1.0 BACKGROUND

This Technical Memorandum addresses the water chemistry and potential water quality effects from the irrigation of Baylands areas. Baylands are addressed separately from other project areas because the soils and drainage characteristics of Baylands soils are fundamentally different. The Baylands consist of former tidal marsh reclaimed (diked) from the Bay for agricultural purposes around the turn of the century. Most Baylands are identified as a member of the Reyes soil series in the northern San Francisco Bay area. Similar soils do not occur outside of Baylands in the project area. Approximately 2,500 acres of Baylands along the Petaluma River, below Lakeville Highway and north of Highway 37, are being considered for agricultural irrigation as an element of the South County Reclamation Alternative (Figure 1). Drainage from irrigation of Baylands would be discharged to the lower Petaluma River estuary.

Based on an initial screening study completed by the project team (see *Baylands-Reyes Soil Screening Study*, HBA, July 1995), in October, 1995, the Board of Public Utilities (BPU) approved further study and evaluation of a Baylands component. The BPU concluded that Baylands areas potentially may be suitable for establishing irrigated pasture and should be considered further. In part, this was based on the apparent success of the establishment of irrigated pasture by the Novato Sanitation District (NSD) on similar lands along Highway 37 just east of Highway 101 near Novato.

Lands irrigated by NSD drain into Novato Creek, which is a tidal estuary and tributary to San Pablo Bay. Sonoma County also operates a reclaimed water pasture irrigation project on Baylands immediately adjacent to San Pablo Bay. None of the reclaimed water irrigation lands of the City of Petaluma are currently located on Reyes soils, although the City is currently considering such lands as part of their wastewater planning project. Vallejo Sanitation and Flood Control District (VSD) applies biosolids (lime stabilized municipal sludge) to Baylands alongside Highway 37 east of Sonoma Creek in the Tubbs Island area of Sonoma County. These lands are used for dry-farmed oat hay. The Napa Sanitation District also has a pasture irrigation project on reclaimed former wetlands of the lower Napa River estuary; however, these lands are not comprised of the acidic Reyes soils but rather are areas reclaimed from freshwater marsh. Agriculturally, all of these projects are successful. An evaluation of the water quality monitoring data associated with these projects was conducted to provide some insight into possible Santa Rosa project water quality impacts. The evaluation also included field site visits, selective water quality sampling and discussions with agency personnel.

2.0 BAYLANDS CHARACTERISTICS

The Baylands are unique geologically and hydrologically. Long-term settlement of the former marsh sediments following diking and drainage has resulted in a landscape with most land elevations at or just below mean sea level (+1.5 to -2.0 msl). In contrast, most marsh plains around San Pablo Bay have surface elevations of about +2.5 to +4.0 msl, the level that supports emergent marsh plant life. The landscape in the less intensively farmed areas is dotted with numerous small depressions, typically about 1 to 1.5 feet lower than surrounding areas. Although the depression sizes vary tremendously, many are roughly 100 by 100 feet and pond water in the winter months. These are seasonal wetlands, and may represent former shallow open water surfaces of the pre-existing marsh plain. Complex and intricate channel meanders of the former dendritic drainage pattern of the marsh are also landscape remnants, clearly visible on aerial photography. These depressions also pond and carry water. A large portion of the northern Baylands areas, east of Hog Island, was formerly a deep tidal water body within the Petaluma River channel. This area, as shown on early topographic maps, was termed “False Bay.”

Reyes soils are fine-textured, expansive, lack structure, and have very low permeabilities. Undrained depressions are typically less numerous in intensively farmed areas, where leveling and cultivation have filled in low-lying areas. Even so, large areas of Baylands, due to their poor drainage, may experience shallow ponding following periods of heavy rain. Many areas that pond water appear to have developed a subsurface hardened or compacted layer (similar to a hardpan) that restricts subsurface water movement.

The soil chemistry of the Baylands areas is also unique. Reyes soils are extremely acidic in their surface layers with pH levels typically between 3.5 and 4.5. Most natural areas of tidal marsh have surface soils with pH levels in the 6.5 to 7.5 range. The extreme acidity of the Reyes soils is the result of the oxidation of natural sulfide compounds which accumulated in the historic marsh sediments under poorly drained anaerobic conditions. The oxidation of the sulfides (following drainage) produces a sulfuric acid-like reaction which is responsible for the acidity. This acidity is significant because it affects soil fertility, results in a hydro-geologic environment where translocation of many heavy metals is more likely, and affects the water chemistry of the shallow groundwater zone and any surface waters in the constructed ditches draining these areas.

Most Reyes soils were also very saline at the time of reclamation. The salinity of most areas now has been greatly reduced by natural leaching of rainfall. However, some low-lying areas may remain saline and sodic. From a soil-salinity perspective, all but the more salt sensitive crops could likely be grown in most Reyes soils. However, the poor tilth, infertility, poor drainage and climate combine to severely restrict crop choice on areas of Reyes soils. For instance, the break between Reyes soils and Clear Lake soils can clearly be seen in the lower portion of vineyard plantings established west of Lakeville Highway, near Highway 37. Reyes soils are currently being used primarily for native grass pasture (ryegrass-oats) or cut for oat-hay. A common practice is to skip over the wet depressions in cultivation, seeding and haying.

3.0 DRAINAGE AND GROUNDWATER REGIME

Observations within the project area and surrounding areas of Reyes soils indicate that the groundwater table is shallow but seasonally variable. It is common in the winter to have the shallow groundwater zone at or within one to two feet below the surface, depending on ground surface elevation and distance from the Petaluma River or Bay. The groundwater table may drop throughout the spring and summer months to maximum depths of approximately eight or nine feet below ground surface in higher lying areas away from the river, and from three to four feet below ground surface along the River. Since these areas are below sea level by one to two feet, the actual elevation of the groundwater surface fluctuates between -2 and -10 feet msl. It is likely that during the winter, the rising groundwater is strongly acidic (pH less than 5.0) from contact with the acidic surface soil layers, and less brackish from freshwater rainfall infiltration. The slightly brackish water may exist as a lens sitting on top of more saline to hyper-saline groundwater conditions, the result of differences in water density. In the summer months, the lens of freshwater may be discharged by the surface drainage system. Interestingly, groundwater acidity may also increase to near neutrality during the summer months as the water table drops to lower soil zones which are unoxidized and anaerobic.

Review of water chemistry data from a number of monitoring wells in Reyes soils (Las Galinas, Novato and Vallejo Sanitation District projects, and Sonoma Baylands) indicates that acidity does indeed often decrease as the groundwater table is drawn down in the spring and summer when the water comes into contact with unoxidized, lower zone strata; salinity levels increase to hyper-saline conditions in some areas. For instance, a monitoring well in similar Reyes soils at the Las Galinas Sanitary District sludge disposal site (San Rafael) showed a drop in pH in groundwater from 7.3 in September 1994, to 4.7 in December 1994, as groundwater levels rose into the upper, seasonally-oxidized zone due to rainfall infiltration. Salinity (i.e., specific conductivity) levels decreased from 25,000 to 5,000 mmhos/cm. Often heavy metals such as cadmium, chromium, copper and lead occur at elevated concentrations in the groundwater beneath Baylands areas, reflective of their highly acidic, mineralized state. These conditions are likely to vary considerably according to season, year and area. They will also change in response to different rainfall and site drainage conditions (reflective of elevation and location), as well as with proximity to drainage ditches and the Petaluma River.

4.0 SURFACE WATER REGIME

Baylands areas are transected by numerous agricultural drainage systems. These ditches are commonly excavated to depths of -4 or -7 feet msl to intersect the groundwater table and thus provide both surface and subsurface drainage for agricultural purposes. Hydrologically, Reyes soils consist of deep clays and silt clays that have very low hydraulic conductivity (i.e., permeability). Normally, shallow zone groundwater would be expected to move very slowly through these soil conditions (far less than one foot per year) to enter the drainage ditches dissecting the farmlands. The water from the drainage ditches is then directed to a master ditch alongside the outer river front levee where it is pumped into the river. Some drainage networks also employ tide gates where drainage is discharged by gravity at low tide.

Observations of the drainage network at the NSD agricultural reclamation lands indicate that preferential flow through the upper Reyes soils may likely occur. The inference is that water not only moves slowly through pores as inter-granular flow, in accordance with Darcy's law, but that a portion of the shallow zone flow probably is moving through more hydraulically permissive routes such as occasional buried silty/sandy strata, or abandoned, buried channels filled with more permeable materials.

This observation is based on the fact that there is typically abundant freshwater in the drainage ditches following summer irrigation of Reyes soils at the NSD facility along Highway 37. Observations during irrigation periods are that only a small amount of this water occurs as a result of irrigation runoff. Direct irrigation runoff is not allowed according to the San Francisco Bay Regional Board waste discharge permit. This ditch water is apparently not well connected hydrologically to the groundwater beneath the irrigation areas; similar areas of unirrigated Reyes soils have much less water in drainage ditches during summer months. The water in these non-irrigated areas is also very brackish. Only very small amounts of freshwater would be expected in the drainage ditches from interpore water movement in the tight Reyes soils areas.

Hydrologic modeling of such areas with preferential flow is difficult. Traditional groundwater flow models based on soil hydraulic conductivity and application of Darcy's law do not accurately account for all of the flow paths, and the root-zone water balance model used in the hydrologic and water quality analysis for the West and South County areas also is not applicable. The models based on Darcy's law would likely predict that irrigation water applied to the center of a field would not enter the perimeter field ditches for decades (or more).

Similar to, and associated with, the winter-summer shift in shallow zone groundwater chemistry (particularly acidity and salinity), a significant seasonal shift is also likely in the chemistry of the surface water. The ditch water is likely to be very fresh and mildly acidic in the winter and early spring periods of active stormwater runoff. The ditch water will be slightly brackish and moderately to strongly acidic in the late spring and mid- summer as the drainage ditches draw water from the shallow oxidized soil zone (where sulfides are being oxidized to acid-forming sulfates). They may return to a mildly acidic state in the later summer and early fall as the ditch water draws largely from groundwater in deeper anaerobic soil zones. These conditions, which depend on water table fluctuations and soil-oxygen deprivation, are likely to vary considerably according to area and season. They also reflect the variability in local elevations, soil and drainage conditions, and rainfall amounts. Data from a number of surface water quality monitoring events of drainage ditches with areas of Reyes soils are summarized in Table 1. Data from a dry-farmed area of Reyes soil on Tubbs Island (Solano County) are from a background or control ditch station monitored by Vallejo Sanitation and Flood Control District as part of their biosolids land application program conducted between 1982 and 1993. They show elevated levels of copper and nickel in waters draining from these fields.

5.0 IMPACT EVALUATION

Unless properly planned and managed, application of reclaimed water to previously non-irrigated lands has the potential to increase non-point source water pollution of a watershed area, including groundwater degradation and impacts to surface water quality in streams and estuaries. Unmanaged irrigation of prior dry-farmed areas or grazing lands also has the potential to negatively impact seasonal wetlands and adjacent riparian areas, as well as downstream receiving waters, wetlands and estuaries. Such impacts are typically associated with poorly controlled irrigation or over-irrigation, when water is applied at rates that exceed soil infiltration capacity or the water needs of the crop. The result is surface runoff (runoff) of excess water or subsurface flow (subflow) of water to local drainage ways and stream courses. The runoff or subflow water can contain sediment, attached pesticides, nutrients and metals that may be native to and leached from the soil, occur in small quantities in the reclaimed water, or come from applied agrochemicals or animal waste. Because constituents in applied irrigation water can be concentrated by evapotranspiration leaving precipitated salts and soil adsorbed metals behind, there is also the possibility that these constituents can be remobilized seasonally in runoff water or in subflow. As previously discussed, these concerns are particularly legitimate in areas of acidic soils with low redox potential.

Because of the characteristics of Baylands soils, available surface and groundwater quality models are not readily applicable to the understanding of potential irrigation-related water quality impacts. These models assume continuous saturated flow through porous media. The NSD irrigation project monitoring data provide the greatest insight as to probable project water quality impacts because of the expected similarity between project soils, hydrology and the irrigation systems. The NSD monitoring data are summarized in Table 2. Column 1 is an average of the NSD effluent chemical composition applied to the fields. The remainder of the table represents sampling data from drainage ditches within their irrigation areas. The locations of the sampling stations are shown in Figure 1.

The following summarizes our conclusions with respect to probable effects from reclaimed water irrigation based on our knowledge of the chemistry and behavior of Reyes soils, the local hydrology, and the NSD monitoring data. This evaluation must be tempered by the fact that the project area lands would be irrigated under the guidance of the Irrigation Management Plan (IMP) not being followed at the NSD site. The IMP contains specific management provisions for areas of Reyes soils. In addition, the Santa Rosa project is expected to produce reclaimed water of better quality than NSD water, particularly for nitrates and copper (see Table 2).

6.0 SURFACE WATER QUALITY

6.1 pH AND ACIDITY

Seasonally, aquatic wetlands can vary considerably in their pH and acidity. Variability occurs temporally (i.e., daily or seasonally), and spatially. Rainfall runoff, irrigation runoff and subflow, leakage of tidal water through tide gates and under levees, and evaporative changes can also cause significant changes in water pH in wetland-associated water bodies. Such changes are evident in the water quality sampling data (Tables 1 and 2).

Currently, the San Francisco Bay Regional Water Quality Control Board requires VSD to conduct bioassays once a month during pump operation episodes (November to April). Results for the 96-hour, static toxicity bioassay conducted during the 1992-93 season indicated extreme toxicity (no survival of test fish). The cause of the toxicity was found to be associated with acidity; when the pH was adjusted to 7.0, the percent survival was above 90 percent.

One of the principal water quality impact concerns associated with the Santa Rosa project is whether the present acidity (due to historic reclamation activities) will remain the same, decrease (become more neutral) or increase as a result of irrigation with reclaimed water. Another issue is whether the water acidity will stay the same or worsen as a result of the overall increase in the total volume of ditch water (irrigation tail water and drain water) that will need to be pumped to the Petaluma River. The total mass of acidic water could increase as a result of irrigation, although the discharge water could be better quality.

Water quality (acidity) could conceivably worsen if the irrigation water leaches more acid forming compounds from the soil into the ditches. The NSD monitoring data do not appear to indicate that this is occurring. Conditions could conceivably improve under an irrigation management plan where the near surface soils are kept in a wet (but not saturated), relatively low redox state, thus minimizing the oxidation of native sulfide compounds to acid-forming sulfates. Initial and periodic liming of the surface soils, combined with the natural buffering capacity of the reclaimed water, would also tend to maintain or somewhat improve drainage water acidity. The Irrigation Management Plan contains similar specific management measures for Reyes soils so that, under careful management and monitoring, acidity conditions could be expected to improve. Although the management would preclude runoff, the total mass or volume of drainage water that would need to be discharged following initiation of irrigation would increase.

Currently, the San Francisco Bay Regional Water Quality Control Board prohibits the NSD from pumping irrigation drainage water to Novato Creek (a tidal estuary) during the irrigation season. This water quality management strategy appears warranted. It tends to maintain saturated conditions in the subsoil of the fields, thereby limiting sulfide oxidation to some degree. In addition, it restricts discharge to the rainy season, when there is freshwater inflow to the fields and Novato Creek, and when the estuary is more capable of withstanding the acidity effects because of natural dilution from the increased flows. Another important factor is that tidal waters have tremendous acid buffering capacities and any effects from discharge of acidic drainage waters to estuaries are likely short-term and localized. Effects could possibly be minimized further if pumping were timed to avoid lower tides.

The proper sizing and depth of the drainage ditches with respect to interception of groundwater and the proper management of irrigation return water stored in the drainage ditches until the permitted late fall discharge period will be important design and management issues to be worked out during detailed irrigation system planning. For instance, the ditch water could conceivably be recirculated through any required mitigation wetlands.

6.2 SALTS

We anticipate that, following irrigation, the average salt concentration of the drainage water that would be discharged to the Petaluma River during the early fall and winter period will decrease substantially over present conditions. This is based on the anticipation of there being preferential subflow and a small amount of irrigation runoff, similar to that observed at the NSD irrigation project. This flow of low salinity irrigation-affected water would dilute the salinity of the ditch water.

However, the total mass discharge of salts is expected to increase over present conditions. This would result from the combined effects of leaching of residual salts from the soils, salts created from oxidation and dissolution of sulfide compounds, and from the evapotranspirative concentration of salts contained in the reclaimed irrigation water. The increase in the mass discharge of salts at the discharge point is expected to be very small incrementally in comparison to the total mass of salts present in the tidal column in the zone where mixing and dispersion would occur.

6.3 SULFATES AND SULFIDES

A significant concern associated with acidity in drainage waters located in reclaimed tidelands is the formation of hydrogen sulfide and oxidation of pyritic-like compounds that result in elevated levels of sulfides and salts. Hydrogen sulfide (H_2S) can be formed in stagnant water bodies with anoxic conditions that have received high inputs of sulfates from the reduction of the sulfate ions in watershed soils. Pyritic compounds (FeS_2) are also formed under reduced conditions from the reduction of ferric and sulfide ions. When slightly reduced to oxidized conditions occur, the concentrations of monohydrogen sulfide (HS) may become significant, impacting aquatic organisms. Undisassociated and toxic H_2S dominates in the acidic pH range. Based on information supplied by Professor K. Tanji (U.C. Davis), at 25° Celsius the fraction of monohydrogen sulfide (HS) of the total dissolved sulfide load is 11.6 percent at pH 6, 56.9 percent at pH 7.0, and 92.8 percent at pH 8.0. Under oxic conditions, the pyritic compounds dissolve, forming strongly acidic solutions. In the presence of calcium and sodium carbonates (which can be provided by tidal water), the acidity is neutralized and elevated levels of TDS are produced, typically 8,000 to 12,000 mg/l. Sulfides were not analyzed in the August 8, 1990, and September 6, 1990, sampling completed by the NSD, nor in the monitoring program completed by VSD. They were not detected in the October 4, 1995, sampling completed by Merritt-Smith Consulting; but, sulfate compounds were detected in moderate concentrations. These concentrations of sulfates are likely a condition associated with the prior reclamation and drainage of the Baylands, and not directly related to irrigation. (See Table 2 for background concentrations of sulfate in other Reyes soil areas.)

6.4 NITROGEN COMPOUNDS

Nitrogen is best measured in aquatic environments associated with wetlands as nitrate (NO_3) plus nitrite (NO_2). Ammonia data must be interpreted with the knowledge that NH_4 is produced in reducing conditions. Nitrogen levels may also vary seasonally in aquatic environments associated with wetlands, reflective of summer biological depletion by algae, and denitrification in shoreline (or ditch edge) vegetative zones.

Nitrates, and to a lesser extent nitrite compounds, are readily mobile and easily transformed and removed in the soil environment. As long as the system is not overloaded with respect to crop N demand, most forage crops, such as the irrigated pasture established on the NSD lands, readily uptake nitrogen contained in the irrigation water.[1] Substantial volatilization of ammonia and denitrification may also occur in wetter portions of fields on Reyes soils.

Elevated levels of nitrate-nitrogen occur seasonally in the drainage ditches which drain the dry-farmed and grazed areas of Reyes soils. For instance at the Cloudy Bend site along the Petaluma River near Stage Gulch Road, nitrate N levels were as high as 13.4 mg/l in March, 1995 (from stormwater runoff), but dropped to 3.3 mg/l in April, and 0.11 mg/l by October (see Figure 1).

Nitrate levels in the NSD effluent are relatively high compared to the Santa Rosa project reclaimed water (16.5 mg/l vs. approximately 11.6 mg/l).[2] However, the effectiveness of the irrigated pasture crop (and ditch-lining wetlands vegetation) in removing nitrate is readily demonstrated by the ditch water quality data. More than 95 percent of the nitrate-nitrogen contained in the effluent is being removed through the irrigation-drainage system. With lower initial concentrations in the Santa Rosa project reclamation water, similar or better reductions are expected. Nitrites were not detected in the ditch water. Ammonia levels in the ditch water samples were also found to be much lower than in the NSD effluent (7.7 mg/l reduced to 0.59 to 1.4 mg/l). This difference may represent direct volatilization, plant uptake, or denitrification in the soil or wetlands environment.

6.5 TRACE METALS

Data for evaluation of probable irrigation impacts on trace metal water quality in receiving waters in similar Baylands environments are limited. However, the available data do not indicate a likely significant problem with trace metals, solubilizing or leaching from the acidic soil, or being concentrated from evapotranspirational effects. This is a potentially significant

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1 Assuming nitrate loading does not exceed crop requirements and irrigation applications do not exceed hydraulic loadings based on infiltration and permeability.

2 Santa Rosa reclaimed water nitrate levels are expected to be about 14.5 mg/l after the interim nitrogen removal system is constructed. Nitrogen losses in reservoir storage are conservatively estimated to be 20 to 25 percent, or 11.2 to 11.6 mg/l reclaimed water N.

concern because the solubility and mobility of heavy metals typically increases markedly in an acidic soil/reducing environment such as occurs on Reyes soils.[3]

Zinc, manganese and copper data are available from the NSD monitoring program and provide three reference points that can be used to evaluate potential irrigation water quality impacts. Other toxic heavy metals which were not analyzed by NSD (lead, nickel, chromium, cadmium) are expected to behave similarly to these elements under certain conditions.

Compared to other heavy metals, zinc is normally present in the soil in moderate quantities (100s to 1,000s of mg/kg versus < 100 mg/kg for other metals) and is an essential element for plant metabolism. Zinc may also be present in the soil in soluble forms in moderate amounts. Zinc can be used as a potential indicator of water quality problems. It is also present in the aquatic environment in relatively large amounts, and is easy to measure and detect. Since other more toxic heavy metals such as lead, chromium and cadmium behave somewhat similarly to zinc, high levels of zinc in drainage ditch waters would be indicative of a propensity of the reclaimed water to leach soluble native zinc (and hence other metals) out of the soil, or to allow concentration and passive transport of metals in the reclaimed water to the surface water ditches without the desired soil uptake, immobilization or attenuation.

Manganese is somewhat similar to zinc in that it is also an essential element present in the soil in relatively high amounts. Although manganese is an essential element for plant growth and animal metabolism, it can be toxic to aquatic organisms at moderate concentrations. However, manganese behaves somewhat differently than zinc in a reducing environment and/or where pH levels change significantly. The solubility and mobility of manganese oxide compounds can be sensitive to changes in the pH:oxidation-reduction (redox) state. Manganese is present in a free cationic state in low pH, low redox soils. Therefore, it may be a good indicator of metals mobility in poorly drained, acidic soils.

Copper, on the other hand, is typically present in low quantities in most soils (< 50 mg/kg). It is not known to be metabolically essential. Of the total copper present in a soil, even less is normally present in a soluble form. Copper is also present in the aquatic environment in very low quantities and is toxic to many life forms in very low concentrations (<0.05 mg/l). Because of its presence in very small concentrations (most often non-detectable), the sudden occurrence of copper in a sampling event must be viewed suspiciously, possibly attributable to solubilization or concentration as the element moves through changed soil-water chemistry, passing through the hydrologic cycle or as a result of bio-magnification. Municipal wastewater can contain modest concentrations of copper, resultant from copper plumbing fixtures in the municipal water supply system.

Based on a comparison of the metals concentrations in the NSD effluent and the occurrence of generally similar concentrations of zinc and copper in ditch water, it appears that metals attenuation occurs within the system (Table 2). Generally, these metals were found to be present in low amounts in the ditch water, at levels similar to the treatment plant effluent. This occurs

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3 See Evaluation of Metals in Irrigation Affected Percolate, West County and South County Reclamation Alternatives, Questa Engineering Corporation, for a more detailed discussion of trace metal attenuation and movement in soils.

even though evapotranspiration effects following irrigation would tend to concentrate the metals by as much as two to three times. The data do not indicate whether heavy metals are, (a) being immobilized and fixed within the soils of the land-based irrigation system, or (b) being removed along with irrigation runoff or subflow and trapped by the soils or wetlands vegetation within the drainage ditches. It is likely that both phenomena occur, perhaps with different effectiveness during the irrigation and rainy seasons. The attenuation appears to be equally effective for zinc and copper compounds, and we believe it will be effective in the stabilization of other metals such as cadmium, chromium and lead. Increases in concentration due to evapotranspiration of water are expected to be overshadowed by the attenuation in the soils. Copper levels in the NSD ditch water, although similar to the effluent, are of concern because of the aquatic toxicity of copper, even at very low concentrations. Based on VSD monitoring data of similar Baylands surface water and groundwater in the Tubbs Island area, it appears that such concentrations may be a natural condition associated with the acidic, mineralized drainage water.

Manganese levels in the ditch water are considerably higher than in the NSD effluent. This is unusual, since manganese is seldom found in surface water at levels greater than 1 mg/l. One possible explanation is that manganese compounds are being solubilized and remobilized by the NSD irrigation project. The historic drainage and consequent oxidation of the surface Reyes soils also may result in the conversion of manganese compounds to more soluble forms. This may be a relict effect of the historic land reclamation, which will take place regardless of irrigation (a background or pre-existing condition). Unfortunately, NSD does not operate a background water quality monitoring station, and VSD monitoring does not include manganese. High rates of irrigation could, under certain conditions, result in the increased flushing of remobilized manganese. Management practices for irrigation of Baylands to minimize manganese in drainage should be similar to management for acidity and sulfides, including liming soils, optimum irrigation management and winter discharge.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Irrigation of Baylands with reclaimed water, if well managed, has the potential to improve (slightly) the quality of drainage water that is discharged to the Petaluma River following early rains in the late fall. Improvements or decreases in water salinity are expected but no significant changes in other inorganic parameters are anticipated. This is in comparison to the existing quality of drainage water intercepted by the ditches in non-irrigated areas. Liming of the soils to neutralize acidic soil pH and water management to minimize or reduce subsoil oxidation of sulfides are also expected to be beneficial in reducing copper, manganese and other heavy metals levels in the ditch water. However, the total volume of drainage water discharged to the Petaluma River, although improved in quality, will increase following irrigation.

These management recommendations for Baylands areas are largely theoretical and conjectural based on the present understanding of the behavior and chemistry of Reyes soils. The IMP calls for the City to cooperate with the Sonoma-Marin Mosquito Abatement District, the Natural Resources Conservation Service, and U.C. Cooperative Extension in developing best management practices for irrigated Baylands areas. Management recommendations will include wetlands, water quality and mosquito abatement considerations as well as agricultural practices.

Management is intended to be flexible and pro-active, responding in a timely fashion to any trends that develop and are identified in the monitoring program, and as more is learned about the behavior and management of the soils. It will be important to establish baseline and control sample data so that trends can be properly evaluated. Monitoring at appropriate time periods will also be important because of the expected seasonal flux of water chemistry.

A management strategy for Baylands irrigation is identified in the IMP to provide the best possible drainage quality. This management strategy includes liming of soils and careful control of irrigation rates such that saturated soil conditions are maintained. This strategy is expected to produce drainage quality that is similar, or possibly superior to, existing drainage quality with respect to key constituents such as pH, copper, sulfides and manganese. The impact of discharging drainage water from ditches to local surface waters such as the Petaluma River is evaluated separately (see *Water Quality Impact Analysis*, Merritt Smith Consulting, May 1996).

The Baylands management strategy may make Baylands more expensive to irrigate than other lands. For this reason, irrigation of other lands may be preferred. The water balance model (see *Water Balance Model*, Parsons ES) shows that irrigation of about 3,900 acres in the South County are necessary to allow for a one percent design discharge rate to the Russian River or Laguna de Santa Rosa. This acreage requirement is based on an assumed average crop consumptive use requirement of 28 inches per year and a 20 percent irrigation application efficiency. To the extent that agricultural practices in place in the South County would apply less water, the acreage requirement would increase from 3,900 acres. Excluding Baylands, over 10,000 acres of irrigable land have been identified in the South County (see *Irrigation Suitability Land Classification and Existing and Potential Agricultural Land Uses, South County Reclamation Study Area*, Questa Engineering, May 1996). Therefore, a one percent South County project may be feasible without invoking the relatively costly Baylands).

8.0 REFERENCES

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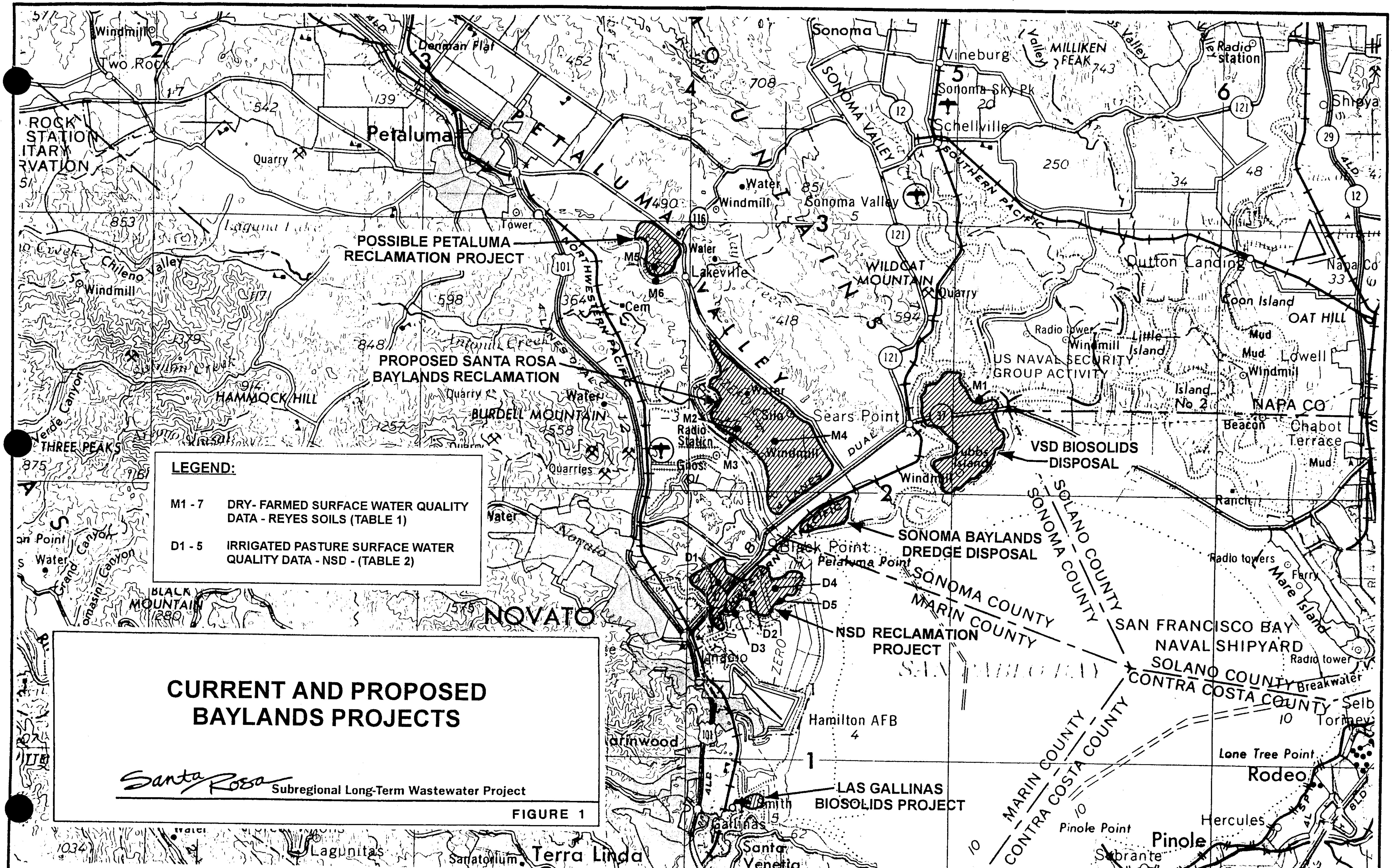
CURRENT AND PROPOSED BAYLANDS PROJECTS
Santa Rosa
Subregional Long-Term Wastewater Project
FIGURE 1
LEGEND:
M1 - 7 DRY- FARMED SURFACE WATER QUALITY DATA - REYES SOILS (TABLE 1)
D1 - 5 IRRIGATED PASTURE SURFACE WATER QUALITY DATA - NSD - (TABLE 2)
POSSIBLE PETALUMA RECLAMATION PROJECT
PROPOSED SANTA ROSA BAYLANDS RECLAMATION
VSD BIOSOLIDS DISPOSAL
SONOMA BAYLANDS DREDGE DISPOSAL
NSD RECLAMATION PROJECT
LAS GALLINAS BIOSOLIDS PROJECT
M1
M2
M3
M4
M5
M6
D1
D2
D3
D4
D5
Petaluma
Sonoma
Vineburg
Schellville
Lakeville
Sears Point
Black Point
Petaluma Point
NOVATO
Hamilton AFB
Marinwood
Terra Linda
Santa Venetia
Lagunitas
Rodeo
Pinole
Hercules
Sobrante
Pinole Point
Lone Tree Point
SONOMA COUNTY
MARIN COUNTY
SOLANO COUNTY
CONTRA COSTA COUNTY
NAPA CO
SAN FRANCISCO BAY NAVAL SHIPYARD
US NAVAL SECURITY GROUP ACTIVITY
WILDCAT MOUNTAIN
BURDELL MOUNTAIN
HAMMOCK HILL
BLACK MOUNTAIN
THREE PEAKS
PETALUMA VALLEY
Mare Island
Dutton Landing
Coon Island
OAT HILL
Lowell
Chabot Terrace
Two Rock
Denman Flat
Sonoma Valley
Tubbs Island
Ignacio
Gallinas

Table 1 Surface Water Quality Data, Areas Draining Reyes Soils

Sample I.D.	Description	Date	pH/Salinity	TDS	SO_4	S_2	NO_3-N	NO_2-N	NH_3-N	Cd	Cr	Cu	Pb	Ni	Zn
VSD #D3 Map #1	Background/control site in ditch draining dry-farmed Reyes soils, not receiving bio-solids (Tubbs Island area, Solano County)	4/93	4.04/7310	--	--	--	--	--	.05	.0038	.0099	.021	ND	1.274	.313
Smith Ranch Mitigation Site Map #2	Ditch draining dry-farmed Reyes soils area near Petaluma River, below Lakeville Highway	9/92	3.18/ 11.42 ppt	--	--	--	--	--	--	--	--	--	--	--	--
Petaluma River @ Smith Ranch mitigation site Map #3	Sample taken from levee bank of Petaluma River at Smith Ranch	9/92	7.35/ 9.87 ppt	--	--	--	--	--	--	--	--	--	--	--	--
Smith Ranch study area Map #4	Ditch draining dry-farmed Reyes soil area below Lakeville Highway	10/4/95	7.9/ 28,000 umhos/cm	16,700	1,500	ND	ND	ND	0.14	--	--	--	--	--	--
Cloudy Bend Map #5	Ditch draining dry-farmed Reyes soil area near Cloudy Bend Pump Station	10/4/95	7.7/ 27,800 umhos/cm	21,300	1,400	ND	.11	ND	.06	--	--	--	--	--	--
Cloudy Bend Map #5	Same as above.	4/11/95	--	--	--	--	13.4	.02	1.6	--	--	--	--	--	--
Petaluma River at Cloudy Bend Map #6	Sample taken from levee bank of Petaluma River at Cloudy Bend	10/4/95	7.7/ 28,500 umhos/cm	22,800	1,400	ND	.37	ND	.18	--	--	--	--	--	--

-- Not analyzed
1 All results in mg/l unless otherwise noted.
2 Sampling stations ("Sample I.D") keyed to Figure 1.

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TABLE 2 Surface Water Quality Data from Novato S.D. Highway 37 Reclamation Project

	Novato	Santa Rosa	Ditch 1			Ditch 2			Ditch 3			Ditch 4			Ditch 5		
	Effluent [1]	Effluent	8/8/90 [2]	9/6/90	10/4/95	8/8/90	9/6/90	10/4/95	8/8/90	9/6/90	10/4/95	8/8/90	9/6/90	10/4/95	8/8/90	9/6/90	10/4/95
pH, Units	7.5	7.0-7.4	3.9	3.2	6.1	3.7	3.5	na	3.6	3.4	6.1	5.5	6.1	na	7.2	4.4	6.4
Conductance, umhos/cm	708	780	3,850	4,270	3,100	3,400	3,540	na	4,880	4,160	2430	7,830	6,410	na	11,000	6,970	5,100
TDS, mg/l	446	450	1,900	2,800	2,100	2,800	2,000	na	3,200	2,700	1,800	5,000	4,300	na	7,900	4,500	3,500
DO mg/l	na	na	na	na	5.2	na	na	na	na	na	3.3	na	na	na	na	na	8.0
Nitrate-N, mg/l	16.5	11.6	< 0.1	< 0.4	ND	<0.1	<0.4	na	<0.1	<0.4	0.16	1.7	<0.5	na	<0.1	<0.4	0.63
Nitrite-N, mg/l	0	0	na	na	ND	na	na	na	na	na	ND	na	na	na	na	na	ND
Ammonia-N, mg/l	7.7	4.1	na	na	0.70	na	na	na	na	na	1.4	na	na	na	na	na	0.59
Sulfate, mg/l	58	na	670	870	280	620	590	na	770	700	390	1,200	1,000	na	1,600	1,200	530
Sulfide, mg/l	na	na	na	na	ND	na	na	na	na	na	ND	na	na	na	na	na	na
Copper, mg/l	0.05	.01	< 0.05	0.06	na	<0.05	0.08	na	<0.05	0.07	na	<0.05	0.07	na	0.05	0.06	na
Manganese, mg/l	.07	na	2.6	3.8	na	2.2	2.0	na	2.8	2.8	na	4.6	3.8	na	2.6	4.8	na
Zinc, mg/l	<0.05	.03	<0.05	<0.05	na	<0.05	<0.05	na	0.08	0.06	na	<0.05	<0.05	na	<0.05	<0.05	na

na Not analyzed.
ND None detected.
1 Based on 17-month average, January 22, 1991 to May 17, 1992, from Novato Sanitary District (NSD).
2 August 8, 1990 and September 6, 1990 sampling by NSD; October 4, 1995 data from sampling by Merritt-Smith Consultants and Questa Engineering Corp.
3 Sampling points referenced to Figure 1. D1 = Ditch 1, etc.

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