Santa Rosa Subregional Long-Term Wastewater Project

TREATMENT WETLANDS EVALUATION

SANTA ROSA SUBREGIONAL
LONG-TERM WASTEWATER PROJECT

Prepared for

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

JANUARY 1996

Prepared by:

Merritt Smith Consulting
Environmental Science and Communications
3675 Mt. Diablo Blvd. #120 Lafayette, CA 94549

For

HARLAND BARTHOLOMEW & ASSOCIATES, INC.

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INTRODUCTION

Nitrogen has been identified as an important nutrient in the Laguna de Santa Rosa and Russian River system because it is a limiting factor in the growth of algae (see 1992, 1993 and 1994 Annual Laguna Monitoring Reports submitted by Subregional System to RWQCB). Removal of nitrogen from reclaimed water prior to discharge to the Laguna de Santa Rosa and/or the Russian River is expected to be necessary to avoid adverse impacts, especially at discharge rates of greater than 5 percent. Two nitrogen removal alternatives have been identified as follows:

- **In-plant Denitrification.** The Laguna Water Reclamation Plant currently converts most ammonia to nitrate (nitrification) by providing increased detention time in aerated basins. Additional basins could be added to provide the additional detention time and anoxic conditions necessary to convert nitrate to nitrogen gas (denitrification). This approach to nitrogen removal is described in CH2M Hill (1995). Information in this report (Treatment Wetlands Evaluation) about in-plant nitrogen removal is based on CH2M Hill (1995).

- **Created Wetlands.** Natural wetland systems have been shown to denitrify reclaimed water reliably (Kadlec and Knight, 1995). Bacterial species are responsible for denitrification in all environments, including treatment plants and wetlands. Favorable conditions for growth of denitrifying bacteria can be created in wetlands by providing plant stems upon which bacteria can attach and grow.

This technical report describes an evaluation of the nitrogen removal potential of created wetlands, and compares created wetlands and in-plant nitrogen removal options for the Santa Rosa Subregional Long-Term Wastewater Project. Specifically, this technical report includes the following sections:

- Conceptual Development of Wetlands;
- Wetlands Design Basis;
- Estimated Wetlands Area Required;
- Comparison of Design Basis With Performance of Kelly Farm Demonstration Wetlands; and
- Comparison of Created Wetlands and In-Plant Denitrification.

CONCEPTUAL DEVELOPMENT OF WETLANDS

Natural wetland systems were a component of the proposed long-term reclaimed water management alternatives. Wetland sites and concepts were developed, and treatment potential was evaluated by the consulting team during alternative screening. Their conceptual development is summarized in four memoranda prepared for the BPU as follows:

1. *Proposed Refined Approach to Wetland Creation* - 28 July 1994;

2. *Wetland Creation Site Selection Criteria* - 22 November 1994;

3. *Status of Created Wetland Conceptual Design Sites* - 8 December 1994; and

4. *Evaluation of Created Wetland Conceptual Design* - 10 March 1995.

Based on the recommendation of the fourth memorandum, created wetlands were eliminated from further consideration by the Board of Public Utilities (BPU) on 6 April 1995. This memorandum was prepared to document the conceptual development of treatment potential in created wetlands that occurred prior to the BPU decision to exclude created wetlands. This memorandum is intended to provide a basis for evaluating nitrogen removal options should a long-term reclaimed water management alternative be selected that requires a nitrogen removal component. Cost and wetland performance data in the memoranda cited above are updated with this memorandum.

WETLANDS DESIGN BASIS

A first-order, area-based design model was developed by Kadlec and Knight (1995) based on information from wetland systems described in the United States EPA North American Wetland Treatment System Database. The design model is described as follows:

where:

A	=	wetland area (m^2)
Q	=	Reclaimed water flow (m^3/year)
C_0	=	background nitrogen concentration (mg-N/L)
C_1	=	inflow inorganic nitrogen concentration (mg-N/L)
C_2	=	outflow inorganic nitrogen concentration (mg-N/L)
k	=	$k_{20}1.1^{(T-20)}$
k_{20}	=	first-order, area-based rate constant at 20°C = 29 m/year
T	=	temperature, °C

Thus, the inputs to the model that are necessary to estimate wetland size are reclaimed water flow, nitrogen concentration (influent, effluent and background), and temperature. Each of these inputs is developed below.

ESTIMATE OF RECLAIMED WATER FLOW

The volume of reclaimed water that would be discharged to the Laguna or Russian River each month has been estimated using a water balance model and is summarized in Table 1. The model and estimated reclaimed water flows are described in a series of technical reports by Parsons ES in 1994 and 1995. The portion of the total reclaimed water that would need to be routed through wetlands for nitrogen removal would vary month. to month. Although the water quality modeling upon which final estimates of nitrogen removal needs will be based is not yet complete, preliminary model results indicate that nitrogen removal is not necessary from November through about mid-February. This is because higher Laguna and Russian River flows and reduced sunlight intensity and day length are insufficient to cause significant algal growth. In the remaining discharge months of October, late-February, March, April and early May, sufficient sunlight is generally available for algae to utilize reclaimed water nutrients for growth. During this algal growth period nitrogen removal would only be necessary during periods of low flow and relatively long hydraulic residence time in the Laguna and River system. Thus, reclaimed water discharged during storm periods in the algal growth season would not need to be routed through wetlands. Table 1 also includes an estimate of the fraction of the total reclaimed water flow that would be discharged in dry weather each month, and thus would be routed through the wetlands. Nitrogen removal would not be necessary between about 14 May and 1 October because no discharge is allowed during this period.

Table 1.

Estimated Average Reclaimed Water Flow Through Created Wetlands

	Dry Weather Fraction[a]	Estimated Average Discharge to Surface Waters (mgd)[b]			
Maximum River Discharge Rate (percent)		1	5	10	20
Annual Average Discharge To Receiving Water (MG/yr)		700	1850	2800	4600
October	1	0	1	6	17
November	0.8	0	3	9	16
December	0.5	1	11	14	20
January	0.33	11	20	8	27
February	0.33	8	13	17	24
March	0.33	1	7	12	22
April	0.67	0	5	10	19
May	1	0	0	0	4

[a]Estimated fraction of total discharge in each month that occurs in association with dry weather (examples: 1=100 percent, 0.67 = 67 percent). Treatment created wetlands of the fraction that is discharged during wet weather is assumed to not be necessary.

[b] Values are average monthly discharge as calculated using Water Balance Model described in related technical reports.

NITROGEN CONCENTRATION

Treated reclaimed water that is produced at the Laguna Water Reclamation Plant contains nitrogen in the form of ammonia, nitrate, and organic matter. During the period from January 1991 through October 1994, the sum of the average ammonia and nitrate concentrations was 20.2 mg-N/L (data are provided in *Reclaimed Water Quality* Technical report). The Laguna Water Reclamation Plant upgrade is expected to reduce the sum of nitrate and ammonia in effluent to 14.2 mg-N/L. The nitrogen in organic matter is not readily available for algal growth and was assumed to be insignificant for purposes of this analysis.

The appropriate concentration of nitrogen in the discharge from the wetland which would not promote algal growth will be determined by the Regional Water Quality Control Board when it sets an effluent limit (if any) for the selected long-term project. Thus, this wetland design basis has not yet been determined. However, preliminary results of the water quality model analysis suggests that 1 to 2 mg-N/L would be appropriate as a basis for this technical report.

The background nitrogen concentration (Co) identified in the above description of the wetland design model refers to the concentration of nitrogen in wetland effluent that is unavoidable because the wetlands is an active biological system. Kadlec and Knight (1995) suggest a value of 0.4, which is used in this analysis.

Table 2 summarizes the nitrogen concentration values used as wetland design model input.

Table 2.

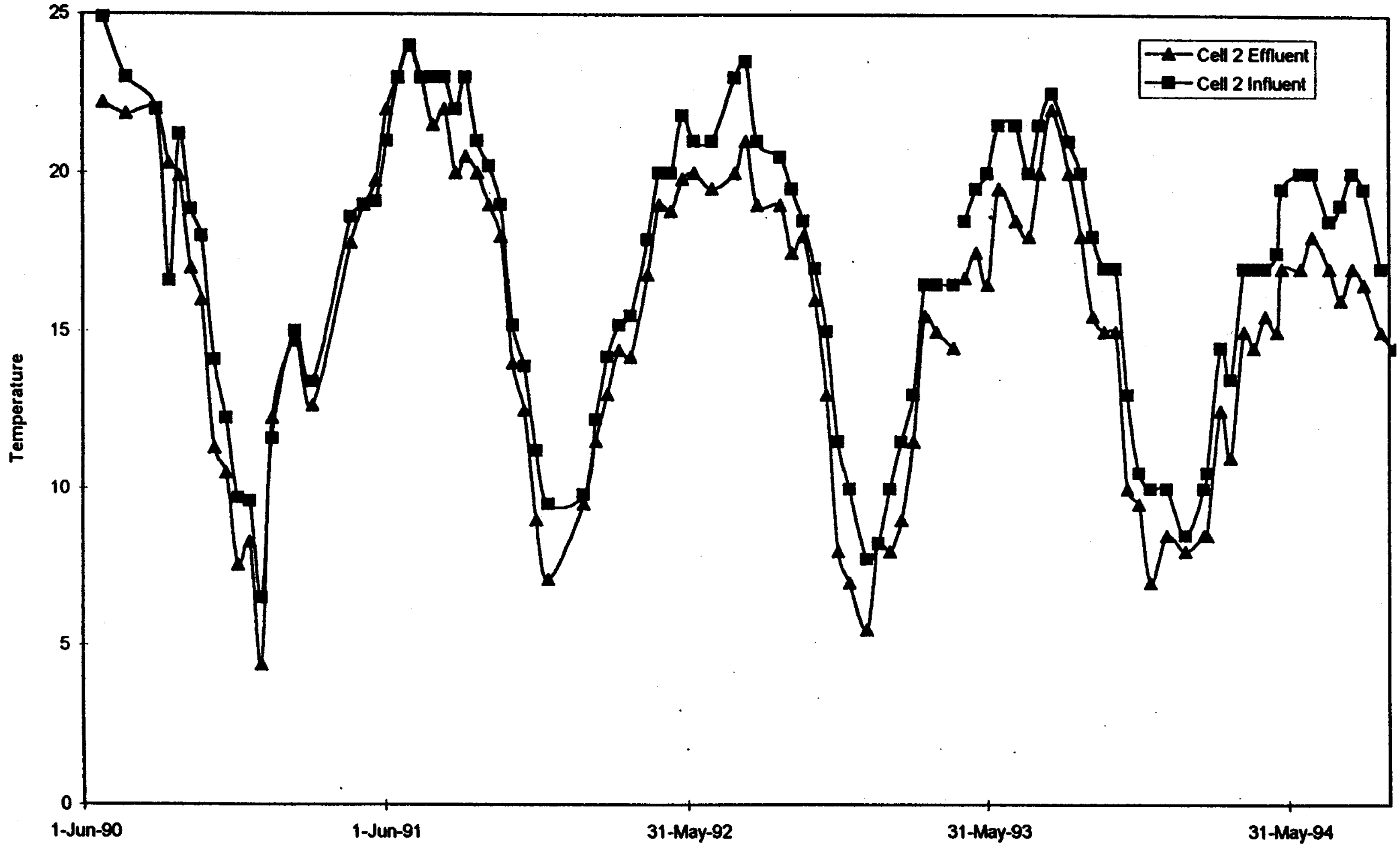
Summary of Nitrogen Concentrations Used As Wetland Design Model Input

Symbol	Description	Input Value (mg-N/L)	Source
C_0	Background	0.4	Kadlec and Knight (1995)
C_1	Wetland Influent	14.2	CH2MHILL (1995)
C_2	Wetland Effluent	1- 2	This report

TEMPERATURE

The temperature values used as input to the wetland design model were derived from monitoring data collected at Kelly Farm Demonstration Wetland (KFDW). Two temperature values were used to reflect conditions in February (12°C) and April (17°C). Figure 1 shows the KFDW temperature data from which these input values were derived.

Figure 1. Temperature In KFDW Cell 2



ESTIMATED WETLANDS AREA REQUIRED FOR POLISHING

Based on the design model, the created wetlands area that would be needed to remove nitrogen was estimated for the following conditions:

- **Reclaimed Water Flows.** Based on flows in Table 1, wetland area necessary for nitrogen removal of typical and maximum reclaimed water flows was estimated. Typical flows are those flows in April and were calculated by multiplying the dry weather fraction for April (0.67) by the estimated discharge to surface water value for each discharge alternative (i.e., 1, 5, 10 and 20 percent) in Table 1. The maximum estimated reclaimed water flow shown in Table 1 that occurs during the algal growth season of October, late-February, March, April and early May was assumed to be equivalent to the maximum expected flow rate through the wetland. The estimated maximum flow occurred in February for each discharge alternative.

- **Temperature.** Temperature values of 12°C and 17°C were used to estimate required wetland area for maximum (February) and typical (May) flows, respectively.

- **Effluent Concentration.** Wetlands area needed for removal down to 1 and 2 mg-N/L was estimated.

Table 3 shows the model output in acres of wetlands required for each condition. Table 3 shows that, for example, in the case of a 5 percent river discharge alternative, 1029 acres would be necessary to remove nitrogen to 1 mg-N/L from the February maximum flow of 13 mgd. However, only about 165 acres would be needed for the typical (April) flow of 5 mgd. If nitrogen removal to 2 mg-N/L is found to be sufficient, nitrogen removal for the maximum flow could be accomplished with only 707 acres. Figure 2 shows the acreage estimates from Table 3, with capital costs based on an assumed cost of $26,500 per acre (from *Comparative Costs for Nitrogen Removal*, a July 1995 technical report by Questa Engineering). The cost associated with the maximum reclaimed water flow for each discharge alternative (i.e., 1, 5, 10, and 20 percent) should be used for planning purposes.

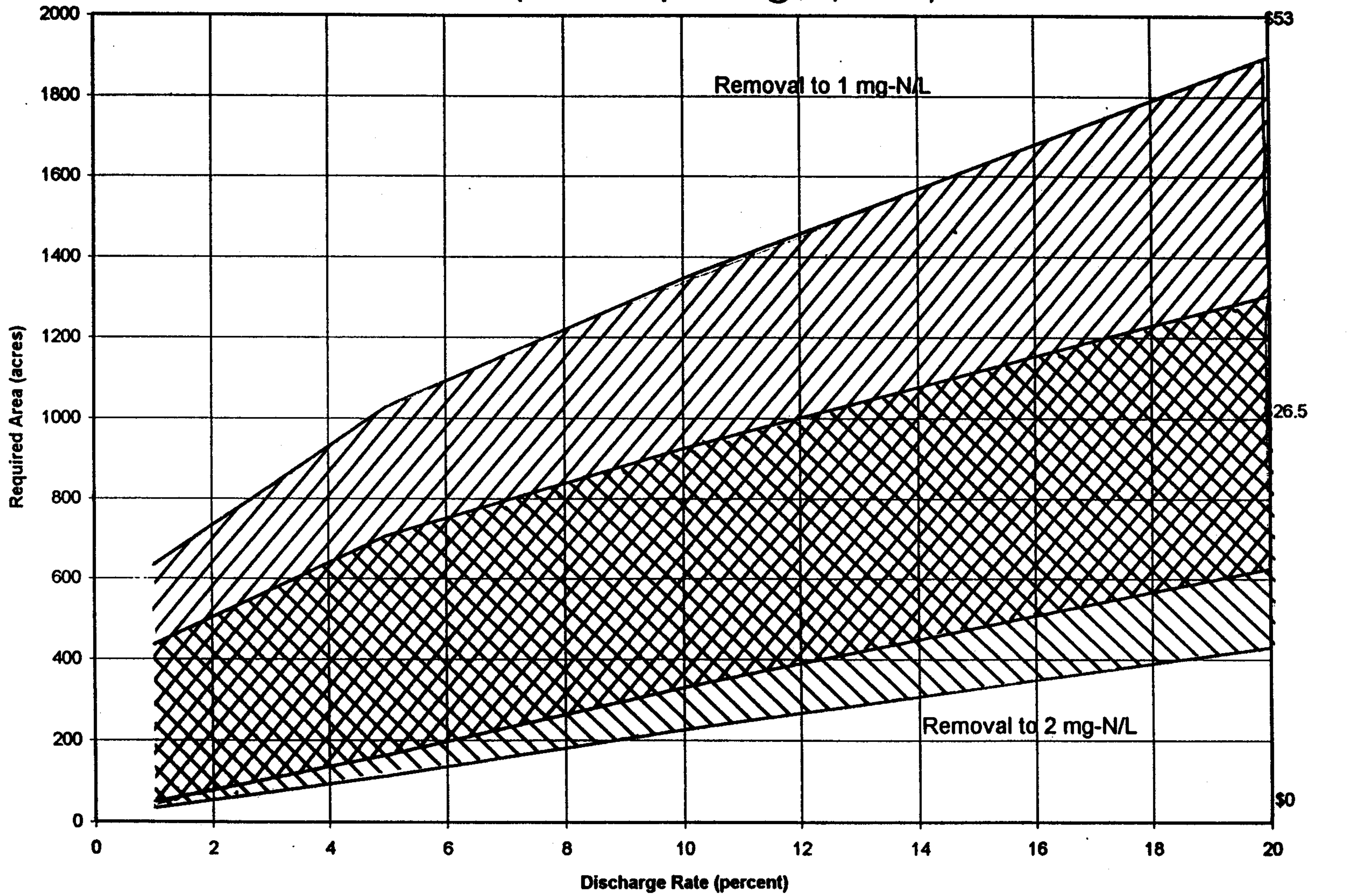
Table 3.

Estimated Wetland Area Requirement

Maximum Discharge Rate (percent)	Reclaimed Water Flow (mgd)		Required Wetland Area (acres)			
	Typical	Maximum	C_2 = 1 mg-N/L		C_2 = 2 mg-N/L	
			Typical	Maximum	Typical	Maximum
1	1	8	49	633	34	435
5	3.3	13	165	1029	113	707
10	6.7	17	329	1349	226	925
20	12.7	24	626	1900	430	1305

Figure 2. Created Wetlands Acreage Requirements

(estimated capital cost @ $26,500/acre)



COMPARISON OF DESIGN BASIS WITH PERFORMANCE OF KELLY DEMONSTRATION WETLANDS

KFDW was constructed so that a site-specific study of the effect of reclaimed water passage through a constructed wetlands system could be conducted. KFDW monitoring data were assembled and evaluated to compare KFDW with the Kadlec and Knight (1995) wetland design model. The purpose of this comparison is to verify the applicability of the model to site-specific conditions and understand differences between the design model and site-specific conditions.

The temperature-adjusted area-based nitrogen removal constant (k_{20}) was calculated for KFDW monitoring data. The average, minimum and maximum k_{20} values from all combined KFDW cells during the period from June 1990 through September 1994 are 41, 4, and 114 m/year, respectively. The KFDW average k_{20} value of 41 m/year is greater than the value of 29 m/year provided by Kadlec and Knight (1995), and the KFDW data are scattered over a wide range. The difference between the average k_{20} value in KFDW and that proposed by Kadlec and Knight (1995), and large scatter of the KFDW k_{20} values are each addressed below. Evapotranspiration data from KFDW are also summarized.

The k_{20} value from Kadlec and Knight (1995) was used to calculate wetland acreage in Table 3. If the average k_{20} value from KFDW (41 m/year) is used instead, the estimated acreage requirement would be about 30 percent less than the acreage estimates shown in Table 3.

AVERAGE K_{20} VALUES

The KFDW average k_{20} value of 41 m/year is greater than the value of 29 m/year provided by Kadlec and Knight (1995), which means that the average KFDW performance is better than that in the systems summarized by Kadlec and Knight (1995). Thus, the use of the Kadlec and Knight (1995) model to estimate wetland acreage is conservative relative to the demonstration project.

SCATTER OF KFDW K_{20} VALUES

The k_{20} values that were calculated using the equation on page 4 were based on nitrogen removal throughout KFDW cells 1 through 3. These k_{20} values for KFDW ranged widely from 4 to 114 m/year. Examination of the k_{20} values within each KFDW cell explains some of this variability. Table 4 shows the average, maximum and minimum k_{20} values for each cell and all three cells combined. Figure 3 shows k_{20} values through time in each cell and all three cells combined.

Figure 3. k_{20} Values at KFDW

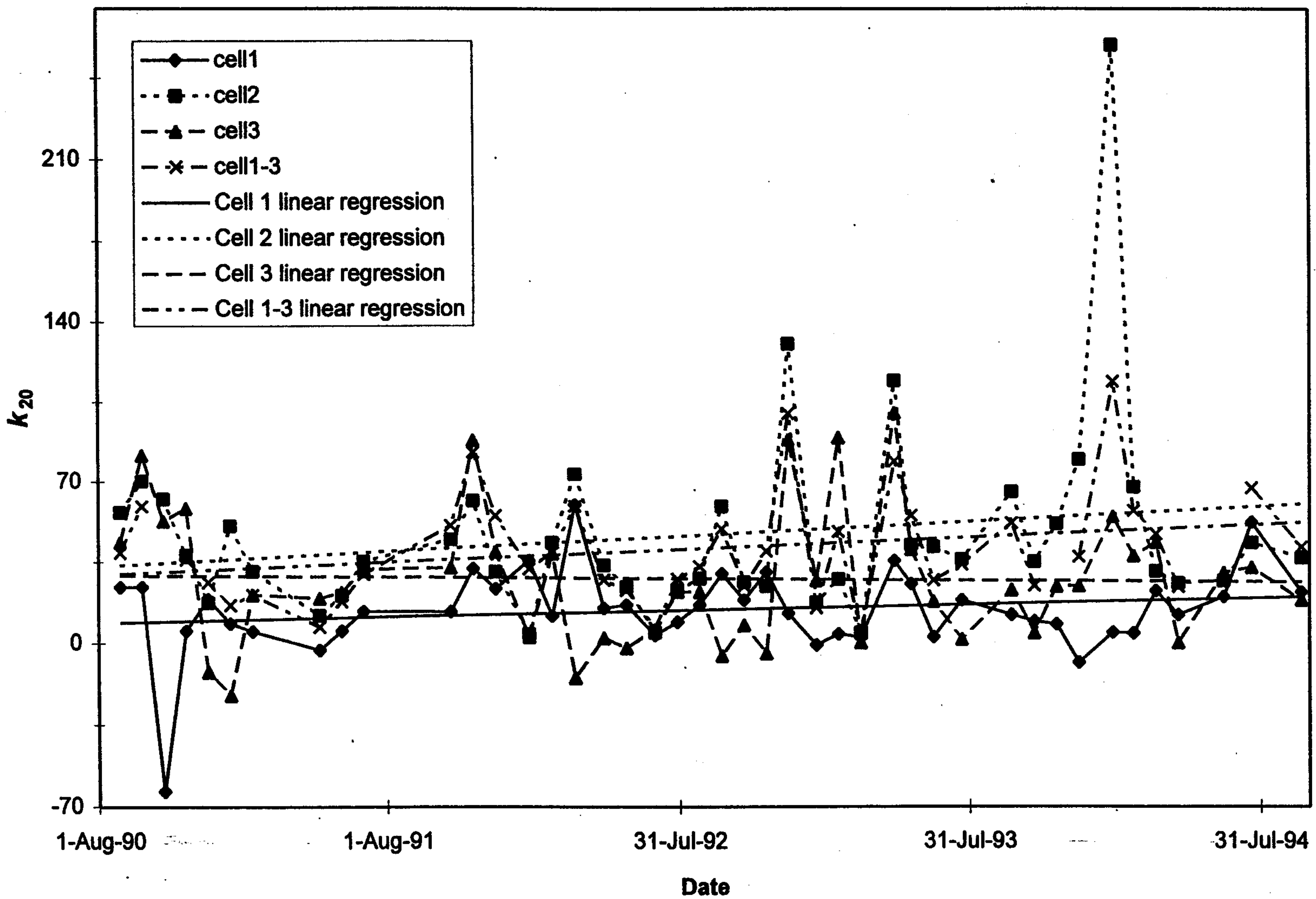


Table 4.

Summary of KFDW k_{20} Values

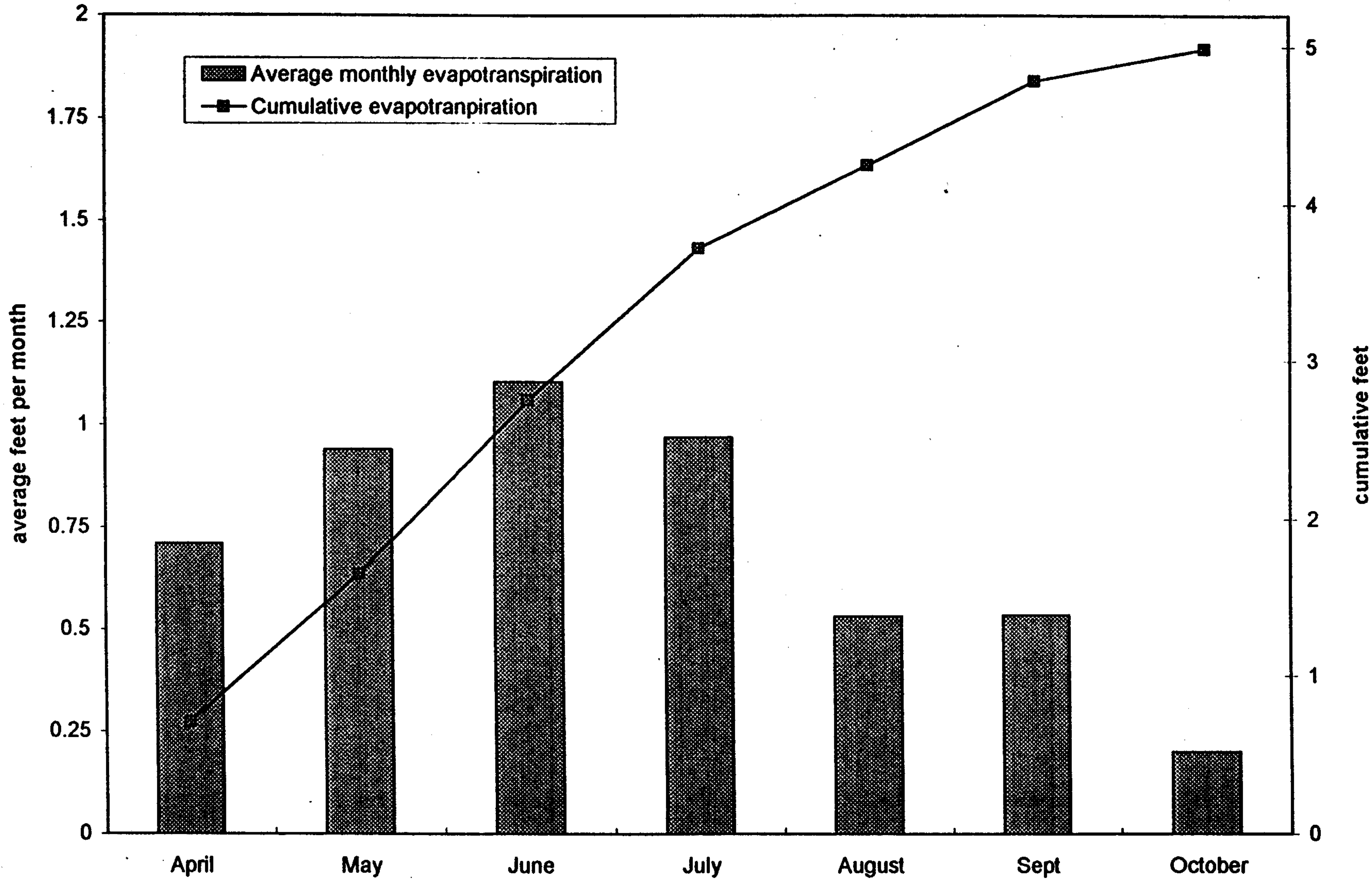
	Cell 1	Cell 2	Cell 3	Cells 1 - 3
Average	14	47	28	41
Maximum	60	259	100	114
Minimum	-63	4	-22	4

Figure 3 and Table 4 show that nitrogen removal in Cell 2 occurred at a higher rate than in Cells 1 and 3. Cell 1 was designed as a deep cell, and consequently has little emergent vegetation to stimulate nitrogen removal. Cell 3 was designed as a shallow cell, and vegetation has become extremely dense. Short-circuiting of the water through the dense vegetation may explain the relatively poor performance of Cell 3. Cell 2 was designed to be a mosaic of open water and emergent vegetation, and this may have developed in such a way that more water passes through stands of emergent vegetation relative to Cell 3. Carbon limitation may also affect nitrogen removal. Additional study of ongoing KFDW monitoring data is recommended prior to design of any wetlands facilities for nitrogen removal, so that the design may reflect lessons from KFDW. Nonetheless, the KFDW monitoring data show that nitrification is occurring at a rate that is generally consistent with other wetlands systems (Kadlec and Knight 1995).

EVAPOTRANSPIRATION

Evapotranspiration (ET) of reclaimed water represents a benefit of created wetlands. Reclaimed water consumption at KFDW has been estimated, using flow gages in marsh influent and between cells, to be about 5 feet per year. Monthly and cumulative annual total ET at KFDW are summarized in Figure 4.

Figure 4. Evapotranspiration at KFDW



COMPARISON OF CREATED WETLANDS AND IN-PLANT DENITRIFICATION

Created wetlands and in-plant nitrogen removal alternatives are compared in this section in terms of technical and cost considerations. This evaluation is preliminary because neither nitrogen removal alternative has been developed sufficiently for a complete comparison.

TECHNICAL CONSIDERATIONS

Table 5 summarizes the technical comparison of the two nitrogen removal alternatives.

Table 5.

Technical Comparison of Created Wetlands and In-Plant Nitrogen Removal

	Created Wetlands	In-Plant
Flexibility	Can be sized to treat the flows that would be discharged to the Laguna for the selected alternative. Insufficient land may be available to adequately treat flows for higher discharge alternatives.	Would probably need to be sized to treat the entire plant flow, which is expected to be approximately 21 mgd.
Amount of Removal	Can be sized to meet the identified nitrogen removal requirement; removal to approx. 0.4 mg-N/L expected.	Removal to 2 mg-N/L or lower is possible.

COST

The cost of wetland construction was estimated in the C*omparative Costs for Nitrogen Removal* technical report. The anticipated construction cost ranges from $26,500 to $46,500 per acre, depending on the need for soil removal. The estimated annual O&M cost is $500,000 for a 1,350-acre wetlands facility, as described in Table 6. A 1,350-acre wetland would meet the maximum flow needs of a 10 percent alternative (Table 3.). The estimated annual O&M cost for a 630-acre (1 percent alternative) is also shown in Table 6.

Table 6.

Estimated Annual O&M Cost for a 1,350-Acre Created Wetlands

	Cost[a]	
Item	630 Acres	1350 acres
Labor ($60,000/Full Time Unit)	$120,000	$180,000
Vehicles and onsite equipment (renewal, repair)	$140,000	$170,000
Monitoring	$75,000	$100,000
Administration, management	$40,000	$50,000
Total	$375,000	$500,000

[a]Assumes 630 and 1,350-acre wetlands, sufficient for 1 and 10 percent alternative, respectively.

The capability to remove nitrogen at the Laguna plant was recently evaluated in CH2MHILL (1995). The enhancement to the plant that is currently being implemented as part of the Laguna Upgrade Project was initially estimated to reduce inorganic nitrogen (nitrate and ammonia) to 14.2 mg-N/L. The estimated cost to reduce inorganic nitrogen from 14.2 to 3 mg-N/L is $21.5 million. However, CH2MHILL (1995) has identified other facilities that are similar to the upgraded Laguna Plant that have achieved final effluent quality (inorganic nitrogen) of 1-2 mg-N/L. CH2MHILL (1995) has recommended a study program to refine the estimated Laguna plant performance prior to completion of the upgrade. Since the Laguna Upgrade Project will not be completed until early 1997 and nitrogen removal costs are needed for the long-term project evaluation and selection process in mid-1996, implementation of the appropriate study program is recommended by the Long-Term Team.

Table 7 provides a comparison of the two nitrogen removal alternatives. The comparison should be considered preliminary because the unit cost estimates are preliminary and because the wetland acreage requirement has not yet been defined. Acreage requirements in this study are conservative because they are based on maximum reclaimed water flow, conservative nitrogen removal performance, and the more stringent wetland effluent requirement of 1 mg-N/L. The treatment plant cost estimate should be considered a maximum value.

Table 7.

Cost Comparison of Nitrogen Removal Alternatives

	Wetlands[a]		
	630 acres	1350 acres	Treatment Plant
Capital	$16,700,000	$35,800,000	$21,500,000
Annual O&M	$375,000	$500,000	$750,000
Net Present Value[b]	$19,000,000	$37,000,000	$26,000,000

[a]Assumes 630 and 1,350-acre wetlands, sufficient for 1 and 10 percent alternative, respectively.

[b]Period = 1999-2010, discount rate = 6%

The cost of created wetlands can also be compared with the cost of alternative uses of potential wetland creation sites. Irrigation is the predominant existing use of wetland creation sites that would be developed. Table 8 compares the cost per million gallons of reclaimed water disposed of by wetlands and irrigation. Four feet of water use is assumed at the wetlands sites, rather than the estimate of 5 feet in Figure 4. Reduced effective ET is assumed at constructed wetlands sites because only about eighty percent of a site can be used for wetlands because of the need for access roads, berms and other facilities. Nearly 100 percent of an irrigation site can be irrigated, except for buffers from streams and high value wetlands.

Table 8.

Cost Comparison of Wetlands and Irrigation

	Capital Cost ($/acre)	Water Use (AF/acre)	Disposal Cost ($/MG)
Irrigation	$10,000	2	$15,000
Wetlands	$26,500	4	$20,000

REFERENCES

CH2MHILL, September 1995. Future Nutrient Removal at the Laguna Facility.

Kadlec, R. H. and R. L. Knight, 1995. *Wetland Treatment Systems*, Boca Raton, Florida: Lewis Publishers.

Questa Engineering,, 1995. Comparative Costs for Nitrogen Removal.

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