CITY OF VENTURA

TREATMENT WETLANDS FEASIBILITY STUDY

REPORT

FINAL
March 2010

Stillwater Sciences

carollo
Engineers...Working Wonders With Water™

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TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1
2.0 PURPOSE AND SCOPE OF STUDY 2
3.0 BACKGROUND 2
3.1 Study Area and Existing Facilities 2
3.2 Regulatory Setting 4
3.2.1 Existing Regulations 4
3.2.2 Future Regulatory Considerations 7
3.3 Previous Reports and Studies 8
3.3.1 Save Open-space and Agricultural Resources (SOAR) Ordinance (1995) 8
3.3.2 Ventura Harbor Wetlands Environmental Art Project Research Report (March 2003) 9
3.3.3 Conservation Plan for the Lower Santa Clara River Watershed and Surrounding Areas (2008) 10
3.3.4 Ventura Harbor Wetlands Ecological Reserve Restoration Plan: Restoration Implementation Plan (December 2009) 11
4.0 WETLAND SITING EVALUATION 11
5.0 WATER BALANCE – EXISTING AND PROJECTED FLOWS 16
6.0 WATER QUALITY ANALYSIS 17
7.0 POLLUTANT REMOVAL IN FREE WATER SURFACE WETLANDS 27
7.1 Removal of Particle Associated Pollutants 29
7.1.1 Total Suspended Solids 29
7.1.2 Phosphorus 30
7.1.3 Metals 30
7.2 Removal of Nitrogen 31
7.3 Removal of Other Constituents of Concern 32
7.4 Wetland Design Hydraulic Residence Time Estimates 36
8.0 TREATMENT WETLAND ALTERNATIVES 40
8.1 On-site Alternative 40
8.2 Off-site Alternatives 44
8.3 Preliminary Cost Estimates for Alternatives 45
9.0 HABITAT OPPORTUNITIES 49
9.1 Existing On-site Habitat 49
9.1.1 Riparian Forest 49
9.1.2 Emergent Freshwater Marsh 51
9.1.3 Ruderal Herbaceous 52
9.1.4 Open Water 52
9.2 Opportunities for Enhancement 53
9.2.1 Enhancement of Emergent Freshwater Marsh 53
9.2.2 Extension of Coastal Dunes 53
9.2.3 Snags with Cavities 54

9.2.4 Downed Wood 54
9.2.5 Island 54
10.0 SUMMARY 54
10.1 Outstanding Issues to Address/Next Steps 56

REFERENCES

LIST OF TABLES

Table 1 VWRF NPDES Permit Limits for Conventional Constituents 7
Table 2 VWRF NPDES Permit Limits for Metals 7
Table 3 Summary of Potential On- and Off-site Wetland Opportunities 13
Table 4 Summary of Existing and Projected Average Annual Flows to On- and Off-Site Treatment Wetlands 17
Table 5 VWRF Average Effluent and Permit Limit Levels of Conventional Constituents 18
Table 6 VWRF Average Monthly Effluent and Permit Limit Levels of Metals (µg/L) ... 20
Table 7 VWRF Average Monthly Effluent and Typical FWS Wetland Effluent Levels of Metals 31
Table 8 Summary of Recent Studies on CEC Removal by Wetlands 34
Table 9 Summary of CEC Removal Efficiencies by Wetlands 35
Table 10 Design Hydraulic Residence Time (HRT) as a Function of Temperature for 60 Percent Reduction in Influent Nitrate (C_i=10 mg/L) Assuming Θ = 1.10 ... 40
Table 11 Nitrate Removal and Treatment Characteristics Observed at Existing Free Water Surface Wetlands 41
Table 12 Existing VWRF Constructed Pond Details 42
Table 13 Estimated Hydraulic Residence Time (HRT) for On-site Treatment Wetlands at Existing and Future Flows 44
Table 14 Summary of Off-site Treatment Wetland Opportunities 44
Table 15 Estimated Hydraulic Residence Time (HRT) Provided by the Off-Site Treatment Wetland Alternatives at Existing and Future Flows 45
Table 16 Implementation Issues and Benefits of the Off-site Treatment Wetland Alternatives 47
Table 17 Summary of Treatment Wetland Opportunity Planning Level Estimates of Total Project Costs 48
Table 18 Existing Vegetation Community Types within VWRF 49

LIST OF FIGURES

Figure 1 Aerial Showing the City of San Buenaventura, VWRF, and Santa Clara River Estuary 3
Figure 2 Process Flow Schematic of the Existing Treatment Plant Processes at VWRF 5
Figure 3 Aerial Showing VWRF, Wildlife Ponds, Effluent Transfer Station and Outfall Junction Structure 6
Figure 4 Aerial Showing Potential Treatment Wetland Opportunities Within Proximity to VWRF and Numbered for Reference in Table 3 12
Figure 5 Aerial Showing On-site and Off-site Treatment Wetland Opportunities for Consideration in Alternative Development. 14
Figure 6 The New Boundary for the City-Owned Site and the Nearby River Haven Housing Project, 36-Inch Sewer Trunk Line, and 10-Inch Recycled Water Line 15
Figure 7 Aerial Showing the Monitoring Stations Referenced in the Water Quality Analysis – Effluent Transfer Station, Downstream (R-004), Upstream (R-005), and the Freeman Diversion 19
Figure 8 Comparison of Aluminum Levels Observed at VWRF, Downstream and Upstream Water Monitoring Stations 21
Figure 9 Comparison of Copper Levels Observed at VWRF, Downstream, and Upstream Water Monitoring Stations 22
Figure 10 Comparison of Lead Levels Observed at VWRF, Downstream, and Upstream Water Monitoring Stations 23
Figure 11 Comparison of Nickel Levels Observed at VWRF, Downstream, and Upstream Water Monitoring Stations 24
Figure 12 Comparison of Selenium Levels Observed at VWRF, Downstream, and Upstream Water Monitoring Stations 25
Figure 13 Comparison of Zinc Levels Observed at VWRF, Downstream, and Upstream Water Monitoring Stations 26
Figure 14 Nitrate Plus Nitrite Observed at VWRF, Downstream, Upstream, and at the Freeman Diversion Water Monitoring Stations 28
Figure 15 Average Monthly Temperature of Effluent in degrees Celsius as Observed at the Effluent Transfer Station 38
Figure 16 First-Order (Exponential) Removal of Nitrate in Free Surface Wetlands as a Function of Hydraulic Residence Time (HRT) and Water Temperature ($k=0.13\ d^{-1}$) 38
Figure 17 Hydraulic Profile of the Ponds Showing Interties and the Outfall Junction Structure Where Effluent is Discharged to the Santa Clara River Estuary 43
Figure 18 Blue Dots Show Various Stakeholders' Preference for a Potential Off-site Treatment Wetland Location. 46
Figure 19 Vegetation Community Types Within the Ventura Water Reclamation Facility 50

1.0 INTRODUCTION

The City of Ventura owns and operates the Ventura Water Reclamation Facility (VWRF), which discharges tertiary treated municipal wastewater to the Santa Clara River Estuary (Estuary) just south of the City near the mouth of the Santa Clara River. Under the Water Quality Control Policy for the Enclosed Bays and Estuaries of California, discharges of municipal wastewater to enclosed bays and estuaries are to be phased out except in circumstances where the discharge is shown to enhance the quality of receiving waters. To address this issue regarding a finding of enhancement, the Regional Board required the City to complete the "Special Studies for the Santa Clara River Estuary" as a condition of the City's NPDES discharge permit (CA0053651). Work plans establishing the breadth and scopes for the special studies were submitted to the Regional Board in September 2008 and approved in December 2008.

The Special Studies include:

- Estuary Subwatershed Study (to be completed by March 2011) – to evaluate the physical and biological function of the Estuary affected by the discharge to determine whether the discharge to the Estuary provides an ecological enhancement now or under different conditions such as a decreased discharge to the Estuary.
- Treatment Wetlands Study (to be completed by March 2010) – to evaluate the feasibility of implementing a constructed treatment wetland to further improve the water quality of the VWRF tertiary discharge by reducing nutrients and other constituent concentrations to further promote receiving water quality improvements.
- Recycled Water Market Study (to be completed by March 2010) – to evaluate and quantify the feasibility of expanding the City's existing reclaimed water system through evaluation of potential users within a five-mile radius of the VWRF (study area).

The NPDES permit and the approved workplans identified a Phase 2 of the Recycled Water Market Study (to begin March 2011) to include an overall plan for incorporating the conclusions of the Estuary Subwatershed Study, Phase 1 Recycled Water Market Study, and the Treatment Wetlands Study. It is anticipated that the Phase 2 study would identify preferred combinations of alternatives to meet discharge diversion goals from the Estuary Subwatershed Study.

The Estuary Subwatershed Study and the Recycled Water Market Study are documented separately. This report focuses on the Treatment Wetlands Feasibility Study.

2.0 PURPOSE AND SCOPE OF STUDY

The goal of this study is to determine how a constructed treatment wetland could further improve the VWRF tertiary discharge water quality. Anticipated water quality improvements through a wetland include the potential to reduce metals, conventional constituents, and nutrient levels to meet effluent limits and to further promote receiving water quality improvement. This study includes estimates of treatment wetland efficiency, evaluation of alternative wetland locations, preliminary specifications for treatment improvement, and preliminary cost estimates for treatment wetland alternatives.

As discussed above, the primary objective of this study is to evaluate water quality improvements through the addition of a treatment wetland. A secondary objective is to consider opportunities for habitat enhancement as part of this study. In support of these two objectives, the overall approach to the study includes:

- Evaluate the existing effluent water quality.
- Determine the opportunities for water quality improvement.
- Consider on-site treatment wetland opportunities.
- Consider off-site treatment wetland opportunities.
- Consider habitat opportunities and how they fit in the treatment wetland opportunities.

For the purposes of this study, it was assumed that a treatment wetland would have a controlled, single and discrete discharge point to a natural receiving water body (i.e., the Santa Clara River/Estuary). The constructed treatment wetlands considered in this study are not intended to mimic a natural wetland consisting of multiple, distributed discharges to a natural water body.

3.0 BACKGROUND

3.1 Study Area and Existing Facilities

The City of San Buenaventura, commonly referred to as Ventura, is located 62 miles northwest of Los Angeles, California. The City is located in Ventura County and encompasses an area of approximately 21 square miles. Ventura is bordered on the northwest by the Ventura River and on the south by the Santa Clara River (Figure 1).

The City provides sewer service to approximately 98 percent of City residences. The total area served includes a population over 109,000. Wastewater collection and treatment for McGrath State Beach Park and the North Coast Communities are also provided.

Approximately 9 million gallons of wastewater are generated per day and are carried by more than 375 miles of sewer mains and 14 lift stations to the VWRF.

Figure 1
AERIAL SHOWING THE CITY OF SAN BUENAVENTURA, VWRF, AND SANTA CLARA RIVER ESTUARY
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CITY OF VENTURA

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The VWRF is a tertiary treatment plant that consists of screenings and grit removal, primary sedimentation, flow equalization, activated sludge, nitrification and partial denitrification, tertiary filters, and chlorination. In addition, solids processing consists of a primary sludge thickener, dissolved air flotation (DAF) secondary sludge thickener, anaerobic digestion, and dewatering. The City is currently in the process of implementing improvements to their activated sludge system designed for nitrification and denitrification to meet discharge limits (nitrite plus nitrate to be less than 10 mg/l). This improvement is scheduled to be complete in March 2011. Figure 2 presents a schematic of the existing treatment plant processes.

Treated wastewater is conveyed to a 20-acre system of wildlife ponds prior to final discharge to the Santa Clara River Estuary. Prior to entering the ponds, a portion of the treated wastewater is diverted as recycled water for landscape irrigation by several users. The remaining treated wastewater is conveyed via the effluent transfer station (ETS) to the wildlife ponds and flows from west to east through “Bone,” “Snoopy,” and “Lucy.” The effluent is discharged through the outfall junction structure (OJS) to the Santa Clara River Estuary via an effluent channel. Figure 3 shows an aerial of the plant including the wildlife ponds and the locations of the ETS and OJS for reference.

3.2 Regulatory Setting

Wastewater discharges are governed by both federal and state requirements. The primary laws regulating water quality are the Clean Water Act (CWA) and the California Water Code. Under the CWA, the Environmental Protection Agency (EPA) or a delegated State agency regulates the discharge of pollutants into waterways through the issuance of National Pollutant Discharge Elimination Systems (NPDES) permits. NPDES permits set limits on the amount of pollutants that can be discharged into the waters of the U.S. The California Water Code and the Porter-Cologne Act, a provision of the Water Code, require the State to adopt water quality policies, plans, and objectives for the protection of the State’s waters. The State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCBs) meet this requirement by establishing water quality criteria in regional Basin Plans, the Inland Surface Waters, Enclosed Bays and Estuaries Plan, the Thermal Plan, and the Ocean Plan.

The point of compliance at which the VWRF treated effluent is monitored for meeting their NPDES permit limits is located after the ETS and prior to the constructed wildlife ponds.

3.2.1 Existing Regulations

The VWRF’s existing NPDES permit (CA0053651) was adopted by the RWQCB on March 6, 2008. The permit establishes limits for conventional constituents, nutrients, metals, and organics. These limits are established to be protective of aquatic life and other beneficial uses of the receiving water. Tables 1 and 2 provide lists of conventional constituents and metals, respectively, along with their permit limit. The same constituents

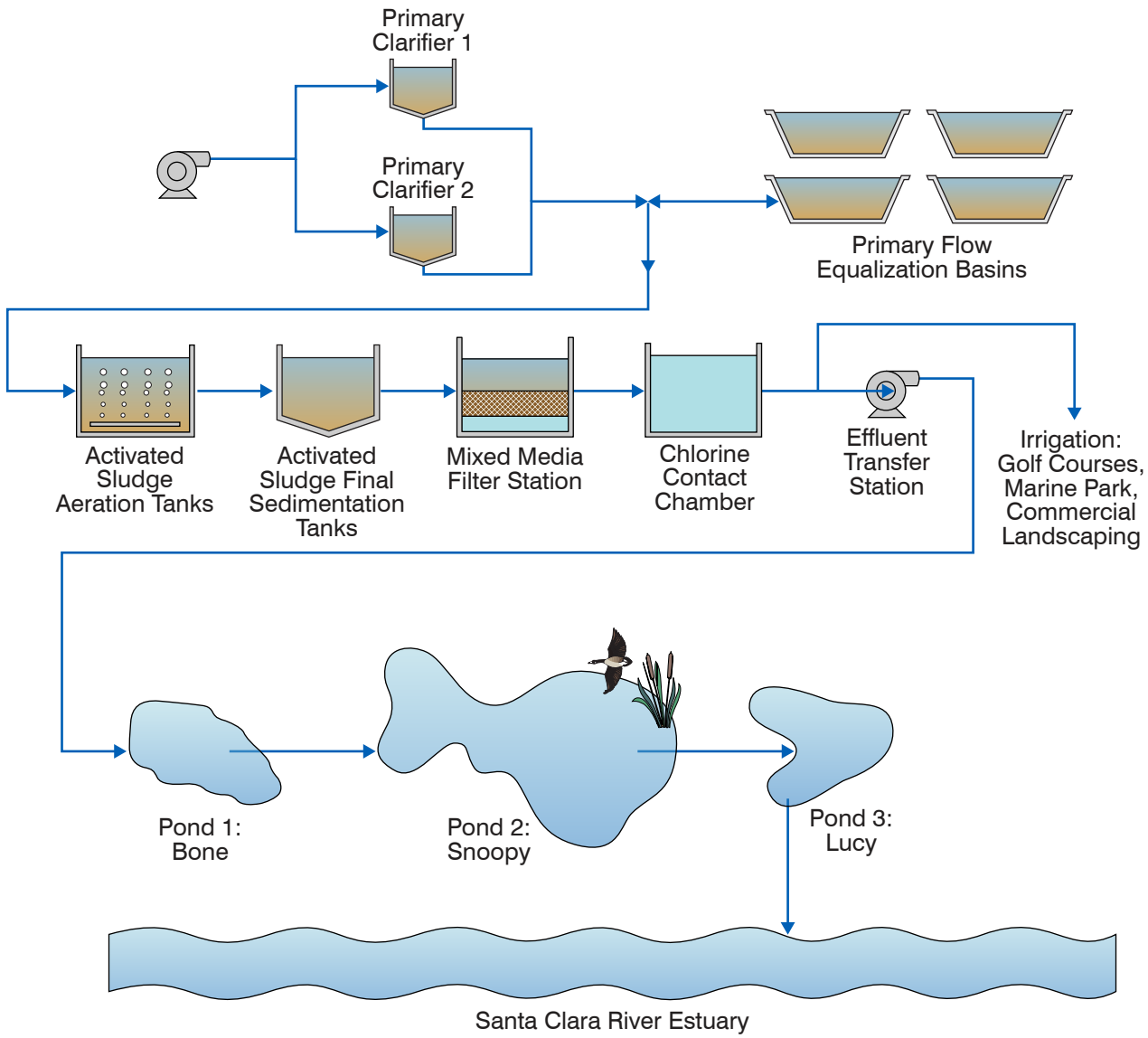

Figure 2
PROCESS FLOW SCHEMATIC OF THE EXISTING TREATMENT PLANT PROCESSES AT VWRF
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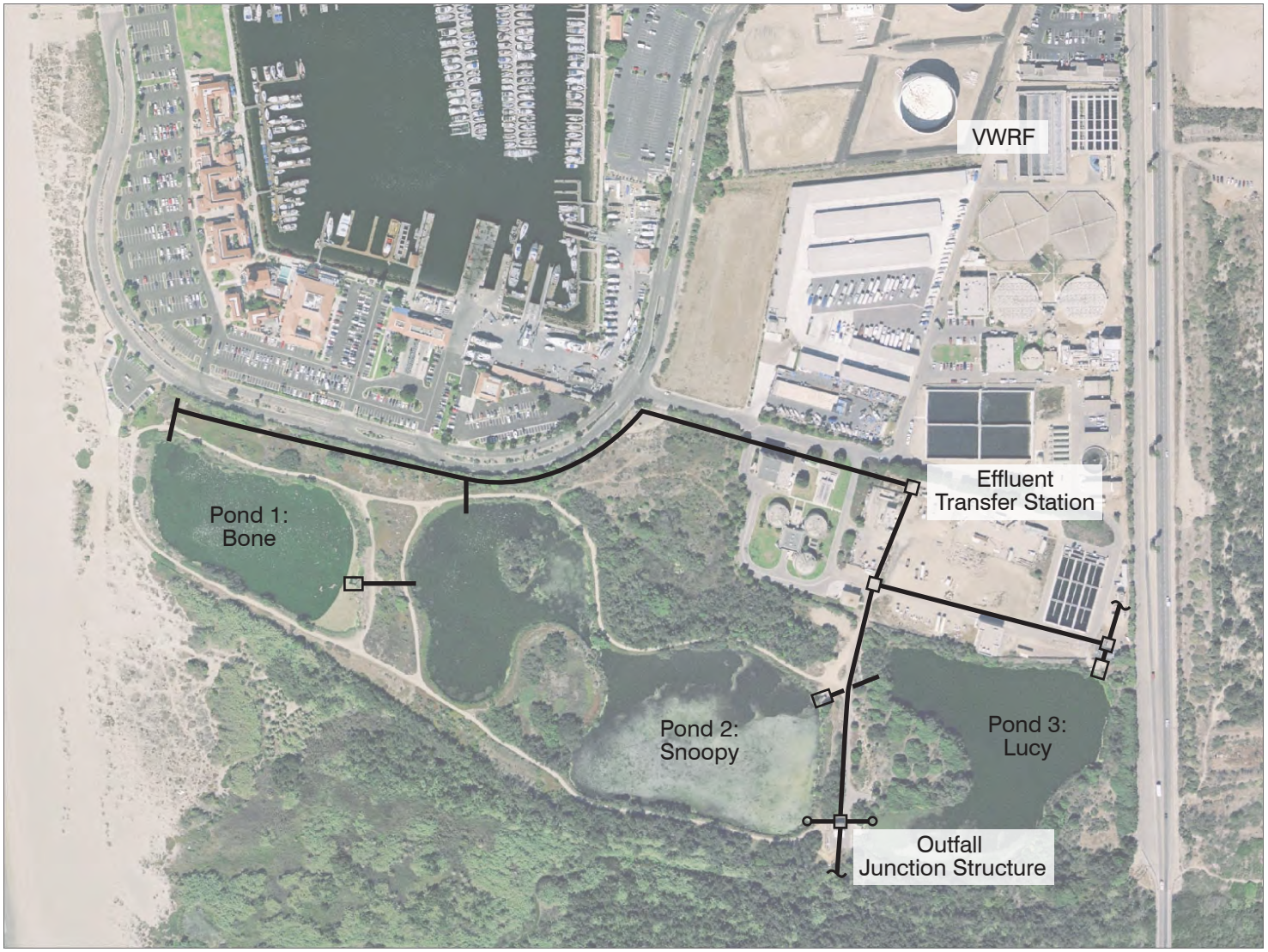

Figure 3
AERIAL SHOWING VWRF, WILDLIFE PONDS, EFFLUENT TRANSFER STATION AND OUTFALL JUNCTION STRUCTURE
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Table 1	VWRF NPDES Permit Limits for Conventional Constituents Treatment Wetlands Feasibility Study City of Ventura	
Constituent (Units)	**Averaging Period**	**Permit Effluent Limits**
BOD_5 (mg/L)	Monthly	20
Total Suspended Solids (mg/L)	Monthly	15
Turbidity (NTU)	24-hour	<2
Temperature (°C)		<30
DO (mg/L)		>5
pH	Instantaneous Minimum and Maximum	6.5 to 8.5
Nitrate + Nitrite as Nitrogen (mg/L)	Monthly	10
Nitrite as Nitrogen (mg/L)	Monthly	1
Nitrate as Nitrogen (mg/L)	Monthly	10

Table 2	VWRF NPDES Permit Limits for Metals Treatment Wetlands Feasibility Study City of Ventura
Metal	**Average Monthly Permit Effluent Limits (µg/L)**
Copper	4.2
Mercury	0.051
Silver	0.71
Zinc	45

and metals are considered in the Water Quality Analysis of this study to determine the purpose and basis for design of the treatment wetland alternatives.

In addition to the discharge limits on the constituents, nutrients, and metals provided above, there are additional receiving water and groundwater limitations that are required to be met based on water quality objectives contained in the Basin Plan. These additional limitations are listed in the NPDES permit.

3.2.2 Future Regulatory Considerations

Future regulatory considerations include potential regulations of “contaminants of emerging concern “(CECs). The CEC terminology is being used within the EPA Office of Water and includes chemicals and other substances that have no regulatory standard, have been

recently “discovered” in natural streams, and potentially cause deleterious effects in aquatic life at environmentally relevant concentrations.

CECs include several types of chemicals:

- Persistent organic pollutants (POPs) such as polybrominated diphenyl ethers (PBDEs; used in flame retardants, furniture foam, plastics, etc.) and other organic contaminants.
- Pharmaceuticals and personal care products (PPCPs), including a wide suite of human prescribed drugs, over-the-counter medications, bactericides, sunscreens, and synthetic musks.
- Veterinary medicines such as antimicrobials, antibiotics, anti-fungals, growth promoters and hormones.
- Endocrine-disrupting chemicals (EDCs), including synthetic estrogens and androgens, naturally occurring estrogens, as well as many other compounds capable of modulating normal hormonal functions and steroidal synthesis in aquatic organisms;
- Nanomaterials such as carbon nanotubes or nano-scale particulate titanium dioxide.

The VWRF discharge is not currently regulated for CECs. However, the City will be required to monitor a suite of these compounds as part of their Monitoring and Reporting program (See Attachment E of WDR R4-2008-0011 / NPDES CA0053651) when analytical methods for these chemicals are applicable and approved by the California Department of Public Health (CDPH). It will be important to track research on CECs in wastewater (occurrence, treatment and environmental effects) and to track the development of any regulations of these compounds in wastewater discharges.

3.3 Previous Reports and Studies

This section provides brief overviews of some of the many plans, reports, and studies that have been developed for the Santa Clara River Watershed and surrounding areas. These reports address the use of land either included in or adjacent to the sites that have been identified as potential treatment wetland opportunities. Each summary addresses how the plan, report, or study is relevant to this study.

3.3.1 Save Open-space and Agricultural Resources (SOAR) Ordinance (1995)

The SOAR Ordinance was signed and adopted November 30th, 1995 by the City of Ventura to ensure (until December 31, 2030) that the general plan provisions governing agricultural land use designation and intent may not be changed except by vote of the people. The Ordinance is to protect existing agricultural (and watershed) land since it is a major contributor to the economy of the City and County of Ventura, creating jobs and generating

tax revenues. Exceptions can be made where land designated as “agricultural use” may be redesignated by City Council to a land use other than “agricultural use” if City Council makes all of the findings supported by evidence stated in the Ordinance under Section 2.c or 2.d. These findings do not exclude the option of land being redesignated for use as a treatment wetland.

The Zoning District Map (developed by the City of Ventura Department of Community Development Planning Division) shows the areas of the City that fall under the SOAR Ordinance. The map will be used to identify whether any of the treatment wetland opportunity sites must be investigated for any conflicts with the SOAR Ordinance.

3.3.2 Ventura Harbor Wetlands Environmental Art Project Research Report (March 2003)

The purpose of this Research Report (led by artist Lorna Jordan) is to provide an analysis of the existing VWRF wildlife ponds (in terms of its place within the community; its location, size, surrounding uses; and its opportunities and constraints) in preparation for the development of the Arts Master Plan. The Master Plan will address environmental art enhancements to the wildlife ponds and the surrounding area, with special consideration for public access and features to improve understanding of and appreciation for the environment (i.e., habitats and living organisms). The Research Report suggests that different “Habitat and Experience” zones surround the wildlife ponds for different uses (e.g., bird watching, active learning, reflective learning, dune activity, sensory, technological, etc.) as well as different features for enhancing access and habitat (e.g., a canopy, an island, a bridge, viewpoints, native plants, etc.).

At the time the Research Report was completed, the “Site Analysis” figure produced shows that open water zones were intended to remain open. However, treatment wetland options may require that most of the “Bone” and “Snoopy” wildlife ponds be vegetated for enhancing the water quality of the effluent. This may result in attracting different types of avian species than outlined in the report (e.g., tricolored blackbird). The environmental artwork (i.e., enhancement to the surrounding land) is not in conflict with modifications necessary for converting the ponds to wetlands nor will it inhibit the performance of a treatment wetland system. The next task for the Arts Master Plan will address enhancements and preservation in support of community goals defined in Ventura’s Vision document, Public Art Plan, and the Harbor Master Plan. In other words, the arts master planning process will consider the following Ventura Vision document strategies: Our Natural Community, Our Sustainable Infrastructure, Our Creative Community, Our Well-Planned and Designed Community, Our Accessible Community, and Our Educated Community.

The vision for the Ventura Harbor Wetlands Environmental Art Project was formed through the artist’s series of questions and dialogues with staff, stakeholders and residents about the site during a planning process involving multiple meetings and workshops. The

stakeholder's included : Audubon Society, CA Coastal Commission, CA Department of Fish and Game, CA Native Plant Society, CA State Parks, Coastal Conservancy, Ventura Unified School District, Santa Clara River Trustee Council, U.S. Fish and Wildlife Services, U.S. Army Corps of Engineers, Ventura Harbor Community Council, and the Ventura Port District. Other stakeholders involved included Public Art Commissioners, as well as representatives of local environmental groups, officers of local community councils, members of the art community, representatives from the tourist industry, and interested community members.

3.3.3 Conservation Plan for the Lower Santa Clara River Watershed and Surrounding Areas (2008)

The Conservation Plan was prepared by The Nature Conservancy and focuses on the lower watershed of the Santa Clara River, which encompasses the treatment wetland opportunity sites considered in this study, including the main stem of the river, tributary watersheds, and the Estuary. The purpose of the Conservation Plan is… "to abate threats and enhance the viability of the watershed's…plants, animals, and natural communities… by protecting the land and waters they need to survive." To do this the planning team identified conservation targets, focus areas, threats/sources of threats, strategies, and success measures in order to achieve the conservation vision, which requires:

- Protecting and enhancing quality representations of each natural community conservation target and the characteristic variation within those communities.
- Protecting and enhancing populations of aquatic vertebrate and wide-ranging terrestrial vertebrate conservation targets, as well as the sensitive plant and animal species that rely on the Santa Clara River and coastal areas for all or a portion of their life cycles.
- Connecting protected natural communities and populations, in large part through the conservation of the wildlife linkages that connect the Santa Monica Mountains to Los Padres National Forest.
- Abating threats to the viability of conservation targets.

The treatment wetland feasibility study considers whether a treatment wetland can enhance the water quality of the VWRF effluent prior to discharge to the Estuary, subsequently enhancing the water quality of the Estuary and protecting the natural community. In addition, the study has a secondary objective to consider opportunities for habitat enhancement that protect and enhance populations of terrestrial and other plant and animal species. These objectives are not in conflict with, but in fact support the goals of The Nature Conservancy's Conservation Plan.

3.3.4 Ventura Harbor Wetlands Ecological Reserve Restoration Plan: Restoration Implementation Plan (December 2009)

The Restoration Plan was prepared by Resource Conservation Partners, Inc (RCP), and is focused on habitat restoration and conservation. The VWRF wildlife ponds and surrounding land (comprising approximately 50 acres) is designated as the Ecological Reserve and is the focus area of the Restoration Plan. RCP proposes a long-term restoration project, which includes removal of non-native plants and revegetation of native species over several years. RCP has funding for the first year of work (Phase 1) to initiate habitat restoration and increase public awareness and education of the Ecological Reserve through public outreach. RCP will continue to work with the City and its partners to implement the three components of the long-term project over several years and phases: non-native invasive plant removal, native plant revegetation, and public outreach. The goals of the Restoration Plan are not in conflict with the goals of the Treatment Wetlands Feasibility Study.

4.0 WETLAND SITING EVALUATION

The wetland siting evaluation considered on- and off- site treatment wetland opportunities documenting their total site area, proximity to VWRF, general site conditions and surroundings, the potential to enhance habitat, special status species access, and availability for human recreation for each of the potential wetland site locations. Potential sites were identified with input from City staff. The details of each potential wetland opportunity are summarized in Table 3 and each site is identified by number on the aerial map shown in Figure 4.

Wetlands can play an important role in a watershed, providing adjacent habitats, flyways, migration patterns, refugia, and avian drinking water sources. All sites are considered to be relatively equal for their opportunity to support wildlife and special status species. The treatment wetland opportunities in this Study are assumed to have a controlled, single and discrete discharge point to the natural receiving water body (i.e., the Santa Clara River/Estuary), which will not allow fish to move up into the treatment wetland. Therefore, no fisheries habitat is considered for any of the sites.

The on-site treatment wetland opportunity would provide areas for human recreation, as the City would continue to allow access to the site. Off-site treatment wetland options have the potential to provide areas for human recreation but may be limited for security reasons or by land use plans or policies already in place. It should be noted that State park lands (i.e., McGrath State Park, Site 10) were also considered for potential off-site treatment wetlands; however, since this land already performs an important public use function that would have to be replaced elsewhere, this site was not carried forward.

Figure 4
AERIAL SHOWING THE POTENTIAL TREATMENT WETLAND OPPORTUNITIES WITHIN PROXIMITY TO VWRF AND NUMBERED FOR REFERENCE IN TABLE 3
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Table 3	Summary of Potential On- and Off-site Wetland Opportunities Treatment Wetlands Feasibility Study City of Ventura			
Site	**Proximity to VWRF (Miles)(1)**	**Total Area (Acres)**	**Condition/Use**	**Opportunity to Enhance Habitat?**
1	(On-site)	20	Ponds	Yes
2	0.2	48	River Haven Project	Yes
3	0.4	68	Golf Course	N/A
4	0.7	152	Golf Course	N/A
5	1.0	28	Mushroom Farm	Yes
6	1.3	61	Agriculture	Yes
7	1.5	40	Agriculture	Yes
8	1.8	26	Agriculture	Yes
9	2.0	141	Agriculture	Yes
10	0.6	172	Estuary and State Park	Yes
11	0.7	222	Estuary/River and Agriculture	Yes

Note:
(1) Distance is estimated from centroid of VWRF to centroid of the treatment wetland opportunity.

Based on City and stakeholder input, the potential treatment wetland opportunity sites were screened based on size, current use, and perceived opportunities. The result was a short list of the on-site and three preferred off-site treatment wetland opportunities (shown and renamed in Figure 5) for further consideration in the alternative development. Each of the sites shown in Figure 5 have been reduced in area (compared to Figure 4) due to site constraints identified during screening.

The off-site treatment wetland opportunities (which were named for their existing owners) were also screened to identify any site constraints. The “City-Owned” site was reduced in size due to transecting below-ground utilities: 1) the 36-inch sewer trunk line and 2) the 10-inch recycled water line. The City also has temporary housing located on the north end of the site, which is referred to as the River Haven Housing Project. The resulting usable area is shown in Figure 6. The “Berry” site was reduced to exclude area within the Santa Clara River Estuary. This site does not lie within the area covered by the SOAR Ordinance and is, therefore, being considered as a potential site. Finally, the “McGrath/TNC” (TNC stands for “The Nature Conservancy”) site’s area for potential use remained the same since the boundaries were already set to avoid developed areas located at the north end of the property. Agricultural land in the McGrath/TNC parcel is being phased out to become open space and is therefore not in conflict with the SOAR Ordinance. In addition, TNC stated at the November 10th, 2009 workshop that they believe changing parcel land use from agricultural to treatment wetlands is not in conflict with the SOAR Ordinance.

Figure 5
AERIAL SHOWING POTENTIAL ONSITE AND OFFSITE TREATMENT WETLAND OPPORTUNITIES FOR CONSIDERATION IN ALTERNATIVE DEVELOPMENT
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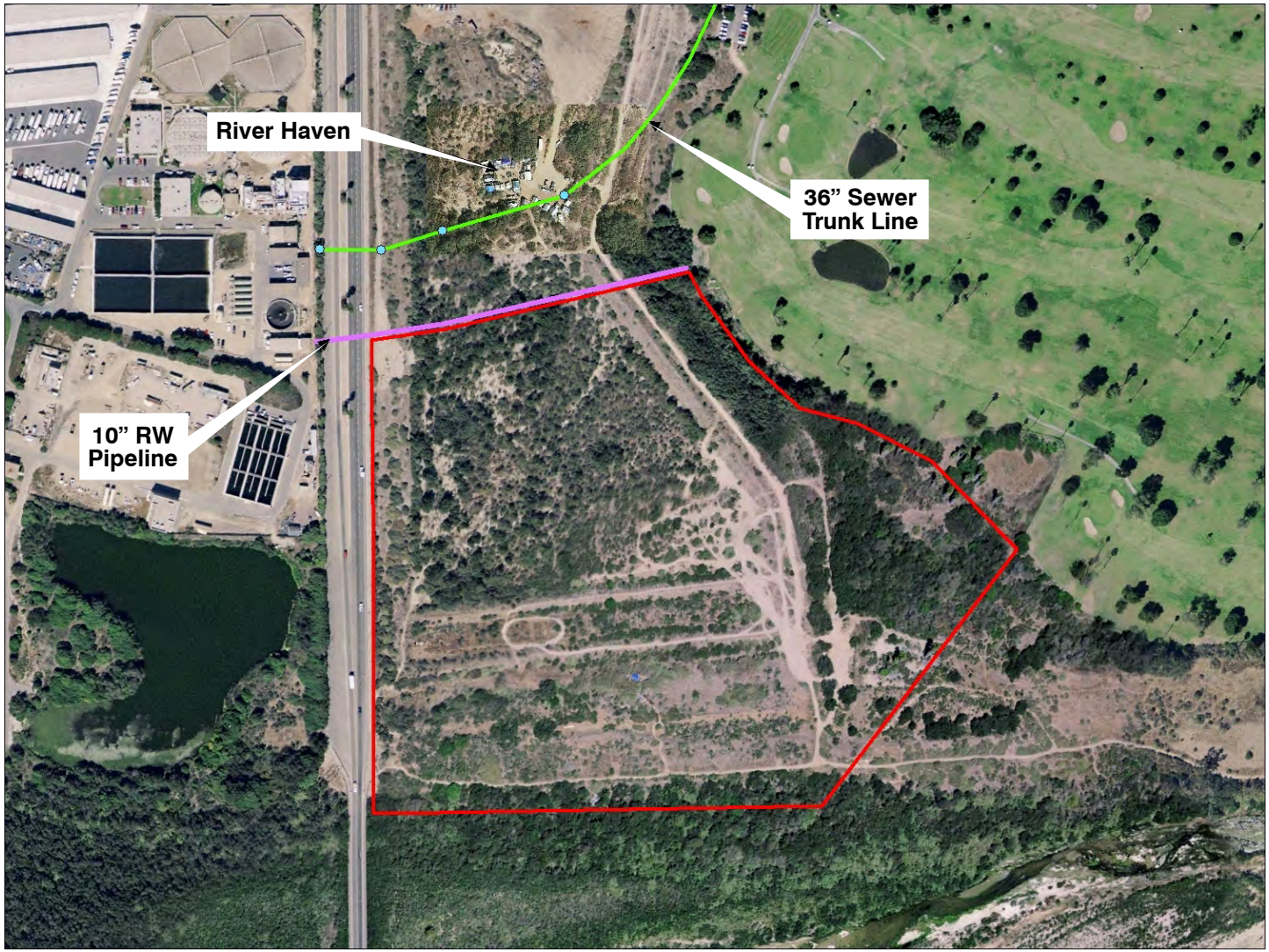

Figure 6
THE NEW BOUNDARY FOR THE CITY-OWNED SITE AND THE NEARBY RIVER HAVEN HOUSING PROJECT, 36-INCH SEWER TRUNK LINE, AND 10-INCH RECYCLED WATER LINE
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In Phase 2 of the special studies, a cost-benefit analysis will be conducted and identification of a preferred proposed treatment wetland site location as well as discussion of the proposed schedule for environmental approval, permitting, and construction will be provided, as it depends on the outcome of the Estuary Subwatershed study.

5.0 WATER BALANCE – EXISTING AND PROJECTED FLOWS

Proper sizing and design of the treatment wetlands, either on- or off-site, requires estimation of the average annual influent and effluent flows. On-site flows were estimated by developing a water balance of the existing VWRF wildlife pond system, using historical records and estimates from VWRF (i.e., wildlife pond influent and effluent flow, precipitation, evaporation, percolation, and recycled water use) and conversations with plant staff.

Under current operating conditions and according to information provided by the City for the years 2006 through 2008, the wildlife pond system receives an average annual flow (AAF) of 6.5 mgd. Since there is no meter immediately prior to the wildlife ponds, the City estimated the influent flow by using the metered flow from the mixed media filtration process and subtracting the various internal recycle streams (i.e., for filter backwash, equalization basin wash down, co-generation cooling, and process water). In addition, recycled water use diversions to off-site customers have historically been diverted from the pond effluent. However, due to concerns over potential for bacterial contributions from the wildlife ponds, the RWQCB required the recycled water diversions to be moved to the VWRF effluent (upstream of the ETS) in the March 2008 NPDES permit (CA0053651). The change in the location of the recycled water line took effect in December 2009. As part of this change in location of the recycled water line, a new meter is to be installed to measure flow out of the ETS. The existing AAF recycled water demand is 0.6 mgd, therefore the estimate of AAF influent to the wildlife ponds at existing conditions is 5.9 mgd (6.5 mgd average flow minus 0.6 mgd).

To maintain the existing public amenity provided by the wildlife ponds, it is assumed likely that the VWRF effluent will flow through the ponds prior to being conveyed to any off-site treatment wetland. In order to size the off-site treatment wetland opportunities, the average annual pond effluent flow needs to be considered. This is determined by taking into account any changes that take place in water volume across the wildlife ponds (i.e., precipitation, evaporation, and percolation). Precipitation and evaporation rates across the existing wildlife ponds are calculated to be 0.1 mgd and 0.02 mgd AAF, respectively, using plant data for the years 2006 to 2008. While evaporation rates and precipitation rates could affect the overall volume, percolation is the dominating factor. The City estimates loss of water volume due to percolation to be approximately 1 mgd AAF (per the current NPDES permit). Therefore, there is a net loss of water volume across the ponds of approximately 1.1 mgd,

and the assumed flow at existing conditions to any off-site treatment wetland would be 4.8 mgd (5.9 mgd average flow minus 1.1 mgd).

Consideration of future conditions is important, as treatment wetlands must be sized for the maximum influent flow. At the City's direction, a future annual average flow of 12 mgd has been assumed for planning purposes. The projected AAF of 12 mgd (prior to recycled water use) is used as the basis for sizing treatment wetland infrastructure and developing cost estimates. Since the existing AAF reuse demand is 0.6 mgd, a flow of 11.4 mgd into the wildlife pond system is assumed for future on-site opportunities. For the case of off-site opportunities (and based on the water balance and previous discussion), a loss of 1.1 mgd is assumed and results in a flow of 10.3 mgd into any off-site treatment wetland. These future flows are representative of the high end of the range of expected flows. If the City expands its recycled water system for additional users, then the flows to any wetlands will be less than the 11.4 mgd.

Table 4 summarizes the estimated existing and projected AAF influent to the on-site and off-site treatment wetland opportunities.

Table 4 Summary of Existing and Projected Average Annual Flows to On- and Off-Site Treatment Wetlands
Treatment Wetlands Feasibility Study
City of Ventura

	Existing AAF (mgd)	Projected AAF (mgd)
ETS Influent	6.5	12
Recycled Water Demand(1)	0.6	0.6
On-site Wildlife Pond Influent	5.9	11.4
Wildlife Pond Losses	1.1	1.1
Wildlife Pond Effluent = Off-site Wetlands Influent	4.8	10.3

Note:
(1) Assuming annual average recycled water demand to existing users. If the recycled water system is expanded, flows to both on-site and off-site treatment wetlands would be reduced.

6.0 WATER QUALITY ANALYSIS

As part of this study, a water quality analysis was performed to determine which conventional constituents, nutrients, and/or metals may need to be targeted for future reduction in a treatment wetland. This section discusses the results of that analysis.

The analysis examined average monthly VWRF effluent data (as observed at the ETS) and compared each constituent to the NPDES permit limit levels as well as to background levels at both down- and up-stream locations (also referred to as stations R-004 and R-005, respectively). The downstream receiving water station (R-004) is located near the end of an effluent dominated channel. In addition, data were collected from the Freeman Diversion (over 10 miles upstream of the VWRF) for nitrite plus nitrate (i.e., NO_2 + NO_3). Figure 7 shows the locations of the ETS and each of the receiving water stations for reference.

Average monthly levels of conventional constituents and nutrients in the VWRF effluent from 2006 through 2008 are shown in Table 5, along with the corresponding NPDES permit limit. Currently, all conventional constituents and nutrients are well below the permitted limits with the exception of NO_2 + NO_3. The average monthly NO_2 + NO_3 levels currently range between 12 and 18 mg/L (with an average of 15 mg/L), which are above the NPDES permit limit of 10 mg/L. The advanced secondary treatment processes (i.e., nitrification and denitrification processes) are designed to achieve average NO_2 + NO_3 levels at or below 10 mg/L. These updates are scheduled to be completed and operational by March 2011.

Table 5 VWRF Average Effluent and Permit Limit Levels of Conventional Constituents
Treatment Wetlands Feasibility Study
City of Ventura

Constituent (Units)	Averaging Period	Permit Limit	2006-2008 Average Level
BOD_5 20°C (mg/L)	Monthly	20	2.27
Total Suspended Solids (mg/L)	Monthly	15	0.83
Turbidity (NTU)	24-hour	<2	<2
Temperature (°C)		<30	21.1
DO (mg/L)		>5	6.47
pH	Instantaneous Minimum and Maximum	6.5 to 8.5	7.2
NO_2 + NO_3 as Nitrogen (mg/L)	Monthly	10	15
NO_2 as Nitrogen (mg/L)	Monthly	1	0.4
NO_3 as Nitrogen (mg/L)	Monthly	10	14.6

Average monthly effluent metals levels from 2006 through 2009 in the VWRF effluent are shown in Table 6, along with the corresponding NPDES permit limit. While the average monthly concentration of each metal is consistently below the permit limit, some are still detected at ETS. However, it is important to note in some cases, metals levels at the receiving water stations are detected at greater levels than at ETS.

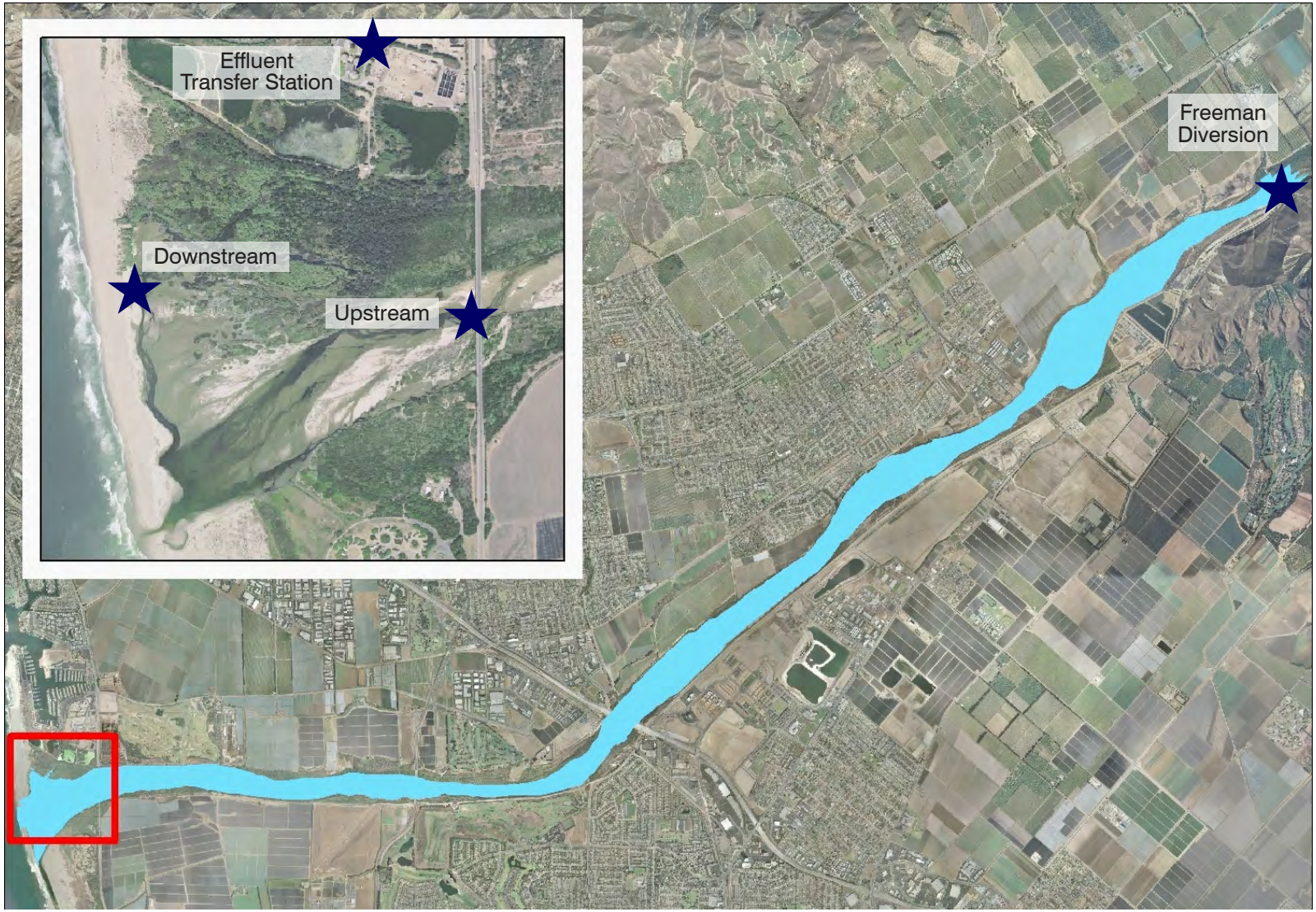

Figure 7
AERIAL SHOWING MONITORING STATIONS REFERENCED IN THE WATER QUALITY ANALYSIS - EFFLUENT TRANSFER STATION, DOWNSTREAM (R-004), UPSTREAM (R-005), AND FREEMAN DIVERSION
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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Table 6	VWRF Average Monthly Effluent and Permit Limit Levels of Metals (µg/L) Treatment Wetlands Feasibility Study City of Ventura	
Metal	**Average Monthly Permit Effluent Limits**	**2006-2009 Average Monthly Effluent Level**
Copper	4.2	3.3(1)
Mercury	0.051	<0.02(2)
Silver	0.71	<0.2(2)
Zinc	45	23.4

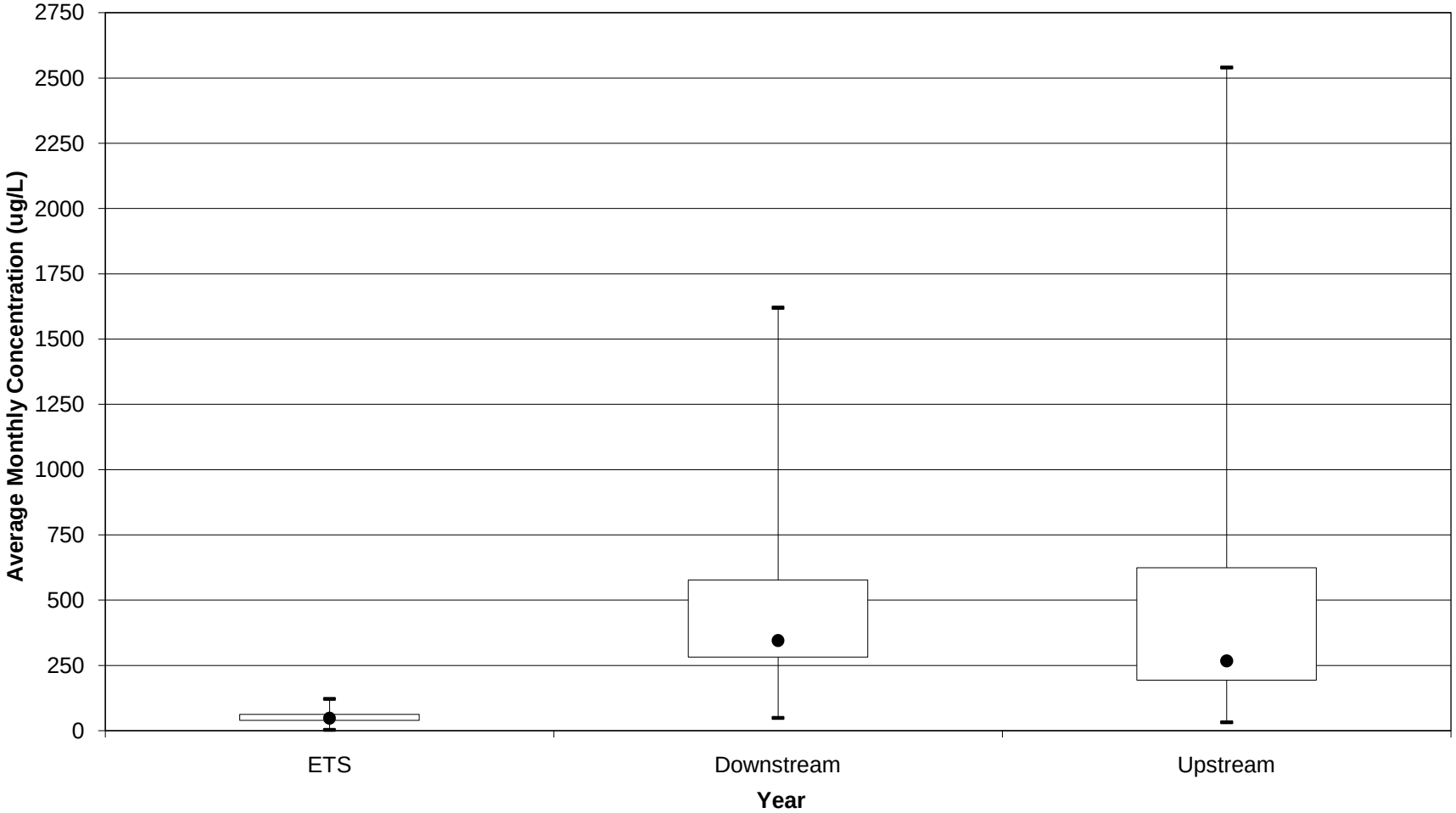
Notes:
(1) More than 50 percent of the samples were below the detection limit (<2 µg/L).
(2) All samples were below detection limit shown.

The metals data were also compared to background levels observed at both down- and up-stream locations (stations R-004 and R-005, respectively) and NO_2 + NO_3 data were also compared to background levels collected from the Freeman Diversion (over 10 miles upstream VWRF). Comparison of the ETS data to the receiving water stations data are performed using box and whisker plots. Box and whisker plots show the median as a point within a box bounded vertically by the 25th and 75th percentile levels observed, and the full span (whiskers) show the minimum and maximum levels observed for that set of data.

Metals data analyzed from the VWRF included those with NPDES permit limits (i.e., copper, mercury, silver, and zinc) as well as aluminum, chromium, lead, nickel, selenium, and thallium. Each of these metals were compared to background levels at the down- (i.e., R-004)[1] and up- (R-005)[2] stream locations. While violation of some metals limits has occurred in the past, improvements in operations have resulted in metals levels being at or below permit limits. The addition of treatment wetlands will only further reduce metals. Figures 8 through 13 show the comparison of the effluent to background levels. Chromium, mercury, silver, and thallium were all non-detect during this period of time and are, therefore, not included in the figures.

As shown in Figure 8, the median level (and range of data) for aluminum at the ETS is well below background levels. Median levels and ranges for copper, lead, nickel, and selenium (Figures 9 through 12, respectively) are all approximately equal to and within the range of background levels. Lastly, while zinc is well below the permit limit, Figure 13 shows that the median level of zinc is slightly greater than background levels, while the range of measured zinc values at the ETS is more narrow than the range of background values.

[1] This receiving water station began monitoring water quality in 2008. Therefore, the data in Figures 8 through 14 for the downstream (R-004) station is only from years 2008 and 2009.
[2] Data for the years 2006 through 2009 are included in Figures 8 through 14.



Note: Box and whisker plots are based on the average monthly concentrations of Aluminum at ETS, Downstream, and Upstream.

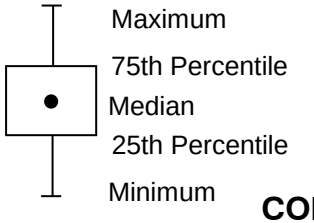


Figure 8
COMPARISON OF ALUMINUM LEVELS OBSERVED AT VWRF AND DOWNSTREAM AND UPSTREAM WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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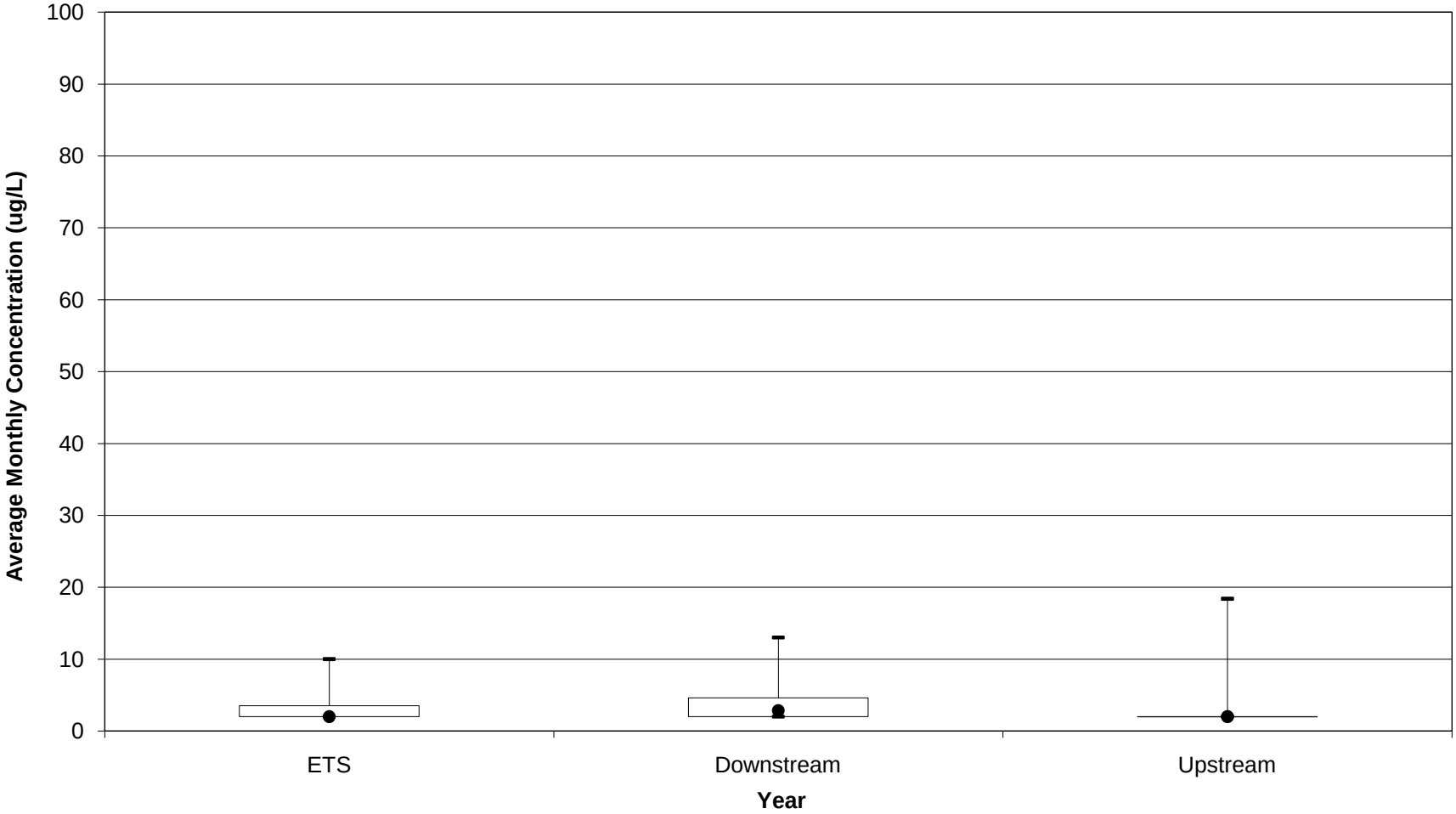

Note: Box and whisker plots are based on the average monthly concentrations of Copper at ETS, Downstream, and Upstream.

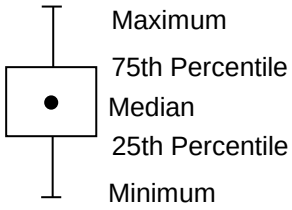

Figure 9
COMPARISON OF COPPER LEVELS OBSERVED AT VWRF AND DOWNSTREAM AND UPSTREAM WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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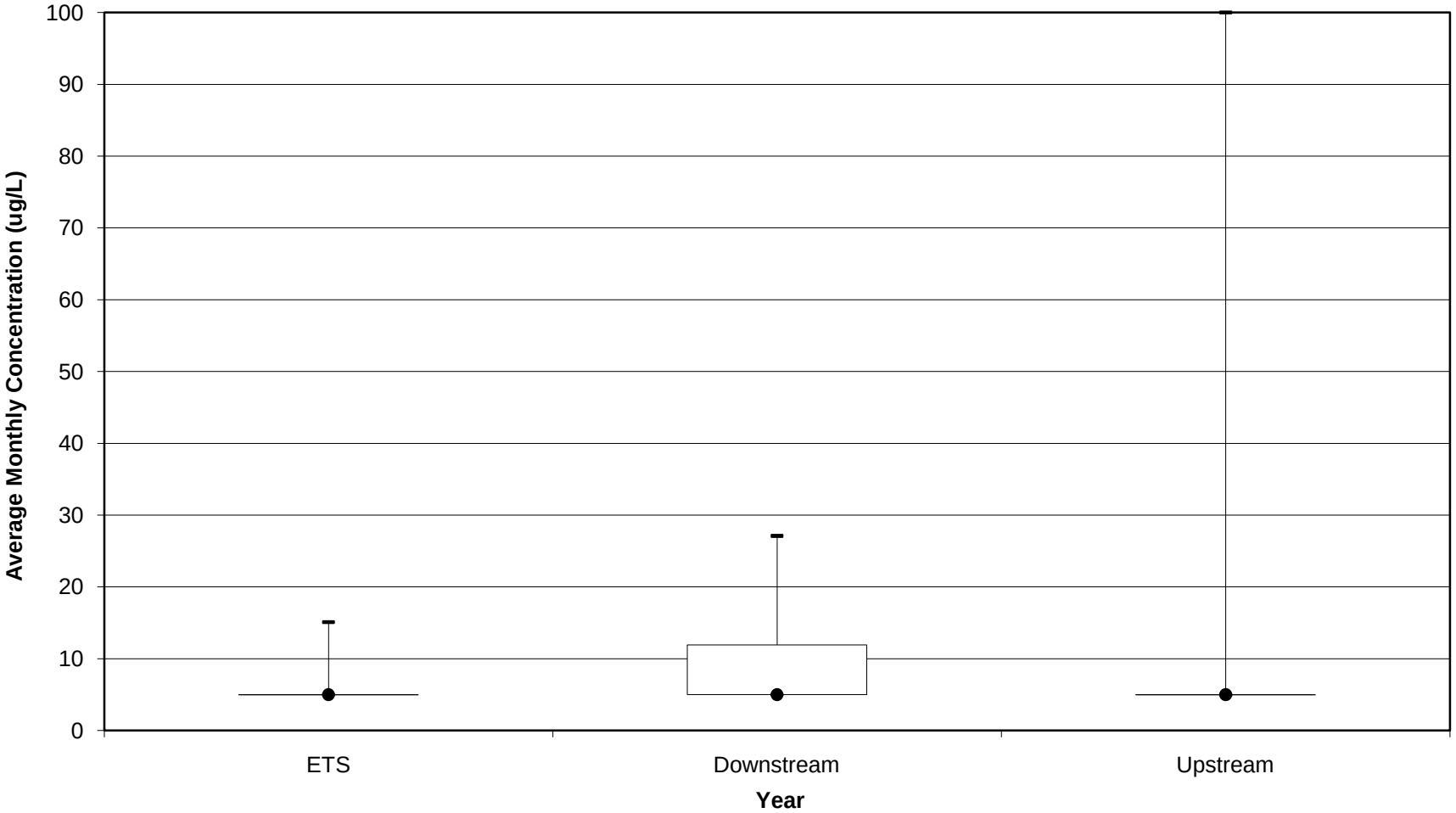

Note: Box and whisker plots are based on the average monthly concentrations of Lead at ETS, Downstream, and Upstream.

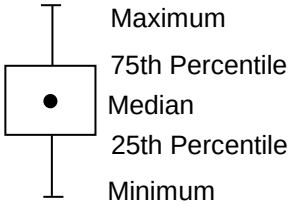

Figure 10
COMPARISON OF LEAD LEVELS OBSERVED AT VWRF AND DOWNSTREAM AND UPSTREAM WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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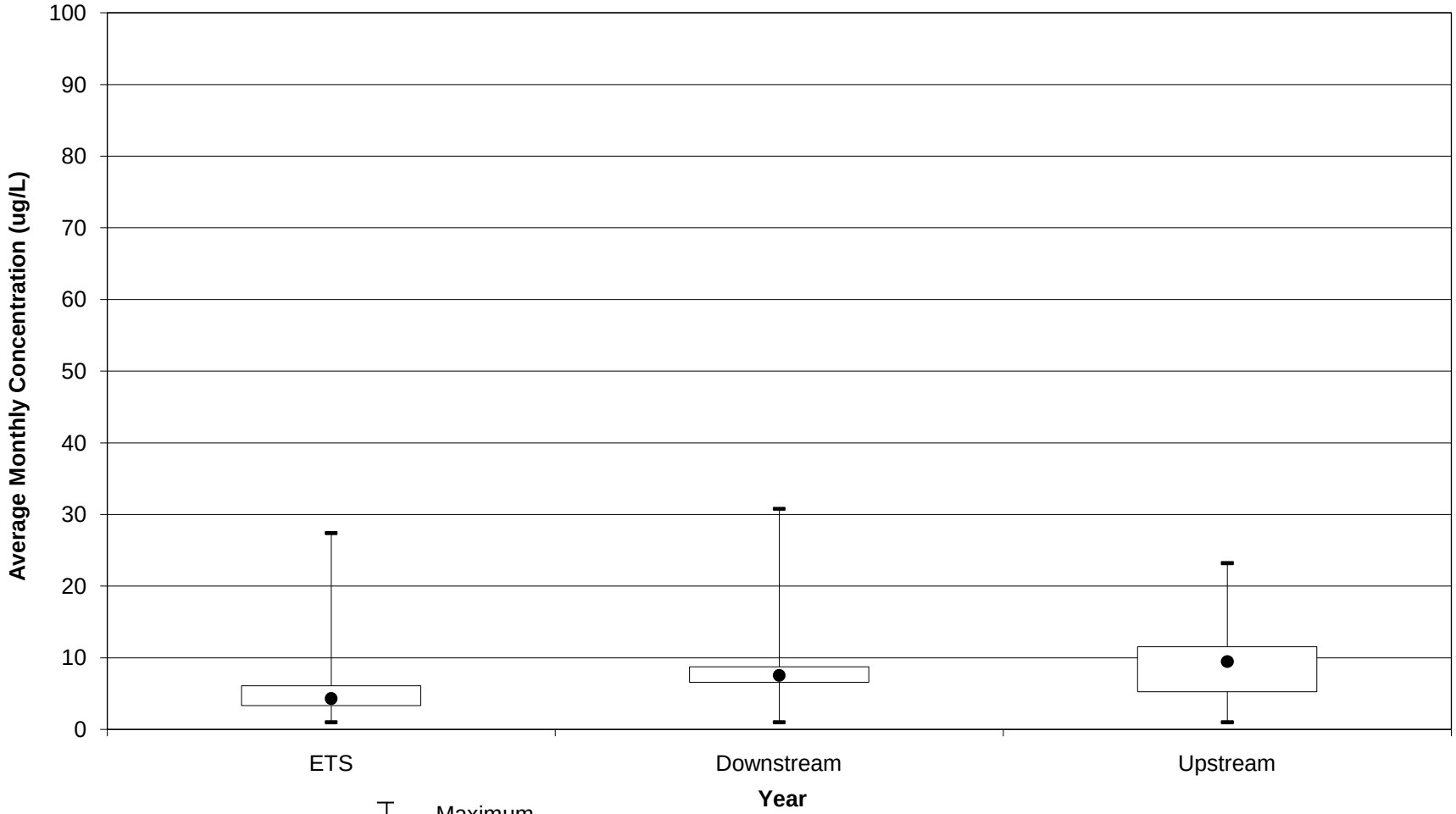

Note: Box and whisker plots are based on the average monthly Concentrations of Nickel at ETS, Downstream, and Upstream.

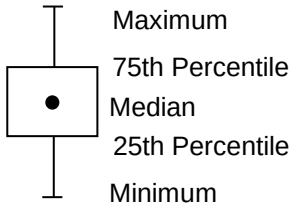

Figure 11
COMPARISON OF NICKEL LEVELS OBSERVED AT VWRF AND DOWNSTREAM AND UPSTREAM WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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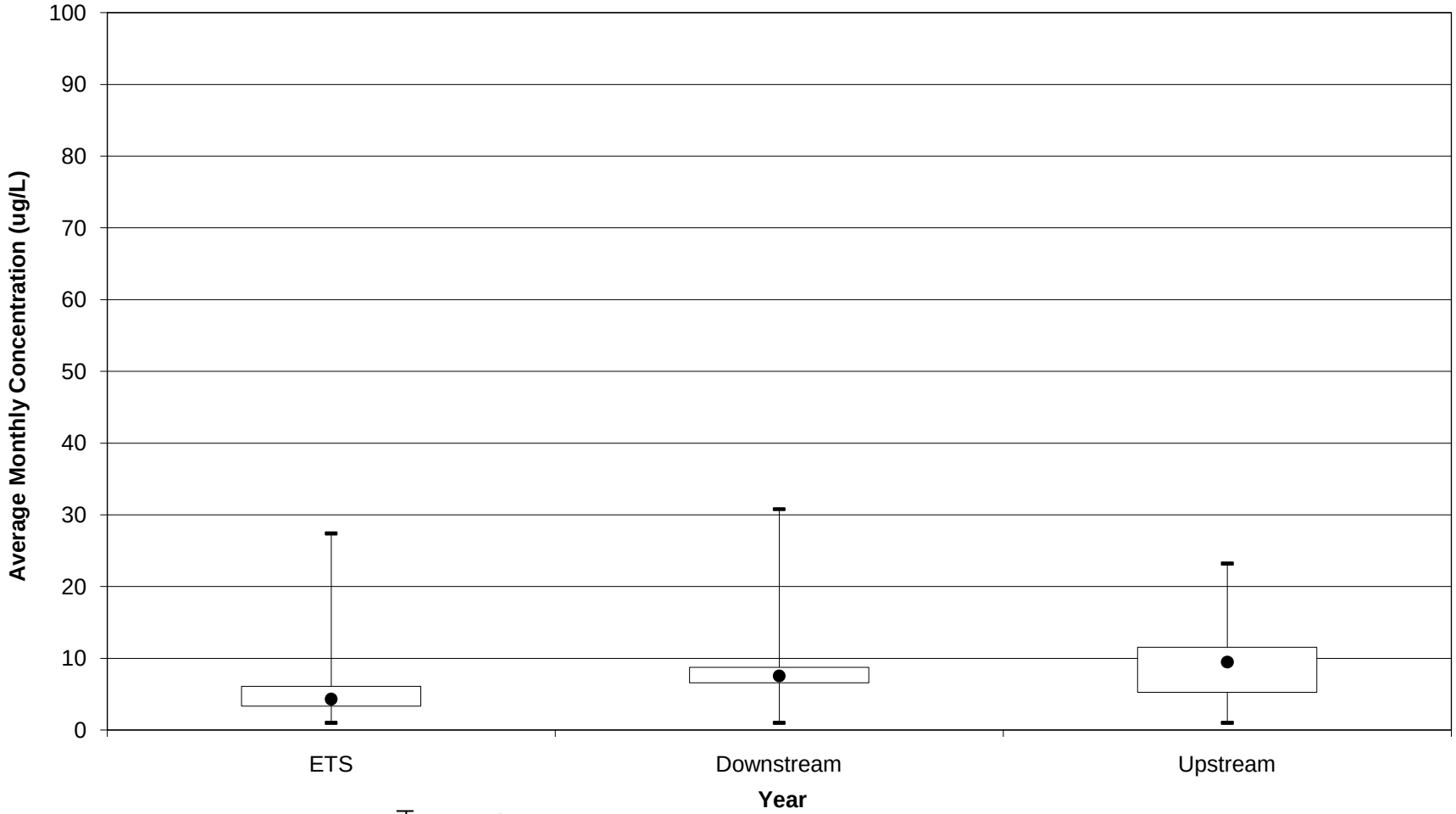

Note: Box and whisker plots are based on the average monthly concentrations of Selenium at ETS, Downstream, and Upstream.

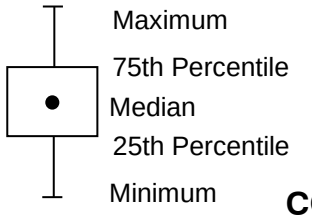

Figure 12
COMPARISON OF SELENIUM LEVELS OBSERVED AT VWRF AND DOWNSTREAM AND UPSTREAM WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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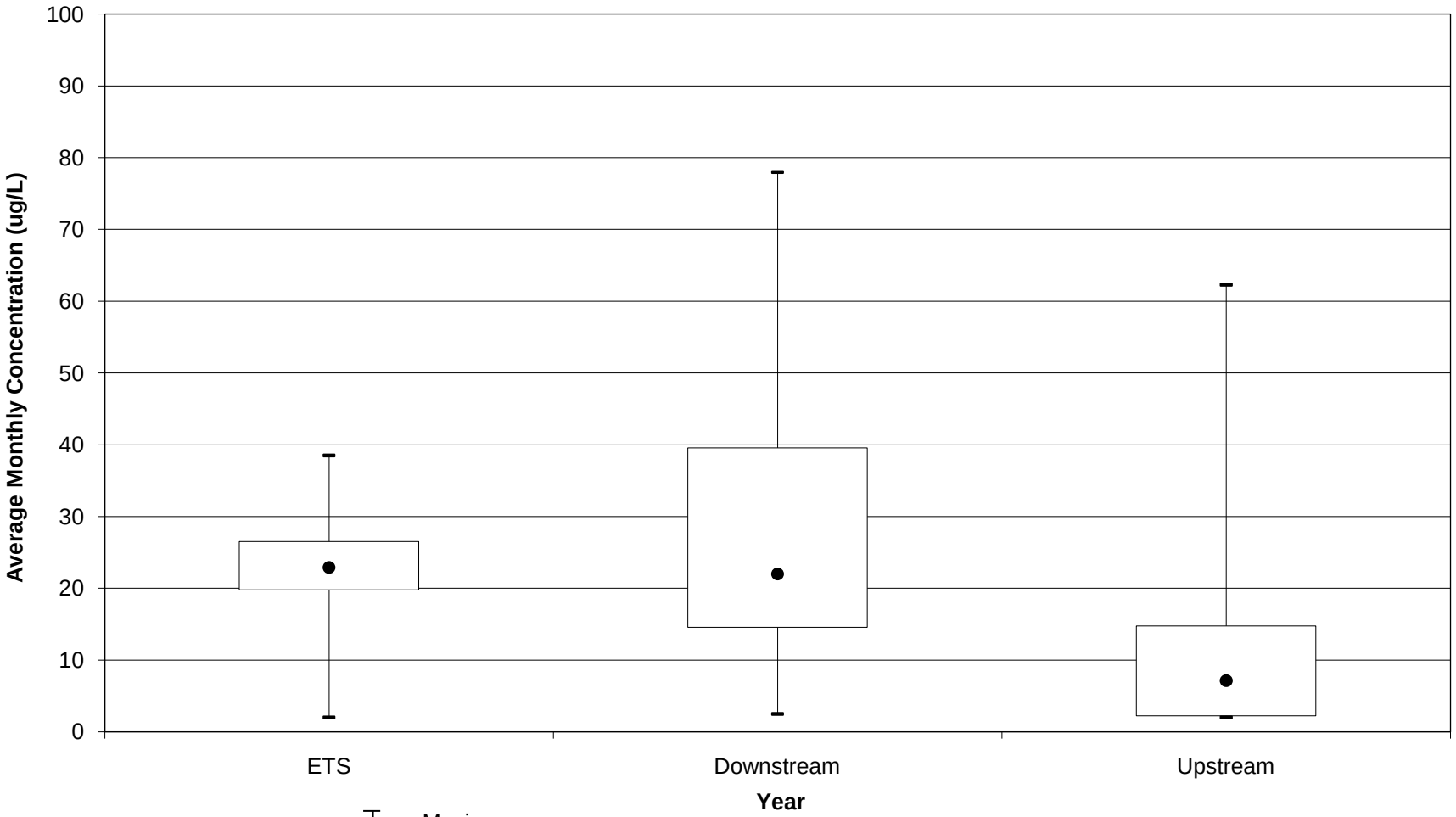

Note: Box and whisker plots are based on the average monthly concentrations of Zinc at ETS, Downstream, and Upstream.

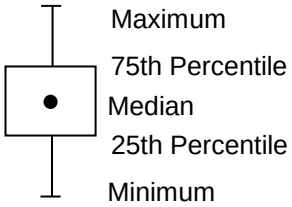

Figure 13
COMPARISON OF ZINC LEVELS OBSERVED AT VWRF AND DOWNSTREAM AND UPSTREAM WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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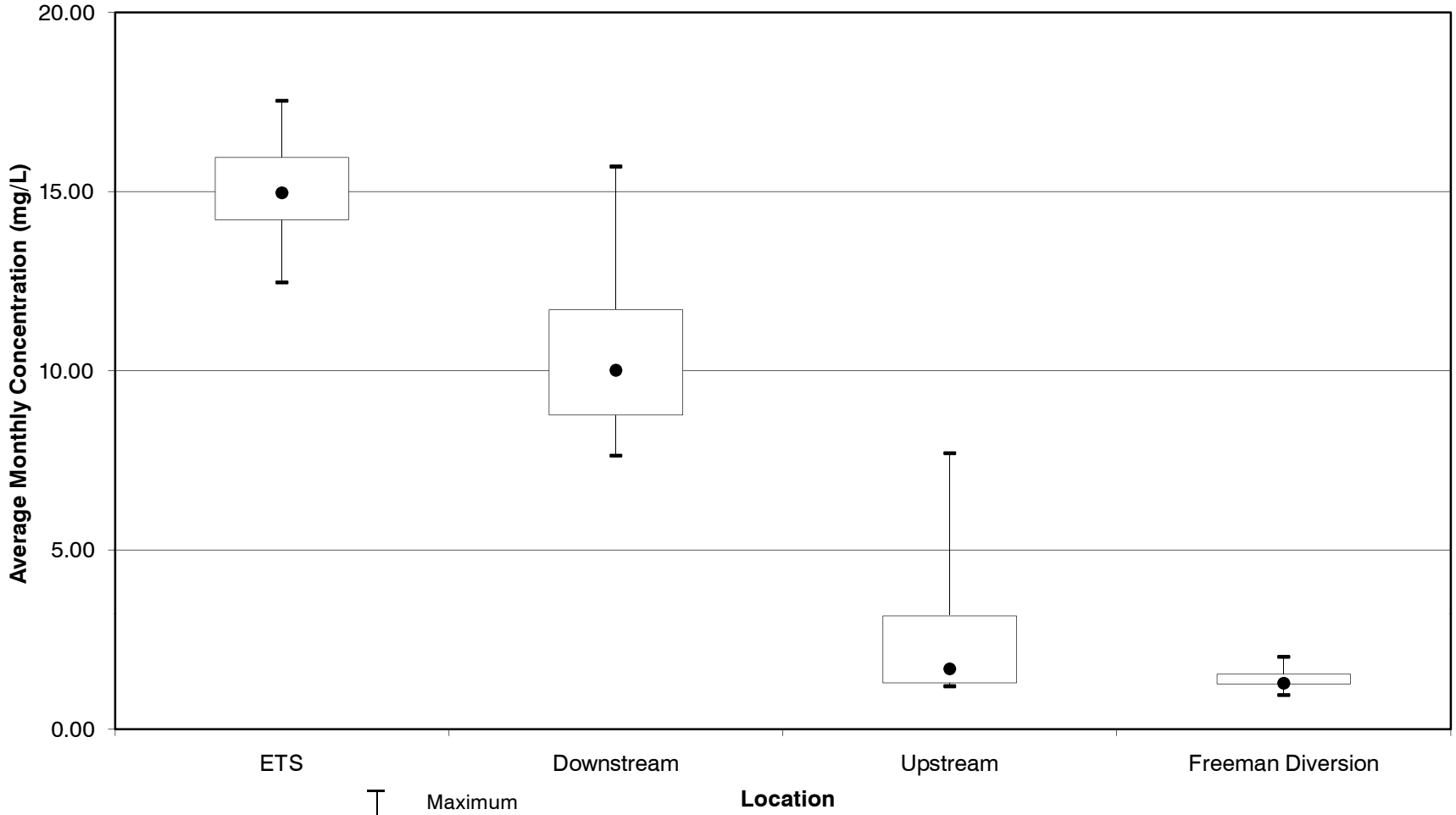
While a treatment wetland could potentially reduce effluent metals further, it does not appear that there is any increase of metals in the estuary due to the discharge and, therefore, further reduction will not likely significantly reduce metals in the estuary.

Nitrite and nitrate data from the VWRF were also compared to background levels collected at the downstream, upstream, and Freeman Diversion receiving water stations. Figure 14 shows the comparison in a box and whisker plot. Note that most of the NO_2 + NO_3 is present as nitrate (NO_3). As previously noted and shown in the figure, the levels at ETS are centered around 15 mg/L. However, median downstream levels are lower, at 10 mg/L. The downstream receiving water station is effluent dominated, so this could mean that some removal is taking place across the ponds and in the effluent channel. When the improvements to the secondary treatment processes are completed, effluent NO_2 + NO_3 is expected to decrease to levels at or below 10 mg/L, on average. However, NO_2 + NO_3 levels at the upstream and Freeman Diversion receiving water stations are consistently measured at 1-2 mg/L. Therefore, additional removal of NO_2 + NO_3 from VWRF effluent may be desirable.

In summary, the water quality analysis has shown that the VWRF effluent is meeting the NPDES permit limits for all metals, conventional constituents, and nutrients with the exception of NO_2 + NO_3. In addition, comparison of the VWRF effluent data to the receiving water stations data shows that for all metals the effluent is at or below background levels, while for nutrients the effluent levels of NO_2 + NO_3 are, and will continue to be, consistently higher than background levels. As a result, the sizing of treatment wetlands for this report focuses on mechanisms reducing NO_2 + NO_3 (specifically, removal of NO_3).

7.0 POLLUTANT REMOVAL IN FREE WATER SURFACE WETLANDS

Treatment wetlands have been shown to effectively reduce levels of a wide range of point and non-point source pollutants including TSS (Kadlec and Wallace 2009), nutrients (e.g., Mitsch et al. 2000, Fleming-Singer and Horne 2005, Horne and Fleming-Singer 2006, Horne 1995), metals (e.g., chromium, copper, selenium), trace organic compounds (pesticides such as atrazine, chlorpyrifos, and endosulfan; Rodgers and Dunn 1992, Alvord and Kadlec 1996, Moore et al. 2000, Schulz and Peall 2001) and pathogens (total and fecal coliform, bacteriophages, and protozoans; Kadlec and Wallace 2009, Karpiscak et al. 1996, Quinonez et al. 1997). Due to their proven pollutant reduction behavior, relatively low maintenance cost and simplicity of operation, and aesthetic and ecological value, treatment wetlands have been used for water quality improvement in a variety of settings, including agricultural and urban applications.



Note: Box and whisker plots are based on the average monthly concentrations of Nitrate + Nitrite (mg/L) observed at each water monitoring station.

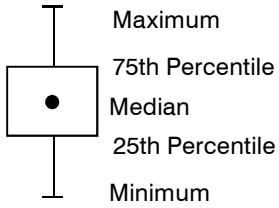


Figure 14
NITRATE PLUS NITRITE OBSERVED AT VWRF, DOWNSTREAM, UPSTREAM, AND THE FREEMAN DIVERSION WATER MONITORING STATIONS
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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Individual treatment wetland designs must be tailored to local conditions and constraints (i.e., seasonal range of water temperature, configuration, constituent to be removed, etc.); however, general design criteria for free water surface (FWS) treatment wetlands include:

- plug flow configuration (i.e., length to width ratios of 5 to 1 or greater);
- gradual slope for maintaining low water velocity;
- varied depth to support a variety of vegetation types and related treatment functions;
- multiple cells to prevent short circuiting; and,
- inlet and outlet structures.

As discussed in the previous section, the greatest opportunity for water quality improvement through a treatment wetland is for removal of nitrogen.

The effluent NO_2 + NO_3 is predominantly (90 percent or more) NO_3. In order to effectively reduce NO_2 + NO_3 levels closer to background levels, the treatment wetland design must foster mechanisms aimed at reducing NO_3 (i.e., denitrification). The denitrification process (NO_3 reduction) is carried out by microorganisms under anaerobic (anoxic) conditions, where NO_3 is the terminal electron acceptor and carbon is the electron donor. Unvegetated open water does not promote effective denitrification.

While denitrification can take place in subsurface flow wetlands, FWS wetlands have been found to support the variety of conditions necessary for more reliable and efficient denitrification removal (U.S. EPA, 2000). In FWS treatment wetlands, submerged plant litter and stems comprise a large wetted surface area (Kadlec and Wallace 2009; Brix 1997) and have been found to contain extensive biofilms (USEPA 1988; Federation 1990; Polprasert et al. 1998), supporting relatively high rates of microbial denitrification (Horne 1995).

In addition to denitrification, FWS treatment wetlands can effectively reduce other pollutants. Consequently, in the following sections we provide a brief overview of FWS treatment wetland removal of total suspended solids (TSS), nutrients (i.e., phosphorous), metals and other constituents of concern, and a more detailed consideration of mechanisms reducing NO_3.

7.1 Removal of Particle Associated Pollutants

7.1.1 Total Suspended Solids

Total suspended solids (TSS) removal in wetlands is generally high due to physical settling of suspended matter from the water column. Upon entering the wetland, horizontal water velocity decreases and solids sink due to density differences between the particles and water. Particle size distribution effects TSS removal, since settling velocity, or the rate at which particles settle in still fluid, is a function of particle diameter (Kadlec and Wallace

2009). Aggregation and filtration/interception are also important removal mechanisms for TSS in wetlands, particularly with respect to organic suspended materials. Once settled from the water column, organic solids are subject to decomposition. Inorganic suspended materials, originating from urban and agricultural runoff, typically include fine clays (<2 µm) and silt (2-20 µm), which can require a relatively long hydrologic residence time (HRT) for removal because their inherent settling velocities tend to be less than 0.01 cm/s. Removal of either inorganic or organic TSS is not likely to be the limiting design parameter for sizing wetlands because settling distances are relatively small compared with typical HRT. With the exception of very fine clay suspensions and colloidal materials, high TSS removal is thus an efficient treatment function in most constructed wetlands (Kadlec and Wallace, 2009).

7.1.2 Phosphorus

The majority of phosphorus in water is present in particulate form, and as with TSS, phosphorus is removed in treatment wetlands primarily through sedimentation (Kadlec and Wallace 2009). Sorption of soluble phosphorus onto mineral precipitates is also an important removal mechanism in wetlands (Reddy and D'Angelo1994). In treatment wetlands in Southern California, total phosphorus removal has been observed to range from 46 to 70 percent expressed as a year-round average of load percent reduction and as high as 49 percent removal for storm water or winter flow. Ortho-phosphorus removal is generally lower, reported at a maximum of 36 percent for year-round average in some systems (Carleton et al. 2000), and it can increase through the wetland on a seasonal basis due to vegetative uptake during the growth season and release during periods of senescence and decomposition (CalTrans 2004, Kadlec and Wallace 2009). However, depending on the amount of standing vegetation in the wetland and the receiving water conditions, there is potential to reduce levels of phosphorous and the associated eutrophication potential of receiving waters.

7.1.3 Metals

High variability in metals removal efficiency is reported for treatment wetlands in general (Kadlec and Wallace 2009). Metals removal in wetlands occurs through a number of processes, including plant uptake, soil adsorption (binding to soil particles) and precipitation (formation of solid compounds), which can vary considerably in relative importance depending on wetland conditions (i.e., <10 to 100 percent, depending on the metal species). In a compilation of results from 49 wetland systems, Carleton et al. (2000) found that removal rates for cadmium, copper, lead, and zinc were generally highest (all incidences >50 percent and 9 out of 12 incidences >75 percent) for wetlands where the ratio of wetland area to watershed area was greater than 0.1. As shown in Table 7, VWRF average monthly effluent concentrations are currently within the range of typical FWS wetlands effluents, indicating significant additional removal in a treatment wetland is not likely to occur. Additionally, analysis of available water quality data indicates that the VWRF effluent is currently meeting the NPDES permit limits for all metals (Table 6), therefore no additional treatment is required.

Table 7	VWRF Average Monthly Effluent and Typical FWS Wetland Effluent Levels of Metals Treatment Wetlands Feasibility Study City of Ventura	
Metal	**Existing Average Monthly Effluent (µg/L)**	**Range in FWS Effluent (µg/L)(1)**
Aluminum	52	40-600
Copper	3.3	2-22
Lead	5.9	0.2-7
Nickel	6	4-16
Selenium	3.1	2-10
Zinc	23	5-56

Note:
(1) Kadlec and Wallace, 2009.

7.2 Removal of Nitrogen

The nitrogen cycle in wetlands involves multiple inorganic and organic nitrogen transformation mechanisms, many of which are mediated by bacteria, including plant uptake (i.e., nitrogen assimilation), nitrification, denitrification, nitrogen fixation, and mineralization of organic nitrogen (i.e., ammonification). While wetlands may reduce effluent total nitrogen (TN) concentrations by storing nitrogen, both seasonally and permanently, through plant uptake and settling of particulate forms (Kadlec and Wallace 2009), the ultimate removal of nitrogen from the system occurs through the microbially mediated process of denitrification.

The denitrification reaction takes place in the sediments and in the periphyton[3] in the water column below or within the layer of fully vegetated growth where dissolved oxygen is low and available carbon is high (Kadlec and Wallace 2009, Fleming-Singer and Horne 2002). Decomposing wetland vegetation and decaying macrophytes[4] are important sources of carbon. The denitrification process is also temperature and pH dependent (Stefan et al., 1994; Reed et al., 1995; Mann and Wetzel, 1996; Ingersoll and Baker, 1998; U.S. EPA, 1999; U.S. EPA, 2000).

In addition to the general design criteria for FWS wetlands, characteristics for improving nitrogen (specifically, NO_3) removal in wetlands include:

- Dense, mature vegetation (e.g., cattail, bulrush) to provide adequate quality and quantity of organic carbon for denitrification.

[3] Periphyton is a mixture of algae, cyanobacteria, heterotrophic microbes, and detritus attached to submerged surfaces in most aquatic ecosystems.
[4] A macrophyte is an aquatic plant that grows in or near water and is either emergent, submergent, or floating.

- Water temperatures >10 degrees C.
- Consistently low redox.
- Steady pH 5–8.
- Water depth <3 feet.
- Hydraulic residence time 4–12 days.

In addition, alternating open water zones with vegetated zones within the treatment wetland supplies edges and varying redox conditions in support of contaminant removal processes, as well as provide habitat for aquatic birds.

7.3 Removal of Other Constituents of Concern

While removal of NO_3 is the basis for the wetlands design for the VWRF, there is interest in understanding whether wetlands treatment would contribute to removal of currently unregulated compounds. The CEC's described in Section 4.2.2 represent a large number of compounds with a wide range of physical and chemical properties. Researchers have documented that CEC's exhibit varying removal efficiencies through different water and wastewater processes that rely on different removal mechanisms (Snyder et al. 2007). In a wetland, natural attenuation processes including photo-transformation, sorption, and biotransformation (or biodegradation) may contribute to the removal of some CEC's. Studies have shown that both the properties of the compound and the physical/chemical conditions in the water column guide the extent of attenuation (Fono et al. 2006). Additional detail on these potential removal/attenuation mechanisms follows:

- Photo-transformation refers to the sunlight-mediated destruction of compounds in the environment. A molecule can absorb energy from a photon that then breaks its chemical bonds (direct photolysis), or it can react with other reactive oxidants that are formed when natural waters are exposed to sunlight (indirect photolysis). The rate at which a compound is photo-transformed depends on the sunlight intensity, water depth, depth of light penetration (i.e., water clarity), and structure of the compound.
- Sorption refers to the attachment of a compound to a particle or soil surfaces. Compounds that are non-polar (not very soluble) are more likely to attach (sorb) to particles as compared to polar (very soluble). Wastewater treatment processes effectively remove particles and compounds sorbed to particles from wastewater. Therefore, most compounds in wastewater effluent are polar and are therefore less likely to be removed by sorption in a polishing treatment wetland. However, sorption can be an important attenuation mechanism even for polar compounds if there is a high solids concentration. Sorption rates depend on compound characteristics, particle characteristics, and particle concentration.

- Biotransformation refers to the removal of compounds by microbial action. Biotransformation can be either aerobic, or anaerobic, and many compounds that are not amenable to aerobic transformation can be degraded anaerobically. Biotransformation rates depend on concentration of microorganisms in the water, temperature, the availability of carbon, compound characteristics, and redox conditions.

There are few published studies showing the removal of CEC's in FWS wetlands. Among these studies there is significant variation in compounds studied, wetland design, wetland operation, vegetation type and density, oxygen concentration, temperature and extent of treatment prior to the inlet to the wetlands. Tables 8 and 9 summarize three recent studies on CEC removal by wetlands. The compounds in Table 9 are listed generally from high removal efficiency to low removal efficiency.

Table 9 shows that there is a wide range of CEC removal efficiencies, suggesting a range of persistence in the natural environment. In addition, removal efficiencies vary within sampling events of a given study and between studies, which is indicative of the challenges associated with quantifying removal of these compounds and the impacts of site-specific conditions.

Researchers propose various removal mechanisms for compounds that were moderately to well removed in their respective studies. Metamoros et al. (2008) suggests that the predominant removal mechanism for most compounds was aerobic biotransformation or the combination of aerobic biotransformation and photo-transformation. Galaxolide and tonalide were likely removed by sorption to particles and ketoprofen removal was attributed to photo-transformation (Metamoros et al. 2008). Park et al. (2009) suggests that the predominant removal mechanism in the wetlands was biotransformation in anoxic conditions. A significant difference between these two studies is the HRTs of 30 days (Metamoros et al. 2008) and 0.03 days (Park et al. 2009), and Metamoros et al. (2008) suggests that the very long residence time contributed significantly removal aerobic biotransformation and or photo-transformation. Gray and Sedlak (2005) suggested that the combination of sorption and biotransformation contributed to the removal of hormones.

Nitrate-removal treatment wetlands may also have the potential to remove some CECs. Gray and Sedlak (2005) and Park et al. (2009) observed high removal (>70 percent) of atenolol, triclosan, naproxen, and moderate removal (30 to 50 percent) of sulfamethoxazole, 17β-ethinyl estradiol, and 17β–estradiol along with NO_3 removal in two studies of treatment wetlands. The observed CEC removals were attributed to the combination of sorption and anaerobic biotransformation, and/or photo-transformation. However, there are a number of unknown with SRTs of about 15 days. Therefore, the occurrence and concentration of CECs in the factors that contribute to uncertainty in predicting the effectiveness of the treatment wetlands for CEC removal based on the cited literature, including:

Table 8 Summary of Recent Studies on CEC Removal by Wetlands
Treatment Wetlands Feasibility Study
City of Ventura

Location/Source	HRT (days)	Depth (ft)	Oxygen Conditions	Dissolved Organic Carbon (mg/L)	Influent Characteristics	Types of Compounds	Description/Comments
Southern California – Prado Wetlands Test Cells Grey and Sedlak (2005)	3.5	1.6	–	Range of 2.4 to 5.2	Tertiary wastewater effluent	Hormones	Dense vegetation. Wetlands were designed for nitrate removal (via nitrification). During study influent and effluent nitrate concentrations ranged from 7 to 13 mg/L, and 3 to 6 mg/L, respectively.
Northeastern Spain Metamoros et al. (2008)	30	Shallow region range of 1 to 1.3. Deep regions 4.9.	Aerobic	–	Secondary wastewater effluent	PPCPs , herbicides, and veterinary drugs	Shallow sections are vegetated. Deep sections are unplanted. Ammonia removals ranged from 79 to 94%.
Damyang, Korea Park et al. (2009)	0.3	0.4	Relatively anoxic	Range of 5.7 to 6	-	Mostly PPCPs	Two vegetated ponds. Total nitrogen and nitrate were effectively removed.

Table 9	**Summary of CEC Removal Efficiencies by Wetlands Treatment Wetlands Feasibility Study City of Ventura**		
	Removal Range		
Compound	**Low**	**High**	**Source**
Ketoprofen	97	99	Metamoros et al. (2008)[2]
Ibuprofen	95	96	Metamoros et al. (2008)[2]
Atenolol	>95	>95	Park et al. (2009)[3]
Tonalide	88	90	Metamoros et al. (2008)[2]
Galaxolide	85	88	Metamoros et al. (2008)[2]
Mecoprop	79	91	Metamoros et al. (2008)[2]
MCPA	79	93	Metamoros et al. (2008)[2]
Triclosan	60	>95	Park et al. (2009)[3]
Naproxen	52	92	Metamoros et al. (2008)[2]
	70	80	Park et al. (2009)[3]
Diclofenac	73	96	Metamoros et al. (2008)[2]
	40	90	Metamoros et al. (2008)[2]
Flunixin	–	64	Metamoros et al. (2008)[2]
Sulfamethoxazole	30	50	Park et al. (2009)[3]
17β -ethinyl estradiol	41		Gray and Sedlak (2005) [1]
17β -estradiol	36		Gray and Sedlak (2005)[1]
Clofibric acid	32	36	Metamoros et al. (2008)[2]
Carbamazepine	30	47	Metamoros et al. (2008)[2]
	-10	70	Park et al. (2009)[3]
Dilantin	10	40	Park et al. (2009)[3]
Terbutylazine	1	80	Metamoros et al. (2008)[2]
Diazepam	-10	0	Park et al. (2009)[3]
TCEP	–	10	Park et al. (2009)[3]

Notes:
(1) Based on a single sampling event in October.
(2) Based on two sampling events, one in May/June, and one in February.
(3) Based on two sampling events, one in May and one in August.

- Occurrence and concentration of CECs – The upgrade to full nitrification and denitrification will increase the sludge retention time (SRT) at the VWRF. Researchers have shown that removal of CECs in biological wastewater processes can be improved VWRF effluent is currently unknown, is likely to change, and may be different from the compounds studied in the cited literature.

- Design parameters (HRT, depth and vegetation) and operating conditions (flow, temperature) – There is not sufficient research on treatment wetlands to develop specific "optimal" design and operational parameters for CEC removal. This is in part due to the variability in physical and chemical characteristics of CECs and the lack of research on CEC removal in wetlands. However, the research suggests that the values of these parameters can influence which attenuation mechanisms are promoted within a wetland and therefore may influence the effectiveness of CEC removal through the wetland.

- Water quality conditions – There is not sufficient research on treatment wetlands to develop specific "optimal" water quality conditions for CEC removal. However, the research suggests that water quality conditions affect attenuation mechanisms and some of the most important parameters include water clarity, oxygen concentration, carbon concentration, particle concentration, and microorganism population.

7.4 Wetland Design Hydraulic Residence Time Estimates

As NO_2 + NO_3 (and more specifically, NO_3) is the limiting design parameter for sizing of the VWRF treatment wetlands, the following section presents estimates of the wetland hydraulic residence time (HRT) necessary to reduce NO_2 + NO_3 to near background levels prior to discharge to the lower Santa Clara River Estuary.

In treatment wetlands, the denitrification process (NO_3 reduction) is carried out by microorganisms under anaerobic (anoxic) conditions. During denitrification, NO_3 in the wetland is reduced to nitrogen gas (N_2) by heterotrophic bacteria requiring a readily available source of organic carbon. Thus, denitrification can be carbon limited (Hume et al. 2002, Isenhart and Crumpton 1993). Because denitrification is a microbial process, rates in treatment wetlands are also controlled by pH and water temperature (Stefan et al., 1994; Reed et al., 1995; Mann and Wetzel, 1996; Ingersoll and Baker, 1998; U.S. EPA, 1999; U.S. EPA, 2000), with higher rates occurring during warmer conditions. Denitrification has most often been modeled as a first-order process in wetlands based on mass transfer limitations of NO_3 diffusion into low-oxygen microbial biofilms where denitrification takes place (Fleming-Singer and Horne 2005).

While some wetland literature presumes that NO_3 reduction is zero-order (implying a constant removal rate), treatment wetlands are best described by first-order denitrification kinetics (with respect to NO_3) even at very high NO_3 concentrations. This is predominantly due to mass transfer limitations of nitrate diffusion into low-oxygen microbial biofilms where

denitrification takes place (Kadlec and Wallace 2009). In addition, because there are strong seasonal effects on the NO_3 rate constant (i.e., k-value), we modeled NO_3 reduction as a function of inlet concentration, HRT, and water temperature.

$$C_e/C_i = \exp(-k_v * t) \qquad (1)$$

Where:

C_e = Effluent concentration of nitrate, mg/L

C_i = Influent concentration of nitrate, mg/L

k = Rate constant (expressed as k_v), 1/day

t = Hydraulic residence time, days

For the effluent concentration (C_e), a treatment goal of 4 mg/L[5] NO_3 was adopted to correspond to typical background levels at the Freeman Diversion (Figure 14). For the influent concentration (C_i), the City is currently upgrading the VWRF's secondary facilities to include nitrification and denitrification processes that will result in a NO_3 concentration consistently at or below the NPDES limit of 10 mg/L. A volumetric rate constant (k_v) of 0.13 d^{-1} at 20 degrees C was selected based upon typical values from the literature (Fleming-Singer and Horne 2002, Kadlec and Wallace 2009), with an Arrhenius based coefficient (Θ) (Kadlec and Wallace 2009) used to account for variations in microbial activity with temperature:

$$k_2/k_1 = \Theta^{(T2-T1)} \qquad (2)$$

Where:

k_1 = Rate Constant at temperature (°C) T_1

k_2 = Rate Constant at temperatures (°C) T_2

Θ = Temperature Coefficient

Kadlec and Wallace (2009) considered over 70 NO_3- dominated FWS wetlands and derived an average temperature coefficient (Θ) of 1.110 with a median value of 1.102, whereas Fleming-Singer and Horne (2005) observed a range of 1.03–1.10 in temperature coefficient for denitrification at the nearby San Joaquin Wildlife Sanctuary in Irvine, California. Because temperature variations within the lower Santa Clara River estuary are relatively moderate (see Figure 15), we have selected a value of 1.10 to reflect a moderate variability in expected denitrification rates with temperature (Table 10). Using Equations (1) and (2) above, Figure 16 shows the variation in estimated outlet concentrations (C_e) as a function of temperature and HRT.

[5] The target level for NO_2 + NO_3 is 4 mg/L instead of 1-2 mg/L since treatment wetlands are a natural treatment system resulting in variable performance depending on climate, flow, vegetation, constituent loading, wetland design, etc. While some existing treatment wetlands have effluent of <1-3 mg/L NO_2 + NO_3, it is not feasible to expect a wetland to consistently perform at that level.

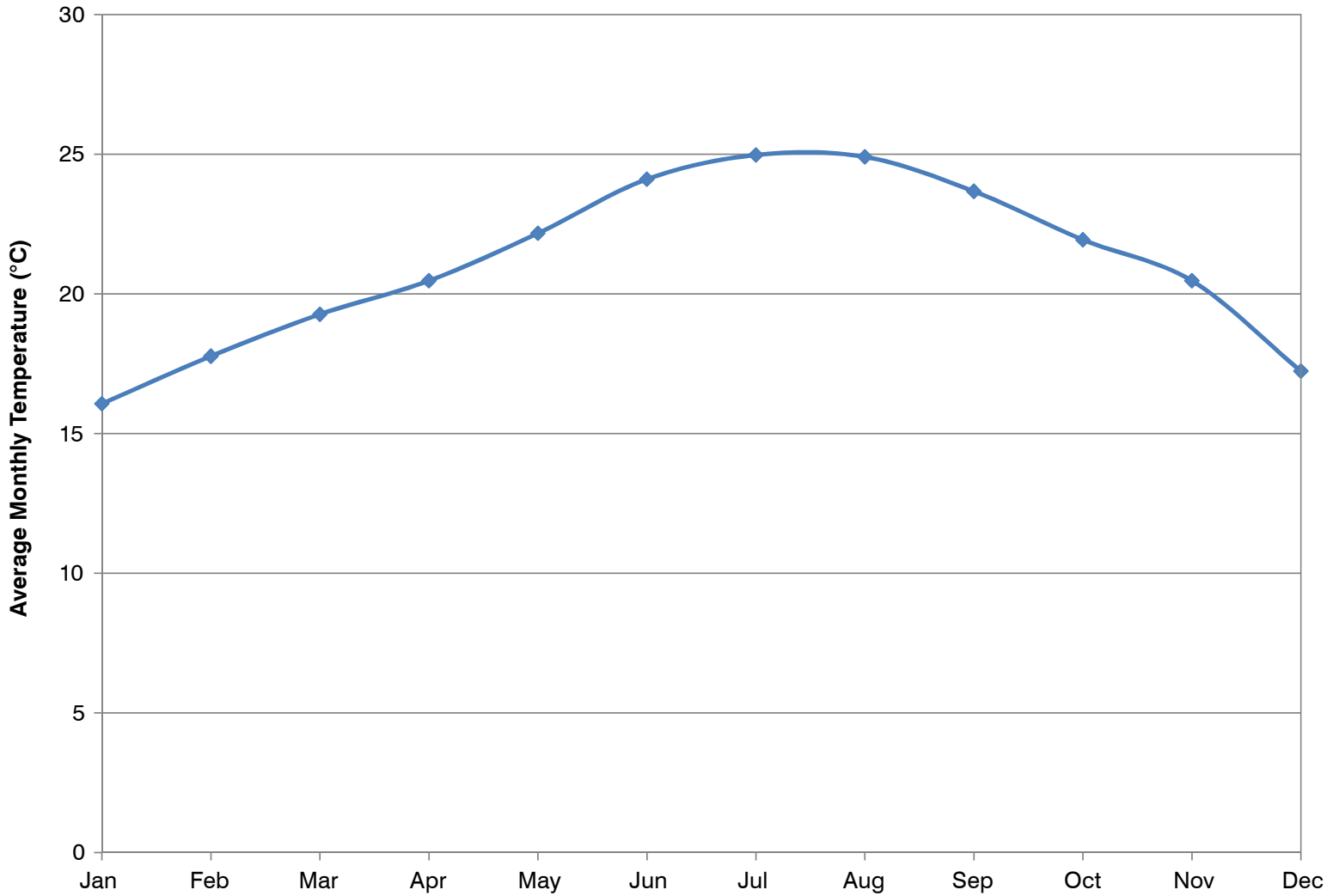

Figure 15
AVERAGE MONTHLY TEMPERATURE OF EFFLUENT IN DEGREES CELSIUS AS OBSERVED AT THE EFFLUENT TRANSFER STATION
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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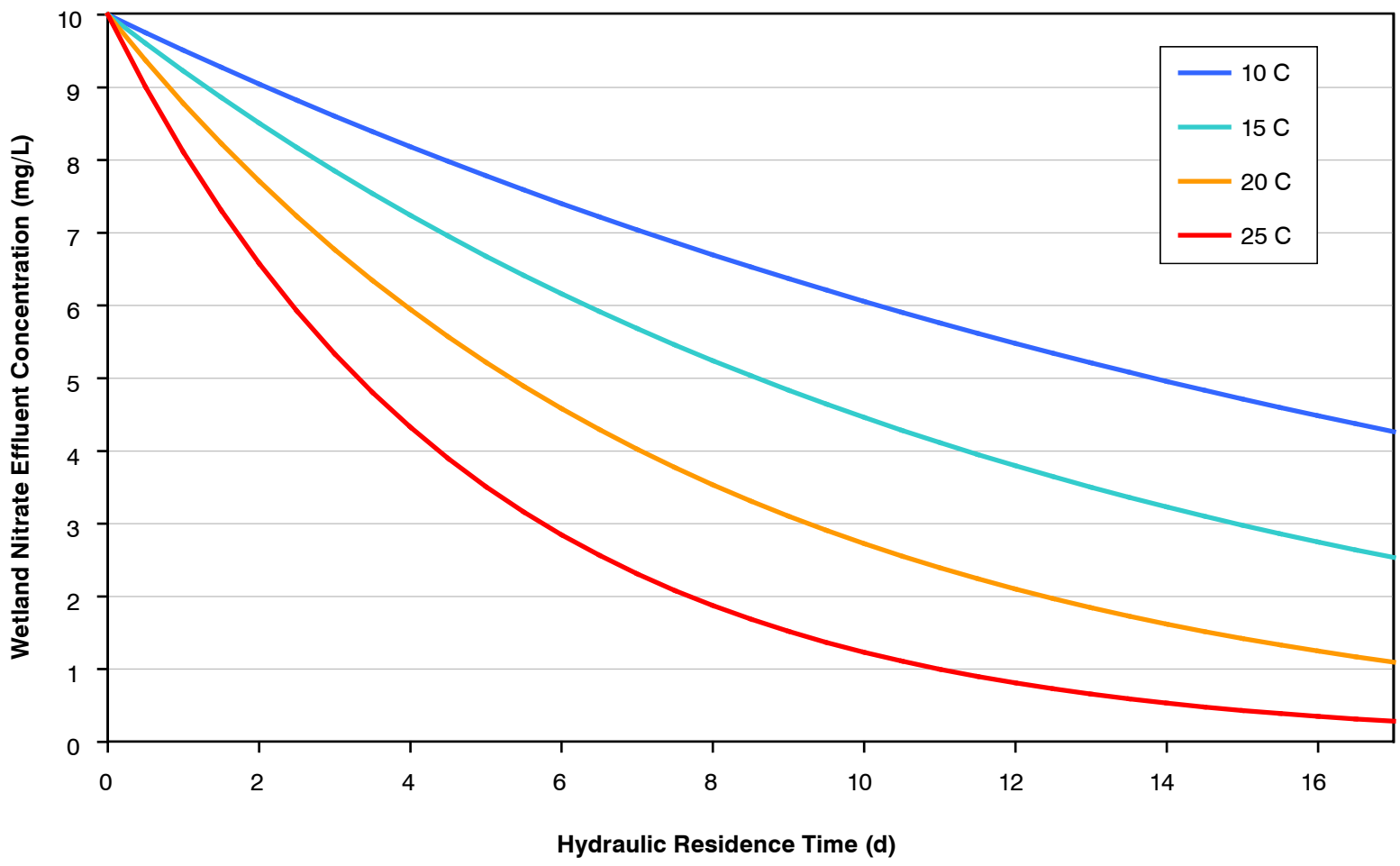

Figure 16
FIRST-ORDER (EXPONENTIAL) REMOVAL OF NITRATE IN FREE SURFACE WETLANDS AS A FUNCTION OF HYDRAULIC RESIDENCE TIME (HRT) AND WATER TEMPERATURE (k=0.13 d-1)
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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Table 10	Design Hydraulic Residence Time (HRT) as a Function of Temperature for 60 Percent Reduction in Influent Nitrate (C_i=10 mg/L) Assuming Θ = 1.10 Treatment Wetland Feasibility Study City of Ventura	
Temperature (°C)	**K_v (d^{-1})**	**HRT (d)**
10	0.05	18.3
15	0.08	11.4
20	0.13	7.0
25	0.21	4.4

Overall, modeling results suggest that for the existing and expected average temperature range within the VWRF effluent of 15 degrees C and 25 degrees C, achieving a discharge concentration of 4 mg/L NO_3 can be achieved at a design HRT as high as 11 to 12 days during winter, to as low as 4 to 5 days in the warmest periods during summer (Table 10). For an intermediate design HRT of 7 days, the corresponding effluent NO_3 concentrations would be on the order of 6 mg/L in winter, to just over 2 mg/L in summer (Figure 16).

Table 11 provides a summary of FWS wetland characteristics and NO_3 removal observed at existing FWS wetlands that were implemented with the goal of further reducing NO_3 concentration from an already low influent concentration. The FWS wetlands shown vary in area, depth, vegetative zones, and influent flows, while the seasonal range of water temperature and low influent concentration of NO_3 are similar to VWRF conditions. Although effluent concentrations of NO_3 for the wetlands shown range from 1 to 10 mg/L, it is not feasible to expect a treatment wetland to consistently perform at the 1 mg/l level since they are natural treatment systems with variable performance depending on climate, flow, vegetation, constituent loading, wetland design, etc. It is our professional opinion that a target effluent NO_3 concentration of 4 mg/L should be used.

8.0 TREATMENT WETLAND ALTERNATIVES

The on-site and three off-site treatment wetland opportunities identified in Section 5 and Figure 5 were further developed into four treatment wetland alternatives. Each of the alternatives is discussed in detail below and all were developed with special consideration of the FWS wetland mechanisms and characteristics that enhance NO_2 + NO_3 (specifically, NO_3) removal.

8.1 On-site Alternative

The existing constructed wildlife ponds were evaluated to determine if and how they could be modified into a FWS wetland system and what the potential performance of that system would be in terms of nitrate reduction. Details of each of the existing constructed wildlife ponds are

Table 11 Nitrate Removal and Treatment Characteristics Observed at Existing Free Water Surface Wetlands
Treatment Wetland Feasibility Study
City of Ventura

Wetland	Flow (mgd)	Area (acres)	Depth (ft)	HRT (days)	T Range ('C)	NO_3 Influent (mg/L)	NO_3 Effluent (mg/L)
Prado Basin (Orange County Water District, CA)	52	465	0.7 - 4			6 - 14	<1 - 6
San Joaquin Wildlife Sanctuary (Irvine Ranch Water District, CA)	3 - 6.5	80	1 - 3	10 - 14	13 - 27	3 - 15	<1 - 4
Arcata (Arcata, CA)	2.3	38	1.5 - 2			10 - 15	<10
Hemet/San Jacinto Wetland (Eastern Municipal Water District, CA)	0 - 0.25	24.5	4 - 6	8 - 12		<1 - 3	<1 - 1.5
Tres Rios (Phoenix, AZ)	2	4	0.5 - 4	0.4 - 5.6	18 - 22	3 - 4	<1 - 2.5
Yakima Basin (WA)	0.4	4		8	10 - 22	1 - 3	<0.1
Summary of other studies–Kadlec and Wallace 2009 (66 FWS wetlands)						5 - 50	4 - 10

provided in Table 12. The area and hydraulics of the ponds limits the options for developing on-site treatment wetlands. Figure 17 shows the existing profile of the wildlife ponds as well as the elevations of the interties and OJS. Since the interties are already constructed, preservation of these existing structures is the most cost effective way to transfer water between the wetland cells.

Table 12 Existing VWRF Constructed Pond Details
Treatment Wetlands Feasibility Study
City of Ventura

Pond	Area (acres)	Depth (feet)	Type
Pond 1: Bone	4.46	4	Open
Pond 2: Snoopy	10.16	4	Open
Pond 3: Lucy	5.74	8	Open

Pond depth and area of open water surface are currently too great to allow for proper treatment wetland function. In order to establish plants that are better-suited for NO_2 + NO_3 removal (e.g., bulrush, cattail), the depth of water should be less than three feet. Therefore, partial or complete conversion of the wildlife ponds is necessary. Wildlife Ponds 1 and 2 ("Bone and Snoopy," respectively) can most easily be converted into constructed FWS wetlands. Due to its depth and small area, Pond 3 ("Lucy") requires a large amount of fill with little gain in wetland area. Therefore, Pond 3 will remain as an open-water habitat and will not be considered as part of the on-site treatment wetland opportunities.

Assuming the area and hydraulics of the wildlife ponds remain the same (i.e., the pond influent is received at the pond floor elevation), the ponds can only be partially filled leaving open water zones near the influent and effluent of each pond. It is assumed a 3:1 slope up to the new floor elevation (i.e., less than three feet from the surface) will be provided to establish a bench for a reed bed for treatment purposes and a 3:1 slope down to the intertie structures will be provided so as not to add any new horizontal loads to the existing structures.

By adding fill to Ponds 1 and 2, vegetated wetland benches can be established in the ponds. This will cause the HRT through the wildlife pond system to decrease from current conditions due to the decreased depth. Table 13 presents the new vegetated areas and depths and resulting HRTs in the vegetated zones available for NO_3 removal.

While the HRT available within the wildlife ponds does not meet the 4 to 12 days needed to reduce NO_2 + NO_3 levels to near background levels, the addition of the treatment wetlands in the on-site wildlife ponds will result in some NO_2 + NO_3 removal. At existing flow rates of 5.9 mgd, the on-site ponds could reduce the NO_3 levels from 10 mg/L to 7 mg/L in the winter and to 5 mg/L in the summer. When flows increase in the future to 11.4 mgd, the removal capabilities on-site would be reduced due to the shorter HRT and effluent NO_3 levels would be approximately 8 mg/L.

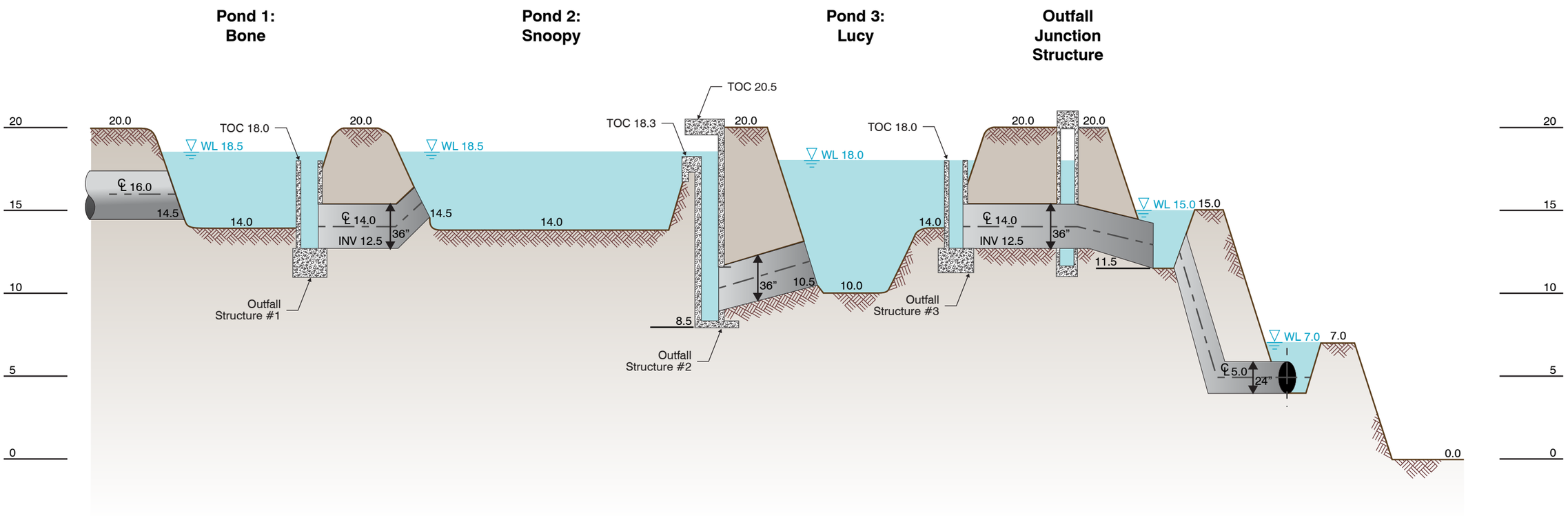

Figure 17
HYDRAULIC PROFILE OF THE WILDLIFE PONDS SHOWING INTERTIES AND THE OUTFALL JUNCTION STRUCTURE WHERE EFFLUENT IS DISCHARGED TO THE SANTA CLARA RIVER ESTUARY
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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Table 13	Estimated Hydraulic Residence Time (HRT) for On-site Treatment Wetlands at Existing and Future Flows Treatment Wetlands Feasibility Study City of Ventura		
Pond	**Vegetated Area/Wetland Depth (acres/ft)**	**HRT at existing flow = 5.9 mgd (days)**	**HRT at future flow = 11.4 mgd (days)**
Pond 1: Bone	3.8 / 2.5	0.5	0.3
Pond 2: Snoopy	8.6 / 2.5	1.2	0.6
Pond 3: Lucy	0 / 8	N/A	N/A
Total effective HRT for NO_2 + NO_3 removal		**1.7**	**0.9**

It is important to note that while planting reed species in the ponds provides means for denitrification, there is a loss of aesthetics with the loss of open water zones as well as a loss of desirable habitat for waterfowl. However, wetlands can provide for adjacent habitats, flyways, migration patterns, refugia, and avian drinking water sources. Habitat opportunities are discussed in more detail in Section 9.

8.2 Off-site Alternatives

Three off-site wetlands were identified as potential off-site treatment wetland opportunities and are shown in Figure 5. Due to various obstacles including existing land use, lot size, etc., these three parcels identified have the greatest potential for off-site opportunities: 1) City-Owned, 2) Berry, and 3) McGrath/TNC. Table 14 summarizes the details of each parcel. For this study, it is assumed that 85 percent of the parcel area will be part of the treatment wetland. Table 15 presents the new vegetated areas, wetland depth, and resulting HRTs available for NO_2 + NO_3 removal.

Table 14	Summary of Off-site Treatment Wetland Opportunities Treatment Wetlands Feasibility Study City of Ventura	
Pond	**Approximate Area (acres)**	**Pipe Length from VWRF (feet)**
1: City-Owned	34	1,425
2: Berry	108	5,965
3: McGrath/TNC	141	17,530

The range of HRTs needed for denitrification to be 4 mg/L is on the order of 4 to 12 days. Assuming flow would pass through on-site treatment wetlands (with 1 to 2 days HRT) prior to passing through off-site wetlands, an additional 3 to 10 days of HRT (depending on the time of year and influent flow) would be required at an off-site treatment wetland. As shown in Table 15, this additional HRT can be achieved at all of the off-site alternatives for the existing flow.

Table 15	Estimated Hydraulic Residence Time (HRT) Provided by the Off-Site Treatment Wetland Alternatives at Existing and Future Flows Treatment Wetland Feasibility Study City of Ventura		
Pond	**Approximate Useable "Wet" Area (acres)(1)**	**HRT at Existing Flow = 4.8 mgd (days)(2)**	**HRT at Future Flow = 10.3 mgd (days)(2)**
1: City-Owned	29	4.9	2.3
2: Berry	92	15.6	7.3
3: McGrath/TNC	120	20.4	9.5

Notes:
(1) Assumes 85 percent of available area is converted to wetland area ("wet area" not including berms, roads, etc.).
(2) Assuming net loss across the wildlife ponds is approximately 1.1 mgd per Section 6.0 and the average water depth for wetlands is 2.5 feet.

For future flows, the McGrath/TNC sites would provide adequate HRT for year-round NO_3 reduction. The combined HRT of the on-site with either the City-Owned or Berry sites would only provide enough HRT for NO_3 reduction in the summer and would result in higher effluent levels in the winter than the desired 4 mg/l. However, summer (due to warmer temperatures) is the more critical time period for nutrient loads in the Estuary. These estimates all assume a phased approach for achieving further NO_2 + NO_3 reduction, assuming the flow would pass through an on-site wetland first, followed by an off-site wetland in the future. If no wetlands were added on-site, then the full 4 to 12 days would be required at an off-site location. Only the McGrath/TNC site will provide adequate HRT for denitrification of the full flow now and in the future.

In addition to the treatment wetland performance of the alternatives, Table 16 provides a summary of the various implementation issues and benefits associated with each off-site treatment wetland alternative considered. In addition to these site-specific issues, for all off-site alternatives, considerable effort would be required for site permitting (such as wetland delineations) and NPDES permitting for a discharge permit at a new location. Other studies have shown that eliminating the discharge of effluent to the Estuary would eliminate habitat (Nautilus Environmental, 2005). The Estuary Subwatershed Study will address this in more detail.

The potential off-site opportunities were presented to a stakeholder group for this project on November 10, 2009. At this workshop, attendees were offered the chance to identify their preference for a wetlands alternative. Figure 18 shows the results of this preference input.

8.3 Preliminary Cost Estimates for Alternatives

This section provides a comparison of estimated planning level costs for each alternative. Planning level cost estimates are typically used for conceptual and screening purposes and

Figure 18
BLUE DOTS SHOW VARIOUS STAKEHOLDERS' PREFERENCE FOR A POTENTIAL OFFSITE TREATMENT WETLAND LOCATION
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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Table 16	Implementation Issues and Benefits of the Off-site Treatment Wetland Alternatives Treatment Wetland Feasibility Study City of Ventura
Alternatives	**Issues/Benefits**
1: City-Owned	Existing utilities (e.g., sewer trunk line) limit the useable area
	Closest to the VWRF (shortest pipeline, lowest cost)
2: Berry	Large area
	Pipeline needs to cross the Santa Clara River
	Potential unwilling seller(1)
3: McGrath/TNC	Largest area (some planned for restoration)
	Disturbance of existing habitat at the southern end and discharge to the Santa Clara River may make permitting difficult
	Furthest from the VWRF (longest pipeline, highest cost)

Note:
(1) While there is an unwilling seller, stakeholders (specifically, representatives from Sate Parks and Fish and Wildlife Services) requested this site be kept for further examination.

are based on a project definition of 0 to 2 percent. A contingency is often used to compensate for lack of detailed engineering data and oversights (-20 percent to -50 percent on the low side, and +30 percent to +100 percent on the high side) depending on the technological complexity of the project, availability and accuracy of appropriate reference information, and the inclusion of an appropriate contingency determination. Project costs presented in this section include construction costs, contingencies and a project cost factor for engineering, construction management, legal and administration.

The planning level estimates of total project costs and annual operations and maintenance (O&M) costs are provided in Table 17. The total project cost estimates include treatment wetland construction, pumping, and pipeline costs as separate line items. The on-site treatment wetland construction cost estimate includes only fill media, earthwork, plants and planting, since the remaining items were already performed or were in place. The off-site treatment wetland construction cost estimates are based on a range of construction costs for FWS wetlands per hectare collected and presented by the U.S. EPA in the Constructed Wetlands Treatment of Municipal Wastewater Manual (U.S. EPA, 2000). The costs were adjusted to current conditions using the January 2010 ENR index for Los Angeles and include surveying/geotechnical work, clearing and grubbing the site, earthwork, a liner, fill media, plants and planting, control structures, plumbing and fencing. The pump cost estimates are based on the AAF and distance the pump will convey the treated effluent from the wildlife ponds to any off-site treatment wetland (accounting for the total dynamic head). The pipeline cost estimates are based on the total length, diameter, and material of the pipe determined to be appropriate for conveying the treated effluent to any off-site treatment wetlands.

Table 17 Summary of Treatment Wetland Opportunity Planning Level Estimates of Total Project Costs
Treatment Wetland Feasibility Study
City of Ventura

	On-site: Ponds 1 & 2	Off-site 1: City-Owned	Off-site 2: Berry	Off-site 3: McGrath/TNC
Approximate Area (acres)(1)	12.4	29	92	120
Pipe Length from VWRF (feet)	N/A	1,425	5965	17,530
Wetland Construction ($)(2)	$2,700,000	$7,700,000	$24,600,000	$32,000,000
Pump Costs ($)	N/A	$2,200,000	$2,400,000	$3,100,000
Pipeline Costs ($)	N/A	$700,000	$2,500,000	$8,700,000
Permitting and CEQA Costs(3)	$100,000	$750,000	$750,000	$750,000
Total Project Costs ($)	$2,800,000	$11,350,000	$30,250,000	$44,550,000
Annual O&M Costs ($)(2)	$30,000	$70,000	$210,000	$280,000

Notes:
(1) Area provided in table is 85 percent of the total area available for the constructed treatment wetland.
(2) Based on Constructed Wetlands Treatment of Municipal Wastewater Manual range of costs for construction ($145,000 to $255,000 per hectare) and the operations and maintenance ($2,000 to $4000 per hectare) of treatment wetlands (U.S. EPA, 2000). Costs from this manual were adjusted to 2010 dollars using the ENR index for Los Angeles.
(3) Assuming off-site wetlands would require site permitting, CEQA and a new NPDES permit for a new discharge location and the associated studies.

Permitting and CEQA costs were grossly estimated based on professional judgment. The on-site alternative would likely require little to no permitting and CEQA evaluation. The off-site alternatives would require an EIR (CEQA evaluation), as well as potentially requiring the following: Section 404 permit, Section 10 Rivers and Harbors Act permit, Section 7 Endangered Species Act (ESA) compliance, Section 401 water quality certification, and Section 1600 streambed alteration agreement. NPDES permitting to secure a new discharge permit would potentially require the following: Antidegradation Analysis, Reasonable Potential Analysis, and Report of Waste Discharge.

The annual O&M cost estimates are based on average annual O&M costs for FWS wetlands per hectare collected and presented by the U.S. EPA in the Constructed Wetlands Treatment of Municipal Wastewater Manual (U.S. EPA, 2000). These costs were adjusted to current conditions using the January 2010 ENR index for Los Angeles and include operator's time spent servicing pumps, checking berms for animal damage and erosion, checking/cleaning effluent screens, observing/adjusting water levels and flow rates, animal (i.e., muskrats) control, vector (i.e., mosquitoes) control, and NPDES monitoring.

9.0 HABITAT OPPORTUNITIES

9.1 Existing On-site Habitat

The existing VWRF wildlife ponds support a variety of biological resources including vegetation communities and fish and wildlife habitat. In addition to reviewing existing information (Nautilus Environmental 2005, Stillwater Sciences 2007, Lorna Jordan Studio 2007), vegetation mapping conducted by Stillwater Sciences (2010) at VWRF and the surrounding Santa Clara River channel, estuary, and McGrath State Beach is included in this synopsis. Community types present include riparian forest, emergent freshwater marsh, ruderal herbaceous, and open water. The community types and associated areas are summarized in Table 18, depicted in Figure 19, and further described in the following sections.

Table 18 Existing Vegetation Community Types within VWRF Treatment Wetland Feasibility Study City of Ventura

Community Type	Area within VWRF
Riparian Forest	13.9 acres
Emergent Freshwater Marsh	3.3 acres
Ruderal Herbaceous	5.8 acres
Open Water	17.5 acres
Developed	2.5 acres

9.1.1 Riparian Forest

The riparian forest within VWRF occurs along the northern edge of the site, as well as in large patches around Snoopy, on the island within Snoopy, and surrounding Lucy and the southern and eastern portions of the site. The total geographic extent of the riparian forest is approximately 13.9 acres. Mapped as the *Salix lasiolepis* Alliance by Stillwater Sciences (2010), it occurs as a woodland form. Vegetation coverage is generally dense in the tree layer (50–100 percent cover), variable in the shrub layer (5–100 percent cover), and absent from the herbaceous layer (<5 percent cover). Arroyo willow (*Salix lasiolepis*) is the dominant species in the tree layer and is dominant or co-dominant in the shrub layer. Cottonwood (*Populus balsamifera*), red willow (*Salix laevigata*), and/or occasionally myoporum trees (*Myoporum laetum*) are also present in the tree layer, but generally at much lower abundance (<30 percent cover). Giant reed (*Arundo donax*) and poison oak (*Toxicodendron diversilobum*) are common co-dominant or sub-dominant components of the shrub layer, with myoporum, red willow, and blackberry (*Rubus ursinus*) also commonly present. The vegetation type conforms to *A Manual of California Vegetation*'s *Salix lasiolepis* Shrubland Alliance (Sawyer et al. 2009).

Figure 19
VEGETATION COMMUNITY TYPES WITHIN THE VENTURA WATER RECLAMATION FACILITY
TREATMENT WETLANDS FEASIBILITY STUDY
CITY OF VENTURA

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Riparian woodlands are valuable for wildlife since they provide water, favorable microclimates, and important movement corridors. Bird species typically associated with riparian forest that are common to this area include black phoebe (*Sayornis nigricans*), warbling vireo (*Vireo gilvus*), bushtit (*Psaltriparus minimus*), Pacific-slope flycatcher (*Empidonax difficilis*), black-headed grosbeak (*Pheucticus melanocephalus*), orange-crowned warbler (*Vermivora celata*), Wilson's warbler (*Wilsonia pusilla*), and song sparrow (*Melospiza melodia*). Special-status bird species that have not been documented at VWRF but have the potential to occur within this riparian forest include southwestern willow flycatcher (*Empidonax traillii extimus*) and Least Bell's vireo (*Vireo bellii pusillus*) (both federally and state-endangered species), yellow warbler (*Dendroica petechia brewsteri*) and yellow-breasted chat (*Icteria virens*) (both state species of special concern). A variety of bat species may roost in trees of riparian habitats including the western red bat (*Lasiurus blossevillii*), a state species of special concern. Other mammals that may use riparian habitats include raccoon (*Procyon lotor*), bobcat (*Lynx rufus*), and shrews (*Sorex* spp.).

9.1.2 Emergent Freshwater Marsh

Emergent freshwater marsh dominates the perimeter of two of the treatment ponds, Bone and Snoopy. This vegetation type was not prevalent around the third pond, Lucy; instead, riparian forest abuts the pond margin. The total geographic extent of emergent freshwater marsh is approximately 3.3 acres. This vegetation community is predominantly two vegetation types, Urtica dioica Provisional Alliance and Ambrosia psilostachya Provisional Alliance (Stillwater 2010 and Sawyer et al. 2009). The Urtica dioca Provisional Alliance is a densely vegetated alliance experiencing periodic inundation and dominated by U. dioca (30 percent). Tree and shrub layers are absent and the herbaceous layer is moderate to dense. Associated species include Euthamia occidentalis (20 percent) and Scirpus californicus (20 percent). The Ambrosia psilostachya Provisional Alliance is found on the sloped banks of the two pond perimeters and has dense (100 percent) vegetative cover, with western ragweed (Ambrosia psilostachya) (60 percent cover) and western goldentop (Euthamia occidentalis) (25 percent cover) as co-dominants. California bulrush (Schoenoplectus californicus) and curly dock (Rumex crispus) occur at lower densities (5–10 percent cover). This alliance conforms somewhat to A Manual of California Vegetation's Ambrosia psilostachya Provisional Herbaceous Alliance (Sawyer et al. 2009).

Emergent freshwater marsh offers high-quality wildlife habitat that provides nesting, foraging, roosting, and cover for a variety of species. Emergent freshwater marsh typically contains many invertebrates that in turn provide an important food source for other species. Dabbling ducks eat invertebrates as well as plant material and seeds in the water. Common herpetofaunal species that use emergent freshwater marsh, such as Pacific chorus frog (*Pseudacris regilla*) and garter snake (*Thamnophis* spp.), also provide a food source for other wildlife including birds and mammals. Common and uncommon bird species typically

associated with emergent freshwater marsh that may be found in the area of VWRF include rails (e.g., Virginia rail [*Rallus limicola*], common moorhen [*Gallinula chloropus*]), herons, egrets, shorebirds, marsh wren (*Cistothorus palustris*), and common yellowthroat (*Geothlypis trichas*). Two state species of special concern that have not been documented at VWRF but have the potential to occur within the emergent freshwater marsh habitat include western pond turtle (*Actinemys marmorata*) and tricolored blackbird (*Agelaius tricolor*). Western pond turtles require basking sites such as logs or mats of vegetation in marsh and open water habitats. Tricolored blackbirds typically nest in large colonies (at least about 50 pairs) within protected substrate such as cattails, tules, blackberry, or willow near open water.

9.1.3 Ruderal Herbaceous

Within VWRF, the ruderal herbaceous community exists scattered throughout the site in disturbed areas; consequently, the species composition is a mix of native and non-native plants. Some the ruderal herbaceous community was mapped as disturbed (3.6 acres); the remainder was mapped as the *Carpobrutus* spp. Alliance (2.3 acres). The total geographic extent of the ruderal herbaceous vegetation community, including both the disturbed and *Carpobrotus* spp. Alliance, is approximately 5.8 acres. The *Carpobrotus* spp. Alliance (Stillwater 2010) and Sawyer et al. 2009) contains one or more of three low-growing (generally <0.5 m), succulent iceplant species: *Carpobrotus edulis*, *C. chilensis*, and *Mesembryanthemum crystallinum*. Other species found in this alliance include sand verbena (*Abronia umbellata)*, silver bur ragweed (*Ambrosia chamissonis)*, cliff buckwheat (*Eriogonum parvifolium)*, common sandaster (*Corethrogyne filanginifolia* var. *filanginifolia*), and Bermuda grass (*Cynodon dactylon*). Coyote brush can occur at low percent cover (10 percent or less), but trees are generally absent. This alliance conforms to *A Manual of California Vegetation*'s *Carpobrotus* spp. Semi-Natural Herbaceous Stands (Sawyer et al. 2009). Iceplant species are listed as moderate to highly invasive in coastal California habitats, particularly sand dunes (Cal-IPC 2007).

Despite a lack of native plant species richness and complexity, ruderal herbaceous vegetation may provide some wildlife species with food resources (e.g., seeds from grasses and forbs), as well as cover and nesting opportunities. Species commonly occurring within ruderal habitats include the western fence lizard (*Sceloperus occidentalis*), mourning dove (*Zenaida macroura*), American crow (*Corvus brachyrhynchos*), European starling (*Sturnus vulgaris*), white-crowned sparrow (*Zonotrichia leucophrys*) pocket gopher (*Thomomys bottae*), and house mouse (*Mus musculus*).

9.1.4 Open Water

Open water occurs in all three treatment ponds. The total geographic extent of open water is 17.5 acres. This habitat does not support terrestrial or emergent vegetation; however it does support a large variety of bird species including dabbling ducks, diving ducks, gulls,

phalaropes, and grebes. Swallows and flycatchers feed on insects that they catch in flight, often over open water and emergent marsh habitats.

9.2 Opportunities for Enhancement

There are opportunities to create, restore, or enhance habitat for rare and common wildlife species while meeting objectives of wastewater treatment. Existing (e.g., emergent freshwater marsh) or adjacent (e.g., coastal dune) vegetation communities may be expanded and enhanced. Existing ruderal herbaceous may be restored to habitats more suitable for native plants and wildlife. Unique habitat elements such as snags, downed wood, and/or islands may be added to the landscape to create additional microhabitats for wildlife.

9.2.1 Enhancement of Emergent Freshwater Marsh

The existing emergent freshwater marsh is limited to two vegetation types (Section 10.1.2). These vegetation communities could be enhanced and expanded to create more diverse habitat. Two important vegetation communities are the *Typha domingensis* Alliance and the *Schoenoplectus californicus* Alliance (Sawyer et al. 2009), both of which occur in large areas within the Santa Clara River Estuary. These vegetation types would support a greater abundance and wider variety of wildlife as a result of increased nesting, roosting, foraging, and cover opportunities. Improvement of the freshwater marsh would provide increased nesting opportunities for both species that may construct nests directly suspended in tules or cattails (e.g., marsh wren, blackbird, common yellowthroat) as well as species that construct nests on matted vegetation or mud while concealed behind emergent vegetation (e.g., ducks, rails, or grebes). Foraging opportunities may be improved with a subsequent increase in prey species, and more emergent vegetation will provide new areas for cover and protection from predators.

9.2.2 Extension of Coastal Dunes

In addition to riparian forest, emergent freshwater marsh, ruderal herbaceous, and open water communities and habitats, dune vegetation occurs adjacent to the VWRF and could be supported within the site. Along the coastal strand on both sides of the mouth of the Santa Clara River, the coastal foredune areas support the *Abronia* spp.–*Ambrosia chamissonis* Alliance (Stillwater 2010 and Sawyer et al. 2009). Common plant species include red sand-verbena (*Abronia maritima*), beach bursage (*Ambrosia chamissonis*), and beach evening primrose (*Camissonia cheiranthifolia* ssp. *suffruticosa*), as well as pink sand-verbena (*Abronia umbellata*), coast buckwheat (*Eriogonum parvifolium*), sea rocket (*Cakile maritima*), and lotus (*Lotus junceus*). The nearby coastal dunes support a variety of wildlife including western fence lizard, side-blotched lizard (*Uta stansburiana*), and killdeer (*Charadrius vociferous*). Two special-status bird species have been documented in the nearby coastal dunes: the federally threatened western snowy plover (*Charadrius alexandrinus nivosus*) and the federally and state-listed California least tern (*Sternula antillarum browni*).

9.2.3 Snags with Cavities

Snags are standing dead trees that provide denning, nesting, roosting, and foraging habitat for wildlife. Snags and decaying live trees can provide cavity nests, chimney roosts, platform nests, perches, food caches, foraging substrates, and nests or bat roosts beneath peeling bark. The installation of one or more snags within the VWRF may provide nesting or roosting opportunities for raptor, other bird, or bat species that may not otherwise have an opportunity to utilize nearby habitats.

9.2.4 Downed Wood

Installing downed wood, or fallen dead trees, into open water or emergent wetland habitats may provide basking opportunities for western pond turtle, a state species of species concern that has not yet been documented in VWRF. Downed wood added to riparian or other terrestrial habitats may also provide new habitat for Pacific chorus frogs, salamanders, and snakes.

9.2.5 Island

Creation of one or more islands within open water or emergent wetland habitat may provide protected nesting habitat for ducks or wading birds such as herons. Constructing islands an adequate distance from the mainland provides safety from mammalian predators (e.g., raccoons, striped skunks, feral cats) while birds are incubating their eggs. Adding large trees or snags in the design of the island may encourage nesting of herons or egrets, which form nesting colonies in trees. Islands could also be constructed as emergent wetlands (cattail or tulle islands) within a larger wetland complex. Establishing new islands may not only benefit bird species, but may provide an aesthetically attractive component for human visitors including birders and hikers.

10.0 SUMMARY

This study evaluated the feasibility and opportunity to improve the VWRF effluent water quality through the implementation of treatment wetlands. The major findings of this study are:

- Water Quality:
  - The existing VWRF effluent meets permit limits for conventional constituents (e.g., BOD, TSS) and for metals.
  - The existing VWRF effluent does not meet permit limits for nitrate and nitrite (NO_3 + NO_2), but the VWRF improvement project currently under construction will correct this deficiency and cause the facility to meet limits of less than 10 mg/l of NO_3 + NO_2.

- Background receiving water sampling compared to effluent shows little opportunity for water quality improvement, other than for NO_3.

- Opportunities for Improvement in Wetlands:
  - Treatment wetlands have been found to be effective at reducing NO_3 levels, with variable performance depending primarily on temperature and HRT.
  - For the purposes of reducing VWRF effluent levels from 10 mg/l NO_3 to background levels of 4 mg/l, a range of 4 to 12 days HRT is required depending on the season/water temperature.

- On-site Opportunities:
  - The existing on-site wildlife ponds provide some limited opportunity for water quality improvement if converted to treatment wetlands
  - Conversion to wetlands would entail filling Ponds 1 and 2 (Bone and Snoopy) to decrease depth to allow wetland plants optimum growth potential. Pond 3 (Lucy) is too deep (8 ft) and therefore would not be cost effective to fill/convert.
  - On-site wetlands would provide between 1 to 2 days HRT.
  - Conversion of existing wildlife ponds to wetlands would eliminate some open water habitat.

- Off-site Opportunities:
  - Nine parcels relatively near the VWRF were considered. A screening process identified three parcels based on size, existing use and perceived opportunity.
  - Potential off-site parcels include City-Owned site (adjacent to VWRF), Berry site (south of Santa Clara River) and the McGrath/TNC site (east of the VRWF along the Santa Clara River).
  - At existing flows, the Berry and McGrath/TNC sites would provide adequate HRT either with or without on-site treatment wetlands to meet the desired 4 mg/l NO_3. The City-Owned site paired with the on-site wetlands would provide adequate HRT for summer NO_3 reduction, but would fall a bit short of the goal during winter time.
  - At future flows, the McGrath/TNC site paired with the on-site wetlands would provide enough HRT to meet the 4 mg/l goal. Both the City-Owned and Berry sites paired with the on-site wetlands would provide adequate HRT for summer NO_3 reduction, but would fall short of 4 mg/l during winter time.
  - Significant permitting and CEQA efforts would be required to implement these off-site alternatives. The off-site alternatives would require an EIR (CEQA evaluation), as well as potentially requiring the following: Section 404 permit, Section 10 Rivers and Harbors Act permit, Section 7 Endangered Species Act (ESA) compliance, Section 401 water quality certification, and Section 1600 streambed alteration agreement. NPDES permitting to secure a new discharge permit would potentially

require the following: Antidegradation Analysis, Reasonable Potential Analysis, and Report of Waste Discharge.

- Habitat Opportunities:
  - There are opportunities to improve local habitat with wetlands through the introduction of the following types of features:
    - Increased variety of freshwater wetlands species.
    - Extension of dune vegetation.
    - Snags with cavities.
    - Downed wood.
    - Islands.

10.1 Outstanding Issues to Address/Next Steps

The Estuary Subwatershed Study (to be completed by March 2011) will evaluate if the VWRF discharge is providing an enhancement to the Estuary. If the Estuary Subwatershed Study indicates that the discharge is not providing an enhancement, then an alternative management scenario for the discharge will be developed. The Estuary Subwatershed Study will form the basis for determining how the discharge should be managed with respect to the volume and quality of discharge to the Estuary. Consequently, the outcome of the Estuary Subwatershed Study will strongly influence the development of management alternatives with respect to treatment wetlands.

Phase 2 of the Recycled Water Market Study follows completion of the Estuary Subwatershed Study, the Treatment Wetlands Feasibility Study, and Phase 1 of the Recycled Water Market Study. The objective of Phase 2 of the Recycled Water Market Study is to identify and evaluate alternatives for increasing recycled water use and/or implementing constructed wetlands based on the integrated findings and conclusions of the Estuary Subwatershed Study. As part of Phase 2, a cost-benefit analysis of alternatives will be conducted to help determine a preferred alternative.

This report evaluated the feasibility of providing treatment wetlands. Based on the findings of the Estuary Subwatershed Study and the Phase 2 Recycled Water Market Study, if treatment wetlands are selected for future implementation, there are several outstanding issues and next steps that would need to be addressed before proceeding with implementation.

- On-site Wetlands:
  - Perform geotechnical and structural analysis to evaluate potential impacts of placing fill in existing wildlife ponds.
  - Engage in discussion with regulatory agencies regarding any permitting issues (e.g., NPDES permit, Army Corp of Engineers). Investigate whether there will be an effluent discharge requirement from the treatment wetlands, or if the point of

compliance will continue to be location just downstream of the chlorine contact channel. Identify other site permits required.

  - Engage in discussion with public and interested parties on best way to meet competing goals for treatment, habitat and public access.
  - Prepare preliminary design including a more detailed cost estimate.

- Off-site Wetlands:
  - Engage in discussions with land owners regarding willingness to sell or partner.
  - Engage in discussions with regulatory agencies and interested agencies regarding converted use of land from agriculture to wetlands, potential impacts to existing habitat in pipe alignment and wetland sites, and additional permits required. Investigate options for how discharge will be regulated from an off-site location (e.g., new NPDES permit for new surface water discharge).
  - Engage in discussion with public and interested parties on best way to meet competing goals for treatment, habitat and public access.
  - Pursue funding opportunities.
  - Select preferred site.
  - Prepare preliminary design (including a more detailed cost estimate), permitting studies, and CEQA.
  - Conduct a cost-benefit analysis of alternatives.

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REFERENCES

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