Depletion to the Ogallala Aquifer
Northern High Plains
Designated Ground Water Basin

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ABSTRACT

The Ogallala Aquifer underlies approximately 9,000 square miles of the Northern High Plains of Colorado. Significant well development began in the southern portion of the basin prior to 1965. It was the rapid pace of well development and concerns about control of this development that was responsible for the passage of the "Ground Water Management Act" in 1965. The basin contained an estimated 118 million acre-feet of ground water in 1965. Since that time, approximately 17 million acre-feet have been mined from the aquifer. The current rate of withdrawal by approximately 4400 large capacity wells is between 800,000 and 900,000 acre-feet of consumptive use per year. This translates to an annual water level decline of approximately one-foot.

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(All Illustrations in Back Pocket)

PURPOSE

This study was undertaken at the request of the Colorado Ground Water Commission in order to determine if the existing rules governing the depletion to the Ogallala Aquifer are adequate to properly manage the ground water resources. The staff of the Colorado Division of Water Resources Geotechnical Services Branch began the study in November of 1989 and presented preliminary findings to the Commission at the May meeting in Denver. This report represents the finding of the study.

PREVIOUS STUDIES

Initial studies of the potential for ground water development were done in the 1950's and culminated in publication of a series of USGS Water Supply Papers and in Colorado Water Conservation Board Ground Water Circular 8 by McGovern and Coffin (1963) which summarizes the previous work. Further Studies were done by the United State Geological Survey which published a number of maps in the hydrologic atlas series and numerous basic data reports with data concerning water levels in wells in the Northern High Plains. Selected references to some of these reports are given at the back of this report.

In the 1960's, the USGS and Colorado State University began monitoring wells in the Ogallala Aquifer. A network was established and was measured by the USGS from the early 1960's until the mid 1980's. Funding for this was in part supplied by the Office of the State Engineer. Beginning in 1987, the Colorado Division of Water Resources was directed to establish and maintain a state-wide ground water monitoring network (Senate Bill 200, 1987). As part of this network, the Division began the collection and publication of water level data for the Northern High Plains. During the winter of each year water level measurements are taken in approximately 700 wells in the Northern High Plains Designated Ground Water Basin. The results of these measurements are published annually by the Division.

INTRODUCTION

Development of the ground water resources of the basin began prior to the 1950's. By 1960, about 400 irrigation wells were producing from the Ogallala Aquifer. Most of these wells were located in the southern portion of the basin around Burlington. Beginning in about the mid 1960's, there was a rapid expansion in irrigated farm land on the eastern plains and consequently a rapid increase in the number of irrigation wells producing from the Ogallala.

For the purpose of this report, the year 1965 has been chosen as the pre-development base year. This has been done for several reasons; 1) the rapid expansion of irrigated acreage began within a few years of this; 2) about this time pumpage began to exceed natural recharge to the aquifer; and 3) this year marks the beginning of extensive collection of water level data for the basin. The year 1989 was chosen for the ending year for the study since it was the last year for which complete data were available at the time the study was initiated.

In order to construct maps for the periods prior to 1989, it was necessary to obtain information concerning water levels, and bedrock elevations throughout the basin. These data were gathered from the U.S. Geological Survey data base, from well permit and logs maintained by the Division, and from water level measurements
collected by the Colorado Division of Water Resources with the assistance of the local Ground Water Management Districts. Data thus obtained were plotted in relationship to present observation wells so that data were related to common points. A data base containing data from the previous USGS network and the present network was established for the basin and was used to produce the maps contained in this report.

GEOLOGY

The Northern High Plains region is underlain by the Ogallala Formation which constitutes the primary aquifer for this area. The Ogallala Formation is of Pleistocene age and unconformably overlies, from north to south, the Chadron Formation, the Pierre Shale, and the Niobrara Formation. The Chadron Formation of Oligocene age consists primarily of low permeability siltstone. The Pierre Shale of Late Cretaceous age, is a dark colored shale to sandy shale. The Niobrara Formation of Late Cretaceous age is a calcareous shale to marlstone. These formations form a generally impermeable surface on which the Ogallala Formation rests. This surface was highly dissected prior to the deposition of the Ogallala causing significant local variations in the thickness of the formation.

The Ogallala Formation is a poorly consolidated alluvial deposit consisting of clay, silt, sand and gravel. The formation is generally coarser near its base and clay and silt fractions increase toward its top. The degree of cementation by calcium carbonate varies irregularly throughout the unit. Sandy fresh-water limestone beds occur occasionally in the formation. Permeabilities consequently are highly variable through the formation.

The Ogallala Formation is overlain by unconsolidated Quaternary age deposits consisting of alluvium, dune sand, or loess. The alluvium occurs in major drainages with the other deposits distributed over the inter-drainage divides. Much of this deposition occurred in the Pleistocene Epoch, and the deposits are currently being eroded. A general diagram of the structure of these formations is shown in Figure 1.

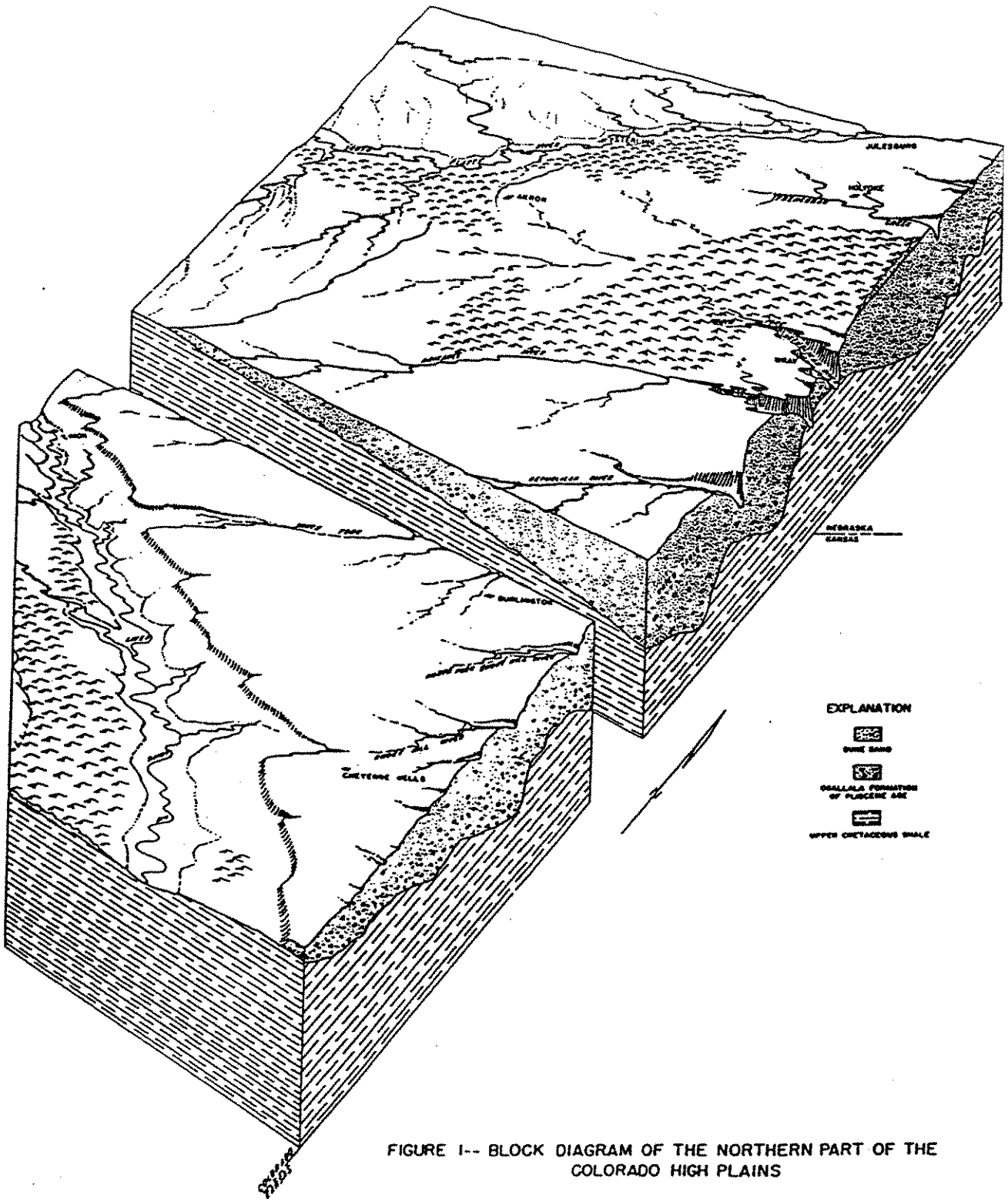

FIGURE I-- BLOCK DIAGRAM OF THE NORTHERN PART OF THE COLORADO HIGH PLAINS

(From McGovern (1963), CWCB Circ. 8)

GROUND WATER

OCCURRENCE

Current saturated thicknesses in the Ogallala Aquifer vary from less than 10 feet to greater than 300 feet. This is depicted on Plate 1. Plate 1A shows the saturated thickness determined for the pre-development year 1965. The greatest saturations are limited in area and are associated with the thickest portions of the Ogallala Formation which is located north of the North Fork of the Republican River. These are most likely associated with deep valleys developed in the pre-Ogallala surface. Saturated thicknesses are less than 50 feet over the western third of the Northern High Plains area, south of Cheyenne County, and in the lower Republican and Arikaree River drainages.

Movement of ground water in the Ogallala Aquifer is generally flowing to the east or northeast as indicated by the water table contour map (Plate 2). Some ground water contributes to surface flow in the lower Republican and Arikaree Rivers. The bulk of the natural discharge from the Colorado portion of the Ogallala Aquifer occurs as underflow into Kansas and Nebraska. Surface discharge to the river systems was estimated at 40,000 acre-feet annually in 1960 and underflow was estimated at 390,000 acre-feet per year. Due to the almost ten-fold increase in pumping in the last 25 years, natural discharge and pumping now substantially exceed the natural recharge from precipitation of approximately 430,000 acre-feet per year.

QUANTITY AND AVAILABILITY

The quantity of ground water in storage in the Ogallala Aquifer is shown in Table 1. The average saturated thickness is an unweighted average of all wells in the Northern High Plains database of the Colorado Division of Water Resources.

Table 1

WATER IN STORAGE IN THE OGALLALA AQUIFER

	Basin Acreage	Saturated Thickness	Specific Yield	Storage AF	Depletion AF
Pre-development (1965)	5.76M	137 ft	15%	118.37M	–
Current (1989)	5.76M	117.7 ft	15%	101.69M	16.69M

** M = Million

The average annual depletion in the Ogallala Aquifer from 1965 to 1989 has been 694,800 acre-feet per year. Approximately 4380 permitted high capacity wells were in the Northern High Plains of Colorado in 1989. Declines for the last two years have averaged 1.0 foot over the Colorado portion of the aquifer yielding an average consumptive use withdrawal per well of 198 acre-feet. Peak pumping most likely occurred in the early to mid 1970's and was probably on the order of 1.2 to 1.5 million acre-feet per year.

RULES FOR THE APPROPRIATION OF GROUND WATER FROM THE OGALLALA AQUIFER

Basically wells are allowed to appropriate ground water at a rate which will deplete the Ogallala Aquifer 40% in 25 years within a three-mile cylinder at the proposed well site. This is modified by existing appropriations within the three mile circle and by an assumption of 15% irrigation return flow to the aquifer (deep percolation) and precipitation recharge. In calculating the allowable appropriation, an application rate of 2 1/2 acre-feet per acre is assumed (400 acre-feet for 160 acres).

ESTIMATED ALLOWABLE APPROPRIATION (DEPLETION CAPABILITY)

As part of this study, it was necessary to determine the capability of existing wells to deplete the aquifer at the 40% in 25 years rate. To estimate this it was first necessary to estimate the volume of water available in each township. This was calculated using the following formula:

Volume = Saturated Thickness (1989) x Specific Yield x Number of Sections in Township x 640 Acres

$$V = Sat \times Sy \times Sec \times 640$$

This was converted into allowable yearly appropriation by multiplying the volume (V) by 40% and dividing by 25 years and a consumptive use factor:

Allowable Appropriation (Approximate)

$$A = \frac{V \times .4}{25 \times .85}$$

The approximate permitted appropriation was obtained by multiplying the number of wells by 400 acre-feet (160 acres x 2.5 acre-feet/acre).

The final step was to compare the allowable appropriation with the permitted appropriation. For most townships the permitted appropriation exceeds the allowable appropriation. This is shown on Plates 4 and 5. The reader is cautioned that these figures are estimates and should be viewed as such. Many of the areas identified on Plate 5 as not being over-appropriated contain less than

50 feet of saturated material and it may not be possible to construct large capacity wells in these areas (the 50 foot saturated thickness line is shown on the plates for reference). Townships which would require between 1 and 4 wells to over-appropriate may well be already over-appropriated when evaluated by the "three-mile circle" procedure.

GROUND WATER TRENDS
(ACTUAL DEPLETION)

At the beginning of the study, several maps were constructed based on detailed data concerning the Ogallala Aquifer obtained from the USGS and the Colorado Division of Water Resources. First, a bedrock surface and pre-development water table map were constructed. Data were obtained for points represented by wells in the current water level monitoring network (approximately 700 data points). The data were used to calculate the change in saturated thickness (decline) throughout the basin and in constructing a water level change map (Plate 3) for the period 1965 to 1989. From this, the actual depletion to the aquifer was calculated by comparing the 1989 saturated thickness to the pre-development (1965) saturated thickness and adjusting for 25 years. This gave the percent depletion in 25 years which was used to construct a map showing areas which have equal rates of depletion (Plate 6). This map is somewhat generalized in that it gives just three zones of depletion 1) less than 20%; 2) 20 to 40%; and 3) greater than 40% in 25 years. This was done for purposes of illustration and more detailed mapping is available in the Division office.

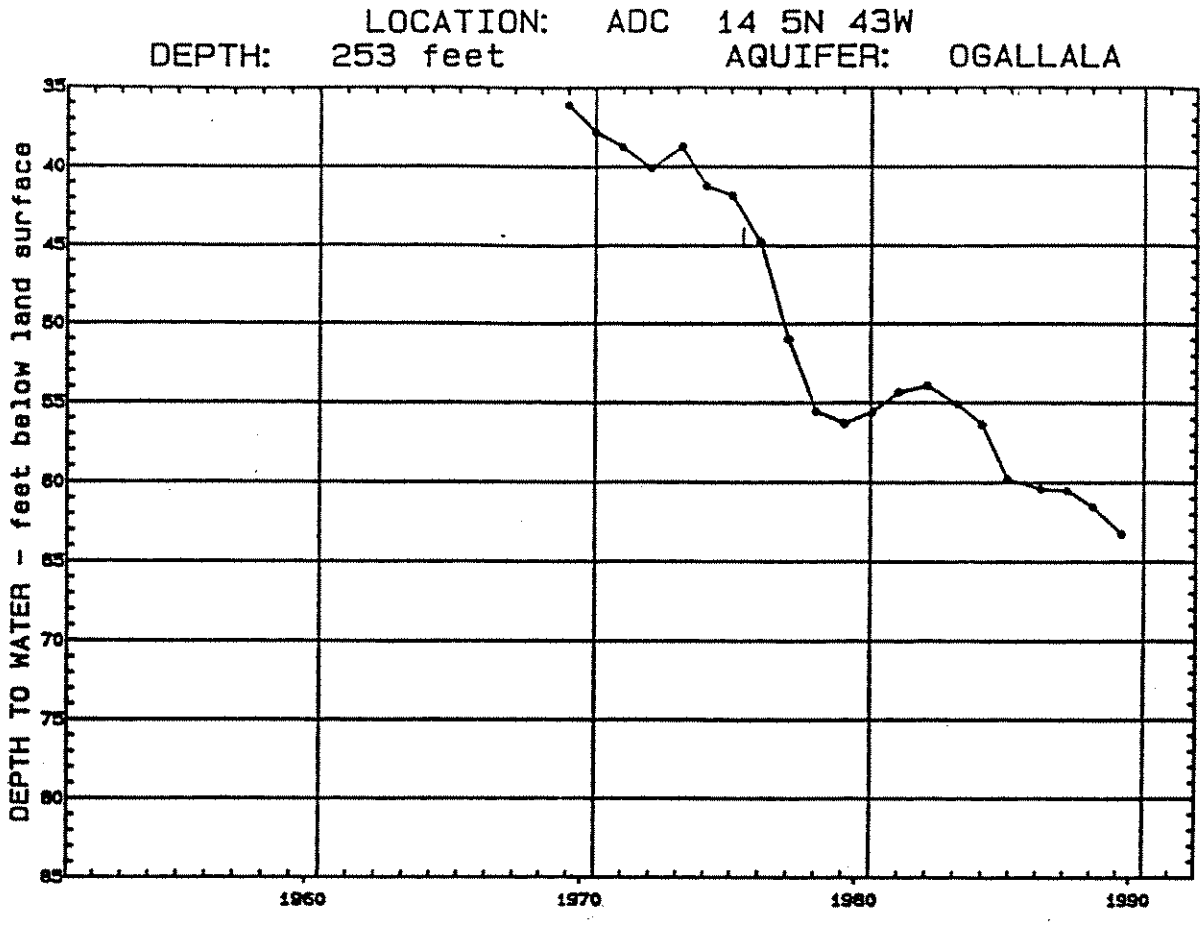

Figure 2

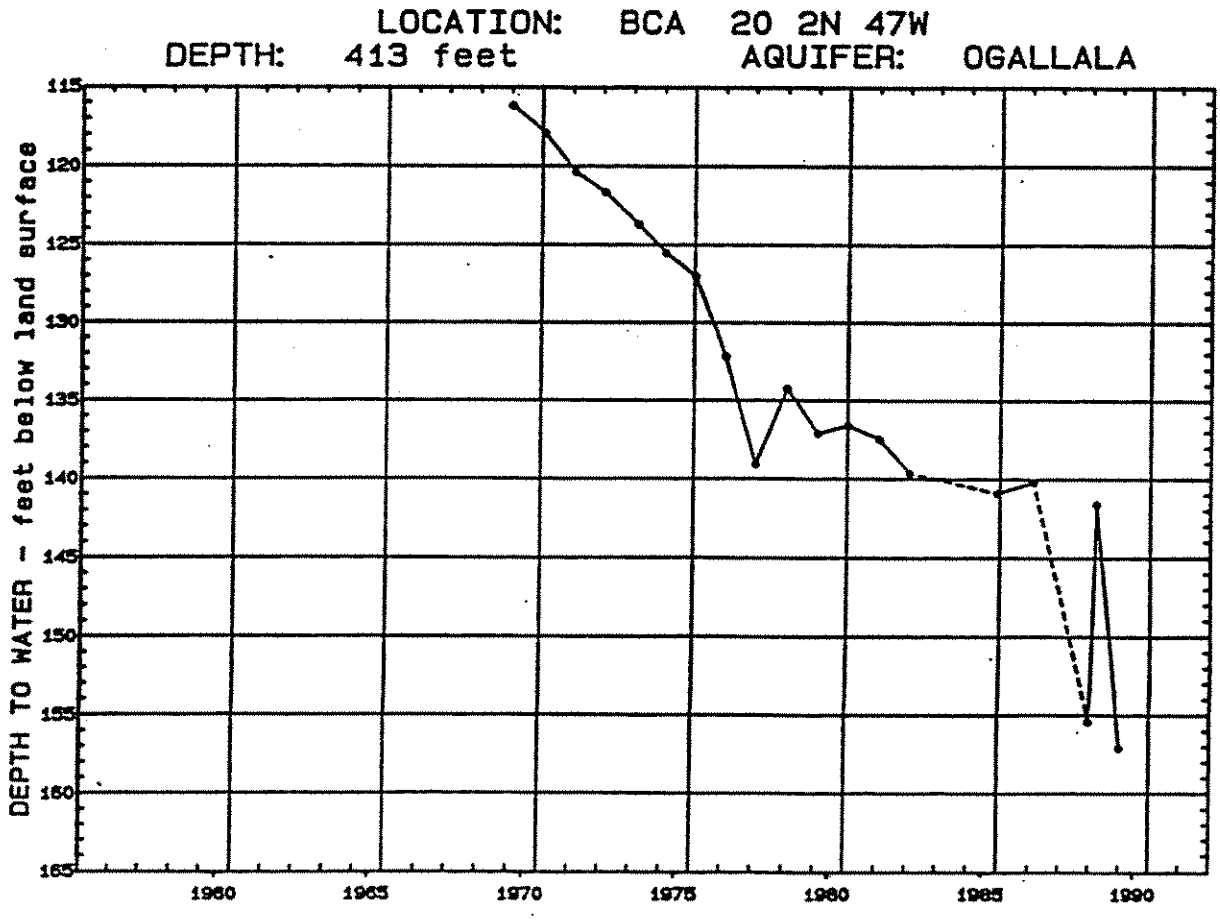

Figure 3

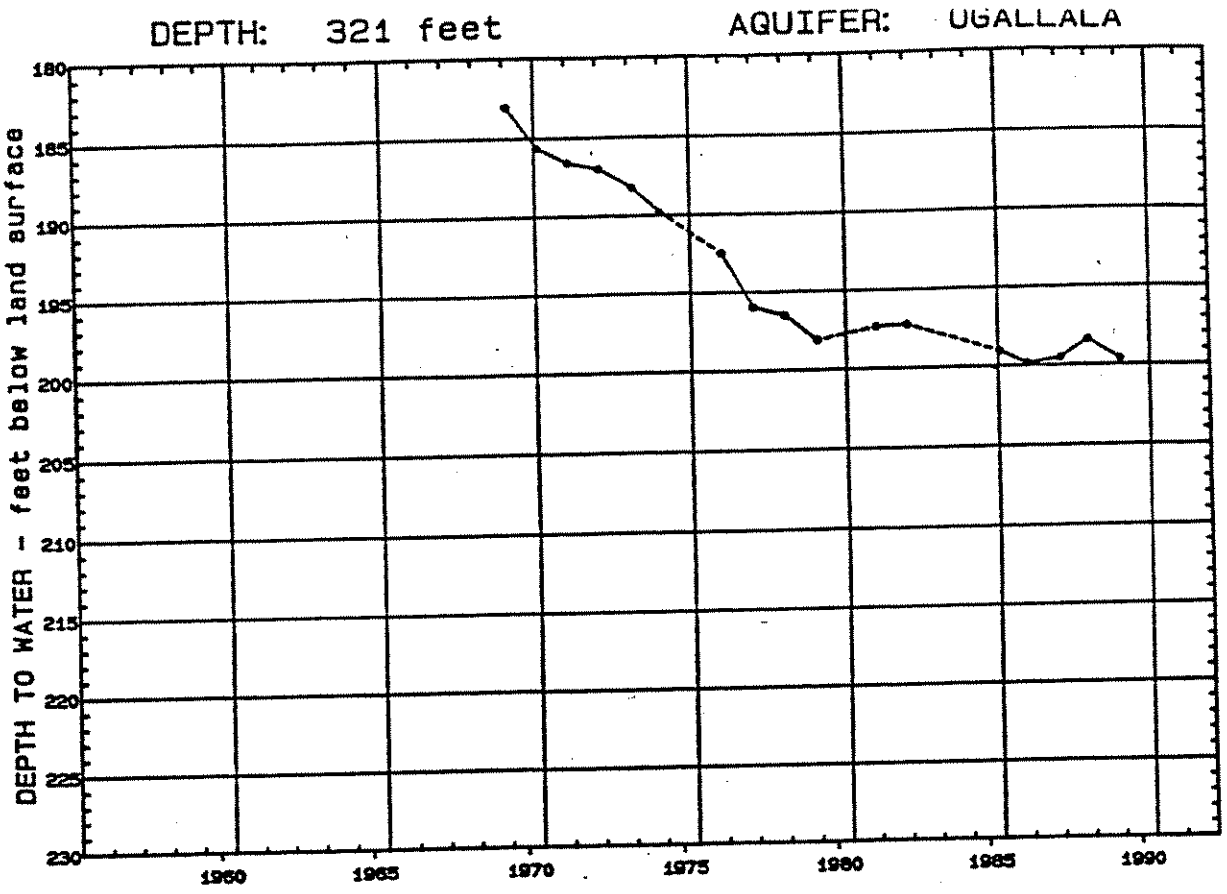

Figure 4

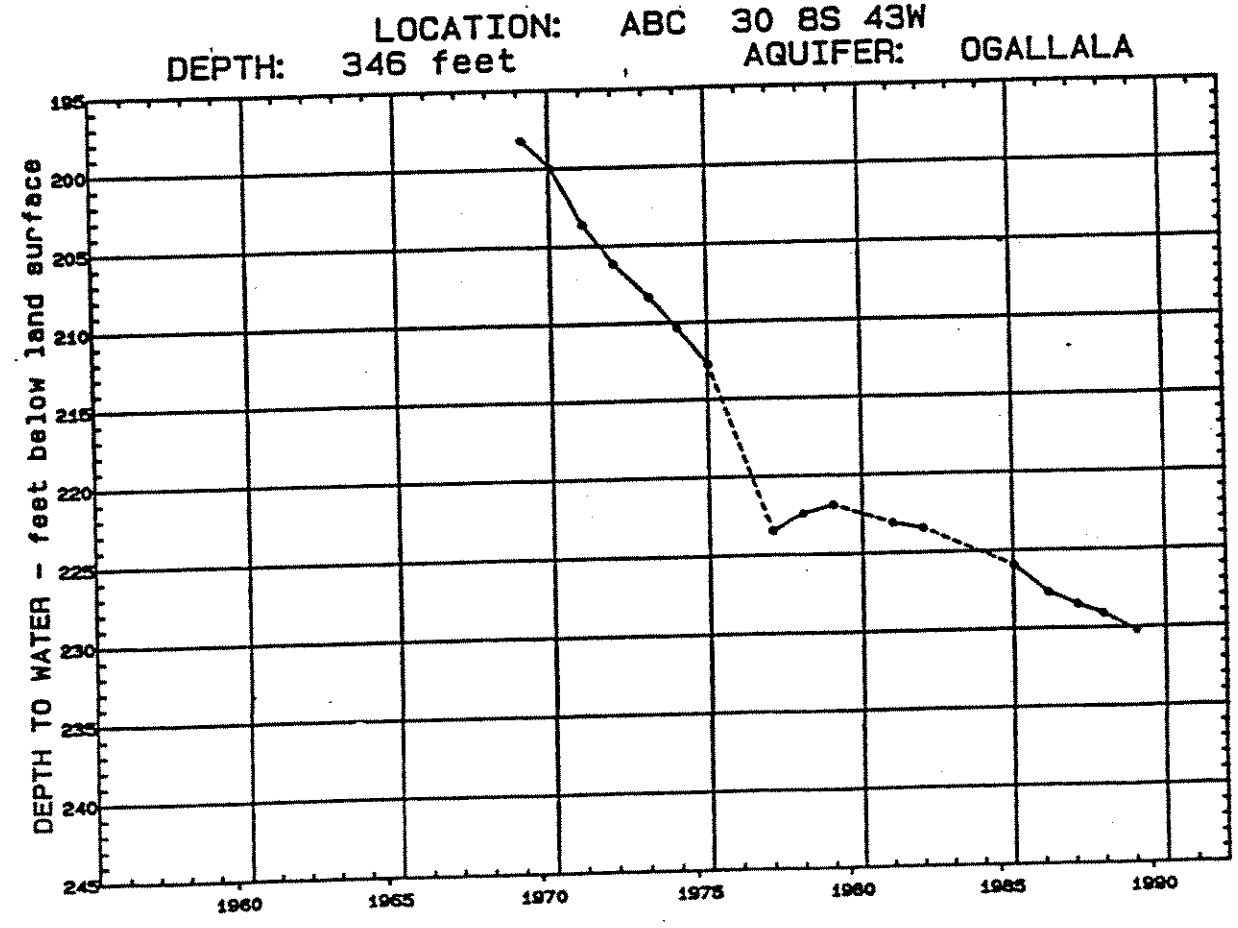

Figure 5

After examining well hydrographs (representative hydrographs are presented as figure 2-5) throughout the basin, it was evident that in the mid to late 1970's there were a number of factors which contributed to changes in the pattern of depletion. These are generally economic in nature but also include items such as changing crop patterns and associated irrigation requirements. For this reason it was decided to construct additional maps showing the depletion trend based on early data (pre-development (1965) to 1978, Plate 7) and later data (1978 to 1989, Plate 8). These trends were adjusted so that the depiction represents the trend as though it was for a 25 year period.

Table 2 shows the calculated 25 year depletions and saturated thicknesses for the period 1965 (pre-development) to 1989. This table is based on strict numeric averages. The data are biased by averaging and by separating the data by management district. However, the overall trends are similar to those shown on Plates 1, 1A, 6, 7 and 8.

Table 2
DEPLETION (BASED ON AVERAGE VALUES) *

BASIN	1965 SAT. THICKNESS	1989 SAT. THICKNESS	CHANGE (feet)	25 YEAR % DEPL.
MARKS BUTTE	150.8	145.9	- 4.9	3%
FRENCHMAN	152.6	139.5	-13.1	10%
SANDHILLS	273.7	257.4	-16.3	7%
CENTRAL YUMA	185.0	167.7	-17.3	10%
W-Y	171.8	150.6	-21.2	13%
ARIKAREE	82.7	69.6	-13.1	18%
PLAINS	123.9	98.3	-25.6	23%
EAST CHEYENNE	107.6	82.0	-25.6	26%
WASHINGTON COUNTY (not in GWMD)	65.1	25.7	-39.4	66%
KIOWA COUNTY	114.8	55.9	-58.8	56%
PROWERS COUNTY	75.0	56.4	-18.6	28%
TOTAL NHP BASIN	137.0	117.7	-19.34	16%

* Averaged for approximately 700 observation wells.

WATER BALANCE

Actual water level declines in the basin have averaged about one-foot per year for the last several years. Based on the previous estimate of the quantity of water in storage in the aquifer, this represents a consumptive use withdrawal of approximately 864,000 acre-feet per year. This would translate into an application rate of about 200 acre-feet per well for the approximate 4400 wells in the basin or 1 1/4 acre-feet of consumptive use per irrigated acre. This is in line with the actual average consumptive use for crops presently grown on approximately 700,000 irrigated acres. If wells were to pump their entire allowable appropriation, declines would average 2-feet per year.

Although the remaining average saturated thickness is still over 100 feet, it should be noted that the practical limit for developing large capacity wells is probably on the order of a minimum of 30 feet of saturated material. Based on averages for from Table 2, in the Plains Ground Water Management District, only about 60 feet of useable aquifer remain while the Arikaree Ground Water Management District has only about 40 feet of useable aquifer. This should be contrasted with the Sand Hills Ground Water Management District where over 200 feet of useable aquifer remains.

CONCLUSIONS

Although the average actual depletion throughout the basin for the past 25 years has been less than 20 percent, there are significant areas where the depletion has exceeded the allowable 40% in 25 years. In addition to this, in most cases the permitted well capacity already exceeds the allowable criteria. The present application (consumptive use) rate of 1 1/4 acre-feet per acre is based upon present cropping with corn and wheat predominating. If in the future crops such as sugar beets and alfalfa again are popular, the amount pumped could approach the 2 1/2 acre-feet per acre.

SELECTED REFERENCES

Boettcher, A.J., 1966 [1967], Ground water development in the High Plains of Colorado; U.S. Geological Survey Water-Supply Paper 1819-1.

Borman, R.G, 1983, Predevelopment and 1980 Water Table in the Northern High Plains of Colorado; and Water-Level Changes, Predevelopment to 1980, and 1975 to 1980. U.S. Geological Survey Hydrologic Atlas HA-670.

Borman, R.G. et al, 1983, The Ogallala Aquifer in the Northern High Plains of Colorado--Saturated Thickness in 1980; Saturated Thickness Changes, Predevelopment to 1980; Hydraulic Conductivity; Specific Yield; and Predevelopment and 1980 Probable Well Yields. U.S. Geological Survey Hydrologic Atlas HA-671.

McGovern,H.E. and Coffin, D.L., 1963, Potential Ground-Water Development in the Northern Part of the Colorado High Plains, Colorado Water Conservation Board, Ground Water Circular No.8.

Reed, R.L., 1988, Ground-Water Hydrographs, 1970-87, and Water-Level Data, 1986-1987, for the Northern High Plains of Colorado. U.S. Geological Survey Open-File Report 88-178.

VanSlyke, G.D., 1989, Water Levels in the Northern High Plains Designated Basin 1988/1989, Colorado Division of Water Resources.

VanSlyke, G.D., 1990, Water Levels in the Northern High Plains Designated Basin 1990, Colorado Division of Water Resources.