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Statewide Evaluation of Trace Element Accumulation from Long-Term Disposal of Wastewater

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STATEWIDE EVALUATION OF TRACE ELEMENT ACCUMULATION FROM LONG-TERM DISPOSAL OF WASTEWATER

by

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TECHNICAL COMPLETION REPORT

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SUMMARY

This report provides the first comprehensive field evaluation of trace element accumulation from land disposal of wastewater in the state of California. Past effects of long-term reuse practices were studied to assist in policy decisions regarding wastewater reuse and future uses of lands which have received wastewater.

In the present study twenty reuse sampling sites were selected on the basis of the following criteria: length of time the site has received wastewater, amount and manner of application, quality of wastewater applied, and the availability of historical data on trace element content in wastewater effluent. Each site was visited once during the two year study. Both soil and vegetation samples were collected from each site. These samples were analyzed for Cd, Cu, Pb, Ni and Zn content. Soil samples were also analyzed for pH, CEC and water content.

This study project indicated that 9% of the fields investigated showed an accumulation of trace elements from reuse practices. Metal enrichment was confined to the upper layers of soil, but penetrated into the soil column depending on soil type and rate of wastewater application. Translocation of metals into plants from these sites was dependent on the plant species as well as the given metal. Cadmium and Zn were the most mobil of the metals tested.

This investigation concludes that land application of wastewater provides useful irrigation waters under most circumstances. Metal Accumulation was noted only for fields which had not been ploughed. Filling the soil most likely dilutes the amount of metal in a given cm core by spreading it over the depth of tillage. Increased chances for significant elevation of soil metal occurs when the level of treatment is reduced below secondary. When the application rate is increased or if a high percentage of the wastewater is from industrial sources.

LITERATURE REVIEW

Wastewater Reuse Principles

The use of sewage effluent for irrigation purposes has stimulated many articles on various aspects of this topic. This report concentrates on one aspect of water reuse, namely, the potential accumulation of trace elements in soils and their translocation into plants from long-term application of wastewater. In order to gain perspective on this question, the literature will be reviewed in the following manner: (1) trace elments of concern in the proposed project and their influences on man, (2) studies involving sewage effluent for various irrigatonal purposes, and (3) studies examining the interactions of trace elements in soil and their effects on plants.

The toxicity of any element is related to the concentration to which the organism is exposed. The toxic effect may be manifested in a number of ways. The element may produce an acute reaction, usually associated with a short exposure to a large concentration of the element, and is not of primary concern here. What is of interest are the chronic or long-term effects of these elements, and any teratogenic or carinogenic effects. Over the past twenty years there has been a trend away from focusing on acute illnesses from contaminated drinking water (namely bacteriological concerns), toward the ever increasing questions of long-term effects. Hence today we see great concern arising over the presence of trace organics (possible carcinogens) in drinking water. As reclaimed water for drinking is still in the conceptual stage for most regions of the United States, studies on its toxcity is limited. Ottoboni and Greenberg (1970) using wastewater of a non-industrial nature have shown

Minamata Disease (due to mercury poisoning via an aquatic food chain), and Itai-Itai disease (due to cadmium poisoning via a terrestrial food chain. Man is constantly exposed to trace elements through water and food ingestion. The intake through water accounts for less than 10 percent of the total intake for 26 or 30 elements examined (Durfor and Becker, 1962; Schroeder, 1971).

Reasons for considering the potential toxicity of trace elements include (1) doses of trace elements tolerable for growth may not be tolerable for prolonged survival, (2) doses of trace elements which do not seem to effect longevity may effect reproduction and (3) certain chronic diseases in man may be mimicked by exposing rats to certain trace elements.

Schroeder (1973) has shown that toxicity of elements varies inversely with the concentration of the element in sea water and in the earth's crust. Many of the substances that exist in low quantities have been shown to have recondite toxicities to animals and man. Elements found in low concentrations tend to accumulate in mammalian tissues with age and exposure, creating physiological changes. Cadmium, for example, has been shown to elevate human blood pressure when as little as 0.5 ppm is ingested in the diet. Lead also has a low threshold for producing measurable effects. In urbanized areas the body burden of lead in man is high enough to cause some inhibition of the enzyme delta-aminolevulinic acid dehyrase (Hernberg, et al., 1970).

Trace Elements in Wastewater

Hunter and Kotalik (1974) have summarized the quality of treated sewage efflucents, dealing with the chemical and biological constitutents in sewage effluent, but not the quantities of trace elements in these effluents. Monthly assessment of the concentration of certain trace elements being discharged is now required of many sewage treatment plants. In Table 1 the concentrations of trace elements from various wastewater effluent is shown. It can be seen that those which have undergone only primary treatment have higher concentrations of trace elements than those receiving secondary treatment. Advanced treatment methods can still further reduce the quantity of trace elements in the effluent (Argo and Culp, 1972a, b).

Wastewater Reuse Practices

There are many articles that examine water reuse from a conceptual point of view (Chaiken, et al., 1973; Linstedt, et al., 1971). In Kugelman's (1974) review article on water reuse, he cites the use of activated sludge effluent in the irrigation of alfalfa fields at Las Virgenes, California. Bernarde (1973) reviewed the use of sewage effluent over the past 100 years and concluded that with proper precautions, it could be used safely for irrigation. Reynolds (1980), after an extensive study of a wastewater reuse site in Utah, concluded "no serious harmful effects occurred as a result of long-term irrigation with wastewater." Proponents of the use of wastewater for irrigational purposes usually point out that by reducing the amount of wastewater entering streams and lakes, the possibility of eutrophication is also reduced. Crook (1978) stated that over 220 separate wastewater reuse programs were in operation in the State of California. Of these, over 90 percent are agricultural in nature. Storm (1971) suggested that "state and federal water pollution control agencies should be prepared to advise affected public entities concerning the short and long-term environmental and ecological consequences from the use of native brush and forest plants for disposal of waste effluent and the possible beneficial uses."

Land use for the disposal of wastewater effluent has many positive aspects. It returns nitrogen and phosphorous to the soil, both of which are necessary for plant growth. Researchers in Pennsylvania have utilized spray irrigation with sewage effluent on approximately 65 acres of forest and cropland. The effluent from these areas showed a 99% removal of phosphorous and 61-85% removal of nitrogen, two prime factors causing eutrophication problems in streams and lakes (Anon., 1972). Sewage effluent also contains many trace elements that are essential for plant life. It has been shown that where sewage is used for irrigation, increased yields result (Day, et al., 1962; Parizek et al., 1967).

When high rate applications of wastewater are used, there exists the possibility of sealing the soil with high organic concentrations. Wastewater containing an average of 30 ppm suspended solids is equivalent to spreading 81 pounds of organic matter on an acre when an acre foot of effluent is applied (Dye, 1958). This increases the chance of ground water contamination and may result in the build up of chemicals which are toxic to plants (Nichols, 1970). Further, runoff may contaminate nearby streams. This was the case with the Michigan Fruit Canners wastewater disposal program (Piwowar, 1973).

When wastewater is applied at low application rates usually high quality recharge water is the result. The improvement of wastewater usually occurs in the first few feet of soil (Amramy, 1968; McGauhey and Krone, 1967; and Parizek et al., 1967). During the percolation of wastewater through the soil, phosphates are removed in the upper layer of soil and metallic ions such as iron, manganese, nickel, copper, zinc, cadmium, and lead are removed very near the surface (Bouwer, 1968; Reynolds, 1980). Fine textured soils are more efficient at removing the above mentioned substances than coarse grained soils. Pennypacker et al. (1967) applied wastewater to three sites: natural mixed hardwoods, a red pine plantation, and an old field plant community. The water table was located approximately 200 feet below the land surface. Rotating sprinklers were used to apply the wastewater which was obtained from Pennsylvania State University wastewater treatment plant. The rate of application was 1 to 2 inches per week for 23 weeks. Effluent being applied was analyzed for pH, apparent ABS, nitrate-nitrogen, organic-nitrogen, phosphorous, potassium, calcium, magnesium, sodium, and chloride. The results showed that nitrogen and phosphorous were removed in the upper 12 inches of soil on all plots. The study further showed that if the application rate was increased to 4 inches per week, then two to four times the soil depth was required to remove equal amounts of nitrogen and phosphorous compared with a two inch per week application rate. Kardos and Sopper (1974) have also shown that canary grass is almost twice as effective as corn in removing phosphorous. These studies indicate that wastewater renovation must not only consider the soil type, depth of water table, etc., but also the type of vegetation which will remove the greatest quantities of the element of interest.

Effect of Wastewater on Plants

The quality of the wastewater applied, the soil type to which it will be applied, the plant material to be grown in the soil, and its eventual use must all be considered in any wastewater reuse project. In low rate applications, used mainly for agricultural operations, several studies have investigated the effect of sewage effluent on yield and quality of the plant species grown. Day et al. (1963) examined the effect of municipal effluent on barley. The study was conducted over a two year period and examined the quality of the wastewater in terms of total salts, total nitrogen, phosphorous, potassium, calcium, magnesium, sodium, hardness, chloride, sulfate and nitrate. The results of the study showed that there was high grain production indicating the use of the nutrients in the waste effluent, but kernel weight, kernel size, and malt extract were decreased by the use of sewage effluent. Day and his co-workers drew no conclusions for the decreased quality of the barley.

Kardos and Sopper (1974) found yield increases when corn, corn silage, red clover, and alfalfa were irrigated with effluent. The crops which recieved two inches of effluent per week usually showed higher nitrogen and phosphorous contents. However, wastewater irrigated forest land had only 70 trees per acre in the 2 inch diameter class, while non-irrigated areas averaged 290 trees.

Murphy et al. (1974) examined the anatomical and physical properties of trees irrigated with effluent. These workers looked at the factors affecting the quality of pulp fibers in red pine and red oak. The findings of their study showed that an application rate of 1 inch per week increased the pulp fiber qualities in red pine and that of 2 inches per week in red oak.

A fourteen year study was conducted on cotton, lettuce, and sorghum using effluent from activated sludge treatment (Day et al., 1972). The findings of this study showed that the yield of the crops remained approximately the same over time, but there were changes in the soil characteristics. Soil irrigated with treatment plant effluent had a lower water infiltration rate and high concentration of soluble salt nitrates, and phosphates than soil irrigated with well water. The trace element content of effluent, soil, or plant material was not examined. The nitrogen, phosphorous, and potassium content of the effluent was measured. The pH of the soil remained the same in both effluent irrigated and well-irrigated soils. When comparing alfalfa plants from sites receiving wastewater with alfalfa plants from adjacent control plots, Reynolds et al. (1980) found higher levels of sodium in alfalfa plants irrigated with wastewater. Additionally, higher concentrations of nitrogen, phosphorous and potassium were noted in plants grown on the effluent site.

The previous studies show the use of sewage efflucents tend to replenish nutrients removed from the soil by plants. Further, the effluents contain many of the major elements necessary for growth. Soil structure and drainage will determine to a large degree the amount of minerals available for uptake. However, negative effects are also seen such as reduced penetrability of the soil, translocation of undesirable elements into plants and changes in quality of the produce. An assessment of site specific parameters appear to be necessary to evaluate these effects.

Effects of Wastewater Reuse on Animals

Very little work has been done concerning the effect of wastewater on animal life. Numerous studies have been conducted examining the transference of trace element from sewage sludge to plant material. Wood et al. (1974) examined the effect of chlorinated effluent on deer and rabbits' feeding patterns. Their finding indicated that rabbits and deer showed no avoidance toward sewage irrigated forage. The forage was believed to be beneficial to the animals due to higher levels of nitrogen, phosphorous, and magnesium. This is additionally supported by the increased winter carrying capacity of treated sites over untreated sites for rabbit populations.

Another consideration is the spread of disease through the use of sewage effluent. Nichols et al. (1971) used sewage to irrigate lettuce and found high concentrations of fecal coliforms present three weeks after the application of wastewater. The study does not indicate the level of treatment or whether the sewage efflucent was chlorinated (the results suggest that it was not). With the current standards for coliforms for irrigational water from sewage treatment plant effluents, there is less chance of contamination of the nature found by Nichols et al. (1971).

Nichol's et al. work suggests that plant diseases may be enhanced by the use of sewage effluents. In certain instances it has been shown that the introduction of irrigation to natural ecosystems can alter the environment in such a manner as to enhance the growth of plant pathogens. In other instances, wastewater reuse has been shown to reduce the number of nematodes in the soil by increasing the moisture content of the soil. It appears that additional investigations should be done in order to determine if the application of wastewater effluent increases plants' susceptibility to disease (Cole et al., 1969).

Land Application of Wastewater Studies

A ten year study utilizing municipal wastewater for the irrigation of various tree species, examined the effect of effluent on the vegetation. Further, the use of soil as a purification method for wastewater was studied. Boron in the effluent ranged from 0.09 to 0.29 ppm, and in the water collected from a 48 inch lysimeters, the values ranged from 0.03 to 0.11 ppm showing a substantial removal by percolation through the soil. Unfortunately, the soil and plant material was not examined to determine if the boron was concentrating in the soil compartment or had been totally removed from the system by plant uptake (Kardos and Sopper, 1973a; Kardos and Sopper, 1974). Further, rate of wastewater application influenced the mobility and concentration of Mn. At an application rate of 1 to 2 inches per week, the distributions of manganese in the soil underwent some changes.

At an application rate of 1 or 2 inches per week, the amount of manganese was less than the control at a depth of 1 foot. The amount of manganese was greater than the control at a depth of 2 feet at an application rate of 1 inch per week. At a depth of 3 to 5 feet both application rates showed more extractable manganese in the soil than did the control (Kardos and Sopper, 1973b). However, this was the only metal examined and many others are known to be prevalent in wastewater and of health concern.

After 1973 the accumulation of trace metals from land application of wastewater gained more attention. An analyses of various secondary effluents in the United States revealed the Cd ranged between 0.2-20 μg/l, Cr 10-170 μg/l, Cu 50-220 μg/l, Pb 15-200 μg/l, Mn 21-380 μg/l, Ni 100-149 μg/l and Zn 47-350 μg/l (U.S. EPA et al., 1977). Sidle et al. (1977) examined soil and plant material for copper, zinc, cadmium, lead, nickel and cobalt. The concentration of these metals in the effluent were generally within the lower range for heavy metal concentrations in wastewater reported by Menzies and Chaney (1974). They found that soil extractable copper and zinc accumulated at one study site and Cadmium also was found to accumulate to a lesser degree. Sidle et al. (1976) also showed that reed canary grass and corn (<u>Zea</u> <u>mays</u> L.) removed less than 7% of the heavy metals applied. Copper and zinc concentrations in reed canary grass were higher than at the control site. Sidle and Sopper (1976) found that there was no effect on the accumulation of trace elements in various hardwoods which were irrigated with secondary domestic effluent.

Olson et al. (1979) found that there was no accumulation of cadmium, cobalt, copper, nickel, zinc, manganese, silver, lead or nickel from spray irrigation of secondary effluent in soil at Las Virgenes, California. Their work also reported that four of these metals (silver, cadmium, copper and zinc) did concentrate at an Orange County site. This site had received wastewater by flood irrigation at low application rates for a fifteen year period. The metals which accumulated were found in the 0-15 cm layer of soil. Only cadmium was elevated in the associated vegetation (coniferous trees). Further, the cadmium to zinc ratios were high ranging from 1.6% at the control sites to 9.9% at the test site. It is important to note that cadmium is more available for translocation into plant materials as the cadmium zinc ratio increases. In another study which examined the movement of trace elements in the soil column of a forested area (Sidle and Kardos, 1977) reported that 0.3, 3.2, and 6.6% of the applied Cu, Zn, and Cd penetrated below 120 cm respectively.

Researchers in Chile examined an area which had been flood irrigated (2.4 m/ha/yr) with untreated wastewater for a period of 6 years (Schalscha et al., 1978). Concentrations in both suspended and soluble forms were 20.7 μg/l Cd, 1150 μg/l Cr, 397.2 μg/l Cu, 44 μg/l Ni, and 90 μg/l Zn. Only the concentrations of Cr and Cu exceeded those reported in the Orange County effluent. There was no evidence of an accumulation of Cd, Cu, Ni and Zn in the surface soil or throughout the profile to a depth of 190 cm. This may be attributed to the fact that the soil was sampled in 0-30 cm increments and is supported by data from a year study examining the mobility of Pb, Cd, Zn, Cu and Cr in soils irrigated with secondary treated sewage effluent (Brown, 1978). Effluent containing 1 mg/l of each metal tested was applied at a rate of 2 cm per week to soils enclosed in a lysimeter. This study found that there was no metal in the lysimeter leachate at approximately 1.4 m. In all cases they found that the metal had accumulated in the top 2 cm of the soil column. Therefore, accumulation of metals from wastewater application are likely to occur in the first few centimeters of surface soil.

The Chilean study which sampled at 30 cm increments would have caused sufficient dilution of any accumulation of metals in the surface to pass unnoticed. This study did detect a noticeable enrichment of Cr at a depth of 70 cm.

A Polish study of cropland which was irrigated by sewage found that accumulation of a number of trace elements had occurred and that the distribution of these elements varied with sampling depth and between sampling locations (Cedula and Kutera, 1978). In Poland, where during dry years, sewage represents over one-half of all the surface water flow in the country, irrigation of crop lands with this water source has been economically important. The irrigation farms examined accepted approximately 93% of the sewage from Worclaw, Poland, which was applied at a rate of approximately 170,000 cm/day as of 1975. These fields were designed in 1890, and have been extended since that time. Increased concentrations of metal were apparent for copper, cobalt, nickel, manganese, zinc, lead, chromium and in certain areas cadmium. The sampling depths ranged from 0-180 cm. The highest values of Cd, Pb, Mn, Ni and Zn occurred in the 0-20 cm layer of soil. The concentrations of Cd, Mn and Ni in these surface soils were 7 μg/g, 1425 μg/g and 73 μg/g, respectively. An enrichment of Zn (186 μg/g) appeared in the surface layer of the soil profiles examined, with one sampling site containing levels over 250 μg/g Zn. Lead reached values as high as 140 μg/g in the surface profile and decreased in content to 15 μg/g at a depth of 150 cm. No decrease in vegetative yield was noted at these 115 systems (sites) examined.

The enrichment of metals examined in the Polish study exceeded soil metals levels at the Las Virgenes and Orange County sites. This is most likely due to the historically low level of treatment, resulting in high levels of metals in the wastewater, and the long period of wastewater application to the crop lands examined.

An infiltration site located in Milton, Wisconsin which received domestic wastewater at a high rate, estimated to be 244 m/y for approximately 20 years, an increase in the amount of Zn in the soil below the infiltration lagoon. These soils had higher levels of extractable Cu but lower levels of total Cr and As than the control site (Benham-Blair and Affiliates, 1979). The effluent from the treatment plant applied to this site contained 20 μg Cd/l, <50 μg Co/l, <50 μg Cr/l, <100 μg Co, <200 μg Pb/l, <50-100 μg Mn/l. Arsenic concentration in the wastewater was not measured in this study.

A spray irrigation facility was operated for 14 years near Seattle, Washington. Soil was irrigated with secondary effluent which had a mean metal concentration of 280 μg/l Cu, 370 μg/l Zn, 50 μg 1 μg, and 20 μg/l Cr (Anderson, 1978). The soil in the irrigated area was described as Lynden loamy sand, a well-drained moderately acid reddish-brown loamy sand with considerable coarse sand and scattering of shot pellets. The application of wastewater to this site was 11 cu m/ha or 0.58 cm per day. The soil pH at the control site varied between 5.25 and 5.5 in the surface soils and increased to 6.25 at a depth of 100 cm. Another irrigated site had a surface pH of 4.5 which also increased in depth to a maximum of 5.25 at 90 cm. These low pH values may have favorably influenced the downward movement of the metals. These irrigated fields showed a surface enrichment of Pb to a depth of 20 cm, Cu to a depth of 50 cm, Cr to a depth of 20 cm, Zn to a depth of 80 cm. In the Orange County soils, the enrichment of metals was limited to the 0-15 cm layer of the soil column. (Olson et al. 1979). The deeper penetration which was noted in the Washington experiment is most likely due to the high sand concentration of the soil corresponding to a lower cation exchange capacity.

A golf course irrigated with secondary wastewater since 1960 showed elevated of Cu, Fe and Zn in soils from the irrigated portion of the golf course (Gaseor and Biever, 1978). The build up of metal concentration was inversely proportional with depth. The golf course is located in El Paso County, Colorado. The source of the irrigation water was effluent from the Air Force Academy Sewage Treatment Plant which received full primary and secondary treatment. The sewage effluent was subsequently pumped into wastewater lagoons, which was aerated. Water from the wastewater lagoon was utilized for irrigation for the golf course. Concentrations of Pb in the irrigation water were <50 μg/g, Mn 100 μg/g, Zn 70 μg/g, hexavalent chromium <10 μg/g and total Cr <50 μg/g, Cd 10 μg/g. The annual irrigation rate was estimated at 4841.97 m^2/hectare/year or 1.58 acre ft/yr. Analysis of the data showed that Zn concentration in the irrigated soil was 26.7 mg/g while the non-irrigated soil contained 0.6 mg/g in the top 7.6 cm of soil.

All of these investigations indicate that metal accumulation can occur when wastewater is applied to land. Sampling methods are important in demonstrating accumulation because the metal is usually confined to the top few centimeters. Further, the most important factors to consider appear to be level of metal in effluents (related to treatment), length of application, rate of application and soil type. The varying results reported in this section appear to be directly directed to one or all of these factors.

Specific Elements of Concern

Cadmium

Cadmium has not been shown to be an essential element and is best known for causing Itai-Itai disease in Japan. Recently, concern has risen over the ingestion of high cadmium containing food stuffs (Bauer, 1978, Kearney

Foundation Reports, Riverside). The controversy over cadmium is related to its possible role in elevated blood pressure and lung cancer. In a survey of 28 cities, a positive correlation was found between the incidence of cardiovascular disease and ambient cadmium levels. Cadmium also is found to concentrate in the kidney. Some researchers have expressed concern over the possibility that Cd accumulated in the kidney may cause decreased kidney function and increased release of proteins in the urine (proteinuria). Research on the application of both wastewater and sludge often focuses on Cd because of its toxic nature and its ability to be translocated up the food chain.

Based on water and sewage effluent concentrations, the estimated flow of Cd into coastal waters is several hundred thousand tons. The estimated anthropogenic cadmium input is approximately 70% of the total flow. Most surface waters contain less than 1 ppb dissolved Cd. A 1969 survey of finished water supplied in the United States indicated that the average Cd concentration was 3 ppb with a maximum value of 3.9 ppm reported (McCabe, 1970). An industrial wastewater survey of 1123 untreated samples indicated that 1.43% and 0.27% of the samples contained between 10-49 ppm and 250 ppm, respectively. Grossly contaminated effluents come from metal treatment and plating plants. Cadmium also enters sewage from cadmium alloys and cadmium stabilized plastics. Chicago sewage effluents contain 3 ppb dissolved Cd and between 70 and 470 ppm particulate associated Cd. Air sources of cadmium include the smelting of ores and the burning of coal or petroleum products. Gasoline, however, contains low concentrations of Cd (less than 0.01 ppb). Its concentration in 33 agricultural soils was found to be 0.88 ppm. In certain areas, cadmium contamination from industrial sources such as smelters, greatly increases the amounts in surface soil. These cadmium levels may reach as high as 95 ppm. In contaminated areas the concentration of cadmium decreased with increasing depth, with well over 90 percent of the cadmium being located in the top 5 cm of soil.

Plant uptake of trace elements, such as Cd, is highly dependent on soil metal content, soil moisture, organic matter, pH, competing cations (Mn, Co, Zn, Pb) as well as plant species. Cadmium has been shown to be slightly less available to rice under flood conditions (Bingham et al., 1976a) which may be due to anoxic conditions. Further, greenhouse studies have shown a 25% yield depression for sudan grass, alfalfa, clover, fescue and bermuda grass with substrate concentrations ranging from 15-145 μg Cd/g (Bingham et al., 1976b).

Jones et al. (1973) stated that dried sewage sludge could contain 100-400 ppm cadmium, and that the majority of this cadmium came from industrial resources. Soybeans grown in simulated sludge containing 129-430 ppm cadmium showed that the amount of cadmium in both soil and plant material concentrated over the 95 day experiment, with the highest accumulation rate at the highest application rates. There is recent evidence that the method of simulating metal contaminated sewage sludge may influence plant uptake (Bloomfield and McGrath, 1982).

In a 4 month study where cadmium was applied in simulated rainfall, vegetation maintained approximately 10% of the total cadmium added during the four month investigation. Cadmium remained in the top inch of soil in the three terrestrial ecosystems and illustrated the possibility of translocation of these elements via irrigation (Oak Ridge, 1973).

John et al. (1972) found that the application of carbonate, nitrate, chloride, sulfate and phosphate salts of calcium only affected the uptake of cadmium in the root portion of the plant. Later, John (1976) reported that calcium applied to the soil negatively affected the uptake of cadmium into the plant. However the extent of which depends on crop species and concentrations employed. Cadmium competes equally with calcium for sites on montmorillonite, illite, and kaolinite clays, but lead's capacity for uptake is 2 or 3 times greater. This indicates that if both lead and cadmium are present in clay soils that more cadmium will be in solution and thus available for plant uptake.

Haghiri (1974) showed that the nfluence of soil organic matter in retarding the uptake of Cd by oat shoots (Avena sativa L.) was primarily due to its high cation exchange capacity rather than its chelating ability. Chaney and Hornick (1977) reviewing the results of several green house and field trials, concluded that soil pH is the prime soil factor controlling plant uptake of Cd, as it affects the strength of adsorption of Cd to soil constituents. Mahler et al. (1980) in their study of Cd uptake in acid and calcareous soils also reported that soil pH exerted an effect on the avilability of Cd present in the soil solution. However, they stated that this pH-Cd uptake effect is also dependent upon the plant species. These researchers found that Swiss chard and tomato accumulate Cd to a greater extent than does corn.

Other investigators (Bingham et al., 1975; Haghiri, 1973; Jarvis et al., 1976; Matthews and Thornton, 1980; Parker et al., 1978; Sidle and Sopper, 1976; and Van Hook et al., 1977) have reported that different plant and tree species located on the same soil will accumulate metals, such as Cd, to different concentration levels. Bingham et al. (1976) in green house studies reported differences in forage species uptake of Cd from sludge amended soils (10 μg/g Cd). Fescue, alfalfa, and bermuda grass accumulated higher levels of Cd (8-10 μg/g Cd) than sudan grass and white clover (5 μg/g Cd). In a field investigation of Cd-Pb-Zn contaminated soils, Matthews and Thornton (1980) found that *Bellis perennis* (daisy) accumulated much higher concentrations of Cd (50.7-54.2 μg/g Cd) than did clover (4.9-7.1 μg/g Cd) or three grass species (1.1-3.2 μg/g Cd) collected from the same site.

Van Hook et al. (1977) reported that *Carya* spp. (oak-hickory) contained higher levels of Cd, Pb and Zn than the other tree species located on the same soil. Schalette (1974) also reported that Shagbark hickory (Carya ovata [Mill.] K. Koch) contained five times more Cd than white oak (Quercus alba L.) colected from the same soil. Quaking aspen (*Populus* *tremuloides* *Mich*.) and black oak (Quercus velutina L.) growing on metal polluted soil contain higher levels of Cd, Zn and Pb than matched species located at an unpolluted area in northwestern India (Parker et al., 1978). However, Sidle and Sopper (1976) examining cadmium distribution in a forested area irrigated with wastewater reported no significant differences between Cd concentrations in two hardwood species, while (Quercus alba L.) and red maple at the control or test site.

Copper

Copper, another essential trace element is used in fungicides and bactericides which are applied to soil. Continued application for prolonged periods can produce soil which is toxic to plants, because copper persists in soil being strongly bound to organic material and usually accumulates at the surface (Jones and Belling, 1967). Copper availability to plants is also affected by soil pH and cation exchange capacity (Thornton and Webb, 1979). Walsh et al. (1972) have shown that the yield of snap beans increases with decreasing copper extractability using either ethylene diaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DPTA). Therefore, it can be seen that copper can have a negative effect on yield of crops even when concentrations of extractable copper are less than 20 ppm. Soil extractable copper increased significantly in soil after milogranite (processed sludge for landscaping) and ion sludge were applied at a rate of 25g/kg. However, no increase in Cu concentrations in lettuce or beets were noted after a six week growth trial (John and Van Laerhoven, 1976). Kelling et al. (1977) also found no increase in copper in corn grain grown on sludge amended soil (86kg/ha).

The effect of copper on corn, Zea mays L. from soil amended with municipal refuse and sludge was examined by King et al. (1977). Although yield was not affected, Cu did accumulate in the grain portion of the plant from refuse additions to the soil. Cunningham et al. (1975a) found increases in copper concentrations in three successive crops (corn-rye-corn) grown on sludge amended soil. Some investigators have expressed concern that increasing metal may become available in sludge amended soils due to the breakdown of organic matter (Williams, 1980). Further, Cunningham et al. (1975b) demonstrated decreasing yield in corn and rye as copper concentration in the sludge applied increased. As the copper concentration increased in the plant tissues the concentration of other metals also rose significantly. Bingham et al. (1976c) reported similar results for wheat and romaine lettuce. Lagerwerff et al. (1977) found increases in yields of rye, Secale cereale, when secondary sewage sludge was added to the soil.

Zinc

Garcia, et al. (1974) examined heavy metal concentrations in the kernels of corn grown on sewage sludge amended and non amended strip mine soil. There was a marked increase in yield in the sewage sludge treated corn. The sludge treated corn kernels contained higher levels of chromium, cadmium, and mercury, and lower levels of zinc, manganese, and lead. Manganese, zinc, and iron are required by plants for proper growth (Lance and Pearson, 1969). However, it has been shown that high concentrations of these elements can cause decreased yield and plant diseases. King and Morris (1972) studied the effect of soil pH on zinc concentrations in rye that was seeded on soil which had previously been treated with liquified sewage sludge. The liquid sludge lowered the pH of the soil, and zinc absorption into plants increases with decreasing soil pH (Wear, 1956; Christiansen et al., 1950). The authors felt that by liming the soil the amount of metals transferred to plant materials could be reduced, and the longevity of the soil as a disposal site would be increased. John and Van Laerhoven (1976) and Cunningham et al. (1975a) confirmed the observations of the privious works by demonstrating that liming did decrease the amount of zinc translocated into romaine lettuce and sugar beets. However, as sludge amendment was increased, zinc concentrations were significantly higher in treated plants than controls. Increased zinc concentrations have also been shown to decrease yield (Cunningham et al., 1975b; Cunningham et al., 1975c; Bingham et al., 1976c).

The movement of these elements is an extremely important factor affecting their uptake by plant material. Zinc movement in soils is affected by the concentration of zinc present, the pH of the soil, and soil texture (Clarke and Graham, 1968; Thornton and Webb, 1979). Zinc diffuses through clays at approximately the same rate for a given concentration (Ellis et al., 1970a; Ellis et al., 1970b). Zinc added to

Orange County soil as $ZnSO_4$ was tested to determine its retention in the soil substrate. The factors which influenced its retention were cation exchange capacity and pH (Brown et al., 1964). Phosphorous concentration did not affect zinc concentration (Sharpless et al., 1969). Wallace amd Mueller (1969) found that chelating agents had little effect on the distribution of zinc in corn. Zinc content exhibited in soybeans and bush beans was not greatly influenced by EDTA addition in most cases. Further, Navrot and Ravikovitch (1969) found that zinc availability in soil was decreased by increases in calcium carbonate particles less than 2 mm.

Silver

Silver as a trace element has received little attention in environmental studies because of its insoluable chemical characteristics and resultant low toxicity to man (Schroeder, 1973). Silver is however, an interesting metal because it is not a general environmental contaminant. Therefore, silver can be used as a conservative tracer giving a good indication that increased values obtained in soil which had received wastewater would most likely be from the wastewater source.

Nickel

Nickel is an essential metal for plants. However, levels in excess of 50 ppm Ni are considered to be phytotoxic. The research of Olson et al. (1978) has shown that nickel does not accumulate from the application of wastewater at two test sites in sputhern California. Sidle et al. (1977) also reported similar findings in both their study sites, a hard wood forest area and a canary grass field.

Most of the data concerning nickel and its effects on vegetation are found in the literature of sludge amended soils. The Woburn Market-

Garden experiment provided some of the first evidence that nickel could be translocated into plants (LeRiche, 1968). This study began in 1942 showed that the concentration of Ni increased 7 times in leeks from experimental sites sampled in 1959 compared to those from control sites, Bradford et al. (1975), found that bean, barley, and tomato plants exhibited increased levels of Ni when irrigated with saturation extracts of sludges.

Decreases in yield from sludge amended soils have been reported by several workers (Cunningham et al., 1975; Bingham et al., 1976c; Cunningham et al., 1975b). The effect that nickel had on yield was effected by soil type, and in certain instances other metals such as zinc and copper were more important in decreasing yield. Even though nickel concentrations increase significantly in a variety of plants, the values within the plant materials are still well below those for phytotoxicity (Cunningham et al., 1975; John and Van Laerhoven, 1976). Oat plants showing chlorosis ranging from moderate to very severe contained Ni in concentrations of 88-308 ppm (Anderson et al., 1973).

The preceding literature review clearly indicates the advances that have been made in understanding trace element-soil and trace element-plant interactions. This literature dramatically points out the site specificity of the information, and how greatly results vary among different studies. Often different researchers report opposite phenomena from the same experiments done at different locations. This report expands on previous work in this field by examining 22 wastewater application sites and determining the important variables regarding effluent trace element interactions. The use of plant-soil ratios for metals provides the ability to compare metal accumulation across sites which previously has not been possible. Further, this study provides basic information on trace element accumulation from reuse practices which can be utilized by public health officials and reclamation project managers to both protect the environment and maximize our use of reclaimed water.

METHODS

This study was divided into two phases. The initial portion of the project (3 months) was concerned with the selection of sampling locations within the State of California which have received long-term wastewater application for either disposal or irrigation purposes. The selection of these sites was based upon a number of criteria outlined in the following section. The last 21 months of the study involved the collection of soil and plant samples from the 20 designated wastewater application sites. Soil characterization at each site and trace element concentrations in soil and plant samples were determined. The selection of metals (Cd, Zn, Ni, Cu) studied was based upon concentration in effluents, translocation into plant materials, toxicity to plants and man, or chemical behavior in soil systems.

Selection of Study Locations

There are now more than 220 wastewater reclamation projects within the State of California. Since it would not be feasible to examine all these sites, criteria were developed to determine which sites would best increase our understanding of the accumulation of trace elements in terrestrial ecosystems which had received long-term land application of wastewater. Factors defined to be of primary importance in thie procedure were: (1) the length of time the site had been receiving wastewater; (2) the quality of wastewater applied; (3) the availability of historical data on trace element concentrations in wastewater; (4) the amount of wastewater applied; (5) the manner of wastewater application (Spreading or spraying). If elevated concentrations of metals were found at a test site, a control site was identified which was of the same soil type and had received no wastewater.

The estimate of the quality of wastewater applied was based on the level of treatment which the effluent had received. Those sites which have at some point received either primary or untreated sewage effluents received high priority for investigation. The data in Table 2 show the treatment processes, application method, years applied and usage of wastewater at the selected California sites.

Soil Procedure

Soil Sampling. Soil samples at each of the study sites were collected once during the research period. The frequent sampling procedures used by Olson and Guinn (1978) indicated that there is no detectable change in soil concentrations over a year period. Further, the aim of this investigation was to establish a historical perspective of the accumulation pattern in soil. Nine cores were taken at each site. The general sampling design is shown in Figure 1. Samples were collected at 15 cm depths with a hand augar to a depth of 120 cm. Since most metal accumulation is known to occur in the 0-15 cm portion of the soil column, this core section was divided up into 4 cm samples which were each analyzed separately.

Plant Sampling. A variety of agricultural crops, native weed species and tree species were sampled at the test sites. Vegetation was gathered at the time of soil collection. Samples were collected within a 5 meter radius of each sampling "hole" or if vegetation was sparse a composite sample of each species was collected across the entire field. Only mature healthy plants were selected, and whenever possible matched to genus and species across the sites. A list of plant species by site and the number of plant samples collected for each plant type are shown in Table 3.

Soil Characterization

Soil pH, and cation exchange capacity were determined using standard procedure. (Chapman, 1962). The percentage of water in the soil at the time of collection was determined by the method reported in Standard Methods for Analysis of Water and Wastewater (1980).

Determination of Trace Elements in Soils

Total metal content was determined through hot nitric acid digestion of 1 g of air-dried soil in 4N nitric acid for 16-18 hours at 75°-80°C. These digested samples were then shaken at 300 RPM for 15 minutes, filtered through Whatman No. 42 ashless filter paper stored (pH 3) at room temperature until time of analysis. Total Cd, Cu, Pb, Ni and Zn concentrations of soil filtrates, standards, and reagent blanks were determined by Perkin Elmer 403 or 5000 Atomic Spectophotometer using flame atomization or graphite furnace.

Determination of Trace Elements in Plants

After the plants were collected, they were stored in labeled polyethylene bags and frozen. Before washing each plant was separated into leaf, stem, and flower material. All parts of the plant were washed at least three times in D.I. water. Each plant was then air-dried for 48-60 hours and oven dried at 50°C for an additional 48 hours. The digestion procedure used for the soil samples was then followed except that concentrated nitric acid was used during digestion rather than 4N nitric acid. If the plant material was not fully digested after heating, several drops of hydrogen peroxide were added. Plant filtrates (pH 3) were then stored in polyethylene bottles until analysis by atomic absorption. The plant filtrates, standards and blanks were analyzed for Cd, Cu, Pb, Ni and Zn using atomic absorption spectroscopy as described in the soil section.

Calculation of Metal Concentration in Wastewater. The total amount of metal applied to the soil at the Fountain Valley, Las Virgenes and Whittier Narrows sites from the application of wastewater was calculated. Historical data on the metal concentration of wastewater were obtained from wastewater treatment plant records (Table 4). Complete records on the concentration of Cu, Zn and Ni in Fountain Valley and Las Virgenes effluent for the period of 1963-1979 were available. Data for Cd and Pb were only available from 1974-1979. Complete records on the Cu, Pb and Zn concentrations in the Whittier Narrows effluent for the period of 1962-1975 were available. Data for Cd were available from 1964-1975 and Ni concentrations in the effluent were reported from 1971-1975. The mean per annum metal concentration of the wastewater applied to the three test locations were determined from these records. The application rates were based on irrigation practices commonly used in this area of the United States, and from information supplied by treatment plant workers. The mean per annum metal concentrations in the wastewater were summed or multiplied by an appropriate factor to estimate the total amount of metal in the wastewater during the irrigation period. The multiplication of the total amount of metal supplied by the appropriate wastewater application rate determined the total amount of metal added to the soil at the Fountain Valley, Las Virgenes and Whittier Narrows test locations (Table 5). Calculations of soil metal concentrations at these locations were based on assumed bulk density of 1.33 g cm^{-3}.

RESULTS

Metal Concentrations in Soils

At the Bakersfield/Oildale site, lead and Zinc appeared to be elevated in the surface soil with a mean concentration of 13.0 µg/g and 62.4 µg/g respectively (Table 9). The three other metals (cadmium, nickel, and copper) examined at this site were evenly distributed throughout the soil column (0-90cm). Cation exchange capacity for this site was low and uniform throughout the soil profile (Table 6). There was some variability in pH in the surface 0-15cm depth across the field ranging between a pH of 6-8 (Table 7). There was less variation in pH at the lower depths of 15-75cm. The water content in the Bakersfield soils also varied depending upon the hole location. The surface layer of soil was drier in some areas, while other segments of the field showed uniform moisture content with depth (Table 8).

At the Camp Pendleton site, cadmium, nickel, lead, copper, and zinc were measured in the soil column over a 0-60cm depth. The area is currently utilized as a golf course as it has been since the beginning of wastewater application. All of the metals examined except cadmium appeared to be elevated in the 0-4cm soil core (Table 10). The cation exchange capacity, as shown in Table 6, varied between the 0-15cm depth and the 16-90cm depth by a factor of 10meq/100g. The cation exchange capacity in the surface soil was quite high, being 39.6meq/100g, and was most likely due to the thick layer of Kukuya grass roots that penetrated the top soil layer. PH values were fairly uniform for the Camp Pendleton site, while moisture content varied both with depth and also among the holes examined. The elevation of metals at this site could be due to the application of wastewater, since secondary wastewater had been applied at this site for 26 years. Two reasons support the contention that wastewater may have been the source of elevation. First, the cadmium level in the surface soil was not elevated. The metal elevations are likely not due to phosphate fertilizer applications because the use of high cadmium phosphate fertilizers would have been expected to enrich the level of cadmium in surface soils. Second, lead is elevated in the surface soil even though there were no direct means for aerial contamination. However, it is important to note that herbicides or fungicides may have been applied at some time in the past, which could also have influenced metal concentrations in the surface soils.

The Chowchilla site was a plowed field planted with alfalfa, and had received primary wastewater for 37 years. It appeared that the soil type changed with depth across the field. Both lead and zinc were elevated in the surface soils (Table 11), while the other metals examined show no change with depth. Cation exchange capacity and pH values were both fairly uniform across holes and depths. The surface soils (1-15cm) were considerably drier than soils from 15-75cm (Table 8).

The Corning location was a disked field covered by a producing olive orchard. This site had received wastewater over a period of 31 years during which the treatment consisted of primary settling for the first 21 years and then secondary via oxidation ponds with final chlorination for the last 10 years (Table 12). The cation exchange capacity (CEC) varied considerably with the 0-16cm soil layer having a very high CEC of 33meq/100g while below that depth it dropped to a level of 16meq/100g (Table 6). The pH for the Corning site was fairly uniform over the field and between depths ranging from 6.4-7.4. The moisture content of the soil also was uniform across the field and among the depths sampled

(Table 8). With the exception of Cd, there appeared to be a decrease in the metal concentration with depth in the field. Ni, Cu, and Zn all show dramatic decreases when the 0-4 cm and 76-90 cm depths are compared. There was, however, an anamolous zone in the 31-45 cm depth where all metals except Pb were elevated and were either higher or approach values seen in the 0-4 cm zone (Table 12). This elevation of metals may be due to the presence of a different soil type.

At the Delano site the cation exchange capacity was uniform throughout the soil column tested and has a value of 37.3 meq/100g soil (Table 6). The pH at the Delano ranged between 7.7 and 9.0 (Table 7). The field was plowed and planted in sugar beets and had received primary effluent for eight years and secondary for an additional eleven years. There appeared to be no elevation of Cd, Ni, or Cu throughout the soil column. However, Zn was highly enriched in the 0-4 cm zone and also in the 46-60 cm portion of the soil column (Table 13).

The concentration of the metals analyzed in Fountain Valley soils is shown in Tables 14 and 14A. At the wastewater disposal site Cadmium (Cd), Lead (Pb), Nickel (Ni), and copper (Cu), were enriched in the 0-15 centimeter layer of soil as compared to the 16-120 cm section of the soil profile. Cadmium also showed a statistically significant difference between surface soil (0-15 cm) concentrations and the lower levels of the soil column (16-120 cm) ($p < 0.05$). Lead and nickel were elevated throughout the soil profile below 15 cm at the Fountain Valley control. A statistical comparison of data at the disposal site made for copper, nickel and lead between the 0-15 centimeter layer of soil and the 16-120 centimeter layer of soil showed a statistically significant difference ($p < .05$).

Gustine is a marshland which is used for duck hunting. This area received primary wastewater via flooding for a period of 40 years. The wastewater was primarily domestic in origin except for a waste from a nearby cheese factory.

Of the five metals investigated at this site, only Pb appeared to be greatly elevated in the surface 0-4 cm level. There was no evidence that traffic could be responsible for the increase in Pb. Because this marshland is near a duck hunting club, it is possible that the Pb enrichment in the surface soil was from lead shot. Some enrichment of Ni and Zn appeared in the 0-4 cm zone of the soil, but these elements were also elevated to an equal or greater degree in the 46-75 cm zone of soil indicating some type of natural soil formation (Table 15). The CEC was uniform throughout the site (38meq/100g) and the pH was fairly uniform varying between 7.4 and 8.2). The marsh conditions at this site produced soils with a high water content especially at the surface with the percent water varying between 28.8 and 31 percent, while the lower level soil 15-75 cm (with more impacted clay soil) varied between 18 and 24 percent.

The Indio site received primary effluent for approximately 20 years and secondary effluent for a period of 10 years. The secondary treatment was comprised of activated sludge, activation ponds with a final but hard treatment of chlorination. The field was plowed fallow for approximately 1.5 years prior to sampling, The CEC of the soil ranged between 17.2 meq/100g in the 1760 cm zone and 18.5 meq/100g for the 0-16 cm zone (Table 6). The pH across the field was approximately 8. The surface soil (0-15cm) contained between 2.9 and 6.5 percent water at the time of sampling. Cd, Ni and Cu were rather uniform throughout the soil column. Pb was elevated in the surface 0-4 cm which was most likely due to aerial fallout from a road located nearby. Zn was elevated in the 0-16cm zone. There appeared to be no evidence of increase in metal concentration due to wastewater application at this site (Table 16).

The concentrations of cadmium, lead, copper and nickel in the soil profiles at the Las Virgenes test sites are shown in Table 32. At each site the cadmium soil concentration was uniform throughout the soil profile (Table 32). Cadmium levels measured at the high rate field were considerably greater than levels typically reported for soils. The control and low rate sites contained similar concentrations of cadmium in the soil (<3 mg kg^{-1}). These levels are considered elevated well above background soils. Values for soil lead, copper and nickel were uniform throughout the soil profile at each site, though differences occur among test locations. The mean nickel concentration throughout the soil profile indicated higher soil concentrations at the Las Virgenes control site compared to the low and high rate test fields. A slight increase in lead was noted in the 0-60 centimeter portion of the soil column at the low rate site and the magnitude of lead enrichment of the soil column decreased with depth. The location of the test field near a two lane highway with high use may explain this finding. Copper soil values were similar at the control and high rate sites. Total soil copper decreased throughout the soil profile examined at the low rate sites. At all sites studied, Zn was fairly uniformly distributed over the depths tested.

The Livermore site (a wheat field) had received secondary effluent via flood irrigation for a period of 13 years. Wastewater treatment for this site was comprised of primary settling, activated sludge, coagulation, filtration, and chlorination. Therefore this system would be viewed as having received treated wastewater. The CEC in the surface soil at the Livermore site was 13.4 meq/100g, while in the 16-90 cm zone the CEC was 14.4 (Table 6). Cd, Ni, Pb, Cu, and Zn do not appear to be elevated at this site (Table 17). Therefore, from land application of tertiary treated wastewater appeared to have no measureable effect in relation to the trace elements studied.

At the March Air Force Base site, which was planted with barley, secondary wastewater effluent has been applied for 41 years (Table 2). Wastewater treatment was comprised of primary settling, trickling filter, followed by chlorination. The pH at March Air Force Base ranged from 6 to 7.3 over the depth and across the field (Table 7). The data indicate some evidence of movement of metals through ths soil column though the concentration of all metals was quite low (Table 18). Cd, in particular, showed ≤ 0.2µg/g Cd in the 0-16 cm zone and increased to between 0.6 and 0.9 g/g CD in the 17-60 cm zone. There was somewhat of an increase in Ni with depth and Pb was elevated in the surface and also in the 61-90 cm zone as well. A slight increase in Cu with depth was observed and Zn was uniform throughout the soil column. There was an extremely low CEC throughout the soil column (approximately 10 meq/100g), which might account for the movement of metals through the soil column and explain the enrichment seen at the lower depths. However, the lack of data on the metal concentrations in the applied wastewater effluent make it difficult to evaluate whether metal enrichment through application occurred.

Moulton Niguel, a golf course, has received secondary effluent for a period of 14 years. The treatment train consisted of primary treatment activated sludge, oxidation ponds followed by chlorination (Table 2). The soil pH ranged across the field and over depth from 6.4 to 7.7 and the water content varied in the surface from 14 to 26 percent and in the subsurface from 8 to 22 percent (Tables 7,8). The CEC was high in the surface soil being 41meq/100g decreasing to 27.8 meq/100g at the 16-90 cm depth (Table 6). The Cd concentration was uniform throughout the 60 cm depth as was Ni, Cu, and Zn. However, the 46-60 cm zone of the soil had lower concentrations of Cu and Zn that the 0-45 cm zone. Pb was elevated in the surface soil and also in the 31-45 cm core (Table 19). The elevated Pb is most likely due to aerial fallout.

The Occidental pastureland site was unplowed and had received secondary wastewater for a period of 12 years (Table 2). The pH at the Occidental site is 3.9 to 5.4 while the water content in the soil ranged from 4.9 to 12 percent in the surface soil and from 10.4 to 14.7 percent in the 15-75 cm depth (Tables 7,8). The metal content in these soils increased with depth and change in metal content with depth is attributed to a difference in the soil type, manifested by a soil color change from black to white (Table 20). The CEC is quite high at this site and quite uniform, approximately 30 meq/100g (Table 6).

At the Palmdale site the CEC of the soil was very low ranging from between 12.5 and 14.0 meq/100g to over the 0-90 cm. depth tested (Table 6). This site had received secondary wastewater for a period of over 14 years and was covered with alfalfa. The pH in the 0-15 cm zone of the soil column core varied from between 5.6 and 8.0 over the field while the lower depths, 15-75 cm, varied from between 7.7 to 9.3 (Table 7). None of the metals studied showed acculumlation in the surface soils (Table 21). The field showed varying water content both in the surface and in the subsurface soil cores (Table 8).

The Pleasanton site had pastureland cover which had received secondary treated wastewater for 30 years (Table 2). The CEC in the surface soils was high at 30.7 meq/100g and decreased slightly in the 15-75 cm zone of the soil of 24.5 meq/100g (Table 6). The pH was alkaline at this site both in the surface and subsurface cores (Table 7), while the water content of the soil varied considerably in the 0-15 cm zone and was fairly uniform in the 15-75 cm zone (Table 8). The metal concentration appeared to be somewhat elevated in the 0-4 cm zone for Cd, Ni, Pb and Zn. Generally the metal concentrations decreased with depth to approximately 30 cm and then began to increase with depth except for Pb which decreased after 60 cm (Table 22).

The Pomona site, an orange grove, has been irrigated for 14 years with secondary effluent. The treatment processes for the irrigation water were primary sedimentation, activated sludge, activated carbon and chlorination (Table 2). The soil pH at this site was acidic in the surface soil ranging from 5.2 to 6.5 and increased in the 15-75 cm zone to pH 8.5 (Table 7). The soil water content was highly variable across the field ranging from 5.7 to 16.3 percent in the surface and from 11.6 to 21.1 percent in the lower depths (Table 8). The Cd concentration was uniform in the 0-30 cm zone and showed a slight increase from 31-90 cm though the increase was not statistically significant. The concentration of Ni was fairly consistent throughout the soil column with a slight increase found in the 31-75 cm soil cores. The Pb concentration was quite elevated in the surface layer (0-16 cm) and decreased with depth to 30 cm, followed by a slight increase. The Zn concentration decreased from the surface to 30 cm in the soil and then increased in concentration in the 61-75 cm zone (70.4 μg/gZn). The surface soil had a relatively low CEC of 10.5 meq/100g, while the 17-90 cm zone had an overall CEC of 8.0 meq/100g (Table 6). These data may partially explain the aforenoted downward movement of Pb and Zn (Table 23).

The San Francisco site had received secondary treated wastewater for 48 years. It is a parkland which is covered by grass and trees (Table 2). This area had a sandy loam soil with a cation exchange capacity of 17.1 in the surface soil (1-15 cm) and 8.0 in the 16-90 depth (Table 6). The pH of the soil in this area was slightly acidic, ranging from 5.4 to 6.9 (Table 7). The water content in both the top and the bottom layers of the soil was quite variable across the sampling holes (Table 8). The metal content in these soils appeared to be uniform across sample depths tested for both cadmium and nickel, while both copper and zinc decrease in metal concentration from the surface core to the bottom core (Table 24). The metal content in these soils appears to be uniform across sample depths tested for both cadmium and nickel. Both copper and zinc decrease in metal concentration from the surface core to the bottom core (Table 24).

At the Santa Maria site, secondary effluent had been applied for six years to a plowed field which was planted in sugar beets (Table 2). The metal concentration for cadmium was slightly elevated relative to background concentrations found in California soils. This was also true for nickel, copper, and zinc which were slightly elevated to a depth of 60 cm (Table 25). Therefore, in terms of trace element accumulation, no effect was seen from the use of reclaimed water at this site.

At the Shaftner site, secondary effluent had been applied for 12 years. Fiber crops were grown at this site, and at the time of sampling this field had recently been plowed and was to be seeded with cotton (Table 2). The cation exchange capacity of the Shaftner site ranged between 16.7 and 20.8 meq/100g (Table 6), and the pH in the surface soils was fairly uniform across the field, varying from 7.1 to 8.1 (Table 7). In the subsurface soil (15-75 cm), the pH was more alkaline, ranging from 6.5 to 8.1 (Table 7). The metal content at this site appeared to be evenly distributed over the 0-90 cm range for cadmium, lead, copper, and nickel. There was somewhat of an elevation of zinc in the surface 0-4 cm. zone with zinc concentration decreasing with depth (Table 26). Although zinc was elevated in the surface soil, no direct evidence suggests the accumulation of this element from the application of secondary wastewater.

The Taft field site had been fallow for a number of years and had received secondary treated effluent for a period of 20 years (Table 2). The area had been deep plowed to a depth of three feet and the uniform distribution of all the metals examined may be a reflection of this deep plowing procedure (Table 27).

The cation exchange capacity of this soil varied markedly with depth, 0-16 cm zone with 22.8 meq/100g compared to the 17-90 cm depth with a CEC of 12.5 meq/100g (Table 6). The cadmium concentrations at this site were uniformly elevated above background levels for the state of California and ranged between 2.2 µg/g at the surface to 3.1 µg/g at a depth of 90 cm (Table 27). This finding is most explained by geological enrichment of the soil.

At the Wasco site wastewater had been applied for 39 years with primary effluent and for a period of one year with secondary effluent. The cation exchange capacity at this site was low both in the surface and subsurface soils (Table 6). The pH of the soil was approximately 6 in the 0-16 cm layer of the soil and ranged between 6 and 7.1 in the 17-90 section of the soil column tested (Table 7). This area was used for growing cotton and had a long history of wastewater application. The wastewater was of domestic origin with some food processing waste on a seasonal basis. Metal levels found throughout the soil depths tested appear to be uniform given environmental variations (Table 28).

The next two sites, Whittier Narrows Disposal and Whittier Narrows Control, will be considered together. These two sites were adjacent to each other, being separated by less than 100 meters. The Whittier Narrows Control had never received wastewater, while the Whittier Narrows Disposal site was used as a recharge basin and had received secondary wastewater for a period of 17 years. The composition of the wastewater at this site was 95 percent domestic and 5 percent industrial (Table 2). There was considerable evidence of metal enrichment for all metals tested at this site when the control area was compared with the disposal area to a depth of 60 cm. The most dramatic increase can be seen in the surface soils for cadmium and lead and in the 9-12 cm zone for nickel, copper, and zinc (Table 30). The amount of metal increase in the 0-16 cm zone becomes even more dramatic when these data are compared with the 0-16cm zone of the control site (Table 29). In the 9-12cm zone of cadmium, the elevation is greater than 20x of the control; for nickel, greater than 5x; for copper, greater than 3x; and for zinc, approximately 3.5x. Lead also shows a greater than 10x increase in the 0-12cm zone of the soil (Tables 29, 30).

Metal Content in Plants. Fountain Valley metal content comparisons of the four tree species studied at the two Fountain Valley sites are shown in Table 33. The concentration of Ag in the leaf/needle and stem tissue of the trees ranged between 0.05 μg/g and 0.3 μg/g Ag. No significant difference was observed between the matched tree samples from both sites. Cadmium levels were significantly greater in both the needle/ leaf and stem tissue of the two pines and the Italian Cypress (C. sempervirens horizontalis) located at the wastewater disposal site compared to those levels found in the matched trees at the control site. However, in the silk oak (Grevillea robusta, Cunn.) Cd concentrations did not differ significantly between the two sites. Cu, Pb and Ni also did not show an accumulation pattern in this tree species.

The mean copper concentrations of needle material from Pinus pinea, L. (5.0 μg/g Cu) and Cupressus sempervirens horiz., Gord (6.0 μg/g Cu) located at the wastewater disposal site were significantly greater than matched samples collected from the control site (4.0 μg/g Cu and 4.9 μg/g Cu, respectively). There were no differences in the Cu content of the stem material of these two trees. Needle, leaf and stem samples from G. robusta and P. halepensis showed no differences in Cu levels between the two test sites. Ni values in the foliage and stem portions of the trees examined varied between 2.4 μg/g Ni to 4.8 μg/g Ni. Of the four trees tested only the leaf material of Cupressus sempervirens horiz., collected from the disposal site exhibited a significantly higher level of Ni compared to matched samples from the control site.

Higher Pb values were observed in both needle and stem materials collected from all tree species at the Fountain Valley control site (Table 33). The Pb values in Table 33 indicated high variability over the course of the study.

The zinc content of the leaf material collected from the Cupressus sempervirens (Italian Cypress) at the disposal site was significantly higher than in the control tree (29.8 μg/g Zn and 20.5 μg/g Zn, respectively). However, the Zn value in the stem material of the control site cypress (52/5 μg/g Zn) approximately doubled that found in stem samples of the Cupressus sempervirens located at the disposal site (27.1 μg/g Zn). The Grevillea robusta at the control site showed a significantly greater accumulation of Zn in its leaf and stem portions than matched material from the wastewater disposal site. Zn was found to accumulate to a higher degree in the stem portion of the control site P. pinea compared to its counter part located at the disposal site.

Las Virgenes. Plants collected at the Las Virgenes test sites were grouped into two categories, Annuals and Perennials, for statistical analysis (Table 34). Results are based on above surface whole plant (leaf, stem, flower and seed) concentrations. An overall comparison of the annuals collected at the three sites showed significant differences for Ag, Cd, Cu, Pb, Ni and Zn. However, accumulation patterns for each of these metals differed. Silver and cadmium accumulated to a greater degree in annuals collected at the high rate appliation site, whereas these same plants exhibited lower concentrations of Cu, Pb, Ni and Zn compared to their matched counterparts at the other two sites.

A more detailed analysis of annuals by genera (Table 35) revealed that both black and wild mustards (Brassica, L. spp.) and Wild Radish (Raphanus sativus, L.) collected at the high rate site contained significantly higher levels of silver (Ag) than matched plant samples collected at the other two sites. The Medicago species (M. apiculata, Wild, M. lupulina, L., M. hispida and M. sativa, collected from the low rate site exhibited higher levels of Ag than the Medicago species collected at the other sites. Silver levels were found not to differ significantly among the matched "grass" species (Bromus spp. and Avena fatua) examined.

Cadmium levels in the five annuals collected at the three Las Virgenes sites ranged between 1.2 μg/g Cd to 6.8 μg/g Cd. The Brassica, Bromus and Medicago species collected at the high rate site (mean soil concentration of 11.4 μg/g Cd) contained significantly higher levels of Cd in their tissues compared to the matched samples from the control and low rate sites (mean soil levels of 3.1 μg/g Cd and 3.4 μg/g Cd, respectively). However, the extent to which these three plants at the high rate site accumulated Cd differed greatly. The Brassica species contained 6.8 μg/g Cd in its tissues, whereas the Bromus sp. and Medicago species contained 4.5 μg/g Cd and 1.9 μg/g Cd, respectively. The wild oats (Avena fatua) collected from the low rate site exhibited a higher concentration of Cd compared to the oats sampled from the control site. The Cd contents of the Wild Radish collected from the control and high rate sites was found not to differ significantly.

The copper (Cu) values in the matched samples of Raphanus sativus, Bromus spp, and Medicago spp. did not differ significantly across the three Las Virgenes sites. The Brassica spp. (mustards) collected at the low rate site contained a higher mean value (6.6 μg/g Cu) than those same plants collected at the control (4.4 μg/g Cu) and high rate site (4.4 μg/g Cu).

The Brassica spp, and Avena fatua (wild oats) collected at the Las Virgenes low rate site exhibited a significantly higher level of Pb in their tissues compared to those same species collected at the other two sites. The other three annuals examined (R. sativus, Bromus spp. and Medicago spp.) showed no differences in their Pb levels.

Nickel concentrations in the vegetation collected from the three Las Virgenes sites ranged between 1.6 μg/g Ni and 6.1 μg/g Ni. Nickel levels in Brassica spp. and Bromus spp. at the low rate site were elevated compared to those matched plants collected at the control or high rate site. The Medicago spp. and Raphanus sativus, L. collected from the control site contained higher levels of Ni than the matched plants sampled at the other two sites.

The Zn content of the five annuals examined at the Las Virgenes sites ranged between 24.2 μg/g Zn and 48.1 μg/g Zn. No significant differences between the Zn content of the matched samples for Brassica spp., R. sativus, Bromus spp. and Medicago spp. were found. The wild oats (Avena fatua) collected at the low rate site exhibited an elevated concentration of Zn in its tissue compared to those wild oats collected at the control site (27.0 μg/g Zn and 12.2 μg/g Zn, respectively).

The perennials examined at the three Las Virgenes sites showed differences in Cd, Cu, Pb, and Zn uptake (Table 34). As seen in the annuals, the perennials collected from the high rate site exhibited elevated Cd levels. Zinc concentrations in perennials collected at the low rate site were greater than in matched perennial samples growing at the control and high rate sites.

Malva parviflora, L. (Cheeseweed) (Table 35), accumulated significantly more Cu, Pb and Zn at the low rate site than matched samples from the control site. A t-test comparison of all the metals under investigation in Hordeum leporinum (wild barley) collected at the low and high rate test sites indicated only elevated Cd levels at the high rate site. Rumex crispus, L. (Curly Dock) found only at the control and high rate sites showed no significant difference in metal concentration for any of the six metals tested.

Whittier Narrows. Three plant species were collected from the two Whittier Narrows test sites. Metal concentrations in these plants are reported for whole plant samples, excluding root portions (Table 36). The Cd levels in both Brassica species and in the Rumex crispus L. (curly dock) at the disposal site were significantly greater ($p < .05$) than those same plant species at the control site. Cadmium concentrations in the disposal Brassica sp. (6.6 μg/g) were significantly higher than the Brassica nigra Koch. (black mustard) 0.8 μg/g) and R. Crispus L. (0.7 μg/g) collected from the disposal site. This is in agreement with John (1976) who reported that different species and cultivars within a genus accumulate Cd at different levels. This disposal Brassica sp. also exhibited higher levels of Zn in its tissues compared to the other plant species examined. Zinc levels in the control and disposal plant tissue of the Brassica nigra Koch. and R. crispus were found not to be significantly different. Copper and nickel levels in the three plant species were found not to differ significantly between the two sites.

Plant/Soil Ratios of Metal Concentrations by Sites

All plant data across the sites were normalized by conversion to plant/soil ratios (PSR), in order to develop a means of comparison. These ratios were calculated by dividing soil metal concentrations into the plant metal concentrations matched by sampling hole at each of the twenty-two sites. Absolute values of plant metal concentrations (μg/g) appear in Tables 38-40. Soil metal concentrations (μg/g) in the 0-15 cm depth which were used in the calculation of these plant soil ratios are shown in Table 37. The results of these calculations (plant/soil ratio) are shown in Tables 41 and 42. A plant/soil ratio of 1.0 indicated that the plant was taking up the same amount of metal as was contained in the soil. If the value fell below 1.0, some exclusionary mechanism appeared to be operating within the plant or between the plant, soil interface thus limiting the amount of metal translocation. A plant/soil value greater than 1.0 indicated that the plant was translocating or "accumulating" metal into its tissues.

Camp Pendelton is a golf course covered with a wide variety of grass, weed and tree species. Two plants at this location; Cynodon dactylon L. (Bermuda grass) and Taraxacum officinale Weber (dandelion), accumulated a relatively small amount of Cd (PSR = 1.31, 1.21, respectively). None of the seven species examined at the site were seen to accumulate Cu, Ni or Zn above soil metal concentrations.

At Chowchilla three plants were collected, all of which showed plant Cd concentrations in excess of soil Cd concentrations. Brassica sp. exhibited an average Cd plant/soil ratio of 1.2, Capsella bursa-pastoris L. (shepherd's purse) and Malva parviflora L. (cheeseweed) all accumulated Cd at a rate exceeding three times that of the soil. Absolute Cd concentrations for both of these plants, however, were relatively low (0.8 μg/g for both plant species). Cu and Ni PSR values were below 1.0 for all Chowchilla vegetation. Zn plant/soil ratios ranged between 1.0 and 1.5 for Capsella and Malva (Table 40). The Zn concentrations of the mustards (Brassica sp.) collected at this site were less than those in the soils (PSR = 0.7).

Five plant species were collected from a Corning olive orchard which had been irrigated with wastewater for 31 years. Bromus spp. (brome grasses) accumulated Cd at a rate four times that of the soil concentration. Three other plant species, C. bursa-pastoris, Rumex crispus, L. (curly dock) and T. officinale also accumulated Cd in concentrations exceeding soil levels (1.67, 1.67, 1.33, respectively). Cu and Ni levels in these five plants were found to be less than levels in the soil, with PSR values ranging between 0.19 to 0.41 (Cu and 0.04 to 0.15 (Ni). With the exception of T. officinale (PSR = 1.02), Zn concentrations in the Corning vegetation were also found to be less than the soil.

At the time of sampling the March Air Force Base was a fallow field, howeever, it had been planted with barley in previous years. Weed species predominated at the time of examination. Extremely high cadmium PSR ratios were seen in all three plant species examined. Cadmium concentrations in the soil at this site were extremely low (mean = 0.12 μg/g). The highest PSR value occurred in Malva parviflora L. with tissue concentrations ten times greater than those in the soil. Raphanus sativus (wild radish) and Chenopodium album L. (lambsquarters) showed Cd PSR ratios of 9.17 and 5.83, respectively. This accumulation trend did not hold constant for Cu, Ni or Zn, with all PSR values for these metals being less than 1.0.

Seven different species of grasses and weeds were collected from a golf course in Moulton Niguel. Only two species, Sonchus sp. (sowthistle) and Taraxacum officinale Weber (dendelion) showed accumulation of Cd at this site (PSR = 6.24, 1.98, respectively). Sonchus also was seen to take up Cu at a rate equal to the Cu concentration in the soil. The other six species had Cu ratios which were less than 1.0. Those plant species examined for Ni content exhibited very low concentrations relative to soil concentrations (plant/soil ratios less than 0.2). There was slight accumulation of Zn in Sonchus spp. and Pinus halepensis Mill. (Allepo Pine), with plant/soil ratios being 1.40 and 1.05, respectively.

The Occidental site was pasture land containing different species of wild Medicago (burclovers). The absolute values of Cd, Cu and Zn in these plants were within normal ranges (0.4 μg/g Cd, 9.8 μg/g and 42.9 μg/g), but the extremely low soil metal values (0.29 μg/g Cd, 4.16 μg/g Cu and 16.04 μg/g Zn) at this site resulted in plant/soil ratios greater than 1.0. These Medicago species were shown to be accumulators of Cd, Cu and Zn (PSR = 1.38, 2.34, 2.67, respectively). Ni was excluded (PSR - 0.03) from these Medicago species.

The Palmdale alfalfa field contained numerous weed species. Five plant species, including alfalfa (Medicago sativa L.), were collected at this location. None of the five species collected at this site were shown to accumulate Cd, Cu or Ni. However, all plants had Zn concentrations exceeding soil levels with PSR ratios ranging from 1.10 to 2.11. It should be noted that Zn values at the Palmdale site were unusually low in the soil (Zn soil concentrations averages 16.8 μg/g).

The Pleasanton site was pastureland which had been flood irrigated with secondary effluent for 30 years. A total of six weed species were collected at this site with all six showing Cd accumulation ratios greater than 1.0 (PSR ranging from 1.39 to 2.22). Hordeum leporinum Link (wild barley) was shown to be the greatest accumulator of Cd with a PSR ratio of 2.22. None of these plants showed accumulation of Cu, N- or Zn.

The Pomona site was part of the agricultural experimental station at Cal Poly Pomona. This field was planted in mature citrus (oranges) and disked to eliminate all week species. The application of herbicides combined with the desking practices made collection of other plant species, besides Citrus sitensis Osbeck, impossible at this site. The leaf and stem material of these orange trees showed very slight accumulation of Cd and Zn (PSR = 1.25 and 1.02, respectively). No accumulation of Cu or Ni was seen in the citrus samples from this site.

The San Francisco site was a turf area located within Golden Gate Park. This site had been irrigated with a blend of secondary effluent and domestic water for approximately 40 years. The two species of plants examined at this site, Bromus spp. and T. officinale (dandelion), were found to contain Cd concentrations slightly higher than soil concentrations (PSR = 1.47). Neither plant accumulated Cu, Ni or Zn from the soil.

The spray irrigated Santa Maria site had received secondary effluent for a period of six years. This field had been recently planted with sugar beets and contained the weed species Raphanus sativus L. (wild radish). Both Raphanus and the sugar beets (Beta vulgaris) accumulated Cd with levels slightly over soil concentrations (Cd PSR = 1.13 and 1.69, respectively). Cu PSR ratios were also relatively high for these two plants at this site, with Raphanus showing a Cu PSR of 1.0 and sugar beet a PSR of 1.44. Although the sugar beet was found to be an excluder of Ni this plant exhibited the highest PSR value (0.68) of all the vegetation examined across the sites. Zn PSR ratios for Raphanus and sugar beet were 1.93 and 2.32 respectively, showing plant Zn concentrations exceeding soil levels. It should be noted that soil metal concentrations for Cd, Cu, Ni and Zn at Santa Maria were relatively low, and therefore although the PSR ratios show accumulation, absolute plant metal concentrations at the Santa Maria site were relatively low (Table 25).

At Shafter, five species of plants were collected. All five species showed accumulation of Cd above soil concentrations, with PSR ratios ranging from 1.18 (Cynodon dactylon) to 3.08 (Capsella bursa-pastoris). None of the plants, however, were shown to be accumulators of Cu, Ni or Zn at the Shafter site. Ni PSR ratios for the five plant species were extremely low with no ratio exceeding 0.01. This indicates that these plants were active excluders of Ni at this site or that Ni was in a form which was unavailable to the plant species.

At the Taft site seven weed species were collected from a field which had been deep plowed but not recently under cultivation. The Taft site showed naturally elevated soil Cd concentrations that averaged 2.43 μg/g. It is interesting to note that although the Cd concentration at the Taft site was relatively high, plants were not shown to be accumulators of Cd at this site.

None of the seven plants collected at the Taft site possessed a PSR ratio exceeding 1.0. This may reflect the fact that despite relatively high soil Cd concentrations at this site the Cd was in an unavailable form. The three grass species (A. fatua, Bromus spp. and H. leporinum) exhibited extremely low Cd plant/soil ratios (0.29). Cu, Ni and Zn were also excluded with PSR ratios for all plants consistently below 1.0. The low ratios may indicate that these grasses at the Taft site are not as active accumulators of the available Cd as the other plant species, or there is an exclusionary mechanism (root to shoot or soil/root interface) in these three grass species.

A recently planted cotton field was sampled at Wasco. Two weed species C. dactylon and M. parviflora were collected at this site, and both showed PSR ratios for Cd in excess of 1.0 (Cd PSR = 1.25 and 2.64). Also Zn PSR ratios were correspondingly high (Zn PSR = 1.33 and 2.74 for Cynodon dactylon and Malva parviflora, respectively). Both Cu and Ni were excluded from both plants collected at the Wasco site.

In Table 42, plant PSR ratios are compared by plant across sites. Avena fatua L. (wild oats) was shown to be an accumulator of Cd at both Gustine and Livermore, but not at Taft (Cd PSR - 2.24, 2.78, 0.29, respectively). Avena fatua followed a pattern seen in many other plants whereby the plant soil Cd ratio decreased as soil Cd concentrations increased. This suggests that plants obtain a certain level of Cd regardless of soil concentration (Figure 2). Brassica spp. (wild mustard) showed a variety of responses to soil concentrations (Table 36), with PSR ratios ranging from 0.82 at the Gustine site to 3.4 at the Bakersfield site. Brassica sp. along with Bromus spp. (brome grass) and Capsella bursa-pastoris (shepherd's purse) showed a similar pattern to that described for Avena fatua whereby plant/soil Cd ratios decreased as soil Cd concentrations increased (Figures 3-5, respectively).

Malva accumulated Cd at a relatively greater rate than other plant species collected during the course of this study. The plant/soil ratios for this plant ranged from 0.91 to 10.00. However, when graphed against absolute soil concentrations Malva parviflora L. (cheeseweed) PSR values were found to decrease as soil Cd concentrations increased (Figure 6). Medicago spp. (burclovers and alfalfa) also exhibited this pattern, with plant/soil ratios ranging from 0.2 at the Camp Pendelton site to 2.22 at the Livermore site (Figure 7).

Relationship of Metal Concentration in Wastewater and Accumulation in Soil

The total amount of metals applied at the three rates to the irrigated Orange County site is shown in Table 43. Metal concentrations of wastewater was calculated to be Zn>Cu>Cr>Pb>Ni>Cd Ag. The amount of metals present in the soil at the irrigated test site and the control site is shown in Table 44.

The results in Table 44 indicate that two metals, Cr and Ni did not accumulate in the soil at the site receiving wastewater. In the wastewater irrigated soil, Cr and Ni concentrations were 9.4% and 5.6% less respectively than in the control soil. All other metals examined were found in higher concentrations at the wastewater irrigation site (Table 45). As shown in Table 45 the maximum wastewater application rate only accounted for between 29.6 and 67.4% of the excess metal found at the irrigated site. At the maximum application rate of 36.2 cm ha per year, 63.2% of the excess Cu and 67.4% of the Zn in the soil at the test site could be accounted for by the maximal practices. Cd, Pb and Ni values in soil at the test site were even less adequately explained by the application of wastewater, accounting for 38.8, 37.0, and 29.6%, respectively of the excess metal at the test site. The paucity of historical data for these three metals suggest that their concentrations in wastewater during the first 12 years of application may have been higher than the years 13-15 for which records were available.

The availability and accuracy of historical records of metal concentrations and application rates of wastewater are the determining factors in accurately assessing metal accumulation in soils from land application of wastewater. Lack of or incomplete data for these factors were problematic in this investigation.

The metal patterns in the test soil for Zn, Cu, Ni and Cr represented two different outcomes: metal accumulation (Cu and Zn) and reduction in metal concentration in soil (Ni and Cr). Increases in Pb, Cd and Ag in the wastewater irrigated soil were also noted. The interpretation of these results were more difficult due to incomplete records for concentrations of these metals in wastewater. It was not likely that airborne sources of Pb accounted for the higher Pb concentrations in test site soil, because traffic patterns are similar at the two study locations. External sources of Cd and Ag are even less likely as both sites are located in residential areas with only light industry in the mediate vicinity. Cadmium dust fallout is estimated to range between 0.04-0.75 mg m^{2-1} $month^{-1}$ in U.S.cities. The close proximity of the two sites would suggest that airborne Cd fallout would be equal. Therefore, the hypothesis which is most plausible is that incomplete historical information has resulted in underestimations may account for the inconsistency between actual (Table 44) and calculated (Table 45) values. Grouping the data by the amount of historical information available resulted in similar percentages of metals accounted for in the test soil, and therefore, supports this hypothesis. Accumulation from land application of wastewater has been reported for Cd, Cu, Ni, Pb and Zn (Brown, 1978) and no effects have also been reported (Sidle, et al., 1977). The metal content of the effluent and application rates appear to be the determining factors in accumulation of metal in soils. The data presented in this study indicated that at moderate irrigation rates between 30 and 67% of the increased metals concentration in the wastewater irrigated soil could be accounted for by land application practices.

Heavy metal accumulation varied among sampling holes within the disposal site at Whittier Narrows as well as between the disposal site and the control site. The soils data collapsed by depth in Table 46 demonstrate ($\alpha \leq 0.05$) that the accumulation of cadmium varied according to the area sampled within the disposal lagoon. One of the coring sites, hole #2, was selected for separate analysis because of the highly elevated levels of metal in the upper soil layers. Since hole #2 was located in a depression at the center of the disposal site, greater amounts of water may have passed over the site, thus resulting in a higher retention of effluent metals in the soil column. Regardless, the scattering of data points in the top soil layers indicates a lack of homogeniety among the various areas sampled within the disposal site. When the anomalous core site was factored out. all of the metals ~~studied~~ still showed significant ($\alpha \leq 0.05$) accumulation of each metal tested when disposal and control sites are compared (Table 46, comparison among holes 1, 3-5).

All elements (Cd, Cu, Ni, Pb, Zn, Cr) analyzed were found in higher concentrations at the disposal field than in the control field to a depth of 90 cm. The maximum concentration of cadmium occurred between 10-15 cm. The same general pattern was observed for nickel, lead, copper, zinc and chromium. Reasons for surface dilution (lower levels of Cd) are still under investigation.

The quality of wastewater effluent being utilized, level of treatment, amount of wastewater applied and duration of application all influence the amount of metal which may ultimately accumulate in the receiving soil. The manner of wastewater application (spray or flooding) may also be important.

Hence, when these factors are minimized, wastewater contributes little metal to surface soils when used for groundwater recharge or irrigation (Sopper and Kardos, 1974, Olson et al., 1978). This study indicates that wastewater containing moderate concentrations of metals, especially if these metals include cadmium, should be monitored closely before and during its application to land to avoid long term contamination of the soil.

DISCUSSION

Accumulation of Metals in Soils from Land Application of Wastewater

A total of 21 locations throughout the state were investigated to determine if land application of wastewater had significant effects on the accumulation and the translocations of metals into plants. The study indicated that the majority of sites were not impacted by the input of metals from the wastewater. Controls for most of the sites were determined to be the level of metal below 30 cm. This is reasonable since most metals are rapidly bound in the first few centimeters of the soil columns..

Thirteen of the 21 sites were ploughed or disked during the application period. It has been found that the disking of soil dilutes the metal concentration which would be present in the surface centimeters by redistributing it over 15-30 cm. Therefore, it is not surprising that no metal elevation was seen for Bakersfield/Oildale, Chowchilla, Corning, Delano, Indio, Las Cirgines, Livermore, March Airforce Base, Occidental, Palmdale, Pomona, Santa Maria, Shaftner, Taft and Wasco.

Of the remaining sites there was definite elevation of metals in the soil at the Fountain Valley and Whittier Narrows sites which could be related to wastewater application. Both of these sites had received wastewater for prolonged periods of time and the soil had not been disturbed. At the Fountain Valley site primary effluent had been applied for an unknown period of time. Because of the inaccuracy of records, it was possible only to estimate the amount of wastewater applied at this site. Therefore, it was only possible to account for between 29.6 and 63.2% of the metals (Table 45) present in the soils. This inability to determine a mass balance can be explained by the lack of data and also the lack of metal measurements over the last 15 years. Importantly, two metals appeared to be mobile in the solid column and could thus impact groundwater, nickel and chromium. This finding is important because of the health implications associated with chromium. However, the form of chromium present is likely to be in the +3 valence and therefore less toxic.

At Whittier Narrows definite accumulation was noted for all metals tested. Further, it showed that when metal was applied in the form of wastewater its distribution over the suface was not equal (Table 46). This indicates that when a field is sampled for the application of wastewater that a careful sampling regime is required in order to detect any changes which might have occurred. The records obtained for Whittier Narrows were the best available for all 21 sites. Interestingly even at this site only 50% of the metal applied could be accounted for in the soil column. Thus, unless careful records are kept for the concentration of material in the wastewater and the application rate there is no way to estimate the relative degradation of the environment without actually sampling the impacted area.

Of the remaining 5 sites, some elevation of metals (Cd, Ni, Pb, Cu, and Zn) appeared between the 0-4 centimeter depth and the 5-8 centimeter depth. It was not possible to ascertain whether these numbers were indeed feasible in relation to application rates and metal concentration because so little historical data were available. At Gustine some elevation was noted for Pb, Ni and Zn, but not for Cd and Cu between the 0-4 cm depth and the 5-8 cm samples. While at Moulton Niguel Pb was the only metal which was elevated. At Pleasonton and the San Francisco site there was evidence of elevation at the San Francisco site. Thus, whether or not metal accumulation occurs in the soil is a definite function of the quality of wastewater applied to it. Unfortunately the lack and the poor quality of records makes it impossible to determine if the sites referred to above indeed contained elevated metal concentration in the soil due to wastewater application or aerial fallout.

Two sites, Taft and Las Virgenes were naturally enriched in Cd due to the underlying geological materials. This can be easily determined by comparing the soil columns. Cadmium is elevated in both of these areas throughout the soil column depths tested. Upon further investigation, it was noted that the Monterey Shale was the geological material beneath the soil.

Translocation of Metals into Plants

An analysis of sites which were matched was carried out for only three sampling locations: Fountain Valley, Las Virgenes and Whittier

Narrows. The validity of the comparison at the Las Virgenes site should be reviewed with some reservation as it has been shown that newly applied Cd is more available for plant uptake than that which has had a long residence time in the environment. At both the Fountain Valley site and the Whittier Narrows site, the irrigated field had higher levels of metal within the plant for those metals tested except Ag at Fountain Valley. It is also interesting to note that within tree genera examined there is considerable variation in uptake. For example, Grevellea robusta did not take up any more metal at the test site than at the control site. Further, it was noted that the coniferous tree species were good translocators of metals and the Cypress was the best translocator among the species tested. It was found that there was also species variation in uptake of metals at the Whittier Narrows site. Here two species of Brassica species were examined and considerable differences in Cd and Zn uptake were observed.

These data suggest that composite samples of natural species should be taken with care. One could include in a sample a plant which has much less or more propensity to take up a given metal and that could result in skewed data collection and thus wrong conclusions could be drawn.

A total of 19 different plant species were collected and analyzed in this study for up to metals. The total number of samples collected from the 21 sites was 619 . This represents one of the most complete collections of natural plants, the metal content in their tissue and metal concentration in the corresponding soil. This complete analysis has contributed to a better understnading of how to sample plants in the field and has given an indication of species variation.

Plant/Soil Ratio

The plant soil ratio has provided a unique means of comparing widely varying data. It has shown that more Cd is taken up by plants when the concentration of the metal is low. This very interesting trend is similar to that seen for required elements. Perhaps Cd will be shown to be required at very low levels as has been the case of Se and As. This type of analysis also allows the determination of which metals in a system may be more available for uptake. Currently there are no analytical methods which enable this type of analysis and therefore, the introduction of this analytical technique into the literature will prove to be very useful.

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Table 1. Trace Elements in Domestic and Domestic-Industrial Sewage Effluents

Trace Element mg/l (ppm)	Secondary	Municipal[2] Primary	Municipal[2*] Secondary	Industrial-Domestic[3] Secondary	Domestic[4] Secondary
Boron	0.7-0.9	-	-	-	-
Cadmium	0.008	0.06	0.02	0.03	0.016
Chromium	-	0.45	0.15	0.86	0.021
Cobalt	-	0.05	0.05	0.01	-
Copper	0.1	0.65	0.25	0.56	0.020
Iron	-	4.8	1.5	9.9	-
Lead	0.08	0.40	0.2	0.25	0.075
Manganese	-	0.4	0.38	0.13	-
Mercury	-	0.01	0.006	0.001	0.00042
Nickel	-	0.5	0.2	0.24	0.034
Silver	-	0.05	-	0.02	0.0049
Zinc	0.2	1.42	0.26	2.4	0.012

- no value given

* 95% of the values are less than or equal to the values given

[1] from Bouer (1974)   [2] from Mytelka, et al., (1973)   [3] from Morel, et al., (1975)   [4] from unpublished data

Table 2: Twenty-Two Sites in California Receiving Reclaimed Wastewater

Site	Treatment Processes	Effluent Quality	Application Method	Years Applied	Use
Camp Pendelton S.T.P. #2	PS, TF, OP, F Ch	2°	spray	26	Golf Course
Chowchilla W.T.P.	AS	1° (27 yrs) 2° (10 yrs)	flood	37	Pasture
Corning S.T.P.	PS, OP, Ch	1° (21 yrs) 2° (10 yrs)	flood	31	Orchard
Delano, City of W.T.P.	PS, OP	1° (8 yrs) 2° (11 yrs)	flood	19	Fiber Crop
Gustine City of W.T.P.	OP	1°	flood	40	Pasture
Laguna County, S.D. (Santa Maria)	OP, Ch, TF	2°	spray	6	Pasture
Las Virgenes					
Control	PS, AS, Ch	2°	spray	0.25	Crop
Low Rate	PS, AS, Ch	2°	spray	8	Fodder
High Rate	PS, AS, Ch	2°	spray	8	Disposal Field
Livermore, W.R.P.	PS, AS, C, F, Ch	2°	spray	13	Fodder
March Air Force Base	PS, TF, Ch	2°	spray	41	Fiber Crop
Moulton Nigel W.D. Rec. Fac.	AS, OP, Ch	2°	spray	14	Golf Course
North of the River S.D. #1 (Bakersfield)	PS, TF	2°	flood	33	Fodder
Palmdale, W.R.P.	PS, OP	2°	flood	14	Pasture
Pleasanton, S.T.P.	TF, AS, OP, Ch	2°	flood	30	Pasture

(Continued)

Table 2 (Continued)

Site	Treatment Processes	Effluent Quality	Application Method	Years Applied	Use
Pomona, W. Ren. P.	PS, AS, AC, Ch	2°	flood	14	Orchard
Occidential, C.S.D.	OP, C, F, Ch	2°	spray	12	Pasture
Fountain Valley	PS, AS, Ch	2°	flood	16	Forest
San Francisco, W.R.P.	PS, AS, Ch	2°	spray	48	Parkland
Shaftner PUD	PS, TF, OP	1°	flood	12	Fiber Crop
Taft, City of WPCF	OP	1°	spray	20	Fodder
Imperial Valley, S.D. (Indio)	PS, AS, OP, Ch	1° (20 yrs) 2° (10 yrs)	flood	30	Pasture
Wasco W.T.P.	PS	1° (39 yrs) 2° (1 yr)	flood	40	Pasture
Whittier Narrows W.R.P.	PS, AS, C, F, Ch	2°	flood	17	Recharge Basin

AS - Activated Sludge; C - Coagulation; Ch - Chlorination; F - Filtration; OP - Oxidation Ponds; PS - Primary Sedimentation; TF - Trickling Filter

1° - Primary Effluent; 2° - Secondary Effluent

Sur. - Surface Flooding; Spr. - Spray Irrigation able 3. Plant Species Collected at Test Sites

Number of Samples Collected at Each Site																						
LI	GU	CH	DE	WA	SH	OI	TA	SM	PAL	LC	LA	LD	WC	WD	PO	MF	IN	FC	FD	MV	CP	Total
10	18	-	-	-	-	1	-	-	-	6	-	8	1	1	-	-	-	-	-	1	-	55
3	6	3	6	1	2	3	6	-	-	2	10	-	-	-	-	2	-	-	-	-	2	53
-	2	2	-	-	-	2	-	-	-	12	14	7	2	3	-	1	-	-	-	-	1	46
-	1	-	-	-	2	-	-	-	-	7	-	4	-	2	2	-	-	-	-	2	-	20
-	-	-	-	-	-	-	-	1	-	9	-	3	-	2	-	4	-	-	-	-	-	19
-	3	-	-	-	-	-	3	-	-	-	-	-	-	-	-	4	-	-	-	-	-	10
4	3	4	-	7	2	1	1	-	5	-	-	-	-	-	-	-	-	-	-	-	-	29
-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	1	1	1	23
7	4	-	-	-	-	12	2	-	9	3	23	3	-	-	-	-	-	-	1	4	1	70
-	-	-	-	-	-	-	2	-	-	13	5	8	-	-	-	-	-	-	-	1	2	34
9	1	-	-	-	-	-	1	-	-	2	4	1	-	-	-	-	-	-	-	-	-	18
8	-	-	-	-	1	-	4	-	8	-	10	2	-	-	-	-	-	-	-	-	-	48

Number of Samples Collected at Each Site

U	CH	DE	WA	SH	OI	TA	SM	PAL	LC	LA	LD	WC	WD	PO	MF	IN	FC	FD	MV	CP	Total
9	-	5	-	-	-	-	-	4	-	-	-	-	-	-	1	-	-	-	1	-	20
	-	-	1	1	-	-	-	-	-	-	-	1	-	-	-	5	-	5	3	1	17
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	12	2	3	39
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	36	1	-	57
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	13	-	-	23
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	11	-	-	21
	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-	-	-	17

Table 4. Mean Concentration of Metal in Irrigation Effluent

Metal, mgl^{-1}	Sites		
	Fountain Valley	Las Virgenes	Whittier Narrows
Cadmium (Cd)	0.042	0.003	0.010
Copper (Cu)	0.185	0.011	0.090
Lead (Pb)	0.011	0.051	0.020
Nickel (Ni)	0.093	0.058	0.130
Zinc (Zn)	0.392	0.280	0.220

Table 5. Effect of Land Application of Wastewater on Soil Metal Concentration

Metals	Concentration of metal in 0-15 cm ($kgha^{-1}$)	Concentration of metal below 15 cm ($kgha^{-1}$)	Amount of metal applied in waste water (Kg)	Percent of metal explained by waste water application
		Orange County Control		
Cd	2.40	2.10	a	a
Cu	38.9	42.4	a	a
Ni	31.6	33.1	a	a
Pb	26.4	24.7	a	a
Zn	139.1	161.5	a	a
		Orange County Wastewater		
Cd	8.60	1.80	3.3	49.3
Cu	66.6	31.80	14.7	42.2
Ni	32.3	22.40	7.4	75.3
Pb	44.6	18.20	9.2	34.8
Zn	192.3	126.70	28.0	47.7
		Las Virgenes Control		
Cd	7.6	1.4	a	a
Cu	52.1	51.6	a	a
Ni	98.5	93.4	a	a
Pb	21.5	19.4	a	a
Zn	129.8	131.7	a	a
		Las Virgenes Low Rate		
Cd	8.8	7.9	8.1×10^{-4}	<0.1
Cu	67.6	53.5	5.0×10^{-4}	<0.1
Ni	59.7	52.1	2.6×10^{-3}	<0.1
Pb	8.4	7.1	2.3×10^{-3}	0.2
Zn	166.4	138.9	1.3×10^{-3}	<0.1
		Las Virgenes High Rate		
Cd	20.2	21.9	2.7×10^{-4}	b
Cu	51.1	53.6	9.8×10^{-4}	b
Ni	56.3	63.1	5.2×10^{-3}	b
Pb	18.4	20.3	4.6×10^{-3}	b
Zn	201.1	207.7	2.5×10^{-2}	b

(Continued)

Table 5 (Continued)

Metals	Concentration of metal in 0-60 cm[c] (Kg)	Concentration of metal below 60 cm (Kg)	Amount of metal applied in waste water[d] (Kg)	Percent of metal explained by waste water application
		Whittier Narrows Control		
Cd	0.03	a	a	a
Cu	3.03	a	a	a
Ni	1.73	a	a	a
Pb	0.37	a	a	a
Zn	5.37	a	a	a
		Whittier Narrows Disposal		
Cd	0.64	0.03	3.64	100.0
Cu	15.21	1.56	29.39	100.0
Ni	13.82	1.81	44.05	100.0
Pb	9.12	0.24	7.37	82.9
Zn	30.64	2.95	60.79	100.0

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[a] Application of wastewater not applicable.

[b] No accumulation in surface soil.

[c] Whittier Narrows disposal site exhibited elevated soil concentrations to a depth of 60 cm (Fountain Valley soil levels were only elevated to 15 cm). Therefore, the total amount of each metal was calculated for the 0-60 cm layer.

[d] Total amount of metal applied to the Whittier Narrows disposal site via wastewater disposal (approximately 12 years).

Table 6. Cation Exchange Capacity Values for Collection Sites

Site #	Site Name	Depth 1-15 cm	 16-90 cm
1	Taft	22.8	12.5
2	Chowchilla	9.7	9.8
3	Gustine	38.4	36.1
4	Wasco	9.8	12.0
5	Delano	37.3	37.5
6	Bakersfield	12.3	12.0
7	Indio	18.5	17.2
8	Moulton Nigel	41.1	27.8
9	Camp Pendelton	39.6	29.5
10	Whittier Narrows Disposal	23.4	8.7
11	Santa Maria	6.3	7.6
12	Shaftner	20.8	16.7
13	March Air Force Base	9.9	9.5
14	Whittier Narrows Control	28.8	12.8
15	Pleasanton	30.7	24.5
16	Livermore	13.4	14.4
17	San Francisco	17.1	8.0
18	Occidental	34.2	32.6
19	Corning	33.0	14.0
20	Pomona	10.5	8.0
21	Palmdale	14.0	12.5

Table 7. pH Values of Test Sites

	Hole:	1	2	3	4	5	6	7	8	9	10	11	"A"	"B"	13
Camp Pendelton	(a)*	6.0	7.0	6.5	5.8	6.8	6.1								
	(b)**	7.1	7.5	7.2	6.9	8.1	7.1								
Chowchilla	(a)	6.2	6.2	6.2	6.1	6.1	6.1	7.1	7.1	7.1	6.7				
	(b)	6.8	6.8	6.8	7.0	7.0	7.0	7.9	7.8	7.8					
Corning	(a)	6.4	6.6	6.8	6.8	6.5	6.5	6.5	6.9	6.7					
	(b)	7.0	7.4	7.4	7.0	6.9	6.8	6.8	7.1	7.2					
Delano	(a)	8.1	8.1	8.1	8.1	8.1	8.1	7.7	7.7	7.7					
	(b)	8.3	8.3	8.3	9.0	9.0	9.0	8.1	8.1	8.1					
Gustine	(a)	7.4	7.5	7.9	7.8	7.8									
	(b)	7.8	7.7	8.2	7.8	8.0									
Indio	(a)	8.0	8.0	8.1	8.1	8.1	8.1								
	(b)	8.1	8.1	8.0	8.0	8.1	8.1								
Livermore	(a)	7.1	6.8	6.9	6.8	6.9	6.7	7.1	6.3	6.3					
	(b)	7.7	7.6	8.4	7.8	8.4	7.8	7.1	7.7	7.6					
North of the River (Bakersfield)	(a)	7.9	7.9	7.9	5.9	5.9	5.9	7.1	7.2						
	(b)	8.4	8.2	8.2	6.9	6.8	6.8	8.3	8.1						
March Air Force Base	(a)	6.1	6.1	6.1	6.3	6.3	6.5	6.5	6.5	6.0		6.0	6.5	6.5	6.0
	(b)	7.0	7.1	7.0	7.0	6.9	6.8	7.2	7.3	7.2	6.9	6.9	7.2	7.2	6.9
Moulton Nigel	(a)	6.7	7.8	6.4	7.0	6.6	6.5								
	(b)	7.3	7.4	7.0	7.7	7.1	7.6								
Occidental	(a)	3.9	4.1	5.2	5.5	5.4	5.0								
	(b)	4.8	5.4	5.1	6.3	5.3	5.3								
Palmdale	(a)	7.3	5.6	7.3	7.9	7.6	7.6	7.6	8.0	7.6					
	(b)	7.8	8.0	7.7	9.1	8.5	7.9	8.5	9.3	7.7					

(Continued)

Table 7 (Continued)

	Hole:	1	2	3	4	5	6	7	8	9	10	11	"A"	"B"	13
Pleasanton	(a)	7.8	6.9	7.3	6.6	7.4	6.4	7.2	6.6	7.0					
	(b)	8.6	7.8	8.1	7.6	8.2	5.2	8.4	7.5	7.8					
Pomona	(a)	6.5	6.4	5.7	6.5	6.0	6.3	5.6	5.2	5.8					
	(b)	7.6	7.6	7.8	8.5	8.1	8.1	8.2	7.7	8.3					
San Francisco	(a)	6.6	5.9	5.7	6.0	5.4	5.7	5.8	5.6	5.6					
	(b)	6.9	6.9	6.2	6.3	6.1	5.2	5.3	6.5	6.1					
Laguna County (Santa Maria)	(a)	5.1	5.1	5.1	6.2	6.2	6.2	5.6	5.6	5.6					
	(b)	5.6	5.8	5.6	5.3	5.0	5.3	5.0	5.1	5.0					
Shaftner	(a)	8.1	7.7	8.1	8.1	7.7	7.7	7.1	7.1	7.1					
	(b)	8.6	8.5	8.6	9.1	8.9	8.5	8.9	8.4	8.4					
Taft	(a)	7.8	7.8	7.8	8.3	8.3	8.3	8.2	8.2	8.2					
	(b)	8.4	8.2	8.2	8.1	8.1	8.1	8.2	8.1	8.1					
Wasco	(a)	6.0	6.0	6.0	5.9	5.9	5.9	5.9	5.9	5.9					
	(b)	7.2	6.3	6.3	6.2	6.0	6.0	7.0	6.3	6.3					
Whittier Narrows	(a)	7.3	5.7	7.3	7.2	6.8	8.1								
	(b)	7.6	7.9	7.9	7.9	7.4	8.1								

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*a = 0 - 15 cm depth
**b = 15 - 75 cm depth

Table 8. Percent Water Values for Test Sites

	Hole:	1	2	3	4	5	6	7	8	9	10	11	"A"	"B"	13
Camp Pendelton	(a)*	26.3	17.9	8.3	12.8	22.3	26.2								
	(b)**	9.2	12.3	8.3	10.8	17.3	9.7								
Chowchilla	(a)	4.5	4.8	9.5	8.9	6.5	6.0	5.3	14.3						
	(b)	8.0	8.1	10.7	8.8	-	8.4	8.9	14.5						
Corning	(a)	19.2	17.3	19.3	16.6	15.0	26.0	12.5	14.9	10.3					
	(b)	15.9	17.7	17.0	11.0	10.4	11.0	11.3	12.2	8.0					
Delano	(a)	12.9	12.2	13.6	18.9	17.9	17.7	15.1	14.2	12.5					
	(b)	14.1	13.2	15.0	15.9	16.0	30.5	14.2	13.5	12.5					
Gustine	(a)	28.9	34.4	26.8	30.2	30.9									
	(b)	18.1	18.2	17.0	19.9	24.0									
Indio	(a)	2.9	3.0	3.9	2.6	6.5	3.3								
	(b)	7.3	7.9	11.5	7.6	14.6	7.5								
Livermore	(a)	11.9	7.3	8.2	11.0	5.8	5.8	8.7	7.9	7.4					
	(b)	7.6	4.7	4.4	6.5	5.5	3.1	4.5	5.3	4.5					
North of the River	(a)	3.6	4.4	4.5	10.0	12.1	13.3	10.9	10.4						
(Bakersfield)	(b)	8.0	3.5	5.2	8.7	-	10.3	10.2	10.0						
March Air Force	(a)	6.9	5.9	10.4	7.3	11.8	3.5	4.4	3.2	2.3	7.6	19.4	4.7	6.6	
Base	(b)	9.6	8.0	8.0	8.7	10.1	6.8	7.1	6.3	7.0	18.9	45.6	8.1	11.9	
MV	(a)	14.2	18.2	25.7	14.7	16.4	22.3								
	(b)	8.3	16.3	16.5	16.1	13.6	22.5								
Occidental	(a)	7.4	15.3	7.5	7.9	4.8	12.2								
	(b)	13.7	14.7	14.3	10.4	10.9	13.9								
Palmdale	(a)	6.6	9.9	13.4	10.9	11.6	13.6	9.0	7.3	11.5					
	(b)	6.5	10.0	11.4	8.2	7.1	11.5	9.5	10.0	7.8					

(Continued)

Table 8 (Continued)

	Hole:	1	2	3	4	5	6	7	8	9	10	11	"A"	"B"	13
Pleasanton	(a)	12.0	15.3	11.0	20.3	13.6	26.3	20.3	23.7	11.6					
	(b)	11.4	14.4	13.9	16.6	14.5	15.4	16.3	18.4	9.5					
Pomona	(a)	10.6	16.2	8.9	10.4	13.8	10.6	5.7	8.1	7.5					
	(b)	15.4	15.6	15.1	13.1	13.5	21.1	14.6	13.5	11.6					
San Francisco	(a)	16.1	16.2	9.2	8.3	16.4	18.8	7.5	13.2	13.6					
	(b)	7.0	7.6	9.8	4.5	6.7	9.2	4.7	6.2	7.7					
Laguna County (Santa Maria)	(a)	10.8	13.5	13.3	6.7	10.4	7.4	9.8	11.4	10.4					
	(b)	6.3	7.5	7.3	5.8	7.8	9.4	7.4	9.6	6.0					
Shaftner	(a)	19.1	16.5	7.0	6.1	8.1	4.4	4.2	1.7	3.0					
	(b)	16.1	16.6	12.3	14.1	15.7	14.0	13.3	12.2	9.7					
Taft	(a)	12.3	11.7	24.0	10.6	13.0	6.0	11.7	10.7	10.6					
	(b)	17.7	16.4	19.4	16.0	18.8	11.2	16.1	14.4	17.4					
Wasco	(a)	5.4	3.8	4.5	4.9	5.7	2.7	4.7	6.2	9.0					
	(b)	9.8	10.0	9.6	5.6	10.4	11.1	9.7	8.3	9.0					
Whittier Narrows	(a)	11.0	6.3	9.3	10.7	14.4	16.8								
	(b)	9.9	14.4	16.2	15.6	12.1	18.9								

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*a = 0 - 15 cm depth
**b = 15 - 75 cm depth

Table 9. Soil Metal Concentrations (μg/g) Bakersfield/Oilsdale

	Cd		Ni		Pb		Cu		Zn	
Depth(cm)	$\overline{X}$	±S.D.	$\overline{X}$	± S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.1	0.1	8.6	2.2	13.0	6.7	13.1	1.2	62.4	10.7
5-8	0.4	0.3	7.6	3.2	7.1	1.7	11.5	0.5	20.7	22.2
9-12	0.4	0.3	7.3	2.9	7.2	2.0	12.1	0.6	24.2	21.4
13-16	0.5	0.3	7.7	1.9	8.0	2.0	12.3	0.9	26.2	20.9
17-30	0.4	0.4	9.1	4.6	7.1	2.7	12.9	0.2	25.0	19.12
31-45	0.3	0.3	8.8	4.5	4.5	2.3	12.1	1.9	34.4	22.2
46-50	1.0	0.1	9.6	3.8	9.4	7.2	13.9	5.6	50.4	16.3
61-75	0.3	0.2	10.3	6.3	1.7	0.7	11.4	4.4	38.3	8.2
76-90	0.5	0.7	12.2	0.4	12.0	0.7	15.4	1.1	39.9	1.2

Table 10. Soil Metal Concentrations (μg/g) at Camp Pendelton

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	1.6	3.4	8.9	5.1	47.1	58.8	19.4	9.3	81.0	40.4
5-8	0.3	0.2	4.2	1.9	10.0	5.1	10.5	1.6	43.4	6.7
9-12	0.3	0.4	4.2	2.6	3.7	2.3	10.0	3.6	64.9	43.6
13-16	0.2	0.2	13.2	20.1	3.1	0.9	12.4	8.6	50.2	13.5
17-30	0.1	0.1	4.5	2.8	2.2	0.4	7.1	2.5	37.0	15.5
31-45	0.4	0.8	4.0	3.2	1.5	0.4	6.3	3.3	37.2	15.8
46-50	0.3	0.5	10.2	7.1	10.1	8.4	12.6	5.2	43.3	14.7

Table 11. Soil Metal Concentrations (μg/g) at Chowchilla

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.
0-4	0.3	0.3	11.9	5.2	14.4	6.5	16.1	6.1	67.1	19.8
5-8	0.2	0.1	7.4	3.7	4.3	2.9	12.7	3.0	24.2	22.1
9-12	0.2	0.2	7.7	3.6	4.6	3.0	12.6	3.1	23.4	23.4
13-16	0.3	0.1	8.9	3.8	8.1	3.5	12.9	2.7	35.1	24.0
17-30	0.2	0.1	10.8	5.1	14.0	8.9	17.7	8.1	62.2	45.8
31-45	0.1	0.1	8.2	2.1	3.8	2.2	13.5	3.0	25.8	22.9
46-50	0.1	0.1	14.4	4.4	11.3	6.5	17.5	4.3	64.9	13.6

Table 12. Soil Metal Concentrations (μg/g) at Corning

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.2	0.2	50.4	23.8	9.0	0.6	38.4	9.6	61.7	35.9
5-8	0.4	0.4	47.2	24.7	10.5	2.9	34.1	12.3	51.5	38.1
9-12	0.3	0.4	24.0	13.9	6.7	4.0	31.3	12.7	28.3	19.5
13-16	0.3	0.4	33.2	17.4	7.7	3.7	25.8	14.8	40.3	21.0
17-30	0.3	0.3	33.8	8.3	6.2	1.7	29.6	15.5	33.2	14.3
31-45	0.7	0.5	62.5	24.8	3.0	2.9	37.4	15.1	60.9	25.5
46-50	0.3	0.2	38.5	37.8	4.0	0.0	27.9	15.9	31.0	32.7
61-75	0.2	0.3	-a		-a		21.3	7.3	22.1	25.1
76-90	0.3	0.4	23.6	17.9	2.1	2.3	22.2	7.5	15.5	26.1

- a = not determined

Table 13. Soil Metal Concentrations (μg/g) at Delano

Depth (cm)	Cd		Ni		Cu		Zn	
	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.5	0.3	15.5	3.7	15.4	3.6	73.8	14.5
5-8	0.6	0.4	16.2	1.2	16.8	0.7	28.8	9.5
9-12	0.7	0.1	16.3	1.4	16.7	0.3	29.3	4.7
13-16	0.6	0.4	15.9	0.9	16.8	0.8	29.8	4.9
17-30	0.6	0.0	16.4	1.2	16.1	0.4	26.1	6.6
31-45	0.3	0.2	18.8	0.7	14.2	0.2	12.1	1.6
46-50	0.2	0.2	16.6	3.7	13.5	1.6	55.9	11.9

Table 14. Soil Metal Concentrations (μg/g) at Fountain Valley Disposal

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	6.0	2.1	21.9	3.8	56.8	8.1	46.0	8.5	116.8	10.9
5-8	5.8	4.8	19.4	4.9	38.2	31.4	41.5	20.4	110.0	43.2
9-12	4.9	5.9	16.9	5.2	29.4	34.2	35.7	24.7	101.2	51.6
13-16	4.1	6.8	15.4	5.6	30.0	42.0	32.9	31.6	106.1	63.0

Table 15. Soil Metal Concentrations (μg/g) at Gustine

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.6	0.3	64.2	3.0	29.9	6.4	45.9	2.7	107.9	37.7
5-8	0.5	0.2	18.7	6.5	16.9	8.6	36.5	17.8	38.4	4.1
9-12	0.4	0.2	24.9	4.0	15.7	4.2	38.3	17.9	24.7	20.2
13-16	0.4	0.4	22.0	8.3	19.5	6.1	17.0	26.7	47.0	3.1
17-30	0.3	0.3	28.5	3.9	11.8	2.9	40.7	17.5	37.5	16.3
31-45	0.3	0.2	29.4	3.6	7.1	2.4	45.6	3.4	29.2	19.8
46-50	0.4	0.3	83.0	3.1	19.1	3.8	49.4	2.2	102.6	3.6
61-75	-a		79.9	1.73	15.9	1.7	47.5	0.8	98.7	1.7

-a - Not determined

Table 16. Soil Metal Concentrations (μg/g) at Indio

Depth (cm)	Cd		Ni		Pb		Cu		Zn	
	$\bar{X}$	± S.D.	$\bar{X}$	± S.D.	$\bar{X}$	± S.D.	$\bar{X}$	± S.D.	$\bar{X}$	± S.D.
0-4	0.3	0.5	26.2	1.2	17.4	9.5	46.5	7.6	162.7	41.3
5-8	0.1	0.3	26.5	1.9	10.9	1.7	29.8	25.1	23.7	1.7
9-12	0.8	0.3	26.5	0.9	11.0	1.9	46.5	5.2	22.2	2.0
13-16	0.8	0.3	25.6	1.0	10.7	2.0	45.1	4.2	19.4	4.0
17-30	0.1	0.6	25.9	1.0	10.7	2.2	46.3	5.0	20.3	1.7
31-45	0.5	0.5	26.5	1.1	8.8	2.6	32.2	24.0	16.8	9.3
46-50	0.5	0.5	26.5	2.5	12.2	10.5	42.4	10.0	127.3	22.9

Table 17. Soil Metal Concentrations (μg/g) at Livermore

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.1	0.2	35.2	47.7	3.2	2.9	26.1	15.8	13.2	21.6
5-8	0.1	0.2	48.8	36.3	7.0	1.6	34.0	3.8	17.0	16.9
9-12	0.9	0.1	68.8	58.3	8.2	1.5	34.4	4.5	29.9	24.0
13-16	0.4	0.4	53.0	37.0	14.1	17.3	33.1	2.8	13.8	16.6
17-30	0.2	0.3	72.7	56.6	12.1	16.0	33.8	3.9	28.0	25.5
31-45	0.1	0.3	63.3	58.6	4.1	1.1	33.7	4.5	24.7	25.3
46-50	0.2	0.3	72.0	59.4	17.1	23.4	34.3	3.9	24.6	24.5
61-75	0.5	0.4	120.0	48.5	4.8	0.0	31.6	2.7	43.0	26.7
76-90	0.2	0.0	45.5	0.0	4.6	0.0	28.1	0.0	4.6	0.0

Table 18. Soil Metal Concentrations (μg/g) at March Air Force Base

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.
0-4	0.1	0.1	5.9	1.2	15.5	15.3	12.8	1.6	53.1	18.3
5-8	0.1	0.1	5.7	1.9	3.9	2.3	10.4	1.8	43.8	6.5
9-12	0.2	0.2	5.8	2.1	3.7	2.5	10.3	2.0	41.3	5.6
13-16	0.1	0.2	6.1	2.2	3.8	2.7	10.8	2.2	44.9	7.7
17-30	0.8	1.0	6.7	2.3	1.6	1.8	11.3	2.0	44.8	5.4
31-45	0.9	1.0	7.2	2.4	1.1	0.8	12.0	2.5	46.8	6.5
46-50	0.6	0.1	7.9	1.6	7.8	11.9	14.5	2.8	54.0	12.5
61-75	0.3	0.6	9.3	1.4	18.5	14.3	14.3	2.0	59.0	3.5
76-90	0.0	0.0	6.9	2.3	20.9	24.7	17.0	3.5	46.1	10.2

Table 19. Soil Metal Concentrations (μg/g) at Moulton Niguel

Depth (cm)	Cd $\overline{X}$	Cd ±S.D.	Ni $\overline{X}$	Ni ±S.D.	Pb $\overline{X}$	Pb ±S.D.	Cu $\overline{X}$	Cu ±S.D.	Zn $\overline{X}$	Zn ±S.D.
0-4	1.5	0.5	11.3	1.2	33.5	19.9	15.4	4.2	64.9	24.8
5-8	1.0	0.5	11.3	6.1	5.0	1.2	13.0	3.4	56.3	9.5
9-12	1.0	0.6	11.8	6.3	4.9	0.0	15.1	4.5	58.5	12.0
13-16	0.8	0.7	10.1	4.9	3.5	1.8	14.2	3.9	54.6	8.8
17-30	0.9	1.0	11.3	7.7	1.4	0.5	13.0	3.9	50.3	8.1
31-45	0.9	1.1	11.2	9.1	13.5	18.1	14.3	5.9	52.0	14.3
46-50	1.0	0.1	9.7	0.9	4.8	3.8	6.8	0.3	39.7	4.9

Table 20. Soil Metal Concentrations (μg/g) at Occidental

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.8	0.3	19.8	4.5	-a		4.7	0.9	18.6	2.8
5-8	0.1	0.9	16.9	7.2	4.2	2.4	0.4	1.0	16.2	3.4
9-12	1.0	0.5	18.1	4.8	1.6	2.2	4.4	0.7	14.7	2.6
13-16	0.7	0.4	15.3	2.8	10.9	7.4	3.7	1.3	14.5	2.9
17-30	0.2	0.0	21.2	5.2	0.7	0.0	5.3	0.8	18.1	6.1
31-45	0.2	0.3	23.3	3.2	1.3	1.8	5.6	0.9	17.0	2.5
46-50	0.6	0.7	26.9	11.8	1.9	2.1	6.9	4.1	19.1	7.1
61-75	1.0	0.5	33.9	11.2	1.3	0.9	10.8	5.3	24.6	8.5
76-90	4.4	6.2	31.6	1.7	3.4	3.2	12.8	2.5	26.2	9.2

-a Not Determined

Table 21. Soil Metal Concentrations (μg/g) at Palmdale

	Cd		Ni		Pb		Cu		Zn	
Depth	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.
0-4	0.4	0.9	7.1	8.8	0.2	0.5	15.6	19.6	14.5	23.9
5-8	0.3	0.5	6.7	9.3	0.4	1.0	16.8	20.0	11.6	21.0
9-12	0.9	0.1	9.6	9.5	0.2	0.4	23.4	19.1	20.1	25.4
13-16	0.1	0.3	9.4	9.3	1.3	3.4	20.4	20.2	21.1	25.5
17-30	0.4	0.8	6.2	9.0	0.7	0.2	13.1	18.6	9.5	16.8
31-45	0.8	1.0	8.1	9.8	0.5	0.6	13.3	19.9	1.5	4.1
46-50	0.2	0.3	8.8	9.5	0.6	1.1	24.4	21.4	13.7	21.5
61-75	0.1	0.2	6.2	10.8	0.4	0.7	12.6	21.9	2.9	5.1
76-90	0.2	0.3	4.0	6.8	0.7	1.2	8.4	14.6	0.5	0.9

Table 22. Soil Metal Concentrations (μg/g) at Pleasanton

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.7	1.2	46.0	6.5	17.4	4.9	30.8	8.3	42.9	29.4
5-8	0.1	0.8	34.3	19.6	13.8	1.4	30.6	7.0	33.0	20.8
9-12	0.3	0.4	32.7	32.3	13.7	4.2	25.9	8.7	37.4	37.0
13-16	0.3	0.3	23.2	27.8	10.3	3.0	26.9	4.8	26.3	19.4
17-30	0.4	0.4	38.3	26.8	17.8	17.3	27.4	6.0	31.4	25.0
31-45	0.3	0.3	48.4	36.4	18.1	24.8	33.9	14.3	34.3	26.8
46-50	0.4	0.4	44.6	44.1	11.2	6.1	38.8	11.3	37.2	24.6
61-75	0.5	0.0	42.3	3.9	9.0	0.0	39.0	4.7	15.5	3.0
76-90	1.0	0.5	7.9	5.3	6.7	0.9	43.1	3.3	24.3	6.9

Table 23. Soil Metal Concentrations (μg/g) at Pomona

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.2	0.3	16.8	3.6	64.6	25.1	32.8	12.1	76.2	28.4
5-8	0.2	0.4	16.7	2.7	67.5	25.8	34.0	26.0	72.5	34.2
9-12	0.3	0.3	15.9	2.0	59.7	22.1	28.1	14.0	61.3	29.7
13-16	0.2	0.2	26.5	38.9	59.0	26.9	22.2	5.1	56.4	24.4
17-30	0.3	0.3	14.2	3.4	21.2	20.6	20.0	4.7	43.4	20.0
31-45	0.4	0.5	19.5	5.9	7.0	9.8	25.6	5.1	56.0	25.6
46-50	0.5	0.4	19.5	3.5	6.1	6.0	25.6	3.3	57.4	23.6
61-75	0.6	0.2	19.0	5.7	-a		23.9	8.5	70.4	21.7
76-90	0.4	0.6	12.0	16.9	0.0	0.0	13.8	19.5	37.7	53.3

-a = Not determined

Table 24. Soil Metal Concentrations (μg/g) at San Francisco

	Cd		Ni		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.4	0.6	25.6	2.6	30.4	7.8	54.7	29.8
5-8	0.3	0.2	29.4	3.9	30.2	6.9	60.7	23.6
9-12	0.3	0.4	29.3	3.2	30.1	8.7	47.5	20.5
13-16	0.3	0.1	29.1	4.2	24.1	10.8	60.6	21.9
17-30	0.2	0.2	34.0	5.3	25.2	3.9	43.0	13.8
31-45	0.3	0.4	28.8	13.1	17.8	12.1	37.8	23.4
46-50	0.2	0.4	26.8	7.9	10.4	11.3	30.0	19.6
61-75	0.3	0.4	26.0	7.5	11.32	19.0	26.1	20.9
76-90	0.4	0.6	29.9	17.4	15.6	25.0	29.0	20.0

Table 25. Soil Metal Concentrations (μg/g) at Santa Maria

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.7	2.1	2.3	1.4	4.0	6.5	4.8	1.5	19.5	24.7
46-50	0.9	0.5	3.3	1.6	4.8	7.4	4.7	1.3	10.4	3.1
76-90	0.7	0.1	3.9	4.0	1.3	1.9	5.7	1.8	15.4	13.1

Table 26. Soil Metal Concentrations (µg/g) at Shaftner

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.3	0.2	16.4	1.5	12.5	4.8	20.0	2.6	81.5	11.5
46-50	0.2	0.1	19.2	3.7	10.2	3.5	21.4	4.1	73.0	13.8
76-90	0.2	0.1	22.6	4.3	10.1	3.0	26.1	3.6	69.9	8.7

Table 27. Soil Metal Concentrations (μg/g) at Taft

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	2.2	0.6	38.2	2.9	11.9	4.5	19.9	1.6	76.9	7.9
5-8	2.9	0.3	41.3	8.2	7.9	0.0	19.6	0.6	60.4	32.0
9-12	2.8	0.2	38.5	3.6	8.4	0.0	18.5	1.0	58.2	28.7
13-16	2.7	0.4	38.5	4.6	8.1	0.0	18.8	1.9	57.9	32.1
17-30	2.9	0.5	37.1	5.0	8.9	0.0	19.4	2.7	62.3	34.4
31-45	2.9	0.8	40.2	3.3	5.6	0.0	19.9	0.1	56.9	21.2
46-50	2.4	0.7	43.6	5.5	14.1	3.0	21.6	2.3	80.0	11.3
61-75	3.1	0.2	41.0	3.9	-a		20.8	1.7	74.1	9.3
76-90	3.1	1.3	27.1	28.7	8.4	2.5	24.8	5.8	85.6	18.4

-a = Not determined

Table 28. Soil Metal Concentrations (μg/g) at Wasco

	Cd		Ni		Cu		Zn	
Depth (cm)	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.	$\overline{X}$	±S.D.
0-4	0.2	0.4	7.8	1.4	10.6	1.2	44.5	10.2
5-8	0.3	0.1	6.6	0.6	9.5	0.3	43.6	1.9
9-12	0.2	0.9	7.1	0.4	9.9	0.6	44.2	5.8
13-16	0.6	0.5	6.3	0.6	11.4	4.7	48.2	9.4
17-30	0.5	0.3	6.4	0.1	10.1	2.9	50.3	14.1
31-45	0.7	0.2	9.8	2.5	9.1	2.6	44.0	3.4
46-50	0.2	0.3	6.7	0.0	9.9	1.9	44.9	5.6
61-75	0.4	0.3	8.5	0.0	8.6	2.4	42.1	0.4
76-90								

Table 29. Mean Soil Metal Concentrations (μg/g) at Whittier Narrows Control

Depth (cm)	Cd	Ni	Pb	Cu	Zn
0-4	0.2	26.0	8.6	41.0	83.0
5-8	0.2	27.0	7.6	46.0	83.0
9-12	0.5	27.0	1.6	44.0	82.0
13-16	1.0	24.0	4.8	41.0	65.0
17-30	1.0	33.0	2.6	51.0	83.0
31-45	0.5	13.0	0.8	19.0	40.0
46-50	0.5	20.0	1.0	27.0	61.0
61-75	0.2	33.0	1.4	51.0	95.0
76-90	0.2	29.0	2.2	38.0	64.3

Table 30. Soil Metal Concentrations (μg/g) at Whittier Narrows Disposal

	Cd		Ni		Pb		Cu		Zn	
Depth (cm)	$\bar{X}$	±S.D.	X	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.
0-4	7.6	7.7	90.3	74.0	135.4	149.0	123.3	100.8	283.5	321.0
5-8	8.3	8.7	135.2	89.1	110.2	134.2	146.0	124.2	345.4	404.9
9-12	8.1	5.7	150.7	70.7	102.8	77.1	174.6	89.6	352.8	240.7
13-16	5.3	4.0	100.7	66.0	45.9	55.43	109.5	76.8	177.6	113.4
17-30	2.0	1.1	70.0	35.1	17.9	11.1	66.7	36.7	113.4	43.0
31-45	1.7	2.5	42.5	21.5	7.4	3.1	42.8	13.21	68.6	27.0
46-50	2.3	6.1	52.4	27.4	6.4	2.4	45.2	21.9	79.5	27.6
61-75	0.7	1.0	41.1	21.6	5.6	1.9	34.4	13.7	67.1	22.4
76-90	0.5	0.5	43.1	15.5	5.6	1.7	38.2	7.9	70.1	14.6

Table 31. Metal Concentrations in Soil at Fountain Valley Sites

	Soil Depth, cm							
Metal, µg/g	0-15	16-30	31-45	46-60	61-75	76-90	90-105	106-120
	Control							
Cd	1.2 ± 0.4	1.2 ± 0.3	1.0 ± 0.3	1.1 ± 0.3	1.0 ± 0.3	1.0 ± 0.3	0.4 ± 0.4	0.9 ± 0.3
Cu	19.8 ± 2.2	21.3 ± 3.4	20.8 ± 2.9	20.3 ± 2.9	20.6 ± 2.1	22.0 ± 2.5	22.0 ± 2.3	21.5 ± 3.3
Ni	15.8 ± 2.9	16.2 ± 2.9	16.9 ± 3.1	16.3 ± 3.1	15.9 ± 2.6	16.8 ± 2.7	17.1 ± 1.5	16.7 ± 2.3
Pb	13.2 ± 4.6	12.6 ± 3.4	12.2 ± 3.6	12.1 ± 4.4	12.1 ± 4.3	11.9 ± 3.2	13.2 ± 3.5	12.3 ± 3.1
Zn	69.7 ±24.8	77.0 ± 9.9	88.1 ±13.7	79.1 ±13.5	77.2 ±10.3	79.6 ± 8.7	82.3 ± 8.4	82.0 ±13.1
	Disposal							
Cd	4.3 ± 2.7	1.1 ± 0.2	1.0 ± 0.3	0.9 ± 0.4	0.8 ± 0.3	0.9 ± 0.3	0.9 ± 0.2	0.9 ± 0.3
Cu	33.3 ± 6.3	15.9 ± 1.8	15.1 ± 2.7	14.6 ± 1.4	14.2 ± 6.3	18.9 ± 3.4	17.2 ± 3.5	15.5 ± 2.6
Ni	16.1 ± 2.8	11.3 ± 2.4	10.9 ± 2.7	9.9 ± 2.0	9.6 ± 3.6	12.2 ± 2.9	12.0 ± 3.2	12.8 ± 3.3
Pb	22.3 ±12.5	9.7 ± 2.8	9.6 ± 2.9	9.2 ± 2.6	7.6 ± 3.0	10.6 ± 3.8	8.7 ± 3.6	8.1 ± 2.6
Zn	96.4 ±22.1	64.2 ±16.1	62.9 ±13.3	55.3 ± 9.6	55.0 ±18.9	71.9 ±10.8	69.0 ±13.8	66.0 ±10.4

Table 32. Metal Concentrations in Soil at Las Virgenes Site

	Soil Depth, cm							
Metal, μg/g	0-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120
				Control				
Cd	3.8 ± 2.4	3.4 ± 0.6	3.4 ± 0.6	3.3 ± 0.7	3.7 ± 0.6	3.2 ± 0.6	3.7 ± 0.9	3.4 ± 0.4
Cu	26.1 ± 4.4	27.4 ± 2.2	26.2 ± 2.7	25.4 ± 1.1	25.9 ± 1.8	23.4 ± 2.8	26.2 ± 3.3	25.5 ± 3.2
Ni	49.5 ±11.4	49.3 ±11.9	47.4 ±10.6	45.9 ± 9.8	44.3 ±11.6	40.7 ± 9.8	47.9 ±16.6	48.3 ±16.7
Pb	10.8 ± 4.4	10.3 ± 4.1	9.4 ± 3.7	9.7 ± 3.0	8.9 ± 3.6	9.1 ± 3.4	9.4 ± 4.9	9.5 ± 4.2
Zn	65.2 ± 6.8	70.8 ±11.7	68.5 ±12.9	65.7 ± 8.3	67.4 ± 6.7	59.8 ± 5.6	66.6 ±14.5	63.0 ± 8.9
				Low Rate				
Cd	4.4 ± 0.7	4.5 ± 0.6	4.2 ± 0.5	4.1 ± 0.9	3.7 ± 0.3	3.7 ± 0.3	3.5 ± 0.5	3.4 ± 0.5
Cu	33.9 ± 3.4	28.7 ± 3.8	24.4 ± 3.2	21.6 ± 2.2	21.7 ± 2.6	20.1 ± 2.6	17.8 ± 1.0	18.8 ± 1.7
Ni	29.9 ± 2.3	29.7 ± 2.1	27.4 ± 3.4	26.5 ± 3.2	25.3 ± 3.8	24.8 ± 2.5	23.0 ± 2.6	21.6 ± 2.8
Pb	13.2 ± 2.4	10.9 ± 2.3	8.1 ± 2.1	7.6 ± 2.2	7.4 ± 2.1	6.8 ± 2.1	6.8 ± 1.9	7.1 ± 2.1
Zn	83.4 ±24.1	84.5 ± 5.2	73.0 ± 9.0	68.6 ±11.4	66.4 ±11.2	62.4 ± 6.9	56.7 ± 4.6	58.5 ± 5.7
				High Rate				
Cd	10.1 ± 1.6	10.5 ± 2.0	11.0 ± 2.2	11.5 ± 2.9	10.6 ± 2.9	10.7 ± 1.7	10.9 ± 3.9	11.4 ± 3.0
Cu	25.6 ± 2.5	26.3 ± 3.6	28.1 ± 4.3	27.6 ± 4.2	27.9 ± 3.4	25.7 ± 2.4	25.6 ± 2.1	27.0 ± 3.5
Ni	28.2 ± 4.9	31.2 ± 8.2	32.5 ± 7.7	34.2 ±10.9	30.8 ± 9.6	32.7 ± 9.2	30.7 ± 5.4	31.8 ± 7.0
Pb	9.2 ± 2.1	10.8 ± 2.5	11.1 ± 2.4	11.7 ± 4.1	11.2 ± 3.9	10.4 ± 1.9	10.2 ± 3.8	10.8 ± 3.1
Zn	100.8 ±10.2	101.0 ±12.9	112.3 ±29.9	105.3 ±18.8	101.0 ±10.7	104.7 ±20.5	101.3 ±11.6	104.1 ±15.2

Table 33. Mean Concentrations in Tree Species Collected at Fountain Valley Sites

Species	Control µg/g $\bar{X}$ ±S.D.	Wastewater µg/g $\bar{X}$ ±S.D.	T Value
<u>Pinus Pinea,</u> L.			
leaf			
Ag	0.1 ± 0.2	0.1 ± 0.1	0.05[a]
Cd	0.6 ± 0.4	1.6 ± 0.7	31.00[c]
Cu	4.0 ± 1.3	5.0 ± 1.5	4.61[b]
Pb	31.6 ±22.1	17.8 ± 9.6	10.69[b]
Ni	2.5 ± 1.8	3.2 ± 1.6	1.80[a]
Zn	26.8 ± 8.6	30.3 ± 7.3	2.80[a]
stem			
Ag	0.2 ± 0.1	0.1 ± 0.2	0.37[a]
Cd	0.8 ± 0.5	1.8 ± 0.8	32.23[c]
Cu	4.8 ± 1.1	5.5 ± 1.5	2.52[a]
Pb	47.15±26.2	17.4 ± 8.9	38.40[c]
Ni	3.3 ± 1.6	3.2 ± 1.7	0.05[a]
Zn	43.4 ±19.8	25.2 ± 7.7	20.95[c]
<u>Pinus Halepensis</u>, Mill.			
needle			
Ag	0.1 ± 0.08	0.1 ± 0.1	0.22[a]
Cd	0.6 ± 0.4	1.1 ± 0.7	6.82[b]
Cu	4.1 ± 1.0	4.2 ± 1.3	0.14[a]
Pb	32.5 ±19.5	15.7 ± 9.4	7.64[b]
Ni	2.4 ± 1.4	2.3 ± 1.7	0.02[a]
Zn	31.9 ±16.0	23.2 ± 4.3	3.02[a]
stem			
Ag	0.05± 0.0	0.3 ± 0.4	1.52[a]
Cd	0.7 ± 0.6	1.8 ± 0.6	18.36[c]
Cu	4.7 ± 1.3	5.2 ± 0.7	1.21[a]
Pb	34.1 ±25.1	26.10±16.3	0.83[a]
Ni	3.8 ± 2.9	2.3 ± 1.6	3.30[a]
Zn	36.5 ±17.6	26.4 ± 5.6	3.71[a]

(continued)

Table 33. (Continued)

Species	Control µg/g $\bar{X}$ ± S.D.	Wastewater µg/g $\bar{X}$ ± S.D.	T value
<u>Cupressus</u> <u>sempervirins</u> <u>horizontalis</u>			
leaf			
Ag	0.05 ± 0.0	0.3 ± 0.3	1.33[a]
Cd	0.7 ± 0.5	2.2 ± 0.9	23.44[c]
Cu	4.9 ± 1.0	6.0 ± 1.4	4.42[b]
Pb	62.9 ±19.7	41.9 ±19.7	4.85[b]
Ni	2.6 ± 1.8	4.8 ± 1.4	8.84[b]
Zn	20.5 ± 5.8	29.8 ± 8.2	9.53[b]
stem			
Ag	0.05 ± 0.0	0.2 ± 0.2	0.75[a]
Cd	0.6 ± 0.3	2.6 ± 0.7	48.64[c]
Cu	6.6 ± 1.7	8.2 ± 2.4	1.90[a]
Pb	56.2 ±42.9	38.6 ±28.2	1.22[a]
Ni	3.1 ± 2.3	4.2 ± 2.0	1.08[a]
Zn	52.5 ±23.9	27.1 ± 7.9	12.21[b]
<u>Grevillea</u> <u>robusta</u>, Cunn.			
Leaf			
Ag	0.2 ± 0.2	0.05± 0.0	1,05[a]
Cd	0.8 ± 0.8	0.8 ± 0.5	0.01[a]
Cu	6.4 ± 1.1	6.5 ± 2.0	0.02[a]
Pb	32.8 ±27.0	21.2 ±19.4	1.24[a]
Ni	3.8 ± 2.2	3.3 ± 1.4	0.25[a]
Zn	23.7 ± 5.6	18.9 ± 5.0	5.09[b]
stem			
Ag	0.1 ± 0.08	0.05± 0.0	1.33[a]
Cd	0.7 ± 0.6	0.6 ± 0.4	0.31[a]
Cu	7.0 ± 2.2	6.0 ± 2.2	1.14[a]
Pb	26.8 ±19.7	25.9 ±25.4	0.01[a]
Ni	2.6 ± 1.5	3.1 ± 1.6	0.50[a]
Zn	33.7 ± 8.9	22.2 ± 8.0	0.64[b]

a = no significance
b = $p<0.05$
c = $p<0.001$

Table 34. Comparisons of Annuals and Perennials Collected at Las Virgenes Sites

	Control μg/g $\bar{X}$ ± S.D.	Low Rate μg/g $\bar{X}$ ± S.D.	High Rate μg/g $\bar{X}$ ± S.D.	F-score	d.f.
Annuals					
Whole Plant					
Ag	0.2 ± 0.3	0.2 ± 0.2	0.5 ± 1.0	4.30^b	2,127
Cd	2.0 ± 1.8	1.6 ± 1.3	4.6 ± 2.7	53.49^c	2,276
Cu	5.1 ± 2.1	7.7 ± 3.3	6.3 ± 2.7	12.67^c	2,169
Pb	4.0 ± 2.6	6.3 ± 4.4	4.7 ± 2.9	8.74^c	2,206
Ni	3.3 ± 118	3.4 ± 1.5	2.5 ± 1.3	3.34^b	2,200
Zn	26.1 ±13.9	32.5 ±13.9	28.2 ± 9.7	4.24^b	2,173
Perrenials					
Whole Plant					
Ag	0.1 ± 0.1	0.2 ± 0.2	0.1 ± 0.1	0.40^a	2,50
Cd	3.0 ± 3.5	5.0 ± 3.4	6.8 ± 6.9	5.50^b	2,95
Cu	8.4 ± 4.3	9.6 ± 3.4	9.3 ± 4.9	0.79^b	2,89
Pb	5.3 ± 3.0	7.5 ± 6.9	7.6 ± 5.3	4.35^b	2,95
Ni	4.7 ± 1.9	4.9 ± 1.6	4.7 ± 2.7	0.89^a	2,95
Zn	25.0 ±14.9	53.2 ±22.3	31.0 ±13.7	21.51^c	2,86

[1] root material excluded
a = not significant
b = $p < 0.05$
c = $p < 0.001$

Table 35. Comparisons of Vegetation Collected at Las Virgenes Sites Based on Whole Plant Samples

	Control µg/g $\bar{X}$ ± S.D.	Low Rate µg/g $\bar{X}$ ± S.D.	High Rate µg/g $\bar{X}$ ± S.D.	F-score	d.f.
Annuals					
Brassica spp.					
Ag	0.5 ± 0.2	0.1 ± 0.1	2.2 ± 2.4	9.23^{b}	2,21
Cd	2.3 ± 1.1	2.8 ± 1.3	6.8 ± 2.9	26.41^{c}	2,55
Cu	4.4 ± 1.1	6.3 ± 2.6	4.4 ± 1.2	4.72^{b}	2,45
Pb	3.4 ± 2.1	6.6 ± 4.0	3.5 ± 1.8	7.91^{c}	2,58
Ni	2.6 ± 2.0	3.4 ± 1.0	2.3 ± 1.6	2.16^{a}	2,55
Zn	31.6 ±14.6	34.8 ±12.9	31.0 ±12.3	0.38^{a}	2,46
Raphanus sativus, L.					
Ag	0.3 ± 0.4	-^{d}	0.9 ± 0.0	2.23^{b}	11
Cd	3.3 ± 0.9	-	4.4 ± 2.3	-1.55^{a}	22
Cu	4.1 ± 1.0	-	3.5 ± 1.0	1.03^{a}	18
Pb	5.4 ± 3.5	-	5.1 ± 2.9	-0.07^{a}	22
Ni	3.2 ± 1.6	-	1.6 ± 1.2	5.04^{b}	26
Zn	24.2 ±13.3	-	25.9 ±13.3	1.94^{a}	20
Bromus spp.					
Ag	0.07± 0.05	-	0.1 ± 0.08	-0.63^{a}	8
Cd	1.9 ± 1.9	1.5 ± 0.7	4.5 ± 1.7	5.21^{b}	2,23
Cu	8.2 ± 5.8	9.5 ± 5.5	7.9 ± 5.9	0.13^{a}	2,19
Pb	4.0 ± 1.9	5.1 ± 1.6	6.3 ± 6.1	1.11^{a}	2,22
Ni	4.0 ± 1.4	6.1 ± 2.8	4.6 ± 2.0	2.03^{a}	2,21
Zn	25.3 ±19.1	48.1 ± 6.5	40.7 ±17.4	3.30^{a}	2,20
Avena fatua					
Ag	0.05± 0.0	0.05± 0.0	-	^{a}	2
Cd	3.7 ± 1.0	18.6 ±12.5	-	-2.98^{b}	8
Cu	-	-	-	-	-
Pb	2.9 ± 1.7	5.9 ± 0.2	-	5.75^{b}	9
Ni	-	-	-	-	-
Zn	12.2 ± 4.6	27.0 ± 9.1	-	14.69^{b}	10
Medicago spp.					
Ag	0.2 ± 0.1	0.4 ± 0.2	0.08± 0.06	4.64^{b}	2,17
Cd	1.2 ± 0.2	1.2 ± 0.7	1.9 ± 0.9	1.78^{b}	2,55
Cu	7.8 ± 1.8	8.3 ± 1.4	8.5 ± 2.7	0.18^{a}	2,42
Pb	3.5 ± 2.8	5.7 ± 4.7	7.1 ± 3.8	0.97^{a}	2.51
Ni	5.0 ± 2.4	2.7 ± 1.8	3.0 ± 0.5	4.27^{a}	2,54
Zn	35.0 ± 5.0	26.7 ± 8.7	26.9 ± 7.4	1.35^{a}	2,38

(Continued)

Table 35 (Continued)

	Control μg/g $\bar{X}$ ± S.D.	Low Rate μg/g $\bar{X}$ ± S.D.	High Rate μg/g $\bar{X}$ ± S.D.	F-score	d.f.
Perennials					
Malva parviflora, L.					
Ag	-	-	-	-	-
Cd	4.8 ± 0.3	5.6 ± 3.3	-	0.38[a]	22
Cu	5.0 ± 0.7	10.4 ± 2.4	-	10.04[b]	19
Pb	5.0 ± 0.0	8.1 ± 1.6	-	6.68[c]	19
Ni	5.0 ± 0.0	4.6 ± 1.3	-	0.16[a]	16
Zn	34.5 ± 4.2	56.3 ±24.7	-	1.48[c]	18
Hordeum leporinum					
Ag	-	0.06± 0.02	0.05± 0.0	6.00[b]	4
Cd	-	0.6 ± 0.3	2.5 ± 0.0	-8.66[c]	10
Cu	-	8.8 ± 4.5	6.9 ± 0.2	0.60[a]	10
Pb	-	7.3 ± 2.5	6.9 ± 0.2	0.20[a]	10
Ni	-	4.0 ± 0.6	4.1 ± 0.9	-0.34[a]	10
Zn	-	33.0 ±11.9	22.0 ± 0.7	1.26[a]	10
Rumex crispus, L.					
Ag	0.08± 0.07	-	0.1 ± 0.1	-0.56[a]	13
Cd	5.7 ± 5.9	-	6.3 ± 3.8	0.73[a]	21
Cu	7.4 ± 2.3	-	8.5 ± 3.9	-0.78[a]	19
Pb	7.0 ± 3.8	-	7.9 ± 4.4	-0.39[a]	17
Ni	4.2 ± 1.2	-	4.7 ± 3.5	-0.49[a]	23
Zn	18.3 ±12.3	-	22.4 ±10.1	-0.81[a]	17

a = not significant
b = p <.05
c = p <.001
d = - no sample collected

Table 36. Metal Content in Three Plant Species Collected at Whittier Narrows Test Sites

	Cd (μg/g) $\overline{X}$ S.D.	Cu (μg/g) $\overline{X}$ S.D.	Ni (μg/g) $\overline{X}$ S.D.	Zn (μg/g) $\overline{X}$ S.D.
		Disposal Site		
Brassica sp.	6.6 ± 0.5	10.3 ± 4.1	2.7 ± 1.5	82.5 ± 18.9
Brassica nigra Koch.	0.8 ± 0.2	7.6 ± 3.0	10.9 ± 9.9	39.9 ± 19.1
Rumex crispus L.	0.7 ± 0.0	7.8 ± 0.4	1.3 ± 0.8	23.6 ± 12.8
		Control Site		
Brassica sp.	0.2 ± 0.0	9.4 ± 3.0	–[a]	43.2 ± 5.1
Brassica nigra Koch.	0.2 ± 0.1	6.4 ± 1.9	0.1 ± 0.1	43.7 ± 14.5
Rumex crispus L.	0.2 ± 0.1	9.3 ± 2.2	1.1 ± 1.6	33.4 ± 12.1

[a] Not determined.

Table 37. Soil Properties and Metal Concentrations by Site

Site	CEC	pH	%H_2O	Cd	Cu	Ni	Zn
Bakersfield	12.3	7.0	8.65	0.23	12.89	8.19	51.16
Camp Pendelton	39.6	6.4	18.96	0.99	15.99	8.07	69.44
Chowchilla	9.7	6.5		0.25	13.77	9.27	45.56
Corning	33.0	6.6	16.79	0.30	32.32	39.43	46.16
Delano	37.3	7.9	15.00	0.55	16.11	15.83	50.23
Gustine	38.4	7.8	30.22	0.49	38.36	39.36	78.05
Indio	18.5	8.0	3.71	0.23	43.87	26.18	113.91
Livermore	13.4	6.8	8.25	0.18	31.64	50.37	17.69
March Air Force Base	9.9	6.3	7.24	0.12	11.67	5.85	49.51
Moulton Niguel	41.1	6.8	18.58	1.01	14.31	11.08	58.00
Occidental	34.2	4.9	9.18	0.29	4.16	17.49	16.04
Palmdale	14.0	7.4	10.43	0.70	19.00	8.10	16.80
Pleasanton	30.7	7.0	15.09	0.36	28.48	34.46	35.07
Pomona	10.5	6.0	10.22	0.24	28.84	19.49	67.79
San Francisco	17.1	5.8	13.25	0.34	28.64	28.43	55.80
Santa Maria	6.3	5.7	10.42	0.71	4.78	2.34	19.47
Shafter	20.8	7.6	7.78	0.39	20.09	17.22	78.77
Taft	22.8	8.1	12.28	2.43	19.58	38.68	70.42
Wasco	9.8	5.9	5.24	0.29	10.49	6.93	44.90
Whittier Narrows Control	28.8	7.1	-	0.12	46.67	26.67	82.67
Whittier Narrows Disposal	23.4	7.0	11.44	8.01	148.01	125.51	327.55

- Not determined

Table 38. Content of *Brassica* spp., *Capsella bursa-pastoris* L, *Chenopodium album* L. and *Malva parviflora* L. Collected at Various California Sites

Site	Metal (µg/g)			
	Cd	Cu	Ni	Zn
Brassica spp.				
Bakersfield	0.8 ± 0.3	9.4 ± 4.9	0.4 ± 0.5	52.9 ±21.7
Camp Pendelton	0.7 ± 0.1	7.0 ± 0.2	-[a]	50.5 ± 1.3
Chowchilla	0.3 ± 0.2	6.4 ± 1.8	0.2 ± 0.3	34.0 ± 4.4
Gustine	0.4 ± 0.4	6.7 ± 1.9	0.1 ± 0.3	33.8 ± 1.9
March Air Force Base	-	5.5 ± 2.2	0.2 ± 0.1	37.2 ± 9.7
Whittier N. Control	0.2 ± 0.1	6.4 ± 1.9	0.4 ± 0.1	43.7 ±13.8
Whittier N. Disposal	0.8 ± 0.2	7.6 ± 3.0	10.9 ± 9.9	39.5 ±18.3
Capsella bursa-pastoris L.				
Bakersfield	0.4 ± 0.1	8.7 ± 1.9	-	39.1 ±14.5
Chowchilla	0.8 ± 0.4	7.0 ± 1.4	0.3 ± 0.3	56.5 ±39.3
Corning	0.5 ± 0.0	8.1 ± 0.0	1.3 ± 0.0	31.7 ± 0.0
Delano	0.9 ± 0.3	8.3 ± 2.0	1.9 ± 2.1	34.9 ±18.0
Livermore	0.9 ± 0.9	4.0 ± 1.5	3.4 ± 1.3	24.2 ± 5.3
Palmdale	0.5 ± 0.1	5.2 ± 1.5	5.4 ± 0.8	21.7 ± 4.8
Pleasonton	0.6 ± 0.0	6.0 ± 0.4	4.5 ± 0.2	20.4 ± 1.6
Shafter	1.2 ± 0.2	7.1 ± 0.8	0.2 ± 0.4	24.4 ± 4.3
Taft	1.9 ± 0.1	4.8 ± 0.3	3.7 ± 0.0	27.2 ± 4.1
Chenopodium album L.				
Gustine	0.4 ± 0.1	7.2 ± 4.0	0.8 ± 1.4	26.4 ± 7.5
March Air Force Base	0.7 ± 0.2	8.3 ± 2.0	0.6 ± 0.6	43.0 ±27.0
Taft	1.8 ± 0.2	9.3 ± 0.8	1.7 ± 1.2	35.7 ± 5.2
Malva parviflora L.				
Bakersfield	0.9 ± 0.4	11.2 ± 3.2	1.4 ± 1.4	59.9 ±16.0
Camp Pendelton	0.9 ± 0.1	5.1 ± 1.0	-	55.7 ± 8.6
Chowchilla	0.8 ± 0.3	6.6 ± 1.7	0.2 ± 0.3	68.4 ±33.0
Delano	1.2 ± 0.6	8.0 ± 1.4	2.1 ± 2.0	22.3 ± 5.5
Gustine	0.7 ± 0.4	9.9 ± 4.3	2.1 ± 2.5	45.0 ±17.9
Livermore	0.4 ± 0.3	7.5 ± 2.0	5.9 ± 2.5	46.2 ± 6.1
March Air Force Base	1.2 ± 0.6	6.4 ± 1.7	4.7 ± 4.6	40.3 ±30.2
Pleasanton	0.6 ± 0.1	7.0 ± 2.3	4.7 ± 1.8	34.8 ±13.7
Shafter	0.7 ± 0.2	8.7 ± 1.4	0.2 ± 0.4	45.8 ±52.8
Taft	2.2 ± 0.9	9.6 ± 2.6	0.8 ± 1.3	30.1 ±15.1
Wasco	1.9 ± 0.3	12.1 ± 1.8	1.7 ± 0.6	26.2 ±11.1

[a] Not determined

Table 39. Metal Content of *Rumex crispus*, *Sonchus* spp., and *Taraxacum officinale*, Weber.
Collected at Various California Sites

Site	Metal (μg/g)			
	Cd	Cu	Ni	Zn
		Rumex crispus L.		
Bakersfield	0.3 ± 0.2	5.5 ± 2.4	0.4 ± 0.8	19.7 ±16.7
Corning	0.5 ± 0.4	11.1 ± 2.8	3.6 ± 1.7	31.1 ± 6.7
Gustine	0.7 ± 0.5	6.3 ± 1.7	0.8 ± 2.0	37.1 ±16.6
Pleasanton	0.6 ± 0.5	8.4 ± 1.1	2.7 ± 2.5	34.0 ± 8.5
Whittier N. Control	0.2 ± 0.1	9.4 ± 2.2	1.1 ± 1.6	33.4 ±11.9
Whittier N. Disposal	0.7 ± 0.0	7.8 ± 0.4	1.3 ± 0.8	23.6 ±11.9
		Sonchus spp.		
Gustine	0.3 ± 0.1	12.1 ± 3.9	0.8 ± 1.0	32.8 ± 7.9
Moulton Niguel	6.3 ± 3.7	14.6 ± 7.6	-[a]	81.1 ±37.7
Shafter	0.9 ± 0.5	10.8 ± 3.9	-	70.0 ±74.4
Whittier N. Disposal		7.4 ± 4.0	3.6 ± 5.2	
		Taraxacum officinale, Weber		
Camp Pendelton	1.2 ± 0.0	11.5 ± 0.4	0.6 ± 1.2	64.2 ± 8.5
Corning	0.4 ± 0.1	13.3 ± 4.6	6.1 ± 0.2	47.3 ± 6.0
F.V. Disposal	19.6 ± 0.7	20.1 ± 5.5	1.6 ± 0.5	107.4 ± 4.6
Moulton Niguel	2.0 ± 1.1	10.7 ± 1.7	1.8 ± 1.5	45.1 ± 5.8
Palmdale	0.4 ± 0.1	11.4 ± 3.0	3.8 ± 2.5	35.4 ±17.3
Pleasanton	0.5 ± 0.1	9.2 ± 1.8	2.8 ± 1.9	28.9 ±11.3
San Francisco	0.5 ± 0.2	14.7 ± 2.4	4.5 ± 1.2	45.7 ±17.8

[a] Not determined

Table 40. Metal Content of Five Grass Species Examined at Various California Sites

Site	Metal (µg/g)			
	Cd	Cu	Ni	Zn
		Avena fatua, L.		
Gustine	1.1 ± 0.0	9.1 ± 0.6	7.2 ± 0.4	21.8 ± 3.6
Livermore	0.5 ± 0.4	3.9 ± 1.0	7.3 ± 5.9	25.5 ± 11.4
Taft	0.7 ± 0.8	6.7 ± 1.3	0.8 ± 1.0	35.6 ± 1.7
		Bromus spp.		
Camp Pendelton	0.4 ± 0.1	7.5 ± 0.4	0.2 ± 0.1	49.0 ± 5.7
Corning	1.2 ± 0.0	13.3 ± 1.0	1.9 ± 0.3	38.8 ± 2.2
Moulton Niguel	0.4 ± 0.2	7.8 ± 0.1	-[a]	45.1 ± 0.9
Pleasanton	0.5 ± 0.2	5.2 ± 0.1	0.8 ± 0.2	23.8 ± 0.3
San Francisco	0.5 ± 0.0	10.7 ± 0.5	4.4 ± 0.1	41.0 ± 2.1
Taft	0.7 ± 0.4	10.2 ± 0.8	0.5 ± 0.3	42.0 ± 6.2
		Cynodon dactylon, L. (Pers.)		
Camp Pendelton	1.3 ± 0.1	12.9 ± 0.5	0.7 ± 1.0	74.5 ± 2.1
F. V. Disposal	2.6 ± 0.8	10.3 ± 0.5	1.2 ± 1.0	61.2 ± 33.6
Indio	0.4 ± 0.1	8.6 ± 1.3	4.2 ± 8.7	50.8 ± 9.5
Mission Viejo	0.7 ± 0.0	6.2 ± 0.5	0.8 ± 0.0	38.3 ± 0.0
Shafter	0.4 ± 0.1	7.7 ± 0.1	0.2 ± 0.3	26.5 ± 0.1
Wasco	0.9 ± 0.1	10.1 ± 0.1	0.3 ± 0.4	110.1 ± 11.8
Whittier N. Control	-	13.1 ± 0.1	0.4 ± 0.0	-
		Hordeum leporinum, Link		
Corning	0.2 ± 0.1	6.1 ± 1.1	2.7 ± 1.1	25.3 ± 17.9
Palmdale	0.3 ± 0.1	5.0 ± 2.1	3.1 ± 1.1	18.5 ± 4.8
Pleasanton	0.8 ± 1.0	4.8 ± 1.3	1.4 ± 1.4	14.6 ± 5.5
Shafter	0.7 ± 0.1	6.6 ± 0.9	-[a]	19.4 ± 2.8
Taft	0.7 ± 0.3	8.3 ± 1.2	0.9 ± 1.4	35.5 ± 8.9
		Lolium spp.		
Delano	0.7 ± 0.4	8.1 ± 0.8	2.2 ± 3.0	95.6 ±153.4
Moulton Niguel	0.2 ± 0.1	5.0 ± 0.8	-	21.9 ± 0.5
Gustine	0.6 ± 0.4	6.9 ± 1.6	1.4 ± 1.4	24.1 ± 6.7
Palmdale	0.3 ± 0.0	4.7 ± 0.2	4.1 ± 0.1	25.3 ± 1.3

[a] Not determined

Table 41. Plant/Soil Ratios for Plant Species Examined at Each Test Site

	Cd	Cu	Ni	Zn
Bakersfield				
Brassica spp.	3.48	0.73	0.05	1.03
Capsella bursa-pastoris L	1.74	0.67	a	0.76
Malva parviflora L.	3.91	0.86	0.17	1.17
Medicago sativa L.	1.74	0.86	0.40	0.73
Rumex crispus L.	1.30	0.43	0.04	0.38
Camp Pendelton				
Brassica spp.	0.70	0.43	a	0.73
Bromus spp.	0.40	0.46	0.01	0.70
Cynodon dactylon (L)Pers.	1.31	0.81	0.09	1.07
Malva parviflora L.	0.91	0.32	a	0.80
Medicago spp.	0.20	0.39	0.18	0.56
Pinus halepensis Mill.	0.30	0.22	0.13	0.28
Taraxacum officinale Weber	1.21	0.72	0.07	0.92
Chowchilla				
Brassica spp.	1.20	0.46	0.02	0.74
Capsella bursa-pastoris L.	3.20	0.51	0.03	1.24
Malva parviflora L.	3.20	0.48	0.02	1.50
Corning				
Bromus spp.	4.00	0.41	0.04	0.84
Capsella bursa-pastoris L.	1.67	0.25	0.03	0.69
Hordeum leporinum Link	0.67	0.19	0.07	0.54
Rumex crispus L.	1.67	0.34	0.09	0.67
Taraxacum officinale Weber	1.33	0.41	0.15	1.02
Delano				
Capsella bursa-pastoris L.	1.64	0.52	0.12	0.69
Lolium spp	1.24	0.50	0.14	1.90
Malva parviflora L.	2.18	0.50	0.13	0.44
Beta vulgaris	1.27	0.50	0.04	0.47
Gustine				
Avena fatua L.	2.24	0.23	0.18	0.28
Brassica spp.	1.02	0.17	0.01	0.43
Chenopodium album L.	0.82	0.19	0.02	0.33
Lolium spp.	1.22	0.18	0.03	0.31
Malva parviflora L.	1.43	0.26	0.05	0.58
Medicago spp.	0.82	0.19	0.01	0.27
Rumex crispus L.	1.43	0.16	0.02	0.47
Sonchus spp.	0.61	0.31	0.05	0.42

(continued)

Table 41 (continued)

	Cd	Cu	Ni	Zn
Indio				
Cynodon dactylon(L)Pers.	1.74	0.33	0.10	0.45
Livermore				
Avena fatua L.	2.78	0.12	0.14	1.44
Capsella bursa-pastoris L.	5.00	0.13	0.07	1.37
Hordeum leporinum Link	2.78	0.14	0.02	1.05
Malva parviflora L.	2.22	0.24	0.12	2.61
Medicago sativa L.	2.22	0.24	0.08	2.20
March Air Force Base				
Brassica spp.	-a	0.47	0.03	0.75
Chenopodium album L.	5.83	0.71	0.10	0.87
Malva parviflora L.	10.1	0.55	0.80	0.81
Raphanus sativus L.	9.17	0.44	0.21	0.73
Moulton Niguel				
Bromus spp.	0.40	0.55	-a	0.78
Cynodon dactylon L.	0.69	0.43	0.07	0.66
Lolium spp.	0.20	0.35	-a	0.38
Medicago spp.	0.30	0.32	-a	0.64
Pinus halepensis Mill.	0.59	0.29	0.01	1.05
Sonchus spp.	6.24	1.02	-a	1.40
Taraxacum officinale Weber	1.98	0.75	0.16	0.78
Occidental				
Medicago spp.	1.38	2.34	0.03	2.67
Palmdale				
Capsella bursa-pastoris L.	0.71	0.27	0.67	1.29
Hordeum leporinum Link	0.43	0.26	0.38	1.10
Lolium spp.	0.43	0.25	0.51	1.51
Medicago sativa L.	0.43	0.42	0.59	1.28
Taraxacum officinale Weber	0.57	0.60	0.47	2.11
Pleasanton				
Bromus spp.	1.39	0.18	0.02	0.68
Capsella bursa-pastoris L.	1.67	0.21	0.13	0.58
Hordeum leporinum Link.	2.22	0.17	0.04	0.42
Malva parviflora L.	1.67	0.25	0.14	0.99
Rumex crispus L.	1.67	0.29	0.08	0.97
Taraxaum officinale Weber	1.39	0.32	0.08	0.82
Pomona				
Citrus sitensis Osbeck	1.25	0.28	0.13	1.02
San Francisco				
Bromus spp.	1.47	0.37	0.15	0.73
Taraxacum officinale Weber	1.47	0.51	0.16	0.82

(continued)

Table 41 (continued)

	Cd	Cu	Ni	Zn
		Santa Maria		
Raphanus sativus L.	1.13	1.00	-a	1.93
Beta vulgaris	1.69	1.44	0.68	2.32
		Shafter		
Capsella bursa-pastoris L.	3.08	0.35	0.01	0.31
Cynodon dactylon L.	1.18	0.38	0.01	0.25
Hordeum leporinum L.	1.79	0.33	-a	0.25
Malva parviflora L.	1.79	0.43	0.01	0.58
Sonchus sp	2.31	0.54	-a	0.89
		Taft		
Avena fatua L.	0.29	0.34	0.02	0.51
Bromus spp.	0.29	0.52	0.01	0.60
Capsella bursa-pastoris L.	0.78	0.25	0.10	0.39
Chenopodium album L.	0.74	0.47	0.04	0.51
Hordeum leporinum Link	0.29	0.42	0.02	0.50
Malva parviflora L.	0.91	0.49	0.02	0.43
Medicago sativa L.	0.45	0.60	0.02	0.55
		Wasco		
Cynodon dactylon L.	1.25	0.22	0.01	1.33
Malva parviflora L.	2.64	0.26	0.06	2.74

Table 42. Plant/Soil Ratios for Different Plant Species Broken by Sites

Site	Cd	Cu	Ni	Zn
		Avena fatua L.		
Gustine	2.24	0.23	0.18	0.28
Las Virgenes Alfalfa	0.31	-	-	-
Las Virgenes Control	0.27	-	-	-
Livermore	2.78	0.12	0.14	1.44
Taft	0.29	0.34	0.02	0.51
		Beta Vulgaris		
Delano	1.27	0.50	0.04	0.47
Santa Maria	1.77	1.44	0.68	2.33
		Brassica spp.		
Bakersfield	3.40	0.73	0.05	1.03
Camp Pendleton	0.70	0.44	-a	0.72
Chowchilla	1.20	0.46	0.02	0.75
Gustine	0.82	0.17	0.01	0.43
Las Virgenes Alfalfa	0.73	-	-	-
Las Virgenes Control	0.64	-	-	-
Las Virgenes Disposal	0.62	-	-	-
March Air Force Base	-	0.47	0.03	0.75
Whittier Narrows Control	0.85 (1.01)	-	-	-
Whittier Narrows Disposal	2.06 (0.2)	-	-	-
		Bromus spp.		
Camp Pendleton	0.40	0.46	0.01	0.70
Corning	4.00	0.41	0.04	0.84
Moulton Niguel	0.40	0.55	-	0.78
Las Virgenes Alfalfa	0.63	-	-	-
Las Virgenes Control	0.67	-	-	-
Las Virgenes Disposal	0.40	-	-	-
Pleasanton	1.39	0.18	0.02	0.68
San Francisco	1.47	0.37	0.15	0.73
Taft	0.29	0.52	0.01	0.60
		Capsella bursa-pastoris L.		
Bakersfield	1.73	0.67	-	0.76
Chowchilla	3.20	0.51	0.03	1.24
Corning	1.67	0.25	0.03	0.69
Delano	1.64	0.52	0.12	0.69
Livermore	4.50	0.13	0.07	1.37
Palmdale	0.71	0.27	0.67	1.29
Pleasanton	1.67	0.21	0.13	0.58
Shafter	3.08	0.35	0.01	0.31
Taft	0.78	0.24	0.09	0.39

(continued)

Table 42. (continued)

Site	Cd	Cu	Ni	Zn
Chenopodium album L.				
Gustine	0.82	0.19	0.02	0.34
March Air Force Base	5.83	-	0.10	-
Taft	0.75	0.47	0.04	0.51
Citrus sivensis Osbeck				
Pomona	1.25	0.28	0.13	1.02
Cynodon dactylon L.				
Camp Pendleton	1.31	0.81	0.09	1.07
Fountain Valley Disposal	-	-	-	-
Indio	1.74	0.33	0.10	0.45
Moulton Niguel	0.69	0.43	0.07	0.66
Shafter	1.18	0.38	0.01	0.34
Wasco	1.25	0.22	0.01	1.33
Whittier Narrows Control				
Hordeum leporinum Link.				
Corning	0.67	0.19	0.07	0.54
Las Virgenes Alfalfa	-	-	-	-
Las Virgenes Disposal	-	-	-	-
Livermore	2.78	0.14	0.02	1.05
Palmdale	0.43	0.26	0.38	1.10
Pleasanton	2.22	0.17	0.04	0.42
Lolium spp.				
Delano	1.24	0.50	0.14	1.90
Gustine	1.22	0.18	0.03	0.31
Moulton Niguel	0.20	0.35	-	0.38
Palmdale	0.43	0.25	0.51	1.51
Malva parviflora L.				
Bakersfield	3.91	0.86	0.17	1.17
Camp Pendleton	0.91	3.20	-	0.80
Chowchilla	3.20	0.48	0.02	1.50
Delano	2.18	0.50	0.13	0.44
Gustine	1.43	0.26	0.05	0.58
Las Virgenes Alfalfa	1.37	-	-	-
Las Virgenes Control	1.75	-	-	-
Livermore	2.22	0.24	0.12	2.61
March Air Force Base	10.00	0.55	0.80	0.81
Pleasanton	1.67	0.25	0.14	0.99
Shafter	1.79	0.43	0.01	0.58
Taft	0.91	0.49	0.02	0.43
Wasco	2.64	0.26	0.06	2.74

(continued)

Table 42 (continued)

Site	Cd	Cu	Ni	Zn
Medicago sativa L.				
Bakersfield	1.74	0.86	0.40	0.73
Las Virgenes Alfalfa	0.33	-	-	-
Livermore	2.22	0.24	0.08	2.20
Palmdale	0.43	0.42	0.59	1.28
Taft	0.45	0.60	0.02	0.55
Medicago spp.				
Camp Pendleton	0.20	0.39	0.18	0.56
Gustine	0.82	0.19	0.01	0.27
Las Virgenes Control	-	-	-	-
Las Virgenes Disposal	-	-	-	-
Moulton Niguel	0.30	0.32	-	0.64
Occidental	1.38	2.34	0.03	2.67
Pinus halepensis Mill.				
Camp Pendleton	0.30	0.22	0.13	0.28
Fountain Valley Control	1.08	-	-	-
Fountain Valley Disposal	1.23	-	-	-
Moulton Niguel	0.59	0.29	0.01	1.05
Raphanus sativus L.				
Las Virgenes Control	1.01	-	-	-
Las Virgenes Disposal	0.49	-	-	-
March Air Force Base	9.17	0.44	0.21	0.73
Santa Maria	1.13	1.00	-	1.93
Whittier Narrows Disposal	0.10	-	-	-
Rumex crispus L.				
Bakersfield	1.30	0.43	0.04	0.38
Corning	1.67	0.34	0.09	0.67
Gustine	1.43	0.16	0.02	0.47
Las Virgenes Control	1.92	-	-	-
Las Virgenes Disposal	0.63	-	-	-
Pleasanton	1.67	0.29	0.08	0.97
Whittier Narrows Control	1.00	-	-	-
Whittier Narrows Disposal	0.19	-	-	-
Sonchus spp.				
Moulton Niguel	6.24	1.02	-	1.40
Shafter	2.31	0.54	-	0.89
Whittier Narrows Disposal	1.10	-	-	-

(continued)

Table 42 (continued)

Site	Cd	Cu	Ni	Zn
		Taraxacum officinale Weber		
Camp Pendleton	1.21	0.72	0.07	0.92
Corning	1.33	0.41	0.15	1.02
Fountain Valley Disposal	4.00	-	-	-
Moulton Niguel	1.98	0.75	0.16	0.78
Palmdale	0.57	0.60	0.47	2.11
Pleasanton	1.39	0.32	0.08	0.82
San Francisco	1.47	0.51	0.16	0.82

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Table 43. Amount of Metal Applied in Wastewater at Orange County Over a 15 Year Period

	Metal (Kg/ha)						
Application Rate CM ha Per Year	Cu	Zn	Cd	Cr	Ni	Pb	Ag
24.8	9.2	14.0	1.52	6.7	3.8	4.6	0.41
37.2	13.9	20.9	2.28	10.1	5.8	6.8	0.62
49.6	18.4	28.0	3.04	13.4	7.6	9.2	0.82

Table 44. Metal Concentration in the 0-15 cm Section of the Soil Column at the Control and Irrigation Sites at Orange County

	Metal Concentrations (Kg/ha)						
	Cu	Zn	Cd	Cr	Ni	Pb	Ag
Control Site	42.5	168.7	1.99	80.4	34.2	28.2	1.99
Irrigation Site	71.8	210.1	10.20	72.8	32.3	51.7	4.78

Table 45. Amount of Metal (Expressed as Percent) in the Soil Which is Accounted for by Land Application of Wastewater at Orange County

	Metal						
Application Rate Cm ha Per Year	CU	Zn	Cd	Cr	NI	Pb	Ag
24.8	31.6	33.7	18.5	-*	-	19.4	14.8
37.2	47.6	50.5	27.7	-	-	27.4	22.2
49.6	63.2	67.4	37.0	-	-	38.8	29.6

*- Control soil metal concentration greater than wastewater irrigated soil

Table 46. One Way Analysis of Variance Comparing Soil Metal Concentrations Across Depths at Whittier Narrows Disposal and Whittier Narrows Control Sites

Metal	Disposal Site Hole	Level of Significance	Mean Metal Concentrations (ppm)*	
			WND	WNC
Cadmium	2	.05	6.79	.11
	1, 3-5	.009	2.36	.11
	1-5	.06**	3.25	.11
Nickel	2	.014	116.44	25.78
	1, 3-4	.003	82.78	25.78
	1-5	.005	89.51	25.78
Lead	2	.058**	127.27	3.40
	1, 3-5	.01	32.34	3.40
	1-5	.12	50.91	3.40
Copper	2	.056**	142.22	39.78
	1, 3-5	.035	74.83	39.78
	1-5	.081	88.31	39.78
Zinc	2	.06**	411.44	73.78
	1, 3-5	.04	158.57	73.78
	1-5	.13**	208.04	73.78
Chromium	2	.006	61.89	27.22
	1, 3-5	.029	93.89	27.22
	1-5	.030	87.63	27.22

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*Mean value from 0-180 cm depths

**Not significant at < 0.05

FIGURE I: Schematic diagram of soil (and associated plant) sampling procedures

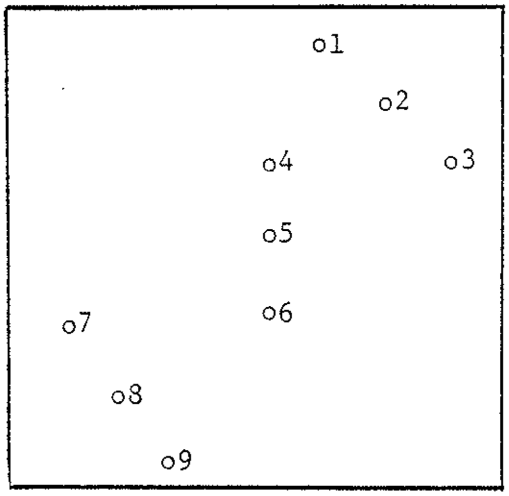

Figure 2. Plant/Soil Ratios for *Avena fatua* L. Across Soil Cadmium Concentrations

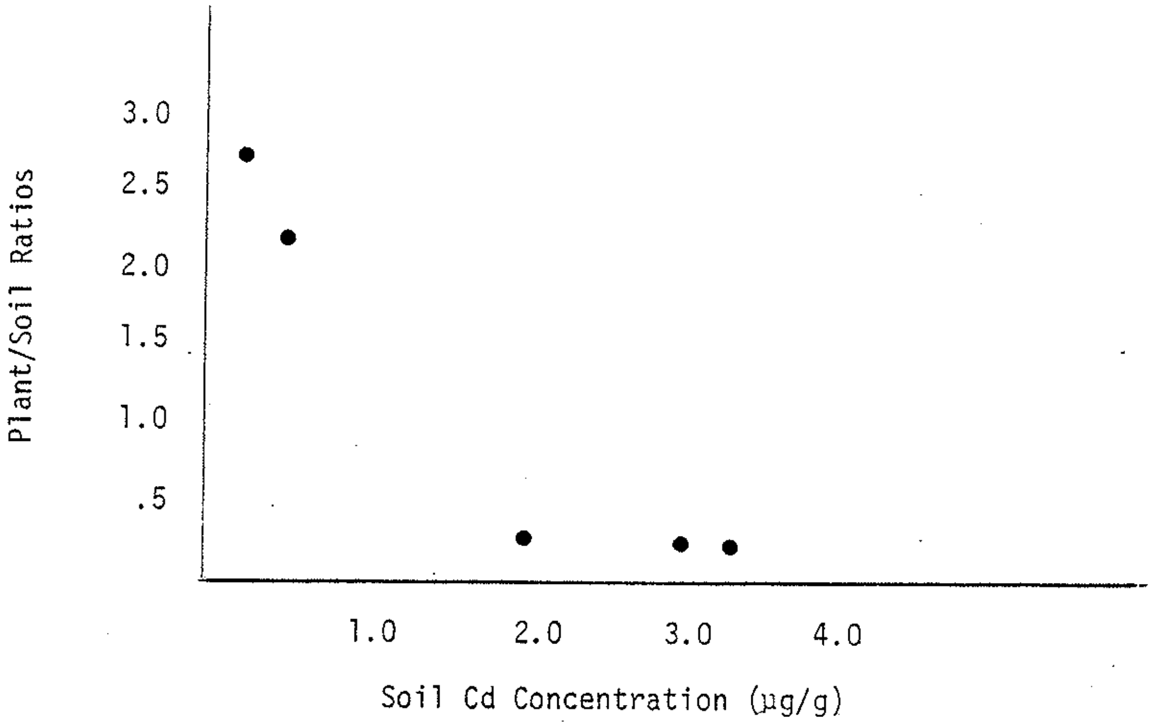

Figure 3. Plant/Soil Ratios for *Brassica* spp. Across Soil Cadmium Concentrations

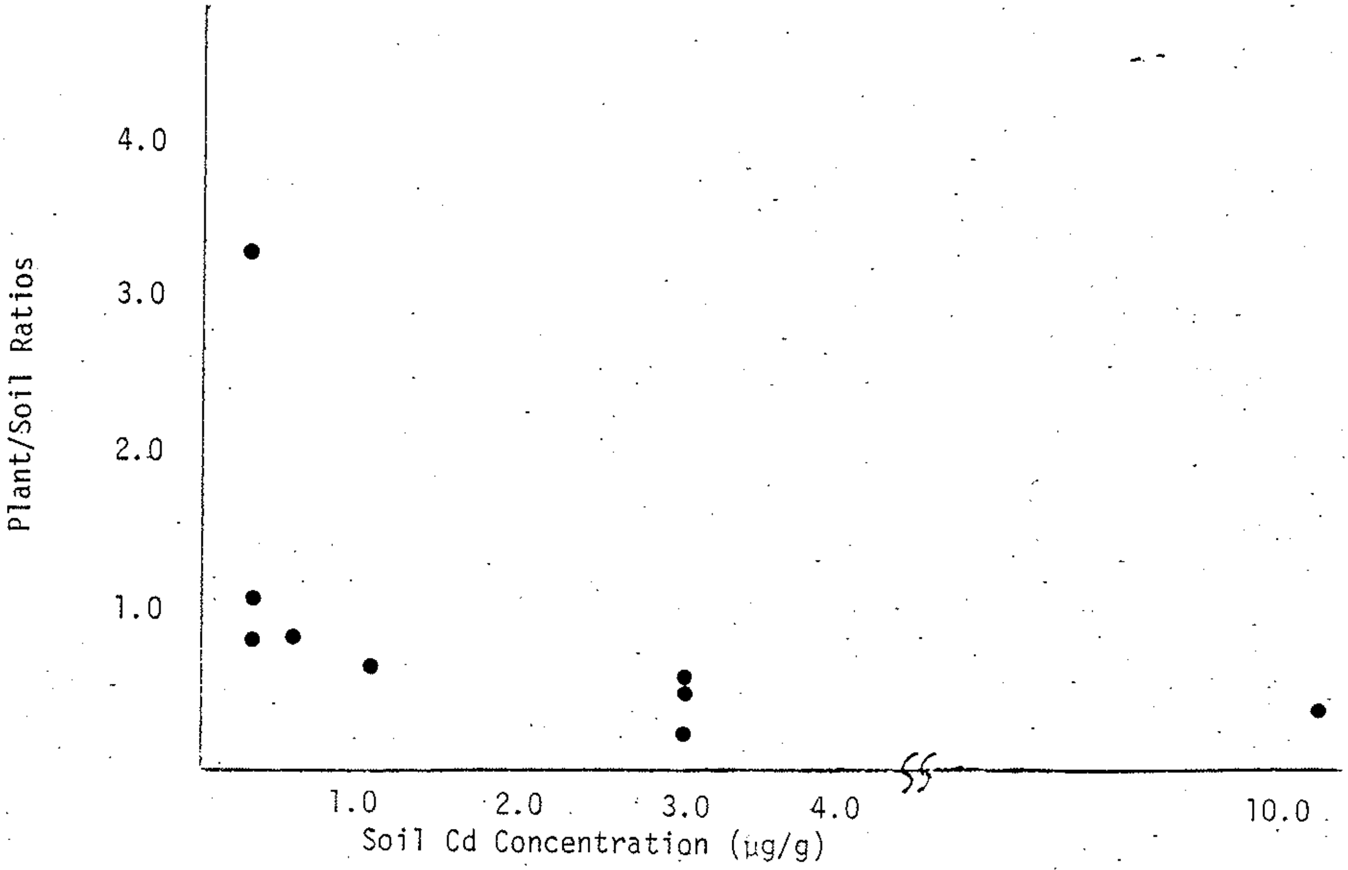

Figure 4. Plant/Soil Ratios for <u>Bromus</u> spp. Across Soil Cadmium Concentrations

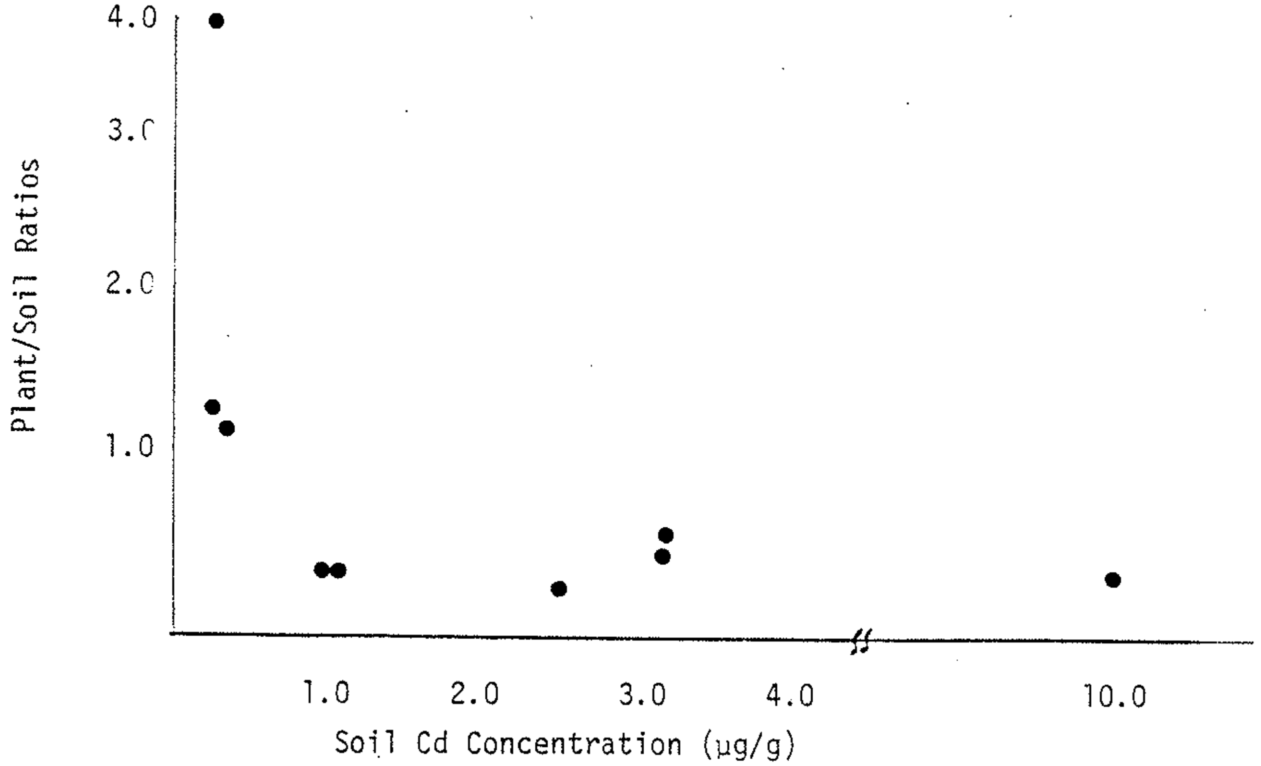

Figure 5. Plant/Soil Ratios for <u>Capsella</u> <u>Bursa-Pastoris</u> L. Soil Cadmium Concentrations

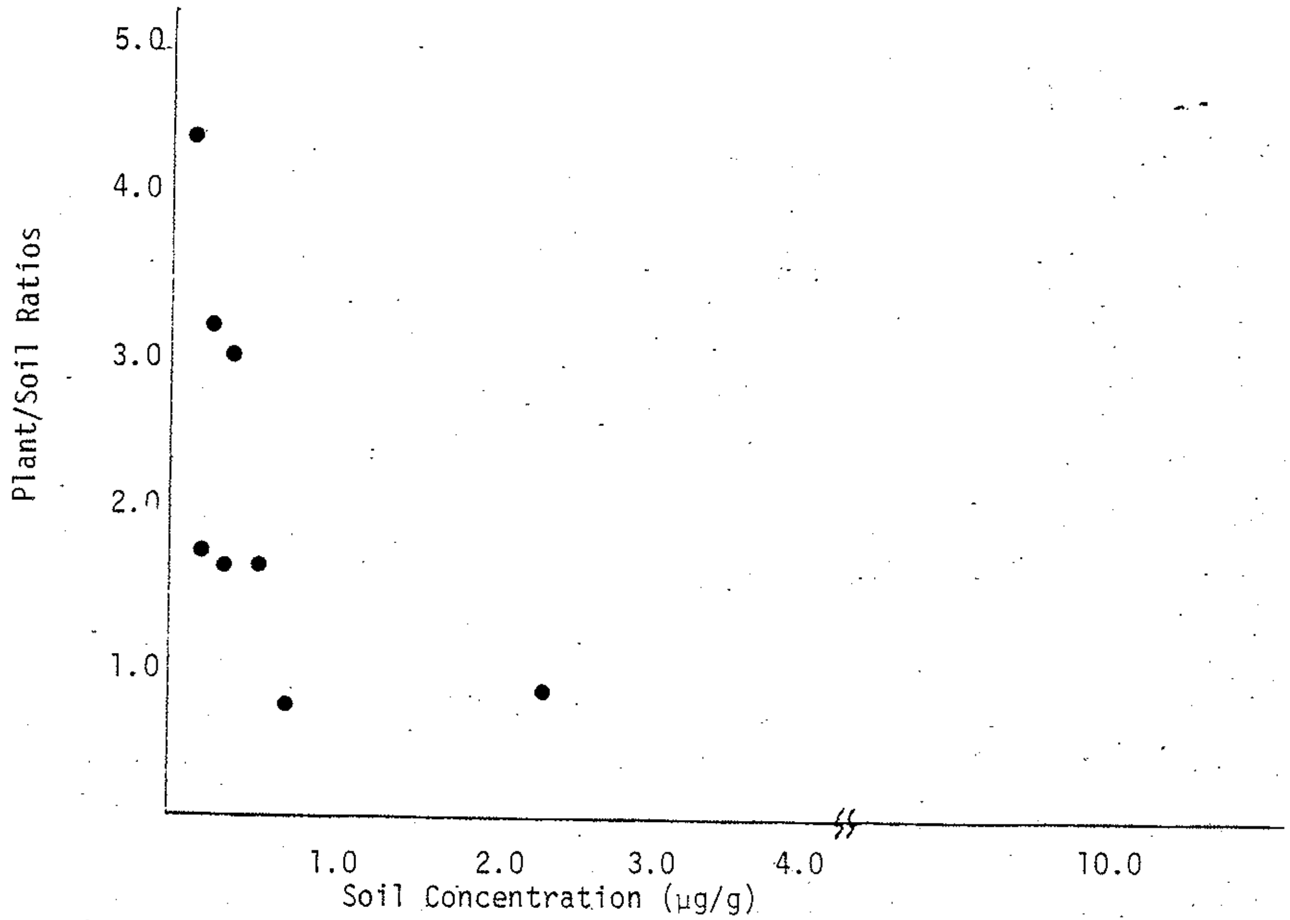

Figure 6. Plant/Soil Ratios for Malva Parviflora, L. Across Soil Cadmium Concentrations

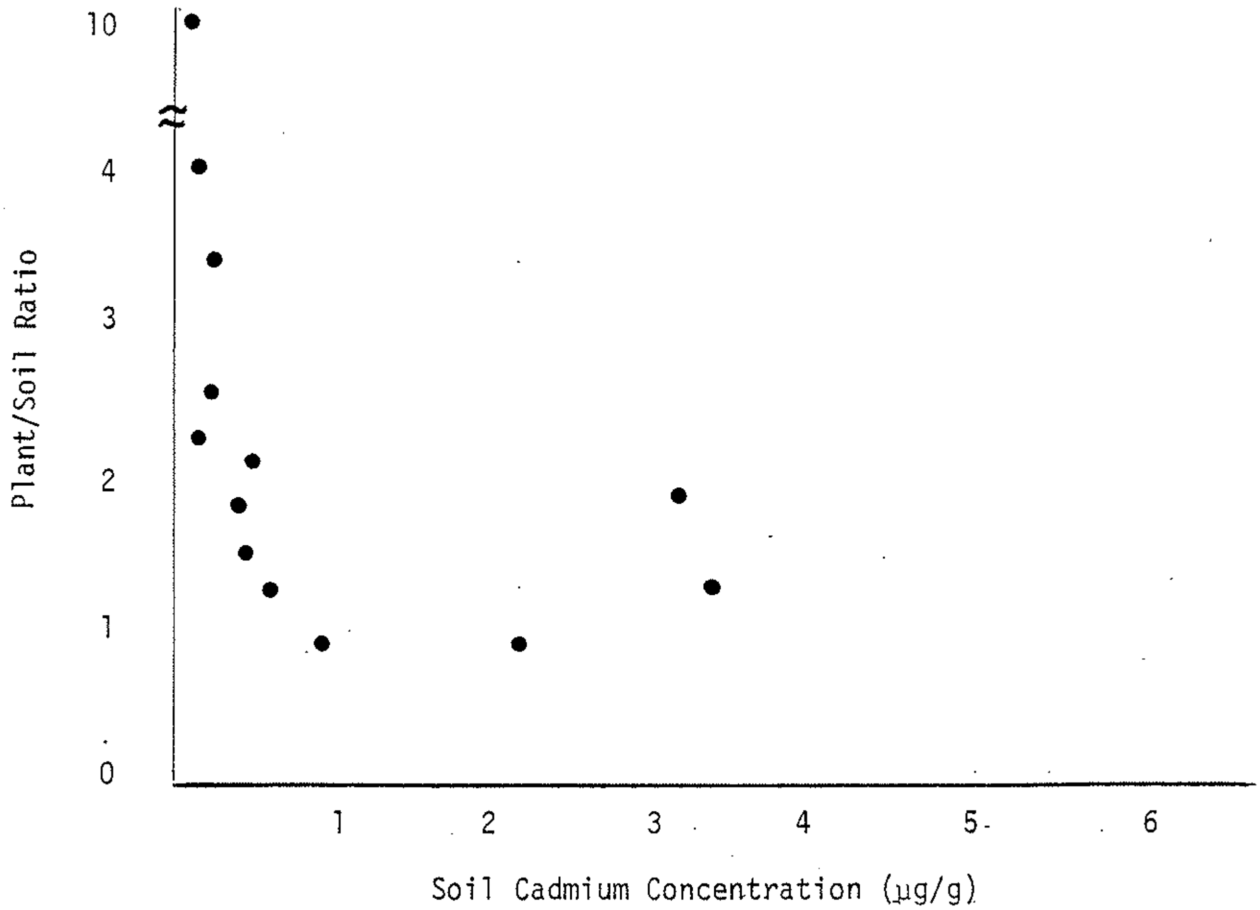

Figure 7. Plant/Soil Ratios for Medicago Sativa, L., and Medicago spp. Soil Cadmium Concentrations