Fort Union Formation Aquifer Monitoring Plan
and
Preliminary Aquifer Management Plan

Gillette Area Water Master Plan
Gillette, Wyoming

PREPARED FOR AND FUNDED BY
Wyoming Water Development Commission
Herschler Building, 4th Floor-West
122 W. 25th Street
Cheyenne, Wyoming 82002

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Wyoming State Engineer's Office
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NOVEMBER, 1995
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SELECTED REFERENCES

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M.O.A - Wyoming Water Development Commission
Wyoming State Engineer's Office

PLATE POCKETS

1. Location and Geologic Map
2. Logs of G-MON-series Observation Wells
3. Fort Union Well Map
Section 1.0 - EXECUTIVE SUMMARY

The adoption of the Gillette Area Water Master Plan by the City of Gillette and Campbell County with financial assistance from the Wyoming Water Development Commission marks a responsible approach to efficient utilization of water, financial, and human resources. The Master Plan-Phase I Report, submitted to the Wyoming Water Development Commission by HKM Associates in 1993, recommends that the State Engineer and the Wyoming Water Development Commission cooperate with local government and water users to establish disciplined ground water management policies specific to the area and implement a ground water monitoring program.

Ground water from the Fort Union Formation in the vicinity of Gillette is the dominant fresh water source used for human consumption in the Gillette area. The city of Gillette and all other water users in the vicinity of Gillette depend solely on ground water for their entire water needs. The Fort Union Formation Aquifer Monitoring Plan implemented by the Wyoming State Engineer's Office under this program provides a regional monitoring network of ground water level observation wells. A large share of the funding appropriated for this program was allocated to the drilling, completion, and outfitting of eight (8) new Fort Union aquifer water level observation wells at selected sites during the summer of 1994. To date, the State Engineer monitors 28 Fort Union
wells (including the eight new wells) which measure water levels in a network centered around Gillette. Data collected from the observation well network will be utilized to determine the focus and extent of future ground water development from the Fort Union Formation Aquifer.

Under the Preliminary Fort Union Aquifer Management Plan, recommendations concerning future ground water management goals and strategies will be discussed and reviewed by the Fort Union Formation Aquifer Advisory Committee which currently consists of the Gillette City Engineer, the Campbell County Engineer, the Ground Water Administrator of the State Engineer's Office, and the Gillette Project Coordinator of the Wyoming Water Development Commission. Expansion of the membership within the Advisory Committee to incorporate representatives of all water user groups (coal mining companies, coal-bed methane producers, oil & gas producers, light/heavy industry, and rural domestic/stock watering users) is anticipated. Once the expanded advisory group is in place, the strategy for achieving the ground water management goals (e.g. horizontal/vertical well spacing, well construction standards, site selection, etc.) submitted as Committee recommendations to the State Engineer for inclusion in the rules and regulations associated with the aquifer management plan for the Fort Union Formation Aquifer. The monitoring plan and analysis of data collected under that program will be used in evaluating whether or not additional management practices are warranted. Public input to this process will also be solicited. As additional
demands are placed on the Fort Union Formation aquifer, changes and modifications to the management plan may be needed.
2.1

ACKNOWLEDGEMENTS

The Wyoming State Engineer's Office thanks the Wyoming Water Development Commission for funding this project and also thanks the numerous individuals who provided technical assistance and expertise in formulating these plans to be integral with the Gillette Area Water Master Plan. In particular, special thanks for the assistance and counsel of the Fort Union Formation Aquifer Advisory Committee consisting of Bill Carson, Gillette City Engineer, Mike McDill, Campbell County Engineer, Evan Green, Project Manager for the Wyoming Water Development Commission, and Dick Stockdale, Wyoming State Engineer's Office.
2.2

USE OF DOCUMENT

This document is a reportage, reference, and guidance vehicle to be made available for present and future decision-making by State of Wyoming water resource agencies, City of Gillette municipal government, the Campbell County Commissioners, and private/commercial entities involved in the development, use, and management of ground water contained in the Fort Union Formation aquifer. The Gillette Area Water Master Plan has been developed to provide an integrated and coordinated approach for development of municipal and other public and private water supply systems into a regional system over a fifty-year planning period. Additional groundwater information collected in future years will influence the opinions and assumptions on new water well development in the vicinity of Gillette.

A 3-ring binder format was chosen to present, report, and accommodate future addenda of data, aquifer analysis, water law/regulation/policy, well spacing/construction guidelines, related publications, etc. Copies of this report or portions thereof are available from:

Wyoming State Engineer’s Office, Ground Water Division
Herschler Bldg., 4-E
Cheyenne, Wyoming  82002
(307) 777-7354

(A fee will be charged to cover printing costs)
Section 3.0 - INTRODUCTION

3.1

NEED FOR MONITORING/MANAGEMENT PLAN

The Fort Union Formation is one of the most prolific Tertiary-age fresh water aquifers in the arid western half of North America. Certainly within the state of Wyoming, and the Powder River Basin in particular, people and industry are highly dependent on this seemingly inexhaustible and exceptional quality ground water. This is especially true when the almost total lack of surface water supplies in this area is considered.

Gillette, Wyoming is the largest population center in the northeastern portion of the state. Water produced from in-town municipal wells completed in the Fort Union Formation is the primary and preferred source for human consumption. Public water supply systems for small communities and subdivisions in areas immediately adjacent to Gillette depend solely on wells delivering water from the Fort Union Formation. Many Fort Union wells also serve as the water supply for private businesses in the area. Fort Union Formation water wells are relatively deep, ranging from approximately 600' to over 2500' in total depth. Because these are deep wells, there is usually some financial consideration (loans, grants, trades, etc.) to be realized before drilling.

The need for additional, dependable water supplies from the
Fort Union Formation in Gillette and surrounding areas will be demonstrated as population growth occurs into the future. Accelerated human consumption places a strain on the aquifer which is compounded when other impacts are also considered. Use of water and incidental effects to the Fort Union aquifer by coal mining, coal-bed methane production, oil & gas drilling, and secondary oil & gas recovery activities raise serious issues as to the sustainability of water quantities and water quality as well. The ultimate situation to be avoided is over-depletion of the aquifer (unless public policy dictates such action) and any activity that poses a threat of aquifer contamination. Hydrologic information from the Fort Union Formation Aquifer is an absolute necessity for regulation of Fort Union ground water.

Observing the equilibrium behavior (water level changes due to pumping, recovery, recharge) of the Fort Union Formation aquifer is accomplished by measuring and recording water levels, on a continual basis, in wells completed in the Fort Union. Because of the nature of the aquifer itself, a thick complex of lenticular sands separated by shales and occasional coal seams, a large number of monitor wells is required to provide significant and reliable data to analyze. Three classifications of water level observation wells are required to obtain useful potentiometric data. The first category of observation wells are pumping wells, which includes data consisting of both pumping water levels and water levels measured between pumping periods (recoveries). Secondly, water level measurements gathered from static (non-pumping) observation
wells located in the production well field provide data reflecting the effect of pumping wells and recharge to the aquifer within the field. Lastly, outlier or "control" observation wells, located away from the influence of withdrawals (pumping), providing static water level data that reflects more ambient water level behavior of the Fort Union Formation aquifer.

The Fort Union Formation Aquifer Monitoring Plan investigation, conducted by the Ground Water Division of the Wyoming State Engineer’s Office, will provide needed information on how to best regulate the Fort Union Formation ground water resource and incidentally to help develop similar policies in other areas of the state. Such information is essential to future policy making decisions by the SEO regarding well permitting, well siting, well spacing, well design, well construction, well completion techniques, and continued or expanded monitoring in the Gillette area. The Preliminary Aquifer Management Plan incorporates hydrologic analysis with present laws, regulations, and conditions/limitations on well permitting enforced by the Ground Water Division as well as guidance specific to the Gillette area regarding new well construction/spacing and protection of existing wells and water rights from potentially threatening land use or water use activities.
3.2
WATER RIGHT PROVISIONS

Under the provisions of Wyoming’s Constitution and Wyoming Statutes, all ground water in the state is property of the state and may be appropriated for beneficial use through a permit process administered by the State Engineer. Adjudication (finalization) of ground water rights is accomplished by a quasi-judicial entity, the State Board of Control, which consists of the state’s four Water Division Superintendents and the State Engineer. The adjudication process "fixes" the nature of the beneficial use, the well location, and the water right priority claim (usually the date an Application to Appropriate Ground Water is received in the State Engineer’s Office). Ground water rights are regulated on the basis of priority date. Ground water levels and artesian pressures in water wells are not guaranteed by law. The State Engineer is directed by statute to maximize the beneficial use of the State’s ground water resources.

In managing the State’s ground water resources the State Engineer has wide latitude in establishing such regulations as he deems necessary to manage the resource (see Section 5.1 for more detail).
3.3

PROJECT LOCATION/AREA OF FOCUS

The Gillette Water Master Plan Study prepared by HKM Associates (Phase II - Final Report, 1994) concentrates on an area of Campbell County, Wyoming centered around the city of Gillette and additional areas adjacent to the Gillette Madison pipeline and well field. An established Planning District Boundary (PDB) encompasses the City of Gillette and nearby subdivision entities within which source/distribution options and recommendations are explored for the development of a regional system. Future Level III, Phase 2 considerations within the plan target other outlying water supply systems outside the PDB.

The study area for the Fort Union Aquifer Monitoring Plan and Preliminary Aquifer Management Plan is not limited to the PDB or any other specific corporate, cultural, or arbitrary boundary. Rather, it is defined or bounded spatially by the expanded and/or concentrated use of the Fort Union Formation aquifer as a source of ground water supplies in an area centered and surrounding the city of Gillette and also throughout the corresponding subsurface section of the Fort Union Formation below the WyoDak-Anderson coal seam. Conceptually, for the purpose of this report, there will be no closed boundary plotted onto a map showing "inside" or "outside" a monitoring/management plan area.

Other aquifers in the region surrounding Gillette, though they are known to be "associated" with the Fort Union Formation
aquifer, will not receive attention in this report except where they perhaps may be observed to be in some significant degree of hydraulic connection with the Fort Union. The Fox Hills Formation, Lance Formation, and Wasatch Formation are recognized in the region as water bearing strata and produce water for various needs. These aquifers however, are not proven to provide the quantity and quality of water that the Fort Union aquifer is known to provide. Although the city of Gillette blends its Fort Union well water with Madison aquifer pipeline water and Fox Hills Formation well water, it is the Fort Union water which is the primary and most economic water resource. It is foreseen that new public water supply needs in the city and outlying subdivisions/settlements will be from wells drilled into the Fort Union Formation in order to develop it first as a fresh water supply source for human consumption.
3.4
PROJECT AUTHORIZATION/FUNDING

A Memorandum of Agreement (MOA) between the Wyoming Water Development Commission (WWDC) and the Wyoming State Engineer's Office (SEO) provides for a study to be conducted by the SEO which addresses monitoring, evaluation, and long-term management of the Fort Union Formation aquifer in the vicinity of Gillette, Wyoming (See MOA in Appendix I). To implement this program, the WWDC requested the 1994 Wyoming Legislature to appropriate funding to WWDC in order to establish formal aquifer monitoring at Gillette utilizing new and existing observation wells. Monitoring is to continue for a minimum 25 year period. The funding request, under Original House Bill No. 0037, was granted by Enrolled Act No. 2 (Level II Feasibility Studies - New Development), House of Representatives, Fifty-Second Legislature of the State of Wyoming, 1994 Budget Session. The appropriation was for a total of $400,000.00.
Prior to the conception of the Gillette Area Water Master Plan, the SEO had been monitoring water levels in and around Gillette mostly in response to concern raised by appropriators related to the impact to ground water and surface water supplies by surface coal mining activities and coal bed methane development. Even earlier ground water level monitoring had been conducted in the eastern Powder River Basin under a cooperative program between the United States Geological Survey and the SEO for their "Ground Water Levels in Wyoming" series reports. The current aquifer monitoring/management plan began in 1994 and steers the SEO toward a disciplined focus on the area’s most valuable ground water asset, the Fort Union Formation.

On March 16, 1994, execution of the MOA between the WWDC and SEO initiated this plan. Soon after execution of the MOA, design and planning got underway towards the first phase of the monitoring plan, which was the emplacement of eight (8) new, strategically located Fort Union Formation water level observation wells. The drilling program began June 21, 1994, and ended October 5, 1994, upon completion and development of the eighth and final well. Installment of recorder equipment was completed by early November of 1994, such that the eight new monitor wells were supplying continuous water level data by that time.

Water level data is now acquired from the eight new monitor
wells; four pre-existing static wells; an out of service subdivision well with recorder equipment placed on-line April 27, 1995; and 15 pumping wells with air-lines. Pumping levels and shut-in static levels are also recorded bi-annually by the city at their in-town Fort Union wells ("S-wells"). Therefore, the second phase of the monitoring program is data acquisition/compilation and continuation of that process.

The third phase is reporting and analyzing retrieved data so that decision making, as the Master Plan is instituted, may be accomplished utilizing known aquifer parameters and best well construction/placement methods. Under the MOA, between WWDC and SEO, this ("final") report for the aquifer monitoring/management plan is due in late 1995. As envisioned, the 1995 report shall, in essence, be the "first" report with subsequent reports containing current data, maps, management guidelines, etc. For planners and those entities involved with instituting the Gillette Area Water Master Plan, this reporting document is only useful if it is updated on a timely basis so that the latest data and management policy information is available.

In a sense, the fourth or last phase of this plan is a combination of the second and third phase such that there is continued coordination with the Master Plan as it accommodates growth and as a regional system evolves. The Fort Union Formation Aquifer Advisory Committee will convene on a regular or "as needed" schedule to discuss aquifer assessment and development issues. Project expansion, if it is foreseen, would occur only via new
directives and funding requests.
The Gillette Area Water Master Plan addresses future water supply and delivery from a regional standpoint because it is more practical for larger systems to deal with Federal Safe Drinking Water Act (SWDA) standards, especially the administrative task of maintaining compliance. Providing for supplies that surpass Federal and Wyoming Department of Environmental Quality primary drinking water standards is also a goal of the Fort Union Aquifer Management Plan. Identification of the chemical nature of Fort Union water, by examination of areal and zonal chemical quality, is explored in this study.

The Fort Union Formation aquifer delivers a source water product that requires virtually no treatment beyond chlorination. Blending practices by the city of Gillette utilize Fort Union supplies to reduce the hardness of Madison Formation well water and reduce the fluoride content of city's Fox Hills Formation well water. It is known however, that some elemental/compound constituent concentrations in water produced from the Fort Union Formation exhibit a significant range of variance. Optimal well siting and completion zones may be identified such that future Fort Union Formation supply wells will be drilled where ground water is determined to be of the best quality obtainable.
Section 4.0 - Fort Union Formation Aquifer Monitoring Plan

4.1

Location

History of Ground Water Development

History of Fort Union Aquifer Monitoring

The Powder River Basin (PRB) occupies most of the northeast quadrant of the state of Wyoming, bounded by the Black Hills to the east, the Big Horn Mountains to the west, and the Laramie Range/Hartville Uplift to the south. This vast structural and topographic basin is renown for its wealth of mineral resources including coal, uranium, oil, and natural gas reserves. The PRB plays host to five stream drainages forming the Upper Cheyenne River, the Belle Fourche River, the Little Missouri River, the Powder River, and the Tongue River. Ironically, none of these streams produce much water. What surface water is available is largely appropriated or allocated under interstate compacts with neighboring states. Plentiful ground water resources occur in basin margin Paleozoic-age aquifers and inner basin Upper Cretaceous and Tertiary-age aquifers.

The city of Gillette, located in Campbell County, is the largest population center in the PRB. Nearby oil discoveries in the 1960’s transformed Gillette from a quiet ranching community into a center of commerce serving the oil industry. The oil boom and the opening of several large open-pit coal mines in the 1970’s
contributed to considerable population growth in a short time. Up until that time period, the city's water supply source was a network of wells completed in the Wasatch Formation (the so-called "H-wells") which yielded water of marginal quality and quantity. In a relatively rapid response to the increased demand and foreseeable future needs, the city then developed an in-town Fort Union/Fox Hills well field consisting of numerous "dry hole" oil and gas test wells. The city also pursued and secured a FmHA (Farmer's Home Association) grant and DEPAD (Wyoming Department of Economic Planning and Development) loan funding to establish a Madison Formation well field, located some forty-two miles northeast of Gillette, and the associated transmission pipeline by the early 1980's.

Sustained prosperity in the Gillette area spawned growth outside the city corporate boundaries in the form of subdivisions, mobile home parks, industrial parks, and small businesses. These entities were not supplied by the municipal system, so Fort Union Formation supply wells were drilled to serve those needs. Outlying uses of the Fort Union aquifer included coal mine facility potable water needs and water supply wells required for oil and gas exploration and recovery activities. To the present day, municipal, public water supply systems, and commercial/industrial needs have continued such that cumulative withdrawals and expansion (new wells) are the dominant concerns from an aquifer evaluation standpoint.

True monitoring of Fort Union wells, versus just routine
record keeping (e.g., see city wells in Section 5.3), began in 1985 as the subject of a cooperative study undertaken by Marvin A. Crist of the United States Geological Survey (USGS) in conjunction with the State Engineer's Office (SEO). This study utilized air-line measurement data from pumping wells (see discussion of Crist report in Section 5.3). The first SEO observation well to have continuous recorder equipment installed was the Dickinson Well, an abandoned well located at J & J Mobile Home Court (NE\textsuperscript{2} NW\textsuperscript{1} 20-50N-72W). The well went on-line December 12, 1985, as part of the SEO cooperative program with the USGS to measure water levels statewide.

The SEO continues to measure those pumping wells cited in the aforementioned USGS report. Since installation of the Dickinson Well, additional static water level measuring wells, including the new wells drilled in 1994, have been added to the SEO inventory of Fort Union observation wells. The Gillette Area Water Master Plan, instituted by WWDC and the City of Gillette in 1993, recognizes the need for the SEO to continue to develop, operate, and oversee monitoring of the Fort Union Formation aquifer at Gillette.
4.2
GENERAL GEOLOGY

Gillette, Wyoming is located in the east-central Powder River Basin (PRB), a 20,000 square mile intermontane basin occupying a large part of northeast Wyoming with a northward extension into southeastern Montana. The broad, elongate basin, a product of Laramide orogenic subsidence, is asymmetric with a north-south axis shifted far to the west (McClurg, 1988). Sedimentary rocks, overlying the downwarped Precambrian crystalline basement, are estimated to exceed thicknesses of 16,000 feet in deep portions of the basin. Maximum observed structural relief, measured vertically from the top of the Precambrian at Cloud Peak in the Bighorn Mountains to the lowest basin axis depression, is approximately 25,000 feet.

Throughout the basin, topographical relief is low to moderate. Elevations range from less than 4000 feet above mean sea level near the Wyoming/Montana border to a maximum of near 6000 feet at Pumpkin Buttes. Surface features include uplands of mostly gentle rolling hilly terrain with occasional buttes or scoria monadnocks; dissected badland areas or breaks transitional to drainage networks; and bottomlands peripheral to the major streams and their tributaries. Gillette (Elevation 4544 feet above sea level) is located in rolling to hilly country a few miles east of a triple drainage divide, where surface water drains either west toward Powder River, north to the Little Missouri River, or easterly into
the Belle Fourche River. Within the PRB sedimentary fill are strata representing each geologic time period (except Silurian, see Figure 4.1). As is common in other foreland basins of Wyoming, Cretaceous and early Tertiary-age sediments constitute at least half of the entire stratigraphic section. Deposits of marine and non-marine origin are present in near equal amounts and hiatuses of non-deposition or erosion are represented by at least 7 major unconformities.

Paleozoic and Mesozoic strata underlying the eastern PRB are representative of those described by Robinson, et al. (1964) on the west flank of the Black Hills uplift. Paleozoic rocks consist of sandstones, siltstones, shales, limestones, and dolomites deposited in marine and shallow marine environments. The Paleozoic section is approximately 2000 feet thick in the eastern PRB. Deposition of marine sediments continued at the beginning of the Mesozoic era and persisted into the late Jurassic when non-marine sedimentation became dominant and endured until the early Cretaceous period. The greater part of Cretaceous rocks were formed from sediments deposited in a north-south trending basin periodically occupied by a shallow epicontinental seaway (Rice and Gautier, 1983). Youngest Mesozoic rocks are fluvio-deltaic sandstone and shale of the upper Cretaceous Lance Formation. The entire Mesozoic section is approximately 6000 feet thick in the eastern PRB.

Deposits of the Cenozoic era are of early Tertiary (Paleocene to Oligocene series) and Quaternary age and floor the major portion of the PRB proper. Coal bearing strata of Tertiary age consist of
Figure 4.1 Stratigraphic Column of the eastern Powder River Basin
as much as 4500 feet of alternating non-marine sandstone, shale, sub-bituminous coal, and lignite of the Paleocene Fort Union Formation and overlying Eocene Wasatch Formation (Mapel, 1958). It is fairly certain that the world’s largest reserve of thick, low ash, low sulfur, sub-bituminous coal is found in the Fort Union and Wasatch Formations of the PRB. The WyoDak-Anderson seam of the Fort Union and two thick seams residing in the Wasatch, the Felix seam and the Big George seam, average over 75 feet thick and together underlie approximately 2000 square miles (McClurg, 1988). Oligocene age conglomerate, clayey sandstone, and claystone of the White River Formation lie unconformably over the Wasatch Formation. The White River, a formerly extensive basin-filling unit, is preserved only as caprock at the Pumpkin Buttes in the central PRB and at local areas in the surrounding uplifts (Mapel, 1959; Sharp, et al., 1964).

Quaternary alluvial deposits occur as terraces along rivers and intermittent streams of the PRB. Terraces along the Belle Fourche, Little Missouri, and Cheyenne river drainages are lower and less extensive, vertically and laterally, than those along the Powder River and Tongue River. The differences are attributed (Leopold and Miller, 1954) to the fact that the Powder and Tongue rivers have their source in the Big Horn Mountains, and are therefore higher energy/capacity streams, whereas the former mentioned streams rise in the central basin and are smaller, sometimes intermittent.

Since the late Tertiary, natural fires have completely or
partially burned exposed coal seams of the Fort Union and Wasatch Formations. The burns left resultant materials including altered underclays, buchite, welded breccia, and baked sandstone, siltstone and claystone. Often referred to as "scoria" or "clinker", this brightly colored (reds, oranges, browns) rock is more resistant to erosion than unaltered sediments and acts as a caprock to butte-like landforms or forms as a line of bluffs which parallel the strike of coal beds (Bauer, 1972).

Surficial bedrock geology in the Gillette area (see Plate 1) consists of exposures of Fort Union Formation, Wasatch Formation, and widespread outcrops of scoria. Reheis (1982) also mapped Pleistocene and Holocene series exposures including residual (weathered) deposits, mass-wasting deposits, eolian deposits, lake sediments, alluvial deposits, and modified (reclaimed) lands.

A bibliography of Powder River Basin geology is perhaps needed at some point to index the extensive work completed in this area. A good source for many of the fine studies produced over the years are the Field Conference Guidebooks published by the Wyoming Geological Association (see guidebooks for 1949, 1958, 1969, and 1988). Many references dealing specifically with the hydrology of the PRB, including ground water hydrogeology, are listed by Lowry, Wilson, et al. (1986)
The National Weather Service has recorded meteorological data at several stations in the Gillette Area, the most recent at stations 18 SW, 2 E, and 9 ESE. The 9 ESE station is the only current facility in operation, relocated from a site near Rozet, it is now located at Sleepy Hollow subdivision in NW 1/4 NW 1/4 17-49N-72W. The new site is "compatible" with the original 2 E station which was located at the old Agricultural Research Station (now Camplex) 2 miles east of Gillette.

The climate in the Gillette area of the PRB is semi-arid. For the period spanning 1951 to 1980 (Figure 4.2), daily mean temperatures range from 20.1°F (-6.6°C) in January to a maximum of 70.6°F (21.4°C) in July. Extreme temperatures range from 104°F (40°C) in summer to a winter low of -34°F (-36.7°C). Annual precipitation averages 16.05 inches for the period 1980 through 1994 with total annual precipitation ranging from a low recorded in 1992 of 11.67 inches to a high of 26.37 inches in 1982 (Figure 4.3).

Wind is also a significant climatological factor inasmuch as it increases evapotranspiration and removes snow cover. Westerly winds prevail in this area of the state with wind velocities averaging about 13 mi/hr annually. Storm fronts moving through the area cause brief periods when wind gusts may exceed 75 mi/hr (Bloyd, Daddow, Jordan, and Lowham, 1986). Precipitation occurs as
Figure 4.2 Mean Temperature and Precipitation 1951 to 1980
(from Wyoming Climate Atlas, 1986)
Figure 4.3
ANNUAL TOTAL PRECIPITATION
GILLETTE 9 ESE STATION

INCHES OF PRECIPITATION

YEAR

rainfall in the warm season and as snow during winter months. Greatest average total precipitation is experienced in the months of May and June. Winter snow cover is usually intermittent but may be persistent during extended cold periods following large storms. Aquifer recharge in the PRB happens as a result of percolation of surface runoff from rain or snowmelt, seepage losses along stream reaches, and ground water in-flow from adjacent areas/aquifers. Recharge rates may be steady or occur as pulses corresponding to such events as heavy or prolonged rainstorms, rapid snowmelt, or peak stream flows. Basinwide, annual recharge infiltration accounts for approximately 0.15 ft/yr (1.8 inches/yr) of available precipitation (Davis and Rechard, 1977; Brown, 1980; Wyoming Water Atlas, 1990), with the balance lost to surface streams and evapotranspiration. Recharge is not uniform across the surface of the PRB, but is dependent on such factors as slope, outcrop conductivity, vegetation, moisture availability, temperature, etc. Though it is obvious that regional recharge constitutes a considerable amount of water, localized quantities of recharge are not particularly significant in the ground water regime.

Relatively severe drought conditions have plagued the PRB in the late 1980’s and early 1990’s. The effect of the drought conditions on the ground water system is difficult to assess. This problem has been compounded by "above average" precipitation during the last few years of data collection.
4.4

GEOLOGY AND HYDROGEOLOGY OF THE FORT UNION FORMATION IN THE GILLETTE AREA OF THE POWDER RIVER BASIN

The Fort Union Formation near Gillette in the eastern PRB is approximately 2500 feet thick based on logs of wells which penetrate entirely through the formation. The lower contact with the underlying Lance Formation is gradational, but marks the full retreat of the Cretaceous inland seaway and the advent of Paleocene syntectonic sedimentation attributed to Laramide orogenic activity in the Black Hills region (Lisenbee and De Witt, 1993). The stratigraphic boundary between the Fort Union Formation and the overlying Wasatch Formation, where it is not readily evident, is a matter of some debate considering its basin-wide variability. The top of the WyoDak-Anderson coal seam is a suitable upper marker for the Fort Union (Dobbin and Barnett, 1928) over most of the eastern PRB but the thick coal seam thins and splits to the west and may be completely absent in some areas (Denson and Keefer, 1974). Most evidence suggests that the Fort Union-Wasatch contact is a regional unconformity/disconformity and that the formations had dissimilar source areas or parent rock (Sharp and Gibbons, 1964). The Fort Union and Wasatch Formations are gently flexed at their respective (eastern) basin margins, with dips measuring 1° to 2° westward toward the basin axis.

The depositional system(s) of the Paleocene responsible for the accumulation of the thick Fort Union sequence have been
variously interpreted based on evidence of similar environmental conditions. It is agreed that the Fort Union Formation is a fresh water, terrestrial deposit, but models posed for depositional environments include complex fluvial system deposition accompanied by lesser lacustrine backswamp condition occurrences (Galloway, 1979; Ethridge, et al., 1981; and Flores, 1979, 1981), lacustrine delta and delta plain deposition (Tewalt, Ayers, et al., 1983; Ayers and Kaiser, 1984), and lacustrine swamp sedimentation in a setting similar to the modern day Okefenokee Swamp and Great Dismal Swamp of the southern United States (McClurg, 1988).

Basinwide, the Fort Union Formation consists of three subunits, the lowermost (oldest) is the Tullock Member which grades upward into the middle Lebo Shale Member. The upper (youngest), Tongue River Member is present only in the northern portion of the basin, according to the latest stratigraphic mapping (Love, Christiansen, 1985), and is absent within the Gillette area. Major coal beds within the Fort Union Formation include the thick WyoDak-Anderson (which splits to the west to form the Anderson and Canyon seams) and minor coals of the Cook, Wall, Upper Pawnee, Lower Pawnee, and Cache seams.

Lithologies encountered in the Fort Union section include fine-grained, unconsolidated sandstones, massive claystones, claystones with thin interbeds of very fine-grained sand or silt, carbonaceous shales, and coals. Sandstones are thin to thick bedded (a few feet to 120+ feet), poorly sorted, quartz rich (>90%), and may exhibit grainsize gradations. Sandstones occur as
lenticular bodies or sets of bodies (interbedded with claystone) with thick bodies or sets being laterally continuous up to several miles. Thin sands are generally not persistent laterally more than a few thousand feet. Thin, very hard layers are encountered at times, when drilling in the Fort Union, which consist of cemented sands or well compacted claystone (shale).

Coals within the Fort Union Formation are low ash, low sulfur, sub-bituminous type. The thickness of the minable WyoDak-Anderson seam ranges from 40 feet to 100+ feet. The "typical" WyoDak-Anderson seam, as it presents itself in well logs and surface exposures (strip mine pits), consists of an upper bench and a lower bench separated by a split. The split is usually a high ash or clay layer. Many exceptions to the "typical" WyoDak Anderson seam are encountered, e.g., the benches or the split may thicken or thin, the entire upper or lower bench may be completely absent, or the entire seam may be absent ("washout", "cut-out", or "want"). The WyoDak-Anderson seam and other coals of the Fort Union present difficulties to mud rotary drilling because the high permeabilities of some fractured coals cause lost circulation problems.

Water wells completed in the Fort Union Formation are screened or are perforated opposite one or more sand intervals that show good porosity on geophysical logs. Fort Union wells in the Gillette area are drilled to various depths depending on the desired production and saturated sands present in the vertical section at a given location. Static water levels, in wells where more than one sand is exploited, in most probability are attained
by composite head pressures. The Fort Union aquifer is anisotropic, composed of several to many discreet water bearing sand intervals of varying lateral continuity, therefore, it must be understood that correlating or mapping measured/calculated aquifer parameters (potentiometric head, pumping levels, specific capacities, transmissivities, storage coefficients, water chemistry, etc.) results in a portrait which reveals apparent aquifer characteristics and/or behavior.

Well yields over 250 gallons per minute (gpm) may be obtained from Fort Union wells penetrating thick saturated sandstones, areas in hydrologic connection with surface water, or areas adjacent to "clinker" recharge zones (Feathers, Libra, and Stephenson, 1981). Average specific capacity (yield per unit drawdown) values for the Fort Union Formation are less than 1.0 gpm/ft of drawdown. Transmissivity values calculated from constant discharge recovery tests for City of Gillette wells (Wester, Wetstein, 1994) range from 690 gallons per day per foot (gpd/ft) to 3540 gpd/ft. Reported storage coefficients values vary from 0.0004 to 0.004.

The ground water flow regime operating in the Fort Union Formation of the eastern PRB is dominated by horizontal, down-gradient movement. Low vertical permeability prevents downward leakage, i.e., clay layers form highly effective aquitards. In general, flow paths are stratigraphically controlled (confined to sands and coals), tend to follow structure, and are influenced by discharge in areas where pumping wells are highly concentrated. A concept of ground water movement is complicated by the non-uniform
distribution of component saturated sands, multiple completion zones in wells, inadequate well completion data, and the probable presence of a gas-pressure head component in wells completed in sands which are in hydraulic association with coal beds (Feathers, Libra, and Stephenson, 1981; Lowry and Cummings, 1966).

Outcrop exposure of the Fort Union Formation east of Gillette is several hundred square miles in areal extent between the WyoDak-Anderson coal outcrop and the lower contact with the Lance Formation. This expanse constitutes the recharge area for the Fort Union Formation aquifer. High infiltration rates probably occur in areas of Fort Union exposures overlain by clinker or scoria. Scoria in the recharge area occurs in beds up to 100 feet thick and is displayed as caprock on buttes, interbeds in steep Fort Union outcrops, and laterally extensive rolling surface deposits. The scoria acts as a sponge by absorbing water and, in many areas, discharges as a sink or a conduit to the underlying Fort Union (Brown, 1980; Heffern, written communication, 1995). Transmissivities in the scoria vary according to degree of fracture permeability, with reported values ranging up to 3,000,000 gpd/ft. Crist (1991) conveniently divided the Fort Union Formation into two hydrogeologic zones. The upper part generally corresponds to the Lebo Shale member and extends from the base of the WyoDak-Anderson coal bed to just below another coal bearing interval containing the upper and lower Pawnee coal bed. The lower aquifer portion of the Fort Union Formation begins in the lowermost Lebo Shale and extends to the base of the Tullock member at the Lance contact. Existing
Fort Union wells in Gillette are mostly drilled into and completed in the upper part. Recently though, more "fully penetrating" wells have been designed and drilled, seeking the largely unexploited lower sands for greater production.
4.5
WATER QUALITY - FORT UNION FORMATION AQUIFER

The chemical quality of ground water is controlled by the solubility of the host rocks, pH, temperature, pressure, duration of time water is held within the aquifer, and reactions that occur to the water as it flows through the aquifer (Lowry, Wilson, et al., 1986). Lee (1981) characterized the Fort Union Formation aquifer system of the northern Powder River Basin (southeastern Montana) as a dual system: a mosaic of shallow, chemically dynamic, and localized recharge-discharge cells superimposed on a deeper, chemically static regional system. This "chemical stratification" has vertical and horizontal components dependent on depth and distance from outcrop recharge area such that apparent reversals may be evident.

Sodium and bicarbonate are the dominant ions and tend to increase with depth. Sodium sulfates are present to a lesser extent and are associated with higher dissolved solids (>500 mg/l). The principal chemical reactions that result in these ion concentrations are (1) dissolution of calcite, dolomite, aragonite, oligoclase, pyrite, and gypsum by percolating water combined with (2) the reaction of cation exchange on clay minerals and (3) sulfate reduction whereby sulfate in the water is reduced in the presence of organic material to form bicarbonate and sulfide (Lee, 1981). Major ion composition variation is probably indicative of horizontal flow within hydrologically isolated sand bodies and the
correlation with depth is only an indicator of relative distance from outcrop recharge zones (Feathers, Libra, and Stephenson, 1981).

Dissolved solids in the Fort Union Formation range from about 200 to more than 3,000 mg/l, but commonly range between 500 and 1,500 mg/l (Hodson, Pearl, and Druse, 1973). Iron and fluoride contents are generally moderate but may be high in some water. Wells completed in zones associated with coals may produce gas. The gas is usually methane with smaller amounts of nitrogen and oxygen.
Plate 1 shows the distribution of ground water level observation wells which monitor the Fort Union Formation aquifer in the Gillette area. The network consists of 28 wells of which 15 are production (pumping) wells equipped with air lines and 13 are static water level observation wells installed with continuous water level recorders. Table 4.1 lists pertinent information for each SEO monitor well.

Eight of the static observation wells are designed specifically as static observation wells for the Fort Union Aquifer Monitoring Program. They were drilled, completed, and placed on-line in summer 1994. The remaining five static wells are former production wells that were abandoned and subsequently outfitted for recording water levels. Each of the static observation wells are equipped with a float-weight pulley mechanism which encodes hourly measurements that are stored by retrievable punch tapes or electronic memory cards. These wells are visited monthly for maintenance checks and calibration measurements by SEO Ground Water Division personnel.

Air lines installed in the production monitor wells are measured monthly. This set of wells consists of 12 public water supply system wells, 2 municipal wells, and the city/county airport supply well. It is noted at each measurement whether the pump is operating.
<table>
<thead>
<tr>
<th>WELL NAME</th>
<th>LOCATION</th>
<th>ELEVATION AT LAND SURFACE*</th>
<th>SEQ PERMIT #</th>
<th>DATE ON-LINE AS MONITOR WELL</th>
<th>TOTAL DEPTH</th>
<th>PERFORATED/SCREENED INTERVALS</th>
<th>STATUS/COMMENTS</th>
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<tbody>
<tr>
<td>G-MON-1 &quot;Sports Bar Well&quot;</td>
<td>NW\NW; 16-50N-72W 457764.47 East** 4907537.35 North**</td>
<td>4447.9'</td>
<td>UW 95451</td>
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<td>UW 95452</td>
<td>11/05/94</td>
<td>1999.0'</td>
<td>1160'-1210', 1450'-1470' 1790'-1810', 1950'-1960'</td>
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<td>SW\NW; 5-49N-72W 456202.05 East 4899555.99 North</td>
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<td>UW 95453</td>
<td>10/13/94</td>
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<td>1145'-1165', 1200'-1230' 1292'-1302', 1314'-1324'</td>
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<td>G-MON-4 &quot;Old Fairgrounds Well&quot;</td>
<td>SE\SE; 21-50N-72W 459188.81 East 4904591.03 North</td>
<td>4557.0'</td>
<td>UW 95665</td>
<td>10/13/94</td>
<td>2371.0'</td>
<td>940'-950', 960'-980' 1030'-1050', 1080'-1090' 1096'-1106', 2170'-2200'</td>
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<tr>
<td>G-MON-5 &quot;Jail Well&quot;</td>
<td>SE\SE; 28-50N-72W 458909.87 East 4902801.25 North</td>
<td>4621.3'</td>
<td>UW 95666</td>
<td>10/13/94</td>
<td>1799.0'</td>
<td>1120'-1160', 1575'-1595' 1740'-1770'</td>
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<td>SE\SE; 13-49N-72W 464011.22 East 4897384.73 North</td>
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<td>UW 95654</td>
<td>11/5/94</td>
<td>1975.0'</td>
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<td>UW 95667</td>
<td>11/4/94</td>
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<td>JIM KINTZ WELL</td>
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<td>UW 91089</td>
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<td>4682.5'</td>
<td>UW 37169</td>
<td>1251.0'</td>
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Table 4.1 Continued

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<th>WELL NAME</th>
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<td>CAMPBELL CO. AIRPORT NO. 1</td>
<td>SE(\frac{1}{4})SE(\frac{1}{4}) 32-51N-72W 457556.63 East 4910870.46 North</td>
<td>4329.4'</td>
<td>UW 63913</td>
<td>7/18/85</td>
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<td>950'-980', 1045'-1055', 1070'-1120'</td>
<td>PUMPING WELL; AIR LINE MEASURE</td>
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<td>PUMPING WELL; AIR LINE MEASURE</td>
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* - Feet above mean sea level  
** - NAD83 UTM Coordinates (meters)
The drilling phase for the new wells to be incorporated into the Fort Union Formation Aquifer Monitoring Program began in June of 1994. Ruby Drilling Company, Inc. of Gillette was awarded the contract for the drilling, casing, cementing, logging, perforating, and development of the new observation wells at the selection bid of $246,000.00. Bid specifications called for the drilling and completion of eight (8) individual wells to various depths into the Fort Union Formation under the direct supervision of the Ground Water Division of the State Engineers Office.

It was estimated that approximately 17,000 total feet of drilling would be required for the eight proposed monitor wells. Each well was to be constructed by drilling a 7-7/8 inch size borehole and setting new 5-1/2 inch I.D. (#14.00) steel casing top to bottom which was to be pressure grouted in place with neat cement. The driller was to stock casing centralizers and cement baskets to insure an efficient cement job at all well sites. Each well was to be logged (gamma-gamma neutron, CCL), jet perforated at intervals chosen by SEO personnel, and developed by air lifting until a satisfactory hydraulic connection between the aquifer and the well was achieved. Setting measurement apparatus, recording equipment, and installation of a shelter and fencing (if needed) completed the envisioned design of each well. In order to make efficient use of time, each well was to be drilled, cased,
cemented, and logged in turn, then crews would rotate back to those cased holes in order to perforate, develop, and sample for chemical analysis.

Eight wells were drilled and completed between June 21, 1994 and September 17, 1994, totaling 15,613 feet of cased hole. Ruby Drilling used their Failing 1500 trailer mounted mud rotary rig for drilling activities at each site. The G-MON-8 well was the last well to be developed on October 8, 1994. All eight wells were on-line with measurement/recorder equipment by November 5, 1994.

The wells were constructed as designed and the drilling project proceeded on-schedule and within budget constraints, however there were some problems encountered. Drilling fluid losses occurred at each site to variable degrees and are attributed to fractured coal seams and highly permeable sand intervals. Lost circulation material (LCM - cedar shavings/cellophane) was available and used at each wellsite to limit fluid loss. Although the bid specifications called for a 50% excess cement allowance, formation losses were such that surface returns were not achieved during the cement jobs for any of the eight wells. The deepest return was approximately 75 feet below land surface (G-MON-5 Well). The driller returned to each site and cemented from the surface into the annulus to complete the cementing of the casing back to the surface. Other difficulties encountered included:

1. The initial G-MON-3 hole was plugged and abandoned after repeated attempts to free a stuck bit. The bit was lost along with several hundred feet of drill collars
and drill pipe. The completed G-MON-3 well is an offset, 690 feet, S 15°E, from the P&A location.

2. In the course of the cement job on the G-MON-5 well, it became apparent that bottom hole plugging would not be possible. The cement shoe was probably defective and was destroyed during circulation of cement. As a result, the bottom of the casing is open or "completed" at the base of a 35 foot sand. A cement bond log reveals less-than-satisfactory cementing in the bottom 200' of the well.

The G-MON-series wells are outfitted with Stevens GS-93 Water Level Systems which are a solid-state electronic data logger with a weight-float pulley coupled to a Stevens Type A/F Encoder and GS-93 Logger. The float-weight assembly consists of a 2-1/2 foot long float constructed from 2-1/2 inch diameter PVC, which is counterweighted by 2 lb. lead eye-weights. The water level data memory is stored within a plug-in Stevens FC-256 data card which is retrieved/replaced during routine maintenance checks. The cased GS-93 recorder unit is armor enclosed to prevent vandalism and enclosed within a standard weather-proof SEO observation well shelter over each well.
4.8

PLAN FOR CONTINUATION OF MONITORING

Ground water level monitoring by the State Engineer in the Gillette area has expanded considerably since 1985 when local entities expressed concerns about reported declines of ground water levels. The Gillette Area Master Water Plan adopted in 1994 directs the SEO to establish a Fort Union Aquifer monitoring plan which is now in place. The present observation well network is generating data needed to define the characteristics and behavior of the aquifer.

Funding appropriated by the Wyoming Legislature and provided to the SEO by WWDC, has been utilized for expenditures on new well drilling, equipping all new wells and re-equipping existing wells, computer software, travel, surveying, water chemistry analysis, rental equipment/vehicles, communications, reporting, etc. The balance of those funds will be obligated to this program for the 1997-1998 biennium after the end of the appropriation period (June 30, 1996). Those remaining funds will be utilized during the 1997-1998 biennium to maintain operation of the Fort Union Aquifer Monitoring/Management program which includes maintenance of the observation well network, travel expenses, reporting, and Fort Union Advisory Committee meetings. As a result, the SEO observation well network budget will require expansion to cover the additional monitoring at Gillette starting the 1999-2000 biennium and beyond. Monitoring of the Fort Union Formation by the SEO
will continue into the future as it is now implemented. The Fort Union Aquifer Monitoring Plan will evolve as Gillette Water Master Plan phases become realized and as development and water needs march forth. It is anticipated that additional observation wells will be added to the network when opportunities or needs arise. It is hoped that some flexibility in SEO spending will be allowable to make any needed changes (new wells, replacement wells, plugging and abandonment, repairs, etc.) in the observation well network. Agency budget planning (each biennium) will direct how the monitoring plan will be limited, expanded, or modified.

Insofar as Fort Union Formation aquifer (source) water quality is addressed, actual monitoring for variance in formation water chemistry is beyond the present scope of this plan. Water quality parameters will be tabulated, updated, and analyzed as that data is collected from new or existing wells. Continued accumulation of water analysis reports should prove to become valuable.
4.9
REPORTING

As stated in Section 3.4, this report is the preliminary submittal covering the implementation of the monitoring program and management goals for the Fort Union Formation aquifer. Included is data collected up to the publishing date and initial analysis of that information.

An updated water level report will be furnished to the Water Development Commission in November of 1996, which will consist of data and analysis addenda covering at least the two preceding water years (Oct. 1994 through Sept. 1996). Thereafter, updates will occur on an "as needed" basis to concur with the phased implementation of the Gillette Area Water Master Plan. All updates will contain the most recent data accumulation, data analysis, monitoring plan status, and management progress.
5.1
STATE ENGINEER AUTHORITY
GOALS AND STRATEGY

Wyoming territorial decision makers and water users adopted a "doctrine of prior appropriation" to regulate the scarce water resources of Wyoming. The Wyoming Constitution declares all waters within the boundaries of the state to be property of the state (Article 8, §1) and grants general supervision of those waters to the State Engineer (Article 8, §5). A water right in the State of Wyoming is the right to use water acquired under the laws of the state, based on the measure of beneficial use, but limited by priority claim and ordered by preferred use (Wyoming Statutes, §41-3-101 and 102(a,b)). Wyoming water law under W.S. §41-3-909 authorizes the State Engineer to administer and enforce the Underground Water Act (W.S. §41-3-901 through §41-3-938), first enacted in 1945 to address the specifics of ground water appropriation.

Specific to ground water regulation as it applies to management of the Fort Union Formation aquifer, the State Engineer is empowered "To make regulations concerning the spacing, distribution, and location of wells in critical areas;"; "To establish standards for the construction of wells..."; and "To make such investigations necessary ... in the effectuation of the policy
of the state to conserve its underground water resources" (W.S., §41-3-909(a)(v,vi)). The Ground Water Division of the SEQ is responsible for issuance, recording, and maintaining permits which grant the right to appropriate and beneficially use ground water pursuant to Part II of SEQ Regulations. Part III of the SEQ regulations contains water well minimum construction standards. The Ground Water Division is also appointed to investigate the occurrence of ground water resources, to coordinate ground water investigations involving the SEQ and other agencies, and to monitor ground water levels in the state of Wyoming.

The goal of the Gillette area Preliminary Aquifer Management Plan is to protect the ground water resource of the Fort Union Formation Aquifer based on water law, knowledge of the hydrologic characteristics and behavior of the aquifer, and for the public welfare. The plan is envisioned to implement and provide:

1. Strict application and permitting procedures for new water wells which are completed in the Fort Union Formation, including requirements on well location, spacing, well design, well construction, water level and water production reporting.
2. Protection of existing Fort Union wells and appurtenant water rights from any activity which would cause interference or damage to those water sources/appropriations.
3. Monitoring and operation of an observation well network which produces accurate and reliable ground water level data from the Fort Union Formation aquifer.
4. Updated analysis, presentation, and interpretation of
results of Fort Union aquifer monitoring.

5. A mechanism for cooperation with local/state/federal agencies and private/commercial entities concerned with land use planning and development and the development of Fort Union aquifer resources.

6. Replacement of this "preliminary plan" with an adopted management plan designed to be contemporaneous with implementation of the Gillette Area Water Master Plan.

Future goals of the Fort Union Aquifer Management Plan include expanded water level monitoring; aquifer testing to establish local hydraulic parameters; and mathematical/statistical modeling to represent and predict cumulative effects to the aquifer and the impact of future development. As the Gillette Area Water Master Plan becomes implemented, the realization of the Plan and funding availability will dictate whether an expanded and more in-depth aquifer assessment approach will be needed.

As the state regulatory agency responsible for the implementation of this plan, the State Engineer intends to combine the application of a continued hydrogeologic study with responsible water policy decisions formulated in the public interest to achieve a disciplined management of the Fort Union aquifer resource. The structure of the following plan consists of (1) presentation of the latest Fort Union aquifer data, (2) discussion and analysis of that information, (3) a tentative diagnosis of the present condition of the aquifer, and (4) preliminary SEO guidelines for management of the aquifer.

5-3
5.2
GEOLOGIC CHARACTER OF THE
FORT UNION FORMATION AQUIFER AT GILLETTE

Stratigraphy of the Fort Union Formation at Gillette is exhibited by gamma-neutron logs for the G-MON-series observation wells on Plate 2. The vertical datum chosen for the illustration is the top of the WyoDak-Anderson coal seam, the upper unit of the Fort Union Formation. To be consistent with Crist (1991), a contact between the upper Fort Union and lower Fort Union is marked below the occurrence of the upper and/or lower Pawnee coal seams.

Sands show on the gamma logs as negative tending (graphing leftward) because of their low clay content. Coals show clean (very low gamma) readings and clays, carbonaceous clays, and clay matrix sands/silts exhibit a higher gamma reading. The array of G-MON-series well logs on Plate 2 clearly illustrates the interbedding of these lithologies, variation of thicknesses, and complex association of sands within and between each of the wells which were drilled in an area encompassing approximately 8 by 9 square miles. The neutron log is a porosity log (true porosity, not effective porosity) where sand is usually represented by an intermediate neutron count. Saturated sands or high porosity sands show a slightly lower neutron count than tight, dry sand.

Clearly, the Fort Union Formation is not a typical "layer-cake" set of subunits, nor is the overlying Wasatch Formation for that matter. This is a result of the ancient depositional
processes and the diagenesis of Fort Union lithologies since deposition (coalification, differential compaction, cementation, etc.). Correlation of sands utilizing subsurface data is usually difficult and so is determining direct hydraulic connectivity.

Generally speaking, the upper and lower parts of the Fort Union Formation aquifer are separated by a coal bearing, claystone dominant zone which may be quite thick (see log of G-MON-3) or seemingly absent (see log of G-MON-6). As mentioned earlier in this report, most Fort Union wells in the Gillette area are completed in the upper part of the Fort Union Formation.

Figure 5.1 is a structural contour (top of WyoDak-Anderson coal seam) showing the general basin-ward dipping trend of the Fort Union Formation in the Gillette area. Moving westward in the Gillette area, wells must be drilled to greater and greater depths to make benefit of sands in the upper part of the Fort Union. Wells drilled to develop sands in the lower part of the Fort Union must be drilled to at least a 1000 foot total depth just west of the Fort Union-Wasatch contact. Fully penetrating Fort Union wells must be drilled to at least a 2000 foot total depth and deeper moving west of the contact.

The distribution of sand in the upper part of the Fort Union Formation is shown in Figure 5.2 as the percent ratio of sand to the total thickness of the upper interval. Sand intervals were measured from logs of 35 water wells penetrating through the upper part of the Fort Union. Only sands greater than 5 feet in thickness were counted in the summation for each well and for
Figure 5.1
plotting iso-percentage contours over the study area. The map shows trends and areas where the probability of encountering (drilling into) a greater amount of sand would be higher than in others for the entire vertical section of the upper Fort Union. For management purposes, it conceivable that well spacing could be relaxed for areas which were "sand-rich", assuming those were effective production sands (thick, laterally extensive, highly conductive). It would also be possible to center well fields in areas/zones where sands are relatively extensive.

Much more data is needed to achieve a clear subsurface representation of Fort Union Formation aquifer geology, especially the lower part, for which there is very limited information. Geophysical well logs are the most accurate source of data for this particular area of study.
5.3

FORT UNION AQUIFER WATER LEVELS
MEASURED AT GILLETTE

Water level changes in 18 Fort Union wells were reported by Crist (1991) for a short study period of monitoring from June 1985 to January 1986. Of the wells, 17 were completed in the upper Fort Union Formation, 1 was completed in the lower Fort Union, and all but 2 of the wells were used as production wells. Hydrographs in the report reveal apparent water level declines in every well from the static water levels reported (SEO well completion records) at the time of each well's respective completion date. The 1985 water level (air-line) measurements show declines ranging from 39 feet to approximately 455 feet compared to initial static water levels measured for these wells which were drilled in the 1970's and early 1980's. In the summary portion of the report, Crist reported an average 120 foot water level decline in the wells over the period 1972 to 1985, with an average length of pumping equal to approximately 7 years.

The city of Gillette has recorded static water levels and pumping water levels on a biannual basis since 1981 for its Fort Union supply wells. Four of the city's "soft"-wells (S-9, S-10, Wenger #1, and Collins #2) are completed in, or plugged back to, the upper part of the Fort Union. Six wells (S-11, S-12, S-17, S-18, S-19, and S-20) are completed in sands of both the upper and lower part. Figure 5.3 shows the record of static water level
Figure 5.3  Static Water Levels in City Wells
measurements for these city wells (written communication with Bill Green, City of Gillette Water Department; Larry Wester, W2 and Associates, Inc.; SEO permit records).

SEO observation wells consist of 13 recorder equipped static wells and 15 air-line measured producing wells (refer to Table 4.1, Section 4.6; and Plate 1). Two wells, the G-MON-3 and the Rawhide Village No. 2, monitor water level changes in the upper part of the Fort Union aquifer only. The other 11 static wells are completed in both the upper part and in sands of the lower portion of the aquifer. Of the 15 pumping wells, 12 are completed in upper Fort Union producing sands, and 3 (Antelope Valley No. 3, Fox Park No. 1, and Heritage Village No. 1) are completed in the upper and lower parts. The Dickinson Well is operated by the SEO as a "co-op" well with the United States Geological Survey (U.S.G.S.) as a portion of a network of wells that monitor ground water levels around the state.

The following set of hydrographs (Figures 5.4 to 5.31) of SEO observation wells in and near Gillette shows water levels measured in feet below the land surface datum for the period of record. The actual posted data points for all the static wells are daily mean water levels (arithmetic average of 24 hourly measurements recorded each day beginning at midnight), except for the Dickinson Well hydrograph which consists of posted daily minimum values. The data points posted for air-line measured producing wells are measurements taken on the date the well was visited. For a discussion of water level changes illustrated by this set of
at the upper left hand side of each hydrograph figure beginning with the township north of the 40th Parallel Base Line, the range west of the 6th Prime Meridian, the section number, and the 10 acre tract quarter-quarter section designation (U.S.G.S. numbering system). At the upper right hand corner of the hydrograph is the well identification number, which is latitude, longitude, and sequence number. The first six digits of the 15-digit number denote the degrees, minutes, and seconds of latitude, the next seven digits denote the degrees, minutes, and seconds of longitude, and the last two digits identify the well within a 1 second grid.

The line-graph on each hydrograph is either solid or dashed. A solid line represents actual recorded data measurements (daily averages, daily minimums). A dashed line on the hydrograph represents missing data and merely connects the last known and next known data value. For the air-line measured (pumping) wells, a small box dot represents the measurement value (air-line pressure conversion) and date of that discrete measurement.
Figure 5.4
Campbell County

Figure 5.5
Figure 5.6

Campbell County

Level below surface, ft

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

G-MON-3

Recorded 1994-1995

1994 1995
Figure 5.7
Campbell County

Figure 5.8
Figure 5.9
Campbell County

Figure 5.10
Figure 5.12

WATER LEVEL, IN FEET BELOW LAND SURFACE

1 Dickinson Well

441748105323301 50-072-20CAB01

Figure 5.12
Figure 5.13

Campbell County

JIM KINTZ WELL

50-73-28cca

1993 1994 1995

Recorded Missing

Level below surface, ft

415 416 417
Figure 5.14

Campbell County

Level below surface, ft

546
551
556
561
566
571

1993 1994 1995

CAMPLEX #1

Recorded --- Missing ----

50-72-25acb

111708105272800
Figure 5.15

Campbell County

51-72-20abcd

Level below surface, ft

1994 1995

Rawhide Village No. 2 Recorded  Missing  Corrected
Figure 5.16
Figure 5.17
Figure 5.18
Campbell County

Level below surface, ft


Crestview No. 1

Figure 5.19
Figure 5.20
Figure 5.21
Figure 5.22
Figure 5.23
Figure 5.24
Figure 5.25
Figure 5.26
Figure 5.27
Campbell County

Figure 5.28
Campbell County

![Graph of Campbell County levels](image)

Figure 5.29
Figure 5.30
Figure 5.31
5.4
WATER QUALITY ANALYSIS FOR G-MON-SERIES WELLS

Completion procedures on four (4) of the G-MON wells were designed such that discrete sampling of the upper part of the Fort Union aquifer was attained. The upper, then the lower sands in these wells (G-MON-1, G-MON-2, G-MON-4, and G-MON-6) were perforated respectively, a month apart, to separately test just the upper water and then the resultant mix. These procedures were performed in an attempt to compare chemical analysis values between the upper and lower waters of the aquifer. The other wells (G-MON-3, G-MON-5, G-MON-7, and G-MON-8) were sampled after all perforations/development in upper and lower intervals was completed. Water samples were collected from each well after air development had produced mostly clear water.

All samples were analyzed by Energy Laboratories, Inc., in Gillette for conductivity, pH, total dissolved solids, major cations, major anions, dissolved metals, and radionuclides. The sample analysis results are listed in Table 5.1 for each of the G-MON-series wells.

Sodium is the dominant cation in Fort Union Formation water and either chloride or sulfate is the dominant anion. High dissolved solid concentrations are common for ground water in the Powder River Basin, however Fort Union water tends to be less saline, as demonstrated by total dissolved solids of about 600 mg/l or less for the G-MON samples. Secondary Drinking Water Standards
<table>
<thead>
<tr>
<th>ANALYSIS CONSTITUENT*</th>
<th>G-MON-1 &quot;SPORTS BAR WELL&quot;</th>
<th>G-MON-2 &quot;WARLOW WELL&quot;</th>
<th>G-MON-3 &quot;DOUD WELL&quot;</th>
<th>G-MON-4 &quot;F-GROUNDS WELL&quot;</th>
<th>G-MON-5 &quot;JAIL WELL&quot;</th>
<th>G-MON-6 &quot;SLEEPY H WELL&quot;</th>
<th>G-MON-7 &quot;MAKI WELL&quot;</th>
<th>G-MON-8 &quot;BELL RD WELL&quot;</th>
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<td>Calcium</td>
<td>11.1</td>
<td>8.9</td>
<td>3.8</td>
<td>7.2</td>
<td>18.1</td>
<td>6.8</td>
<td>8.4</td>
<td>18.6</td>
</tr>
<tr>
<td>Magnesium</td>
<td>3.3</td>
<td>2.8</td>
<td>1.5</td>
<td>2.0</td>
<td>9.9</td>
<td>2.8</td>
<td>2.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Sodium</td>
<td>94.7</td>
<td>118</td>
<td>132.8</td>
<td>239</td>
<td>137.0</td>
<td>100.8</td>
<td>101</td>
<td>186.1</td>
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<td>5.5</td>
<td>2.9</td>
<td>4.3</td>
<td>7.6</td>
<td>4.3</td>
<td>4.8</td>
<td>6.4</td>
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<td>Sulfate</td>
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<td>7.2</td>
<td>17.3</td>
<td>8.6</td>
<td>81.1</td>
<td>6.9</td>
<td>3.2</td>
<td>138</td>
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<td>Chloride</td>
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<td>15.1</td>
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<td>6.0</td>
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<td>&lt;0.10</td>
<td>&lt;0.10</td>
<td>&lt;0.10</td>
<td>&lt;0.12</td>
<td>&lt;0.10</td>
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<td>Fluoride</td>
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<td>0.87</td>
<td>0.98</td>
<td>0.98</td>
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<td>TDS</td>
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<td>589</td>
<td>419</td>
<td>260</td>
<td>268</td>
<td>274</td>
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<td>Conductance, umhos/cm</td>
<td>522</td>
<td>568</td>
<td>587</td>
<td>1031</td>
<td>664</td>
<td>499</td>
<td>499</td>
<td>985</td>
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<td>Alkalinity</td>
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<td>257</td>
<td>278</td>
<td>514</td>
<td>283</td>
<td>230</td>
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<td>235</td>
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<td>8.45</td>
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<td>8.46</td>
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<td>0.16</td>
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<td>0.17</td>
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<td>Gross Alpha, pCi/L</td>
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<td>4.4</td>
<td>--</td>
<td>1.4</td>
<td>--</td>
<td>4.5</td>
<td>1.4</td>
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</table>

*Mg/L unless otherwise stated
*A sample = Upper Ft. Union
*O sample = Mix - Upper & Lower Ft. Union
(set by EPA) for iron concentrations recommend a maximum concentration of 0.3 mg/l. High iron content causes taste and staining problems. Iron content of samples from the Fort Union Formation aquifer are all above the maximum standard.

Fluoride content of ground water is closely observed in Gillette water supplies because of potential health risks when high concentrations are encountered. The health risks/benefits of fluoride have been questioned on a national scale over the years since fluoridation of water supplies became a tooth decay prevention practice. Fluoride is unusual among trace elements because the same range of human exposure to fluoride that can produce beneficial physiological effects can also produce harmful effects (Hileman, 1988). High levels of fluoride can cause dental fluorosis (young children are highly susceptible) and skeletal fluorosis, a potentially crippling bone disorder. Studies have also linked high fluoride exposure to kidney disease, birth defects, and cancer. The maximum concentration level recommended by the E.P.A. is 4.00 mg/l. All samples from G-MON-wells exhibit fluoride counts below the present national standards.

Fort Union water is slightly more alkaline (basic) on the pH scale where the recommended range is between 6.5 and 8.5 units. Nitrate and trace metal levels are quite low. Radioactivity levels are well below the primary drinking water standard of 15 pCi/l.

Comparing analysis constituent values within and between each well sample for the G-MON data set reveals a general increase in major cation concentration with depth, especially the sodium and
potassium ions levels. Dissolved solids and fluoride also appear to present in higher concentrations in the lower part of the aquifer. Constituent values reported for the G-MON-6 well however, exhibit a reversal to the aforementioned trends, i.e., higher ion, TDS, and fluoride levels in the upper aquifer. The G-MON-8 well, being the G-MON well furthest from the outcrop (recharge area), has the highest ionic concentration plus TDS when combining those constituents.

Concentrations of iron do not fall into any depth related pattern, but are relatively high in the upper Fort Union at the G-MON-2 well and in the lower Fort Union at the G-MON-6 well. Radioactivity counts are apparently higher in the upper Fort Union than in water of the lower part.

More water quality data is required to attempt any statistical analysis or modeling of Fort Union aquifer water quality at the source. Accumulation and study of water analysis laboratory reports would help define undesirable portions of the aquifer from a water quality standpoint.
It is highly probable that most every significant sand body within the Fort Union Formation is partially to wholly saturated with water. A "dry hole" has not been reported for a water well completed in the Fort Union Formation. Production wells drilled and/or completed into the Fort Union, which are perforated or screened opposite thicker sands which show good porosity and are not associated with gas producing coal seams, are highly dependable. Soundly constructed delivery systems (well, pump, controls, storage, and conveyance pipelines) should and have had lengthy life-spans due to the soft, non-corrosive properties of Fort Union water.

Beginning in the early 1970's, ground water withdrawals from the Fort Union Formation were initiated and multiplied as it became recognized as a highly dependable fresh water source. Since then, it is estimated that perhaps 20,000 to 30,000 acre feet of water (Lake DeSmet in Sheridan County stores approximately 25,000 acre feet) have been pumped from the prolific aquifer sands via approximately 100 deep water wells in the Gillette area (not counting several Fort Union supply wells at the nearby coal mines). Pumping from the Fort Union will continue from existing wells and from new wells at rates and volumes equal to or greater than those realized today. The aquifer management plan, in essence, provides
for an optimal design for use from the aquifer by setting guidelines and policy which provide for new wells, abandonment/plugging of old wells, and control of existing wells such that conservation and protection of this valuable resource is maintained.

An aquifer management plan for the Fort Union Formation must include a review of aquifer facts and considerations, or logical criteria by which water use policy may be formulated. "Aquifer facts and considerations" consist of contemporary assessment of the state of the aquifer, use from the aquifer, types of wells, stress placed on the aquifer, symptomatic behavior of the aquifer to that stress, methods/alternatives to relieve that stress, and other impacts to the aquifer. A particular flaw to be avoided is assuming today's facts, which were perhaps not applicable 10 years ago, will be applicable 10 years hence. The condition of the Fort Union aquifer at Gillette must be re-assessed on a timely basis and be in-phase with the current regional water development activities.

**Water Levels, Declines, Recharge**

Hydrographs in the preceding Section 5.3 reveal a variety of water level changes. The hydrographs for the new G-MON-series wells show static water levels responding mostly to the influence of nearby pumping wells, but also to other processes including recharge recovery, subsurface out-flow, and atmospheric pressure changes. The other five static wells (Dickinson, Kintz, Camplex, Rawhide Village No. 2, and Pine Buttes No. 1) exhibit subdued to
dramatic water level changes. The air-line measured well hydrographs consist of measurement values for either pumping levels, recovery levels, or static levels, yet they provide an illustration of water level behavior over a 10 year period since data measurements used in the Crist (1991) report.

Although the eight G-MON wells are located in a relatively small sector (8 x 9 square miles), the resultant hydrographs are quite dissimilar. The only similarity is evidence of rising or relatively stable water levels through the month of May 1995, followed by a sharp drop in June for the G-MON-1 through G-MON-6 wells. The G-MON-7 hydrograph exhibits a more or less level attitude from November 1994 into July 1995 when a sharp (approximately 18’) drop occurs, followed by a steep recovery (this event is attributed to the development of a nearby well that had just been drilled for a new subdivision). The G-MON-8 well shows a 6 foot decline over 4 months beginning November 1994, followed by very little change into August 1995.

The Dickinson well hydrograph reveals some dramatic water level fluctuations in the period since late 1985, with the steep mid year declines most probably due to pumping of a nearby city well (S-20). Water level changes at the Kintz well are only very slightly pronounced (see also G-MON-7 hydrograph - NOV 1994 to JULY 1995), on the order of less than an inch, however some annual pattern is evident. Micro-fluctuations in the Kintz hydrograph are probably hydrostatic responses to changes in atmospheric pressure. The Camplex No. 1 well hydrograph exhibits a symmetrical annual
signature over its short (2 year) period of record with about a 20 foot range in decline and recovery. The closest pumping well to the Camplex No. 1 is the Fox Park No. 1 well which is approximately 3/4 mile ESE. Hydrographs for the Rawhide Village No. 2 well and the Pine Buttes No. 1 well show only 9 and 5 months of recorded data respectively. Although the Rawhide Village No. 2 was placed on-line early in 1994, mechanical problems with the float-weight assembly precluded any continuous recording until December 1994. Beginning at that time, the water level rose 9 feet until June when the level dropped 27 feet. The Pine Butte No. 1 well rose steadily about 7 feet between late April and early June 1995, then began to fall steadily.

A seemingly common trait, observed by Crist (1991), is the initial decline of water levels in production wells completed in the Fort Union Formation aquifer. The observed decline is the difference between new well static water level measurements and subsequent static or pumping water levels (see Crist report, hydrographs for air-line measure wells in Section 5.3, and Figure 5.3, static water level measurements of city wells). After a period, the apparent decline stabilizes such that a relatively consistent static/pumping level is achieved. Observed departures from stable levels are probably a result of drought, higher demand, or lower demand, but some degree of recovery to stable levels is apparent. The physical, or hydraulic, explanation for the initial (and sometimes steep) decline is not clear. Perhaps the formation simply becomes depressured to a relatively steady or equalized
hydrostatic pressure in the local area of influence of the well. It is also plausible, because of the complex differential head nature of the aquifer, that after initial pumping, higher pressure intervals are bled off so that eventually, dominant interval (lower) pressure heads prevail in the subsequent life of the well. Testing the aquifer to isolate individual interval properties (transmissivity, storage coefficient, hydrostatic psi, etc.) has been attempted in the past but is quite a laborious and expensive undertaking. It is believed that the water level declines, as mentioned here and identified in the Crist report do not represent chronic water level declines or "mining" of the aquifer. These declines represent short term response to aquifer stress. Areas in Gillette however, where Fort Union wells are highly concentrated and/or closely spaced could be adversely impacted by emplacement of new wells such that compounded declines would be realized.

Accelerated use of the Fort Union Formation aquifer, beginning in the 1970's, placed a demand on the natural equilibrium of the aquifer. That demand could only be met by ground water released from storage within the aquifer to replace discharge at wells. Recharge in this area, however slight, originates from precipitation (rainfall, snowmelt), percolation from surface streams crossing Fort Union outcrop areas (specifically Donkey Creek, Belle Fourche River, and their tributaries), and groundwater inflow (from scoria and peripheral aquifer units). To date, ground water withdrawals from the Fort Union have dictated a new equilibrium (recharge ≈ discharge) that makes present withdrawals
a possibility without the development of serious water level declines. The question that must be posed is whether continued withdrawals and new wells will destroy that equilibrium and how may that be avoided. The SEO monitoring and management plan as designed will provide a warning system and guidelines for wise use.

Use of the Fort Union Formation Aquifer, Types of Wells

Plate 3 is a map showing locations of Fort Union wells in the Gillette area according to the records of the State Engineer’s Office. Fort Union wells not used for municipal purposes by the city of Gillette include public water supply (subdivision, industrial park, mobile home park) wells, facility (e.g. airport, mine site) wells, commercial/business supply wells, oil and gas secondary recovery water source wells, and domestic/stock wells. Refer to Appendix 1, Final Report (Phase II), Gillette Area Water Master Plan, for a tabulation and description of all wells within the Planning District Boundary and most other wells in the immediate area serving as public water sources.

Gillette municipal use from their Fort Union wells for the 10-year period 1985 to 1994 is shown in Figure 5.32. The city is the largest user from the Fort Union aquifer in the area. The bar graph shows the volume of production dropping since the mid 1980’s. This is partially due to the fact that the S-11 and S-12 wells have been out of service since 1986 and 1992 respectively, leaving only eight wells in production. Four new Fort Union wells are slated to be emplaced by 1996, so production will probably increase again as
GILLETTE MUNICIPAL PUMPING TOTALS
FORT UNION WELLS

Figure 5.32
those wells go into service. Table 5.2 is a breakdown of city of Gillette ground water production from all sources showing the percentage contribution from supplemental sources (Wasatch Formation, Fox Hills Formation, and Madison Formation) since 1978.

The second largest users of water from the Fort Union are public water supply systems which serve subdivisions adjacent to the city and in outlying areas. Most of these entities have one water supply well but larger subdivisions such as Sleepy Hollow, Heritage Village, and Cedar Hills operate with two or more wells. The Fort Union Formation is the only source of fresh water supply for newly platted subdivisions outside the established planning district.

Generally, three types of wells are emplaced to withdraw water supplies from the Fort Union Aquifer:

- Converted oil & gas test wells ("dry holes") which are plugged back to some depth, usually the bottom of the 9 5/8" surface pipe, then logged and perforated opposite the Fort Union sands. Many wells in the area are this type construction, including several of the early city wells. The advantage of this design is the cost savings of taking over an abandoned, cased drill hole. Disadvantages include the used oil field casing that is commonly used for surface casing, drilling fluid contamination, and "trash" (wireline, drilling tools, timbers, etc.) sometimes left in the abandoned well.

- "Straight pipe" wells emplaced utilizing the oil field
Table 5.2
GROUND WATER PRODUCTION FROM THE CITY OF GILLETTE WELL FIELD

|----------------|------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|

* WENGER No. 2 ADDED INTO SYSTEM
* COLLINS No. 2 ADDED INTO SYSTEM

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<td>FT. UNION (S)</td>
<td></td>
<td>830 Ac.Ft.</td>
<td>1,031 Ac.Ft.</td>
<td>916 Ac.Ft.</td>
<td>678 Ac.Ft.</td>
<td>797 Ac.Ft.</td>
<td>813 Ac.Ft.</td>
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methods of cementing casing (usually 6 5/8" or 8 5/8" steel) top to bottom and jet perforating. Advantage to this design is the relative simplicity of construction utilizing mud rotary drilling methods. Disadvantage is the high cost for a deep well using large diameter casing and the inefficiency of using jet perforating.

- "Telescope"-type wells designed with a small diameter (4" to 6 5/8") screened production string hung below a larger diameter (8 5/8" to 10 3/4") pump chamber. Surface casing (10 3/4" to 16") is usually set for this particular well design. Advantage is the low cost for a high production well where a large size pump can be set. Disadvantage is difficulty of construction, particularly the lower "screened" portion which may incur additional costs and time on the drilling site. Swelling shales, bentonite layers, incompetent sand zones, etc., may cause lower hole collapse which could also cause "screened" intervals to be misplaced.

Zone of Influence for Pumping Wells, Potentiometric Maps, Well Spacing

Existing city of Gillette Fort Union wells are suitably dispersed to reduce interference between pumping wells. Other (non-municipal) Fort Union wells are placed as they were needed and in some areas are somewhat tightly clustered (see Plate 3). Well spacing was not considered when a good many of these wells were
emplaced during the boom times of the mid-1970’s. Drawdown interference has not been problematic at Gillette, however it does exist and must be considered in the course of aquifer management.

When two closely spaced wells are pumped simultaneously from the same confined aquifer, the intersecting cones of depression produce a compound drawdown which (mathematically) is the sum of the drawdowns at any point within the zone of influence of both wells. When several pumping wells are in operation, the total effect in any one well is the sum of the drawdowns produced by all the others within their zone(s) of influence (Driscoll, 1986).

The Fort Union Formation is essentially a complex of many confined aquifers (sands) but the drawdown interference rule holds for wells completed in the same, hydraulically connected sands.

An good example of drawdown interference is occurring in an area south of Gillette involving wells located at Sleepy Hollow, Antelope Valley, Crestview, and Hitching Post subdivisions (see Plate 1 for relative locations). These subdivisions, especially Sleepy Hollow (with 3 Fort Union wells) and Antelope Valley (with 4 Fort Union wells), together pump large quantities of Fort Union water during peak demand periods in the summer months. The new G-MON-6 observation well is located approximately central, relative to the wells serving these subdivisions. The effects of Fort Union ground water pumping is clearly illustrated by the G-MON-6 hydrograph for the summer of 1995 in Section 5.3. After a gradual water level rise of about 29 feet over the period of November 1994 to sometime in late June or early July of 1995, a sharp drop of 35
feet occurs about the time when the unusually wet spring weather of 1995 subsided. This is when increased demand was initiated (chiefly for lawn watering) at the surrounding subdivisions. The 35 foot static loss at the G-MON-6 is the composite result of crossing zones of influence generated by the sustained pumping at the subdivisions over the duration of the summer.

Figures 5.33 to 5.37, are potentiometric contour maps constructed from G-MON-well data showing water levels recorded at 01:00 a.m. on the first day of DEC 94, FEB 95, APR 95, JUNE 95, and Aug 95. The difference in potentiometric values between DEC 94 and AUG 95 is illustrated in Figure 5.38. The contour plots show the "bowl of depression" resulting from constant withdrawals (pumping) from the aquifer. As cumulative demands increase into the summer months, the "bowl" deepens. More study of this particular phenomena is warranted to more closely characterize this annual occurrence. This also illustrates the more regional effect of drawdown interference on the aquifer.

Well spacing requirements constitute responsible aquifer management in the Gillette Area and compels water users to:

- Reduce drawdown interference > In areas where two or more wells are competing for the same ground water supply, water users may be faced with 3 types of drawdown. Those are, (1) drawdown caused by pumpage of their own well, (2) drawdown caused by interference from neighboring pumping wells, and (3) drawdown caused by regional water level declines resulting from drought, overpumping of the aquifer, etc. Minimum well
Figure 5.33

STATIC WATER LEVEL
DECEMBER 1, 1994
FORT UNION AQUIFER

CONTOUR INTERVAL: 25 FEET
DATUM FEET ABOVE SEA LEVEL
Figure 5.34

STATIC WATER LEVEL
FEBRUARY 1, 1995
FORT UNION AQUIFER

CONTOUR INTERVAL: 25 FEET
DATUM FEET ABOVE SEA LEVEL

PREPARED BY:
THE WIDAYE STATE ENGINEER'S OFFICE

5-58
Figure 5.35

STATIC WATER LEVEL
APRIL 1, 1966
FORT UNION AQUIFER

CONTOUR INTERVAL 25 FEET
DATUM FEET ABOVE SEA LEVEL
Figure 5.36

STATIC WATER LEVEL
JUNE 1, 1995
FORT UNION AQUIFER

CONTOUR INTERVAL 25 FEET
DATAUM FEET ABOVE SEA LEVEL
Figure 5.37

STATIC WATER LEVEL
AUGUST 1, 1995
FORT UNION AQUIFER

CONTOUR INTERVAL: 25 FEET
DATUM FEET ABOVE SEA LEVEL
Figure 5.38

WATER LEVEL CHANGE
MAP-FORT UNION
AQUIFER

CONTOUR INTERVAL: 2 FEE

5-62
spacing would relieve each of these stages.

- **Avoid water rights/use conflicts** > Investigation of well interference claims over ground water use can be complex, time consuming and costly. Fortunately, very few ground water conflicts have arisen in the Gillette area, due to the large saturated reservoir of the Fort Union Formation. However, the potential for future problems is very real if the implementation of equitable well spacing requirements for new wells is not put in place.

**Source Water Quality**

The superior quality of Fort Union water is an attribute which must be preserved and protected. It is known however, that there are zones in the formation which are gas (methane) producing or have significantly high concentrations of certain undesirable chemical constituents (dissolved solids, fluoride, iron, etc.). Better identification of these zones is needed in the application of a management plan.

The city of Gillette has facilities which remove gas from the Fort Union and Fox Hills source water then blends Madison water, chlorinate, and deliver to the city distribution system. Other public water supply systems which depend on Fort Union water supply only, are required to have treating with chlorination systems. Still, even without the treatment safeguards, Fort Union water is virtually ready for the tap.

Prevention of contamination to the Fort Union aquifer is of
utmost importance and is best accomplished at the well-head via proper sanitary sealing techniques. Recharge area protection for Gillette area Fort Union supplies is an undertaking that is not within the scope of this plan, but may become a consideration for the Fort Union Aquifer Advisory Committee in the future. The current perception is that a comprehensive "Well Head Protection Plan" would be difficult to institute in the Gillette setting.

Other Impacts to the Fort Union Aquifer

Incidental effects to the Fort Union aquifer associated with fossil fuel extraction (coal, oil & gas, coalbed methane) have been a matter of concern because of the proximity of those activities to populated areas and Fort Union wells. Seven open-pit coal mines are within a 10 mile radius (to the north and east) from the Gillette city limits. Oil and gas exploration test wells are commonly drilled quite close to town and coal bed methane is produced (with large amounts of by-product water) at fields both north and south of town.

Surface coal mining activities disrupt overburden aquifers (Wasatch Formation and scoria) and destroy the (WyoDak-Anderson seam) coal by removal. The type of effects and the scale of the impact to the underlying Fort Union aquifer as a result of open pit disturbance and subsequent reclamation are largely unknown. Ground water monitoring at the mines is almost exclusively restricted to Wasatch overburden, reclaimed lands, and the minable coal (WyoDak-Anderson seam). The State Engineer’s Office requires all coal
mines in the eastern PRB to report annual withdrawals from their deeper Fort Union facility supply wells.

Coal-bed methane recovery requires the production of water from favorable structures within the coal bed thereby reducing the formation pressure to a point which releases methane molecules adsorbed onto the coal. The coal is effectively dewatered at rates which maintain gas production but less and less water is withdrawn as gas production commences. The hydrologic relationship between water-saturated portions of the Wyodak-Anderson coal seam and the underlying Fort Union Formation aquifer is not altogether understood. Most subsurface evidence generally precludes any vertical leakage however some local connectivity may exist. So far, there is no evidence to suggest that coal-bed methane recovery activities have any scale of impact on the reservoir or use of the Fort Union aquifer nor to the quality of water contained therein.

The area in and around Gillette is an extremely active oil and gas exploration and production area. The Wyoming Oil and Gas Conservation Commission (WOGCC) requires operators/drillers of oil and gas test wells to set cemented surface casing opposite fresh water aquifers used by nearby water wells. In the Gillette area, the general WOGCC policy is to require surface casing to at least 100 feet below the total depth of the nearby water well(s). Unfortunately, new Fort Union water wells are often hundreds of feet deeper than the old existing Fort Union wells which negates the WOGCC surface casing policy in the case of new water wells. Migration of contaminating drilling fluids or hydrocarbons pose a
real threat, especially to municipal wells and public water supply system wells depending on the Fort Union aquifer. Discussion with the WOGCC concerning their surface casing requirements should take place in the near future so that the Fort Union Aquifer is fully protected from oil and gas drilling and production procedures.
5.6

MANAGEMENT POLICY

FOR THE FORT UNION FORMATION AQUIFER AT GILLETTE

Historical management of ground water resources in the area of Gillette is based on the constitutional power of the state engineer, statutory requirements (water law), and ground water rules and regulations of the Wyoming State Engineer's Office. In the early 1970's, water supplies (surface water and ground water) in the eastern PRB and Black Hills area came under intense scrutiny as ETSI (Energy Transportation Systems, Inc.) proposals for a coal slurry pipeline began to take shape. Exploration for ground water in the Madison Formation was taking place at the same time permits for new Fort Union wells in the Gillette area were approved as a matter of course to cope with their water supply needs. Since that time some restrictions have evolved in the permitting process and relate to depth of well, construction, cementing and casing requirements, production reporting and water level reporting, etc. Adjudication of ground water rights in the vicinity of Gillette, supplied from the source Fort Union aquifer, is a continuing process undertaken by the State Board of Control.

In the early 1990's, well permit applications for use of Fort Union aquifer water supplies for secondary recovery (waterflood) operations in mature oil fields were no longer approved anywhere near Gillette or near the operating coal mines. Deep injection of large quantities of fresh Fort Union water was deemed to be
tantamount to waste of water which is illegal under Wyoming water law. Common sense and sensitivity to public perception of resource management weighed heavily in this change-of-policy measure. Unit operators were forced to seek other sources such as the deeper Lance/Fox Hills aquifer.

The promulgation of this Preliminary Aquifer Management Plan under the Gillette Area Water Master Plan, raises SEO management policy in the Gillette area to a new level. Management will be based on hydrologic evidence gathered under the Fort Union Aquifer Monitoring Plan and up-dated assessment of the condition, use, and vulnerability of the aquifer. The remainder of this section details specific requirements and recommendations regarding well permitting and well spacing under this plan.

Current Fort Union Well Permitting Procedures

- **New Fort Union well applications** shall be submitted to the SEO on the standard Form U.W. 5 - Application to Appropriate Ground Water along with the appropriate filing fee.

- **Conditions and Limitations** to the granting of a new Fort Union well permit are enumerated as follows and shall amend, but not be retroactive, to previously imposed conditions and limitations:

  1. A meter acceptable to the State Engineer is required to accurately measure the total quantity of water produced from this well.

  2. This well shall be cased with new or new-like quality
casing and shall be cemented in the borehole from a depth of ______________ feet below land surface to the land surface. The State Engineer may require a cement bond log to ensure proper cement placement.

3. An annual report shall be submitted to the State Engineer no later than February 15 of each year stating the total amount of water produced from this well each month during the previous January 1 to December 31, twelve (12) month period.

4. The report shall identify the well by name, location, permit number and shall identify the type of meter used for the measurement.

5. An air-line or some other method acceptable to the State Engineer shall be utilized to obtain monthly measurements of ground water levels in the well. The measurements should be approximately thirty (30 days apart. The annual report submitted to the to the State Engineer no later than February 15 of each year, shall contain the measured static water levels, the date upon which the monthly ground water level in the well was measured, the method of measurement, length of time since the well was pumped, and the name of the individual who made the measurement. A standard "shut-in" time should be utilized when possible prior to each monthly static water level measurement. It is recommended that the "shut-in" period be a minimum of twenty-four (24) consecutive hours prior to measuring the static water level.

6. Additional conditions and limitations may be imposed on this permit regarding the appropriation granted herein.
7. The State Engineer may, upon written request, waive all or any of these conditions and limitations.

- **Subsequent Notices**, including Form U.W. 6 - Statement of Completion and Description of Well and Form U.W. 8 - Proof of Appropriation and Beneficial Use of Ground Water, shall be submitted at the time required to validate a water right. In the future, it is possible that extensions for expiration of completion of the well and completion of beneficial use will be restricted or eliminated in order to maintain equitable water rights management in the Gillette area.

- **Adjudication of the water right**, associated with new well emplacement and subsequent beneficial use of the well supply, shall proceed on a timely basis. Petitions to amend adjudicated or unadjudicated water rights shall also be considered with just speed.

**Recommendations to the State Engineer for New Well Permitting and Construction**

These recommendations are suggested as guidelines not included in Part II and III of State Engineer’s Office Rules and Regulations (revised 1974).

- **A geophysical log** (SP-Resistivity, gamma-neutron, or equivalent) of the total depth of the well and a **chemical analysis** of the well water shall be submitted to accompany Statement of Completion and Description of Well (Form U.W. 6). The water
quality analysis shall include, but not be limited to, reported values for pH, conductance, and constituent concentrations of major ions, trace metals, nitrate, fluoride, and total dissolved solids.

- **Casing** of production string or pump chamber should be minimum 6 5/8" O.D., #24, threaded and collared steel pipe.

- **Re-entered wells** (conversion of abandoned oil & gas tests), done so in order to complete as a Fort Union water well, should not have been in place for a period of more than five (5) years. Such wells are typically surface plugged and filled with drilling fluids which degrade the quality of the casing pipe over a lengthy period of time.

- **Other** recommendations/requirements for new well construction may be implemented under this plan as recommended by the Fort Union Formation Aquifer Advisory Committee and deemed necessary by the State Engineer.

**Recommendations to the State Engineer for New Well Spacing**

- **A three-quarter (3/4) mile minimum horizontal well spacing**, from any existing Fort Union production well, is **recommended** for a new Fort Union well location where production will exceed 25 gallons per minute.

- **A one-half (½) mile minimum horizontal well spacing**, from any existing Fort Union production well, is **required** for a new Fort Union well location where production will exceed 25 gallons per minute. New well permit applications will not be approved unless this well spacing requirement is met. If the new well is to be
drilled to replace an existing well, the older well must be removed from service and/or plugged and abandoned per State Engineer’s Office Rules and Regulations (Part III, Minimum Well Construction Standards, p. 12-13)

- **A vertical completion interval spacing** may be required for any new Fort Union well, regardless of production rate, which would require such a well to be completed in producing sands vertically separate from those developed by neighboring existing wells. For example, if a several closely clustered existing wells were completed in sands of the upper Fort Union Formation aquifer, a new well in that area would be required to be completed in the lower portion of the aquifer only to prevent any additional drawdown interference.

**Water Well - Oil & Gas Test Well Spacing, Surface Casing**

- It is recommended that new oil and gas tests known to be drilling within significant proximity (less than or equal to a mile) to Fort Union wells should be required to surface case to the top of the Lance Formation.

- In the near future, the SEO plans to secure a Memorandum of Agreement (MOA) with the Wyoming Oil & Gas Conservation Commission in order to establish a buffer zone for oil & gas exploration and development in the Gillette area. The buffer zone will act as a safeguard barrier to protect existing Fort Union wells used for human consumption. The MOA will also provide for cooperation and
a free flow of communication and data base information between the agencies. Mineral rights, water rights, and aquifer protection are potentially entangling from a philosophical standpoint. Cooperation between all interests hopefully serves the public welfare on the grand scale.

Recommendations for Ground Water Conservation Measures

- Emplacing and enforcing annual volumetric limits on pumping from individual well or well fields
- Enforced water application scheduling or rotation schemes to reduce pumping stress during high demand seasons.
- Volunteer application restrictions or rotation scheduling.
- Other conservation measures or procedures developed by the Fort Union Formation Aquifer Advisory Committee.
SELECTED REFERENCES


Driscoll, F.G., 1986, Groundwater and Wells, 2nd Ed.,


Love, J.D., and Christiansen, A.C., 1985, Geologic Map of Wyoming: U.S.G.S. Map, Scale 1:500,000


MEMORANDUM OF AGREEMENT
BETWEEN
WYOMING WATER DEVELOPMENT COMMISSION
AND
THE WYOMING STATE ENGINEER
GILLETTE AREA MASTER PLAN - AQUIFER MONITORING

1. Introduction

This Memorandum of Agreement (MOA) between the Wyoming Water Development Commission, hereinafter referred to as WWDC, and the State Engineer's Office, hereinafter referred to as SEO is entered into on this 16th day of March, 1994.

2. Purpose

The purpose of the MOA is to provide for the development of a long-range monitoring program to evaluate the condition and capability of the Fort Union and associated aquifers in the area of Campbell County in the vicinity of the City of Gillette. The anticipated end product of this monitoring program is a report on the current usage and condition of the aquifer and a plan recommending aquifer management practices which will insure the long-term responsible use of the water resource. The specific scope of work, budget and completion dates are included in Appendix I, which is attached to this MOA and incorporated by reference as part of this MOA.

3. SEO Responsibilities

A. Personnel

The SEO shall provide the personnel necessary to conduct existing well investigations, monitor water levels in observation wells, prepare monitor well specifications and bid packages, select drillers, supervise construction and prepare maps and reports.

B. Advisory Committee/Coordination

The SEO shall assume responsibility for directing the work of the Fort Union Advisory Committee, including scheduling meetings, notifying members, establishing the agenda and reporting the results.

The SEO shall coordinate project activities with members of the Advisory Committee, and with the WWDC consultant responsible for the Gillette Well Rehabilitation project.
C. Contract for Well Construction, Bids, Bidding Procedure

The SEQ shall prepare the plans and specifications for new monitor wells, prepare and distribute bid packages and select a contractor to construct the wells.

D. Supervision During Construction

The SEQ shall supervise the construction of monitor wells.

E. Monitoring

The SEQ shall conduct the monitoring and recording activities necessary for the successful completion of the project.

F. Maps and Reports

The SEQ shall prepare the maps, reports and other project documents necessary to record and interpret project findings. The SEQ shall prepare an aquifer management plan with recommendations for efficient management of the aquifer.

4. WWDC Responsibilities

A. Reimburse SEQ for costs incurred to perform work specified in this Agreement on the project described in Appendix I.

Such reimbursement will not exceed the budget as shown in the Appendix I without an amendment to the MOA.

B. Examine all studies, reports, opinions, and other documents presented by the SEQ to the WWDC and shall promptly render in writing the WWDC's decisions pertaining thereto.

C. Provide a project manager to attend and participate in Advisory Committee meetings and other activities related to the project.

D. Respond within a reasonable time to requests for information, document review or other assistance necessary for successful completion of the project.

5. Schedule

The SEQ will submit reports in a manner compatible with the completion dates included in Appendix I.
6. **Billings**

Billing reports shall be submitted no more often than monthly.

7. **Changes**

The WWDC or the SEQ may request changes in the work to be performed hereunder. Such changes, including any increase or decrease in the amount of the compensation, which are mutually agreed upon by and between the WWDC and the SEQ shall be incorporated in written amendment to the MOA.

8. **Budget**

The total budget amount shall not be exceeded without an amendment to this MOA. The task budget items contained in Appendix I are estimates. The WWDC project manager assigned to this project has the authority to authorize deviations from the task budget items, but such deviations must be requested in advance of actual expenditures. The amount of money earmarked in Appendix I shall be considered to be approved and authorized by WWDC.

9. **Final Completion and Payment**

The execution of the final MOA amendment by the SEQ shall constitute a waiver of all claims for payment by the SEQ.

10. **Termination**

If required by either party, the Agreement may be terminated. Such termination action may be initiated by written notice to the other party 60 days prior to the proposed effective date of the termination. Prior to the effective date of the termination, the rights and duties of both parties shall continue in full force and effect.
IT WITNESS WHEREOF, the WWDC and the SEO have executed this Memorandum of Agreement as of this __th day of ___, 1994.

Gordon Fassett
Wyoming State Engineer

Chairman
Wyoming Water Development Commission

Secretary
Wyoming Water Development Commission

Approved as to form and execution, this ___ day of ______, 1994.

S. Jane Caton
Attorney General's Office
IT WITNESS WHEREOF, the WWDC and the SEO have executed this Memorandum of Agreement as of this ___ day of ___ , 1994.

Gordon Fassett  
Wyoming State Engineer

Leslie Peterson  
Chairman  
Wyoming Water Development Commission

Rene Hilgen  
Secretary  
Wyoming Water Development Commission

Approved as to form and execution, this ___ day of ___ , 1994.

S. Jane Caton  
Attorney General's Office
APPENDIX I
TO THE
MEMORANDUM OF AGREEMENT
BETWEEN
WYOMING WATER DEVELOPMENT COMMISSION
AND
THE WYOMING STATE ENGINEER
GILLETTE AREA MASTER PLAN - AQUIFER MONITORING

I. Budget

The following establishes the project scope and budget for work to be performed by the Wyoming State Engineer in the Gillette Area Master Plan - Aquifer Monitoring Project.

A. Travel

1. Per Diem (exclusive of drilling) $10,000.00
2. Milage (exclusive of drilling) 10,000.00

B. Existing Well Investigations

1. Water quality analysis 40,000.00
2. Geophysical logging, cement bond logging, packer and perforation surveys 10,000.00

C. Water Level Measuring Sites (10 sites)

1. Shelters, hardware, armor, fencing 5,000.00
2. Recorders, transducers 30,000.00

D. Monitor Wells (6 wells) - Drilling, completion, water level equipping, travel, per diem 290,000.00

E. Report and map printing 5,000.00

TOTAL BUDGET $400,000.00

II. Schedule

A. Existing well investigations, securing of water monitoring sites and construction of monitor wells shall be completed by September 1, 1994.

B. The draft final report including the aquifer monitoring plan and a draft preliminary aquifer management plan shall be submitted no later than October 1, 1995. This date may be extended upon agreement of both parties.
C. Submission of the final project report including the aquifer monitoring plan and the preliminary aquifer management plan shall be made by the SEO within 30 days of approval of the draft report by WWDC. It is understood that the preliminary aquifer management plan will be subject to continuing revision based on the results of the aquifer monitoring program. Therefore, the aquifer management plan shall be finalized and submitted to the WWDC when the SEO decides adequate data has been accumulated through the monitoring program.

III. Scope of Services

A. Travel - The SEO shall be reimbursed for vehicle, travel and per diem costs associated with the project.

B. Existing Well Investigations - The SEO shall conduct water quality analyses, geophysical logging, cement bond logging, packer and perforation surveys of selected wells within the project area.

C. Water Level Measuring Sites - The SEO will establish a minimum of ten (10) water level measuring sites within the project area, provide the monitoring equipment necessary to measure and record fluctuations in water levels, and take the precautions necessary to prevent tampering with equipment.

D. Monitor Wells - The SEO will site, design, and contract for the construction of six monitor wells. Upon completion and development, the wells shall be equipped with water level monitoring equipment and secured. Travel and per diem for personnel to supervise the construction of the monitor wells and record data from the completed wells is included in this task.

E. Reports and Map Printing - The SEO shall provide to the WWDC at the completion of the study 35 copies a final report describing the results of the data analysis, including maps and other graphics, the aquifer monitoring plan and the preliminary aquifer management plan for the Fort Union and associated aquifers in the study area.