced about 73% of the state's total according to 1987 production records (Montana Board of Oil and Gas Conservation, 1987). Current trends are towards decreasing oil production, although oil production will undoubtedly continue to be a major economic factor in the Williston Basin as well as the rest of the state of Montana.

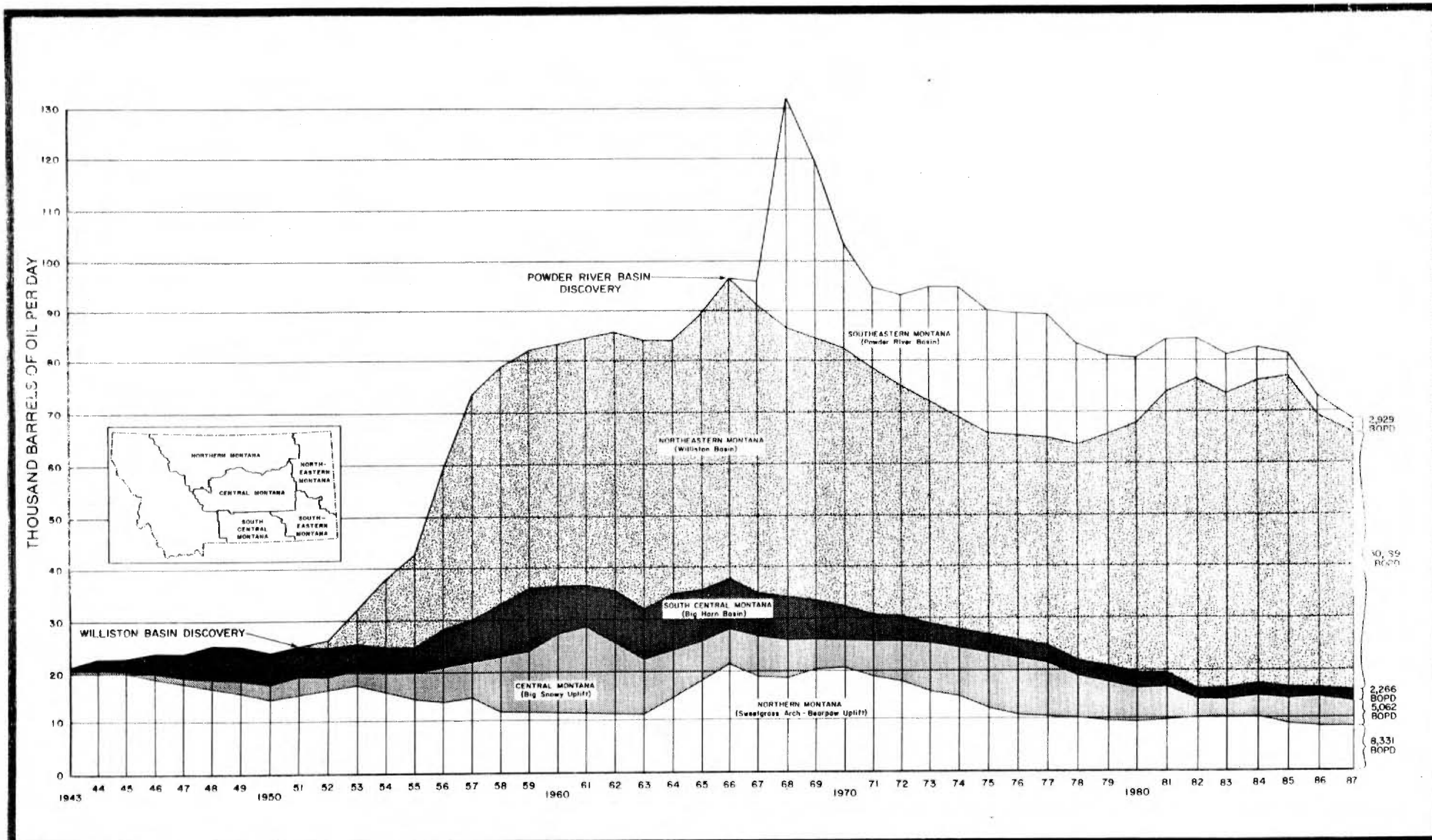

Figure 2. Crude oil production in Montana 1943-1987 (DNRC, 1987)

The potential for soil and water contamination from oil field activities depends upon regional geologic setting, site specific geologic (drilling) conditions, and methods of waste disposal or containment.

Regional geologic conditions control the geochemistry of fluids produced in association with the hydrocarbons. Many Montana oil fields produce water containing relatively low concentrations of dissolved solids. Consequently, potential impact to soils and shallow aquifers are minimal. In contrast, produced water from the Williston Basin is commonly highly concentrated in dissolved solids, therefore creating a greater risk of degrading shallow aquifers and damaging soils. Table 1 compares the water chemistry of produced water from a typical "fresh water" region to the water chemistry of produced water from a typical "salt water" region.

Fresh water based, salt-water based, and oil-based drilling fluids are commonly used in the oil industry depending on geologic conditions. Salt water based fluids are the most common in the Williston Basin (Davis, 1987). They are usually derived from produced water and they function primarily to prevent dissolution washouts when penetrating evaporite beds often associated with oil producing zones.

Regional geology and site specific drilling conditions combine to dictate the types and concentrations of various additives used in constructing the optimal drilling fluid. Many of the additives contain trace metals or other materials that can potentially degrade shallow aquifers and damage soils. These additives are

Table 1. Comparison of Standard Constituents from selected Madison Group water samples from fresh water oil fields in northwestern Montana to salt water oil fields in the Williston Basin

Units are parts per million with the exception of pH which is in standard log units.

Location	Field	County	Calculated Dissolved Solids	pH	Sodium	Calcium	Magnesium	Sulfate	Chloride	Carbonate	Bicarbonate
35N05W07	Blackfoot Nose	Glacier	4,155	8.9	1,632	22	34	168	1,009	120	2,375
35N05W06	Blackfoot Nose	Glacier	3,980	8.5	1,581	24	35	4	981	185	2,375
35N05W06SESW	Cut Bank	Glacier	4,077	7.5	1,570	61	39	36	1,017	0	2,750
35N04W01SWNE	Wildcat	Toole	2,601	7.8	1,007	53	26	0	370	0	2,325
Mean of northwest Montana Data Set			3,703	N/A	1,447	40	33	52	844	76	2,456
25N58E19SENW	Sioux Pass	Richland	327,626	5.8	112,177	13,490	1,254	626	200,000	0	160
25N58E19SENW	Sioux Pass	Richland	319,071	5.7	109,070	13,110	1,368	444	195,000	0	160
24N58E13SWNW	Wildcat	Richland	310,492	5.8	103,076	15,681	1,269	145	190,280	0	85
Mean of Williston Basin Data Set			319,063	N/A	108,107	14,094	1,297	405	195,093	0	135

mixed into the drilling fluid to perform specific functions ranging from inhibiting corrosion to increasing mud weight (Table 2) (Murphy and Kehew, 1984).

Drilling fluids are contained in a reserve pit that is excavated at the drill site. Typical dimensions of Williston Basin reserve pits are 150 feet long, 60 feet wide, and 10 feet deep. During the drilling operation from 54,000 to 90,000 cubic feet of drilling fluid is maintained in the pit (Murphy and Kehew, 1984). Reserve pits are commonly lined with a plastic liner to prevent seepage especially when pits have been excavated into permeable materials.

Prior to the mid-1970's many of the reserve pits were left open and used for storage and disposal of produced brines or simply backfilled. This method of backfilling commonly left surface depressions and a generally unstable land surface. Since the mid-1970's the pits have been reclaimed by a variety of methods. Most commonly, the less viscous portion of the drilling fluid is removed for disposal into an injection well. Radial trenches are excavated away from one side of the pit. Fill is then pushed into the pit causing the remaining drilling wastes to flow into the trenches. The unlined trenches are then backfilled and levelled, minimizing the surficial instability. One consequence of the trenching method of reclamation is the potential for contaminating shallow aquifers. Other waste disposal methods have been used in the last ten years including offsite disposal of the waste mud and solidification of the pits.

Table 2. Function and general purpose of drilling fluid additives (from Murphy and Kehew, 1984).

Function	General Purpose	Common Additives
Weighting Material	Control formation pressure, check caving facilitate pulling dry pipe, and well completion operations	Barite, lead compounds, iron oxides
Viscosifier	Viscosity builders for fluids for a high viscosity-solids relationship	Bentonite, attapulgite clays, all colloids, fibrous asbestos
Thinner Dispersant	Modify relationship between the viscosity and percentage of solids, vary gel strength, deflocculant	Tannins (quebracho), polyphosphates, lignitic materials
Filtrate Reducer	Cut the loss of the drilling fluids's liquid phase into the formation	Bentonite clays, sodium carboxymethyl cellulose (CMC), pregelatinized starch, various lignosulfonates
Lost Circulation Material	Primary function is to plug the zone of loss	Walnut shells, shredded cellophane flakes, thixotropic cement, shredded cane fiber, pig hair, chicken feathers, etc.
Alkalinity, pH Control	Control the degree of acidity or alkalinity of a fluid	Lime, caustic soda, bicarbonate of soda
Emulsifier	Create a heterogeneous mixture of two liquids	lignosulfonates, and detergent, petroleum sulfonate
Surfactant	Used to the degree of emulsification, aggregation, dispersion, interfacial tension, foaming and defoaming (surface active agent)	Include additives used under emulsifier foamers, defoamers, and flocculators
Corrosion Inhibitor	Materials attempt to decrease the presence of such corrosive compounds as oxygen, carbon dioxide, and hydrogen sulfide	Cooper carbonate, sodium chromate, chromate-zinc solutions, chrome lignosulfonates, organic acids and amine polymers, sodium arsenite
Defoamer	Reduce foaming action especially in salt water based muds	Long chain alcohols, silicones, sulfonated oils
Foamer	Surfactants which foam in the presence of water and thus permit air or gas drilling in formation producing water	Organic sodium and sulfonates, alkyl benzene sulfonates
Flocculants	Used commonly for increases in gel strength	Salt, hydrated lime, gypsum, sodium tetraphosphates
Bactericides	Reduce bacteria count	Starch preservative, paraformaldehyde, caustic soda, lime, sodium pentachloraphenate
Lubricants	Reduce torque and increase horsepower at the bit by reducing the coefficient of friction	Graphite powder, soaps, certain oils
Calcium Remover	Prevent and overcome the contamination effects of anhydrite and gypsum	Caustic soda (NaOH), soda ash, bicarbonate of soda, barium carbonate
Shale control Inhibitors	Used to control caving by swelling or hydrous disintegration	Gypsum, sodium silicate, calcium lignosulfonates, lime, salt

PREVIOUS STUDIES

Interest into the contamination potential of oil field wastes developed shortly after the United States Environmental Protection Agency began implementing the Resource Conservation and Recovery Act (RCRA) program. Soon, several research projects were initiated evaluating the toxicity of drilling fluids. The results of these projects are summarized in the following two sections.

Regional Research

A nationwide program conducted by the EPA evaluated the toxicity of spent drilling fluid, produced waters, and other wastes associated with oil well, gas well, and geothermal well drilling (U.S. Environmental Protection Agency, 1987). Composited samples from both the liquid phase and the solid phase (basal sludge) in the reserve pits were collected. Nearly all the samples were analyzed for 229 organic compounds, 68 metals and 22 conventional parameters. Most total metals concentrations for the reserve pit liquids and sludge fell within or below the normal range observed for metals in soils. The exceptions were barium, cadmium, magnesium, molybdenum, and sodium. Normal hydrocarbons were the predominant organic compounds detected. Other organic compounds detected were aromatic hydrocarbons, organic acids and pesticides.

A study by Dames and Moore (1982) for the American Petroleum Institute evaluated environmental effects of drilling mud pits and produced water impoundments at 8 sites in 3 major hydrogeologic regions. Each site had a different potential for leachate migration and detection. This study concluded drilling muds do not exceed RCRA guidelines for hazardous wastes. Dames and Moore found that sodium and chloride are the most mobile ions to leach from both mud pits and surface impoundments. Heavy metals migrate slowly and are attenuated by clays in the drilling mud.

Leuterman and others (1987) sampled both the mud phase and the water phase from 125 reserve pits in the southern and western United States. Samples were analyzed for total metal concentrations and soluble metals in the mud phase and soluble metals in the liquid phase. They concluded 85% of the reserve pits had soluble heavy metal concentrations below hazardous waste standards prior to reclamation. Standard ion constituents tended to be higher in the water phase than the mud phase. They suggested proper closure and sampling of the pit materials would mitigate potential degradation of shallow aquifers.

The organic fraction of fluids from 48 reserve pits in Alberta Canada was characterized by Strosher (1984). The total organic carbon of these fluids averaged 350 mg/L. The pit fluids on the average contained 45 percent organic polymers, 18 percent hydrocarbons, 11 percent sulfonates, 6 percent volatile organics, 1 percent acidic organic compounds, and 0.5 percent organic bases, and 19.5 percent other unspecified organic compounds. The hydrocarbon fraction was determined to be the largest contributor to aquatic toxicity.

A statistical screening model for drilling disposal pits was developed by Kemblowski and Deeley (1987) to examine the transport of leachate in the subsurface. They identified the reduced hydraulic conductivities caused by the self-sealing behavior of fresh water drilling muds, which substantially lowered the flux rate of leachate moving out of reserve pits. Concentrations of both inorganic and organic constituents in the liquid phase of the drilling mud were attenuated by sorption and chemical precipitation. Dispersion and biodegradation further reduce concentrations of leachate that does leave a disposal pit.

Drilling fluid toxicity data from previous research was compiled and summarized by Davis, (1987). Nationwide drilling waste disposal practices were surveyed and environmental effects associated with each of these practices were assessed. In addition he evaluated research concerning the fundamental processes of contaminant transport associated with drilling waste disposal including leachate seepage rates, deleterious impacts of brines and certain organic compounds on clay liners, solubility of reserve pit metals over common pH ranges, and increased solubility of some metals (cadmium, lead, and zinc) by chloride complexing.

Williston Basin Research

Produced water from the East Poplar Field has contaminated an alluvial aquifer and elevated chloride concentrations in the Poplar River (Levings, 1984). Brine-disposal wells and evaporation pits have been used to dispose of produced water with dissolved solids concentrations ranging 16,000 to 201,000 mg/L. The method and location of the contamination is unknown but could be the result of leaks in casing or pipelines caused by the corrosive nature of the brines and/or leaks from evaporation pits.

Murphy and Kehew (1984) identified leachate generation at four reclaimed reserve pits in western North Dakota. Leachate volume and concentration are being minimized by adsorption onto clays in the unsaturated zone and mechanical dispersion in the saturated zone. The chloride ion is the best indicator of the extent of leachate movement because of high concentrations in the pit fluids, low concentrations in the shallow ground water in most of the Williston Basin, and the high mobility of the chloride ion in the subsurface.

Another study in North Dakota (Murphy and others, 1988) mapped brine migration from reclaimed salt water disposal ponds using earth resistivity surveys and groundwater chemistry. The ponds were excavated in low permeability glacial till. Little dilution has occurred to the leachate plume; and the plume is restricted to the low conductivity till aquitard. Lateral salt migration has damaged soils and killed trees within a 250,000 ft^2 area surrounding the ponds. Heavy concentrations of brine within the reclaimed brine ponds indicate little dilution has occurred over the last 10 years. Without remediation the site will generate high salt leachate for tens and possibly hundreds of years. Two recommendations are made to minimize further contamination: 1.) mounding the site with fill, 2.) setting up an infiltration gallery around the site, then irrigating the site with fresh water, and intercepting the leachate for disposal into an injection well.

Dewey (1984) examined the effects of reserve pit reclamation practices on ground water quality at two oil well sites in Richland County, Montana. Electrical resistivity methods were evaluated for detecting ground water contamination of these sites and five others in McKenzie County, North Dakota. Apparent resistivities proved to be an effective method of identifying ground water contamination. She concluded current reclamation methods are inadequate to prevent ground water contamination.

Records of 27 complaints regarding contamination from oil field wastes filed with state and federal regulatory agencies are summarized in a programmatic environmental impact statement (PEIS) (Montana Board of Oil and Gas Conservation, 1989). Many of the complaints are from Williston Basin oil fields in Montana. The complaints document concerns regarding impacts of oil well drilling on nearby domestic and stock wells, evidence of illegal dumping of oil field wastes, and chloride contamination of surface water and springs.

CLIMATE

The Sidney-Fairview area has a semiarid continental climate, characterized by cold, dry winters, moderately hot and dry summers, and cool, dry falls. Winters are often interrupted by warming trends, with summers dominated by hot days and cool nights. January is generally the coldest month and July the warmest.

Sidney, Montana has a 14.9° F average January temperature and a 74.0° average temperature for July. Average precipitation at Sidney is approximately 14 inches/year with about 65 percent of the precipitation falling from May through August, and June being the wettest month. Monthly precipitation for the 1980's is shown in Table 3. Evaporation is typically much higher than precipitation in this area. Based on data from a Class A evaporation pan near Sidney, potentially between 25 and 35 inches of water evaporate annually. Wind and hot temperatures contribute to an average 5 to 7 inches of monthly evaporation from May to August (Donovan, 1988).

Long term climatic trends show a large range of monthly precipitation for individual months (Table 3). This trend is most evident from April through September. A 10-20 year periodicity of below average precipitation is often accompanied by above average temperatures resulting in drought conditions. Consequently cycles of drought are common in this region. The 1980's were drier than average resulting in drought during much of the decade.

REGIONAL HYDROGEOLOGY

Eight major aquifer systems underlie Richland County from the Paleozoic Madison Group to the Quaternary alluvium. Aquifers within 200 to 300 feet of ground surface in Richland County are the Tongue River Member of the Tertiary Fort Union Formation, the Tertiary/Quaternary terrace deposits, and the Quaternary glacial, terrace and alluvial deposits. The water table in these shallow aquifers usually reflects the land surface topography. Deeper

Table 3. Measured total monthly precipitation in the Sidney-Fairview area.
Data collected by the National Oceanic and Atmospheric Administration
from the weather station 3 miles north of Sidney.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
80	0.76	0.28	0.12	0.37	0.27	1.92	0.74	2.91	1.46	1.94	0.49	0.63	11.89
81	0.04	0.2	0.12	1.09	0.57	3.19	2.54	2.57	0.61	0.76	0.4	0.55	12.64
82	0.86	0.33	1.78	0.66	2.33	2.39	2.14	1.76	1.81	3.19	0.15	1.05	18.45
83	0.19	0.06	0.88	0.04	1.31	1.72	1.86	0.22	0.42	0.32	0.26	0.44	7.72
84	0.69	0.07	0.35	0.76	0.42	4.24	0.61	0.79	1.39	0.22	0.13	0.52	10.19
85	0.09	0.07	0.64	1.29	1.19	0.5	1.47	1.54	1.27	2.13	0.68	0.48	11.35
86	0.4	0.61	0.38	1.35	3.37	2.34	4.34	0.43	3.37	0.35	1.32	0.14	18.4
87	0.07	0.11	1.06	0.58	3.21	4.02	2.87	0.97	0.92	0.1	0.21	0.05	14.17
88	0.56	0.49	0.58	0.17	0.79	1.27	0.92	0.12	1.68	0.13	0.38	0.75	7.84
89	0.56	0.43	0.43	2.47	1.6	1.4	0.64	1.24	0.36	1.99	0.51	0.42	12.05
Ten Year Average	.42	.27	.63	.88	1.51	2.30	1.81	1.26	1.33	1.11	.45	.50	12.47
Historical Average	0.38	0.34	0.53	1.11	1.99	2.74	1.91	1.57	1.42	0.90	0.43	0.40	13.84
Years of Record	48	48	48	49	49	48	49	49	49	49	49	49	47
1961-1985 Average	0.43	0.34	0.56	1.21	2.05	2.74	1.76	1.51	1.41	0.85	0.43	0.52	13.81

aquifers, below 300 feet, have a regional flow direction towards the Yellowstone and Missouri rivers. The lower Hell Creek-Fox Hills aquifer is the deepest source of potable water in this region. Depth to this aquifer ranges from 1000 to 1200 feet.

Groundwater generally is recharged in the topographically high areas and is discharged in the valley bottoms. Snow melt and precipitation are the major contributors of recharge, however, irrigation in the Yellowstone River valley contributes large quantities of water to the shallow aquifer(s). Groundwater recharge is greatest in the spring when snow melt and precipitation are at their peak and irrigation begins (Torry and Kohout, 1956).

SUMMARY

The following five results directly address the study objectives listed at the beginning of this report:

1.) "Lost" formation fluids from Williston Basin oil fields contain high concentrations of sodium chloride salts. Calculated dissolved solids of these brines range from 100,000 mg/L to over 300,000 mg/L. Average percent reacting values for brine cations are: calcium -- 29%, magnesium -- 5%, and sodium plus potassium -- 66%. Average percent reacting values for brine anions are: chloride -- 99%, bicarbonate -- less than 1%, and sulfate -- less than 1%.

    Trace constituents are also present at high concentrations in the brines. High concentrations of boron, lithium, bromide, and strontium are the result of geochemistry of brines associated with oil producing zones. High concentrations of silver, cadmium, lead, chromium, barium, aluminum, nickel, and zinc are probably the result of drilling additives. Several of these constituents are found at levels exceeding drinking water standards in waste drilling mud.

2.) Brine plumes are highly mobile and movement is dominated by site specific hydrogeologic conditions.

At the Hunter site, brine plumes move vertically through the unsaturated zone and develop when rainfall or snowmelt infiltrates through the salt saturated drilling muds, mobilizing salts into the recharge water. The rate of plume movement was not precisely determined and is dependent on soil moisture conditions prior to recharge. The rate of plume movement can be estimated by the time it takes for elevated salt concentrations to be observed in the underlying aquifer. This time period ranges from several days to several weeks.

At the Iverson site, brine plumes move horizontally and are remobilized during summer months when the seasonally high water table intersects the buried reserve pit.

3.) Site specific hydrogeologic conditions impact the dispersion and dilution effects.

At the Hunter site mechanical dispersion in the unsaturated zone has caused mixing of uncontaminated recharge water with recharge water contaminated by the salts. The product of the dispersion is to dilute the concentration of the plume. The dilution process is complicated by clay layers that pond and divert the recharge water. Dispersion and dilution continues when the plume reaches the water table reducing the impact of the contaminant.

At the Iverson site mechanical dispersion in the saturated zone has caused mixing of uncontaminated water with aquifer water contaminated by the salts. Most of the dispersion and dilution occurs in the top half of the aquifer. Wells in the lower part of the aquifer show little evidence of brine contamination.

4.) The contaminant plume at the Hunter site is diluted enough for stock or domestic use by the time it intersects the water table.

The contaminant plume at the Iverson site is diluted enough for stock or domestic use within a few hundred feet of the site. However, since precipitation and recharge were below average during the study period these results may not represent normal conditions.

5.) Most cases of oil field related soil contamination are commonly either at too large of scale to be within the context of this project or too small of scale to be considered a significant problem.

Soil sampling at the Iverson site detected limited contamination that was restricted to the area immediately above the reserve pit. Consequently, no reclamation was conducted at this site.

Contamination was more extensive at the Hunter site with salt crusts exposed at the surface and depressions overlying the disposal cells. Smoothing the land surface over the pits, covering exposed salt crusts with topsoil, and revegetation were the reclamation methods conducted at this site.

The damaged soils at the Propp site were more extensive and reclamation methods were designed to leach salts deeper into the soil profile by applying sulfuric acid and over-irrigating the site. Unfortunately, high summertime water levels mobilized the salts up to the surface by capillary action reducing the effectiveness of the leaching experiment.

Damaged soils at the Watt site cover about 5 acres. Saline seeps developed in a complicated geologic setting have mobilized reserve pit salts. Investigations are being continued at this site by the Montana Salinity Control Association.

In addition to the specific objectives of the study several tools and methods were tested for their applicability in the collection of field data.

1.) Lysimeters installed as deep as 50 feet provided sufficient water for laboratory and field water quality samples. The lysimeters proved to be an extremely useful sampling tool in the unsaturated zone.

2.) Electromagnetic conductivity surveys are fast effective ways of identifying areas of brine contamination.

3.) Field chloride titrators proved effective for measuring chloride concentrations. The titrators will measure chloride concentrations ranging from 40 mg/L to about 5000 mg/L without dilution. At higher salt concentrations the sample can be diluted without significantly affecting measurement accuracy.

Other recommendations and observations are listed below:

1.) There is a high potential for degradation of ground water resources and damaging soils when reserve pits are reclaimed by trenching in areas having high water tables such as flood plains, alluvial terraces and saline seeps. Where water tables are within a few feet of the land surface, soils are damaged when salts are transported to the surface by capillary action. In addition, salts are periodically dissolved from the wastes and degrade aquifer water quality. Brine saturated reserve pit wastes should be removed from areas having high water tables and disposed of at properly engineered centralized disposal facilities.

2.) Several methods are available for decreasing further soil and water contamination from improperly reclaimed reserve pits including:

   a.) Excavating and removing the drilling wastes from critical sites.

   b.) Excavating and diluting the wastes by washing with fresh water and injecting the waste liquids into non-potable aquifers.

   c.) Setting up an in situ dilution process using methods such as infiltration galleries and irrigation.

   d.) Encapsulation of the waste muds

   e.) Mounding and capping reserve pits.

3.) The oil industry should be encouraged to decrease the amount of wastes produced by promoting recycling spent fluids. Recycling of drilling fluids has been demonstrated as a economical alternative to environmentally sound waste disposal (Lal and Thurber, 1989).

4.) Although significant localized contamination from oil field wastes has occurred, widespread degradation of soils and shallow aquifers has not developed in Richland County. Dilution of salt plumes by mixing and dispersion in both the unsaturated zone and saturated zone mitigate the impacts of contamination. In general, this restricts significant contamination to within several hundred feet of the source.

REFERENCES - PART I

Dames and Moore, 1982. Analysis of hydraulic and environmental effects of drilling mud pits and produced water impoundments, Volume I: unpublished executive summary and report, Houstan, Texas.

Davis, Stephen K., 1987. An assessment of ground water contamination from the disposal of spent drilling fluids; Masters thesis, Univ. of Wyoming, Laramie, Wyoming, 145 p.

Dewey, M.B., 1984. Effects of reserve pit reclamation on ground water quality at selected oil well sites in eastern Montana and western North Dakota: unpublished masters thesis, University of Montana, 111 p.

Donovan, J.J., 1988. Ground-water geology and high-yield aquifers of northeastern Montana: MBMG Open-File Report #209, Butte, MT, 116 p.

Kemblowski, M.W. and Deeley, G.M., 1987. A ground water screening model for drilling fluid disposal pits: unpublished report presented at the Third National Conference on Drilling Muds, sponsored by the Environmental and Ground Water Institute, Univ. of Oklahoma, Norman, Oklahoma, May 28-29, 1987, 29 p.

Lal, Manohar and Thurber, Neal, 1989. Drilling wastes management and closed-loop systems in drilling wastes, edited by Englehardt, F.R., Ray, J.P., and Gillom, A.H.: Elsevier Applied Science, London and New York, 867 p.

Leuterman, J.J., and others, 1987. Drilling fluids and reserve pit toxicity: unpublished report presented at the Third National Conference on Drilling Muds, May 28-29, 1987, 26 p.

Levings, Gary W., 1984. Reconnaissance evaluation of contamination in the alluvial aquifer in the east Poplar oil field, Roosevelt County, Montana: U.S. Geological Survey Water Resources Investigations Report 84-4174, 19 p.

Montana Department of Natural Resources and Conservation, 1975-1987. Annual review(s) for the 1975-1987 relating to oil and gas, Vol. 19-31, Oil and Gas Conservation Division, Dept. of Natural Resources and Conservation, Helena, MT.

Montana Board of Oil and Gas Conservation, 1989. Draft programmatic environmental impact statement on oil and gas drilling and production in Montana, 244 p.

Murphy, E.C., and Kehew, A.E., 1984. The effect of oil and gas well drilling fluids on shallow groundwater in western North Dakota: Report of Investigation No. 82, North Dakota Geological Survey, Grand Forks, North Dakota, 156 p.

Murphy, E.C., Kehew, A.E., Groenewold, G.H., and Beal, W.A., 1988. Leachate generated by an oil and gas brine pond site in North Dakota: Ground water, Vol. 26, No. 1, pp 31-38.

Strosher, M.T., 1984. A comparison of biological testing methods in association with chemical analyses to evaluate toxicity of waste drilling fluids in Alberta: Volume 1, Canadian Petroleum Association, Calgary, Alberta

Torry and Kohout, 1956. Geology and ground water resources of the lower Yellowstone River valley between Glendive and Sidney, Montana: U.S. Geological Sur. Water Supply Paper 1355, 92 p.

U.S. Environmental Protection Agency, 1987. Technical report -- exploration, development, and production of crude oil and natural gas -- field sampling and analytical results: EPA 530-SW-87-005, Office of Solid Waste and Emergency Response, Washington, D.C.