California State University, Sacramento
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# Effectiveness of Existing Highway Vegetation As Biofiltration Strips

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## Disclaimer:

# Effectiveness of Existing Highway Vegetation As Biofiltration Strips

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## ABSTRACT

The California Department of Transportation (Caltrans) establishes vegetation adjacent to roadways to accommodate a range of functions, including: aesthetic, safety, environmental mitigation, storm water pollution prevention, and erosion control purposes. Due to the range of functions that these vegetated areas serve, the design of a vegetated area may not necessarily conform to the design guidelines for biofiltration strips. Caltrans initiated a two-year study to assess the treatment effectiveness of existing vegetated areas adjacent to its highways. The study examines eight vegetated areas adjacent to highways located throughout California. Each vegetated area has one to four 30-meter (m) collection channels to capture storm water runoff as it passes through various sections of the vegetated area. In addition to the 30 m collection channels, an edge of pavement sample is collected to compare as a baseline. The collected samples are analyzed for nutrients, total metals, and total suspended solids (TSS). This paper introduces the methodology for the study and the preliminary results of TSS and total copper data for the first monitoring season. As expected, as the biofiltration strip length increases the TSS and total copper concentrations decrease. Biofiltration strips with relatively steep slopes (greater than 35%) also provide notable TSS reduction. Preliminary data trends are identified and discussed.

## INTRODUCTION

A vegetated filter strip, or biofiltration strip, is an area of perennial grasses through which storm water runoff flows before leaving a site or entering a storm sewer system. Pollutants suspended in the runoff or attached to suspended soil particles are removed by filtration, absorption, and gravity sedimentation (NJDEP, 2000). Over the past twenty years, numerous studies have been conducted to document pollutant removal efficiencies of biofiltration strips. Additionally, other studies have assessed the optimal design and maintenance criteria for biofiltration strips.

The California Department of Transportation (Caltrans) establishes vegetation adjacent to roadways to accommodate a range of functions, including: aesthetic, safety, environmental mitigation, storm water pollution prevention, and erosion control purposes. Furthermore, Caltrans maximizes the use of vegetated areas for highway improvement projects. Due to the range of functions that these vegetated areas serve, the design of a vegetated area may not necessarily conform to the design guidelines for biofiltration strips.

The Caltrans Hydraulically Designed Biofilter Evaluation Study (CHD Study) is a two-year study to assess the treatment effectiveness of eight vegetated areas adjacent to highways. Design variables such as width, slope, vegetation density, and hydraulic loading are evaluated by studying the runoff through vegetated areas at four locations in Northern and four locations in Southern California. The objective of this study is to assess the data to determine if the existing roadway design requirements result in functionally equivalent biofiltration strips as a Best Management Practice (BMP) for storm water treatment.

## TEST SITES

The site selection process involved an initial inspection of the vegetated right-of-ways along California freeways and highways. A range of test conditions specified for the CHD Study included: minimum biofiltration strip width (direction perpendicular to flow) of 152 meters (m); minimum biofiltration strip length (direction parallel to flow) of 8 m; slopes between 5 percent to 60 percent; and adequate site access. The eight selected sites are summarized in Table 1.

### Table 1. Summary of Test Sites

| Site No. | Location (City) | Freeway | Slope (%)[1] | Avg Annual Rainfall (in) | Avg Annual Daily Trips (AADT) | Number of Test Strips[2] | Distance of Test Strips from EOP (m) |
|---|---|---|---|---|---|---|---|
| Northern California | | | | | | | |
| 1 | Sacramento | I-5 | 5 / 33 | 17.2 | 75,000 | 4 | 1.1, 4.6, 6.6, 8.4 |
| 2 | Cottonwood | I-5 | 52 | 39.4 | 38,500 | 1 | 9.3 |
| 3 | Redding | SR-299 | 10 | 39.4 | 11,800 | 3 | 2.2, 4.2, 6.2 |
| 4 | San Rafael | US-101 | 50 | 35.9 | 151,000 | 1 | 8.3 |
| Southern California | | | | | | | |
| 5 | Yorba Linda | SR-91 | 14 | 14.1 | 226,000 | 4 | 1.7, 4.9, 7.6, 13.0 |
| 6 | Irvine | I-405 | 11 | 12.8 | 237,000 | 3 | 3.3, 6.0, 13.0 |
| 7 | Moreno Valley | SR-60 | 13 | 10.3 | 106,000 | 4 | 2.6, 4.9, 8.0, 9.9 |
| 8 | San Onofre | I-5 | 8 / 13 | 10.3 | 124,000 | 3 | 1.3, 5.3, 9.9 |

Notes:

1 The Sacramento and San Onofre test sites have breaks in the slopes.

2 Number shown does not include the edge of pavement (EOP) collection trench.

## METHODOLOGY

At each site, one to four 30 m concrete collection trenches was constructed into the slope of the vegetated area, referred to as test strips in Table 1. The collection trenches capture storm water runoff as it passes through various sections of the biofiltration strip. One additional concrete collection trench captures storm water runoff at the edge of the pavement. A generic schematic of the collection system is shown in Figure 1. Test sites with slopes greater than 35 percent have one collection trench to capture storm water runoff from the edge of pavement and one collection trench to capture storm water runoff at the toe of the biofiltration strip. Figure 2 shows the Cottonwood site, which is an example of a test site with a slope greater than 35 percent. The remaining test sites have one collection trench to capture storm water runoff from the edge of pavement and the remaining collection trenches are constructed at approximately 2 m, 4 m, 6 m, and 8 m from the edge of pavement. Figure 3 shows the Redding site, which is an example of a test site with multiple collection trenches.

## Water Quality Monitoring

The CHD Study utilizes automatic water quality sampling equipment that can be controlled remotely. The sampling equipment measures the storm water runoff flow captured in each collection trench. A 60-degree trapezoidal flume, with a depth measuring device, was constructed at the end of each collection trench. The sampling equipment also takes composite samples of storm water runoff in a flow-proportioned manner. One monitoring station is allocated to each collection trench. A monitoring station contains: a data logger and control module; a flow meter; an automated peristaltic sampler; a cellular modem; interface electronics; power supply; and a tipping bucket rain gauge.

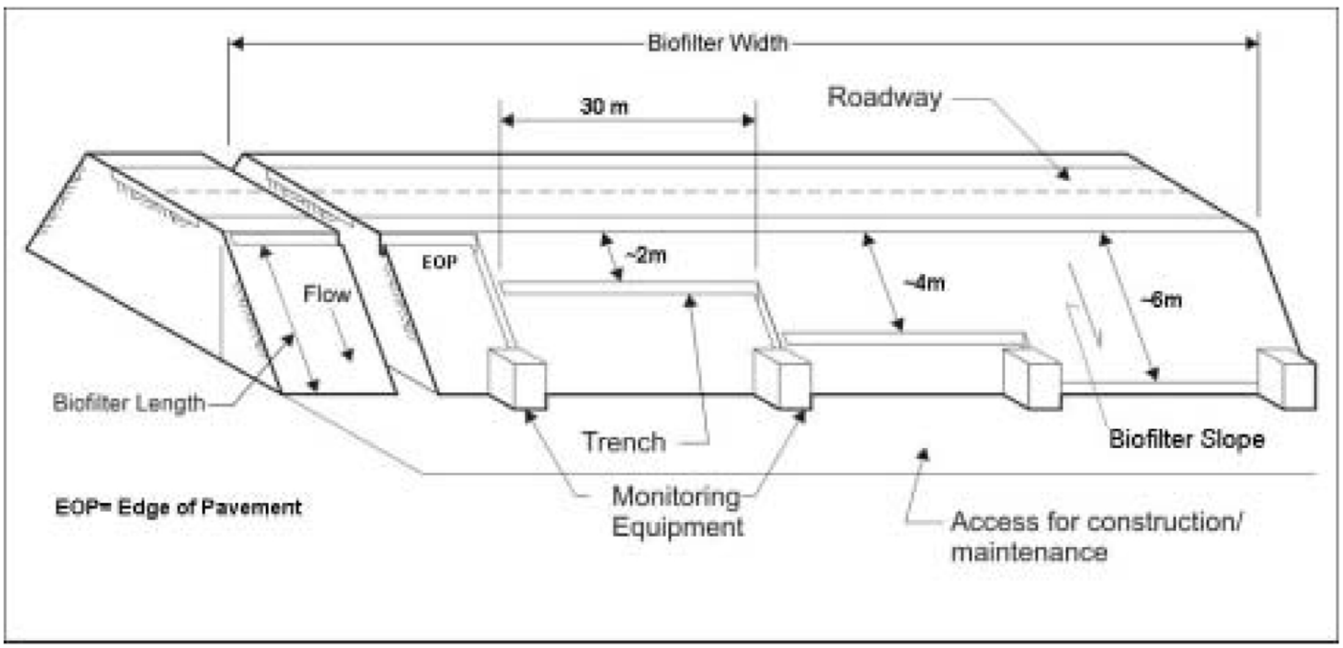


**Figure 1. Schematic of Collection System**

**Figure 2. Cottonwood Test Site**

**Figure 3. Redding Test Site**

The monitoring season for the first year of the CHD study was defined as October 1, 2001, through April 15, 2002. Weather forecasts were tracked and documented throughout the entire monitoring season. Storm events monitored were based on rain events forecasted to deposit at least 0.20 in of rain, and were to be preceded by at least 24 hours, preferably 72 hours, of dry conditions. The number of successfully sampled storms targeted at each test site was eight.

The minimum constituent list for water quality monitoring is described in the *Caltrans Guidance Manual: Storm Water Monitoring Protocols* (Caltrans, 2000). The selection of constituents for the minimum constituents list was initiated by evaluating all Caltrans runoff monitoring data compiled in the Caltrans Statewide Storm Water Database from storm water runoff monitoring conducted during the years 1997 through 1999. For the CHD Study, iron was added to the list of constituents to be analyzed for the Redding and Cottonwood sites. Table 3 summarizes the constituents selected for analysis along with the required analytical procedure.

### Table 3. List of Analytes

| Conventionals | | | Nutrients | | | Metals (Total and Dissolved) | | |
|---|---|---|---|---|---|---|---|---|
| Analyte | Analytical Procedure | Reporting Limits | Analyte | Analytical Procedure | Reporting Limits | Analyte | Analytical Procedure | Reporting Limits |
| Hardness as $CaCO_3$ | EPA 130.2 | 1 mg/L | Ammonia | EPA 350.3 | 0.1 mg/L | Arsenic | EPA 206.3 | 0.5 µg/L |
| TDS | EPA 160.1 | 1 mg/L | Nitrate as Nitrogen | EPA 300.0 | 0.1 mg/L | Cadmium | EPA 200.8 | 0.2 µg/L |
| TSS | EPA 160.2 | 1 mg/L | TKN | EPA 351.3 | 0.1 mg/L | Chromium | EPA 200.8 | 1 µg/L |
| Conductivity | EPA 120.1 | 0.1 µmhos/cm | Total Phosphorus | EPA 365.2 | 0.03 mg/L | Copper | EPA 200.8 | 1 µg/L |
| Temperature | EPA 170.1 | 0.1 °C | Dissolved Ortho-Phosphorus | EPA 365.2 | 0.03 mg/L | Iron | EPA 236.1 | 25 µg/L |
| pH | EPA 150.1 | 0.1 units | | | | Lead | EPA 200.8 | 1 µg/L |
| TOC | EPA 415.1 | 1 mg/L | | | | Nickel | EPA 200.8 | 2 µg/L |
| DOC | EPA 415.1 | 1 mg/L | | | | Zinc | EPA 200.8 | 5 µg/L |

## PRELIMINARY RESULTS

Three of the four test sites in Southern California are located near metropolitan Los Angeles. The fourth test site in Southern California is located near metropolitan San Diego. During the first monitoring season, precipitation in Southern California was below average. The cities of Los Angeles and San Diego have received 30 and 29 percent, respectively, of their average annual rainfall (DWR, 2002). The number of storms successfully monitored in Southern California ranged from two to eight. Precipitation in Northern California was approximately average. The number of storms successfully monitored in Northern California ranged from 14 to 18.

Water quality samples collected from the concrete collection trenches constructed into the slope were compared to the water quality sample collected at the edge of pavement for each storm event. Preliminary results for total suspended solids (TSS) and total copper are presented below. In general, the analysis for the other metals followed the same preliminary trend as total copper. The nutrient data is still being evaluated. Due to the small number of storm events sampled in Southern California, the data is not presented in this paper.

Southern California test sites had measured TSS concentrations at the edge of pavement ranging from 55 mg/L to 320 mg/L with an average concentration of 150 mg/L. Northern California test sites had measured TSS concentrations at the edge of pavement ranging from less than 10 mg/L to 110 mg/L with an average concentration of 55 mg/L. The difference in TSS concentrations at the edge of pavement between Northern and Southern California may be attributed to factors such as a difference in annual rainfall totals or the difference in traffic volumes. Figure 4 shows the TSS concentration as a function of strip length for the Sacramento and Redding CHD sites. Figure 5 shows the total copper concentration as a function of strip length for the Sacramento and Redding CHD sites. The trend lines identified in Figures 4 and 5 are based on linear regression indicate trends on concentration reduction and should not be interpreted as a performance curve. As shown by the trend lines in Figure 5, as the vegetated area length increases, the total copper concentration decreases.

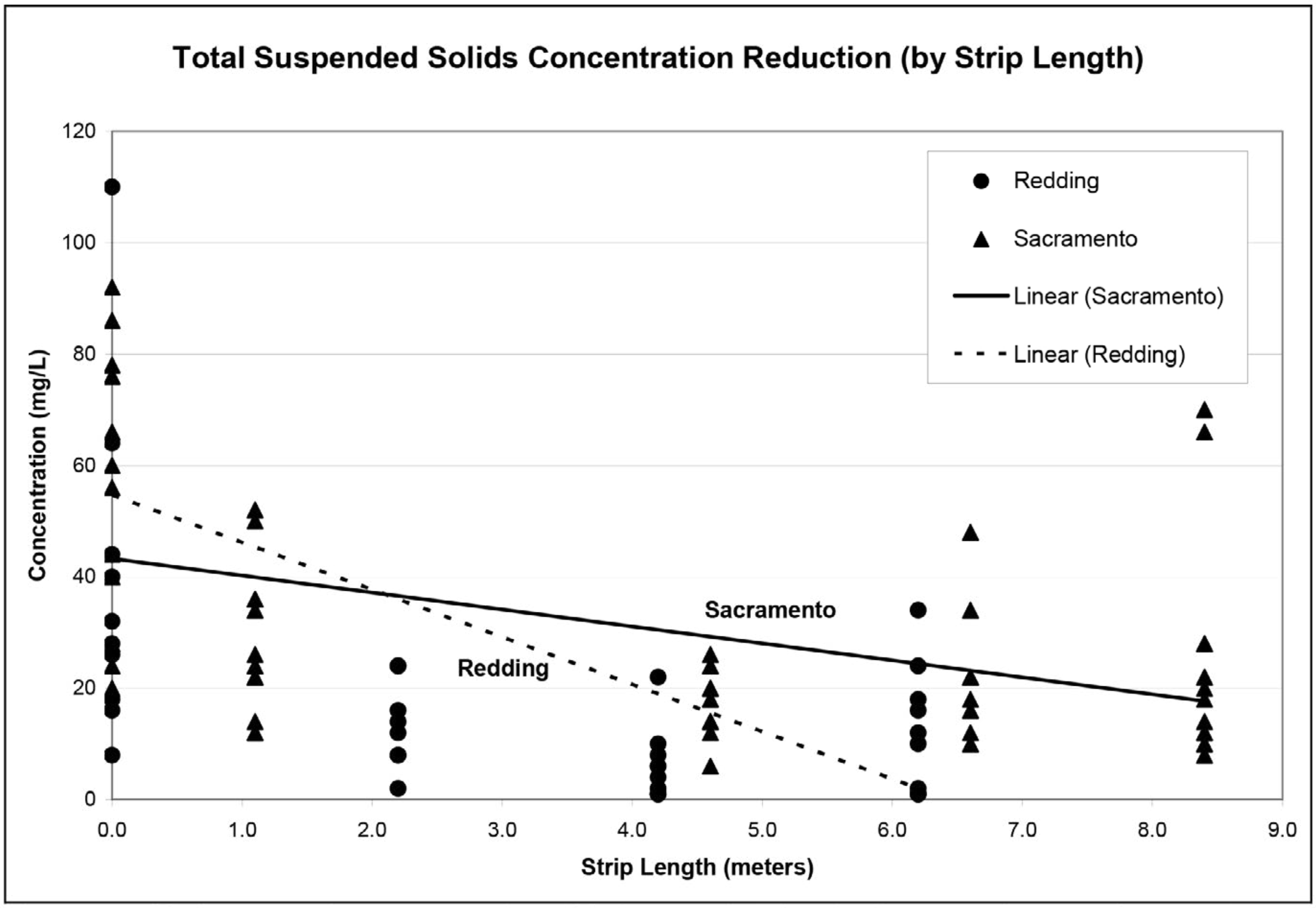


**Figure 4. TSS Concentration as a Function of Strip Length (Lines indicate trend, not performance)**

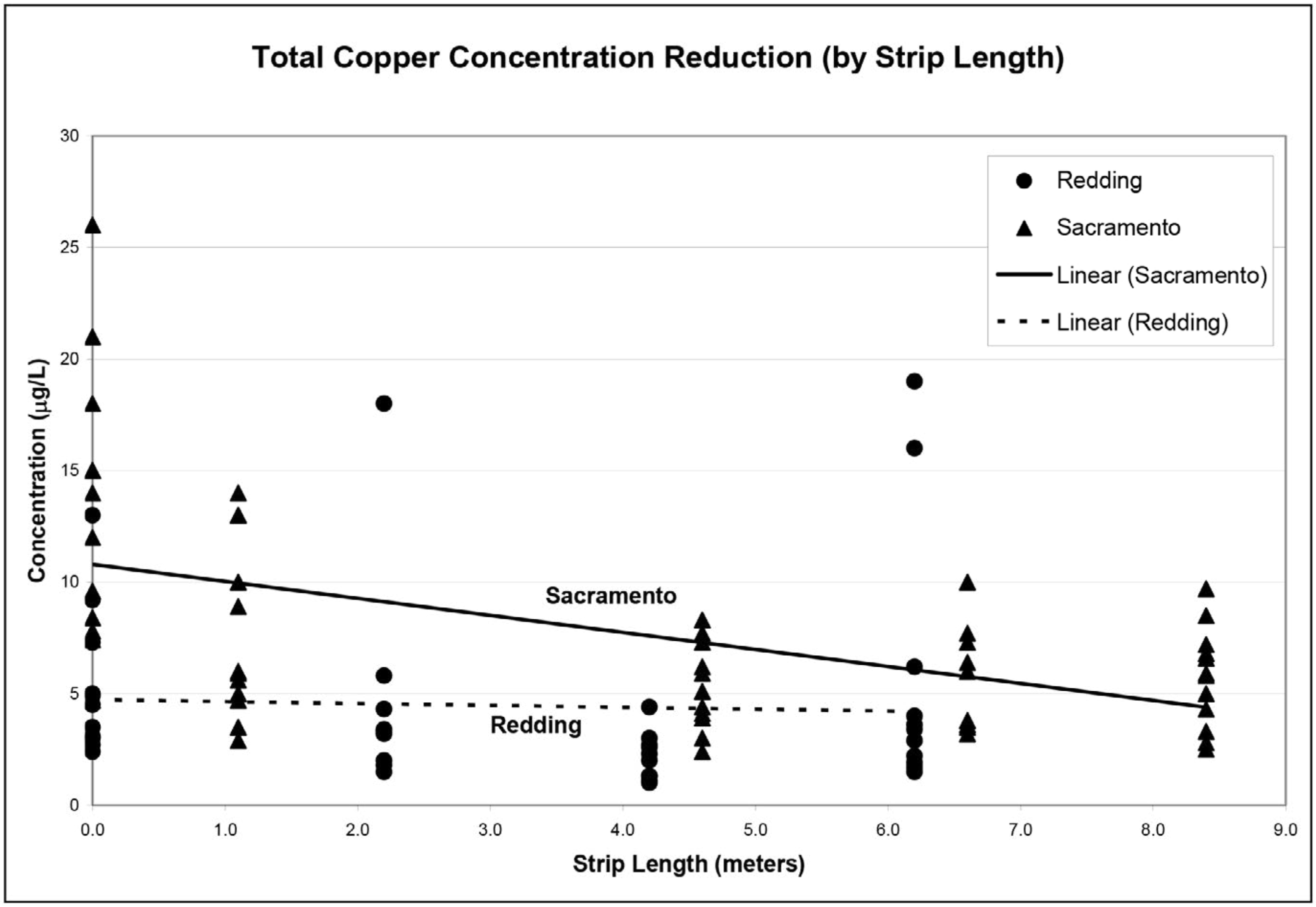


**Figure 5. Total Copper Concentration as a Function of Strip Length (Lines indicate trend, not performance)**

## DISCUSSION

The results presented above are preliminary. Performance evaluation based on loading calculations has yet to be completed. The study will continue for another monitoring season. Additional analysis of other metals and nutrients will be performed as the study continues. Preliminary trends based on the TSS data are discussed below.

### Antecedent Dry Period

As previously mentioned, the first year of the CHD study recorded less than average rainfall in Southern California. Monitored storm events in Southern California ranged from 0.2 inches to 1.0 inch. The less than average rainfall in Southern California resulted in a longer dry period between storms. The antecedent dry period ranged from 5 days to 2 months. As a result, most of the monitored storm events in Southern California resulted in 100 percent infiltration at the four CHD sites. The 100 percent infiltration rate translates to a 100 percent reduction of pollutants in storm water runoff.

### Slopes of Vegetated Areas

Based on the preliminary data presented in Figure 4, a trend that may be identified is: as the slope decreased the reduction in TSS concentration increased. The Redding CHD site with a 10 percent slope recorded the highest reduction in TSS concentration. In general, a flatter slope will result in lower flow velocities which will enhance sediment deposition and minimize erosion of the soil.

The preliminary results also indicate that steeper slopes, greater than 30 percent, also show notable TSS removal. The Cottonwood and San Rafael CHD sites have slopes at 52 and 50 percent, respectively. The average edge of pavement TSS concentrations for the Cottonwood and San Rafael CHD sites are 107 mg/L and 96 mg/L, respectively. The average toe of slope TSS concentrations for the Cottonwood and San Rafael CHD sites are 30 mg/L and 34 mg/L, respectively. The reduction in the average concentration for the CHD sites is 72 and 64 percent, respectively. The preliminary TSS removal for the CHD Study vegetated areas with steep slopes is approximately comparable to dry extended detention basins which can remove 70 to 80 percent of TSS (USEPA, 1983).

### Length of Vegetated Areas

Based on the preliminary data presented in Figure 4, an expected trend is the increase in TSS removal with longer vegetative area lengths. The preliminary results also show notable TSS removal for shorter slopes. At the Redding CHD site, TSS concentrations were reduced further away from the edge of pavement. For the Redding CHD site, the edge of pavement TSS concentration average was 59 mg/L and the TSS concentration in the first collection trench averaged 30 mg/L. The resulting reduction in TSS concentration is 49 percent. At the Sacramento CHD site, storm water runoff flows through a vegetated area 1.1 m in length to the first collection trench. For the Sacramento CHD site, the edge of pavement TSS concentration averaged 57 mg/L and the TSS concentration in the first collection trench averaged at 26 mg/L. The resulting reduction in TSS concentration is 55 percent. As the number of highway lanes gets expanded, the reduction in vegetated area length may not have an adverse impact on the treatment effectiveness of the vegetated area.

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## REFERENCES


Caltrans (California Department of Transportation). 2000. *Caltrans Guidance Manual: Stormwater Monitoring Protocols.* CTSW-RT-00-005. July.

DWR (California Department of Water Resources). 2002. "Executive Update: Hydrologic Condition in California." April 2002. http://cdec.water.ca.gov/cgi-progs/printfv/EXECSUM.html.

NJDEP (New Jersey Department of Environmental Protection). 2000. *Draft Revised Manual for New Jersey: Best Management Practices for Control of Nonpoint Source Pollution from Stormwater.* May

USEPA (United States Environmental Protection Agency). 1983. *Results of the Nationwide Urban Runoff Program.* Final Report, Water Planning Division, Washington D.C.


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