Chapter 1. Introduction

I. Introduction

Coal mining in the Powder River Basin of northeastern Wyoming began in earnest in the middle 1970s, with an increase in production during the 1980s. The 1990s saw the beginning of coal-bed methane production to the west of the coal mines (Figure 1-1). Of interest to many parties has been the determination of the effects of drawdowns in the coal aquifer, due both to strip-mining and coal-bed methane production, on the water supply of the Powder River Basin.

The Bureau of Land Management has been recording water levels in a pair of wells, which monitor both the coal and the sand lens aquifers, since 1993 (Brogan and Meyer, 1996)(Figure 1-2 and 1-3). A steady drawdown in the coal has been observed over this period. A drawdown in the sand lens aquifer is evident as well. What is unknown is whether the drawdowns observed in the sand lens aquifer are caused by drawdowns in the coal aquifer.

II. Objectives

This study examines the confining layer separating the Eocene Wasatch Formation from the underlying Wyodak coal seam of the Paleocene Fort Union Formation from a modeling perspective. Specifically, this study attempts to estimate the vertical hydraulic conductivity of the material separating a particular sand lens (Figure 1-4) in the Wasatch Formation from the underlying Wyodak coal bed. In addition this study details how the Wyodak coal layer should be represented in the model.

III. The inverse problem and data adequacy

Solving the groundwater flow equation for groundwater elevation using known aquifer parameters, stresses and boundary conditions is the direction in which such problems are generally solved. Solving the groundwater flow equation for aquifer parameters, stresses and boundary conditions using known ground water elevations is referred to as solving the inverse problem. The difficulty of this approach in this case is

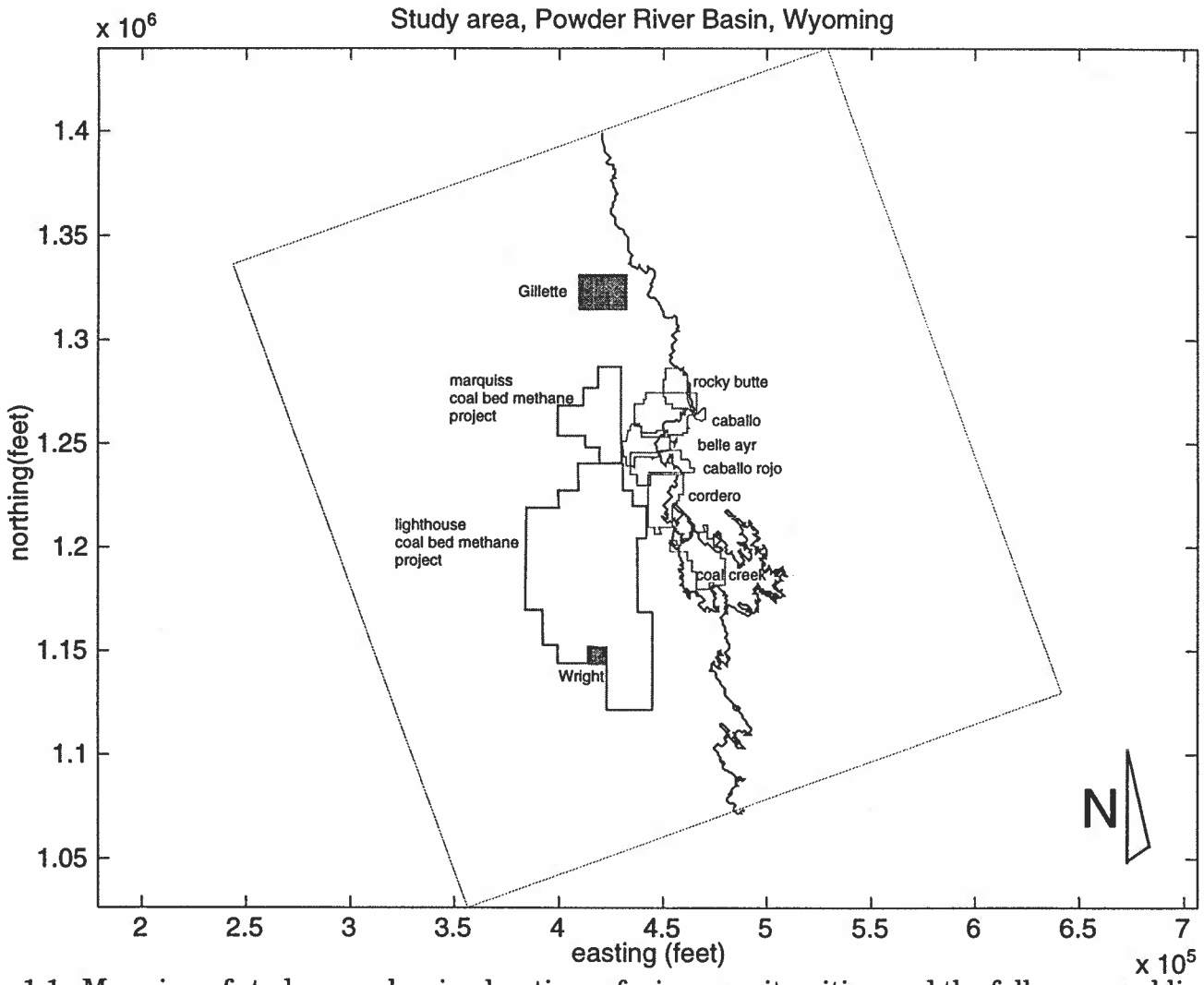
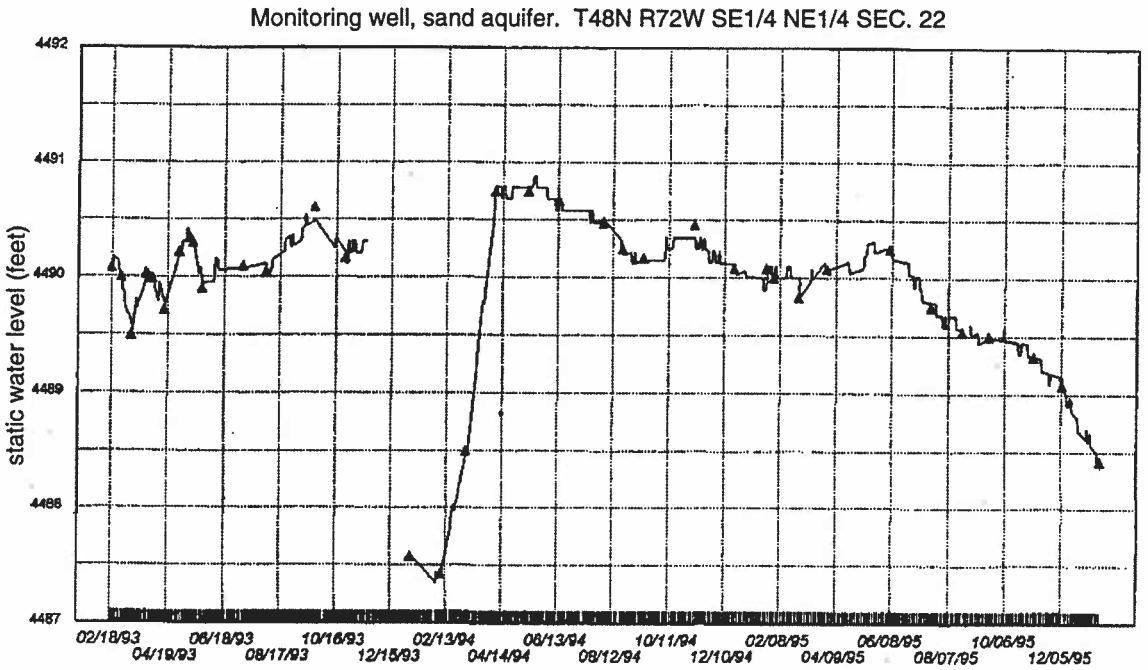


Figure 1-1. Map view of study area showing locations of mine permits, cities, and the full seam coal line also known as the cropline. In the area of Coal Creek mine the two lines shown represent the cropline of two different coal seams.



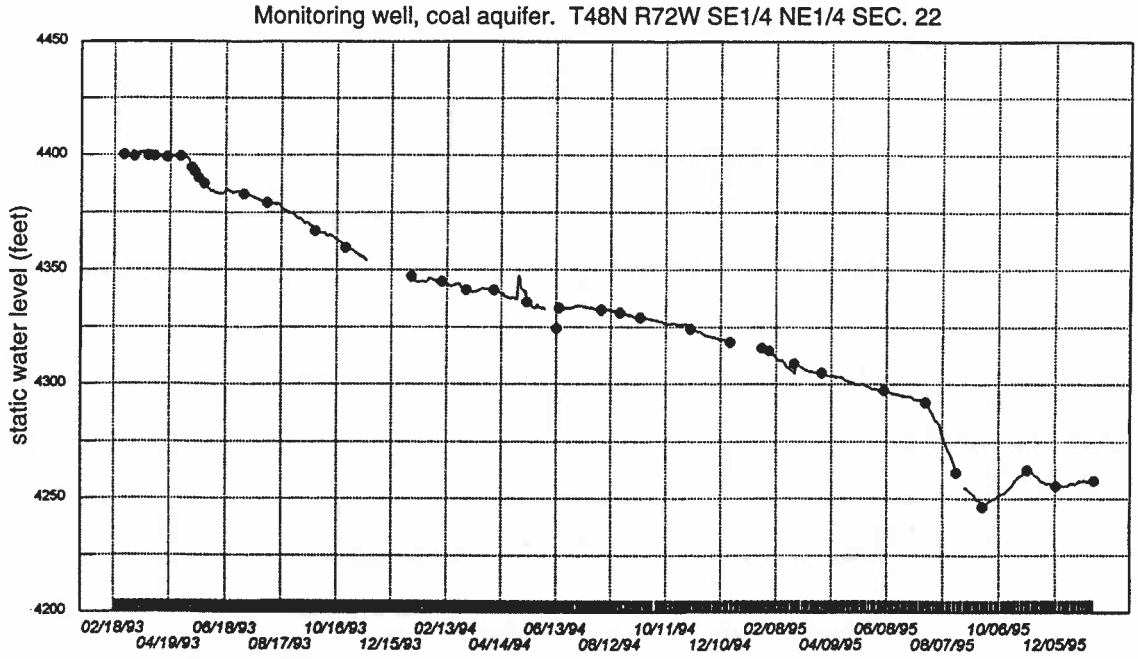


Figure 1-2. Plots of water level over time, in a well which monitors both the sand lens and coal aquifers.

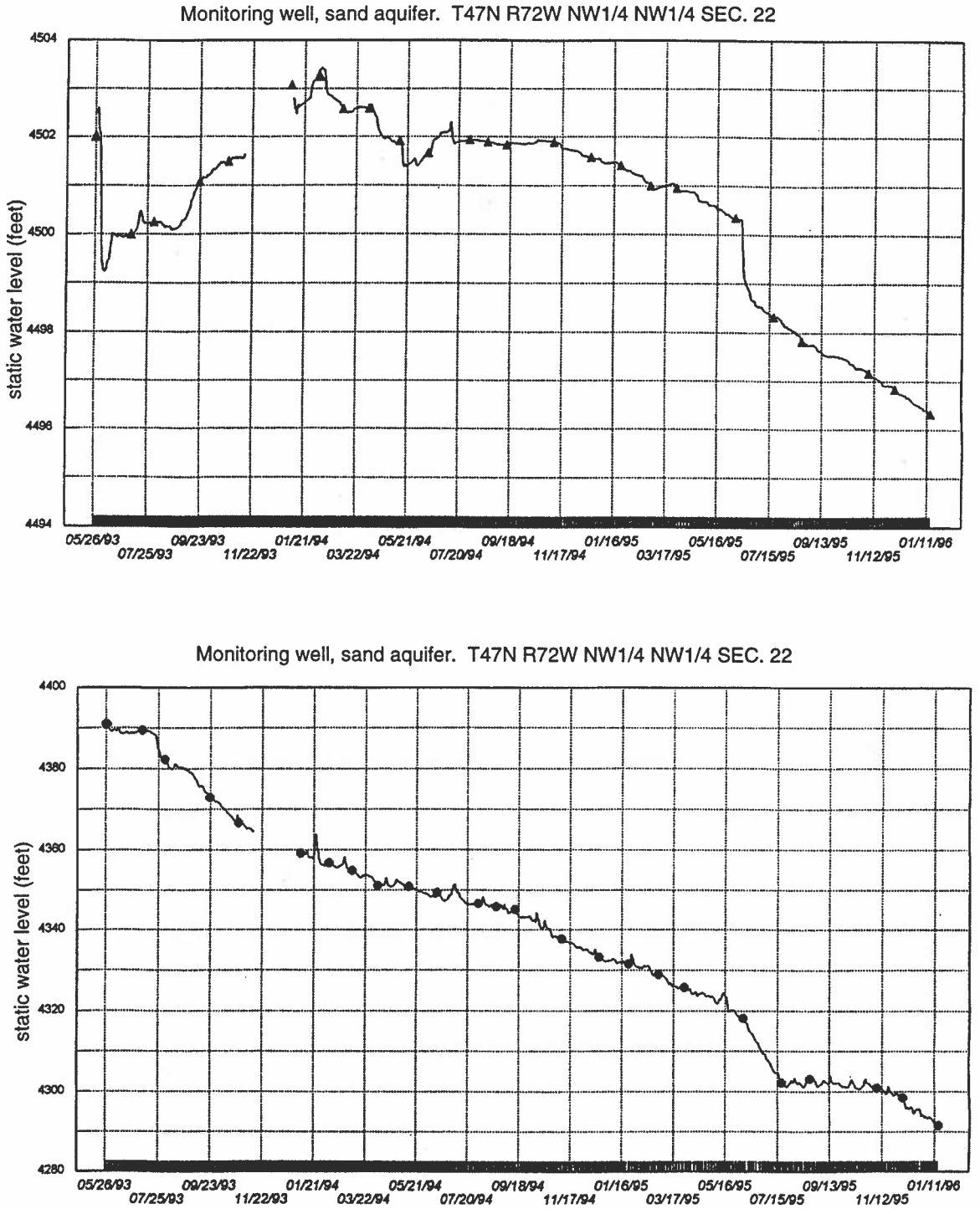


Figure 1-3. Plots of water level over time, in a well which monitors both the sand lens and coal aquifers.

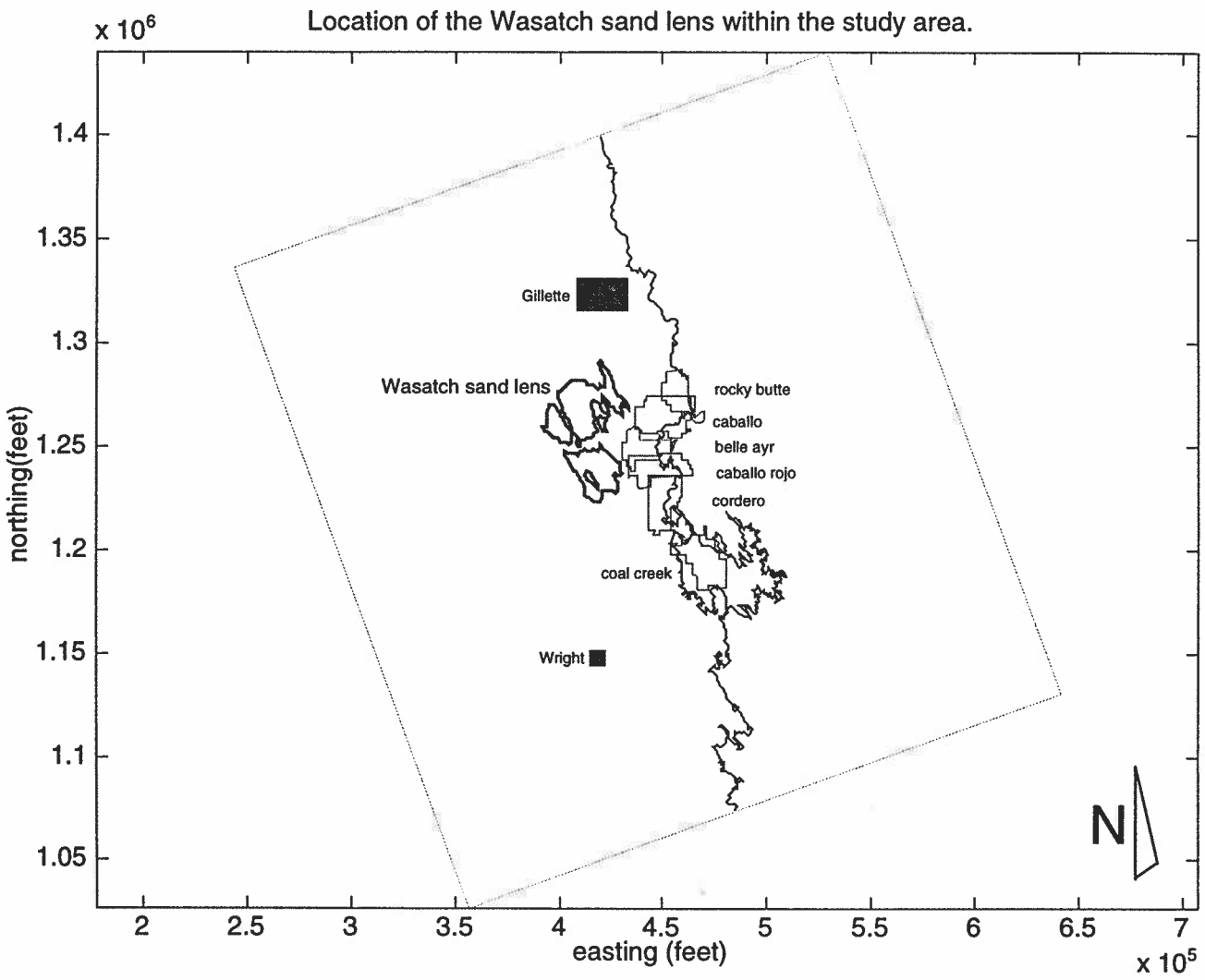


Figure 1-4 . Map of the study area including the location of the Wasatch sand lens west of the mines. The sand lens is represented by the 20 foot isopach.

compounded by a paucity of data. The majority of the data were collected by industry, in the vicinity of the mines. No systematic data collection for the domain is available. For this reason geologic data and water level data are clustered near the eastern boundary of the domain (Figure 1-5). There is a large expanse to the west which contains little or no data. As a result, conceptualization of the natural system plays an important role in the construction of the model.

IV. Modflow and Modflowp

The United States Geological Survey (USGS) computer codes Modflow (McDonald and Harbaugh, 1988) and Modflowp (Hill, 1990) were utilized to solve the ground water flow equation. Modflow utilizes a finite difference approach to solve the groundwater flow equation, and forms the core of Modflowp. Modflowp allows the modeler to estimate aquifer parameters and determine how they affect the heads and fluxes of the model. Modflowp cycles these estimates through Modflow, determines how closely the resulting head matches given calibration points and alters the estimates to improve the calibration. Modflowp is an evolving program; in fact a new version was released during the course of this investigation.

V. Geographic setting

The model domain for this study is located in the Powder River Basin of northeast Wyoming, and extends from Gillette, to the north, to south of Wright, to the south, in Campbell County, Wyoming (Figure 1-6). The study area encompasses Rocky Butte, Caballo, Belle Ayr, Caballo Rojo, Cordero, and Coal Creek coal mines, the Marquiss coal-bed methane project area, and the Lighthouse coal-bed methane project area.

VI. Geologic setting

The Powder River Basin, formed during the Laramide orogeny, is a large northwest trending asymmetric syncline, bounded to the west by the Bighorn Mountains, to the south by the Laramie Range, to the southwest by the Casper Arch, to the southeast by the Hartville Uplift, to the east by the Black Hills, and to the northeast by the Miles

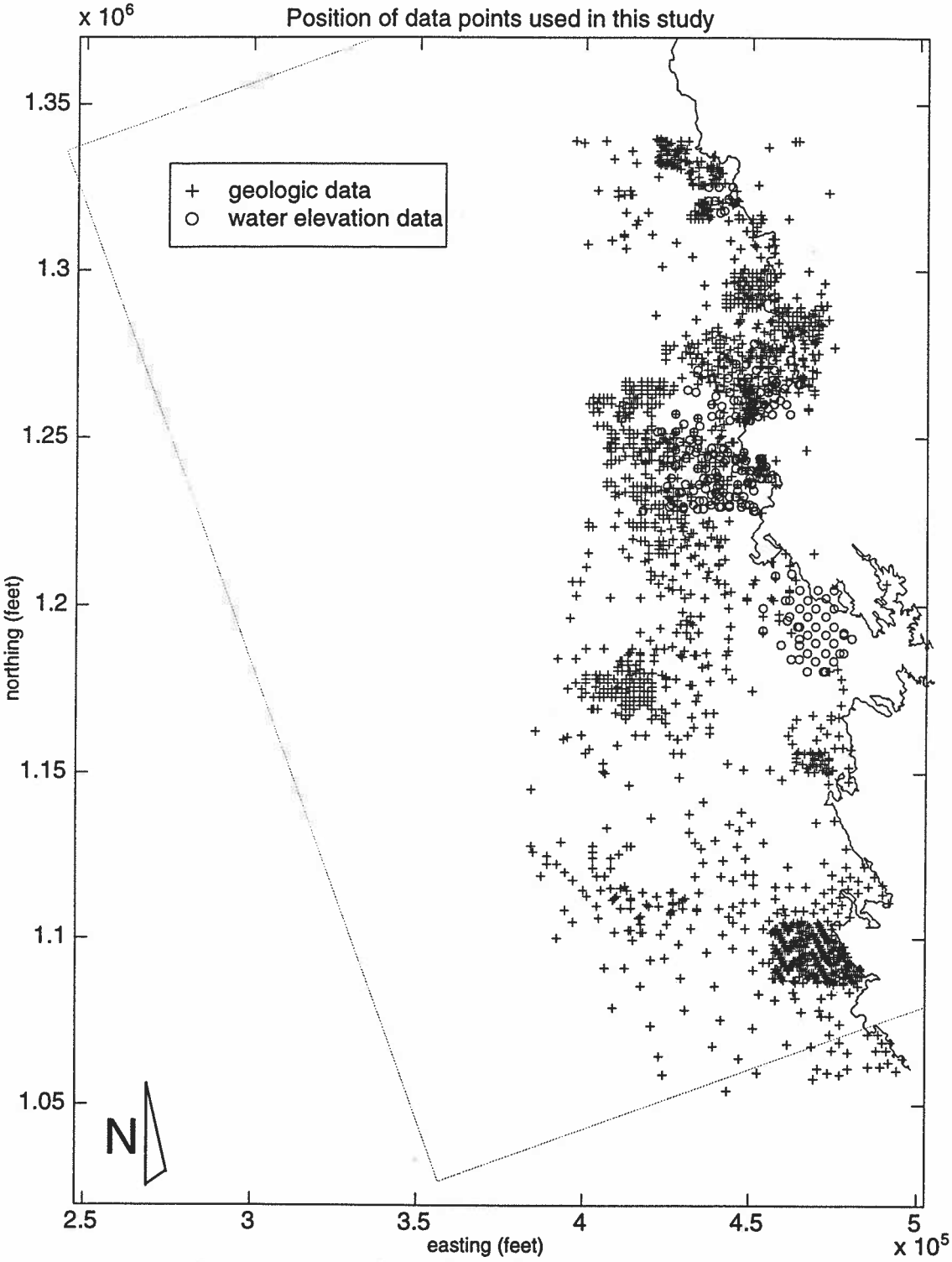


Figure 1-5. Location of data used in this study. Notice the clustering along the cropline, and the paucity of data to the west. Study domain boundary shown in gray.

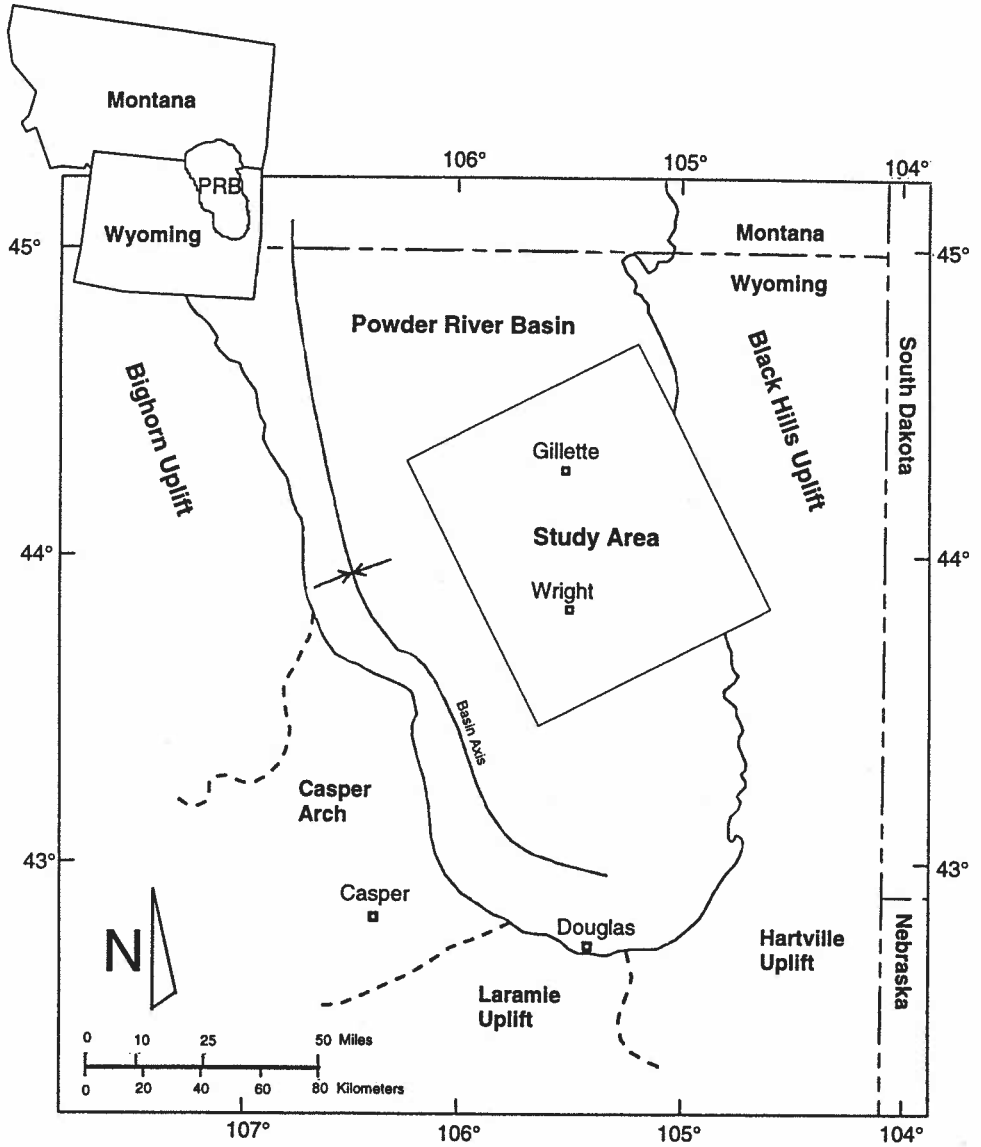


Figure 1-6. Location of study area within the Powder River Basin, Wyoming. Modified from Dobson (1996).

City Arch (Figure 1-6). The Powder River Basin contains a sedimentary package more than 13000 feet thick of Phanerozoic sediments overlying the Precambrian basement, about 6600 feet of which resulted from post deformational sediment influx and consist mainly of stream and lacustrine deposits (Lisenbee 1988).

Stratigraphy

The units of interest in the present study include those that are affected by coal and coal-bed methane production. These include the Tongue River member of the Paleocene Fort Union Formation, and the Eocene Wasatch Formation (Figure 1-7).

The Tongue River Member is the uppermost member of the Paleocene Fort Union Formation and consists of interbedded light-gray, very-fine to fine-grained, moderately-sorted, friable sandstone, gray siltstone, gray sandy shale, mudstone, and laterally continuous thick coal seams. The Tongue River member tends to be coarser and more conglomeratic on the western margin of the basin (Weaver et. al. 1987). It is typically 1200 to 1500 feet thick in the model area (Pierce et. al. 1990). Sandstone percentages in the Tongue River are highest at the basin margins with about 50% decreasing to about 30% toward the center of the basin (Curry 1971, Ayers 1986). Sand body geometry and lithofacies distribution suggest that the Tongue River Member is basin fill consisting of delta deposits prograding into ancient Lake Lebo (Ayers 1986). Primary deltaic sediment influx was from the east with minor deltas to the northwest and southwest (Ayers 1986). The Tongue River member is the most prodigious coal producing unit in the Powder River Basin (Glass 1991), and is the object of the mines in the study area.

The Eocene Wasatch Formation is lithologically similar to the Tongue River Member of the Fort Union Formation. The Wasatch Formation is second only to the Fort Union Formation in coal-bearing rocks in the basin; with as many as eight, laterally persistent, coal beds (Glass 1991). In the model area the Wasatch formation can be described from driller's logs as consisting predominantly of shale with interbedded sandstone, siltstone and coal. The shale is generally gray, sometimes sandy, silty, or carboniferous. Of particular interest in this study is a Wasatch sandstone lens which has been identified west of the coal mines (Figure 1-4). This lens consists of medium to fine-grained sandstone with pockets of coarse sand to gravel and minor pockets of

<table>
<tr><th>System</th><th>Series</th><th colspan="2">Stratigraphic Unit</th><th>Hydrostratigraphic Unit</th></tr>
<tr><td rowspan="4">Tertiary</td><td rowspan="2">Eocene</td><td colspan="2" rowspan="2">Wasatch Formation</td><td>Wasatch Sand Lens Aquifer</td></tr>
<tr><td>Upper Tongue River/
Lower Wasatch Confining Layer</td></tr>
<tr><td rowspan="2">Paleocene</td><td rowspan="2">Fort Union Formation</td><td rowspan="2">Tongue River Member</td><td>Wyodak Coal Seam Aquifer</td></tr>
<tr><td>Lower Tongue River Confining Layer</td></tr>
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Figure 1-7. Stratigraphic and hydrostratigraphic units considered in this study.

argillaceous sandstone to sandy or silty shale. The Wasatch Formation is thickest in the center of the basin, about 1575 feet, and thins toward the basin flanks (Fogg et al 1991).

The Wasatch Formation and the Tongue River member of the Fort Union Formation contain clinker adjacent to coal seams. Clinker is rock that has been thermally metamorphosed by the combustion of adjacent coal, resulting in hardened, melted or sintered rock. Clinker is differentially resistant to erosion due to its increased hardness over unaltered rock and also due to its high fracture permeability, caused by heating and subsidence, which allows water to infiltrate and minimizes surface runoff, leaving clinker to cap ridges, buttes, mesas, and knobs which stand out above the eroded, unaltered and less resistant country rock (Mears et. al. 1991).

VII. Hydrogeologic setting

The study domain is divided into four hydrostratigraphic units as described from driller's logs and Martin et. al. (1988)(Figure 1-7). At the greatest depth is the Lower Tongue River confining unit. This unit consists of shale and sandy shale with minor coal, siltstone, argillaceous siltstone, and carboniferous shale.

Overlying the Lower Tongue River confining layer is the Wyodak Coal Seam aquifer. The coal aquifer is quite impermeable except in cleat and other fractures (Dobson 1996, Stone and Snoeberger, 1977). Flow through the coal is believed to be localized along fractures and may be correlated to surface lineaments (Dobson 1996).

Overlying the Wyodak Coal Seam aquifer is the Upper Tongue River / Lower Wasatch confining layer. This unit is dominated by shale. Data from paired monitoring wells in the Wyodak Coal Seam aquifer and the Wasatch Sandstone Lens aquifer indicate that this confining layer may be only semiconfining, allowing some water to pass between the two aquifers (Figures 1-2 and 1-3).

Overlying the Upper Tongue River / Lower Wasatch confining layer is the Wasatch Sandstone Lens aquifer. The Sandstone Lens aquifer is a discrete lens of Sandstone in the Wasatch Formation separated from the underlying coal by the Upper Tongue River / Lower Wasatch confining layer. The Sandstone Lens aquifer is confined from the land surface by another shale-dominated layer.

The Clinker is not a member of the aquifer / confining layer system described above, but comprises the fourth hydrostratigraphic unit. Its unique hydrologic properties affect the boundary conditions of the model.