



EVALUATION OF METALS IN IRRIGATION AFFECTED PERCOLATE, WEST COUNTY AND SOUTH COUNTY ALTERNATIVES

SANTA ROSA SUBREGIONAL LONG-TERM WASTEWATER PROJECT

Prepared for

**City of Santa Rosa
and
U.S. Army Corps of Engineers**

APRIL 1996

Prepared by

QUESTA ENGINEERING CORPORATION
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For

HARLAND BARTHOLOMEW & ASSOCIATES, INC.

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1.0 INTRODUCTION

This memorandum summarizes the results of our evaluation of the potential water quality effects on surface water and shallow zone groundwater from additions of select trace or heavy metals contained in reclaimed water following long-term irrigation of agricultural lands in the West County and South County project areas. The evaluation methodology is similar to that presented by CH2M Hill in Draft Technical Memorandum No. R11 1 (September 5, 1990, *Groundwater Response to Reservoir Leakage and Reclaimed Water Irrigation in Stemple and Americano Creeks Drainage Basin.*) However, the present study updates and extends the previous work by:

- Expanding the list of metals evaluated from four to ten (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc);
- Providing a more in-depth analysis and discussion of metals attenuation and uptake/mobilization in the soils, distinguishing between different metals in the West and South County soils; and,
- Providing an analysis of predicted long-term effects on West and South County groundwater resources.

2.0 RELATED STUDIES

The reader is referred to several related Technical Memoranda which provide additional background on project hydrology, water quality effects and irrigation management approaches including:

1. Baseline Hydrology And Irrigation Drainage Evaluation For West And South County Reclamation Alternatives (Questa Engineering Corp., November 1995).
2. Irrigation Nitrogen Loading to Groundwater, West County and South County Reclamation Alternatives (Questa Engineering Corp., November 1995).
3. Water Quality Evaluations on Wastewater Irrigation in West County and South County Alternatives, Santa Rosa Long-Term Wastewater Project (Professor K. Tanji, U.C. Davis, July 1995).
4. Estimation of Nitrogen, Salts and Herbicide/Pesticide Concentrations in Surface Water, and Mass Loading Analysis from Irrigation with Reclaimed Water, West County and South County Alternatives (Questa Engineering Corp., November 1995).
5. Trace Element Soil Loading Analysis for the South and West County Reclamation Alternatives (Questa Engineering Corp., September 1995).
6. Evaluation of Soil Erosion Impacts of the West and South County Alternatives (Questa Engineering Corp., September 1995).
7. Estimated Temperature of Irrigation Subflow Intercepted by Surface Streams, West County and South County Reclamation Project (Questa Engineering Corp., October, 1995).
8. Irrigation Management Plan for the West County and South County Alternatives, (Questa Engineering Corp., November, 1995).
9. Cropping Scenarios Technical Memorandum (Questa Engineering Corp., September, 1995).
10. Hydrologic/Water Quality Evaluation of Irrigation of Baylands (Reyes Soils) with Reclaimed Water (Questa Engineering Corp., March, 1996).

3.0 METHODOLOGY AND APPROACH

The potential impacts of reclaimed water irrigation on surface and shallow zone groundwater were estimated using a water balance approach. This is sometimes referred to as a root-zone model. The water balance approach tracks water entering an agricultural field (rainfall and applied irrigation water) and divides water exiting the field into: 1) runoff, 2) evapotranspiration; and, 3) shallow zone groundwater. Constituents of interest, in this case trace metals, are assumed to move in a dissolved form with the water through the root zone hydrologic system. The model has been simplified since it does not consider metals associated with eroded soil particles, leaching of native soil metals, local surface water storage, deep groundwater percolation and groundwater usage by domestic wells. In addition, the model assumes that for the West County and Tolay Creek area, the shallow zone groundwater (from combined rainfall and irrigation) is entirely discharged after a one to four-month time lag, reflecting slow subflow movement through the soil to the nearby surface stream. During this time period, the metals content of the shallow zone soil-water (the water contained in pores in the soil and shallow aquifer materials from irrigation application) is concentrated somewhat by evapotranspiration losses, with some subsequent attenuation or dampening of this effect by various physical-chemical reactions during movement through the soils. Metals immobilization or retention in the soil occurs as a result of various adsorption, fixation and chemical reactions with organic matter, clay minerals and other naturally occurring substances in the soil (hydroxides, carbonates, sulfides).

For the South County area, surface storage and groundwater usage also are not considered and all applied water (irrigation and rainfall) in excess of evapotranspiration (ET) losses is assumed to percolate and enter the shallow zone groundwater as leachate or percolate where it mixes with existing or resident shallow zone groundwater. This resident groundwater represents recharge from the previous winter through rainfall infiltration. The quantity of the shallow zone groundwater is estimated based on net rainfall amounts entering the soil profile after adjustment for runoff and ET losses. Depending on the concentration of metals in the shallow zone groundwater, this comingling usually dilutes the metals concentrations of the reclaimed water that enters this lower zone as percolate or leachate. Concentrations of metals from deeper groundwater sample analyses were used to calculate the comingling/dilution effect. Over a long period of time (25+ years) and for a shallow aquifer of limited saturated thickness and storage capacity, this percolating water provides a very conservative estimate of the future quality of the irrigation affected aquifer water. In reality, aquifer dilution may be 100-fold or more in West County aquifers, since the irrigation percolate will constitute less than one percent of the water volume of the aquifer.¹

For the West County, it was assumed that the presence of shallow restrictive layers within five to six feet of the surface (clay pans and bedrock) serves to guide and direct the applied surface water through preferential flow paths at the soil-restrictive layer contact, and through permeable zones (sandy lenses, old stream channels and animal burrows) to be intercepted by nearby entrenched streams. Water movement may take from one to four months to enter the stream. This is an idealized model

¹ The dilution provided by the volume of water in the aquifer is relative to the volume of water contributed by irrigation affected groundwater.

which is not strictly the uniform case throughout all of the West County area. Some areas lack restrictive layers, which allows a portion of the water to move through pores in the soil and to recharge deeper aquifers, below the zone that can discharge to streams. We estimate this deep percolating water to be about five to ten percent of the applied irrigation water.

The hydrology model matches observations of stream response to rainfall. However, it should be assumed that the model over estimates impacts on surface water for the West County. The calculated annual average concentration of the percolating groundwater prior to discharge to the stream can be taken as an estimate of the impact of irrigation-affected groundwater on the shallow aquifer over a prolonged period of time.

Shallow restrictive layers are much less widespread in the South County area, and creek channels are typically less incised than in the West County. The exception is the Tolay Creek watershed, which is more similar to the West County systems. Therefore, except for the Tolay watershed, the hydrology model assumes that rainfall and irrigation water move through the generally deep clayey soils by inter-pore movement to enter the shallow groundwater zone. The quality of the percolating soil- water as predicted by the model will therefore be a highly conservative yet reasonable estimate of long-term impacts on groundwater for the South County area. Considering the size and saturated thickness of some South County aquifers, aquifer dilution of the percolate may be over 1,000 fold.

The shallow zone soil-water subflow that is discharged as baseflow to nearby creeks will then mix with existing baseflow in the creek, where it may be diluted. The Questa baseline hydrology and irrigation drainage model, and the hydrologic effects on streams from reservoir construction are utilized in a subsequent technical analysis to estimate the dilution effects and predict the metals content of the stream water during the summer low flow period.

Water quality effects of irrigation can be safely assumed to be negligible during periods outside late summer to early fall. Irrigation will normally not occur outside of these periods, and when it does it will be at very low application rates. When irrigation is initiated in early spring, rainfall fed subflow to creeks greatly overwhelms any irrigation-contributed subflow because of the time lag associated with when the irrigation water enters the creeks. In the late fall or early winter, the irrigation affected subflow, which has slowly made its way to the creeks from earlier summer application (because of the time lag effect), will normally be masked by rainfall runoff. The greatest time of concern would be in early fall (before rains) when the small amount of surface water in ephemeral drainages in irrigated areas would approach 100 percent percolate from subsurface flows (excluding incidental runoff). These potential impacts are addressed utilizing the metals concentrations predicted in the irrigation affected-percolate (in this report) with the hydrologic impacts estimated from irrigation drainage and reservoir effects.

4.0 SOIL ATTENUATION AND METALS

IMMOBILIZATION

Movement of reclaimed water through the soil is influenced by a variety of physical processes and chemical reactions that determine the capacity of a natural soil body to immobilize metals and renovate or cleanse the wastewater. The mechanisms of removal are complex and depend on both the characteristics of the trace elements, the nature and chemistry of the soil, and the rate of water movement through the soil. Metals present in the reclaimed water adsorbed on particulates and present in suspended forms or as fine organic matter are primarily removed through filtration processes as water moves through fine pores in the soil. Nearly all suspended solids and associated nutrients and metals are deposited in the upper 0.5 to 1.5-feet of the soil profile following irrigation. For the Santa Rosa project effluent, this is a very small part of the total metals load.

Such filtering has little effect on removing metals (as well as nutrients and salts) that are present in the reclaimed irrigation water in a dissolved form. Depending on the particular metal, soil-chemical reactions such as ion exchange, formation of organic complexes and chelates, surface adsorption, and precipitation as iron and manganese hydrous oxides and sulfide compounds, are important.

The clay content, cation exchange capacity, organic matter content, oxidation/reduction state and soil pH all influence the mobility of metals in the soil to some degree or another. Lead generally has limited mobility in the soil column. In slightly acidic, non-calcareous soils such as occur in the majority of the project area, lead tends to precipitate as lead hydroxides or lead polymorphites and does not readily reach groundwater.

The solubility, and hence mobility, of copper, nickel, zinc, cadmium and chromium compounds are significantly pH dependent. The solubility increases as pH levels decline (become more acidic). These metals are associated with iron and manganese hydrous oxide compounds whose solubility increases with decreasing soil pH. The hydrous oxide compounds are also more soluble under reducing conditions. As a result, poorly drained, acidic conditions that occur in Reyes soils (Baylands areas) tend to favor mobilization of metals, while well drained, non-sandy basic to slightly acidic soils tend to immobilize most cationic metals. Because the Reyes soils are fundamentally different (chemically and hydrologically) from other soils within the West and South County project areas, potential water quality impacts are discussed in a separate technical memorandum (see Hydrologic and Water Quality Evaluation of Irrigation of Baylands [Reyes Soils] with Reclaimed Water, Questa Engineering Corp., March 1996).

The amount of finely divided, stable organic matter (humic and folic acids) in the soil can also greatly affect the mobility of metals in the soils by forming insoluble or slightly soluble complexes. Other reactions include adsorption onto clay surfaces and ion exchange, particularly of divalent cations. The organic and clay-rich bottom land soils of the West and South County should strongly immobilize metals through organic complexing and cation exchange.

However, due to the complexity of all of the possible interactions of metals between the soil and reclaimed water, it is difficult to accurately predict metals concentrations in water from an irrigation water source containing trace elements as it leaches through the root zone and moves through the groundwater flow system. This difficulty is compounded when there is a need to consider water movement through the soil and subsequent deep percolation or stream discharge. A process-based physical model is employed that uses conservative assumptions to provide an estimate of metals concentrations in the creeks.

Table 1 summarizes the importance of various physical/chemical processes in the soil as they affect the mobility of metals. Included are K_d values (a coefficient or measure of the mobility or adsorption propensity of the metal while moving with groundwater through porous media) determined for typical soils for various elements. Based on our knowledge of typical soil conditions in the West County and South County areas, an overall uptake/immobilization factor (U) was assigned for each metal for various areas in the West and South County (Table 2). The higher the U factor the greater the mobility of the metal. Experience with several municipal wastewater irrigation systems suggests concentration reductions for copper of 85 to 95 percent, and 25 to 95 percent for zinc. This U factor is used in the next section on the modeling equation for metals movement in the soil-water system.

Table 1 Soil Attenuation Mechanisms

Chemical	Mean K _{ds}	Mobility			Fe/Mn Oxides	Primary Attenuation Mechanisms		
		Acid pH < 5.5	Neutral pH 5.5 to 7.0	Alkaline pH > 7.0		Organic Matter	Other	Primary Attenuation Mechanism
As-Arsenic	1.2	Medium	Medium	Medium	Yes	--	sulfide, clay conditions	precipitation (iron), specific adsorption
Cd-Cadmium	1.9	Medium	Medium	Medium	--	--	reducing conditions	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Cr-Chromium	7.7	V. Low	V. Low	V. Low	--	--	--	precipitation (hydroxides)
Cu-Copper	3.1	High	Med to Low	V. Low	Yes	Yes	sulfide, adsorption, insoluble carbonate, sulfate, phosphate, reducing conditions	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Pb-Lead	4.6	Low	Low	Low	--	--	--	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Hg-Mercury	--	Medium	Low	Low	Yes	--	sulfide	--
Ni-Nickel	--	High	Med to Low	V. Low	--	--	sulfide adsorption, silicate minerals	precipitation (hydroxides, carbonates, sulfides), specific adsorption
Se-Selenium	1.0	High	High	V. High	Yes	--	reducing conditions, absorption	precipitation (iron), specific adsorption
Ag-Silver	4.7	High	Med to Low	V. Low	Yes	Yes	reducing conditions, sulfide	cation exchange
Zn-Zinc	2.8	High	High to Med	Low to V. Low	Yes	Yes	sulfide, precipitation by carbonate	precipitation (hydroxides, carbonates, sulfides), specific adsorption

Typical West County Soils -- Moderately acidic, medium organic matter, medium to high cation exchange, few free carbonates.

Typical South County Soils -- Slightly acidic, medium organic matter, high cation exchange, few free carbonates/sulfides.

Reyes Soils -- Strong acidic, low organic matter, medium cation exchange, high sulfides.

Source: Compiled from Dragun, 1988; Baes and Sharp, 1983.

93012MET.T1

5.0 MODEL EQUATION FOR METALS

CONCENTRATION IN IRRIGATION AFFECTED SOIL-WATER PERCOLATE

The following equation provides an estimate of the concentration of metals in the irrigation affected groundwater (percolate) and includes the influence of uptake and immobilization/attenuation as well as existing groundwater concentrations:

$$C_{pm} = \frac{(U)(F_{gw})(C_{ir})(dir) + (C_{gw})(dgw)}{(LF)(dir) + (dgw)}$$

Where:

C_{pm} = Concentrations of metal in the irrigation affected groundwater (percolate) in mg/l.

U = Uptake/immobilization factor for metal (1 to 100 percent uptake/ immobilization, use one (1) for no uptake/immobilization). Separate values are provided for each area based on typical soil characteristics, and for each metal based on expected behavior in the soil. A high adsorption will have a low U , approximately 0.1 to 0.2, while a mobile metal will have a high U of .8 to .85.

C_{ir} = Concentration of metal in reclaimed irrigation water (mg/l). For constituents non-detected in analysis, half the detection limit was utilized. The source of these data is the long-term average provided by the Laguna Treatment Plant Laboratory.

dir = Depth of applied irrigation water (feet). Irrigated pasture was used for both West and South County areas. The application rate is similar to that for forage crops.

C_{gw} = Concentration of metal in groundwater (mg/l). Data were taken from project monitoring well sampling program by Parsons ES (October 1995). Wells nearest the stream of interest or thought to be representative of regional conditions were utilized. For Americano Creek, Well AM (middle Americano) was used; for Stemple Creek, Well SS (Stemple South) was used, and for Tolay Creek, LS (Lakeville South) was used. For constituents not detected in analysis, the detection limit was utilized.

F_{gw} = Fraction of mass loading that reaches the groundwater (86 percent).

Lf = Leaching Fraction, or the fraction of the total volume of water that enters groundwater (13 percent).

dgw = Is the depth (feet) of precipitation that becomes groundwater (3.6 inches).

Tables A-1, A-2 and A-3 in Appendix A list the input parameters that were used in the equation outlined in Section 5.0 for Stemple, Americano and Tolay Creeks.

Table 2 Assigned U Values

Chemical	W. County/ Americano, Stemple	Sebastapol	S. County/Tolay	Reyes Soil
Arsenic	0.80	0.80	0.75	0.6
Cadmium	0.75	0.75	0.70	0.6
Chromium	0.15	0.15	0.1	0.3
Copper	0.4	0.4	0.35	0.2
Lead	0.25	0.25	0.20	0.35
Mercury	0.5	0.5	0.45	0.5
Nickel	0.5	0.5	0.40	0.2
Selenium	0.85	0.85	0.80	0.5
Silver	0.25	0.25	0.25	0.3
Zinc	0.6	0.6	0.55	0.4

6.0 MODEL RESULTS, SOIL-WATER PERCOLATE CONCENTRATIONS

The Section 5.0 Cpm model results for the metals of interest for Americano, Stemple and Tolay Creek Watershed areas are summarized in Table 3.

Table 3

	Existing Concentration Groundwater (mg/l) ¹	Concentration Irrigation Water (mg/l) ¹	Predicted Percolate Concentration in May (mg/l)	Predicated Percolate Concentration in August (mg/l)
Stemple Creek				
Arsenic (As)	0.0005	0.00250	0.00225	0.00963
Cadmium (Cd)	0.0005	0.00032	0.00063	0.00117
Chromium (Cr)	0.0025	0.00089	0.00216	0.00074
Copper (Cu)	0.0100	0.00960	0.01169	0.01884
Lead (Pb)	0.0010	0.00170	0.00121	0.00208
Mercury (Hg)	0.0001	0.00010	0.00013	0.00024
Nickel (Ni)	0.0060	0.00340	0.00646	0.00840
Selenium (Se)	0.0025	0.00075	0.00263	0.00316
Silver (Ag)	0.0005	0.00072	0.00057	0.00088
Zinc (Zn)	0.0250	0.03200	0.03808	0.09320
Americano Creek				
Arsenic (As)	0.0005	0.00250	0.0024	0.00963
Cadmium (Cd)	0.0005	0.00032	0.0006	0.00117
Chromium (Cr)	0.0025	0.00089	0.0021	0.00074
Copper (Cu)	0.0100	0.00960	0.0118	0.01884
Lead (Pb)	0.0010	0.00170	0.0012	0.00208
Mercury (Hg)	0.0001	0.00010	0.0001	0.00024
Nickel (Ni)	0.0025	0.00340	0.0037	0.00827
Selenium (Se)	0.0025	0.00075	0.0026	0.00316
Silver (Ag)	0.0005	0.00072	0.0006	0.00088
Zinc (Zn)	0.0230	0.03200	0.0373	0.09315
Tolay Creek				
Arsenic (As)	0.0005	0.0025	0.0035	0.00903
Cadmium (Cd)	0.0005	0.0003	0.0007	0.00110
Chromium (Cr)	0.0025	0.0009	0.0018	0.00053
Copper (Cu)	0.0100	0.0096	0.0123	0.01653
Lead (Pb)	0.0010	0.0017	0.0012	0.00167
Mercury (Hg)	0.0001	0.0001	0.0001	0.00022
Nickel (Ni)	0.0550	0.0034	0.0387	0.00870
Selenium (Se)	0.0025	0.0008	0.0227	0.00298
Silver (Ag)	0.0005	0.0007	0.0006	0.00088
Zinc (Zn)	0.0380	0.0320	0.0549	0.08603

1 1/2 MDL was used for all ND analytes

Ref.: 93012MET.T3

7.0 CONCLUSIONS

Due to evapotranspiration losses, irrigation application of reclaimed water can result in the magnification or concentration of certain metals in the soil-water. However, physical and chemical processes of natural soil including filtration, adsorption, ion exchange, organic matter complexing and precipitation as hydrous oxides can remove a large percentage of the irrigation applied metals. The amount of removal or soil attenuation depends on the natural chemistry of the soil and the behavior of the element in question in the soil-hydrologic system. The background concentration of the metal in the naturally occurring groundwater may also have a significant effect on the extent of groundwater dilution. Soil conditions throughout most of the West County and South County areas are generally favorable for the retention or immobilization of most divalent cationic metals contained in the reclaimed water. This, coupled with the low concentrations in the reclaimed water and a high level of irrigation management (which minimizes the volume of water available for evapotranspirative magnification), means that the effects on surface water and the shallow groundwater body are likely to be relatively small. It will be difficult to detect changes in metals concentrations in shallow zone groundwater or surface streams (compared to upstream/upgradient control stations) using the monitoring program recommended in the Irrigation Management Plan. A very sophisticated, statistically-oriented monitoring program would likely be required to detect the very small changes in metals concentrations that we have conservatively estimated.

The metals are retained in the upper soil layers; but, because of their low concentrations in the reclaimed water, the levels will not impact the productivity or toxicity of the soil. Lead and chromium, which have relatively high rates of immobilization in the soil, are either only concentrated very slightly over levels in the reclaimed water, or have dampened (lower) levels. Copper, zinc, mercury and nickel are slightly concentrated in the soil-water leachate over initial reclaimed water levels. They have concentration effects of about 1.7 to 2.9 times during the late summer. Arsenic, cadmium and selenium, which have lower uptakes rates, are concentrated by a factor of about 2.5 to 4.2 times. These metals are considered more mobile and are expected to be retained in the soil less effectively under typical West County and South County soil conditions than other metals.

8.0 REFERENCES

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