Delineation of brine contamination in and near the East Poplar oil field, northeastern Montana, Williston Basin

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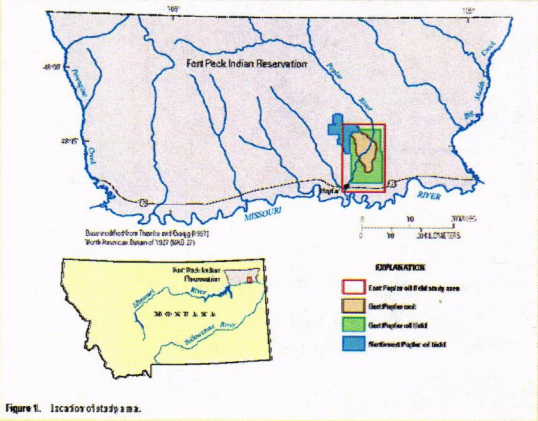
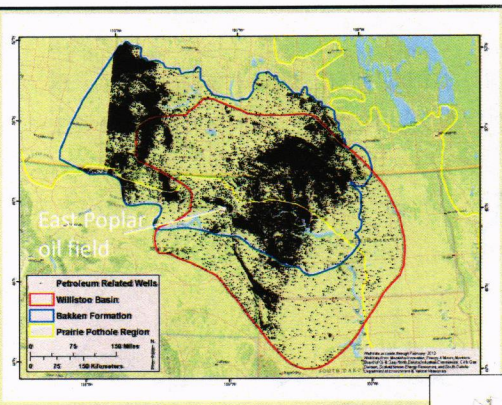


Figure 1. Location of study area.

July 10, 2014
Montana Environmental Quality Council

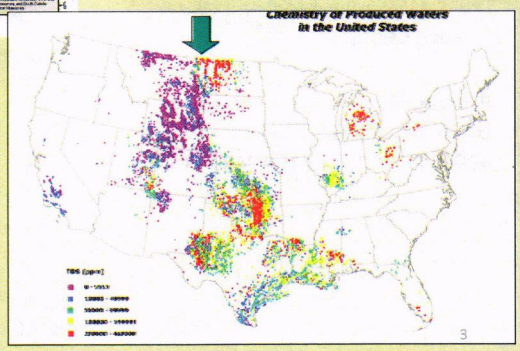
Support and Collaboration

- -Fort Peck Tribes, Office of Environmental Protection
  - -S.S. Papadopulos & Associates, Inc.
- -US Geological Survey
- -Bureau of Land Management
- -US Environmental Protection Agency
- -US Bureau of Reclamation
- -Pioneer Natural Resources USA
  - -Condor Consulting
  - -Daniel B. Stephens & Associates, Inc.
  - -HKM
- -Pioneer Natural Resources/Murphy Exploration & Production Company/Samson/Marathon
  - -Land & Water/PBS&J
  - -HydroSolutions
- -Montana Department of Environmental Quality



- East Poplar oil field producing since early 1950s.
- Conventional oil wells are about 6,000 ft deep
- As much as 10 barrels of brine for every barrel of oil
- ~200 Mgal produced annually
- Produced water is some of most-saline water in the Nation

- East Poplar oil field on western flank of Williston Basin
- No oil wells from Bakken Fm yet



USGS

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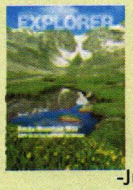
Collaborative approach

-2007 and 2008 AAPG DEG Research Awards

-2012 EPA Silver Medal

-2008 Environmental Achievement Award



-June 2009 AAPG Explorer Magazine

USGS

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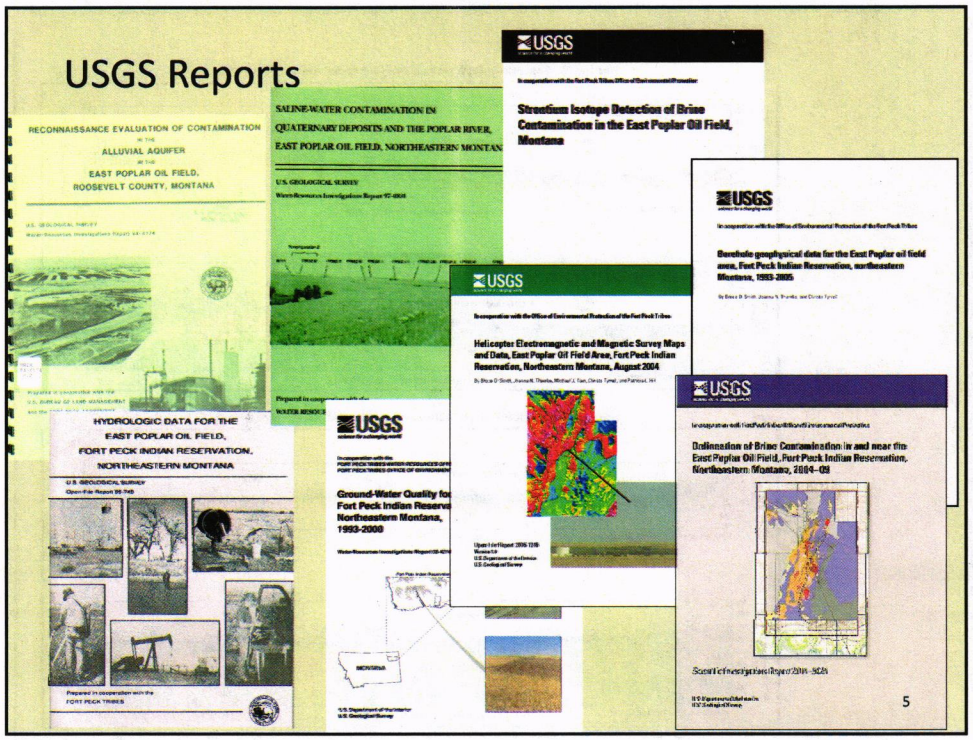
USGS Reports
RECONNAISSANCE EVALUATION OF CONTAMINATION
ALLUVIAL AQUIFER
EAST POPLAR OIL FIELD,
ROOSEVELT COUNTY, MONTANA
SALINE-WATER CONTAMINATION IN
QUATERNARY DEPOSITS AND THE POPLAR RIVER,
EAST POPLAR OIL FIELD, NORTHEASTERN MONTANA
USGS
Strontium Isotope Detection of Brine Contamination in the East Poplar Oil Field, Montana
Borehole geophysical data for the East Poplar oil field area, Fort Peck Indian Reservation, northeastern Montana, 1993-2005
Helicopter Electromagnetic and Magnetic Survey Maps and Data, East Poplar Oil Field Area, Fort Peck Indian Reservation, Northeastern Montana, August 2004
HYDROLOGIC DATA FOR THE
EAST POPLAR OIL FIELD,
FORT PECK INDIAN RESERVATION,
NORTHEASTERN MONTANA
Ground-Water Quality for Fort Peck Indian Reserve Northeastern Montana, 1993-2000
Delineation of Brine Contamination in and near the East Poplar Oil Field, Fort Peck Indian Reservation, Northeastern Montana, 2004-08
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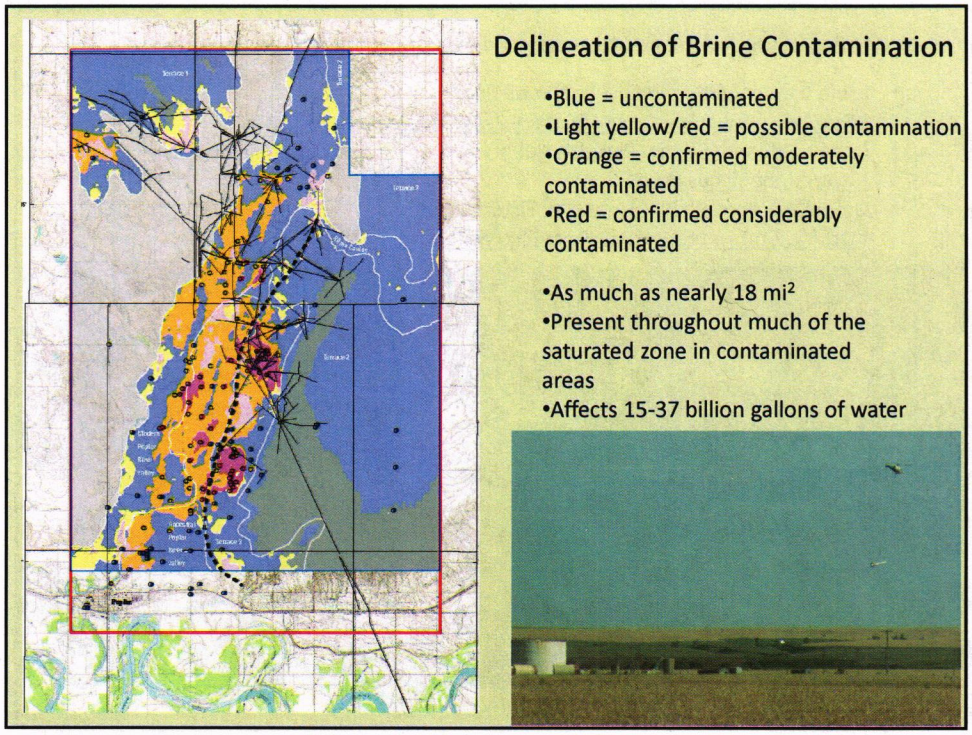
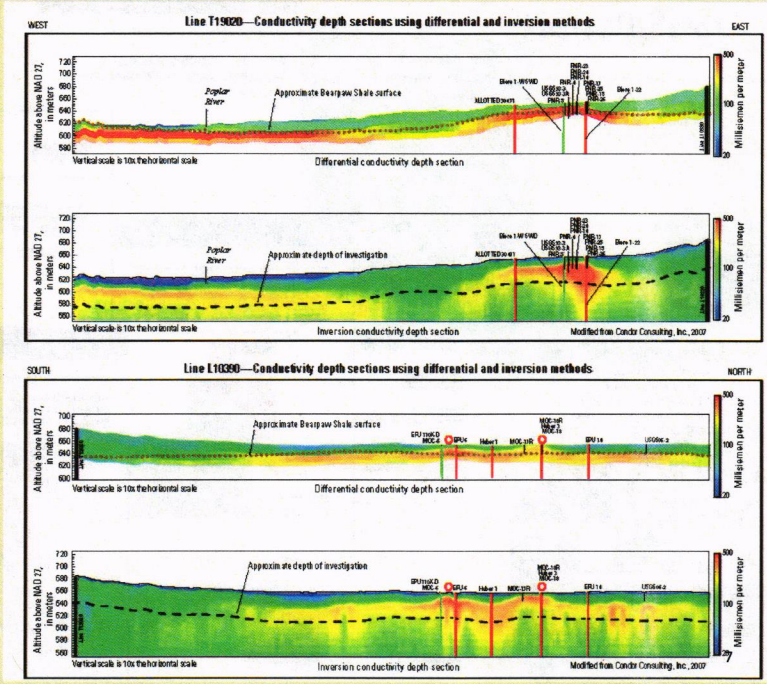

Delineation of Brine Contamination
•Blue = uncontaminated
•Light yellow/red = possible contamination
•Orange = confirmed moderately contaminated
•Red = confirmed considerably contaminated
•As much as nearly 18 mi²
•Present throughout much of the saturated zone in contaminated areas
•Affects 15-37 billion gallons of water



Ongoing USGS work related to energy and environment in Williston Basin

- Brine contamination in East Poplar oil field
  http://wy-mt.water.usgs.gov/projects/east_poplar/index.html
- Brine contamination in Sheridan County and other parts of Williston Basin
  http://steppe.cr.usgs.gov
- Groundwater availability in the Williston Basin
  http://wy-mt.water.usgs.gov/projects/WaPR/index.html

Wetland contaminated by oil-field brine, Photo by Jerry Rodriguez, USFWS

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Delineation of Brine Contamination in and near the East Poplar Oil Field, Fort Peck Indian Reservation, Northeastern Montana, 2004–09

By Joanna N. Thamke and Bruce D. Smith

Abstract

The extent of brine contamination in the shallow aquifers in and near the East Poplar oil field is as much as 17.9 square miles and appears to be present throughout the entire saturated zone in contaminated areas. The brine contamination affects 15–37 billion gallons of groundwater. Brine contamination in the shallow aquifers east of the Poplar River generally moves to the southwest toward the river and then southward in the Poplar River valley. The likely source of brine contamination in the shallow aquifers is brine that is produced with crude oil in the East Poplar oil field study area. Brine contamination has not only affected the water quality from privately owned wells in and near the East Poplar oil field, but also the city of Poplar's public water-supply wells.

Three water-quality types characterize water in the shallow aquifers; a fourth water-quality type in the study area characterizes the brine. Type 1 is uncontaminated water that is suitable for most domestic purposes and typically contains sodium bicarbonate and sodium/magnesium sulfate as the dominant ions. Type 2 is moderately contaminated water that is suitable for some domestic purposes, but not used for drinking water, and typically contains sodium and chloride as the dominant ions. Type 3 is considerably contaminated water that is unsuitable for any domestic purpose and always contains sodium and chloride as the dominant ions. Type 3 quality of water in the shallow aquifers is similar to Type 4, which is the brine that is produced with crude oil.

Electromagnetic apparent conductivity data were collected in the 106 square-mile area and used to determine extent of brine contamination. These data were collected and interpreted in conjunction with water-quality data collected through 2009 to delineate brine plumes in the shallow aquifers. Monitoring wells subsequently were drilled in some areas without existing water wells to confirm most of the delineated brine plumes; however, several possible plumes do not contain either existing water wells or monitoring wells. Analysis of groundwater samples from wells confirms the presence of 12.1 square miles of contamination, as much as 1.7 square miles of which is considerably contaminated (Type 3). Electromagnetic apparent conductivity data in areas with no wells delineate an additional 5.8 square miles of possible contamination, 2.1 square miles of which might be considerably contaminated (Type 3). Storage-tank facilities, oil wells, brine-injection wells, pipelines, and pits are likely sources of brine in the study area. It is not possible to identify discrete oil-related features as likely sources of brine plumes because several features commonly are co-located. During the latter half of the twentieth century, many brine plumes migrated beyond the immediate source area and likely mix together in modern and ancestral Poplar River valley subareas.

Introduction

For more than half a century, millions of barrels of brine have been produced with oil from the East Poplar oil field and surrounding area. The brine, which contains 37,900 to 210,000 milligrams per liter (mg/L) dissolved solids, was placed in pits and ponds or injected into subsurface geologic units through disposal wells. Handling and disposal of the brine has resulted in contamination of not only the shallow aquifers in the East Poplar oil field, but also the Poplar River (Thamke and Craigg, 1997). The shallow aquifers primarily consist of unconsolidated sands and gravel that are as much as 45 feet (ft) thick and are overlain by unsaturated clay, silt, and sand that are as much as 100 ft thick. The shallow aquifers are underlain by 700 to 1,000 ft of impermeable Upper Cretaceous Bearpaw Shale (Bearpaw Shale).

The shallow aquifers are the only available source of potable groundwater in the area, and had provided water for more than 100 residents with household wells northeast of Poplar in addition to 2,900 residents that relied on the city of Poplar public water-supply wells. The city of Poplar, headquarters of the Fort Peck Tribal government, is downgradient from multiple sources of brine and brine-contaminated groundwater in the East Poplar oil field. Data collected by the USGS during 2009–10 confirmed that water from the city of Poplar's public water-supply wells is enriched in constituents that are present in oil-field brines (Peterman and

others, 2010). As a result of the affected public-water supply wells, a pipeline was completed during 2011 that supplies treated water from the Missouri River to the city of Poplar and nearby residents, replacing the use of the shallow aquifers as a source of water (Debi Madison, Fort Peck Tribes, written commun., 2013).

Electromagnetic methods were first used to delineate brine plumes in the East Poplar oil field during the early 1990s (Thamke and Craigg, 1997). Areas with brine contamination were identified in more than 12 square miles (mi^2) of shallow aquifers in and near the East Poplar oil field. In the 10 years since the first delineation, dissolved-solids concentrations in groundwater changed markedly in and near brine contamination, yet dissolved-solids concentrations remained constant in areas unaffected by brine contamination (Thamke and Midtlyng, 2003). The changes in the groundwater quality indicated that the extent of brine contamination likely had changed since the early 1990s. The water-quality data were insufficient to delineate, with any detail, a new extent of brine contamination.

In 2003, the U.S. Geological Survey (USGS), in cooperation with the Fort Peck Tribes Office of Environmental Protection (FPOEP), initiated a follow-up investigation that combined historical and recent geophysical, hydrologic, and water-quality data with the objectives to delineate brine contamination, document movement of contamination, and identify possible brine sources in and near the East Poplar oil field. This investigation expanded on previous USGS studies (Levings, 1984; Thamke and Craigg, 1997; and Thamke and Midtlyng, 2003) and extended the study area southward to the northern edge of the Missouri River valley and westward to include the city of Poplar.

Purpose and Scope

This report delineates brine contamination in and near the East Poplar oil field using information collected by the USGS and other entities through 2009. As part of this report, a comprehensive historical map of oil-related features was compiled; the altitude and configuration of the top of the shallow aquifers and the Bearpaw Shale was determined; areas of low, moderate, and high apparent conductivity were delineated; and extent of brine contamination was interpreted and delineated.

This report is the fourth USGS publication that documents the results of this investigation to delineate brine contamination in and near the East Poplar oil field. Airborne electromagnetic data collected during 2004 and electromagnetic maps are published in Smith and others (2006a). Strontium isotope and major dissolved ion data collected during 2009 and 2010 by the FPOEP and USGS are published in Peterman and others (2010); however, only the major dissolved ion data from 2009 are used for interpretations in this report. Borehole geophysical data collected during 1993, 2004, and 2005 by the USGS and lithologic logs of these wells are published in Smith and others (2014).

Description of Study Area

The study area encompasses about 126 mi^2 and includes the city of Poplar, the East Poplar oil field, and most of the Northwest Poplar oil field (fig. 1). Land uses in the study area include dryland farming, livestock ranching, oil production, and residential development. The Poplar River flows south and west through the study area into the Missouri River that flows eastward near the southern edge of the study area. Throughout nearly all of the study area, shallow aquifers directly overlie the thick and impermeable Upper Cretaceous Bearpaw Shale and are the only available source of potable groundwater for residents in the study area (Thamke and Craigg, 1997). The shallow aquifers primarily consist of sand and gravel in Quaternary alluvium or Wiota Gravel, except in the northern one-quarter of the study area where shallow aquifers also can include sandstone in the Upper Cretaceous Fox Hills and Hell Creek Formations, sandstone interbedded with minor coal seams in the Tertiary Fort Union Formation, and gravel in the Tertiary Flaxville Formation. Quaternary alluvium and Wiota Gravel were deposited fluvially in a typical channel geometry pattern with variable sands and gravel. Previous investigations on geologic structure, stratigraphy, and hydrogeology in the East Poplar oil field study area are summarized by Thamke and Craigg (1997).

Site Identification and Well-Naming Systems

Site numbers are used to identify wells in the same manner as used in previous investigations (Thamke and Midtlyng, 2003; Thamke and Craigg, 1997; Thamke and others, 1996; Levings, 1984). Site numbers are based on the rectangular system for the subdivision of public lands (fig. 2). The number consists of as many as 14 characters and is assigned according to the location of a site within a given township (T), range (R), and section (sec.). The first three characters specify the township and its position north (N) of the Montana Base Line, whereas the next three characters specify the range and its position east (E) of the Montana Principal Meridian. The next two characters indicate the section; the next four characters indicate the position of the site within the section. The first letter denotes the quarter section (160-acre tract), the second letter denotes the quarter-quarter section (40-acre tract), the third letter denotes the quarter-quarter-quarter section (10-acre tract), and the fourth letter denotes the quarter-quarter-quarter-quarter section (2.5-acre tract). These lettered subdivisions of the section are indicated as A, B, C, and D in a counterclockwise direction beginning in the northeast quadrant. The last two characters form a sequence number based on the order that a site was identified in that tract. For example, site number 28N51E22CBAC02 represents the second well identified in the SW¼ of the NE¼ of the NW¼ of the SW¼ in sec. 22, T. 28 N., R. 51 E.

Wells also are identified by an alpha-numeric well name, allowing for ease of cross reference between wells plotted on the figures and tables in this report and on figures and tables in

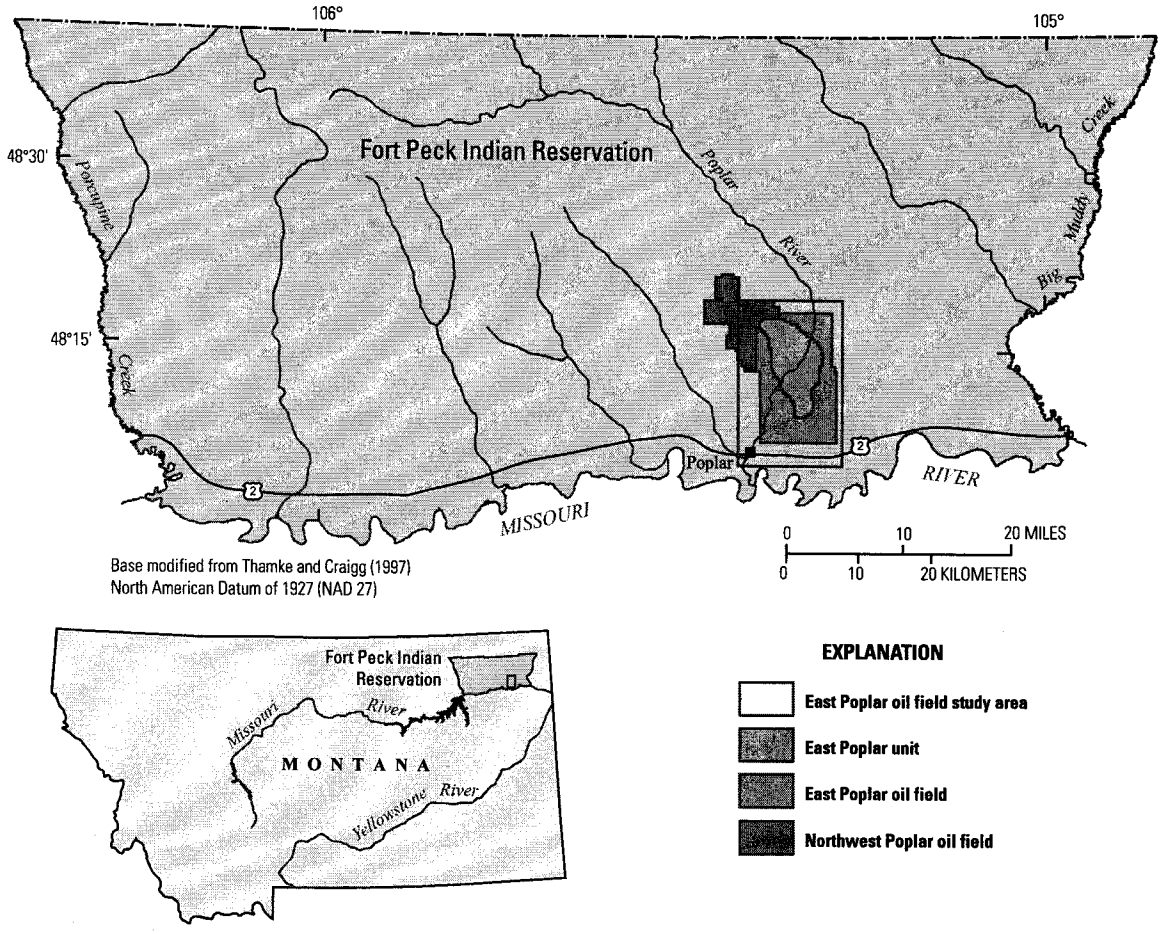

Figure 1. Location of study area.

numerous previous reports by the USGS and other agencies. The well name consists of as many as four alpha characters and four numeric characters. The alpha characters denote the well type: LAW—monitoring well installed for Land and Water Consulting, Inc.; MBMG—monitoring well installed by Montana Bureau of Mines and Geology; MOC—monitoring well installed for Murphy Oil Company; MSCA—monitoring well installed by Montana Salinity Control Association; PNR—monitoring well installed for Pioneer Natural Resources USA, Inc.; USGS—monitoring well installed for or by the USGS; and M or W—privately owned well. The first two numeric characters for USGS and MBMG monitoring wells denote the year that the well was drilled. The last two numeric characters for USGS monitoring wells denote the sequence that the wells were drilled during 1992, 1993, and 2009. The numeric characters for privately owned wells are assigned only as a convenient cross reference between relevant figures and tables. Privately owned wells that were drilled after September 1993 and not published in Thamke and others (1996) are numbered sequentially after M-57, the last well in the original 1996 list. Brine-injection wells and oil wells are identified using the well name provided by the Montana Board of Oil and Gas Conservation's (MBOGC) online oil and gas information system (Montana Board of Oil and Gas Conservation, 2005).

Methods of Investigation

This investigation of brine contamination in and near the East Poplar oil field included a comprehensive review of existing data and extensive collection of additional field data. Existing data for water wells, monitoring wells, oil wells, brine-injection wells, and water quality were obtained from various sources that are identified throughout this report.

As an initial step in this investigation, existing photographs, maps, and the MBOGC's online oil and gas information system (Montana Board of Oil and Gas Conservation, 2005) were used to develop a comprehensive map of oil-related features in the study area dating from 1952 to 2005. Existing wells were sampled during 2003 to compare with historical water-quality information. To further delineate the

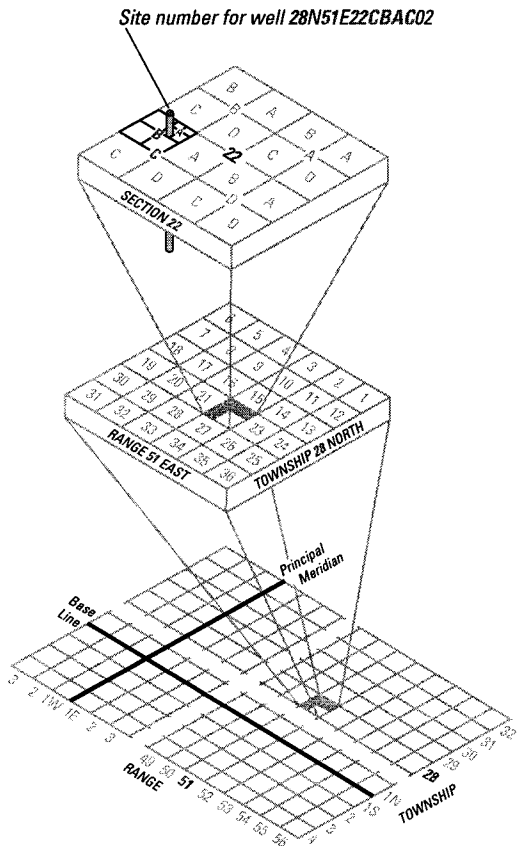

Figure 2. Diagram showing site-numbering system.

extent of potential brine contamination, an airborne electromagnetic survey was conducted over an area of about 106 mi^2 in 2004. Borehole natural gamma and electromagnetic data were collected in selected wells during 2004 and 2005 to provide vertical and lateral correlation at known points throughout the study area. Ground electromagnetic surveys were conducted in five small areas during 2005 to guide interpretation of relevant measurement sets. Monitoring wells were installed during 2006 for subsequent aquifer testing or in areas where high apparent conductivity values were recorded with the airborne electromagnetic equipment. Geologic information from maps and lithologic information from selected wells were used to develop maps showing the approximate altitude and configuration of the top of the shallow aquifers and the top of the Bearpaw Shale. Aquifer tests were conducted during 2007 in selected monitoring wells to determine aquifer characteristics. Monitoring wells were installed during 2009 to provide lithologic data in the southwest part of the study area. Water from monitoring wells was sampled between 2003 and 2009 to confirm if water was uncontaminated, moderately contaminated, or considerably contaminated. Previous data and the data collected during this investigation were used to delineate brine contamination in and near the East Poplar oil field.

Historical Oil-Related Features

Aerial survey photographs and maps obtained from eight discrete periods (1956, 1967, 1974/1975, 1980, 1991/1992, 1996, 2001, 2005) and data between 1952–2005 from the MBOGC's online oil and gas information system (Montana Board of Oil and Gas Conservation, 2005) were used to identify historical and existing oil-related features, such as pits and ponds, tank facilities, oil wells, and pipelines (fig. 3, table 1). Tank batteries were identified as cylindrical tanks at the site on the aerial photograph. Oil-well names and locations were obtained from MBOGC's online oil and gas information system (Montana Board of Oil and Gas Conservation, 2005). Linear features that seemed to connect two oil-related facilities on the photographs were delineated as pipelines. An early-1990s field map from MOC was used to help locate pipelines, although many more pipelines were identified using the aerial photographs than were depicted on the MOC field map.

Oil-related features that were identified on the aerial photographs were hand-digitized into a Geographical Information System (GIS) coverage. Root-mean-square (RMS) errors between the registration tics placed on the photograph at road intersections and the inferred longitude and latitude coordinates of those locations ranged from 0.0 meters (1974, 1980, 1991, and 1992) to 0.037 (1967) and 0.042 meters (1956). Oil-related features identified on the 1996 digital orthophotographic quadrangle maps were transferred electronically to figure 3. If necessary, the digitized 1956–92 oil-related features were adjusted visually in the GIS coverage on a computer screen using the 1996 digital orthophotographic quadrangle maps.

Linear features from utilities, such as electrical and telephone lines, are not included in figure 3. A powerline map delineated with 2004 electromagnetic data (fig. 6 from Smith and others, 2006a) was used to omit linear features that appeared on the photographs from utility lines. A map from NEMONT Telephone Cooperative, Inc. was used to omit linear features that appeared on the photographs from telephone lines (NEMONT Telephone Cooperative, Inc., 2005, written commun).

Terry Ross, field manager of Nautilus Poplar LLC [which currently (2014) manages most of the East Poplar Unit, an area of pooled oil production among several operators], reviewed figure 3 to verify the identified oil-related features. Mr. Ross identified several additional features that were neither visible in the photographs nor listed in MBOGC's online oil and gas information system (Montana Board of Oil and Gas Conservation, 2005).