Dealing with Changes in Volume and Quality of Effluent at the Dodge City Wastewater Recycling Project over the last Sixteen Years – 1986 through 2001

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Abstract

The Dodge City Wastewater Recycling Project began handling effluent from the municipality of Dodge City, Kansas and a beef packing plant in 1985. The project was originally designed to irrigate 1,400 acres through center-pivot sprinklers. Initially, City management and farmers adopted methods to deal with salinity. Various factors have increased effluent volume and N content of the effluent. Extensive soil monitoring showed that sodium tended to accumulate more in certain soil types and nitrate is leaching through the subsoil. Management has dealt with these challenges by adding to the land base and including alfalfa in the crop mix to remediate nitrate-laden soils. Expanded treatment and storage facilities are in the design stages.

Introduction

The managers of the Dodge City Wastewater Recycling Project (DCWRP) have adapted to unforeseen layers of complexity. The project designers focused primarily upon engineering solutions to conveyance and treatment of wastewater. They did not foresee the challenges that would be caused by changes in domestic and industrial influent nor the intricate interplay of effluent volume, quality and cropping choices. Project priorities have changed from only managing effluent volume to simultaneously managing salinity, volume, and nutrients.

The Dodge City Wastewater Recycling Project was conceived and proposed in the late 1970's by a prominent Dodge City businessman and farmer (Engineering Enterprises, 1980). He was the managing partner of a beef packing plant that utilized the wastewater treatment facility operated by the City of Dodge City. The facility discharged into the Arkansas River. It was outdated and a new plant was being planned at the time. The packing plant would have been charged 25% of the cost of the new conventional wastewater treatment facility. So he was looking for a less expensive alternative and was interested in obtaining the effluent to irrigate his farmland.

State and federal regulatory agencies looked favorably upon the land application alternative. It was especially attractive in western Kansas where the primary water source, the Ogallala aquifer, was being depleted. The irrigation aspect was put out to bid and two neighboring farmers located closer to town joined forces to win the bid. The farmers would receive the value of the crop nutrients in the effluent and the benefits of reduced pumping costs. In return the City would be deeded 160 acres for the treatment plant and receive future groundwater rights from the farmers equal to the effluent volume.

Project Details

The project was largely funded by the Environmental Protection Agency and began operating in the latter half of 1985. Much of the system infrastructure remains close to its original design today (Engineering Enterprises, 1985) (Slattery and Looney, 2002). Originally the influent from the packing plant comprised 19% of the total volume, by 2001 it was roughly 30% of the flow. The rest came from domestic sources. There are no other significant industrial contributors to the waste stream. The untreated sewage is collected and combined at the site of the former wastewater treatment plant. It is pumped eleven miles from the collection point to the treatment facility. The sewage enters two covered, anaerobic digesters each 1.2 acres in surface area. It passes into two aeration basins each 0.8 acres and then into two storage lagoons covering a total of 92 acres. The combined capacity of the storage lagoons is 1,642 ac-ft.

There are four electric, centrifugal pumps that supply 10,000 gpm to the network of irrigation systems located within a three-mile radius. Two nearby fresh water wells are plumbed to supply dilution water to the storage lagoons. The system is managed by Operations Management International under contract with the City.

Originally the effluent was used to irrigate 1,400 acres under eleven center-pivots and a small amount of gated pipe furrow irrigation. There were 2,550 acres under irrigation in 2001, with 21 center pivots irrigating 2,505 acres and 45 acres flood-irrigated. The irrigated acreage base has grown in order to accommodate increased effluent volume and nitrogen content. Another 120-acre center-pivot will be added in the year 2003 and additions to the treatment plant are in the design stage.

Salinity Concerns

Farmers noticed leaf burn on alfalfa during the first full growing season of 1986 and asked our agronomic consulting firm, Servi-Tech, Inc., to assess the situation and recommend solutions. Thus began our association with the project.

The leaf damage was most prevalent within the innermost spans of the center-pivots. Most of the systems at that time had overhead, impact nozzles that emitted a fine spray along the inner spans. Farther out from the center, the water droplets were larger and the effect was less noticeable. We concluded that the finer droplets were drying upon the leaf surfaces and desiccating the leaves of the alfalfa.

The electrical conductivity (EC_w) of the effluent at the time of the leaf burn was 2.4 dS/m. The sodium adsorption ratio (SAR) was 8.7. The engineering design (Engineering Enterprises, 1980, 1982) anticipated salinity and sodicity levels to be about this level and the overall water quality was rated as "good" by the laboratory that did the initial analyses. These salinity and sodicity levels would be acceptable where wastewater disposal has priority over yield expectations (FAO, 1985). However, these farmers had farmed this land for multiple generations and were accustomed to high yields. Thus they were alarmed at the possible risk to their land and their livelihoods.

We designed a soil and effluent monitoring protocol to provide the necessary feedback to make the project successful. Permanent monitoring sites of each soil series on each field were sampled incrementally to at least five feet (60 inches) in spring and fall. The surface soil increment was split into two six-inch segments (0"-6" and 6"-12"). The remaining soil depths were divided into twelve-inch increments (12"-24", 24"-36", etc). This sampling protocol has been carried out since 1987, except that some fields were sampled to greater depths.

Both storage lagoons were sampled monthly and analyzed for salts and nutrients. The state regulatory agency also mandated that monitoring wells be placed at various locations near the effluent-irrigated fields.

Based upon our previous experiences elsewhere, we expected to see runoff problems with SAR levels exceeding 5.0. The soils across the project were loess-derived silt loams with slopes as steep as six-percent and were potentially prone to infiltration problems when irrigated with sodic effluent. Corn grain yield reductions of 20 percent were expected with an EC_w of 2.4 dS/m due to osmotic effects (FAO 1985). Leaf burn caused by saline effluent could reduce alfalfa yields. Normal annual precipitation in the Dodge City area is 21 inches so dilution of soil salts can ameliorate the negative osmotic effect on crops and at the same time exacerbate the sealing effect caused by sodium saturation of soil cation exchange sites. The potential effect on corn yields depended on the distribution of in-season rainfall. Normal rainfall from June through August averages 9 inches.

Based upon our recommendations, the growers and the City agreed to a contract that allowed the farmers to dilute the effluent in the storage lagoons with fresh water to a point where the EC_w would not exceed 1.5 dS/m and the SAR would be less than 5.0.

The City agreed to pay for gypsum application to soils where the exchangeable sodium percentage began to climb beyond 5 percent. The soil-monitoring program tracked soils with rising exchangeable sodium percentages and identified soil series that accumulated sodium faster than others. Every fall since 1989, the City has used funds derived from user load fees paid by the packing plant to apply gypsum to several fields.

The farmers have adopted several tillage techniques that decreased runoff from their fields. The corn fields have all been converted to ridge-till. They have also used in-row rippers and dammer-dikers to aid water infiltration. Spike tillage tools were used in alfalfa fields to create small reservoirs that enhance infiltration.

The farmers averted the problem of salt buildup on leaves by converting their sprinklers from higher-pressure overhead nozzles to lower-pressured drop nozzles. The land application system was originally designed for high-pressure impact sprinklers with a predicted efficiency of 75 percent and it called for an application rate of 36 ac-in/ac. The change in nozzle packages effectively decreased crop demand but increased the risk of runoff.

Both dilution and the change in sprinkler design had the effect of increasing the amount of water to be disposed of. Additionally, the population of Dodge City went from 21,000 to 25,000 and the slaughter capacity of the packing plant doubled.

Increasing Effluent Volume

The initial influent flow volume to the treatment system was 8.6 ac-ft/day with 17 percent of the volume coming from the packing plant. This equated to 3,139 ac-ft/yr. Loss to seepage and evaporation less precipitation was estimated at 323 ac-ft/yr. A total of 2,816 acre-feet of effluent - about 2 acre-feet per acre per year - was predicted to be available for irrigating 1,400 acres.

Fresh water dilution of the storage lagoons began in 1987. About 450 acre-feet of low EC_w water (< 0.50 dS/m) was pumped into the lagoons. The quantity of diluent has varied through the years according to the amount of in-season precipitation received, but has averaged about 400 ac-ft/yr.

By the year 2001, influent flow volume had increased 36 percent to 11.7 ac-ft/day or 4,270 ac-ft/yr and the packing plant influent had increased to 29 percent of total volume (Slattery and Looney, 2002). The system was designed to handle 12.7 ac-ft/day by 1997 but logistical problems have made it difficult to handle even the current volume properly.

The growers have never been able to utilize the 36 ac-in/ac-yr as slated in the original design. Annual application to corn has run about 19 ac-in/ac and alfalfa about 27 ac-in/ac (Servi-Tech, 1987-2001).

Fortunately, there was ample land available in the vicinity of the treatment plant to expand the acreage base by 82 percent – from 1,400 to 2,550 acres in 2001. Most of the problems were the result of undersized storage capacity. The irrigators ran short of water in-season. In the off-season they were often forced to over-irrigate alfalfa and wheat or “pre-irrigate” row crop fields. If the fields were saturated, frozen or snow-covered the state regulatory agency granted temporary permission to divert overflow to three different farm ponds.

The farmers have retained the option to switch to groundwater wells on a few fields during the peak demand periods from mid-June to mid-August. This has been necessary to produce a crop in dry years. For example, if one assumed an ET demand of 0.25 in/day across 2,550 acres for those 90 days, there would be a demand for 4,781 ac-ft. The storage capacity was 1,642 ac-ft and influent for 90 days would be 1,053 ac-ft for at total available supply of 2,695 ac-ft. Ignoring rainfall, dilution and evaporation, there is a shortfall of 2,086 ac-ft during the peak demand season. Most of the deficit should be made up if the normal rainfall of nine inches occurs during that period. Off-season storage becomes an issue. Figure 1 illustrates the average annual precipitation compared to the water demand for corn and alfalfa. Irrigation demand tapers off dramatically at the end of August and the storage lagoons are nearly empty. Alfalfa can usually be irrigated until the end of September or early October. Irrigation is often not feasible after mid-October due to freezing temperatures. It has not been uncommon to accumulate 1.5 times the lagoon storage capacity in cold or wet years. Even in dry years some excess irrigation was applied in the off-season.

Nitrate Leaching Concerns

The original proposal for the project (Engineering Enterprises, 1980) stated that since groundwater was over 100 feet deep there was no “significant chance for groundwater pollution from lagoons or the irrigation area.” It further stated that since the wastewater would supply only 20-30 percent of crop requirements for nitrogen and phosphorus there was practically no chance for groundwater pollution. Groundwater lies between 75 to 170 feet beneath various fields.

The original design assumed influent concentrations of total nitrogen at 22 mg/L and phosphorus at 3.4 mg/L. During the 1987 growing season, the first year of the monitoring program, N concentration averaged 27 mg/L and P was 14 mg/L. Thus about 170 lbs N/ac and 75 lbs P_2O_5 /ac was available for land application. Phosphorus has not accumulated to levels of concern.

The farmers made few adjustments to their normal nitrogen fertilization practices for many years even though the deep soil profile monitoring results indicated significant carryover nitrate. The farmers were unsure how much of the effluent nitrogen would be available to their crops (Nicholson, 2001). They were reluctant to reduce fertilizer nitrogen applications, fearing significant yield loss. Soil samples taken by their crop consultants often indicated that the top two feet of the soil profile lacked enough carryover nitrate to sustain the upcoming corn crop (see Figure 2). They were also unsure of the degree of loss from ammonia volatilization. At least 100 lbs of fertilizer N/ac was applied to corn prior to planting until very recently.

We were unsure as to how much of the N would become plant available nitrogen (PAN). Review of post-season soil tests and crop yields helped us to estimate that approximately 65% became plant available. Assuming 65% PAN factor then approximately 110 lb PAN/ac was available from effluent in the early years of the project. However, the nitrogen concentration of the influent wastewater has increased steadily, more than tripling over the sixteen years of the project. In 2001, the applied effluent averaged 91 mg/L total nitrogen; equivalent to 411 lbs total N/ac or 267 lbs PAN/ac.

The early results of the soil monitoring showed that significant amounts of nitrate were passing beyond the upper five feet of the soil profile. We sought to understand how deeply these plumes or slugs of nitrate moved.

We initially sampled some fields to ten feet and then twenty feet. As of this date, the deepest depth that we have sampled is 50 feet.

The semi-annual sampling of the soil monitoring sites has allowed us to track the movement of nitrate slugs leaching through the upper vadose zone. We have estimated that once the slugs leave the upper five feet of the root zone they can leach as much as four feet in a wet year. Figure 2 illustrates the nitrate concentrations to a twenty-foot depth, located under a pivot irrigation system that was connected to effluent within the last five years and has been planted to corn for fifteen years. The nitrate distribution patterns beneath this field do not look different than other fields with a long history of corn. Thus we believe that much of the nitrate found in the upper vadose zone was derived from commercial fertilizer applied before the onset of the project.

There are fourteen monitoring wells placed near effluent-irrigated fields. Nitrate levels have increased in four of those wells. We are unsure as to the source but based on the soil monitoring data. Soil nitrate could reach the groundwater beneath these fields if not removed from the soil profile or a dry-zone, hydraulic barrier is not created.

Crop Choices for Effluent Management

Crop uptake is an important nitrate mitigation strategy. Corn is the primary crop grown at the Dodge City project. The corn fields received an average of 19 inches of effluent in 2001. This volume of effluent would have supplied 253 lbs PAN/ac. It takes a very high yielding corn grain crop (250 bushels per acre or greater) to utilize this amount of nitrogen. Irrigated corn yields have typically been about 180 bushels per acre.

Other crop management practices can help improve nitrate removal. Harvesting corn as silage removes the nitrogen in the stalks as well as the grain. Double-cropped winter wheat followed by soybeans or grain sorghum can remove fairly large quantities of nitrogen. Winter wheat production also provides a sink for off-season effluent application.

However, the most effective practice was to simply produce less corn and more alfalfa. Soil monitoring showed that alfalfa utilized virtually all the applied nitrogen and removed soil profile nitrate as well. Figure 3 illustrates the dramatic effect that alfalfa had on removal of nitrate from the soil profile at depths of five feet and greater. The graph shows changes in the profile nitrate concentrations from a monitoring site sampled in 1997 and planted to alfalfa for the previous six years. We do not know the history of that field prior to the DCWRP project but we do know that it was planted to corn from 1987 through 1989, grain sorghum in 1990, then planted to alfalfa in April 1991. The higher nitrate levels in the soil surface in 1997 would be the result of effluent applications the previous fall that had not been utilized by the crop.

By 2001 the primary management concerns had shifted from salinity to volume to nitrate leaching. We estimate that the alfalfa crops have removed well over 300 lbs N/ac/yr as protein in forage tissue and that volatile nitrogen losses through leaf surfaces may have also occurred. Alfalfa production became a strategy to mitigate nitrate leaching. The shift toward producing more alfalfa production also extended the irrigation season, but stretched an already short in-season effluent supply.

The crop mix across the project in 2001 was 67% corn, 24% alfalfa, 5% soybeans, 2% winter wheat, and 2% grain sorghum. The project managers would prefer more alfalfa production for increased effluent and nutrient disposal, while the farmers prefer corn production for greater profitability. Corn has historically generated higher income than alfalfa and is eligible for federal farm programs. Alfalfa has recently been a profitable crop, but has had wide price fluctuations in the last 16 years (Schuckman, 2002). Alfalfa also has less production flexibility. Once a farmer plants alfalfa he is committed to that crop for at least five years. Alfalfa production is labor intensive and somewhat more difficult to market than corn.

All parties now realize that crop mix is a critical component. Long-term success of the project will depend upon wise cropping choices. City management, the farmers and their consultants are considering crop choice carefully because of the increased nitrogen content of the effluent. The treatment plant expansion will remove more ammonia from the effluent. The increased storage capacity will allow the growers to better match irrigation timing with crop demand. Until the expansion is fully implemented, the various parties are working toward solutions that will allow the City to effectively dispose of wastewater, the farmers to grow crops profitably, and at the same time protect ground water.

Conclusions

The project designers of the Dodge City Wastewater Recycling Project did not anticipate the layers of complexity that future project managers would face. Agronomic considerations coupled with engineering considerations have been necessary to assure success of this project. The availability of extra land and groundwater provided critical flexibility. Future designers of effluent irrigation projects can take a lesson from this one and note that volume, salinity, and nutrient content must be balanced to properly manage an effluent-irrigation project. These factors are interrelated; changing one factor often requires secondary changes to manage the other factors properly.

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Figure 1. Relative seasonal water use demand by alfalfa and corn.

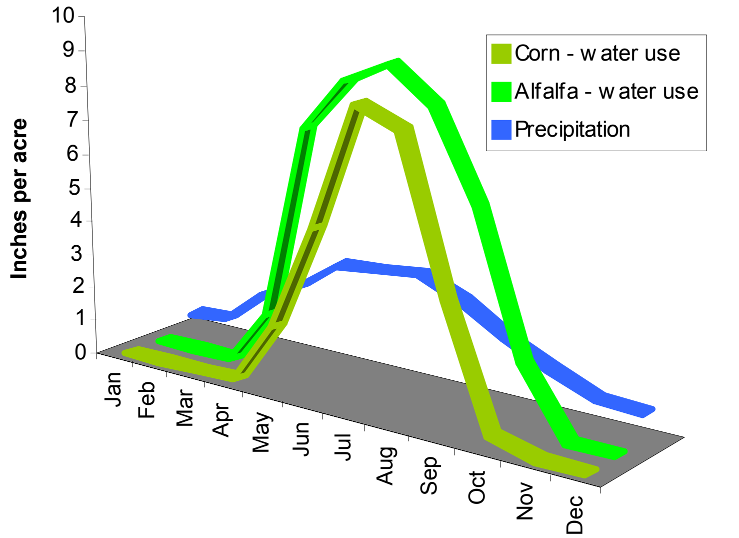

Figure 2. Typical distribution curve of soil nitrate in corn fields.

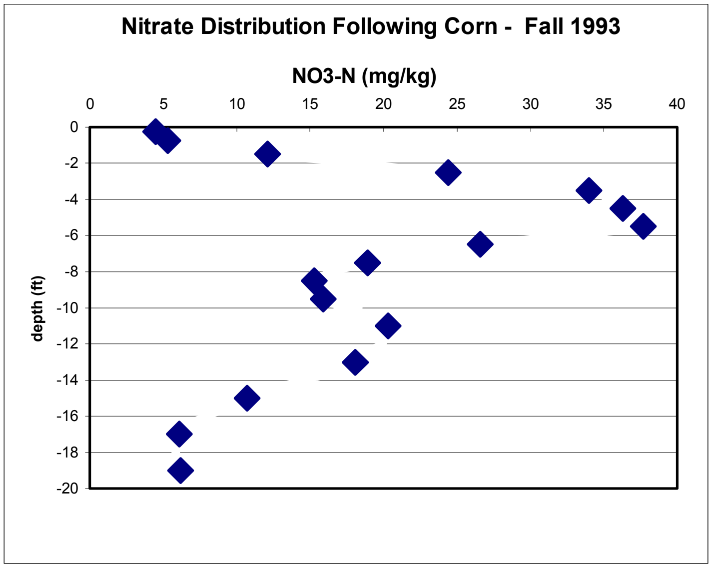

Figure 3. Decrease of soil nitrate with alfalfa following corn.