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Environmental Changes from Long-Term Land Application of Municipal Effluents

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TECHNICAL REPORT

ENVIRONMENTAL CHANGES FROM LONG-TERM LAND APPLICATIONS OF MUNICIPAL EFFLUENTS

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Project Officer's Note: The Bakersfield, CA, and the Lubbock, TX, wastewater irrigation systems are both being expanded and modernized to operate more effectively. Expansion of the Lubbock system is coupled with a comprehensive research program to evaluate the performance of the past operations to performance based on the present day basis for design and operation of wastewater irrigation projects. Results from this comprehensive effort will be an important part of the rapidly expanding data base regarding today's design technology as well as the soil-plant environment, surface waters, and groundwaters.

NOTES

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PREFACE

In Sec. 201(b)(2)(B) of the 1972 Federal Water Pollution Control Act Amendments, PL 92-500, it is required that the Administrator of EPA will not make grants for the construction of publicly owned sewage treatment works unless the applicant has satisfactorily demonstrated that "the works proposed for grant assistance will take into account and allow to the extent practicable the application of technology at a later date which will provide for the reclaiming or recycling of water or otherwise eliminate the discharge of pollutants." Furthermore, the Administrator is required to encourage the construction of revenue producing facilities that provide for (1) recycling of potential sewage pollutants through the production of agriculture, silviculture or aquaculture products; (2) reclamation of wastewater; (3) elimination of the discharge of pollutants; and (4) treatment management that combines open space and recreational considerations. All of these are conceptually achievable by the use of soil-plant complexes to renovate effluents from conventional primary or secondary wastewater treatment works. The concept for utilizing soil-plant complexes has become identified as the land treatment process. Land disposal of raw and treated sewage effluents is not new, but was recognized only in recent times. There are many sites where relatively large volumes of sewage effluent are used to irrigate agricultural lands. The Muskegon, Michigan, system is an example of a large land treatment system that has been recently established. Since operations were initiated in 1974, this 40 mgd facility has produced a higher quality effluent at a lower cost than is achievable with more conventional in-plant systems for providing tertiary treatment and nutrient removal. However, questions about the effective life of land treatment systems for removing various wastewater contaminants, especially phosphorus, still persist. To obtain information about changes in chemical properties of soils subjected to long-term irrigation with sewage effluent, two sites were selected for study.

This report contains the results of various chemical analyses performed on soil and plant samples collected from sewage effluent disposal sites during March 1975 at Bakersfield, California, and at Lubbock, Texas, in June 1976. At both sites approximately 16 mgd of effluent is applied daily throughout the year on land used for the production of row and forage crops. Parts of both farms have been annually irrigated with sewage effluent for more than 35 years. Except for changes in phosphorus concentrations, soil chemical properties were not markedly affected by sewage effluent irrigations. Long-term irrigations with sewage effluent have caused very little changes in the chemical composition of plants grown on the disposal sites.

From the few data available, it appears that long-term disposal of sewage effluent on farm land may have caused unacceptable concentrations of nitrates in groundwaters. This problem could be easily corrected at both sites by storing effluent during winter months. With adequate storage facilities, effluent applications could be regulated so that nitrogen inputs were in balance with nitrogen uptake by crop plants. If they were managed to remove nitrogen, soils at both sites have potential capacities for removing contaminants from wastewaters for many more years.

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Preliminary Assessment of Environmental Changes Resulting From Long-Term Applications of Sewage Effluent on Land

In recent years a rather voluminous literature has developed regarding the benefits to be derived by society from various schemes to use soil-plant complexes for renovating municipal sewage effluents. A sprinkler irrigation network constructed at Muskegon, Michigan, and put into operation in 1974 is an example of a large system designed specifically for renovating wastewater. Many questions have been raised with regard to how long land treatment systems will provide effective treatment of wastewaters. Several of the questions center on long-term gradual changes in soil physical and chemical properties, which may affect plant growth. To assess the long-term effectiveness of land treatment systems, two sites where wastewaters have been annually applied on land for more than 35 years were selected for study. These two sites handle portions of the wastewater flows from Bakersfield, California and Lubbock, Texas, respectively.

Background Information

1. Bakersfield, California. Bakersfield is located about 100 miles northeast of Los Angeles in about the center of Kern County and is the most populous city in the county. Census population for the City of Bakersfield was 69,515 in 1970 and for the Greater Bakersfield Area it was 178,316. Both are probably somewhat greater now, but growth in the last few years has been slow (1 percent or less) because the economy is based mainly on agriculture and the decreasing influence of oil associated industries.

The Greater Bakersfield Area is served by five wastewater treatment plants, three of which are operated by the City of Bakersfield. The other

two treatment plants, known as the Mount Vernon County Sanitary District and the North of the River Sanitary District plants, serve some of the suburban areas around Bakersfield. The two treatment plants of interest from the standpoint of collecting information relative to environmental changes associated with long-term applications of sewage effluent and sludges are the City of Bakersfield's Plant No. 1 and Plant No. 2, located in the southeastern part of the city.

The City of Bakersfield has had a sewer system since 1911, but did not have a treatment plant until Plant No. 1 was constructed in 1939 as a WPA project. From 1911 through 1939, raw sewage was irrigated on the land owned by the city which lies southeast from the present location of treatment Plant No. 1. When Plant No. 1 was constructed to provide primary treatment, it had a design capacity of 9.0 mgd but an earthquake in 1952 destroyed the chemical coagulation equipment ($FeCl_3$). Subsequently, its practical capacity was reduced to about 4.0 mgd. At the present time, Plant No. 1 receives average sewage flows of about 3.8 mgd, but it has pumping capacity to handle peak flows of 6.6 mgd with one pump on standby. Effluent from primary clarifiers is pumped without disinfection to a holding pond prior to its use in irrigating grain, fiber and forage crops.

The City of Bakersfield's Plant No. 2 is also a primary treatment plant and is located approximately two miles south of Plant No. 1. The second plant, constructed in 1952, has a design flow of 16 mgd and peak flow capacity of 23 mgd. Inplant treatment consists of about six hours of aeration prior to transferring the sewage to clarifiers where the solid material is allowed to settle and is scraped to a sludge hopper by mechanical sludge rakes. The solids are pumped to a primary anaerobic digester. Effluent flows from the

clarifiers by gravity either to a small reservoir with a detention capacity of 3 days or directly to a pumping station. From the reservoir effluent can be transferred through ditches for irrigation of crops in fields lying southeast of Plant No. 2. Effluent going directly to the pumping station is lifted toward the northern part of the city owned farm (toward Plant No. 1). It is pumped to the northern part of the farm where land surfaces have a grade of about 0.1 percent from north to south, permitting the use of furrow or border application methods. This results in some intermingling of effluents from Plants No. 1 and No. 2 as applied on part of the 2,400 acre farm. City owned farm lands include parts of sections 3, 9, 10, 15, 16, 21 and all of 22, T.30S, R.28E. Only the land south of treatment Plant No. 1 in section 3 has been irrigated exclusively with water from that plant. Land south of treatment Plant No. 2, irrigated by gravity flow, has occasionally received anaerobically digested sludge. All of these circumstances were considered in selecting soil and crop sampling sites in order that the information collected could be related to a particular sewage treatment plant effluent.

The city owned farm is leased to a local farmer. The lease contract is for a 5-year period and requires the farmer to handle the entire quantity of effluent from both city Plants No. 1 and No. 2. The contract results in revenues of about 16 dollars per acre for the city. Apparently, it is also rather rewarding for the farmer, because he does not use any supplementary fertilizers to grow cotton, corn, barley, and alfalfa on the farm. Alfalfa, irrigated twice and cut once a month from March to October has yielded 7 to 8 tons/acre during the growing season. Barley yields have varied from 1½ to 2½ tons/acre. Corn, harvested for silage and produced in a double-cropping system with barley, has yielded between 18 and 30 tons per acre. Barley is

usually irrigated at two week intervals from the middle of March to the middle of May. After corn is planted on the land in late May or early June, it is irrigated at a rate to supply about 2½ to 3 inches of effluent per week. Cotton yields of 600 to 800 lbs. of lint per acre have been about 20% below county averages. Land planted to cotton is generally irrigated with 1 to 2 ft. of effluent prior to planting in April. These application rates provide too much nitrogen, causing too much vegetative growth and low set of cotton bolls. To overcome this problem, the farmer blends well water with the sewage effluent used for cotton irrigation from about the first of June to the last of August. About 750 to 800 acres of the less productive soil areas are used to produce grass for grazing beef animals. Pasturelands irrigated with 3 to 4 inches of blended tailwaters and effluents at a frequency of once during each 2 week interval during the year, have supported 1.5 to 2 animal units per acre. Except for cotton, crop yields and pasture carrying capacities have been somewhat higher than those reported as county averages.

Total annual rainfall is only about 6 to 6.5 inches and potential evapotranspirational moisture losses are in the neighborhood of about 5 ft., thus, in such an area, effluent has considerable value as an irrigation water supply. Irrigation water costs about $15 per acre-ft. whether it is pumped from wells or purchased from one of the water supply services or districts. Volumes of effluent supplied to city-owned farm lands amount to about 9 acre-ft. per year. However, the lack of winter effluent storage facilities forces the farmer to apply effluent continuously throughout the year. Most of the rainfall occurs during the period from December through March when evaporational losses are low and thus during this period of the year, effluent applications cause a serious hydraulic overload. While there is some collection and storage

of tailwater at the south end of the farm which is returned for blending with effluent in the latter part of June, July, and August it is not enough to meet requirements during this peak water demand period for growing crops. During this period some supplemental well water is used for irrigation of cotton on the city farm, as mentioned above.

2. Lubbock Texas. Lubbock is located on the southern High Plains of West Texas that would be featureless except for ubiquitous shallow depressions, called "playas". The playas range in size from a fraction of an acre to about 200 acres and have a density of about one per square mile. They collect water from surrounding uplands when amounts of precipitation are intermittently sufficient to cause runoff. Minor amounts of playa stored water are used for irrigation and some infiltrates to ground water, but most of it is lost by evaporation.

Where Lubbock is located, average annual precipitation is about 18 inches and potential evapotranspiration losses of soil moisture is about 65 inches per year. Thus, water is the most limiting factor for crop production. Nevertheless, the increase in Lubbock's population from about 128,000 in 1960 to 165,000 in 1975 is attributed mainly to the existance of a thriving agricultural economy made possible by the use of water from the Ogallala aquifer for irrigation of crops. This aquifer underlies much of the high plain area. However, the ground water is being mined because less than 5 percent of the 6 to 8 million acre-ft. of water pumped from the aquifer each year is replenished by natural recharge. During the last 30 years the aquifer water table has been dropping at the rate of 1 to 3 feet per year. Because fuel and electrical power prices have drastically increased at a time when higher amounts are required to pump water from ever increasingly greater depths, many farmers are now reverting to dry land farming operations.

Until about 1925 the City of Lubbock discharged primary effluents to a tributary of the Brazos River, which is a small intermittently flowing stream in the bottom of a 45 to 75 foot-deep canyon located in the north and east part of the city. To remove the threat of contaminating privately owned recreational lakes in Yellow House Canyon, several miles downstream from the sewage treatment plant, operations were changed to permit the discharge of effluent to a nearby upland area. In 1937, the city entered into a 20-year contract with Frank Gray, a local farmer, to take the effluent from a city owned reservoir and spread it on land. At that time Mr. Gray was responsible for handling about 1 to 1.5 mgd. In the beginning he was able to dispose of the effluent on about 200 acres of land, where alfalfa and small grains were grown. But, as the city grew, more land had to be purchased to handle steadily increasing flows. The first trickling filter plant was constructed in 1941 with a design capacity of 6 mgd. A second trickling filter plant with a design capacity of 7 mgd was put into operation in 1950. After a newly constructed waste activated sludge treatment plant, capable of treating 12 mgd, was put into operation in 1972, the plan was to abandon the trickling filter plants. However, because of the rapid growth of the city, both trickling filter plants are now being returned to service. Until about 4 mgd of effluent was diverted for use as cooling water by a power plant constructed in 1971 near Lubbock, Mr. Gray was required to take about 16 mgd of secondary effluent. Most of this quantity of treated wastewater had to be applied each day because the effluent storage reservoir was only large enough to store 60 to 70 hours of flow. No animal or human health problems were ever observed even though secondary effluents were not chlorinated until the waste activated sludge treatment plant was put into operation in 1972.

Effluent is applied on 3,680 acres of land that is managed directly by Mr. Gray and, before the 4 mgd was diverted to the power plant, some was sold to neighboring farmers during the growing season. Until 1974, all effluent was applied by the furrow and border irrigation methods. In 1974 Mr. Gray installed 5 center-pivot sprinkler irrigation systems, each capable of irrigating almost 160 acres. However, he does not plan to change to sprinkler application systems throughout the farm because he has to continue to apply secondary effluents during winter periods. Ice formation on the sprinkler equipment being used now would cause insurmountable problems.

Irrigation of various row crop, small grain and forage species with secondary-treated sewage effluent has been rather profitable for Mr. Gray. Alfalfa yields of 7 to 8 tons/acre compare favorably with yields produced with well water. Grain sorghums yields have been about 6,500 lbs. per acre as compared to 4,000 to 5,000 lbs./acre under well water irrigation. Wheat yields have averaged nearly 80 bu/acre as compared to 30-40 bu/acre on adjacent farm land irrigated with well water. Lint cotton yields have generally been in the range of 900 to 1200 lbs. per acre as compared to 600 to 800 lbs. per acre on land irrigated with well water. Since very little supplementary fertilizer is used on the farm, production costs for row crops are considerably less than those for other farmers. However, to handle the effluent in a satisfactory manner, over the years Mr. Gray has bench leveled about 1600 acres of land and constructed about 40 miles of underground concrete and plastic pipelines plus ponds at the lower ends of fields to collect tailwaters for later reuse.

Several similarities exist between the sewage effluent irrigation systems at Bakersfield and Lubbock. Both were established at about the same time for the same purpose of avoiding the discharge of partially treated effluent to

streams which flowed only intermittently. Both systems have been expanded during the last 40 years until they are presently handling about the same quantities of effluent on about the same land acreage where about the same kinds of crops are grown. Both systems employed surface irrigation systems, until Mr. Gray recently installed center-pivot sprinklers. Winter storage of effluent is not practiced at either of the operations at Bakersfield and Lubbock. At both locations, the farmer is required to take the effluent throughout the year compelling him to apply large quantities (15 to 16 mgd) during the winter time when row crops are absent and forage crops are not growing. A disease incident involving man or livestock has never been linked to the effluent irrigation operation at either location. This is in spite of the absence of chlorination at Bakersfield since 1952 and at Lubbock until 1972. Beef animals are used to harvest grass and other forage crops from areas where surplus effluent is applied during the part of the year when it is not needed for small grain and row crop production on both farms. The lack of facilities for storing effluent for about 3 months is probably the major deficiency at both locations. The main difference between the two operations is that at Bakersfield, practically all the effluent is applied on city owned lands, while at Lubbock, practically all of the effluent is applied on privately owned lands.

Wastewater Characteristics - Bakersfield and Lubbock

Very little data for characterizing the effluents applied on land was available from treatment plants at either Bakersfield or Lubbock. What information was available has been summarized by Crites (1974) for Bakersfield and by Sweazy and Whetstone (1975) for Lubbock. These data, as previously reported, were summarized here in Table 1 for the readers' convenience. Crites stated that the concentrations for several constituents in effluents at

Table 1. Characteristics of Effluents Applied on Land at Bakersfield, California and Lubbock, Texas.

Analyte	Bakersfield[a/]	Lubbock[b/]
	----mg/l except as noted-----	
COD	---	32-129
BOD	150	8-22
Total organic carbon	---	20
Suspended Solids	48	8-19
Total Dissolved Solids	380	1194-1235
Dissolved oxygen	---	2-6
Total N	28	12-15
NH_4-N	25	2-4
NO_3-N	0	5-8
Org.-N	3	3-4
Total P	6	11-12
Chloride	60	318
Sulfate	90	---
Boron	0.5	---
Calcium	15	39*
Magnesium	18	24*
Sodium	112	344*
Potassium	12	16*
Alkalinity	220	236-262
Sodium Adsorption-ratio	4.4	6
Soluble Sodium Percentage	65%	---
pH, units	7.2	7.4-7.5

a/ Crites, R. W. 1974 - Primary effluent.

b/ Freese, Nichols and Endress Consulting Engineers Report, 1971. Sweazy and Whetstone, 1975. Wells, Sweazy, Gray, Jaynes, and Bennett, 1976 - Secondary effluent.

* Estimated from Northwest Lubbock treatment plant data reported by Sweazy and Whetstone, 1975.

Bakersfield were those to be expected in a blend of effluents from the two treatment plants as used for irrigation. All of the values reported in Table 1 for Lubbock effluents are characteristic of wastewaters from the Southeast treatment plant that are applied on the Gray farm, except Ca, Mg Na, and K concentrations which were estimated from contents of these elements in effluents from the small (0.75 mgd) Northwest treatment plant in Lubbock. Total dissolved solids and chloride contents in effluents from the small treatment plant in Northwest Lubbock are about 2 times higher than levels in the Southeast Plant. The differences are evidently the result of the use of large quantities of demineralized water in campus laboratories and the heating and cooling plant of Texas Tech University. Residual waters, with increased levels of soluble substances, are discharged to the Northwest Wastewater Treatment Plant sewers. Concentrations of Ca, Mg, K, and Na in effluents from the Southeast treatment plant were assumed to be about one-half those reported by Wells et al. (1976) as concentrations in effluents from the Northwest Treatment Plant.

Comparing wastewater characteristics at Bakersfield with those produced at the Lubbock Southeastern treatment plant, the former has considerably higher BOD and total N levels while the latter has higher concentrations of total dissolved solids, Cl, and Na. Differences in BOD may not be as great as indicated in Table 1, because Wells, et al. (1976) stated that researchers at Texas Tech University had found that the BOD of effluents from the Lubbock Southeastern plant had averaged about 75 mg/l over the past ten years. Both BOD and total N concentrations in effluents at Bakersfield and Lubbock are about what would be expected on the basis of differences in levels of wastewater treatment practiced at the two locations prior to application on land.

Total dissolved solids concentrations are relatively high in Lubbock wastewaters because they are high in city water supplies. Prior to the construction of Lake Meredith on the Canadian River, north of Amarillo, Texas, water supplies for the city of Lubbock were obtained from wells penetrating the Ogallala aquifer. Water samples collected from 42 wells in the Southern High Plains area of Texas had conductivities that ranged from 476 to 1750 micromhos/cm (Cronin, 1964). Beginning in 1968, Lubbock has received a portion of its water supply from Lake Meredith. Total dissolved solids concentrations in lake water varies, but averages about 1,200 mg/l. Currently, about 75% of the water used in Lubbock comes from the lake.

Soil and Site Characteristics

1. Bakersfield, California. The predominant soil on the City of Bakersfield's effluent irrigation farm is classified as belonging to Panoche series. The Panoche series consists of well drained, calcareous, light brownish gray and very pale brown loam and clay loam soils, found on alluvial fans derived from granitic rock sources. Slopes are less than 2 percent and in several places on the farm, are practically level. Soils belonging to the Panoche series have profiles which are moderately alkaline and water permeabilities classed as moderate to moderately slow. Available water holding capacities range from 0.20 to 0.25 inches per inch depth. In the surface horizon, Panoche soils have pH values of 8.0 to 8.2 and sodium occupies 6 to 18 percent of the total cation exchange capacity. Productivity has been much improved by effluent irrigation on several sandy loam basin and alkali flat areas on the farm. At the beginning of effluent irrigation of alkali flat areas sodium occupied more than 70 percent of the cation exchange capacity. At a depth of 10 to 15 feet, nearly all of the farm is underlain by densely

compacted subsoil materials which are only very slowly permeable to water infiltrating the soil surface. Until lost by slow percolation and evapotranspirational processes during the summer months, excess water accumulates to produce perched groundwater tables under the low-lying southern part of the farm.

2. Lubbock, Texas. The soils on the Gray farm at Lubbock, Texas, are mapped as Acuff loam and Friona loam, with some Amarillo fine sandy loam along the north side of the farm. Most of the cultivated areas have slopes varying from practically level to about 3 percent, with runoff drainage to playas in the northern and to constructed ponds on the edge of Yellow House Canyon (mentioned earlier) in the southern part of the farm. All soil types have a horizon at 20 to 36 inches below the surface where $CaCO_3$ masses make up 30 to 40 percent of the soil volume. These soils are moderately permeable and have available water holding capacities that range from 0.15 to 0.20 inches per inch depth. Evidently, no water impermeable layers exist between the soil surface and the Ogallala aquifer since surface applications of effluent have, over the years, resulted in higher water table levels in the formation where it underlies the farm.

Sample Collection and Preparation

2. Bakersfield, California. In March, 1975, soil and vegetation (barley) samples were collected from one field immediately south of Plant No. 1, on the effluent irrigated farm at Bakersfield. This field had been irrigated with primary effluent for at least 35 years and was irrigated with raw sewage for about 10 years prior to the construction of Wastewater Treatment Plant No. 1.

Six soil samples were collected to a depth of 36 inches, using 1-inch diameter stainless steel tubes, at each of three sites about 150 feet south of an effluent distribution ditch lying in an east to west direction adjacent to the small holding reservoir associated with treatment Plant No. 1. At each of the sampling sites, the 6 soil core samples were segmented into depth samples of 0-7, 7-13, 13-24, 24-33 and 33-36 inches, conforming to differences in soil horizons. Soil samples were composited by incremental depths and placed in labeled polyethylene-lined paper bags. At each of the 3 locations where soil samples were collected, 25 to 30 whole barley plant samples were collected, washed in distilled water, placed in paper bags and dried overnight in an oven at 60°C. Both soil and vegetation samples were collected in a similar manner from a field in the southwest 160 acres of section 11 of T.30S, R.28E (one mile east of the Bakersfield City farm) which had been irrigated with well water only. All soil and plant samples were shipped to the U.S.E.P.A. Water Research Laboratory, Ada, Oklahoma where they were analyzed for selected chemical elements.

2. Lubbock, Texas. In much the same way as described for the sampling operations at Bakersfield, soil samples were collected from 3 fields on the Gray Farm at Lubbock, Texas, which had been annually irrigated with effluent for a period of at least 38, 19, and 6 years. Soil samples were collected in each field from sites located about 50 feet from the effluent distribution ditch, midway through the length of the field and about 150 feet inside the tailwater end of the field. For each of the two soil types sampled on the sewage effluent irrigated farm, representative sites were sampled in adjacent fields which had been irrigated with well water only. Corn was growing on the field that had been irrigated with sewage effluent for 19 years and was

at tassel stage of growth. Samples of corn leaves, located nearest the primary ear formation, were collected from plants growing in the vicinity of each of the soil sampling sites. All soil samples, collected in polyethylene-lined bags, were dried, crushed, split, and pulverized to pass a 60-mesh screen and leaf tissue samples, which had previously been rinsed in distilled water, were dried at 60°C in a forced air oven and ground in a Wiley mill. After these operations had been performed on the samples in the Department of Plant and Soil Science laboratories at Texas Tech University, the samples were subdivided and portions were shipped to the Department of Agronomy, University of Illinois. Responsibilities for analyses and measurements to characterize the soils on sewage effluent and well water irrigated farms were divided between laboratories at the two Universities.

Analytical Procedures

Methods used to analyze soil samples were the same as those described in American Society of Agronomy Monograph No. 9 with few exceptions. One important exception was that soil samples from Bakersfield were analyzed for surface adsorbed or precipitated heavy metals using the HNO_3 and HCl digestion procedure outlined by Oliver (1973), whereas total heavy metals were determined in soil samples from the Lubbock sites. Soil samples from Lubbock sites were ashed at 500°C, digested in concentrated HCl-HF and subsequently dissolved in 1 N HCl prior to analysis by atomic absorption spectroscopy techniques. Another difference between analytical methods was that plant tissue samples from Bakersfield were dry ashed in a furnace at 450°C, whereas corn leaf samples from Lubbock were wet ashed by digesting in HNO_3 at 90°C. At both laboratories, metal contents were determined on atomic absorption spectrometry instruments equipped to make simultaneous deuterium

arc background corrections to the data. All determinations were made from triplicate subsamples of each soil and plant sample. After no appreciable differences were observed in results from soil samples collected at different locations within a particular field at the Lubbock site, they were presented for discussion as average values.

Results

1. Bakersfield, California. In comparison with concentrations in the same soil irrigated with well water, results in Table 2 show that sewage effluent applications on the Bakersfield farm caused increased soil organic matter and total N concentrations to depths of 2 feet. Concentrations of Ca and Mg were higher and Fe and Al were lower in soil from all depths on the sewage effluent irrigated farm as compared to concentrations of these elements in soil from the control site. Total P concentrations were higher in the surface of the sewage effluent irrigated soil (0-7 inches), but concentrations were not different than those in control soil at deeper depths. Iron and Al concentrations appeared to have been decreased throughout the soil profile by sewage effluent applications. Concentrations of surface adsorbed and/or precipitated Zn and Cu were apparently increased in the 0 to 24 inch depth of soil by sewage effluent applications. Concentrations of surface adsorbed and/or precipitated Ni, Pb and Cd were higher throughout the profile of the effluent irrigated soil than where effluent had never been used for irrigation. Extractable levels of Cd in the soil irrigated with only well water were 0.2 to 0.5 ppm higher in subsurface layers than generally reported as typical total levels in soils. If sewage effluent irrigations have caused any changes in exchangeable Ca, Mg, and Na contents in the soil, it may be that exchangeable Ca levels were increased at the expense of exchangeable Na

Table 2. Average contents of selected chemical elements in the profile of a Panoche clay loam soil irrigated with sewage effluents for about 38 years as compared to chemical characteristics of the same soil type treated with gypsum and irrigated with well water at sites near Bakersfield, California (All results are based on dry weight of soil).

Irrigated with	Soil Depth (inches)	Total							Surface adsorbed and/or precipitated					Exchang.			Extract.
		Org. Mat.	N	P	Ca	Mg	Fe	Al	Zn	Cu	Ni	Pb	Cd	Ca	Mg	Na	P
		%							ppm					%			ppm
Effluent	0-7	3.6	0.22	0.17	1.6	3.2	1.6	5.6	156	29	30	56	2.0	0.44	0.041	0.054	470
	7-13	2.5	0.12	0.10	3.0	3.4	1.2	5.4	119	26	28	43	2.1	0.44	0.048	0.053	390
	13-24	1.4	0.06	0.08	4.0	3.6	1.5	4.8	86	24	28	36	2.0	0.40	0.054	0.059	440
	24-33	0.9	0.04	0.07	6.5	3.5	1.5	4.2	57	16	30	19	2.2	0.42	0.056	0.065	340
	33-36	0.8	0.03	0.06	7.9	3.2	1.3	3.7	51	15	31	19	2.1	0.41	0.057	0.063	320
Well Water	0-7	2.1	0.09	0.10	0.6	2.0	2.9	6.3	67	15	24	13	0.9	0.37	0.051	0.080	100
	7-13	1.3	0.07	0.10	0.7	2.1	2.9	6.0	66	14	24	12	1.2	0.39	0.050	0.077	80
	13-24	1.0	0.04	0.09	0.8	2.1	2.6	6.5	76	15	24	11	1.5	0.39	0.054	0.081	70
	24-33	0.7	0.03	0.10	0.8	2.2	2.5	5.8	67	15	24	11	1.3	0.35	0.050	0.161	80
	33-36	0.6	0.03	0.09	0.9	2.3	2.7	5.3	60	14	23	11	1.2	0.37	0.059	0.155	80

levels, especially in the lower subsoil horizons. No doubt, long-term annual sewage effluent applications caused appreciable increased extractable P levels in soil as determined by the method discussed by Taylor and Gurney (1965). Resin-extractable P levels were uniformally increased 4- to 5-fold in all soil horizons by sewage effluent irrigations as compared to levels in respective soil horizons where well water was used for irrigation. Except for extractable P, concentrations of all elements in all soil samples were within ranges of concentrations found in normal agricultural soils.

Levels of selected chemical elements in whole barley plant tissues, as presented in Table 3, suggest that sewage effluent applications have not materially affected the chemical composition of plants. However, low Fe contents in plant tissue from the sewage effluent irrigated farm as compared to tissue from plants growing on soil irrigated with well water, may be a reflection of differences in contents of the element in soils, as previously noted.

2. Lubbock, Texas. Total concentrations of 15 elements and organic matter, as shown in Table 4, indicate very few changes in the chemical status of soils associated with long-term sewage effluent applications at Lubbock. Other than increased concentrations of total P throughout the soil profile irrigated with sewage effluent for 38 years, no other differences in chemical composition of soils can be attributed to the use of wastewater. Regardless of treatment, all of these soils contained heavy metals at levels somewhat below those considered as typical contents of normal agricultural soils. Concentrations of B in all of the soils were in the upper range generally reported for agricultural soils, but apparently were not affected by applications of sewage effluent.

Table 3. Average total concentrations of selected chemical elements in whole barley plants collected at boot stage from the sewage effluent irrigated farm at Bakersfield, California, and from a farm where only well water had been used for irrigation (all results are based on dry weight of tissue) in comparison to typical range for forage grasses and legumes.

Irrigation with	Total Concentrations										
	N	P	K	Ca	Mg	Na	Fe	Zn	Cu	Cd	Pb
	----------%----------					----------ppm----------					
Effluent	2.42	0.43	3.20	0.36	0.11	253	87	59	7	<1	<6
Well Water	3.16	0.37	2.99	0.45	0.21	269	159	43	9	<1	<6
Comparative range	(2-4)	(.2-.4)	(1.2-2.8)	(.6-.9)	(.2-.4)		(250-600)	(8-60)	(2-15)	(.2-.8)	(1-10)

( ) Range for common range grasses and legumes from R.D. Johnson, et. al., Selected Chemical Characteristics of Soils, Forages, and Drainage Water from the Sewage Farm Serving Melbourne, Australia. Department of the Army, Corps of Engineers, page 23, January 1974.

Table 4. Average total contents of selected chemical elements, in the profiles of Acuff loam and Friona loam soils annually irrigated with sewage effluents for various periods of time at Lubbock, Texas. (All results are based on dry weight of soil.)

Acuff loam																	
Irrigated with	Soil Depth (inches)	Org. Mat.	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Ni	Pb	Cd	Cr	B
		%								ppm							
Effluent for 38 years (Gray Farm)	0-12	1.6	0.09	0.058	1.77	0.32	0.23	0.20	1.04	139	53	8	9	18	<0.25	17	129
	12-18	1.1	0.05	0.043	2.39	0.28	0.35	0.31	1.69	209	43	7	14	16	<0.25	23	150
	18-24	0.9	0.05	0.041	2.33	0.25	0.34	0.30	1.62	203	46	6	15	8	<0.25	22	149
	24-30	0.8	0.05	0.038	2.45	0.21	0.37	0.32	1.65	204	52	8	17	9	<0.25	23	152
	30+	0.6	0.04	0.033	2.35	2.17	0.37	0.30	1.54	178	40	7	16	13	<0.25	23	137
Well Water (Cotton Compress land)	0-12	1.3	0.07	0.020	1.93	0.39	0.32	0.19	1.43	161	33	7	14	9	<0.25	21	129
	12-18	1.2	0.03	0.020	2.44	0.42	0.42	0.28	1.98	199	47	8	19	14	<0.25	27	131
	18-24	0.8	0.05	0.018	2.28	0.30	0.34	0.28	1.65	177	37	5	18	15	<0.25	24	127
	24-30	0.8	0.04	0.018	2.31	0.29	0.28	0.26	1.63	158	39	7	18	4	<0.25	20	127
	30+	0.6	0.03	0.016	2.16	0.50	0.31	0.24	1.39	143	33	6	13	18	<0.25	18	119

Table 4. (cont.) Average total contents of selected chemical elements, in the profiles of Acuff loam and Friona loam soils annually irrigated with sewage effluents for various periods of time at Lubbock, Texas. (All results are based on dry weight of soil.)

Friona loam																	
Irrigated with	Soil Depth (inches)	Org. Mat.	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Ni	Pb	Cd	Cr	B
		%								ppm							
Effluent for 19 years (Gray Farm)	0-12	1.4	0.07	0.042	2.05	0.35	0.28	0.25	1.35	174	43	6	12	15	<0.25	20	125
	12-18	1.0	0.04	0.028	2.38	0.28	0.31	0.29	1.59	197	31	5	12	14	<0.25	22	130
	18-24	1.2	0.05	0.024	2.25	0.26	0.31	0.27	1.36	189	38	7	14	11	<0.25	21	125
	24-30	0.8	0.05	0.026	2.37	0.74	0.34	0.35	1.51	211	43	7	19	17	<0.25	26	123
	30+	0.8	0.04	0.023	1.89	5.31	0.29	0.26	1.10	150	32	4	12	17	<0.25	17	108
Effluent for 6 years (Gray Farm)	0-12	1.9	0.09	0.022	1.85	2.19	0.28	0.24	1.10	157	34	5	8	14	<0.25	20	91
	12-18	1.4	0.07	0.031	2.01	4.42	0.32	0.27	1.28	173	33	4	12	13	<0.25	29	113
	18-24	1.1	0.08	0.028	2.09	5.68	0.39	0.28	1.49	177	38	7	18	13	<0.25	33	123
	24-30	1.1	0.06	0.028	1.44	7.30	0.28	0.22	0.89	123	28	5	13	20	<0.25	19	99
	30+	0.8	0.04	0.021	1.01	16.73	0.28	0.16	0.58	73	19	1	10	21	<0.25	12	86
Well Water (Fritz Farm)	0-12	0.8	0.05	0.019	1.67	0.48	0.24	0.17	0.93	158	26	6	9	16	<0.25	12	103
	12-18	1.2	0.06	0.024	2.23	1.63	0.33	0.30	1.43	232	42	5	14	14	<0.25	23	116
	18-24	1.8	0.04	0.025	2.25	2.47	0.31	0.34	1.39	246	40	5	16	11	<0.25	30	106
	24-30	1.0	0.05	0.025	2.40	3.70	0.38	0.38	1.49	261	43	9	20	9	<0.25	34	121
	30+	1.1	0.05	0.024	2.40	16.72	0.42	0.38	1.63	237	51	8	17	22	<0.25	33	123

Toward a more complete characterization of the Lubbock soils, several other measurements were made for which the results are exhibited in Table 5. First, it may be observed that where the Acuff loam soil has been irrigated for 38 years with sewage effluent, soil pH has been decreased by about one unit in the 0-18 inch surface layer. Soil pH has been decreased only slightly in Friona loam irrigated for 19 years with sewage effluents. Results from electrical conductivity measurements of water saturated soil extracts show that 38 years of irrigating Acuff loam soil with sewage effluent has caused an increase in its salinity levels at all sampled depths of the profile. In this soil, salinity levels are approaching the lower end of the range where yields of many crop plants may be reduced (Wadleigh et al., 1951). Where effluent has been applied for 19 and 6 years on Friona loam, soil salinity levels were increased at all depths. The most notable differences in salinity levels occurred at the lower depths of the profile. Concentrations of K and P extracted with NH_4OAC from soils have been markedly affected by sewage effluent irrigations. Except in the surface 0-12 inch zone, the Acuff loam soil had nearly 2-fold contents of extractable K as compared to the well water irrigated control soil. Friona loam soil irrigated with effluent for 19 years had higher concentrations of extractable K at all depths than were found in control soil. Concentrations of P significantly increased at all soil depths where effluent was applied for 38 and 19 years. Organic P levels were increased in the surface (0-12 inches) of Acuff loam subjected to long-term sewage effluent applications.

Average total contents of selected chemical elements in corn leaf tissues, collected from the Friona loam site at the same time as were soil samples, are shown in Table 6. Irrigating this soil for 19 years did not affect

Table 5. Comparison of several characteristics of soils annually irrigated with sewage effluent for different lengths of time with those of soils irrigated with well water at Lubbock, Texas.

Acuff loam												
Irrigated with	Soil Depth (inches)	pH	Elect. Cond.	Carbonates	Cation Exchange Capacity	NH_4OAc Extractable					0.5 M $NaHCO_3$ Extractable P	Organic P
						Ca	Mg	Na	K	P		
			mmhos/cm	%	me/100 g.	ppm						
Effluent for 38 years (Gray Farm)	0-12	6.9	3.73	0.6	12.2	2267	387	867	625	205	82	91
	12-18	6.7	4.14	0.9	15.3	1967	560	1477	665	89	78	66
	18-24	7.0	4.63	0.7	17.7	2033	709	1270	672	84	64	60
	24-30	7.0	3.18	1.2	17.7	1800	717	1073	620	73	65	64
	30+	7.2	2.76	3.5	17.0	4050	907	1322	604	69	52	53
Well Water (Cotton Compress) Land	0-12	7.6	1.65	0.5	14.1	2500	580	1900	465	21.3	1.3	60
	12-18	7.7	1.63	0.5	17.4	2500	580	920	264	6.5	0.3	51
	18-24	7.4	1.32	0.5	17.4	2700	400	1150	297	10.7	2.0	58
	24-30	7.5	1.71	1.3	17.3	4900	555	2550	352	17.8	0.8	54
	30+	7.6	1.49	1.1	15.6	5940	465	1365	356	17.6	2.0	16

Table 5. Comparison of several characteristics of soils annually irrigated with sewage effluent for different lengths (cont.) of time with those of soils irrigated with well water at Lubbock, Texas.

Friona loam												
Irrigated with	Soil Depth (inches)	pH	Elect. Cond.	Carbonates	Cation Exchange Capacity	NH_4OAc Extractable					0.5 M $NaHCO_3$ Extractable	Organic
						Ca	Mg	Na	K	P	P	P
			mmhos/cm	%	me/100 g.	ppm						
Effluent for 19 years (Gray Farm)	0-12	7.3	2.53	1.0	10.4	2400	390	1293	582	107	36	78
	12-18	7.4	1.61	1.5	10.6	2433	460	1090	489	26	20	70
	18-24	7.5	1.65	1.6	17.6	3400	383	1023	414	19	9	64
	24-30	7.7	1.78	9.7	18.9	6567	933	1136	384	26	8	42
	30+	7.7	2.19	20.4	17.8	6367	787	1488	332	39	6	45
Effluent for 6 years (Gray Farm)	0-12	7.8	2.98	8.8	--	8000+	210	1000	273	24.2	3.4	--
	12-18	7.7	2.70	12.8	--	8000+	290	700	249	15.0	2.7	--
	18-24	7.7	1.20	15.9	--	8000+	420	900	280	15.8	5.0	--
	24-30	7.7	1.22	17.9	--	8000+	1480	2000	260	55.5	4.7	--
	30+	7.7	1.07	62.2	--	8000+	1925	2335	208	76.5	2.4	--
Well Water (Fritz Farm)	0-12	7.7	2.01	0.7	--	3400	470	1100	337	27.3	3.4	--
	12-18	7.6	1.21	2.3	--	8000+	400	1300	234	21.7	1.9	--
	18-24	7.6	1.15	5.8	--	8000+	250	820	208	16.1	1.7	--
	24-30	7.6	0.90	6.9	--	8000+	350	1080	241	19.2	1.8	--
	30+	7.6	0.90	11.4	--	8000+	565	1450	266	17.2	2.1	--

Table 6. Average total contents of selected chemical elements in corn leaf tissues collected in June 1976 from a field that had been annually irrigated with sewage effluent since 1957 at Lubbock, Texas in comparison to range for common grasses and legumes. (Results are based on dry weights of tissue samples.)

Chemical Element														
N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	Ni	Cd	Cr	Pb	B
%					ppm									
2.62	0.223	3.65	0.47	0.22	131	103	99	30	9	2.5	0.17	1.2	2.6	149
(2-4)	(.2-.4)	(1.2-2.8)	(.6-.9)	(.2-.4)		(250-600)	(15-200)	(8-60)	(2-15)	(.1-3.5)	(.2-.8)	(.1-.5)	(.1-10)	(1-80)

( ) Range for common range grasses and legumes from R.D. Johnson, et. al., Selected Chemical Characteristics of Soils, Forages, and Drainage Water from the Sewage Farm Serving Melbourne, Australia. Department of the Army, Corps of Engineers, page 23, January 1974.

plant composition since concentrations of selected chemical elements were within the range to be expected in corn leaf tissues. However, leaf concentrations of Na and Fe were in the low and B in the high range of expected levels in leaves from healthy corn plants. Eaton (1944) found that corn plants suffered from B toxicity when leaves contained as much as 179 ppm of the element.

Groundwater

1. Bakersfield, California. Very little is known with regard to groundwater changes underlying the sewage effluent irrigated farm at Bakersfield. What is known was summarized in a report prepared for the City of Bakersfield by Metcalf and Eddy, Inc. (1973). Samples of water from a confined aquifer below the effluent irrigated farm (300 ft.) had concentrations of nitrate ranging from 50 to 60 ppm. However, it was pointed out that several miles east of the effluent irrigated farm, water samples from wells in 40 percent of the sections in Township 30S/Range 29E had maximum nitrate concentrations of 90 ppm or greater. Water from 2 shallow wells (13 to 14 ft. deep) near the eastern edge and middle of the sewage effluent irrigated farm, where perched water tables were found at 11 to 12 ft. below the surface, had concentrations of nitrates that ranged from 4 to 39 ppm. Water from a deep well (170 ft. deep) near one of the shallow wells in the center of the effluent irrigated farm contained 4 ppm of nitrates. With only this limited information it is not possible to assess groundwater quality changes attributable to the practice of using sewage effluent for irrigation.

2. Lubbock, Texas. Only slightly more information about groundwater quality at the Lubbock effluent irrigation farm is available than was found for the Bakersfield operation. Sweazy and Whetstone (1975) reported that

water from a well on the effluent irrigated farm at Lubbock had a total dissolved solids concentration of 1692 ppm. For comparison, Wells et al. (1976) reported that water from a well near the Texas Tech University Campus had a total dissolved solids concentration of 1140 ppm. Well water from the effluent irrigated farm contained 50 ppm of NO_3-N, whereas water from the University well contained only 8.5 ppm of NO_3-N. The former well water had a pH of 7.9 and the latter a pH of 7.7. Water from the University well contained 228 ppm of Cl while water from a spring fed by accumulated subsurface water from the effluent irrigated farm had a mean concentration of 252 ppm of Cl. No comparative information was found, but well water samples from the sewage effluent irrigated farm had no measurable amounts of total coliform and fecal coliform organisms, nor BOD_5. The same water samples did contain 10 ppm COD and had a total phosphorus concentration of 0.08 ppm. From the few data available, it appears likely that the long-term effluent irrigation operation at Lubbock has caused increased dissolved solids and NO_3-N concentrations in the groundwater immediately underlying the farm.

In an area where groundwater levels have been receding at an alarming rate, the water table under nearly all of the effluent irrigated farm at Lubbock is within 10 to 15 feet of the land surface. The water table under the farm is high enough to supply water to playa lakes, used as a water source by cattle, during periods of the year in which they would be dry under normal conditions. If the farm had not been located adjacent to Yellow House Canyon, to which natural subsurface drainage of the farm occurs, it probably would have been necessary to have either curtailed amounts of effluent applied or to have installed subsurface drains. However, because of the abundant availability of good quality water underlying the effluent irrigated farm, plans

are presently being implemented by the City of Lubbock to recover it for use as make-up water in a series of 4 recreational lakes that have been constructed in Yellow House Canyon. The first stage construction of the 4 lakes provides a continuous 8 mile chain of impounded water for recreational use within the City. Make-up water will be pumped from 27 wells, being drilled on the effluent irrigated farm, through 14 miles of pipeline varying in diameter from 24 to 18 inches, to the upper lake. Some of the recovered water will be used for irrigating parks and cemeteries and cooling water at a small city owned power plant.

Before initiating the water reuse project, it was determined that the percolated effluent from the farm would provide for a more dependable, higher, water quality and at a lower cost than could be obtained from two alternative tertiary treatment processes evaluated (Freese, Nichols and Endress, 1971). From the results obtained from a model of the canyon lakes, Headstream et al. (1974) concluded that following percolation through soils, the sewage effluent was suitable as a source of make-up water in lakes to be used for primary contact recreation. However, because of the relatively high level of NO_3-N in recovered effluent waters, some uncertainty exists with regard to eutrophication problems that may arise in the first and second lakes. Since the levels of P are rather low in recovered effluent water, eutrophication may not be as serious as would be anticipated from considerations based on nitrate levels alone. From both public health and eutrophication considerations, several questions exist with regard to the collection of storm runoff water in the series of constructed lakes.

Discussion and Conclusions

In general, crop production has been increased by the use of municipal sewage effluent for irrigation over that obtained with other sources of

water and commercial fertilizer on neighboring farms. Increased production has been realized in spite of frequent periods of hydraulic overloading with effluent.

Measurements were not made, but visual observations did not indicate that soil physical properties had been adversely affected by long-term effluent irrigations. Only a few changes in soil chemical properties were found. At Bakersfield, long-term annual effluent irrigations have probably caused increased soil organic matter and total N and P levels in the soil surface, while Ca concentrations may have been increased and Fe concentrations decreased throughout the whole of the soil profile. Apparently long-term effluent irrigations have caused increased concentrations of surface adsorbed and/or precipitated heavy metals in the soil surface at Bakersfield, although only Zn and Pb levels were markedly different from those in soils irrigated with well water. Long-term irrigations with effluents have apparently caused a reduction in concentrations of exchangeable Na at depths below 24 inches and concentrations of extractable P have been increased markedly throughout the soil profile. Only concentrations of total and extractable P and total dissolved solids in soils have been appreciably increased by long-term sewage effluent irrigations at Lubbock, Texas. Effluents applied for 38 years, appeared to have caused increased concentrations of NH_4OAc extractable K throughout the soil profile, although total K concentrations were not increased.

Increased conductivity of water saturated extracts of soil irrigated with effluent at Lubbock, but not at Bakersfield, is evidently the result of relatively high levels of total dissolved salts in the water source used by the city. Considering the length of time that effluent has been irrigated on land at Lubbock, it seems unlikely that salinity will be a serious problem as

long as adequate over-irrigation is practiced to keep soluble salt levels below those presently existing in the soil profile. Also, when subsurface water tables have been lowered by the recycling program, the border-line salinity problem may be dissipated.

The accumulations of P and heavy metals to higher levels in soils at Bakersfield as compared to levels in soils at Lubbock may have been due to the higher level of wastewater treatment practiced at the latter location. No information about concentrations of metals in effluents was available at either location. Nevertheless, levels of the elements in soil at Bakersfield do not yet represent a potential problem. Zinc, Cu and other trace elements supplied as constituents of effluent at Lubbock may significantly benefit both plants and animals. Except for B, soils in the high plains area have relatively low total concentrations of essential trace elements for plants.

On both the Bakersfield and Lubbock effluent irrigation farms, the groundwater quality could be much improved with respect to NO_3-N concentrations if effluent-nitrogen loading rates were matched with crop uptake of the element. At both sites it appears likely that the relatively high NO_3-N concentrations in groundwater are due to applying too much effluent containing N on lands during periods when growing crops are either absent or making little growth. Effluent storage facilities would provide a means for making more efficient use of both water and the plant nutrients contained in it.

Recommendations

The few data summarized in this report were inadequate for confidently predicting the wastewater renovation capacities of soil-plant complexes. Both of these sites are suitable for an in-depth characterization of long-term effects with a well designed sampling and analytical program.

At Lubbock, special attention should be given to amounts of B supplied on agricultural land as a constituent of effluent. Because natural total B levels are already relatively high in soils, additional accumulations in soils may lead to reduced crop growth. Priority should also be given to determining B levels in effluents and soils at Bakersfield.

Studies should be initiated to determine changes in soluble salt levels in soils on the Lubbock farm as groundwater tables are lowered by the pumping of make-up water for recreational lakes. Much work is needed to establish minimum annual effluent applications required to keep soluble salts in soils at a level sufficiently low for good plant growth. This information will be especially valuable if the farm is expanded and emphasis is placed on efficient use of wastewater for crop production rather than on effluent disposal.

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