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I.K. Iskandar, R.P. Murrmann and D.C. Leggett

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Wastewater disposal sites at Manteca, California, and Quincy, Washington, were evaluated for their current performance and for the long-term impact of wastewater application. These sites have been operated as slow-infiltration, land-disposal systems for up to 20 years. Current performance was evaluated in terms of water quality, while soil chemical parameters were measured to determine the effects of prolonged wastewater application at the sites. No significant effects on the performance were found to be due to differences in pretreatment. A difference between the performances of the two sites was attributed mainly to management practices, site history and climatic differences. While leaching of nitrate was observed at both sites, the impact on groundwater quality generally was found to be within the accepted limits (< 10 mg/l of NO_3-N). Leaching of phosphorus to a depth of 150 cm was found

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at both sites but was higher at Manteca. This was thought to be due to problems associated with crop management, land use, and mode and schedule of wastewater application. Total and extractable phosphorus increased in the surface soil layers with time. However, soil nitrogen appeared to decrease, probably because of mineralization. Soil organic matter and cation exchange capacity increased. Some increase in exchangeable Na was noted, but not enough to produce alkaline or saline conditions. A drop in soil pH at Quincy after prolonged application is thought to have been due to removal of carbonates by leaching and by H^+ from nitrification. If these disposal areas were managed as treatment sites, leachate quality should meet proposed Environmental Protection Agency guidelines for drinking water.

PREFACE

This report was prepared by Dr. I.K. Iskandar, Research Chemist, and D.C. Leggett, Research Chemist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); and by Dr. R.P. Murrmann, Assistant Area Director, Agricultural Research Service (U.S. Department of Agriculture), formerly Research Chemist, Earth Sciences Branch, Research Division, CRREL.

The work covered by this report was conducted under Civil Works Project *Environmental Quality Program – Land Treatment*; Program *Wastewater Management*, Subprogram *Land Treatment*; CWIS 31280, *Evaluation of Existing Facilities for Wastewater Land Treatment.*

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The authors wish to thank Ronald Roduner, Plant Operator, Sanitary Treatment Plant, Quincy, Washington, and Manuel Oliveira, Sanitation Plant Operator, Wastewater Quality Control Facilities, Manteca, California, for their willing assistance during the course of this study. They also acknowledge the technical participation of Bruce E. Brockett, Physical Science Technician, CRREL, who was largely responsible for collection of field samples and collection and reduction of data. Warren Rickard, Botanist, CRREL, participated in planning and taking the initial photos of the research.

CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY AND CONCLUSIONS

The need to protect this country's water resources has led to the passage of Public Law 92-500. To meet the requirements of this law, a number of federal agencies including the Corps of Engineers have been assigned the task of developing better alternatives to the existing methods of wastewater treatment and disposal. In particular, land treatment of wastewater *must* now be considered by a municipality requesting federal construction grant funds. At Corps of Engineers District and Division levels, this has created a need for criteria to compare the cost and environmental impact of land treatment with other alternatives.

This has caused considerable confusion in the past, since the development of design criteria has lagged behind the need to proceed with design and construction of new wastewater treatment facilities. As a result, land treatment has not always been given fair consideration. The reasons for this situation are clear. First, investigation of land treatment systems is new; research is still being conducted on small-scale prototype systems. Second, the concept of land treatment of wastewater is complicated by the number of different modes that are possible depending on site characteristics. Third, little is known of long-term effects on the land treatment system or of good management practices.

The study of existing systems using land treatment for disposal of wastewater was initiated at CRREL to help fill in this information gap while research on prototype systems is still in progress. A number of land treatment facilities have been operated in this country and in other countries for many years. The reason for using data from existing systems is to develop engineering design criteria based on the relatively long-term experience that has been gained from the field. This report describes a study of two existing treatment facilities that have been in operation for up to 20 years.

The following are the essential conclusions drawn from this study and leading to the formulation of design criteria for future land treatment systems.

1. No health hazards or public complaints have been recorded during the 20 years of application of undisinfected wastewater to land at the sites studied.
2. The amount of nitrogen leaching from land treatment systems is influenced mainly by the nitrogen loading rate and plant uptake. Thus, the design of systems should consider first the concentration of nitrogen that can be tolerated in the leachate; this in turn should be determined by the intended water reuse and by the specific hydrologic characteristics of the site .
3. Crops need to be managed to maximize the efficiency of nutrient removal from the percolating effluent.
4. Secondary pretreatment of wastewater is not necessary.
5. Some consideration needs to be given to the rate and method of wastewater application for given soil characteristics; leaching of phosphorus in Manteca was related to too rapid application of wastewater to a sandy loam soil.
6. Buffer zones are not needed for detecting odor complaints when land spreading of wastewater is practiced.
7. Managers of land treatment systems should have a sufficient background on land use and crop management. In addition, a groundwater and soil solution monitoring system should be included in the design of new land treatment systems.

EVALUATION OF EXISTING SYSTEMS FOR LAND TREATMENT OF WASTEWATER AT MANTECA, CALIFORNIA, AND QUINCY, WASHINGTON

I.K. Iskandar, R.P. Murrmann and D.C. Leggett

INTRODUCTION

Population growth and urbanization in recent years has resulted in increased production of municipal and industrial wastes that have to be treated and disposed of. Also, demands for drinking and irrigation water have increased in arid and semiarid regions. At the same time, more stringent water-quality legislation has been enacted to prevent eutrophication of lakes and streams and to protect human health from an increasing number of potentially toxic chemicals being released into the environment. Also concurrently, the realization that our present supplies of potable water are not infinite has led to a re-evaluation of wastewater treatment practices with the goal of effectively reclaiming this water resource.

One method of renovating wastewater that has received increased attention in recent years is application of the wastewater to land (Reed et al. 1972; Iskandar et al. 1976). This practice is not new, since the use of wastewater for agricultural purposes dates back at least to the 16th century (Evans 1973). There are many examples of disposal of wastewater on land instead of into open waterways. But the distinction between *disposal* and *recycling* of wastewater is a relatively new concept (Reed et al. 1972). Although in the past it was probably assumed that wastewater disposed of on land was "cleansed" as it passed through the soil, this was not of as much concern as it is today.

Land treatment of wastewater has been divided into three basic types: slow infiltration, rapid infiltration, and overland flow (Reed et al. 1972). The type considered to be of most general applicability is slow infiltration. With this method, wastewater is applied to soils of medium permeability by spraying or flooding. Water quality of leachates of several prototype slow-infiltration systems spray-irrigated with sewage effluents has been reported by Iskandar et al. (1976). Also reported in this study, and in studies by Palazzo (1976) and Iskandar (1977), were the effects of wastewater on vegetation and soils. However, the long-term effects of wastewater application are unknown, since no controlled experiments have run longer than a few years (Kardos and Sopper 1973) or have covered a wide range of environmental conditions. If land treatment is to be considered a viable alternative to other types of secondary and tertiary waste treatment, it appears that both the impact on the environment and the longevity of such systems should be understood.

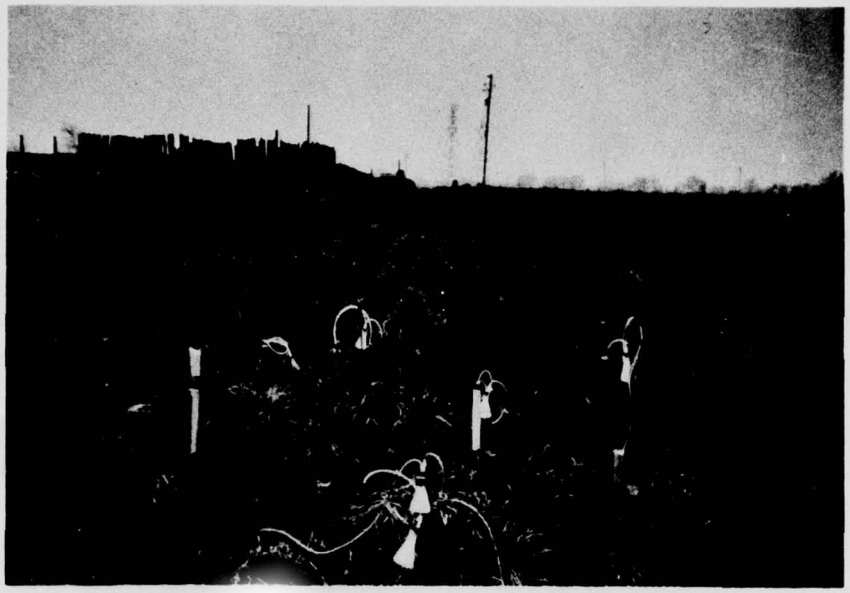
Upon completing a field investigation of 67 municipal and 20 industrial facilities, EPA (1973, 1976) concluded that land disposal of wastewater had been practiced successfully and extensively in the United States and elsewhere throughout the world. However, in spite of this survey, it was apparent that several demonstration projects were needed to convince local and state officials of the safety of land treatment. Instead of constructing and operating regional demonstration facilities for years, at great expense of time and money, it was concluded that an alternative strategy would be to evaluate *established* systems in the various climatic zones.

This report is the result of an evaluation of two existing systems, at Manteca, California, and Quincy, Washington, which have been in operation for up to 20 years. It is hoped that this and future evaluations of existing systems will answer many of the questions related to the longevity and performance of systems for land treatment of wastewater.

EXPERIMENTAL PROCEDURES

Sampling

The major objectives of evaluating existing facilities for land disposal of wastewater are to determine the



l solution sampling at Manteca.

b. Installing soil solution sampling at Quincy.

Figure 1. Soil solution sampling at Manteca, California, and Quincy, Washington.

current renovative performance of the facilities and the long-term changes that have taken place in the soil systems. Since the initial performance and site conditions are not known, it is necessary to deduce the changes that have resulted from wastewater application by comparing the disposal sites with control sites that have the same soil types but that have never received wastewater.

At both Manteca, California, and Quincy, Washington, soil cores were taken from wastewater application and control sites to a depth of 1.6 m. At both sites, the control fields are under agricultural production. Composite samples from four cores from each field were taken for chemical analysis. Samples were composited at 0.15-cm intervals to a depth of 0.60 cm and, thereafter, at 30-cm intervals. At Manteca, samples were taken from the 2-year and 11-year application fields, and at Quincy, from the 17-year and 20-year application fields. Water samples were collected from the pretreatment facilities, lagoons, drainage ditches, and drainage tiles at each site. Soil solution samples were collected with suction lysimeters (Fig. 1) installed at 80- and 160-cm depths in the soil of both the disposal and control fields. Groundwater samples were also collected from existing wells at each site. Three sets of samples were collected at both locations during 1974 so that seasonal changes in water quality parameters could be taken into account. Samples were collected at Manteca in June, September, and November, and at Quincy in May, August, and November. During each site visit, water analysis was conducted at each sampling station over a three-day interval.

Soil and water analysis

Soil samples were air dried (25°C), thoroughly mixed and sieved, and a < 2-mm fraction was taken for chemical analysis. Soil pH (1:1 weight/volume), soluble salts (measured as specific conductance), cation exchange capacity, exchangeable Ca, Mg, Na, K, organic carbon, organic nitrogren, free iron oxides, organic-P, total-P (acid digestion), extractable-P, and soluble-P (1:2 soil: water) were determined according to Black (1965). Two forms of heavy metals were determined, total and acid-extractable (plant-available). Details of the analytical procedures are presented in Appendix A.

Water samples were analyzed in the field for NH_4-N, NO_3-N, pH and ortho-P, using a Hach Model DR/2 spectrophotometer according to methods described by Hach Chemical Co. (1973). Total heavy metals (Ni, Zn, Cu, Cr and Cd) were determined in the laboratory. For heavy metal analysis, water samples were acidified to pH < 1 with concentrated HNO_3. The analyses were performed directly using a Perkin-Elmer Model 304 atomic absorption spectrophotometer with a graphite furnace (HGA 70).

SITE CHARACTERISTICS

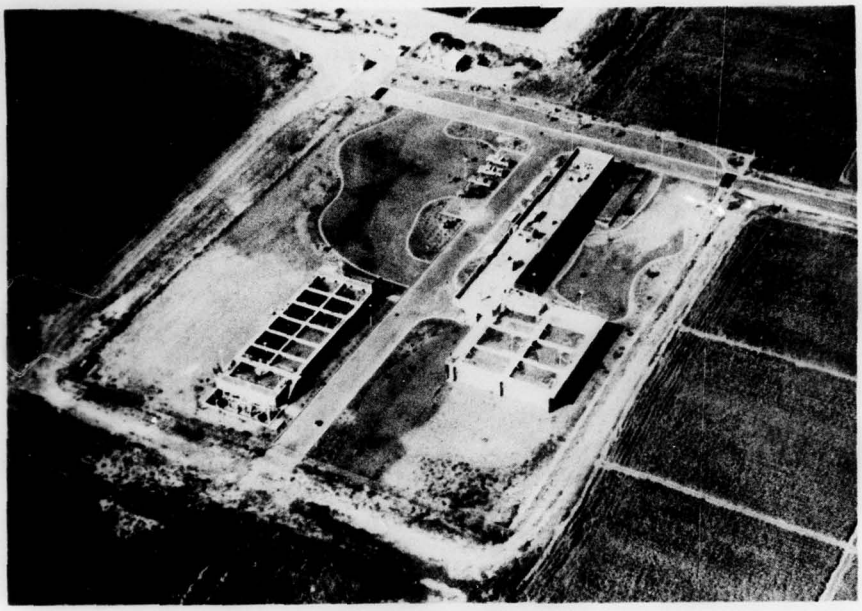
The selection of land application over alternative methods for wastewater treatment is complicated in that it is difficult to assess the relative importance of the many factors that need to be taken into account. Among these are site characteristics, which include local groundwater hydrology and quality, climate, soil types, wastewater quality and volume produced, land pattern, land use and projected population growth in the area. The extent of this type of information available for the two study sites is summarized below.

Manteca

The Manteca wastewater treatment plant, which serves a population of 20,000 (1977) is located approximately 150 km (80 miles) east of San Francisco. Manteca has a mild climate, with a mean maximum temperature (July) of 34.5°C (94.2°F) and a minimum (January) of 2.6°C (36.7°F). The mean number of days with temperatures below 0°C is 23 and the overall average temperature is 16.1°C (61.0°F). Average annual precipitation is approximately 30 cm (11.1 in.). The 10-year record of temperature and precipitation data (1951-1960) is summarized in Table BI (App. B).

The design flow of the sewage treatment plant is 9.5×10^6 l/day (2.5 mgd). In 1973, the maximum and minimum flows were 5.84×10^6 l/day (September) and 3.30×10^6 l/day (January), with an overall average flow of 4.7×10^6 l/day. Figure 2 shows the wastewater treatment plant, and the activated sludge tank at Manteca, California. Since 1971, wastewater has received secondary treatment (activated sludge) before application on land. The wastewater is stored, when necessary, in a holding pond (Fig. 3a). Sludge from the secondary settling tank is cycled to the activated sludge or disposed to the holding pond where settling occurs; however, considerable amounts of solids are probably applied to the land during irrigation. Solids skimmed from the top of the settling tanks are collected and buried in an area directly east of the main treatment plant facility.

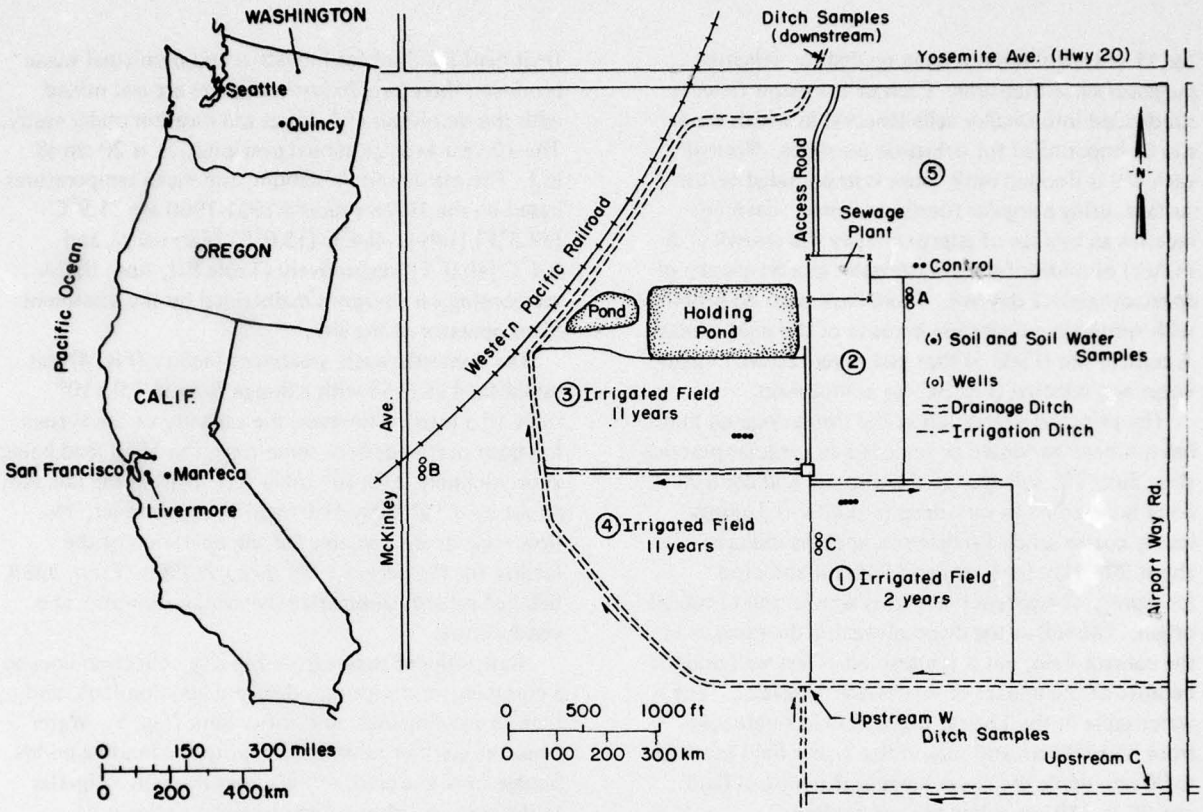
The disposal site itself consists primarily of four different areas (Fig. 3a), roughly 64.8 ha (160 acres) in total area. Field 1 has been in operation only since 1971. Field 2 was established in 1971 but has received wastewater only on an intermittent basis for about one year. Field 3 has received wastewater for 11 years but was graded in 1971. Field 4 has also received wastewater



a. Sewage treatment plant.

b. Activated sludge tank.

Figure 2. Sewage treatment plant and activated sludge tank at Manteca, California.



a. Sampling locations.

b. Disposal site.

Figure 3. Wastewater disposal site and sampling locations at Manteca, California. Wells A (northeast) represent control area; wells C (north central) represent groundwater under disposal area; and wells B (northwest) represent groundwater after leaving disposal area.

for 11 years but has not been graded for irrigation purposes since that time. Each of the major fields is subdivided into smaller cells (checks) in which water can be impounded for irrigation purposes. Normally, each cell is flooded until water is impounded on the surface, using a regular rotation scheme. Each cell receives an average of approximately 4.6 cm/wk (1.8 in./wk) of undisinfected wastewater at a frequency of approximately 1 day/wk. There have been no problems with wintertime operation because of the mild climate. A control site (Field 5) that had never received wastewater was selected (Fig. 3a) for comparison.

The principal vegetation at the site is ryegrass that has not been harvested or removed as a regular practice (Fig. 3b). The soil type in the disposal and control areas is classified as very deep (> 150 cm) Tujunga loamy coarse sand. Particle size analysis indicates about 20% clay (< 5 μm) and 80% silt and sand (> 5 μm). The parent material is alluvial soil of mixed origin. The soil at the disposal areas is the same as in the control field, but it is classified as less well-drained because of the impact of wastewater irrigation. The water table in the 11-year disposal field fluctuated from 45 to 90 cm and that in the 2-year field from 65 to 90 cm, while the water table in the control field was 90 to 150 cm below the soil surface.

Most of the wastewater applied at the site infiltrates to the groundwater table, although during flooding operations in Fields 2 and 3, water may run overland, since a small collection ditch has been constructed from which the water can be pumped back to the holding pond. Groundwater flow appears to be in a southwesterly direction towards a river in the area, but possibly a substantial portion of the water is intercepted by a major drainage ditch that bounds the north, west, and southern sides of the disposal area (Fig. 3a).

No published data are available on the quality of water infiltrating through the soil. However, three sets of monitoring wells (A, B and C, Fig. 3a) were installed when the disposal site was constructed. At each well site, individual wells were driven to depths of 2, 3, and 6 m. The plant operator has occasionally collected water samples for nitrogen analysis from the wells and from upstream and downstream locations of the drainage ditch. He has been unable to detect any increases due to operation of the site.

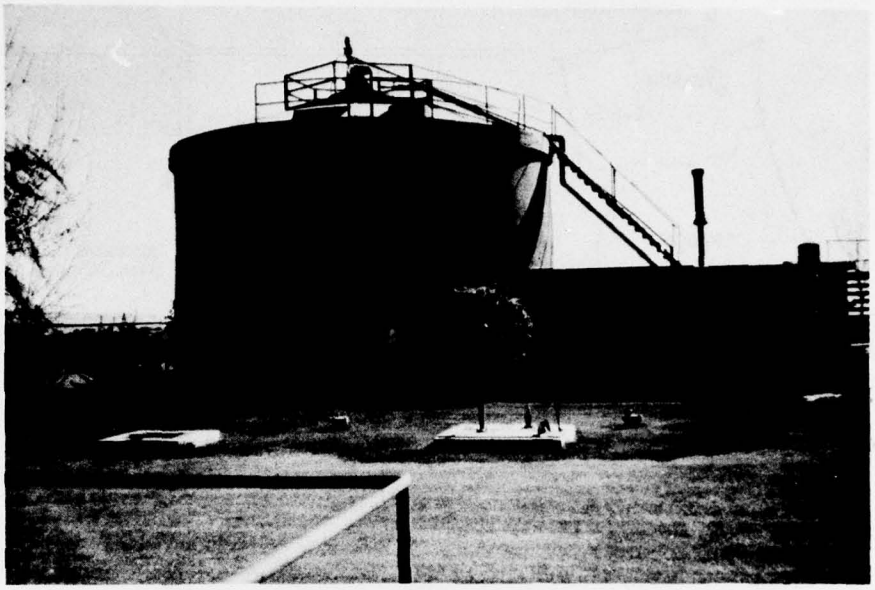
Quincy

Quincy (population 3200) is located about 407 km (220 miles) east of Seattle, Washington, in an arid region that depends completely on irrigation for crop water supply. The main industry in the area is vegetable processing. The city has separate wastewater treatment facilities for industrial and municipal waste products; therefore, industrial wastes are not mixed with the municipal effluent at the location under study. The 10-year average annual precipitation is 20 cm (8 in.). The maximum, minimum, and mean temperatures based on the 10-year record 1951-1960 are 31.9°C (89.5°F) (July), -9.4°C (15.0°F) (February), and 9.4°C (49.0°F), respectively (Table BII, App. B). A meteorological station is maintained by the treatment plant operator at the site.

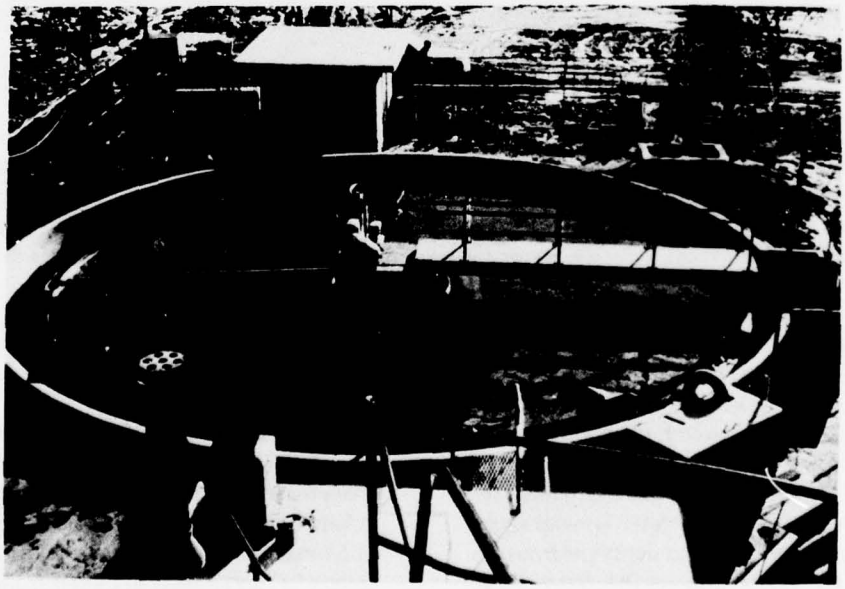
The domestic waste treatment facility (Fig. 4) was established in 1954 with a design flow of 1.9×10^6 l/day (0.5 mgd). However, the capacity of the system has been overloaded for some time, the 1973 load being approximately 2.6×10^6 l/day (0.7 mgd) in the fall and about 3.8×10^6 l/day (1.0 mgd) in the summer. No flow records are available for the operation of the facility for the period 1954 through 1968. From 1968, detailed records summarize the average monthly and yearly flows.

Raw effluent passes from the city collection lines to a comminutor device (grinder) and aeration tank, and then to a sedimentation clarifier tank (Fig. 5). Water from the clarifier tank is pumped to the holding ponds. Sludge from the clarifier tank goes through a digester to drying beds, after which the dried sludge is deposited in a local dump. Some consideration has been given to application of the dried sludge to the disposal site land, but this idea has never been implemented. After treatment, the wastewater is directed to one of the two holding pond areas. From a holding pond, the water moves through head ditches where it is fed by gravity flow into five fields that are under agricultural production by a tenant farmer. Fields are about 2 ha (5 acres) in size with a total of 11 ha (27 acres) available for irrigation. In early 1954, when the treatment facility was constructed, there was no sludge digester and only one pond, referred to as pond 1 in Figure 5. In 1957, ponds 2 and 3 were added. The sludge digestion system was constructed in 1960.

According to the history of the site, field C has been irrigated since 1954, and fields A, B, D and E have been irrigated since 1957. Crops grown on the disposal site are primarily corn and wheat. The farmer attempts to irrigate the crops during the summer on an as-needed basis, with application of excess water to a fallow field held in reserve for this purpose; however, since he is obligated to remove the water from the ponds, he is applying more water than required to irrigate the crop. The ditch distribution system is in poor condition; therefore, the different disposal fields have not necessarily received equal amounts of water. In winter months, the fields are vacant, with no cover



a. Anaerobic digestion tank.



b. Clarifier tank.

Figure 4. Digestion tank and clarifier tank of the sewage treatment plant at Quincy, Washington.

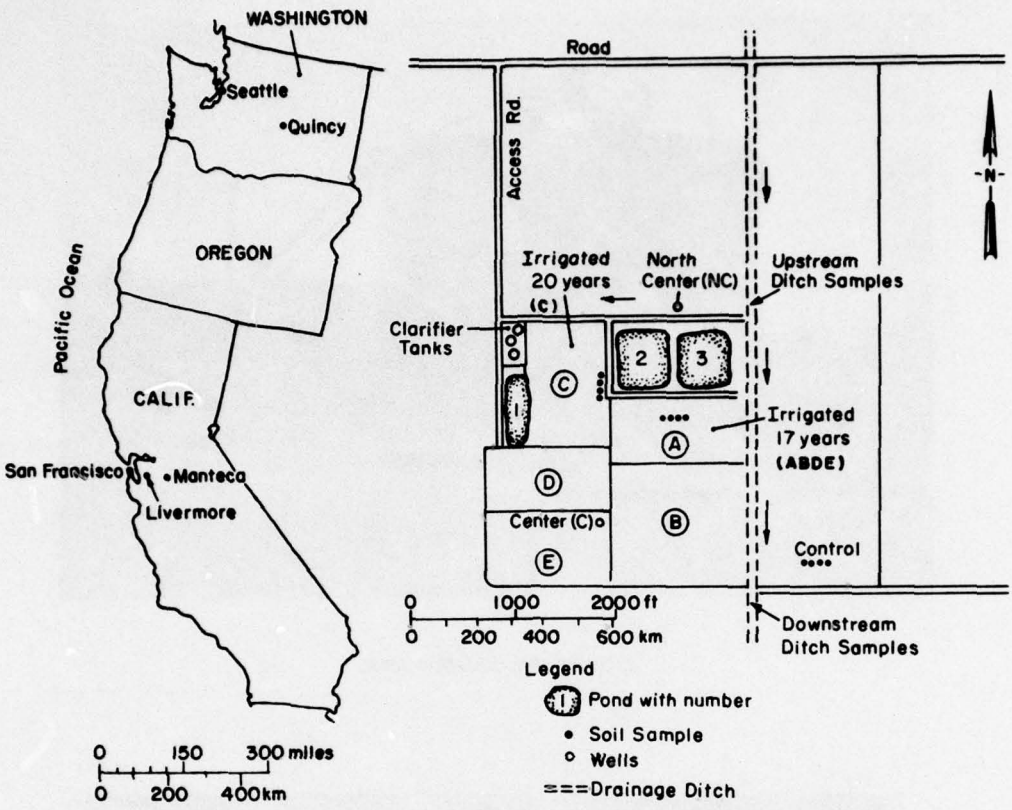


Figure 5. Wastewater disposal site and sampling locations at Quincy, Washington.

crops. During this period, water overflows from the lagoons through the irrigation ditches, primarily to fields A, B, and E (Fig. 5). No previous data are available on the quality of groundwater directly under the disposal sites.

According to soil survey information, the soil is classified as a well-drained Warden very fine sandy loam (2% slope). It has developed from wind-deposited material and reworked lake sediments. The soil texture is very fine sandy loam to a depth of about 45 cm (18 in.), with calcareous silt loam from 45 to 150 cm (60 in.). Water erosion hazard is slight or nonexistent and wind erosion hazard is moderate. Groundwater in the area is commonly found at depths of from 1.5 to 4.5 m (5-15 ft). At the disposal site, water is frequently ponded on the surface during winter months, possibly because of temporary soil freezing, but the water table is generally at a deeper level, indicating an overloading of the soil in terms of its infiltration capacity. The groundwater is reported to flow in a southeasterly direction and should be intercepted by the large, irrigation return-flow collection ditch; however, seepage of the groundwater to the collection ditch is seldom observed, except when water is ponded in the field during winter. Recognizing hydraulic overloading conditions at the disposal site, Quincy has acquired additional land for increasing the size of the disposal area when funds become available for its development.

RESULTS AND DISCUSSION

Manteca

Data for average water quality gathered for each of the three sampling periods are presented in Table I and data for individual days in Tables BIII, BIV, and BV (App. B). Average NH_4-N concentrations were 8.8-12.7 mg/l during the three sampling periods after secondary treatment, and water from the storage lagoon (applied wastewater) contained concentrations within this range. Average NO_3-N concentrations were < 2 mg/l in the secondary effluents and storage lagoon. Ortho-P in the storage lagoon ranged from 4.1 to 12.0 mg/l. The pH values of the secondary effluent ranged from 7.5 to 7.9, while those of water from the storage lagoon ranged from 7.3 to 8.3. The applied effluents were thus typical of large municipal secondary treatment systems with respect to pH, NH_4, NO_3, and PO_4.

Table I. Average values for water quality at wastewater disposal site, Manteca, California.

Sample*	pH			NO_3-N (mg/l)			NH_4-N (mg/l)			Ortho-P (mg/l)		
	June 74	Sept 74	Nov 74	June 74	Sept 74	Nov 74	June 74	Sept 74	Nov 74	June 74	Sept 74	Nov 74
Secondary treatment	7.6	7.5	7.9	1.4	1.9	1.2	12.7	12.2	8.8	4.1	6.1	3.8
Storage lagoon	8.3	7.3	7.9	<0.1	2.0	1.2	7.6	11.3	9.6	4.2	12.0	6.1
Drainage ditch	8.1	7.7	8.1	1.3	4.5	3.8	0.8	0.5	0.5	0.5	0.3	1.3
Wells A – northeast	7.8	7.4	8.1	0.5	0.7	1.0	1.3	1.0	0.8	0.4	0.6	0.6
Wells C – center east	7.7	7.3	7.9	2.6	2.5	2.5	0.4	0.3	0.4	0.8	1.8	1.6
Wells B – center west	7.9	7.4	7.9	11.0	11.6	9.6	0.4	0.3	0.4	0.3	0.6	0.7
Control field – 0.8 m	7.6	ns†	ns	4.9	ns	ns	0.4	ns	ns	<0.1	ns	ns
– 1.6 m	7.7	7.9	8.1	0.4	1.1	0.7	0.2	0.6	0.2	0.7	0.8	0.8
2-year disposal field – 0.8 m	7.6	7.3	7.8	19.7	8.0	6.4	1.0	0.7	0.4	7.3	9.2	10.0
– 1.6 m	7.6	7.2	7.7	2.6	16.4	12.2	0.4	0.8	0.2	9.0	9.1	8.0
11-year disposal field – 0.8 m	7.6	7.2	7.8	5.0	6.9	1.0	0.8	0.8	0.4	8.6	8.3	8.6
– 1.6 m	7.7	7.1	7.9	2.7	7.0	3.8	0.6	0.8	0.4	9.9	9.8	7.7

* Sampling location as in Figure 3.

† *ns* indicates insufficient sample for analysis.

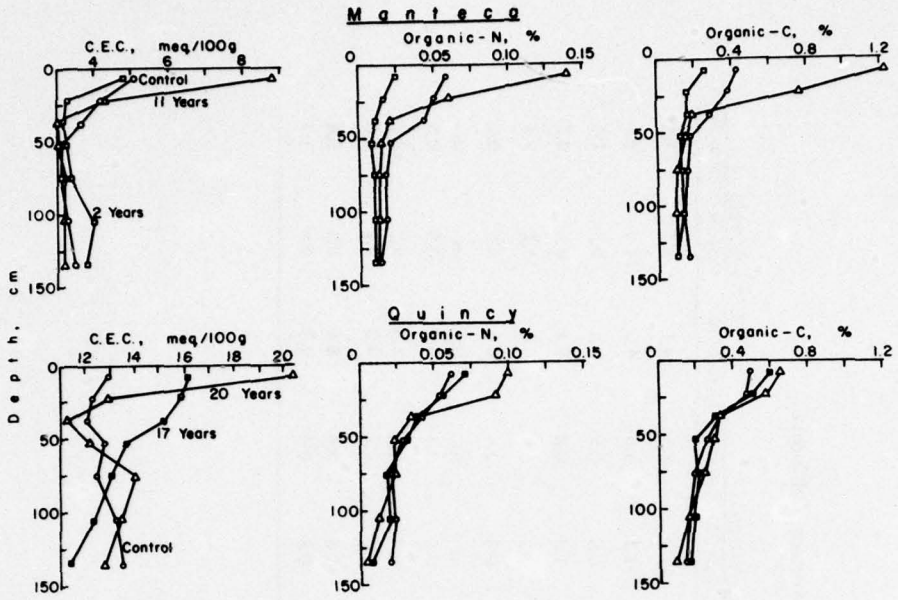


Figure 6. Distribution of CEC, organic-N and organic-C with depth in soils from wastewater disposal and control sites at Manteca and Quincy.

Average ammonium-N concentrations in the soil solution sampled by suction lysimeter remained < 1 mg/l throughout the sampling period in both the 2-year and 11-year disposal fields. These values do not appear to be significantly greater than those of the control, which received fertilizer and irrigation water only, indicating that conversion to nitrate (nitrification) is complete in the top 0.8 m. Similar NH_4-N concentrations were found in the well water in both the treated and control fields and in the drainage ditch downstream from the disposal site.

Nitrate-N concentrations in soil solution were highly variable [Table I and Tables BIII, BIV, and BV (App. B)]. The average values seem to reflect a seasonal dependence which is most clearly seen in the 2-year disposal field. The data suggest a wave of nitrate passing slowly through the profile. This is understandable because nitrification is due to the presence of microorganisms whose activity is highly temperature dependent. Nitrification occurs significantly only at temperatures above 4°C (Alexander 1965) and is optimum at 25°-35°C. Since the mean temperature at Manteca ranges from 8°C in January to 25°C in July, it is not surprising to see seasonal fluctuation in soil water nitrate concentrations.

Nitrogen applied as NH_4-N in the winter is stored on cation exchange sites high in the soil profile and slowly moves downward as these sites become saturated. This gives rise to a wavelike fluctuation, since cation exchange capacity (CEC) is highest in the surface soil layer (Table II). This seasonal effect on NO_3 concentrations has also been observed in prototype slow-infiltration systems (Iskandar et al. 1976, Iskandar and Leggett 1976). Conversion of soil organic nitrogen to ammonium (mineralization) is also a function of biological activity, with the additional NH_4-N released in the spring adding to that stored on ion-exchange sites. The effects on water quality were consistent with changes in soil organic N (Table II and Fig. 6).

Comparing the NO_3 data from the 11- and 2-year fields gives an estimate of the magnitude of mineralization, assuming other parameters are the same. The average of the three sampling periods gives concentrations of 10.4 and 4.5 mg/l respectively for the 2- and 11-year fields. Thus, the bulk of nitrogen leaching from the 2-year field appears to be of natural origin, and from the 11-year field more representative of the long-term behavior of the system. The nitrogen loading rate calculated for the Manteca site based on a 5-cm/wk application rate is 275 kg/ha-yr. This is less than the maximum uptake that can be expected from a ryegrass cover crop under good management conditions (Palazzo 1976, Iskandar et al. 1976). Since the cover crop was not removed from this disposal site, it is difficult to assess the actual removal by the crop, but the relatively low soil solution NO_3-N concentration in the 11-year field indicates acceptable renovation, which could probably be improved further by better agronomic management of the site.

Table II. Soil chemical data for wastewater disposal site, Manteca, California.

Depth interval (cm)	pH			Conductivity (mmhos/cm)			CEC (meq/100 g)			Base saturation (%)			(Na+K) saturation (%)			(Ca+Mg) saturation (%)		
	Control	2-yr	11-yr	Control	2-yr	11-yr	Control	2-yr	11-yr	Control	2-yr	11-yr	Control	2-yr	11-yr	Control	2-yr	11-yr
0- 15	5.8	7.0	6.9	0.71	0.35	0.26	5.1	4.8	8.8	86	85	89	6	8	7	80	77	82
15- 30	6.2	7.4	7.1	0.36	0.20	0.31	4.2	3.3	4.3	100	118	95	7	12	9	93	106	86
30- 45	6.4	7.5	7.3	0.21	0.23	0.28	3.7	3.2	3.0	100	119	117	8	12	13	92	107	104
45- 60	6.6	7.7	7.4	0.15	0.20	0.16	3.1	3.3	3.0	116	115	113	10	12	10	106	103	103
60- 90	6.8	7.8	7.6	0.12	0.20	0.29	3.1	3.4	3.2	110	126	116	10	12	12	100	114	104
90-120	6.7	7.8	7.6	0.14	0.20	0.24	3.3	4.0	3.2	115	110	90	12	10	12	103	100	78
120-150	6.8	7.9	7.6	0.20	0.62	0.24	3.5	3.8	3.2	126	182	106	11	10	12	115	172	94

	Free iron oxides (%)			Organic carbon (%)			Total N (%)			C/N ratio			Total-P (µg/g)			Extractable-P (µg/g)		
0- 15	0.69	0.67	0.56	0.43	0.26	1.23	0.059	0.025	0.140	7.3	10.4	8.7	506	480	699	40	55	117
15- 30	0.69	0.62	0.55	0.38	0.16	0.76	0.051	0.017	0.061	7.4	9.4	12.4	459	455	512	39	58	85
30- 45	0.65	0.63	0.53	0.29	0.17	0.19	0.044	0.012	0.022	6.6	14.2	8.6	439	441	515	44	52	69
45- 60	0.63	0.63	0.55	0.18	0.13	0.16	0.022	0.008	0.016	8.2	16.2	10.0	424	404	450	34	41	70
60- 90	0.55	0.59	0.49	0.15	0.12	0.11	0.018	0.010	0.013	8.3	12.0	8.5	363	424	476	29	40	38
90-120	0.55	0.55	0.46	0.14	0.14	0.10	0.018	0.010	0.014	7.8	14.0	7.1	340	419	435	28	38	36
120-150	0.52	0.46	0.38	0.16	0.10	0.10	0.013	0.010	0.012	12.3	10.0	8.3	378	386	409	29	30	37

	Organic-P (µg/g)			Soluble-P (µg/g)			Total-Hg (µg/kg)			Extractable-Hg (µg/kg)			Total-Cd (µg/kg)			Extractable-Cd (µg/kg)		
0- 15	56	64	94	0.49	1.20	1.29	928	928	1056	34	35	56	148	128	232	68	21	288
15- 30	28	25	53	0.41	0.70	0.27	640	832	958	138	37	30	107	136	182	42	13	109
30- 45	19	19	26	0.56	0.68	0.22	1488	712	945	66	70	32	99	82	56	41	24	65
45- 60	16	13	29	0.38	0.54	0.24	992	848	1241	36	62	44	58	77	78	42	20	45
60- 90	14	15	21	0.16	0.42	0.38	960	1216	1147	222	30	64	49	36	75	20	11	42
90-120	14	12	15	0.19	0.09	0.27	971	1360	763	366	24	22	98	32	79	66	10	38
120-150	13	11	13	0.23	0.13	0.20	944	1376	875	44	32	35	61	78	64	47	5	40

	Total-Cu (µg/g)			Extractable-Cu (µg/g)			Total-Zn (µg/g)			Extractable-Zn (µg/g)			Total-Ni (µg/g)			Extractable-Ni (µg/g)		
0- 15	16.8	15.4	23.7	2.3	1.2	4.6	39	38	71	13.8	10.2	40.6	7.2	7.4	8.8	1.88	1.70	8.20
15- 30	16.4	23.4	19.8	2.2	1.6	2.1	35	40	48	7.7	10.4	13.0	6.9	8.5	11.7	1.97	1.66	2.65
30- 45	14.5	22.5	22.1	1.8	6.1	1.7	35	39	46	7.0	12.6	13.4	5.7	6.2	10.1	1.90	1.69	2.11
45- 60	13.7	20.1	16.4	1.4	1.6	1.5	31	95	40	11.8	6.4	5.6	6.4	8.6	10.8	1.84	2.45	1.96
60- 90	13.0	19.3	15.5	1.6	1.8	1.2	32	52	36	4.2	7.6	4.5	6.7	8.4	11.9	1.85	2.20	1.99
90-120	12.9	19.6	18.3	1.2	1.6	1.3	35	53	36	3.2	4.3	8.4	6.9	9.4	10.6	1.66	2.53	2.05
120-150	20.4	20.2	16.2	1.1	1.8	1.6	38	48	38	9.6	5.9	6.2	7.1	9.8	9.8	1.73	2.39	1.88

	Total-Cr (µg/g)			Extractable-Cr (µg/g)			Total-Pb (µg/g)			Extractable-Pb (µg/g)		
0- 15	43	71	48	4.06	3.71	14.50	1.98	1.49	5.99	0.118	0.031	0.120
15- 30	44	43	45	3.97	3.80	4.45	1.87	1.49	2.81	0.063	0.017	0.048
30- 45	43	51	47	3.94	3.62	4.02	1.37	1.82	1.96	0.036	0.015	0.029
45- 60	41	52	49	3.88	3.74	3.81	1.33	3.17	2.10	0.028	0.021	0.038
60- 90	42	54	38	3.99	3.65	3.53	1.23	2.07	1.12	0.010	0.019	0.007
90-120	43	47	39	3.67	3.63	3.58	1.46	1.77	1.55	0.008	0.008	0.008
120-150	44	47	38	3.55	3.97	3.96	1.57	4.85	1.19	0.004	0.006	0.014

With respect to groundwater quality, the NO_3-N concentrations in the control wells (A, Fig. 3a) were similar to those found in the control field leachate at 1.6 m. The values in water from the field monitoring wells (C, Fig. 3a) were increased somewhat, averaging about 2.5 mg/l of NO_3-N. The reason for the 10-12 mg/l NO_3-N values found in the wells outside the disposal site (B, Fig. 3a) is not readily apparent; it may be due to leachate from the sites, or to contamination from another source. This needs further evaluation. The slight increase in NO_3-N concentrations in the drainage ditch downstream of the disposal site is probably due to wastewater disposal. However, in all cases NO_3-N concentration in the drainage ditch was less than 10 mg/l.

The ortho-P concentrations in soil solution from the treated fields were higher than those from the control site (Table I). They were, in fact, higher than the applied ortho-P concentrations; however, allowing for evapotranspiration, the values are consistent with the concentration in the applied wastewater. This suggests that there is no significant uptake of P by the soils in either the 2- or the 11-year fields, an unusual finding, if true. From the soils data for total P at the Manteca site (Table II), there appears to be no net immobilization of P during at least the first 2 years of wastewater application, and only the 0-15 cm concentration appears significantly increased in the 11-year field compared with that in the control.

These data could be misleading, however, as the control field was fertilized and irrigated, which probably increased total P values in the control as well. Unfortunately, no background data were taken at the actual disposal sites before any wastewater was applied, to serve as a true control. Plant uptake probably did not account for significant removal of applied phosphorus at this site, since the crop is not harvested. The absence of increased soil P is consistent with the high ortho-P values in soil solution. This is at variance with the experience of others (Kardos and Sopper 1973), who reported no P leaching to similar depths after eight years of wastewater application. However, Ellis and Erickson (1969) reported leaching of P in some Michigan land treatment soils. This point needs further investigation, since short- and long-term removal of phosphorus and nitrogen are perhaps the most important reasons for choosing land treatment over conventional treatment for renovation of domestic wastewater.

The cation exchange capacity (CEC) of soils from the control and disposal sites correlates well with their organic matter content (Fig. 6 and Table II). Organic matter was mineralized during the first two years of wastewater application, and it accumulated in the surface layer during subsequent years. The CEC of the soils at this site is largely influenced by the organic matter content, since soil organic matter generally has a CEC of 300-500 meq/100 g (Kononova 1966), or 600-1000 meq/100 g-C. The increase in organic carbon in the surface layer of from 0.4 in the control to 1.2% in the 11-year field thus readily accounts for the increase in CEC of 5 to 9. Johnson et al. (1974), on the other hand, report a lower figure of 1.4 meq per 1% increase in organic C. Calcium was the major exchangeable cation followed by magnesium, then sodium. Exchangeable Ca was 6 meq/100 g in surface soil from the 11-year field (Fig. 7). Exchangeable Na also increased because of the increased CEC, but the percentage of base saturation remained < 15% and was the same as that in the control site. No alkalinity problems were observed at this site. It is interesting that one of the farmers near the disposal site claims that he reclaimed his saline-alkaline soil by the addition of wastewater.

Accumulation of heavy metals in the disposal sites because of wastewater application appears to be negligible (Table II). But this is not surprising since the applied effluents are of domestic origin and contain low concentrations of heavy metals (Table III). Although the overall increases in heavy metals are small, the relative changes in extractable heavy metals in the treated fields compared with those in the control field appear to be highly correlated with CEC and soil organic matter, as discussed previously. The increases in heavy metals in the 0 to 15-cm layer of the 11-year field and slight decrease in the same in the 2-year field correspond to the changes in CEC and in organic matter. The increase in total heavy metals during long-term application (11-year field) was small and within the ranges reported by Bowen (1966) for soils of the world. However, the increase in extractable heavy metals relative to the total is noteworthy because it is an indication of the availability of metal to vegetation grown on the site.

Unfortunately, plant tissue analyses were not conducted; but these analyses are unimportant in management of this site because the vegetation is not harvested. In general, however, it is important to evaluate the availability of heavy metals to protect elements of the human food chain from potentially toxic buildup. This is especially critical because the increasing use of land treatment systems for producing food crops in the future is anticipated. The increase in extractable heavy metals may be due to the input of metals from plant residue upon decomposition or to native sources, or to a combination of both of these factors.

Table III. Heavy metals in water from wastewater disposal site, Manteca, California.

Parameter by sampling date.

Location of sample collection	Cu (µg/l)				Cr (µg/l)				Cd (µg/l)				Ni (µg/l)				Zn (µg/l)			
	June	Sept	Nov	Avg	June	Sept	Nov	Avg	June	Sept	Nov	Avg	June	Sept	Nov	Avg	June	Sept	Nov	Avg
Secondary treatment	25.0	7.7	5.1	12.6	1.4	1.7	1.9	1.7	<0.1	3.6	5.2	3.0	21.5	8.6	14.6	14.9	4.1	110.0	27.0	47.0
Storage lagoon	19.0	12.4	3.1	11.5	1.4	2.1	1.7	1.7	0.5	4.4	14.7	6.5	25.0	40.9	65.0	43.6	4.4	176.0	29.4	69.9
avg	22.0	10.0	4.1	12.0	1.4	1.9	1.8	1.7	0.3	4.0	10.0	4.8	23.2	24.8	39.8	29.3	4.2	143.0	28.2	58.5
Drainage ditch – upstream one	5.1	10.5	1.6	5.7	0.9	1.1	1.5	1.2	0.7	6.7	1.7	3.0	25.0	77.9	18.7	40.5	2.4	225.0	5.6	77.7
– upstream two	64.0	5.5	4.7	24.7	2.4	0.3	<0.1	0.9	<0.1	2.2	7.9	3.4	24.3	13.4	10.3	16.0	6.5	88.0	7.0	33.8
– downstream	111.0	9.1	3.0	41.0	1.8	0.9	1.4	1.4	<0.1	20.0	2.6	7.6	27.2	14.7	84.4	42.1	1.1	85.0	5.4	30.5
avg	60.0	8.4	3.1	23.8	1.7	0.8	1.0	1.2	0.3	9.6	4.1	4.7	25.5	35.3	37.8	32.9	3.3	133.0	6.0	47.3
Control field – 0.8 m	ns*	7.0	2.4	4.7	ns	1.8	2.0	1.9	ns	2.2	40.2	21.2	ns	14.2	161.5	87.8	ns	242.0	51.9	147.0
– 1.6 m	23.2	7.9	4.7	11.9	0.4	0.2	1.5	1.0	0.6	3.2	6.7	3.5	8.2	15.9	33.8	19.3	60.7	79.0	23.4	54.4
avg	23.3	7.4	3.6	9.0	0.4	1.0	1.8	1.2	0.6	2.7	23.4	10.6	8.2	15.0	97.6	46.7	60.7	160.0	37.6	91.4
2-year disposal field – 0.8 m	149.0	8.6	8.0	55.2	1.4	2.0	1.6	1.7	2.3	4.2	5.1	3.9	21.6	44.7	62.6	43.0	6.6	144.0	24.2	58.3
– 0.8 m	135.0	12.5	6.8	51.4	1.2	2.2	1.4	1.6	0.6	9.0	4.5	4.7	22.5	94.5	47.6	54.9	120.0	196.0	8.9	108.0
avg	142.0	10.6	7.4	53.3	1.3	2.1	1.5	1.6	1.4	6.6	4.8	4.3	32.0	69.6	55.1	49.0	63.3	170.0	16.6	83.3
2-year disposal field – 1.6 m	8.5	14.8	6.9	10.1	1.2	6.0	1.4	2.9	0.6	22.1	4.5	9.1		93.0	20.0	56.5	3.0	149.0	33.4	61.8
– 1.6 m	ns	6.0	6.8	6.4	ns	1.0	1.5	1.2	ns	3.1	6.0	4.6		64.3	50.8	57.6	ns	95.0	26.7	60.8
avg	8.5	10.4	6.8	8.6	1.2	3.5	1.4	2.2	0.6	12.6	5.2	7.3		78.6	35.4	57.0	3.0	122.0	30.0	61.4
2-year disposal field overall avg				33.0				1.9				5.6				52.2				72.4
11-year disposal field – 0.8 m	21.5	6.8	5.6	11.3	1.2	1.2	1.5	1.3	0.2	10.2	2.0	4.1		39.2	28.2	33.7	1.4	272.0	4.5	94.3
– 0.8 m	143.0	12.0	10.4	55.1	0.6	1.2	1.4	1.1	1.7	19.4	4.5	8.5	30.0	49.1		39.6	4.0	280.0	116.0	133.0
avg	82.2	9.4	8.0	33.2	0.9	1.2	1.4	1.2	1.0	14.8	3.2	6.3	30.0	44.2	28.2	36.6	2.7	276.0	62.8	114.0
11-year disposal field – 1.6 m	187.0	9.0	6.9	67.6	0.7	4.7	1.4	2.3	4.6	2.5	6.1	4.4	14.0	55.0	54.6	41.2	120.0	183.0	10.9	105.0
– 1.6 m	37.5	6.2	6.4	16.7	1.4	0.3	1.5	1.1	0.5	3.4	9.6	4.5	20.3	58.8	59.1	46.1	5.1	175.0	30.7	70.3
avg	112.0	7.6	6.6	42.1	1.0	2.5	1.4	1.7	2.6	3.0	7.8	4.4	17.2	56.9	56.8	43.6	62.6	179.0	20.8	87.5
11-year disposal field overall avg				37.6				1.4				5.4				40.8				101.0

* ns indicates insufficient sample for analysis.

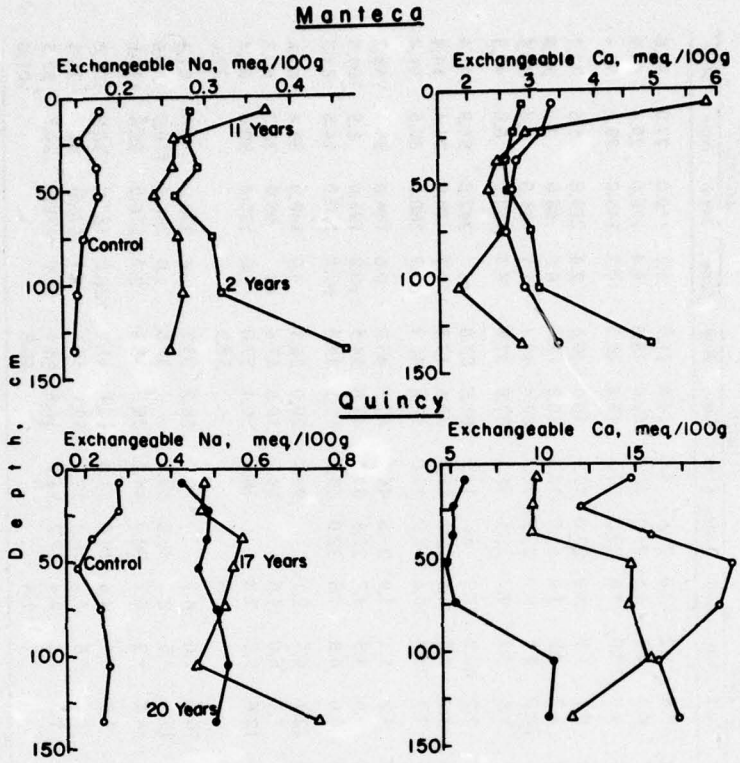


Figure 7. Distribution of exchangeable Na and exchangeable Ca with depth in soils at Manteca and Quincy.

Quincy

The water quality data obtained at the Quincy, Washington, land disposal site are summarized in Table IV and in Tables BVI, BVII, and BVIII (App. B). Again the bulk of the nitrogen was applied in the form of NH_4^+. In this case, there appeared to be greater seasonal fluctuation in the applied NH_4-N, ranging from 11 to 26 mg/l in the primary clarifier effluent. The NH_4-N concentrations in the storage lagoons were about 60% of those in the clarifier. This was probably due mainly to the use of ammonium for growth by algae and other denizens. Volatilization of ammonium was not likely because of the relatively low pH and there was no evidence of conversion of the ammonium to nitrate. Nitrate-N averaged < 2 mg/l and ortho-P around 4 mg/l in the storage lagoons. Some increase in pH in the storage lagoon relative to the clarifier was also noted. The applied effluents were thus typical for municipal treatment plants.

Soil solution collected from the disposal fields contained slightly higher concentrations of NH_4-N than the control field during the May and August sampling periods; also, the wells in the disposal area (center) contained levels similar to those of the control wells (north center). The tile underdrain contained barely detectable levels and the water in the drainage ditch contained levels similar to those of the soil solution from the control field. Thus, no groundwater pollution with NH_4-N is indicated, even though the system is stressed, with approximately 19 cm (7.5 in.) of domestic wastewater being applied per week.

Nitrate-N was increased markedly in the disposal fields, as expected, because of the nitrification of NH_4-N in the applied wastewater. The NO_3-N concentration showed some seasonal influences; for instance, it was higher in the May sampling period than in the other periods. Relatively high concentrations of NO_3-N in the spring are expected because of the immobilization of NH_4-N in the colder winter months, as discussed earlier. The reason for a relatively high concentration (17.9 mg/l) in soil solution at 0.8 m in the 20-year field in November is not clear but could be the occurrence of a peak in effluent application.

Overall renovation of N appears to be quite good, as the NO_3N concentration in leachate from the disposal fields averages about 6.5 mg/l if the May sampling period is neglected. This is compared with an average of 12.5 mg/l (NH_4-N + NO_3-N) in the applied effluent.

Table IV. Average values of water quality at wastewater disposal site, Quincy, Washington.

Sample*	pH			NO_3-N (mg/l)			NH_4-N (mg/l)			Ortho-P (mg/l)		
	May 74	Aug 74	Nov 74	May 74	Aug 74	Nov 74	May 74	Aug 74	Nov 74	May 74	Aug 74	Nov 74
Primary clarifier	7.3	7.1	7.3	1.9	2.2	1.7	21.9	11.3	25.6	4.1	2.1	3.1
Storage lagoons	8.3	8.4	7.4	0.8	0.8	2.8	12.2	7.2	13.6	3.9	2.7	5.3
Drainage ditch	7.6	7.7	7.6	1.2	1.1	3.7	0.3	0.3	0.2	0.1	0.2	0.1
Tile to drainage ditch	7.6	7.5	7.6	2.8	2.5	3.3	0.1	<0.1	<0.1	0.2	0.1	0.1
Well – north center	7.2	7.2	7.2	0.8	0.9	0.3	0.4	0.9	0.8	0.3	0.2	0.2
Well – center	7.1	6.9	7.0	1.2	2.5	1.4	1.7	0.3	0.2	1.6	4.3	4.6
Control field – 0.8 m	7.2	7.2	ns†	2.7	1.2	ns	0.2	0.2	ns	0.2	0.2	ns
– 1.6 m	7.2	7.2	ns	0.7	1.4	ns	0.3	0.3	ns	0.2	0.2	ns
17-year disposal field – 0.8 m	6.9	6.8	6.9	71.2	13.8	3.7	0.7	0.5	<0.1	1.0	1.1	1.7
– 1.6 m	6.8	6.9	6.9	7.9	3.6	1.2	1.2	0.6	0.2	2.8	2.2	2.9
20-year disposal field – 0.8 m	6.7	6.7	6.8	1.5	2.7	17.9	0.5	0.2	0.2	1.1	1.5	1.2
– 1.6 m	7.1	7.1	6.9	19.2	4.0	4.7	0.4	1.5	0.1	0.6	1.2	0.5

* Sample location as in Figure 5.
† Insufficient sample for analysis.

Table V. Selected soil chemical data from wastewater disposal site, Quincy, Washington.

Depth interval (cm)	Control-I	Control-II	17-yr	20-yr	Control-I	Control-II	17-yr	20-yr	Control-I	Control-II	17-yr	20-yr
	pH				Conductivity (mmhos/cm)				CEC (meq/100 g)			
0- 15	7.6	7.8	7.2	7.2	0.35	0.20	0.25	0.21	12.9	14.6	16.2	20.5
15- 30	7.8	7.6	6.8	7.1	0.35	0.14	0.78	0.27	12.3	13.3	15.9	12.9
30- 45	7.9	7.7	7.3	7.4	0.26	0.10	0.31	0.15	12.1	14.5	15.2	11.4
45- 60	7.7	8.1	7.9	7.3	0.40	0.25	0.29	0.19	12.8	13.3	13.6	12.2
60- 90	8.1	8.4	8.3	7.3	0.50	0.21	0.34	0.36	12.5	12.6	13.0	14.1
90-120	8.0	8.3	8.2	7.8	0.81	0.30	0.36	0.51	13.2	13.1	12.4	13.3
120-150	8.3	8.4	8.3	7.8	0.41	0.11	0.40	0.69	13.5	13.1	11.4	12.8
	Free iron oxides (%)				Organic carbon (%)				Total N (%)			
0- 15	0.97	0.94	1.32	1.10	0.49	0.40	0.61	0.66	0.062	0.054	0.072	0.099
15- 30	0.84	0.92	0.98	0.93	0.47	0.36	0.51	0.58	0.054	0.041	0.056	0.082
30- 45	0.93	0.91	0.82	0.76	0.33	0.28	0.31	0.33	0.042	0.037	0.039	0.035
45- 60	0.94	0.78	0.84	0.79	0.26	0.24	0.20	0.30	0.030	0.034	0.032	0.024
60- 90	0.86	0.84	0.79	0.79	0.20	0.22	0.19	0.24	0.022	0.022	0.020	0.023
90-120	0.84	0.77	0.76	0.81	0.17	0.19	0.19	0.16	0.025	0.015	0.022	0.013
120-150	0.59	0.64	0.65	0.69	0.15	0.20	0.16	0.10	0.022	0.016	0.009	0.007
	Organic-P (µg/g)				Soluble-P (µg/g)				Total-Hg (µg/kg)			
0- 15	53	42	61	83	1.26	0.60	4.39	6.76	753	963	886	496
15- 30	44	40	48	72	1.23	0.63	2.44	4.47	622	766	1021	832
30- 45	42	36	38	40	0.37	0.50	2.18	4.44	433	1043	466	1296
45- 60	33	20	22	31	0.24	0.51	1.16	0.64	848	1252	576	1152
60- 90	36	22	26	34	0.13	0.32	1.03	0.44	878	598	692	1232
90-120	28	19	20	22	0.14	0.20	0.56	0.29	1239	512	684	1200
120-150	21	15	7	14	0.18	0.27	0.63	0.32	752	521	752	1424
	Total Cu (µg/g)				Extractable-Cu (µg/g)				Total-Zn (µg/g)			
0- 15	35.4	33.3	35.2	28.8	5.0	5.6	5.4	4.3	86	64	83	85
15- 30	36.2	42.8	37.1	32.4	5.1	4.4	5.8	4.6	88	79	84	81
30- 45	35.0	32.6	34.0	30.8	0.4	3.5	5.9	3.5	85	67	72	74
45- 60	36.2	36.9	40.5	28.6	0.4	0.3	4.3	4.3	75	72	78	73
60- 90	35.8	32.0	36.8	35.1	0.4	0.4	0.9	4.2	69	78	75	76
90-120	34.1	35.7	33.5	41.3	0.3	0.2	0.6	1.7	66	89	73	78
120-150	38.2	31.5	32.7	33.7	0.4	2.1	0.7	0.6	73	75	80	78
	Total Cr (µg/g)				Extractable-Cr (µg/g)				Total-Pb (µg/g)			
0- 15	46	36	39	40	4.16	3.55	4.04	1.73	5.02	5.92	5.41	4.71
15- 30	47	40	41	38	3.92	3.42	3.77	1.34	5.23	2.65	3.52	3.17
30- 45	44	38	39	35	1.44	3.24	3.46	0.95	3.52	3.75	3.71	4.53
45- 60	45	39	38	34	1.25	1.33	3.32	0.83	3.57	3.41	3.91	3.95
60- 90	43	40	37	37	1.28	1.24	2.54	0.81	3.06	2.64	3.95	4.34
90-120	41	42	36	36	1.29	1.31	0.65	0.74	3.30	3.52	3.87	4.51
120-150	43	37	38	38	1.24	3.03	0.87	0.61	3.38	2.58	4.63	4.28

Table V (cont'd).

Depth interval (cm)	Control-I	Control-II	17-yr	20-yr	Control-I	Control-II	17-yr	20-yr	Control-I	Control-II	17-yr	20-yr
	Base saturation (%)				(Na+K) saturation (%)				(Ca+Mg) saturation (%)			
0- 15	133	80	92	51	127	75	84	44	6	5	8	7
15- 30	115	99	90	74	110	94	84	65	5	5	6	9
30- 45	148	112	91	77	145	110	86	68	3	2	5	9
45- 60	175	142	140	73	173	140	133	64	2	2	7	9
60- 90	174	164	138	70	171	162	132	63	3	2	6	7
90-120	145	127	160	114	140	124	154	107	5	3	6	7
120-150	156	137	138	113	150	133	128	106	6	4	10	7
	C/N ratio				Total-P (µg/g)				Extractable-P (µg/g)			
0- 15	7.9	7.4	8.5	6.7	883	746	1121	1274	37	13	106	169
15- 30	8.7	8.8	9.1	7.1	902	850	1100	1155	33	9	97	184
30- 45	7.9	7.6	8.0	9.4	850	892	1072	969	20	4	58	111
45- 60	8.7	7.1	6.2	12.5	965	940	1041	1002	4	4	49	123
60- 90	9.1	10.0	9.5	10.4	951	916	1029	951	3	2	45	90
90-120	6.8	12.7	8.6	12.3	960	966	1011	1005	4	4	21	52
120-150	6.8	12.5	17.8	14.3	894	986	1001	982	7	5	24	51
	Extractable-Hg (µg/kg)				Total-Cd (µg/kg)				Extractable-Cd (µg/kg)			
0- 15	34	39	51	50	263	198	381		214	150	159	183
15- 30	56	34	238	96	179	155	272		186	136	131	160
30- 45	440	304	90	247	173	126	344		62	120	92	122
45- 60	394	296	82	104	212	159	369		26	40	107	101
60- 90	204	344	80	51	159	131	222		32	34	143	64
90-120	88	339	88	66	122	212	197		60	35	113	66
120-150	86	56	53	122	166	186	204		45	70	94	71
	Extractable-Zn (µg/g)				Total-Ni (µg/g)				Extractable-Ni (µg/g)			
0- 15	21.4	9.8	14.1	15.0	31.2	25.9	29.2	28.0	3.33	2.31	3.07	0.99
15- 30	25.2	10.1	11.8	15.5	30.4	31.4	26.6	26.4	3.03	2.74	2.96	1.02
30- 45	1.0	4.4	4.8	12.3	34.4	34.7	28.7	27.2	0.55	3.08	2.67	1.09
45- 60	0.9	0.8	3.2	8.1	34.9	34.5	34.3	26.5	0.60	1.02	3.00	1.03
60- 90	0.8	0.8	2.8	6.4	33.2	35.2	31.7	29.3	0.58	0.69	2.11	1.00
90-120	0.8	1.4	1.6	2.5	34.3	34.3	32.2	36.0	0.73	1.64	0.98	0.59
120-150	0.9	3.2	2.8	1.4	33.8	30.1	29.4	35.7	0.99	2.35	1.03	0.55
	Extractable-Pb (µg/g)											
0- 15	0.034	0.024	0.133	0.066								
15- 30	0.035	0.027	0.048	0.067								
30- 45	0.029	0.042	0.034	0.061								
45- 60	0.028	0.046	0.023	0.018								
60- 90	0.030	0.020	0.026	0.024								
90-120	0.025	0.014	0.022	0.023								
120-150	0.031	0.019	0.025	0.031								

The N removal efficiency was thus about 50%, and correction for evapotranspiration losses would improve this figure to roughly 60%, assuming that about 20% of water was lost by evapotranspiration. The N-loading rate calculated from treatment plant flow data and an average concentration of 12.5 mg N/l is 1200 kg/ha-yr. The 60% of N unaccounted for thus represents 720 kg/ha-yr.

In a study of prototype slow-infiltration land treatment systems, Iskandar et al. (1976) reported removal of 800 kg of N/ha-yr from wastewater applied at 15 cm/wk (27 mg N/l) to sandy soil with a forage grass cover crop. Of this, approximately 550 kg/ha-yr were accounted for by crop uptake, while the remaining 250 kg/ha-yr were attributed to gaseous losses due to denitrification. Pratt et al. (1972) also report loss of up to 43% of N applied to citrus by denitrification. It appears that a portion of the N unaccounted for at Quincy must also be due to denitrification, since the corn and wheat cover crops cannot be expected to remove as much as 700 kg N/ha-yr.

The control wells (north center) contain concentrations of NO_3-N similar to those of the soil solution from the control field, and there appears to be slight impact on groundwater quality, as indicated by the low NO_3-N concentrations in the wells in the disposal area (center) and in the drainage ditch. The tile underdrain does appear to contain slightly higher NO_3-N concentrations, but these are evidently reduced by dilution at the drainage ditch.

Orthophosphate concentrations in soil solution collected at 0.8 and 1.6 m in the disposal fields were higher than the corresponding values in the control field. Likewise, the wells in the disposal area contained higher ortho-P values than those in the control wells. There was no net impact on the drainage ditch, which contained levels similar to those of the soil solution from the control site. The soils analysis data for Quincy (Table V) also indicate higher levels of both soluble and extractable P in all sections of the profile than in the control. The calculated P loading rate for the disposal fields is 380 kg of P/ha-yr. Of this, 130 kg/ha-yr is typical of crop uptake (Palazzo 1976), while an additional 100 kg/ha-yr is accounted for in the increase in total P in the 0 to 30-cm layer of soil (20-year field), leaving an additional 150 kg/ha-yr unaccounted for, or 40% of the applied P. Assuming this amount is leached, the resulting concentration in ortho-P in soil solution should be about 2 mg/l. The measured ortho-P concentrations in soil solution from the disposal fields were actually about 1 mg/l higher than in the control, except for the 1.6-m level in the 17-year field, which averaged > 2 mg/l more than the concentrations in the control, indicating poorer retention in the 17-year field than in the 20-year field. The reason for this is not clear.

Cation exchange capacity (CEC) increased in the surface soils from the disposal fields (Fig. 6) as did organic carbon and nitrogen. In the 20-year field, the change in CEC was mainly confined to the top 15 cm, while in the 17-year field some change in CEC to the 45-cm depth was noted in comparison with the control area. The increases in CEC were about 3 and 7 meq/100 g respectively for the 17- and 20-yr fields, while the changes in organic carbon were only about 0.2% for both. If the increase in CEC were entirely due to organic matter, this represents a CEC of 750-1750 meq/100 g for the organic matter, a figure that is higher than the usual values quoted for soil organic matter (Kononova 1966, Johnson et al. 1974). The increase in CEC correlates well with the increases in total P values.

The predominant exchangeable cation was Ca^{++}, which decreased during wastewater disposal, as shown in Figure 7. In the top 45 cm, exchangeable Ca dropped from about 15 to 10 and 5 meq/100 g respectively for the 17- and 20-year fields. On the other hand, exchangeable Na increased slightly; however, it never exceeded 10% of base saturation, and no salinity problems were observed. Also, there was little or no increase in specific conductance as is reported for saline soils (Richards 1954). The decrease in exchangeable Ca during wastewater disposal could be related to the slight decrease in pH which was noted (Table V) in the disposal fields.

Lowering of soil pH during wastewater application has been attributed to nitrification of NH_4 by Iskandar et al. (1976), since H^+ ions are generated according to the reaction $NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$. These investigators have also cited nitrification-induced acidity as the cause of heavy metal and phosphorus movement in prototype slow-infiltration systems (Iskandar and Leggett 1976), which could be another reason for the leaching of phosphorus at this site. Organic acids derived from applied and decomposed organic matter may also be responsible for a drop in soil pH. The heavy metal data in effluent and soil solution are summarized in Table VI. No heavy metal accumulation occurred at this site relative to the control field with the possible exception of that of Cd (Table V).

Comparison of sites

The contrast in behavior between the two sites is of interest, as it illustrates the role of management practice on the performance of land treatment systems. First, the higher loading rate of wastewater at Quincy (19 cm

Table VI. Heavy metals in water from wastewater disposal site, Quincy, Washington.

Location of sample collection	Cu (µg/l)				Cr (µg/l)				Cd (µg/l)				Ni (µg/l)				Zn (µg/l)			
	May	Aug	Nov	Avg	May	Aug	Nov	Avg	May	Aug	Nov	Avg	May	Aug	Nov	Avg	May	Aug	Nov	Avg
Primary clarifier	2.0	12.3	6.7	7.0	4.6	37.4	1.8	14.6	<0.1	9.5	18.7	9.4	40.5	52.4	21.4	38.0	4.6	121.0	20.6	48.7
Storage lagoon 1	46.5	13.3	6.9	22.3	1.4	28.9	2.1	10.8	<0.1	4.6	6.5	3.7	44.6	64.8	24.3	44.6	3.7	100.0	38.2	47.3
2	5.0	13.5	8.7	9.1	6.4	59.5	2.1	22.7	<0.1	16.1	3.0	6.4	35.2	68.9	16.9	40.3	4.8	115.0	21.0	46.9
3	5.0	6.6	7.5	6.4	16.5	23.2	2.0	13.9	<0.1	3.2	3.1	2.1	28.0	58.5	12.2	32.9	120.0	56.0	14.4	63.5
avg	18.8	11.1	7.7	12.5	8.1	37.2	2.1	15.8	<0.1	8.0	4.2	4.1	35.9	64.0	17.8	39.3	42.8	90.3	24.5	52.6
Pretreatment avg				9.8				15.2				6.8				38.6				50.6
Drainage ditch – upstream	1.8	5.7	6.7	4.7	2.0	4.1	1.6	2.6	<0.1	31.8	22.9	27.4	24.7	18.2	7.6	16.8	3.9	61.0	20.4	28.4
– downstream	1.6	6.9	2.0	3.5	1.5	2.7	1.6	1.9	<0.1	4.5	2.5	3.5	32.5	26.0	8.3	22.3	3.4	76.0	18.1	32.5
avg	1.7	6.3	4.4	4.1	1.8	3.4	1.6	2.2	<0.1	18.2	12.7	15.4	28.6	22.1	8.0	19.6	3.6	68.5	19.2	30.4
Control field – 0.8 m	ns*	5.4	ns	5.4	ns	2.0	ns	2.0	ns	14.1	ns	14.1	ns	47.0	ns	47.0	ns	92.0	ns	92.0
– 0.8 m	ns	5.0	ns	5.0	ns	2.0	ns	2.0	ns	31.8	ns	31.8	ns	34.1	ns	34.1	ns	114.0	ns	114.0
avg	ns	5.2	ns	5.2	ns	2.0	ns	2.0	ns	23.0	ns	23.0	ns	40.6	ns	40.6	ns	103.0	ns	103.0
Control field – 1.6 m	ns	6.0	ns	6.0	ns	1.9	ns	1.9	ns	16.8	ns	16.8	ns	37.2	ns	37.2	ns	183.0	ns	183.0
– 1.6 m	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
avg	ns	6.0	ns	6.0	ns	1.9	ns	1.9	ns	16.8	ns	16.8	ns	37.2	ns	37.2	ns	183.0	ns	183.0
Control field overall avg				5.5				1.9				12.4				39.4				130.0
17-year disposal field – 0.8 m	ns	5.4	6.9	6.2	ns	2.0	1.5	1.8	ns	26.7	13.4	20.0	ns	40.5	51.3	45.9	ns	99.0	25.6	62.3
– 0.8 m	ns	9.3	8.6	9.0	ns	0.9	1.7	1.3	ns	4.4	1.3	2.8	ns	45.6	42.1	43.8	ns	82.0	22.5	52.2
avg	ns	7.4	7.8	7.6	ns	1.4	1.6	1.5	ns	15.6	7.4	11.4	ns	23.0	46.7	44.8	ns	90.5	24.0	57.2
17-year disposal field – 1.6 m	ns	ns	14.6	14.6	ns	ns	2.0	2.0	ns	ns	31.7	31.7	ns	ns	136.0	136.0	ns	ns	46.5	46.5
– 1.6 m	ns	ns	4.7	4.7	ns	ns	2.4	2.4	ns	ns	46.6	46.6	ns	ns	23.0	23.0	ns	ns	7.7	7.7
avg	ns	ns	9.6	9.6	ns	ns	2.2	2.2	ns	ns	39.2	39.2	ns	ns	79.5	79.5	ns	ns	27.1	27.1
17-year disposal field overall avg				8.3				1.8				25.3				56.4				47.2
20-year disposal field – 0.8 m	ns	6.7	ns	6.7	ns	4.8	ns	4.8	ns	4.2	ns	4.2	ns	138.0	ns	138.0	ns	223.0	ns	223.0
– 0.8 m	ns	4.6	13.1	8.8	ns	1.5	1.6	1.6	ns	10.6	25.8	18.2	ns	73.5		73.5	ns	111.0	41.7	76.4
avg	ns	5.6	13.1	8.1	ns	3.2	1.6	2.6	ns	7.4	25.8	13.5	ns	106.0	ns	106.0	ns	167.0	41.7	125.0
20-year disposal field – 1.6 m	ns	5.9	6.5	6.2	ns	3.2	1.7	2.4	ns	5.4	4.2	4.8	ns	94.0	27.3	60.7	ns	78.0	51.3	64.6
– 1.6 m	ns	3.9	5.6	4.8	ns	0.9	1.7	1.3	ns	3.9	2.5	3.2	ns	88.5		88.5	ns	74.0	25.6	49.8
avg	ns	4.9	6.0	5.5	ns	2.0	1.7	1.8	ns	4.6	3.4	4.0	ns	91.3	27.3	70.0	ns	76.0	38.4	57.2
20-year disposal field overall avg				6.9				2.2				8.1				84.3				86.4

* ns indicates insufficient sample for analysis.

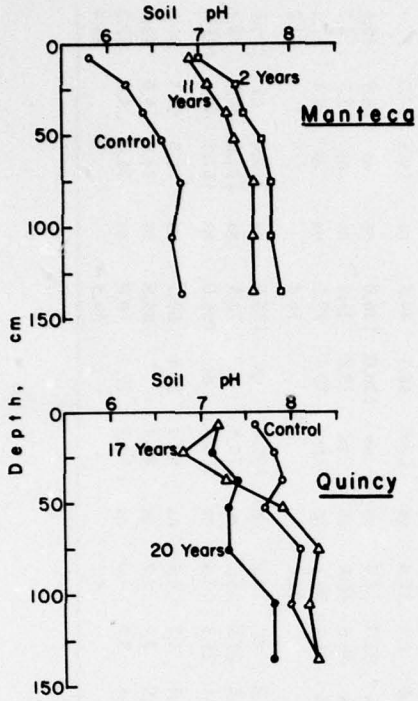


Figure 8. Distribution of soil pH with depth at Manteca and Quincy.

water/wk) that that at Manteca (5 cm/wk) might have been expected to result in poorer water quality. However, this was not observed, as NO_3-N concentrations in groundwater (soil solution, wells, drains) were generally no higher (except for seasonal effects) in Quincy than in Manteca, although the rate of applied N was roughly four times greater in Quincy than in Manteca. Ortho-P concentrations at the Manteca site were, in fact, markedly higher than at Quincy.

There are several possible reasons for the better overall performance in Quincy. One is probably efficient crop uptake at the site, resulting from its being a managed farm on which corn and wheat are grown and harvested. In contrast, at Manteca the cover crop is ryegrass that is not removed from the field. Another reason may be the schedule of application. At Manteca, wastewater is applied within two hours once a week, while at Quincy wastewater is applied several times a week. The former method does not allow enough time for soils to sorb phosphorus.

Other differences relating to effects on the sites, but not directly related to water quality, were also noted. For example a slight decrease in soil pH was attributed to wastewater disposal at Quincy, whereas an increase was attributed to the disposal at Manteca (Fig. 8). Again, this is probably related to the larger amount of N applied at the Quincy site. Consisten with this, there was a decrease in exchangeable Ca a the Quincy site and an increase at Manteca. This may have had an indirect effect on water quality in terms of P mobilization at Quincy because pH plays a major role in P retention by soils. Lowering of soil pH has been cited as the reason for heavy metal and phosphorus movement in prototype slow-infiltration systems (Iskandar and Leggett 1976). However, neither the mechanisms nor the kinetics of P fixation by soils are completely understood, with many possible reactions occurring simultaneously. [For a discussion, see Bailey (1968)]. Cation exchange capacity increased in the surface soil layer of the long-term disposal fields of both sites, but was accompanied by a smaller corresponding increase in the organic carbon content at the Quincy site than at Manteca. Greater accumulation of heavy metals in the soils was observed at Manteca. This may have been related to their higher concentrations relative to other cations in the wastewater applied or to the higher soil organic matter content at that site.

In summary, if managed properly, both sites are good examples of successful land treatment of wastewater. Wastewater renovation for nitrogen was acceptable at both sites despite the high loading rate at Quincy. The greater success at Quincy was probably due in part to more efficient agronomic practice at that site than at Manteca, resulting in more complete utilization of N and P by the crops. However, phosphorus was found to be a problem inasmuch as leaching was indicated at both sites, particularly at Manteca. No salinity or alkalinity problems were associated with wastewater application at either site. However, some changes in soil pH did occur at both sites as a result of long-term application of wastewater. The applied wastewater at Quincy and Manteca contained relatively low amounts of heavy metals, and no unusual accumulations were observed.

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APPENDIX A. METHODS OF SOIL CHEMICAL ANALYSIS

Where appropriate, a reference for a similar standard method is indicated as a source of additional information that must be consulted to establish the procedure employed.

Sample preparation

Soil samples were composited after collection when necessary and then air dried on an open bench before being shipped to the U.S. Testing Laboratory, Memphis, Tenn., for analysis. Upon arrival at the laboratory, the samples were again air dried in a draft oven (75°F) (23.9°C), passed through a 2-mm stainless steel sieve, and the less than 2-mm fraction stored in plastic-lined paper bags for analysis. After a sample was sieved, the fraction of it that was less than 2 mm in diameter was determined. The soil remaining (the < 2 mm fraction), after completion of the analytical work, was returned to CRREL for storage.

Soil pH

The method used to determine pH was similar to that reported in *Methods for Soil Analysis* (Black 1965, section 60-3.4). Twenty ml of distilled water were added to 20 g of soil. The suspension obtained was mixed with a mechanical stirrer for 1 hour. The pH was read immediately using a standard glass/calomel electrode pair. The mixture was agitated while the pH reading was being obtained. Results were reported to the hearest 0.1 pH unit.

Soluble salts (conductivity)

The solution from the sample prepared for the pH determination was obtained by filtering the sample through a Buchner funnel (Whatman no. 1 filter paper). The overall procedure was similar to that reported in *Methods for Soil Analysis* (Black 1965, section 62-1.3.2.2 and 62-2). Electrical conductivity was determined using a standard Wheatstone bridge with a dip-type conductivity cell (cell constant = 1.0). Results were reported to the nearest 0.01 mmho/cm.

Cation exchange capacity

The method used to determine CEC is similar to that reported in *Methods for Soil Analysis* (Black 1965, section 57-2.1 and 57-2.3). One hundred ml of 1 N NH_4OAc, pH 7 were added to 20 g of soil. The mixture was shaken for 1 hour and allowed to settle overnight. It was then filtered through a Buchner funnel fitted to a suction flask. The sample was leached incrementally with additional NH_4OAc solution to obtain a total volume of 200-225 ml of filtrate. The filtrate was transferred to a 250-ml volumetric flask and completed to that volume with NH_4OAc. This solution was set aside for determination of individual exchangeable cations, as described in the next section.

The soil in the Buchner funnel was then leached incrementally with 200-250 ml of isopropyl alcohol to remove excess NH_4OAc. Water was used to transfer the soil to a Kjeldahl flask (800 ml). Boiling stones, a total volume of about 450-500 ml of distilled water, and 25 ml of 1 N NaOH were then added to the flask. Next, the sample was distilled into 50 ml of 4% boric acid. A total of about 200 ml of distillate was collected. The final distillate was titrated with 0.1 N HCl using a standard indicator solution. The milliequivalents of NH_3 collected are equivalent to the exchange capacity when expressed in milliequivalents per 100 g of soil.

Exchangeable cations

The NH_4OAc extract from the exchange capacity determination was analyzed for individual exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) with a Perkin-Elmer Model 403 atomic absorption spectrometer using an air/acetylene flame. Instrument settings were established using procedures recommended by the manufacturer (Perkin Elmer 1971). Results were expressed as parts per million of cations on a weight basis. This procedure for extraction of exchangeable cations is similar to that recommended by Jackson (1958, section 5-11).

Organic carbon

Organic carbon was determined by a Walkely-Black method similar to that outlined in *Methods for Soil Analysis* (Black 1965, section 90-3). Either 1.0 g or 0.5 g of soil, depending on the level of organic matter, was mixed with 10 ml of 1 N $K_2Cr_2O_7$ in a 250-ml Erlenmyer flask. Twenty ml of concentrated H_2SO_4

were added to the flask, the mixture was swirled for 1 min, and then allowed to cool for about 30 min. Water (150 ml) and several drops of o-phenanthrolene indicator were added, and the resulting mixture was allowed to recool. The suspension was titrated with 0.5 N $Fe(NH_4)_2(SO_4)_2$. The chromate was standardized repeating the procedure without soil. The percentage of organic carbon was calculated using the following equation (Black 1965):

% Organic C =

$$\frac{\text{meq } K_2Cr_2O_7 - \text{meq } Fe(NH_4)_2(SO_4)_2}{\text{g dry soil}} \times 0.3 .$$

No correction factor (normally x 1.33) was applied in making the calculation.

Organic-Nitrogen

Organic nitrogen was determined using a Kjeldahl method similar to that outlined in *Methods for Soil Analysis* (Black 1965, section 83-3). It was assumed that the exchangeable ammonium ion contribution was insignificant so that the result represented organic nitrogen. Ten g of soil were mixed with 20 ml of water in an 800-ml Kjeldahl flask and allowed to stand for 30 min. Then 10 g of K_2SO_4, 1.0 g $CuSO_4 \cdot 5H_2O$, 0.1 g HgO (red), and 30 ml of concentrated H_2SO_4 were added. The mixture was digested, according to the standard procedure, for 5 hours. The sample was cooled, 500 ml distilled water was added, and the sample was then recooled. To the same flask, 25 ml of 16% $Na_2S_2O_3$ solution, several granules of mossy zinc, and 50 ml of 50% NaOH were added. The flask was immediately connected to a distillation column. About 200-250 ml of distillate was collected in 50 ml of 4% boric acid. The distillate was titrated with 0.1 N HCl using the standard indicator solution. The results were expressed in terms of percentage of organic-N on a weight basis.

Free iron oxides

The procedure followed was that given in *Methods of Soil Analysis* (Black 1965, section 65-4). Five g of air-dried soil, 5 g of $Na_2S_2O_4$ and 100 ml of water were placed in a flask, which was then immediately shaken for 16 hours. The suspension was transferred to a 250-ml beaker, and the pH adjusted to 3.5 to 4.0 with 1 N HCl. The suspension was then stirred several times over the period of an hour.

The suspension was transferred to a 250-ml volumetric flask, diluted to that volume with water, and mixed. Five ml of clear filtered extract were transferred to a 250-ml beaker using a mechanical source of suction to fill a 50-ml pipette. The solution was diluted to about 100 ml, and 15 ml of H_2O_2 added. The contents of the beaker were warmed on a hot plate, cooled and then boiled for 10 to 15 min. Another 5 ml of H_2O_2 was added and the contents were boiled again for 5 to 10 min.

A slight excess of 7 N NH_4OH was added and the solution was boiled 15 to 20 min. The $Fe(OH)_3$ precipitate was dissolved by adding 15 ml of 6 N HCl through the lip of the covered beaker. The solution was heated to 90°C, and the Fe reduced by adding $SnCl_2$ reagent dropwise and stirring the solution until the yellow color disappeared. An excess of 4 drops of $SnCl_2$ was added, the solution was cooled to room temperature, and 15 ml of saturated $HgCl_2$ were added rapidly from a volumetric cylinder.

The solution was diluted to about 125 ml, and then 5 ml of 85% H_3PO_4 and 10 drops of 0.16% barium diphenylamine sulfonate were added. The solution was titrated with standardized 0.1 N $K_2Cr_2O_7$ to a violet-blue endpoint. The free Fe oxides as percentage of Fe_2O_3 in the soil were calculated as follows:

Free Fe oxides =

(ml of $K_2Cr_2O_7$)(Normality of $K_2Cr_2O_7$)(7.92).

Organic phosphorus

The method used for determination of organic phosphorus was adopted from those recommended in *Methods of Soil Analysis* (Black 1965, secton 73-3) and Sanders (1955). Two g of soil were ignited in a silica crucible for one hour at 550°C. The ignited sample and a duplicate 2-g unignited sample were then extracted for 2 hours with 100 ml of 0.2 N H_2SO_4 in a shaker. Inorganic phosphorus in the extracts was determined using a standard molybdate method (Orr 1971). An aliquot of a sample 3-10 ml in volume, depending on concentration, was mixed with 2 ml of ammonium molybdate-HCl reagent and 2 ml of Elon reagent. The solution was diluted to a 25-ml volume with 15 min allowed for color development. Color intensities of the samples, blanks, and standards carried through the soil sample extraction procedure were determined using a colorimeter. The increased phosphorus resulting from ignition was taken to represent organic phosphorus. Results were expressed as parts per million on a weight basis.

Total phosphorus

Total phosphorus was determined using two methods. The first method was an acid-digestion technique. Later,

in determining organic phosphorus, it was found that total phosphorus obtained by ignition was different (frequently higher) than that obtained by digestion. Consequently, both values were reported when available.

Acid digestion

The digestion method employed was that in *Methods of Soil Analysis* (Black 1965, section 73-2). Two g of soil were added with 30 ml of 60% $HClO_4$ to a 250-ml volumetric flask. The mixture, after digestion on a hot plate until white $HClO_4$ fumes appeared (3-4 hours), was cooled and made up to a 250-ml volume with distilled water. The solution was then filtered before analysis for phosphorus using the molybdate method (Orr 1971) employed above for analysis of organic phosphorus. Results were expressed as parts per million of phosphorus on a weight basis.

Ignition

The value obtained for ignited samples during the procedure for determination of organic phosphorus was taken to represent total phosphorus.

Exchangeable phosphorus

Exchangeable phosphorus was extracted using the Bray technique for estimating plant available phosphorus. The extraction procedure used was similar to that in *Methods of Soil Analysis* (Black 1965, section 73-4.1). One g of soil was shaken for 5 min with 10 ml of 0.03 N NH_4F - 0.025 N HCl solution. The suspension was filtered to obtain the clear extract. Two ml of the extract were added to 4 ml of extracting solution. The phosphorus was determined colorimetrically using the procedure (Black 1965) described for organic phosphorus, except that 0.5 ml each of molybdate and Elon reagents were added directly to the 6 ml of prepared sample. Results were expressed as parts per million phosphorus on a weight basis.

Soluble phosphorus

A procedure similar to that described in *Methods for Soil Analysis* (Black 1965, section 73-4.3) was employed to extract soluble phosphorus. Twenty ml of distilled water were added to 10 g of soil in a sample bottle. The mixture was shaken for 24 hours. The clear extract was obtained by filtering. Molybdate and Elon reagents (0.5 ml each) were added directly to 6 ml of soil solution. The colorimetric procedure (Orr 1971) was similar to that used for organic phosphorus. Results were expressed as parts per million on a weight basis with respect to soil. Soluble phosphorus with respect to solution concentration is equal to one-half the reported value, since 10 g of soil was equilibrated with 20 g of water.

Total heavy metals

Cadmium, copper, zinc, nickel, chromium, lead

Two g of soil were digested with 20 ml of concentrated HNO_3 in a 100-ml volumetric flask on a hot plate for 30 min. The mixture was cooled, after which 10 ml of concentrated $HClO_4$ and 5 ml of concentrated H_2SO_4 were added. The sample was redigested for 5 hours or until the volume of remaining acid was reduced to about 5 ml. The volume was then increased to 100 ml with distilled water and the sample filtered. The concentrations of heavy metals were determined directly on the extract using a Perkin-Elmer 403 atomic adsorption spectrometer. An air/acetylene flame was used when the concentration of a given element was sufficiently high. For low concentrations, a Perkin-Elmer (1973) HGA 2100 graphite furnace was employed. Instrument settings were established using procedures recommended by Perkin Elmer (1971, 1973). Results were reported on a parts per million or billion by weight basis.

Mercury

One g of soil was predigested with 5 ml of concentrated HNO_3 in a 300-ml BOD bottle by heating on a hot plate for 30 min at 60°C after the initial oxidation of organic matter occurred. A second stage of digestion was achieved by adding 15 ml of aqua regia with further heating for 60 min at the same temperature. The above digestion procedure has been reported in detail by Hamm (1973). Mercury in the digestate was determined with a Coleman Mercury Analyzer MAS-50 using the manufacturer's (Perkin Elmer 1972) suggested procedure. The digested sample was diluted to 100 ml with distilled water. Five ml of 5% $KMNO_4$ were then added and the solution was mixed. Other oxidizing reagents were added next in sequence: 5 ml of 5.6 N HNO_3 (swirl and wait 15 s); 5 ml 18 N H_2SO_4 (swirl and wait 45 s). Reducing agents were then added in the order: 5 ml of 1.5% hydroxylamine hydrochloride; 5 ml of 10% stannous chloride. At this point the solution was ready for analysis using the Coleman Analyzer. Results were reported in parts per billion by weight.

Extractable heavy metals

Cadmium, copper, zinc, nickel, chromium, lead

Ten g of soil were shaken with 50 ml of 0.1 N for 1 hour and filtered. The concentrations of extractable heavy metals in solution were determined by atomic

absorption spectroscopy as described for total heavy metals.

Mercury

Five g of soil were shaken with 50 ml of 0.1 N HCl for 1 hour. The suspension was filtered, and the soil leached with an additional amount of 0.1 N HCl until a total filtrate volume of 100 ml was obtained. The extractable mercury was then determined using the Coleman Mercury Analyzer procedure described above in determining total mercury.

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APPENDIX B. CLIMATOLOGICAL AND WATER QUALITY DATA AT MANTECA, CALIFORNIA, AND QUINCY, WASHINGTON

Table BI. Total precipitation and monthly mean temperature at Manteca, California, 1951-1960.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
						TOTAL PRECIPITATION (cm)							
1951	4.82	5.18	1.14	2.18	0.68	0.00	0.00		0.00	1.77	3.53	11.73	25.85
1952	8.55	2.33	7.39	5.00	0.00	0.20	0.88	0.00	0.05	0.00	2.43	10.05	36.88
1953	3.30	0.17	2.23	3.68	1.06	0.88	0.00	0.45	0.05	0.83	1.24	2.71	16.60
1954	2.92	1.67	7.13	1.98	0.68	0.40	0.00	0.00	0.00	0.00	4.64	8.07	27.49
1955	9.16	1.90	0.66	6.50	1.16	0.00	0.00	0.00	0.66	0.05	2.76	16.10	38.95
1956	11.07	2.00		4.95	2.05		0.00	0.00	0.71	1.24	0.02	0.58	22.62
1957	5.33	5.23	2.97	2.05	3.63	0.12		0.00	0.50	4.29	0.76	6.32	31.20
1958	8.35	12.67	10.21	12.42	2.97		0.00	0.00	0.22	0.00	0.27	1.60	48.71
1959	7.69	8.71	0.38	0.68	0.53	0.00		0.12	5.28	0.00	0.00	1.57	24.96
1960	3.81	5.37	1.29	2.10	0.20	0.00	0.00	0.00	0.17	0.10	5.68	1.29	21.01
MEAN	6.50	4.62	3.34	4.15	1.29	0.16	0.08	0.05	0.76	0.82	2.13	6.00	26.30
						MEAN TEMPERATURE (°C)							MEAN
1951	8.00	10.00	12.05	15.33	19.16	21.61	23.83	23.50	22.11	16.77	12.22	7.33	15.99
1952	7.38	9.55	10.27	15.11	19.66	19.44	25.50	23.94	22.66	18.38	10.22	8.44	15.87
1953	10.33	10.05	11.72	14.66	16.11	19.83	25.77	22.27	22.61	16.61	12.33	8.22	15.87
1954	8.16	9.50	10.55	17.33	19.55	21.38	25.83	21.88	20.33	16.50	10.66	6.77	15.70
1955	5.55	8.05	12.16	12.50	18.33	21.22	22.83	24.00	21.72	17.22	10.50	9.72	15.31
1956	9.16	8.00	12.38	14.83	18.72	22.11	24.33	22.55	21.66	15.94	11.27	7.44	15.69
1957	6.11	11.66	13.11	15.88	18.16	24.05	25.11	22.72	21.72	16.27	10.66	7.38	16.07
1958	8.16	12.61	11.00	15.61	20.16	21.83	24.44	26.61	23.33	19.72	13.05	10.38	17.24
1959	10.33	10.27	15.00	18.27	18.44	23.83	26.50	24.05	21.16	19.00	12.05	7.88	17.23
1960	8.11	10.11	13.55	15.38	18.05	24.83	26.16	24.11	22.11	17.27	11.00	6.94	16.47
MEAN	8.13	9.98	12.19	15.49	18.63	22.01	25.03	23.56	21.94	17.37	11.40	8.05	16.14

Table BII. Total monthly precipitation and mean temperature at Quincy, Washington, 1951-1960.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
						TOTAL PRECIPITATION (cm)							Total
1951	2.26	0.99	1.27	0.60	2.79	4.54	2.10	2.66	0.48	1.60	3.35	-	22.64
1952	2.38	1.95	0.20	.58	1.42	1.67	0.78	0.00	0.00	0.10	0.81	2.41	12.30
1953	5.66	0.93	0.99	3.83	3.55	3.73	0.00	1.44	0.17	0.38	2.41	1.06	24.15
1954	2.79	1.01	1.04	0.27	0.58	1.01	0.40	1.24	0.71	0.22	2.46	0.78	12.51
1955	2.08	0.20	0.71	3.12	1.60	0.38	2.03	0.00	1.42	0.55	4.41	4.62	21.12
1956	4.01	2.13	0.50	0.35	1.54	0.43	0.00	0.25	1.16	5.79	0.07	0.30	16.53
1957	4.11	0.35	5.51	2.64	2.76	1.34	0.00	0.55	1.09	4.14	0.68	0.53	23.70
1958	3.93	5.61	3.86	3.83	0.27	1.85	0.45		0.58	0.60	4.62	2.48	28.08
1959	4.34	3.22	1.90	0.10	2.33	0.07		0.05	5.76	2.48	1.27	1.01	22.53
1960	0.73	3.98	1.27	3.42	2.81	0.10		0.05	0.66	0.25	3.04	0.68	16.99
MEAN	3.22	2.03	1.71	1.87	1.96	1.51	0.57	0.62	1.20	1.89	2.31	1.38	20.05
						MEAN TEMPERATURE (°C)							
1951	-2.38	0.22M	1.77	11.05	14.83	18.33M	23.27	22.33	17.77M	10.11M	2.38	-9.38M	9.23
1952	-7.83	-1.27	4.44	11.66	15.83	18.50	23.50M	-	19.33	14.27	0.44	-0.33	8.21
1953	2.94	3.50	5.94	8.77	13.11	15.66	22.11	21.55	18.05M	11.83	5.11	1.55	10.84
1954	-4.22	1.66	3.55	8.11	15.88	16.38	21.38	19.88	16.58M	8.94	5.94	-0.94	9.41
1955	-3.50	- 0.94	1.83	7.00	12.22	19.22	20.83	22.38	16.77	10.66	-3.16	-5.77	8.12
1956	-3.55	-6.50	2.94	12.22	16.72	16.83	23.27	21.27	18.22	8.94	- 0.33	-1.83	9.24
1957	-10.83	-2.11	3.83	11.00	17.51	19.38	20.50	19.50	18.17	8.55	2.94	1.05	9.13
1958	0.72	5.66	4.88	9.11	18.77	21.61	24.38	24.33	16.27	10.61	2.66	-0.33	11.55
1959	-1.50	-1.33	5.72	11.11	12.44	18.00	22.94	19.50	14.77	9.33	-0.05	-1.05	9.15
1960	-5.83	1.50	5.05	9.44	12.22	18.16	24.44	19.72	17.05	10.22	3.11	-3.11	9.33
MEAN	-3.59	0.03	3.99	9.94	16.72	18.25	22.66	19.04	17.27	10.34	1.90	-2.01	9.42

Table BIII. Water quality at wastewater disposal site, Manteca, California, 4-6 June 1974. Parameter by sampling rate.

Location of sample collection	pH*				NO_3 - N(mg/l)				NH_4 - N(mg/l)				Ortho-P (mg/l)			
	4 June	5 June	6 June	Avg	4 June	5 June	6 June	Avg	4 June	5 June	6 June	Avg	4 June	5 June	6 June	Avg
Secondary treatment	7.6	7.6	7.6	7.6	0.6	1.6	1.9	1.4	14.5	15.3	8.2	12.7	7.3	2.7	2.2	4.1
Storage lagoon	8.3	8.3	8.4	8.3	<0.1	<0.1	<0.1	<0.1	10.0	5.8	7.0	7.6	4.1	4.2	ns	4.2
Drainage ditch - upstream one	8.2	8.0	8.3	8.2	3.2	1.6	1.4	2.1	0.5	0.9	0.4	0.6	0.5	0.3	2.0	0.9
- upstream two	8.0	7.9	7.8	7.9	0.4	0.3	0.2	0.3	1.2	2.2	2.0	1.8	0.7	0.3	0.5	0.5
- downstream	8.2	8.0	8.3	8.2	1.8	1.6	0.9	1.4	0.1	0.3	0.1	0.2	0.1	0.2	<0.1	0.1
Avg	8.1	8.0	8.1	8.1	1.8	1.2	0.8	1.3	0.6	1.1	0.8	0.8	0.4	0.3	0.8	0.5
Well A, northeast† - 2.8 m	ns**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
(control) - 5.6 m	7.9	7.8	7.7	7.8	0.4	0.6	0.4	0.5	1.4	1.2	1.4	1.3	0.3	0.3	0.5	0.4
- 8.4 m	7.9	7.8	7.8	7.8	0.5	0.7	0.4	0.5	1.0	1.4	1.4	1.3	0.2	0.4	0.5	0.4
Avg	7.9	7.8	7.8	7.8	0.4	0.6	0.4	0.5	1.2	1.3	1.4	1.3	0.2	0.4	0.5	0.4
Well B, center west† - 5.6 m	7.8	7.8	7.8	7.8	14.1	12.0	12.0	12.7	0.4	0.5	0.8	0.6	0.5	0.3	1.0	0.6
- 8.4 m	8.2	8.0	8.0	8.1	7.0	9.9	10.8	9.2	0.3	0.2	0.2	0.2	0.1	<0.1	<0.1	<0.1
Avg	8.0	7.9	7.9	7.9	10.6	11.0	11.4	11.0	0.4	0.4	0.5	0.4	0.3	0.2	0.5	0.3
Well C, center east† - 2.8 m	7.6	7.7	7.6	7.6	1.3	1.6	1.6	1.5	0.3	0.4	0.5	0.4	1.0	1.0	1.2	1.1
- 5.6 m	7.8	7.9	7.8	7.8	2.3	2.5	2.4	2.4	0.4	0.6	0.5	0.5	0.3	0.4	1.0	0.6
- 8.4 m	7.8	7.8	7.8	7.8	3.6	4.6	3.9	4.0	0.1	0.2	0.2	0.2	0.4	0.8	1.0	0.7
Avg.	7.8	7.8	7.7	7.7	2.4	2.9	2.6	2.6	0.3	0.4	0.4	0.4	0.6	0.7	1.1	0.8
Control field - 0.8 m	7.6	7.6	7.5	7.6	4.5	4.6	5.7	4.9	0.4	0.7	0.2	0.4	0.1	<0.1	<0.1	<0.1
Control field - 1.6 m	7.7	7.7	7.8	7.7	0.4	0.4	0.5	0.4	0.3	0.2	0.2	0.2	0.6	0.6	0.8	0.7
2-year disposal - 0.8 m	ns	7.5	7.7	7.6	ns	20.5	30.0	25.2	ns	0.8	1.1	1.0	ns	9.1	ns	9.1
field - 0.8 m	7.7	7.6	7.6	7.6	12.0	12.0	24.0	16.0	0.9	0.7	1.7	1.1	4.1	8.0	ns	6.0
Avg	7.7	7.6	7.6	7.6	12.0	16.2	27.0	19.7	0.9	0.8	1.4	1.0	4.1	8.6	ns	7.3
2-year disposal - 1.6 m	7.6	7.7	7.6	7.6	2.4	2.6	3.1	2.7	0.3	0.2	0.4	0.3	9.3	6.1	ns	7.7
field - 1.6 m	7.5	7.6	7.5	7.5	2.6	2.4	2.5	2.5	0.7	0.3	0.4	0.5	9.9	8.9	10.8	9.9
Avg	7.6	7.6	7.6	7.6	2.5	2.5	2.8	2.6	0.5	0.2	0.4	0.4	9.6	7.5	10.8	9.0
11-year disposal - 0.8 m	7.4	7.5	7.5	7.5	0.8	1.0	1.0	0.9	0.8	0.6	0.7	0.7	9.5	9.7	ns	9.6
field - 0.8 m	7.6	7.6	7.5	7.6	8.8	8.5	10.0	9.1	1.1	0.9	0.8	0.9	6.5	8.7	ns	7.6
Avg	7.5	7.6	7.5	7.6	4.8	4.8	5.5	5.0	1.0	0.8	0.8	0.8	8.0	9.2	ns	8.6
11-year disposal - 1.6 m	7.6	7.6	7.8	7.7	1.7	3.1	3.1	2.6	0.9	0.4	0.7	0.7	8.2	9.2	ns	8.7
field - 1.6 m	7.6	7.6	7.8	7.7	2.7	2.8	3.0	2.8	0.6	0.6	0.6	0.6	10.9	11.1	ns	11.0
Avg	7.6	7.6	7.8	7.7	2.2	3.0	3.0	2.7	0.8	0.5	0.6	0.6	9.6	10.2	ns	9.9

* Averages are based on pH values rather than on hydrogen ion activity.
† See Figure 3.
** ns indicates insufficient sample collected for analysis.

Table BIV. Water quality at wastewater disposal site, Manteca, California, 9-11 September 1974.
Parameter by sampling date.

Location of sample collection	pH*				NO_3 - N(mg/l)				NH_4 - N(mg/l)				Ortho-P (mg/l)			
	9 Sept	10 Sept	11 Sept	Avg	9 Sept	10 Sept	11 Sept	Avg	9 Sept	10 Sept	11 Sept	Avg	9 Sept	10 Sept	11 Sept	Avg.
Secondary treatment	7.5	7.6	7.4	7.5	2.2	1.6	1.0	1.9	14.8	11.0	10.8	12.2	2.6	10.6	5.0	6.1
Storage lagoon	7.3	7.5	7.2	7.3	2.2	2.0	1.7	2.0	18.0	8.0	8.0	11.3	11.4	11.3	13.3	12.0
Drainage ditch - upstream one	7.8	7.6	7.6	7.7	4.0	3.4	4.7	4.0	0.4	0.6	0.3	0.4	0.5	0.6	0.6	0.6
- upstream two	7.7	7.8	7.5	7.7	6.1	7.2	5.2	6.2	0.6	1.0	0.4	0.7	0.2	0.2	0.3	0.2
- downstream	7.8	7.9	7.5	7.7	2.7	2.4	4.4	3.2	0.4	0.2	0.1	0.2	0.2	0.2	0.3	0.2
Avg	7.8	7.8	7.5	7.7	4.3	4.3	4.8	4.5	0.5	0.6	0.3	0.5	0.3	0.3	0.4	0.3
Well A, northeast† - 2.8 m	7.8	7.3	7.4	7.5	0.8	0.9	0.2	0.6	0.8	1.3	1.5	1.2	0.8	1.1	0.5	0.8
(control) - 5.6 m	7.8	7.2	7.2	7.4	0.6	0.9	0.5	0.7	1.2	0.8	1.0	1.0	0.7	0.9	0.3	0.6
- 8.4 m	7.5	7.1	7.2	7.3	1.0	0.8	0.6	0.8	1.0	0.8	0.7	0.8	0.4	0.5	0.2	0.4
Avg	7.7	7.2	7.3	7.4	0.8	0.9	0.4	0.7	1.0	1.0	1.1	1.0	0.6	0.8	0.3	0.6
Well B, center west† - 5.6 m	7.5	7.3	7.4	7.4	14.0	12.5	15.2	13.9	0.3	0.5	0.2	0.3	1.0	0.9	1.1	1.0
- 8.4 m	7.5	7.4	7.3	7.4	7.9	8.4	11.8	9.4	0.4	0.4	0.2	0.3	0.4	0.3	0.2	0.3
Avg	7.5	7.4	7.4	7.4	11.0	10.4	13.5	11.6	0.4	0.4	0.2	0.3	0.7	0.6	0.6	0.6
Well C, center east† - 2.8 m	7.3	6.9	7.0	7.1	2.3	2.2	2.0	2.2	0.4	0.4	0.3	0.4	2.3	2.6	3.0	2.6
- 5.6 m	7.5	7.3	7.3	7.4	1.4	1.3	1.8	1.5	0.5	0.4	0.3	0.4	0.5	1.3	1.0	0.9
- 8.4 m	7.5	7.4	7.3	7.4	2.8	3.4	4.9	3.7	0.2	0.4	<0.1	0.2	1.4	1.8	2.0	1.7
Avg	7.4	7.2	7.2	7.3	2.2	2.3	2.9	2.5	0.4	0.4	0.2	0.3	1.4	1.9	2.0	1.8
Control field - 0.8 m	ns**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control field - 1.6 m	7.8	8.0	7.8	7.9	1.6	1.0	0.7	1.1	0.9	0.6	0.2	0.6	0.6	0.8	0.7	0.7
2-year disposal - 0.8 m	7.3	7.3	7.1	7.2	9.0	10.1	15.9	11.7	0.9	0.4	0.4	0.6	11.4	10.9	12.0	11.4
field - 0.8 m	7.3	7.3	7.2	7.3	6.2	3.3	3.3	4.3	1.0	1.1	0.5	0.9	6.0	6.8	8.2	7.0
Avg	7.3	7.3	7.2	7.3	7.6	6.7	9.6	8.0	1.0	0.8	0.4	0.7	8.7	8.8	10.1	9.2
2-year disposal - 1.6 m	7.4	7.3	7.1	7.2	11.5	10.9	21.8	14.7	0.8	1.0	0.8	0.9	8.8	9.9	9.1	9.3
field - 1.6 m	7.2	7.2	7.2	7.2	13.8	18.3	22.0	18.0	0.8	1.0	0.2	0.7	9.2	8.9	8.9	9.0
Avg	7.3	7.2	7.2	7.2	12.6	14.6	21.9	16.4	0.8	1.0	0.5	0.8	9.0	9.4	9.0	9.1
11-year disposal - 0.8 m	7.2	7.1	7.3	7.2	2.4	1.5	14.2	6.0	1.4	0.5	1.3	1.1	7.4	7.1	7.3	7.3
field - 0.8 m	7.2	7.1	7.3	7.2	8.5	11.0	3.9	7.8	0.5	0.6	0.3	0.5	9.7	7.7	10.7	9.4
Avg	7.2	7.1	7.3	7.2	5.4	6.2	9.0	6.9	0.6	0.6	0.8	0.8	8.6	7.4	9.0	8.3
11-year disposal - 1.6 m	7.1	7.1	7.1	7.1	2.8	2.3	3.7	2.9	0.8	1.2	0.7	0.9	11.2	11.2	10.0	10.8
field - 1.6 m	7.1	7.1	7.1	7.1	11.2	8.2	13.8	11.1	0.9	0.7	0.2	0.6	7.3	8.8	10.4	8.8
Avg	7.1	7.1	7.1	7.1	7.0	5.2	8.8	7.0	0.8	1.0	0.4	0.8	9.2	10.0	10.2	9.8

* Averages are based on pH values rather than on hydrogen ion activity.
† See Figure 3.
** ns indicates insufficient sample collected for analysis.

Table BV. Water quality at wastewater disposal site, Manteca, California, 11-13 November 1974.
Parameter by sampling date.

Location of sample collection	pH*				NO_3 - N (mg/l)				NH_4 - N (mg/l)				Ortho-P (mg/l)			
	11 Nov	12 Nov	13 Nov	Avg	11 Nov	12 Nov	13 Nov	Avg	11 Nov	12 Nov	13 Nov	Avg	11 Nov	12 Nov	13 Nov	Avg
Secondary treatment	7.9	7.9	7.8	7.9	1.5	1.2	1.0	1.2	7.2	4.8	14.5	8.8	2.2	2.6	6.5	3.8
Storage lagoon	7.9	7.9	7.8	7.9	1.0	2.0	0.6	1.2	8.8	3.0	17.0	9.6	5.2	6.5	6.7	6.1
Drainage ditch - upstream one	7.9	8.3	8.4	8.2	6.6	3.1	2.8	4.2	0.8	0.2	0.1	0.4	0.3	0.3	0.3	0.3
- upstream two	7.9	8.1	8.2	8.1	3.5	3.2	2.9	3.2	0.3	0.3	0.4	0.3	0.4	0.4	0.5	0.4
- downstream	7.7	8.0	8.2	8.0	3.3	5.2	3.7	4.1	0.4	0.9	1.4	0.9	2.6	3.3	3.5	3.1
Avg	7.8	8.1	8.3	8.1	4.5	3.8	3.1	3.8	0.5	0.5	0.6	0.5	1.1	1.3	1.4	1.3
Well A, northeast† - 2.8 m	ns†	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
(control) - 5.6 m	7.7	8.2	8.1	8.0	2.1	0.7	0.5	1.1	0.3	1.4	1.1	0.9	0.6	0.8	1.2	0.9
- 8.4 m	7.8	8.0	8.5	8.1	1.4	0.8	0.5	0.9	0.8	0.7	0.6	0.7	0.5	0.3	0.3	0.4
Avg	7.8	8.1	8.3	8.1	1.8	0.8	0.5	1.0	0.6	1.0	0.8	0.8	0.6	0.6	0.8	0.6
Well B, center west† - 5.6 m	7.6	8.1	8.2	8.0	16.2	10.3	8.9	11.8	0.4	0.2	0.2	0.3	1.2	0.8	0.6	0.9
- 8.4 m	7.7	8.0	8.0	7.9	6.6	7.2	8.5	7.4	0.8	0.6	0.1	0.5	0.1	0.1	1.2	0.5
Avg	7.6	8.0	8.1	7.9	11.4	8.8	8.7	9.6	0.6	0.4	0.2	0.4	0.6	0.4	0.9	0.7
Well C, center east† - 2.8 m	7.4	8.1	8.0	7.8	2.3	1.9	2.2	2.1	0.3	0.3	0.2	0.3	3.3	1.3	1.6	2.1
- 5.6 m	7.7	8.2	8.2	8.0	1.2	1.7	1.3	1.4	1.4	0.3	0.3	0.7	1.0	1.0	1.4	1.1
- 8.4 m	7.5	8.1	8.2	7.9	5.3	3.9	3.2	4.1	0.2	0.1	0.1	0.1	1.7	1.4	1.4	1.5
Avg	7.5	8.1	8.1	7.9	2.9	2.5	2.2	2.5	0.6	0.2	0.2	0.4	2.0	1.2	1.5	1.6
Control field - 0.8 m	ns**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control field - 1.6 m	8.1	8.2	8.1	8.1	0.8	0.7	0.7	0.7	0.3	0.2	0.2	0.2	0.6	0.6	1.2	0.8
2-year disposal - 0.8 m	7.7	7.8	8.0	7.8	9.2	11.9	11.8	11.0	0.4	0.2	0.3	0.3	9.8	9.6	10.2	9.9
field - 0.8 m	7.5	7.7	8.2	7.8	2.8	1 5	1.3	1.9	0.6	0.3	0.3	0.4	11.3	7.9	11.2	10.1
Avg	7.6	7.8	8.1	7.8	6.0	6.7	6.6	6.4	0.5	0.2	0.3	0.4	10.6	8.8	10.7	10.0
2-year disposal - 1.6 m	7.3	7.5	8.2	7.7	9.8	10.8	10.3	10.3	0.2	0.3	0.3	0.3	9.9	7.2	10.8	9.3
field - 1.6 m	7.3	7.5	8.2	7.7	10.9	16.6	14.8	14.1	0.3	0.2	0.2	0.2	5.2	7.3	6.9	6.5
Avg	7.3	7.5	8.2	7.7	10.4	13.7	12.6	12.2	0.2	0.2	0.2	0.2	8.0	7.2	8.8	8.0
11-year disposal - 0.8 m	7.4	7.6	8.1	7.7	0.8	0.7	0.7	0.7	0.6	0.4	0.4	0.5	9.2	7.2	10.0	8.8
field - 0.8 m	7.6	7.7	8.2	7.8	1.2	0.6	0.8	1.3	0.6	0.4	0.3	0.4	8.3	7.8	9.4	8.5
Avg	7.5	7.6	8.2	7.8	1.0	0.6	0.8	1.0	0.6	0.4	0.4	0.4	8.8	8.0	9.7	8.6
11-year disposal - 1.6 m	7.6	7.8	8.2	7.9	1.8	1.9	1.9	1.9	0.6	0.3	0.4	0.4	8.0	8.5	7.8	8.1
field - 1.6 m	7.6	7.8	8.1	7.8	8.9	4.7	3.5	5.7	0.8	0.4	0.2	0.5	6.8	7.5	7.4	7.2
Avg	7.6	7.8	8.2	7.9	5.4	3.3	2.7	3.8	0.7	0.4	0.3	0.4	7.4	8.0	7.6	7.7

* Averages are based on pH values rather than on hydrogen ion activity.
† See Figure 3.
** ns indicates insufficient sample collected for analysis.

Table BVI. Water quality at wastewater disposal site, Quincy, Washington, 21-23 May 1974.
Parameter by sampling date.

Location of sample collection	pH*				NO_3 - N (mg/l)				NH_4 - N (mg/l)				Ortho-P (mg/l)			
	21 May	22 May	23 May	Avg	21 May	22 May	23 May	Avg	21 May	22 May	23 May	Avg	21 May	22 May	23 May	Avg.
Primary clarifier	7.2	7.3	7.5	7.3	2.2	2.1	1.5	1.9	21.2	20.8	23.7	21.9	5.0	3.5	3.7	4.1
Storage lagoon 1	8.0	8.1	7.8	8.0	1.0	1.0	0.5	0.8	13.2	13.8	15.5	14.2	4.0	3.9	5.2	4.4
Storage lagoon 2	8.1	8.1	8.1	8.1	0.9	1.0	0.6	0.8	13.8	12.8	13.5	13.4	4.8	3.9	5.0	4.6
Storage lagoon 3	8.5	9.0	8.8	8.8	0.7	1.0	0.9	0.9	10.5	7.0	10.0	9.2	3.0	2.2	2.8	2.7
Avg	8.2	8.4	8.2	8.3	0.9	1.0	0.7	0.8	12.5	11.2	13.0	12.2	3.9	3.3	4.3	3.9
Drainage ditch - upstream	7.7	7.6	7.4	7.6	1.0	1.2	1.2	1.1	0.4	0.3	0.5	0.4	0.1	0.1	0.2	0.1
Drainage ditch - downstream	7.8	7.7	7.5	7.7	1.6	1.3	1.0	1.3	0.2	0.2	0.4	0.3	0.1	0.1	0.1	0.1
Avg	7.8	7.6	7.4	7.6	1.3	1.2	1.1	1.2	1.3	0.2	0.4	0.3	0.1	0.1	0.2	0.1
Tile to drainage ditch	7.5	7.6	7.6	7.6	2.8	2.8	2.7	2.8	0.1	<0.1	0.2	0.1	0.2	0.2	0.2	0.2
Well-north center(control wells)	7.2	7.1	ns†	7.2	0.8	0.9	ns	0.8	0.6	0.3	ns	0.4	0.3	0.3	ns	0.3
Well-center	7.1	7.1	ns	7.1	1.3	1.1	ns	1.2	1.9	1.5	ns	1.7	1.4	1.8	ns	1.6
Avg	7.2	7.1	ns	7.1	1.0	1.0	ns	1.0	1.2	0.9	ns	1.1	0.8	1.0	ns	1.0
Control field - 0.8 m	7.2	7.1	6.9	7.1	1.6	2.3	1.6	1.8	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
- 0.8 m	7.2	7.5	7.1	7.3	1.8	3.2	5.7	3.6	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Avg	7.2	7.3	7.0	7.2	1.7	2.8	3.6	2.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Control field - 1.6 m	7.1	7.3	7.1	7.2	0.6	0.8	0.6	0.7	0.3	0.5	0.2	0.3	0.3	0.2	0.2	0.2
- 1.6 m	ns†	ns	7.1	7.1	ns	ns	0.8	0.8	ns	ns	0.3	0.3	ns	ns	0.2	0.2
Avg	7.1	7.3	7.1	7.2	0.6	0.8	0.7	0.7	0.3	0.5	0.2	0.3	0.3	0.2	0.2	0.2
17-year disposal - 0.8 m	7.1	6.7	6.7	6.8	41.0	80.0	90.0	70.3	1.0	0.2	1.3	0.8	1.0	0.7	0.7	0.8
field - 0.8 m	7.0	6.9	7.0	7.0	0.8	0.8	0.9	0.8	1.3	0.2	0.2	0.6	1.3	1.2	1.2	1.2
Avg	7.0	6.8	6.8	6.9	20.9	40.4	45.4	71.2	1.2	0.2	0.8	0.7	1.2	0.9	0.9	1.0
17-year disposal - 1.6 m	6.9	6.9	6.7	6.8	2.7	4.2	38.0	15.0	2.9	0.3	1.1	1.4	2.9	3.3	3.2	3.1
field - 1.6 m	7.0	6.9	6.9	6.9	0.7	0.8	0.8	0.8	2.6	0.3	0.3	1.4	2.6	2.3	2.6	2.5
Avg	7.0	6.9	6.8	6.8	1.7	2.5	19.4	7.9	2.8	0.3	0.7	1.2	2.8	2.8	2.9	2.8
20-year disposal - 0.8 m	6.7	6.7	6.9	6.8	1.0	1.5	1.6	1.4	1.2	0.1	0.2	0.5	1.2	1.1	1.2	1.2
field - 0.8 m	6.6	6.7	6.5	6.6	1.6	1.9	1.5	1.7	0.9	0.2	0.3	0.5	0.9	1.2	0.9	1.0
Avg	6.6	6.7	6.7	6.7	2.3	1.7	1.6	1.5	1.0	0.2	0.2	0.5	1.0	1.2	1.0	1.1
20-year disposal - 1.6 m	6.8	6.9	7.2	7.0	39.0	46.0	23.0	36.0	0.2	0.5	0.5	0.4	0.2	0.4	0.6	0.4
field - 1.6 m	7.5	7.2	7.1	7.3	3.0	2.0	2.3	2.3	0.7	0.4	0.4	0.5	0.7	0.7	0.9	0.8
Avg	7.2	7.0	7.2	7.1	21.0	24.0	12.5	19.2	0.4	0.4	0.4	0.4	0.4	0.6	0.8	0.6

* Averages are based on pH values rather than on hydrogen ion activity.
† ns indicates insufficient sample collected for analysis.

Table BVII. Water quality at wastewater disposal site, Quincy, Washington, 27-29 August 1974. Parameter by sampling date.

Location of sample collection	pH*				NO_3 - (mg/l)				NH_4 - N (mg/l)				Ortho-P (mg/l)			
	27 Aug	28 Aug	29 Aug	Avg	27 Aug	28 Aug	29 Aug	Avg	27 Aug	28 Aug	29 Aug	Avg	27 Aug	28 Aug	29 Aug	Avg
Primary clarifier	6.8	7.2	7.4	7.1	2.3	2.2	2.1	2.2	7.8	10.5	15.5	11.3	2.1	2.6	1.6	2.1
Storage lagoon 1	7.9	7.6	7.5	7.7	0.9	1.0	1.0	1.0	9.2	9.2	10.5	9.6	3.6	3.9	3.4	3.6
Storage lagoon 2	9.2	8.1	8.3	8.5	0.4	0.8	0.6	0.8	1.2	10.0	5.0	5.4	1.6	3.6	2.8	2.7
Storage lagoon 3	8.9	8.9	8.8	8.9	0.9	0.5	0.8	0.7	4.8	4.8	9.8	6.5	1.9	1.8	1.6	1.8
Avg	8.7	8.2	8.2	8.4	0.9	0.8	0.8	0.8	5.1	8.0	8.4	7.2	2.4	3.1	2.6	2.7
Drainage ditch - upstream	7.5	7.9	8.1	7.8	0.9	0.7	0.9	0.8	0.3	0.6	0.1	0.3	0.2	0.2	0.1	0.2
Drainage ditch - downstream	7.5	7.5	7.7	7.6	1.1	1.6	1.5	1.4	0.7	0.3	<0.1	0.3	0.2	0.1	0.1	0.1
Avg	7.5	7.7	7.9	7.7	1.0	1.1	1.2	1.1	0.5	0.4	<0.1	0.3	0.2	0.2	0.1	0.2
Tile to drainage ditch	7.4	7.5	7.7	7.5	2.4	2.8	2.3	2.5	<0.1	<0.1	<0.1	<0.1	0.1	0.2	0.1	0.1
Well-north center(control wells)	7.3	7.2	7.1	7.2	1.0	0.8	0.8	0.9	1.1	1.0	0.6	0.9	0.2	0.2	0.1	0.2
Well-center	6.9	6.9	6.8	6.9	2.3	2.8	2.5	2.5	0.2	0.4	0.4	0.3	4.8	4.1	4.0	4.3
Avg	7.1	7.0	7.0	7.0	1.6	1.8	1.6	1.7	0.6	0.7	0.5	0.6	2.5	2.2	2.0	2.2
Control field - 0.8 m	7.0	7.2	7.3	7.2	1.6	0.8	1.0	1.1	0.5	0.1	<0.1	0.2	0.2	0.3	0.1	0.2
- 0.8 m	7.0	7.2	7.2	7.1	1.6	1.2	1.2	1.3	0.3	0.2	<0.1	0.2	0.2	0.2	0.2	0.2
Avg	7.0	7.2	7.2	7.2	1.6	1.0	1.1	1.2	0.4	0.2	<0.1	0.2	0.2	0.2	0.2	0.2
Control field - 1.6 m	7.1	7.2	7.2	7.2	1.5	1.0	1.3	1.3	0.8	0.2	<0.1	0.3	0.2	0.2	0.2	0.2
- 1.6 m	7.0	7.2	7.2	7.2	2.0	1.2	1.2	1.5	0.8	0.2	<0.1	0.3	0.3	0.1	0.1	0.2
Avg	7.0	7.2	7.2	7.2	1.8	1.1	1.2	1.4	0.8	0.2	<0.1	0.3	0.2	0.2	0.2	0.2
17-year disposal - 0.8 m	6.9	6.8	6.7	6.8	35.0	6.9	5.6	15.8	1.0	0.4	0.3	0.6	0.7	0.7	0.8	0.7
field - 0.8 m	6.8	6.8	6.7	6.8	10.0	15.0	9.9	11.6	0.5	0.4	0.4	0.4	1.5	1.5	1.6	1.5
Avg	6.8	6.8	6.7	6.8	22.5	11.0	7.8	13.8	0.8	0.4	0.4	0.5	1.1	1.1	1.2	1.1
17-year disposal - 1.6 m	7.1	7.1	6.8	7.0	6.5	1.4	1.0	3.0	1.0	0.2	0.2	0.5	2.6	2.6	2.9	2.7
field - 1.6 m	6.9	6.8	6.7	6.8	4.2	5.1	3.5	4.3	0.6	0.7	0.5	0.6	1.8	1.6	1.6	1.7
Avg	7.0	7.0	6.8	6.9	5.4	3.2	2.2	3.6	0.8	0.4	0.4	0.6	2.2	2.1	2.2	2.2
20-year disposal - 0.8 m	6.8	6.6	6.7	6.7	3.0	2.7	2.5	2.7	0.2	0.2	0.1	0.2	1.5	1.4	1.5	1.5
field - 0.8 m	ns†	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Avg	6.8	6.6	6.7	6.7	3.0	2.7	2.5	2.7	0.2	0.2	0.1	0.2	1.5	1.4	1.5	1.5
20-year disposal - 1.6 m	6.8	ns	6.7	6.8	2.8	3.5	3.5	3.3	0.9	ns	1.6	1.2	0.4	2.9	0.5	1.3
- 1.6 m	7.3	ns	7.5	7.4	5.5	ns	5.0	5.2	1.3	ns	2.3	1.8	0.7	1.8	0.8	1.1
Avg	7.0	ns	7.1	7.1	4.2	3.5	4.2	4.0	1.1	ns	2.0	1.5	0.6	2.4	0.6	1.2

* Averages are based on pH values rather than on hydrogen ion activity.
† ns indicates insufficient sample collected for analysis.

Table BVIII. Water quality at wastewater disposal site, Quincy, Washington, 6–8 November 1974.
Parameter by sampling date.

Location of sample collection	pH*				NO_3 - N (mg/l)				NH_4 - N (mg/l)				Ortho-P (mg/l)			
	6 Nov	7 Nov	8 Nov	Avg	6 Nov	7 Nov	8 Nov	Avg	6 Nov	7 Nov	8 Nov	Avg	6 Nov	7 Nov	8 Nov	Avg.
Primary clarifier	7.2	7.4	7.2	7.3	2.3	1.6	1.2	1.7	37.2	32.2	7.5	25.6	4.7	2.5	2.0	3.1
Storage lagoon 1	7.3	7.4	7.4	7.4	1.8	10.5	1.4	4.6	13.8	16.3	12.8	14.3	5.0	4.6	5.4	5.0
Storage lagoon 2	7.4	7.3	7.3	7.3	2.8	2.0	1.5	2.1	10.5	15.5	16.5	14.2	5.8	4.8	6.0	5.5
Storage lagoon 3	7.3	7.4	7.4	7.4	1.8	0.9	2.7	1.8	15.3	10.0	11.5	12.3	5.4	4.4	6.1	5.3
Avg	7.3	7.4	7.4	7.4	2.1	4.5	1.9	2.8	13.2	13.9	13.6	13.6	5.4	4.6	5.8	5.3
Drainage ditch - upstream	7.6	7.5	7.6	7.6	5.1	3.8	3.3	4.1	0.2	0.6	<0.1	0.3	0.1	0.2	0.1	0.1
Drainage ditch - downstream	7.6	7.3	7.6	7.5	3.5	3.3	3.2	3.3	<0.1	0.2	<0.1	0.1	<0.1	0.1	0.1	0.1
Avg	7.6	7.4	7.6	7.6	4.3	3.6	3.2	3.7	0.1	0.4	<0.1	0.2	<0.1	0.2	0.1	0.1
Tile to drainage ditch	7.6	7.5	7.7	7.6	3.2	2.7	4.1	3.3	<0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1	0.1
Well-north center(control wells)	7.4	7.2	7.0	7.2	0.4	0.3	0.3	0.3	0.8	0.7	1.0	0.8	0.2	0.2	0.2	0.2
Well-center	7.1	7.0	7.0	7.0	1.2	1.1	1.5	1.4	0.4	0.1	0.1	0.2	5.0	4.1	4.6	4.6
Avg	7.2	7.1	7.0	7.1	0.8	0.7	0.9	0.8	0.6	0.4	0.6	0.5	2.6	2.2	2.4	2.4
Control field - 0.8 m	ns†	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control field - 0.8 m	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Avg	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control field - 1.6 m	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control field - 1.6 m	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Avg	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
17-year disposal field - 0.8 m	7.1	6.9	6.9	7.0	2.0	0.9	0.9	1.3	0.2	<0.1	<0.1	<0.1	0.6	0.6	0.6	0.6
17-year disposal field - 0.8 m	7.0	6.9	6.8	6.9	5.8	6.9	5.5	6.1	0.2	<0.1	<0.1	<0.1	2.5	2.7	3.3	2.8
Avg	7.0	6.9	6.8	6.9	3.9	3.9	3.2	3.7	0.2	<0.1	<0.1	<0.1	1.6	1.6	2.0	1.7
17-year disposal field - 1.6 m	7.0	6.9	6.8	6.9	0.9	0.6	0.7	0.7	0.6	<0.1	0.2	0.3	3.0	2.6	3.3	3.0
17-year disposal field - 1.6 m	6.9	6.9	6.8	6.9	1.3	1.7	2.1	1.7	0.3	<0.1	0.1	0.1	2.4	2.7	3.3	2.8
Avg	7.0	6.9	6.8	6.9	1.1	1.2	1.4	1.2	0.4	<0.1	0.2	0.2	2.7	2.6	3.3	2.9
20-year disposal field - 0.8 m	6.9	6.8	6.7	6.8	2.2	6.2	7.8	5.4	0.1	0.3	0.1	0.2	1.4	1.1	1.4	1.3
20-year disposal field - 0.8 m	6.9	6.8	6.8	6.8	39.0	24.0	28.0	30.3	0.7	0.1	0.2	0.3	0.9	1.0	1.4	1.1
Avg	6.9	6.8	6.8	6.8	20.6	15.1	17.9	17.9	0.4	0.2	0.2	0.3	1.2	1.0	1.4	1.2
20-year disposal field - 1.6 m	6.9	6.9	6.8	6.9	4.8	4.9	6.2	5.3	0.3	0.1	0.1	0.2	0.3	0.3	0.4	0.3
20-year disposal field - 1.6 m	7.0	6.9	6.7	6.9	3.2	3.8	4.9	4.0	0.4	0.1	0.1	0.2	0.6	0.5	0.9	0.7
Avg	7.0	6.9	6.8	6.9	4.0	4.4	5.6	4.7	0.4	0.1	0.1	0.2	0.4	0.4	0.6	0.5

* Averages are based on pH values rather than on hydrogen ion activity.
† ns indicates insufficient sample collected for analysis.

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