Layne GeoSciences

Computer Model Evaluation of Groundwater Potential of the Glacial Drift Aquifer in the Vicinity of Coffey, Missouri

March 2003

Prepared for

Harrison County Public Water Supply District No. 2
Bethany, Missouri

Prepared by

Layne GeoSciences
Kansas City, Kansas

Hydrogeological Specialists

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EXECUTIVE SUMMARY

The Harrison County Public Water Supply District No. 2 (District) has experienced significant growth in recent years within the areas that it serves. Withdrawals have increased from 100,000 gallons per day (GPD) in the late 1980's to approximately 357,000 GPD presently (Figure 1.3). The demand is projected to increase to 717,000 GPD by the year 2020. The District currently has four active production wells in the vicinity of Coffey, Missouri (Figure 1.1 and 1.2), which withdraw water from the drift-filled aquifer. In order to meet increased demand in the future, the District is interested in expanded the wellfield by constructing additional wells. The present modeling study was conducted to determine the capability of the drift-filled aquifer to supply the projected water demands in the future.

Glacial deposits of Pleistocene age and alluvial deposits of more recent times overlie the Pennsylvanian age bedrock throughout the study area. The glacial deposits have extremely variable lithologies and thicknesses. At some locations, these deposits are largely made up of sand and gravel, while at other locations they are a heterogeneous mix, predominantly of clay with some sand. It is difficult to identify a specific location where substantial thickness of sand and gravel can be encountered.

The computer model developed for this study, simulated groundwater flow in the drift-filled glacial aquifer. The model was first calibrated, which involved adjusting aquifer parameters in the glacial aquifer until the model output (water levels) reproduced observed field conditions. The model was primarily calibrated to water levels observed in the District wellfield. The calibrated model was then utilized to run model simulations in which withdrawals of 360,000 GPD from 4 new production wells was simulated. The model was run for a period of 20 years (up to 2022) with pumpage in the existing wells maintained at 2002 levels. The simulation results indicate that it is possible to withdraw an additional 360,000 GPD from the drift-filled channel to meet a total raw water demand of 717,000 GPD by the year 2022.

Based on review of well logs in the area, it is recommended that the District conduct a test-drilling program along the edges of the drift-filled channel (south of the existing wellfield) to identify suitable locations for new wells. Due to the large drawdowns anticipated in the expanded wellfield, it is necessary that an appreciable sand and gravel zone be present at depth of 650 feet (or lower) at the new well sites.

The increased withdrawals in the expanded wellfield will induce drawdowns at the existing District wells. Additional drawdowns of 10, 50, 60, and 40 feet are expected at Wells 1, 2, 3, and 4 respectively. Well No. 1 is already experiencing drawdown within the well screen. With additional pumpage in the area, the production from this well may need to be curtailed.

It is recommended that the first test well be constructed near the center of the proposed wellfield presented in Figure 3.5. On completion of the test well, an extended 60-day pump test (followed by 30 days of recovery) should be conducted. The data obtained from the pump test should be used to corroborate model results, and if necessary, be used to update the groundwater model. If desired, the updated model could be used to obtain more precise drawdown projections in the expanded wellfield.

CHAPTER 1

INTRODUCTION

1.1 STUDY OBJECTIVES

Layne Western Company (Layne) was retained by Harrison County Public Water Supply District No. 2 (District) to perform a groundwater modeling study of the drift-filled pre-glacial aquifer in the vicinity of Coffey, Missouri. The District currently has four active production wells in the area (Figure 1.1 and 1.2), which withdraw water from the drift-filled aquifer. The District primarily serves rural customers in addition to meeting the municipal needs of the cities of Coffey and Gilman, and the north part of Public Water Supply District No.2 of Daviess County.

The district has experienced significant growth in the area that it serves. Groundwater withdrawals have increased from 100,000 GPD in the late 1980's/early 1990's to approximately 350,000 GPD presently (Figure 1.3). The increased withdrawals have resulted in declining water levels in the District's wellfield and vicinity. In order to meet increasing demand in the future, the District is interested in expanding the wellfield by constructing additional wells and the necessary treatment, storage, and transmission facilities.

Prior to expanding the wellfield and investing in the infrastructure, the District is interested in assessing the potential of the drift-filled aquifer to meet increased demand, which is projected at 717,000 GPD by the year 2022. The objective of the present modeling study therefore is to construct a computer groundwater model of the drift-filled valley, capable of simulating flow in that aquifer. The model is to be utilized to determine the long-term impacts of withdrawals from the current wellfield, and determine the potential of the aquifer to safely sustain the desired withdrawals on completion of the expanded wellfield.

1.2 PROJECT SCOPE OF WORK

The scope of work included a detailed review of existing geologic investigation reports and compilation of existing hydrogeologic data with state regulatory agencies and Layne. The reviewed hydrogeologic data was incorporated as initial estimates of hydrogeologic parameters in the computer model. The model was then calibrated to historically observed water levels in the District's wellfield. The calibrated model was utilized to make drawdown projections due to present and future pumpage in the expanded wellfield. Model results are presented in Chapter 3 of this study. Conclusions and recommendations are provided in Chapter 4.

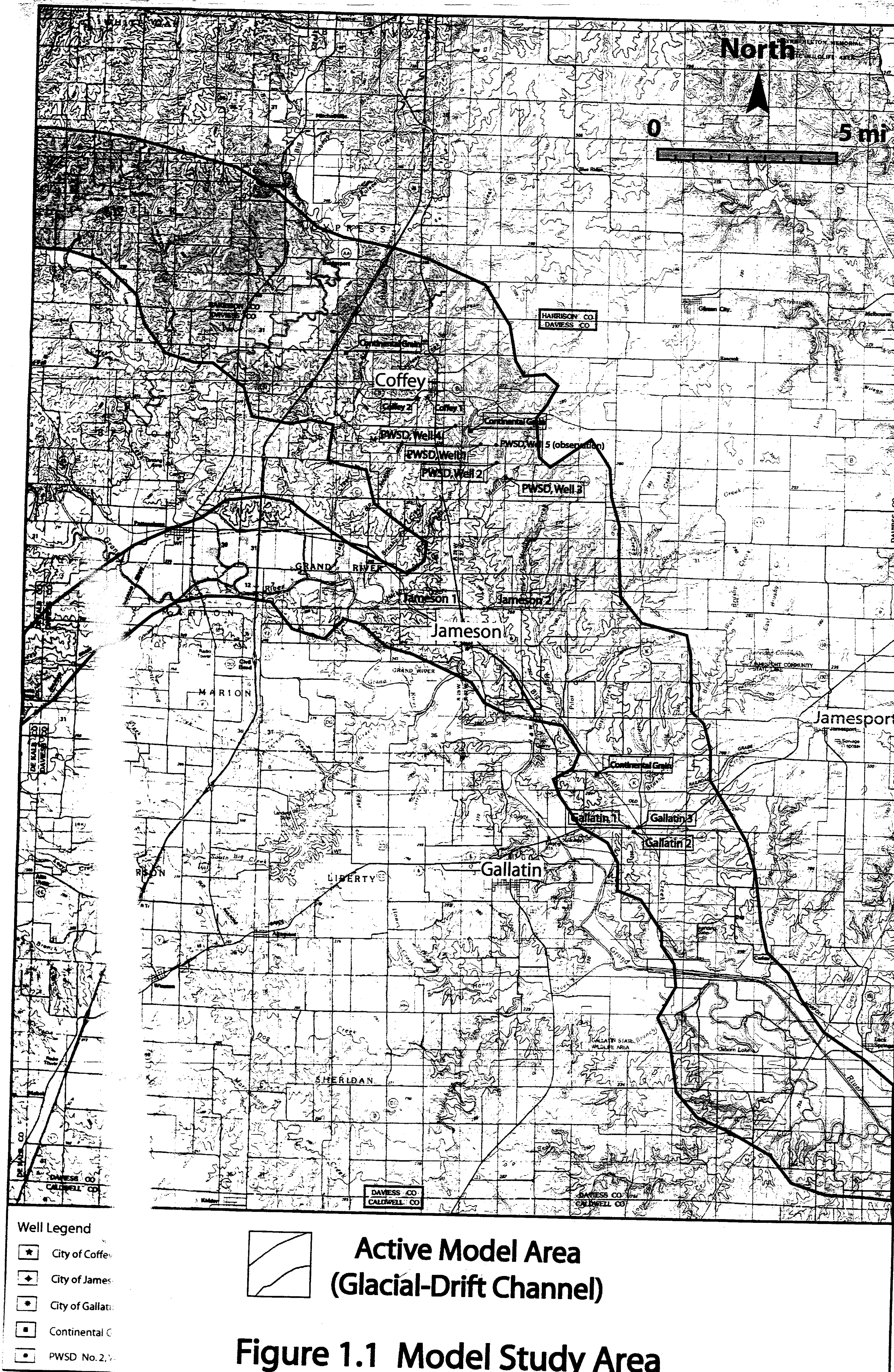
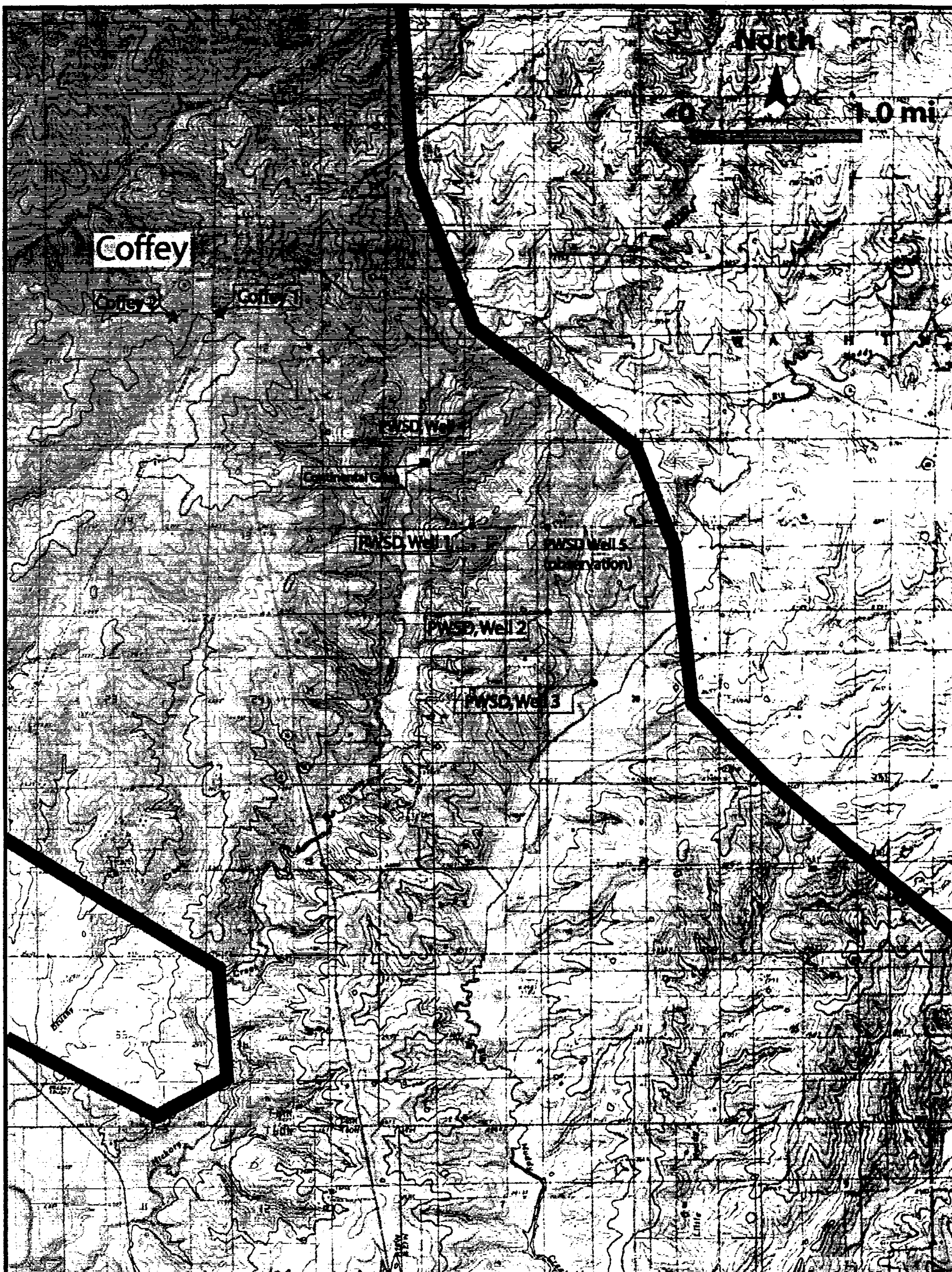


Figure 1.1 Model Study Area



Well Legend

- ★ City of Coffey
- ■ Continental Grain
- ● PWSD No. 2, Well 1-5

Active Model Area (Glacial-Drift Channel)

Figure 1.2 Wells in the vicinity of Coffey, Mo

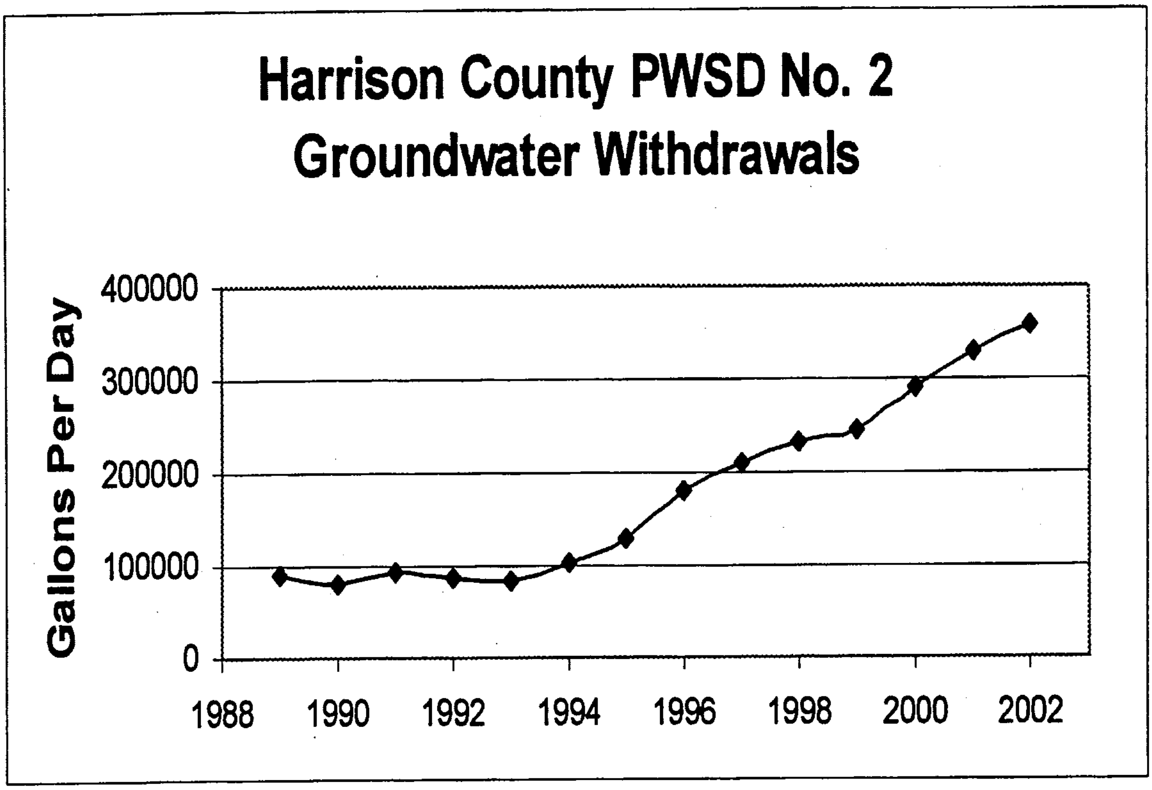


Figure 1.3 Annual Groundwater Withdrawals in Harrison County PWSD No. 2 Wellfield

CHAPTER 2

HYDROGEOLOGIC SETTING AND GROUNDWATER WITHDRAWALS

2.1 GEOGRAPHIC AND GEOLOGIC SETTING

Glacial deposits of Pleistocene age and alluvial deposits of more recent times overlie the Pennsylvanian age bedrock throughout the study area (Table 2.1). The alluvial deposits of sand and gravel, interbedded with silt and clay, are generally found within stream valleys in the area. The glacial strata evolved as ice sheets moved southwards towards the Missouri River, carrying boulder, gravel, sand, silt, and clay. On melting of the ice sheets, the glacial deposits, which locally are up to 300 feet thick, were left behind in the pre-glacial valleys. The glacial deposits have extremely variable lithologies and thicknesses. At some locations, these deposits are largely made up of sand and gravel, while at other locations they are a heterogeneous mix, predominantly of clay with some sand. A general term for all such types of deposits is simply the glacial-drift (Miller and Van Dike, 1997).

Erosion has greatly altered the landscape since the end of the ice age. In some places, the glacial drift has largely eroded, exposing the bedrock surface. The pre-glacial valley however appears to be quite extensive in northwestern Missouri (Figure 2.1). The extent of the surficial deposits, loess, and glacial drift, overlying the bedrock is presented in Figure 2.2. In general, there is no expression of the pre-glacial valleys on the surface, which would indicate its presence in the subsurface (Miller and Van Dyke, 1997). This is depicted in Figure 2.3, which represents a geologic cross section near Gallatin, Missouri. It can be noted from the figure that the present day alluvium valley is distinctly separate from the pre-glacial valley.

The model study area for the present study (Figure 1.1) covers the entire glacial drift and the overlying material within the pre-glacial valley channel in Harrison and Daviess counties. The surface topography has rolling hill characteristics with creeks and streams draining water from elevated regions in the area. The ground surface slopes slightly in the southeast direction, however substantial relief is found within short distances in all directions as is evident from the land surface elevation profile presented in Figure 2.4. The surface elevation map was constructed for this study from the Digital Elevation Model data compiled by United States Geological Survey at an interval of 30 meters.

The surface boundary of the pre-glacial channel was delineated for this study after constructing a thickness map of the drift and surficial deposits overlying the bedrock. This involved subtracting the ground surface elevation from the bedrock surface elevation. The bedrock surface elevation, constructed for this study, from field data collected by the Missouri Geological Survey (Fuller and others; 1956, Fuller and others, 1957), is presented in Figure 2.5. The resulting thickness map is presented in Figure 2.6.

System	Series	Group or Formation	Lithology	Hydrology
Quaternary	Recent	Alluvium	Sand and gravel, with interbedded silt and clay deposited by stream action	Yields 30-500 gpm where sufficient thickness of saturated permeabile sand and gravel is present
	Pleistocene	Glacial Till or Drift	Heterogeneous mixture of clay, silt, sand, gravel, and boulder-size material	3-50 gpm available to well where clean, permeable sand and gravel are present
		Preglacial valley fill	Sand and gravel, silt and clay intermixed. Stream-deposited material	Preglacial alluvium may yield as much as 500 gpm where saturated thickness and permeabilities allow
Pennsylvanian	Virgilian	Wabaunsee Group	Shale, siltstone & sandstone	Not considered to be water bearing. Very small quanities of water (1/2-1 gpm) may be obtained locally from the limestone sequences.
		Shawnee Group	Thick limestone formations with intervening shale beds	
		Douglas Group	Dominantly clastic formations. Shale, sandstone & thin limestone	
	Missourian	Pedee Group	A thick sequence of shale with limestone at the top	Small amounts of water (1-3 gpm) locally from thicker limestone formations
		Lansing Group	Two thick limestone sequences separated by shale & sandstone	
		Kansas City Group	Thick limestone formations with intervening shale, some sandstone beds, black, fissile shale in lower part.	Not generally water bearing
		Pleasanton Group	Thick shale sequence with sandstone in lower part. Few thin limestone beds and silt-stones. Scattered coal beds	
	Desmoinesian	Marmaton Group	Shale, limestone, clay and coal beds	
		Cherokee Group	Sandstone, siltstone and shale	Small yields (1-3 gpm) of potable water at depths less than 100 feet in outcrop area.
Units older than Pennsylvanian typically yield highly mineralized water.				

Table 2.1 Geologic Section in Northwest Missouri

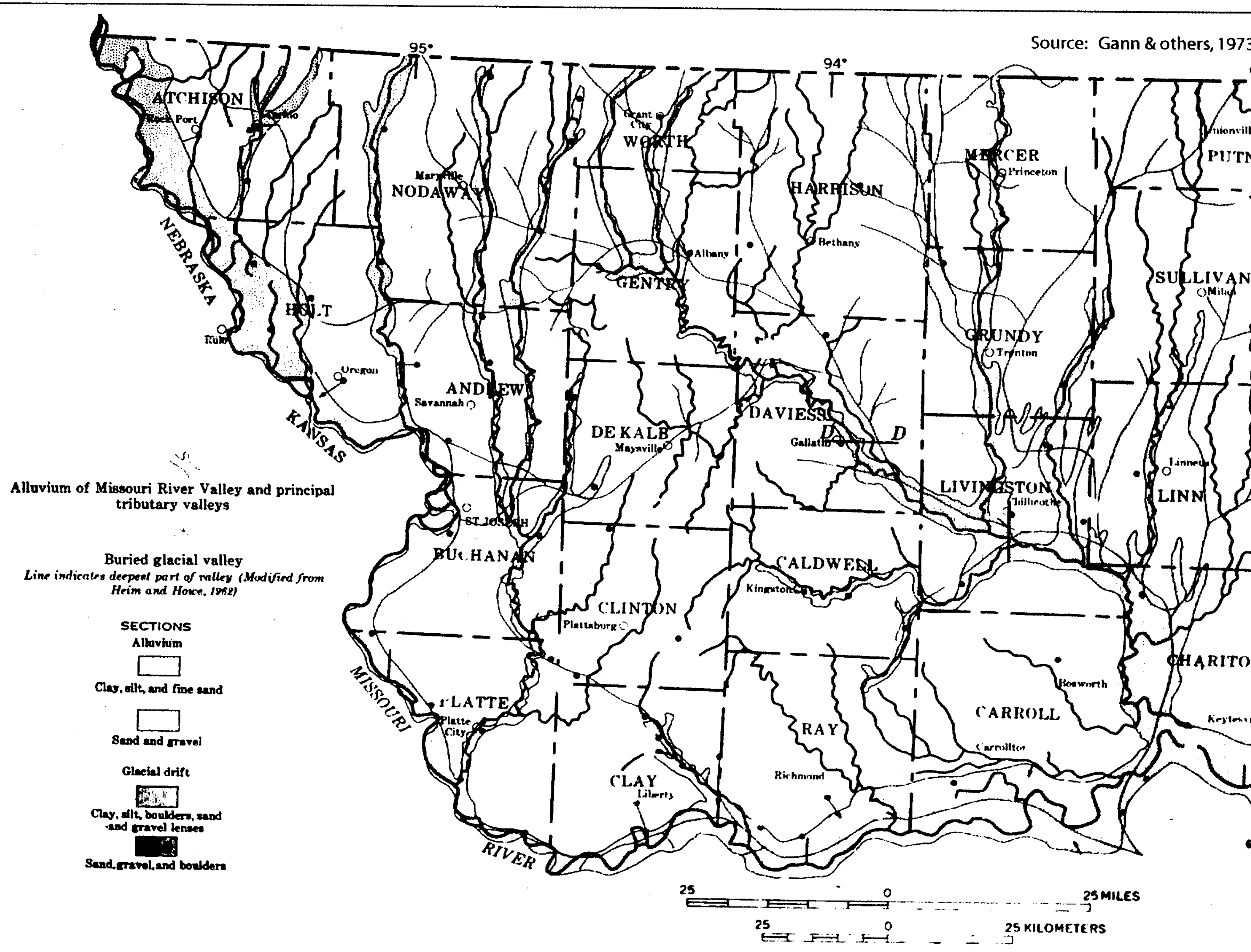


Figure 2.1 Unconsolidated Aquifers in Northwest Missouri

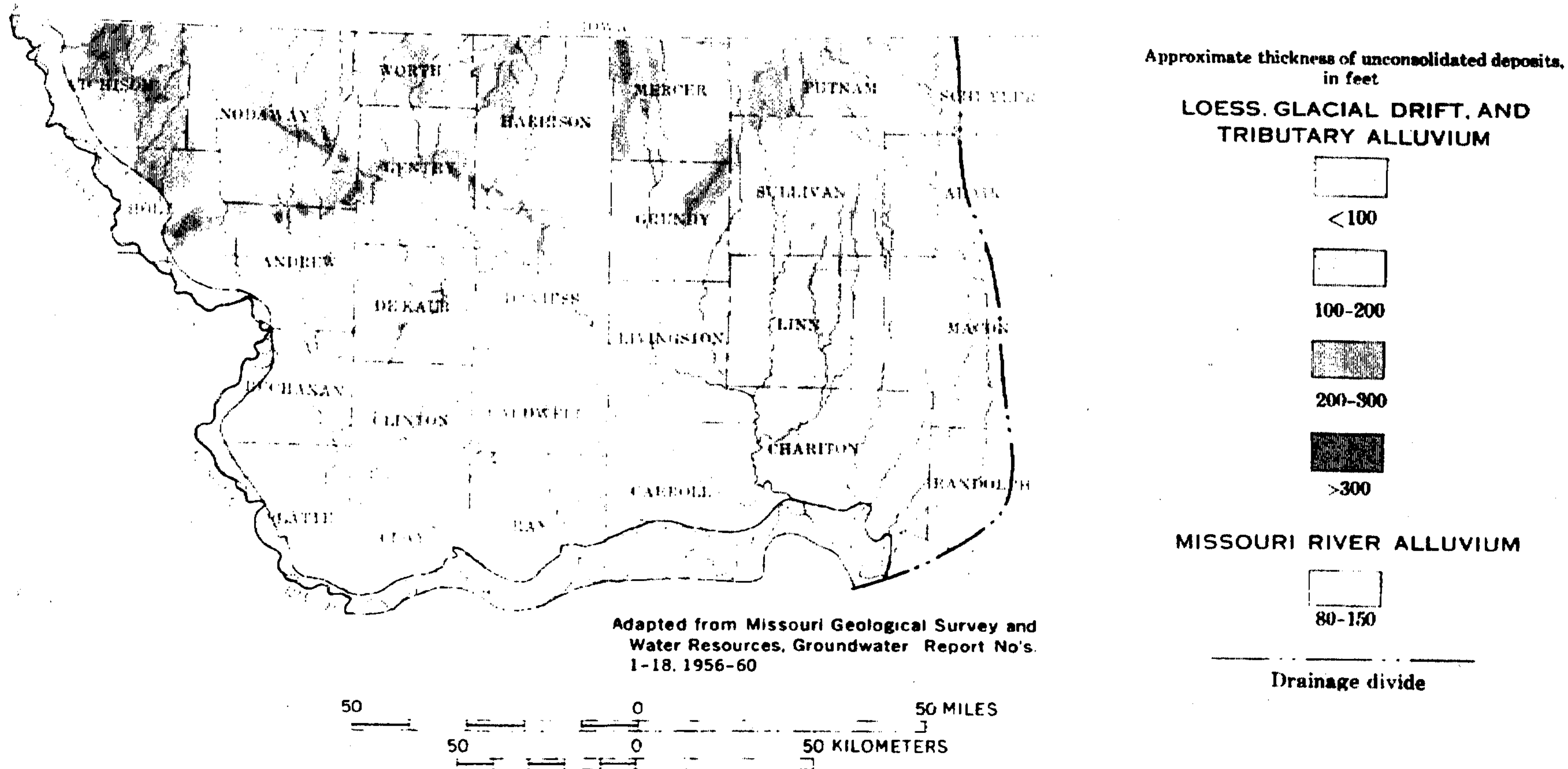
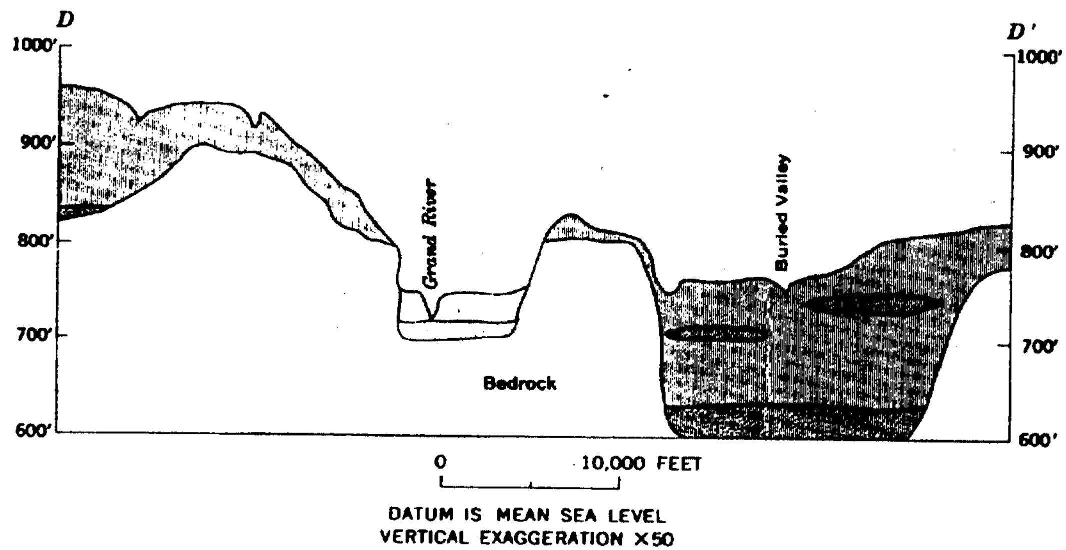


Figure 2.2 Thickness of Loess, Glacial Drift, and Alluvium Deposits



Source: Gann & others, 1973

Figure 2.3 Geologic Cross Section through Gallatin, Missouri (refer to Figure 2.1 for location of cross section)

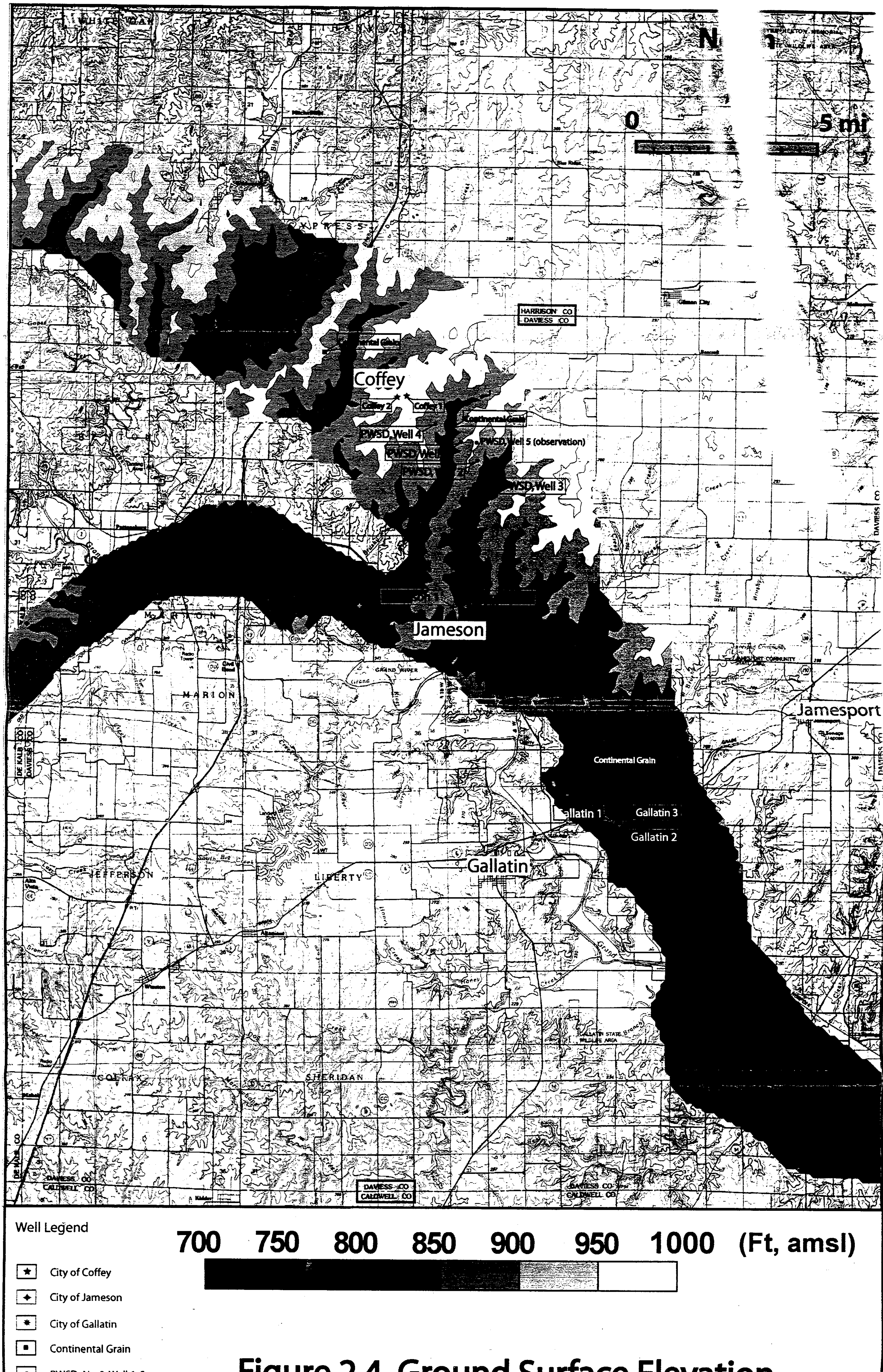


Figure 2.4 Ground Surface Elevation

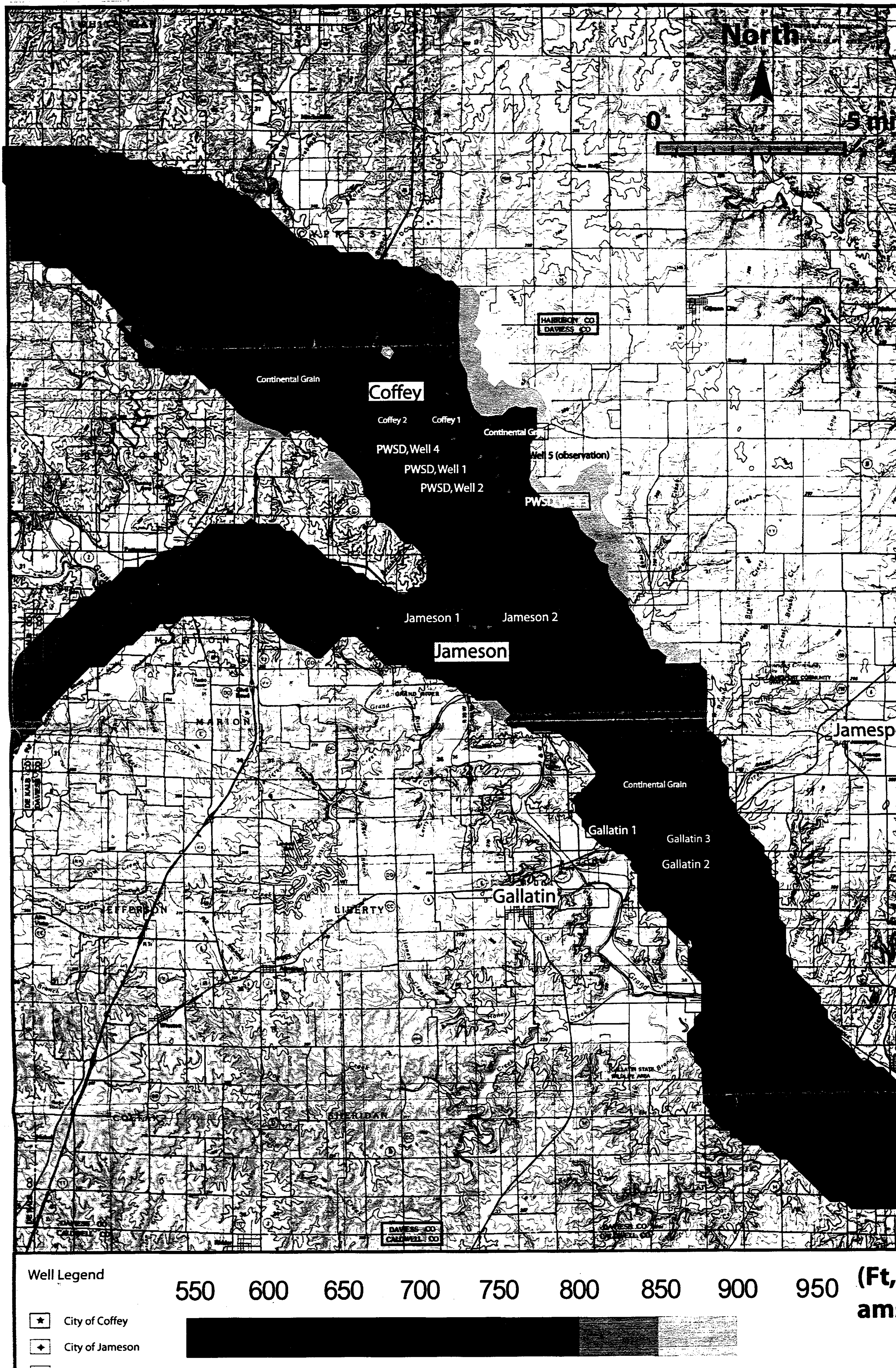


Figure 2.5 Bedrock Surface Elevation

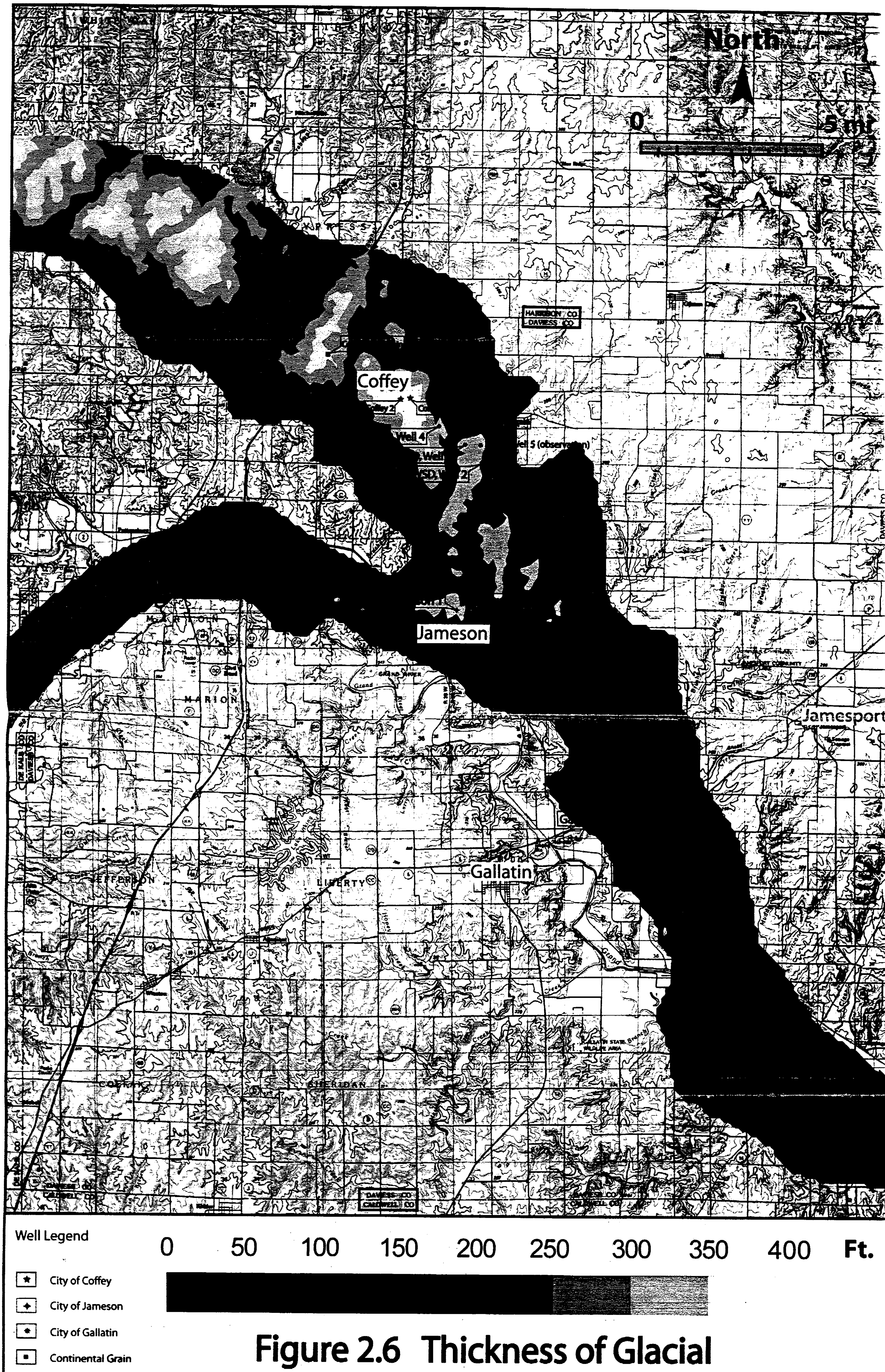


Figure 2.6 Thickness of Glacial and Alluviul Deposits

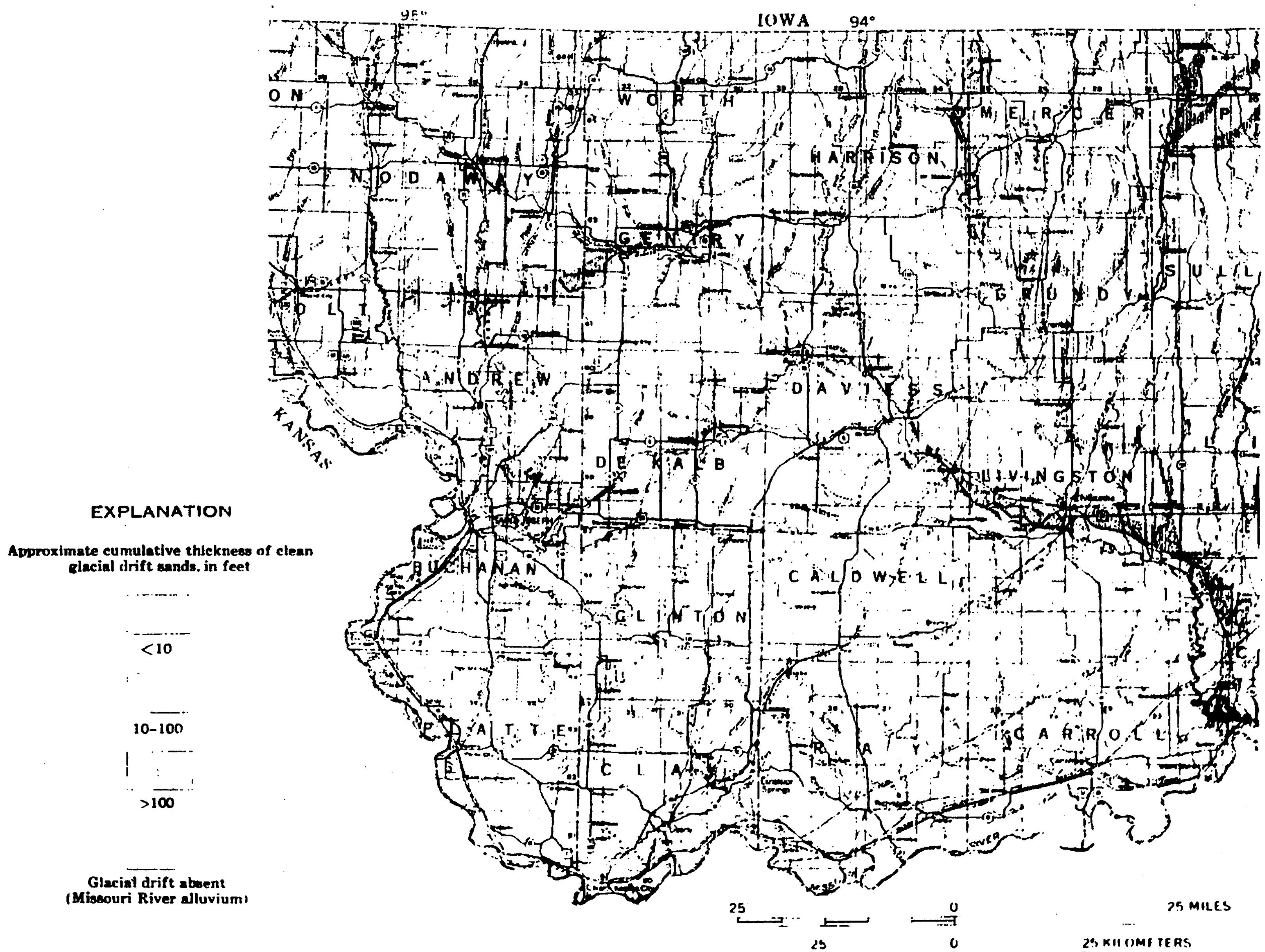
For modeling purposes, the boundary of the pre-glacial drift-filled valley was established along the edges of the valley where the thickness of the drift and overlying material was 10 feet or less. An exception to this is in the northern part of the delineated channel where the thickness along the edge is larger. The valley was not extended northward because previous investigators (Fuller and others, 1956) have not identified that region to contain substantial drift-filled water bearing formation.

2.2 REGIONAL HYDROGEOLOGY

Groundwater resources in northwest Missouri are fairly limited. The bedrock formation is capable of yielding limited quantities of water, but the quality of the (highly mineralized) water is poor. Shallows wells in the surficial deposits yield minor quantities of water, sufficient for domestic and irrigation uses. The alluvium, in general, yields small quantities of water, except within stream valleys, where larger yields are possible. The glacial deposits are capable of yielding reasonable quantities of water, and are viewed as the most promising source of water in the study area. However, "the stratigraphy and geomorphology of this area is so complex and site specific, it is difficult to predict either the lithologic character or the thickness of material likely to be encountered at any drill site... It is often necessary to drill several test holes to locate the most water-productive materials at a particular site. It is not unusual to find pocket or lenses of permeable material that are completely surrounded by nearly impermeable clay or silt. The lenses may contain water, but due to limited recharge through the impermeable material, do not have good sustained-yield characteristics" (Miller and Van Dyke, 1997).

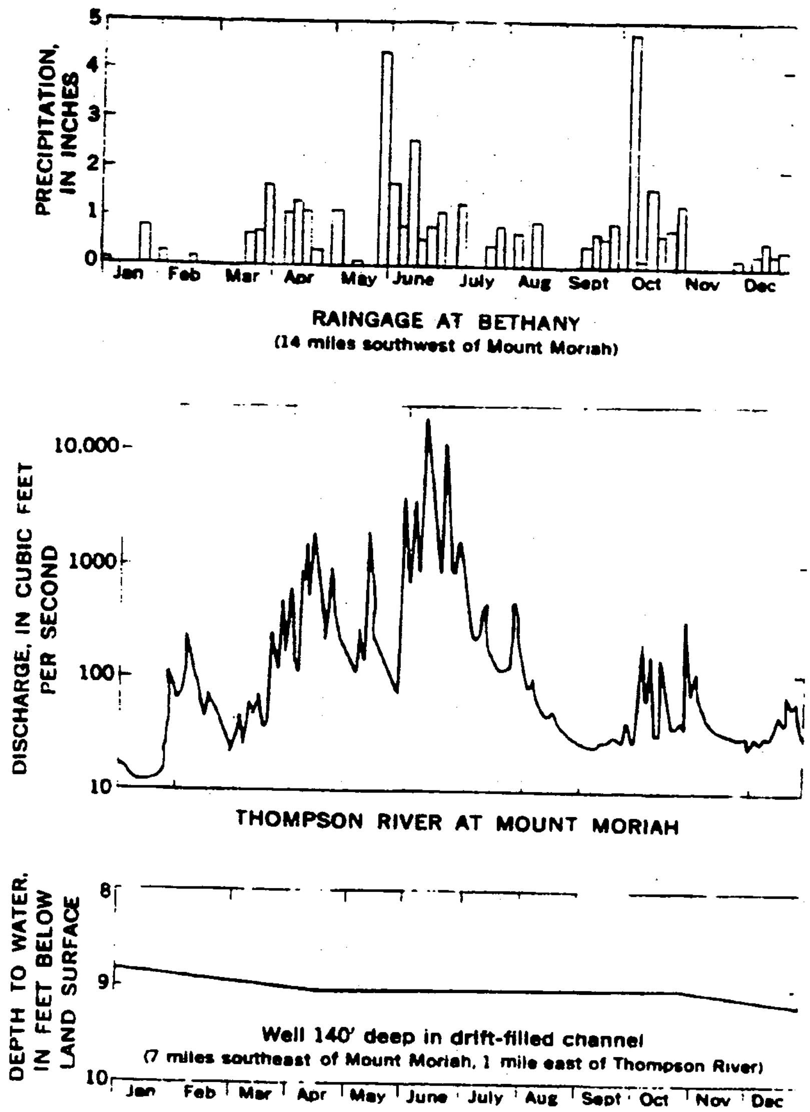
In areas with sufficiently thick sand and gravel layers, yields of up to 500 gpm have been reported from wells constructed in the pre-glacial channel. The thickness of clean sands in the glacial drift is presented in Figure 2.7. A band several miles wide traverses from the southeast to the northwest corner of Daviess County. The thickness of the drift material within the band exceeds 100 feet and is known locally to exceed 300 feet. However the absence of extensive layers of sand may results in low well yield in most portions of the drift-filled channel. The drift material gets progressively less coarse as one moves northward in the pre-glacial channel (James Van Dyke, Missouri Department of Natural Resources, personal communication).

Hydraulic connection between the more recent alluvium and the underlying drift-filled valley is generally very poor due to the presence of a significant thickness of clay and silt material separating the two aquifers. Hence, water levels in the drift material are generally not influenced by climatic variations and hydrologic conditions at the surface. This is depicted in Figure 2.8, in which there appears to be no measurable relationship between water level fluctuations in the drift material and seasonal variations in rainfall and stream stage.



Source: Gann and others, 1973

Figure 2.7 Approximate Thickness of Clean Glacial Drift Sand



Source: Gann and others, 1973

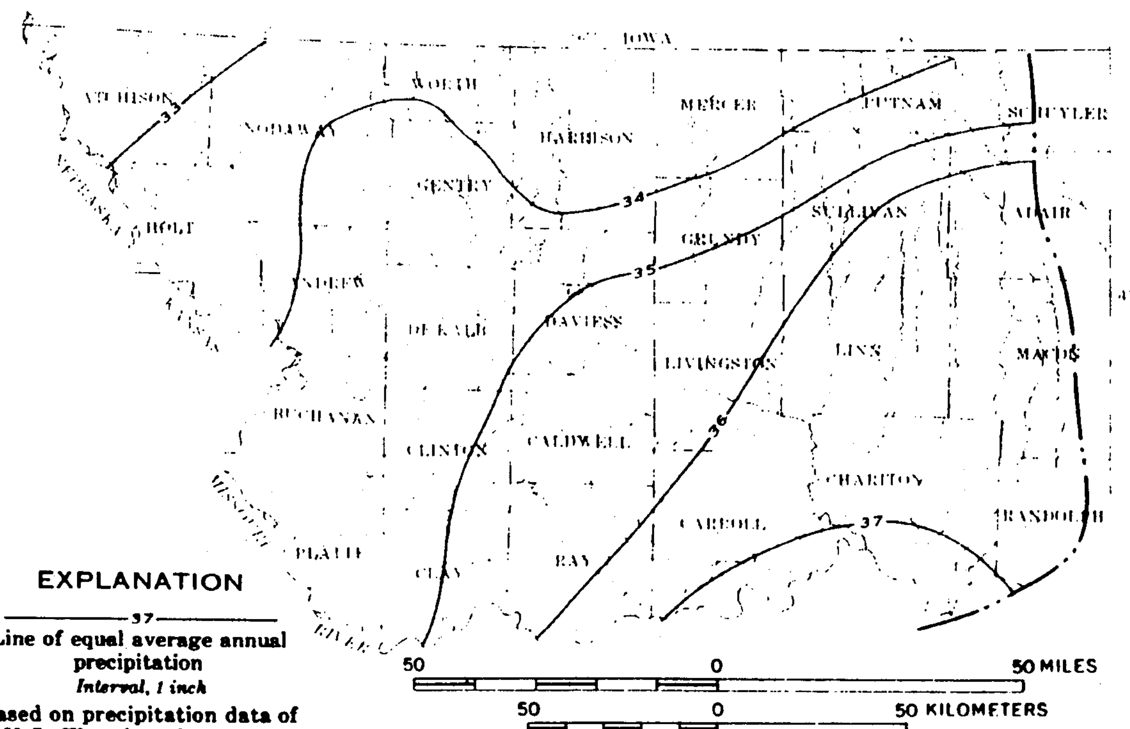
Figure 2.8 Relationship between rainfall, stream stage and water levels in the drift-filled channel

A review of test hole logs (Appendix A) at the District's production well sites indicate the presence of two distinct sand layers of approximately 15-25 feet thickness. The top of the first sand layer is generally present at an elevation of approximately 770 ft amsl, while the second sand and gravel layer is generally present at the bottom of the test holes (above bedrock) at an elevation of approximately 650 ft amsl. At the City of Coffey well sites, only the top sand layer is present. This, and data at other test hole sites suggests that perhaps multiple sand layers of sufficient thickness are present along the edges of the drift-filled valley and not in the center, which may have experienced more consolidation. This can also be inferred from production data at the City of Gallatin wellfield, where two wells along the edges of the valley are more productive than one further within the channel (refer to Figure 1.1 for location of the City of Gallatin wells).

Information on aquifer hydrogeologic properties in the drift-filled valley is essentially non existent in the study area, with the exception of an aquifer pump test conducted in 1984 at the City of Coffey Well No. 2 (Layne-Western, 1984), and a pump test conducted in 1985 at the District's Well No. 1 (Layne-Western, 1985). The pump test in 1985 however was for duration of only 24 hours, and hence is expected to represent hydrogeologic conditions only in the vicinity of the pumped well. Static water level data at the District's well sites, presented and discussed below, indicate that water levels have been declining since inception of the wellfield. Hence, the zone of influence or recharge to a well occurs over several miles. The data therefore obtained during the pump test in 1985 is not expected to yield representative values of aquifer properties on a regional basis and therefore is not of particular benefit for the modeling study. For modeling purposes, aquifer parameters, which represent average values over a larger area, are required. In order to obtain such representative regional values, the pump test should ideally be conducted over a period of several weeks in order for a representative cone of depression to evolve.

The 1984 pump test at the City of Coffey Well No. 2 was for a longer duration of 10,000 minutes (approximately 7 days) and hence is more useful for estimating aquifer hydrologic properties. Well No. 2 was pumped at a rate of 194 gallons per minute (GPM) from March 22 to March 29, after which it was shut off for a period of nearly 9,000 minutes during which recovery was recorded. Unfortunately though, the City of Coffey Well No. 1 was activated during the pump test to meet municipal water demand, which impacted drawdown in the observation well network (Layne-Western, 1984). The amount of pumpage in Well No. 1 was not recorded during the pump test. The consequence of the unintended pumpage during the pump test, was a wide range in the estimated aquifer parameter values. The estimated saturated hydraulic conductivity ranges from 27 ft/d to 589 ft/d. The estimated storativity at a piezometer (PZ# 3-83), which appeared to be least influenced by pumpage, ranged from 0.0000470 to 0.000429.

In addition to lack of information on aquifer hydraulic properties, there are no estimates of effective recharge to the drift material in the pre-glacial channel either. The average precipitation in the study area is approximately 35 inches per year (Figure 2.9). Due to the presence of the clay material overlying the sand lenses, the effective recharge to the drift-filled aquifer is expected to be a small fraction of the total precipitation.



EXPLANATION

37 — Line of equal average annual precipitation
Interval, 1 inch

Based on precipitation data of U.S. Weather Bureau for period 1931-60.

— · · — Drainage divide

PRECIPITATION
P avg. = 33.7 inches
(35.0 inches for northwestern Missouri only)

Source: Gann and others, 1973

Figure 2.9 Average Anual Precipitation in Northwest Missouri

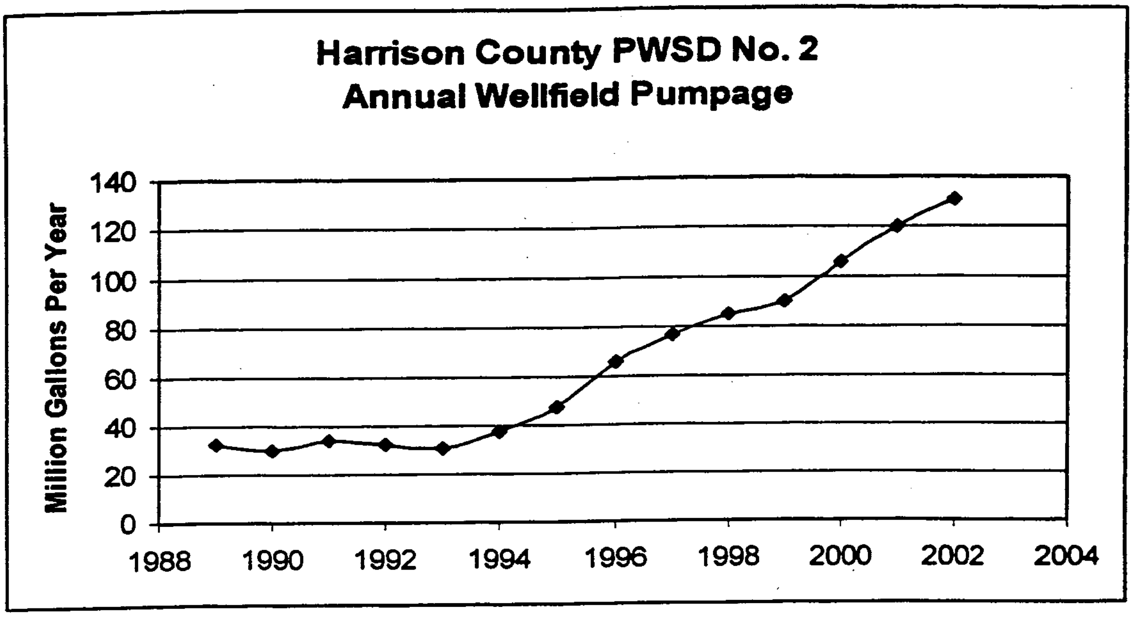
2.3 GROUNDWATER WITHDRAWALS

The District withdraws groundwater from the drift-filled valley from four production wells shown in Figures 1.1 and 1.2. Well No. 1 was constructed in 1985, Wells 2 and 3 in 1988, and Well No. 4 constructed in 1997. A fifth well (Well No. 5) was constructed in 1997, but due to low well yield, is now used as an observation well, in which water levels are recorded continuously. Well construction details and test hole logs at the well sites are provided in Appendix A.

Well No. 1 is screened in the upper sand layer between elevations of 749-769 ft amsl, Well No. 2 between 617-637 ft amsl, and Well No. 3 is screened between 604-624 ft amsl. Well No. 3 was originally screened in the upper sand layer as well, but due to poor quality water emanating from that zone, the upper screen was packered off. Well No. 4 has three screened zones within the intervals 625-634, 638-662, and 704-730 ft amsl. The screen interval for observation Well No. 5 is between 744-760 ft amsl.

Partial production in the District wellfield commenced in fall 1988. Total annual withdrawals since inception of the wellfield is presented in Figure 2.10, which shows a steady increase from approximately 39 million gallons per year (MGY) in 1989 to 130 MGY by the year 2002. The corresponding monthly withdrawal is also presented in Figure 2.10. The average daily production since inception is presented in Figure 1.3, which also highlights the significant increase in demand from 100,000 GPD in 1989 to 350,000 GPD in 2002. Total daily wellfield production is only recorded at the water treatment plant. Pumpage in individual wells are not recorded, since flow meters at the wellhead are not considered to be well calibrated. Hence, reliable estimates of production in individual District wells are not available. Pumpage in the individual wells vary from 80-150 GPM.

The City of Coffey, until recently, withdrew groundwater from the two production wells shown in Figures 1.1 and 1.2. Well No. 1 was constructed in 1965, and Well No. 2 was constructed in 1981. Both wells are screened in the upper sand layer only, since the lower sand layer is absent at these locations. Well No. 1 has a 10 feet screen in the interval 765-775 ft amsl. Well No. 2 is screened in the interval 770-780 ft amsl. Details of well construction and test logs at the well sites are presented in Appendix A. The City has maintained production records since 1987, which indicate a total average daily withdrawal in recent years of approximately 60,000 GPD (Figures 2.11). It is estimated that in years prior to 1987, total withdrawals were approximately the same as in recent years, since the number of customers served by the city has remained approximately the same since the inception of the wellfield (Joe Salmon, City of Coffey, personal communication). Water levels in the Coffey wells have steadily declined since construction of the wells, and by the year 2000, static water levels had declined by over 35 feet from predevelopment levels. The decline has caused the pumped water levels to drop below the top of the screen, due to which the City has ceased operations in the wellfield since 2000.



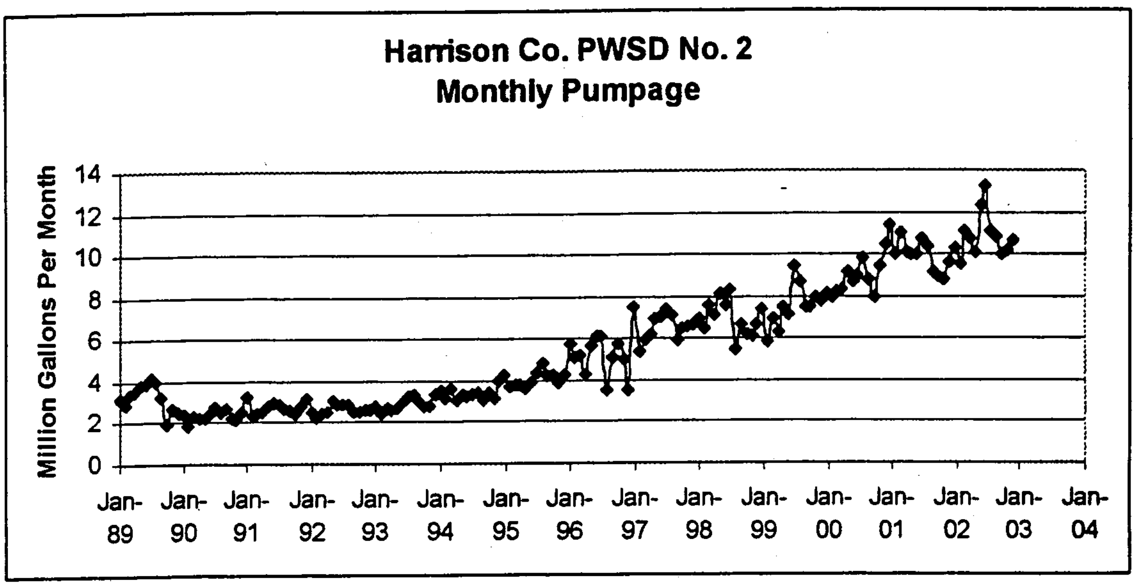
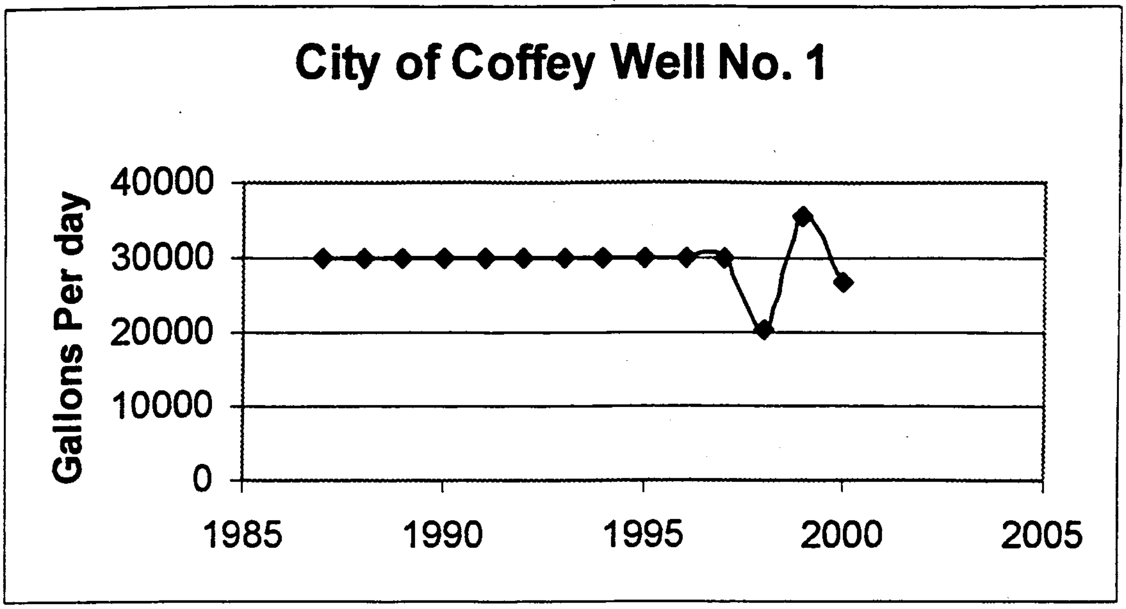


Figure 2.10 Annual and Monthly Pumpage in Harrison County PWSD No. 2 Wellfield



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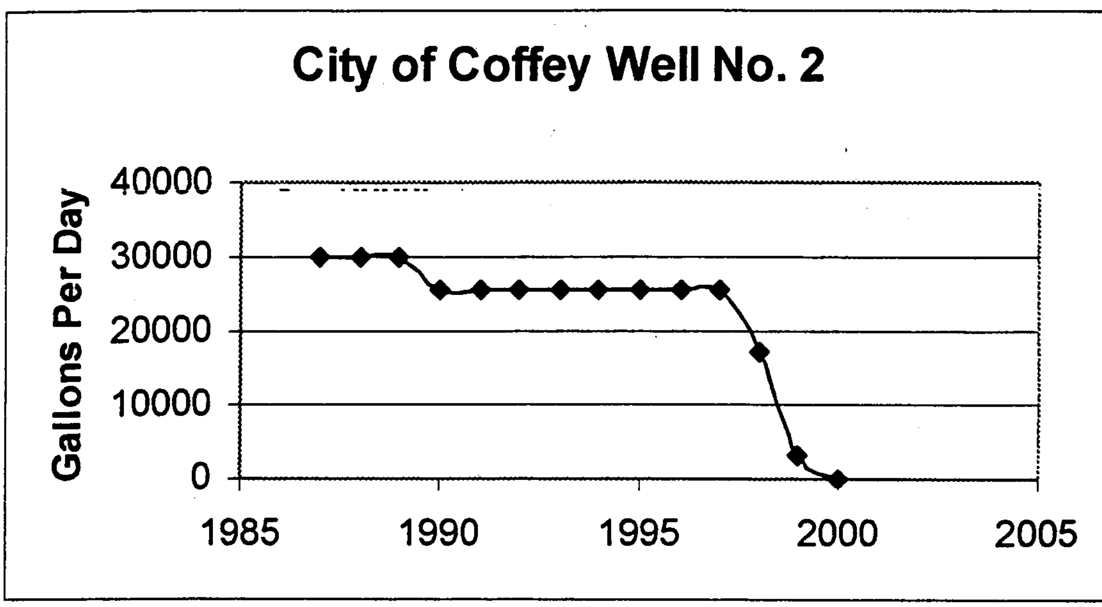


Figure 2.11 Average Daily Pumpage in City of Coffey Wellfield

In addition to the District and the City of Coffey, groundwater is also withdrawn from the glacial drift by the towns of Jameson and Gallatin (Figure 1.1). The City of Gallatin has three wells in the glacial drift at depth of approximately 135 feet. Wells 1 and 2 are the active producer, while Well No. 3 is essentially dormant due to low yield in that well. The average daily production in the wellfield is presented in Figure 2.12. In recent years, approximately 60 MGY is withdrawn from the wellfield. The City estimates average annual production prior to 1995 to be in the 45-48 MGY range (Roger Laxterman, City of Gallatin, personal communication). The City of Jameson has two dormant wells at depths of approximately 90-95 feet depth. Both wells ceased production approximately 8 years ago due to water levels falling below the top of the well screen. Prior to that period, it is estimated that the City of Jameson withdrew approximately 10,000-12,000 GPD on an average basis.

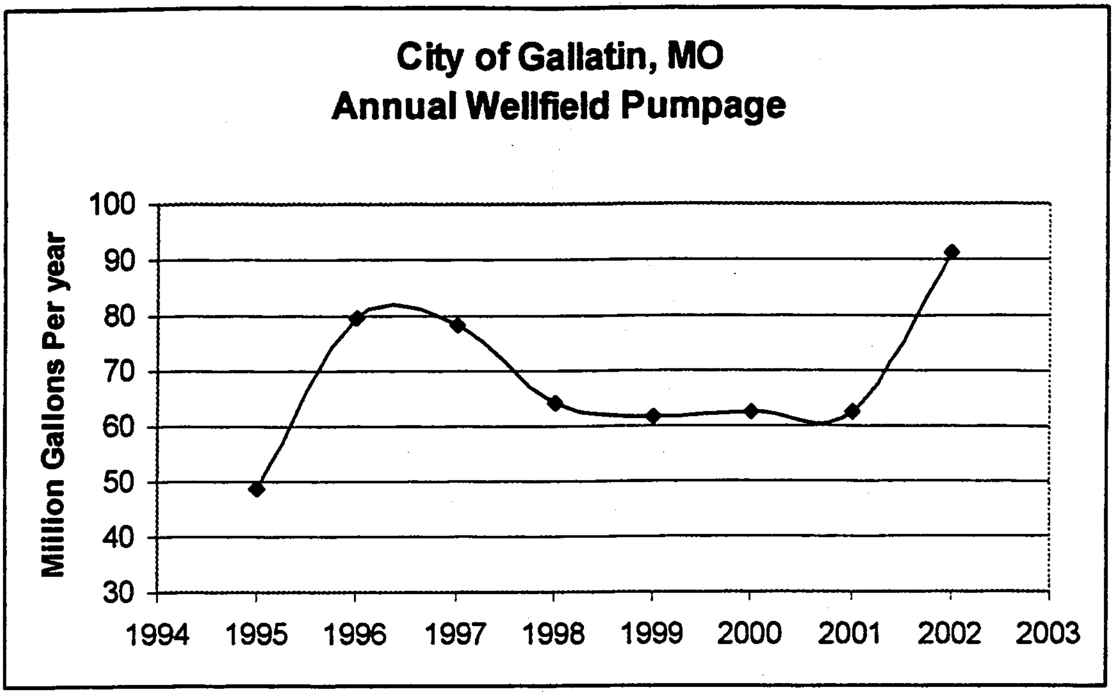
Continental Grain Corporation of Princeton, Missouri also draws groundwater from three wells in drift-filled valley (Figure 1.1). The well operated at the Hickory Creek Farm east of the District's Well No. 4 and north of the District's Well No. 1, is the primary producer of the corporation. Current production in the well, which was constructed in 1994, fluctuates between 30,000-60,000 GPD (Figure 2.12). Minor quantities are withdrawn since 1999 from the other two wells located in Gallatin, and west of Coffey, Missouri.

2.4 GROUNDWATER LEVELS

Information on water level trends in the drift-filled valley is almost non-existent except for data collected in the District's production wells. There has not been any attempt in the past to construct a potentiometric (water level) surface, which would depict the general flow pattern in the area. However, since the land and bedrock surfaces slope southeastward, the general groundwater flow direction is also expected to replicate this profile. This is confirmed by the model results discussed in Chapter 3.

Water levels in the District's production wells have been in a state of decline since commencement of production from the wellfield in late 1988/early 1989. Static water levels in Wells 1-5 are presented in Figure 2.13a-e. Well No. 1 is screened only in the top sand layer within the interval 749-769 ft amsl. It has experienced a decline of approximately 30 feet since 1989. Static water level in the well is currently at an elevation of approximately 770 ft amsl. The pumped water level therefore occasionally drops below the top of screen, reducing well yield. It should be noted that the apparent recovery in 1998 for this well is a result of faulty instrumentation in the well during this period and is not a reflection of actual conditions in this well (source: Randy Garrett, Harrison County Public Water Supply District No. 2).

The District's Well No. 2 and 3 are both screened in the bottom sand layer and have experienced a decline of approximately 80 feet since commencement of production in



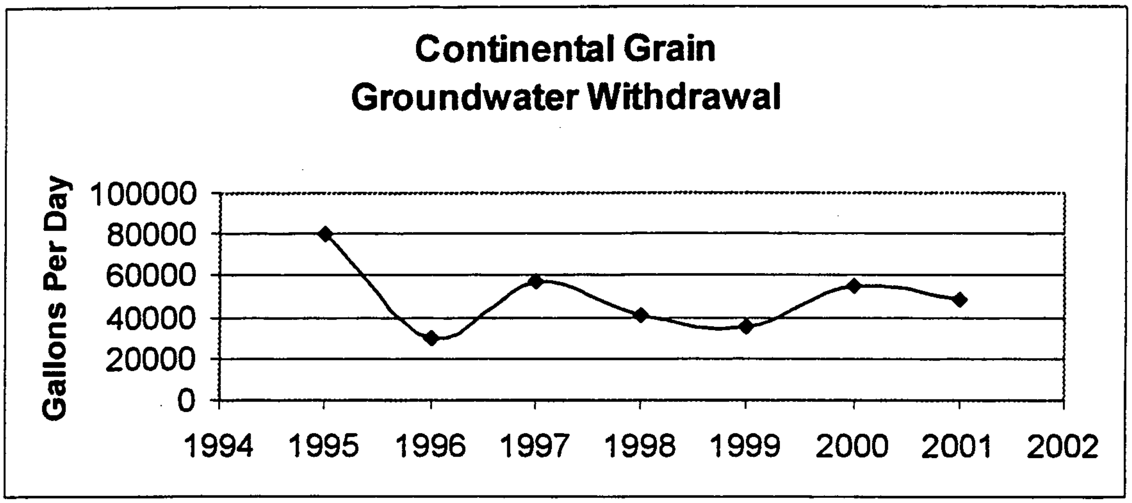


Figure 2.12 Pumpage in a) City of Gallatin and b) Continental Grain Well No. 1

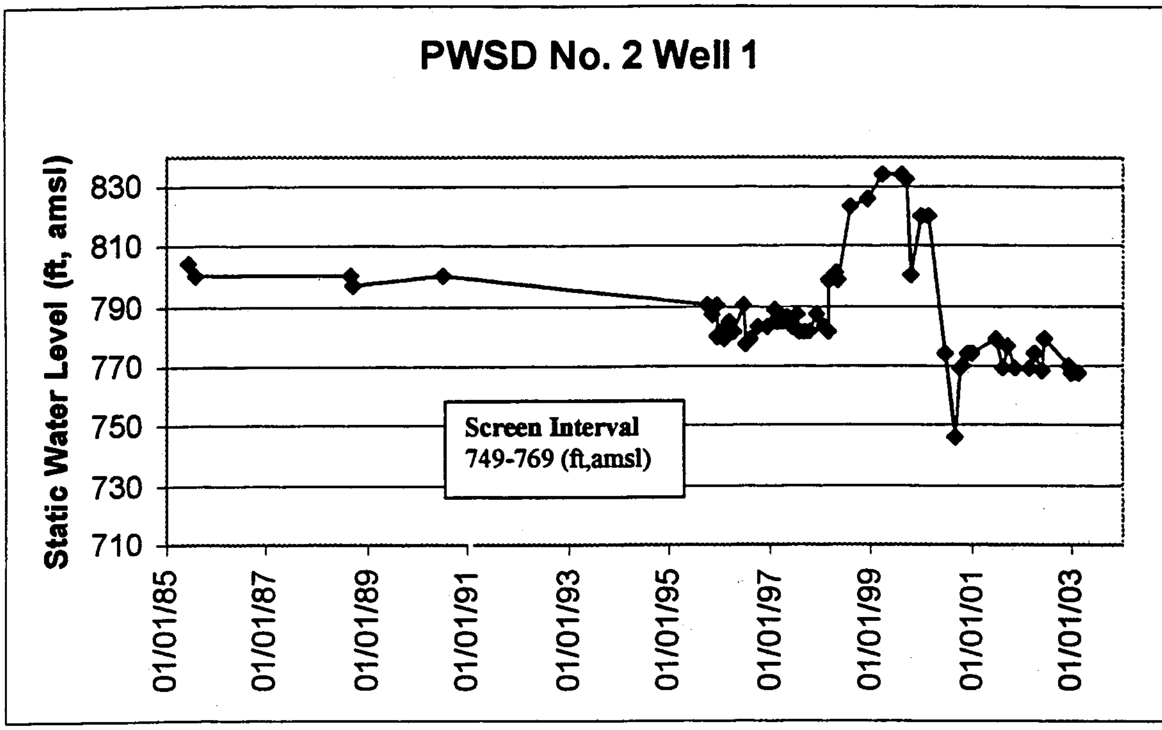


Figure 2.13a Static Water Level in Well No. 1, Harrison County PWSD No. 2

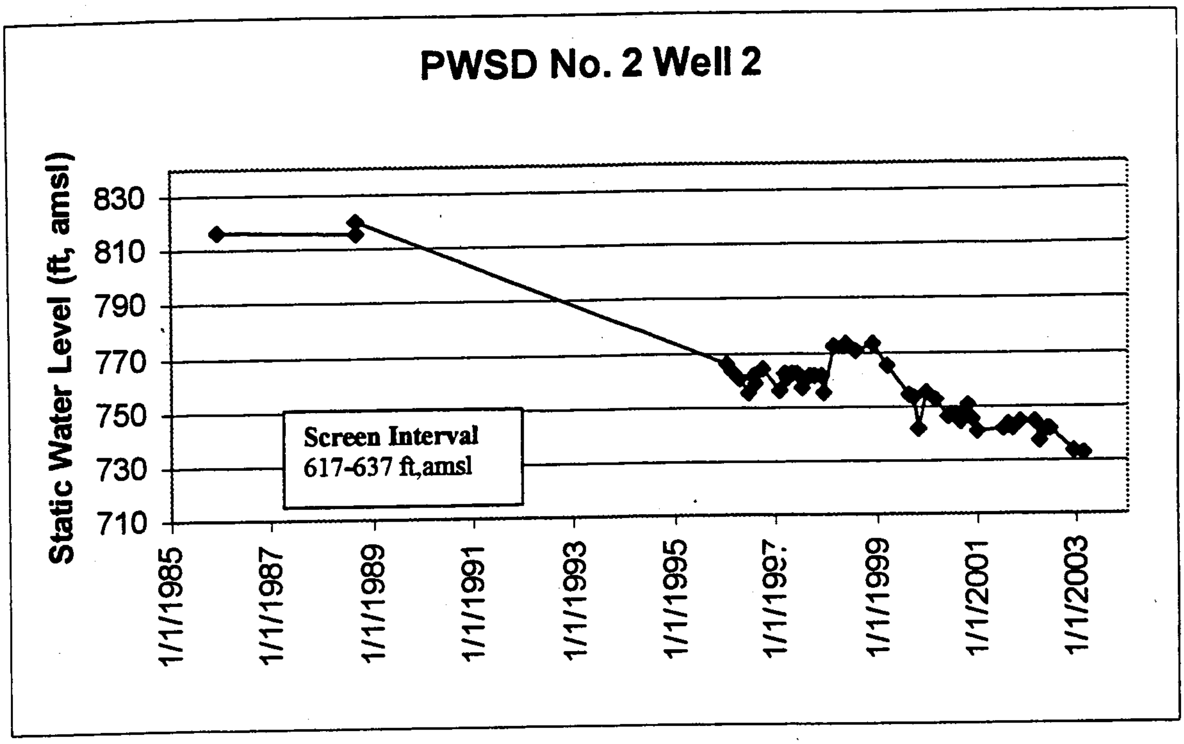


Figure 2.13b Static Water Level in Well No. 2, Harrison County PWSD No. 2

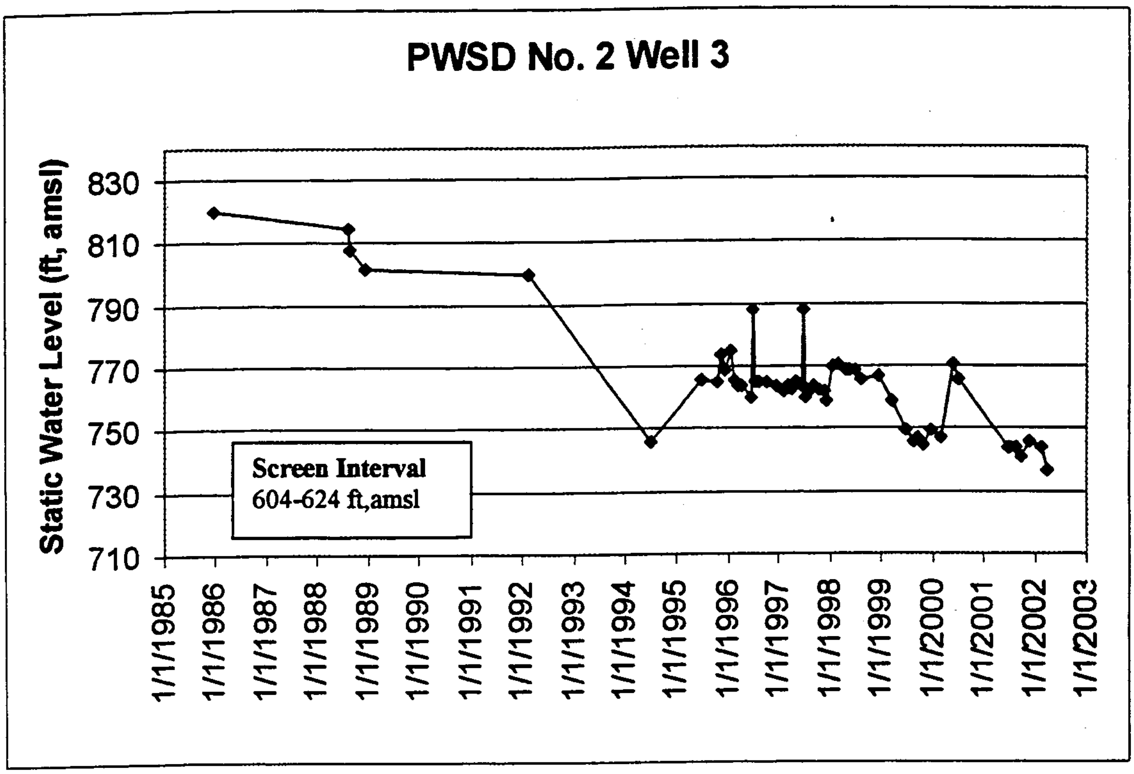


Figure 2.13c Static Water Level in Well No. 3, Harrison County PWSD No. 2

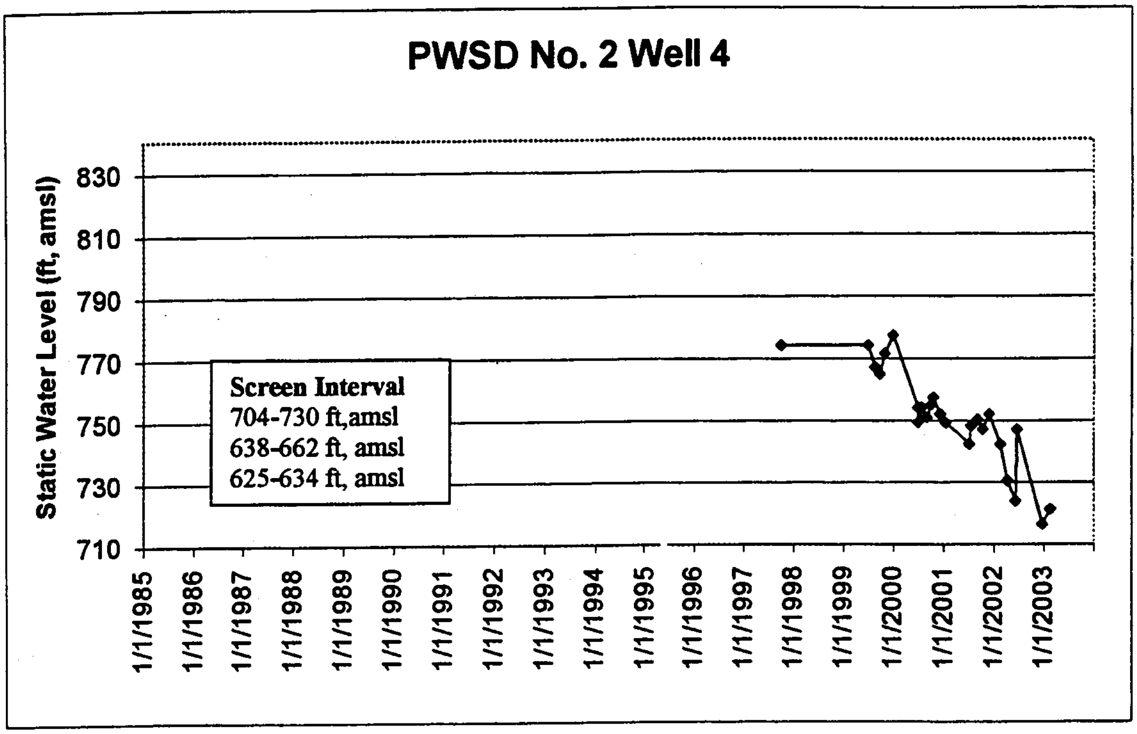


Figure 2.13d Static Water Level in Well No. 4, Harrison County PWSD No. 2

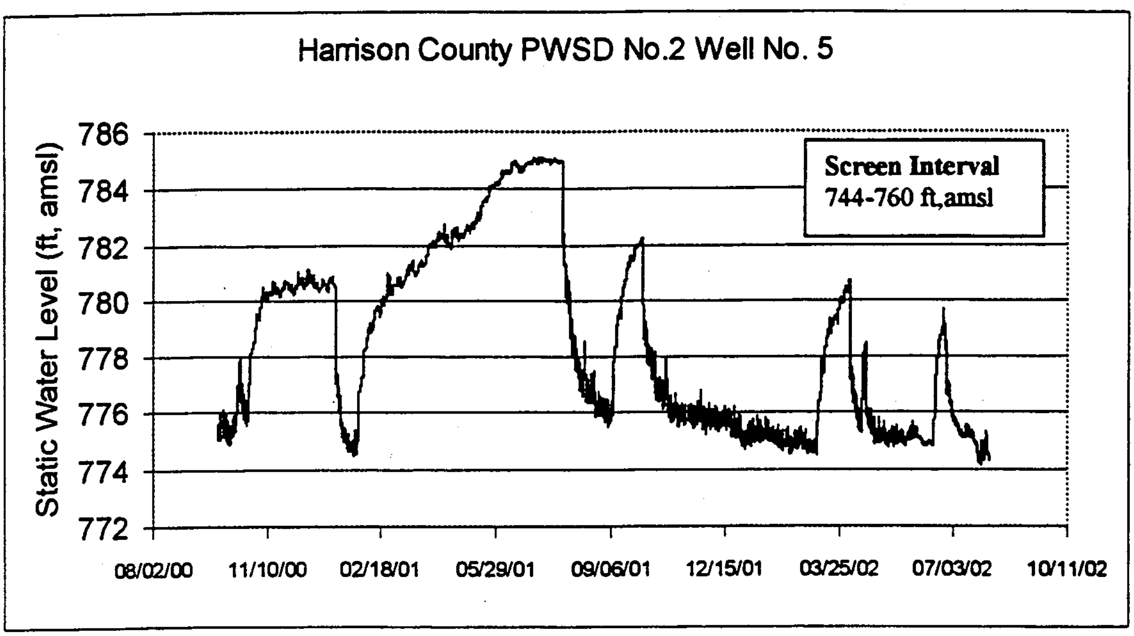


Figure 2.13e Static Water Level in Observation Well No. 5, Harrison County PWSD No. 2

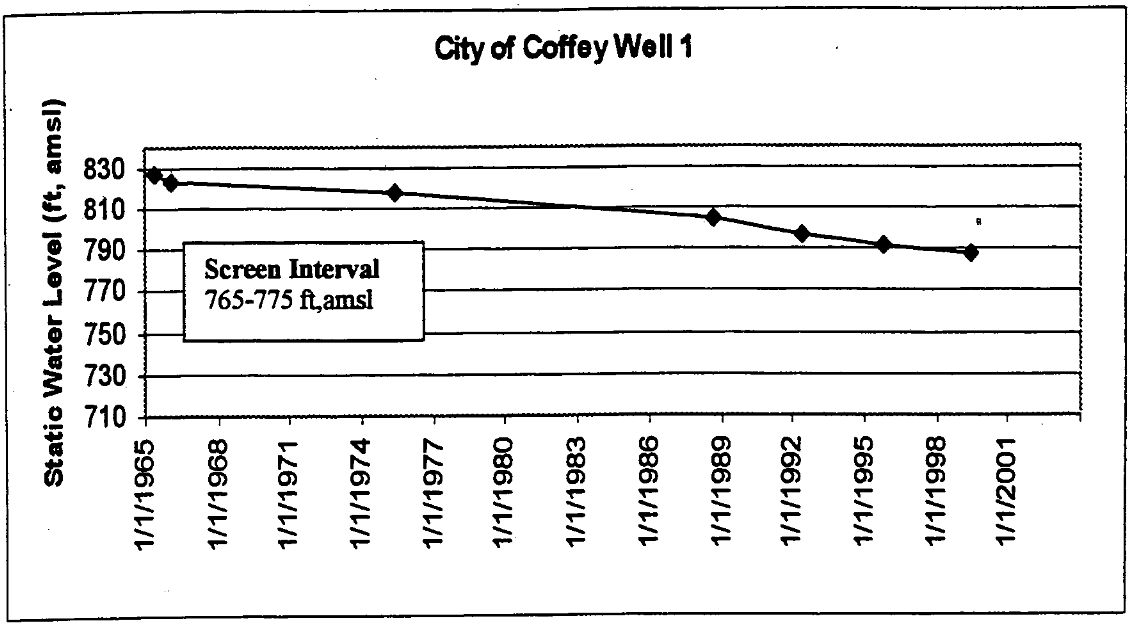
1989. The static water level in both wells is currently at an elevation of approximately 730 ft amsl. Well No. 2 is screened within the interval 617-637 ft amsl. Well No. 3 is screened within the interval 604-624 ft amsl. Well No. 3 was initially also screened in the upper sand layer, but in 1992 the upper screen was isolated with a packer on account of poor quality water emanating from the upper sand layer. Pumpage in Well No. 2 varies from 80-140 GPM, and it experiences a drawdown of approximately 20 ft. Well No. 3 has a higher specific capacity and therefore experiences a much smaller drawdown (less than 10 ft). Both wells therefore have adequate water cover above the top of the screen.

District's Well No. 4 has already experienced a drop in static water level of 60 ft since commencement of pumpage in 1999. The static water level in the well is currently at approximately 720 ft amsl, and is exhibiting a declining trend. This well is screened in the intervals 625-634, 638-662, 704-730 ft amsl. Pumpage from Well No. 4 is generally in the 120-150 GPM range, and drawdown varies from 5-10 ft.

Well No. 5 was initially constructed as a production well in 1999, but due to low yield it was converted to an observation well. It is screened in the upper sand layer only. Since 2000, water levels in this well have been recorded continuously by the Missouri Department of Natural Resources and are presented in Figure 2.13e. Water levels fluctuate within a range of 10 feet between elevations of 774-784 ft amsl. This fluctuation is likely a consequence of pumpage from well No. 1 in the upper sand layer. There appears to be a slight declining trend.

Water levels in the two City of Coffey wells, which are measured occasionally, are presented in Figures 2.14. Both wells are screened in the upper sand layer in the drift-filled valley. Well No.1 is screened within the interval 765-775 ft amsl, while Well No. 2 is screened in the interval 770-780 ft amsl. Well No.1 was constructed in 1965, while Well No. 2 was constructed in 1981. Similar to the trends observed in the PWSD wells, the Coffey wells have also experienced declining water levels. By 1999, water level in Coffey Well No. 1 had declined by approximately 40 feet to an elevation of 785 ft amsl. The water level in Well No. 2 had declined to approximately 780 ft amsl. Since 2000, the Coffey wells are no longer active, since water levels have dropped below the screen intervals.

It is interesting to note that the District Wells 2, 3, and 4, which are screened in the lower sand layer have similar static water levels in the 720-730 (ft, amsl) range. District Wells 1 and 5, and the two City of Coffey wells, all of which are screened in the upper sand layer, have static water levels approximately 50 feet higher in the 770-785 ft amsl range.



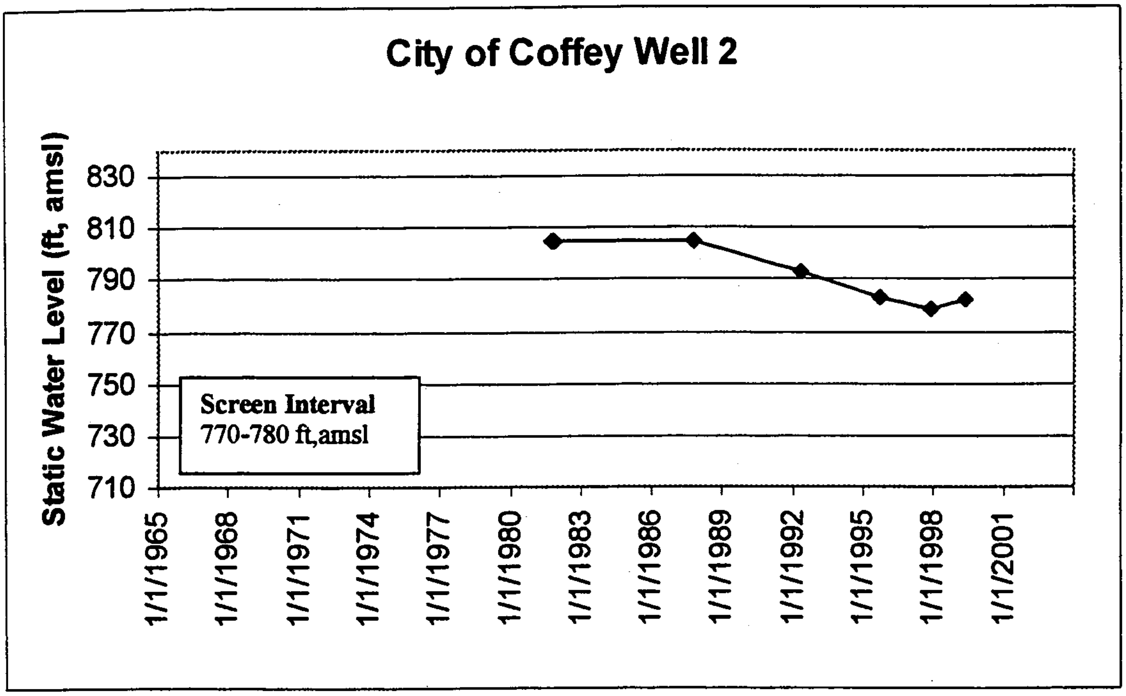


Figure 2.14 Static Water Level in City of Coffey, Mo, Wellfield

Chapter 3

GROUNDWATER MODELING

3.1 INTRODUCTION

The overall modeling approach for the present study involved the development of a regional groundwater model, with emphasis on flow within the glacial aquifer in the vicinity of the District's wellfield near Coffey, Missouri. The objective of the modeling exercise was to assess the state of the glacial aquifer, estimate long term drawdown impacts due to pumpage at existing production rates, and to determine the potential of the glacial drift aquifer to support additional withdrawals of approximately 360,000 GPD in the future.

The model was constructed using the USGS three-dimensional modeling code MODFLOW (McDonald and Harbaugh, 1988). MODFLOW is designed to simulate steady state or transient groundwater flow through heterogeneous, anisotropic porous media in three dimensions. It uses a modular method of data entry to simulate various aspects of the flow system, such as: pumping wells, rivers, recharge, evapotranspiration, aquifer characteristics, and boundary conditions. The aquifer is represented in the model by a series of grid cells. Information about the aquifer characteristics such as aquifer thickness, hydraulic conductivity, storativity, recharge, etc. are input to each model cell. This enables specifying heterogeneous conditions to the model by varying the value of a particular parameter from cell to cell.

3.2 REGIONAL MODEL

The model study area (Figure 1.1) covers the entire glacial drift valley in Harrison and Daviess counties, Missouri. The large areal extent of the model was required to ensure that uncertainties at the model boundaries do not impact results in the primary area of interest, i.e. the District wellfield. The study area was discretized by 159 rows and 138 columns (Figure 3.1). Grid spacing varies from 35 feet to 2700 feet. The three-dimensional groundwater flow model was discretized by seven vertical layers in order to ensure numerical stability for the computationally challenging variably saturated hydrogelogic conditions in the glacial aquifer. The bedrock surface formed the base of the model. The bedrock surface elevation (Figure 2.5) was utilized to specify the bottom elevation at each grid cell. Similarly, the land surface elevation (Figure 2.4) was utilized to specify the elevation along the top of the model. Every layer of the model was specified as a variably saturated hydrogeologic unit. If the water levels dropped below the top of the cell, the model treated the corresponding cells as unconfined, otherwise it was treated as a confined unit.

No flow boundary conditions were prescribed along the edges of the drift channel. In reality, there may be minor quantities of watering flowing across the model boundary through the (subcropping) bedrock. However, the rates are negligible compared to lateral

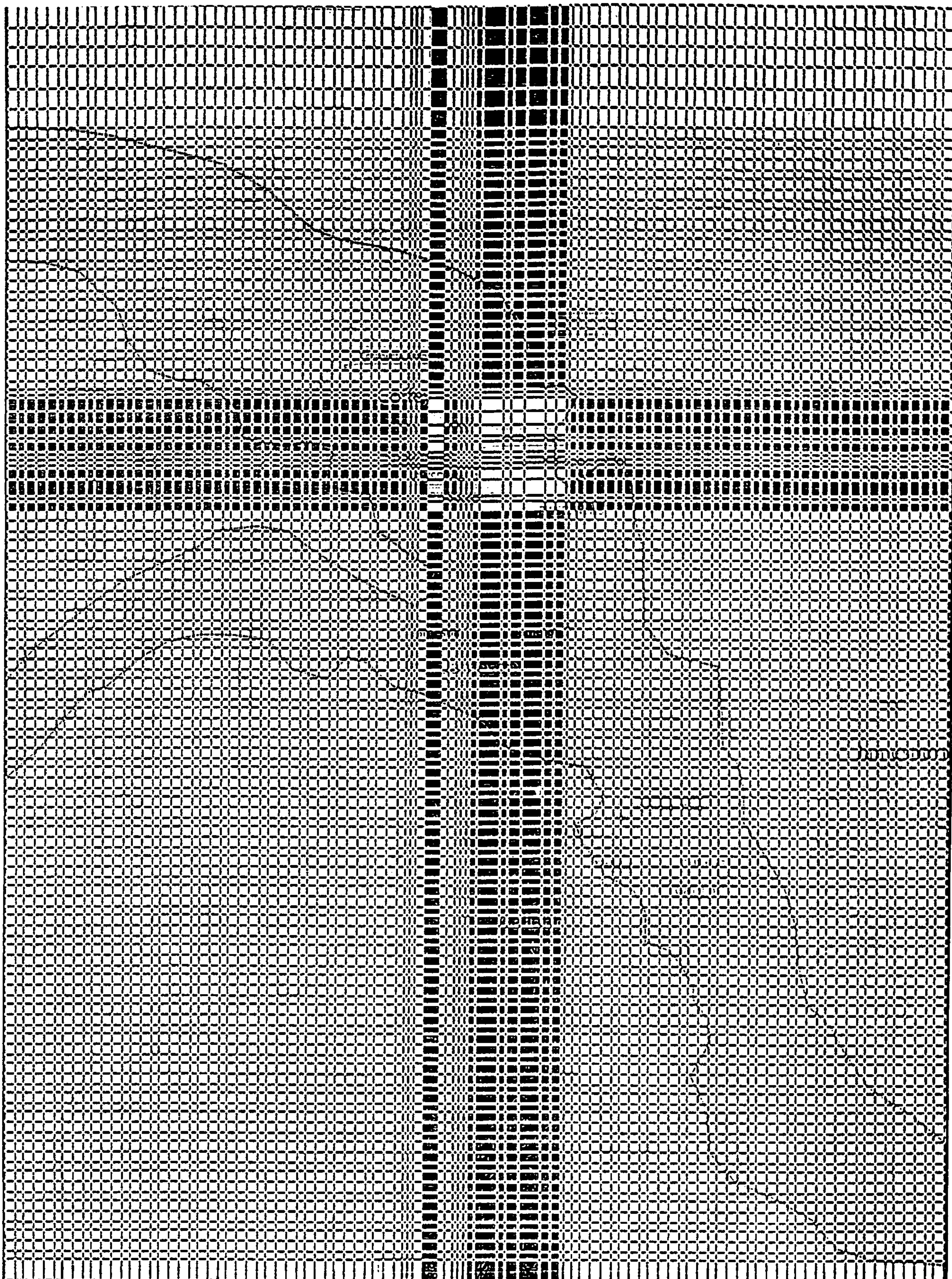


Figure 3.1 Model Grid

flow within the drift-filled channel. No flow boundary conditions were also prescribed along the base of the drift channel since negligible exchange of water is expected to occur between the drift filled aquifer and the underlying bedrock unit.

A seepage-face recharge boundary condition was specified along the top of the model. Hence, recharge was only induced, if the water level in the topmost model layer dropped below land surface. Constant head boundary conditions were specified along the western edges of the drift-filled channel in both the northern and southern forks of the channel. Constant head boundary conditions were also specified along the southern boundary of the channel. A constant head of 840 ft amsl was specified along the western boundary in the north fork, while 830 ft amsl was specified in the southern fork. Along the eastern model boundary in the south, a constant head of 690 ft amsl was specified. The constant head values are close to the land surface elevations in their respective areas. Given the fact that most wells flowed under predevelopment conditions, and that the model boundaries are located in areas where there is relatively minor groundwater development, the specified values of heads are reasonable. Sensitivity analysis on the model indicated that the simulation results in the primary area of interest, i.e. the District wellfield, are not sensitive to variations in the specified magnitude of water levels along the boundaries. This is not surprising since there is a 150 feet drop in water levels from the northern to the southern end of the model.

The process of model calibration involves adjusting model input parameters within reasonable ranges until the model output (water levels) replicate observed field conditions. The aquifer hydraulic conductivity, storativity, leakance, and recharge to the drift-filled valley were the primary model calibration parameters. The model was primarily calibrated to water levels observed in the District wellfield, and to a lesser extent, water levels in the City of Coffey wells. The process of calibration involved conducting numerous simulations during which the aquifer hydrogeologic properties, along with the effective recharge to the aquifer, were adjusted until a reasonable match between the observed and simulated water levels were obtained. The City of Coffey commenced pumpage in 1965, and therefore the calibration period spanned from 1965-2002. Withdrawals from the District wellfield commenced in fall 1988.

Since pumpage in individual District wells is not recorded, for modeling purposes, the total annual pumpage in the wellfield was distributed equally in each of the District's active production well for a calendar year. This was deemed adequate, as can be observed from Figure 1.3 and Figure 2.10, which shows a similar trend for average daily, monthly, and annual withdrawal rates. Municipal and industrial pumpage specified to the drift-filled aquifer, is presented and discussed in Section 2.3.

For each calibration run, a steady state simulation without pumpage was first conducted in order to obtain initial conditions for the transient simulations. The steady state simulation results represent "predevelopment" conditions in the area. Numerous simulations were conducted, in which the calibration parameters were varied until the simulated water levels matched the observed water levels satisfactorily. The calibrated steady state "predevelopment" water levels in the two sand layers in which the District wells are screened is presented in Figure 3.2a-b. As expected, groundwater flow is

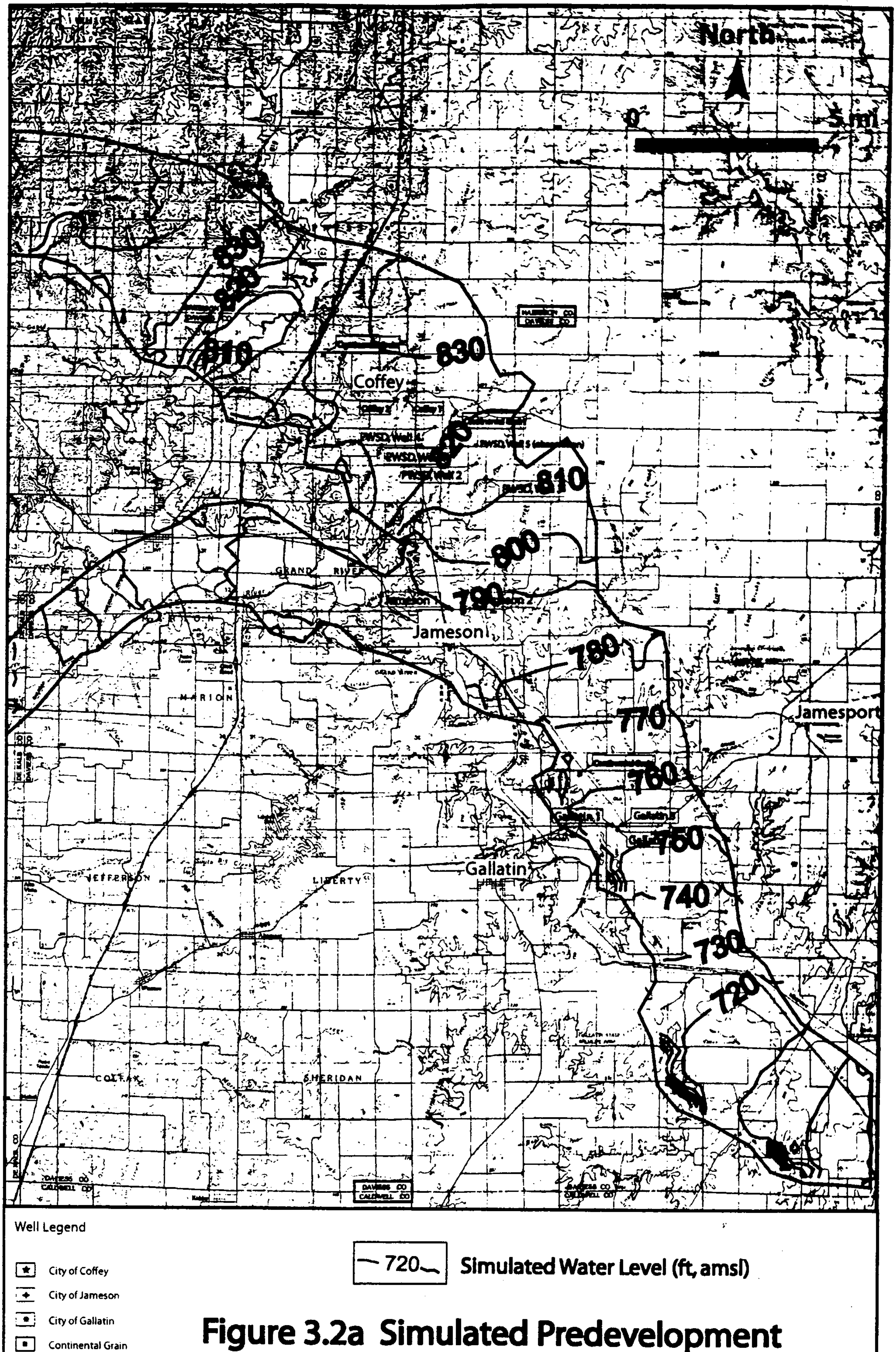


Figure 3.2a Simulated Predevelopment Water Levels in Model Layer 4

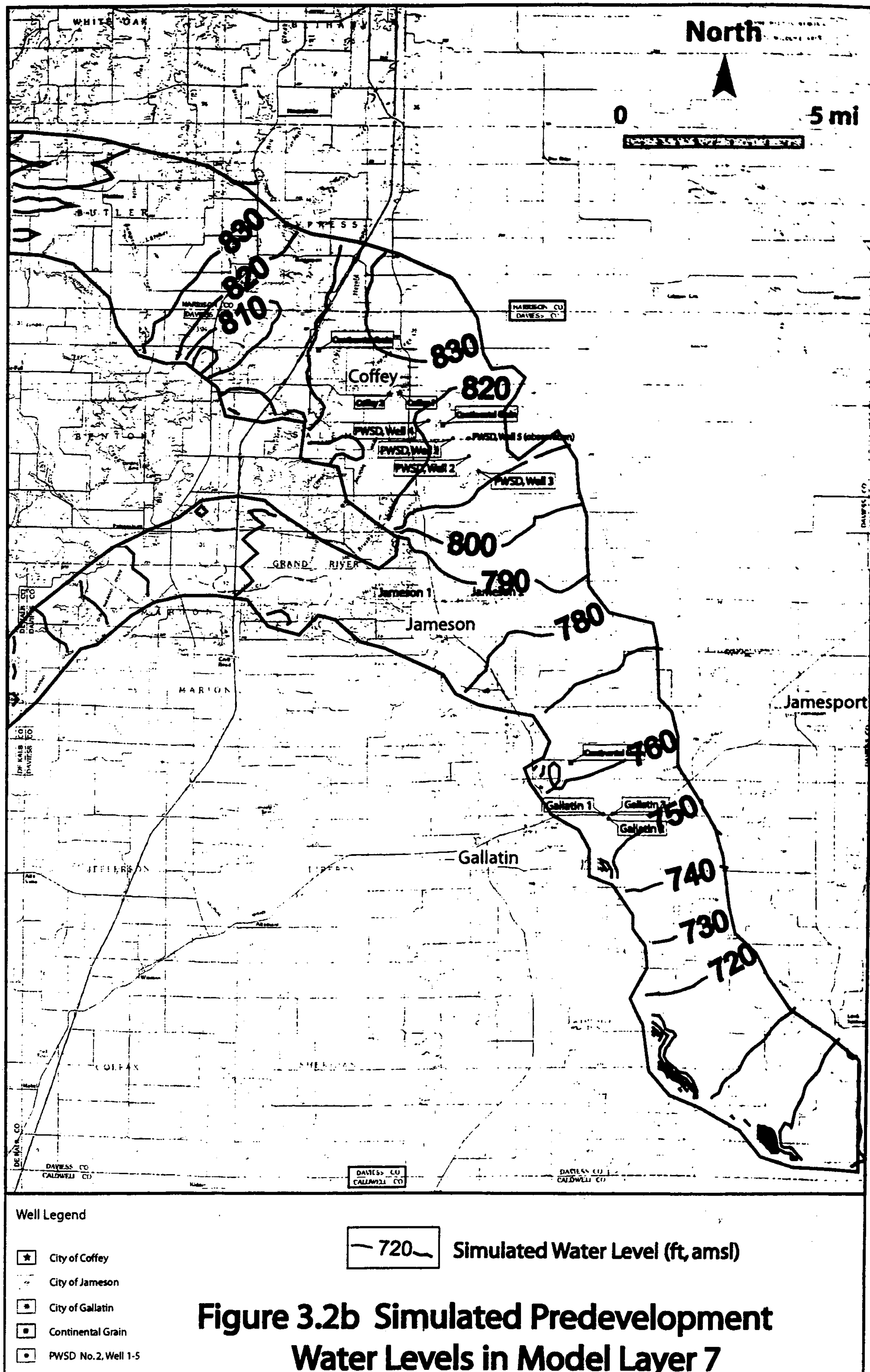


Figure 3.2b Simulated Predevelopment Water Levels in Model Layer 7

generally in the southeastward direction, except in the north where low conductivity material causes discharge along low-lying areas (refer to Figure 2.4 for representation of the surface elevation). The water level in the vicinity of the Coffey wellfield is approximately 828 ft amsl, which is in agreement with observed water levels at the site as depicted in the hydrograph for the City of Coffey Well No.1 (Figure 2.14).

Results of transient simulations at the District wells are presented in Figure 3.3a-d, which depict the observed and simulated water levels. In general, a reasonable match can be inferred from the hydrographs. Water levels in the District wells remained fairly steady between 1965-1988, indicating that pumpage at Coffey did not appreciably impact water levels in the District wellfield. As discussed above, since, pumpage in individual wells was not known, the total annual withdrawal in the District wellfield was distributed uniformly in each well. This conforms to District's preferred practice to rotate pumpage equally in all production wells (Randy Garrett, PWSD No. 2, personal communication). Therefore, since information regarding actual pumpage in individual wells is not known for any period, there are variations between the observed and simulated water levels. The overall declining trend however is adequately reproduced by the model, as can be observed from the simulated water level hydrographs (Figures 3.3a-d).

Hydrographs for Well No. 1 represent water levels in the upper sand layer as discussed in Section 2.4. Wells 2, 3, and 4 primarily draw water from the lower sand unit and have fairly similar water levels, which are generally about 35 ft lower than water levels in the upper sand layer. As discussed in Section 2.4, the apparent recovery in observed water levels in Well No. 1 during 1998 is the result of faulty instrumentation in the well during this period. Therefore, comparison between the observed and simulated water levels in Well No. 1 during this period is not possible.

The simulated present day (2002) water levels in the vicinity of the District's wellfield are presented in Figure 3.4a-b. Figure 3.4a represents water levels in layer 4, which represent the screened interval in Wells 1 and 5. Figure 3.4b represents water levels in model layer 7 in which Wells 2, 3, and 4 are screened.

A final model calibrated recharge value of 0.15 in/year was specified to the drift-filled aquifer. The hydraulic conductivity distribution ranges from 1.0E-04 for the clay material to 60 ft/day for the sand units. A (vertical to horizontal) anisotropic ratio of 0.1 was specified, which is a representative value for soils in the plain states region. A specific storage of 0.50E-04, and a specific yield of 0.15 were derived for model layers 1-4. The specific storage and specific yield in the deeper model layers 5-7 were specified as 0.5E-05 and 0.15 respectively. It should be noted that the calibrated values of specific storage and saturated hydraulic conductivity of the sand and gravel material compare well with estimates obtained during the pump test conducted in 1984 and discussed in Section 2.2. The hydraulic conductivity estimated during the pump test range from 27 ft/d to 589 ft/d, with the lower end of the range obtained during later periods of the pump test, which is more representative of actual long term pumping conditions. The storativity estimate ranged from 0.0000470 to 0.000429 as discussed in Section 2.2.

Figure 3.3a Simulated and Observed Water Levels in District Well No. 1

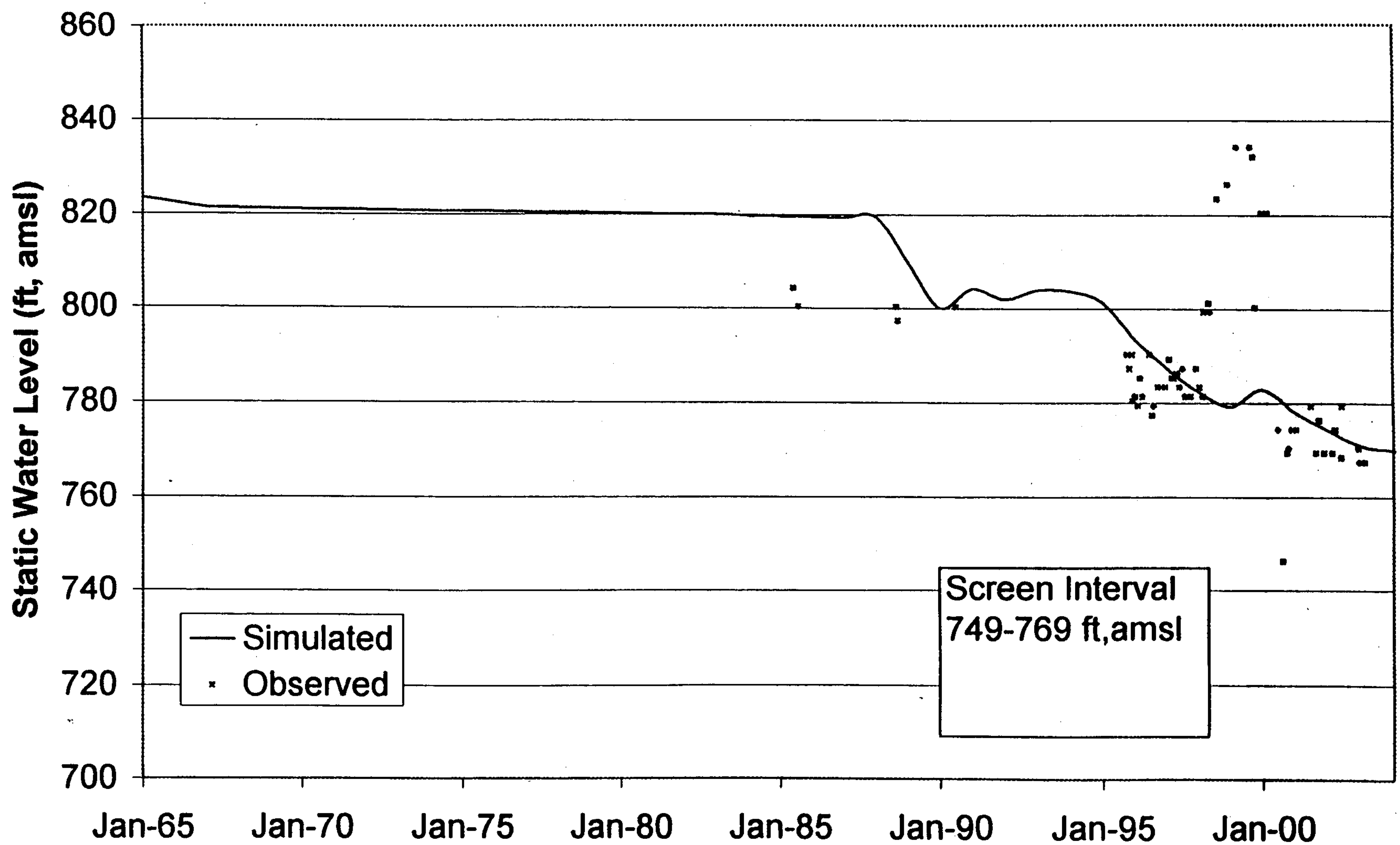


Figure 3.3b Simulated and Observed Water Levels in District Well No. 2

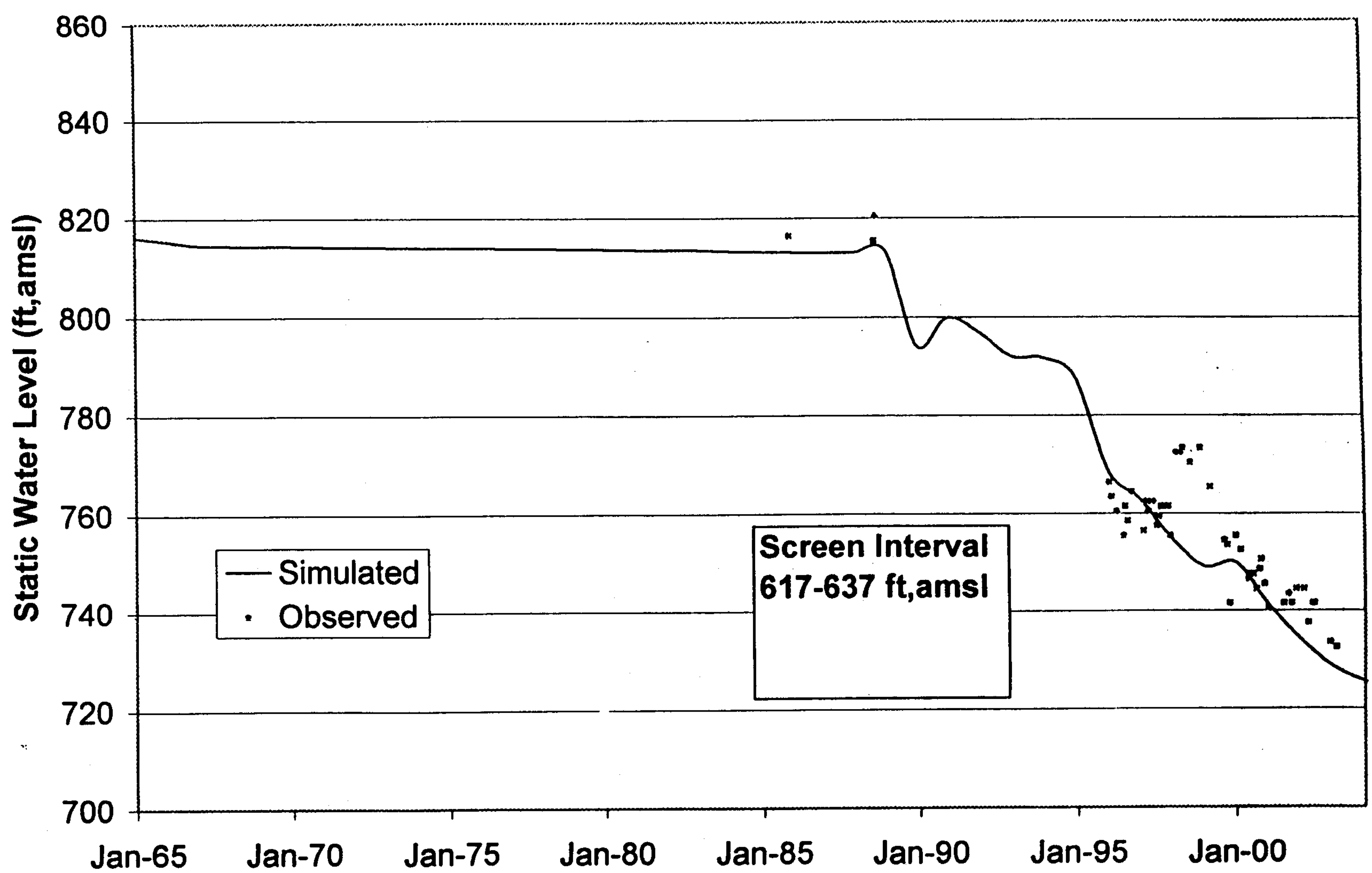


Figure 3.3c Simulated and Observed Water Levels in District Well No. 3

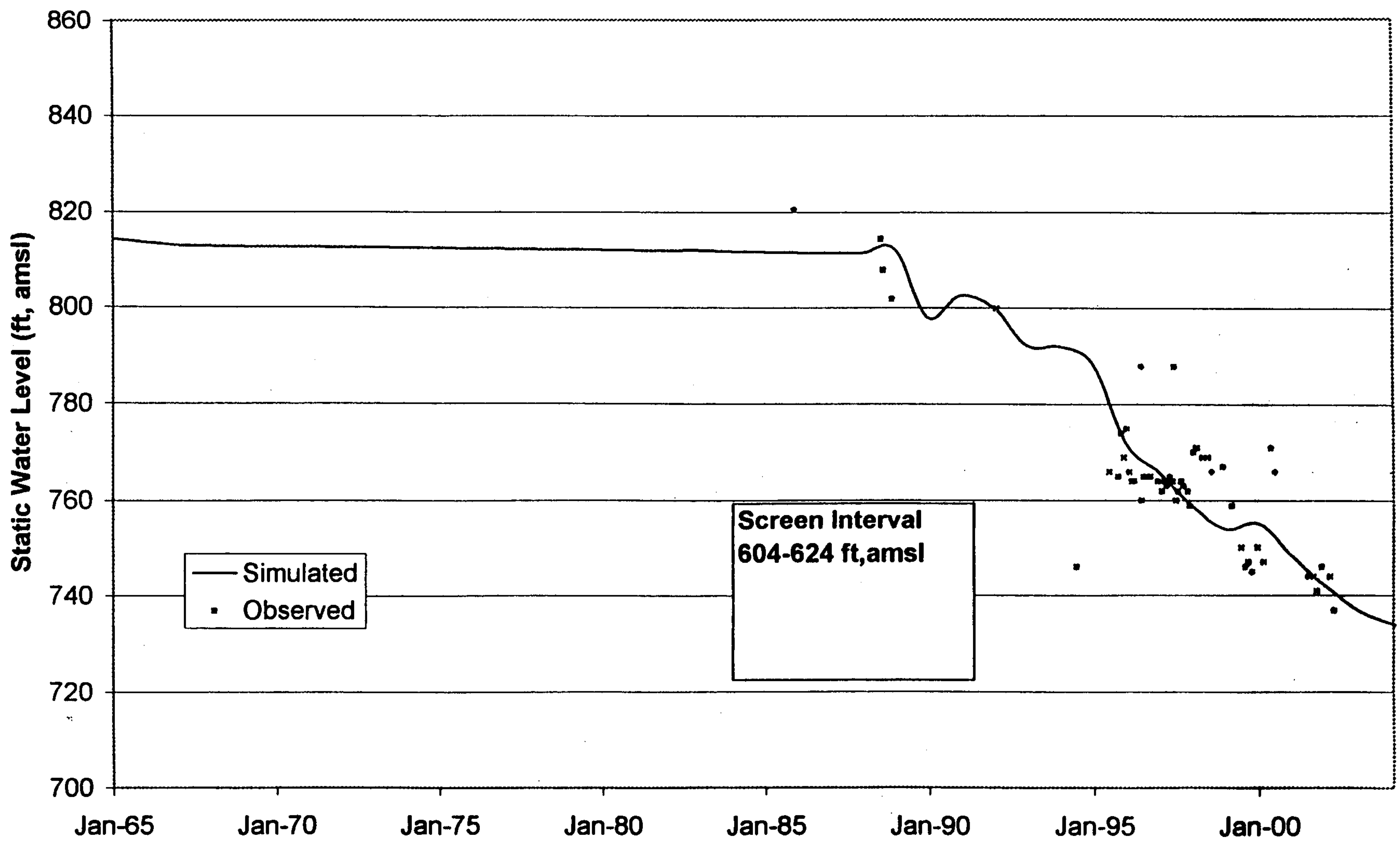
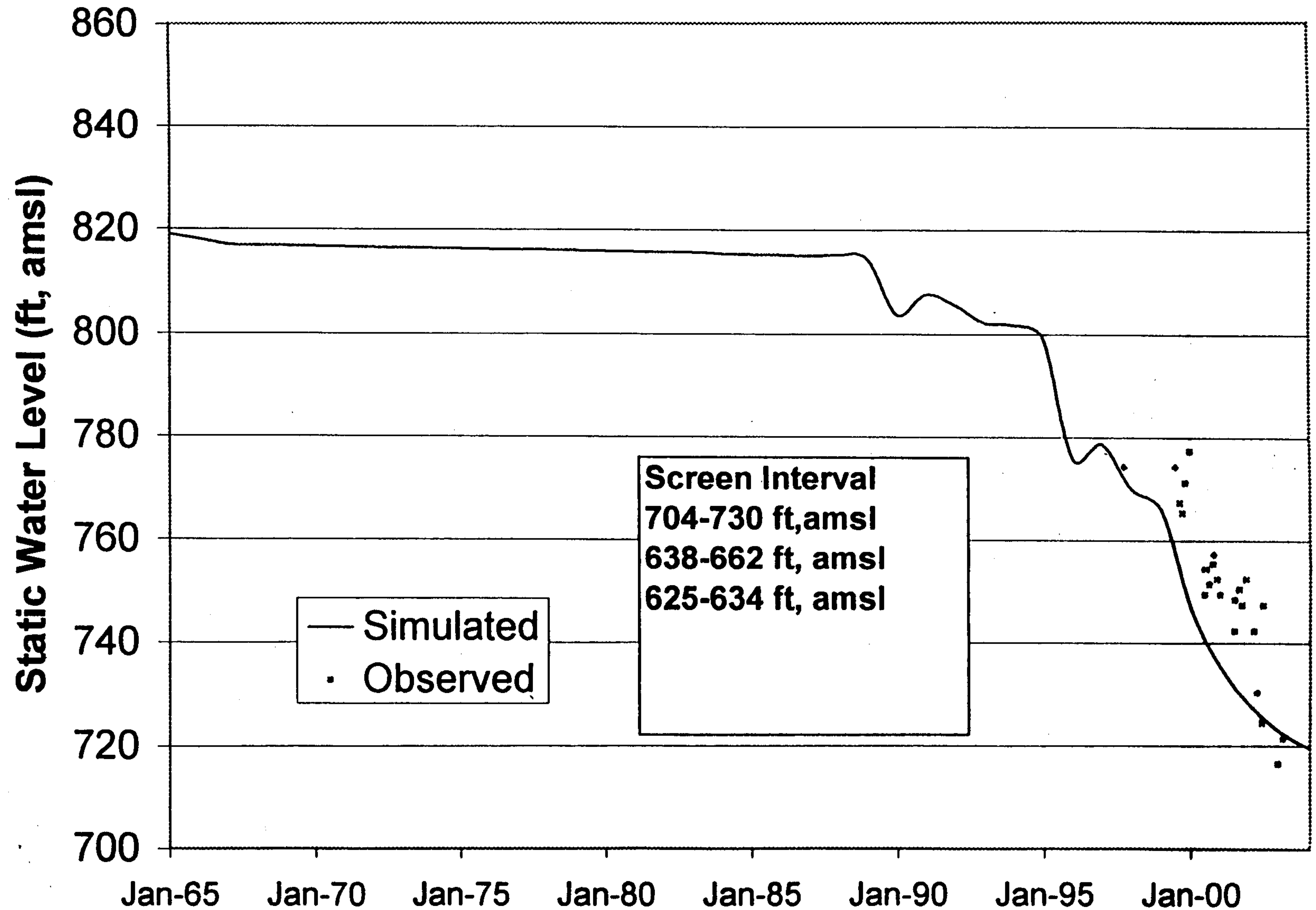
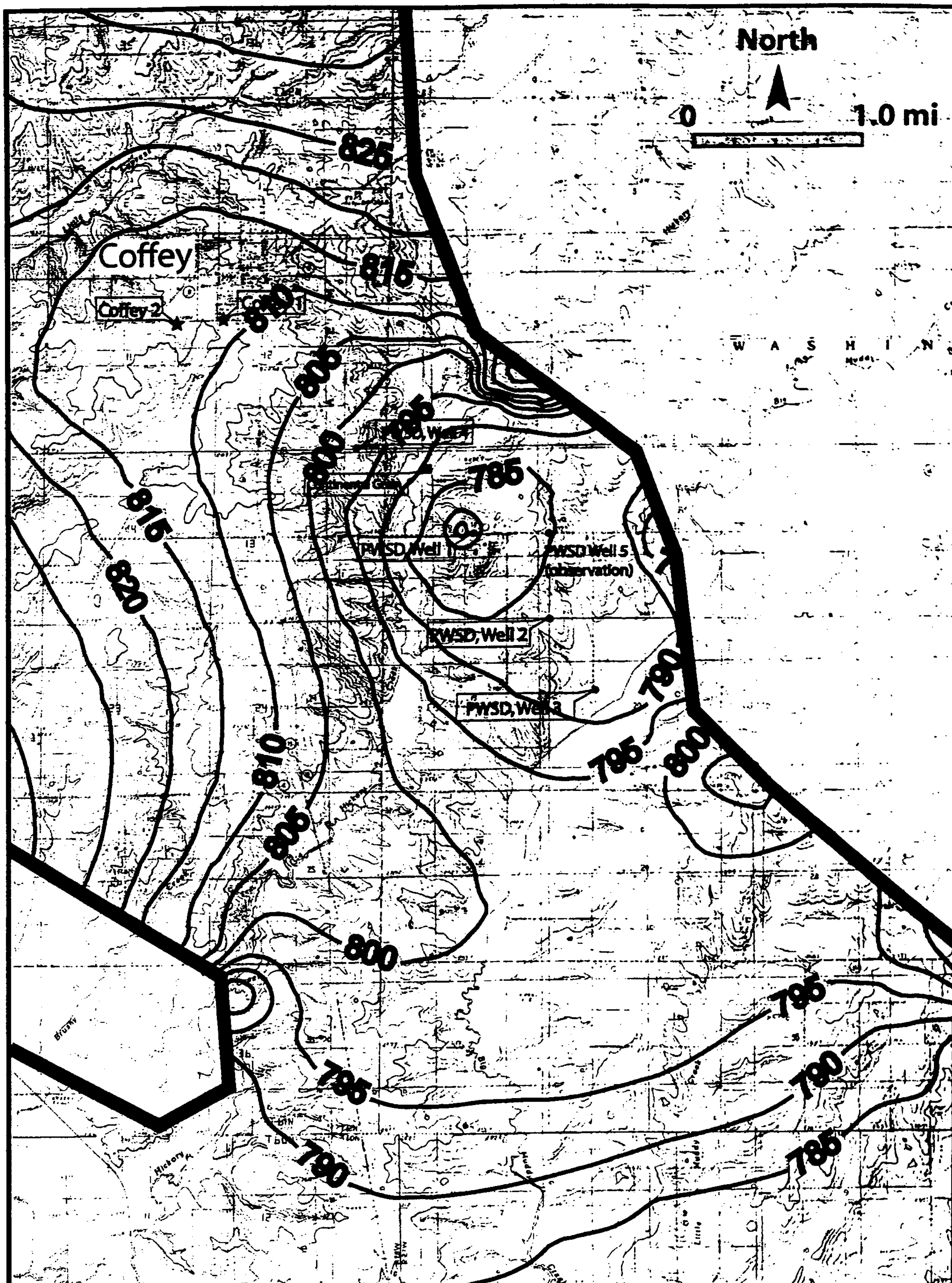


Figure 3.3d Simulated and Observed Water Levels in District Well No. 4



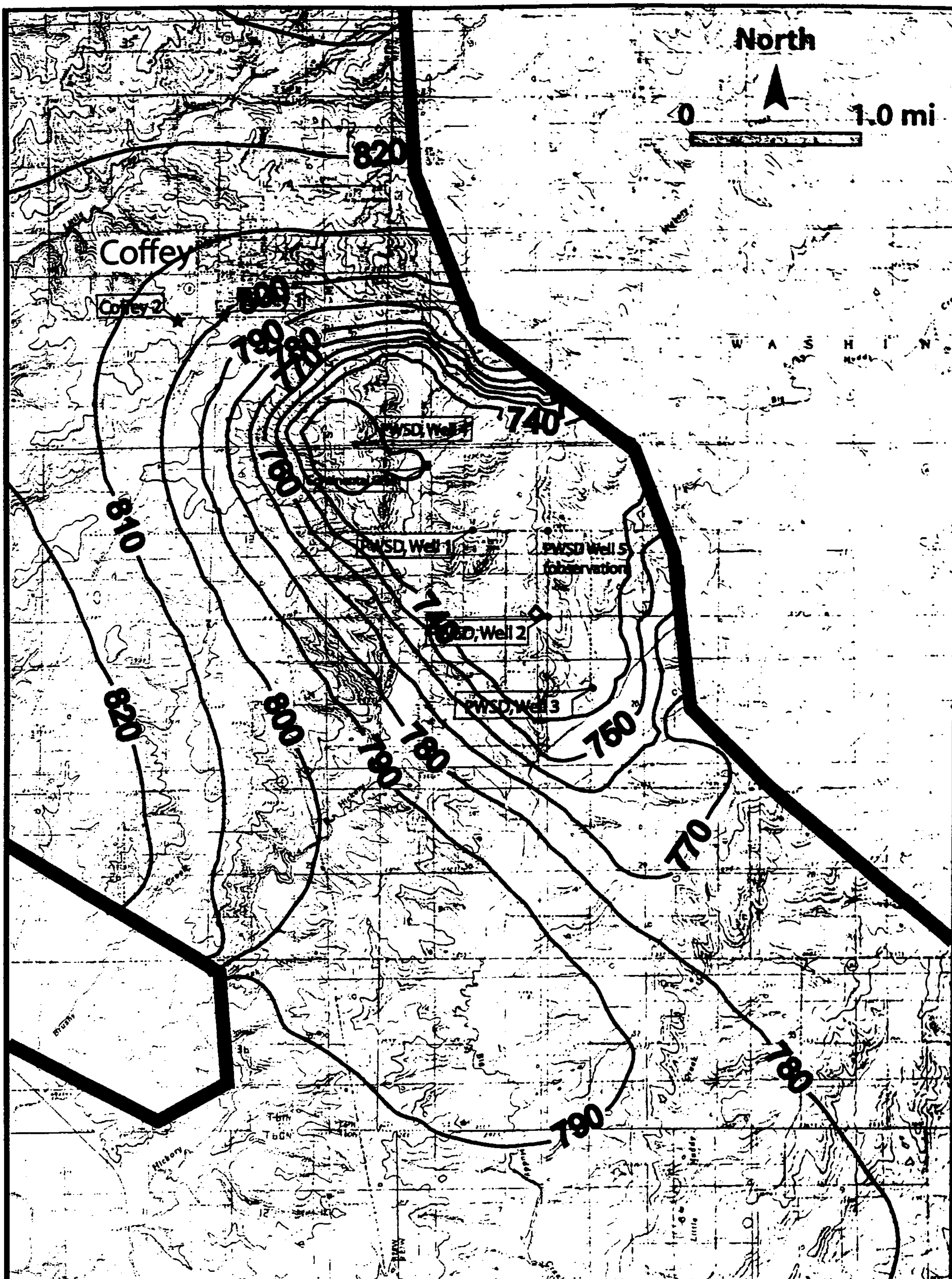


Well Legend

- ★ City of Coffey
- ■ Continental Grain
- ● PWSD No. 2, Well 1-5

— 720 — Simulated Water Level (ft, amsl)

Figure 3.4a Simulated 2002 Water Levels in Model Layer 4



Well Legend

- City of Coffey
- Continental Grain
- PWSD No. 2, Well 1-5

720 Simulated Water Level (ft, amsl)

Figure 3.4b Simulated 2002 Water Levels in Model Layer 7

3.3 EXPANDED WELLFIELD SIMULATIONS

Current (2002) production in the wellfield is approximately 357,000 GPD. Demand is projected to reach 717,000 GPD by the year 2002, thereby requiring an additional 360,000 GPD. In order to meet the anticipated demand, the District will need to install additional wells in the drift-filled channel. Static water level in the District's Well No.1 is already close to the top of the screen, and with pumpage in the well, water levels drop within the screen interval. The District's Wells 2, 3, and 4, which are screened in the lower sand layer have adequate water cover, but water levels will decline with additional pumpage.

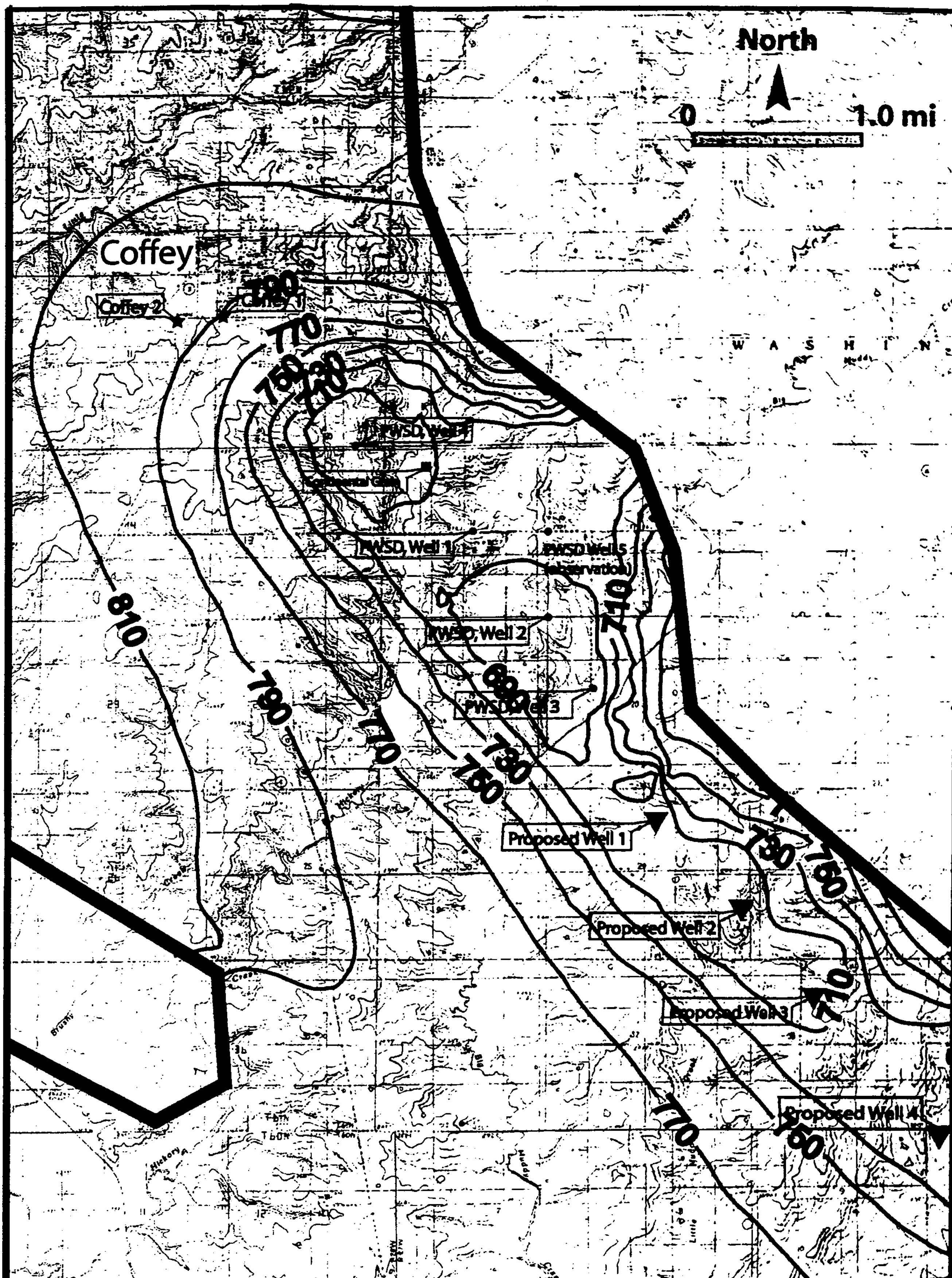
In order to determine the capability of the drift-filled valley to meet the additional demand of 360,000 MGD, model runs were conducted with different well pumpage and placement configurations. Based on geologic information reviewed for the project, it appears that, in the vicinity of the District's wellfield, the lower sand layer occurs more commonly along the edges of drift-filled channel, where melt-water velocities were higher. With declining water levels, and the prospect for additional drawdowns with future pumpage, it is necessary to construct new wells that are screened in the lower sand zone in order to prevent water levels from dropping below the top of the screen in the future.

A model simulation run was conducted with a withdrawal of 360,000 GPD from 4 new production wells south of the existing wellfield as indicated in Figure 3.5. The model was run for a period of 20 years with pumpage in the existing wells maintained at 2002 levels. The new well closest to the existing Well No. 3 had an average daily pumpage of 60,000 GPD, and the following three wells from north to south were specified withdrawals of 90000, 105000, 105000 GPD respectively.

Water levels in (the bottom-most) model layer 7 at the end of the 20-year simulation period (2022) are presented in Figure 3.5. The simulated water level hydrographs in each of the existing District well and the 4 proposed wells is presented in Figure 3.6a-h.

The hydrographs indicate that static water levels in the District Wells 1, 2, 3, and 4 will further decline to 760, 685, 680, 685 ft amsl respectively. Due to decreased saturated thickness and increased entrance velocity, the well specific capacities are also expected to reduce. In order to maintain the same well yield, the pumped water levels would likely experience an additional drawdown of approximately 25, 15, and 12 feet in Wells 2, 3, and 4 respectively. This would still maintain pumped water levels above the top of the screen. It should be noted that the scenario simulated assumes the expanded wellfield pumpage of 360,000 GPD to commence immediately (2003). In reality, pumpage will increase gradually, and therefore the drawdowns in the near future would be lower than that depicted for the extreme pumpage conditions being simulated.

The hydrographs at the proposed well sites (Figure 3.6e-h) indicate that the static water levels at the new well sites will be in the range of 690-720 ft amsl. Assuming an induced



Well Legend

★ City of Coffey
■ Continental Grain
● PWSD No. 2, Well 1-5
▼ Proposed Well Sites

720 Simulated Water Level (ft, amsl)

Figure 3.5 Simulated 2022 Water Levels in Model Layer 7

Figure 3.6a Projected Water Levels in District Well No. 1 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

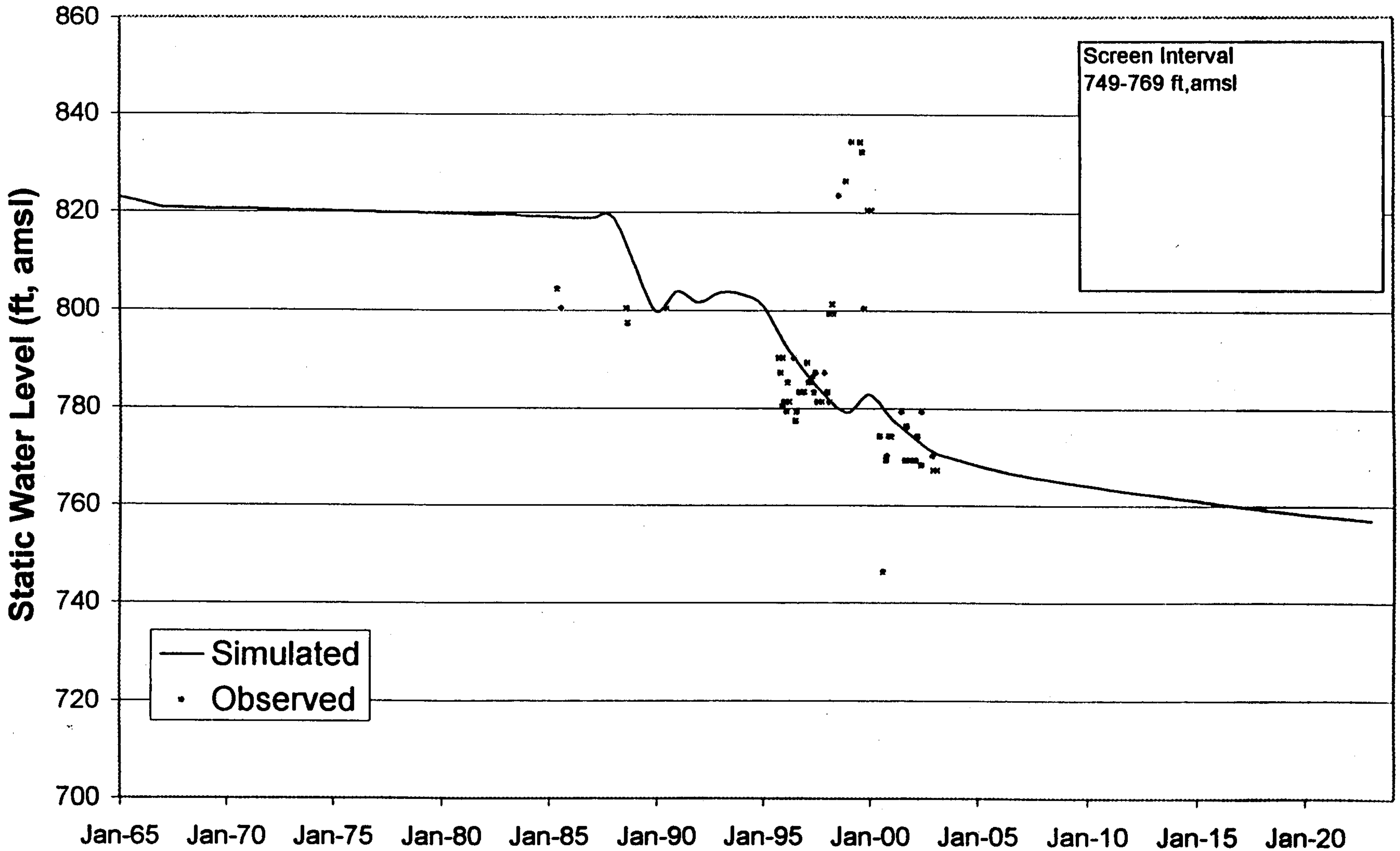


Figure 3.6b Projected Water Levels in District Well No. 2 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

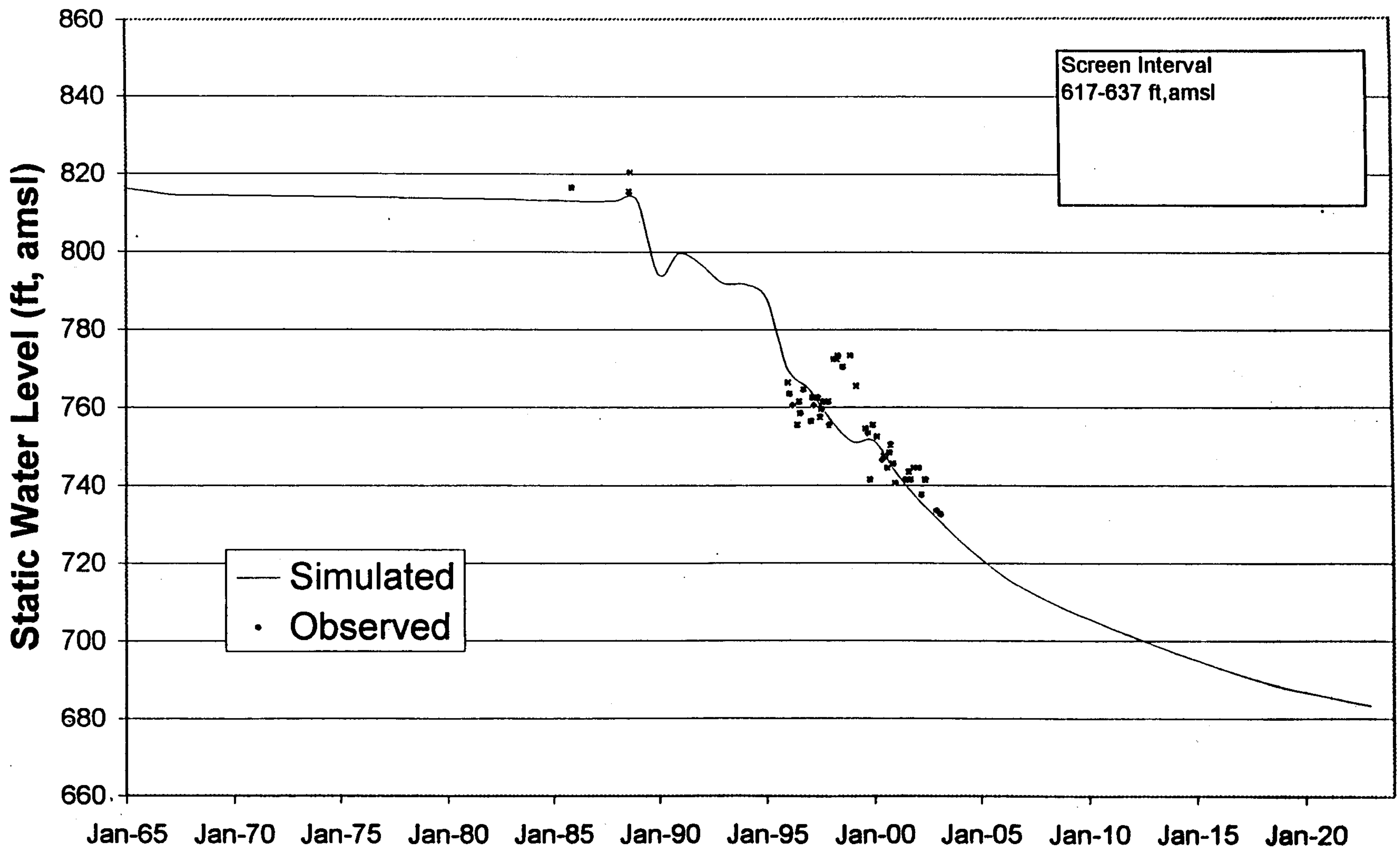


Figure 3.6c Projected Water Levels in District Well No. 3 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

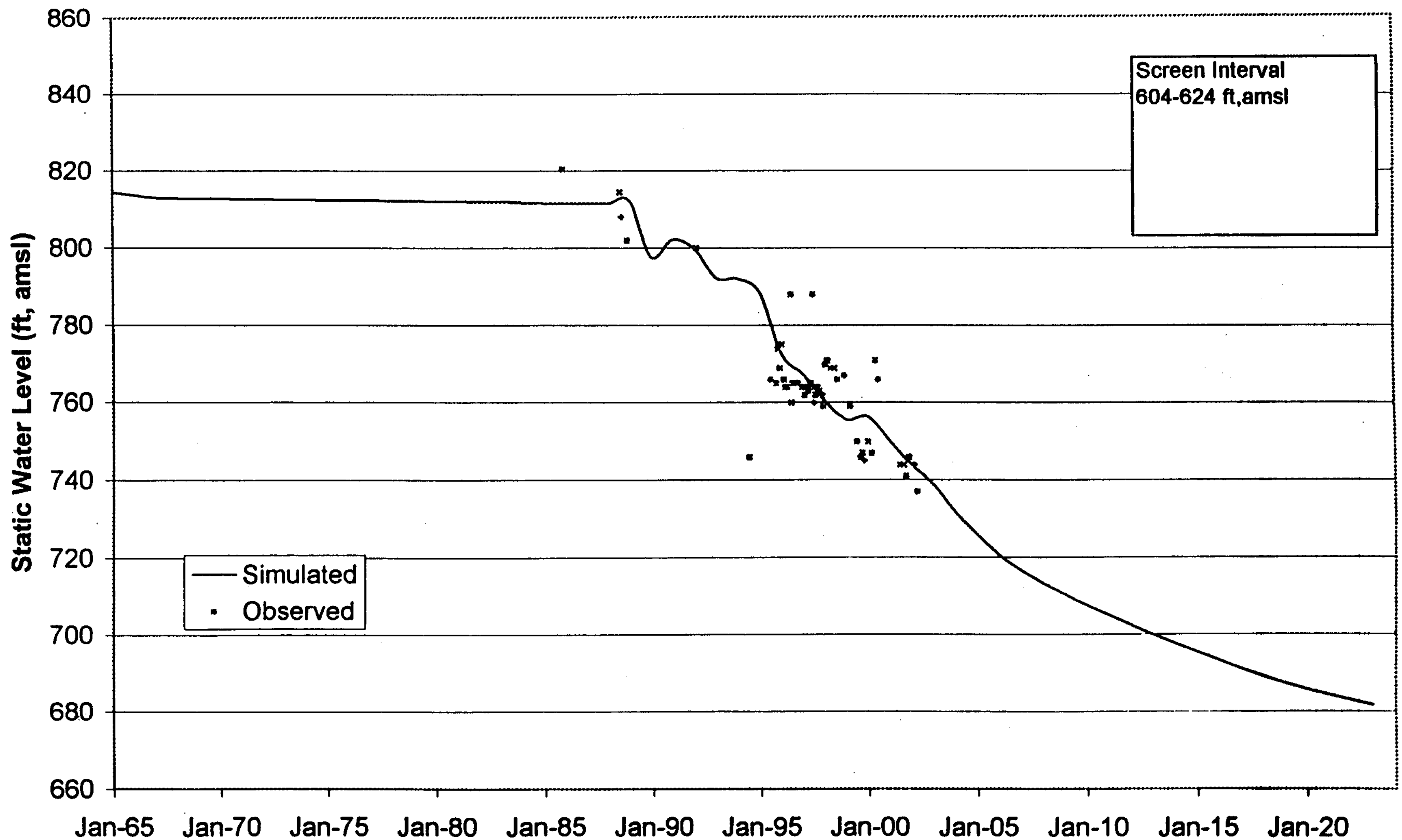


Figure 3.6d Projected Water Levels in District Well No. 4 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

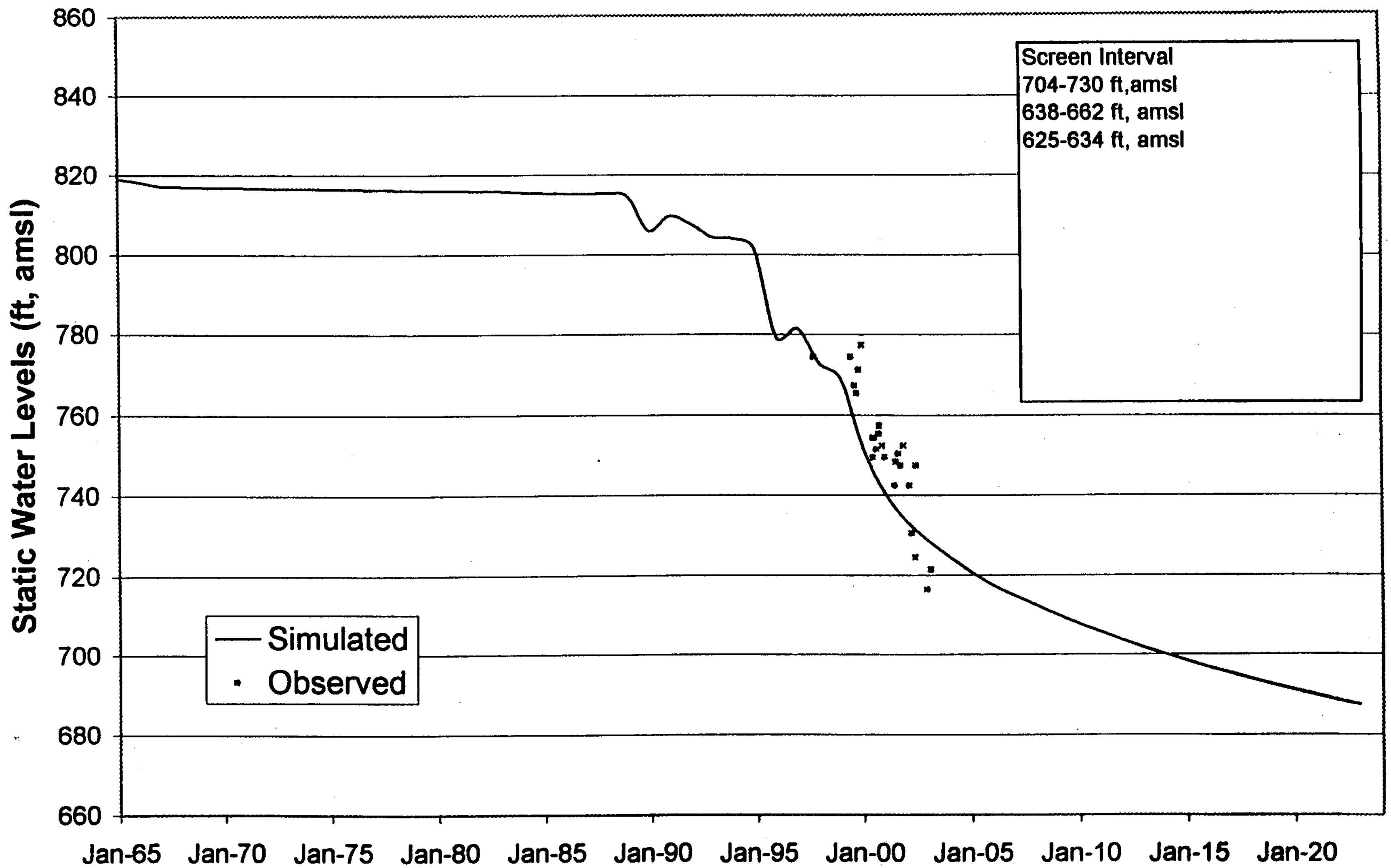


Figure 3.6e Projected Water Levels at Proposed Site No. 1 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

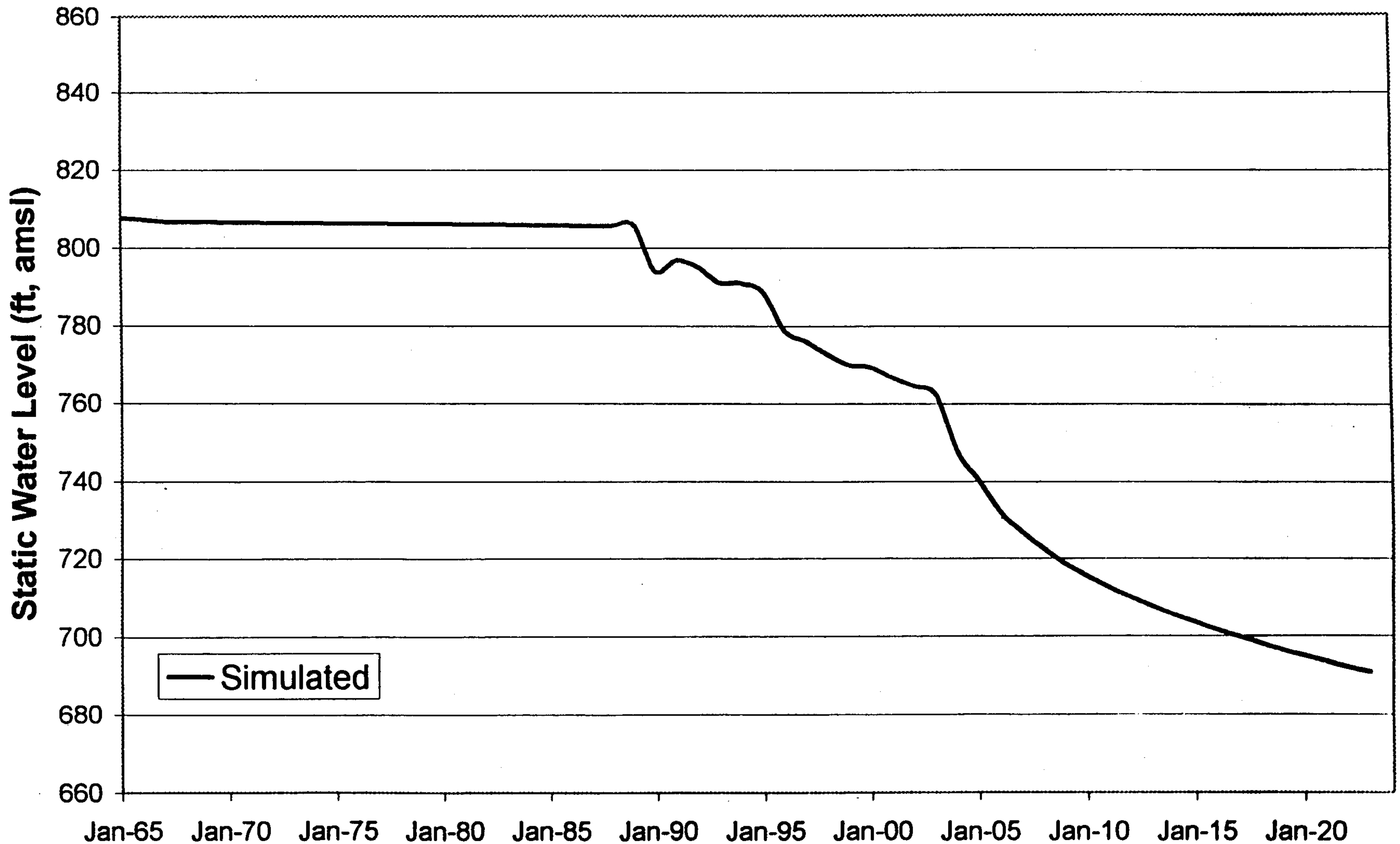


Figure 3.6f Projected Water Levels at Proposed Site No. 2 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

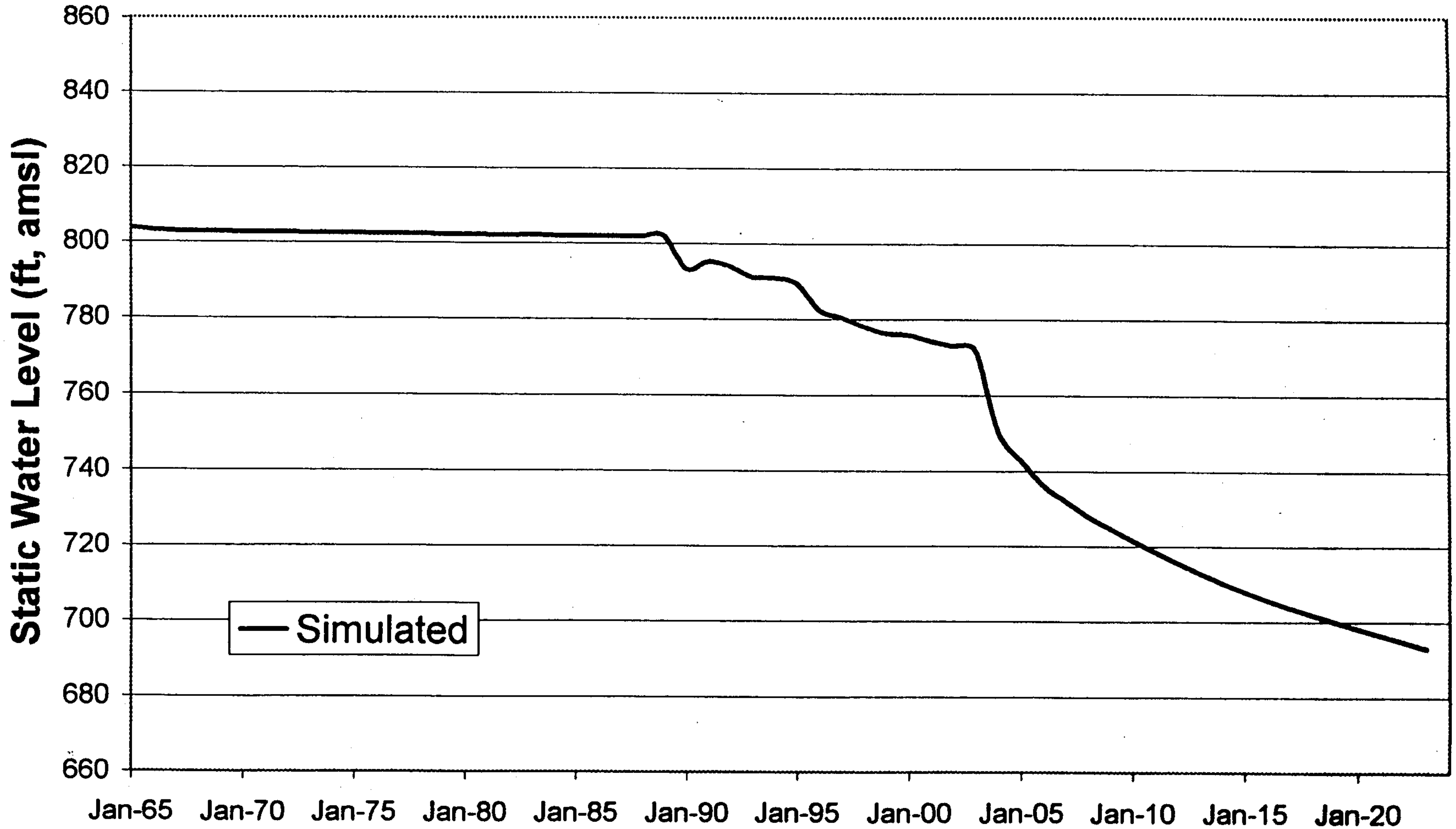


Figure 3.6g Projected Water Levels at Proposed Site No. 3 with 717,000 GPD Pumpage in Existing and Expanded Wellfields

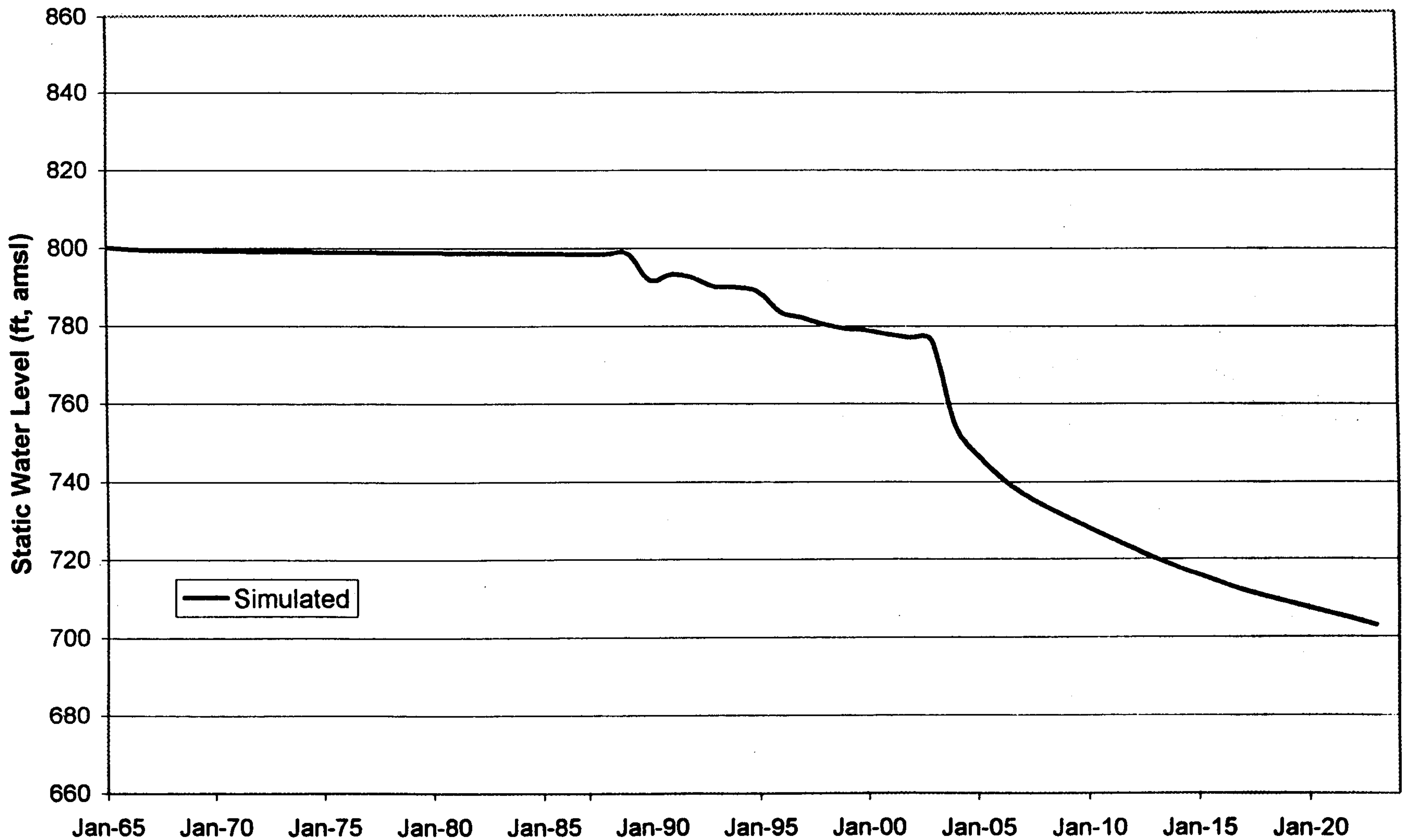
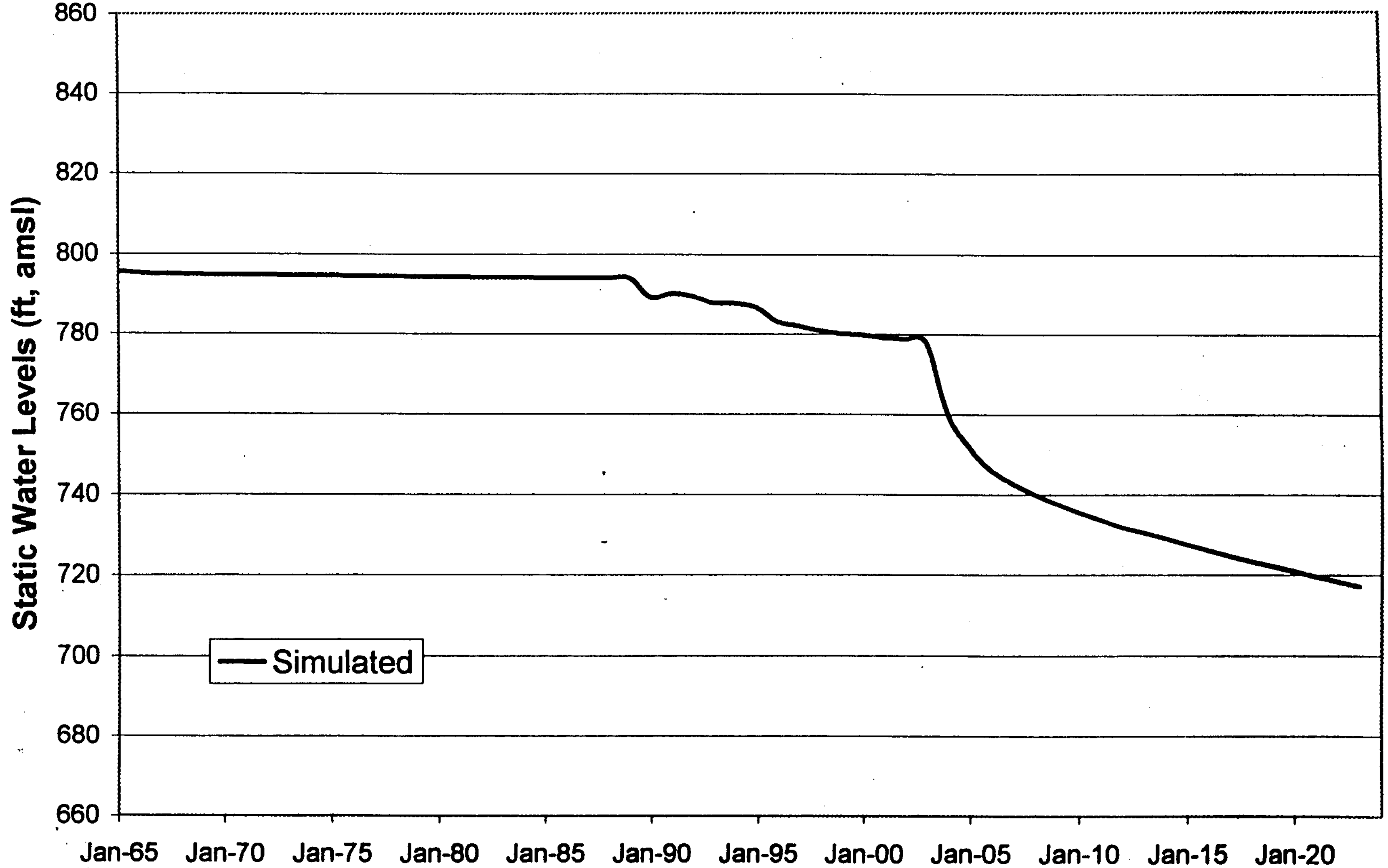


Figure 3.6h Projected Water Levels at Proposed Site No. 4 with 717,000 GPD Pumpage in Existing and Expanded Wellfields



drawdown of approximately 30 feet to produce 100 GPM from a new well, the pumped water levels would be in the 660-690 feet range. Allowing for a water cover of at least 10 feet, and assuming a screen length of 20 feet in the lower sand layer, it will be necessary to encounter bedrock at a depth of 630 feet or lower, and contain sand and gravel of appreciable thickness (15-20 feet) starting at depth of 650 feet or lower. Fortunately, the bedrock elevation in the area can be found at depths of 650 feet amsl in the area, with locally the bedrock encountered at even greater depths. Bedrock elevation at the District's Well no. 1, 2, 3, and 4 and at the Continental Grain well are at 624, 616, 608, 623, and 614 ft amsl respectively.

Chapter 4

CONCLUSIONS

The groundwater flow model of the (drift-filled) preglacial valley constructed for the study, indicates that the that it is possible to withdraw an additional 360,000 MGD from the drift-filled channel to meet a total raw water demand of 717,000 GPD by the year 2022

Based on review of well logs in the area, it is recommended that the District conduct a test drilling program along the edges of the drift-filled channel and south of the existing wellfield to identify suitable locations for new wells. Due to the large drawdowns anticipated in the expanded wellfield, it is necessary that a sand and gravel zone of at least 15-20 feet be present at a depth of 650 feet (or lower) at the new well sites. Model simulation results indicate that four new production wells, spaced approximately 3,500 feet apart, would be adequate to meet the projected average daily demand by the year 2022.

The increased withdrawals in the expanded wellfield will also induce drawdown at the existing District wells. Additional drawdowns of 10, 50, 60, and 40 feet can be expected at Well 1, 2, 3, and 4 respectively. Well No. 1 is already experiencing drawdown within the well screen. With additional pumpage in the area, the production from this well may need to be curtailed.

It is recommended that the first proauction well be constructed near the center of the proposed wellfield area presented in Figure 3.5. On completion of the test well, an extended 60-day pump test should be conducted. The data obtained from the pump test should be used to corroborate the model results, and if necessary, be used to update the groundwater model. The updated model can be used to obtain fresh drawdown projections for the expanded and existing wellfields.

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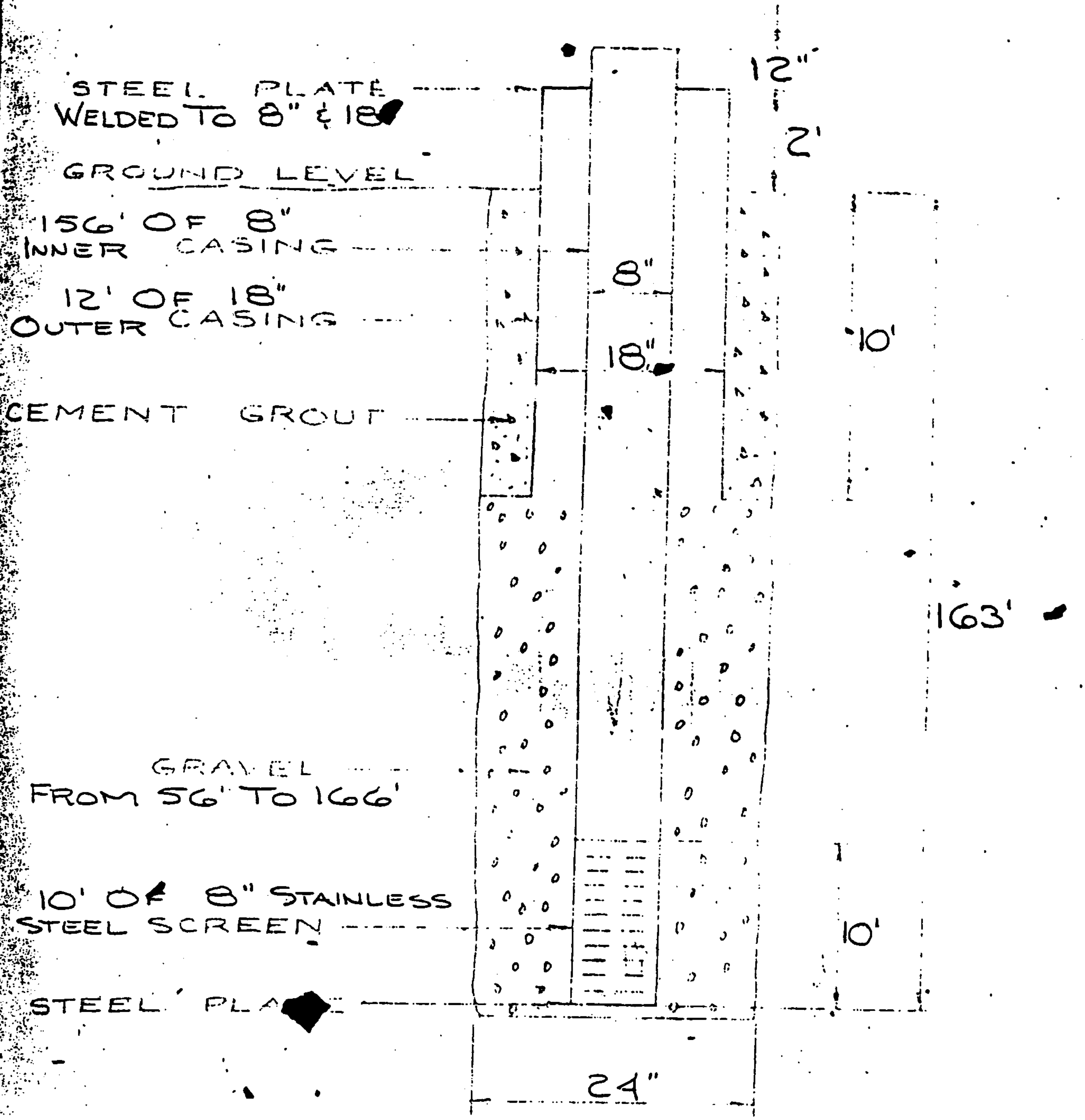
Appendix A

Well Construction and Test Hole Logs



JULY 1965

WELL NO. 1
CITY OF COFFEY
COFFEY, MISSOURI

Layne-Western Company
1010 W. 39TH STREET
KANSAS CITY, MISSOURI

Layne-Western Company

Contract Name City of Coffey

Job No. KC 68 Date 5/12/65

City Coffey State Missouri

TEST HOLE No. 1-65

Driller J. Harper

Test Hole Location 30' N. and 37' E. of S.W. corner of property
Distance and Direction from Permanent Landmark or Previous Test Hole

TEST LOG

Static Water Level 102'6" Meas[ured]
2½ Hours After XXXXXXX pum[ping]

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
0'0"	1'6"			Top soil
1'6"	15'0"			Gray & brown clay, stiff
15'0"	63'0"			Brown sandy clay, stiff
63'0"	115'0"	-		Gray sandy clay, stiff
115'0"	143'0"			Gray sandy clay, med.
143'0"	145'0"			Gray med. to coarse sand, gravel, driftwo
145'0"	150'0"	38	1"	Gray med. to coarse, some fine sand, grav boulders
150'0"	155'0"	38	3"	Gray med. to coarse, tr. fine sand, gravel boulders
155'0"	160'0"	38	3"	Gray coarse & med. tr. fine sand, gravel, boulders
160'0"	163'0"	38	2½"	Gray coarse & med. tr. fine sand, gravel, boulders
163'0"	165'0"			Gray sandy clay, med.
165'0"	210'0"			Gray sandy clay, few boulders, stiff
210'0"	Total depth			

NOTES: Size of Pit 4'6" X 3'6" X 3'0" DEEP

Set 163' of 2" screen and casing and pumped hole 2½ hrs. @ 5 gpm with air

5/13/65

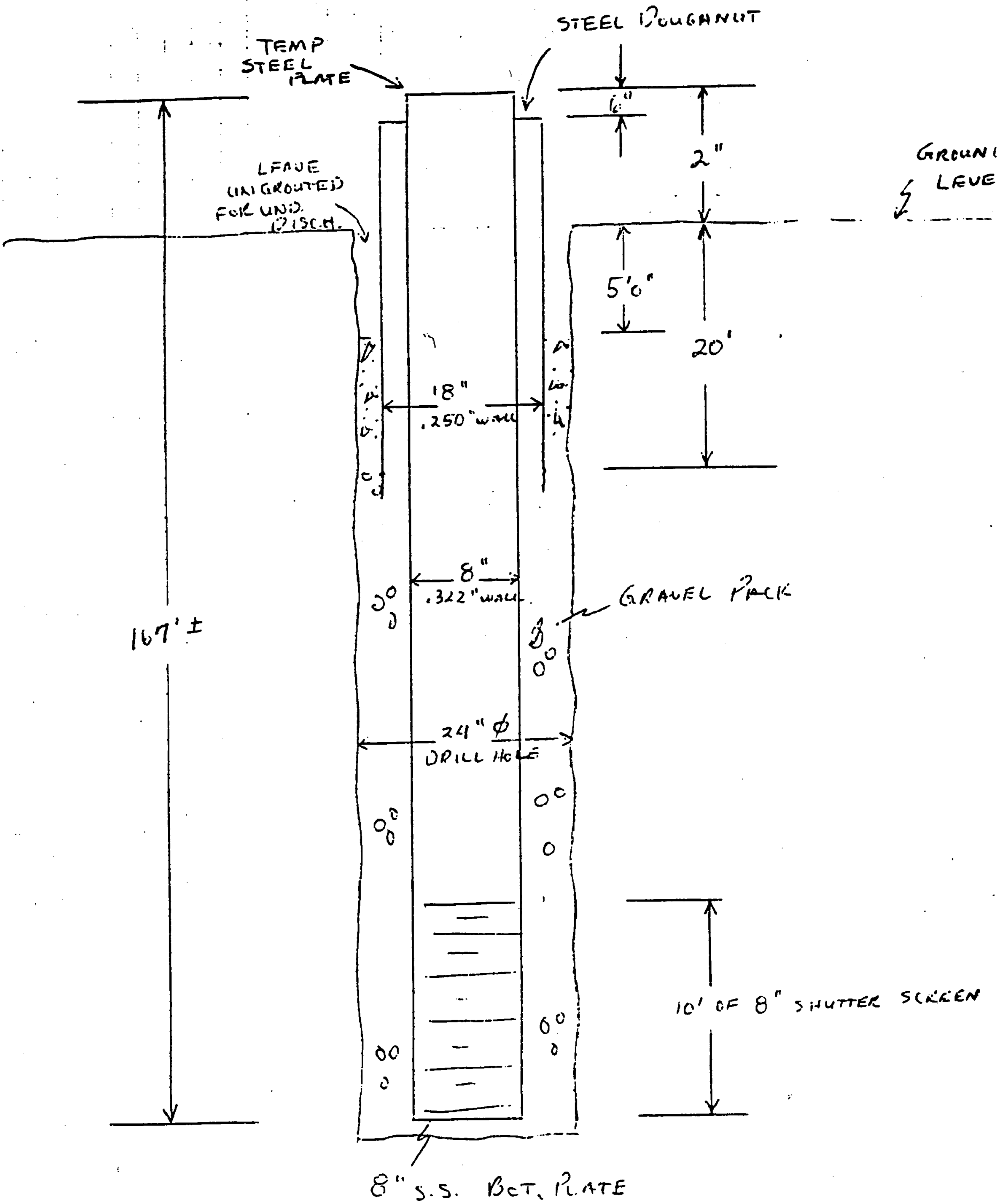
SCO 2-65

Map on Back

Layne-Western Company, Inc.

Subject: COFFEY, MO. Date: 7-7-81

WELL NO. 2



TEST HOLE REPORT

Layne-Western Company, Inc.

Contract Name: City of Coffey

Job No. A-917-D Date 10/16/80

City Coffey State Missouri

TEST HOLE No. 2-80

Driller V. Campbell

Test Hole Location Approx. 75' S. & 1335' W. of existing Well No. 1

Distance and Direction from Permanent Landmark or Previous Test Hole

TEST LOG

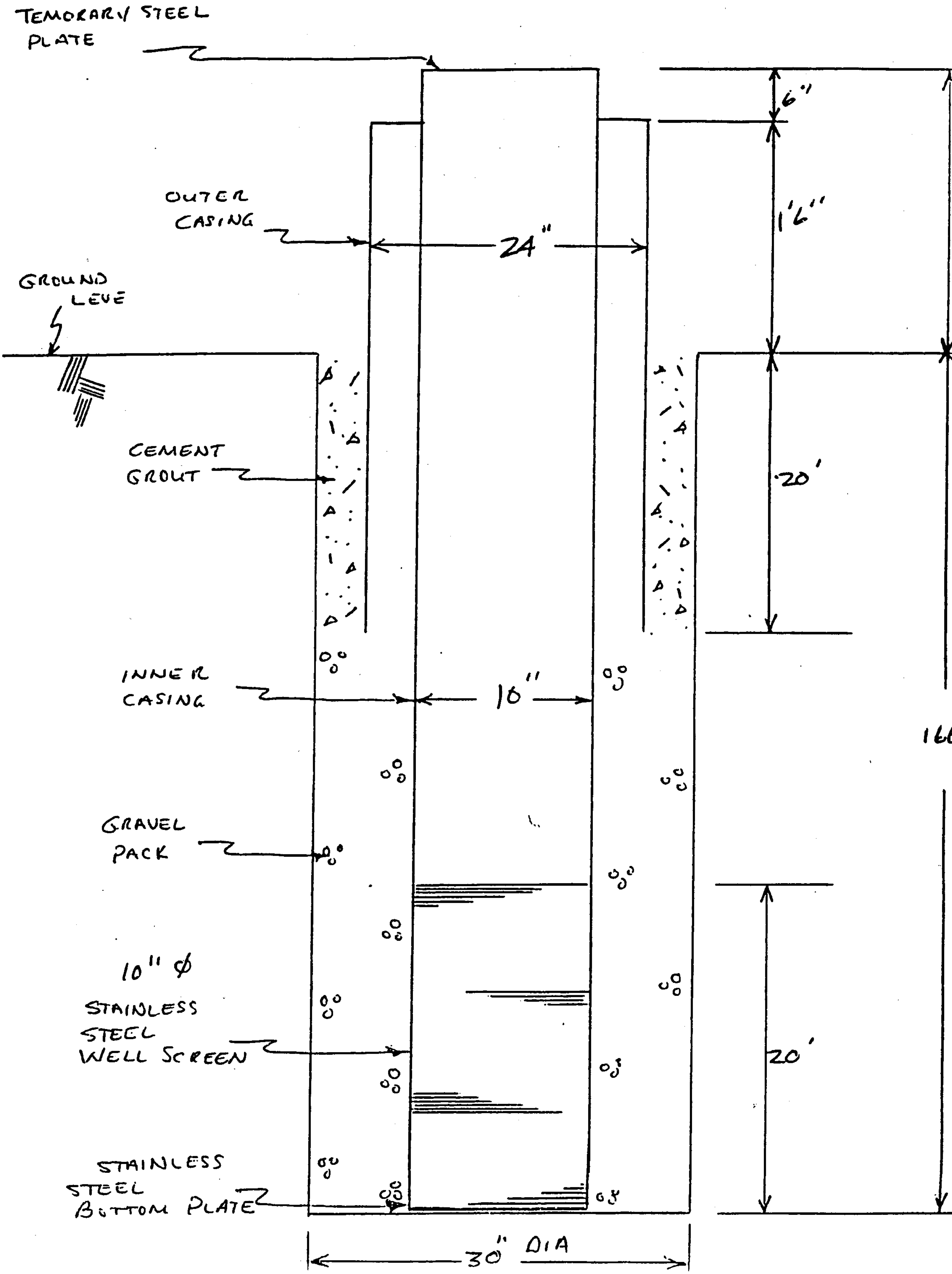
Static Water Level ______ Measured ______ Hours After Completion

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
0.0'	1.0'			Topsoil
1.0'	13.0'			Brown silty clay, stiff
13.0'	14.0'			Gray silty clay, stiff
14.0'	32.0'			Gray brown silty clay, stiff
32.0'	68.0'			Brown silty clay, stiff
68.0'	84.0'			Gray silty clay, stiff
84.0'	87.0'			Gray brown med. to coarse sand
87.0'	150.0'			Gray sandy clay, med.
150.0'	153.0'			Gray med. to coarse sand & gravel w/boulders
153.0'	155.0'	41	1/4	Gray med. to coarse sand & gravel w/boulders trace fine sand
155.0'	160.0'	41	1/2	Gray coarse to very coarse sand & gravel w/ boulders
160.0'	165.0'	41	1/2	Same
165.0'	173.0'			Gray sandy clay
173.0'	174.0'			Gray med. to coarse sand w/some fine sand
174.0'	251.5'			Gray sandy clay w/boulders

251.5' Total depth

NOTES: Size of Pit 7' x 8' x 4' DEEP

HARRISON CO PWSD #2
WELL #1



TEST HOLE REPORT

Layne-Western Company, Inc.

Contract Name: Harrison County P. W. S. D. No. 2

Job No. A-1405 D   Date 6/7/85

City Coffey   State Missouri

TEST HOLE No. 12-85

Driller O. J. Harper

Test Hole Location 1000' W of TH 8-85, 45' N of centerline of E/W Road

Distance and Direction from Permanent Landmark or Previous Test Hole.

TEST LOG

Static Water Level 112' Measured 48 Hours After Completion

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
0.0'	1.0'			Topsoil
1.0'	36.0'			Brown sandy clay, stiff
36.0'	113.0'			Gray sandy clay, stiff
113.0'	143.0'			Gray sandy clay, medium to stiff
143.0'	146.0'			Gray medium to coarse sand, some fine sand & gravel, dense
146.0'	146.3'			Boulder
146.3'	150.0'	43	1/2"	Gray medium to coarse sand, trace fine sand & gravel, boulders
150.0'	155.0'	43	1/2"	Same
155.0'	160.0'	43	1/2"	Same
160.0'	166.0'	40	1-3/4"	Same
166.0'	214.0'			Gray very sandy clay, medium to stiff
214.0'	222.0'			Gray very fine to fine sand, very dense
222.0'	238.0'			Very sandy clay, medium
238.0'	243.0'			Gray gravely & sandy clay, stiff to medium
243.0'	283.0'			Gray sandy clay, very stiff

NOTES: Size of Pit ______ X ______ X ______ DEEP

LW-100

TEST HOLE REPORT

Layne-Western Company, Inc.

Contract Name Harrison County P. W. S. D. No. 2

Job No. A-1405 D Date

City State

TEST HOLE No. 12-85

Driller

Test Hole Location

Distance and Direction from Permanent Landmark or Previous Test Hole.

TEST LOG

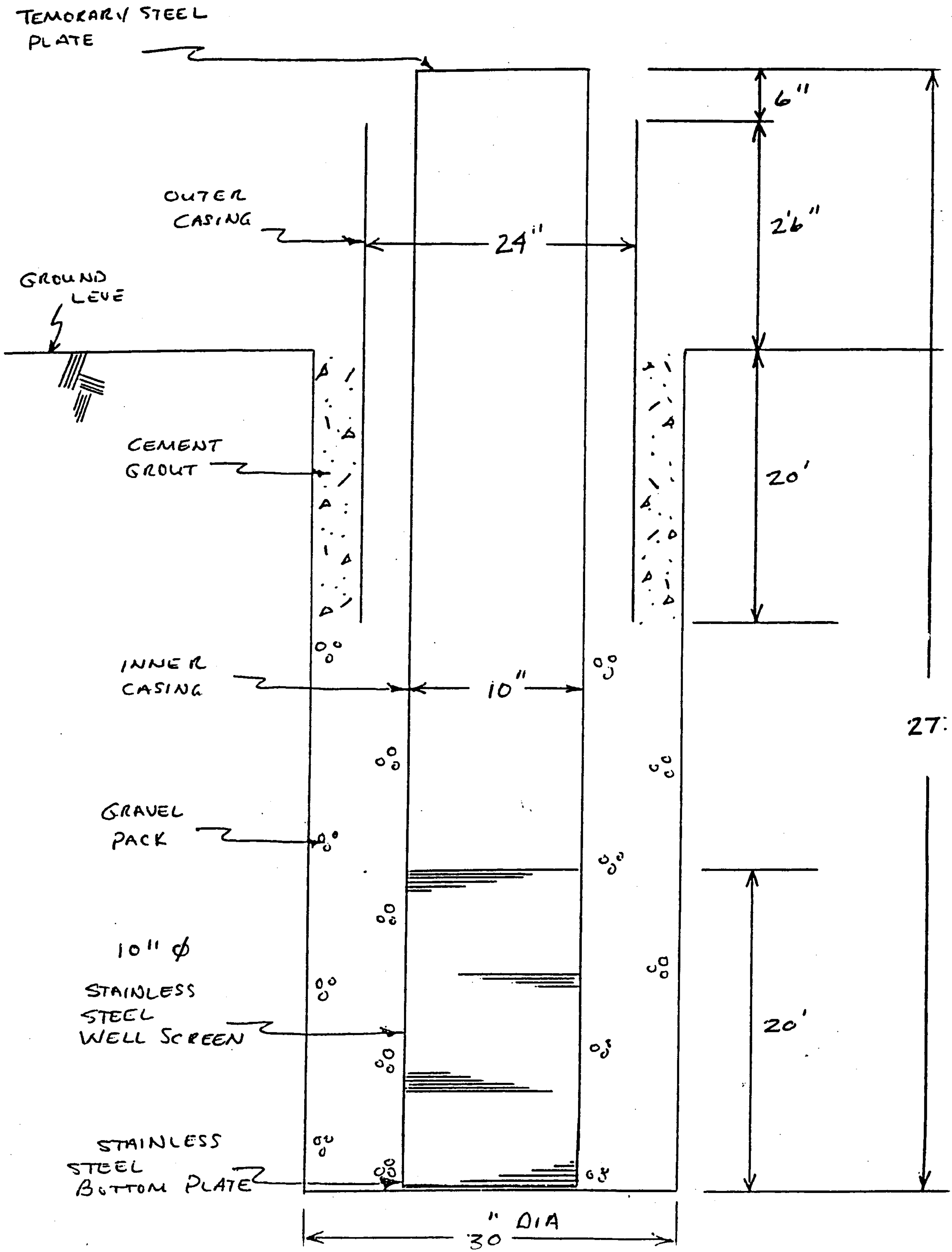
Static Water Level ______ Measured ______ Hours After Completion

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
283.0'	285.0'			Gray broken limestone
285.0'	288.0'			Gray shale, very hard
288.0'	Total depth			

NOTES: Size of Pit Portable X X DEEP

LW-100

HARRISON CO. PWSD #2
WELL #2



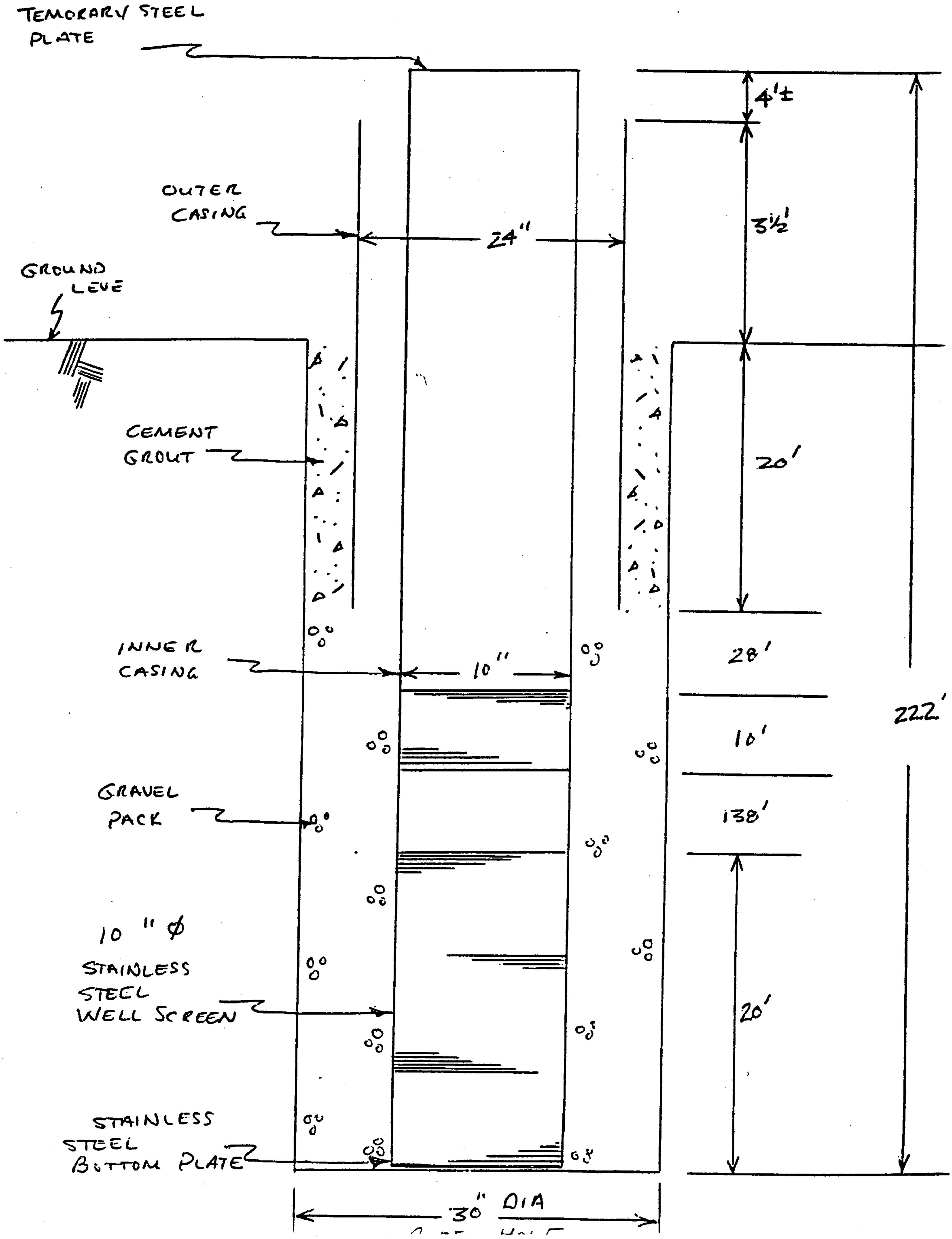
PWSD No. 2

Well No. 2

LOG OF WELL

Ft.	In.	to	Ft.	In.	Formation
0			1		TOP SOIL
1			35		BR. SANDY CLAY
35			46		GR. SILTY CLAY
46			87		GR. SANDY CLAY
87			92		GR. MED-CRS SAND & GRAVEL
92			107		GR. SANDY CLAY
107			113		GR. MED-CRS SAND & GRAVEL
113			117		GR. SANDY-CLAY
117			122		GR MED-CRS SAND
122			137		GR FINE TO MED. SAND
141			202		GR SANDY CLAY
202			207		GR MED TO FINE SAND
207			242		GR. SANDY CLAY
242			270		GR. MED. TO CRS SAND
270			271		GR. SHALY LIMESTONE
			271		TOTAL DEPTH

HARRISON CO PWSD #2
WELL NO. 3



TEST HOLE REPORT WELL #3

Layne-Western Company, Inc.

Contract Name: Harrison County PWSD No. 2

Job No. A-1405 D Date 12/5/85

City Coffey State Missouri

TEST HOLE No. 15-85

Driller O. J. Harper

Test Hole Location

Distance and Direction from Permanent Landmark or Previous Test Hole

TEST LOG

Static Water Level 13.5 Measured 1 Hours After Completion

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
0.0'	2.5'			Topsoil
2.5'	22.0'			Gray brown silty clay
22.0'	43.0'			Gray silty clay, soft
43.0'	45.0'			Gray medium to coarse sand, some clay
45.0'	50.0'	45	4"	Gray coarse to medium sand & gravel, trace clay
50.0'	55.0'	45	3"	Same
55.0'	60.0'	55	5"	Same
60.0'	81.0'			Gray sandy clay, stiff
81.0'	143.0'			Gray sandy clay, medium
143.0'	158.0'			Gray very sandy clay, w/thin layers of fine sand, very soft
158.0'	162.0'			Gray very sandy clay, stiff
162.0'	165.0'			Gray very fine to fine sand
165.0'	170.0'			Gray medium to fine sand
170.0'	176.0'	55	1/4"	Gray medium to coarse sand, trace fine sand & gravel, some clay
176.0'	177.0'			Gray sandy clay, stiff

NOTES: Size of Pit ____ X ____ X ____ DEEP

LW 100

WELL #3

TEST HOLE REPORT

Layne-Western Company, Inc.

Contract Name Harrison County PWSD No. 2

Job No. A-1405 D Date 12/5/85

City Coffey State Missouri

TEST HOLE No. 15-85

Driller O. J. Harper

Test Hole Location

Distance and Direction from Permanent Landmark or Previous Test Hole

TEST LOG

Static Water Level ______ Measured ______ Hours After Completion

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
177.0'	178.4'			Boulder
178.4'	182.0'			Gray sandy clay, stiff
182.0'	190.0'			Gray medium to fine sand, trace coarse sand
190.0'	195.0'	40	1/2"	Gray medium to coarse sand, trace fine sand, trace clay
195.0'	200.0'	40	1/2"	Same
200.0'	205.0'	40	1/2"	Gray medium to coarse sand, trace fine sand & gravel, dense
205.0'	210.0'	40	1/2"	Same
210.0'	215.0'	40	1"	Same
215.0'	216.4'	40	1/2"	Same
216.4'	218.0'			Gray shaly limestone, hard
218.0'	Total depth			

16

6

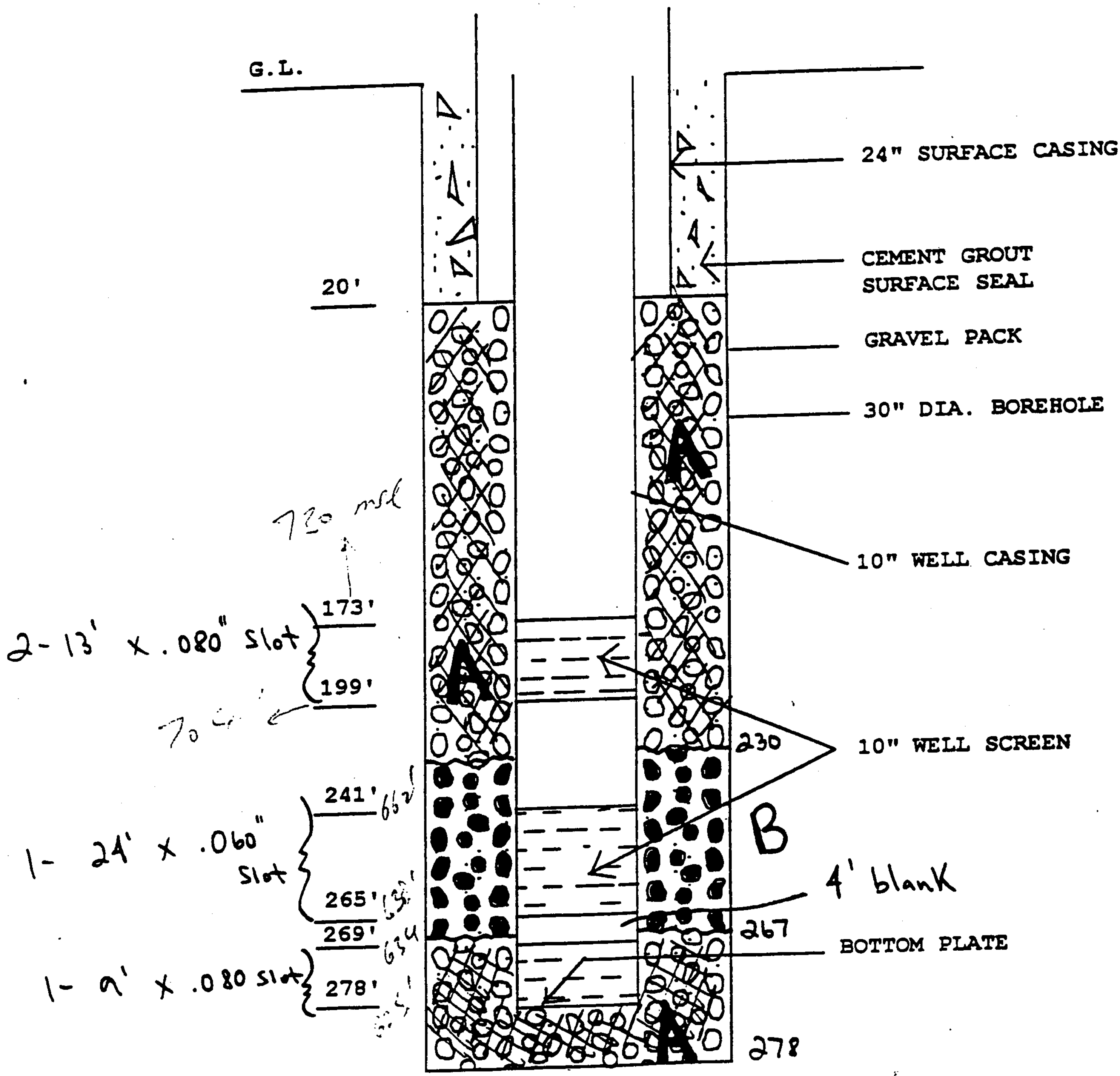
NOTES: Size of Pit ______ X ______ X ______ DEEP

LW-100

Layne WATER SUPPLY WELL
NO. 5

PWSD No 2
Well No. 4

(TH4-96)



NOTE:
ALL MEASUREMENTS ARE FROM
GROUND LEVEL.

Note: Gravel Pack A
+
Gravel Pack B

LAYNE-WESTERN COMPANY

...CT NAME: HARRISON CO #2

...: 748-4308 DATE: 10/03/96

...TY: COFFEY STATE: MO

TEST HOLE NO: ~~1-96~~ (Site of Well #

DRILLER: O.J. HARPER

AWSD NO. 2 Well No. 4

LOCATION: 373.0' E & 75.0' N OF SW CORNER OF NATION PROPERTY

TEST LOG

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	STATIC WATER LEVEL ______ MEASURED ______ HOUR AFTER COMPLETION FORMATION
0.0	1.0			TOP SOIL
1.0	15.0			GRAY BROWN SANDY CLAY
15.0	50.0			BROWN SANDY CLAY
50.0	63.0			GRAY BROWN SANDY CLAY STIFF
63.0	118.0			GRAY SANDY CLAY STIFF
118.0	122.0			GRAY FINE TO MED TRACES OF COARSE SAND
122.0	132.0	40	2"	GRAY MED TO COARSE. TRACES OF FINE SAND & GRAVEL FEW BOULDERS
132.0	156.0			GRAY SANDY CLAY MED
156.0	157.0			GRAY COARSE TO MED SAND & GRAVEL W/ BOULDERS
157.0	173.0			GRAY SANDY CLAY
173.0	175.0	41	1"	GRAY MED TO COARSE SAND & GRAVEL W/ BOULDERS
175.0	180.0	41	1 1/2"	GRAY COARSE TO MED SAND & GRAVEL W/ BOULDERS
180.0	185.	41	1 1/2"	GRAY COARSE TO MED SAND & GRAVEL W/ BOULDERS
185.0	190.0	41	2"	GRAY COARSE TO MED SAND & GRAVEL W/ BOULDERS
190.0	195.0	41	2"	GRAY COARSE TO MED SAND & GRAVEL W/ BOULDERS

NOTES: SIZE OF PIT PORTABLE DEEP

TEST HOLE REPORT

LAYNE-WESTERN COMPANY

CONTRACT NAME: HARRISON CO. #2

TEST HOLE NO: 4-96

JOB NO.: 48-4308 DATE: 10/03/96

CITY: COFFEY STATE: MO

DRILLER: O.J. HARPER

LOCATION:

TEST LOG

STATIC WATER LEVEL ______ HOURS AFTER COMPLETION MEASURED

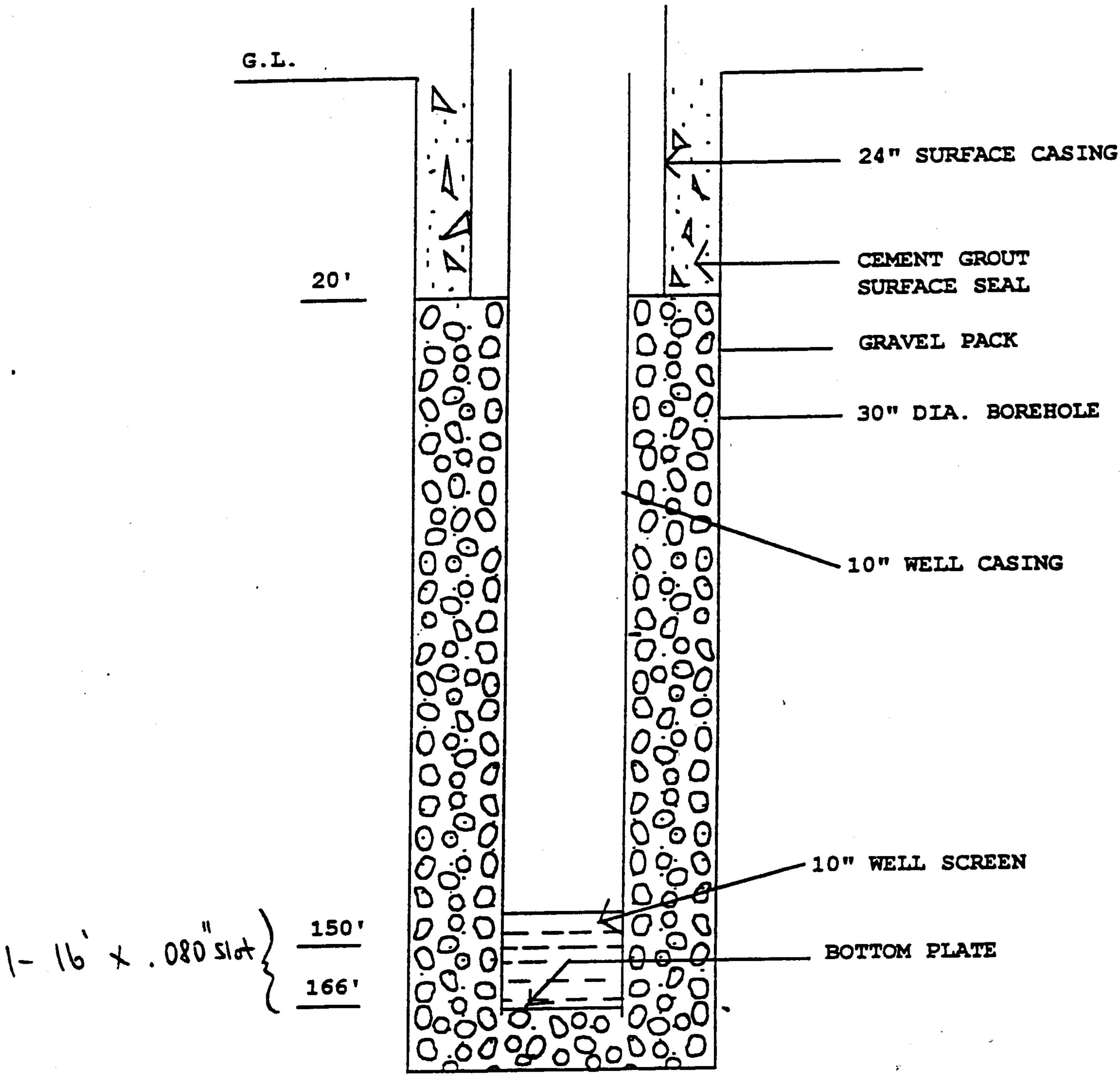
FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
195.0	199.0	40	1 1/2"	GRAY COARSE TO MED SAND & GRAVEL W/ BOULDERS
199.0	230.0			GRAY SANDY CLAY SOFT TO MED
230.0	241.0			GRAY VERY SANDY THIN SAND LAYERS SOFT
241.0	245.0	40	1/2"	GRAY FINE TO MED. TRACES OF SAND DENCE
245.0	250.0	40	1/2"	GRAY FINE TO MED. TRACES OF SAND DENCE
250.0	255.0	40	1/2"	GRAY FINE TO MED. TRACES OF SAND DENCE
255.0	260.0	40	1"	GRAY MED TO COARSE. SOME FINE SAND. TRACES OF GRAVEL
260.0	265.0	40	2"	GRAY COARSE TO MED. TRACES OF FINE SAND & GRAVEL
265.0	269.0			GRAY SANDY CLAY
269.0	275.0	40	1"	GRAY MED TO COARSE. SOME FINE SAND & GRAVEL W/ BOULDERS
275.0	278.0	40	1"	GRAY MED TO COARSE. SOME FINE SAND & GRAVEL W/ BOULDERS. TR OF CLAY
278.0	280.0			GRAY SHALEY LIMESTONE HARD

NOTES: SIZE OF PIT PORTABLE DEEP

WATER SUPPLY WELL
LAYNE NO. 4

PWSD No. 2
WELL No. 5

(TH9-85)



NOTE:
ALL MEASUREMENTS ARE FROM GROUND LEVEL.

LAYNE-WESTERN COMPANY

(Site of Well # 4

CONTRACT NAME: HARRISON CO PWSD #2
JOB NO.: 48-
DATE: 12/10/96
CITY: COFFEY
STATE: MO

TEST HOLE NO: 9-85-96
Site of PWSD No. 2 Well No.

DRILLER: O.J. HARPER

LOCATION: 30.0' S OF EW RD & CENTER LINE OF N RD TO BETHAN

TEST LOG

STATIC WATER LEVEL ______ MEASURED ______ HOUR AFTER COMPLETION

FROM	TO	MARSH FUNNEL VISCOSITY SECONDS	MUD PIT LOSS INCHES	FORMATION
0.0	1.0			TOP SOIL
1.0	27.0			BROWN SANDY CLAY STIFF
27.0	28.6			BROWN MEDIUM TO COARSE SAND
28.6	41.0			BROWN VERY SANDY CLAY SOFT
41.0	111.0			GRAY SANDY CLAY STIFF
111.0	113.0			GRAY FINE TO MEDIUM SAND
113.0	119.0			GRAY SANDY CLAY STIFF TO MEDIUM
119.0	138.0			GRAY SANDY CLAY, THIN LAYERS OF FINE SAND
138.0	140.0			GRAY FINE TO VERY FINE SAND
140.0	144.0			GRAY FINE TO MEDIUM SAND, TRACES OF CLAY
144.0	150.0	38	1"	GRAY COARSE TO MEDIUM, TRACES OF FINE SAND & GRAVEL
150.0	155.0	38	1"	GRAY COARSE TO MEDIUM, TRACES OF FINE SAND & GRAVEL
155.0	160.0	38	1"	GRAY COARSE TO MEDIUM, TRACES OF FINE SAND & GRAVEL
160.0	166.0	38	2"	GRAY COARSE TO MEDIUM, TRACES OF FINE SAND & GRAVEL
166.0	~~170.0~~			GRAY VERY SANDY CLAY MEDIUM TO SOFT

22'

NOTES: SIZE OF PIT PORTABLE DEEP

LAYNE GEOSCIENCES
a division of Layne Christensen Company

GROUNDWATER EXPLORATION AND DEVELOPMENT
- Geologic analysis
- Surface geophysics
- Fracture trace analysis
- Aquifer testing and characterization
- Groundwater flow analysis/computer modeling
- Well and well-field design (vertical, collector and horizontal)
- Water quality analysis
- Regulatory compliance/permitting assistance

GROUNDWATER SYSTEM PROTECTION AND MANAGEMENT
- Wellhead protection programs
- Salt water intrusion analysis and mitigation
- Water rights support
- Dewatering services
- Well and well-field monitoring
- Well and system rehabilitation
- Distribution system analysis
- Failure analysis/corrosion protection

ENVIRONMENTAL SERVICES
- Environmental site characterization
- Remediation technology evaluation
- Remediation system design and implementation
- Remediation system operation and maintenance
- Facility closure programs