Status Report to the 1998 Research Plan for the Tres Rios Demonstration Constructed Wetland Project

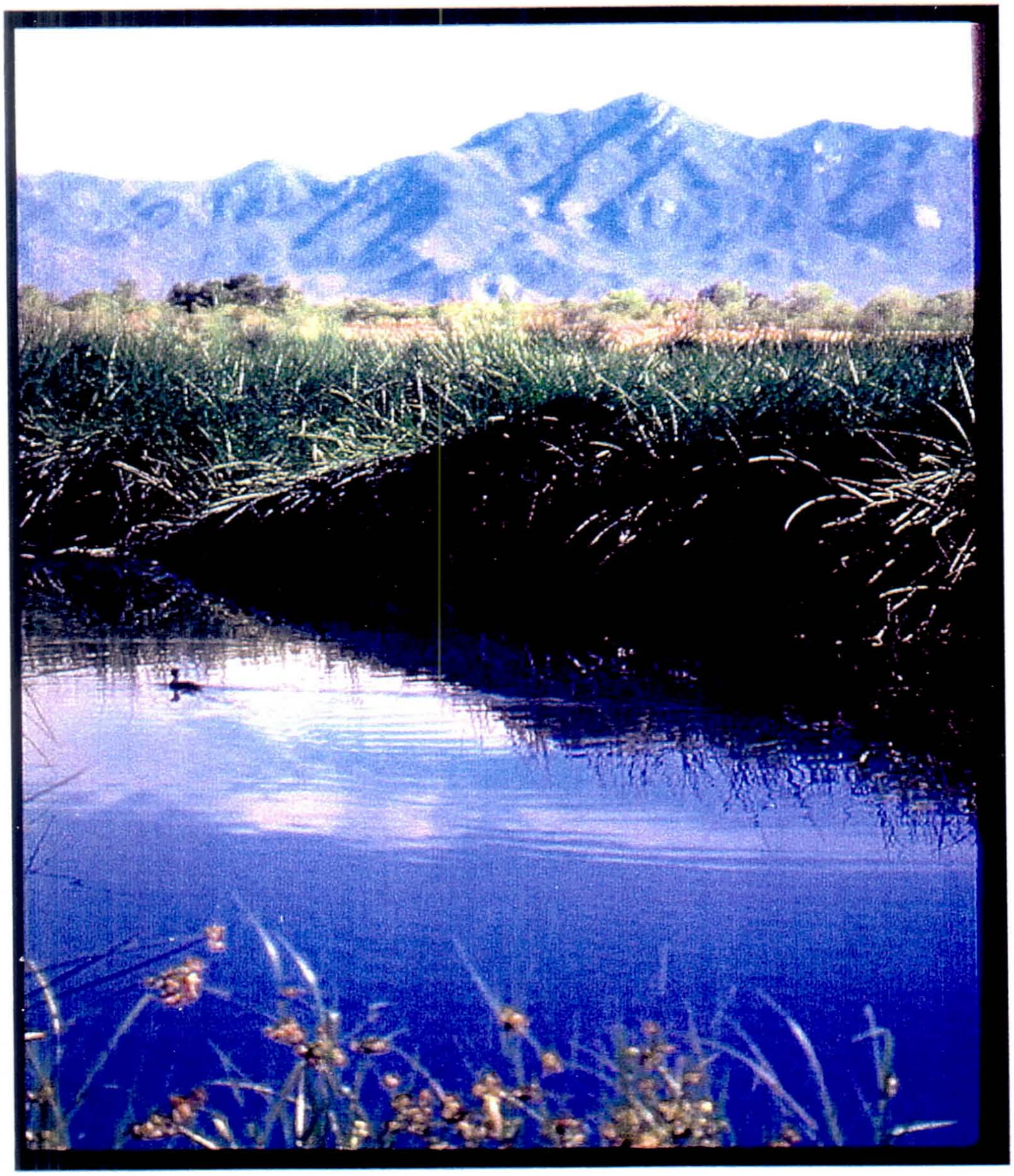

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Table of Contents

Table of Contents
(Continued)

Appendices

Appendix

List of Tables

List of Tables
(Continued)

List of Tables
(Continued)

List of Tables
(Continued)

List of Tables
(Continued)

List of Tables
(Continued)

List of Figures

Introduction

Background
The Tres Rios Demonstration Constructed Treatment Wetlands Project (Demonstration Project) has been operational since August 1995. During that time it has successfully polished almost 2 million gallons a day of secondary-advanced treated municipal wastewater. The Project has been operated in cooperation with the US Bureau of Reclamation (USBR), the City of Phoenix (COP), and the Subregional Operating Group (SROG) partners. In addition, both monetary and intellectual input was provided from the Arizona Department of Water Resources (ADWR), Arizona Game and Fish (AZ G&F), the Arizona Department of Environmental Quality (ADEQ), Maricopa County (MC), US Environmental Protection Agency (US EPA), Corps of Engineers (COE), Arizona State University (ASU), and the University of Arizona (U of A). Since start-up, the project has utilized the continuing contribution of some of the Nation's leading wetland experts including Robert Knight (CH2MHill), Robert Kadlec (Wetland Management Services), Robert Gearheart (Humboldt State University), Bob Bastian (US EPA), and Eric Stiles (USBR). The Project was also used to address concerns of local residents including the Holly Acres community.

Project History
The Demonstration Project consists of approximately 11 acres of emergent marsh, free-water surface wetlands, and is located adjacent to and within the confines of the City of Phoenix/SROG 91st Avenue Wastewater Treatment Plant (See Aerial Photographs Appendix A). There were three operational wetlands sites. These included the Cobble (4 acres), Hayfield (6 acres), and the Research Cell sites (1 acre). The Research Cell site was subsequently decommissioned in the fall of 1998. The first phase of research on the Demonstration Project was a two-year, $3.5 million study funded by the USBR, SROG, ADWR, and AZ G&F with three primary objectives; 1) To determine if wetland systems can polish pre-treated wastewater to a level which will meet perceived future discharge requirements, 2) Develop scale-up parameters for an approximately 800 acre system, and 3) Determine the net environmental benefit such a system and associated riparian habitat would have in the Salt/Gila, and Agua Fria River area. The results of this research were published in the *Tres Rios Demonstration Constructed Wetland Project 1996/1997 Operation and Water Quality Report* (Wass, 1997).

Project Objectives
The 1998 Research Plan (USBR, 2000) was developed to further investigate the performance and sustainability of the Demonstration Project. Data from January 1998 to December 2000 have been collected from these facilities and the following section provides a brief overview of the results. During this time period, three of the four demonstration basins did undergo large disturbances which entailed basin dewatering, vegetation removal, and in the case of the Cobble Site basins, morphological changes. The south Hayfield Basin H2 was not disturbed. Results prior to 1998 are included when appropriate to demonstrate long-term water quality or performance trends.

The four primary research objectives defined in the 1998 Research Plan are as follows:

1. Evaluate the water quality of secondary effluent from inlet through outlet of the wetland basins.
2. Assess the effectiveness of vector control methods such as water level fluctuation and larvacide application.
3. Evaluate the impacts of habitat diversity on wildlife use in the reconfigured Cobble Site and throughout the entire system.
4. Assess the sustainability of the Demonstration Project to serve as a model for full scale design.

Two other goals of the Demonstration Project are to create a resource with which to educate the public about the benefits of wetlands and wastewater reuse, and to provide an environment for passive recreation such as bird watching and walking.

Facilities Description

The 91st Avenue WWTP, located at 5615 South 91st Avenue, Tolleson, Arizona, serves the wastewater treatment needs of the greater Phoenix metropolitan area. The regional treatment facility is owned jointly by the Cities of Phoenix, Glendale, Mesa, Scottsdale, and Tempe, and treats flows from these cities and the towns of Guadalupe and Paradise Valley. The facility currently consists of five plants (1A, 1B, 2A, 2B and 3A) with a treatment capacity of 161.75 mgd. Plant 3B is nearing completion, bringing the treatment capacity to 179.25 mgd.

Over the duration of the Demonstration Project, the wetland basins have received highly treated effluent from Plant 3A. Plant 3A produces an advanced-secondary product water that has undergone nitrification/denitrification. The final effluent is chlorinated and typically is low in BOD, solids, and nutrients.

A brief description of the wetland sites studied for this report is provided below while aerial site maps of the facilities are provided in Appendix A.

Cobble Site

The Cobble Site consists of two elongated wetland cells whose flow-paths are oriented from east to west and possess identical surface areas. They are located within the Salt River floodway. Adjacent to the cells on the north and west are Cottonwood (*Populus fremontii*) and Willow (*Salix spp.*) galleries and some fairly dense stands of Salt Cedar (*Tamarix spp.*). To the south is the main channel of the Salt River, which is braided and only vegetated in discrete areas.

The northern basin, C1, is unlined while the southern basin, C2, is lined with 6 to 8-in (15 to 20- cm) of top-soil obtained from an agricultural field in the proximity of the project site. Flows enter the site by means of a two-way splitter-box outfitted with 60° V-notch weirs. These cells are operated in parallel and flows exit each basin through another 60°

V-notch weir, which spills into an underground conveyance system that discharges to the main 91st Avenue effluent channel.

Each Cobble Site basin is approximately 900 ft (275 m) long and 115 ft (35 m) wide, which result in a wetted surface area of approximately 2.2 acres (0.9 ha) when a depth of 1.0 ft (0.3 m) is maintained in the emergent marsh areas. This produces an aspect ratio (Length/Width) of almost 9:1, and at design hydraulic loadings results in a design theoretical hydraulic retention time between 0.5 and 5 days. Both C1 and C2 have inlet, outlet, and interior deep zones, which together comprise roughly 20% of their surface area.

Hayfield Site
The Hayfield Site is located on what was once an agricultural field. This site consists of two kidney-shaped Wetland cells whose flow-paths are oriented from west to east, and again have identical surface areas. The site is situated on a level terrace above the Salt River floodway and would be subject to inundation by flows in excess of a 100 year return interval flood. Located along the south side of the site is an established riparian corridor which has mature stands of Cottonwoods, Willows, Elderberry and numerous other deciduous trees and shrubs.

The two Hayfield basins each have approximately 20% of their surface area as open water deep zones. Both cells have inlet and outlet deep zones, but H1 has five narrow (top width approximately 30 ft (9 m)) interior deep zones, while H2 has only 2 (top width 75 ft (23 m)). Within the interior deep zones of H2, three waterfowl islands were constructed.

Each Hayfield Cell is approximately 3 acres (1.2 ha) in surface area (assumes a 1.0 ft (0.3 m) depth in emergent areas), and including the surrounding terrestrial improvements provides a total site area just under 7 acres (2.9 ha). Both Hayfield basins are approximately 750 ft (228 m) long and 200 ft (60 m) wide, which result in an aspect ratio of 3.8. The theoretical design hydraulic retention times for this site range from 2.0 to 20 days.

Hydraulic control over this site is slightly different than the Cobble in that the mode of operation can be either parallel or series. Flows entering the Hayfield are split between the two basins by means of 60° V-Notch Weirs housed within a three-way splitter box. An additional splitter box was added to this site at the east end, which allows effluent from H1 to be routed to the inlet splitter box and ultimately into H2 when the site is operated in the series mode. Flows leaving the Hayfield are combined underground and discharged into a pool / riffle system which conveys the flows into a riparian corridor along the north bank of the Salt River.

Water Quality and Operational Monitoring

In order to achieve some of the research objectives, monitoring plans and strategies were devised. The first such plan is termed Baseline Monitoring, and is critical for evaluating changes in water quality and documenting the wetland operating conditions. The 1998 Research Plan described baseline monitoring to consist of the volumetric measurement of inflow and outflow, as well as water depths near outlet of each basin. Water, plant, and sediment samples were also routinely collected at the inlet, outlet, and on occasion throughout the wetland basins. Adult mosquito and larval samples were collected at fixed locations throughout the wetland basins and surrounding areas. Appendix A contains maps that indicate the location of each wetland basins and corresponding sample collection points. The Cobble Site (CS) and Hayfield Site (HS) each contain two wetland basins in parallel, referred to as C1, C2, H1, and H2. C1 is an unlined basin. The Research Cells (RC) contains twelve individual basins (R1 – R12).

Water Quality and Operational Monitoring Goals

Numerous monitoring goals were developed for the research period 1998 – 2000 at the Demonstration Project. Data was collected on flow and depth (daily); pH, temperature, electrical conductivity, and dissolved oxygen (twice per week); and conventional water quality parameters (monthly), for inclusion in the Tres Rios database.

1. Use baseline monitoring data to assess wetland system treatment performance.
2. Use baseline monitoring data to assess the transferability of treatment performance for the design of southwest arid land treatment wetlands.
3. Development of reaction rate constants, K-values.

Hydraulics and Operational Data

Operational parameters such as flow rates in and out of basins and water depth were measured and used to develop water balances for each of the four, wetland demonstration basins. Evapotranspiration was estimated from data collected at an Arizona Meteorological Network Stations (Litchfield Park, AZ) and checked with Pan evaporation values obtained from statewide NOAA sites. Infiltration rates were solved for out of the water balance. Hydraulic loading rates and retentions times were calculated from the water balance and confirmed with tracer testing.

Operating Depths

The previous research phase utilized basin depths that ranged from 1.0 to 1.5 feet in the emergent areas. The original Research Plan indicated that a range of depths from 0.5 to 2.0 ft. would be tested in the Hayfield and Cobble Site wetland emergent areas. In the first phase, two operational depths were tested at the Hayfield Site Basins (1.0 and 1.5 ft), and one at the Cobble Site (1.0 ft). In the current phase, depths of up to 2.7 feet have been assessed.

During the 1998 – 2000 time period, emergent area depths in the Cobble Site ranged from 1.1 ft to a maximum of 3.2 feet (Table 1). Much of the operational data has been collected at a depth of approximately 2.5 ft for C1 and 1.5 ft for C2. In March 1998, the Cobble Site was taken out of service for approximately 7 months to facilitate reconfiguration activities to address vector issues and to increase the habitat value of the site. From a physical standpoint, this consisted of providing additional deep-zones in the north basin C1 and the addition of linear islands in the south basin C2. In both basins vegetation density was reduced and diversity increased. After the reconfiguration activities were completed, basin levels were operated at increased depths during 1999. The maximum emergent area depth recorded was 3.21 ft in basin C1. Basin C2 was operated from 1.5 to approximately 2 feet. During 2000, C1 was operated at close to 2.5 feet while C2 was usually closer to 1.3 to 1.5 feet in depth.

Table 1. Operational depth history for the Cobble Site Basins C1 & C2. Note that March through September 1998 both basins were out of service.

Month	Depth (ft)	Month	Depth	Month	Depth
Jan.1998	C1 = 1.25 C2 = 1.13	Jan.1999	C1 = 2.40 C2 = 1.64	Jan.2000	C1 = 2.52 C2 = 1.61
Feb. 1998	C1 = 1.28 C2 = 1.11	Feb. 1999	C1 = 2.67 C2 = 1.84	Feb. 2000	C1 = 2.44 C2 = 1.61
March 1998	C1 = BOS C2 = BOS	March 1999	C1 = 2.95 C2 = 2.01	March 2000	C1 = 1.80 C2 = 1.56
April 1998	C1 = BOS C2 = BOS	April 1999	C1 = 2.94 C2 = 2.28	April 2000	C1 = 1.75 C2 = 1.87
May 1998	C1 = BOS C2 = BOS	May 1999	C1 = 2.99 C2 = 1.94	May 2000	C1 = 2.23 C2 = 1.54
June 1998	C1 = BOS C2 = BOS	June 1999	C1 = 2.99 C2 = 2.11	June 2000	C1 = 2.38 C2 = 1.39
July 1998	C1 = BOS C2 = BOS	July 1999	C1 = 2.95 C2 = 2.16	July 2000	C1 = 2.53 C2 = 1.38
Aug. 1998	C1 = BOS C2 = BOS	Aug. 1999	C1 = 3.12 C2 = 2.26	Aug. 2000	C1 = 2.57 C2 = 1.40
Sept. 1998	C1 = BOS C2 = BOS	Sept. 1999	C1 = 3.18 C2 = 2.22	Sept. 2000	C1 = 2.60 C2 = 1.38
Oct. 1998	C1 = 2.32 C2 = 1.29	Oct. 1999	C1 = 3.21 C2 = 2.21	Oct. 2000	C1 = 2.61 C2 = 1.40
Nov. 1998	C1 = 2.11 C2 = 1.40	Nov. 1999	C1 = 2.79 C2 = 2.04	Nov. 2000	C1 = 2.68 C2 = 1.36
Dec. 1998	C1 = 1.99 C2 = 1.29	Dec. 1999	C1 = 2.69 C2 = 1.89	Dec. 2000	C1 = 2.71 C2 = 1.35

(BOS = Basin Out of Service)

Hayfield Site depths were shallower than those at the Cobble Site. For the majority of the time period, the emergent area depth was maintained below 2.0 feet except the north Hayfield basin H1 in January and September 1999 (2.35 ft and 2.02 ft respectively). The south Hayfield basin H2 was operated at 2.07 ft during September 1999. Monthly average emergent area depths for these two basins are shown in Table 2. During 1998, the Hayfield basins were operated at a depth of approximately 1.4 ft from January through May. During the summer months, the depths in both basins were increased to 1.6 – 1.8 ft. Basin H1 was dewatered during this time period (July and August 1998) to facilitate the removal of dead vegetation. Water level was then varied during the month of September 1998 to encourage regrowth of vegetation from root structures left after the dead vegetation was removed. By the end of October 1998, the depth in basin H1 was at approximately 1.0 feet while basin H2 was operated at 1.5 feet. During 1999, water levels in the Hayfield site ranged from zero, because of pump problems in March to 2.0 feet in September. The majority of the time in 1999, water levels at this site ranged between 1.5 and 1.9 feet.

During 2000, operational problems with the pump facilities and additional O&M challenges, e.g. herbivorous mammals, did not allow an average water depth to be calculated on several occasions. Those data that were recorded show that the basin depths were fluctuated between approximately 1.0 ft and 2.0 ft. O&M challenges included damage resulting from herbivorous mammals burrowing into containment dikes, damming and clogging outlet structures, etc.

Table 2. Operational depth history for the Hayfield Site Basins H1 & H2. For most the study period a 1.0 to 2.0 ft depth has been maintained in both basins. H1 basins was out of service July through September 1998 and H1 and H2 basins were out of service October 2000.

Month	Depth (ft)	Month	Depth	Month	Depth
Jan.1998	H1 = 1.36 H2 = 1.37	Jan.1999	H1 = 2.35 H2 = 1.57	Jan.2000	H1 = 1.61 H2 = 1.99
Feb. 1998	H1 = 1.39 H2 = 1.40	Feb. 1999	H1 = 1.50 H2 = 1.73	Feb. 2000	H1 = 1.56 H2 = 1.97
March 1998	H1 = 1.40 H2 = 1.41	March 1999	H1 = BOS H2 = 1.32	March 2000	H1 = 1.61 H2 = NR
April 1998	H1 = 1.42 H2 = 1.46	April 1999	H1 = 1.71 H2 = 1.57	April 2000	H1 = 1.26 H2 = NR
May 1998	H1 = 1.57 H2 = 1.48	May 1999	H1 = 1.76 H2 = 1.98	May 2000	H1 = NR H2 = 1.40
June 1998	H1 = 1.47 H2 = 1.84	June1999	H1 = 1.74 H2 = 1.64	June 2000	H1 = 1.11 H2 = 1.78
July 1998	H1 = BOS H2 = 1.80	July 1999	H1 = 1.86 H2 = 1.74	July 2000	H1 = 0.98 H2 = 1.34
Aug. 1998	H1 = BOS H2 = 1.61	Aug. 1999	H1 = 1.85 H2 = 1.90	Aug. 2000	H1 = 1.12 H2 = 1.58
Sept. 1998	H1 = BOS H2 = 1.48	Sept. 1999	H1 = 2.02 H2 = 2.07	Sept. 2000	H1 = NR H2 = NR
Oct. 1998	H1 = 1.05 H2 = 1.53	Oct. 1999	H1 = 1.70 H2 = 1.80	Oct. 2000	H1 = BOS H2 = BOS
Nov. 1998	H1 = 0.99 H2 = 1.89	Nov. 1999	H1 = 1.72 H2 = 1.76	Nov. 2000	H1 = 1.25 H2 = NR
Dec. 1998	H1 = 1.80 H2 = 1.68	Dec. 1999	H1 = 1.76 H2 = 1.88	Dec. 2000	H1 = 1.28 H2 = 1.19

(BOS = Basin Out of Service; NR = Not Recorded)

Hydraulic Loading Rate & Nominal Hydraulic Retention Time (HLR & nHRT)

Hydraulic loading rates (HLR) for the Tres Rios Demonstration Wetlands are based upon inlet flow rate, e.g.

HLR = (Inlet Flow Rate) / (Surface Area of Basin) [L/Time].

The nominal hydraulic loading rates (nHRT) is defined as,

nHRT = (Basin Volume)/(Inlet Flow Rate) [Time].

Cobble Site

During the 1998 to 2000 research phase Basin C1 received a range of HLR's from 0.4 ft/d to a maximum of 2.15 ft/d. During this time C1 and C2 were out of service for 7 months to facilitate reconfiguration activities. Prior to reconfiguration, C1 was supplied a 0.44 to 0.49 ft/d HLR. After configuration and to facilitate the refilling of C1 (unlined) the HLR was increased to over 2.0 ft/d. This rate was reduced to 0.87 ft/d in November and 0.6 ft/d in December 1998. During 1999, C1 received HLR's around 1.0 ft/d from January through August with a maximum of 1.65 ft/d during May 1999. During the fall of 1999, the HLR to C1 was gradually reduced to approximately 0.85 ft/d. In 2000, HLR's to C1 were less than or equal to 1.0 ft/d for January through May. This was increased to almost 2.0 ft/d in August and September, and subsequently reduced to 1.9 ft/d for the remainder of the year.

Basin C2 was operated such that for the majority of the time, the HLR was less than 1.0 ft/d. Because of the reconfiguration activities, HLR's are not available during March through July 1999. In January and February of that year, nominal flows were supplied to C2, 0.11 and 0.19 ft/d respectively. Again, to facilitate the refilling of the basins, the August 1998 HLR was the highest for the research period (1.17 ft/d). During October and November of 1998, the HLR to C2 was gradually reduced 0.17 ft/d in December. During 1999, the water delivery to basin C2 was managed such that peak HLR's (Approximately 1.0 ft/d) occurred during peak mosquito breeding seasons (April, August, September, and October). The spring and fall time periods were characterized by lower HLR's that ranged from 0.47 to 0.93 ft/d. This pattern of water delivery was mimicked in 2000 with a maximum HLR of approximately 1.0 ft/d occurring during the same months. A complete listing of monthly average HLR for the Cobble Site Basins are supplied in Appendix B, while nominal hydraulic retention times (nHRT) corresponding to these loading rates are presented in Table 3.

Table 3. Monthly average nominal hydraulic retention times for the Cobble Site Operations, January 1998 through December 2000.

Month	nHRT (d)	Month	nHRT (d)	Month	nHRT (d)
Jan.1998	C1 = 2.79 C2 = NR	Jan.1999	C1 = 2.05 C2 = 3.19	Jan.2000	C1 = 3.12 C2 = 3.26
Feb. 1998	C1 = 2.75 C2 = NR	Feb. 1999	C1 = 2.31 C2 = 3.89	Feb. 2000	C1 = BOS C2 = 3.15
March 1998	C1 = BOS C2 = BOS	March 1999	C1 = 2.30 C2 = 2.75	March 2000	C1 = 4.20 C2 = 3.24
April 1998	C1 = BOS C2 = BOS	April 1999	C1 = 3.19 C2 = 2.38	April 2000	C1 = 2.52 C2 = 2.05
May 1998	C1 = BOS C2 = BOS	May 1999	C1 = 1.81 C2 = 2.80	May 2000	C1 = 2.14 C2 = 1.45
June 1998	C1 = BOS C2 = BOS	June 1999	C1 = 2.89 C2 = 3.46	June 2000	C1 = 1.63 C2 = 2.14
July 1998	C1 = BOS C2 = BOS	July 1999	C1 = 3.09 C2 = 3.03	July 2000	C1 = 1.53 C2 = 1.76
Aug. 1998	C1 = BOS C2 = NR	Aug. 1999	C1 = 2.69 C2 = 2.52	Aug. 2000	C1 = 1.33 C2 = 1.97
Sept. 1998	C1 = NR C2 = NR	Sept. 1999	C1 = 2.42 C2 = 2.12	Sept. 2000	C1 = 1.36 C2 = 1.26
Oct. 1998	C1 = 0.75 C2 = 2.86	Oct. 1999	C1 = 2.61 C2 = 2.28	Oct. 2000	C1 = 1.46 C2 = 1.69
Nov. 1998	C1 = 2.35 C2 = 4.96	Nov. 1999	C1 = 3.61 C2 = 3.18	Nov. 2000	C1 = 1.49 C2 = 1.60
Dec. 1998	C1 = 3.18 C2 = 6.56	Dec. 1999	C1 = 3.13 C2 = 3.44	Dec. 2000	C1 = 1.51 C2 = 1.56

(BOS = Basin Out of Service; NR = Not Recorded)

The loading rates applied to the Hayfield basins are more typical of constructed treatment wetlands than those of the Cobble Site due in part to the less permeable soils and hence less water loss to infiltration at this site. For the period of record, the Hayfield site has been operated at HLR's between 0.1 and 0.8 ft/d. As was the case with the Cobble site, HLR's were slightly increased during the summer months and when mosquito breeding was thought to be the highest. In contrast to the Cobble site, the maximum HLR's were less than 0.6 ft/d. Graphical and tabular forms of this information are available in Appendix B, while the corresponding operational monthly average theoretical (nominal) HRT (nHRT) corresponding to these loading rates are presented in Table 4. The nHRT is defined as the available wetland volume divided by the flow rate. The available wetland volume takes into account the volume occupied by plant material by using a porosity term. The literature suggests a range of wetland porosity values from 0.65 to 1.0. For the purposes of this report, porosity was assumed to be equal to 1.0. In many cases the flow rate used is either the inlet rate or an average of the inlet and outlet flow rates. For this report, the inlet flow rate was used to reduce the impact of losses and inaccuracies of reading the outlet weirs. The Hayfield basins were both taken out of service in October 2000, and pump problems in March 1999 resulted in nHRT of 12.24 days for H2 while no data was recorded for H1.

Table 4. Monthly average nominal hydraulic retention times (nHRT) for the Hayfield Site Operations, January 1998 – December 2000.

Month	nHRT (d)	Month	nHRT (d)	Month	nHRT (d)
Jan.1998	H1 = 2.79 H2 = 2.67	Jan.1999	H1 = 4.19 H2 = 2.83	Jan.2000	H1 = 3.17 H2 = 3.73
Feb. 1998	H1 = 2.83 H2 = 2.72	Feb. 1999	H1 = 9.91 H2 = 3.23	Feb. 2000	H1 = 3.32 H2 = 5.69
March 1998	H1 = 2.86 H2 = 2.75	March 1999	H1 = BOS H2 = 12.24	March 2000	H1 = 3.02 H2 = NR
April 1998	H1 = 2.91 H2 = 2.86	April 1999	H1 = 3.92 H2 = 4.99	April 2000	H1 = 3.55 H2 = NR
May 1998	H1 = 3.17 H2 = 2.86	May 1999	H1 = 13.16 H2 = 6.23	May 2000	H1 = NR H2 = 6.26
June 1998	H1 = 5.54 H2 = 2.24	June 1999	H1 = 3.3 H2 = 4.99	June 2000	H1 = 3.31 H2 = 1.94
July 1998	H1 = BOS H2 = 2.21	July 1999	H1 = 4.25 H2 = 3.56	July 2000	H1 = 9.32 H2 = 3.51
Aug. 1998	H1 = BOS H2 = 2.66	Aug. 1999	H1 = 3.52 H2 = 3.43	Aug. 2000	H1 = 10.37 H2 = 6.14
Sept. 1998	H1 = BOS H2 = 2.74	Sept. 1999	H1 = 3.95 H2 = 3.86	Sept. 2000	H1 = NR H2 = NR
Oct. 1998	H1 = 5.60 H2 = 2.90	Oct. 1999	H1 = 4.35 H2 = 4.37	Oct. 2000	H1 = BOS H2 = BOS
Nov. 1998	H1 = 7.66 H2 = 3.63	Nov. 1999	H1 = 3.52 H2 = 3.40	Nov. 2000	H1 = 4.21 H2 = NR
Dec. 1998	H1 = 4.58 H2 = 3.23	Dec. 1999	H1 = 3.76 H2 = 3.82	Dec. 2000	H1 = 4.31 H2 = 3.19

(BOS = Basin Out of Service; NR = Not Recorded)

Evapotranspiration (Et) Losses

Evapotranspiration was not measured at the site, rather an approximation was obtained from the Arizona Meteorological Network (AZMET) weather station located 1 mile North of McDowell Rd. on Cotton Lane in Litchfield Park, Arizona. AZMET provides reference evapotranspiration values (Et_o) which are determined using a weather-based model known as the Penman Equation. Et_o can be converted to "actual" evapotranspiration (Et) using a multiplicative factor know as a "crop-coefficient" (K_c). Because the wetlands are continuously saturated, the assumption that $K_c = 1.0$ is used.

Since Et is estimated from off-site, the rates are applied equally to all basins subject to the amount of surface area each basin possesses. Tables 5 and 6 indicate the percentage lost to Et. Note that the Et rates vary with both year and basin. This likely attributable to the different vegetative coverage and densities found in the different basins over time.

Infiltration Losses

Infiltration losses are solved for from the water balance. At the Hayfield Site Basins, infiltration losses have been reasonably stable since startup with the exception of H1 in 1998 and both H1 and H2 in 2000. This site is characterized by fine sediments deposited during flood events of the Salt River. For the study period (1998 – 2000) the average infiltration loss from Basin H1 = 0.08 ft/d, while Basin H2 = 0.11 ft/d. These rates are similar to those recorded in the previous data summary for 1995 – 1997 as is the rate calculated for the lined Cobble Basin C2 = 0.14 ft/d. The other Cobble Basin (C1), located within the Salt River Floodway and constructed on well-draining sand, gravel, and cobble has behaved differently. For this study period, C1 has lost an average of 0.5 ft/d to subsurface flow. At maximum infiltration rates, this represents almost 75% of the incoming wastewater and for the data period 1998 – 2000, an average of almost 44%. The annual average breakdown of water losses, as a percent of the influent flow, is provided in Tables 5 for the Hayfield site and in Table 6 for the Cobble Site.

Table 5. Hydraulic losses (% of Influent) from the Hayfield Site Basins For the years 1998, 1999, and 2000. Note, the Et data are obtained from AZMET and their Litchfield Park, AZ weather-station, while infiltration is estimated from the water balance.

Year	Basin	Surface Discharge	ET	Infiltration	Sum
1998	H1	94%	4.8%	2.9%	101.7%
1999	H1	69%	5.4%	16.4%	90.8%
2000	H1	47%	4.7%	48.1%	99.8%
1998	H2	85%	2.9%	15.3%	103.2%
1999	H2	53%	4.0%	25.8%	82.8%
2000	H2	36%	8.1%	56.1%	100.2%

Table 6. Hydraulic losses (% of Influent) from the Cobble Site Basins For the years 1998, 1999, and 2000. Note, the Et data are obtained from AZMET and their Litchfield Park, AZ weather-station, while infiltration is estimated from the water balance.

Year	Basin	Surface Discharge	ET	Infiltration	Sum
1998*	C1	2%	0.5%	14.8%	17.3%
1999	C1	25%	1.8%	50.2%	77.0%
2000	C1	47%	2.4%	50.7%	100.1%
1998*	C2	10%	1.9%	2.7%	14.6%
1999	C2	51%	3.2%	28.0%	82.2%
2000	C2	70%	1.4%	27.9%	99.3%

*Note: 1998 was a reconstruction year for the Cobble Site Basins.

One will notice that Hayfield basins have a better water balance closure than do the Cobble Site basins, as evidenced by the sum of losses equaling less than 100% of the incoming flow. Such a lack of balance indicates that the wetlands were not operated hydraulically at steady state during significant portions of those years. Given the possible errors associated with calculating the infiltration losses, a sum between 90% and 110% likely reflects a pretty good balance. Lack of a 100% balance is likely attributable to several factors including reconstruction of the Cobble site basins, inconsistent delivery of water due to problems with the pump gallery, and construction activities at the 91st Avenue WWTP that occurred periodically throughout the 1998-2000 research plan. In addition, lack of 100% closure of the water balances could be the result of inaccurate outlet measurements, e.g. misreading the weir staff gage or taking a reading during filling or draining. It was also discovered that at times, inlet flows at the pump station were changed before readings were taken at the basin outlets. Additionally, errors can be introduced into the water balance because Et is estimated and then a rate developed based upon the wetted surface area of a given basin. If this rate or basin areas are incorrect, it can influence the water balance, and result in the findings presented in Tables 5 and 6.

Of interest is the increase in infiltration rates recorded at the Hayfield Site, H2 is now losing as much as 56% to infiltration. Because of the reconfiguration activities at the Cobble Site, infiltration rates were expected to increase. In essence, the construction activities disrupted the clogging layer that had formed in the unlined Cobble basin C1, and the soil liner in C2. This would readily explain the increased infiltration rate in C2. However, no such activities occurred at the Hayfield site with the exception of dead vegetation removal in the Hayfield basin H1. During that activity, the wetland soils were dried, but only minimally disturbed. A possible explanation may be that the beaver activity in H2 has compromised the integrity of the basin. Another possibility is that the beaver-proof outlets installed at the Hayfield site basins influence the outlet weir measurements.

Field Monitoring

Goals and Results

Field measurements of temperature, pH, dissolved oxygen, and electrical conductivity were collected to evaluate the conditions within the wetland system. According to the 1998 Research Plan goals, twice weekly field measurements focus primarily on physical parameters and are made with field instruments calibrated daily. An earnest attempt is made to complete these measurements within the first 2 - 4 hours after sunrise at each inlet (splitter box) and outlet for all Wetland cells.

Inlet and outlet monitoring of water quality parameters and sampling for water quality constituents was conducted at two frequencies. For the first two years, monitoring of the field parameters (temperature, pH, electrical conductivity, and dissolved oxygen) was conducted on a daily basis thereafter they were measured twice a week. The sampling frequency was reduced since daily readings had not varied since startup to a degree that justified the additional monitoring effort.

Temperature

Temperature measurements are made at the inlet and outlet of each Demonstration Basin (C1, C2, H1, H2, CS, and HS). These measurements are recorded approximately 4 inches below the water surface with a Hanna pH/Temperature meter. Data presented in this report have been reduced to monthly averages, when more than one reading per month was available, for the time period January 1998 through December 2000. For the Demonstration Project period of record, maximum water temperatures have been recorded at the inlet structures to both sites, CS Inlet Max. = 32.9 ^{o}C, and HS Inlet Max. = 32.7 ^{o}C, which reflects the thermal character of the conventionally treated wastewater used. Minimum temperatures at these two points are CS Inlet 21.6^{o}C and HS Inlet 22.0^{o}C. After conventional treatment, wastewater temperatures tended to drop due to heat transfer with the underlying soils, evaporation, evapotranspiration, and shading in the treatment wetlands. Table 7 provides the average, maximum, and minimum difference in water temperature between the inlet and outlet structures for the 1998 – 2000 time period.

Table 7. Temperature difference (°C) between wetland inlet and outlets for the Tres Rios Demonstration Basins. The dates maximum and minimum differences occurred are provided in ( ).

Statistic	Basin C1	Basin C2	Basin H1	Basin H2	HS EFF
Average	5.9	7.6	8.2	7.3	6.5
Maximum Difference	12.6 *(12/99)*	14.1 *(12/99)*	16.0 *(11/98)*	14.5 *(12/99)*	14.2 *(12/99)*
Minimum Difference	0.4*(5/99)*	2.7 *(5/99)*	1.3 *(5/99)*	-0.4 *(7/99)*	1.5 *(7/99)*

The overall average temperature difference between wetland inlets and outlets is approximately 6-8 °C, with Basin C1 having the least amount of difference at 5.9°C, and Basin H1 having the greatest at 8.2 °C. These basins showed the same trend in the initial phase of investigation (1995 through 1997). The maximum inlet/outlet differences in temperature occurred in December 1999 for basins C2, H1, and H2, while the H1 maximum temperature difference occurred in November 1998. Minimum temperature differences occurred during May 1999 for C1, C2, and H1. An increase in temperature was actually found in H2 during July 1999. As a side note, the HS EFF results are based upon data collected from January 1998 through January 2000 because after this time, sampling at this point was discontinued.

Maximum temperature differences appear to occur during the winter months (high temperature effluent from Plant 3A, subsequent cooling in wetland), while the minimum temperature difference occurs during the summer. In fact, temperature differences between inlet and outlet are related to the time of year and maybe to the amount of vegetative cover (at least during vegetation startup). As can be seen in Table 7, the minimum temperature difference occurred during May 1999 when the vegetation was regrowing from the previous year's reconfiguration efforts and normal winter senescence that shaded the water surface. There are several factors that potentially cause this maximum temperature difference in May. As the macrophytes established themselves, the physical presence of the vegetation reduced near surface wind velocity, and shaded the water surface. In addition, vigorous plant growth during the early summer may have contributed to increased evapotranspiration, which in turn acted in a manner similar to an evaporative cooler and further depressed water column temperatures.

On an annual basis, all flows (inlet and outlet) from all demonstration wetland basins exhibited a temporal pattern. At the Cobble Site inlet, maximum water temperatures occurred in September 2000, while minimum water temperatures occurred in February 1998. Cobble Site outlet temperatures were maximum during July 1999, while minimum temperatures were recorded in January 1998 (C1 and C2) and February 1998 (C1). Monthly maximum temperatures at the Hayfield Site Inlet occurred in August 1998, while minimum water temperatures occurred in February 1998. Hayfield Site outlet temperatures were maximum during July 1999, while minimum temperatures were recorded in January 1998 (H2) and January 1999 (H1). These data are presented in Tabular and Graphical form in Appendix C.

pH

Measurements of pH were obtained at the Inlet and Outlets of all Demonstration Basins. These measurements are typically conducted in moving water approximately 4 inches below the surface. Data presented in this report represent the averages obtained for all data collected in each month during the research plan time period.

After 24 months of operation the Cobble and Hayfield Site monthly average inlet and outlet pH values were found to be all circumneutral (~ pH of 6.5 to 7.5), this was also the case for the period 1998 to 2000. The highest pH values (< 8.7) obtained for both sites occurred during February of 1999. At this time, emergent and floating aquatic vegetation had not filled-in and shaded the basins. As a result, algae production was high which could have easily caused alkaline pH measurements to be obtained.
Algae utilize carbon from carbon dioxide for growth and development producing oxygen as a byproduct. The use of carbon dioxide alters the carbonate equilibrium and reduces the amount of carbonic acid while increasing the amount of carbonate present in the system. Since carbonate is the natural pH buffer of the system, algal respiration during daylight hours typically causes high pH values. Table 8 gives a summary of the monthly average, and extreme pH values for both the Cobble and Hayfield Site wetlands. A value of 1.97 was recorded for C2 EFF in February 2000; this value was eliminated from the analysis as unlikely and unrepresentative of system operations.

Table 8. Average, Maximum, and Minimum monthly-average pH values for inlet and outlet flows at the Tres Rios Demonstration Basins. Months where extremes occurred are in ( ).

Statistic	CS Inlet	C1	C2	HS Inlet	H1	H2
Average	6.91	7.24	7.18	6.89	7.38	7.23
Maximum	7.17 *(12/00)*	8.40 *(6/99)*	8.67 *(2/99)*	7.26 (2/99)	8.54 *(2/99)*	7.65 *(7/00)*
Minimum	6.34 *(9/99)*	6.73 *(9/00)*	6.69 (5/00)	6.09 (3/00)	6.77 *(9/99)*	6.86 *(12/99)*

A complete listing of monthly inlet and outlet pH average values is provided in Appendix C, as are long-term average and raw data plots covering the time period from January 1, 1998 through December 31, 2000.

Dissolved Oxygen

Dissolved oxygen (D.O.) measurements are typically obtained in the first 1 to 3 hours after sunrise. As such, the values recorded may be biased low, due to the diurnal D.O. sag experienced during the night. These measurements were all made with an YSI D.O. meter in moving water approximately 4 inches below the surface.

Table 9 provides the average, maximum, and minimum of all 36 average monthly D.O. values. Upon inspection one sees that the high (supersaturated) D.O. levels (> 11 mg/L) were recorded at C1 EFF, C2 EFF, and H1 EFF. Inlet maximum D.O. levels were 6 mg/L or less for both Cobble and Hayfield sites. HS outlet, the combined discharge point of the Hayfield Site, has the highest average monthly D.O. level of 6 mg/L. This higher average D.O. is likely attributable to the elevation difference and turbulent flow regime which tends to entrains air into the water column and increase the area for gas exchange between the atmosphere and the water that exists between the wetland outlets (H1 & H2 EFF) and the combined measurement point, HS EFF (approx. 15 ft.).

Table 9. Summary of the average D.O. readings obtained at the inlets and outlets of the Cobble and Hayfield Site Wetlands. Months where extremes occurred are denoted in ( ).

Statistic	CS Inlet	C1 EFF	C2 EFF	HS Inlet	H1 EFF	H2 EFF	HS EFF
Average	3.3	4.2	3.4	2.7	2.8	2.8	6.0
Maximum	6.0 *(6/00)*	11.4 *(6/00)*	11.6 *(1/99-2/99)*	4.5 *(3/00-4/00)*	11.0 *(4/99)*	8.9 *(7/99)*	9.8 *(12/98)*
Minimum	1.9 *(10/00)*	0.7 *(10/00)*	0.2 *(7/96)*	1.3 *(5/99)*	0.3 *(9/99)*	0.6 *(7/98)*	4.1 *(7/98)*

As with the temperature extremes, the D.O. follows a temporal pattern. In general, the highest wetland effluent D.O. values are recorded in December and January, while the lowest appear to occur during the summer months. This is likely attributable to higher summer water temperatures that reduce the solubility of oxygen and increase aerobic biological activity In general the rate of biological activity doubles with every 10°C increase in temperature.

When inspecting plots of the monthly average inlet and outlet dissolved oxygen (see Appendix C), the seasonal trends can be seen as well as the impacts of dead and living vegetation. From January through July 1998 the Hayfield dissolved oxygen levels appear to be decreasing from just over 2.0 mg/l to < 0.5 mg/L. During this period, both Hayfield wetland basins had significant amounts of standing and lodged dead vegetation and detritus, which in turn exerted an oxygen demand on the system. In July 1998, the north Hayfield Basin H1 was dewatered and the "dead" vegetation removed by means of pushing with a backhoe. Water was reintroduced into H1 in late August and whatever viable root structures left, were allowed to regrow. This resulted in less than 50% vegetative cover on the basin and allowed an algal dominated system to develop. By December 1998, D.O. levels in H1 were consistently greater than 5 mg/L. The next spring (1999), the basin was still very open and one sees maximum D.O. levels for that basin. The standing dead vegetation in Basin H2 was not removed, rather it was allowed to persist and decay by "natural" processes. Although the D.O. levels in H2 did follow the same seasonal pattern as that of H1, the magnitude was much less, typically < 5.0 mg/l and was probably a function of the decaying organics exerting an oxygen demand.

A similar pattern can be seen at the Cobble site. In this case, both basins were completely dewatered and the majority of the vegetation removed. Dewatering began at this site in March 1998, but data was collected in January and February of that year. Because both basins were essentially covered with dead macrophytes little sunlight penetrated the water column and hence algal growth could not be supported. This produced typical D.O. levels in the range of 2 to 4 mg/L for that time of year. After the drying and subsequent revegetation activities the vegetated cover was approximately 27% in C1 and in C2, 54 %. Interestingly, the basin with more vegetative cover, C2, demonstrated a higher D.O. level than C1 in the spring of 1999. The reason for this anomaly is likely the location of the plant cover with respect to the outlets where D.O. measurements are made. In C2, the last emergent zone was left devoid of vegetation with the exception of isolated bulrush clumps. This allowed a fairly robust algal bloom to develop immediately upstream of the D.O. measurement point and probably contributed to the high readings obtained in January through March of 1999 (> 11.0 mg/L) for C2. Conversely, the north Cobble Basin C1 had a fairly extensive cover of Hydrocotyle (Pennywort) over the last 1/3 of the basin. This cover likely reduced algal growth in the downstream portion of the basin, which in turn produced lower D.O. levels. These trends can be readily seen in the plots of the raw D.O. data included in Appendix C.

Conductivity

Conductivity measurements are obtained from the inlet and outlets of the Demonstration basins at the time the other physical parameters are measured. A summary of monthly average conductivity measurements are provided in Table 10.

Table 10. Long-Term Average, maximum, and minimum Conductivity measurements (υS/cm) for the inlet and outlets at the Hayfield and Cobble Site Demonstration Wetlands. The time-period includes January 1998 through December 2000 and the months in which extremes occurred are denoted in ( ).

Statistic	CS Inlet	C1 EFF	C2 EFF	HS Inlet	H1 EFF	H2 EFF
Average	1564	1552	1532	1507	1528	1510
Maximum	1966 *(11/00)*	1929 *(11/00)*	1894 *(11/00)*	1970 *(11/00)*	2076 *(7/00)*	1852 *(7/00)*
Minimum	1237 *(2/99)*	1259 *(2/98)*	1226 *(2/99)*	1242 *(2/99)*	1216 *(4/98)*	1226 *(4/98)*

Monthly average conductivity at the inlets is only slightly less than the outlets, while the maximum difference is at the Hayfield site where H1 EFF is 21 υS/cm higher than the inlet. In all cases, the increase should be expected due to the evaporative concentration of anions and cations. Maximum monthly average conductivity measurements at both inlets and outlets occurred in July and November 2000. Minimum conductivity was recorded during February and April.

Tabular summaries and graphical displays of these data are located in Appendix C. Plots of conductivity for the Cobble and Hayfield sites each show a similar pattern, one which depicts a gradual increase in the summer months due to concentration of salts via evapotranspiration from the wetland basins. Inspection of these plots also indicates a gradual increasing trend in conductivity throughout time for both the source and wetland treated water. This trend may be the result of increased water reuse in the contributing area. In short, many of the communities that currently supply wastewater flows to the 91st Avenue WWTP have constructed reclamation plants where some of the water receives partial treatment and is reused within the community. The remaining wastewater has a higher concentration of salts, and is sent to 91st Avenue for treatment.

Diurnal Variation in Temperature, pH, D.O. and Conductivity

Diurnal monitoring was conducted in 2000 by US Bureau of Reclamation researchers using a YSI instrument, outfitted with various probes to assess what if any patterns could be discerned between daylight and nighttime for the Demonstration Basins of the Hayfield and Cobble Sites. The parameters measured included: Temperature, pH, D.O., Conductivity, TDS, Oxidation Reduction Potential (ORP), and turbidity. Measurements were obtained every two hours during the following time periods:

<u>Cobble Basins</u>	<u>Hayfield Basins</u>
C1: 5/8/2000 12:01pm – 6/5/2000 8:01 am	H1: 2/14/2000 12:01 pm – 3/14/2000 12:01 pm
C2: 2/23/2000 12:01pm – 4/28/2000 8:01 am	H1: 6/22/2000 12:01 pm – 7/25/2000 8:01 am

Goals and Results

In general it is easier to see a diurnal trend in the Cobble Site data. It could be that since this site is less densely vegetated and more exposed than the Hayfield, that the forces that bring about diurnal fluctuations (temperature, solar radiation, wind) are also more pronounced. A series of plots are located at the end of Appendix C which present these data for both the Hayfield and Cobble Site Wetlands.

To summarize, most all parameters showed a diurnal fluctuation. For instance, water column temperatures fluctuated between 5 and 15 °F within each day. The pH showed only a slight variation throughout the day, remaining in the neutral range around 7. However, in June-July pH values in the Hayfield site ranged between 8 and 10 that were likely due to algal dynamics. Conductivity values showed little variation, within each day and study period as did TDS. In the Cobble site, ORP was positive, while in the Hayfield basin H1, exhibited negative potentials during the June/July endeavor. Spikes in turbidity were recorded during each deployment.

The most significant fluctuations occurred with the D.O. measurements that varied significantly throughout the course of each day. Peak daily values were as high as 300 % of saturation levels and ranged from 0 to 30 mg/L within the same day. This large daily fluctuation is a clear indication of effects of algae and the excellent capacity of wetland systems to provide both anoxic and aerobic treatment.

Some indication of fouling of the YSI probes was apparent for nitrate as it recorded values up to 100 times higher than the effluent source water. As such those data were not included in this report. In addition, the dissolved oxygen probe during the June-July Hayfield deployment recorded negative D.O. values that were not included in this report.

Water Quality Monitoring

Goals and Methods
Water quality sampling and analysis were performed monthly to evaluate treatment performance and to assess trends with respect to seasonality, system maturity, and operation conditions. Further the development of a long-term data set is necessary to demonstrate the transferability of results of the Demonstration Project to the full scale Tres Rios facilities and other treatment wetlands in the arid southwest.
Inlet and outlet monitoring of water quality parameters and sampling for water quality constituents was conducted at different frequencies. Water quality samples for nutrient, oxygen demand, and chemical parameters were collected weekly for the first two years, and monthly thereafter. Gradient sampling for the above parameters and constituents was conducted in the Hayfield site from the onset of the project through Spring 2000, while gradient sampling of the Cobble Site basins occurred on a monthly basis beginning in January 1999 and continued through the winter of 2000.

Parameters of Interest
Water quality performance is based upon the sampling and analysis of the following wastewater constituents:

Alkalinity	PO_4-P
TSS	Total-P
TDS	COD
Cl^-	cBOD
TKN	NH_4-N
NO_2+ NO_3-N	TOC

Sample Collection
From January 1998 to December 2000, the above parameters were to be sampled once per month to represent the overall monthly water quality exiting a given wetland basin. Water quality samples were collected as "grabs" upstream of both the inlet and outlet weirs, approximately 4 to 6" below the water surface between the hours of 6am and 12pm.

Water Quality sampling at the inlets and outlets were scheduled to occur every month in all four of the Demonstration Wetland Basins during the 1998 – 2000 time period. Over the course of the study period circumstances prevented that from actually occurring. In particular, the dewatering and reconfiguration activities that took place in 1998 reduced the number of sample events in both Cobble basins and H1. In addition, revegetation efforts, periodic problems associated with the source water pumps, and construction activities at the conventional treatment works caused some sampling events to be missed. Table 11 provides a summary of the inlet/outlet sampling that took place during the 1998 – 2000 study period.

Water Quality Assessment Results

Cobble Site Inlet/Outlet Constituent Concentrations

Alkalinity

Alkalinity has varied between 125 and 200 mg/L since startup. A slight increase is noted during the winter months and may be due to slower rates of nitrification and other biologically mediated reactions that occur in wetland systems. Alkalinity is not a conservative element in wetlands in that it is consumed along with D.O. during nitrification. Conversely, during denitrification, alkalinity can be introduced into the system in the form of $HC0_3^-$. Algal dynamics and their influence on the carbonate equilibrium of the system can also influence alkalinity levels.

On a monthly basis, outlet alkalinity averaged equal or slightly higher than the inlet. For the three year period, average inlet alkalinity was 173.8 mg/L, while the outlet alkalinity averaged C1 = 173.8 and C2 = 179.8 mg/L. The difference between maximum and minimum monthly average alkalinity was reasonably constant at the C1 EFF and C2 EFF (approx. 42 and 54 mg/L respectively), while the Cobble Site Inlet exhibited a larger difference, 71 mg/L. Table 14 shows a summary of these data. A full data set is located in Appendix D-1 to D-5, and plot of the results is contained in Appendix D-6.

Table 14. Cobble Site long-term average and extreme Alkalinity (mg/L) results for the period beginning in January 1998. Months where extremes occurred are denoted in ( ).

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	173.8	173.8	179.8
Maximum	198.0 *(2/99)*	195.0 *(2/99)*	202.0 *(2/99)*
Minimum	127.0 *(11/99)*	153.0 *(11/99)*	148.0 *(11/99)*

Total Suspended Solids (TSS)

Monthly TSS concentrations at the Cobble Site basins have, for the most part been below 15 mg/L with the exception of one month for each the Inlet, C1, and C2. In January 2000 a maximum value of 62 mg/L was detected for the Inlet sample. The maximum values in the effluent occurred during the month of May 2000 at the outlet to C1 (TSS = 16 mg/L) and October 2000 at the outlet of C2 (TSS = 40 mg/L). A minimum value of 1.0 mg/L occurred at all sampling locations during August 1999. Table 15 shows the summary data, while tables and plots of the monthly values are located in Appendix D-1 to D-5 and Appendix D-7. This is in contrast to the performance in previous years and is likely a function of the reduced vegetative cover and increased algal dynamics of the 1998 – 2000 study period.

Table 15. Cobble Site long-term average TSS values (mg/L) for the period January 1998 through December 2000 with months extremes occurred in ( ).

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	6.9	5.9	6.4
Maximum	62.0 *(1/00)*	16.0 *(5/00)*	40.0 *(10/00)*
Minimum	1.0 *(8/99)*	1.0 *(8/99)*	1.0 *(4/99, 8/99 - 11/99)*

Total Dissolved Solids (TDS)

Cobble site Inlet, C1 EFF and C2 EFF TDS concentrations show a wide range from lows below 800 mg/L in February 1999 to highs above 1000 mg/L. This variation was also evident in the influent concentrations. Overall, the changes in TDS from inlet to outlet TDS were minimal (< 1 %). In most cases, contributors to TDS are conservative and one would expect changes from inlet to outlet as a result of evaporative concentration. Table 16 provides summary statistics of the eighteen TDS values collected at the inlet and outlets of the Cobble Site, while a complete data set is presented in Appendix D-1 to D-5. D-8 contains a plot of the Cobble Site TDS.

Table 16. Cobble Site long-term average TDS values (mg/L) for the period January 1998 through December 2000. Month(s) extremes occurred in are provided in ().

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	920.2	924.2	923.5
Maximum	1050.0 *(6/99)*	1040.0 *(6/99)*	1090.0 *(8/99)*
Minimum	756.0 *(2/99)*	734.0 *(2/99)*	760.0 *(2/99)*

Chloride (Cl^-)

Wetland effluent Chloride values at the Cobble Site have closely tracked the inlet concentration. An expected increase of this conservative element due to evaporation is present and is denoted by an average increase in concentration of < 2 % in C1. C2 data reflected a loss of < - 2 % of influent chloride, which may be attributed to inaccuracies in the water balance for that basin or in the analytical methods used.

A general increase in Cl^- during the summer months can be seen in plot located in Appendix D-9. Summary statistics of the monthly Cl^- values at the Cobble site are shown in Table 17.

Table 17. Cobble Site long-term average Cl- (mg/L) for the period January 1998 through December 2000. Month(s) extremes occurred are in ().

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	254.3	258.4	250.1
Maximum	320.0 *(5/00)*	328.0 *(5/00)*	300.0 *(9/99)*
Minimum	153.0 *(2/99)*	160.0 *(2/99)*	125.0 *(2/99)*

Total Kjeldahl Nitrogen (TKN: Organic-N + NH_4-N)

Average TKN concentrations for the period January 1998 to December 2000 were < 5 mg/L, with the exception of C1 EFF February 1999 (TKN = 7.8 mg/L). In more than half of the sampling events, the inlet concentration was higher in TKN than both outlets (see plot in Appendix D-10). Table 18 provides summary statistics for the data collected

Carbonaceous Biological Oxygen Demand (cBOD)

For the 18 months monitoring was conducted, Cobble Site wetland effluent cBOD levels have been at the detection limit of 2.0 mg/L on 11 and 12 (for C1 and C2 respectively) events. Disregarding the C1 outlet value of 10 mg/L reported in June of 1999 as unrepresentative of system performance, the inlet and outlet cBOD values are less than or equal to 5 mg/L (see plot in Appendix D-17). Long-Term monthly averages for the CS Inlet = 2.3 mg/L, while C1 EFF = 2.4 mg/l and C2 EFF = 2.5 mg/L (Table 23). It is thought that as the system matured, the wetland would begin to produce a higher internal BOD load, but evidence for this does not yet exist and may be a function of the high HLR's administered to this site.

Table 23. Cobble Site long-term average cBOD values and summary statistics for the data period January 1998 through December 2000. Note that the detection level was 2.0 mg/L. The months maximum and minimum cBOD concentrations occurred are shown in ().

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	2.3	2.4	2.5
Maximum	4.0 *(2/99)*	4.0 *(5/00)*	5.0 *(4/99)*
Minimum	1.0 *(1/99,6/99, 7/99 -11/99, 1/0 – 12/00)*	2.0 *(2/99, 5/99,7/99-11/99,1/00, 10/00- 12/00)*	2.0 *(5/99 - 12/99, 9/00 – 12/00)*

Chemical Oxygen Demand (COD)

The chemical oxygen demand of waters entering and exiting the Cobble Site wetlands has been fairly constant with a couple of notable exceptions that occurred in C1. In April 1999 and June 1999, effluent from C1 had a COD of > or = to 60 mg/L. (See plot Appendix D-18). Otherwise, COD values at this site have been close to 35 mg/L. Table 24 presents the average monthly value as well as minimum and maximum.

Table 24. Cobble Site long-term average monthly COD values (mg/L) and extremes for the data period January 1998 through December 2000. Maximum and minimum months are shown in ( ).

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	34.1	34.8	35.8
Maximum	51.0 *(2/00)*	63.0 *(4/99)*	52.0 *(10/00)*
Minimum	10.0 *(10/00)*	13.0 *(10/00)*	21.0 *(9/00)*

Phosphorous (Total-P and PO_4-P)

Phosphorous, both total and ortho-P do not change much in character or concentration from inlet to outlet in both Cobble Site basins C1 and C2. Tables 25 and 26 will demonstrate this trend, as well as, the plots located in Appendix D-19 and D-20.

Table 25. Cobble Site long-term average monthly Total-P (mg/L) summary statistics for the 1998 – 2000 study period. Months where maximum and minimums occurred are shown in ().

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	2.7	2.7	2.8
Maximum	4.0 *(2/99, 6/99, 9/99)*	4.0 *(1/99, 2/99, 10/99)*	4.0 *(6/99, 9/99, 10/99)*
Minimum	1.1 *(12/00)*	0.8 *(12/00)*	0.8 *(12/00)*

Table 26. Cobble Site long-term average monthly PO_4-P (mg/L) concentrations and summary statistics for January 1998 through December 2000. Months where extremes occurred are provided in ().

Statistic	CS Inlet	C1 EFF	C2 EFF
Average	2.4	2.2	2.2
Maximum	3.4 *(2/99)*	3.6 *(1/99)*	3.1 *(10/98)*
Minimum	1.2 *(10/98)*	1.0 *(6/99)*	1.1 *(9/98)*

Hayfield Site Inlet/Outlet Constituent Concentrations

Alkalinity

Alkalinity in the Hayfield Site effluents and inlet flow has varied between 120 and 220 mg/L since startup, with the wetland discharges (H1 EFF and H2 EFF) showing a increase over inlet concentration, with the exception of August 2000. As mentioned above, alkalinity is not a conservative parameter in wetlands so the change is expected. Data shown in Table 27 indicates that the long-term average of the wetland discharges is approximately 10 to 15 mg/L higher than the inlet. Monthly water quality data is contained in Appendix E-1 to E-5, and a plot of monthly Alkalinity is contained in Appendix E-6.

Table 27. Hayfield Site long-term average monthly Alkalinity (mg/L) and summary statistics during the data period January 1998 through December 2000.

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	172.1	187.1	181.7
Maximum	199.0 *(11/00)*	209.0 *(12/99)*	202.0 *(12/99)*
Minimum	129.0 *(11/99)*	157.0 *(11/99)*	141.0 *(11/99)*

Total Suspended Solids (TSS)

Overall TSS levels have increased significantly during the period January 1998 to December 2000, similar to, but more dramatic than at the Cobble site. This is likely a function of algal dynamics but it is also influenced by the activity of beavers, muskrats, and waterfowl disturbing/re-suspending sediments from the wetland bottom (See plot in Appendix E-7). Initial monthly average effluent TSS values for both H1 and H2 were less than 15 mg/L. These levels increase to 79 mg/L and 60 mg/L for H1 and H2 over time and correspond with less vegetative cover and increased mammal activity. In addition, water levels have been fluctuated at this site from moist soils to > 1.5 feet to accommodate planting efforts which may have also increased the TSS concentrations in the water column. The long-term monthly average shows a gain in TSS between inlet and outlets of about 10 mg/L in H1 and 20 mg/L in H2 (Table 28).

Table 28. Hayfield Site long-term average TSS values and statistics (mg/L) for the period January 1998 through December 20000. Monthly maximum and minimum dates are provided in ( ).

Statistic	HS Inlet	H1	H2
Average	3.8	13.3	21.3
Maximum	18.0 *(5/99)*	79.0 *(8/00)*	60.0 *(11/00)*
Minimum	1.0 *(1/98)*	1.0 *(1/98)*	9.0 *(6/99, 8/99)*

Total Dissolved Solids (TDS)

As shown on a plot of Hayfield Site TDS in Appendix E-8, the concentration between inlet and outlets do not differ greatly. However, the curves diverge during the summer months due to evaporative concentration, with the inlet having less TDS than the outlet discharges. In an overall sense TDS has been increasing in both the source water and wetland discharges for the reasons previously discussed. Table 29 shows that the maximum TDS concentration recorded at all sample points occurred in August 2000, while minimum values occurred in November and December of 1999.

Table 29. Hayfield Site long-term average TDS statistics (mg/L) for the period January 1998 to December 2000. The month(s) that extreme values occurred are provided in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	931.5	958.5	951.1
Maximum	1150.0 *(8/00)*	1230.0 *(8/00)*	1150.0 *(8/00)*
Minimum	806.0 *(11/99)*	822.8 *(12/99)*	824.0 *(11/99, 12/99)*

Chloride (Cl^-)

Plots of Chloride show almost a sinusoidal pattern with maximums occurring during the summer and minima occurring during the winter months (Appendix E-9). Slight increases in Chloride concentration are very likely a result of evaporative loss of water, as Cl^- is typically considered a conservative constituent. A look at the percent increase of the Cl^- in the outlets versus the inlets shows that H1 has a 2.3 % change. This is a little higher than that observed at the Cobble site and a possible explanation may be that since the Hayfield Site basins lose less water to infiltration and the effect of evapotranspiration is higher, hence the concentration of a conservative element is more notable.

The value of 41 mg/L obtained for H2 outlet on May 25, 2000 was eliminated from the analysis as unrepresentative for the time period and conditions. Considering the inlet value was 319 mg/L and chloride was found to be fairly conservative in the Cobble and Hayfield Sites throughout the remainder of the study period. On a long-term monthly average basis, the Hayfield basins show an insignificant increase in Cl^- over the inlet of < 5 mg/L. Maximum Cl^- values occur at the same time the TDS did, August 2000 (Table 30).

Table 30. Hayfield Site long-term monthly Cl^- summary for the period January 1998 through December 2000. The times maximum or minimum values were obtained are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	249.0	254.6	247.1
Maximum	362.0 *(8/00)*	410.0 *(8/00)*	364.0 *(8/00)*
Minimum	158.0 *(2/98)*	167.0 *(4/98)*	160.0 (2/98)

Total Kjeldahl Nitrogen (TKN: Organic-N + NH_4-N)

During phase one and in 1998, TKN concentrations leaving the Hayfield Site wetlands were typically below that of the inlet. However in 1999 and 2000 this trend was not continued (Plot in Appendix E-10). Inlet and outlet concentrations varied without an obvious pattern. Again, this is likely attributable to the export of algal cells in which much of the nitrogen is likely bound in its organic form. Overall for the three year of monitoring, average wetland effluent TKN reflects a gradual decrease from average inlet concentration, see Table 31.

Table 31. Hayfield Site TKN long-term average and summary statistics for the data period January 1998 through December 2000. Months exhibiting extremes are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	3.1	2.8	2.4
Maximum	7.7 *(6/98)*	5.8 *(6/98)*	4.2 *(6/98)*
Minimum	0.9 *(11/99)*	0.8 *(1/98)*	0.6 *(8/98)*

Nitrite Plus Nitrate Nitrogen (NO_2+NO_3-N)

The inorganic forms of nitrogen, NO_2+NO_3-N have varied in the inlet and outlet streams of the Hayfield site from non-detectable to > 5 mg/L (See plots in Appendix E-11 to E-13). In all cases outlet concentrations were less than or equal to inlet values. Over this research phase, the average wetland effluents have been approximately 1.6 to 2.0 mg/L less than the inlet, H2 and H1 respectively. Maximum NO_2+NO_3-N concentrations from the wetland basins occurred during the winter months (1/99, 11/00), and are probably a function of the reduced biological activity. Minimum concentrations are noted during the spring and summer months (Table 32).

Table 32. Hayfield Site NO_2+NO_3-N long-term average concentration and summary statistics (mg/L) for the data period January 1998 through December 2000. Times when maximum or minimum values occurred are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	3.0	1.0	1.4
Maximum	5.5 *(6/99)*	3.2 *(11/00)*	4.4 *(1/99)*
Minimum	1.1 *(6/98)*	0.2*(4/98-6/98, 5/99, 7/99-9/99, 8/00)*	0.2 *(5/98-7/98, 5/99)*

Ammonia-N (NH_4-N)

Ammonia nitrogen has been transformed or removed in the Hayfield Wetland basins during the study period from January 1998 through December 2000 (See Plot in Appendix E). The highest outlet ammonia concentrations were observed in December 1999 and could be related to source water ammonia inlet increases and/or plant biomass from winter senescence may have been actively decomposing, thereby releasing ammonia nitrogen.

On average, effluent ammonia concentrations from the Hayfield wetlands have been 20 percent lower than the average inlet NH_4-N concentration. Maximum wetland NH_4-N effluent concentrations in both H1 and H2 occurred during December 1999 (Table 33).

Table 33. Hayfield Site NH_4-N long-term monthly average and statistics (mg/L) for the data period January 1998 through December 2000. Months in which maximum and minimum concentrations were observed are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	1.6	1.3	1.1
Maximum	4.9 *(6/98)*	4.0 *(12/99)*	3.4 *(12/99)*
Minimum	0.2 *(11/99)*	0.1 *(1/98)*	0.1 *(1/98, 2/98)*

Total Nitrogen (Total-N: Organic-N + NO_2+NO_3-N + NH_4-N)

Total nitrogen concentrations at the Hayfield site reflect the trends shown in the individual nitrogen species (Appendix E-15). One can see the increase in effluent Total-N during the winter of 1998/1999. Lastly, Total Nitrogen at the wetland basins has averaged 3.9 and 3.8 mg/L for H1 EFF and H2 EFF respectively (Table 34).

Table 34. Hayfield Site Total Nitrogen (mg/L) long-term monthly average and summary statistics for the data period January 1998 through December 2000. Months in which extremes occur are provided in ( ).

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	6.1	3.9	3.8
Maximum	10.6 *(11/00)*	7.6 *(12/98)*	8.1 *(1/99)*
Minimum	3.1 *(3/98)*	1.6 *(3/98)*	0.9 *(8/98)*

Total Organic Carbon (TOC)

Inlet and outlet TOC concentrations were similar during the majority of the testing. H1 outlet values were noticeable greater than inlet during May to August 2000 (Plot Appendix E-16). In most cases, TOC in the wetland effluent has been equal or less than 10 mg/L. As can be seen in Table 35, the long-term average TOC inlet and outlet concentrations differ by less than 0.5 mg/L, when an unrepresentative, high H2 EFF value (TOC = 367 mg/L on November 20, 2000) is excluded from the data set.

Table 35. Hayfield Site TOC (mg/L) long-term average and summary statistics for the data period January 1998 through December 2000. Months in which extremes occur are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	8.4	8.6	8.0
Maximum	10.0 *(1/99, 4/99, 2/00)*	15.6 *(8/00)*	11.0 *(4/99)*
Minimum	6.9 *(8/00)*	6.1 *(2/97)*	5.7 *(1/98)*

Carbonaceous Biological Oxygen Demand (cBOD)

As was the general case at the Cobble Site, wetland effluent cBOD concentrations have not changed much since the first research phase. Exceptions did occur in the Fall of 2000 with H1 = 18 mg/L (August 2000), H1 =10 mg/L and H2 = 7 mg/L (November 2000). Otherwise, cBOD from the Hayfield wetlands has been equal to or below 4.0 mg/L (See plot Appendix E-17). Summary statistics for the 1998 – 2000 study period are presented in Table 36. Spikes in the H1 effluent cBOD concentrations during August and October of 2000 are possibly the result of decomposing vegetation and suspended organic material. Decomposing wetland vegetation liberates carbohydrates and sugars which can be detected analytically as cBOD and or COD for that matter.

Table 36. Hayfield Site cBOD (mg/L) long-term average and statistic summary for the period January 1998 through December 2000. Months of maximum and minimum cBOD are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	2.3	3.6	3.0
Maximum	4 *(4/99)*	18.0 *(8/00)*	7.0 *(11/00)*
Minimum	2.0 *(1/98, 1/99, 6/99-10/99, 1/200-12/00)*	2.0 *(1/98, 1/99, 6/99-2/00,12/00)*	2.0 *(1/98, 1/99, 6/99, 10/99, 11/99,1/00, 8/00,12/00)*

Chemical Oxygen Demand (COD)

Chemical oxygen demand has in general been below 65 mg/L for both the inlet and outlets. A notable exception on the plot of Hayfield COD (Appendix E-18), occurred in Basin H1 during August 2000 (H1 = 100 mg/L COD). Otherwise, inlets and outlets have basically tracked one another. Inspection of Table 37 shows that the long-term average at the Hayfield inlet is only around 6.0 mg/L lower than the outlets. COD data showed a spike similar to cBOD in H1 effluent COD during August and October of 2000. As such, it is likely that the same phenomena are the cause, namely carbohydrates liberated from decaying vegetation and the export of algal cells.

Table 37. Hayfield Site COD (mg/L) long-term average and summary statistics for the period January 1998 through December 2000. Months with maximum and minimum values are provided in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	33.1	38.3	39.0
Maximum	58.0 *(11/00)*	100.0 *(8/00)*	63.0 *(4/99)*
Minimum	20.0 *(8/00)*	22.0 *(11/99)*	23.0 *(8/00)*

Phosphorous (Total-P and PO_4-P)

As was the case at the Cobble Site, the Hayfield Wetlands phosphorous compounds do not change appreciably in form or concentration from inlet to outlets. Tables 38 and 39 show this, as well as, the plots located in Appendix E-19 and E-20.

Table 38. Hayfield Site long-term average Total-P (mg/L) and summary statistics for January 1998 through December 2000. Months in which extremes occurred are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	2.9	3.3	3.4
Maximum	4.8 *(12/98)*	6.3 *(3/98)*	5.8 *(3/98)*
Minimum	1.2 *(12/00)*	0.8 *(11/00-12/00)*	0.7 *(12/00)*

Table 39. Hayfield Site long-term average PO_4-P (mg/L) and summary statistics for January 1998 through December 2000. Months in which extremes occurred are shown in ().

Statistic	HS Inlet	H1 EFF	H2 EFF
Average	2.3	2.1	2.0
Maximum	3.5 *(2/99)*	3.2 *(5/98)*	3.6 *(1/99)*
Minimum	1.1 *(4/99)*	1.2 *(1/99)*	1.0 *(5/99 –6/99)*

Mass Loading and Percent Removal

Hydraulic data was combined with inlet/outlet parameter concentrations to develop mass loadings going into and exiting the Demonstration Wetland basins. Because the inlet and outlet flow rates are used in combination with the concentrations to develop mass, the inaccuracies in the water balance are likely reflected in the following results. In an attempt to reduce that impact, data from the 1998 – 2000 study period were combined. Tables showing the mass loadings received by the individual basins are provided in Appendices D-28 and D-29 for the Cobble basins and E-28 and E-29 for the Hayfield basins. Overall basin mass removal efficiencies are summarized in Tables 40 - 43, shown below. Positive percentages indicate net removal, while negative percentages imply an increase in a given constituent.

Table 40 Hayfield and Cobble Site Average Inorganics Mass Removal (%) for the data period January 1998 to December 2000.

Basin	Alkalinity	TSS	TDS	Cl^-	Sulfate
C1	24.3 %	-82.8 %	24.7%	24.7 %	23.4 %
C2	57.9 %	9.0 %	59.3 %	60.0 %	50.3 %
H1	1.6 %	-355.9 %	8.4 %	5.1 %	4.8 %
H2	1.9 %	-367.4 %	26.9 %	16.9 %	-8.2 %

Inspection of Table 40 indicates a couple of interesting aspects. First, there is a large difference between the amount of alkalinity removed between the Cobble and Hayfield site basins. Second, the TSS values for 3 of the four basins indicate a net production of suspended solids, with the exception of Basin C2. It is thought that the increase in TSS during this period is due to algal dynamics fostered by the reduction in vegetative cover the basins underwent during reconfiguration activities. Finally, the Cl^- numbers show increases that do not reflect the evaporative concentration of this compound except for the Hayfield site basins. The large removals in the Cobble site are thought to be an artifact of the water balance inaccuracies.

Table 41 Hayfield and Cobble Site Average Nitrogen Species Mass Removal (%) for the data period January 1998
to December 2000.

Basin	NO_2+NO_3-N	NH_3-N	TKN	TN
C1	38.9 %	40.9 %	33.9 %	39.6 %
C2	80.3 %	65.2 %	63.8 %	74.5 %
H1	70.8 %	-8.8 %	2.2 %	41.0 %
H2	62.8 %	19.2 %	11.7 %	36.6 %

Table 41 provides mass removal estimates for the nitrogen species. In all cases, net removal is indicated with the exception of NH_3-N in basin H1. Overall, the nitrogen removal performance has not decreased as it was expected under the higher loading rates supplied to the wetlands during the 1998 – 2000 research phase. One would expect that under higher HRL's and hence lower HRT's, that removal efficiency would be reduced. This was not the case and really adds to the treatment wetland technology. In essence, it has been shown through these data that even lightly loaded wetlands systems can be operated at extreme HLR's and still obtain reasonable removal rates with respect to oxidized forms of nitrogen.

Table 42 Hayfield and Cobble Site Average Phosphorous and Total Organic Carbon Mass Removal (%) for the data period
January 1998 to December 2000.

Basin	PO_4-P	Diss. P	TOC
C1	59.1 %	20.8 %	25.6 %
C2	78.9 %	58.4 %	56.8 %
H1	16.8 %	-6.6 %	-0.8 %
H2	-17.0 %	7.4 %	-6.0 %

Table 42 indicates positive removal/reduction in mass of the phosphorous species in the Cobble site basins for the current study period. Dissolved Phosphorous increase in H1, while PO_4-P increased in basin H2. TOC was reduced in the Cobble sites as well, while TOC did not appear to be significantly reduced in the Hayfield site wetland effluents.

Table 43 Hayfield and Cobble Site Average Oxygen Demanding Substances Mass Removal (%) for the data period January 1998 to December 2000.

Basin	cBOD	COD
C1	6.7 %	19.6 %
C2	55.1 %	52.9 %
H1	-68.3 %	-16.3 %
H2	15.2 %	8.9 %

Table 43 shows a range of mass removals of the oxygen demanding substances. In the Cobble site, up to 55% of the cBOD and 53% of the COD were removed in basin C2. H1 on the other hand showed a net increase of mass for these parameters very possibly a result of the significant amount of vegetation decomposition that took place in that basin.

Bacteria Monitoring Results

Bacterial levels were monitored in the source water and wetland discharges between January 1998 and December 2000. Samples were obtained on the same day and in the same manner as the conventional parameters just presented. Analysis is conducted on-site at the 91st Ave. WWTP process laboratory using the 51-Well Quanti-Tray method for determining the most probable number (mnp) of Total Coliform and *E. coli* bacteria present. Please note that the bacteria concentrations presented herein are typically on the conservative side, which can be attributed to the dilutions used during enumeration. Often times the dilution was insufficient to produce a real number, instead a ">" value was presented. For those instances where this has occurred, the number associated with the ">" has been used for calculation purposes. An example is the maximum number of Total Coliforms exiting both C1 and C2 as shown in Table 44. These numbers were presented by the analyst as > 242,000 and > 20,050 respectively in the raw data, but for calculation purposes; 242,000 and 20,050 were used.

Review of the study period plots of bacterial concentrations located in Appendix F, show that at the Cobble site, bacteria levels greatly increased during the Fall and Winter of 2000. At the Hayfield site bacterial levels were much lower and only showed a notable increase in December 2000.

Of particular interest in Tables 44 and 45 is the fact that average Total Coliform bacteria are highest in Basins C1 and H2. As it happens, these basins are the closest, at each site, to mature riparian vegetation stands, and it is thought that wildlife from these areas impacts the bacterial quality of the wetlands. On average *E. coli* bacteria was higher in C2 and H1. When one compares these results to those obtained during the 1995 – 1997 study period another interesting aspect is revealed. At the Cobble site, there was a large increase in Total coliform bacteria in C1, but a reduction occurred in C2 during 1998 - 2000. At the Hayfield site, both H1 and H2 show a decrease over that found in previous years. All four basins had reduced E. coli levels in 1998 – 2000 when compared to the 1995 – 1997 time period. This is possible due to more bird activity during start-up which was limited in 1998 and 2000 due to reconfiguration activities. After the reconfiguration, most basins were also more exposed to sunlight and were subjected to the algal dynamics previously discussed. The higher D.O. and pH conditions brought about by the algal communities may have also produced conditions that were lethal (high pH and High D.O.) to some of the bacterial species present in the wetlands or supplied to them via the source water.

Table 44. Summary of Total Coliform and E. coli (mpn/100 mL) values for the Tres Rios Demonstration Wetlands Cobble Site for the period January 1998 through December 2000.

Statistic	CS Inlet	C1 EFF	C2 EFF
	Total Coliform Bacteria	Total Coliform Bacteria	Total Coliform Bacteria
Average	96	69,678	48,476
Maximum	276 *(12/00)*	242,000 *(10,00)*	120,330 *(8/99)*
Minimum	0 *(11/99)*	2419 *(1-2/99, 5/99)*	1203 *(2/99)*
	E. coli Bacteria	E. coli Bacteria	E. coli Bacteria
Average	12	163	2071
Maximum	91 *(8/99)*	690 *(9/00)*	17,329 *(8/99)*
Minimum	0 *(1-2/99, 11/99,1/00)*	11 *(2/99)*	0 *(2/99)*

Table 45. Summary of Total Coliform and E. coli (mpn/100 mL) values for the Tres Rios Demonstration Wetlands Hayfield Site for the period January 1998 through December 2000.

Statistic	HS Inlet	H1 EFF	H2 EFF
	Total Coliform Bacteria	Total Coliform Bacteria	Total Coliform Bacteria
Average	9305	6707	15,442
Maximum	46,100 *(12/00)*	16,200 *(12/00)*	50,400 *(8/98)*
Minimum	4 *(8/98)*	2419 *(1/99)*	2419 *(1/99)*
	E. coli Bacteria	E. coli Bacteria	E. coli Bacteria
Average	117	805	565
Maximum	579 *(12/00)*	1990 *(12/00)*	1000 *(8/98)*
Minimum	0 *(1/98, 8/98)*	74 *(1/99)*	88 *(11/00)*

Biomonitoring Goals and Results

Biomonitoring samples were typically collected three times a year during the period January 1998 to December 2000. Sampling consists of collecting Four-Liter aliquots at the inlet to each Tres Rios Demonstration site, HS Inlet or CS Inlet, which are used to represent the 91st Avenue WWTP Plant 3A effluent. At roughly the same time, 4-L samples are obtained at the wetland effluent sample points, H1, H2, C1, or C2 discharge structures. Only one Demonstration Site inlet and one Demonstration Basin outlet are sampled in any one month.

Toxicity Testing

Toxicity evaluation procedures used are those specified in the 91st Avenue WWTP's National Pollutant Discharge Elimination System permit; "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms" (EPA/600/489/001, USEPA EMSL, Cincinnati, Ohio, March 1989 and its supplement EPA/600/489/001a), and the update (EPA/600/491/002, USEPA ORD, Cincinnati, Ohio, July, 1994). The specific test performed is the Chronic Static-Renewal 7-day survival and reproduction test using *Ceriodaphnia dubia*.

End points used to describe organism survival and reproduction is defined as follows:

- **LC_{50} or EC_{50}** - Value represents a point estimate of the effluent concentration that would adversely affect 50% of the test organisms.
- **No Observable Effect Concentration (NOEC)** - The highest concentration of effluent to which organisms were exposed which caused no statistically significant adverse effect on the observed parameters (e.g. survival, growth, or reproduction).
- **Lowest Observable Effect Concentration (LOEC)** - The lowest concentration of effluent to which organisms were exposed which caused a statistically significant adverse effect on the observed parameters (e.g. survival, growth, or reproduction).
- **Inhibition Concentration (IC)** - The point estimate of the effluent concentration that causes a given percent reduction in the reproduction or growth of the test organisms.

Performance Assessment

During the 1998 – 2000 time period, the wetland discharges have been tested 9 times and have exhibited no chronic or acute toxicity (See Appendix G-1). The number of young produced in each dilution was also tracked. Table 46 provides summary statistics for the number of young produced in 100% wetland effluent, while Appendix G-2 and G-3 contains plots of this information and a comparison between the Wetland effluents and the Plant 3A source water. Briefly, the number of young produced in 100% dilutions from both the plant and wetlands are very similar. Out of 9 months, Plant 3A had more young produced in the 100% dilution 3 times and the wetlands had more young produced in the 100% dilution 6 times. This trend is almost identical to that of previous years. In fact, the only toxic responses indicated for the entire period of record (1995 – 2000) occurred as a result of a malathion fogging application for mosquito control which occurred during the October 1996 biomonitoring testing.

Table 46. Tres Rios Biomonitoring Summary statistics for the number of young produced in 100% wetland effluent. Data period is January 1998 through December 2000. NA = Not Applicable

Statistic	Value	Basin	Date	Laboratory
Average	296	NA	NA	NA
Maximum	347	H1	April 1998	City of Phoenix
Minimum	165	C2	May 1999	City of Phoenix

Tracer Testing Goals and Results

Tracer testing conducted at the Hayfield Riparian site is designed to assess differences in hydraulic retention time (HRT) and mixing characteristics with respect to the configuration of open-water deep zones within a constructed treatment wetland. This information is then being used with water quality measurements obtained along the wetland gradient(s) to explore possible uptake and release as a function of time spent within each wetland zone and to ultimately define the time and hence area required to achieve desired nutrient removals and organic transformations in such systems receiving nitrified municipal effluent. Further, the impact of vegetation density, basin configuration and degree infiltration are also being explored.

The Tres Rios Demonstration Sites used for this set of tracer testing included the Hayfield Riparian Wetland Basins H1 and the Cobble Site basins C1 and C2. Hayfield basin H1 is approximately 3 acres in wetted surface area, with 20% of the total as open water deep-zones. Basin H1 has 20% open water configured into 5 narrow, (top-width = 30 ft) sinusoidal deep-zones placed perpendicular to the main flow path and spaced at roughly 88 ft intervals. The Cobble Site basins are each approximately 2.2 acres in wetted surface area. Basin C1 is unlined and has almost 50% deep water, while C2 is lined and has roughly 20% of its surface area as deep-zone. Further basin C2 has approximately 0.3 acres of islands located in the emergent zone areas. Remaining basin morphology is presented in Table 47.

Basin volumes for tracer analysis were developed using the basin parameters given in Table 47 as a guide, and USBR aerial survey data to define discrete areas (individual deep and emergent zones), and individual zone depths obtained by level survey. Results of this endeavor are provided in Table 48.

Table 47. Tres Rios Demonstration Site Basin Geometry.

Parameter	H1	C1&2
Length	228 m (748 ft)	275 m (748 ft)
Width	60 m (200 ft)	35 m (115 ft)
Aspect Ratios	3.8:1	7.9:1
Exterior Berm Top-Width	3.7 m (12 ft)	3.7 m (12 ft)
Ext. Berm Side-Slope	3:1	3:1
Elev. Gradient Inlet to Outlet	0.15 m (0.5 ft)	0.15 m (0.5 ft)
Basin Slope	0.0007 ft/ft	0.0007 ft/ft
Inlet Deep-Zone Top-Width	8.5 m (28 ft)	10.6 m (35 ft)
Interior Deep-Zone Top-Width	9 m (30 ft)	9 m (30 ft) & 25 m (85 ft)
Deep-Zone Spacing	27 m (88 ft)	55 m (180 ft)
Deep-Zone Depth	1 m (3.3 ft) below cell floor	1 m (3.3 ft) below cell floor
Deep-Zone Side-Slope	3:1	3:1

Table 48. Wetland Basin Volumes.

Basin	Emergent Area Depth	Volume	USBR Model Flight Date
H1	1.0 ft (0.3 m)	6,838.4 m^3	4/8/96
C1	1.5 ft (0.46 m)	6,724.0 m^3	1/00
C2	1.5 ft (0.46 m)	4,780.9 m^3	1/00

Tracer Testing Methods

The tracer chosen for these tests was Br-, which was obtained in the form of regent grade NaBr. Br- was chosen because of low background levels (0.2 - 0.3 mg/L), and the ease with which it can be analyzed for in aqueous solutions.

The amount of tracer used for each test was based upon achieving a peak concentration of 10 mg/L, assuming the basins behaved as a CFSTR. For tracer testing basins H1 and C2, approximately 100.0 kg of NaBr was used which resulted in 71.2 kg of Br^- being added to each inlet. Because of increased losses in the unlined basin C1, 125.0 kg of NaBr was used which resulted in an addition of Br- equal to 89.0 kg.

Tracer was added to the basins by means of a slug-impulse. To accomplish this, the pre-measured NaBr was dissolved in two large plastic containers using approximately 265 L (70 gallons) of plant reuse water (Secondary-Advanced treated wastewater used as process water within the WWTP). After complete dissolution, achieved by mixing each container for approximately 30 minutes, the Br^- solution was dumped immediately downstream of the Basin's inlet weir. This condition allowed for vigorous mixing of the tracer with incoming wastewater prior to entering the inlet deep-zone of the basin undergoing testing.

Just prior to the slug addition of tracer, an automatic sampler was set at the outlet of the Basin being tested. The sampler used for this study was an ISCO Model 3700 configured to take 24 discrete hourly samples and place them into plastic containers. The duration of testing basins H1 and C2 was 11 days while the test in C1 continued for 6 days which corresponds to 3.0 and 6.0 times the nominal detention time (V/Q) for each of the basins, respectively. During the test period, each afternoon individual samples were placed into 250 mL plastic containers and stored at 4°C until shipment under chain of custody to the City of Phoenix Compliance Laboratory.

Samples all three tests were submitted to the City of Phoenix Compliance Laboratory for analysis. The method employed was EPA 300.0, Ion Chromatography.

Inlet flows for each basin were recorded at the Hayfield Site inlet splitter box. This structure houses 60o V-Notch weir which serve as a primary measurement device. Flows exiting the basins were measured with similar V-Notch weirs. Both inlet and outlet measurements were obtained each morning for the duration of each test.

Tracer Concept

The model framework as proposed by Kadlec is a tanks-in-series (TIS) concept which accounts for the water mass balance effects due to losses from evapotranspiration and infiltration, and gains from precipitation. Using both the water and tracer mass balance equations, moment equations can be derived which are equivalent to those presented in the literature which do not account for the water mass balance effects.

Using linear operator theory (LaPlace Transforms), the results as developed by Kadlec are:

$$M_{o,N} = \int_0^{\infty} Q_o\, C_N(t)dt = W/Q_o \sum_{j=1}^{N} a_j \qquad (1)$$

$$M_{1,N} / M_{o,N} = 1/ M_{o,N} \int_0^{\infty} tC_N(t)dt = \tau \qquad (2)$$

$$M_{2c,N} / M_{o,N} = 1/ M_{o,N} \int_0^{\infty} (t-\tau)^2 C_N(t)dt = \sigma^2 = \tau^2 \sum_{j=1}^{N} \tau_j^2 \qquad (3)$$

where,

$M_{n,N}$ = the n^{th} moment of the exit concentration distribution.
$C_N(t)$ = the exit tracer concentration as a function of time (t).
W = total mass of tracer recovered.
Q_o = inlet flow rate.
a_j = water mass balance correction for gains and losses to the system.
N = total number of units in the TIS model.
τ = mean tracer detention time.
τ_j = individual unit detention time.
∞ = infinity.

For tracer testing, the first three moments are of interest. $M_{o,N}$ is a measure of the tracer recovered, $M_{1,N}$ is a measure of the detention time, and $M_{2c,N}$ is a measure of the number of units (The number of units refers to the number of well mixed tanks necessary to model the system using the plug flow assumption). Equation (1) shows that the area under the exit concentration curve is not always equal to the amount of tracer added divided by the inlet flow, rather it is scaled upward if there is evaporative losses, or downward if there is rainfall. Equation (2) indicates that the mean tracer detention time (τ) is the ratio of $M_{1,N} / M_{0,N}$, which is the same result if there were not significant losses or gains from the system under investigation. Equation (3) provides a means for determining the appropriate number of units for the TIS model. Given the measures of σ^2 and τ from the experimental data, a dimensionless variance may be calculated as,

$$\sigma^2_\theta = \sigma^2/\tau^2 = \sum_{j=1}^{N} \tau_j^2 \qquad (4)$$

Basin Tracer Retention Time

In 1999, three tracer tests were completed at the Cobble Site C1 and C2 and at Hayfield Site H1 under the following operating conditions shown in Table 49.

Table 49. Tracer Test Operating Conditions.

Test	Emergent Area Depth	HLR (cm/d)	Duration (days)
H1D	1.0 ft	15	11
C1A	1.5 ft	25	13
C2A	1.5 ft	15	13

For all tests, reagent grade NaBr was dissolved in approximately 227 (60 gal.) of source water by stirring with paddles for a minimum of 30 minutes. The NaBr solution was then added immediately downstream of the inlet weir structure. Total time for the slug addition was less than 5 minutes. The exit concentration curve was obtained by sampling 1-Liter of wetland effluent every hour for the test duration, which was defined as 3 times the nominal hydraulic retention time (V/Q_{inlet}).

Samples were then analyzed for Br- using Ion Chromatography (IC). Recovery of tracer for the 1999 tracer tests ranged from a low of 24% to a high of 91.4%. Table 50, provides a summary of these tracer recoveries.

Table 50. Tracer Recovery.

Test	% Br- Recovery	Test Duration	Analytical Method
H1D	91.4	Jun. 22 – Jul. 3, 1999	IC
C1A	24.2	Jun. 24 – Jul. 6, 1999	IC
C2A	83.9	Jun. 24 – Jul. 6, 1999	IC

Mixing Characterization and Hydraulic Performance

The tracer exit concentration curves are shown in Appendix I-3 to I-5, for all three tests, while the Tanks In Series numerical analysis of the moments is provided in Table 51.

Table 51. Summary of the moment analyses for the 1999 tracer testing conducted at the Hayfield and Cobble sites.

Parameter	H1D	C1A	C2A
Nominal τ (V/Q)(d)	3.56	4.7	3.34
Moment τ_α (M_1/M_0) (d)	3.89	4.01	2.43
As-Built τ_0 (d)	3.56	2.95	3.34
Inferred τ_0 (d)	3.48	2.38	1.84
Dispersion Number D	0.12	0.15	0.22
No. of Tanks N	5	4	3
No. of Deep-Zones	5	3	3
Depth (ft)	1	1.5	1.5

These results indicated similar trends to the results of previous tracer testing. Results indicated a correlation between the number of tanks in series and the number of deep zones. Short circuiting in C2 was apparent and is likely a function of the linear islands placed in 1998.

Subsurface Investigation Goals and Results

Background

City of Phoenix staff assisted in the collection of subsurface samples, but the majority of the analytical work and interpretation of these data was conducted by researchers at Arizona State University (ASU). The principal researcher for this project was Dr. Peter Fox who was assisted by Shaila N. Nahar, an ASU graduate student in the Department of Civil and Environmental Engineering. The following summary was adapted from a paper written by the two aforementioned ASU researchers and co-authored by Roland Wass of the City of Phoenix.

Very few studies have examined the impact of infiltration through wetland sediments on water quality. Concerns over potential contamination of groundwater have resulted in the requirement of liners for most wetlands at considerable costs. In a "leaky" wetland, a significant vertical gradient provides greater contact between the water and wetlands sediments, thereby, changing the flux of nutrients and other contaminants into the sediments. This study was intended to examine water quality changes as a function of depth below a "leaky" wetland system. The "leaky" wetland will provide treatment with mechanisms that occur during wetlands treatment and treatment as water percolates through the vadose zone similar to Soil Aquifer Treatment.

Sampling Plan

A total of 22 monitoring devices including 18 geo-probes and 4 shallow wells were installed at the unlined cobble basin C1 with the assistance of United States Geological Survey staff from Boulder, CO. Geo-probes, in order to obtain samples directly below the wetlands, were installed in three well clusters. These well clusters were located in the first vegetative zone near the inlet, the center vegetative zone and the vegetative zone near the outlet. Six geo-probes were installed at depths ranging from 0 to 21 feet at each cluster of wells. The approximate depths of the well heads at the West (Effluent) Cluster are 0, 1, 5, 10, 15 and 20 feet and these wells are addressed as CE0, CE1, CE5 etc. (according to depth). The depths of the well heads of the Center Cluster and East (Influent) Cluster are approximately 0, 1, 5, 11, 15.5 and 19.5 feet and 0, 1, 5, 10, 15 and 21 feet, respectively. Similarly the center cluster wells and the west cluster wells are addressed as CM0, CM1 etc. and CW0, CW1 etc. respectively (according to depth). In addition, four shallow groundwater-monitoring wells were installed in July 1997 around the perimeter of the wetlands located North, South, East, and West of the C1 wetland basin. These wells are addressed as SWN, SWS, SWE and SWW respectively (See Figure 1 in Appendix J, which presents an aerial photograph of the site with approximate well locations.). The four shallow groundwater-monitoring wells are approximately 20 feet deep and screened the entire depth except for the top 5 feet. Groundwater was encountered between 15 and 20 feet below ground surface at each well site during installation.

Samples to illustrate a depth profile at three different locations below the wetlands were taken as described in Table 1 in Appendix J. Table 1 in Appendix J also includes the average infiltration rate at the time of sampling. Therefore, each depth profile represents infiltrating water that was pre-treated for different times in the wetland prior to infiltration. Preliminary testing of the wells demonstrated that saturated conditions existed directly below the wetlands and unsaturated conditions develop at a depth of approximately 1-foot. Saturated conditions redevelop at a depth of approximately 15 feet and the groundwater level was approximately 12 feet.

All 18 wells located below the wetlands were tested and 12 of the wells were sampled during the first three sampling trips. No samples could be obtained at depths of 5, 10 or 11 feet from any of the well clusters indicating that unsaturated conditions existed at these depths. This was consistent with water depth measurements in the shallow monitoring wells. Gases pumped up from depths of 5 to 11 feet had a strong hydrogen sulfide odor indicating that anaerobic conditions were prevalent. Samples were easily obtained at 0 foot and at depths greater than 15 feet indicating saturated conditions at these depths. At a depth of 1 foot, a considerable amount of gas was pumped with the samples indicating that the conditions were slightly unsaturated. The gas had a strong hydrogen sulfide odor.

During the last two sampling trips in February 1998, samples were taken from 14 of the 18 monitoring wells located below the wetlands and during the last three sampling trips, samples from the four shallow monitoring wells were also taken. Samples were obtained from CE5 and CE10, which correspond to depths of 5 feet and 10 feet below the wetlands at the East (Inlet) end. Water depth in the shallow monitoring wells ranged from 7 to 10 feet below the ground surface, which represented a rise in the water table of several feet as compared to previous sampling events. The increase in water table might have created more saturated conditions in the wetlands at the time of sampling.

City of Phoenix personnel initiated regular measurement of water depth in the shallow monitoring wells during January of 1998. At the time of the February 6, 1998 sampling event, the water levels in SWS was 0.08 feet higher than the water level in SWN. The water level in SWE was 1.58 feet lower than that in SWS and the water level in SWW was 2.1 feet lower than the water level in SWS. The 91st Avenue Wastewater Treatment Plant effluent channel runs north of the Tres Rios Cobble Site. As mentioned previously, the channel is not lined and significant infiltration is expected. The regional gradient would be expected from the Southeast to the Northwest. Mounding from the infiltrating wetlands, infiltration from the effluent channel, drawdown from either irrigation pumping or de-watering activities might affect the local gradient (See Figure 1 in Appendix J).

All the samples were collected in 1-liter amber glass bottles after discharging four times the well volume to get a representative water sample. The samples were filtered through 0.45 um cellulose membrane filters by vacuum filtration as soon as possible. Then they were stored in the cold room before further analyses were made. Analysis of samples included ion chromatography for chloride (Cl^-), bromide (Br^-), nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}) and phosphate (PO_4^{3-}). In addition, dissolved organic carbon

(DOC) and ultraviolet absorbance (UVA254) were measured to characterize organic carbon.

The objective of this study was to determine changes in water quality with respect to horizontal flow through the wetland above ground and vertical flow through ground, and also to determine impacts of wetland treatment on vertical flow.

Dionex DX-500 Ion Chromatograph (IC) was used to measure anions. The Ion Chromatograph consists of a filter device (0.45 um), anion separator column, conductivity detector, and a data analysis system. The anion separator column is packed with low-capacity anion-exchange resin capable of resolving fluoride, chloride, nitrite, bromide, nitrate, orthophosphate and sulfate. Dissolved Organic Carbon (DOC) was measured using a Rosemount Dohrmann TOC analyzer (DC-180) combined with an autosampler. The UV-absorption at 254 nm was measured using a Hewlett-Packard 8452A Absorption Spectrophotometer and a 1-cm cell.

Results

Analysis and changes in water quality in samples from the East, Center and West Well Clusters

Several interesting trends have been observed from the analysis of the five data sets collected. These data are presented in Appendix J, Figures J-2 to J-4. One of the most striking trends was the sulfate concentration (See plot in Appendix J-2). The sulfate concentration tended to decrease as water flowed from the influent to the effluent. Conversely, the chloride concentration increased as expected from evaporation as water flowed over the surface (Appendix J-2). The changes in sulfate concentration with depth were dramatic at the center and effluent cluster with major decreases between 0 and 1 foot. During the first foot at the effluent cluster, the sulfate concentration decreased over 50% at certain locations. This decrease in sulfate concentration is probably due to sulfate reduction in the sediments. Decreases in chloride concentration are observed over the first foot of profile, however, it is much less when compared with large percent changes in sulfate concentrations. The trend of increasing sulfate reduction with distance through the wetlands might correspond to the decrease in nitrate concentrations (See Appendix J-3). The low nitrate concentrations in the center and the effluent clusters allow the redox potential to decrease and support increased sulfate reduction. Oxidation of sulfide to sulfate during percolation through the unsaturated zone might explain the increase in sulfate concentrations in the groundwater at 15 feet and deeper. A strong sulfide odor was present in most of the samples taken. When samples were taken from CE5 and CE10 on the fourth sampling event (2/6/98), the sulfate concentration continued to decrease from a depth of 1 to 5 feet and then began to increase at 10 feet. Variations in sulfate concentrations between 15 and 20 feet are probably the result of blending with groundwater combined with sulfide oxidation.

Chloride concentration depth profiles are also presented in Appendix J-2. The chloride concentration depth profiles almost all follow a similar trend with typically a 10% decrease in chloride concentration between the surface water and 1 foot below the water surface. A large decrease in chloride concentration over the first foot of depth is observed for the 10/27/97 sampling event. The wetland had been dried out until flow was initiated for several days prior to the 10/27/97 sampling event. The increase in chloride concentration with flow through the wetland was also significant. Generally, chloride concentrations increase from the inlet to the outlet from evaporation. The increase in chloride concentrations as depth increases to 15 feet or greater are likely from blending with groundwater. Chloride concentrations from the influent cluster on 2/6/98 were relatively constant from 0 to 15 feet in depth.

The nitrate concentration depth profiles are presented in Appendix J-3. Nitrate concentrations decrease with flow through the wetlands and nitrate concentrations immediately decrease to low levels (below detection levels for the first and fifth set of samples) at a depth of 1 foot. The reducing conditions in the sediments and abundance of organic material make conditions favorable for denitrification. For the 2/6/98 sampling plan, nitrate concentrations increase at depths of either 10 or 15 feet. These increases probably represent mixing from high nitrate groundwater infiltrating from the effluent channel to the north of the basin. Nitrate concentrations increase at the 10 feet level at the influent cluster and increase at the 15 feet level at the center cluster and then increase at the 20 feet level at the effluent cluster. Nitrate concentrations also decrease again at the 15 feet and below at the influent cluster. This appears to represent blending with a layer of high nitrate water that is being moved upward by groundwater rising from the east end of the wetland. However, the shallow monitoring well water depths are not consistent with this observation. The last set of samples shows the same trend as the first one.

The phosphate (soluble only) concentration depth profiles are also presented in Appendix J-3. Soluble phosphate tends to increase with surface flow from the influent to the center of the wetlands and then decrease with surface flow to the effluent. Soluble phosphate variations with depth appear to change during each sampling event. During the 9/19/97 sampling event, with the exception of the influent cluster, the depth profiles reveal a consistent increase in soluble phosphate concentration with depth. This could be due to dissolution of precipitated phosphate or the release of organic phosphorous. The increase at the effluent cluster was the greatest as the phosphate concentration increased from 3.2 mg/L to almost 20 mg/L. This might be related to the changes in redox potential that were evident in the sulfate depth profiles. The phosphate depth profiles for the 2/6/98 sampling event exhibit a consistent increase in phosphate concentration over 1 foot of depth and subsequent decreases in phosphate concentration with greater depth. The largest decreases in phosphate concentration were at the influent and center cluster. The last set of samples also followed the same trend as the fourth one. The decreases in phosphate concentration are probably related to blending with groundwater as was evident with the changes in nitrate concentrations. Increases in NH_4^+-N concentration with depth paralleled soluble phosphate concentrations indicative of anaerobic carbon degradation.

DOC concentration depth profiles are presented in Appendix J-4. The highest DOC concentration appears to be at the surface of the effluent cluster. Since significant amounts of organic carbon are produced in wetlands, increases in DOC concentrations with flow through the wetlands are possible from plant contributions. The DOC concentrations tend to decrease with depth to a depth of 15 feet as removal occurs during unsaturated flow. For the 12/11/97 and 2/6/98 sampling events, DOC concentration did not increase significantly from the influent to the effluent. Changes below 15 feet are probably related to blending with groundwater.

The specific UV (UVA254/DOC) profiles are also presented in Appendix J-4. The trends in the specific UV profiles tend to be opposite to the DOC depth profiles indicating that UV absorbing organics are not removed as efficiently as the other organic compounds. The largest specific UV values are in the groundwater at the effluent cluster. A greater contribution from plant material might result in elevated levels of refractory UV absorbing compounds. The 2/6/98 sampling event exhibits variable behavior that is likely associated with increased blending with native groundwater.

Analysis and changes in water quality in samples from the four shallow monitoring wells i.e. SWN, SWS, SWE and SWW:

The anions measured in the samples from the shallow monitoring wells located around the perimeter of the Tres Rios Cobble Site are presented in Table 2 of Appendix J. There are significant differences between all four wells. Wells SWN and SWE have lower chloride concentrations than wells SWS and SWW. Well SWN had higher nitrate concentrations that could represent infiltration from the effluent channel. Well SWE has lower phosphate concentration than the rest of the wells.

DOC concentrations and UV absorbance data for the shallow monitoring wells are also presented in Table 2 of Appendix J. With the exception of the SWN sample taken on 2/6/98, the DOC concentrations range from 2.73 to 3.45 and ground water blending with infiltrated water has consistent DOC concentrations. A similar trend has been observed with the UV254 data.

Discussion/Findings

After analyzing the data for the five sets of samples collected from the monitoring wells from the Tres Rios Cobble Site, some conclusions can be reached. Sulfate reducing conditions prevail in the sediments and affect both vertical and horizontal flow. Data on nitrate concentrations are consistent with the data on sulfate concentrations. Nitrate was removed effectively both vertically and horizontally. Denitrification occurs in the anoxic zone and sulfate reduction occurs in the anaerobic zone, which means very low nitrate concentrations were necessary before sulfate reduction could occur. From the phosphate data, it appears that phosphate has become soluble with increases in depth, which corresponds to the anaerobic zones. This could be due to a biological mechanism such as solubilization of organic phosphorous or a physical one, or a combination of both. DOC concentrations do not vary significantly with horizontal flow through the wetlands, however the specific UV increases providing evidence for organic carbon transformations. DOC concentrations consistently decrease with depth and the majority of DOC is removed over the first foot of depth. The specific UV increases with depth indicating that non-UV-absorbing organics are preferentially removed.

Heavy Metal Bioavailability Monitoring

Goals and Results

Goals of the Heavy-Metal Analysis of Inlet& Outlet Waters

A) To assess presence and character, e.g. total vs. dissolved, of heavy metals entering and exiting the constructed wetland basins in surface waters.
B) To determine if seasonal or operational changes influence the character and/or quantity of heavy metals exiting the treatment wetlands.

Metals of Interest: Al, As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Se, Zn
Sample Points - CS INLET C2 EFF

Goals of the Heavy Metal Analysis of Sediments

A) To determine quantity, form (Total versus Dissolved), and the location of metals along the flow path in a treatment wetland.
B) To assess the bioavailability of heavy metals as indicated by Acid Volatile Sulfide to Simultaneously Extracted Metals ratios (AVS: SEM).
C) To determine if temporal changes influence the availability of heavy metals in treatment wetlands.
D) To perform a heavy metals mass balance in order to gain an understanding of influent metals versus those exiting the system, and those held in sediments and biomass.
E) To determine if heavy metals are bioavailable
F) To evaluate if heavy metals are more bioavailable in the winter or summer, or transitional periods which occur in spring and fall.
G) To determine if metals will be mobilized and become more available in the wetland sediments are oxidized.

Metals of Interest: Al, As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Se, Zn
Sample Points – C2 INLETDZ, C2 EZ1, C2 DZ1, C2 EZ2, C2 DZ2,
C2 EZ3, C2 DZ3, C2 EFFDZ

System Performance

Heavy-metal investigation entails sampling the inlet and outlet flows, gradient sampling of the water column and sediments, and the development of Acid Volatile Sulfide and Simultaneously Extracted Metals (AVS:SEM) ratios. The corresponding reduction oxidation potential of the water column and sediments is also measured. During the 1998 – 2000 research period, one 24-hour composite sample of a wetland inlet and outlet, offset by one-hydraulic retention time, has been conducted. Results of this endeavor are provided in Table 52.

As one can see by inspection of Table 52 the analytical techniques for this run did not produce reliable results as evidenced by several of the dissolved metal concentrations being higher than the total metal analysis. This issue is being addressed by the City's Laboratory in that they are developing ultra clean methods and refurbishing their metals laboratory. It is anticipated that these improvements will be completed so that metal sampling can be reinitiated in the spring of 2001.

Table 52. Hayfield Site 24- hour composite sample results (mg/L) for total and dissolved metals from the inlet and the basin H1 outlet works.

Metal	HS Inlet (Dissolved)	HS Inlet (Total)	H1 EFF (Dissolved)	H1 EFF (Total)
Arsenic	< 0.010	< 0.010	< 0.010	< 0.010
Selenium	< 0.010	< 0.010	< 0.010	< 0.010
Aluminum	0.210	0.052	0.304	0.097
Cadmium	< 0.001	< 0.001	0.001	< 0.001
Chromium	0.006	0.005	0.006	0.007
Copper	< 0.010	< 0.010	< 0.010	< 0.010
Iron	< 0.30	< 0.30	< 0.30	< 0.30
Nickel	0.011	0.016	0.016	0.017
Lead	< 0.010	< 0.010	< 0.010	< 0.010
Zinc	< 0.10	< 0.10	< 0.10	< 0.10
Mercury	< 0.0002	< 0.0002	< 0.0002	< 0.0002

During the spring of 2000, operational issues regarding pumps supplying the demonstration wetland basins have slowed data collection efforts with respect to the heavy-metals investigation. It is paramount for the inlet outlet composite metals samples that the basin(s) be operating at steady-state with respect to flow which was not been possible due to pump malfunction(s) and construction of new chlorination facilities at the 91st Avenue wastewater treatment plant.

Sediment and vegetation samples were not collected in August 1999 as proposed due to pump malfunctions which did not allow the wetland basins to be operated in a steady-state mode. Again, the goal is to conduct this sampling during 2001.

In order to test field collection and sample preparation methods, a trial sediment sampling effort was conducted in February 2000 in Basin H2. Those samples have been submitted to the City's 23rd Avenue Water Quality Laboratory to work out sample handling and preparation techniques with their staff. The 23rd Avenue Laboratory analysts were successful in refining analytical methods and sample extraction procedures, but did not produce results.

Vector Monitoring and Control Goals, Methods, and Results

Adult and larval mosquito populations have been monitored at the Tres Rios Demonstration wetland facilities since the summer of 1997. These 1997 data have been included in this section of the report to describe conditions prior to implementing refined mosquito management techniques in the summer of 1998. Such techniques include vegetation manipulation, decreased density, but increased diversity, and less overall basin coverage. Improved larvicide application using commercial hydro-seeding equipment has also been employed with success. In terms of adult mosquito populations adult counts have consistently dropped since implementing management measures in the summer of 1998. From June 1997 through August 1997 almost 135,000 adult mosquitoes were caught in 10 traps associated with the project sites during 13 sample events. During the same time-period in 1998, the same 10 traps captured a little over 75,000 adult mosquitoes during 13 sample events. During the summer months of 1999, less than 9,000 were caught. For the same time period in 2000, adult counts dropped even further, less than 4000 during 12 sample events. Larval numbers have followed a similar trend. Although the drop in both larval and adult mosquito populations is encouraging, it is still early in the life of the reconstructed wetlands so monitoring and assessment activities will continue.

Mosquito Control

The Tres Rios Demonstration Constructed Wetland Project implemented several measures during the 1998 Mosquito Season in an attempt to minimize the numbers of mosquitoes breeding within and adults caught adjacent to or associated with the Tres Rios Demonstration wetland treatment systems. Adult counts in 1999 and 2000 (post treatments), have been significantly lower than in 1997 and 1998. This can be attributed to a combination of less dense vegetation and improved larvicide application techniques. Reductions in adult and larval counts can also be attributed to offsite treatment(s) of a potential breeding area(s), and natural fluctuations in mosquito populations.

Abatement Measures Applied to the Tres Rios Demonstration Wetland Facilities in 1998

Several abatement measures were enacted in and around the Tres Rios Demonstration Wetland facilities during the spring and summer of 1998. These were designed to minimize the number of mosquitoes breeding within and caught at the wetland sites. These treatments consisted of 1) Basin redesign and reconfiguration, 2) Reduced vegetation density and increased diversity, and 3) Improved larvicide application technique.

Basin Redesign & Revegetation

Basin redesign and reconfiguration was conducted in the two Cobble Site wetland basins (See drawings in Appendix K). Construction took place during the summer of 1998.

Reconfiguration efforts consisted of removing 2400 yd^3 of bottom material from the unlined basin (C1) such that all shallow emergent areas are surrounded with open-water deep zones on at least three sides. The goal is to provide better mosquito fish access to potential breeding areas located within densely vegetated zones.

Bottom material removed from C1 was placed as gravel bars within the emergent zones of the lined Cobble Basin C2. This effectively reduced the amount of wetted area by approximately 0.3 acres and it is envisioned that higher loading rates can be used to reduce the amount of quiescent mosquito breeding areas within this basin, (*i.e.* more water through the reduced flow path should result in higher water velocities). These bars were then planted with riparian vegetation such as cottonwood and willow trees to shade the water surface. Shading will help reduce the density of emergent species. Further, the amount of the two species of bulrush originally used was reduced to approximately 20% of the total vegetated area and augmented with additional species. To provide surface area lost to the less dense emergent zone plantings, liberal use was made of floating aquatic plants. The two species used were Pennywort (*Hydrocotyle* sp.) and False-Loosestrife (*Ludwegia* sp.), both of which are found growing in the Salt River. These two species are desirable in that they provide refuge for mosquito fish breeding and development while serving as forage for muskrat and waterfowl.

The Cobble Site basins were the only ones reconfigured, but all sites, including Hayfield Basins 1 and 2 underwent planting efforts in attempts to provide a more diverse, but less dense assemblage of vegetation. Lower vegetation densities are expected to allow better access to mosquito larvae for biological controls, such as fish and other macro invertebrates. More diversity will also encourage greater usage by a more diverse group of animals, thereby maximizing habitat values. Table 53 provides a summary of vegetative cover for the four demonstration wetland basins. Vegetative cover estimates were obtained from aerial photographs taken in February 1997 and January 2000 and interpreted by the USBR, Phoenix Area Office.

Table 53 Comparison of vegetation coverage before and after control measures were implemented in the summer of 1998 at the Tres Rios Demonstration wetland basins.

Basin	H1		H2		C1		C2	
Date	Area (Acres)	% Coverage	Area (Acres)	% Coverage	Area (Acres)	% Coverage	Area (Acres)	% Coverage
2/10/97	2.67	80.9	2.43	76.9	1.91	84.1	2.02	90.2
1/14/00	1.07	32.3	0.38	12.1	0.61	26.7	1.05	54.3

Improved Larvicide Application Technique

Another important abatement technique with respect to minimizing mosquito breeding within the wetland basins themselves concerns a change in the application of the bacterial larvicides (*Bacillus thuringiensis* and *B. sphaericus*). Prior to July 19, 1998 granular formulations of these two larvicides were applied to the basins via a mechanical blower (MD 80). Visual observations indicated that this technique allowed for roughly 30 to 40% basin coverage with little or no penetration of larvicides through the dense or lodged vegetated areas. Delivery of the granular larvicides is now accomplished via water slurries provided by a commercial "Hydro-Seeder" truck. Granular larvicides applied as a slurry provides two major improvements over dry application; 1) Slurry application results in approximately 90% basin coverage because the water cannon can span the width of the wetland; 2) Slurry application with the water carrier allows the granular larvicide to penetrate or otherwise be "washed" through dense or lodged vegetation to the water column.

Mosquito Monitoring Methods

Both larval and adult populations are sampled on a weekly basis. Larval monitoring is accomplished using a standard dipping method, while adults are trapped with Encephalitis Vector Survey (EVS) CO_2 traps. Mosquito larva monitoring is conducted by staff from Aquatic Consulting and Testing Inc., Tempe, Arizona (ACT). The results of this effort are probably biased in that ACT staff have been directed by the City of Phoenix to aggressively dip areas within each wetland that have the highest probability of providing refuge for developing larva, (*i.e.*. quiescent, densely vegetated zones). Adult monitoring is accomplished by placing 10 traps at fixed locations around the wetland systems, the 91st Avenue WWTP and the Salt River bottom (See Appendix K). Lastly, ACT counts and determines the sex and species of trapped adults. As of 2000, COP staff identify and count populations while ACT provides QA/QC.

Adult Mosquito Monitoring Results

During the spring and early summer of 1998 the mosquitoes trapped at the Tres Rios sites were predominately two marsh-breeding species, *Culex tarsalis* and *C. erythrothorax* with the latter being present in higher numbers. Both species are capable of transmitting encephalitides. Another *Culex* species, *C. pipiens* was also detected on at least three (3) occasions. Also noted in the early summer were *Culiseta inornata* and *Aedes vexans*. As the summer progressed the species of mosquito trapped changed coinciding with the time abatement measures were enacted.

In late July through the reminder of the season (October/November 1998) an increase in floodwater species was detected, particularly at the Hayfield Site. A commensurate decrease in the marsh-breeding mosquitoes *C. tarsalis* and *C. erythrothorax* was also noted. Reduction in marsh-breeding species likely reflects the positive results of the abatement measures, while the increase in floodwater species is a function of the manner in which the terrestrial/riparian vegetation is irrigated. Floodwater species identified include *Aedes vexans*, *Psorophora confinnis* and *P. signipennis*. Finally on one occasion the stagnant water mosquito *Anopheles punctatus* was identified.

Mosquitoes species trapped in and around the Tres Rios Demonstration Project facilities include both marsh breeding and flood-water species. To facilitate the analysis of mosquito trap count data, trap locations were combined to show total mosquito counts based upon whether the trap was proximal to wetland sites (Wetland-Area), or if they reflect background breeding (Contributing-Area) in the Salt River channel or in adjacent agricultural and dairy facilities. Wetland-Area traps are numbered 2,3,4,6, and 9, while Contributing-Area traps are numbered 1,5,7,8, and 10, and map containing the location of the traps is contained in Appendix K-4. Trap 3 was included in the Contributing-Area after the Research cells were taken out of operation.

Prior to enacting the management measures in July 1998, *Culex* mosquitoes represented over 93% of the total adults caught, even during winter months. During the period from September 1998 through December 1998, this percentage dropped to roughly 83%. *Culex* percentage rose again to greater than 90% from January 1999 through May 1999. The first larvicide application in 1999 was conducted in May, and during the subsequent 3 month period, *Culex* percentage dropped to approximately 73%. Increasing in percentage during this time were the floodwater mosquitoes of the genus *Psorophora* and *Aedes*, and the stagnant water *Anopheles* mosquito. The following Tables (54 and 55) present the genus distribution and total mosquito numbers for the months of June through August for the years 1997, 1998, 1999, and 2000.

Table 54. Adult mosquito species summary for summer periods in 1997, 1998, 1999, and 2000.

Location & Genus	June97 – Aug97		June98 – Aug98		Jun99 – Aug99		Jun00 – Aug00	
Contributing-Area	Count	%*	Count	%*	Count	%*	Count	%*
Psorophora	538	1.0%	348	1.0%	521	12.3%	171	13.7%
Aedes	132	0.2%	387	1.1%	259	6.1%	185	14.8%
Anopheles	10	0.0%	26	0.1%	357	8.4%	22	1.8%
Culex	54045	98.8%	34810	97.9%	3103	73.2%	871	69.7%
Culiseta	0	0.00%	0	0.00%	0	0.0%	0	0.0%
Wetland-Area								
Psorophora	282	0.4%	433	1.1%	1238	29.3%	87	3.9%
Aedes	118	0.2%	147	0.4%	68	1.6%	97	4.3%
Anopheles	0	0.0%	5	0.0%	195	4.6%	9	0.4%
Culex	79,743	99.5%	39255	98.5%	2719	64.4%	2043	91.4%
Culiseta	0	0.0%	0	0.0%	0	0.0%	0	0.0%

*Note: Percentages may not add to 100% due to rounding errors.

Comparison of Mosquito Seasons 1997, 1998, 1999, and 2000

Cobble Site Traps 1 and 2 showed little or no difference in the number of adult mosquitoes caught in 1997 versus 1998 until August. This was unexpected because the Cobble Site basins were out of service from March 1998 through August 1998. Results such as these indicate breeding is occurring elsewhere in the project area. This is further substantiated in that the background sites, Traps 5, 7, 8, and 10 also show no difference between 1997 and 1998, even in September which is opposite of what occurred at the Research Cell and Hayfield Site trap locations. In 1999, traps 1 and 2 both showed significant reductions. This was after the reconfiguration and replanting and the vegetation was approximately 9 months old. In 1999, the vegetation was "open" and access by predators and thorough larvicide coverage was effectively achieved. In the summer of 2000, after the vegetation had gone through one complete life cycle, a further reduction in traps 1 and 2 was seen.

Table 55 . Tres Rios Demonstration Project Monthly Average Adult Mosquito Trapping Results, summer 1997, 1998, 1999, and 2000.

Trap No.	1	2	3	4	5	6	7	8	9	10
Date										
Jun-97	1335	727	892	2911	4121	2116	18	3	637	1898
Jul-97	1362	3548	291	1859	1633	1880	71	8	356	226
Aug-97	2670	1887	392	923	1417	1601	31	11	335	132
Sept-97	1493	2152	264	458	533	814	56	tnis	100	134
Oct-97	393	961	375	221	435	333	21	37	79	148
Jun-98	934	491	60	1790	2630	2349	22	30	768	1887
Jul-98	269	112	103	1489	1333	687	14	12	240	195
Aug-98	46	28	29	100	239	85	11	4	28	25
Sept-98	219	69	13	75	165	54	88	9	55	26
Oct-98	200	33	10	138	136	103	11	1	125	148
Jun-99	40	110	6	161	258	61	2	4	44	291
Jul-99	83	62	12	59	36	26	13	4	10	50
Aug-99	66	150	94	149	87	51	11	21	30	66
Sept-99	77	132	73	163	110	270	18	18	29	69
Oct-99	35	22	4	34	22	15	3	5	31	15
Jun-00	21	53	13	89	66	18	4	2	16	65
Jul-00	19	25	2	54	70	8	2	2	18	13
Aug-00	5	8	2	10	154	6	5	1	7	10
Sep-00	39	52	4	66	105	18	7	43	15	15
Oct-00	24	13	3	18	22	3	4	4	8	11

Note: tnis = trap not in service.

Research Cell Trap 3 adult counts were significantly lower in 1998 than in 1997 for the months of June, September and October. Although average 1998 counts were lower in July and especially August, they were not judged to be significantly different from those recorded in 1997. During that time period, three basins (R9, R10, and R11) were completely out of service with only incidental water present. In 1999, Trap 3 counts were also reduced, but not significantly different from previous years. During 2000 the Research Cell site was not utilized and counts were noticeably reduced from previous years, with average counts ranging from 2 to 13 adult mosquitoes per trap night.

Hayfield Site Traps 1, 2, 4, 5 and 6 were the most active of the Tres Rios mosquito-monitoring network. At these trap locations, adult counts greater than 3,500 per trap night during the summer and fall of 1997 and during the months of June and July 1998. High numbers of adults continued to be caught in 1997 through October. In 1998, numbers drop drastically after July, 100 or less per trap-night. This reduction coincides with the time when the larvicide slurry application method was implemented and continued until August and September 1999. During these two months, adult mosquito counts actually rose and are attributable to two "flood water" (*Psorophora spp.*) mosquito hatches recorded 8/5/99 and 9/2/99. A decreasing trend is observable for the remainder of the study period.

Counts at Traps 9 and 10 were also reduced in 1999 and 2000. As such, it is likely that the Salt River Traps, 1, 5, 9, and 10 do, at times reflect mosquito breeding in the Demonstration wetland basins as well as breeding within natural areas in the channel.

Finally, reduced trap-counts were not expected in the North and Northeast perimeter traps (7 and 8) because these are not really reflective of breeding in the wetland basins or the Salt River. Rather, these two traps are indicative of mosquito breeding in irrigation ditches and other damp areas located in and around the adjacent agricultural and dairy facilities. Though trap counts decreased in traps 7 and 8, the decrease is not as significant as the decrease in and around the wetland basins. Therefore, one might surmise that action being taken around the wetlands was effective in reducing larva counts.

In general, since enacting the July 1998 mosquito management techniques, adult counts in Trap 4, 5, and 6 have dropped. This is especially evident for the 1999 and 2000 summer months, over which time total adult mosquito counts have dropped by up to a magnitude over those obtained during the same time period in previous years. These data are generated from a total 12 trapping events in 1997, 14 trapping events in 1998, 13 trapping events in 1999, and 12 trapping events in 2000. Appendix K contains a graphical representation of the results.

Larval Mosquito Monitoring Results

As Table 56 indicates, mosquito larvae were readily observed in all four wetland basins during the summer of 1997. Since the Cobble Site basins were not in service for the majority of the spring and summer of 1998, only results for the Hayfield Site are available that year. At both sites, larval counts drop after the July 1998 abatement measures were enacted and coincide with the introduction of the slurry application method used for larvicide application in the wetland basins.

The reduction in the number of mosquito larvae found in the Cobble and Hayfield wetland basins is likely attributable to the improved larvicide coverage and improved access by fish and predatory invertebrates to mosquito breeding areas (*i.e.* dense aquatic vegetation). Larval dipping is also subject to a large amount of variability due to the difficulty in actually obtaining larvae. Often times, larvae can escape capture because of flight responses brought on by shadows, vegetation movement and or water movement. As such, Table 56 reports the total larvae captured during the summer months June, July, and August in aggregates for each basin C1, C2, H1 and H2. Although Table 56 indicates that zero larvae were found in the Hayfield Basins during 1999 and 2000, they were found on several occasions by Tres Rios staff. As such the results in Table 56 should only be used to show that mosquito larvae were reduced, not eliminated from the wetlands.

Table 56 . Total Larval counts for the Tres Rios Demonstration Wetland Basins during the summer months of 1997, 1998, 1999, and 2000.

Time Period	# of Efforts	Basin C1	Basin C2	# of Efforts	Basin H1	Basin H2
Jun97 – Aug97	7	525	190	12	394	340
Jun98 – Aug98	0	Basin Out of Service		10	101	240
Jun99 – Aug99	13	2	0	12	0	0
Jun00 – Aug00	13	1	0	13	0	0

Table 57. Tres Rios Demonstration Project 1999 and 2000 Larval Treatment Costs.

LARVICIDE (granular)	1999	2000
Quantity	1,400 lbs./year	2,800 lbs./year
Unit Cost	$4.67 per lbs.	$4.67 per lbs.
Total Material Cost	$6,538	$13,076
APPLICATION		
Average Area Treated	10.5 Acres	10.5 Acres
Hydro-Seeder Unit Cost	$375 per application (contract)	$375 per application (contract)
Number of Applications	12	23
Hydro-Seeder Application Cost	$4,500 (contract)	$8,626
Unit Application Cost	$625.15 per Acre	$821.43 per Acre
Total Annual Cost	$11,038 ($1,055 per acre)	$21,702 ($2,067 per acre)

Table 57 provides the material and equipment cost associated with larvicide activities for the entire year of 1999 and 2000. In all, larvicide was applied 12 times during the year in 1999 and 23 times during the year in 2000, with varying frequency.

In 1999, larvicide was applied once during the months of February, May, June, September, November, and December. During July, August and October 1999, larvicide applications were conducted twice a month. In total, 1,400 lbs. of granular larvicide was used with a total material cost of $6,538. When one combines the material and equipment costs, the total annual cost for the larvicide program was $11,038 for 10.5 acres of wetland or $1,055 per acre.

In 2000, larvicide was applied once during the months of January, February, March, November, and December. During June and October, larvicide applications were conducted twice a month. Three applications were used in July, August, and September, and four applications were used in April and May. In total, 2,800 lbs. of granular larvicide was used with a total material cost of $13,076. When one combines the material and equipment costs, the total annual cost for the larvicide program was $21,702 for 10.5 acres of wetland or $2,067 per acre.

During the year 2000, a total of 12 gallons of VectoBac larvicide was used on four occasions. The goal of the VectoBac application was to prevent the development of resistance to VectoLex in the targeted mosquito population.

Summary

During the Spring and Summer of 1998 abatement measures were enacted at the Tres Rios Demonstration Wetland Facilities to reduce the potential for breeding and the numbers of adult mosquitoes caught in and around the sites. These were successful in that post treatment adult counts and larval dipping results were lower in 1998, 1999, and

2000 than for the same time period in 1997. If one were to rank the treatments in order of effectiveness, the improved larvicide application technique and less dense vegetation would probably lead the group. In essence, it appears that in order to achieve mosquito control in wetlands, one must get the control agent, e.g. a fish, a macro invertebrate, or a larvicide, to the target organism. Reduced vegetation densities and more open-water appear to satisfy this condition.

Sulfur Driven Autotrophic Denitrification

Nitrogen removal in both constructed and natural wetlands is a well-documented phenomenon. Reduced forms of nitrogen such as ammonium (NH_4^+) and ammonia (NH_3) are transformed in the presence of oxygen by bacteria to nitrite and nitrate nitrogen forms (NO_2, NO_3^-). These oxidized nitrogen species can be further transformed and removed from the system as di-nitrous oxide (N_2O) and nitrogen (N_2) gas via another group of bacteria and in the absence of oxygen. It is the conventional wisdom that nitrate reduction (denitrification) in wetland systems occurs using a heterotrophic pathway in which organic carbon compounds are electron donors and nitrate molecules act as acceptors (Reddy and Graetz, 1988; Mitsch and Gosselink, 1993; Dahab, 1991; Kadlec and Knight, 1996).

Sulfur driven autotrophic denitrification is another nitrogen removal pathway that likely exists in wetland systems but has received much less attention. Under this scenario, ammonia and ammonium must again be oxidized to nitrate. The nitrate is reduced to N_2 gas, but instead of carbon, bacteria capable of autotrophic metabolism use reduced sulfur compounds as the electron donors. Although identified in the 1970's as a means of nitrogen removal for high strength nitrate waste streams from industrial processes (*i.e.* explosive and fertilizer manufacturing), little work has been done at the field scale to assess the role this mechanism plays in overall nitrogen removal from a wetland treatment system.

Method and Rationale

Preliminary water quality and sediment data obtained from the Tres Rios Demonstration Constructed Wetland facilities indicates that sulfur driven autotrophic denitrification may occur in these wetlands. Insight into this phenomenon was obtained primarily through batch testing with sediment samples from each of the four wetland demonstration basins. In these experiments, sediment bacteria were cultured under aerobic and anaerobic conditions and supplied with various electron donor and acceptor pairs. Nitrate removal, increased sulfate concentrations, and gas production (N_2) indicated nitrogen removal via microbial denitrification was occurring in these sediments. Further, since both heterotrophic and autotrophic populations were enriched from these sediments, it is likely that both heterotrophic and autotrophic denitrification mechanisms occur simultaneously in the wetland. This is likely because of the varied physical, chemical, and biological regimes that exist in such systems at the field scale.

This section reports on the monitoring results for water quantity and quality collected at the Tres Rios Demonstration Wetland facilities from January 1997 through December 2000. These data have been analyzed and used to construct partial material balances for nitrate-nitrogen, sulfate, and total organic carbon. In turn this information was used to develop molar ratios relating sulfate concentration increase and nitrate concentration reduction during operational periods when sulfur-driven autotrophic denitrification was likely occurring. Lastly, these ratios are compared to a range of ratios reported in the literature that relate to the stoichiometry of autotrophic denitrification reactions.

Autotrophic Denitrification Theory

Nitrogen dynamics have been studied in four freewater surface constructed treatment wetlands at the Tres Rios Demonstration Wetlands facilities in Phoenix, Arizona. Since 1995, source water to the wetlands has consisted of a nitrified/denitrified municipal effluent exhibiting 10mg/l or less of nitrate-N, and 100 to 200 mg/l of sulfate. Material balances have been developed for nitrate, total organic carbon and sulfate that suggest that sulfur-driven autotrophic denitrification is a plausible nitrate removal pathway when bio-available carbon is limited. When bio-available carbon is in excess, simultaneous heterotrophic denitrification and sulfate reduction were indicated.

It is proposed that bio-available carbon drives denitrification in the studied systems in two ways: 1) Bio-available carbon acts as an electron donor and nitrate the electron acceptor during heterotrophic denitrification, and 2) Bio-available carbon is used for sulfate reduction with the resulting sulfides stored in the wetland sediments (Figure 1). When the system is lacking in bio-available carbon, reduced sulfur species from the sediments act as electron donors and nitrate nitrogen the acceptor.

To date, it has been the convention in treatment wetland technology to assign the denitrification role to heterotrophic bacteria occurring on the submerged surfaces and sediments of the wetland. The conventional wisdom is that carbon availability drives nitrogen removal via heterotrophic denitrification and that this mechanism is an efficient and reliable means of removing nitrate nitrogen from waste streams at the expense of a carbon source. Although the carbon source can become limiting, Gersberg et al. (1983, 1984) showed that this limitation could be overcome. At the lab scale, he and co-workers added shredded plant biomass, methanol, or primary treated wastewater and produced some of the highest wetland nitrogen removal rates (1.9 – 3.1 g $m^{-2}d^{-1}$) recorded. Others have also found success in achieving nitrogen removal via denitrification in carbon-limited systems through the introduction of other external carbon sources such as glucose and glycerol (Dahab, M.D., 1991). Unfortunately, the addition of an external carbon source can translate into high costs, pose site safety hazards, and/or the delivery of sufficient amounts of carbon to sustain a denitrification process may be impractical.

Labile organic carbon is also a necessity for heterotrophic denitrification to occur. In a treatment wetland several carbon sources, dissolved and particulate, exist. Particulate carbon can originate in the pretreated wastewater stream and from plant and animal biomass. Dissolved organic carbon can result from the decomposition of plant and animal matter and the decay of microbial populations. Inorganic carbon in the form of carbonate is another potential dissolved carbon source.

A probable scenario (Figure 1) is that heterotrophic denitrifying bacteria and heterotrophic sulfate reducing bacteria utilize the same carbon source, but the availability is spatially and temporally dependent. Particulate carbon entering the system is unavailable to sulfate and nitrate reducing bacteria because of its physical state and location. First, it must settle into the benthos where an active microbial layer exists (Figure 2). This layer is comprised of an aerobic zone, on the order of a couple of millimeters to several centimeters, underlain by an anaerobic zone which is often much thicker (Reddy and Graetz, 1988). The juxtaposition of an aerobic zone immediately adjacent to an anaerobic zone provides an environment conducive to reduction oxidation reactions. It is within this zone that carbon compounds are degraded under aerobic, anaerobic, and or fermentation pathways. The primary end products of the anaerobic fermentation are fatty acids such as acetic, butyric, and lactic acids and the gases CO_2 and H_2. Acetic acid is the primary acid formed in most wetland sediments and soils (Reddy and Graetz 1988) and represents a labile organic carbon source that can subsequently be used for nitrate reduction, methane production, and/or for sulfate reduction.

Reduced sulfur species that result from sulfate reduction are subsequently stored in the anaerobic muds of the wetland. Over time, sulfides may diffuse into zones where biological nitrogen removal can occur involving bacteria that utilize these reduced sulfur species via an autotrophic denitrification pathway such as the relationship shown below.

$$H_2S + HS^- + 3.2NO_3^- + 0.2H^+ \quad = \quad 1.6N_2 + 1.6H_2O + 2SO_4^=$$

The equation just presented is but one of the numerous autotrophic pathways in existence. Often times this relationship is a function of the bacterial species present, the form of the sulfur used as a substrate, and the organic formula used to represent biomass formation. As a result, there exists a range of stoichiometric ratios of nitrate consumption and sulfate production that describe sulfur driven autotrophic denitrification. Some representative relationships are provided in Table 58 and represent a range of stoichiometric molar ratios from 0.625 to 1.62.

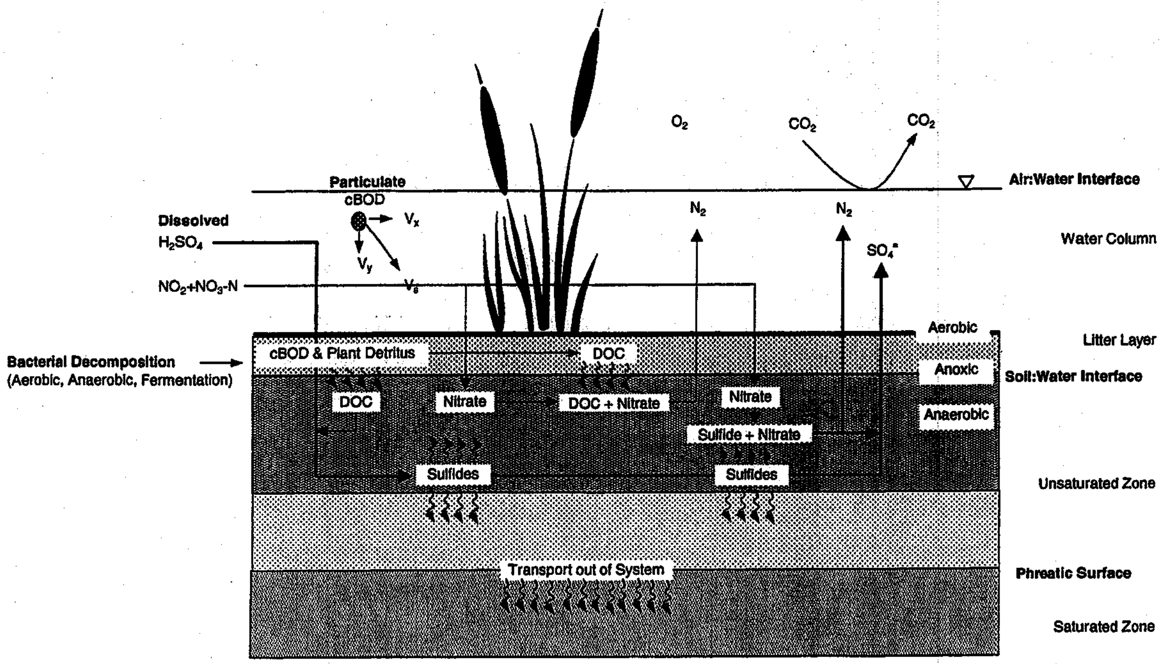
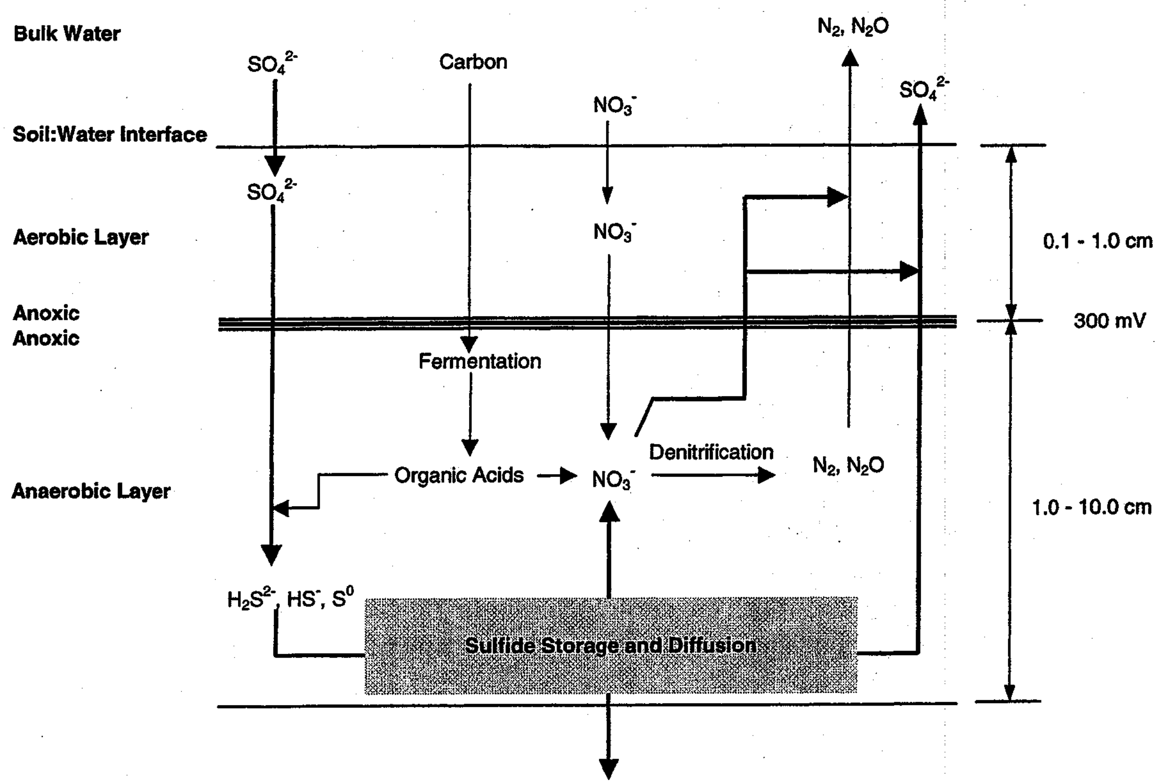


Figure 1. Carbon, sulfur, nitrite, and nitrate interactions in a treatment wetland.



Aerobic:Anaerobic Soil Layer System in Flooded Sediments

Figure 2. Aerobic:Anaerobic soil layer system in flooded sediments (Adapted from Reddy and Gaetz, 1988).

Table 58. Sulfur-Driven autotrophic relationships and resulting sulfate production and nitrate utilization stoichiometric ratios.

Relation	$SO_4^{=}/NO_3^{-}$ Molar Ratio	Source
$H_2S + HS^- + 3.2NO_3^- + 0.2H^+ = 1.6N_2 + 1.6H_2O + 2SO_4^{=}$	0.625	Balanced ½ Reaction
$NO_3^- + 1.1S + 0.4CO_2 + 0.76H_2O + 0.08NH_4^+ = 0.8C_5H_7O_2N + 0.5N_2 + 1.1SO_4^{2-} + 1.28H^+$	1.1	Batchelor and Lawrence, 1978
$5S_2O_3^{2-} + 8NO_3^- + H_2O = 10SO_4^{2-} + 4N_2 + 2H^+$	1.25	Justin and Kelly, 1978
$0.42H_2S + 0.42HS^- + NO_3^- + 0.35CO_2 + 0.865HCO_3^- + NH_4^+ = 0.5N_2 + 0.0865C_5H_7O_2N + 0.84SO_4^{=} + 0.5H^+$	0.84	Alonzo 1978
Chemostat	1.62	Claus and Kutzner, 1985

Data Analysis

From the operational parameters, field measurements, and water quality investigations described above, operating conditions, material balances, removal and accretion rates were developed for each of the four demonstration basins. This information was used to describe the stoichiometric removal of nitrate and production of sulfate and to further compare those results with literature and bench-scale sulfur driven autotrophic denitrification stoichiometry. In the future this information will be used in an attempt to correlate wetland operation and vegetative cover with wetland performance, specifically heterotrophic versus autotrophic nitrogen removal and sulfate production.

Material Balances Results

Partial material balances have been completed for chloride, alkalinity, sulfate, nitrite/nitrate, and total organic carbon. These data were then plotted to confirm nitrate reduction and commensurate sulfate production. Plots in Appendix L from gradient sampling efforts are presented that show nitrogen removal during times of sulfate production and sulfate reduction. Sulfate production and commensurate nitrate reduction support the hypothesis that sulfur driven autotrophic denitrification is occurring in the Tres Rios wetland basins. Data used to generate these plots were further corrected for evaporative concentration using a chloride balance. These data were used to develop the stoichiometric molar ratios of nitrate removed to sulfate concentration increase during time periods when sulfate production was occurring.

Long-Term Cumulative Mass Balance Results

Carbon, measured as total organic carbon showed an overall decrease from inlet to outlet in each of the four basins for the study period 1997 through 2000. TOC removals were more pronounced in the Hayfield than at the Cobble site wetlands. C1, the unlined Cobble basin had the lowest average removal of just a couple of kilograms per month, while the Hayfield basin H2 had the highest, close to 37 kg per month. On average, the amount of TOC (kg) "consumed" was 21.9 kg for basin H1 and 35.6 for basin H2. The Cobble site showed smaller removals with C1 losing approximately 2.4 kg, and C2 18.1 kg on average per month. However, long-term plots of the inlet and outlet TOC concentrations indicate there are times when the basins serve as both a source and a sink of TOC (Figures L-1 and L-2 in Appendix L).

Figures L-1 and L-2 shows the difference in Inlet TOC minus Outlet TOC for the study period 1/97 through 12/00 for representative basins from the Hayfield and Cobble Sites. As can be seen, there are times in both Cobble and Hayfield wetland basins when carbon, measured as TOC, is either being produced or consumed as water travels from the inlet to the outlet of these wetlands. Positive values indicate TOC removal, while negative values indicated TOC is exported from the wetland. Breaks in the data indicate times when basins were out of service or sampling data was unavailable.

Sulfur, measured as sulfate was produced in all wetland systems studied during the period beginning January 1997 and ending December 2000 with the exception of basin H1. In H1, sulfate was "consumed' over the long term with a net mass reduction of approximately 47 kg. The remaining three basins exhibited overall average sulfate production with basin H2 (393 kg) and C1 (266 kg) showing the highest and C2 (66 kg) showing much less.

Nitrate nitrogen was effectively removed over the long-term in all four wetland basins. For this constituent, average removals were fairly consistent between basins located at the same site. Nitrate removal between H1 and H2 differed by less than 10 kg while C1 and C2 differed by close to 30 kg. Overall, the Hayfield site removed more nitrate by mass, than did the Cobble site basins.

Figure L-3 shows the average change in mass from inlet to outlet for the four Tres Rios Demonstration wetland basins. Negative results indicate a net increase in a constituent, while positive values indicate removal attenuation within the system. In general, all wetland basins reduced nitrate and total organic carbon concentrations. Sulfate was produced in basins H2, C1, and C2, while H1 showed an overall average net removal.

Gradient Sampling Results

Samples obtained along the flow path of the wetland provided a snap-shot of the water quality within the wetlands and some indication of the transformations that were ongoing. At times, gradient sampling showed nitrate reduction with no increase, or even a decrease in sulfate concentrations (Figure L-4). It is thought that during these times sufficient carbon is available to support sulfate reduction and heterotrophic denitrification. However, several of the gradient sampling efforts resulted in plots showing a decrease in nitrate concentration with a commensurate rise in sulfate concentration as one traversed the system from inlet to outlet (Figure L-5). In many of these cases, the molar ratio of the decrease in nitrate and increase in sulfate fell within the range of literature values reported previously (Table 58). It is at these times, that the contribution of autotrophic denitrification may be indicated in the Tres Rios Wetlands.

Figure L-6 shows gradient sampling of basin H1. Here nitrate-n decreases from inlet to outlet, as does sulfate indicating that sulfate reduction is occurring throughout the wetland flow path. The 4/98 data were collected 2 months prior to aboveground vegetation removal in basin H1. At that time, almost all of the emergent vegetation was dead, the decay of which likely resulted in an overabundance of dissolved organic carbon and hence satisfied both sulfate reduction and heterotrophic denitrification metabolic requirements. Basin C1 on 10/00 was only sparsely vegetated with emergent macrophytes, but had a significant amount of floating aquatic plant and a detritus layer.

Gradient sampling of basins H1 and H2 show a decrease in nitrate nitrogen from inlet to outlet while sulfate is increasing, possibly indicating autotrophic denitrification using reduced sulfur species is occurring (Figures L-6 and L-7).

Performance and Discussion

Molar Ratios

Long-term water quality data collected at the wetland inlet and outlets were combined with the inlet water flows and were used to develop molar ratios of the mass of sulfate produced to the mass of nitrate removed. Table 59 provides ratios that fell within the range of literature values which are shown in Table 58. In general terms, ratios within the autotrophic range were found on more occasions in the Hayfield basins H1 and H2, while the fewest were found in basin C1.

Table 59. Molar ratios, corrected for evaporative concentration, developed for the Tres Rios Demonstration Wetland Basins at the Hayfield and Cobble Sites for the time period January 1997 through December 2000.

Date	Basin C1 $SO_4^{=}:NO_3^{-}$-N	Date	Basin C2 $SO_4^{=}:NO_3^{-}$-N	Date	Basin H1 $SO_4^{=}:NO_3^{-}$-N	Date	Basin H2 $SO_4^{=}:NO_3^{-}$-N
10/21/97	0.80	12/9/97	0.71	4/18/97	1.04	4/18/97	1.26
1/29/97	1.28	2/28/99	1.20	7/22/97	1.03	7/22/97	1.45
6/29/99	1.60	6/29/99	0.67	8/19/97	0.74	8/19/97	1.03
7/27/99	1.39	7/27/99	0.64	9/16/97	1.51	9/16/97	1.23
9/23/99	1.00	8/24/99	0.73	12/9/97	0.59	3/24/98	1.17
		10/26/99	0.73	9/29/98	1.33	5/19/99	0.67
		1/20/00	1.27	5/19/99	0.70	6/29/99	0.64
				6/29/99	0.93	7/27/99	0.71
				7/27/99	0.76	1/20/00	0.98

Discussion of Autotrophic Denitrification

The Tres Rios wetland basins have been studied since the fall of 1995. During that time water delivery and outflows were monitored and select water quality parameters were measured. The reader is cautioned that the systems studied were open to the atmosphere and this posed some challenges with respect to developing mass balances. For instance, the water surface was open to gaseous exchanges of sulfides, nitrogen gas, and CO_2. Each of these parameters can play a role in the carbon, nitrogen, and sulfur interactions of a wetland. To reduce the impact of these variables, long-term data sets were used to develop averages and to assess the potential trends reported. Bearing these difficulties in mind, these data were analyzed to investigate the potential for documenting the occurrence of sulfur-driven autotrophic denitrification within field-scale treatment wetlands.

As was stated, available carbon likely drives the nitrogen removal in most wetlands. The Tres Rios systems appear to be a sink for this parameter. Long-term plots of inlet and outlet TOC concentrations do show there are times when carbon is produced, although the majority of the time, inlet TOC was higher than outlet TOC. Increased TOC concentrations at the outlet may be the result of algal cells being exported from the system, or the result of decay of plant litter and/or incoming wastewater solids. The occurrence of stoichiometric ratios indicating autotrophic influence was generally observed at times when the wetlands were acting as a "sink" for total organic carbon. This may support the theory that when the system is low in available carbon, reduced sulfur species diffuse from sediment storage and act as the electron donor in lieu of carbon. When the systems were exporting TOC, nitrate reduction was occurring, but there was also a decrease in sulfate concentration from inlet to outlet. This may be attributable to an excess of available carbon, e.g. enough to satisfy both sulfate reduction and heterotrophic denitrification demands. There are excursions from these trends and they attest to the difficulty working with dynamic systems.

The long-term average net production of sulfate in three of the four basins is consistent with autotrophic denitrification. However, basin H1 exhibited a net removal of sulfate. This may be a function of attempting to use open-systems to study sulfur dynamics, or it may be due to different carbon loadings from internal plant production and decay. A possible explanation is that vegetation was removed from basin H1 in July 1998 whereas in H2, vegetation was left to decay. This in turn may have resulted in more carbon available for heterotrophic sulfate and nitrate reduction in H2. Since the vegetation was removed in H1, the system had less available carbon and the labile carbon that was present was used for the more energy producing sulfate reduction reactions.

In the Cobble site, a similar difference in sulfate production was also noted. C1 produced almost four times more sulfate than did C2. Again, different carbon loadings may provide a partial explanation. On average C1 was supplied 3 to 4 times more water than C2 because of the lack of a liner in C1.

Nitrate nitrogen was effectively removed in all wetland basins studied for the period of record. This removal was fairly consistent both within wetland basins at the same site, and between the Cobble and Hayfield wetland complexes. Although monitoring data provided stoichiometric ratios that suggest the removal mechanism may be in part due to sulfur-driven autotrophic denitrification, it is difficult to partition that contribution when compared to heterotrophic pathways.

In summary, inlet/outlet sampling and field transect data obtained along the flow path of the wetland systems show nitrate reduction with a commensurate increase in sulfate concentration. At times the stoichiometry was consistent with autotrophic denitrification, whereas at other times it was not. In any case, it would appear that autotrophic denitrification does take place within the wetlands, at least on a transient basis. This is supported by the results of batch testing experiments using sediments obtained from the Tres Rios facilities that produced a stable population of microbes capable of autotrophic denitrification (Nahar et.al., 2000).

If one assumes that autotrophic denitrification is occurring, then this phenomenon provides a plausible explanation for denitrification rates for the Tres Rios wetlands that appear to be independent of vegetation cycles and of organic carbon concentrations, measured as total organic carbon (TOC). This also supports the hypothesis that carbon compounds in wastewater effluents are associated with particulates that must first settle, and then undergo decomposition in the bottom sediments of the wetlands before being available for microbial utilization. Finally, this work adds to the treatment wetland literature in that another nitrate reduction pathway is available in wetland geo-chemical cycles, namely reduced sulfur species acting as electron donors in lieu of carbon compounds in denitrification.

Public Use

Natural wetlands have been becoming more desirable for recreation and educational purposes in recent years. It would appear that treatment wetlands can provide many of the ancillary benefits and features that attract visitors to natural systems. This has certainly been the case at the Demonstration Project facilities. Although located at a wastewater treatment facility, literally hundreds of people, children to adult have purposely spent time at the Tres Rios wetlands. These visitors represent a cross-section of society that ranges from school children to cutting edge research scientists to the casual birder.

Data regarding the total number of visitors and their reasons for frequenting the Tres Rio facilities is incomplete, because often times, visitors showed up without but did not record their name in the guest log. However, the records available are impressive. Since August 1995, over 254 (232, during 1998-2000) people visited the Demonstration Project for the specific purpose of birding. Some of these events were organized by Arizona Game and Fish or the Audubon Society. Liberty Wildlife also used the project to release rehabilitated birds of prey on several occasions.

The majority of the visitors came to the Demonstration Project to tour the wetland facilities and learn about wastewater treatment, reuse, and desert riparian habitat values and functions. These tours included school children, elementary through college level, professional consultants, professionals from land and wildlife resources management agencies, scientists and researchers, and the interested public. In all, over 2,760 people have visited the Demonstration Project since August 1995. For the study period 1998-

2000, almost 1,670 toured the facilities. Ninety-Three of these visitors were from abroad. Countries of origin include: Uzbekistan, Southeast Asia, Mexico, Netherlands, Australia, Philippines, Jordan, Israel, Russia, Czechoslovakia, Great Britain, the United Arab Emirates, and Canada.

A very special class of visitors included the volunteer groups that have constructed public use facilities, cleared and built trails and bridges, planted upland grasses and forbs, and established riparian plantings. In all 23 projects have been completed by 298 people from various volunteer groups such as Boy Scout Troops, Brownies, Military Clubs, and those interested in contributing to their environment.

Discussion of Results

The 1998 –2000 study period was characterized by higher hydraulic loading rates, greater depths, and significant dewatering, reconstruction, and revegetation activities. The systems were in the 3 – 5 year old range and biotic communities have established themselves. These communities, mosquitoes, beavers, and vegetation all produced insight into long-term operation and transferability of wetland systems operated for wastewater treatment and habitat benefits in arid areas. The necessity to manage mosquito breeding within the system influenced the majority of the research and reconfiguration activities during the 1998 – 2000 time period. Major configurational changes were made to both basin form and the vegetation used, both aquatic and riparian because of the mosquito issue. Also identified as a critical issue, is the sustainability of the aquatic vegetation used at Tres Rios. To date, the majority of the emergent macrophytes used at Tres Rios require a disturbance, e.g. basin dewatering, removal of vegetative material, etc. every two to three growing seasons to ensure robust new growth. Beavers and muskrat also have impacted the design and operation of the demonstration facilities, beavers from the standpoint of basin berm integrity and outlet design, and muskrats from the standpoint of herbivory. To summarize, the wetland basins have been pushed operationally during this second research period. As an example, typical HLR's used at wetland treatment systems range 0.08 to 0.16 ft/d (WPCF, 1990) or 0.05 to 0.21 ft/d (Kadlec and Knight, 1996). For this phase of the Demonstration Project, the wetland systems received a range of HLR's varying from 0.1 to over 2.0 ft/d.

Interestingly, water quality did not decline for the majority of the parameters investigated and several actually improved. For example, the % removal of NO_2+NO_3-N improved, even under higher HLR's in basins C2, H1, and H2. CBOD and COD concentrations in the wetland effluents did not degrade appreciably even under these extreme operating conditions. The parameters showing the greatest decline in water quality such as TSS are all associated with algal dynamics. Algal cells that form in the wetlands can be exported along with the surface discharge. These cells will show up analytically as suspended solids, increased BOD, COD, and nutrients. Increased algal growth and hence the impacts that occurred is likely attributable to the reduction in vegetative cover experience by the wetland systems during the 1998 –2000 study period. In some cases, the algal dynamics may have improved the removal of bacteria. In both sites during 1998 – 2000, total Coliform and *E. coli* bacteria populations were reduced over those recorded in 1995 – 1997. As previously discussed, algal photosynthesis influences the carbonate equilibrium in aquatic systems often resulting in high pH values and super saturated D.O. concentrations during daylight hours.

The following text will discuss and put into context some of the findings with respect to basin design, operation, seasonality, sustainability, and regional transferability.

Design Ramifications

Cobble Site Basin C2 Soil Liner

Performance of the simple soil liner used in Cobble basin C2 demonstrates that it is an effective means of reducing infiltration losses in the cobble, sand and gravel matrix of the Salt River channel. Operationally, the liner has withstood dewatering, revegetation, and island construction activities without drastically increasing the loss rate. This should indicate that it is a sustainable and transferable means of lining wetland ponds in the full-scale Tres Rios project and other similar facilities planned for the region.

Leaky Wetland

When surface water conservation is not desired, or infiltration/recharge is a goal, the subsurface investigation of the unlined Cobble site basin C1 indicates that little impacts to groundwater are realized if the supply water is biologically safe. The Subsurface Investigation results indicate that nitrate is effectively removed in the top 1-foot of the wetland bottom due to a very active microbial layer and varying redox conditions. This is very applicable to disinfected and nitrified wastewaters that could be potentially recharged through a treatment wetland system that also afford habitat, educational, and recreation benefits. Not having to line the basins could result in significant cost-savings as conventional liners can cost as much or more than the earthwork needed to create the basins.

Beaver Impacts

Beaver have existed at the sites since the fall of 1996 and their activities have impacted the basin integrity, operations, and water quality, not to mention the aquatic and terrestrial riparian vegetation. Because of their activities, the basin outlets at the Hayfield site basins were redesigned and thoughts given to providing either submerged or broad crested control structures that are less susceptible to being clogged by beaver debris. The beavers also comprised the integrity of wetland berms indicating the need in the full-scale system to minimize the use of above-ground containment structures.

Vector Control

Great gains have been made during the 1998 – 2000 study period at Tres Rios with respect to management of mosquitoes. Changes in basin configuration and vegetative structure have resulted in significant reduction in both adult mosquito counts and larval occurrence in and around the wetland basins. Improved application of larvicides has also been very beneficial. From a design standpoint, less dense but more diverse vegetation improves mosquito control, which also improves the overall habitat value of the wetlands without suffering dramatic reductions in water quality. It also sets the basin dimensions in that widths and locations of densely vegetative zones can be determined by the distance application equipment can effectively distribute control agents.

Operational Ramifications

Increased Hydraulic Loading Rates and Water Quality

Criteria used to operate the Tres Rios Demonstration Wetlands were based on water quality and ecosystem objectives. The hydraulic loading rate or HLR (Q_{in}/Basin Area) levels used at Tres Rios should be applicable to other lightly loaded wetland systems treating nitrified municipal wastewater. Typically, the Tres Rios basins produced the best water quality when receiving a HLR in the range of 2.2 cm/d (0.87 in/day) to 15 cm/d (6.0 in/day). For systems where recharge of the underlying aquifer is desirable, and nitrogen removal is either not necessary due to pretreatment or the source water is completely nitrified a leaky bottom may be provided. In such cases, the Cobble Site subsurface investigation results suggest that loading rates may be increased significantly, up to 25-75 cm/day (10.0 – 30.0 in/day).

Operating Depths

The depth range used at the Tres Rios Demonstration wetlands is typical for most free-water surface treatment wetlands, 15 cm to 46 cm (0.5 to 1.5 ft) in the emergent areas, and this regime would be suitable for other similar systems, including others in the Phoenix Active Management Area (AMA). With respect to water quality, the depth range employed during the Demonstration Project did not have an impact on water quality parameters tested. However, recent research and personal communication suggests that vegetation density may be controlled to some extent by depth. This is of interest for vector control and is likely some basins may be operated at a depth of 61cm to 76 cm (2 to 2.5 feet) to assess this potential.

Together, the depth and hydraulic loading rate determine the hydraulic retention time (HRT) within the wetland. Since the Tres Rios Demonstration Project has been operational, wetland HRT's ranged from as little as 0.5 days in the un-lined basin, to as great as 30 days in some of the lined research cells. This retention time range was adequate for the removal of all pollutants of interest with the exception of phosphorous species. For similar systems desiring nitrogen reduction, these retention times should be adequate. If phosphorous removal is necessary, it is likely that extended retention, e.g. > 40 days will be necessary. This must be balanced with the potential to accumulate salts and by-products of biodegradation within the systems.

Seasonal/Sustainability Considerations

At the Demonstration Project, cottonwood and willow have been the riparian species of choice because both species are native to the region and provide habitat for many of the endemic and migratory species that utilize wetland and riparian systems in the desert southwest. Both species have been successfully established from seed, pole-plantings, and live-trees. To date, most success has been achieved utilizing seed from adjacent mature stands of cottonwood/willow. This method is extremely water intensive and can only be done in areas with a generous supply of irrigation water for the first 2 to 3 years.

Although the Salt River is hydraulically controlled by a system of dams, and hence spring time flooding which is necessary for deposition of new soils and dispersal of riparian seeds, small-scale recruitment of cottonwood and willow may be possible as was achieved at the Tres Rios Demonstration Hayfield Site. There, the seed source was from mature cottonwood and willow stands located on the south side of the site. Prevailing wind patterns distributed the seed over the site and into areas that could be flood irrigated. Lessons learned included the need for an uneven soil surface to strand seeds. Otherwise, seeds would drift and concentrate on the perimeter of the flood irrigated areas and the result was dense, linear stands of trees. In other similar projects, this technique can likely be used to recruit new cottonwood and willow growth if consideration is given to wind patterns, tree placement, and water delivery system configuration during design.

Transferability to Full-Scale and Regional Projects

Vegetation Establishment and Maintenance

Although the original planting method used for the Tres Rios Project Site produced a vegetative cover in less than 120 days, there may be less rigorous means available that provides for a more sustainable system. Originally, the Tres Rios basins were planted using a small section of tuber and shoot, placed on 3-foot centers in staggered rows, and then back-filled with slow release fertilizer. This produced 90% vegetative cover in less than 120 days, necessary for meeting the time-line of the Demonstration Project. However, as the systems matured, the fertilized bulrush bolted and lodged (grew too fast/large for structural support system and subsequently fell). This set-up vector and nuisance conditions and also prevented re-growth in subsequent years. To re-establish this vegetation, the dead material had to be removed. To prevent rapid filling in of the basins with dead bulrush, the revegetation project planted bulrush in large clumps (1 – 2 meter diameter) and spaced them at 7.6 to 10.5 m centers. This allowed for more time before vegetation removal needed to be conducted and maintained open-space in the emergent areas over time. This contributed to successful management of mosquito breeding in those sites. Unfortunately, the species currently used still need disturbance on a 2 to 3 year cycle to achieve vigorous regrowth.

For other systems in the Phoenix area planning to use bulrush as their primary wetland vegetation, they should keep in mind the life cycling of this type of material and consider the use of *Scirpus californicus* (giant bulrush) which may not need frequent disturbance. Bulrush thrives on periodic disturbance. Observation in the Salt and Gila rivers has shown that native bulrush stands occur on the bank margins, and around the confluence points where turbulent flows periodically disturb the bottom material. In fact, areas of the Tres Rios Demonstration wetlands that suffered large die-backs of vegetation, when physically disturbed were surrounded with thriving new-growth bulrush. If a bulrush monoculture is to be used, it is likely, that some type of vegetation removal or disturbance will be necessary every 2 to 3 growing seasons to maintain healthy stands. This is another good reason to consider a broad assemblage of macrophytes when planting the Full-Scale Tres Rios wetland features, as this may increase the time before vegetation maintenance is required.

Outlets used at the Tres Rios Demonstration Wetlands were designed to provide very accurate flow measurements for the purpose of the study. They consist of 60° V-notch weirs and an array of skimmer boards. These have worked well for the Demonstration Project, but were not recommended for the full-scale basins because they concentrate the outlet flows to a single point, which can be clogged or obstructed easily by wildlife or debris flows. Instead, broad-crested outlets or those with multiple submerged and/or perforated risers are used that draw water in from the sides, instead of directly into the outlet works. These configurations dampen/reduce noises and allow beavers to build debris dams immediately in front of the outlet works while still maintaining control of the water surface elevation and discharge rate.

On any restoration project, flow measurement is important in developing an accurate water balance. A wide variety of flow measurement technologies exist. The selection of measurement device is typically a factor of the cost of technology versus the need for accurate data. The Demonstration Project utilizes magnetic flow meters on the influent supply lines for continuous flow measurement with a high degree of accuracy. The problems associated with closing the hydrologic balance at the demonstration facilities during the 1998-2000 research phase was not so much due to errors in reading the flow meters, rather they are more closely associated with a lack of achieving steady-state flow to the wetland basins because of construction at the conventional treatment plant and pump facilities.

Basin Configuration for Vector Control and Mammal Management

The Demonstration Project found that basin size should be constrained by operational needs such as retention time (*i.e.* desired water quality), vegetation management, vector monitoring and control. If the designer adheres to common aspect ratios (length: widths) of 3 to 7, the desired surface area of the basin and width will determine the necessary length of the basin. The operating depths used in the emergent areas of Tres Rios have fluctuated between 15 cm and 61 cm (0.5 and 2.0 ft). This range is suitable for most constructed wetland applications and, as such, should also be appropriate for similar projects in the Phoenix AMA.

For the past two years, Tres Rios has been assessing greater depths in an attempt to improve vector control and manage vegetation densities. Deep-Zone depths used at Tres Rios ranged from approximately 1 m to 1.3m (3.0 to 4.0 feet). Although this was enough to discourage vegetation from migrating into these zones, some question the sustainability of these features because they can silt up or clog with detritus material. As a result, Demonstration basins needing reconstruction and or the full-scale wetland basins, were to be outfitted with deep-zones having a depth of 1.4m to 1.5m (4.5 to 5.0 feet) below the level of the emergent areas.

The construction method used to create the Tres Rios basins consisted of establishing above-grade berms for containment. Over the course of the project, the integrity of wetland berms was compromised by wildlife activity. Basins should be constructed downward, into existing soils instead of using containment dikes. If above-grade containment, they should be armored and the tops have a minimum width of 2.5 m (8 ft), preferably closer to 3.65 m (12 ft), so that maintenance and monitoring crews can access the entire wetland perimeter.

Future Research Needs

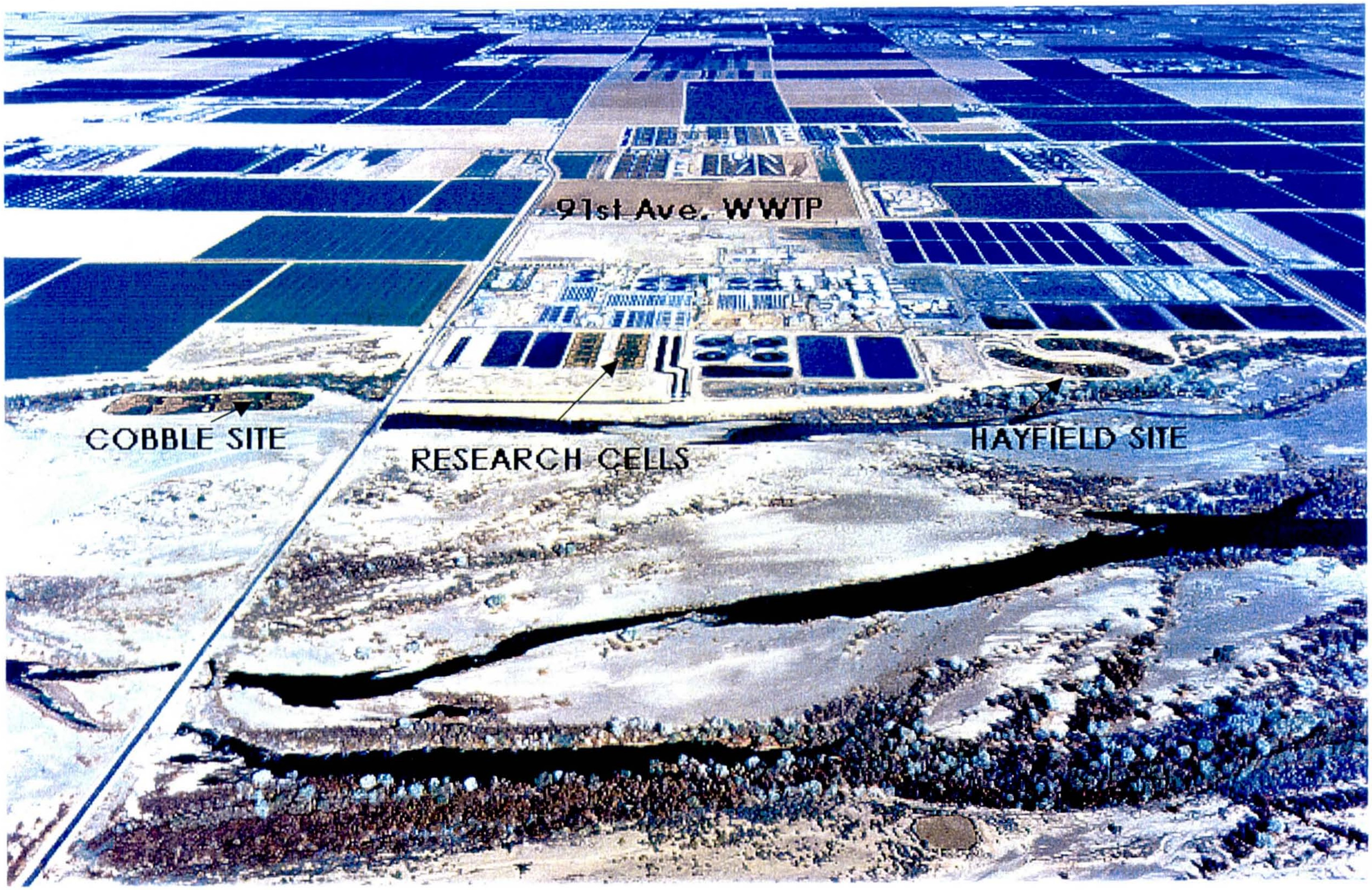
1) Vegetation sustainability needs to be assessed with respect to the aquatic macrophytes used. The goals of such a study should look at vegetation type, species, and establishment. Further, some assessment needs to be made of the impact herbivores have upon vegetation fitness, survival, and life-cycling.
2) Work should also continue with respect to investigating the fate of trace organic compounds and pharmaceuticals with respect to their impact on biota frequenting or residing within the wetland complexes.
3) More work should also be focused upon design of hydraulic and containment structures with respect to mammal activities, in particular beaver.
4) Continued work regarding vector control is also needed. Although control of breeding within the basins has apparently been achieved, larvicide material and application costs need to be minimized prior to implementing the full-scale facilities.

Appendices

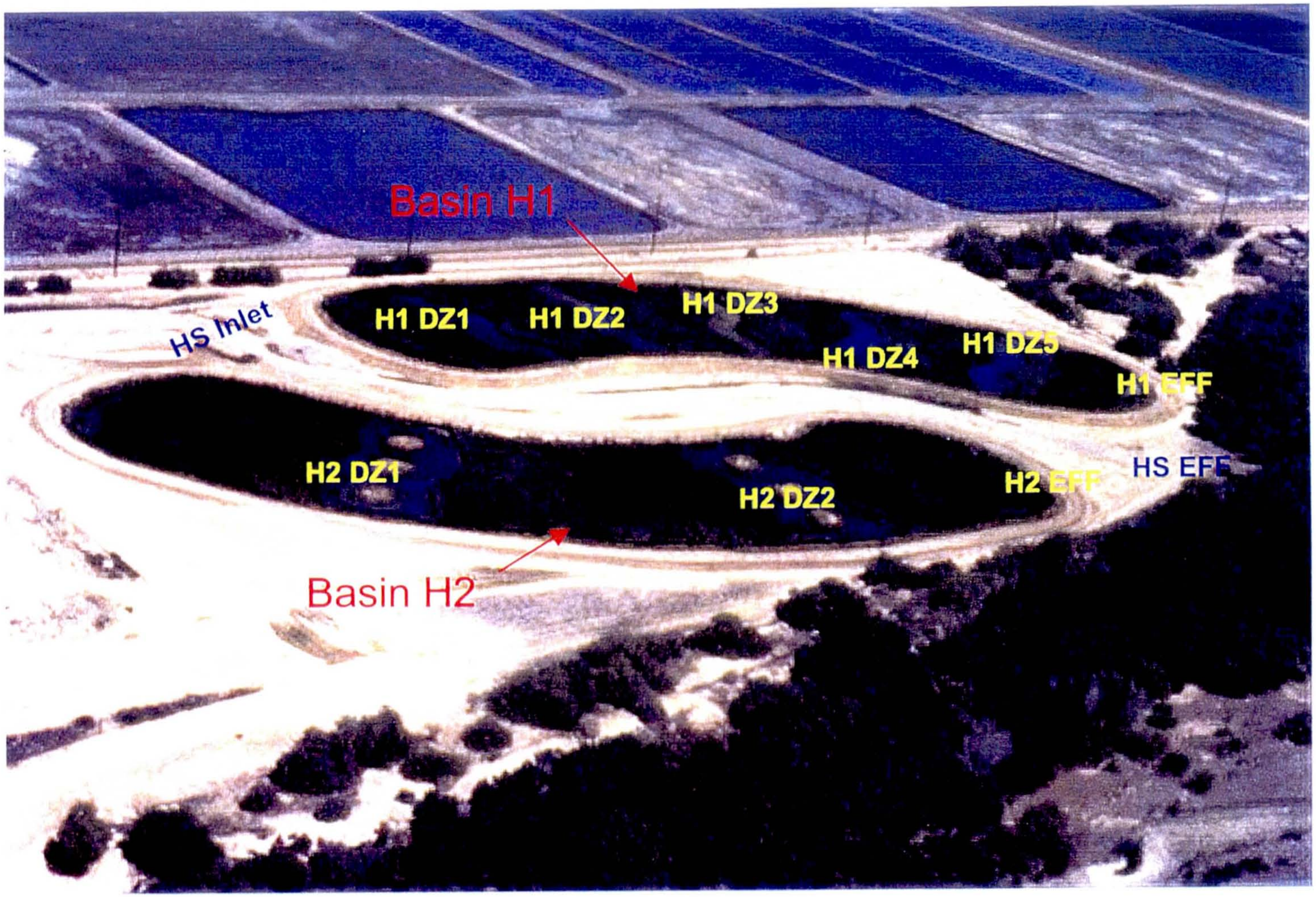
Appendix A

Aerial Site Map
And
Sample Points

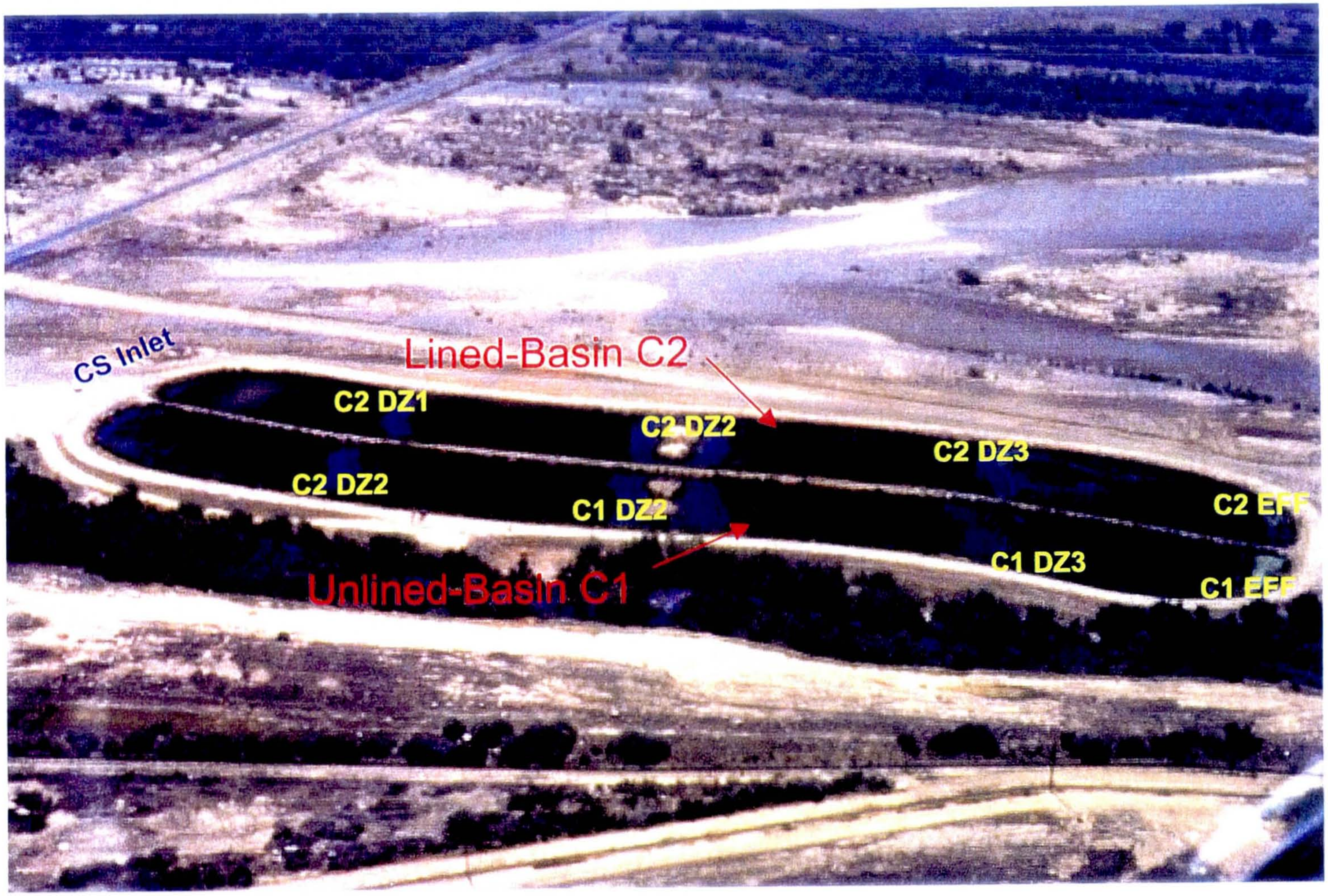
TRES RIOS DEMONSTRATION PROJECT WETLAND FACILITIES
SITE MAP



Hayfield Site



Cobble Site


CS Inlet
Lined-Basin C2
C2 DZ1
C2 DZ2
C2 DZ3
C2 DZ2
C1 DZ2
C2 EFF
C1 DZ3
C1 EFF
Unlined-Basin C1

Appendix B

Hydraulics

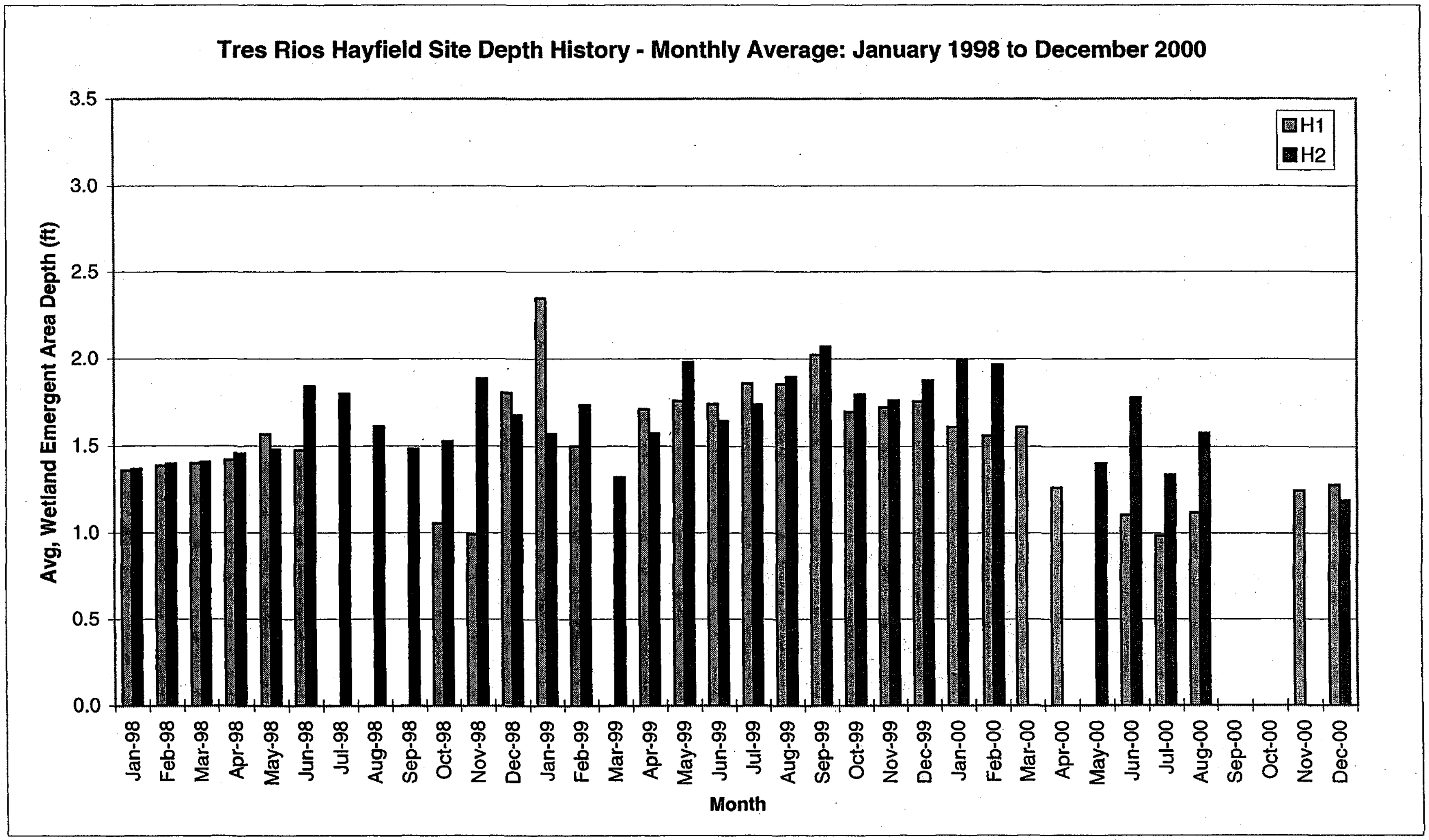
Cobble and Hayfield Sites Operating Depths
Date Period: January 1998 to December 2000

Location	Jan-98	Feb-98	Mar-98	Apr-98	May-98	Jun-98	Jul-98	Aug-98	Sep-98	Oct-98	Nov-98	Dec-98
C1	1.25	1.28	BOS	BOS	BOS	BOS	BOS	BOS	BOS	2.32	2.11	1.99
C2	1.13	1.11	BOS	BOS	BOS	BOS	BOS	NR	NR	1.29	1.40	1.29
H1	1.36	1.39	1.40	1.42	1.57	1.47	BOS	BOS	BOS	1.05	0.99	1.80
H2	1.37	1.40	1.41	1.46	1.48	1.84	1.80	1.61	1.48	1.53	1.89	1.68

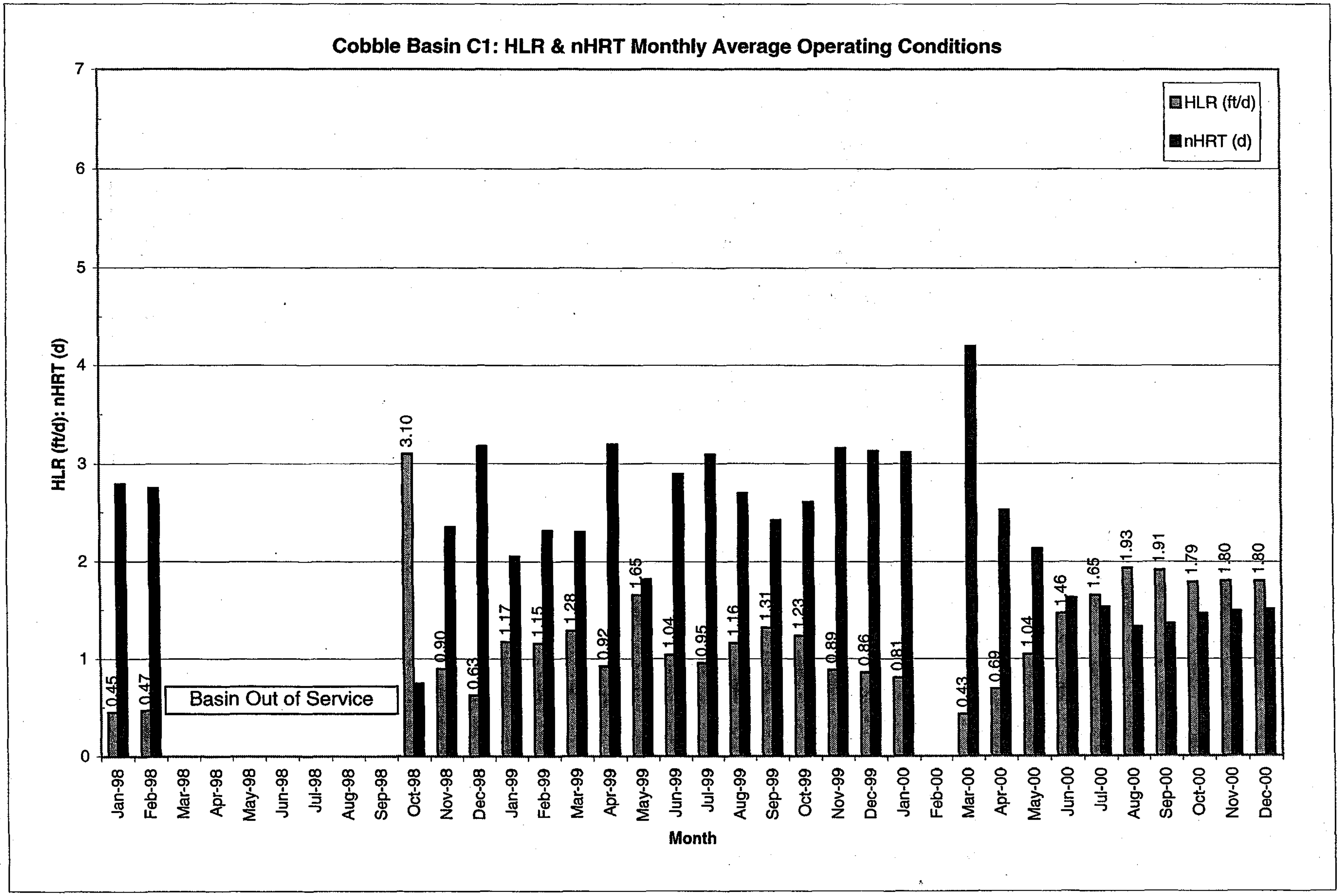
Location	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-99	Nov-99	Dec-99
C1	2.40	2.67	2.95	2.94	2.99	2.99	2.95	3.12	3.18	3.21	2.79	2.69
C2	1.64	1.84	2.01	2.20	1.94	2.11	2.16	2.26	2.22	2.21	2.04	1.89
H1	2.35	1.50	***Pumps***	1.71	1.76	1.74	1.86	1.85	2.02	1.70	1.72	1.76
H2	1.57	1.73	1.32	1.57	1.98	1.64	1.74	1.90	2.07	1.80	1.76	1.88

Location	Jan-00	Feb-00	Mar-00	Apr-00	May-00	Jun-00	Jul-00	Aug-00	Sep-00	Oct-00	Nov-00	Dec-00
C1	2.52	2.44	1.80	1.75	2.23	2.38	2.53	2.57	2.60	2.61	2.68	2.71
C2	1.61	1.61	1.56	1.87	1.54	1.39	1.38	1.40	1.38	1.40	1.36	1.35
H1	1.61	1.56	1.61	1.26	NR	1.11	0.98	1.12	NR	BOS	1.25	1.28
H2	1.99	1.97	NR	NR	1.40	1.78	1.34	1.58	NR	BOS	NR	1.19

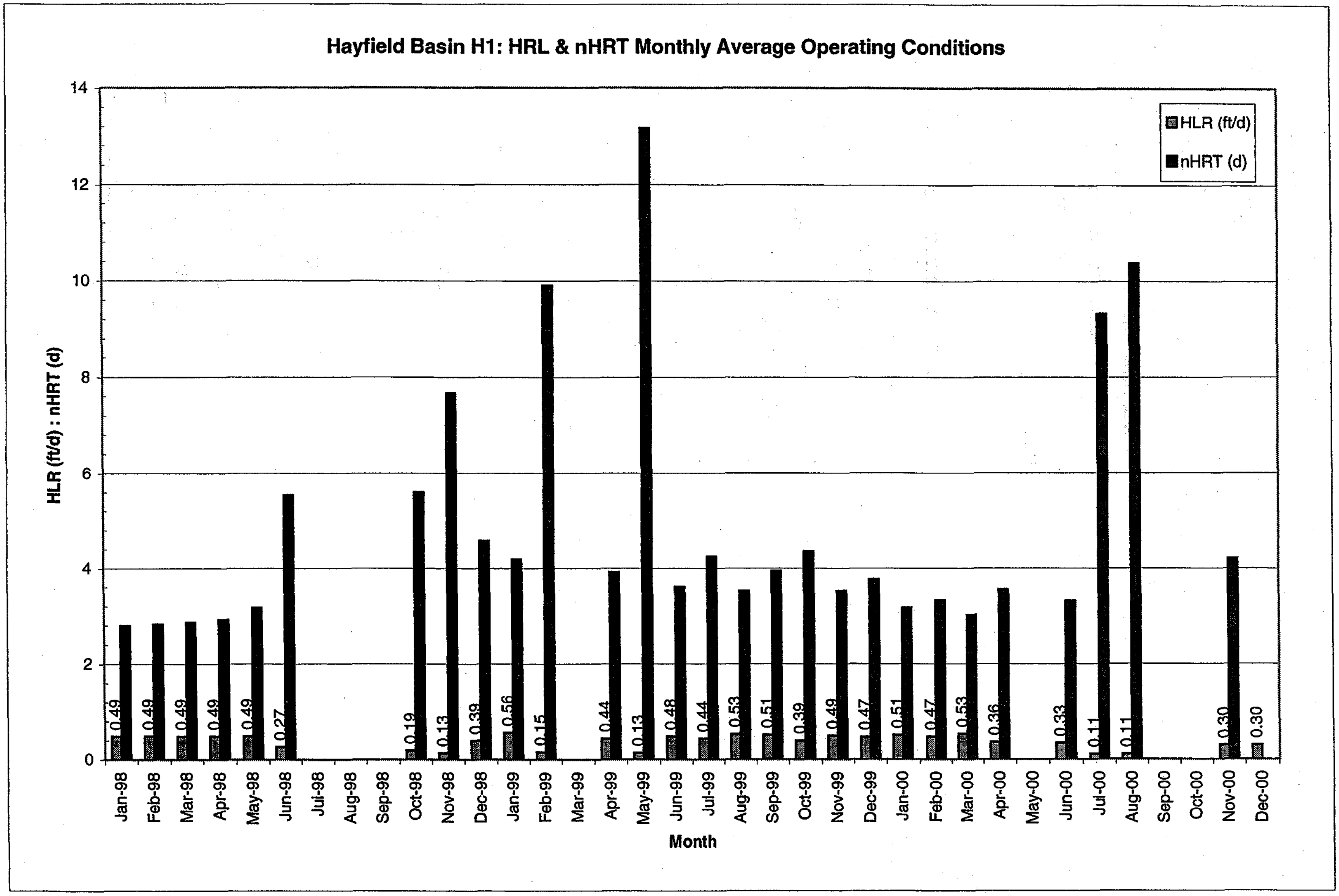
BOS = Basin out of Service
NR = Data Not Recorded



Tres Rios Hayfield Site Depth History - Monthly Average: January 1998 to December 2000
Avg, Wetland Emergent Area Depth (ft)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
H1
H2
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Month



Cobble Basin C1: HLR & nHRT Monthly Average Operating Conditions
HLR (ft/d)
nHRT (d)
HLR (ft/d); nHRT (d)
Basin Out of Service
0.45
0.47
3.10
0.90
0.63
1.17
1.15
1.28
0.92
1.65
1.04
0.95
1.16
1.31
1.23
0.89
0.86
0.81
0.43
0.69
1.04
1.46
1.65
1.93
1.91
1.79
1.80
1.80
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Month



Hayfield Basin H1: HRL & nHRT Monthly Average Operating Conditions
HLR (ft/d)
nHRT (d)
HLR (ft/d) : nHRT (d)
Month
0
2
4
6
8
10
12
14
0.49
0.49
0.49
0.49
0.49
0.27
0.19
0.13
0.39
0.56
0.15
0.44
0.13
0.48
0.44
0.53
0.51
0.39
0.49
0.47
0.51
0.47
0.53
0.36
0.33
0.11
0.11
0.30
0.30
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
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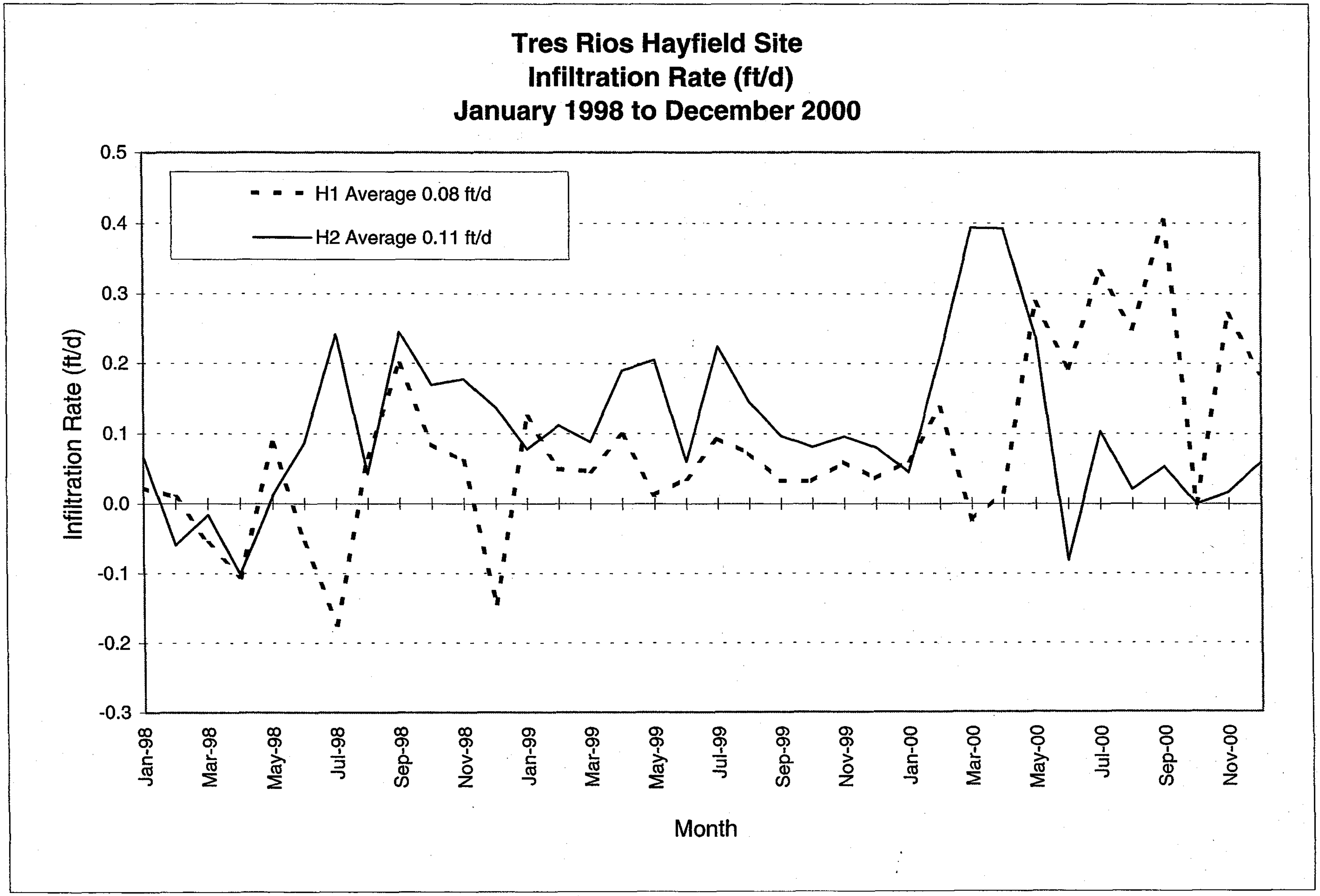
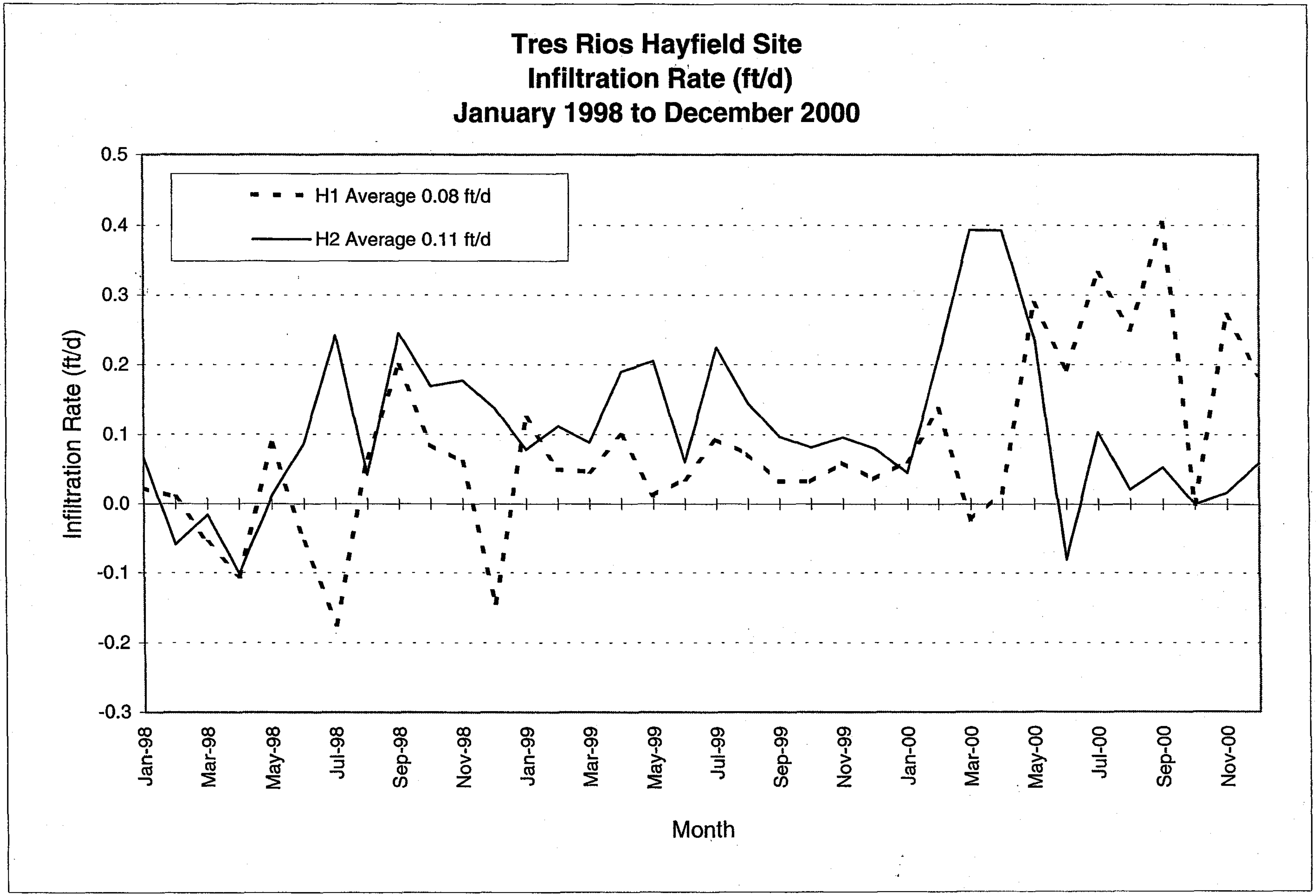
Sep-00
Oct-00
Nov-00
Dec-00


Tres Rios Hayfield Site
Infiltration Rate (ft/d)
January 1998 to December 2000
H1 Average 0.08 ft/d
H2 Average 0.11 ft/d
Infiltration Rate (ft/d)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Month



Tres Rios Hayfield Site
Infiltration Rate (ft/d)
January 1998 to December 2000
H1 Average 0.08 ft/d
H2 Average 0.11 ft/d
Infiltration Rate (ft/d)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Month

Appendix C

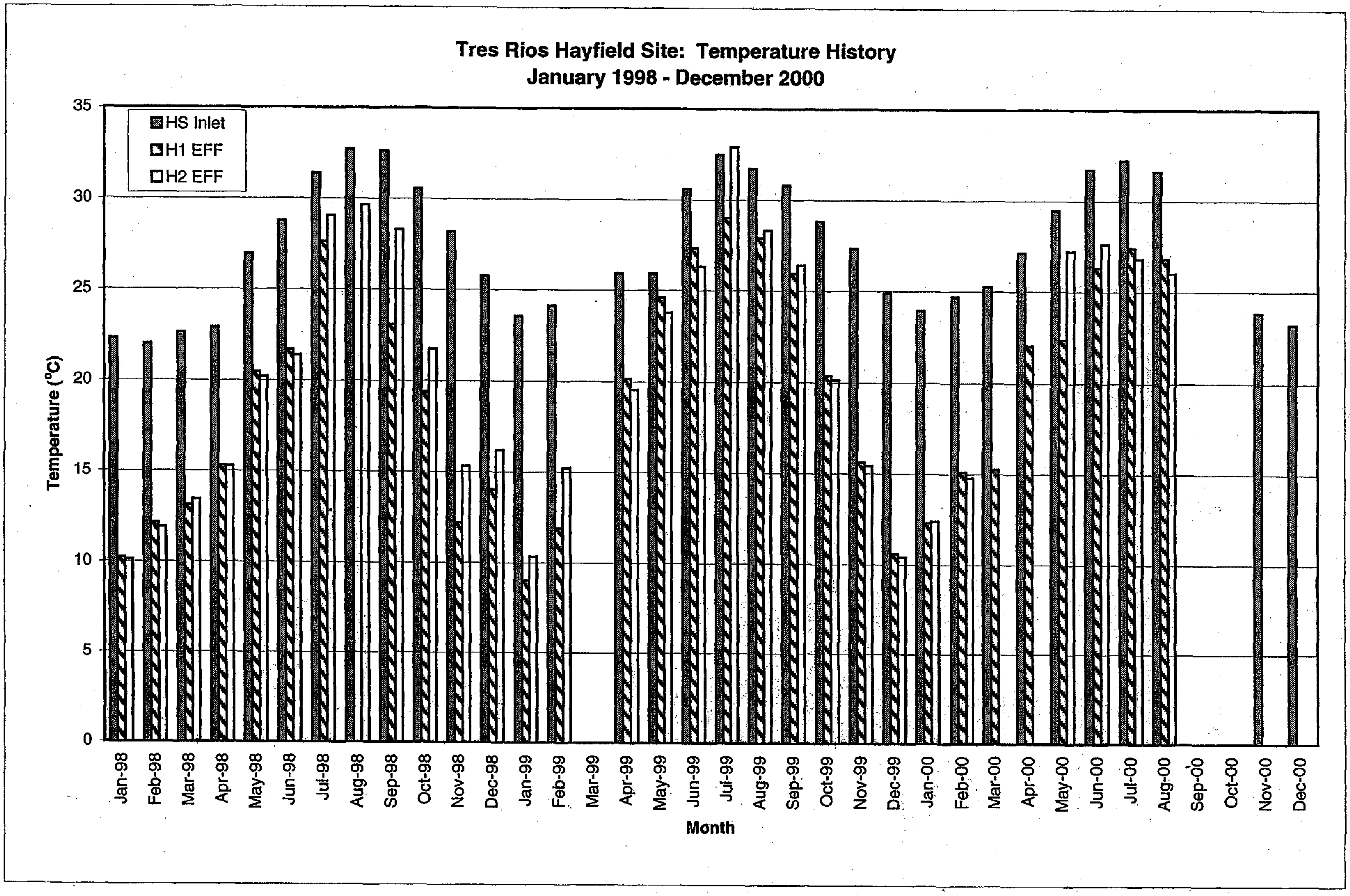
pH
Temperature
Dissolved Oxygen
Conductivity

Tres Rios Demonstration Project
Monthly Average Influent and Effluent Temperatures
January 1998 - December 2000

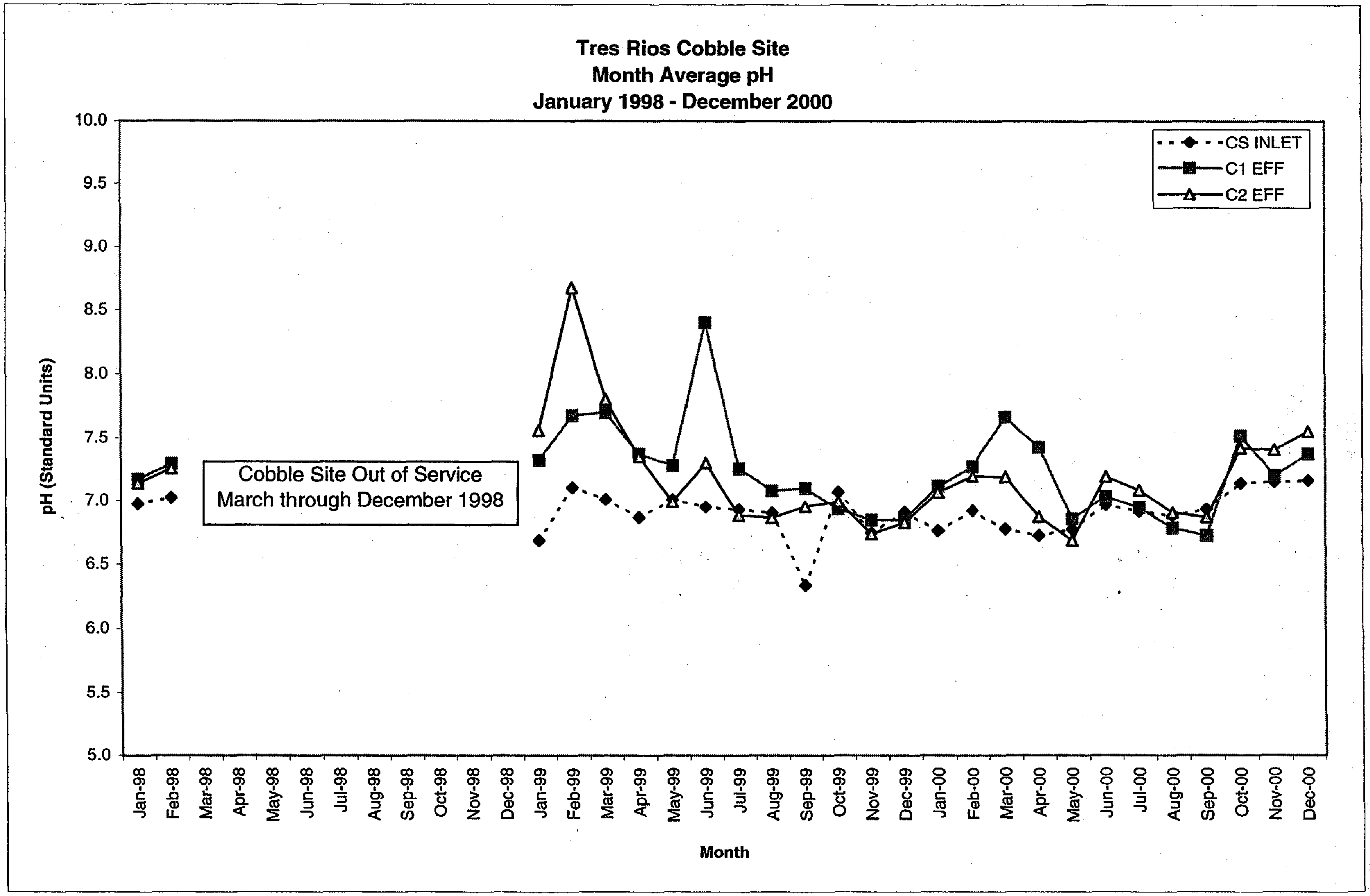
Sample Date	CS Inlet	C1 EFF	C2 EFF
	Temp. (°C) Monthly Avg.		
Jan-98	21.7	10.2	9.0
Feb-98	21.6	10.2	10.2
Mar-98	BOS	BOS	BOS
Apr-98	BOS	BOS	BOS
May-98	BOS	BOS	BOS
Jun-98	BOS	BOS	BOS
Jul-98	BOS	BOS	BOS
Aug-98	BOS	BOS	BOS
Sep-98	BOS	BOS	BOS
Oct-98	BOS	BOS	BOS
Nov-98	BOS	BOS	BOS
Dec-98	BOS	BOS	BOS
Jan-99	23.4	12.7	9.6
Feb-99	23.5	16.1	13.2
Mar-99	26.4	24.0	20.4
Apr-99	25.9	20.8	19.2
May-99	25.6	25.2	22.9
Jun-99	32.5	30.6	26.9
Jul-99	32.5	30.9	29.0
Aug-99	31.9	30.2	28.4
Sep-99	31.4	28.8	27.1
Oct-99	30.0	24.8	23.3
Nov-99	27.5	16.6	16.4
Dec-99	25.1	12.5	11.0
Jan-00	24.3	15.6	13.3
Feb-00	24.7	17.0	15.8
Mar-00	25.3	18.1	17.6
Apr-00	27.2	20.7	21.9
May-00	29.4	25.6	25.2
Jun-00	31.7	29.5	28.1
Jul-00	32.1	29.9	28.3
Aug-00	31.7	26.9	25.9
Sep-00	32.9	27.2	25.3
Oct-00	31.6	25.5	24.9
Nov-00	25.9	17.9	15.4
Dec-00	23.5	17.6	14.4
Average	27.7	21.7	20.1
Maximum	32.9	30.9	29.0
Minimum	21.6	10.2	9.0

Sample Date	HS Inlet	H1 EFF	H2 EFF	HS EFF
	Temp. (°C) Monthly Avg.			
Jan-98	22.3	10.2	10.1	10.5
Feb-98	22.0	12.1	11.9	12.1
Mar-98	22.6	13.1	13.4	13.4
Apr-98	22.9	15.3	15.3	15.4
May-98	26.9	20.5	20.2	20.1
Jun-98	28.8	21.7	21.4	21.2
Jul-98	31.4	27.6	29.1	28.7
Aug-98	32.7	NR	29.7	30.6
Sep-98	32.6	23.1	28.3	29.8
Oct-98	30.6	19.4	21.7	24.5
Nov-98	28.2	12.2	15.3	23.4
Dec-98	25.7	14.0	16.2	16.0
Jan-99	23.6	9.0	10.3	17.4
Feb-99	24.1	11.9	15.2	18.7
Mar-99	NR	NR	NR	NR
Apr-99	25.9	20.2	19.6	21.5
May-99	25.9	24.6	23.8	22.6
Jun-99	30.6	27.3	26.3	28.0
Jul-99	32.5	29.0	32.9	31.0
Aug-99	31.7	27.9	28.3	29.2
Sep-99	30.8	25.9	26.4	27.9
Oct-99	28.8	20.4	20.2	23.1
Nov-99	27.3	15.6	15.4	16.0
Dec-99	24.9	10.6	10.4	10.7
Jan-00	23.9	12.3	12.4	9.9
Feb-00	24.7	15.1	14.8	NR
Mar-00	25.3	15.3	NR	NR
Apr-00	27.1	22.0	NR	NR
May-00	29.5	22.4	27.2	NR
Jun-00	31.7	26.3	27.6	NR
Jul-00	32.2	27.4	26.8	NR
Aug-00	31.7	26.8	26.0	NR
Sep-00	NR	NR	NR	NR
Oct-00	NR	NR	NR	NR
Nov-00	23.8	NR	NR	NR
Dec-00	23.2	NR	NR	NR
Average	27.5	19.3	20.6	20.9
Maximum	32.7	29.0	32.9	31.0
Minimum	22.0	9.0	10.1	9.9

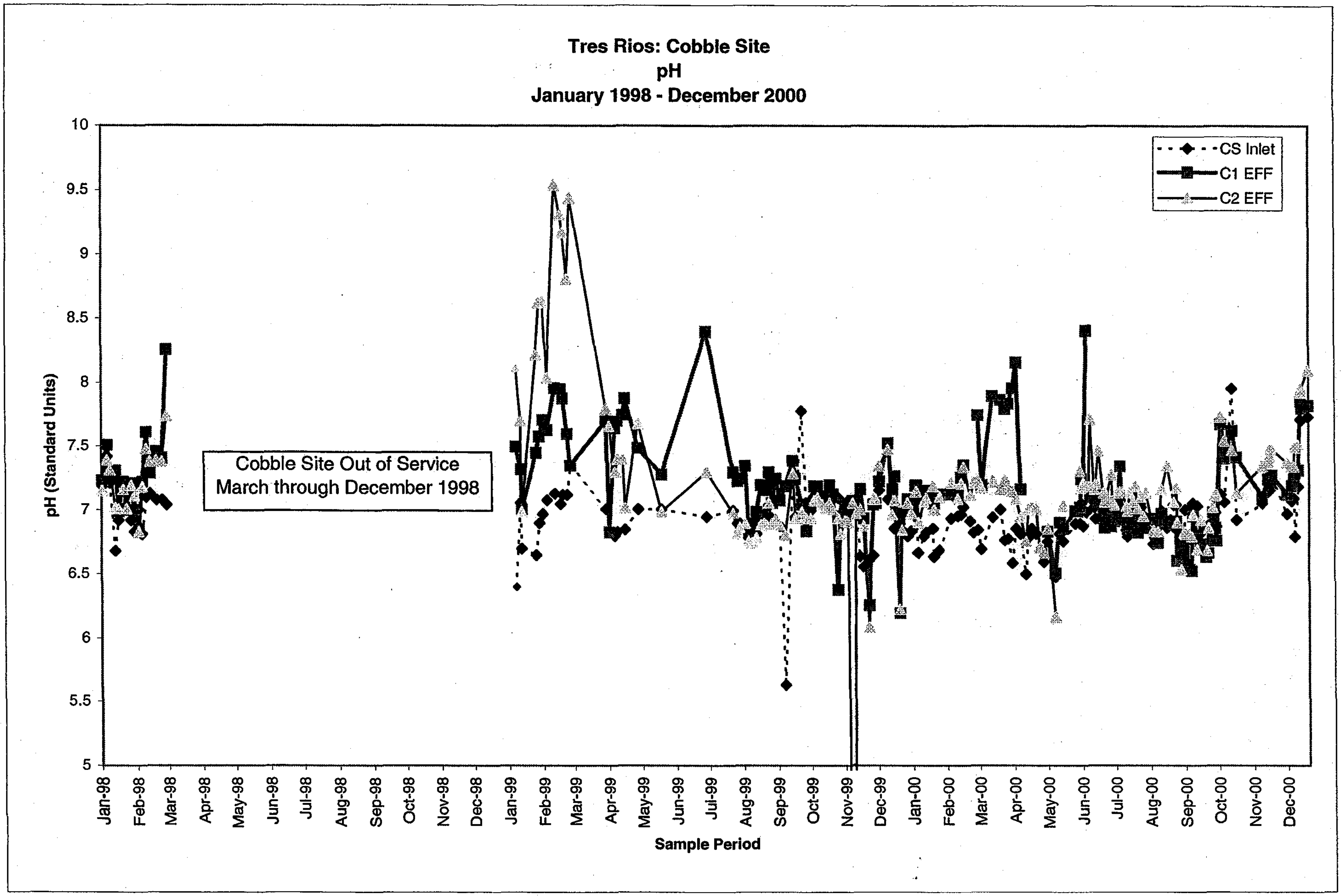
BOS = Basin Out of Service
NR = Data Not Recorded



Tres Rios Hayfield Site: Temperature History
January 1998 - December 2000
HS Inlet
H1 EFF
H2 EFF
Temperature (°C)
0
5
10
15
20
25
30
35
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Month



Tres Rios Cobble Site
Month Average pH
January 1998 - December 2000
pH (Standard Units)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
CS INLET
C1 EFF
C2 EFF
Cobble Site Out of Service
March through December 1998
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Month



Tres Rios: Cobble Site
pH
January 1998 - December 2000
pH (Standard Units)
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
CS Inlet
C1 EFF
C2 EFF
Cobble Site Out of Service
March through December 1998
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Sample Period

Tres Rios Demonstration Project
Monthly Average Influent and Effluent Dissolved Oxygen
January 1998 - December 2000

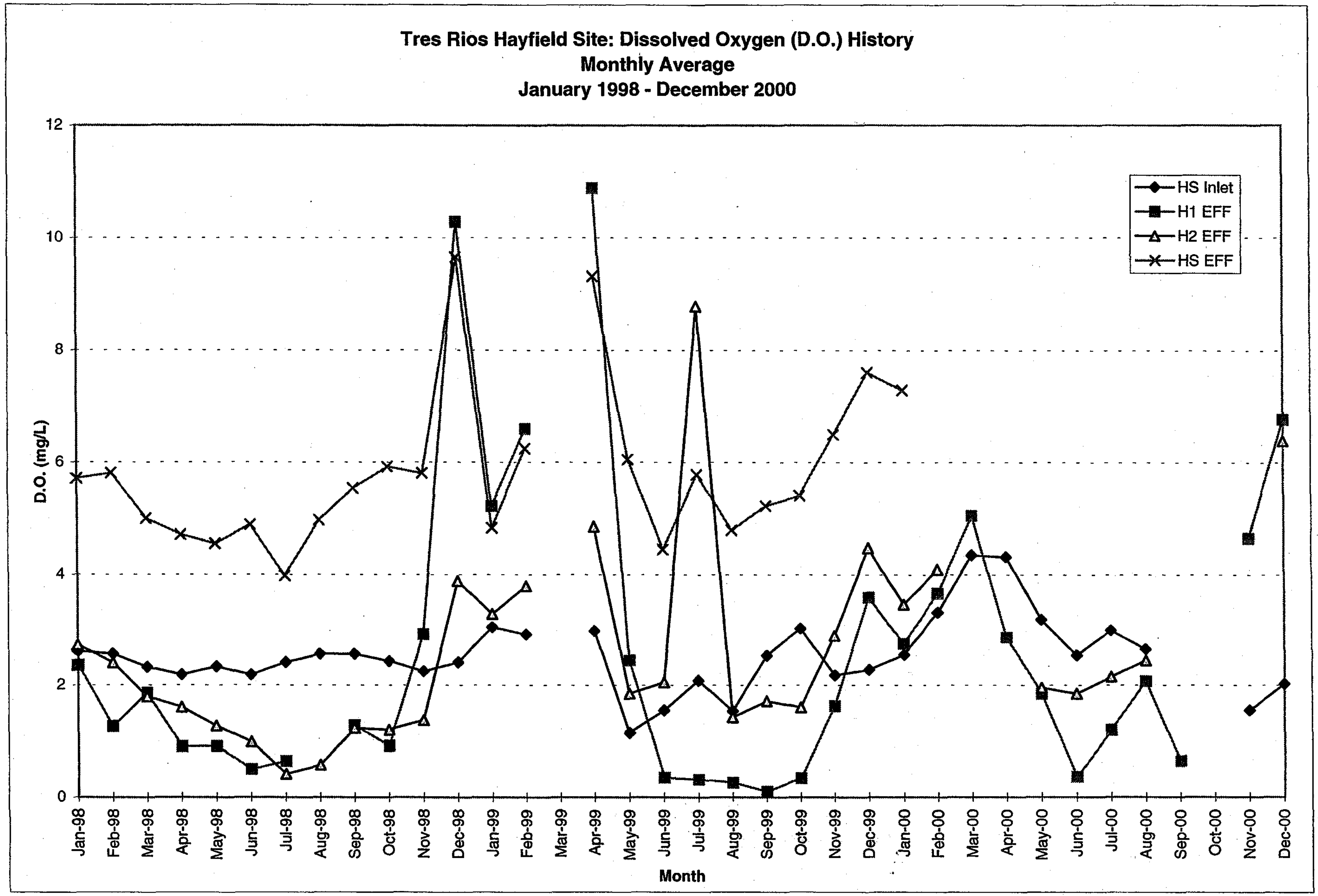
D.O. (mg/L) Monthly Average

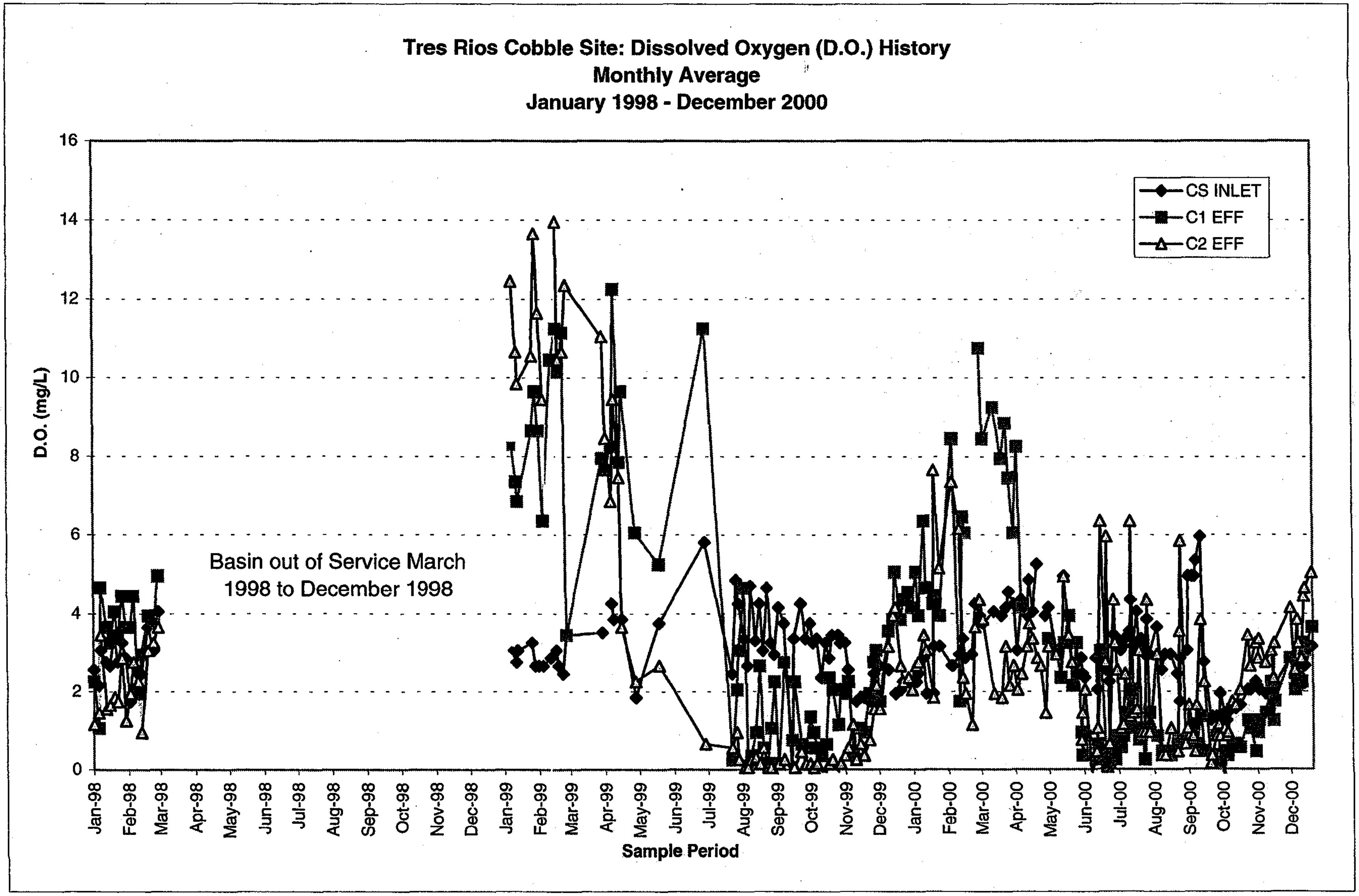
Sample Date	CS Inlet	C1 EFF	C2 EFF
Jan-98	3.0	3.5	2.0
Feb-98	2.9	3.8	2.7
Mar-98	BOS	BOS	BOS
Apr-98	BOS	BOS	BOS
May-98	BOS	BOS	BOS
Jun-98	BOS	BOS	BOS
Jul-98	BOS	BOS	BOS
Aug-98	BOS	BOS	BOS
Sep-98	BOS	BOS	BOS
Oct-98	BOS	BOS	BOS
Nov-98	BOS	BOS	BOS
Dec-98	BOS	BOS	BOS
Jan-99	3.1	8.3	11.6
Feb-99	3.0	8.9	11.6
Mar-99	3.7	8.1	11.2
Apr-99	3.6	8.8	6.5
May-99	3.9	5.4	2.8
Jun-99	6.0	11.4	0.8
Jul-99	4.0	1.9	0.7
Aug-99	3.7	1.6	0.3
Sep-99	3.3	1.3	0.3
Oct-99	3.4	1.4	0.2
Nov-99	2.1	1.8	1.0
Dec-99	2.4	4.0	2.9
Jan-00	2.7	4.8	3.9
Feb-00	3.4	6.8	4.0
Mar-00	4.3	8.2	2.8
Apr-00	4.4	6.4	2.9
May-00	3.3	2.7	2.9
Jun-00	2.9	0.8	2.8
Jul-00	3.6	1.3	2.3
Aug-00	2.9	0.8	2.0
Sep-00	3.4	0.9	1.4
Oct-00	1.9	0.7	2.1
Nov-00	2.2	1.6	3.1
Dec-00	2.8	2.9	4.0
Average	3.3	4.2	3.4
Maximum	6.0	11.4	11.6
Minimum	1.9	0.7	0.2

D.O. (mg/L) Monthly Average

Sample Date	HS Inlet	H1 EFF	H2 EFF	HS EFF
Jan-98	2.8	2.5	2.9	5.9
Feb-98	2.7	1.4	2.6	6.0
Mar-98	2.5	2.0	1.9	5.1
Apr-98	2.3	1.1	1.8	4.9
May-98	2.5	1.1	1.4	4.7
Jun-98	2.3	0.7	1.1	5.0
Jul-98	2.6	0.8	0.6	4.1
Aug-98	2.7	NR	0.7	5.1
Sep-98	2.7	1.4	1.4	5.7
Oct-98	2.6	1.1	1.4	6.1
Nov-98	2.4	3.1	1.5	6.0
Dec-98	2.6	10.4	4.0	9.8
Jan-99	3.2	5.4	3.4	5.0
Feb-99	3.1	6.8	3.9	6.4
Mar-99	NR	NR	NR	NR
Apr-99	3.1	11.0	5.0	9.5
May-99	1.3	2.6	2.0	6.2
Jun-99	1.7	0.5	2.2	4.6
Jul-99	2.2	0.5	8.9	5.9
Aug-99	1.7	0.4	1.6	4.9
Sep-99	2.7	0.3	1.9	5.4
Oct-99	3.2	0.5	1.8	5.6
Nov-99	2.3	1.8	3.0	6.7
Dec-99	2.4	3.7	4.6	7.8
Jan-00	2.7	2.9	3.6	7.5
Feb-00	3.5	3.8	4.2	NR
Mar-00	4.5	5.2	BOS	NR
Apr-00	4.5	3.0	BOS	NR
May-00	3.3	2.0	2.1	NR
Jun-00	2.7	0.5	2.0	NR
Jul-00	3.1	1.4	2.3	NR
Aug-00	2.8	2.2	2.6	NR
Sep-00	BOS	0.8	BOS	NR
Oct-00	BOS	BOS	BOS	NR
Nov-00	1.7	4.8	BOS	NR
Dec-00	2.2	6.9	6.5	NR
Average	2.7	2.8	2.8	6.0
Maximum	4.5	11.0	8.9	9.8
Minimum	1.3	0.3	0.6	4.1

BOS = Basin Out of Service
NR = Data Not Recorded


Tres Rios Hayfield Site: Dissolved Oxygen (D.O.) History
Monthly Average
January 1998 - December 2000
D.O. (mg/L)
0
2
4
6
8
10
12
HS Inlet
H1 EFF
H2 EFF
HS EFF
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Month



Tres Rios Cobble Site: Dissolved Oxygen (D.O.) History
Monthly Average
January 1998 - December 2000
D.O. (mg/L)
16
14
12
10
8
6
4
2
0
CS INLET
C1 EFF
C2 EFF
Basin out of Service March 1998 to December 1998
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Dec-00
Sample Period

Tres Rios Demonstration Project
Monthly Average Influent and Effluent Conductivity
January 1998 - December 2000

Conductivity (uS) Monthly Average

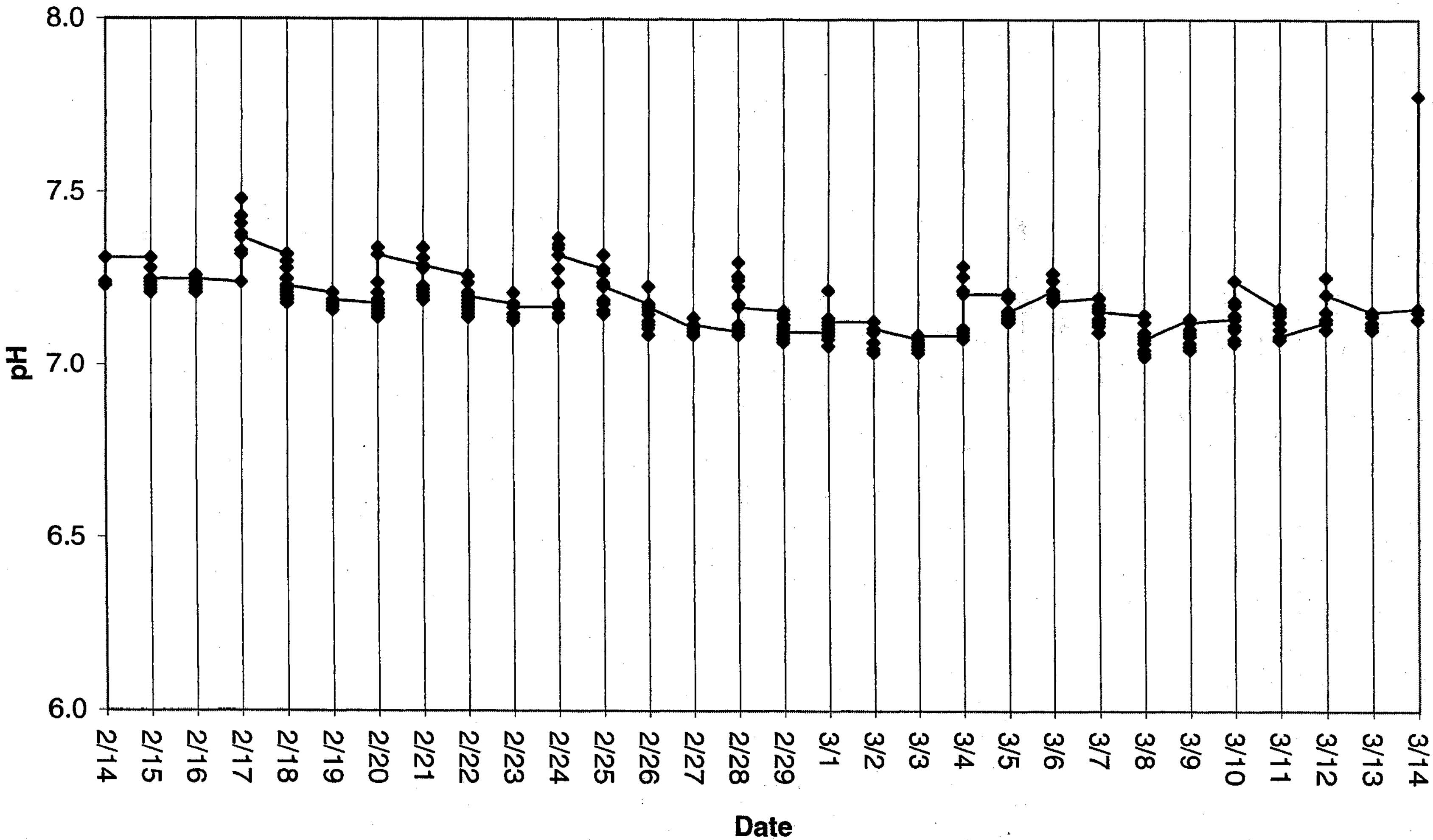
Sample Date	CS Inlet	C1 EFF	C2 EFF
Jan-98	1413	1420	1329
Feb-98	1398	1259	1322
Mar-98	BOS	BOS	BOS
Apr-98	BOS	BOS	BOS
May-98	BOS	BOS	BOS
Jun-98	BOS	BOS	BOS
Jul-98	BOS	BOS	BOS
Aug-98	BOS	BOS	BOS
Sep-98	BOS	BOS	BOS
Oct-98	BOS	BOS	BOS
Nov-98	BOS	BOS	BOS
Dec-98	BOS	BOS	BOS
Jan-99	1356	1336	1328
Feb-99	1237	1271	1226
Mar-99	1498	1517	1494
Apr-99	1475	1493	1478
May-99	1483	1328	1336
Jun-99	1670	1693	1642
Jul-99	1611	1622	1592
Aug-99	1638	1671	1657
Sep-99	1675	1646	1632
Oct-99	1597	1574	1563
Nov-99	1387	1407	1370
Dec-99	1351	1321	1314
Jan-00	1349	1327	1316
Feb-00	1415	1326	1342
Mar-00	1495	1414	1376
Apr-00	1529	1562	1395
May-00	1598	1658	1678
Jun-00	1713	1725	1746
Jul-00	1774	1769	1776
Aug-00	1779	1755	1742
Sep-00	1672	1775	1765
Oct-00	1794	1826	1805
Nov-00	1966	1929	1894
Dec-00	1779	1736	1712
Average	1564	1552	1532
Maximum	1966	1929	1894
Minimum	1237	1259	1226

Conductivity (uS) Monthly Average

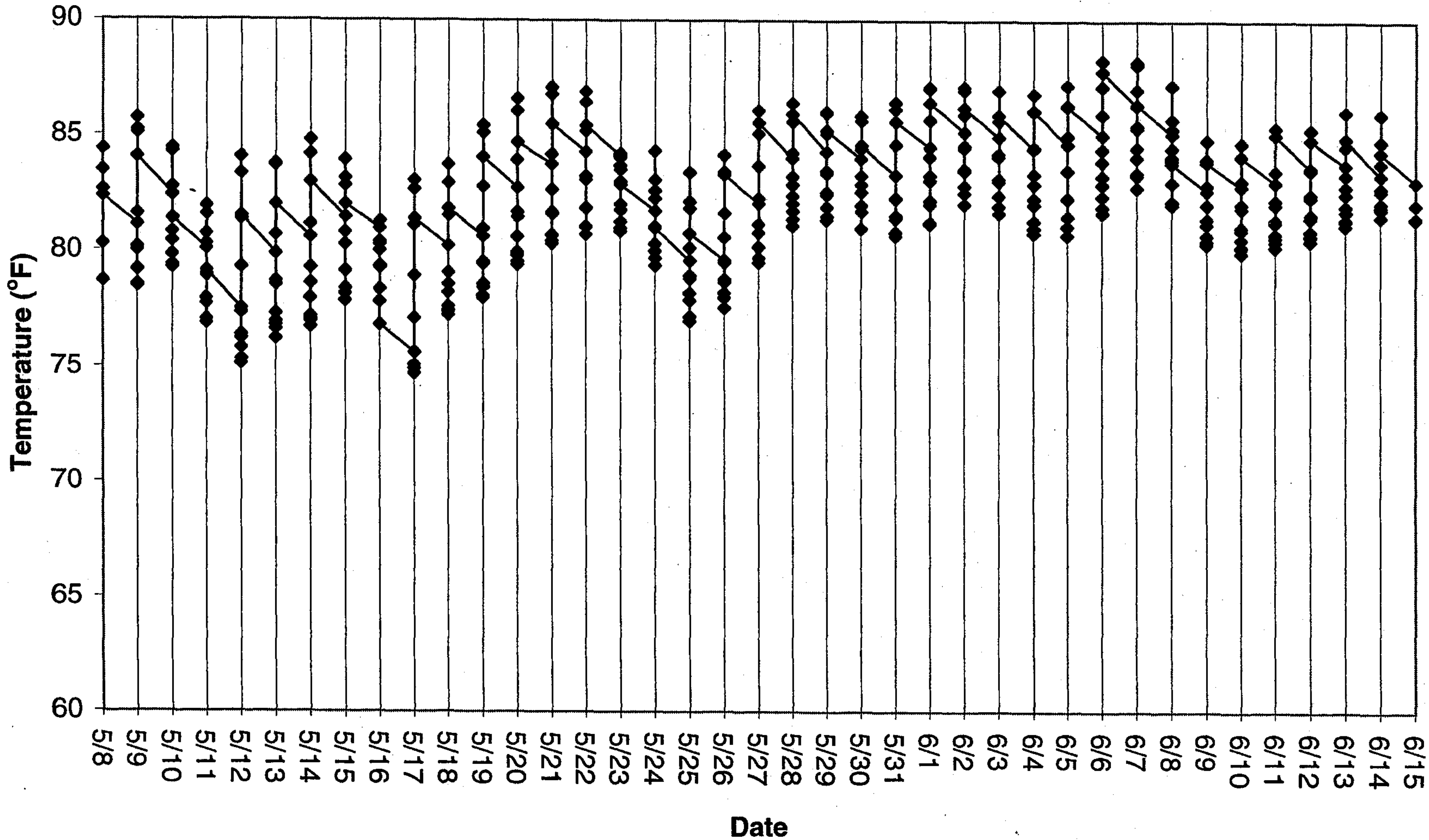
Sample Date	HS Inlet	H1 EFF	H2 EFF
Jan-98	1394	1381	1358
Feb-98	1382	1366	1344
Mar-98	1326	1328	1333
Apr-98	1243	1216	1226
May-98	1299	1295	1300
Jun-98	1284	1369	1339
Jul-98	1583	1590	1698
Aug-98	1740	NR	1735
Sep-98	1704	1855	1697
Oct-98	1399	1546	1484
Nov-98	1294	1318	1284
Dec-98	1324	1290	1309
Jan-99	1364	1327	1334
Feb-99	1242	1298	1252
Mar-99	NR	NR	NR
Apr-99	1480	1533	1509
May-99	1412	1532	1563
Jun-99	1721	1744	1730
Jul-99	1609	1612	1634
Aug-99	1656	1681	1711
Sep-99	1675	1681	1689
Oct-99	1604	1612	1635
Nov-99	1373	1421	1397
Dec-99	1347	1328	1322
Jan-00	1360	1327	1320
Feb-00	1421	1384	1373
Mar-00	1505	1494	NR
Apr-00	1547	1564	NR
May-00	1590	1797	1748
Jun-00	1720	1869	1784
Jul-00	1816	2076	1852
Aug-00	1860	1999	1846
Sep-00	NR	NR	NR
Oct-00	NR	NR	NR
Nov-00	1970	NR	NR
Dec-00	1496	NR	NR
Average	1507	1528	1510
Maximum	1970	2076	1852
Minimum	1242	1216	1226

BOS = Basin Out of Service
NR = Data Not Recorded

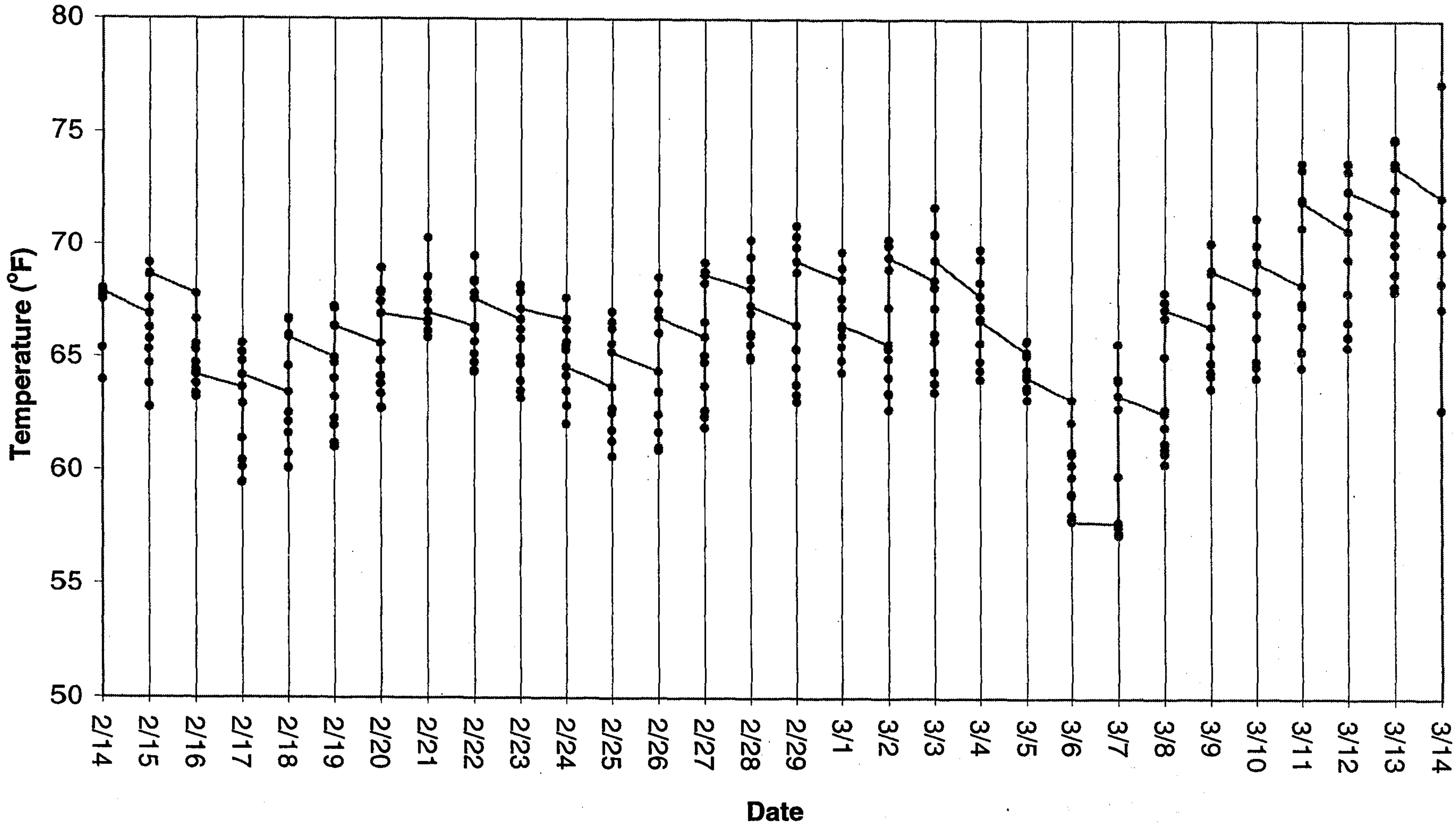
Tres Rios Hayfield Site H1 - pH
February 14, 2000 through March 14, 2000



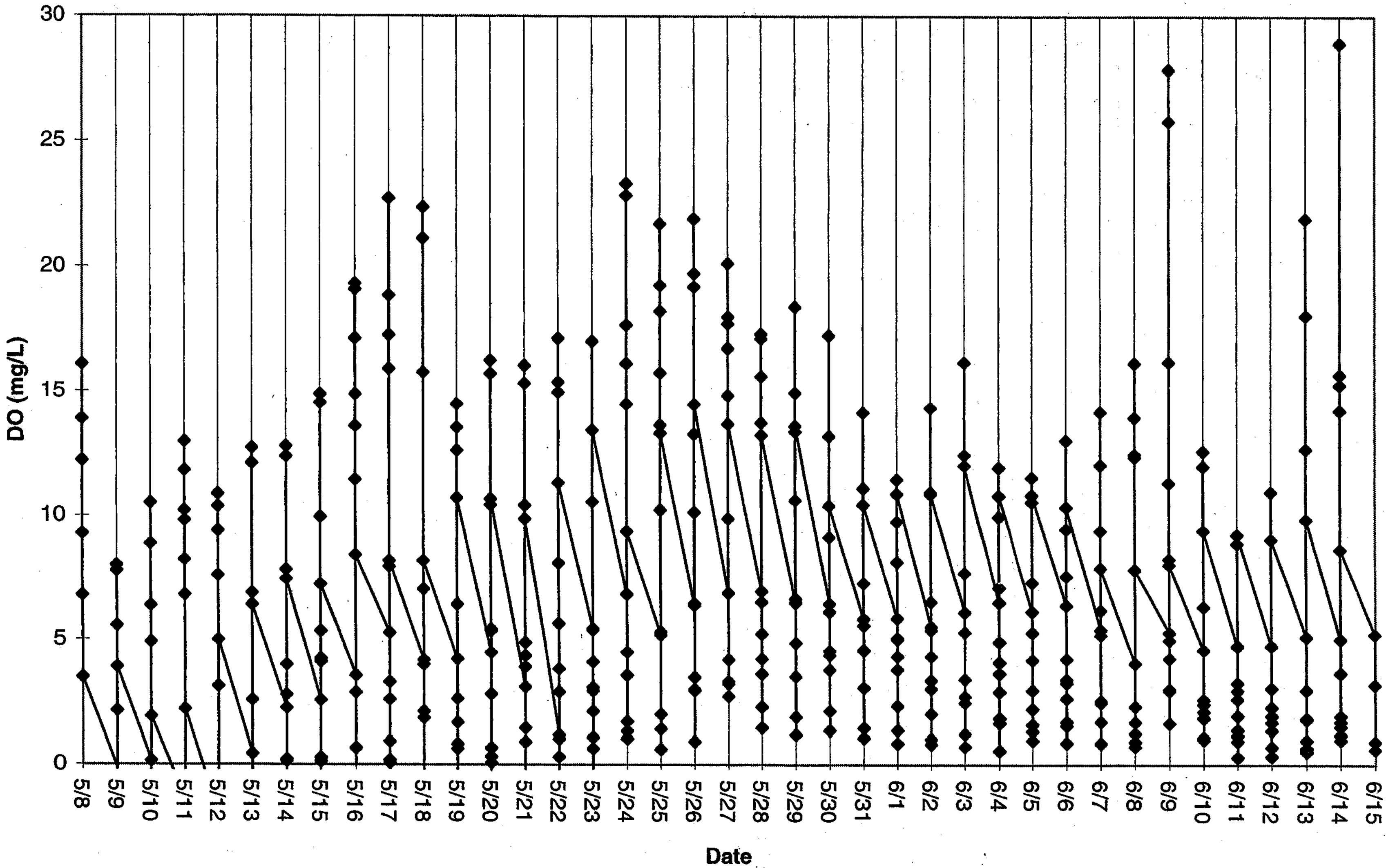
Tres Rios Cobble Site C1 - Temperature
May 8, 2000 through June 15, 2000

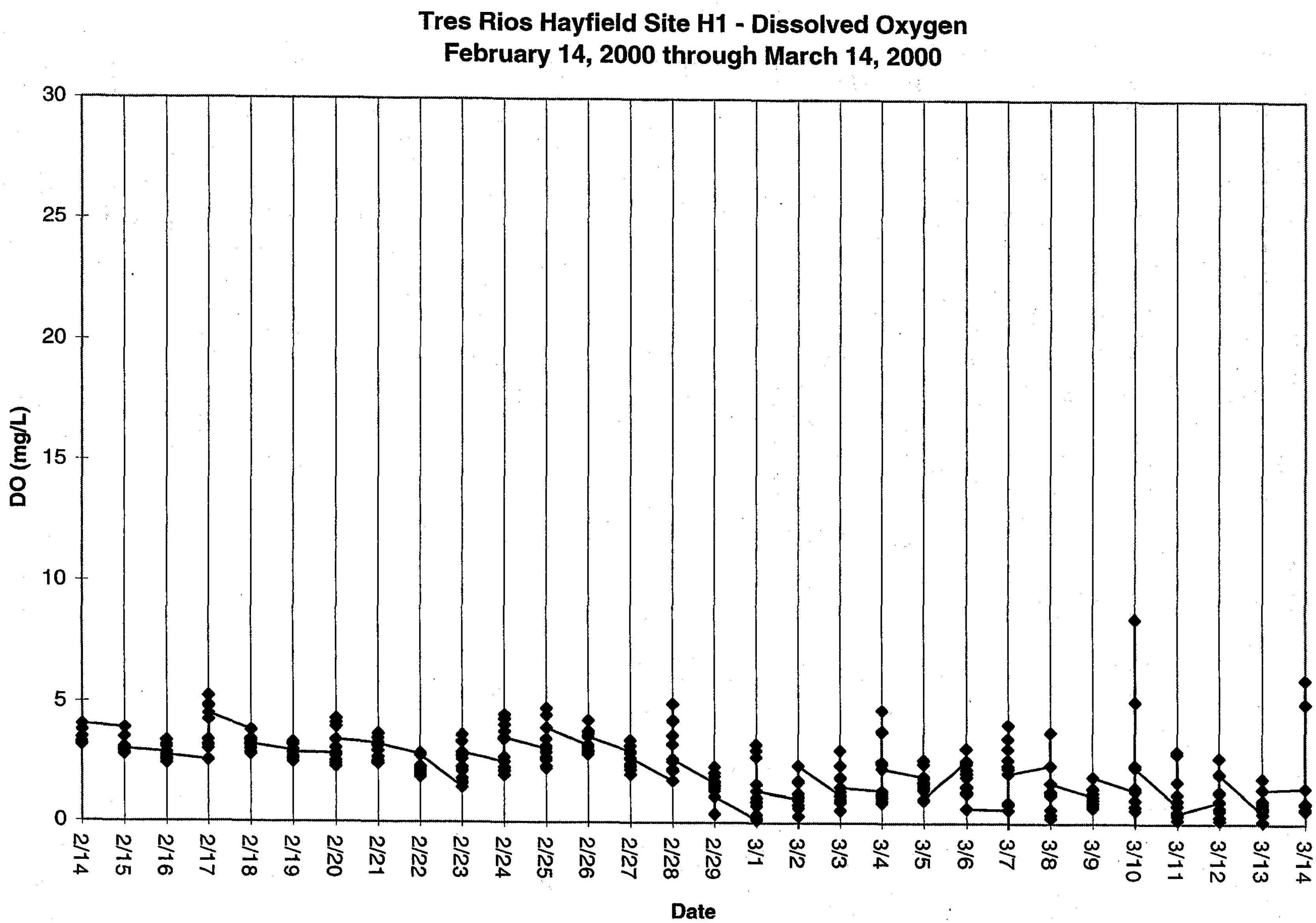


Tres Rios Hayfield Site H1 - Temperature (F)
February 14, 2000 through March 14, 2000



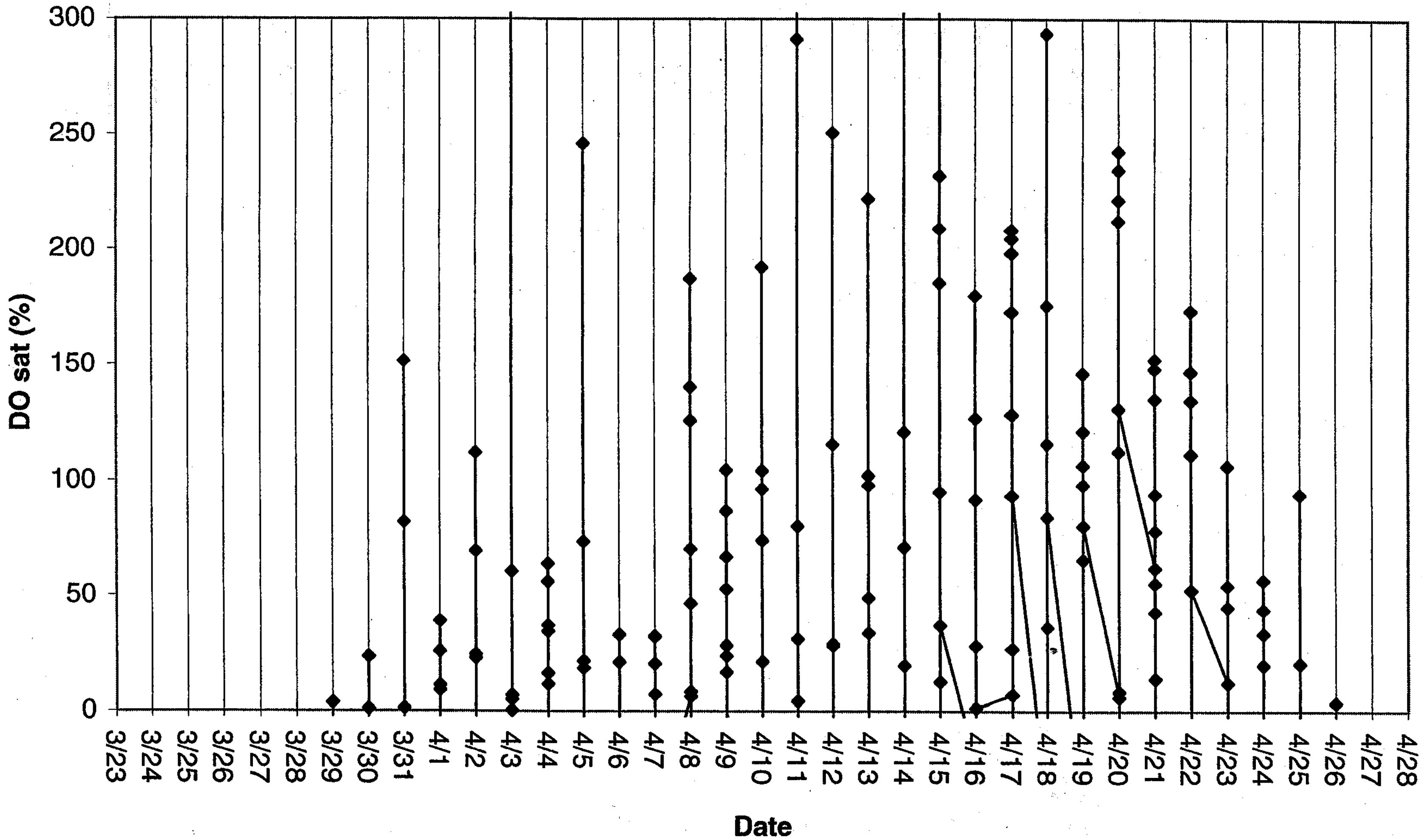
Tres Rios Cobble Site C1 - Dissolved Oxygen
May 8, 2000 through June 15, 2000

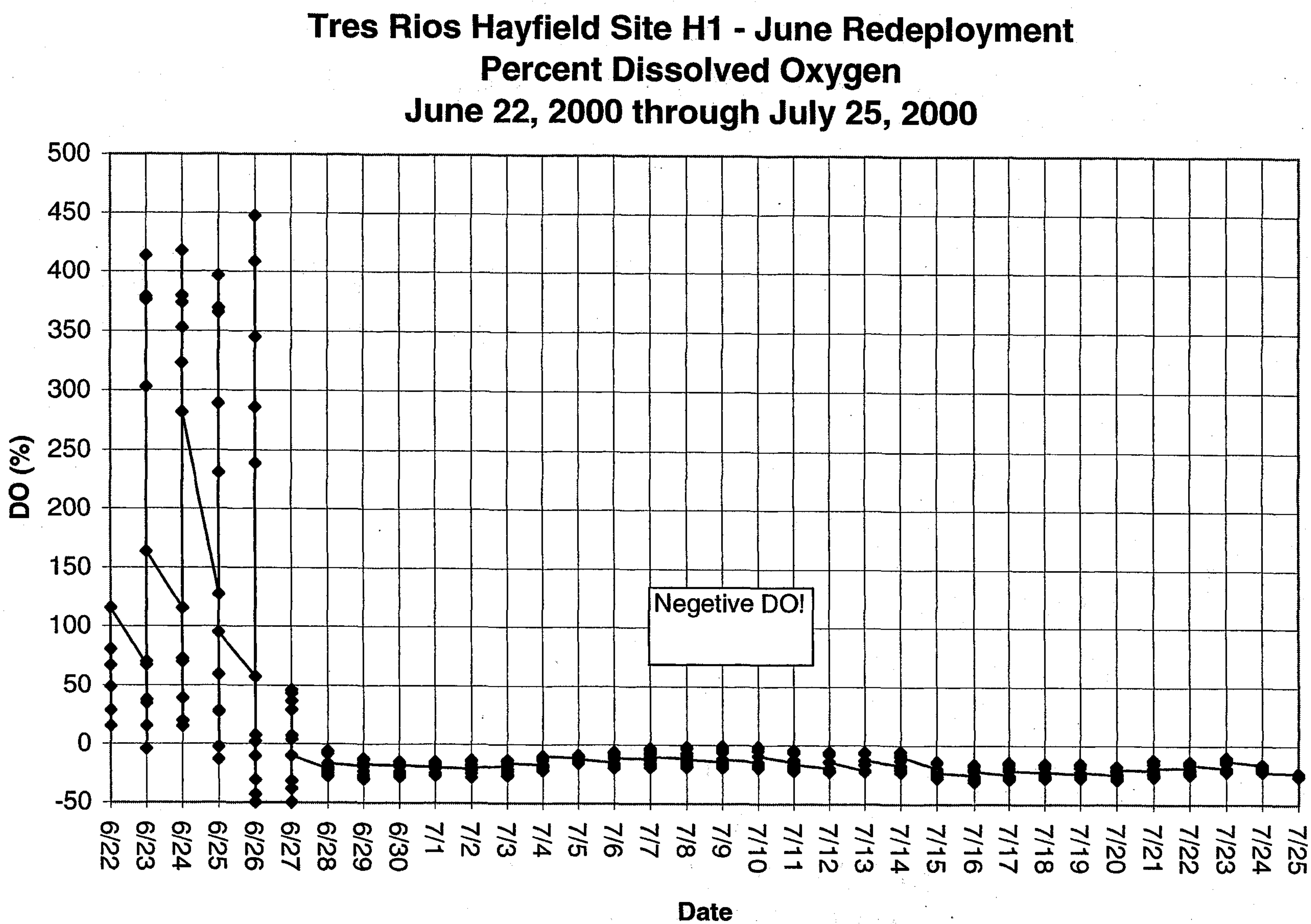




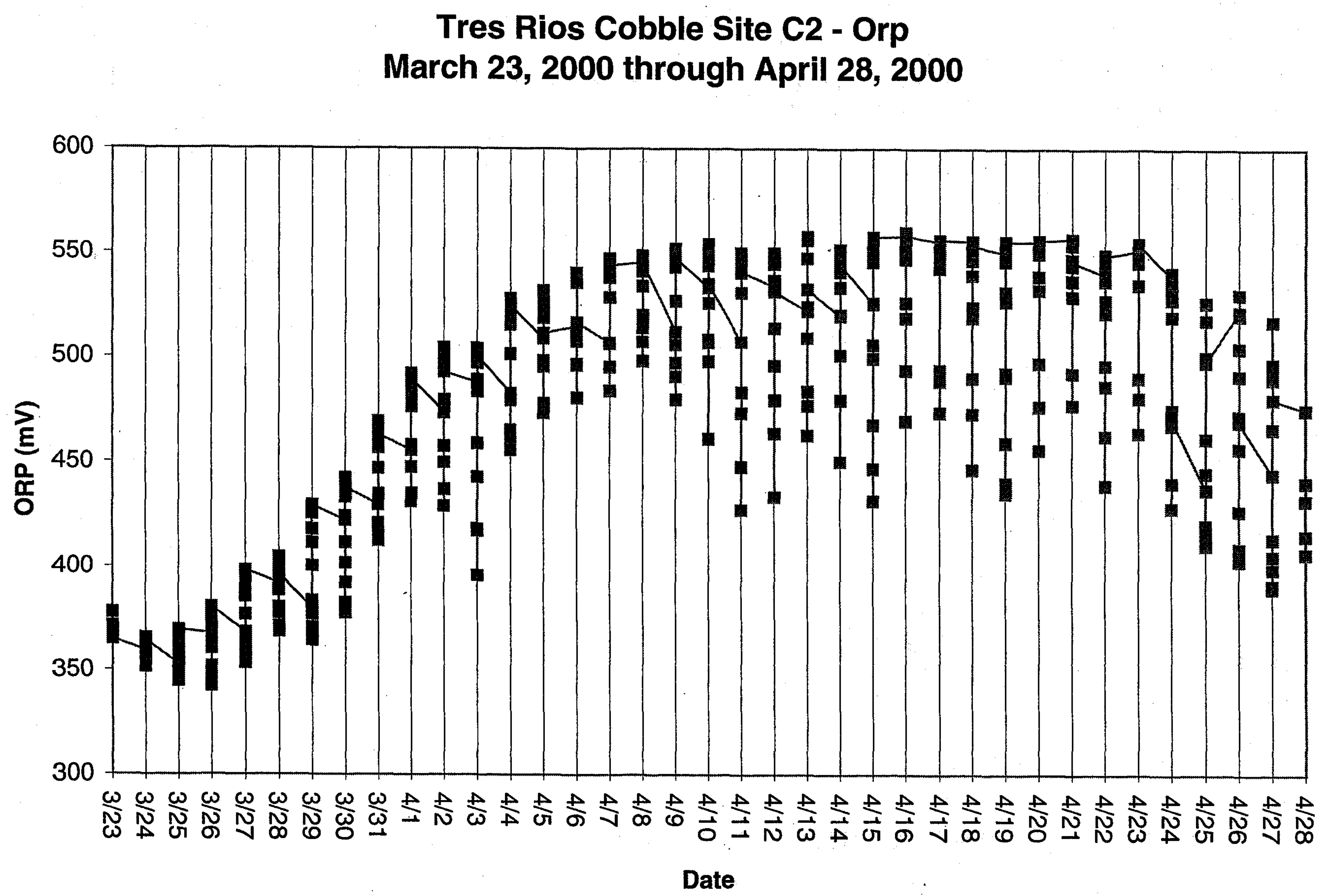
Tres Rios Hayfield Site H1 - Dissolved Oxygen
February 14, 2000 through March 14, 2000
DO (mg/L)
30
25
20
15
10
5
0
2/14
2/15
2/16
2/17
2/18
2/19
2/20
2/21
2/22
2/23
2/24
2/25
2/26
2/27
2/28
2/29
3/1
3/2
3/3
3/4
3/5
3/6
3/7
3/8
3/9
3/10
3/11
3/12
3/13
3/14
Date

Tres Rios Cobble Site C2 - Percent Dissolved Oxygen
March 23, 2000 through April 28, 2000

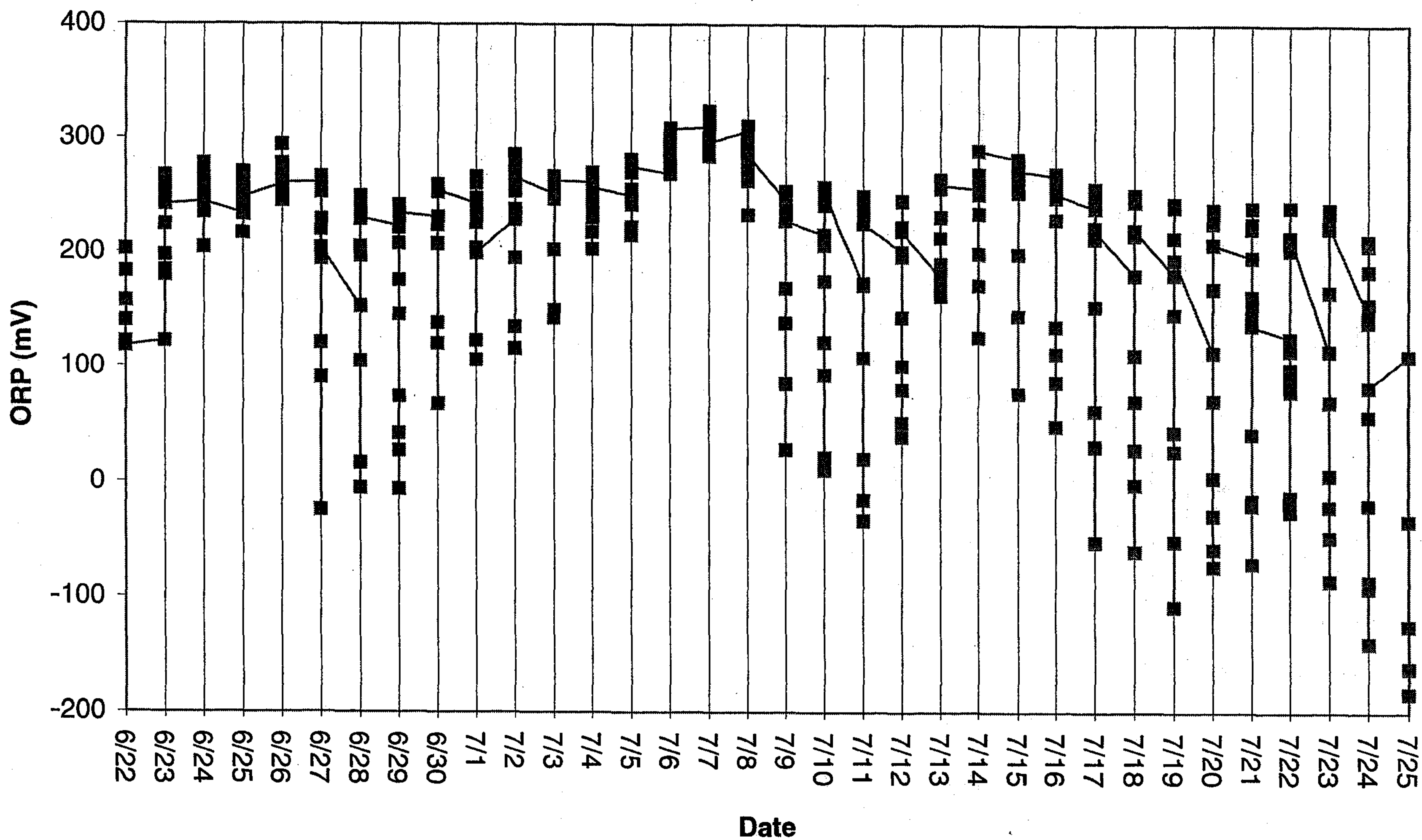




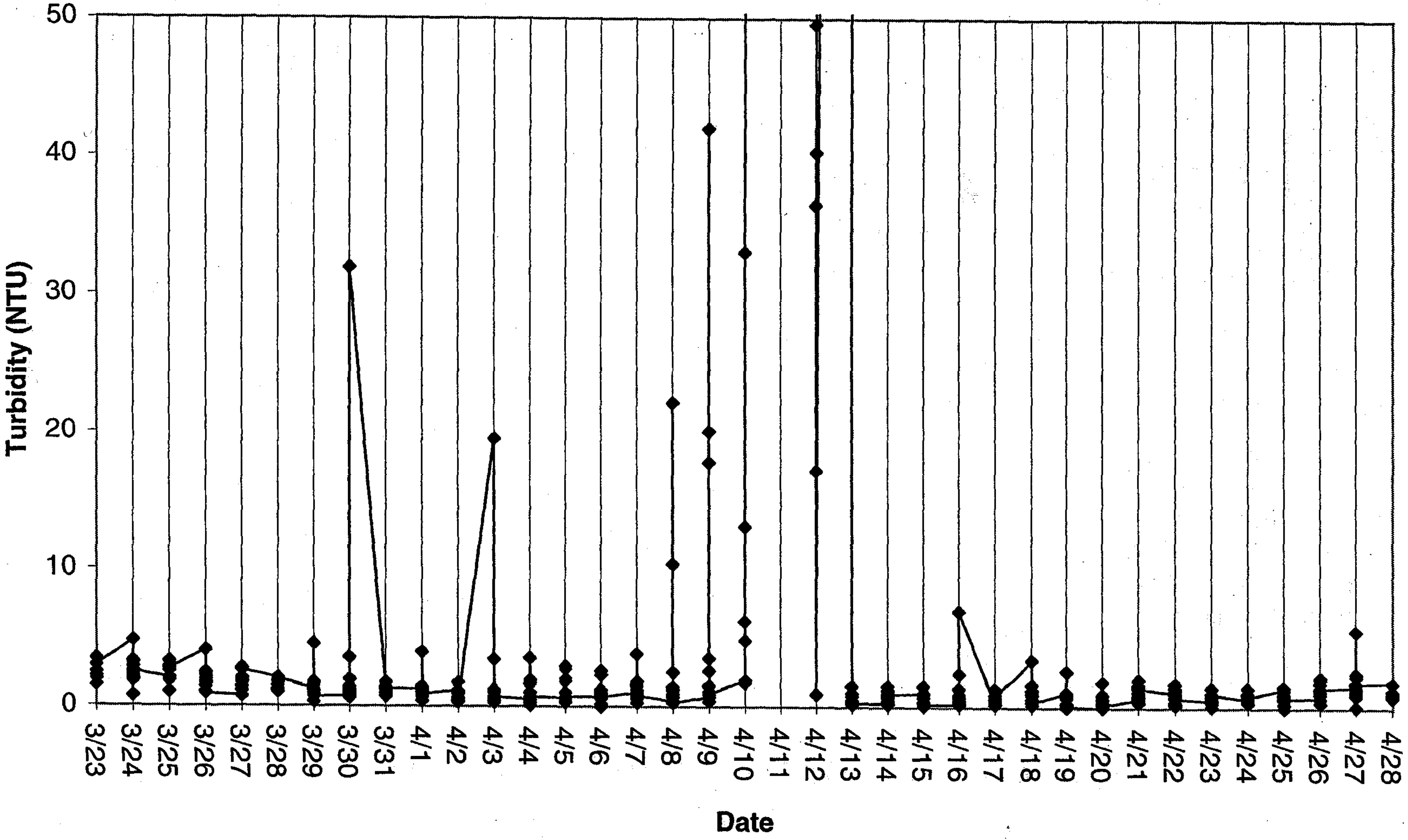
Tres Rios Hayfield Site H1 - June Redeployment
Percent Dissolved Oxygen
June 22, 2000 through July 25, 2000
DO (%)
500
450
400
350
300
250
200
150
100
50
0
-50
Negetive DO!
6/22
6/23
6/24
6/25
6/26
6/27
6/28
6/29
6/30
7/1
7/2
7/3
7/4
7/5
7/6
7/7
7/8
7/9
7/10
7/11
7/12
7/13
7/14
7/15
7/16
7/17
7/18
7/19
7/20
7/21
7/22
7/23
7/24
7/25
Date


Tres Rios Cobble Site C2 - Orp
March 23, 2000 through April 28, 2000
ORP (mV)
600
550
500
450
400
350
300
3/23
3/24
3/25
3/26
3/27
3/28
3/29
3/30
3/31
4/1
4/2
4/3
4/4
4/5
4/6
4/7
4/8
4/9
4/10
4/11
4/12
4/13
4/14
4/15
4/16
4/17
4/18
4/19
4/20
4/21
4/22
4/23
4/24
4/25
4/26
4/27
4/28
Date

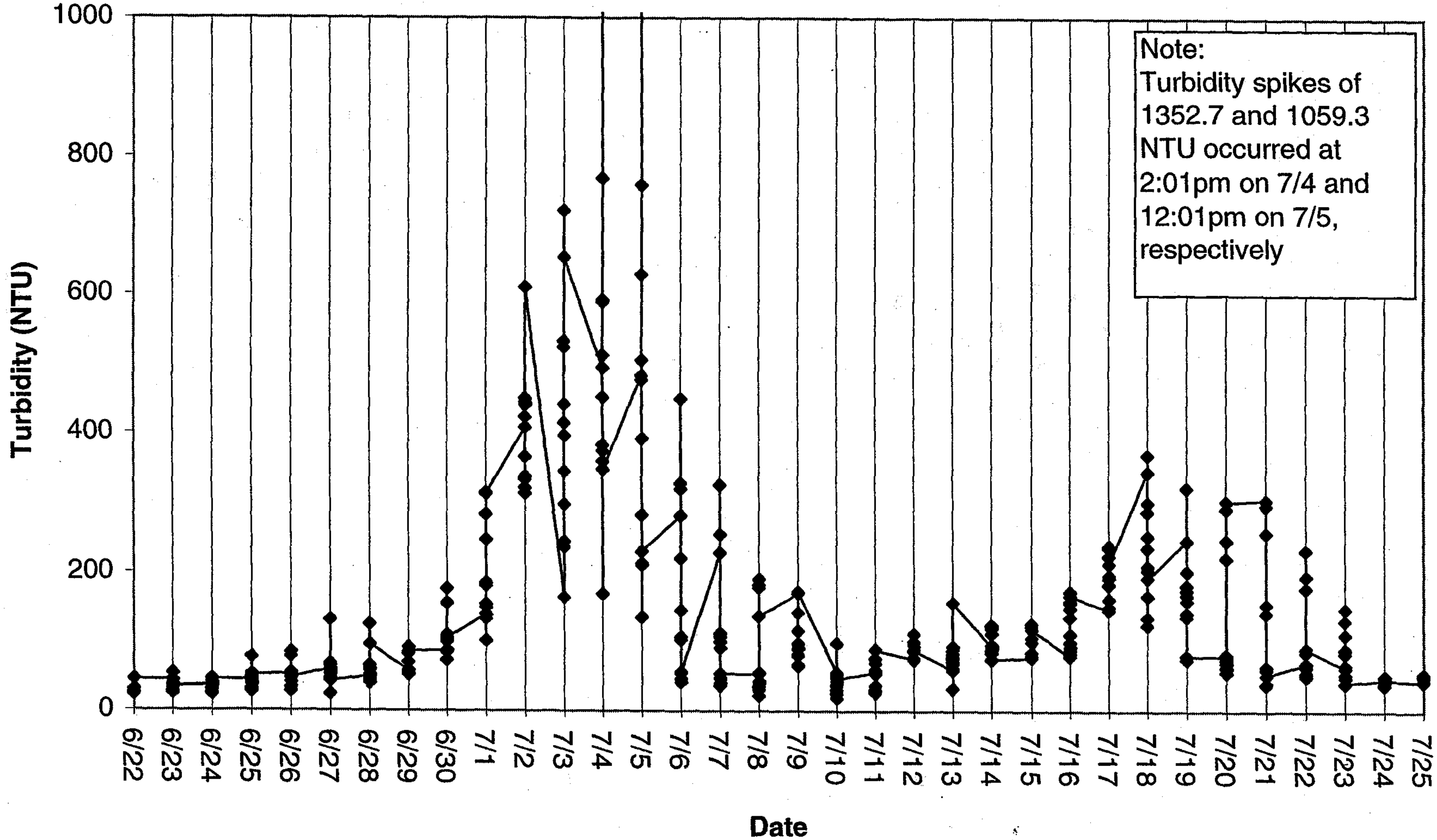
Tres Rios Hayfield Site H1 - June Redeployment - Orp
June 22, 2000 through July 25, 2000



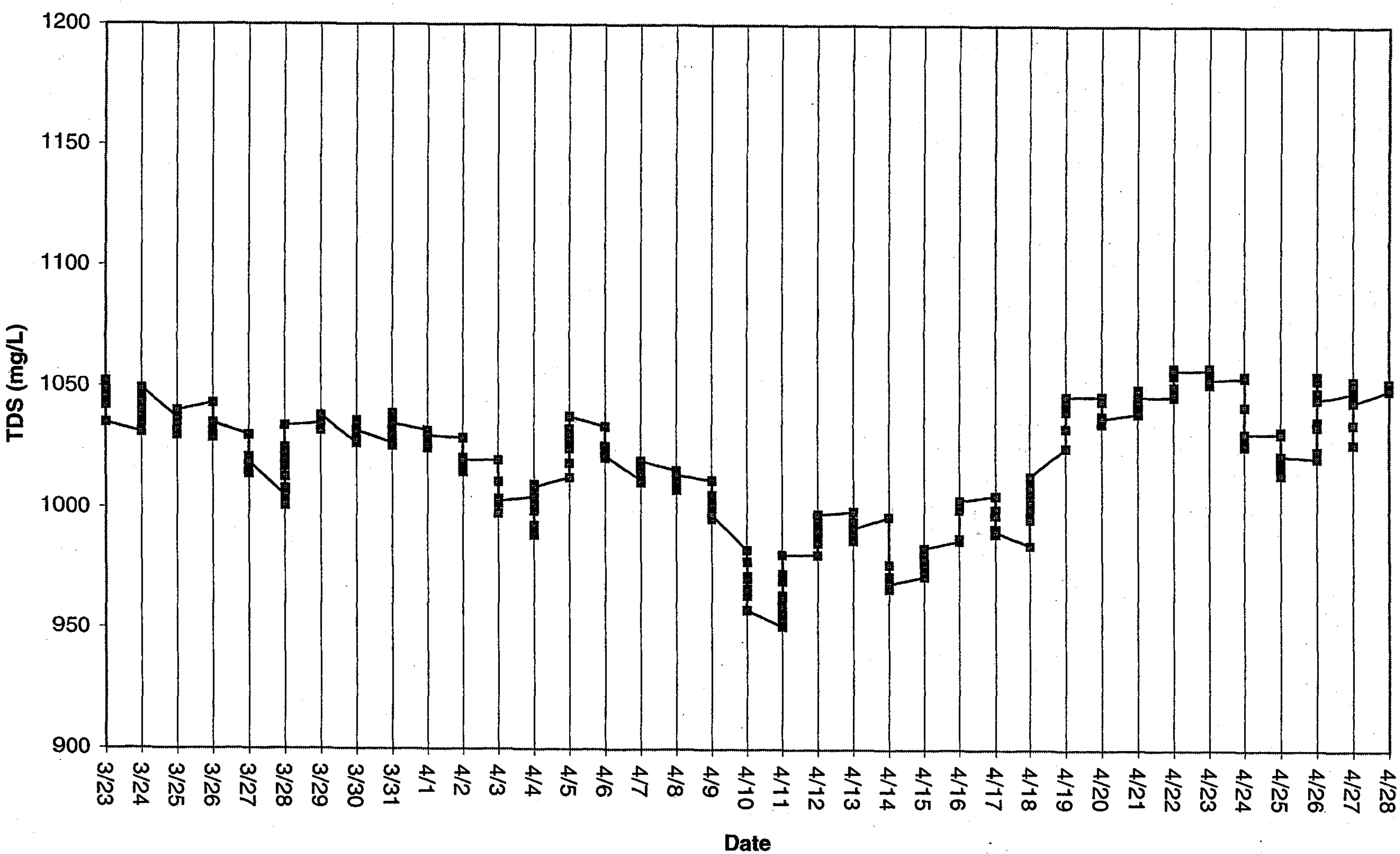
Tres Rios Cobble Site C2 - Turbidity
March 23, 2000 through April 28, 2000



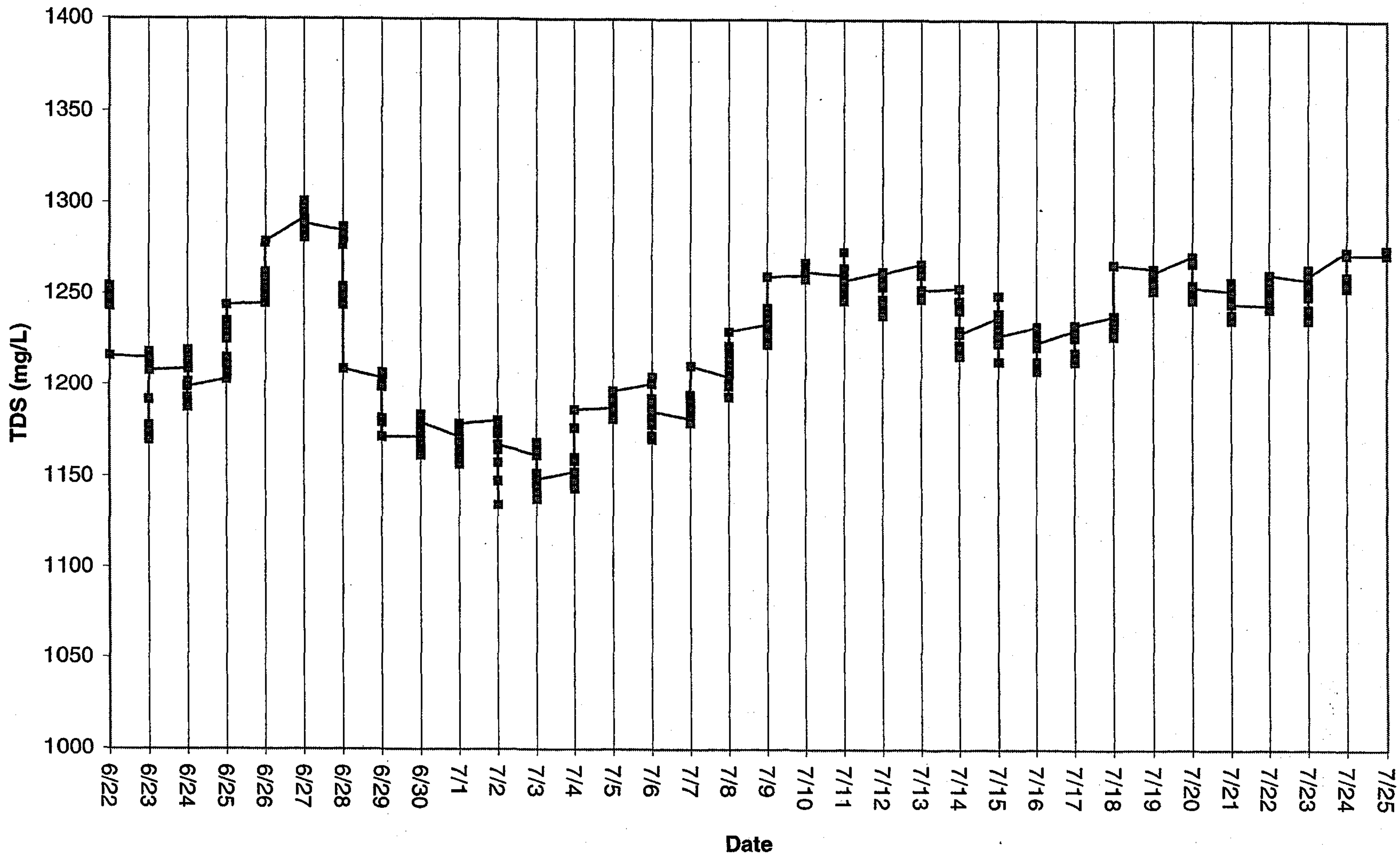
Tres Rios Hayfield Site H1 - June Redeployment - Turbidity
June 22, 2000 through July 25, 2000



Tres Rios Cobble Site C2 - Total Dissolved Solids
March 23, 2000 through April 28, 2000



Tres Rios Hayfield Site H1 - June Redeployment - Total Dissolved Solids
June 22, 2000 through July 25, 2000



Appendix D

Cobble Site
Water Quality
Data & Plots

Tres Rios Cobble Site
Water Quality Analytical Results

CS INLET

SAMPLE DATE	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Organic-N (mg/L)	Sulfate EPA 300.0	Br- EPA 300.0
1/20/98	171	1	874	210	3.4	0.2	2.7	2.9	2.8	3.6	50	2	1.7	8.8	6.3	1.7	188	0.2
2/19/98				174	2.8	0.1	1.6	1.7	2.8	3.7			1.1		4.5	1.7	170	
Basin Out of Service March 3, 1998															0	0		
9/29/98				312	3.5	< 0.1	2.2	2.3	1.3	3.4			1.7	7.9	5.8	1.8	141	
10/27/98	172	3	748	209	3.9	0.2	1.7	1.9	1.2	< 2	21	2	2.3	7.8	5.8	1.6	152	
12/9/98	164	4	742	197	3.4	< 0.1	2.7	2.8	3	4.8	< 10	3	1.2	8	6.2	2.2	149	
1/26/99	175	2	846	236	4.8	0.2	4	4.2	3.2	3	35	< 2	1.8	10.4	9	3	126	
2/23/99	198	3	756	167	4.5	0.2	4.3	4.5	3.4	4	31	4	1.4	NR	9	3.1	126	
4/28/99	166	6	928	250	4.3	0.2	1.5	1.7	2	NR	28	3	2.1	10.2	6	2.2	196	
5/19/99	172	4	942	259	4.3	0.5	3	3.5	2.8	NR	26	3	3.4	NR	7.8	0.9	172	
6/29/99	161	4	1050	307	1.9	< 0.5	4.7	5.2	1.8	4	49	< 2	0.87	8.1	7.1	1.03	142	
7/27/99	168	2	988	302	1.9	< 0.1	3.1	3.2	NR	***3***	42	< 2	0.91	8	5.1	0.99	143	
8/24/99	172	1	996	298	1.7	< 0.1	1.8	1.9	NR	***2***	48	3	1.1	8.8	3.6	0.6	151	
9/23/99	179	9	980	306	2.1	< 0.1	2.4	2.5	NR	***4***	22	< 2	1.5	8.4	4.6	0.6	145	
10/26/99	175	8	918	273	2.9	0.1	1.8	1.9	NR	***3***	31	2	1	7.1	4.8	1.9	145	
11/23/99	127	3	814	220	0.8	< 0.1	3	3.1	NR	***2***	34	< 2	< 0.2	7.5	3.9	0.6	143	
12/21/99	184	5	844	204	2.8	0.2	3.8	4	NR	***<2***	40	3	1.9	8.8	6.8	0.9	145	
1/20/00	165	62	858	213	1	< 0.1	4.2	4.3	NR	***3***	38	< 2	< 0.2	9	5.3	0.8	178	
2/22/00	174	3	844	194	2.7	< 0.1	3.5	3.6	NR	***3.1***	51	< 2	1.3	9.4	6.3	1.4	199	
5/25/00	173	1.6	958	320	1.6	< 0.5	2.09	2.59	NR	***2.3***	34	< 2	1.3	8.3	4.19	0.3	181	
9/6/00	177	4	1040	232	2.6	0.1	2.2	2.3	1.9	***2.2***	35	< 2	1.3	7.9	4.9	1.3	216	
10/19/00	190	2	970	280	2.2	0.2	2.4	2.6	NR	***1.8***	10	< 2	1.5	7.1	4.8	0.7	234	
11/20/00	184	3	934	259	1.6	< 0.1	4.7	4.8		***2.9***	40	2	< 0.5	7.44	6.4	1.1	181	
12/20/00	189	2	898	258	1.8	0.1	4.2	4.3	NR	***1.1***	19	< 2	0.52	7.8	6.1	1.28	205	

NR = Data Not Recorded

Tres Rios Cobble Site
Water Quality Analytical Results

C2 EFF

SAMPLE DATE	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Organic-N (mg/L)	Sulfate EPA 300.0	Br- EPA 300.0
1/20/98	168	<1	884	219	0.9	0.1	1.7	1.8	2	4	22	< 2	< 0.1	6.5	2.7	0.8	192	0.3
2/19/98				170	0.8	0.1	1.6	1.7	2.2	2.9			0.11		2.5	0.69	161	
Basin Out of Service March 3, 1998															0	0		
9/29/98				327	3.1	0.2	0.3	0.5	1.1	2			0.31	9.6	3.6	2.79	157	
10/27/98	168	3	710	200	3.1	< 0.1	< 0.1	0.2	3.1	4.2	26	3	0.2	9	3.3	2.9	137	
12/9/98	165	8	764	185	3	0.3	2.1	2.4	2.2	3.3	17	4	0.37	10	5.4	2.63	161	
1/26/99	184	7	870	248	2.5	0.5	4.2	4.7	2.9	3	48	3	0.86	10.8	7.2	1.64	128	
2/23/99	202	5	760	175	2.8	0.3	2.1	2.4	1.8	2	41	3	0.27	NR	5.2	2.53	128	
4/28/99	177	1	960	254	2.5	< 0.1	0.2	0.3	2.1	NR	26	5	0.24	13.5	2.8	2.26	210	
5/19/99	174	3	962	262	4	0.4	0.3	0.7	2.5	NR	32	2	2.4	NR	4.7	1.6	178	
6/29/99	181	4	1090	300	1.9	< 0.5	0.2	0.7	2.2	4	37	< 2	0.74	8.8	2.6	1.16	159	
7/27/99	172	3	954	285	1.5	< 0.1	0.2	0.3	NR	***3***	36	< 2	0.66	8	1.8	0.84	147	
8/24/99	182	1	1010	299	3.1	< 0.1	< 0.1	0.2	NR	***3***	49	2	1.9	8.5	3.3	1.2	160	
9/23/99	185	1	984	300	1.1	< 0.1	0.9	1	NR	***4***	23	< 2	0.7	7.8	2.1	0.4	146	
10/26/99	177	1	906	257	1.4	< 0.1	0.6	0.7	NR	***4***	23	< 2	0.33	6.5	2.1	1.07	142	
11/23/99	148	1	830	224	1.5	< 0.1	0.5	0.6	NR	***2***	33	2	0.58	7.1	2.1	0.92	143	
12/21/99	198	6	826	199	3.7	0.4	1.2	1.6	NR	***4***	38	2	2.7	8.2	5.3	1	145	
1/20/00	184	8	860	207	1.5	0.1	2.7	2.8	NR	***3***	41	3	0.26	9.6	4.3	1.24	185	
2/22/00	185	4	848	208	1.1	0.2	1.1	1.3	NR	***2.8***	45	4	0.93	9.6	2.4	0.17	194	
9/6/00	178	3	1010	222	1.8	0.1	1.4	1.5		***2.4***	21	< 2	0.75	7.3	3.3	1.05	204	0.3
10/19/00	175	40	950	270	1.7	0.1	1.3	1.4	NR	***1.6***	52	2	0.74	7.3	3.1	0.96	229	
11/20/00	174	8	966	275	1.4	0.1	6	6.1	NR	***1.7***	37	2	< 0.5	9.56	7.5	0.9	183	
12/20/00	181	13	914	267	1.6	0.3	5.1	5.4		***0.8***	26	2	0.41	7.4	7	1.19	215	

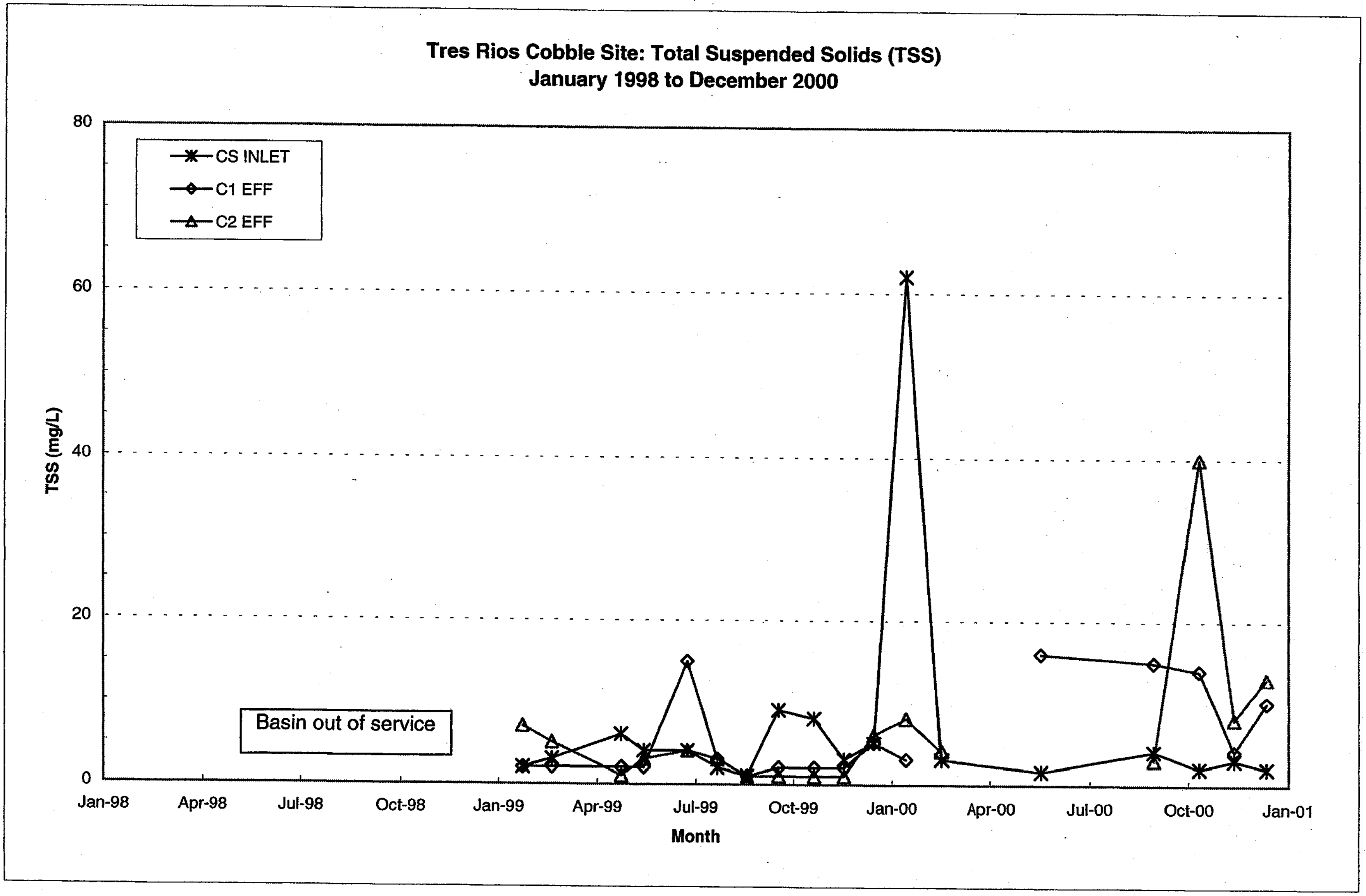
NR = Data Not Recorded

Tres Rios Cobble Site
Water Quality Analytical Results

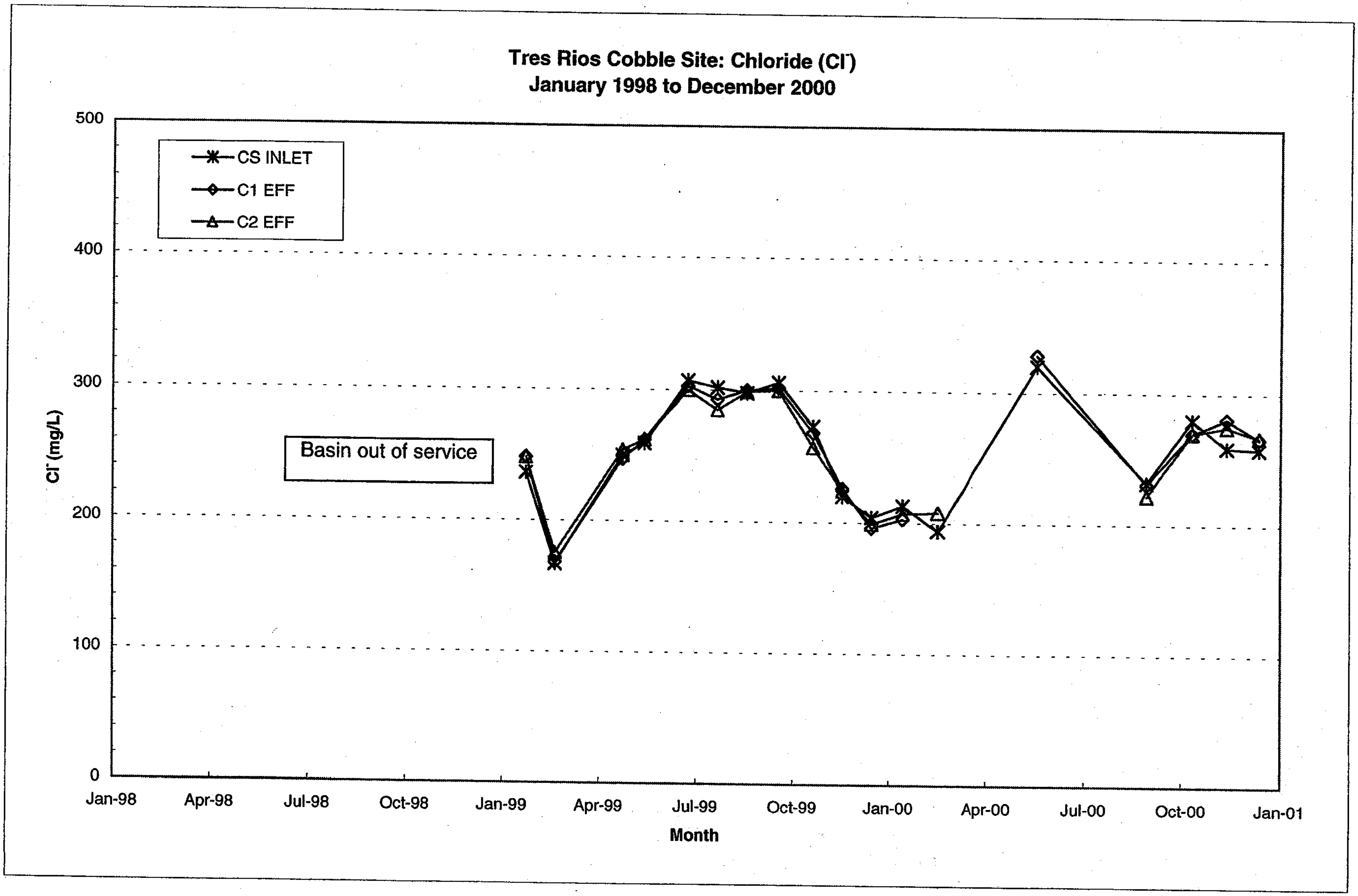
C2 EFF Duplicate

SAMPLE DATE	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)		NO2 - N EPA 300.0 (mg/L)		NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)		cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Organic-N (mg/L)	Sulfate EPA 300.0	Br- EPA 300.0
1/20/98	170	1	864	214	1	<	0.1		1.7	1.8	1.8	2.7	19	<	2	NR	6.5	2.8	#VALUE!	191	0.2
1/26/99	180	6	884	247	2.7		0.6		4.3	4.9	2.8	3	32		3	0.81	11.1	7.6	1.89	128	
4/28/99	180	2	966	256	2.6	<	0.1		0.2	0.3	2.1	NR	23		4	0.2	13.6	2.9	2.4	209	
5/19/99	178	2	956	267	4.4		0.4		0.2	0.6	2.5	NR	31		2	2	NR	5	2.4	182	
6/29/99	182	2	1050	305	2	<	0.5		0.2	0.7	2.2	4	38	<	2	0.76	8.9	2.7	1.24	162	
8/24/99	180	1	1000	298	3.2	<	0.1	<	0.1	0.2	NR	*3*	38		2	1.9	8.8	3.4	1.3	160	
10/26/99	175	2	896	263	1.3	<	0.1		0.5	0.6	NR	*4*	24	<	2	0.34	6.6	1.9	0.96	142	
12/21/99	200	7	792	201	3.2		0.5		1.2	1.7	NR	*4*	36		3	2.7	8.4	4.9	0.5	145	

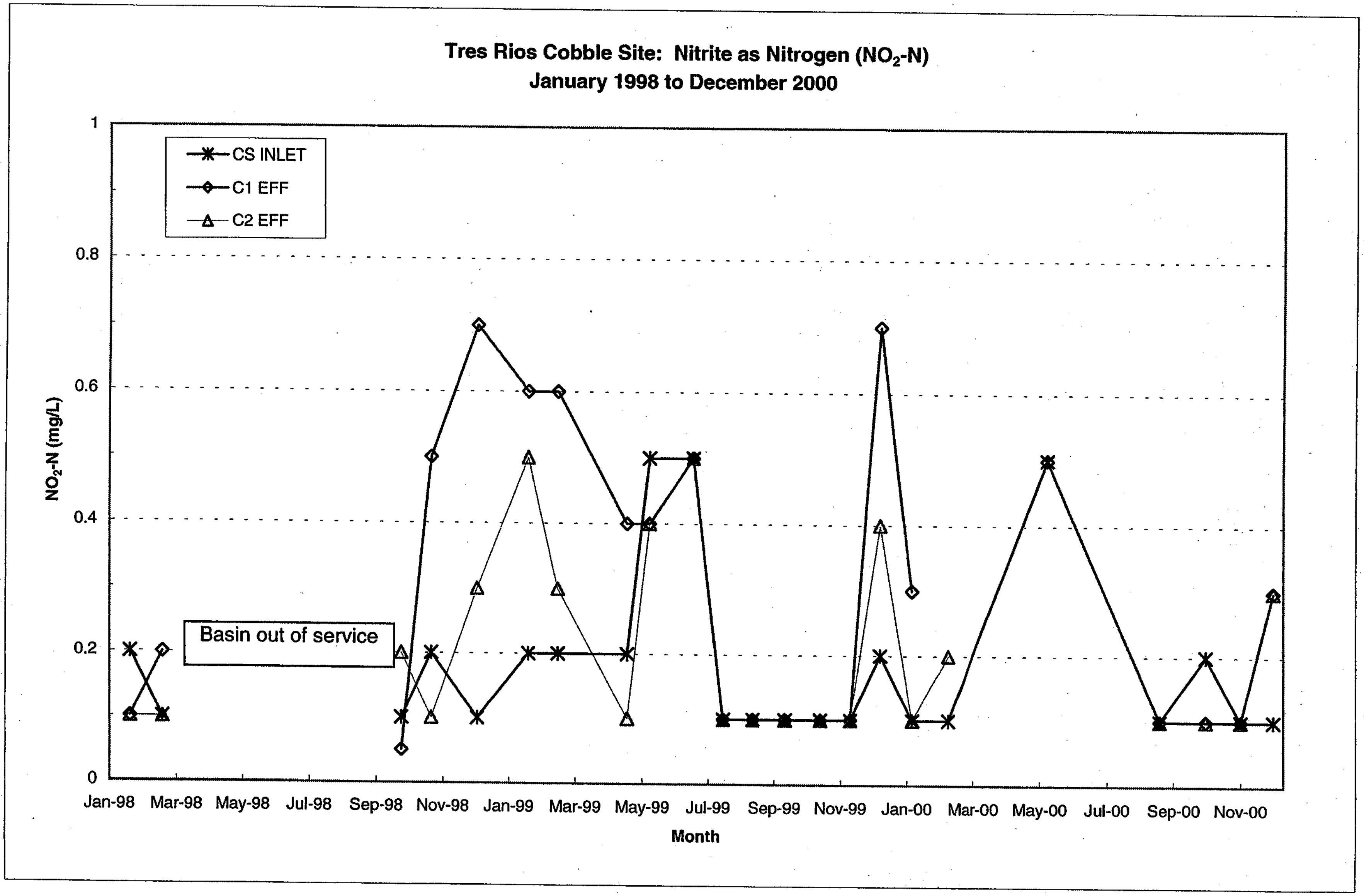
NR = Data Not Recorded



Tres Rios Cobble Site: Total Suspended Solids (TSS)
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
TSS (mg/L)
80
60
40
20
0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month



Tres Rios Cobble Site: Chloride (Cl⁻)
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
Cl⁻ (mg/L)
500
400
300
200
100
0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month



Tres Rios Cobble Site: Nitrite as Nitrogen (NO_2-N)
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
NO_2-N (mg/L)
1
0.8
0.6
0.4
0.2
0
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
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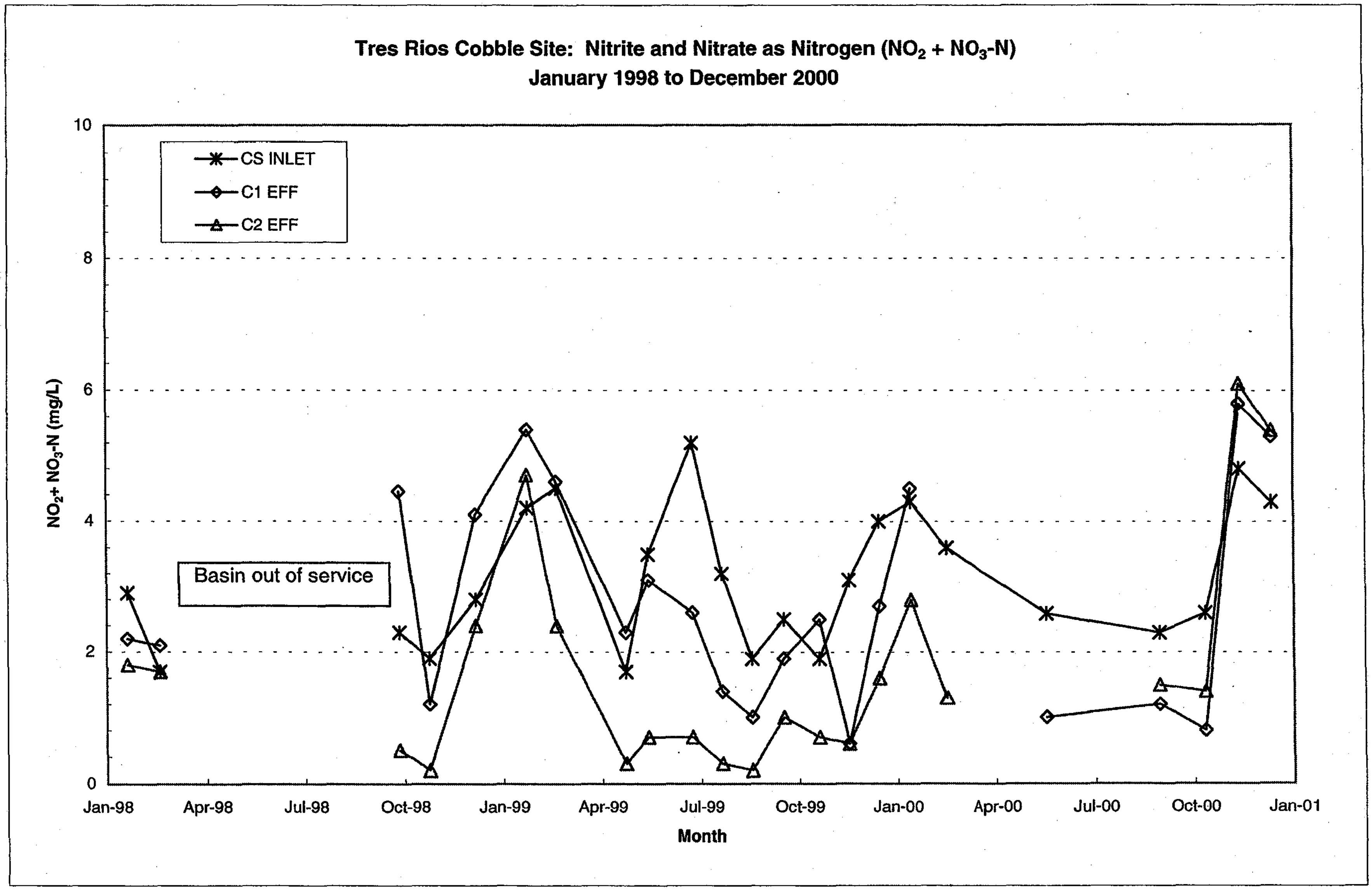
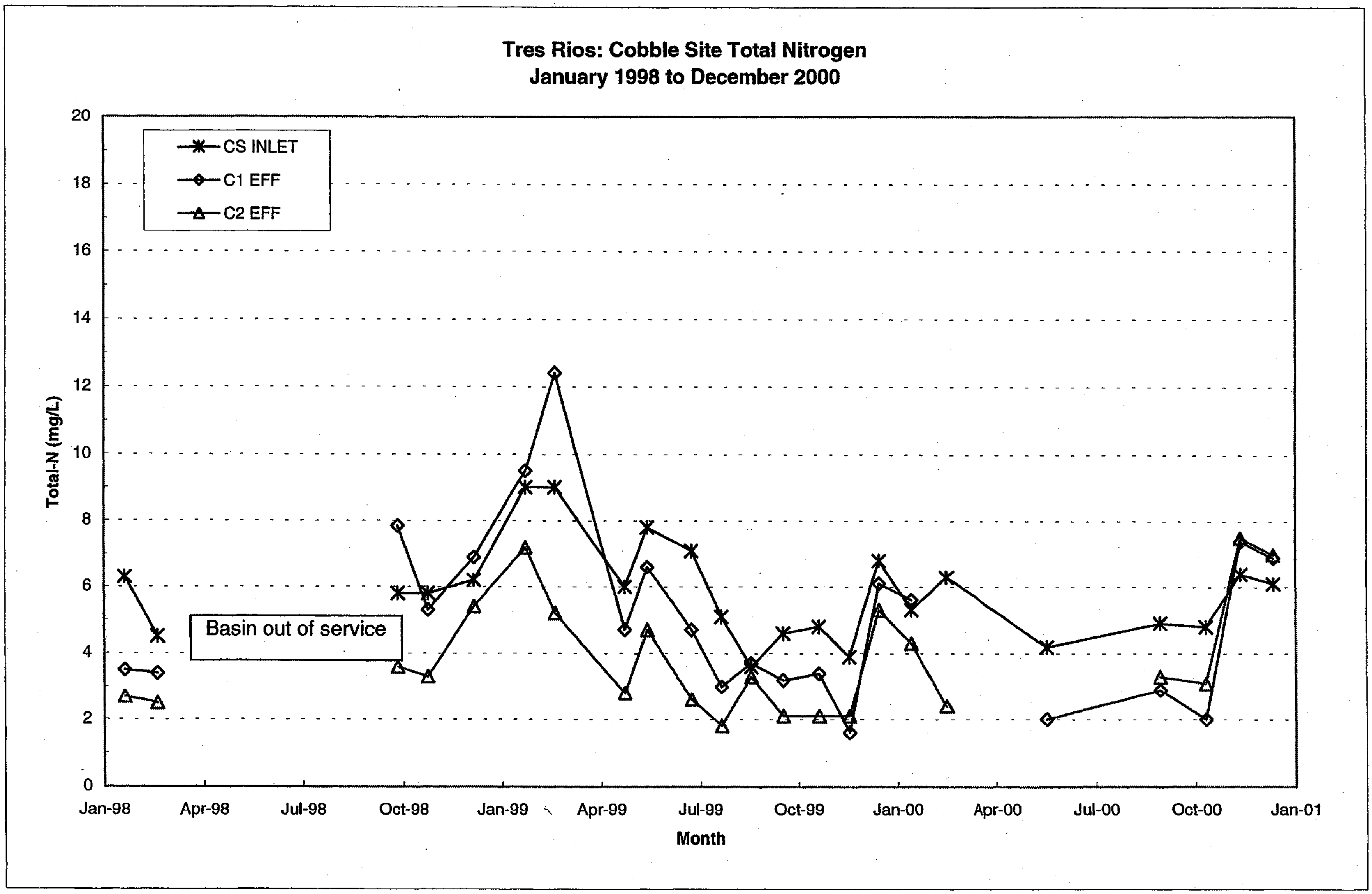
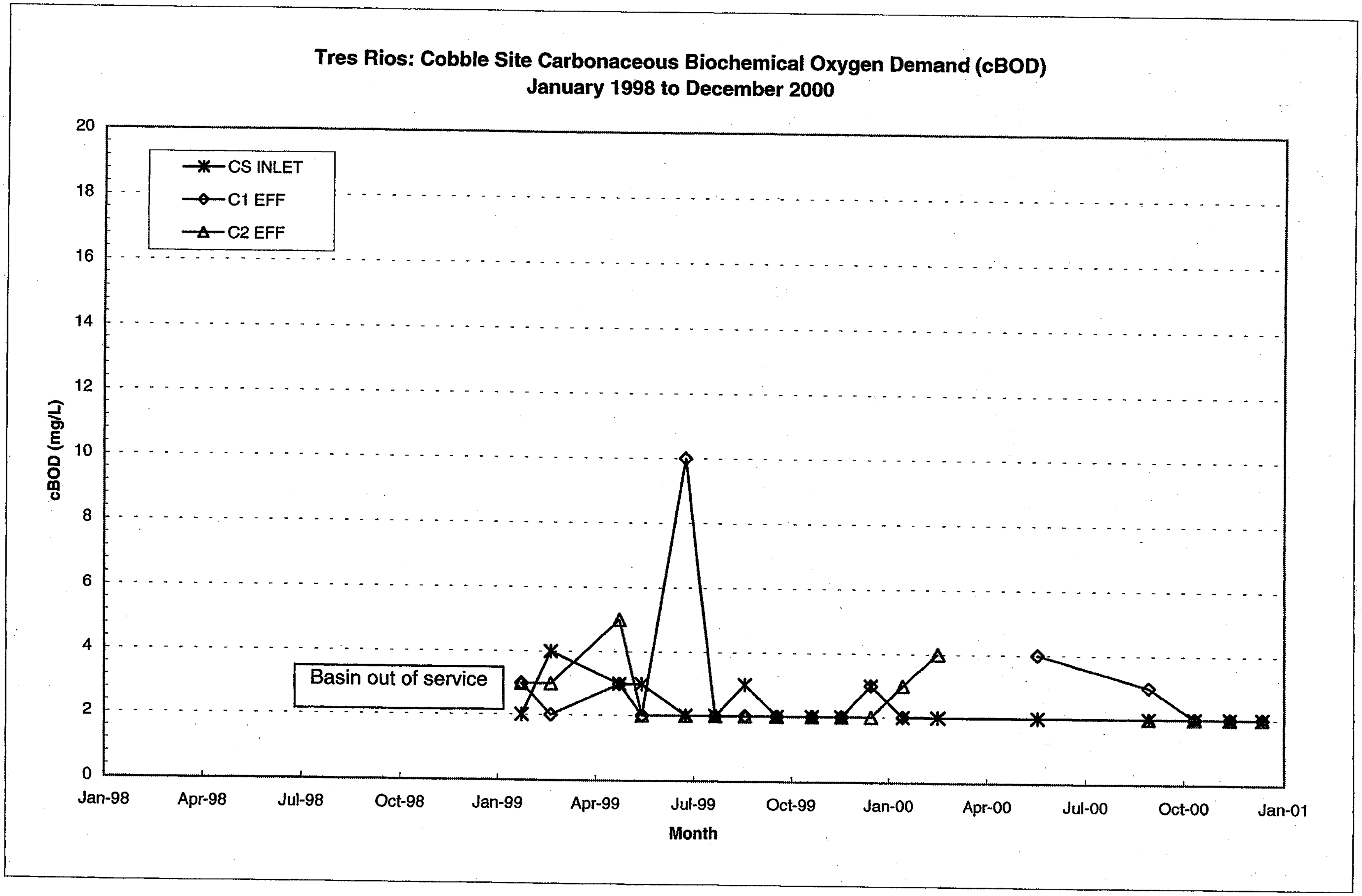
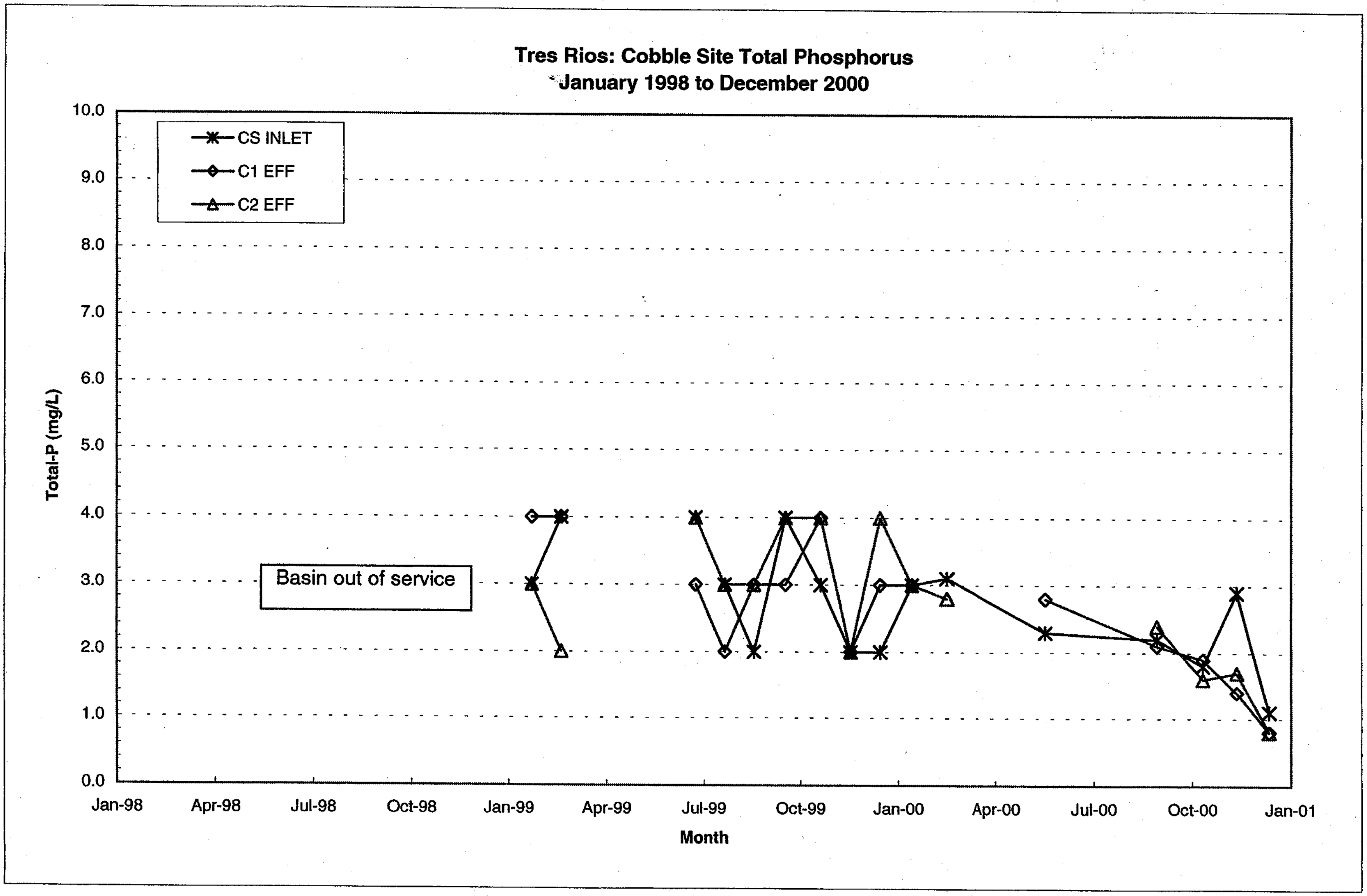
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Month


Tres Rios Cobble Site: Nitrite and Nitrate as Nitrogen ($NO_2 + NO_3$-N)
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
$NO_2 + NO_3$-N (mg/L)
0
2
4
6
8
10
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month


Tres Rios: Cobble Site Total Nitrogen
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
Total-N (mg/L)
20
18
16
14
12
10
8
6
4
2
0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month


Tres Rios: Cobble Site Carbonaceous Biochemical Oxygen Demand (cBOD)
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
cBOD (mg/L)
0
2
4
6
8
10
12
14
16
18
20
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month



Tres Rios: Cobble Site Total Phosphorus
January 1998 to December 2000
CS INLET
C1 EFF
C2 EFF
Basin out of service
Total-P (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month

TRES RIOS Demonstration Constructed Wetland Project
Cobble Site Gradient Water Quality - Basin 1

SAMPLE DATE	SAMPLE LOCATION	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	Total-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)	Br- (EPA 300.0)	Total Sulfide (mg/L)
2/23/99	CS INLET	198	3	756	167	4.5	0.2	4.3	4.5	3.4	4	31	4	1.4	NR	9	3.1	126		
2/23/99	C1 INLETD	203	4	756	165	3.3	0.3	3.7	4	3.1	4	34	4	1.7	NR	7.3	1.6	125		
2/23/99	C1 DZ1	197	5	756	168	4.1	0.4	4.5	4.9	3.1	4	41	2	1.7	NR	9	2.4	124		
2/23/99	C1DZ2	195	3	742	159	4.2	0.6	4.3	4.9	3.1	4	35	2	1.9	NR	9.1	2.3	121		
2/23/99	C1DZ3	198	2	738	159	2.7	0.6	3.8	4.4	3.3	4	31	2	1.7	NR	7.1	1	121		
2/23/99	C1 EFF	195	2	734	168	7.8	0.6	4	4.6	3.2	4	27	< 2	1.4	NR	12.4	6.4	123		
4/28/99	CS INLET	166	6	928	250	4.3	0.2	1.5	1.7	2	NR	28	3	2.1	10.2	6	2.2	196		
4/28/99	C1 DZ1	170	4	908	248	4.4	0.3	1.6	1.9	1.9	NR	< 10	< 2	2	9.2	6.3	2.4	190		
4/28/99	C1DZ2	170	< 1	906	248	3.3	0.4	1.6	2	1.7	NR	12	< 2	1.5	9.9	5.3	1.8	184		
4/28/99	C1DZ3	164	1	906	250	2.7	0.3	1.9	2.2	1.6	NR	28	2	0.78	9.8	4.9	1.92	185		
4/28/99	C1 EFF	162	2	906	247	2.4	0.4	1.9	2.3	1.7	NR	63	3	0.75	10.1	4.7	1.65	184		
5/19/99	CS INLET	172	4	942	259	4.3	0.5	3	3.5	2.8	NR	26	3	3.4	NR	7.8	0.9	172		
5/19/99	C1 INLETD	169	8	936	264	4.4	0.5	3	3.5	1.9	NR	25	2	3	NR	7.9	1.4	176		
5/19/99	C1 DZ1	167	5	946	272	4.5	0.6	2.9	3.5	2.3	NR	28	2	3.7	NR	8	0.8	177		
5/19/99	C1DZ2	168	4	952	276	4.9	1.6	2.8	4.4	2	NR	53	< 2	3.2	NR	9.3	1.7	173		
5/19/99	C1DZ3	159	4	952	260	3.5	0.4	2.8	3.2	2	NR	27	< 2	1.7	NR	6.7	1.8	176		
5/19/99	C1 EFF	161	2	964	262	3.5	0.4	2.7	3.1	2.1	NR	20	2	2.1	NR	6.6	1.4	179		
6/29/99	CS INLET	161	4	1050	307	1.9	< 0.5	4.7	5.2	1.8	4	49	< 2	0.87	8.1	7.1	1.03	142		
6/29/99	C1 INLETD	165	143	1020	309	4.1	< 0.5	3.7	4.2	1.8	5	133	7	1.1	10.8	8.3	3	146		
6/29/99	C1 DZ1	165	8	1090	302	2.6	< 0.5	3.7	4.2	1.7	4	46	4	1	8.8	6.8	1.6	149		
6/29/99	C1DZ2	165	8	990	296	1.6	< 0.5	2.9	3.4	1.6	4	45	4	0.35	9.4	5	1.25	155		
6/29/99	C1DZ3	168	28	1070	304	2.6	< 0.5	1.4	1.9	1.2	3	57	9	< 0.1	10.5	4.5	2.5	168		
6/29/99	C1 EFF	166	15	1040	303	2.1	< 0.5	2.1	2.6	1	3	60	10	< 0.1	8.9	4.7	2	168		
7/27/99	CS INLET	168	2	988	302	1.9	< 0.1	3.1	3.2	NR	*3*	42	< 2	0.91	8	5.1	0.99	143		
7/27/99	C1 INLETD	165	2	984	297	2	< 0.1	2.9	3	NR	*3*	32	< 2	0.88	7.8	5	1.12	142		
7/27/99	C1 DZ1	165	5	948	292	2.6	0.2	2.1	2.3	NR	*3*	37	< 2	1.3	7.6	4.9	1.3	146		
7/27/99	C1DZ2	165	7	932	286	1.9	< 0.1	1.9	2	NR	*3*	43	3	0.62	7.7	3.9	1.28	148		
7/27/99	C1DZ3	165	15	964	293	1.8	< 0.1	1.5	1.6	NR	*3*	41	2	0.53	8	3.4	1.27	152		
7/27/99	C1 EFF	168	3	956	293	1.6	< 0.1	1.3	1.4	NR	*2*	41	2	0.46	8.4	3	1.14	155		
8/24/99	CS INLET	172	1	996	298	1.7	< 0.1	1.8	1.9	NR	*2*	48	3	1.1	8.8	3.6	0.6	151		
8/24/99	C1 INLETD	173	5	1040	307	2.1	< 0.1	2.3	2.4	NR	*2*	50	2	1.5	8.8	4.5	0.6	150		
8/24/99	C1 DZ1	178	3	1030	311	2.7	0.2	2.1	2.3	NR	*2*	37	2	2.6	8.4	5	0.1	151		
8/24/99	C1DZ2	173	2	1020	304	3.1	0.2	1.5	1.7	NR	*3*	37	2	2.2	8.4	4.8	0.9	157		
8/24/99	C1DZ3	168	3	1010	295	2.3	0.2	1	1.2	NR	*3*	46	3	1.3	9.1	3.5	1	163		
8/24/99	C1 EFF	172	< 1	1030	300	2.7	< 0.1	0.9	1	NR	*3*	44	2	1.5	9.4	3.7	1.2	167		

NR = No Result

TRES RIOS Demonstration Constructed Wetland Project
Cobble Site Gradient Water Quality - Basin 1

SAMPLE DATE	SAMPLE LOCATION	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	Total-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)	Br- (EPA 300.0)	Total Sulfide (mg/L)
1/20/00	CS INLET	165	62	858	213	1	< 0.1	4.2	4.3	NR	3	38	< 2	< 0.2	9	5.3	0.8	178		
1/20/00	C1 INLETD	160	9	854	210	1.2	< 0.1	4.5	4.6	NR	4	34	< 2	0.35	9.2	5.8	0.85	178		
1/20/00	C1 DZ1	174	2	836	206	1.6	0.2	4.9	5.1	NR	4	37	< 2	0.76	9.2	6.7	0.84	179		
1/20/00	C1DZ2	173	6	848	202	1.7	0.3	4.8	5.1	NR	4	35	< 2	0.83	8.6	6.8	0.87	180		
1/20/00	C1DZ3	174	5	832	202	1.3	< 0.5	3.5	4	NR	3	41	< 2	0.61	9.5	5.3	0.69	184		
1/20/00	C1 EFF	175	3	850	203	1.1	0.3	4.2	4.5	NR	3	32	< 2	0.49	9.7	5.6	0.61	184		
5/25/00	CS INLET	173	1.6	958	320	1.6	< 0.5	2.09	2.59	NR	2.3	34	< 2	1.3	8.3	4.19	0.3	181		
5/25/00	C1 INLETD	176	3	1000	322	1.9	< 0.5	2.05	2.55	NR	2.3	35	< 2	1.4	8.9	4.45	0.5	181		
5/25/00	C1 DZ1	175	2	968	327	3.1	< 0.5	1.94	2.44	NR	4	37	< 2	1.6	8.5	5.54	1.5	189		
5/25/00	C1DZ2	178	65	966	329	3.6	< 0.5	1.15	1.65	NR	3.2	55	8	0.44	12.1	5.25	3.16	194		
5/25/00	C1DZ3	180	5	976	331	1.6	< 0.5	0.63	1.13	NR	3	34	2	0.38	8.7	2.73	1.22	194		
5/25/00	C1 EFF	180	16	980	328	1	< 0.5	< 0.5	1	NR	2.8	44	4	0.31	8.8	2	0.69	191		
9/6/00	CS INLET	177	4	1040	232	2.6	0.1	2.2	2.3	1.9	2.2	35	< 2	1.3	7.9	4.9	1.3	216	0.2	
9/6/00	C1 INLETD	176	4	1050	233	2.4	0.1	2.2	2.3	NR	2.2	29	< 2	1.2	8	4.7	1.2	214		
9/6/00	C1 DZ1	178	211	1010	235	26	0.2	2.1	2.3		2.6	383	21	1	12	28.3	25	212		
9/6/00	C1DZ2	175	52	1030	236	3	0.2	2.3	2.5		2.3	131	5	1.1	9	5.5	1.9	212		
9/6/00	C1DZ3	176	11	1030	225	2.3	0.2	1.7	1.9	NR	2.3	28	2	0.95	7.8	4.2	1.35	206		
9/6/00	C1 EFF	176	15	1020	231	1.7	0.1	1.1	1.2		2.1	31	3	0.42	7.9	2.9	1.28	210		
10/19/00	CS INLET	190	2	970	280	2.2	0.2	2.4	2.6	NR	1.8	10	< 2	1.5	7.1	4.8	0.7	234		
10/19/00	C1 INLETD	189	7	992	280	2.6	0.3	2	2.3		2	17	< 2	1.8	7.4	4.9	0.8	235		
10/19/00	C1 DZ1	190	4	976	277	2.8	0.2	1.7	1.9		2	12	2	2	NR	4.7	0.8	234		
10/19/00	C1DZ2	175	18	954	269	1.9	0.1	1.3	1.4		1.9	24	6	1	8.1	3.3	0.9	228		
10/19/00	C1DZ3	177	84	942	265	2	< 0.1	0.5	0.6	NR	1.6	34	5	0.52	7.3	2.6	1.48	226		
10/19/00	C1 EFF	183	14	958	270	1.2	< 0.1	0.7	0.8		1.9	13	< 2	0.44	6.7	2	0.76	229		
11/20/00	CS INLET	184	3	934	259	1.6	< 0.1	4.7	4.8		2.9	40	2	< 0.5	7.44	6.4	1.1	181		
11/20/00	C1 INLETD	182	2	940	260	1.6	< 0.1	4.8	4.9		2.9	8	2	< 0.5	7.34	6.5	1.1	181		
11/20/00	C1 DZ1	178	14	950	264	2.2	0.1	5.4	5.5		2.8	22	< 2	< 0.5	8	7.7	1.7	181		
11/20/00	C1DZ2	172	7	962	270	1.6	0.2	6.9	7.1		2.5	31	< 2	< 0.5	7.34	8.7	1.1	180		
11/20/00	C1DZ3	175	2	980	271	1.5	0.1	6	6.1		1.7	35	2	< 0.5	10.1	7.6	1	180		
11/20/00	C1 EFF	175	4	984	281	1.6	0.1	5.7	5.8		1.4	27	< 2	< 0.5	341	7.4	1.1	182		
12/20/00	CS INLET	189	2	898	258	1.8	0.1	4.2	4.3	NR	1.1	19	< 2	0.52	7.8	6.1	1.28	205		
12/20/00	C1 INLETD	188	10	900	260	1.7	0.1	4.3	4.4	NR	1.1	27	< 2	0.46	7.8	6.1	1.24	206		
12/20/00	C1 DZ1	186	25	884	264	3.1	0.4	5.2	5.6		1.8	52	6	0.28	12.4	8.7	2.82	207		
12/20/00	C1DZ2	178	51	888	267	3.6	0.5	5.3	5.8		1.4	84	NR	0.6	10.2	9.4	3	210		
12/20/00	C1DZ3	184	9	868	263	1.7	0.4	4.9	5.3		0.9	32	3	0.58	7.5	7	1.12	212		
12/20/00	C1 EFF	180	10	888	266	1.6	0.3	5	5.3		0.8	39	2	0.53	7.7	6.9	1.07	213		

NR = No Result

TRES RIOS Demonstration Constructed Wetland Project
Cobble Site Gradient Water Quality - Basin 2

SAMPLE DATE	SAMPLE LOCATION	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	Total-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)	Br- (EPA 300.0)	Total Sulfide (mg/L)
8/24/99	CS INLET	172	1	996	298	1.7	< 0.1	1.8	1.9	NR	*2*	48	3	1.1	8.8	3.6	0.6	151		
8/24/99	C2 INLETD	171	3	1000	306	1.4	< 0.1	2.4	2.5	NR	*2*	52	2	1.2	9	3.9	0.2	150		
8/24/99	C2DZ1	173	4	1050	309	2.1	0.2	2.4	2.6	NR	*2*	34	2	1.3	9	4.7	0.8	150		
8/24/99	C2DZ2	177	3	1050	314	2.9	0.2	2.1	2.3	NR	*2*	42	< 2	2	9.2	5.2	0.9	151		
8/24/99	C2DZ3	190	3	1020	295	2.3	< 0.1	0.1	0.2	NR	*3*	38	< 2	2.2	8.6	2.5	0.1	157		
8/24/99	C2 EFF	182	1	1010	299	3.1	< 0.1	< 0.1	0.2	NR	*3*	49	2	1.9	8.5	3.3	1.2	160		
9/23/99	CS INLET	179	9	980	306	2.1	< 0.1	2.4	2.5	NR	*4*	22	< 2	1.5	8.4	4.6	0.6	145		
9/23/99	C2 INLETD	177	8	976	307	1.5	< 0.1	2.5	2.6	NR	*4*	26	< 2	1.3	8.3	4.1	0.2	146		
9/23/99	C2DZ1	175	7	982	310	1.8	0.2	2.5	2.7	NR	*4*	22	< 2	1.1	7.6	4.5	0.7	148		
9/23/99	C2DZ2	174	24	986	312	2.2	0.2	2.6	2.8	NR	*4*	31	3	1	9	5	1.2	149		
9/23/99	C2DZ3	180	12	984	305	1.9	< 0.1	1.4	1.5	NR	*4*	31	< 2	0.78	7.8	3.4	1.12	149		
9/23/99	C2 EFF	185	1	984	300	1.1	< 0.1	0.9	1	NR	*4*	23	< 2	0.7	7.8	2.1	0.4	146		
10/26/99	CS INLET	175	8	918	273	2.9	0.1	1.8	1.9	NR	*3*	31	2	1	7.1	4.8	1.9	145		
10/26/99	C2 INLETD	170	8	908	262	2.3	0.2	1.9	2.1	NR	*3*	35	2	1	7.8	4.4	1.3	140		
10/26/99	C2DZ1	167	10	920	269	2.3	0.3	2.3	2.6	NR	*3*	38	2	0.78	7.5	4.9	1.52	140		
10/26/99	C2DZ2	167	2	920	274	2.1	0.2	2.8	3	NR	*3*	43	< 2	0.86	6.9	5.1	1.24	140		
10/26/99	C2DZ3	172	8	906	256	2.4	0.1	1.5	1.6	NR	*3*	40	< 2	0.54	6.6	4	1.86	139		
10/26/99	C2 EFF	177	1	906	257	1.4	< 0.1	0.6	0.7	NR	*4*	23	< 2	0.33	6.5	2.1	1.07	142		
11/23/99	CS INLET	127	3	814	220	0.8	< 0.1	3	3.1	NR	*2*	34	< 2	< 0.2	7.5	3.9	0.6	143		
11/23/99	C2 INLETD	129	3	792	222	0.9	< 0.1	2.8	2.9	NR	*2*	31	2	< 0.2	7.5	3.8	0.7	136		
11/23/99	C2DZ1	139	48	780	211	2.8	< 0.1	1.6	1.7	NR	*3*	72	4	< 0.2	9.5	4.5	2.6	137		
11/23/99	C2DZ2	145	2	782	207	1.5	< 0.1	0.8	0.9	NR	*3*	47	< 2	0.34	7.6	2.4	1.16	137		
11/23/99	C2DZ3	136	8	806	225	3.7	< 0.1	0.8	0.9	NR	*3*	35	2	0.59	8.1	4.6	3.11	141		
11/23/99	C2 EFF	148	1	830	224	1.5	< 0.1	0.5	0.6	NR	*2*	33	2	0.58	7.1	2.1	0.92	143		
12/21/99	CS INLET	184	5	844	204	2.8	0.2	3.8	4	NR	*<2*	40	3	1.9	8.8	6.8	0.9	145		
12/21/99	C2 INLETD	180	5	842	213	3.3	0.3	3.8	4.1	NR	*2*	44	3	2.1	9.2	7.4	1.2	147		
12/21/99	C2DZ1	184	99	842	221	10.5	1.8	3.2	5	NR	*3*	73	8	2.6	11.2	15.5	7.9	149		
12/21/99	C2DZ2	193	5	820	204	4.3	0.6	1.7	2.3	NR	*3*	39	2	3.2	9	6.6	1.1	142		
12/21/99	C2DZ3	196	4	810	200	3.8	0.5	1.1	1.6	NR	*4*	34	< 2	2.7	12	5.4	1.1	144		
12/21/99	C2 EFF	198	6	826	199	3.7	0.4	1.2	1.6	NR	*4*	38	2	2.7	8.2	5.3	1	145		

NR = No Result

TRES RIOS DEMONSTRATION WETLAND COBBLE SITE BASIN 1: MASS REMOVAL

C1

Date	ALKALINITY	TSS	TDS	Cl-	TKN	NO2 - N	NO3 - N	NO2+NO3 - N	PO4 - P	Diss. P	COD	cBOD	NH3 - N	TOC	TOTAL-N	Organic-N	Sulfate
Jan-98	23.8%	21.1%	21.4%	17.7%	69.8%	60.5%	38.6%	40.1%	29.5%	16.7%	44.8%	21.1%	95.4%	30.0%	56.2%	44.3%	18.6%
Feb-98	NR	NR	NR	32.0%	66.1%	-46.1%	13.2%	9.7%	47.8%	44.7%	NR	NR	78.1%	NR	44.8%	58.3%	33.4%
Sep-98	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Oct-98	98.1%	99.4%	98.2%	98.3%	98.0%	95.4%	99.2%	98.8%	97.2%	NR	98.1%	98.1%	98.8%	98.0%	98.3%	97.0%	98.2%
Dec-98	99.9%	100.0%	99.9%	99.9%	99.9%	99.2%	99.9%	99.8%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Jan-99	19.6%	21.9%	19.8%	17.9%	33.2%	-134.4%	6.2%	-0.5%	12.1%	-4.2%	19.6%	-17.2%	13.2%	25.6%	17.5%	45.3%	21.9%
Feb-99	21.4%	46.8%	22.5%	19.7%	-38.4%	-139.5%	25.7%	18.4%	24.9%	20.2%	30.5%	60.1%	20.2%	NR	-10.0%	-64.8%	22.1%
Apr-99	46.3%	81.7%	46.3%	45.7%	69.3%	-10.0%	30.3%	25.6%	53.3%	NR	-23.7%	45.0%	80.4%	45.6%	56.9%	58.8%	48.4%
May-99	52.9%	74.8%	48.5%	49.1%	59.0%	59.7%	54.7%	55.4%	62.2%	NR	61.3%	66.4%	68.9%	NR	57.4%	21.7%	47.6%
Jun-99	33.3%	-142.5%	36.0%	36.2%	28.5%	35.3%	71.1%	67.7%	64.1%	51.5%	20.8%	-223.3%	92.6%	29.0%	57.2%	-25.5%	23.5%
Jul-99	25.5%	-11.7%	28.0%	27.8%	37.3%	25.5%	68.8%	67.4%	NR	50.4%	27.3%	25.5%	62.4%	21.8%	56.2%	14.3%	19.3%
Aug-99	12.6%	NR	9.6%	12.0%	-38.9%	12.6%	56.3%	54.0%	NR	-31.1%	19.9%	41.7%	-19.2%	6.6%	10.1%	-74.8%	3.3%
Sep-99	27.5%	83.2%	24.7%	25.5%	53.3%	24.5%	43.4%	42.6%	NR	43.4%	17.6%	24.5%	71.8%	25.4%	47.5%	6.9%	23.5%
Oct-99	18.8%	78.2%	12.7%	14.5%	73.0%	12.9%	-16.2%	-14.6%	NR	-16.2%	43.8%	12.9%	82.6%	20.2%	38.3%	67.9%	14.1%
Nov-99	-2.4%	43.3%	15.0%	12.7%	-6.2%	15.0%	85.8%	83.5%	NR	15.0%	25.0%	15.0%	-23.2%	24.1%	65.1%	-0.6%	15.0%
Dec-99	-0.9%	4.3%	6.8%	8.1%	-16.2%	-234.9%	49.6%	35.4%	NR	NR	4.3%	4.3%	-36.0%	9.7%	14.2%	25.6%	4.3%
Jan-00	-4.9%	95.2%	2.0%	5.7%	-8.8%	-196.7%	1.1%	-3.5%	NR	1.1%	16.7%	1.1%	-142.3%	-6.6%	-4.5%	24.6%	-2.2%
May-00	-1.1%	-871.7%	0.6%	0.4%	39.3%	2.8%	76.8%	62.5%	NR	-18.3%	-25.8%	-94.3%	76.8%	-3.0%	53.6%	-123.5%	-2.5%
Sep-00	1.6%	-271.1%	3.0%	1.5%	35.3%	1.0%	50.5%	48.4%	100.0%	5.5%	12.4%	-48.4%	68.0%	1.0%	41.4%	2.6%	3.8%
Oct-00	4.4%	-594.9%	2.0%	4.3%	45.9%	50.4%	71.0%	69.5%	NR	-4.8%	-29.1%	0.7%	70.9%	6.3%	58.6%	-7.8%	2.9%
Nov-00	5.2%	-32.9%	-5.0%	-8.1%	0.4%	0.4%	-20.8%	-20.4%	NR	51.9%	32.7%	0.4%	0.4%	NR	-15.2%	0.4%	-0.2%
Dec-00	5.1%	-398.1%	1.5%	-2.7%	11.4%	NR	-18.6%	-22.8%	NR	27.5%	-104.5%	0.4%	-1.5%	1.6%	-12.7%	16.7%	-3.5%
Average	**24.3%**	**-82.8%**	**24.7%**	**24.7%**	**33.9%**	**-13.3%**	**42.2%**	**38.9%**	**59.1%**	**20.8%**	**19.6%**	**6.7%**	**40.9%**	**25.6%**	**39.6%**	**13.7%**	**23.4%**
Minimum	**-4.9%**	**-871.7%**	**-5.0%**	**-8.1%**	**-38.9%**	**-234.9%**	**-20.8%**	**-22.8%**	**12.1%**	**-31.1%**	**-104.5%**	**-223.3%**	**-142.3%**	**-6.6%**	**-15.2%**	**-123.5%**	**-3.5%**
Maximum	**99.9%**	**100.0%**	**99.9%**	**99.9%**	**99.9%**	**99.2%**	**99.9%**	**99.8%**	**100.0%**	**99.9%**	**99.9%**	**99.9%**	**99.9%**	**99.9%**	**99.9%**	**99.9%**	**99.9%**

NR = No Result

Appendix E

Hayfield Site
Water Quality
Data & Plots

Tres Rios Hayfield Site
Water Quality Analytical Results

HS INLET

SAMPLE DATE	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Organic-N (mg/L)	Sulfate EPA 300.0	Br- EPA 300.0
1/20/98	173	1	860	208	3.5	0.2	2.7	2.9		3.6	38	2	1.8	9.2	6.4	1.7	186	
2/19/98				158	2.5	< 0.1	1.7	1.8	2.8	3.8			1.4		4.3	1.1	155	
3/24/98				177	1.9	0.1	1.1	1.2	3	3.5			0.93	9.9	3.1	0.97	145	0.2
4/28/98				182	3.7	0.1	2.6	2.7	2	2.7			1.8	9	6.4	1.9	120	
5/19/98				230	2.3	0.1	2.2	2.3	3	3.5			1.7	9	4.6	0.6	122	
6/16/98				210	7.7	0.2	0.9	1.1	1.6	NR			4.9	10.2	8.8	2.8	112	
7/28/98	163			342	2.7	< 0.1	2	2.1	2	2.4			1.5	9.1	4.8	1.2	143	
8/25/98	162	3	1070	330	3.8	< 0.1	1.1	1.2	NA	2.3	116	7	0.79	7.2	5	3.01	148	
9/29/98				320	4.4	< 0.1	2.8	2.9	1.6	3.2			1.7	7.5	7.3	2.7	142	
10/27/98	172			206	4.3	0.2	1.8	2	1.2	< 2			2.2	8.1	6.3	2.1	152	
12/9/98	169			197	3	< 0.1	2.7	2.8	3.4	4.8			1.2	7.8	5.8	1.8	150	
1/26/99	177	2	862	243	3.8	0.3	4.1	4.4	3.2	3	38	2	1.6	10	8.2	2.2	129	
2/23/99	204			164	4.5	0.2	3.1	3.3	3.5	4			1.8	NR	7.8	2.7	126	
4/28/99	171	7	918	250	4.4	0.4	1.6	2	1.1	NR	29	4	2.9	10	6.4	1.5	197	
5/19/99	157	18	924	256	3.3	< 0.1	2.9	3	2.1	NR	38	No Result	1.2	NR	6.3	2.1	171	
6/29/99	167	2	1000	310	2.8	< 0.5	5	5.5	2	3	31	< 2	1.8	7.9	8.3	1	143	
7/27/99	170	3	1000	298	2.2	< 0.1	3.2	3.3	NR	*3*	26	< 2	1.2	7.8	5.5	1	143	
8/24/99	180	2	1000	281	3	< 0.1	3	3.1	NR	*2*	32	2	2.2	9.1	6.1	0.8	147	
9/23/99	179	2	984	308	2.2	< 0.1	3.1	3.2	NR	*4*	20	< 2	1.6	7.4	5.4	0.6	149	
10/26/99	169	2	916	267	3	< 0.1	3.2	3.3	NR	*3*	23	< 2	1.2	7.6	6.3	1.8	141	
11/23/99	129	3	806	220	0.9	< 0.1	3	3.1	NR	*2*	31	3	< 0.2	7.5	4	0.7	136	
12/21/99	181	4	850	213	2.6	0.2	4.2	4.4	NR	*<2*	39	3	2	8.8	7	0.6	146	
1/20/00	167	3	854	215	1.3	< 0.1	5	5.1	NR	*4*	29	< 2	0.43	8.7	6.4	0.87	156	
2/22/00	165	3	850	199	2.5	< 0.1	3	3.1	NR	*3*	38	< 2	1.3	10	5.6	1.2	200	
5/25/00	172	3	1010	319	2	< 0.5	1.33	1.83	NR	*2.1*	32	2	0.45	8.4	3.83	1.55	183	
8/10/00	194	3	1150	362	1.4	< 0.1	1.7	1.8	NR	*1.5*	20	< 2	0.88	6.9	3.2	0.52	189	
11/21/00	199	3	952	261	5.3	0.3	5	5.3	NR	*3.2*	58	< 2	3.5	7.69	10.6	1.8	184	
12/21/00	187	3	900	241	1.8	0.1	4.4	4.5	NR	*1.2*	41	< 2	0.54	7.4	6.3	1.26	193	

NR = Data Not Recorded

Tres Rios Hayfield Site
Water Quality Analytical Results

H2 EFF

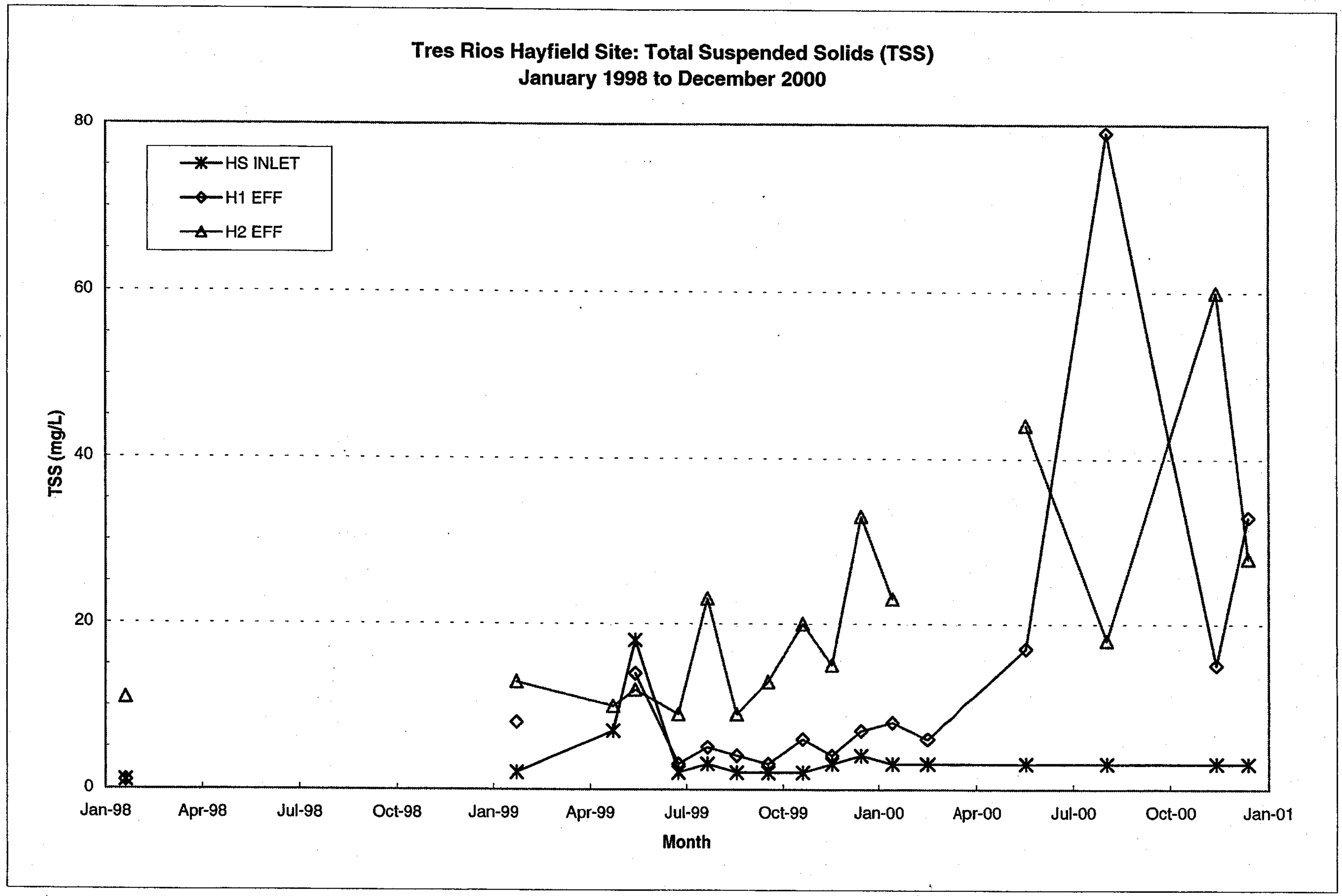
SAMPLE DATE	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)		TKN EPA 351.2 (mg/L)		NO2 - N EPA 300.0 (mg/L)		NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)		cBOD sm17 5210B (mg/L)		NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Organic-N (mg/L)	Sulfate EPA 300.0	Br- EPA 300.0
1/20/98	165	11	870	214		0.7	<	0.1		2	2.1	2.4	3.9	33	<	2	<	0.1	5.7	2.8	0.6	191	0.3
2/19/98				160		0.8	<	0.1		0.9	1	2	3.1				<	0.1		1.8	0.7	149	
3/24/98				180	<	1	<	0.1		0.3	0.4	2.3	5.8					0.17	7.1	1.4	0.83	154	0.2
4/28/98				168		1.5	<	0.1		0.2	0.3	1.7	4.2					0.43	8	1.8	1.07	120	
5/19/98				228		2.7	<	0.1	<	0.1	0.2	2.2	4					1.2	9.6	2.9	1.5	118	
6/16/98				202		4.2	<	0.1	<	0.1	0.2	2.3	NR					1.9	10.1	4.4	2.3	117	
7/28/98	176			327		2.7	<	0.1	<	0.1	0.2	2	3.3					1.4	8.2	2.9	1.3	140	
8/25/98	171	14	978	316		0.6	<	0.1		0.2	0.3	NA	2.9	73		2		0.61	7.6	0.9	-0.01	140	
9/29/98				318		4.1	<	0.1		0.8	0.9	1.4	3.8					1.1	6.8	5	3	144	
10/27/98	184			198		2.9	<	0.1		0.3	0.4	1.7	5.3					1.8	7.6	3.3	1.1	147	
12/9/98	174			193		3.9		0.1		2.4	2.5	2.2	3.4					1.1	7.1	6.4	2.8	151	
1/26/99	182	13	868	249		3.7		0.4		4	4.4	3.6	4	34		2		2	9	8.1	1.7	127	
2/23/99	207			160		4		0.2		3.1	3.3	3.3	5					1.5	NR	7.3	2.5	120	
4/28/99	181	10	978	268		1.9	<	0.1		0.2	0.3	1.4	NR	63		4		0.45	11	2.2	1.45	200	
5/19/99	178	12	946	259		3.2	<	0.1		0.1	0.2	1	NR	44		3		1.1	NR	3.4	2.1	186	
6/29/99	179	9	1050	314		2.5	<	0.5		1.6	2.1	1	4	39	<	2		1.2	8	4.6	1.3	160	
7/27/99	182	23	994	291		2	<	0.1		0.8	0.9	NR	*3*	33		4		1.2	8.1	2.9	0.8	151	
8/24/99	189	9	984	291		2.2	<	0.1		0.5	0.6	NR	*3*	48		4		1.7	9	2.8	0.5	160	
9/23/99	192	13	1000	306		1.9	<	0.1		0.5	0.6	NR	*4*	30		4		1.1	7.8	2.5	0.8	146	
10/26/99	173	20	928	267		1.8		0.1		1.7	1.8	NR	*4*	34	<	2		0.8	6.3	3.6	1	146	
11/23/99	141	15	824	224		1.2	<	0.1		1.4	1.5	NR	*2*	30		2		0.37	6.9	2.7	0.83	144	
12/21/99	202	33	824	198		3.9		0.7		1.4	2.1	NR	*3*	39		3		3.4	8.1	6	0.5	145	
1/20/00	186	23	868	207		2.2		0.2		3.2	3.4	NR	*3*	33		2		1.1	8.6	5.6	1.1	161	
2/22/00																							
5/25/00	193	44	1050	41		2.8	<	0.5		0.5	1	NR	***2.6***	41		3		0.51	9.9	3.8	2.29	197	
8/10/00	194	18	1150	364		1.9		0.3		1.3	1.6	NR	***1.7***	23		2		1.2	7.6	3.5	0.7	187	
11/21/00	182	60	990	306		2.5		0.3		3.2	3.5	NR	***2.2***	51		7	<	0.5	367	6	2	180	
12/21/00	194	28	894	243		1.8		0.3		2.7	3	NR	***0.7***	49		2		0.5	7.3	4.8	1.3	200	

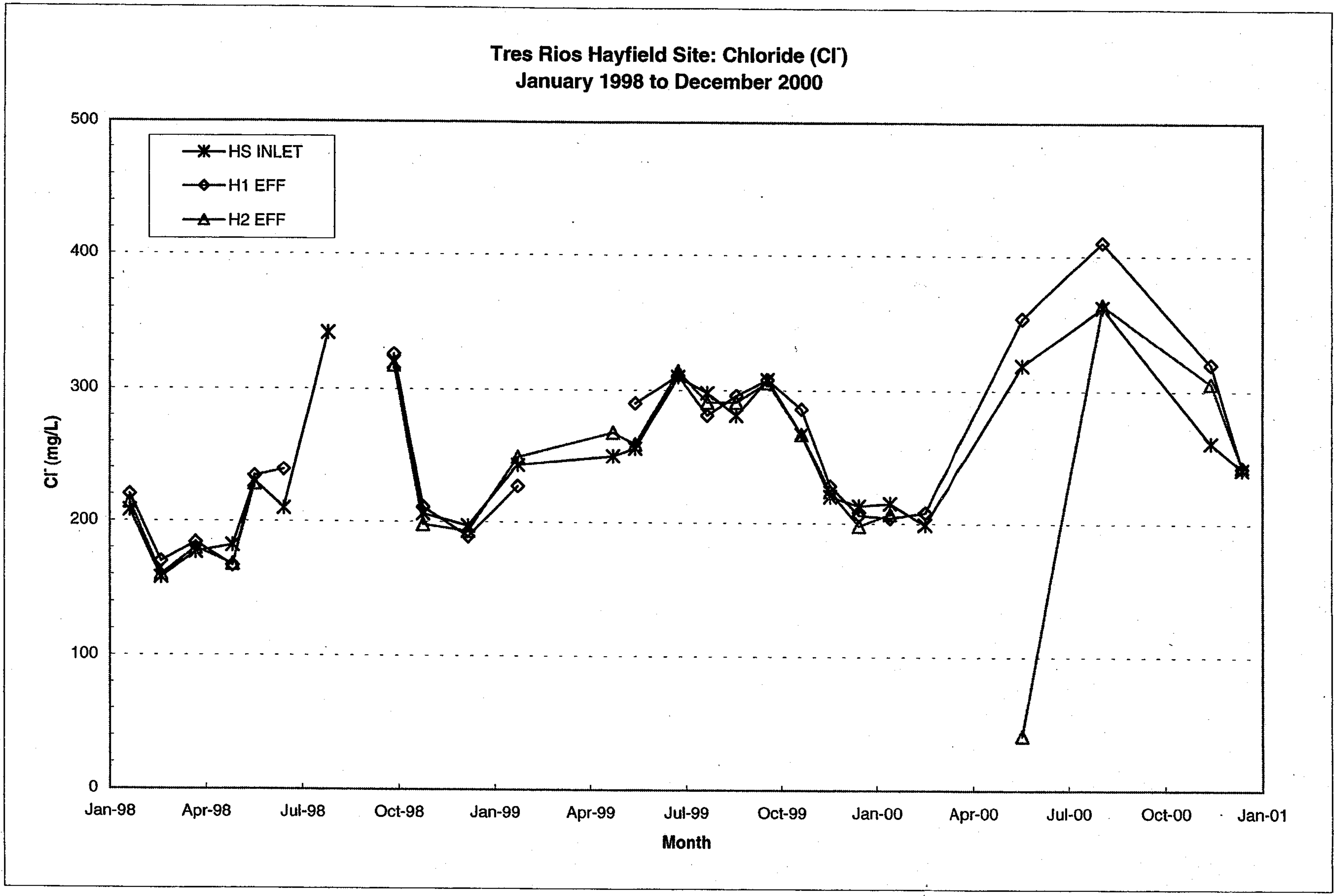
NR = Data Not Recorded

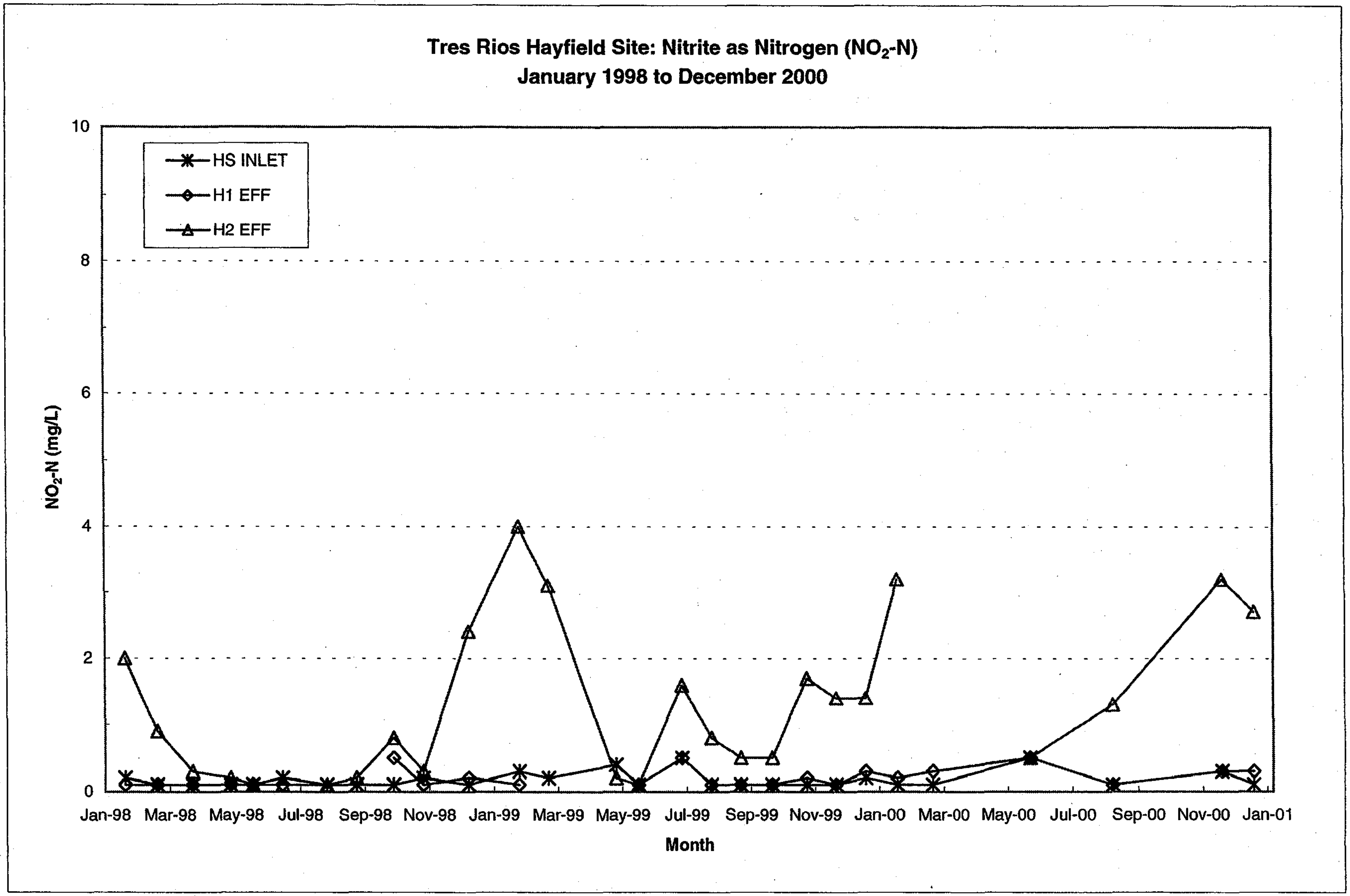
Tres Rios Hayfield Site
Water Quality Analytical Results

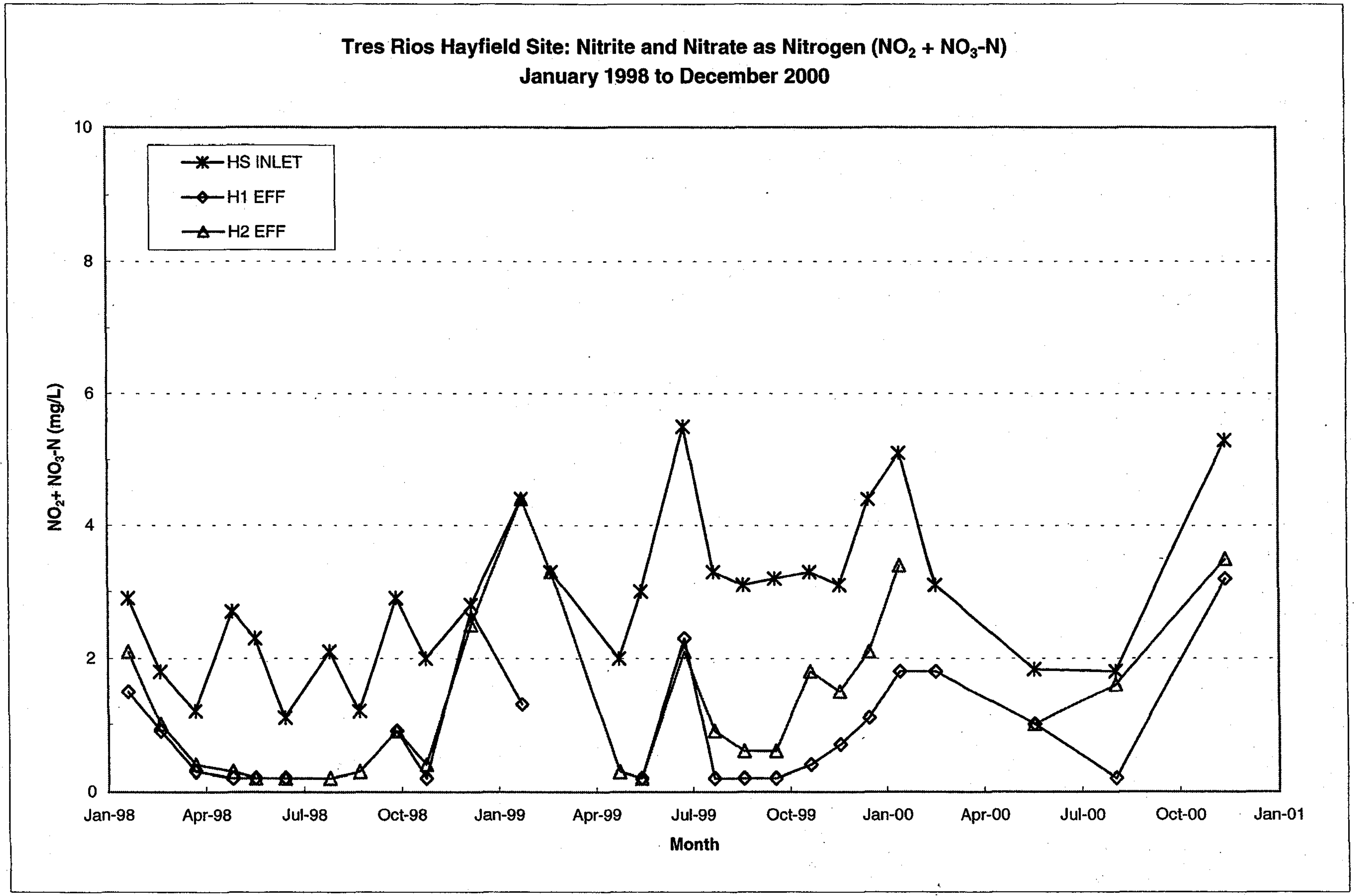
SAMPLE DATE	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Organic-N (mg/L)	Sulfate EPA 300.0	Br- EPA 300.0
H1 EFF Dup.																		
2/19/98				178	1	< 0.1	0.8	0.9	2.2	3.2			0.3		1.9	0.7	165	
4/28/98				164	3.2	< 0.1	< 0.1	0.2	2	4.4			1.9	8.7	3.4	1.3	112	
6/16/98				239	6.3	< 0.1	< 0.1	0.2	2.7	NR			2.3	16.9	6.5	4	107	
12/9/98	163			192		0.2	2.5	2.7	2.2	3.5			0.86	7.7	2.7	-0.86	158	
7/27/99	186	7	984	301	2.2	0.1	0.1	0.2	NR	***3***	56	< 2	1.2	8.6	2.4	1	152	
11/23/99	160	3	856	229	1.3	< 0.1	0.6	0.7	NR	***2***	26	< 2	0.64	6.2	2	0.66	147	
1/20/00	195	8	866	170	2.3	0.1	1.5	1.6	NR	***4***	30	< 2	1.9	8.4	3.9	0.4	151	
5/25/00	196	11	1050	346	2.1	< 0.5	< 0.5		2		46	3		11.7			201	
H2 EFF Dup.																		
3/24/98				180	< 1	< 0.1	0.3	0.4	2	5.8			0.17	7	1.4	0.83		
5/19/98				230	3	< 0.1	0.2	0.3	1.9	4.2			1.7	9.4	3.3	1.3	118	
7/28/98	176			329	3.6	< 0.1	< 0.1	0.2	1.8	3.3			1.4	8.1	3.8	2.2	137	
8/25/98	171	16	972	317	0.8	< 0.1	0.2	0.3	NA	2.8	98	2	0.61	6.8	1.1	0.19	138	
9/29/98				315	3.2	< 0.1	0.9	1	1.4	3.9			1	6.8	4.2	2.2	144	

NR = Data Not Recorded

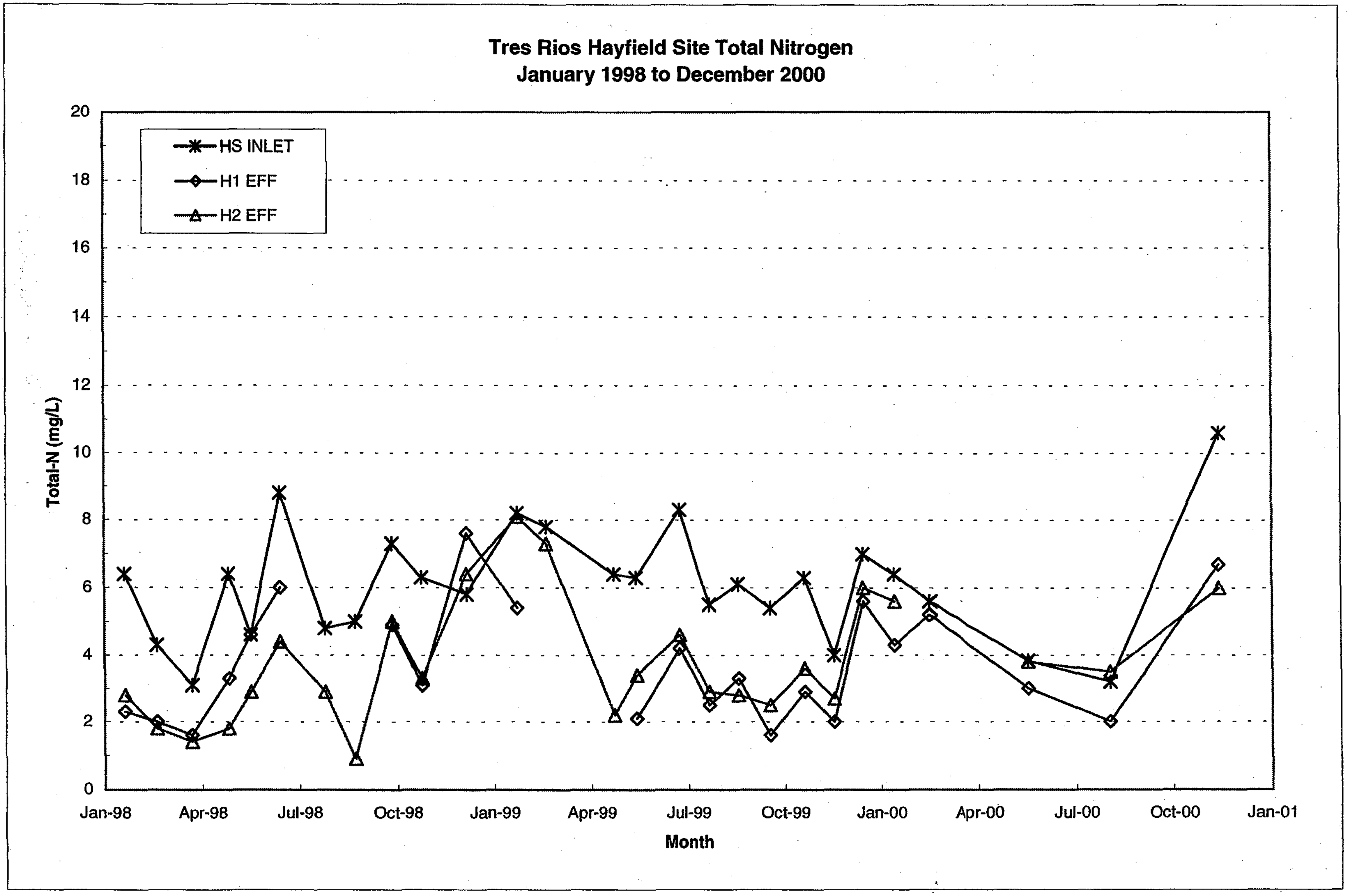

Tres Rios Hayfield Site: Total Suspended Solids (TSS)
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
TSS (mg/L)
80
60
40
20
0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month

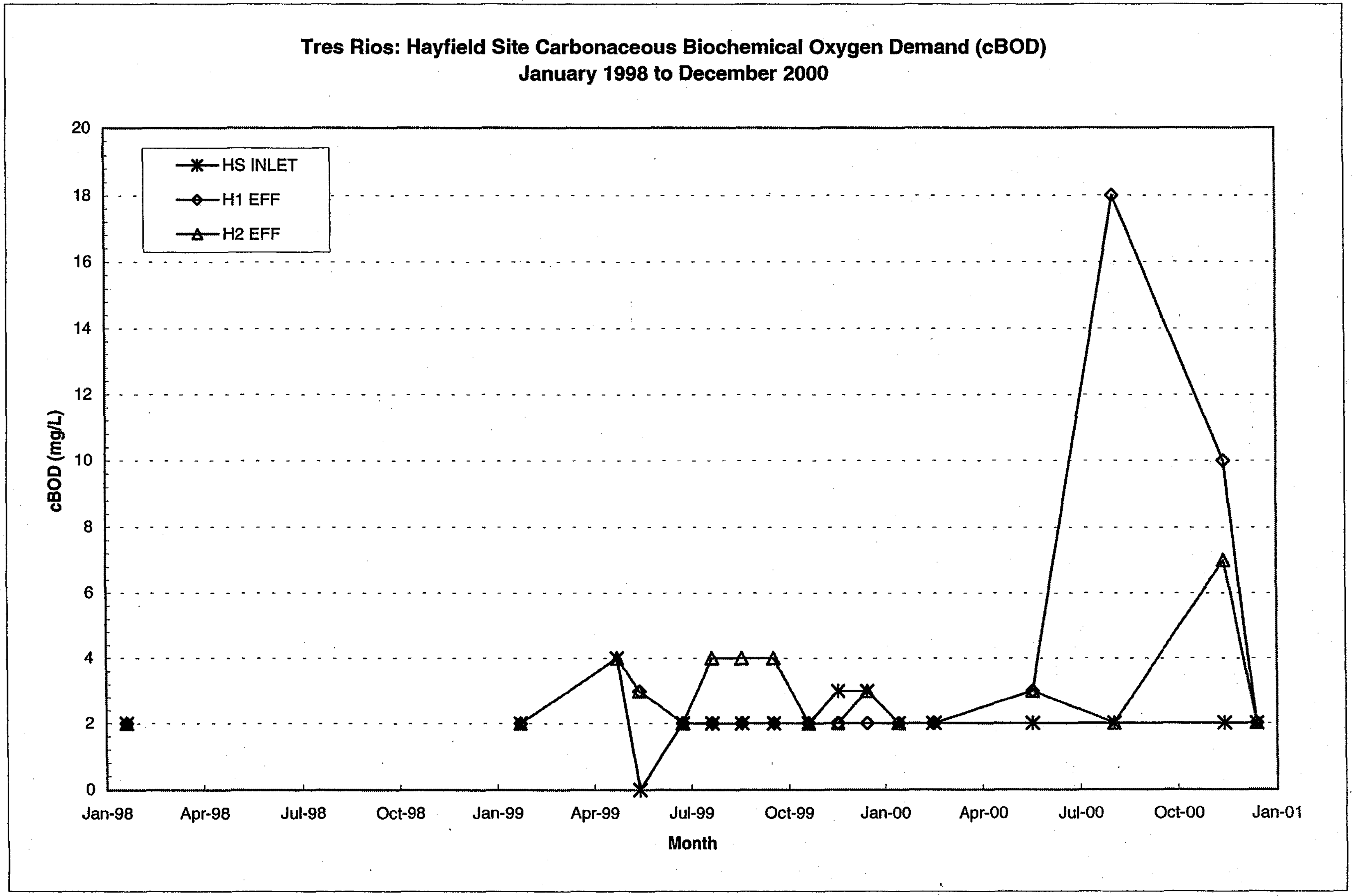

Tres Rios Hayfield Site: Chloride (Cl⁻)
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
500
400
300
200
100
0
Cl⁻ (mg/L)
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month


Tres Rios Hayfield Site: Nitrite as Nitrogen (NO_2-N)
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
NO_2-N (mg/L)
0
2
4
6
8
10
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Jan-01
Month

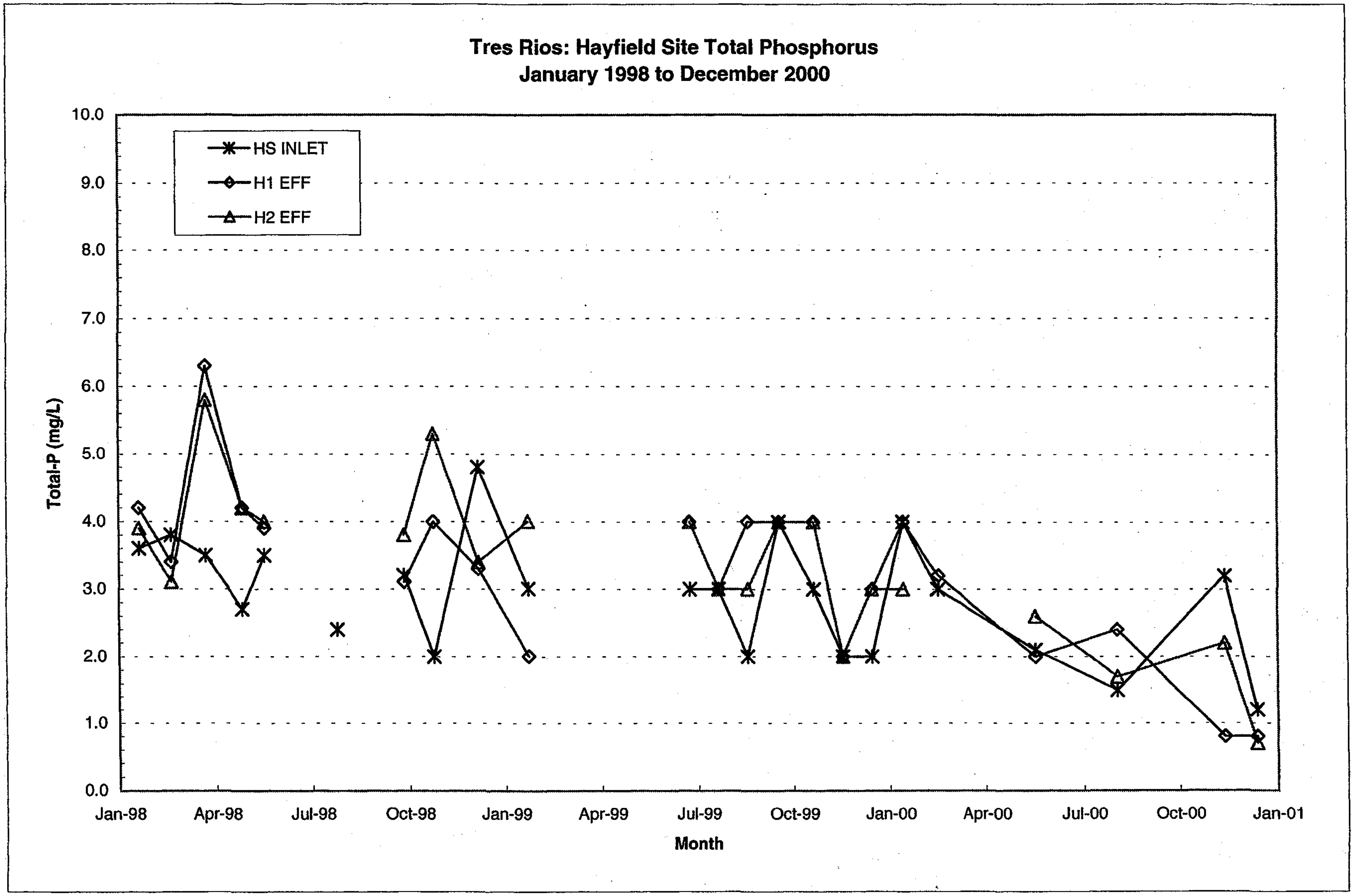


Tres Rios Hayfield Site: Nitrite and Nitrate as Nitrogen (NO_2 + NO_3-N)
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
NO_2+ NO_3-N (mg/L)
10
8
6
4
2
0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month


Tres Rios Hayfield Site Total Nitrogen
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
Total-N (mg/L)
20
18
16
14
12
10
8
6
4
2
0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month



Tres Rios: Hayfield Site Carbonaceous Biochemical Oxygen Demand (cBOD)
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
cBOD (mg/L)
0
2
4
6
8
10
12
14
16
18
20
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month



Tres Rios: Hayfield Site Total Phosphorus
January 1998 to December 2000
HS INLET
H1 EFF
H2 EFF
Total-P (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Month

TRES RIOS Demonstration Constructed Wetland Project
HAYFIELD SITE Gradient Water Quality - Basin 1

SAMPLE DATE	SAMPLE LOCATION	Alkalinity EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)	Br- (EPA 300.0)	Total Sulfide (mg/L)
1/20/98	HS Inlet	173	1	860	208	3.5	0.2	2.7	2.9		3.6	38	2	1.8	9.2	6.4	1.7	186		
1/20/98	HIDZ	169	5	870	206	3.5	0.3	3.1	3.4	2.7	3.8	47	2	1.5	9.1	6.9	2	185	0.2	
1/20/98	H1D1	160	4	884	214	2.7	0.4	4.6	5	3	4	37	< 2	1	7.9	7.7	1.7	186	0.2	
1/20/98	H1D2	164	4	848	210	2.7	0.4	3	3.4	2.9	3.9	36	< 2	1.1	7.4	6.1	1.6	186	0.2	
1/20/98	H1D3	167	2	842	204	2.4	0.3	2.6	2.9	2.5	4.1	26	< 2	1.1	7.3	5.3	1.3	184	0.2	
1/20/98	H1D4	172	6	854	209	1.9	0.1	1.5	1.6	1.6	4.2	22	< 2	0.55	6.8	3.5	1.35	186	0.2	
1/20/98	H1D5	173	2	868	210	1.5	< 0.1	1.6	1.7	1.5	4.4	21	< 2	0.4	6.8	3.2	1.1	187	0.2	
1/20/98	H1 EFF	175	< 1	878	220	0.8	< 0.1	1.4	1.5	2.5	4.2	23	< 2	< 0.1	6.1	2.3	0.7	190		
2/19/98	HS Inlet				158	2.5	< 0.1	1.7	1.8	2.8	3.8			1.4		4.3	1.1	155		
2/19/98	HIDZ				168	2.4	0.1	1.7	1.8	2.6	3.7			1.1		4.2	1.3	168		
2/19/98	H1D1				176	2.2	0.2	2.3	2.5	2.2	3			0.9		4.7	1.3	161		
2/19/98	H1D2				174	2.2	0.2	1.7	1.9	2	2.8			0.87		4.1	1.33	158		
2/19/98	H1D3				171	1.8	0.1	1.5	1.6	1.9	2.8			0.69		3.4	1.11	159		
2/19/98	H1D4				173	1.7	0.1	0.8	0.9	2.1	3.3			0.55		2.6	1.15	159		
2/19/98	H1D5				174	1.6	< 0.1	0.7	0.8	1.8	3.1			0.57		2.4	1.03	160		
2/19/98	H1 EFF				170	1.1	< 0.1	0.8	0.9	2.4	3.4			0.31		2	0.79	154		
3/24/98	HS Inlet				177	1.9	0.1	1.1	1.2	3	3.5			0.93	9.9	3.1	0.97	145		
3/24/98	HIDZ				182	3.3	0.1	1.4	1.5	2.6	3.6			1.4	9	4.8	1.9	145		
3/24/98	H1D1				185	2.9	0.2	1.3	1.5	3	4			1.6	8.6	4.4	1.3	145		
3/24/98	H1D2				170	2.9	0.2	0.4	0.6	3.4	5.3			1.6	8.5	3.5	1.3	137		
3/24/98	H1D3				167	2.6	0.1	0.2	0.3	3.3	5.7			0.87	8.8	2.9	1.73	135	0.2	
3/24/98	H1D4				178	3.3	< 0.1	< 0.1	0.2	1.8	6.4			1.4	10.6	3.5	1.9	139		
3/24/98	H1D5				179	2.5	< 0.1	< 0.1	0.2	1.8	6.3			1.4	8.6	2.7	1.1	166	0.2	
3/24/98	H1 EFF				184	1.3	< 0.1	0.2	0.3	1.9	6.3			1	8.4	1.6	0.3	143		
4/28/98	HS Inlet				182	3.7	0.1	2.6	2.7	2	2.7			1.8	9	6.4	1.9	120		
4/28/98	HIDZ				189	3.8	0.2	2.5	2.7	2.1	2.4			1.8	9	6.5	2	121		
4/28/98	H1D1				180	4.2	0.3	1.7	2	2.8	3.3			1.7	9	6.2	2.5	118		
4/28/98	H1D2				174	3	0.3	1.2	1.5	2.9	3.8			1.7	8.6	4.5	1.3	118		
4/28/98	H1D3				170	4	0.2	0.7	0.9	2.8	3.9			1.6	8.7	4.9	2.4	116		
4/28/98	H1D4				167	3.2	0.1	0.2	0.3	2.6	4.3			1.8	9.2	3.5	1.4	116		
4/28/98	H1D5				166	3.3	< 0.1	< 0.1	0.2	2.3	4			1.6	8.7	3.5	1.7	115		
4/28/98	H1 EFF				167	3.1	< 0.1	< 0.1	0.2	1.9	4.2			1.6	8.6	3.3	1.5	112		
5/19/98	HS Inlet				230	2.3	0.1	2.2	2.3	3	3.5			1.7	9	4.6	0.6	122		
5/19/98	HIDZ				223	2.9	0.1	2.1	2.2	2.8	3.2			1.9	8.8	5.1	1	120		
5/19/98	H1D1				209	4.7	< 0.1	< 0.1	0.2	2.8	2.8			3	9.4	4.9	1.7	113		
5/19/98	H1D2				210	4.5	0.2	0.2	0.4	2.5	3			3.1	9.2	4.9	1.4	115		
5/19/98	H1D3				213	4.1	< 0.1	< 0.1	0.2	2.7	3.2			3	9.3	4.3	1.1	114		
5/19/98	H1D4				218	4.1	< 0.1	< 0.1	0.2	3.1	3.8			2.8	9.4	4.3	1.3	111		
5/19/98	H1D5				227	4.4	< 0.1	< 0.1	0.2	3.2	3.9			2.9	9.5	4.6	1.5	111		
5/19/98	H1 EFF				234	4.4	< 0.1	< 0.1	0.2	3.2	3.9			2.4	10	4.6	2	105		
6/16/98	HS Inlet				210	7.7	0.2	0.9	1.1	1.6	NR			4.9	10.2	8.8	2.8	112		
6/16/98	HIDZ				210	9.5	0.2	0.8	1	1.8	NR			5.1	12.5	10.5	4.4	112		
6/16/98	H1D1				216	7.3	< 0.1	0.1	0.2	2.5	NR			6.4	10.7	7.5	0.9	110		
6/16/98	H1D2				202	6.8	< 0.1	0.1	0.2	2.6	NR			3.7	12.1	7	3.1	101		
6/16/98	H1D3				218	NR	< 0.1	< 0.1	0.2	2.9	NR			2.3	13			104		
6/16/98	H1D4				228	7	< 0.1	< 0.1	0.2	2.4	NR			1.8	14.5	7.2	5.2	98		
6/16/98	H1D5				228	4.8	< 0.1	< 0.1	0.2	2.6	NR			1.4	13.2	5	3.4	101		
6/16/98	H1 EFF				239	5.8	< 0.1	< 0.1	0.2	2.8	NR			2.1	17.3	6	3.7	111		

NR = No Result

TRES RIOS Demonstration Constructed Wetland Project
HAYFIELD SITE Gradient Water Quality - Basin 1

SAMPLE DATE	SAMPLE LOCATION	Alkalinity EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)	Br- (EPA 300.0)	Total Sulfide (mg/L)
7/27/99	HS Inlet	170	3	1000	298	2.2	< 0.1	3.2	3.3	NR	3	26	< 2	1.2	7.8	5.5	1	143		
7/27/99	HIDZ	168	5	994	298	2.6	< 0.1	3.2	3.3	NR	3	31	< 2	1.2	9.2	5.9	1.4	147		
7/27/99	H1D1	172	5	972	294	2.8	0.2	2.1	2.3	NR	3	30	< 2	1.7	8	5.1	1.1	149		
7/27/99	H1D2	185	6	952	290	3.2	< 0.1	< 0.1	0.2	NR	3	40	3	1.9	9.2	3.4	1.3	147		
7/27/99	H1D3	184	10	962	279	2.8	0.2	0.1	0.3	NR	3	36	3	1.8	8.5	3.1	1	148		
7/27/99	H1D4	185	21	970	281	2.3	0.2	0.1	0.3	NR	3	47	4	1.5	8.2	2.6	0.8	154		
7/27/99	H1D5	186	12	982	292	2.7	< 0.1	< 0.1	0.2	NR	3	47	4	1.2	9.5	2.9	1.5	152		
7/27/99	H1 EFF	182	5	988	281	2.3	< 0.1	0.1	0.2	NR	3	35	< 2	1.2	8.2	2.5	1.1	150		
8/24/99	HS Inlet	180	2	1000	281	3	< 0.1	3	3.1	NR	2	32	2	2.2	9.1	6.1	0.8	147		
8/24/99	HIDZ	178	6	1030	296	3.2	< 0.1	2.6	2.7	NR	2	35	3	2.7	9	5.9	0.5	149		
8/24/99	H1D1	185	5	1020	291	4.5	< 0.1	1.8	1.9	NR	3	46	2	4	8.3	6.4	0.5	152		
8/24/99	H1D2	193	6	1030	290	4.3	< 0.1	1.1	1.2	NR	3	51	2	3.9	10.4	5.5	0.4	155		
8/24/99	H1D3	190	4	1010	289	3.7	< 0.1	0.5	0.6	NR	3	31	3	3.2	9.1	4.3	0.5	158		
8/24/99	H1D4	182	3	1010	288	3.2	< 0.1	0.5	0.6	NR	4	52	2	2.6	9.4	3.8	0.6	161		
8/24/99	H1D5	185	16	1020	288	2.5	< 0.1	0.3	0.4	NR	4	75	2	2.5	8.9	2.9	0	161		
8/24/99	H1 EFF	186	4	982	296	3.1	< 0.1	0.1	0.2	NR	4	40	2	2.6	9.7	3.3	0.5	164		
9/23/99	HS INLET	179	2	984	308	2.2	< 0.1	3.1	3.2	NR	4	20	< 2	1.6	7.4	5.4	0.6	149		
9/23/99	HIDZ	177	9	998	308	2.4	< 0.1	2.7	2.8	NR	4	25	< 2	1.4	7.7	5.2	1	146		
9/23/99	H1D1	176	5	994	307	3.8	< 0.1	2.6	2.7	NR	4	17	2	1.5	7.6	6.5	2.3	149		
9/23/99	H1D2	184	6	994	302	2.2	< 0.1	1.6	1.7	NR	4	22	< 2	1.6	7.8	3.9	0.6	146		
9/23/99	H1D3	184	4	990	306	1.9	< 0.1	1.1	1.2	NR	4	19	< 2	1.3	7.4	3.1	0.6	146		
9/23/99	H1D4	190	9	996	310	2.3	< 0.1	0.1	0.2	NR	4	21	3	1.6	8.2	2.5	0.7	146		
9/23/99	H1D5	187	11	992	310	2	< 0.1	0.1	0.2	NR	4	24	6	1.2	8.3	2.2	0.8	147		
9/23/99	H1 EFF	188	3	990	308	1.4	< 0.1	0.1	0.2	NR	4	35	2	1.1	8.1	1.6	0.3	146		
10/26/99	HS INLET	169	2	916	267	3	< 0.1	3.2	3.3	NR	3	23	< 2	1.2	7.6	6.3	1.8	141		
10/26/99	HIDZ	167	7	930	274	2	0.2	3.2	3.4	NR	3	29	< 2	1.2	7	5.4	0.8	142		
10/26/99	H1D1	170	10	912	271	1.9	0.2	2.6	2.8	NR	3	33	< 2	1.1	6.9	4.7	0.8	142		
10/26/99	H1D2	174	29	926	264	2.3	0.2	1.7	1.9	NR	4	31	2	1.3	7	4.2	1	143		
10/26/99	H1D3	177	4	918	264	1.7	0.2	1.2	1.4	NR	4	29	< 2	1.2	6.7	3.1	0.5	143		
10/26/99	H1D4	187	4	942	269	1.8	0.2	0.5	0.7	NR	4	37	2	1.8	7.4	2.5	0	145		
10/26/99	H1D5	186	20	940	269	2.9	0.2	0.3	0.5	NR	4	34	3	1.7	6.8	3.4	1.2	143		
10/26/99	H1 EFF	185	6	940	286	2.5	0.2	0.2	0.4	NR	4	26	< 2	1.4	6.6	2.9	1.1	149		
11/23/99	HS INLET	129	3	806	220	0.9	< 0.1	3	3.1	NR	2	31	3	< 0.2	7.5	4	0.7	136		
11/23/99	HIDZ	135	5	794	212	0.9	< 0.1	2.2	2.3	NR	2	35	< 2	< 0.2	7.4	3.2	0.7	134		
11/23/99	H1D1	150	30	796	216	1.4	< 0.1	0.8	0.9	NR	3	32	< 2	0.5	7.6	2.3	0.9	142		
11/23/99	H1D2	151	19	814	217	1.6	< 0.1	0.7	0.8	NR	3	33	2	0.61	7.3	2.4	0.99	141		
11/23/99	H1D3	152	9	814	221	1.4	< 0.1	0.7	0.8	NR	2	34	2	0.63	7	2.2	0.77	142		
11/23/99	H1D4	155	6	832	226	1.4	< 0.1	0.7	0.8	NR	2	31	< 2	0.62	6.5	2.2	0.78	145		
11/23/99	H1D5	158	4	844	221	1.4	< 0.1	0.7	0.8	NR	2	30	< 2	0.62	6.4	2.2	0.78	145		
11/23/99	H1 EFF	157	4	838	228	1.3	< 0.1	0.6	0.7	NR	2	22	< 2	0.64	6.2	2	0.66	149		
12/21/99	HS INLET	181	4	850	213	2.6	0.2	4.2	4.4	NR	<2	39	3	2	8.8	7	0.6	146		
12/21/99	HIDZ	183	17	844	212	3.4	0.3	3.6	3.9	NR	2	39	3	2.7	8.8	7.3	0.7	146		
12/21/99	H1D1	203	24	834	210	4.9	0.3	1.6	1.9	NR	3	38	2	4.4	8	6.8	0.5	144		
12/21/99	H1D2	210	19	836	203	4.8	0.2	0.8	1	NR	4	38	3	4.5	8	5.8	0.3	143		
12/21/99	H1D3	210	37	818	196	5	0.3	0.7	1	NR	3	40	3	4.5	8	6	0.5	142		
12/21/99	H1D4	212	14	826	199	5	0.2	0.7	0.9	NR	3	38	3	4.5	8	5.9	0.5	144		
12/21/99	H1D5	210	10	832	199	4.5	0.2	0.7	0.9	NR	3	36	2	4.2	7.8	5.4	0.3	144		
12/21/99	H1 EFF	209	7	822	206	4.5	0.3	0.8	1.1	NR	3	34	2	4	7.8	5.6	0.5	150		

NR = No Result

TRES RIOS Demonstration Constructed Wetland Project
HAYFIELD SITE Gradient Water Quality - Basin 2

SAMPLE DATE	SAMPLE LOCATION	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)	Br- (EPA 300.0)	Total Sulfide (mg/L)
1/20/98	HS Inlet	173	1	860	208	3.5	0.2	2.7	2.9		3.6	38	2	1.8	9.2	6.4	1.7	186		
1/20/98	H2 IDZ	173	2	842	208	3.5	0.3	2.4	2.7	2.7	3.7	39	2	1.7	9	6.2	1.8	186	0.2	
1/20/98	H2D1	164	4	846	212	1	0.1	2.1	2.2	1.3	3.9	26	< 2	< 0.1	6.2	3.2	0.9	187	0.2	
1/20/98	H2D2	157	4	868	220	1.2	< 0.1	4.2	4.3	2.2	4	25	< 2	0.12	6.8	5.5	1.08	190	0.2	
1/20/98	H2 EFF	165	11	870	214	0.7	< 0.1	2	2.1	2.4	3.9	33	< 2	< 0.1	5.7	2.8	0.6	191		
2/19/98	HS Inlet				158	2.5	< 0.1	1.7	1.8	2.8	3.8			1.4		4.3	1.1	155		
2/19/98	H2 IDZ				155	2.7	0.1	1.3	1.4	2.5	3.8			1.2		4.1	1.5	154		
2/19/98	H2D1				175	0.9	< 0.1	1.8	1.9	2	3			< 0.1		2.8	0.8	162		
2/19/98	H2D2				170	0.9	< 0.1	1	1.1	1.7	2.9			< 0.1		2	0.8	160		
2/19/98	H2 EFF				160	0.8	< 0.1	0.9	1	2	3.1			< 0.1		1.8	0.7	149		
3/24/98	HS Inlet				177	1.9	0.1	1.1	1.2	3	3.5			0.93	9.9	3.1	0.97	145		
3/24/98	H2 IDZ				174	2.7	0.1	1	1.1	2.7	3.6			1.3	9	3.8	1.4	143		
3/24/98	H2D1				180	1.3	0.1	0.4	0.5	3	4.2			0.52	7.6	1.8	0.78	143		
3/24/98	H2D2				179	1.1	< 0.1	0.3	0.4	2.4	5.3			0.2	7.6	1.5	0.9	146	0.2	
3/24/98	H2 EFF				180	< 1	< 0.1	0.3	0.4	2.3	5.8			0.17	7.1	1.4	0.83	154	0.2	
4/28/98	HS Inlet				182	3.7	0.1	2.6	2.7	2	2.7			1.8	9	6.4	1.9	120		
4/28/98	H2 IDZ				186	3.3	0.2	2.2	2.4	2.2	2.6			1.7	8.8	5.7	1.6	119		
4/28/98	H2D1				173	2.3	0.2	1.1	1.3	2.8	3.9			0.95	8.5	3.6	1.35	118		
4/28/98	H2D2				164	1.3	0.1	0.3	0.4	3	4.3			0.54	8.2	1.7	0.76	119		
4/28/98	H2 EFF				168	1.5	< 0.1	0.2	0.3	1.7	4.2			0.43	8	1.8	1.07	120		
6/16/98	HS Inlet				210	7.7	0.2	0.9	1.1	1.6	NR			4.9	10.2	8.8	2.8	112		
6/16/98	H2 IDZ				210	7.7	0.2	0.7	0.9	1.8	NR			4.7	10.1	8.6	3	113		
6/16/98	H2D1				205	6.8	0.3	0.4	0.7	2	NR			3.4	10	7.5	3.4	118		
6/16/98	H2D2				204	4.7	0.1	0.2	0.3	2	NR			2	10.6	5	2.7	122		
6/16/98	H2 EFF					4.2										4.2	4.2			
7/28/98	HS Inlet	163			342	2.7	< 0.1	2	2.1	2	2.4			1.5	9.1	4.8	1.2	143		
7/28/98	H2 IDZ	167			338	4	0.1	2	2.1	1.5	2.4			1.3	8.4	6.1	2.7	142		
7/28/98	H2D1	172			320	2.8	< 0.1	< 0.1	0.2	2	3			1.1	8.4	3	1.7	145		
7/28/98	H2D2	172			332	2.8	0.4	0.8	1.2	1.7	2.8			2	8	4	0.8	140		
7/28/98	H2 EFF					2.7										2.7	2.7			
9/29/98	HS Inlet				320	4.4	< 0.1	2.8	2.9	1.6	3.2			1.7	7.5	7.3	2.7	142		
9/29/98	H2 IDZ				304	4.1	< 0.1	2.9	3	1.5	3.2			1.6	8	7.1	2.5	135		< 0.05
9/29/98	H2D1				307	3.4	0.2	2.5	2.7	1.5	3.1			1.4	7.55	6.1	2	143		< 0.05
9/29/98	H2D2				311	3.3	< 0.1	1.2	1.3	1.7	3.5			1	7.2	4.6	2.3	142		< 0.05
9/29/98	H2 EFF				318	4.1	< 0.1	0.8	0.9	1.4	3.8			1.1	6.8	5	3	144		<0.05
10/27/98	HS Inlet	172			206	4.3	0.2	1.8	2	1.2	< 2			2.2	8.1	6.3	2.1	152		< 0.05
10/27/98	H2 IDZ	172			207	4.8	0.2	1.6	1.8	1.2	< 2			2.1	8.4	6.6	2.7	152		< 0.05
10/27/98	H2D1	175			203	4.8	0.3	1.4	1.7	1.8	2.1			2.3	7.9	6.5	2.5	150		< 0.05
10/27/98	H2D2	181			197	4.7	0.1	0.6	0.7	2.2	4.5			1.9	8.8	5.4	2.8	146		< 0.05
10/27/98	H2 EFF	184			198	2.9	< 0.1	0.3	0.4	1.7	5.3			1.8	7.6	3.3	1.1	147		< 0.05
12/9/98	HS Inlet	169			197	3	< 0.1	2.7	2.8	3.4	4.8			1.2	7.8	5.8	1.8	150		
12/9/98	H2 IDZ				192	3.4	< 0.1	2.2	2.3	2.2	4.7			1.2	8	5.7	2.2	148		
12/9/98	H2D1				196	3.7	0.2	2.9	3.1	2.9	3.9			1.4	7.6	6.8	2.3	150		
12/9/98	H2D2				193	3.6	0.2	2.7	2.9	2.1	3.4			1.3	7.5	6.5	2.3	151		
12/9/98	H2 EFF	174			193	3.9	0.1	2.4	2.5	2.2	3.4			1.1	7.1	6.4	2.8	151		

NR = No Result

TRES RIOS Demonstration Constructed Wetland Project
HAYFIELD SITE Gradient Water Quality - Basin 2

SAMPLE DATE	SAMPLE LOCATION	ALKALINITY EPA 310.1 (mg/L)	TSS (mg/L)	TDS EPA 160.1 (mg/L)	Cl EPA 300.0 EPA 325.2 (mg/L)	TKN EPA 351.2 (mg/L)	NO2 - N EPA 300.0 (mg/L)	NO3 - N EPA 300.0 (mg/L)	NO2+NO3 - N EPA 353.2 (mg/L)	PO4 - P EPA 300.0 (mg/L)	Diss. P EPA 200.7 (mg/L)	COD (mg/L)	cBOD sm17 5210B (mg/L)	NH3 - N EPA 350.3 (mg/l)	TOC EPA 415.1 (mg/L)	TOTAL-N (mg/L)	Org-N (mg/L)	Sulfate (EPA 375.2)
1/20/00	HS INLET	167	3	854	215	1.3	< 0.1	5	5.1	NR	4	29	< 2	0.43	8.7	6.4	0.87	156
1/20/00	H2 IDZ	169	11	860	209	1.7	< 0.1	4.8	4.9	NR	4	33	< 2	0.65	9.4	6.6	1.05	179
1/20/00	H2D1	181	8	872	210	2.1	0.1	5.1	5.2	NR	4	33	< 2	1.4	9.1	7.3	0.7	182
1/20/00	H2D2	183	23	860	201	1.7	0.2	3.4	3.6	NR	3	42	2	0.72	9.2	5.3	0.98	185
1/20/00	H2 EFF	186	23	868	207	2.2	0.2	3.2	3.4	NR	3	33	2	1.1	8.6	5.6	1.1	161
5/25/00	HS INLET	172	3	1010	319	2	< 0.5	1.33	1.83	NR	2.1	32	2	0.45	8.4	3.83	1.55	183
5/25/00	H2 IDZ	167	25	1020	351	0.7	< 0.5	1.25	1.75	NR	2.2	41	2	< 0.2	7.9	2.45	0.5	198
5/25/00	H2D1	176	20	1010	334	3.3	< 0.5	1.55	2.05	NR	2.1	32	2	1.1	9.2	5.35	2.2	198
5/25/00	H2D2	184	28	1030	349	2.4	< 0.5	< 0.5	1	NR	2.4	42	NR	0.69	11	3.4	1.71	205
5/25/00	H2 EFF	193	44	1050	41	2.8	< 0.5	< 0.5	1	NR	2.6	41	3	0.51	9.9	3.8	2.29	197
8/10/00	HS Inlet	194	3	1150	362	1.4	< 0.1	1.7	1.8	NR	1.5	20	< 2	0.88	6.9	3.2	0.52	189
8/10/00	H2 IDZ	193	6	1150	355	1.5	< 0.1	1.4	1.5		1.5	18	< 2	0.91	8.4	3	0.59	189
8/10/00	H2D1	195	7	1140	359	1.9	0.2	1.8	2		1.6	20	< 2	1.3	7.4	3.9	0.6	189
8/10/00	H2D2	193	16	1130	364	2.2	0.2	1.5	1.7	NR	1.6	28	2	1.6	8	3.9	0.6	185
8/10/00	H2 EFF	194	18	1150	364	1.9	0.3	1.3	1.6	NR	1.7	23	2	1.2	7.6	3.5	0.7	187
11/21/00	HS Inlet	199	3	952	261	5.3	0.3	5	5.3	NR	3.2	58	< 2	3.5	7.69	10.6	1.8	184
11/21/00	H2 IDZ	198	398	954	258	5.5	0.4	4.8	5.2		3.4	65	< 2	3.1	302	10.7	2.4	184
11/21/00	H2D1	184	19	952	264	3.3	0.3	5.3	5.6		2.4	38	3	1.7	355	8.9	1.6	183
11/21/00	H2D2	183	99	948	274	3.8	0.2	4.1	4.3	NR	1.8	54	3	0.52	19.3	8.1	3.28	181
11/21/00	H2 EFF	182	60	990	306	2.5	0.3	3.2	3.5	NR	2.2	51	7	< 0.5	367	6	2	180
12/21/00	HS Inlet	187	3	900	241	1.8	0.1	4.4	4.5	NR	1.2	41	< 2	0.54	7.4	6.3	1.26	193
12/21/00	H2 IDZ	190	5	902	243	1.6	0.1	4	4.1		1.2	29	2	0.49	7.3	5.7	1.11	196
12/21/00	H2D1	185	22	904	248	2.8	0.4	4.6	5		1.2	40	2	1.5	8.6	7.8		197
12/21/00	H2D2	187	24	882	243	2.3	0.3	3.2	3.5	NR	0.9	32	3	0.75	7.1	5.8	1.55	199
12/21/00	H2 EFF	194	28	894	243	1.8	0.3	2.7	3	NR	0.7	49	2	0.5	7.3	4.8	1.3	200

NR = No Result

TRES RIOS DEMONSTRATION WETLAND HAYFIELD SITE BASIN 2: MASS REMOVAL

H2

Date	ALKALINITY	TSS	TDS	Cl-	TKN	NO2 - N	NO3 - N	NO2+NO3 - N	PO4 - P	Diss. P	COD	cBOD	NH3 - N	TOC	TOTAL-N	Organic-N	Sulfate
Jan-98	5.5%	-990.2%	-0.3%	-2.0%	80.2%	50.4%	26.6%	28.2%	NR	-7.4%	13.9%	0.9%	94.5%	38.6%	56.6%	65.0%	-1.8%
Feb-98	NR	NR	NR	-1.6%	67.9%	-0.4%	46.9%	44.2%	28.3%	18.1%	NR	NR	92.8%	NR	58.0%	36.1%	3.5%
Mar-98	NR	NR	NR	1.0%	48.8%	2.6%	73.4%	67.5%	25.4%	-61.3%	NR	NR	82.2%	30.2%	56.0%	16.7%	-3.4%
Apr-98	NR	NR	NR	12.8%	61.7%	5.5%	92.7%	89.5%	19.7%	-46.9%	NR	NR	77.4%	16.0%	73.4%	46.8%	5.5%
May-98	NR	NR	NR	5.8%	-11.5%	5.0%	95.7%	91.7%	30.3%	-8.6%	NR	NR	32.9%	-1.4%	40.1%	-137.5%	8.1%
Jun-98	NR	NR	NR	NR	-76.0%	-61.3%	64.2%	41.3%	NR	NR	NR	NR	-25.1%	-219.4%	-61.3%	-165.0%	-237.0%
Jul-98	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Aug-98	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Sep-98	NR	NR	NR	-57.1%	-47.3%	-58.1%	54.8%	50.9%	-38.3%	-87.7%	NR	NR	-2.3%	-43.3%	-8.3%	-75.7%	-60.3%
Oct-98	-224.9%	NR	NR	NR	-104.8%	-51.8%	49.4%	39.3%	-330.2%	NR	NR	NR	-148.5%	-184.9%	-59.1%	-59.1%	-193.7%
Dec-98	-84.8%	NR	NR	-75.9%	-133.4%	-79.5%	-59.6%	-60.3%	-16.2%	-27.2%	NR	NR	-64.6%	-63.4%	-98.1%	-179.3%	-80.7%
Jan-99	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Feb-99	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Apr-99	25.8%	-0.1%	25.3%	24.9%	69.7%	82.5%	91.2%	89.5%	10.8%	NR	-52.3%	29.9%	89.1%	22.9%	75.9%	32.2%	28.8%
May-99	-76.2%	-3.6%	-59.1%	-57.2%	-50.7%	-55.4%	94.6%	89.6%	26.0%	NR	-79.9%	NR	-42.4%	NR	16.1%	-55.4%	-69.0%
Jun-99	44.4%	-133.5%	45.5%	47.4%	53.7%	48.1%	83.4%	80.2%	74.1%	30.8%	34.7%	48.1%	65.4%	47.5%	71.2%	32.5%	41.9%
Jul-99	12.4%	-527.5%	18.6%	20.1%	25.6%	18.2%	79.5%	77.7%	NR	18.2%	-3.9%	-63.7%	18.2%	15.0%	56.8%	34.5%	13.6%
Aug-99	4.2%	-310.6%	10.2%	5.5%	33.1%	8.8%	84.8%	82.3%	NR	-36.9%	-36.9%	-82.5%	29.5%	9.8%	58.1%	43.0%	0.7%
Sep-99	14.5%	-417.9%	19.0%	20.8%	31.2%	20.3%	87.1%	85.1%	NR	20.3%	-19.5%	-59.3%	45.2%	16.0%	63.1%	-6.2%	21.9%
Oct-99	12.3%	-756.8%	13.2%	14.3%	48.6%	14.3%	54.5%	53.3%	NR	-14.2%	-26.7%	14.3%	42.9%	29.0%	51.0%	52.4%	11.3%
Nov-99	-1.4%	-364.0%	5.1%	5.5%	-23.7%	7.2%	56.7%	55.1%	NR	7.2%	10.2%	38.1%	-71.7%	14.6%	37.4%	-10.0%	1.7%
Dec-99	-2.3%	-655.9%	11.2%	14.8%	-37.4%	-220.7%	69.5%	56.3%	NR	NR	8.4%	8.4%	-55.8%	15.7%	21.5%	23.6%	9.0%
Jan-00	10.1%	-518.8%	18.0%	22.3%	-36.6%	-61.4%	48.3%	46.2%	NR	39.5%	8.2%	19.3%	-106.5%	20.2%	29.4%	-2.1%	16.7%
May-00	30.8%	-804.0%	35.9%	92.1%	13.7%	38.4%	76.8%	66.3%	NR	23.7%	21.0%	7.5%	30.1%	27.4%	38.8%	8.9%	33.6%
Aug-00	78.3%	-30.3%	78.3%	78.2%	70.5%	34.9%	83.4%	80.7%	NR	75.4%	75.0%	78.3%	70.4%	76.1%	76.2%	70.8%	78.5%
Nov-00	96.6%	25.0%	96.1%	95.6%	98.2%	96.3%	97.6%	97.5%	NR	97.4%	96.7%	86.9%	99.5%	-78.9%	97.9%	95.8%	96.3%
Dec-00	86.4%	-22.0%	87.0%	86.8%	86.9%	60.8%	92.0%	91.3%	NR	92.4%	84.4%	86.9%	87.9%	87.1%	90.0%	86.5%	86.5%
Average	**1.9%**	**-367.4%**	**26.9%**	**16.9%**	**11.7%**	**-4.2%**	**67.1%**	**62.8%**	**-17.0%**	**7.4%**	**8.9%**	**15.2%**	**19.2%**	**-6.0%**	**36.6%**	**-2.0%**	**-8.2%**
Minimum	**-224.9%**	**-990.2%**	**-59.1%**	**-75.9%**	**-133.4%**	**-220.7%**	**-59.6%**	**-60.3%**	**-330.2%**	**-87.7%**	**-79.9%**	**-82.5%**	**-148.5%**	**-219.4%**	**-98.1%**	**-179.3%**	**-237.0%**
Maximum	**96.6%**	**25.0%**	**96.1%**	**95.6%**	**98.2%**	**96.3%**	**97.6%**	**97.5%**	**74.1%**	**97.4%**	**96.7%**	**86.9%**	**99.5%**	**87.1%**	**97.9%**	**95.8%**	**96.3%**

NR = No Result

Appendix F

Hayfield and Cobble Site Bacteria

Tres Rios Demonstration Project

Bacteria Data

CS INLET

Date	Total Colif./100 mL (TC)	E. Coli /100 mL (EC)
Jan-98	38	1
Aug-98	BOS	BOS
Jan-99	18	0
Feb-99	12	0
May-99	186	31
Jul-99	60	3
Aug-99	157	91
Oct-99	248	16
Nov-99	0	0
Jan-00	6	0
Sep-00	71	1
Oct-00	88	1
Nov-00	91	2
Dec-00	276	4
Average	**96**	**12**
Maximum	**276**	**91**
Minimum	**0**	**0**

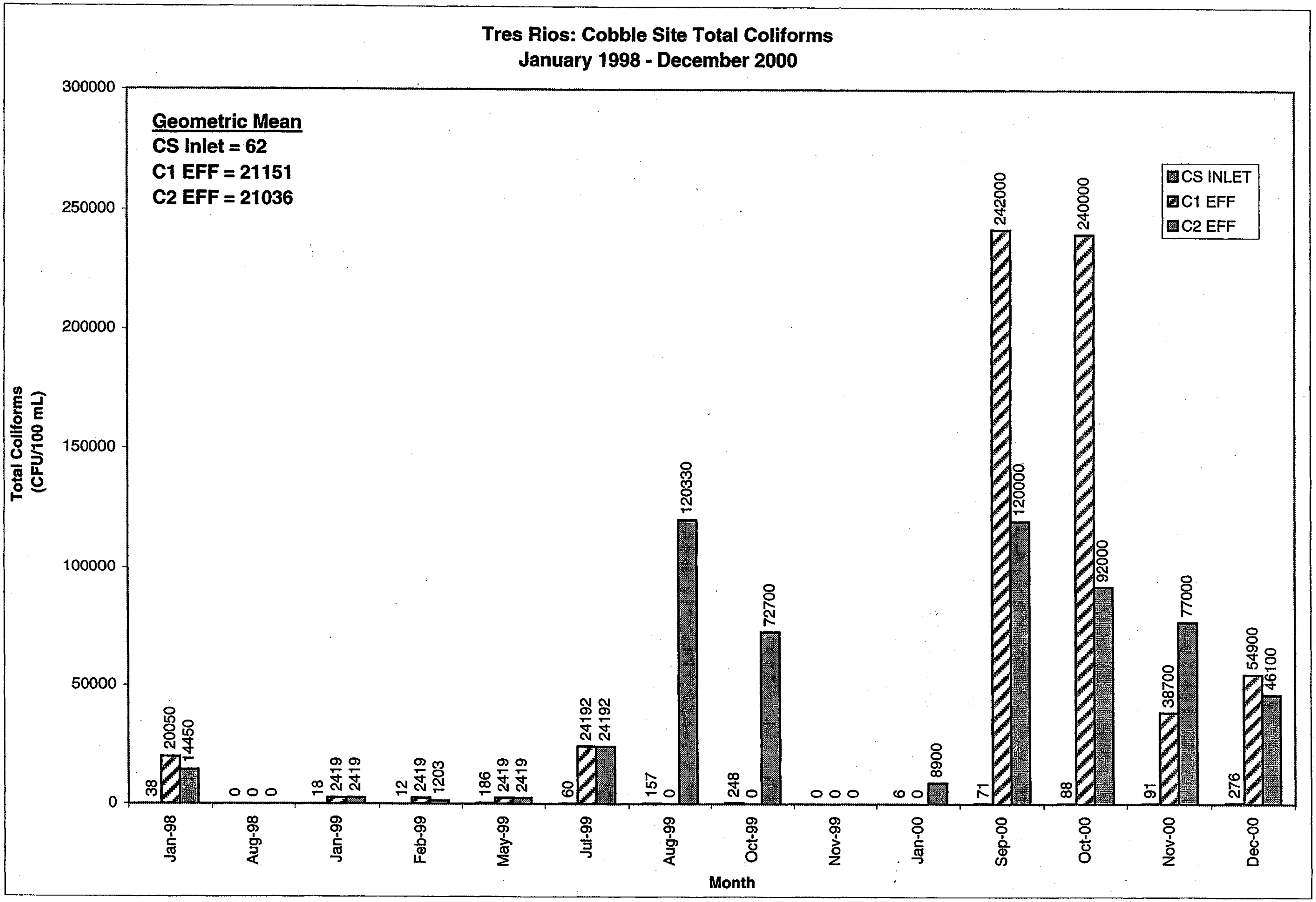
C1 EFF

Date	Total Colif./100 mL (TC)	E. Coli /100 mL (EC)
Jan-98	20050	100
Aug-98	BOS	BOS
Jan-99	2419	104
Feb-99	2419	11
May-99	2419	122
Jul-99	24192	19
Aug-99	NR	NR
Oct-99	NR	NR
Nov-99	NR	NR
Jan-00	NR	NR
Sep-00	242000	690
Oct-00	240000	340
Nov-00	38700	44
Dec-00	54900	40
Average	**69678**	**163**
Maximum	**242000**	**690**
Minimum	**2419**	**11**

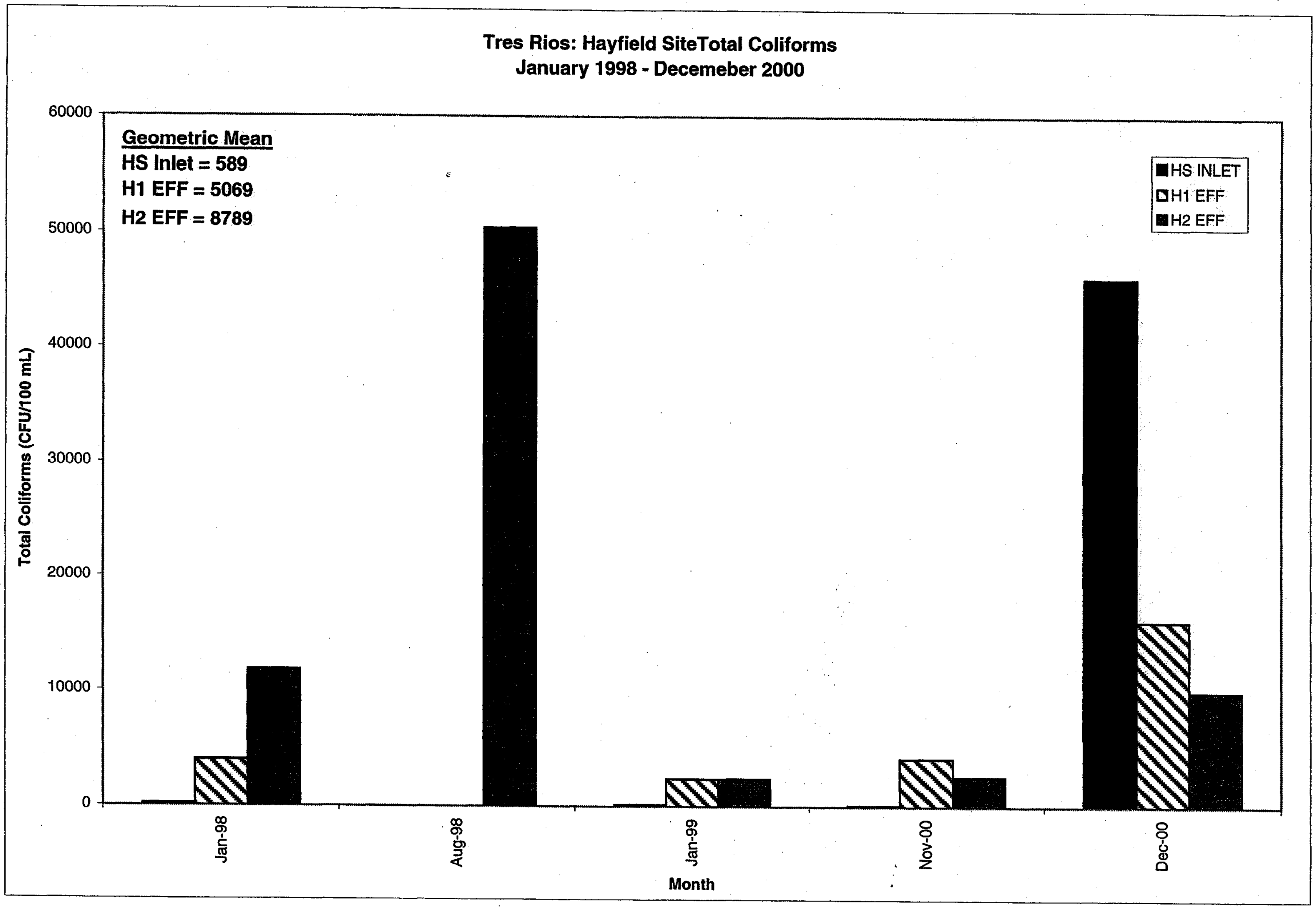
C2 EFF

Date	Total Colif./100 mL (TC)	E. Coli /100 mL (EC)
Jan-98	14450	640
Aug-98	BOS	BOS
Jan-99	2419	18
Feb-99	1203	0
May-99	2419	195
Jul-99	24192	150
Aug-99	120330	17329
Oct-99	72700	5200
Nov-99	NR	1414
Jan-00	8900	900
Sep-00	120000	202
Oct-00	92000	130
Nov-00	77000	172
Dec-00	46100	579
Average	**48476**	**2071**
Maximum	**120330**	**17329**
Minimum	**1203**	**0**

BOS = Basin Out of Service
NR = Data Not Recorded



Tres Rios: Cobble Site Total Coliforms
January 1998 - December 2000
Geometric Mean
CS Inlet = 62
C1 EFF = 21151
C2 EFF = 21036
CS INLET
C1 EFF
C2 EFF
Total Coliforms (CFU/100 mL)
300000
250000
200000
150000
100000
50000
0
38
20050
14450
0
0
0
18
2419
2419
12
2419
1203
186
2419
2419
60
24192
24192
157
0
120330
248
0
72700
0
0
0
6
0
8900
71
242000
120000
88
240000
92000
91
38700
77000
276
54900
46100
Jan-98
Aug-98
Jan-99
Feb-99
May-99
Jul-99
Aug-99
Oct-99
Nov-99
Jan-00
Sep-00
Oct-00
Nov-00
Dec-00
Month

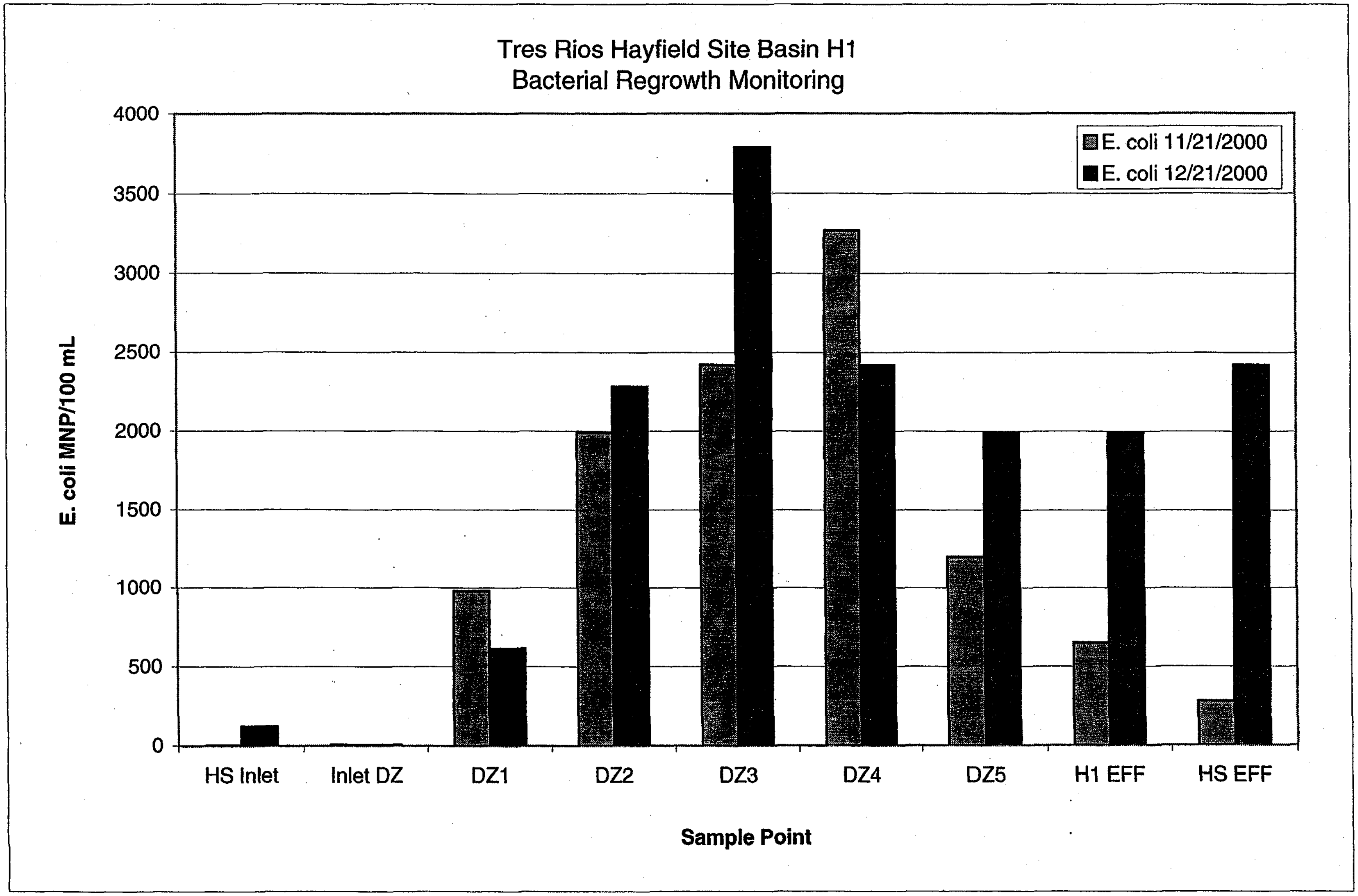


Tres Rios: Hayfield SiteTotal Coliforms
January 1998 - Decemeber 2000
Geometric Mean
HS Inlet = 589
H1 EFF = 5069
H2 EFF = 8789
HS INLET
H1 EFF
H2 EFF
Total Coliforms (CFU/100 mL)
60000
50000
40000
30000
20000
10000
0
Jan-98
Aug-98
Jan-99
Nov-00
Dec-00
Month

Tres Rios Demonstration Constructed Wetland Project
Bacterial Regrowth Monitoring in Hayfield Basin H1

Date	Sample Point	Total Coliforms per 100 mL		E.Coli per 100 mL
11/21/00	HS Inlet	107	<	1
11/21/00	Inlet DZ	77		4
11/21/00	DZ1	29100		980
11/21/00	DZ2	13700		1990
11/21/00	DZ3	14000		2420
11/21/00	DZ4	22500		3270
11/21/00	DZ5	8840		1200
11/21/00	H1 EFF	4200		649
11/21/00	HS EFF	4350		276

Date	Sample Point	Total Coliforms per 100 mL		E.Coli per 100 mL
12/21/00	HS Inlet	121	<	121
12/21/00	Inlet DZ	194		4
12/21/00	DZ1	7670		613
12/21/00	DZ2	29100		2280
12/21/00	DZ3	19000		3790
12/21/00	DZ4	18600		2420
12/21/00	DZ5	10500		1990
12/21/00	H1 EFF	16200		1990
12/21/00	HS EFF	14000		2420

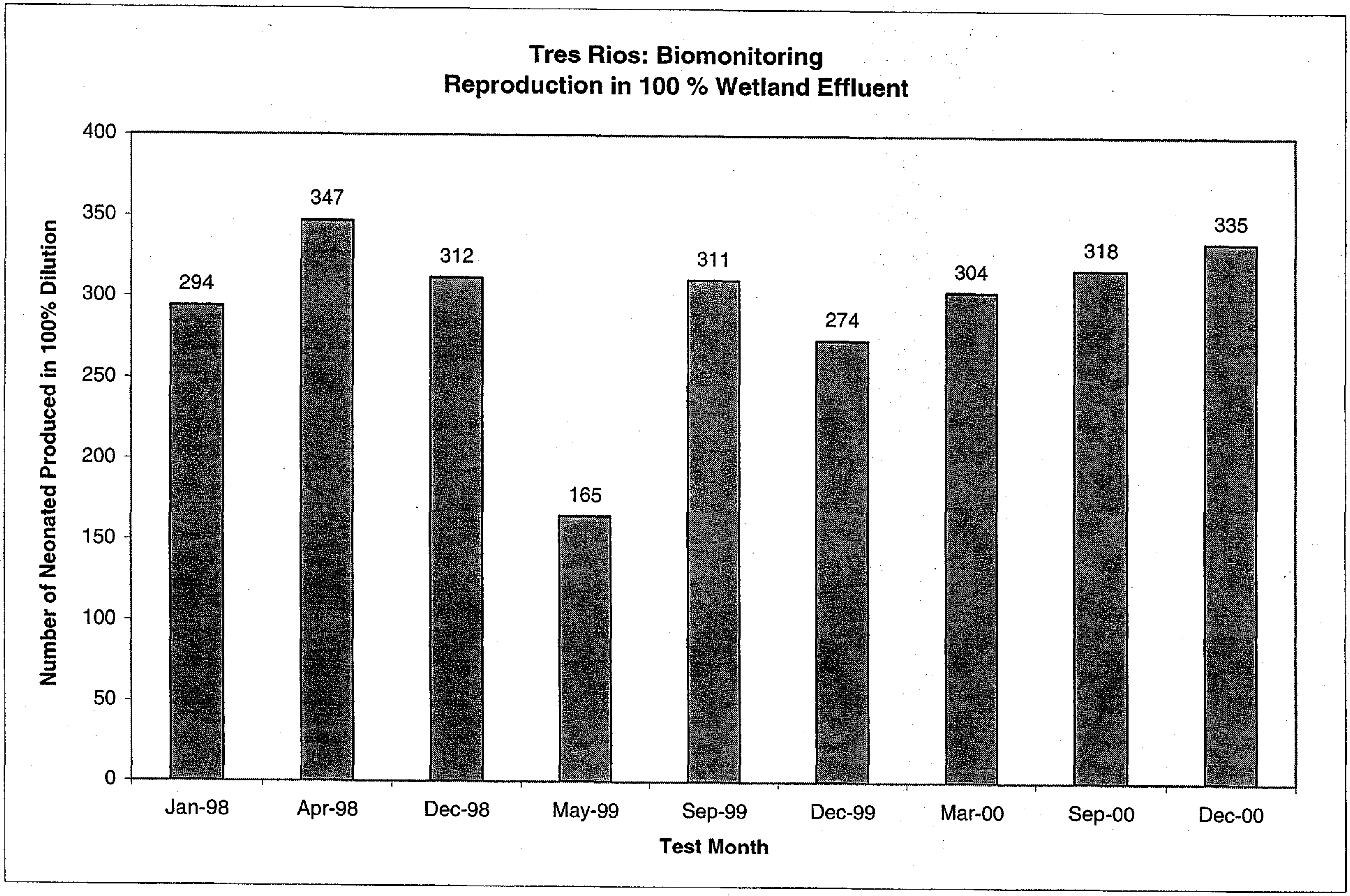

Tres Rios Hayfield Site Basin H1
Bacterial Regrowth Monitoring
E. coli 11/21/2000
E. coli 12/21/2000
E. coli MNP/100 mL
4000
3500
3000
2500
2000
1500
1000
500
0
HS Inlet
Inlet DZ
DZ1
DZ2
DZ3
DZ4
DZ5
H1 EFF
HS EFF
Sample Point

Appendix G

Hayfield and Cobble Site Biomonitoring

Tres Rios Biomonitoring Results
City of Phoenix 23rd Avenue Water Services Laboratory
Number of Young Produced in 100% Dilutions

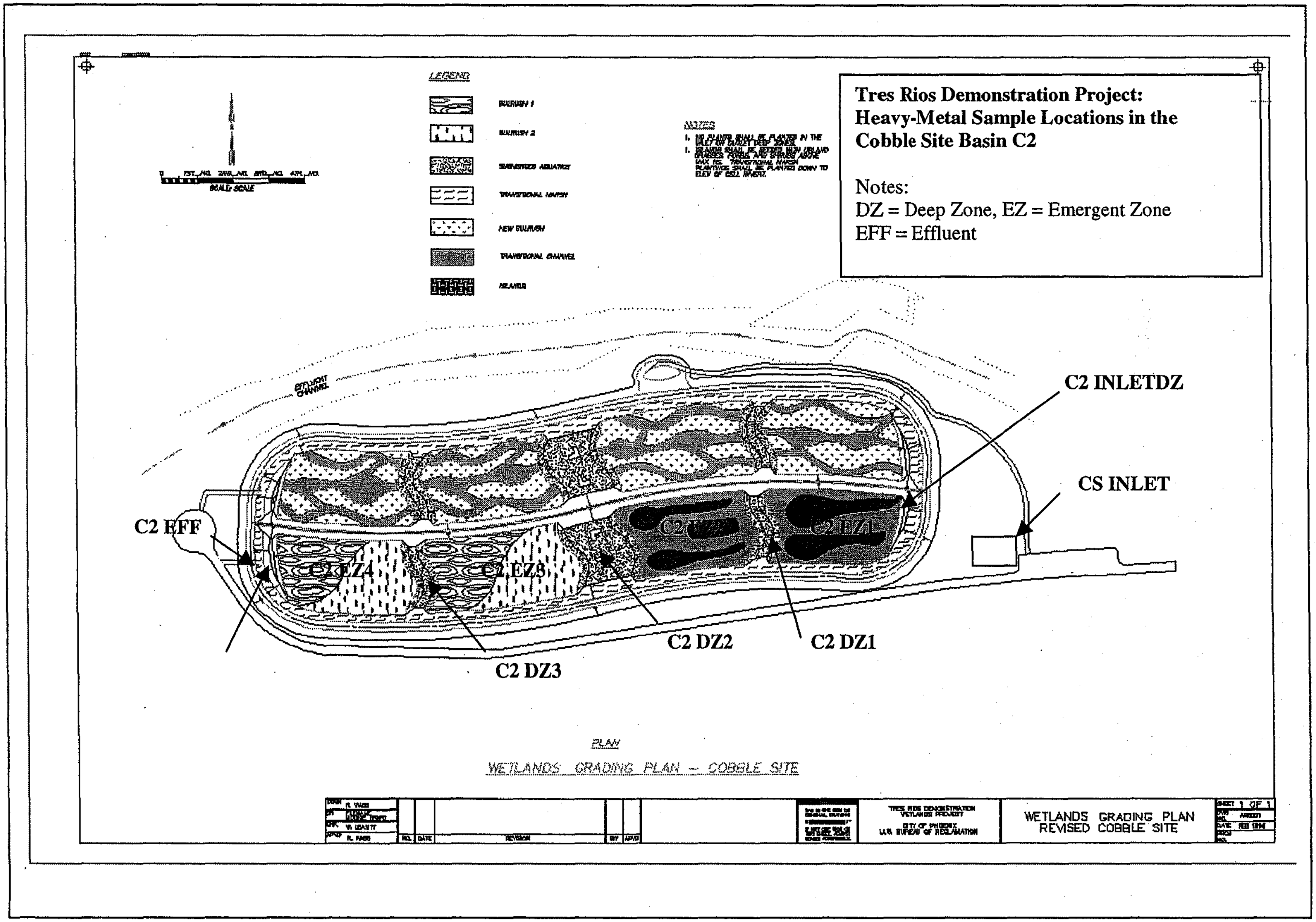
	Cobble Site				Hayfield Site					
Date	**Inlet**	**C1**	**C2**	**Date**	**Inlet**	**H1**	**H2**	**Date**	**Plant 3A**	**Wetlands**
Jan-98	235	294		Jan-98				Jan-98	235	294
Apr-98				Apr-98	241	347		Apr-98	241	347
Dec-98				Dec-98	288		312	Dec-98	288	312
May-99	278		165	May-99				May-99	278	165
Sep-99	379		311	Sep-99				Sep-99	379	311
Dec-99	60	274		Dec-99				Dec-99	60	274
Mar-00	160		304	Mar-00				Mar-00	160	304
Sep-00	301	318		Sep-00				Sep-00	301	318
Dec-00				Dec-00	353	335		Dec-00	353	335
Average	**236**	**295**	**260**		**294**	**341**	**312**		**255**	**296**
n	**6**	**3**	**3**		**3**	**2**	**1**		**9**	**9**


Tres Rios: Biomonitoring
Reproduction in 100 % Wetland Effluent
Number of Neonated Produced in 100% Dilution
400
350
300
250
200
150
100
50
0
294
347
312
165
311
274
304
318
335
Jan-98
Apr-98
Dec-98
May-99
Sep-99
Dec-99
Mar-00
Sep-00
Dec-00
Test Month

Appendix H

Hayfield and Cobble Site Heavy Metals

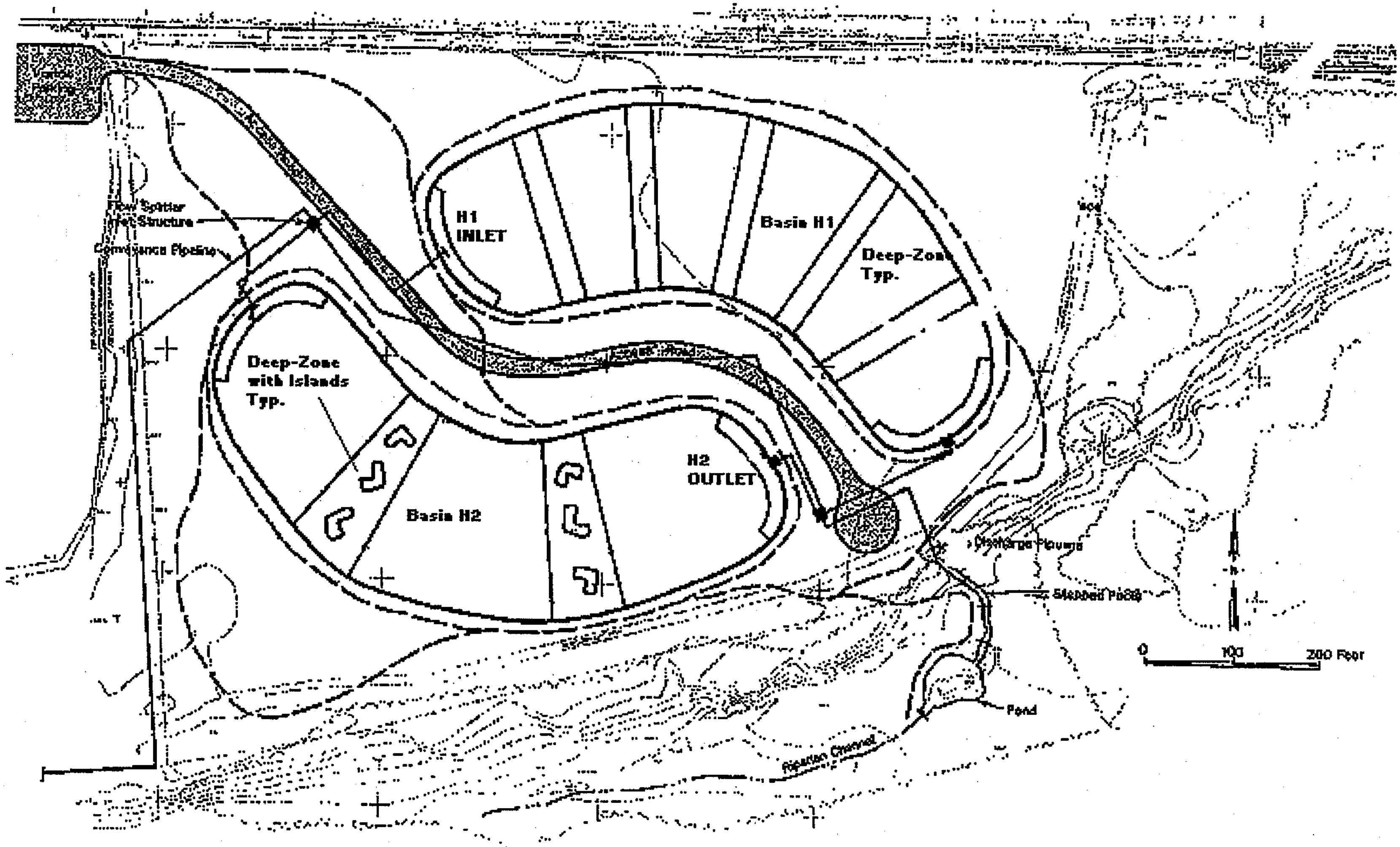
Plan View of the Cobble Site Heavy-Metal Sampling Locations

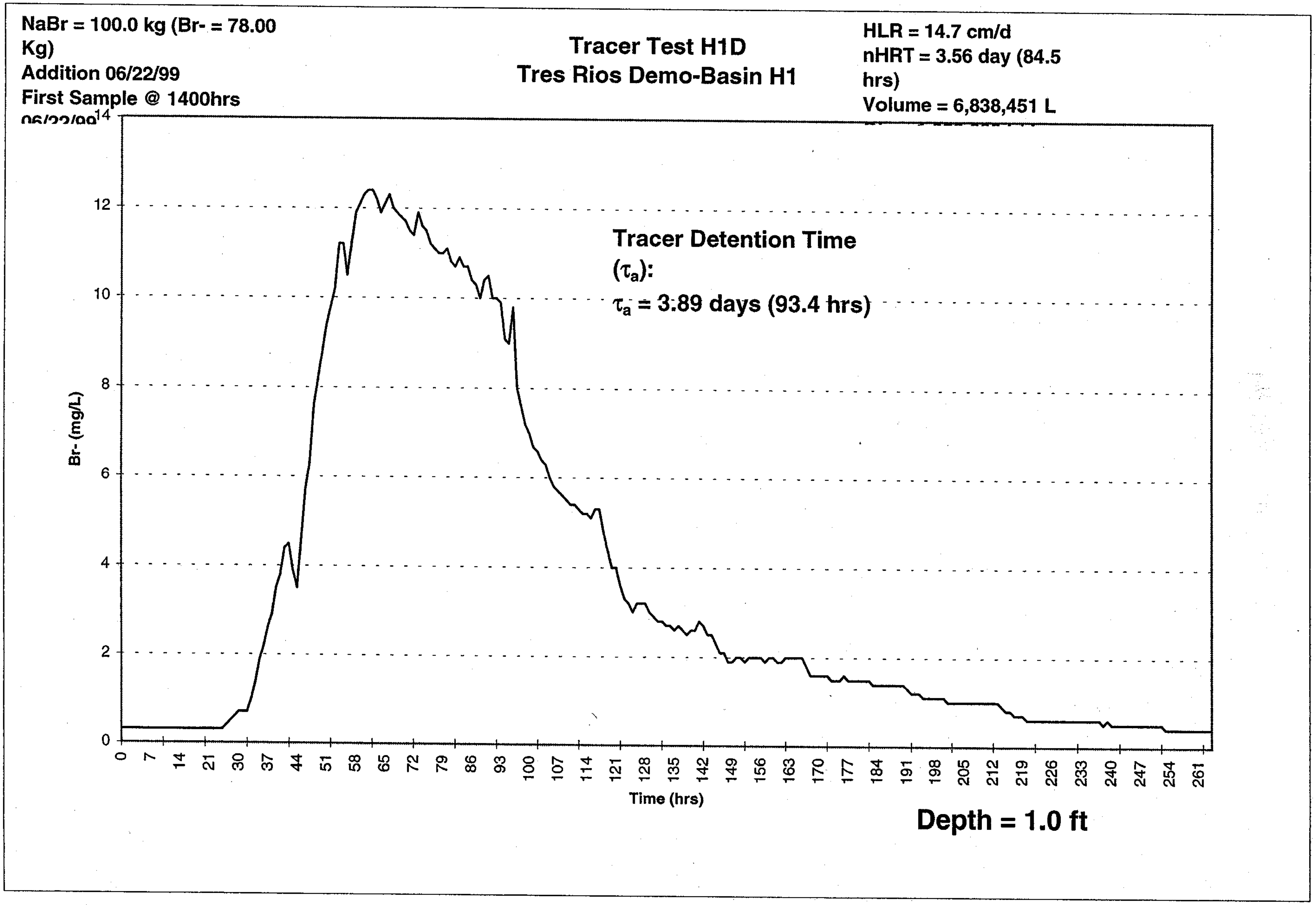


Appendix I

Hayfield Site
Tracer Testing

Tres Rios Demonstration Wetlands, Hayfield Riparian Site Basins H1 and H2.

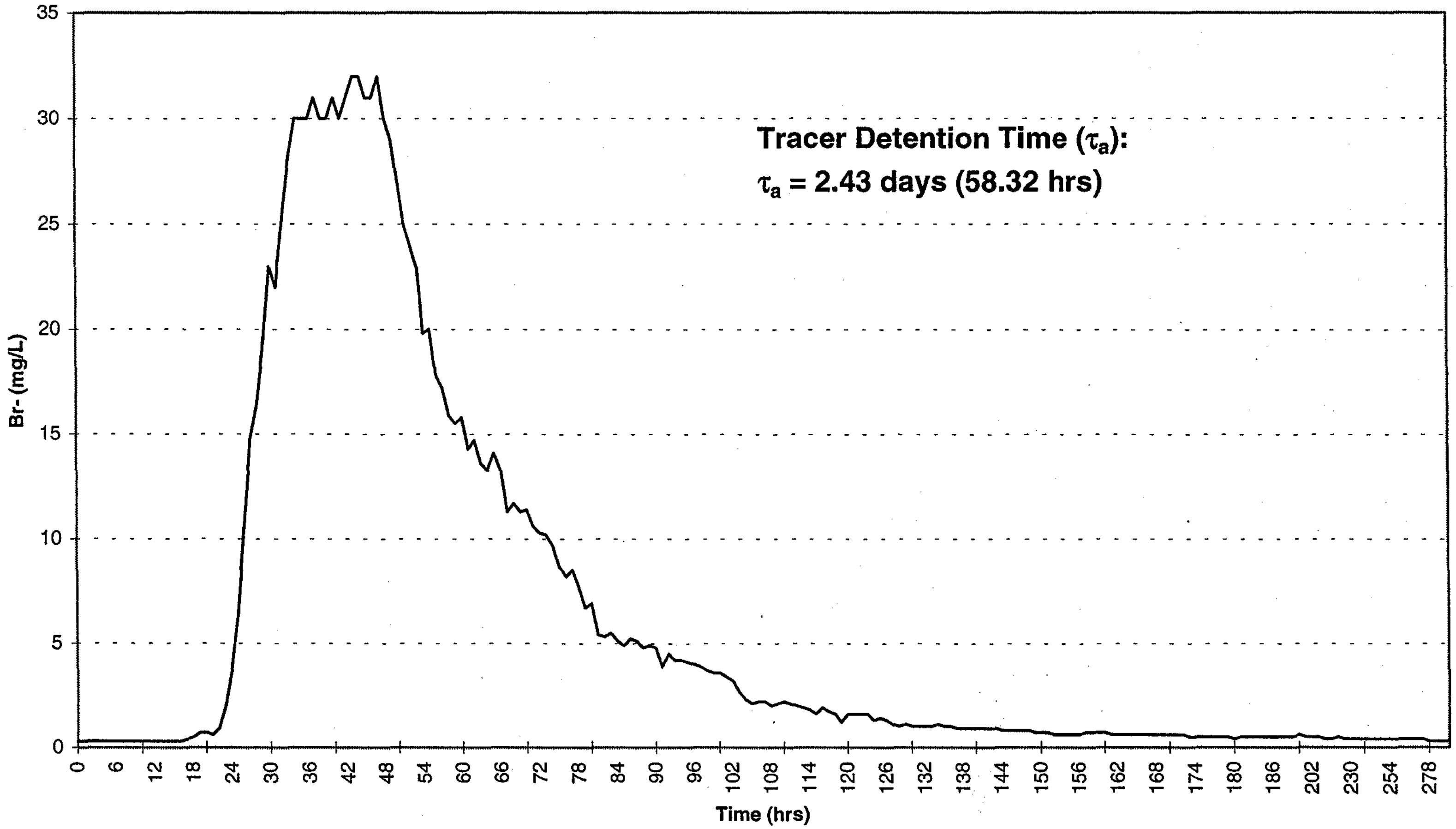



NaBr = 100.0 kg (Br- = 78.00 Kg)
Addition 06/22/99
First Sample @ 1400hrs 06/22/99
Tracer Test H1D
Tres Rios Demo-Basin H1
HLR = 14.7 cm/d
nHRT = 3.56 day (84.5 hrs)
Volume = 6,838,451 L
Tracer Detention Time (τ_a):
τ_a = 3.89 days (93.4 hrs)
Br- (mg/L)
Time (hrs)
Depth = 1.0 ft

NaBr = 100.0 kg (Br- = 78.0 Kg)
Addition 06/24/99
First Sample @ 1400hrs 06/24/99
Last Sample @ 1600hrs 07/06/99

Tracer Test C2A
Tres Rios Demo-Basin C2

HLR = 25 cm/d
nHRT = 3.34day (80.2 hrs)
Volume = 4,780,960 L
Qin = 1,431,515 L/d

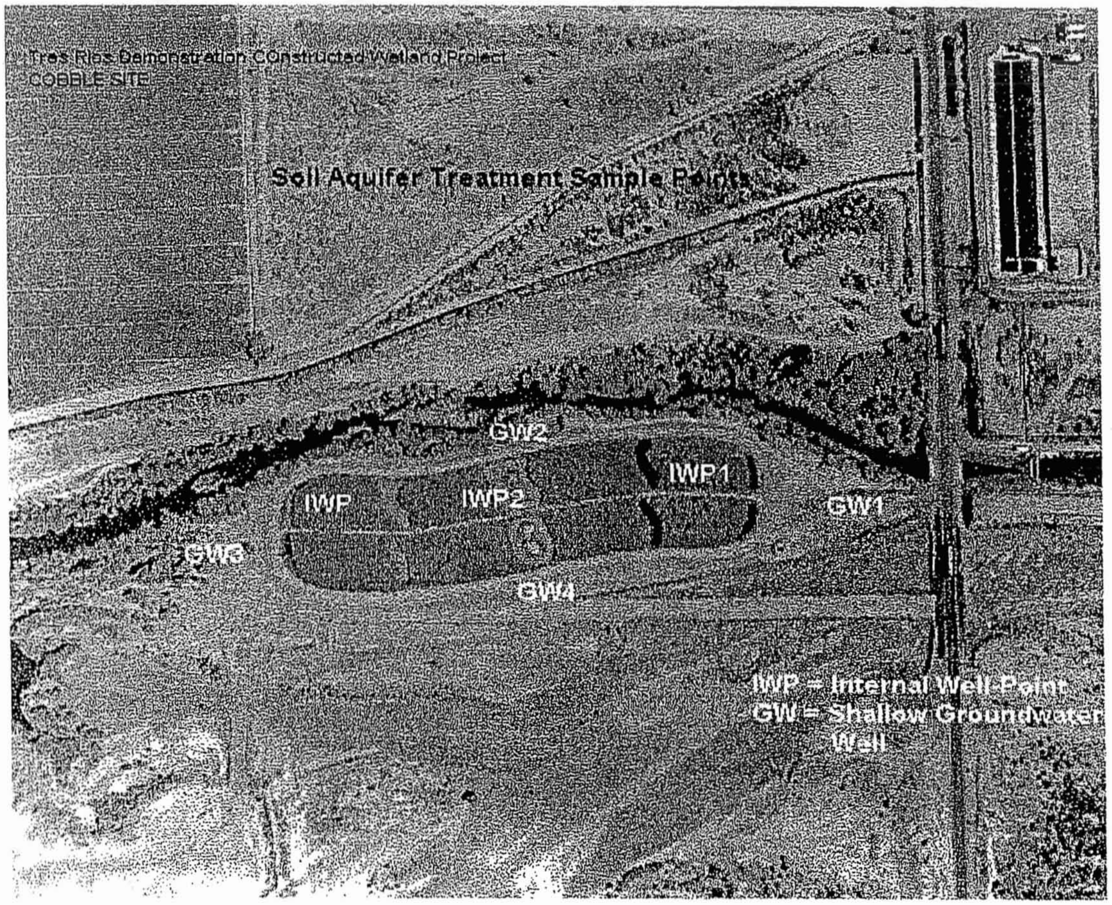


Depth = 1.5 ft

Appendix J

Subsurface Investigations

Figure 1 - Tres Rios Cobble Site Aerial Photograph with Approximate Well Locations



IWP = Proposed Internal Well Points
IWP1 = East Well Cluster
-- CE0 to CE21
IWP2 = Center Well Cluster
-- CM0 to CM19.5
IWP3 = West Well Cluster
-- CW0 to CW20

GW = Proposed Shallow Groundwater Wells
GW1 = SWE
GW2 = SWN
GW3 = SWW
GW4 = SWS

Cobble Site Tres Rios Demonstration Wetlands.
Two parallel wetlands cells receive denitrified effluent from the 91st Avenue WWTP in Phoenix, AZ. The lower wetlands is lined while the upper wetlands is not lined. The unlined wetlands will be studied during this proposed research.

Figure 3 - Nitrate and Phosphate Concentration Depth Profiles at Tres Rios Cobble Site

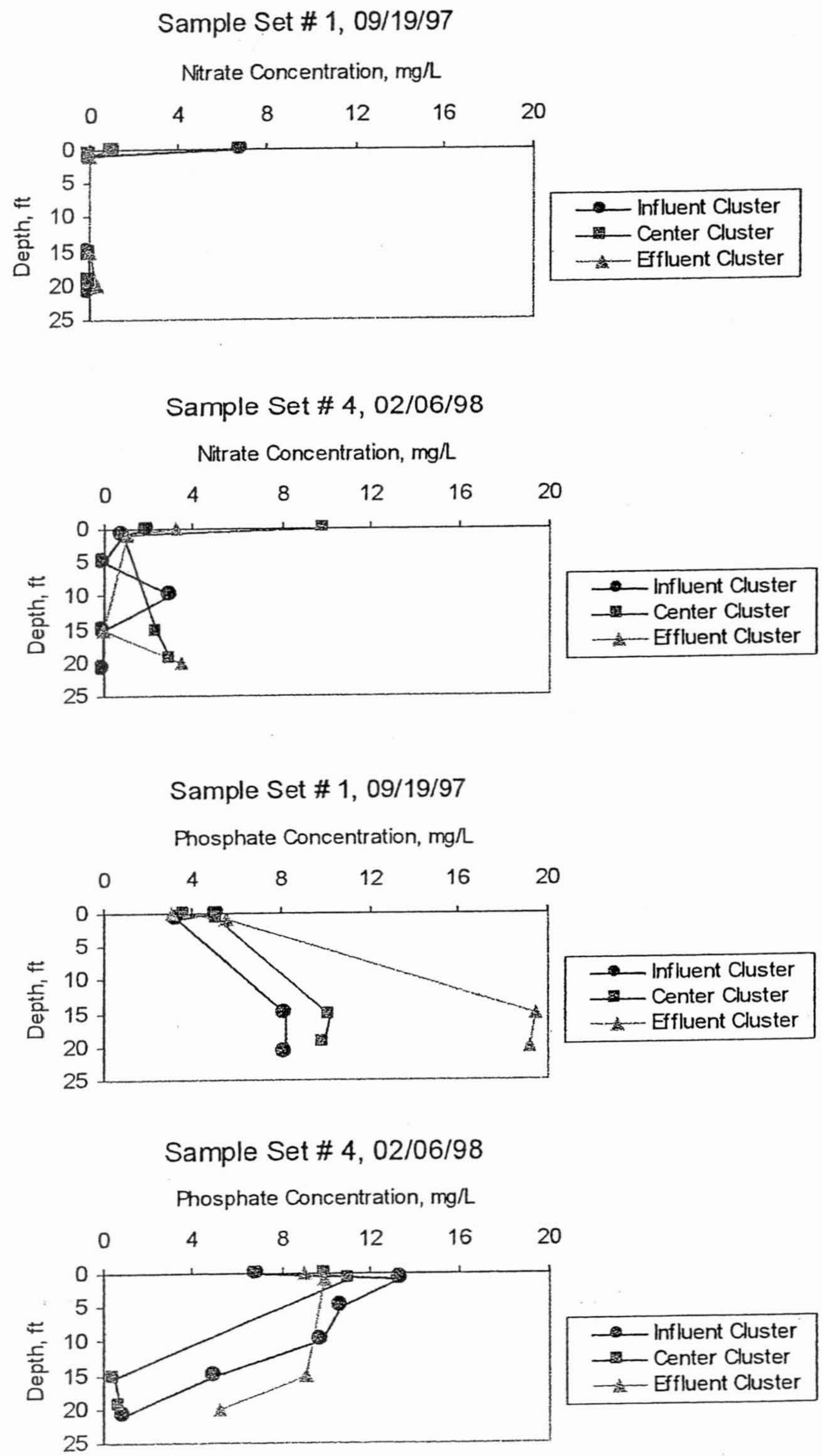
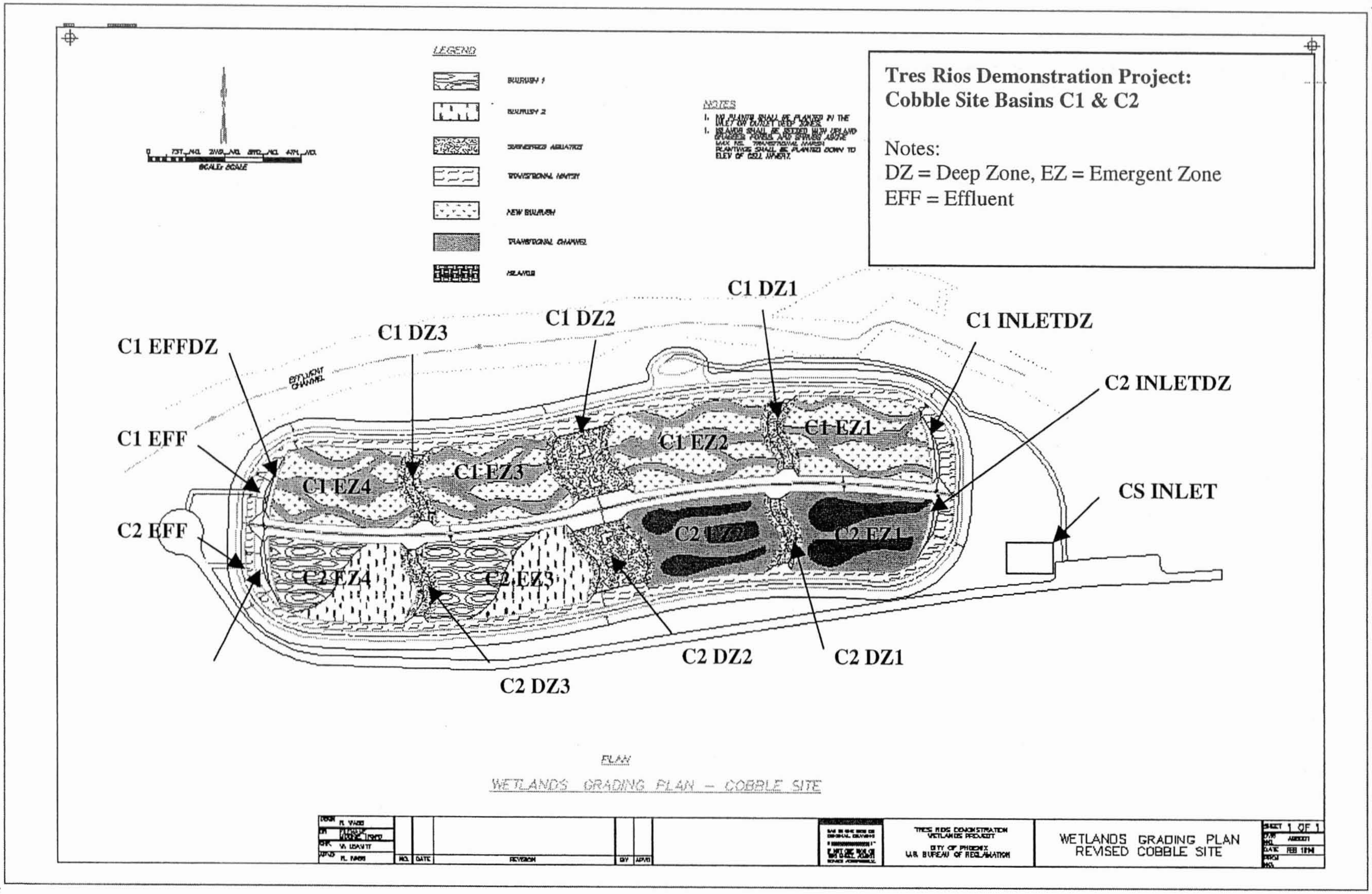


Table 1 - Sampling Dates at Tres Rios Cobble Site

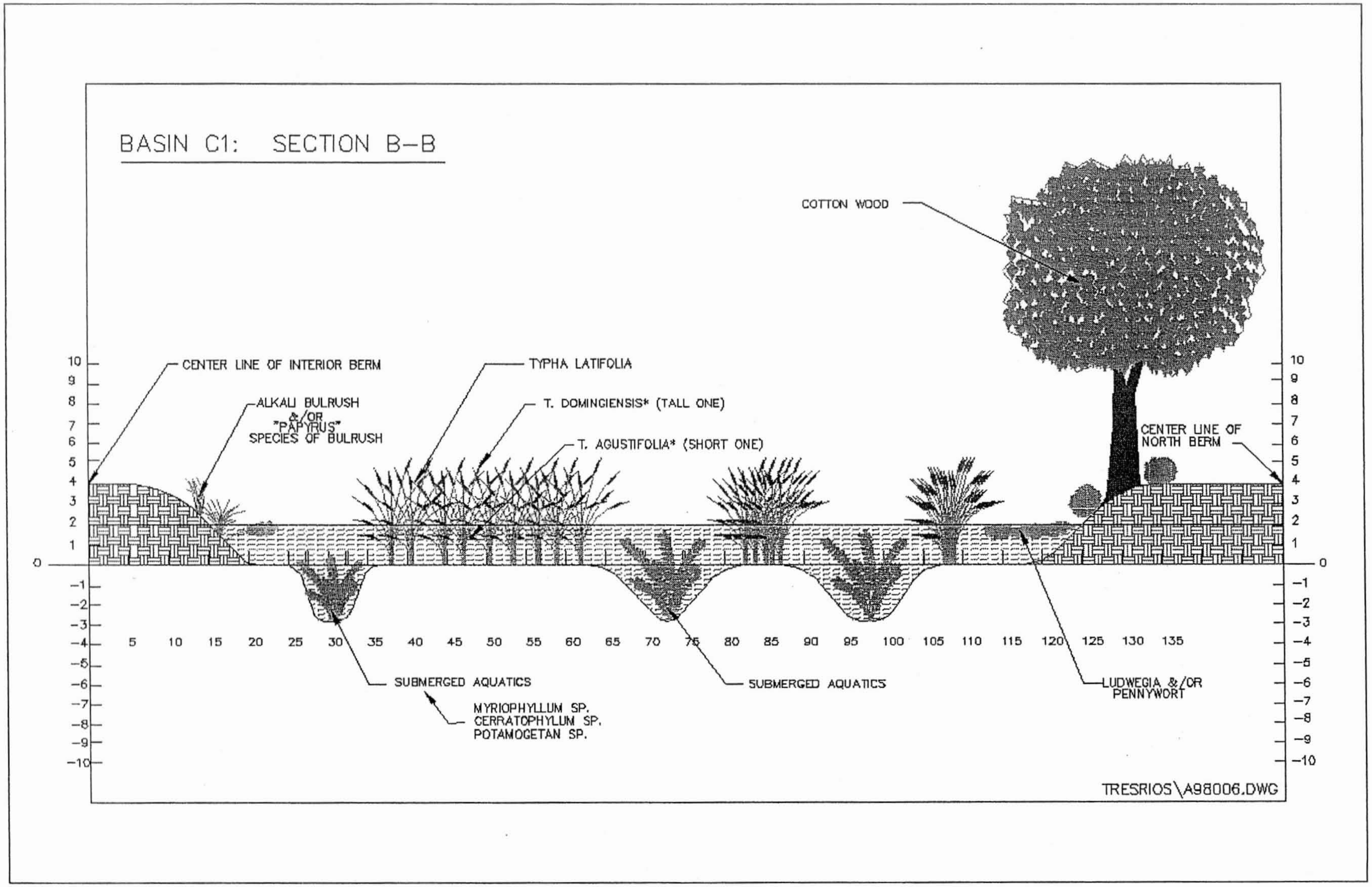
Sample	9/19/97	10/27/97	12/11/97	2/6/98	2/27/98
CE0	x	x	x	x	x
CE1	x	x	x	x	x
CE5				x	x
CE10				x	x
CE15	x	x	x	x	x
CE21	x	x	x	x	x
CM0	x	x	x	x	x
CM1	x	x	x	x	x
CM15.5	x	x	x	x	x
CM19.5	x	x	x	x	x
CW0	x	x	x	x	x
CW1	x	x	x	x	x
CW15	x	x	x	x	x
CW20	x	x	x	x	x
Infiltration	0.85	0.29	0.30	0.72	
Rate, ft/d					
SWE			x	x	x
SWN			x	x	x
SWW			x	x	x
SWS			x	x	x

Appendix K

Vector Control



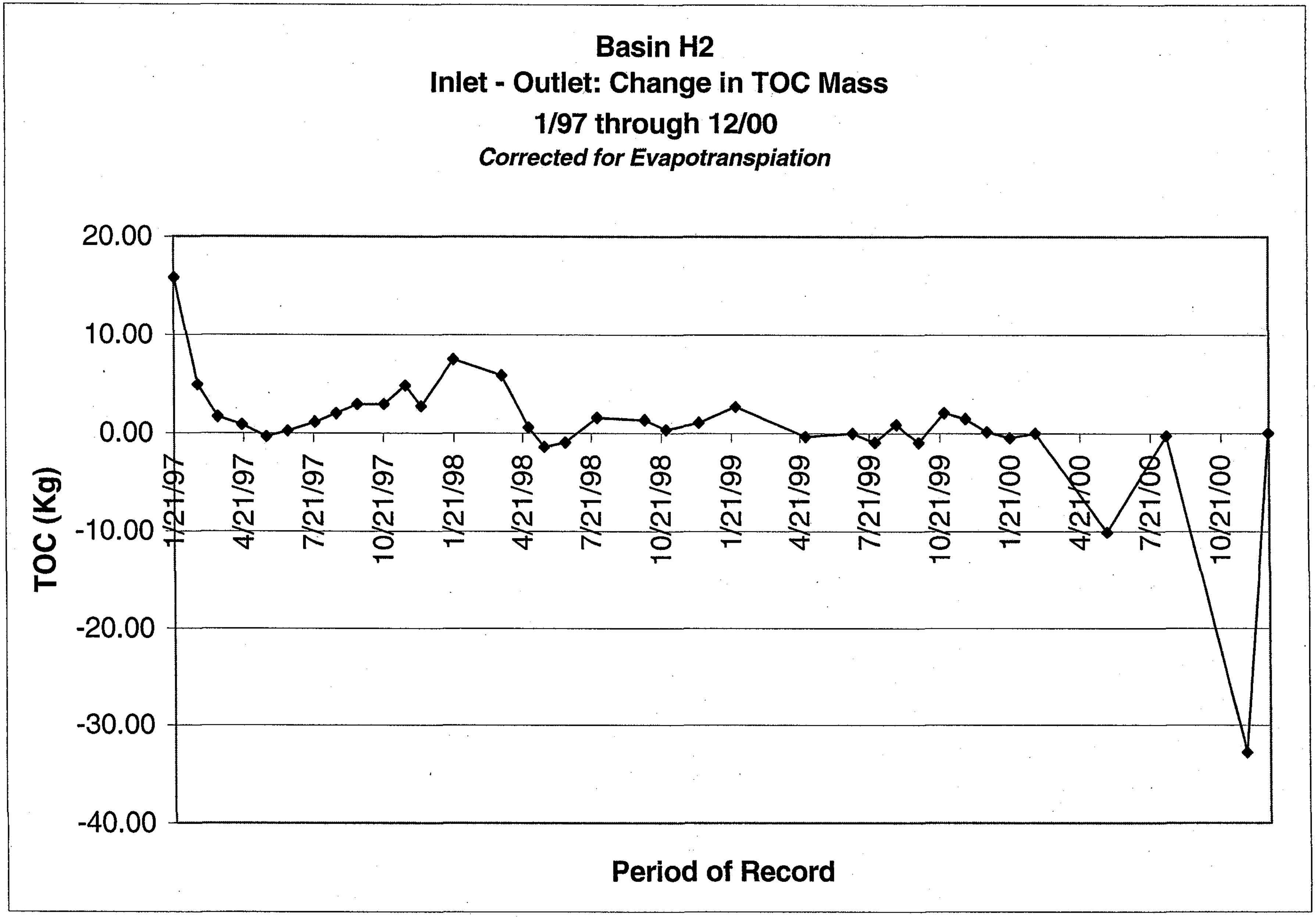
Plan view of the Post Reconfigured Cobble Site Sampling Locations.

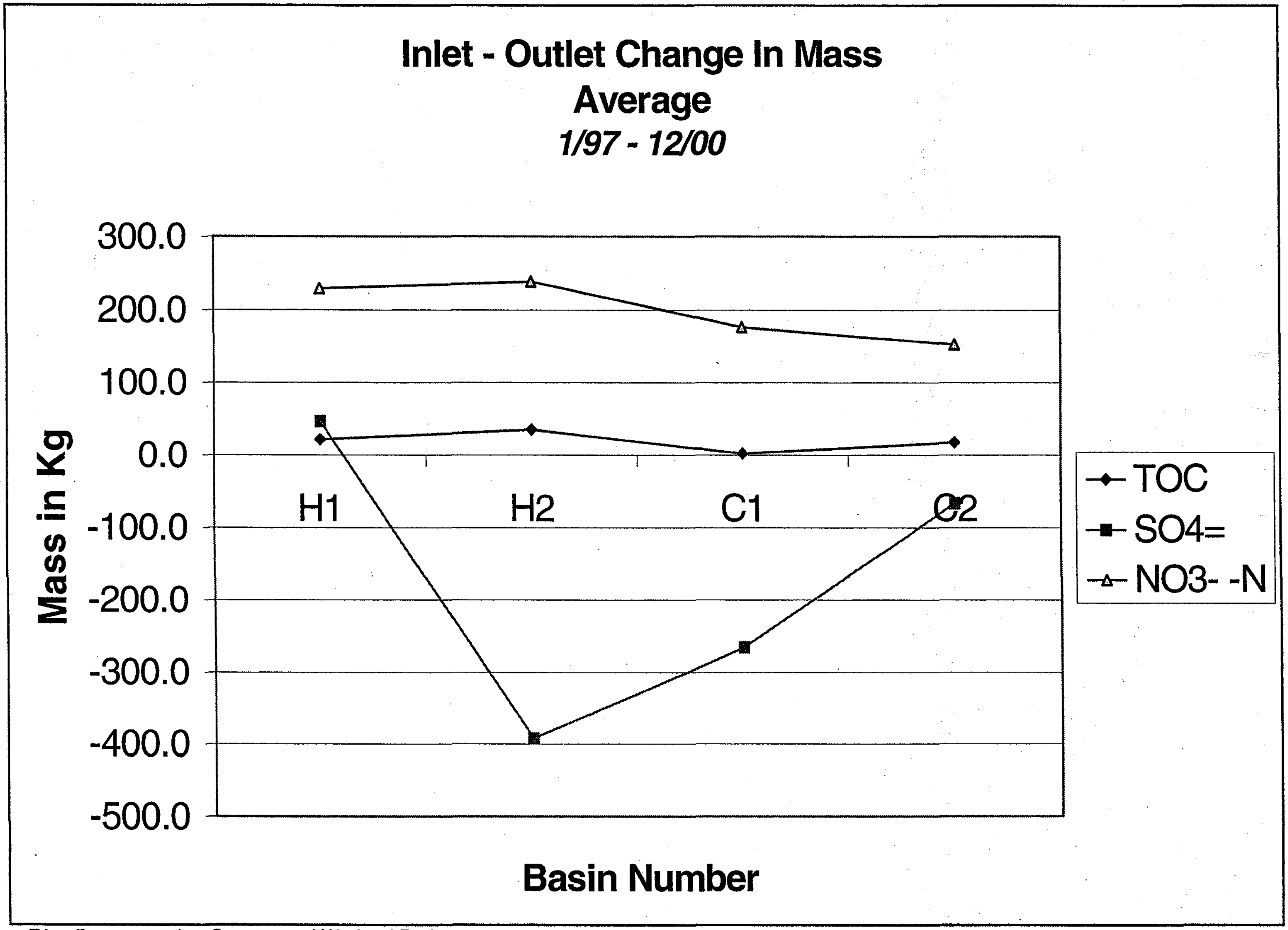


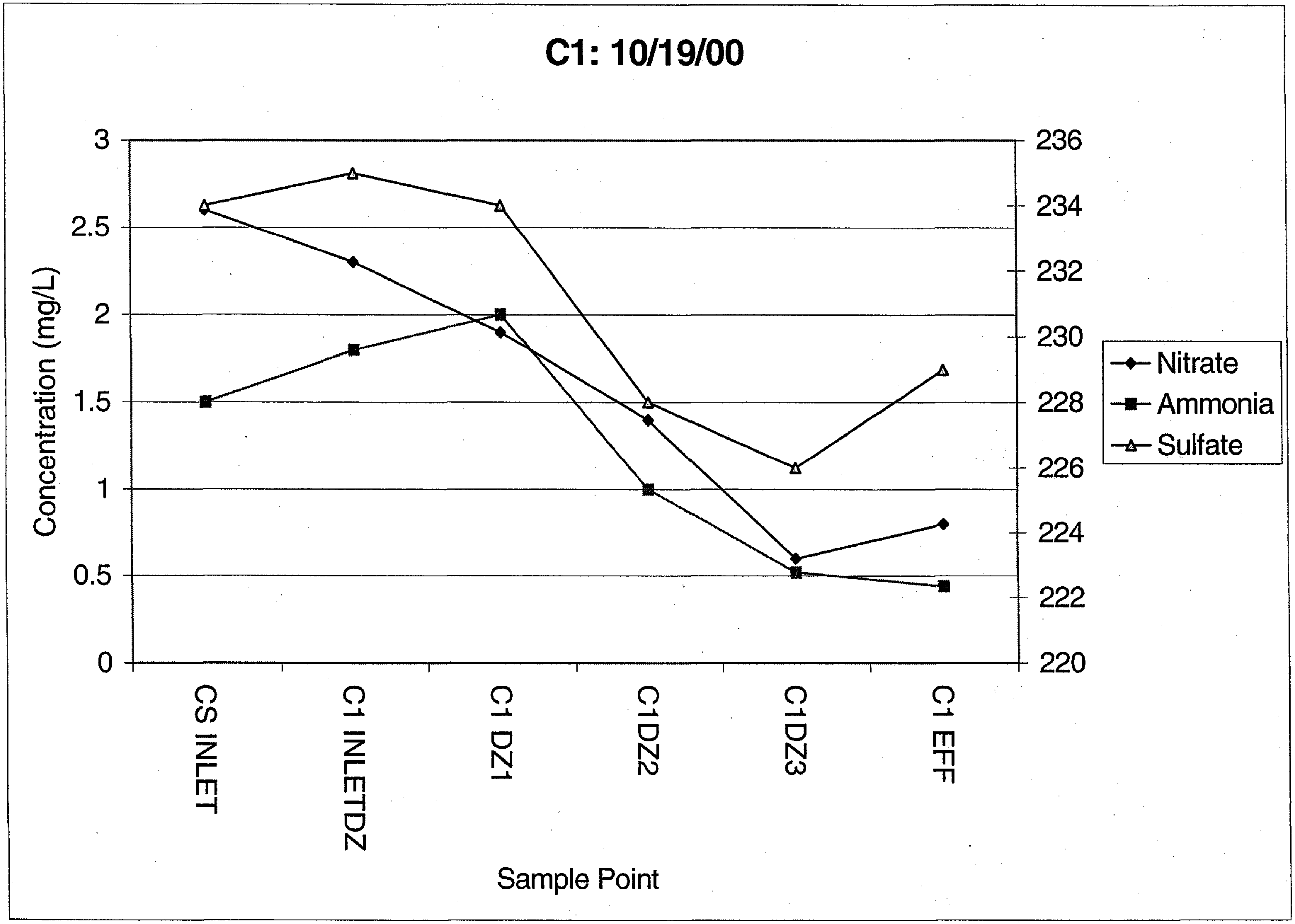
Cross-section of Cobble Basin C1 showing internal deep-zones and planting scheme.

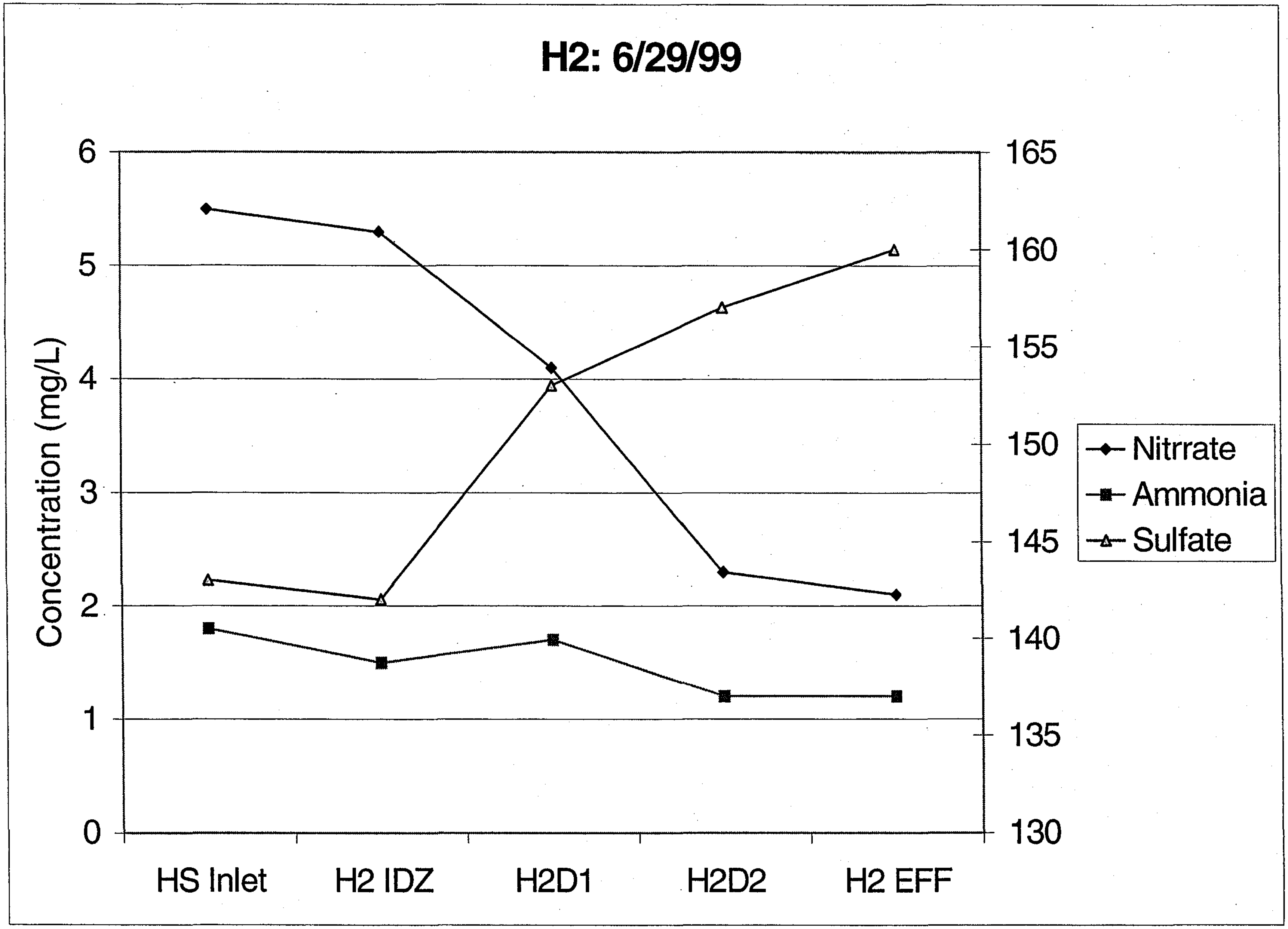
Appendix L

Sulfur-Driven Autotrophic Denitrification


Basin H2
Inlet - Outlet: Change in TOC Mass
1/97 through 12/00
Corrected for Evapotranspiation
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
TOC (Kg)
1/21/97
4/21/97
7/21/97
10/21/97
1/21/98
4/21/98
7/21/98
10/21/98
1/21/99
4/21/99
7/21/99
10/21/99
1/21/00
4/21/00
7/21/00
10/21/00
Period of Record


Inlet - Outlet Change In Mass
Average
1/97 - 12/00
300.0
200.0
100.0
0.0
-100.0
-200.0
-300.0
-400.0
-500.0
Mass in Kg
H1
H2
C1
C2
Basin Number
TOC
SO4=
NO3- -N


C1: 10/19/00
Concentration (mg/L)
3
2.5
2
1.5
1
0.5
0
236
234
232
230
228
226
224
222
220
Nitrate
Ammonia
Sulfate
CS INLET
C1 INLETDZ
C1 DZ1
C1DZ2
C1DZ3
C1 EFF
Sample Point



H2: 6/29/99
Concentration (mg/L)
6
5
4
3
2
1
0
165
160
155
150
145
140
135
130
HS Inlet
H2 IDZ
H2D1
H2D2
H2 EFF
Nitrrate
Ammonia
Sulfate