CONSTRUCTED WETLANDS FOR SWINE WASTEWATER TREATMENT

F. J. Humenik, A. A. Szogi,, P. G. Hunt, J. M. Rice and G. R. Scalf*

ABSTRACT

Constructed wetlands are an acceptable method for mass removal of nutrients from animal wastewaters. However, dischargeable effluent concentrations are difficult to achieve. The study objectives were to determine if a dischargeable effluent could be obtained from a constructed wetland treatment system with a loading of 3 kg TKN ha^{-1} day^{-1} and to determine mass removals for nitrogen and phosphorus. Wetland system mass removal of TKN was >90%, and effluent total nitrogen concentrations could have met local stream discharge requirements during some time periods. Wetland system mass removal of TP was only about 73%, and effluent TP concentrations generally exceeded discharge allowances. As nutrients build up and the wetland systems become a carbon generator, it will be difficult to meet stream discharge requirements with constructed wetlands for swine wastewater treatment. However, effluent TOC levels are inconsequential for terminal land application. Therefore, an enhanced wetland treatment system at the increased loading rate of 10 kg TKN ha^{-1} day^{-1} including an overland flow and an alternative media filter pretreatment is being evaluated to determine if more effective nitrogen and phosphorus mass removal can be obtained.

KEYWORDS. Swine wastewater, Constructed wetlands, Nitrogen and phosphorus removal

INTRODUCTION

Reports on the use of constructed wetlands to produce a dischargeable effluent have heightened interest in constructed wetlands for swine wastewater treatment. One such article noted that when water leaves the cell, it carries only a fraction of the pollution it contained upon entry (Leidner, 1992.) The article postulated that two or three additional cells would produce mostly clean water. Another report noted that constructed wetlands are an ideal secondary treatment system. They are relatively inexpensive to build, need almost no maintenance, have a pleasant view, and effectively remove bacteria and nutrients (Clanton, 1992). Constructed wetlands are also reported to be easy to design, build, maintain, and use for difficult pollution sources such as livestock waste (TVA-EPA, 1990). However, reports also allow that just how well constructed wetlands work for hog units is still in debate (Leidner, 1992).

Early recommendations for municipal wastewater had an upper five-day biochemical oxygen demand (BOD_5) loading of 60 to 70 kg ha^{-1} day^{-1} (Metcalf and Eddy, 1991) and a total Kjeldahl nitrogen (TKN) or ammonia (NH_3-N) loading rate of 18 kg ha^{-1} day^{-1} (Davis and Cathcart, 1992). Natural Resources Conservation Service (NRCS) Guidelines are BOD_5 <112 kg ha^{-1} day^{-1}, 1500 mg L^{-1} total solids (TS), and 100 mg L^{-1} ammonia (Boyd, 1995; Krider and Boyd, 1992; and SCS, 1991). Tennessee Valley Authority (TVA) nitrogen loading criteria for constructed wetlands for livestock wastewaters for advanced discharge standards have been reduced to <70 kg ha^{-1} day^{-1} for BOD_5 and total suspended solids (TSS) and <3 kg ha^{-1} day^{-1} for TKN or NH_3-N (Hammer, 1994).

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The objectives of this study were to determine if a dischargeable effluent could be obtained from a constructed wetland treatment system with the low loading of 3 kg TKN ha^{-1} day^{-1} and to determine mass removals for nitrogen and phosphorus.

MATERIALS AND METHODS

Wetland Cells

Six 3.6 x 33.5 m wetland cells were constructed in Duplin County, North Carolina, in 1992. They were divided into three parallel sets of two end-on-end cells (Hunt et al., 1994). The cell bottoms and sidewalls were lined with clay, which was covered with 20 to 30 cm of loamy sand soil. Slopes were 0.2% or less and water depth at the end of the slope was maintained below 15 cm.

Plant Materials

Four cells were planted to natural wetland vegetation in 1992. Wetland system 1 consisted of cells 1 and 2 connected (end-on-end), and it contained rushes *(Juncus effusus)* and bulrushes *(Scirpus americanus, Scirpus cyperinus, and Scirpus validus).* Wetland system 2 consisted of cells 3 and 4, and it contained bur-reed *(Sparganium americanum)* and cattails *(Typha angustifolia and Typha latifolia).*

Monitoring Equipment

Four v-notch weirs and four PDS-350 ultrasonic open-channel flow meters (Control Electronics, Morgantown, PA) were installed at the inlet and outlet of each wetland system. Five ISCO 3700 samplers (ISCO, Lincoln, NE) were installed; one sampler collected samples of the wastewater influent and the other four sampled the water at the end of each single cell. A CR7X data logger with two multiplexers (Campbell Scientific, Logan, UT) were installed for hourly acquisition of flow, weather parameters and soil redox potential data. The water sampler combined hourly samples into composites.[1]

Wastewater Analyses

Samples for TKN and TP were taken in three-day composites, acidified, filtered and analyzed on alternate samples (i.e. days 1,2,3 composite sample not analyzed, days 4,5,6 composite sample analyzed). Total organic carbon (TOC) analyses were made on unfiltered three-day composite samples and analyzed on one out of four composite samples (i.e. one three-day composite sample for days 10, 11, 12 was analyzed). Total Kjedahl nitrogen and TP analyses were accomplished by use of a TRAACS 800 Auto-Analyzer. Total organic carbon was analyzed with a Dhorman DC-190 carbon analyzer. Nitrogen and phosphorus concentrations in non-diluted wastewater (Table 1) indicate that 95% of TKN was in the soluble NH_3-N form and 97% of TP was in soluble form as ortho-phosphate-phosphorus.

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the North Carolina Cooperative Extension Service or the USDA and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

Nutrient Loads

Lagoon wastewater (Table 1) was diluted ≥ 10 fold with fresh water to obtain the relatively low daily TKN application rate of 3 kg ha^{-1} day^{-1} and to meet evapotranspiration demands during summer months. Wastewater flow (from the lagoon) was continuous and float control valves in a mixing tank were set to provide the desired proportion of lagoon liquid and dilution water. The TKN concentrations in the influent wastewater were lower in the summer period because of the dilution needed to maintain the wetland and the 3 kg ha^{-1} day^{-1} TKN mass load.

Table 1. Characteristics of Non-Diluted Wastewater from the Anaerobic Lagoon (Hunt et al., 1994)

Parameters	Units	Mean	Standard Deviation
pH		7.53	0.14
Total Solids	g kg^{-1}	1.86	0.47
Volatile Solids	g kg^{-1}	0.73	0.32
Total Organic Carbon	mg L^{-1}	235	124
Chemical Oxygen Demand	mg L^{-1}	737	237
Biochemical Oxygen Demand	mg L^{-1}	287	92
Total Kjeldahl Nitrogen	mg L^{-1}	365	41
Ammonia-Nitrogen	mg L^{-1}	347	52
Nitrate-Nitrogen	mg L^{-1}	0.04	0.03
Total Phosphorus	mg L^{-1}	93	11
Orthophosphate-Phosphorus	mg L^{-1}	90	9

The TKN loading increased to 10 kg ha^{-1} day^{-1} on July 11, 1994. Effluent from all wetland systems was pumped back to the lagoon to avoid discharge. Neither odors nor mosquitos were a problem.

RESULTS AND DISCUSSION

Influent TKN averaged 40 and 80 mg L^{-1} for the TKN loading of 3 and 10 kg ha^{-1} day^{-1}, respectively (Figure 1). During August-October 1993 and March-July 1994 when influent TKN was about 30 mg L^{-1}, effluent TKN from both wetland systems was generally below 8 mg L^{-1}. However, during October-December 1993 influent TKN was above 50 mg L^{-1} and both wetland treatment systems had effluent TKN over 10 mg L^{-1} during this period (Figure 2).

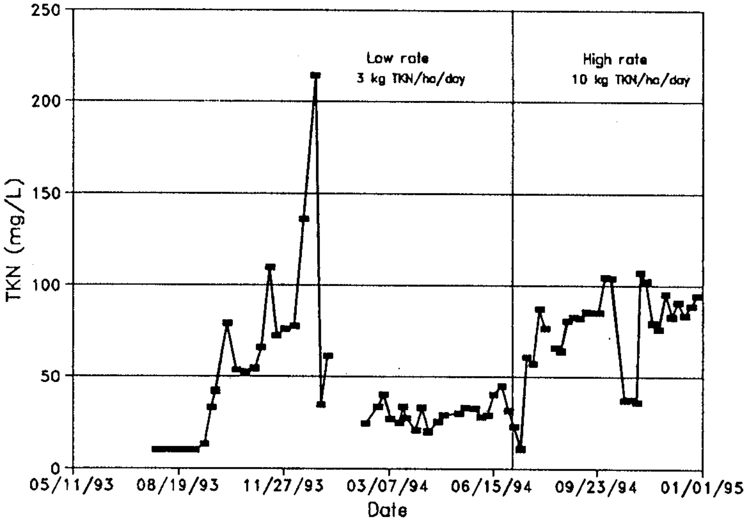

Figure 1. Influent TKN concentrations to constructed wetland systems 1 and 2.

After the TKN loading rate was increased to 10 kg ha^{-1} day^{-1}, effluent TKN concentrations for both wetland systems sometimes exceeded local stream discharge requirements of about 4 mg L^{-1} total nitrogen for summer and 8 mg L^{-1} total nitrogen for winter (Figure 2).

Percent TKN removals on a mass basis for the TKN loading of 3 kg ha^{-1} day^{-1} were 96% and 91% for wetland system 1 and wetland system 2, respectively (Table 2).

Table 2. Mean Nitrogen and Phosphorus Mass Removals from Swine Wastewater Treated in Constructed Wetlands

Loading Rate System~	System*	% Mass Removal TKN	% Mass Removal TP
Low Rate	1	96	73
	2	91	73
High Rate	1	86	10
	2	85	17

*System 1: Rush/bulrushes; kg ha^{-1} day^{-1} System 2: Bur-reed/cattails
~Low Rate: TKN = 3 kg ha^{-1} day^{-1}, TP = 0.8 kg ha^{-1} day^{-1} ; High Rate: TKN = 10 kg ha^{-1} day^{-1}, TP = 2.6 kg ha^{-1} day^{-1}

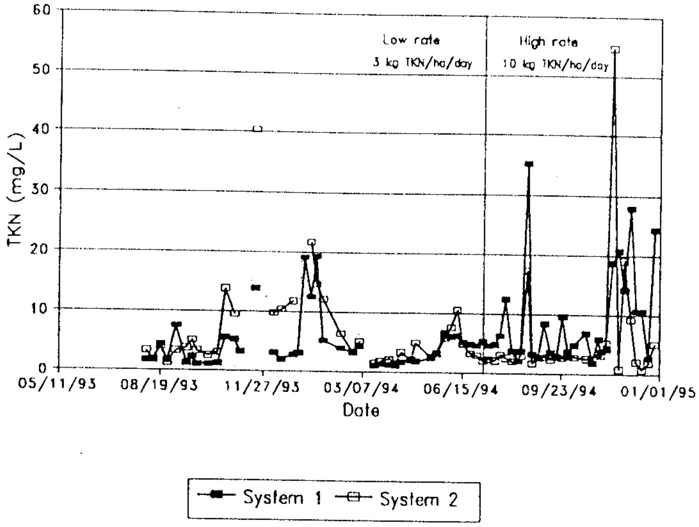

Figure 2. Effluent TKN concentrations from constructed wetland treatment systems.

Effluent TP averaged 7 and 15 mg L^{-1} for the TKN loading of 3 and 10 kg ha^{-1} day^{-1}, respectively (Figure 3). Effluent concentrations from startup generally exceeded the discharge allowance of about 2 mg L^{-1} total phosphorus year round (Figure 4). The TP loading rate (for calculating percent removal on a mass basis) was estimated from the NH_3:o-PO_4-P ratio (3.8:1) in the lagoon wastewater (Table 1). Total TP removal on a mass basis was 73% when wetland systems 1 and 2 were loaded at 3 kg ha^{-1} day^{-1} of TKN. When loaded at 10 kg ha^{-1} day^{-1} of TKN, only 10% and 17% were removed by wetland system 1 and wetland system 2, respectively (Table 2). Total phosphorus removals on a mass basis decreased significantly with time and the higher loading rates. Lower phosphorus removal efficiencies resulted most likely from limited plant uptake and anaerobic wetland conditions that solubilize iron phosphates and limit soil adsorption capacity.

Wide temporal variations in both influent and wetland systems effluent TOC concentrations were observed for both loading rates (Figures 5 and 6). Effluent TOC concentrations for both wetland systems were similar to influent concentrations and even higher for some periods. Thus at times the wetlands were a source of organic carbon due to plant-root exudate and decomposition of dead plant materials (Hunt et al., 1994). For this reason, TOC treatment efficiency was variable and particularly low during autumn and winter seasons (October 1993 - March 1994).

CONSTRUCTED WETLAND SYSTEM ALTERATION

The TKN loading of 3 kg ha^{-1} day^{-1} was initially chosen because it is the currently recommended level for constructed wetlands for livestock wastewater for advanced discharge requirements. Results at this loading rate for wetland systems 1 and 2 show good mass removal of TKN and total nitrogen concentrations which could meet local stream discharge requirements during some time periods. However, wetland system mass removal of TP was only about 73%, and effluent

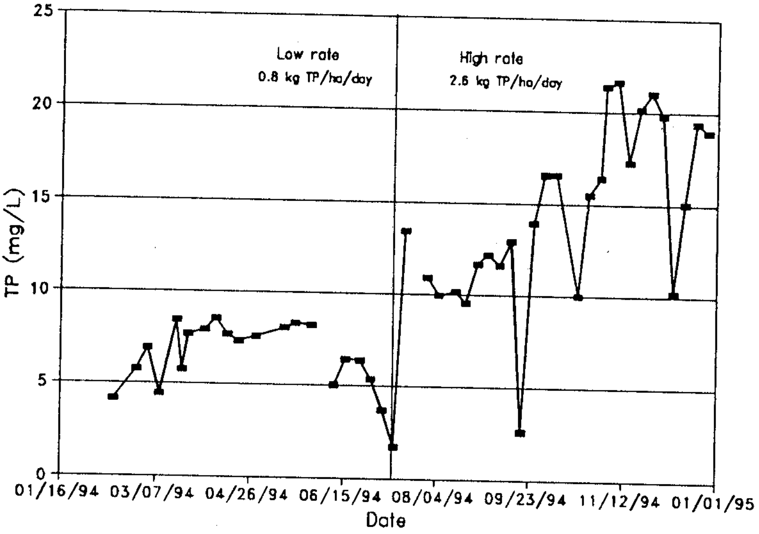

Figure 3. Influent TP concentrations to constructed wetland systems 1 and 2.

TP concentrations exceeded discharge allowances except for wetland system 2 for a short period before the TKN loading increase. As nutrients build up and the wetland systems become a carbon generator, it will be difficult to meet stream carbon discharge requirements with constructed wetlands for swine wastewater treatment. However, effluent TOC levels are inconsequential for terminal land application. In addition, the procedure of diluting swine wastewater to obtain constructed wetland loading rates for livestock waste for advanced discharge standards is not consistent with basic principles of wastewater volume reduction and pollution prevention. Therefore, an enhanced wetland treatment system at the increased TKN loading rate of 10 kg ha^{-1} day^{-1} including an overland flow or media filter pretreatment is being evaluated to determine if more effective nitrogen and phosphorus removals can be obtained in an enhanced constructed wetland treatment system.

Overland Flow

Reports on overland flow pretreatment of poultry manure (Overcash et al., 1976a and Overcash et al., 1976b) conclude that an overland flow and a pond system can reduce land requirements for raw manure by 50 to 70 percent. However, effluent quality from the overland flow system or the overland flow-pond system for poultry manure was not sufficient to allow direct stream discharge.

The pretreatment overland flow unit being installed is 4 m wide by 20 m long with 2 percent slope. Stoichiometric amounts of alum for phosphorus precipitation will be added to the wastewater. Wastewater will be applied as a fine spray over the first six meters of the overland flow system. This system will be operated with wet and dry periods to allow maintenance of

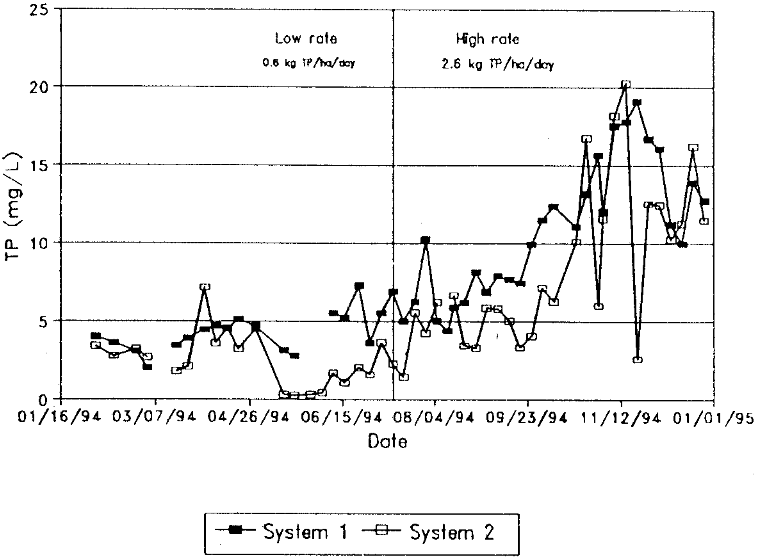

Figure 4. Effluent TP concentrations from constructed wetland treatment systems.

plant and soil surface and removal of phosphate sludge. The overland flow system design, operation and maintenance that has been successfully used will be employed (Hunt and Lee, 1976 and Overcash et al., 1976a, 1976b).

Media Filters

Recirculating sand filter systems have become popular for small waste generators, especially where soil conditions are not suitable for subsurface disposal systems.

These recirculating sand filter systems provide excellent BOD and suspended solids removal and achieve a high degree of nitrification (Mote et al, 1991 and Hines and Favreau, 1975).

A media filter with marl gravel which has high phosphorus removal capability is being installed as an alternative pretreatment prior to the wetland system. Crushed brick with a high aluminum and iron content will be used as a surface layer after steady-state conditions have been achieved to determine if additional phosphorus removal can be obtained using this media. The media filter will have a recycling capability with the initial loading rate being 84 L m^{-2} day^{-1}. The wastewater will be applied to the surface with sprinklers that provide a fine spray. Procedures currently being successfully used for on-site wastewater treatment systems will be employed (Rubin et al; 1994).

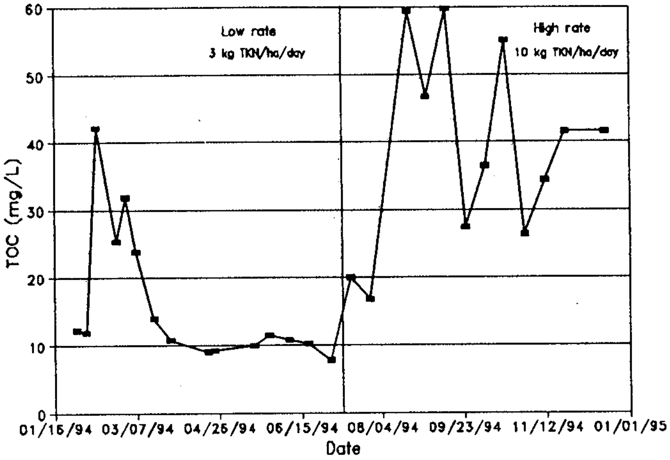

Figure 5. Influent TOC concentrations to constructed wetland systems 1 and 2.

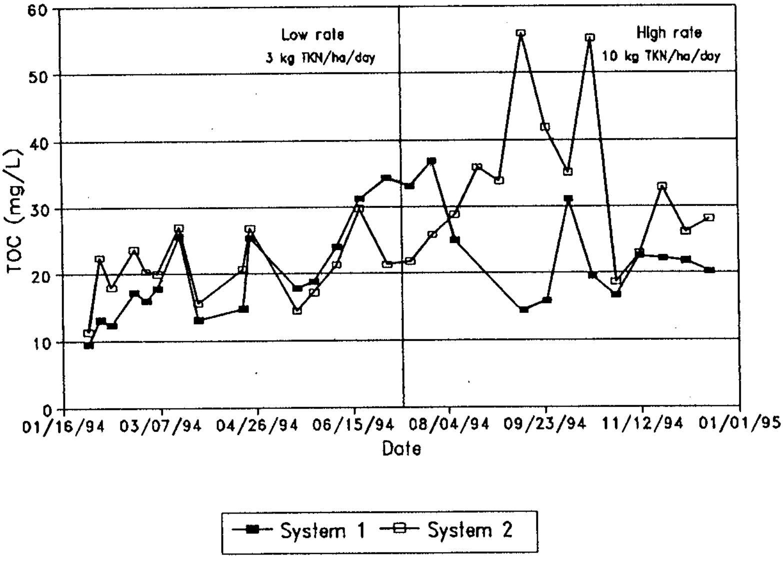

Figure 6. Effluent TOC concentrations from constructed wetland treatment systems.

Revised Operational Strategy

The overland flow and media filter pretreatment units will be evaluated for phosphorus and nitrogen removal and amount of nitrification achieved. The effluent from these pretreatment units will be returned to the lagoon during this evaluation period (Figure 7) so the current wetland TKN loading of 10 kg ha^{-1} day^{-1} can be evaluated over an annual cycle. After this annual cycle evaluation period, the pretreatment unit and wetland performance will be evaluated to determine the best procedure for maximum nitrogen and phosphorus removal with emphasis on phosphorus precipitation and nitrification-denitrification with sequential aerobic and anaerobic treatment units.

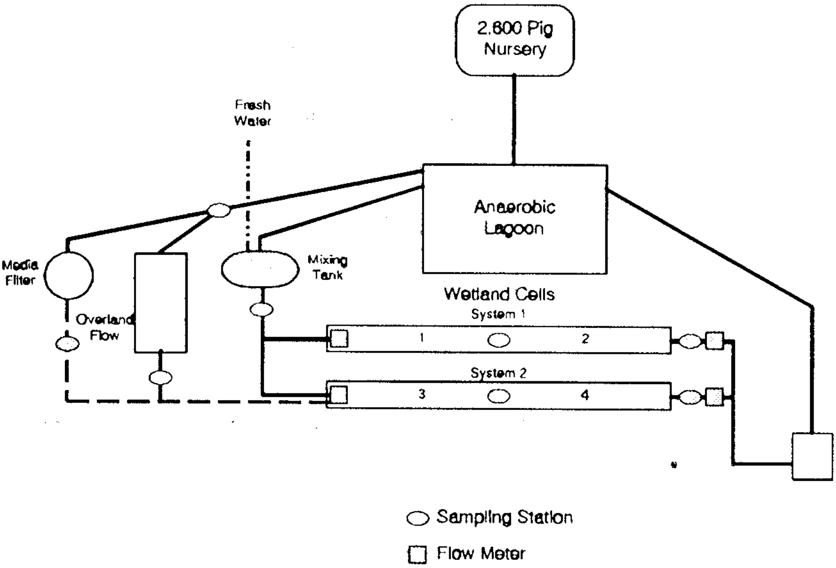

Figure 7. Schematic diagram of constructed wetland system alteration.

SUMMARY

1. The TKN mass reductions at a loading of 3 kg ha^{-1} day^{-1} TKN were above 90%. Effluent TKN was generally below 8 mg L^{-1}, and during some periods below 4 mg L^{-1}. These concentrations could meet local stream discharge requirements during some time periods. Additionally, the procedure of diluting a high nitrogen and phosphorus wastewater to obtain constructed wetland loading rates for a livestock waste for advanced discharge standards is not consistent with basic principles of wastewater volume reduction and pollution prevention.

2. The TP mass removal at a TKN loading of 3 kg ha^{-1} day^{-1} was 73%. However, effluent concentrations in both wetland treatment systems generally exceeded 2 mg L^{-1} which would not satisfy local stream discharge requirements.

3. Effluent TOC concentrations from wetland systems were similar to influent concentrations and even higher for some periods. Thus effluent TOC concentrations limit the use of constructed wetlands for system discharge. However, effluent TOC is inconsequential for terminal land application.

4. An enhanced wetland treatment system including overland flow or media filter pretreatment is being added to the wetland systems with the increased TKN loading of 10 kg ha^{-1} day^{-1} to determine if more effective mass removal of nitrogen and phosphorus can be obtained in an enhanced constructed wetland treatment system.

5. The role of constructed wetlands in total systems for animal waste treatment that will effectively reduce overall cost and land requirements needs further investigation.

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