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REPORT OF FINDINGS

OF THE

EQUUS BEDS GROUNDWATER RECHARGE PROJECT

OF THE

CITY OF WICHITA

WATER & SEWER DEPARTMENT

By

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TABLE OF CONTENTS

FIGURES

INTRODUCTION

1.1 The Board of Directors of Equus Beds Groundwater Management District No. 2, at the March 9, 2004, meeting approved a motion authorizing Carl E. Nuzman to review the City of Wichita's Aquifer Storage and Recovery Program water applications No. 45,567 through No. 45,576 for the District. The scope of services for this Consulting Agreement is limited to the review of the information submitted with the City of Wichita's applications that was submitted to the Equus Beds Groundwater Management District No. 2 (GMD No. 2), by the Division of Water Resources, and such other published or available information contained in the files of the GMD No. 2, furnished by the Staff as appropriate, and make recommendations to the Board of Directors for the approval, changes or modifications that would be in the best interests of all concerned with the project. The Consultant is expected to be able to address the following issues and others as may be raised by the review of information or raised by members of the GMD No. 2.

1.2 Such issues pertain to the source water recharge wells, the aquifer geology, the Little Ark river bed infiltration rate, the depth of aquifer penetration by source water wells, spacing between source water recharge wells, the spacing from domestic and other water right wells, aquifer drawdown and recovery control, Little Ark river minimum flow control, structures and facilities that may be required, and monitor wells needs for the source water wells and recharge-recovery wells.

1.3 Another issue of concern is the source water wells location; land acquisition policy, environmental impact on adjacent property, and property owners' compensation. The issue of the aquifer recharge system concerns are as follows; the soil profile and aquifer geology, the water table hydraulic gradient existing and design conditions, the depth to water level, the method of control and monitoring, the type of system for recharge, i.e., trenches or wells, water storage capacity of the soils and aquifer, metering of aquifer water recharged, water use accounting in the vicinity, and the monitor wells needs at recharge sites. Concern was expressed about the general aquifer recharge in the vicinity of City wells, the method of recharge, location of recharge wells, if used, and water quality control monitoring.

1.4 The review of this Consultant is focused on the northern portion of the project on the diversion of water from wells adjacent to the Little Arkansas River and the recharge and recovery of injected water in the northern part of the Wichita well field.

DESCRIPTION OF THE PROJECT

2.1 The concept of the project is to take water directly from the channel flow of the Little Arkansas River when flows are in excess of the minimum desirable stream flow and of sufficient quality as to be suitable for recharge of the aquifer for potable water supply. If the quality is less than desired, such water treatment schemes will be employed to meet all Environmental Protection Agency and Kansas Department of Health and Environment policies and regulations. Another alternative that is the primary subject of this review is to develop wells near or adjacent to the Little Arkansas River channel and infiltrate the flow of water in the channel into the connecting aquifer for diversion and recharge of the center portion of the Equus Beds aquifer utilized by the City of Wichita and to protect the principle aquifer from outside contamination.

2.2 The Equus Beds Groundwater Recharge the Demonstration Project is a phased, small-scale research project to test the feasibility of a full scale groundwater recharge, storage and recovery project. In brief, the demonstration project by the City of Wichita proved the project is feasible and is needed to insure the long term viability of the Equus Beds aquifer for the future supply of the City of Wichita.

2.3 The first step to implementation of the project is to file with the Division of Water Resources, of the Kansas Department of Agriculture, for water rights to divert water from wells adjacent to the Little Arkansas River for delivery to the northwest portion of the well field to halt the spread of high chloride water from the Burrton oil well field that will in time impact the water quality of the northern portion of the Wichita well field that has been in service since about 1944. As the project develops, water from the Halstead area will be diverted for direct supplemental recharge to the well field.

SOURCE WATER RECHARGE WELLS

3.1 Aquifer Geology

3.1.1 The aquifer geology in the vicinity of the test well site TH-04 at Halstead consists of a shallow aquifer generally in direct communication with the Little Arkansas River channel followed by a clay layer of a different depositional period, overlying a deeper alluvial type aquifer consisting of permeable sands and gravel with usually thin intermittent clay lenses throughout the lower aquifer. The lower aquifer is the thickest and most productive aquifer in the Equus Beds geologic formation. The City of Wichita wells were developed in the thickest part and most productive area of the Equus Beds aquifer.

3.1.2 The clay layer separating the shallow aquifer from the deep unconsolidated aquifer was found between 30 and 60 feet below ground level in all but one of the boring logs reviewed in the Halstead area. The shallow aquifer of varying thickness was identified in the boring logs reviewed to be between 10 and 40 feet below ground surface. The deep aquifer extended to depths from about 130 feet below land surface to 160 feet at boring DW-TW-03. Because of the thicker and more permeable sands and gravel formation in the lower aquifer, it is more economical to construct wells of high production in the lower aquifer than in the shallow aquifer in this vicinity.

3.1.3 Northwest of Halstead, in Section 8, Township 23 South, Range 3 West, the bed of the Little Arkansas River in some places is connected directly to the shallow aquifer. In other places, some intermittent clay layers may separate the bed of the Little Ark river from the shallow aquifer. The clay layers in the deep aquifer are intermittent and do not appear at any consistent level in this aquifer. However, the clay layer separating the upper aquifer from the lower aquifer appears nearly continuous and apparently deposited in a quiet geologic period and absent only where erosion forces associated with the deposition of the shallow aquifer fully penetrated this layer. West of the Halstead test well at EB-145-A3, the thick separating clay layer was absent and another area was found near the Sedgwick test area. The separating clay layer between the shallow aquifer and deep aquifer was identified in most of the well logs reviewed in the Halstead area.

3.2 Little Ark River Bed Infiltration Rate

3.2.1 In examining the test pumping data furnished in the published reports, the Consultant was not able to determine a specific rate of infiltration from the Little Ark river to the test well. This is partly due to the way the test well was constructed and the arrangement of the piezometers in the shallow aquifer and the lack of piezometers in the bed of the river.

3.2.2 Typical river bed infiltration rates determined by the Consultant in other areas vary from greater than 748 gallons per day per square foot (gpd/ft^2) (river bed conductance of 100 ft^2/d) of bed wetted area for a coarse sand and gravel river bed like the Platte in Nebraska, to less that 25 gpd/ft^2 (3.3 ft^2/d for a stream bed similar to that of the Little Ark river. Other investigators have determined that sandy bottom streams with considerable clay content typically have bed conductance rates in the 6 to 10 ft^2 /d range. The infiltration rate of the stream cells used by the

Wichita Consultants was 469.5 ft^2/d which converts to 3,512 gpd/ft^2 of wetted area of the stream bed.

3.2.3 The river bed conductance value used by the Wichita Consultants not only reflects the infiltration of the Little Ark river water to the shallow aquifer but includes aquifer recharge from natural precipitation, leakage from the shallow aquifer to the deep aquifer and aquifer boundary flow. In many places the actual width of the Little Ark river water flow is less than the 100 foot cell width used in the Mod-Flow sub-regional ground water model. What the Wichita Consultants sub-regional model work did show was that the recharge to the deep aquifer in the vicinity of the Little Ark river is greater than the natural recharge from precipitation to the Wichita well field area.

3.2.4 The unique characteristics and flow through clays is not well understood by many Hydrogeologist. The porosity of clays typically varies from about 45% to 55% of the total volume, while the porosity of sands and gravel typically varies from 30% to 35% depending upon the mix of particle sizes. Thus clays are more porous than sand and gravel but much less permeable.

3.2.5 Porosity and permeability are sometimes confused. Permeability as developed by Henri Darcy (1856) while measuring flow vertically through sand filter beds in effect defined the limit of laminar flow for the existing fluid viscosity through sands. The direct flow through sands and gravels can be 100 or more feet/day (ft/d) where as the actual flow through clay is typically about 1 ft/d. Thus the permeability of clay is very low. However, clay can transmit water pressure at a rate of about 1000 feet/minute. Thus the rise or fall of water level in the Little Ark river can be observed in aquifer wells in a matter of a few seconds to a few minutes at considerable distance away from the river.

3.2.6 Clays can transmit considerable water vertically by the pressure gradient established by the drawdown of a pumping well. In this situation, a drop of water enters the top of the clay, and quickly a drop of water leaves the bottom of the clay layer, but it is not the same drop that entered the top. This is best demonstrated by stacking dominos on end and pushing the first one and finally the end one falls down. Thus the appearance of large leakage rates through clays can occur when the physical movement of water through clays is limited.

3.2.7 The issue of fluid viscosity was not discussed by the Wichita Consultants in addressing the river infiltration rate. The viscosity of a fluid decreases as the fluid temperature increases. In the summer months the infiltration rate will be greater than in the winter months. Therefore aquifer water levels need to be used as a gauge in the regulation of the source water well pumpage in addition to that of the flow of the river.

3.3 Depth of Aquifer Penetration by Source Water Wells

3.3.1 The test well at site TH-04 was designed and constructed to the normal public water supply standards set by the Kansas Department of Health and Environment for direct use to the public. These standards need not apply to a source water wells for recharge to an aquifer when the water is not used directly for public water supply. The suggested design criteria is to penetrate the full saturated thickness, regardless of clay layers as is commonly done in building construction dewatering work to a depth of 20 feet below ground level, where a grout seal is placed to prevent the direct entry of any storm water runoff to the well. A large diameter bore hole should be used with a minimum of 48 inches and 60 inches is the preferred diameter. Casing and screen diameters should be between 24 inches and 30 inches in diameter. The only blank sections of the screen should be used where fine to very fine sand layers are encountered. The clay lenses should have continuous screen through these layers of formation to reduce the differential pressure across these clay layers created by the drawdown of the well. Typically most irrigation wells are constructed in this manner. Drawdown into the top of the screen when the zone is aerobic does not cause precipitation of minerals or plugging of the screen. Excessive drawdown into the anaerobic zone of the aquifer or cascading of water from one zone to another in the well casing can cause some well plugging problems. Thus the need to continue the gravel pack through clay layers in the geologic formations especially when the clay layers are intermittent.

3.3.2 The development of Arsenic in the test well at Halstead was due to the reduction of pore pressure at the bottom of the 20 foot thick clay layer from 40 to 60 feet at the top of the well screen. The clay was in an anoxic state and the consolidation of the bottom portion of the montmorillonite type clay, due to the reduction of pore pressure from pumping and accompanied by a small amount of land subsidence, converted the natural arsenic in this type of clay to a slightly soluble form of arsenic as As III and As V that was detected in the mineral analysis of the pumped water. Another purpose of extending the well screen and gravel pack across these clay layers is to reduce the pressure differential across the clays to limit to the extent possible, any development of Arsenic in the pumped water. The pressure differential is always greatest at the top of the well screen or directly opposite the termination of the pump suction if set into the screen. The larger diameter well bore hole will also help in the reduction of arsenic from the pumped well.

3.4 Spacing Between Source Water Recharge Wells

3.4.1 Since the direct infiltration of water from the Little Ark river is limited and water is withdrawn from aquifer storage that is eventually replaced by the delayed influence of recharge from the Little Ark river, such well spacing should comply with the rules and regulations of the Groundwater Management District No. 2 and the Division of Water Resources, of the Kansas Department of Agriculture. Using double the distance drawdown transmissivity determined from the 24-hour parallel line of piezometers of 14,480 ft^2 /day reflecting the influence of the Little Ark river infiltration, the storativity of 0.006 for 30-days of continuous pumping, and a well radius of 2 feet for a 48-inch bore hole, and plotting on a distance-drawdown semi-log plot, the radius of influence was found to be approximately 4,000 feet. The 10 percent mutual interference level occurs at about 1500 feet distance, therefore it is recommended that the minimum spacing between source water wells be 1320 feet.

3.5 Spacing from Domestic and other Water Right Wells

3.5.1 The spacing between any source water recharge wells and domestic wells should be a minimum of 660 feet in compliance with the Division of Water Resources regulations. The spacing to other water right wells should be a minimum of 1320 feet in compliance with current regulations. The physical travel of water in the aquifer is slow with gradients of a few feet per mile.

3.6 Aquifer Drawdown and Recovery Control

3.6.1 Aquifer drawdown and recovery control becomes key to the successful operation of the source water recharge wells without having an adverse impact on current water right appropriators. Source water recharge wells should be located within 300 feet of the edge of the stream water at normal low flow.

3.6.2 The ground water recharge to the aquifers near the Little Ark river is greater than the natural recharge to the majority of the Equus Beds aquifer. Referring to the model study done by the Wichita Consultants, the recharge may be as much as two to three times greater than the average recharge to the Equus Beds aquifers. It was reported that the aquifer reached steady-state conditions about 16 days into the constant rate test pumping.

3.6.3 The observation of the recovery of water levels after pumping stops is essential to show river infiltration effects on the aquifer. The recovery data was not fully reported in the data reviewed but indications were that substantial recovery of water levels occurred within 7 days from the cessation of pumping.

3.6.4 The timing of pumpage from the source water recharge wells should not begin until stream flow is at or above the minimum flow specified by the Division of Water Resources and ground water levels are at or near normal base levels. Normal base ground water levels can be established by examining a number of years of water level measurements in key observation wells located within about 2-miles of the Little Ark river when the stream flow is near the minimum desired flow rate as established for this project.

3.6.5 The drawdown shall not exceed about 10 feet below the normal base level ground water level established at a distance of 660 feet from any source water recharge well in a general westerly direction in either aquifer. Further the combined drawdown from any or all source water recharge wells when operating shall not exceed 7 feet below normal base ground water levels in either aquifer at approximately ½ mile in any direction at any time.

3.7 Little Ark River Minimum Flow Control

3.7.1 The minimum desirable stream flow at Alta Mills is 8 c.f.s and 20 c.f.s at the Valley Center gauging station set by Statute in the Water Appropriation Act, K.S.A. 82a-703c.

3.7.2 A review of the gage heights and flow records of the Little Ark river from November 9, 2002 through March 17, 2003 showed a flow generally of 20 c.f.s or less at the Highway 50 gage site. When flows in the river are in excess of 20 c.f.s, ground water levels near the river will normally be above normal base flow levels unless significant dewatering of the aquifer has occurred from prior pumping from the aquifer. Therefore, the Consultant concurs with the Division of Water Resources that pumpage from the source water recharge wells shall be further limited to operation when the stream flow in the Little Ark river at the Highway 50 gage site shall be equal to or greater than 20 c.f.s during the months of October through March, and equal to or greater than 42 c.f.s. during the months of April through October for this project in the Halstead area.

3.8 Structures and Facilities that may be Required

3.8.1 Due to the slope of the bed of the stream and to maximize the wetted area of the stream bed, it may be desirable to install channel rip-rap to a height of about 18 inches above the normal flow level every ½ mile or so to increase the infiltration of water from the channel to the shallow aquifer. Where rock aggregate is not available, concrete rubble from sidewalks or building foundations has been used successfully for this purpose. Sometimes some lean concrete is added for stability of the structure. The low height structures do not interfere with the natural scouring of the channel during high flows that help maintain communication of the stream bed to the shallow aquifer.

3.8.2 It may be possible to establish a stream gage height at each source water recharge well to allow automatic operation of pumping from these wells. There should be some input from nearby ground water level monitoring wells that if the drawdown is excessive, the pumping rate is reduced or the pump motor is turned off until conditions allow continued operation.

3.9 Monitor Wells Needed for Source Water Recharge Wells

3.9.1 It is difficult to have a monitor well every place desired and reasonableness must prevail. Working along a tree line parallel to the river, the City of Wichita should desire some observation or monitor wells in both the shallow aquifer and lower portion of the deep aquifer at approximately 50 feet, 150 feet and at 660 feet to monitor the condition of the source water recharge wells for operating efficiency and maintenance.

3.9.2 For aquifer protection, monitor wells need to be placed roughly 660 and 2640 feet in a general westerly direction from the source water recharge wells. Where wells with water rights exists east of the Little Ark river, monitor wells of similar spacing should be installed toward those wells.

3.9.3 To observe the effects of pumping the source water wells in all seasons, it is recommended that two pairs of monitoring wells be installed on the opposite bank of the Little Ark river from each source water well installed. The drawdown in these monitor wells should be significantly less than that observed in monitoring wells on the same side as the source water recharge wells. It is expected that the drawdown in the shallow aquifer across the river would be no greater than about 5 feet at 660 feet from the source water recharge wells while pumping 1200 gpm, but the drawdown in the deep aquifer may be similar to that observed in other monitor wells of like distance from the pumping wells.

SOURCE WATER WELLS LOCATION

4.1 Land Acquisition Policy

4.1.1 Land acquisition is a very sensitive issue and varies with each individual situation. In general when ever a public entity takes ownership of land in a rural area, a significant change in the Township tax base occurs and revenue is lost to the area.

4.1.2 It is strongly suggested that the City of Wichita in the implementation of the Aquifer Storage and Recovery project follow the policy of using a long term lease of land from the individual owners with an annual cash reimbursement for the acreage used. This will result in the least disruption of economic conditions in the area. After installation of facilities in most areas, the land owner has the privilege of farming or grazing unused portions of the leased land.

4.2 Environmental Impact on Adjacent Property

4.2.1 The environmental impact on adjacent property with respect to ground water levels is expected to be minimal if the operation criteria of the source water wells is followed. As previously indicated, pumpage in the cold weather months may result in added drawdown in the principle aquifer due to the higher viscosity of the water and therefore ground water level monitoring may be the control limiting pumping from the source water wells.

4.2.2 In the test pumping of the Halstead well, it was the protocol of the U.S.G.S. to take measurements of the water temperature, conductivity and pH at every sampling event. In the reports reviewed by the Consultant, the temperature of the water pumped from the test well was not reported nor was the temperature noted in the observation wells. The significance of this is that the direct flow of water from the river will be reflected by a temperature change in the aquifer and the physical movement in the aquifer can be traced by temperature logs in the intervening piezometers. Also the ground water will get colder than normal with long term winter pumping, and it is expected that pumping will be limited during the summer months when stream water temperature is warmer than normal. This cooling effect in the aquifer should be localized and not affect adjacent property owners.

4.2.3 In areas where recharge takes place, the restoration of ground water levels to predevelopment levels in the 1940's could have a serious impact on adjacent property. An example of this is the dead trees around the Sedgwick infiltration pond that held water levels in the soil in the root zone for and extended period of time that suffocated the vegetation depriving the root system of needed oxygen. Again the effect was localized to the immediate area of the pond.

4.2.4 Pump houses and pump pedestals can be an eye sore to some property owners. The submersible pump has proven to be more cost effective in recent years and can be installed with a pitless adapter leaving only a unit some what larger than a fire plug at ground level visible at the well head. A vent line is extended into the air above the 100 year flood level and electrical transformers and controls can be mounted in weather resistant housing on nearby poles limiting the building structures needed for the project. High voltage electrical service and piping can be placed underground to each source water well site.

4.2.5 The water quality issue is of major concern to many land owners in the vicinity. The arsenic issue has been addressed with a change in well design for the source water recharge wells. The proposed change in well construction also blends a small portion of the higher conductivity water in the shallow aquifer with the lower conductivity water in the principle aquifer for transport to recharge areas. In the recharge areas, the physical movement of water will be very limited and most of the water will be captured by the recovery wells or the City wells and will not spread to other wells in the area.

4.2.6 The high chlorides associated with flows in the Little Ark river at Hwy 50 bridge occur at low flow in the river. High flows are very low in chlorides. Pump operation of the source water recharge wells should be further limited to operation with a stream conductivity value that corresponds to a chloride content of less than 200 mg/L

4.2.7 Triazine (Atrazine) increases in the Little Ark river with the spring planting of crops and decreases late summer and fall with the runoff from thunderstorms. Triazine is adsorbed to silts and clays in the streambed and shallow aquifer. Our analytical technology allows measurement in terms of a parts per billion which gives us information of minute amounts that have questionable impact.

4.3 Property Owners Compensation

4.3.1 In leasing land, the property owners compensation for the acreage leased should be commiserate with the land use plus some additional compensation for the nuisance value associated with the disruption. In rural area where the land use is agricultural, the compensation suggested is the average annual cash rental of irrigated land in the area. This value needs to be adjusted periodically as economic conditions change.

AQUIFER RECHARGE SYSTEM

5.1 Soil Profile and Aquifer Geology

5.1.1 The soil profile changes rapidly from the vicinity of recharge and recovery well, RRW-1 to be located in the southwest corner of Section 12, Township 23 South, Range 3 west, near the corner of NW 12th road and Willow Lake road to the south. The reported depth to static water level for domestic wells in the area was typically 30 to 40 feet below ground level. Fine dune sand was reported in some well logs from near land surface to various depths from 10 to 40 feet, more or less. The typical clay layer separating the upper aquifer from the principle aquifer often identified as the Equus Sands, occurred in most all of the well logs (WWC-5's) obtained from the Kansas Geological Survey.

5.1.2 Two well logs were found in the files for the southwest corner of Section 12 (RRW-1) filed by Clarke Well & Equipment Co., one with all clay from 2 to 75 feet depth, followed by 40 feet thickness of sand and gravel from 75 to 115 feet depth, where black shale was encountered. The second log reported to be in the same vicinity had clay to 17 feet followed by 10 feet of loose, coarse to fine sand to a depth of 27 feet, with 31 feet of clay thickness separating the shallow sands from the principle aquifer. The profile from 58 feet to 124 feet depth showed alternate layers of sand and clay, typical of the Equus Beds aquifer with black shale encountered at 129 feet depth. It is assumed the second log is the corrected copy.

5.1.3 South in Section 14 in an irrigation well (log) located in the W ½ of the SW ¼ , the shallow aquifer was reported from 13 to 30 feet depth, followed by 35 feet of clay thickness to the 65 foot depth followed by fine to coarse sand and gravel to 130 feet total depth. Another well drilled near the center of Section 14 reported clay to 20 feet and sand from 20 to 95 feet.

5.1.4 Near the center of the SE ¼ of Section 22 to the southwest an irrigation well was constructed in an aquifer below the principle Equus Beds aquifer with screen set from 160 feet to 240 feet depth below land surface. The drillers log reported at this location reported clay from 17 feet to about 30 feet with sand and gravel mixed with clay to 60 feet depth. The principle aquifer was present from 60 to 140 feet but was not screened in the construction of the well, however the gravel pack was extended outside of the casing from total depth of 240 feet to 20 feet from land surface. A clay layer sometimes mixed with sand existed from 140 feet to about 170 feet depth with sand and gravel formation that was screened in the well construction to a total depth of 240 feet.

5.1.5 The above well brings up a side issue in that most of the irrigation wells constructed in the area have gravel pack material installed in the large bore hole, typically drilled 28 to 32 inches in diameter with casing and screen of 16 inches in diameter installed in the bore hole. The gravel pack allows movement of water vertically from one portion of an aquifer to another, depending upon the vertical hydraulic gradients that exist. To the west of Willow Lake road, one deep well constructed in the lower most aquifer reported a depth of 6 feet to static water level when first drilled. These data would indicate the deepest aquifer was under artesian head initially and some leakage of water existed in prior time from the deepest aquifer upward to the overlying aquifers.

5.1.6 The significance of this situation is two-fold. First, in plugging any irrigation well in the area of similar construction, the casing must be perforated at the principle clay layers separating the aquifers present to allow lean neat cement grout to penetrate the gravel pack opposite these clays to provide a seal to prevent the movement of water vertically from one aquifer to another through the old gravel pack material. The clay intervals can be determined by running a natural gamma geophysical log of the well to be abandoned to identify the zones to be perforated and sealed in the well prior to the abandonment process. The second concern is that the gravel pack allows water from overlying aquifers to move down the gravel pack to the well screen and be discharged with the pumped water. The vertical movement of water in the gravel pack may be less than 100 gpm, but can significantly alter the water quality, especially when salt brine contamination exists in the shallow aquifer. In the normal operation of an irrigation well, the leakage over winter is pumped out on the crops in the first few hours of operation when first used in the spring. However, this second concern presents a challenge to the design of a hydraulic barrier to halt the movement of salt brine in the fresh water aquifers when water pressure gradients are changed.

5.1.7 The drillers log for RRW-2 proposed to be constructed in the northeast corner of Section 23, T- 23-S, R-3-W, shows clay to 13 feet with only 6 feet thickness of the shallow aquifer at this location. The clay separating the shallow aquifer from the principle Equus Beds aquifer exists from 19 feet depth to 62 feet depth with a few gravel streaks indicated. The principle aquifer with alternating layers of sand and clay exists 62 feet to 154 feet depth at this site. A thick clay layer from 154 feet to 190 feet depth separates this aquifer from then lower most aquifer with alternate layers of sand and clay to 253 feet depth. Black shale was encountered at 257 feet indicating the total depth of the unconsolidated aquifer at this location. In 1990, the GMD2 constructed a monitoring well in the northwest corner of the section a mile west in the lower aquifer only with all other aquifers sealed and the depth to water was only 15 feet indicating significant upward pressure existed in the deep aquifer. This upward pressure prevented the downward migration of salt water from the shallow aquifer and through the gravel pack of some wells, recharged locally in a limited way, the principle aquifer used by other irrigation wells in the vicinity. Along the south edge of Section 23, the deepest aquifer disappears and black shale is again encountered at 193 feet depth below land surface.

5.1.8 The drillers log for the proposed location for RRW-3 to be located on the south side of highway 50 next to Willow Lake road intersection, shows the shallow aquifer in two significant layers from 13 to 22 feet depth and again at 33 to 47 feet depth separated by clays. The principle aquifer consists of alternating layers of sand and clay from approximately 73 feet to 189 feet depth where black shale was encountered. A domestic well to the east of this location was completed in a sand from 60 to 70 feet depth in the top of the principle aquifer with a depth to static water level of 13 feet in 1986. A deeper well drilled in the principle aquifer had a depth of 34 feet to the static water level in 1987. The 21 foot difference in static water levels in this vicinity reflects the drawdown from pumpage by the City of Wichita wells from the principle aquifer. There is sufficient areal extent of the clays to limit vertical movement of water in the aquifer.

5.1.9 The concern in regard to the design of recharge and recovery wells in this area is; should the wells be screened only in the principle aquifer similar to the City wells, or should they be screened in the full sequence of sands in the saturated section below 20 feet depth? The resolution of this issue depends on the quality of water in the shallow and/or deep aquifer and whether salt brine contamination is in close proximity to affect the future quality of water withdrawn from the aquifer by the RRW wells. Time of travel calculations can be made with the modified hydraulic gradient to help resolve this issue. If the static water level is restored in the principle aquifer to the approximate level of the shallow aquifer, then there is no vertical gradient to move salt water to the lower aquifer.

5.2 Water Table Hydraulic Gradient Existing and Design Conditions

5.2.1 The water table hydraulic gradients vary with each aquifer identified due to areal extent of the separating clay layers. Typically the static water levels were found to be 15 to 30 feet higher in the shallow aquifer than those observed in the principle aquifer depending on the proximity to irrigation wells and pumpage by the City of Wichita.

5.2.2 The predevelopment hydraulic gradient from near the southeast corner of Burrton east to the range line along River Park Road, a distance of approximately 4.3 miles was 3.7 feet per mile (1435' to 1419') taken from the U.S.G.S. Water Resources Investigations Report 03-4298, published in 2004. October 1992, the hydraulic gradient increased to 7.9 ft/mile (1428' to 1394'), more than double the original gradient in the same distance. In April of 2000, the hydraulic gradient decreased to 6.3 ft/mile (1436' to 1409') with the static water level at P-30 only about 1 foot lower than historic water levels in the area. In January 2003, the hydraulic gradient was reduced to 5.1 ft/mile (1431' to 1405') between P-30 and 3001 observation well. To completely halt the flow of high chloride water from the Burrton area to the Wichita well field, the hydraulic gradient at the front of the plume must be zero or negative to a small extent.

5.2.3 If the intent of the project is to completely halt the movement of the Burrton Area high chloride water and hold it in its present position, then a modification to initial proposed program of the aquifer recharge and recovery wells (RRW's) is needed. To develop a hydraulic barrier at the down-gradient edge of the plume, it is proposed that a series of injection wells only be installed beginning at the NW corner of Section 15, T-23-S, R-3-W, penetrating the A-zone of the aquifer, and proceeding southeast diagonally across Section 15 to the center of Section 23 where penetration of the full thickness of the aquifer is needed, then south to the middle of Section 11 in the vicinity of Wichita Well No. 41, penetrating the B and C zones of the aquifer. As much as 75 percent to 90 percent of the injected water in the proposed hydraulic barrier wells can be captured by down gradient wells such as those proposed along Willow Lake road. Details of the design for the hydraulic barrier wells will be furnished upon request.

5.2.4 An analysis of the proposed recharge and recovery wells was made beginning with RRW-1. The sand formation thickness is limited at this location in the southwest corner of Section 12, T-23-S, R-3-W to about 48 feet. The suggested screen setting is from 55 to 125 feet, a total of 70 feet of continuous screen. The design at this location has a thick clay layer from 27 feet to 58 feet that could contribute Arsenic to the discharged water when pumped for long continuous periods. An alternate site to the west or to the south may be preferred.

5.2.5 The average permeability of the Equus Beds sands is about 1,000 gpd/ft^2. This value multiplied by the sand thickness gives an estimated formation transmissivity of 48,000 gpd/ft. Using semi-confined aquifer conditions, the well specific capacity may approach 28 gpm/ft of drawdown when pumped or the inverse with the injection of water up to a limit.

5.2.6 All injection wells have a limit of flow that can be readily accepted by the formation. Wells can be pumped in turbulent flow which causes sand production if not properly gravel packed but injection wells will not receive water in turbulent flow. Therefore it is possible to pump five (5) times more water from a well than can be injected into the same well.

5.2.7 The limit of laminar flow for a given well can be determined by using equation 4-2 found on page 57 of Groundwater Manual M-21, 3rd Edition (2003) published by the American Water Works Association;

$$Q_L = K_G \times L_S \times D_W / 5500 \qquad \text{Eq 4-2}$$

Where;

Q_L = The limit of laminar flow in gpm (Assume uniform flow vertically),
K_G = The formation permeability in gpd/ft^2,
L_S = The length of screen or thickness of the formation which ever is less in ft,
D_W = The bore hole diameter in inches, divided by
5500, a conversion coefficient to convert units including Pi, which is rounded.

Note the product of K_G and L_S is equivalent to the formation transmissivity in gpd/ft.

5.2.8 Using the above equation, the limit of laminar flow assuming uniform flow vertically from all units of sand equally into the well screen, the flow was 420 gpm. Since in fluid mechanics there are three states of flow. Laminar flow such as Darcy flow, the head loss is linear with the flow rate. In turbulent flow, the head loss varies with the square of the flow usually expressed as $V^2/ 2g$. Between these to states of flow is the transitional phase from one to the other. This transitional phase from field tests averages about 2.35 times the laminar flow rate defined above and identifies the beginning of turbulent flow which is the probable limit of water that can be injected into a well. For RRW-1 this value was found to be 990 gpm using a 48 inch diameter bore hole. The distance drawdown curve was then developed using the Thiem equation for the estimated transmissivity, giving a radius of influence of about 3000 feet for this well.

5.2.9 RRW-2, to be located in the northeast corner of Section 23, T-23-S, R-3-W, has about 70 feet of permeable sand formation, however it is suggested that the well be constructed with continuous screen from about 53 feet to 253 feet for a total of 200 feet of well screen. The estimated formation transmissivity for this well is 70,000 gpd/ft (9,358 ft^2/d). The well specific capacity is expected to be about 40 gpm/ft for either pumping or injection. The limit of laminar flow was estimated to be 610 gpm with the development of turbulent flow, the normal limit of injection at 1400 gpm. The radius of influence was developed graphically at 4,000 feet. The rise in water level midway between two similar wells spaced ½ mile apart injecting at the rate of 1200 gpm is approximately 8 to 10 feet when operating simultaneously for several days.

5.2.10 RRW-3, to be located in the northwest corner of Section 25, T-23-S, R-3-W, has about 85 feet of permeable sand formation giving an estimated transmissivity of 85,000 gpd/ft (11,364 ft^2/d). The well specific capacity estimated for both confined and semi-confined aquifer conditions varies from 38 to 50 gpm/ft. It is suggested that 24-inch diameter well screen be installed from 30 feet depth to 190 feet total depth. The limit of laminar flow for a 48-inch bore hole was 740 gpm giving a probable injection rate limit of 1700 gpm. The radius of influence was plotted and found to be about 10,000 feet. The cone of impression midway between two wells spaced one mile apart injecting simultaneously is between 6 and 10 feet.

5.2.11 RB-1 recharge bed, located in the southwest corner of Section 25, T-23-S, R-3-W, just west of Paxton, had an observation well EB-20B drilled across the road south in 1979. The WWC-5 bore hole log had 40 feet of clay followed by clay and sand layers to 57 feet before the shallow aquifer was encountered. Nearby irrigation wells show clay in the 30 to 40 foot depth range corresponding to the clay in the monitoring well. Due to the depth of clay in the area, this location should be considered for a RRW-4 well. One mile west of this location the deep C aquifer is present from 170 to 270 feet depth. Design parameters would be similar to those discussed previously.

5.2.12 RB-2 recharge bed to be located in the northeast corner of Section 2, T-24-S, R-3-W, was limited in the readily available formation data. The effectiveness of the recharge beds are limited where two or more clay layers of several feet in thickness exist in the soil profile.

5.2.13 RB-3 located in the vicinity of Wichita Well No. 41 presents a unique opportunity to compare recharge bed performance to that of injection wells. It is suggested that both be installed in this area as was done similarly at Well No. 4. If the line of injection wells are installed as previously suggested, then the need of the recharge basin no longer exists at this location.

5.3 Depth to Water Level, and Method of Control and Monitoring

5.3.1 Due to the complexity of three aquifer systems, although they are poorly interconnected, three different water level controls need to be monitored. The hydraulic gradient in the A-aquifer should be somewhat similar to the predevelopment condition defined previously. As the distance from Burrton to the east increases, the differential in water levels increase, developing a strong vertical gradient downward to the lower aquifer. Due to the extensive clay layer separating the A-aquifer from the B-aquifer, this differential is maintained through most of the area currently proposed for the RRW wells. In 1986 and 1987, the data reviewed showed about 21 feet difference in water level in the vicinity of RRW-3 between the A-aquifer and B-aquifer.

5.3.2 The depth to water level in the B-aquifer typically varies from about 30 to 50 feet below ground level in the area considered for the RRW wells. In the area northeast of Burrton, the A-aquifer has reported depths to water level of 35 to 50 feet or more in the area of the proposed injection wells. This area has some dune sand and somewhat higher land surface elevation.

5.3.3 Both the water quality and water level depth in the shallow A-aquifer needs to be monitored separately from the other two deeper aquifers. Where the B and C-aquifers are present, separate monitoring wells for both quality and water level need to be monitored individually.

5.3.4 In the vicinity of the proposed hydraulic barrier wells, each aquifer needs its own monitoring wells and level control. Further, consideration needs to be made of the viability of the soil profile as to not raise water levels to close to land surface as to damage crops. An unsaturated soil depth of 15 to 17 feet is about ideal for agriculture. If injections wells are used as proposed, the cone of impression should be no higher than 10 feet below ground level in the shallow aquifer, at a radial distance of 100 feet from the injection well or RRW well when injecting water to an aquifer(s).

5.3.5 Water levels measured in the confined aquifers such as the B and C aquifers may be much higher then that specified above. Historically, the deep aquifers were artesian in some areas in that the water level in the lower aquifers were sometimes higher than the water levels observed in the shallow aquifer. It is this fact that allowed better quality of water to be found in the lower aquifer than in the upper or the shallow A-aquifer.

5.3.6 The technology of using programmable logic controllers (PLC's) for control of pumps and valves has advanced in recent years to allow real time continuous control of water levels. Transducers can be installed in monitoring wells with control wiring buried below plow depth (typically 3 to 4 feet) for automatic flow control to injection wells. Solar panel and batteries can be installed at remote sites and not require a separate electric power supply at each injection well.

5.4 Type of System for Recharge, i.e., Trenches or Wells

5.4.1 The type of system for recharge depends on the soil profile present at the site and whether the focus of the recharge is primarily for the shallow aquifer. Where thick clay layers of approximately 20 feet or more exist in the boring profile, regardless of depth, injection wells are essentially required.

5.4.2 To restore saturation to shallow aquifers where dewatering has occurred, trenches are the more efficient way to proceed with recharge. In aquifers that are still saturated with a small coefficient of storativity, the injection wells are more efficient especially where significant depth is involved.

5.5 Water Storage Capacity of the Soils and Aquifer

5.5.1 The water storage capacity of soils varies with the moisture content and particle size of the grains making up the soil. The porosity of sands is in the 30+ percent range and that of clay can be in the 50+ percent range. Typically dry soils vary in the middle portion of the porosity range.

5.5.2 It is more difficult to recharge dry soils than moist soils. The High-Plains Water Management District in the Panhandle of Texas used compressed air in the unsaturated portion of the aquifer above the water producing zones in the Ogallala aquifer and were able to drive water to wells increasing the productivity of those wells, they thought. However later, they found they had negated the natural recharge to the aquifer from precipitation. The soil moisture has to be replaced to near field capacity before recharge can occur to the underlying aquifer in the soil profile. The result is a specific yield for recharge to unconfined or partial semi-confined aquifer normally varies from about 0.10 to 0.20 or 10 to 20 percent of the rise in water level with the average being 15 percent.

5.5.3 The specific yield coefficient for semi-confined to confined aquifers will vary from 0.001 to about 0.02 depending upon the character of the overlying soil strata in which the water level occurs. If thick saturated clay zones overly the aquifer in which the injection of water occurs, the smaller is the coefficient of storativity. If an unsaturated zone lies above the zone of injection in which the static level is measured, the larger is the coefficient of storativity due to slow leakage upward from the aquifer.

5.6 Metering of Aquifer Water Recharged

5.6.1 The water to each injection well and RRW well to be recharged must be metered. As was observed in the injection well constructed at Wichita Well No. 4, the initial injection rate can be quite high. As the cone of impression builds, the rate of flow decreases because the hydraulic gradient away from the well decreases. The normal aquifer transmission and leakage losses to an injection well are expected to be less than 5 percent. Thus most of the recharged water injected into a well is recoverable.

5.6.2 Water injected into a hydraulic barrier well must first stabilize with the desired ground water level to be maintained. After that, about 80 to 90 percent of the water injected can be recovered some distance down gradient from the line of injection wells. Some of the recovered water will be diverted by near-by irrigation wells. Some of the recharged water may be diverted by domestic wells where a concentration exists such as in the City of Burrton.

5.6.3 Water losses from a trench that is covered should be a little greater than that experienced from operating injection wells. There will be a small amount of evaporation and transpiration loss from the soil near the site of the trench. Pond or basin recharge is the least water efficient system considered.

5.7 Water Use Accounting in the Vicinity

5.7.1 Water use accounting must be based on actual measured volume of water metered to the recharge injection system less some small percentage for allowable losses. No system is 100 percent efficient.

5.7.2 Natural recharge from precipitation or recovery of water levels from non-pumpage is not allowable. The non-pumpage issue just proves that the natural recharge process is working. The Equus Beds aquifers are fortunate to have the sometimes extra recharge from the storm water flows of the creeks crossing the aquifer such as Kisiwa in the area of study.

5.8 Monitor Well Needs at Recharge Sites

5.8.1 Primary monitoring should be in a west to east direction parallel to the hydraulic flow of the water in the aquifer. Separate monitoring wells should be installed in the shallow aquifer so as not the penetrate the separating clay layers at that site. Deep monitoring wells must have the proper bentonite grout seals where significant clay layers are present.

5.8.2 Monitor wells in the Equus Beds aquifer should be open both at the top and bottom of the aquifer in a manner similar to the near-by well construction, except where significant water quality variation may exist in the aquifer. This can be done more economically by alternating sections of screen with blank pipe in between.

5.8.3 A minimum of three pairs of monitoring wells should be installed at each RRW well site. One pair, one in the A-aquifer and one in the B-aquifer constitute a control point. In some areas a third monitoring well in the C-aquifer at the same location may be warranted. One pair should be up gradient about 660 feet more or less, one pair down gradient roughly the same distance, and one pair to the north or south depending upon the situation at that location and the availability of access. It is not always going to be convenient or necessary to have the monitoring wells exactly at the suggested spacing. Some may be as much as ½ mile away at a more convenient location that is accessible. One of the minimum group may be about 100 feet more or less from the RRW well to be used for flow control.

5.8.4 The proposed barrier injection wells need sufficient additional monitoring wells from those already established in the area to properly map the water level elevation in each aquifer to at least 1 mile on either side of the injection wells and a few between the injection wells to insure proper operation of the barrier system. Each barrier injection well needs a monitoring control pair about 100 feet from the well.

5.9 Appropriate Storage Area Thresholds for Recharge and Recovery

5.9.1 The primary control of water levels in the vicinity of the recharge and recovery wells during the recharge cycle will be the water levels in the shallow aquifer or A-zone which ever is most critical. The highest level of ground water that should be maintained under conditions of average precipitation is about 15 to 17 feet depth below the land surface. This is much lower than the predevelopment conditions that existed when the City of Wichita first installed the water production wells.

5.9.2 In the predevelopment time, in wet years the static water level was sometimes less than 4 feet below ground level and crops were lost due to water logging of the soils. Agriculture has flourished as a result of some lowering of the static water level in the area. The effect of excessive recharge was well demonstrated by the death of the trees around the recharge basin. The effect was limited in area due to the cone of impression of the recharge lowering as the distance from the basin increased. The concern is that some allowance needs to be made for above average years of natural recharge from precipitation in the area. If the artificial recharge system raises water levels too high during a wet year, some water logging of soils may occur affecting deep rooted plants such as trees mostly. It is suggested that the target level of water in the shallow aquifer be no higher than about 15 feet below land surface. The deep aquifers may exhibit a small amount of artesian pressure of a few feet without detrimental effect.

5.9.3 If the guide lines of water level is maintained at 15 feet more or less below ground level, the lagoons, septic systems, basements, and buildings should not be affected. The problems always occur during excessive wet weather when soils become saturated and there is no downward percolation of effluent from septic tank drain lines. There was an area south of Wichita next to the floodway several years ago that experienced this problem. Occupants had their sump pumps pumping drainage out of the basements to the septic system, only to have it recirculated to the basement again. There was no place for the water to go but horizontal to a point of relief which was into the basements.

5.9.4 Wetlands is a separate issue. In some places it may be desirable to restore some wetlands by artificial recharge to the shallow aquifer. To maintain the wetlands, the water level in the deeper aquifers needs to be raised also to limit the vertical leakage downward. This is a situation where recharge basins may be more appropriate to restore wetlands habitat.

5.9.5 The City has evaluated the area around the existing water supply well field and has established an area for the ASR project of approximately 134 square miles. Using a simple water budget approach with the natural recharge being about 6 inches per year, then the available safe yield of this area is roughly 42,880 acre-feet per year. The well field was initially design to produce about 40,000 acre-feet per year to the City of Wichita, which was within the capabilities of the aquifer.

5.9.6 Based on the flow history in the Little Arkansas River, The City estimates that the system will be able to recharge an average of 20,700 acre-feet per year, and that the maximum annual quantity that could be recharged into the aquifer during an extremely wet year will be approximately 80,000 acre-feet.

5.9.7 Based on these figures, the average annual net consumptive water usage for steady-state conditions with the recharge system in place would be approximately 63,580 acre-feet per year for all water users from the aquifer. During wet years some additional recharge could replace water withdrawn from aquifer storage during dry years.

5.9.8 Aquifers are most efficient in water production when water is withdrawn at a near constant rate equivalent to the average annual recharge during the year. Both the City and irrigation demands are greatest in the hot summer months. In the winter months irrigation demand is near zero with a lower demand for City use. Some adjustment in diversion between Cheney Reservoir and the Equus Beds aquifer may have to be made weekly by the City depending upon existing aquifer conditions.

GENERAL AQUIFER RECHARGE IN THE VICINITY OF CITY WELLS

6.1 Method of Recharge

6.1.1 There are some areas of the well field where good vertical communication may exist between the shallow aquifer and the deeper aquifers where the recharge trench system will work satisfactorily. For most of the well field area, a satellite approach of recharge wells around each of the City production wells will provide the recharge capacity needed to meet future water supply demands. The advantage of the satellite well system approach is that nearly 100 percent of the water injected is captured by the production well in the vicinity and recharged water does not spread to other wells if properly spaced.

6.1.2 As was discussed earlier in this report, water can be pumped out of a well with water flow through the aquifer in the turbulent state of flow, but water cannot be pushed into the aquifer in turbulent flow. Typically, three to four satellite recharge wells need to be placed somewhat symmetrically around each City well that will provide the recharge capacity to accept the high flows of recharge water when available.

6.2 Location of Recharge Wells

6.2.1 The location of recharge wells can be along roads or property lines and spacing can be adjusted to fit the situation at each well. Your Consultant is the inventor of an in situ iron and manganese treatment process that uses satellite wells around a production well in which 10 to 15 percent of the pumped water from the well is returned to small diameter wells, usually 6 satellite wells with air or other oxidants to react and reduce the iron and manganese in the aquifer. At a spacing of 100 foot radius, the satellite wells provided approximately one day travel time to the production well, in the typical aquifer. The recommended travel time from any recharge well to a City well or any other well should be a approximately 3 to 5 days to allow for appropriate water quality monitoring.

6.2.2 The recommended spacing between a satellite recharge injection well and City well is from about 500 feet to about 1,000 feet. The spacing between the satellite well and any other large capacity well should be a minimum of 1320 feet. If the satellite well concept is used, then smaller diameter bore hole and well screen may be used for the three or four injection wells to be located near each City well. The design capacity of the satellite injection wells should allow for a 50 per cent reduction in flow in the future. Some of the injection wells may be equipped with submersible pumps that become RRW wells also.

6.3 Water Quality Control Monitoring

6.3.1 Three parameters that should be monitored in real time are; Specific Conductance, pH, and Temperature. Any significant change in one of these parameters represents a changed condition to be investigated. Other parameters may need to be monitored in some areas of the well field are nitrates, total organic carbon, oxidation-reduction potential, and others.

6.3.2 The water quality parameters should be compared at the injection well head to that of the source water wells or the point of water treatment. Any significant change in water quality should result in automatic shutdown of the system to allow an operator to identify the problem and take appropriate action.

OVERVIEW OF THE ASR PROJECT

7.1 The City of Wichita should be commended for the farsighted effort to stabilize ground water levels in the Equus Beds aquifer for the future and to protect the water quality for all users of water. The project concept is sound and is feasible to construct and operate.

7.2 The legal rules and regulations that we impose upon ourselves, sometimes get in the way of the best water management practices needed for a project of this type. The safe yield concept devised by the Division of Water Resources is an excellent concept for aquifers such as the Ogallala where recharge is mostly from precipitation and return flows from irrigation, but does not always work to the best interests for all users where streams interact with aquifers. Such is the present situation where the City of Wichita and their Consultants have tried to skew the results of the testing program to fit the present rules and regulations, rather than present a straight forward analysis of the real world situation. The Division of Water Resources was aware of some of the problems that could occur when the term permit was issued for the testing program.

7.3 Historically, the Little Arkansas River was a drain to remove excess recharge received by the aquifer system. Since land surface slope was rather flat toward the river, the aquifer transmissivity was not capable of conducting the full ground water flow needed so that the static water level during times of wet weather rose to near the surface of the land to be evaporated directly to the atmosphere. The development of the City well field in the central portion of the Equus Beds aquifer harvested this excess recharge from natural precipitation and improved the arability of the land for agriculture. The improvement brought additional ground water resource use in the form of irrigation that combined with the City pumpage now exceeds the average recharge from precipitation in the central portion of the aquifer.

7.4 The cone of depression has expanded to the north, west, south and eastward to the edge of the Little Ark river to meet the total pumpage demand from the aquifer. In doing so, the cone of depression has captured the pollution in the Burrton area and the poor quality water associated with the Arkansas River to the south. The aquifer transmissivity near the Little Ark river is not capable of conducting the quantity of water needed to meet the current demands on the aquifer and therefore needs the assistance of this project for the benefit of all water users.

7.5 The aquifer geology is somewhat unique along and near the Little Ark river is that extensive clay layers inhibit the direct infiltration of river flow to the principle aquifer. There are a few places observed in the data where past erosion has breached the clay layer separating the shallow A-aquifer from the B-aquifer but in the Halstead area, the separating clay layer is of substantial areal extent between the two aquifers. In the testing program there was observed substantial leakage of water through these clays with drawdown created by pumping wells. The side effect of prolong pumpage due in part to the design and construction of the test well, was the generation of arsenic from these clays.

7.6 The presence of the Little Ark river does add recharge to the aquifer in the immediate vicinity of the river. This amount may be double that received in the central portion of the aquifer from natural precipitation, justifying the use of source water wells for aquifer recharge to be constructed along the river bank. Monitoring of both the ground water levels and stream flow needs to be coordinated in the operation of these wells.

7.7 The ground water model system used by the Wichita Consultants does not account separately for the depletion of water in the river channel and treated the river as a constant head boundary to the aquifer. The cell structure of the model was terminated at the Little Ark river. The aquifer needs to be modeled extending the aquifer model to the eastern edge of the Equus Beds aquifer which includes the influence of Emma Creek and Sand Creek to the east of the Little Ark river. In geologic deposits such as the Equus Beds aquifer, the separating clay layers are often absent near the boundary of the aquifer allowing for good vertical permeability in that region.

7.8 The storm water flows of the Little Ark river are substantial most years and provide an excellent source of water for recharge to the central portion of the aquifer. The City should consider the installation of low-head, high volume pumps to be installed near the test well site at the low head dam for diversion to an off-channel reservoir in the vicinity. Water could then be pumped and treated from the reservoir to the recharge system when stream flows are less than the minimum flow rates established for the Little Ark river. High volume, non-vortexing pump intake screens are available from Hendrick Screen Company in Owensboro, KY.

7.9 It is suggested that the City of Wichita adopt a leasing policy for land acquisition for this project so as not to disrupt the property tax base of the area. Annual compensation may be based on the cash rental value of the land as if it were irrigated agricultural use. Periodic adjustment of payment should be made as economic conditions change.

7.10 Due to the geologic conditions in the central portion of the aquifer, injection wells will work best in most areas. Recharge basins or trenches have limited effectiveness with the presence of numerous clay layers at depth. A hydraulic barrier should be established first along the eastern edge of the contamination plume in the Burrton area. Then recharge and recovery wells can be established along the down gradient toe of the barrier recovering much of the water used to maintain the barrier, once it is established.

7.11 Recharge to the aquifer should limit the rise in water level in the shallow aquifer to an average of about 15 to 17 feet below land surface to preserve the arability of the soil and to allow some soil storage capacity for above normal precipitation when it occurs. Monitoring controls should be in place to prevent over recharge at any specific location.

7.12 All aquifer water recharged should be metered. The City should not expect to recover 100 per cent of the water recharged to the aquifer. Typical losses due to aquifer flow away from the capture zone of wells and to maintain any hydraulic barrier system are 10 to 15 percent of the water injected.

7.13 Recharge in the vicinity of the City wells should consider the satellite well concept where an average of two to four injection wells are constructed within a 3 to 5 day travel time to the production water well. Some of these satellite wells may be equipped with pumps and become recharge and recovery wells that can help the City meet future peak demands from the well field.

7.14 The goal of the project is to stabilize ground water levels of the Equus Beds aquifer and meet future water needs of the City of Wichita while maintaining present authorized water usage from the aquifer without degradation of the water quality. It is unrealistic not to expect some change in water quality since there are areas of the aquifer where the water quality is nearly pristine. Following the concepts covered in this report, the effects on those areas should be very limited in that most of the recharged water will be captured and used by the City of Wichita.

RECOMMENDATIONS

8.1 It is recommended that the Board of Directors of Groundwater Management District No. 2, give a conditional Approval of Applications No. 45,567 through No. 45,576, filed by the City of Wichita with the Division of Water Resources of the Kansas Department of Agriculture, to allow limited pumpage to induce recharge to the aquifer system in the immediate vicinity of the Little Arkansas River when stream flow in the river is in excess of in-stream needs, to be treated as needed to meet or exceed the water quality standards set by the Kansas Department of Health and Environment for potable water, and to transport said water to the central portion of the Equus Beds aquifer for recharge to protect the aquifer from further degradation of the water quality, and to recover and stabilize water levels in the aquifer.

8.2 The City of Wichita shall have Rights to recover recharged water in excess of the needs to protect the aquifer water quality and to stabilize the water levels in the aquifer.

8.3 The City of Wichita shall not impair the use of water in quantity or quality of any established water right holders of record or any domestic water user in the vicinity of any of the project wells.

Respectfully submitted,

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