Santa Rosa Subregional Long-Term Wastewater Project

IRRIGATION WATER QUALITY AND SALT MANAGEMENT LEACHING REQUIREMENTS, SOUTH COUNTY AND WEST COUNTY RECLAMATION ALTERNATIVES

SANTA ROSA SUBREGIONAL LONG-TERM WASTEWATER PROJECT

Prepared for

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

February 1996

Prepared by

QUESTA ENGINEERING CORPORATION
1220 BRICKYARD COVE ROAD, POINT RICHMOND, CA 94807 • 510/236-6114

For

1. SCOPE

This memorandum presents the results of our evaluation of the suitability of the reclaimed water in the Santa Rosa project for use in irrigated agriculture in the West and South County project areas. Also addressed is the potential for salt and/or sodium build-up in the surface soils from the compounds present in the reclaimed irrigation water and the need for irrigation salt management, including leaching.

Although the soils in the West County or South County project areas are non-saline, they may become unproductive if excess soluble salts or exchangeable sodium are allowed to accumulate because of improper irrigation and soil management practices and inattention to drainage needs. Leaching is the process of dissolving and transporting soluble salts by the downward movement of water through the soil and below the root zone. It may require that irrigation be applied beyond that needed by the plants to meet evapotranspirational demands in order to maintain the desired salt balance. This is a matter of concern because any additional leaching required for salt management may flush salts, nitrates, metals and other constituents into the surface water or groundwater. Significantly increased irrigation applications for salt management could also affect baseflow in nearby creeks and cause local groundwater mounding. The potential for trace metals accumulation in the soils is addressed in a separate technical memorandum entitled: *Trace Element Soil Loading Analysis for the South and West County Alternatives*, Questa Engineering Corporation (September 1995).

2. IRRIGATION WATER QUALITY

The suitability of reclaimed water for irrigation is dependent on, in the short term, the direct potential adverse effects of soluble constituents on plant growth, and, in the long term, on the detrimental build-up of these constituents in the soil. Salts and other dissolved constituents (boron, chloride, etc.) at excessive concentrations may harm plant growth and reduce the quality and yield of crops by direct metabolic reactions caused by toxic constituents (termed specific ion effects), or through modification of water uptake mechanisms (termed osmotic effects). High nitrates, on the other hand, may stimulate foliar or green growth in plants, not allowing flowering, seed or fruit set. Because of the wide range in salt tolerance among crops, specific limits of permissible salt concentrations in irrigation water are seldom given (other than a maximum upper range).

The salt concentration where plants begin to show a yield reduction is called the Salt Tolerance or Yield Reduction Threshold (EC_t). The measurement unit is Electrical Conductivity (EC, determined on a conductivity bridge). Electrical conductivity is a quick and accurate method used to estimate salinity. The threshold EC increases with increasing salt content, and is expressed as mmho/cm.[1] **Table 1** lists the EC_t for a number of crops being considered for the West or South County alternatives. It should be emphasized that these values are given for the salt content of the soil-water solution in the root zone, not the applied irrigation water. Soil water, which includes soluble salts resident in the soil and concentrated during evapotranspiration, may contain salt concentrations from five to ten times that of applied irrigation water. (Note: the salt tolerance threshold is used in the next section to determine leaching requirements.)

Irrigation water quality evaluations must take into account the soils to which the water would be applied. Generally, more saline water can be applied to sandy, well drained and permeable soils with a deep groundwater table, than to clayey, poorly drained soils and slowly permeable soils, since salts can move readily through the soil and will not accumulate. The amount of post-irrigation season rainfall is also an important consideration, since the salt balance is affected by the rain water leaching accumulated soluble constituents.

Some water quality constituents, such as sodium, not only have harmful specific ion effects, they also adversely effect soil infiltration and permeability by dispersing or sealing clayey soils. The effect is most noticeable where there is a relatively high concentration of sodium relative to calcium plus magnesium. A measure of this potential effect is the Sodium Adsorption Ratio (SAR).

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1 The unit mmho/cm is now seldom used. The new SI unit is deciSeismens/meter, or ds/m, which is equivalent to mmho/cm.

TABLE 1

Salt Tolerance of Some Agricultural Crops
as a Function of the Salinity of the Saturation Extract.

Common Name	Botanical Name	Yield Reduction Threshold (mmho/cm)	Percent Yield Reduction per mmho/cm
Alfalfa	*Medicago sativa L.*	2.0	7.3
Barley (forage)	*Hordeum vulgare L.*	6.0	7.1
Barley (grain)	*Hordeum vulgare L.*	8.0	5.0
Bean	*Phaseolus vulgaris L.*	1.0	19.0
Blackberry	*Rubus sp.*	1.5	22.0
Boysenberry	*Rubus ursinus*	1.5	22.0
Broccoli	*Brassica oleracea var botrytis*	2.8	9.2
Cabbage	*Bassicia oleracea var capitata*	1.8	9.7
Carrot	*Daucus carota*	1.0	14.0
Clover, alsike	*Trifolium hybridium L.*	1.5	12.0
Clover, ladino	*Trifolium repens L.*	1.5	12.0
Clover, red	*Trifolium partense L.*	1.5	12.0
Corn (forage)	*Zea mays L.*	1.8	7.4
Cowpea	*Vigna unguiculata L.*	1.3	14.0
Cucumber	*Cucumis sativus L.*	2.5	13.0
Fescue, tall	*Festuca elatior*	3.9	5.3
Lettuce	*Lactuca sativa L.*	1.3	13.0
Onion	*Allium cepa L.*	1.2	16.0
Orchardgrass	*Dactylis glomerata L.*	1.5	6.2
Pepper	*Capsicum annuum L.*	1.5	14.0
Potato	*Solanum tuberosum L.*	1.7	12.0
Radish	*Raphanus sativus L.*	1.2	13.0
Ryegrass, perennial	*Lolium perenne L.*	5.6	7.6
Sorghum	*Sorghumbicolor (L.) Moench*	6.8	16.0
Spinach	*Spinacia oleraea L.*	2.0	7.6
Strawberry	*Fragaria sp.*	1.0	33.0
Sudangrass	*Sorghum sudanense*	2.8	4.3
Vetch	*Vicia angustifolia L.*	3.0	11.0

TABLE 1

Salt Tolerance of Some Agricultural Crops
as a Function of the Salinity of the Saturation Extract.

Common Name	Botanical Name	Yield Reduction Threshold (mmho/cm)	Percent Yield Reduction per mmho/cm
Wheatgrass, fairway crested	*Agropyron cristatum L.*	7.5	6.9
Wheatgrass, tall	*Agropyron elongatum*	7.5	4.2
Wildrye, beardless	*Elymus triticoides*	2.7	6.0

Adapted from Maas and Hoffmann, 1977.
Ref.: 93012IWG.T1

Under certain circumstances, the bicarbonate concentration as related to the concentration of calcium plus magnesium must also be considered, since both these constituents may clog sprinkler orifices.

In summary, the most important characteristics defining irrigation water quality are:

1. The total concentration of dissolved salts, (TDS or Electrical Conductivity);

2. The relative proportion of sodium to other cations (SAR);

3. The concentrations of boron and other toxic elements; and,

4. The concentration of bicarbonates and other solids that may form precipitates in the irrigation pipes and sprinkler heads.

Table 2 compares the quality of reclaimed water from the existing Santa Rosa wastewater treatment plant with irrigation water quality standards as developed by the University of California Cooperative Extension (1977) and the United Nations Food and Agricultural Organization (FAO, 1985). The criteria applied are the relative yield of a crop grown on a salt-effected soil (or effected by another constituent) compared with a non-saline soil. Increasing salinity or specific ion concentrations will effect yield. The divisions are: “No Problem,” “Increasing Problem” or “Severe Problem.” Generally, there will be no effect on yield under the “No Problem” and greater than a 50 percent yield reduction in the “Severe Problem” division.

As can be seen from **Table 2**, the reclaimed water is of high quality and no significant direct toxicity or specific ion effects are anticipated. According to U.C. Cooperative Extension, salinity could become an increasing problem. The potential long-term effects on soil structure from sodium build-up, as determined by adjusted SAR, are also low. Salinity falls near the upper levels of acceptability under FAO guidelines. This requires that consideration be given to the soils and climatic variables of the irrigation area to determine the extent of the problem and management needs. The potential for long-term build-up of salts and the need for leaching in salt management are discussed in the next section.

Table 2

Reclaimed Water Quality and Irrigation Suitability

Common Anions/Cations

Characteristic	Reclaimed Water Quality	No Problem	Increasing Problem	Severe Problem	FAO Irrigation Water Guidelines
pH, units [1]	7.0-7.4	6.5-8.4	---	---	6.5-8.4
Total Dissolved Solids [2]	450	---	---	---	450-1000
Salinity (mmhos/cm) [3]	.78	<.75	.75-3.0	>3.0	.5-.8
SAR (adj) [4]	2.8	<6.0	6.0-9.0	>9.0	<6.0
Sodium (mg/l) [5]	80	<69	>69	---	70 to 80
Chloride (mg/l) [5]	120	<142	142-355	>355	140-200
Boron (mg/l) [6]	.48	<0.5	0.5-2.0	2.0-10.0	<.7-1.5
Ammonium nitrogen (mg/l)	4.1	<5	5-30	>30	5 to 30
Nitrate nitrogen (mg/l) [7]	16.3	<5	5-30	>30	5 to 30
Bicarbonate (HCO_3) (mg/l) [8]		<1.5	1.5-8.5	>8.5	---

Table 2

Reclaimed Water Quality and Irrigation Suitability

Common Anions/Cations

Heavy Metals

Characteristic	Reclaimed Water Quality	No Problem	Increasing Problem	Severe Problem	FAO Irrigation Water Guidelines
		For Waters used continuously on all soils	**For use up to 20 years on textured soils of pH 6.0 to 8.5**		
Aluminum (mg/l)	.03	5.0	20.0		---
Arsenic (mg/l)	.002	.10	2.0		0.1
Cadmium (mg/l)	.001	.01	.05	---	.01
Chromium (mg/l)	.002	.10	1.0		.10
Copper	.01	.20	5.0		0.2
Lead	.005	5.0	10.0		5.0
Nickel	.004	.20	2.0		
Selenium	.005	.02	.02		.05
Zinc	.03	2.0	10.0		3.0

Sources: Water Quality Data Source: Compiled by Parsons Engineering Science and used in Human Health and Aquatic Life Risk Assessments. Some data also from CH2M Hill, 1989.

Criteria Source: University of California Cooperative Extension Service, 1977.

FAO Guidelines as contained in CH2M Hill, 1992.

Agricultural Salinity and Drainage, U.C. Davis, 1993.

1 Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience of special conditions of crop, soil and method of irrigation.

2 Refer to **Table 1** for crop tolerance. Mmhos/cm x 640 - approximate total dissolved solids (TDS) in mg/l or ppm; mmhos x 1000 = micromhos.

3 Assumes water for crop plus needed water for leaching requirements (LR) will be applied. Crops vary in tolerance to salinity.

4 SAR (Adjusted Sodium Adsorption Ratio) is calculated from a modified equation developed by U.S. Salinity Laboratory to include added effects of precipitation or dissolution of calcium in soils and related to CO_3 + HCO_3 concentrations.

To evaluate sodium (permeability) hazard:

$$SAR = \frac{Na\,[1 + (8.4 - pHc)}{\sqrt{\frac{Ca + Mg}{2}}}$$

pHC is a calculated value based on total cations, Ca + Mg and CO_3 + HCO_3. Calculating and reporting will be done by reporting laboratory. NOTE: Na, CA - Mg, CO_3 + HCO_3 should be in me/l.

Permeability problems, related to low EC or high adj. SAR of water, can be reduced if necessary by adding gypsum. Usual application rate per acre foot applied water is from 200 to about 1,000 lb. (234 lb. of 100% gypsum added to 1 acre foot of water will supply 1 me/l of calcium and raise the ECw about 0.2 mmho.) In many cases, a soil application may be needed.

5 Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use salinity tolerance tables). For boron sensitivity, refer to boron tolerance tables.

6 Below 0.5 mg/l - Satisfactory for all crops.
0.5-1.0 mg/l - Satisfactory for most crops; sensitive crops may show injury (may show leaf injury but yields may not be affected)
1.0-2.0 mg/l - Satisfactory for semi-tolerant crops. Sensitive crops are usually reduced in yield and vigor.
2.0-10.0 mg/l - Only tolerant crops produce satisfactory yields.

7 Excess N may affect production or quality of certain crops, e.g., sugar beets, citrus, avocados, apricots, grapes, etc.

8 Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride absorption under low-humidity, high-evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads.)

3. SALT MANAGEMENT AND LEACHING REQUIREMENT

Some soluble salts are normally present in all soils in temperate climates. The salts can be native to the soils from weathering of minerals, wicking of shallow subsurface groundwater, accumulation in low land areas from inflow and evaporation, or concentrated fertilizers or applied irrigation water. In areas reclaimed for agriculture from the bay, high salts are naturally present in the former marsh sediments. However, within the project area salinities of the Baylands soils have been significantly reduced from that following initial reclamation by natural rainfall leaching. Salinities of the Baylands soils are generally in the range of 1.0 to 2.0 mmho/cm.

The gradual accumulation of salts in the soil can have a detrimental effect on crop yield and, unless managed correctly, can prevent the growing of some salt-sensitive crops. Ultimately under difficult drainage, soils and irrigation management practices, serious salt build-up can preclude the growing of anything but the most salt-tolerant crops. However, such crops may not be compatible with the agricultural economy of the area.

When salts begin to accumulate in the soil (typically from applications of irrigation water with a high salt content) an extra amount of irrigation water must be added to the soil to leach or flush the salt from the root zone. This may lead to the translocation of the salts to the shallow groundwater, or, in certain hydrogeologic environments, to nearby stream channels. The additional flushing or leaching requirement for salt management will also mean that other chemical constituents (nitrates, metals, etc.) in the irrigation water (reclaimed water) may also be leached to the shallow groundwater or surface water in amounts higher than may be desirable. Adverse salt build-up in the soil might also potentially occur in irrigation systems with very high irrigation application rate efficiencies, such as is required by the Irrigation Management Plan, where flushing salt is restricted for surface water protection.

As previously discussed, to prevent detrimental salt accumulation in the root zone, soluble salts may need to be leached periodically in some agricultural operations with the application of irrigation water in excess of crop evapotranspiration (ET) needs. More leaching typically is required in more arid areas where the irrigation water has a higher salt load. If irrigation water has a high salinity, irrigation management must include even more water to meet the leaching requirement. “Leaching Requirement” is defined as the minimum fraction of the total applied irrigation water that must be moved through the root zone to prevent a reduction in the yield of a crop due to adverse salt accumulations. Leaching occurs whenever irrigation and rainfall taken together exceed the crop ET and moisture storage capacity of the soil. In areas of moderate to high rainfall, the winter rain passing through the soil is normally sufficient to flush salts accumulated from summer irrigation applications of good quality water. Depending on the significance of the salinity management required, leaching applications of irrigation water may need to be applied at intervals of every few weeks, months or years.

4. DETERMINING LEACHING REQUIREMENTS

Leaching requirements depend upon three variables: 1) the concentration of salt in the irrigation water; 2) salt concentration in the soil solution at the root; and, 3) the salt tolerance of the crop (or the salt management objective of the land). The salt tolerance of various crops that can be grown in the project areas was shown previously in **Table 1**. A hypothetical salt balance can be calculated to determine the leaching requirement for each crop. A soil-water balance is used to determine the annual depth of irrigation required which takes into account soils, climate and crop variables. The assumption is made that the soil-water balance will be similar between the beginning and end of the irrigation season, and that no salts are wicking up to the surface from areas of very shallow groundwater.

The amount of excess irrigation water required for salt management can be estimated using the leaching fraction. The leaching fraction is the percent of the gross irrigation and rainfall application that actually leaches and is calculated by the following equation:

$$Lf = \frac{Pd}{(Ii + Ri)} \qquad (1)$$

Where:

Lf = leaching fraction
Ii = amount of irrigation that infiltrates soil (15% of application)[2]
Ri = amount of rainfall that infiltrates soil (55% of rainfall)[3]
Pd = amount of deep percolation

An expression of the irrigation requirement as a function of the leaching fraction is as follows:

$$Ii = \frac{ET}{(l\text{-}Lf) - Ri} \qquad (2)$$

[2] Irrigation efficiency is defined as the ratio of the average depth of irrigation water applied, expressed as a percent. Beneficial uses include satisfying the soil-water deficit and any leaching requirement to remove salts from the root zone. High irrigation efficiencies are typically above 80 percent, meaning that about 20 percent of the water applied does not go to meet plant water needs.

[3] Based on data contained in "Baseline Hydrology and Irrigation Drainage Analysis" by Questa Engineering (November 1995).

Where:

ET = combined evaporation from the soil and transpiration from plants

Since the project irrigation amount has been defined as the crop ET plus 15 percent application efficiency, the Ii for the project is known and we can proceed directly to the next step. To compute the leaching requirement, the ratio of the electrical conductivity at the crop tolerance threshold (ECt) to the electrical conductivity of the applied water (ECw) is calculated. Since there is some dilution from rainwater infiltration into the soil, the ECw is calculated as follows:

$$ECw = (ECi \times Ii)/(Ii + Ri) \quad (3)$$

Where:

ECw = electrical conductivity (mmhos/cm) of the applied water in the soil root zone.
ECi = electrical conductivity of the irrigation water

The analysis assumes salt additions from rainfall, ocean breeze or in fertilizers are negligible.

From the ECt/ECw ratio the leaching requirement is determined from attached **Figure 1**:

Since the West and South County project areas have different climates, separate leaching requirements are determined for each area. The determination is made for irrigated pasture (tall fescue).

West County	**South County**
ECi = .78 (data)	ECi = .78
Ii = 3.42” (irrigation 20% inefficiency)	Ii = 3.7”
Ri = 19.11” (55% of rainfall)	Ri = 15.6”
ECt = 3.9 mmho/cm (Table 1, Fescue, tall)	ECt = 3.9

1. ECw = (EC x Ii)/(Ii + Ri)
ECt/ECw

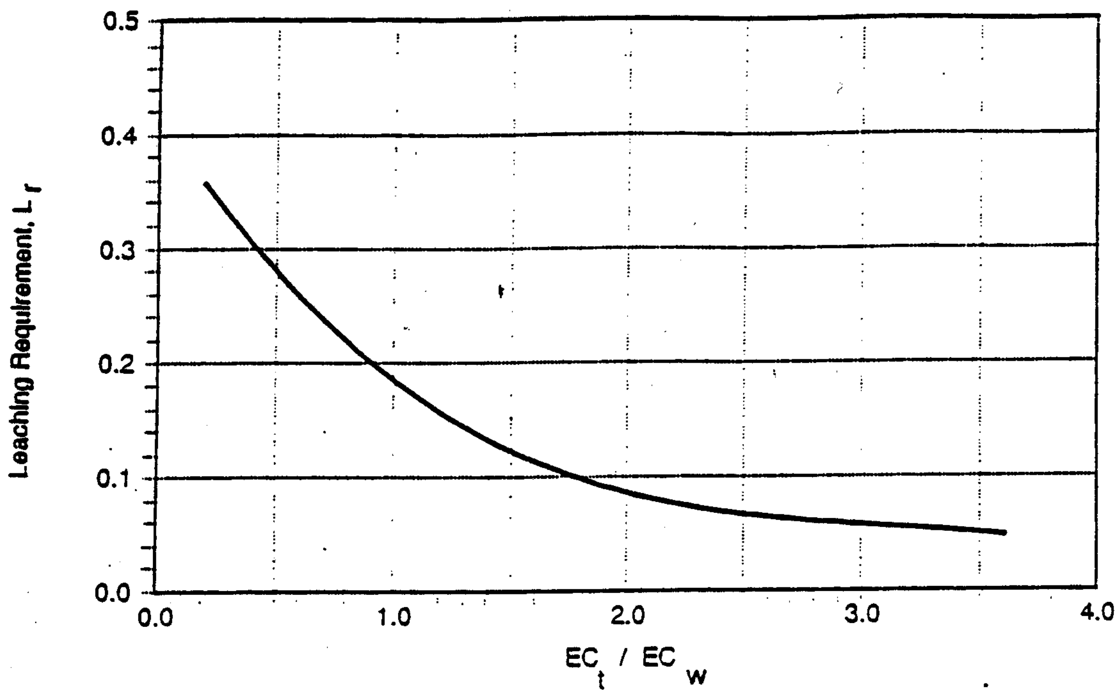

Figure 1. Figure used to predict the leaching requirement based on crop tolerance and water salinity.

West County

ECw = (.78 x 3.42”)/(3.42” + 19.11”) = 2.67”/22.53” = 0.12”

$$ECt/ECw = \frac{3.9\ \text{mmho/cm}}{0.12''} = 32.5$$

South County

ECw = (.78 x 3.7”)/(3.7” + 15.6”) = 2.89”/19.3” = 0.15”

$$ECt/ECw = \frac{3.9\ \text{mmho/cm}}{0.15''} = 26$$

As can be seen in **Figure 1**, the leaching requirement for ECt/ECw values greater than about 3.8 is very low and is normally met by inefficiencies in irrigation application. This means there is sufficient annual rainfall to accomplish the required leaching to grow tall fescue, taking into account the high water quality. Rearranging the equation to solve for ECt and given the need to maintain an ECt/ECw less than 3.8 and an irrigation water quality of 0.78 mmhos/cm, any crop with a yield tolerance of more than 1.0 mmhos/cm (**Table 1**) can be grown in the West County and South County. No crops are excluded because of salt management considerations in normal rainfall years.

It should be pointed out that these calculations are based on average rainfall amounts, evapotranspiration rates and average irrigation applications. The concept of leaching requirement has its greatest usefulness when applied to steady-state water flow rates or to total depths of water used for irrigation and salt management over a long period of time. Some salt accumulation could conceivably occur when higher than normal irrigation volumes are applied (in frequent shallow applications) during hotter than normal summers, there are successive winters with much lower than normal rainfall and techniques to control salts by movement of water below the root zone are not practiced. Such effects have been observed occurring on turf grass irrigation of golf courses in the Rohnert Park area (personal communication, John Cummings). Frequent light water applications by sprinkler irrigation, such as occur at golf courses, exacerbate salt management problems.

To test this “worst case” scenario, irrigation applications were increased by 20 percent to reflect a “hot summer,” and rainfall amounts were reduced to 75 percent of normal. The salt content of the reclaimed water was also increased 22 percent to 1.00 mmhos/cm to account for possible increased concentrations from the City’s Water Conservation Program. For reference purposes, **Table 3** presents salt concentrations where a yield reduction of 25 percent occurs.

The calculated Lr under this hot summer/dry winter scenario is as follows:

ECw = (ECi x Ii)/(Ii + Ri)
ECt/ECw

West County
ECw = (1.0 x 4.1")/(4.1" + 14.3") = 4.1"/18.4" = 0.23"

ECt/ECw = 3.9/0.23 = 17.0

Table 3

Salinity Tolerances for Improved Pasture Species
(at 25% Yield Reduction)

Grass Crops	Ect_{25} (mmhos/cm)
Meadow Foxtail	4.1
Orchard Grass	5.5
Narrowleaf Birdsfoot Trefoil	7.5
Tall Fescue	7.8
Perennial Ryegrass	8.9
Crested Wheatgrass	9.8
Tall Wheatgrass	13.0

Source: CH2M Hill, 1992, Draft Modified West County Reclamation Project, PL 984 Application Report, Vol. 1, p IV-2.

South County
ECw = (1.0 x 4.44")/(4.44" + 11.7") = 4.44"/16.1" = 0.28"

ECt/ECw = 3.9/0.28 = 13.9

Under these conditions, the estimated leaching requirement for irrigated pasture can still be met by rainfall. Even without good salt management practices, and over a period of several successive hot summers and dry winters, it appears that only slight crop yield reductions from salt accumulation effects would occur, and that a salt balance would be restored following resumption of normal rainfall, that would not restrict yields. Salt sensitive crops such as carrots or strawberries might experience yield reductions if poor irrigation practices are followed in dry years.

As outlined in the Irrigation Management Plan, soil monitoring will include periodic monitoring of pH, salts, sodium, metals and other constituents. These data should allow for the timely recognition of any unforeseen salt management problems and the development of appropriate management actions.

5.0 REFERENCES

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