Water Quality Assessment of a Restored Urban Stream: Measuring Success of Best Management Practices at Minimizing Impacts of Stormwater Runoff in Strawberry Creek

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Abstract Clean, fresh water is necessary to sustain life, and its importance will only increase as the global population increases and earth's natural resources continue to be depleted. Development threatens fresh water sources as urban sprawl proliferates, as urban sprawl involves a dramatic increase in impervious surface. Impervious surfaces disconnect the precipitation that falls on a watershed during storms from the groundwater of that watershed, instead increasing peak flows and carrying pollutants directly into the stream. Parking lots are a drastic example of impervious surfaces' affects on a stream. Best Management Practices (BMPs) are methods for reducing impervious surface, both structurally and non-structurally, and thereby reconnecting the groundwater with the precipitation that recharges it. Here one such BMP, a grassy swale that drains the effluent from a parking lot, was studied to determine if it effectively removed copper, a heavy metal representative of other toxic metals present in stormwater runoff, from entering the stream. Initially, low flow samples taken from the creek were taken to establish that stormwater runoff is the primary source of copper in the creek. Furthermore, this study determined how efficiently the swale removed copper from runoff. The results were inconclusive statistically, due to low sample sizes, but on a qualitative level, the swale was shown to be effective and efficient and such qualities were not hampered by a prolonged rainy period, as had been hypothesized. This result suggests that similar installations be made to mitigate pollutant loads from parking lots into Strawberry Creek, however additional study is needed to confirm these results.

Introduction

Population growth and associated human impacts threaten all aspects of human life. Fresh water is one specific area of concern threatened by this growth, as it is necessary to sustain life. Water is among the most valuable natural resources, both for its economic value and for the services it provides in the form of recreational, industrial and agricultural uses (EPA 2001). With the expanding global population and decreasing available arable land, half of the world's population currently lives in urban areas (World Bank 2008). The implications of such urban sprawl for water quality are drastic. Forty percent of watersheds in the U.S. face water quality issues from urbanization, agricultural and other factors, according to the Environmental Protection Agency report on water (EPA 2001). The effects of urbanization and development have been proven to have deleterious effects on streams and their watersheds (Morse et al. 2002, Voelz et al. 2004, Kearns et al. 2005, Walsh et al. 2005). The modification of landscape by human development and urbanization can exacerbate erosion, sedimentation and bank undercutting (ACCWP 2004), and smaller watersheds, such as streams, are at even greater risk from such development (Paul and Meyer 2001).

The deleterious effects of urbanization and human development result from an increase in impervious surfaces throughout a watershed (Paul and Meyer 2001, Walsh et al. 2005), which has the effect of altering ecosystem structure and function (Kearns et al. 2005), especially for urban streams. An increase in impervious surface significantly alters the flow regime of the stream, particularly during high flow events such as storms (Walsh et al. 2005). It tends to create a "flashy" regime in which even small amounts of precipitation are carried directly into the stream, rather than being absorbed by soils or other pervious surfaces first. Increasing the flashiness of the flow regime results in high peak flows, even from small amounts of precipitation, that are short in duration but wreak havoc on the geomorphology, or physical characteristics, of the stream (Paul and Meyer 2001). This trend increases with increasing levels of impervious surface cover throughout the watershed. Such flashy flow regimes have drastic effects on the geomorphology and tend to result in increased erosion, sedimentation and bank destabilization (ACCWP 2004). Destabilized banks are also at risk of losing the riparian vegetation that serves to support them and filter some of the pollutants carried by runoff (Walsh et al. 2005) Urban runoff also tends to contain elevated levels of harmful chemicals, including heavy metals and organic nutrients such as phosphorous and nitrogen (Morse et al. 2002). The introduction of such chemicals threatens the biological communities of streams by degrading habitat (ACCWP 2004) and altering the water chemistry in ways that make it unlivable for less tolerant species (Morse et al. 2002).

Restoration of streams impacted by urbanization is accomplished through a number of engineering methods that increase pervious surface throughout the watershed in an attempt to restore and maintain the integrity of the stream channel. Revegetatation efforts are also made in the hopes of restoring a buffer zone that filters runoff and decreases the flashiness of the flood regime (Riley 1998). Paul and Meyer (2001) concluded that these structural methods used to date have not been adequately studied, as their goal is to reestablish the hydrologic regime that had existed previously. Instead, the authors feel that additional attention must be paid to the biological communities of the streams as well as the ecosystem services provided by the stream. This sentiment is echoed throughout the restoration community, as subsequent studies have focused on the effects of urbanization on invertebrate species richness and abundance as a metric of stream health (Charbonneau and Resh 1991, Barbour et al. 1999, Morse et al. 2002, Sawyer et al. 2004, Voelz et al. 2005).

One system in which all these factors have been addressed and progress has been made in terms of water quality is Strawberry Creek on the UC Berkeley campus (Charbonneau and Resh 1991, Paul and Meyers 2001, Walsh et al. 2005). Strawberry Creek is a central feature of the UC Berkeley campus (37° 52' 18" N, 122° 16' 18" W) and was one of the primary reasons that the location was chosen for the campus when it moved from Oakland in the late 19th century (Charbonneau 1987). The moderate size of the watershed draining into the creek (4706494 m^2) and the Mediterranean climate of the area combined with high levels of urbanization and development, make the creek an ideal model for urban stream restoration (Charbonneau and Resh 1991, Paul and Meyers 2001, Walsh et al. 2005). In fact, Strawberry Creek was the first documented instance of urban stream condition being improved by restoration (Walsh et al. 2005), and the restoration plan has been used as a model for other urban stream restoration projects globally (Charbonneau and Resh 1991). While progress has been made since the Strawberry Creek Management Plan’s inception in 1972, there are still major obstacles to stream health facing the creek (Hans and Maranzana 2006).

One such obstacle and an aspect of urbanized watersheds that drastically increases the flashiness of the flow regime are parking lots (Loechl et al. 2003). Due to the large area they occupy and impermeable nature of their constituent materials, parking lots present a special challenge to storm water management (Loechl et al. 2003). This is due to the large quantities of pollutants from engine oil and other materials transported on the vehicles that are deposited on the asphalt and then carried to the stream via runoff Loechl et al. 2003). This characteristic of parking lots, and impervious surfaces generally, has its most drastic effects during the first significant storm of the season (Paul and Meyer 2001). This is due to accumulation of pollutants on impervious surfaces over the dry season, which is then carried into streams by the first rains. This first flush effect has its greatest consequence for streams in Mediterranean climates, which alternate between dry summers and wet winters (Gasith and Resh 1999). As a result, many restoration efforts focus on minimizing imperviousness, increasing infiltration, reducing use of pipe and increasing natural channels, all while storing runoff temporarily to allow a decrease in downstream non-point source pollution (Loechl et al. 2003).

Such restoration efforts are included in the Strawberry Creek Management Plan (Charbonneau 1987), and new installations focusing on minimizing the impacts of parking lots have been made on campus since the last major water quality monitoring effort on the Creek, which was published in 2006 (Hans and Maranzana 2006). One method, a dry swale- a biofiltration method employing an open vegetated channel (Loechl et al. 2003) which feeds into a retention pond- has been installed just south of the Valley Life Science Building at the drainage of the Dwinelle parking lot. Prior to this installation, runoff from this parking lot drained directly to the South Fork of Strawberry Creek via a pipe connection. A second installation, a new design for a parking lot integrating permeable surfaces into the design of the parking lot itself, has been installed in the Wellman Courtyard parking lot, which drains to the North Fork (Pine 2008, pers. comm.). In order to ensure meaningful results through adequate sampling, only the initial swale draining the Dwinelle parking lot will be studied here.

The questions guiding this investigation relate to the effectiveness and efficiency of the swale at removing heavy metals from stormwater runoff, as no such investigation has been made previously. The heavy metal to be used in this study is copper. It was chosen to represent heavy metals for its ubiquitous use in automobile parts and the results of the 2006 Strawberry Creek Water Quality Update, which showed copper was present in the creek at levels exceeding EPA standards for health (Hans and Maranzana 2006). As the swale is designed to minimize the impacts of stormwater runoff in the creek, my first research question is: how effectively does the

Dwinelle swale remove copper from storm runoff before it enters Strawberry Creek? A secondary question is how does the swale's effectiveness at removing copper vary from storm to storm? The purpose of this second question is to determine firstly if the swale's effectiveness decreases as the rainy season progresses, and secondly if there is a limit, in terms of precipitation density (amount of precipitation over a given period of time), to the swale's effectiveness. Identifying and defining such a limit could be useful in the design of future installations around campus as it would define the ratio of impervious surface to area of swale that would successfully filter the runoff during storm events up to that limit. This will be accomplished by measuring the concentration of copper, a representative heavy metal in the runoff both before treatment by the swale and after. Samples will also be taken to measure baseline copper concentrations in Strawberry Creek at the inputs from the two parking lots into the creek. The purpose of such sampling is to establish that copper is not present during dry, low flow periods and that stormwater runoff must therefore be the primary source of copper entering the creek. The soil underlying the swale is highly compacted due to daily traffic and use. Compaction of soil has been shown to have a negative impact on removal of pollutants (Paul and Meyer 2001). Additionally, the preexisting irrigation treatment applied to the swale further decreases removal efficiency as saturated soil retains less moisture and therefore pollutants (Carbonneau 1987). It is therefore hypothesized that the swale will remove some copper, but will not be as effective as other reported removal rates (Strecker et al. 2000). It is my prediction that a limit exists to the effectiveness of the swale above a certain precipitation density. I also predict that the swale's effectiveness will diminish as the rainy season progresses due to the accumulation of previous storms' runoff and sustained saturation.

Methods

Study Site The focus of my research is a grassy swale, installed in 2007 **(**Pine 2008, pers. comm.) located adjacent to the north Side of the Valley Life Sciences Building on campus in Berkeley. The runoff from the Dwinelle parking lot just north of the swale is drained through the swale and enters a pipe at the west end of the lawn that drains into Strawberry Creek.

Sampling Procedure The first step was to establish that stormwater runoff is the primary source of copper entering the Creek. To do this, low flow samples were pulled after the rainy season on April 27 from two locations in the creek at the outputs of the two parking lots into the creek. The samples were pulled long after rain had ceased, to determine baseline concentrations of copper in the creek itself. Next, it was necessary to establish that the swale is in fact effective at limiting the amount of copper that enters Strawberry Creek. To accomplish this, three sampling sites were used. The first was the drainage for a different parking lot on campus, the A+E lot, which applies no treatment to its runoff. This site is highlighted in Figure 1 as the smaller red circle to the right and served as control. The measurements taken there determined a baseline for pollutants. The parking lots are of similar sizes and capacities and are located close geographically, therefore I assume that the pollutant loads will be of similar compositions at both places. The other two sampling points were located at the input and output to the swale, the management practice in question. The larger red circle to the left in Figure 1 highlights the locations of the two sites of sampling. Every sample was accompanied by a measurement of the flow at the time of sampling. Sampling occurred during a rainy period between February 5-February 17 characterized by 7 unique storm events occurring over the 12 days. This rainy period was considered a first flush as it was preceded by over 40 dry days. Each unique event was sampled once, about an hour after rainfall began, and once runoff was observed. These samples were tested for copper using a LaMotte Storm Drain Kit (Model SSDK, Chestertown, MD, USA). The test involves the addition of 5 drops of copper reagent to 10 milliliters of a sample and comparing the change in color to a standard slide that yields the concentration of copper in the sample in parts per million. Multiplying this parts per million by the volume of precipitation received during each discrete storm event, the total load of copper was determined for each event at both the control and the output of the swale. These loads represent the amount of copper contributed to Strawberry Creek from each location as a result of each storm event. Since the lots are of similar size, comparing the loads from the two locations with the precipitation amounts via a two –way analysis of variance (ANOVA) will establish whether the treatment results in a decreased copper load or the treatment had no effect (the null hypothesis).

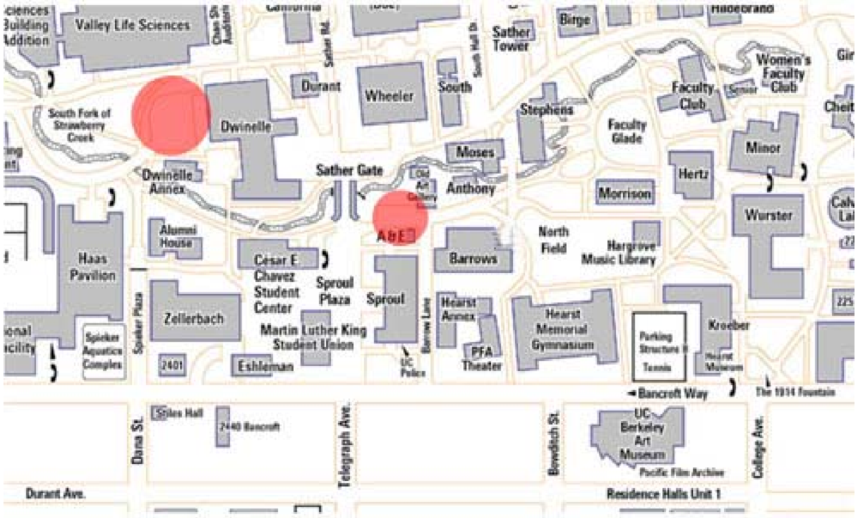

Figure 1- Map of Southern UC Berkeley Campus. A+E parking lot is the smaller dot, while Dwinelle parking lot and swale are the larger dot on the left. The creek is the curving line that travels between the two dots.

Next it was necessary to establish how effective the swale is at removing copper from runoff. The American Society of Civil Engineers has developed a procedure to monitor the effectiveness of swales and other Best Management Practices (BMPs) **(**Kim et al. 2004**).** By doing so, they hope to allow for better comparisons to be made between studies of BMPs through the use of consistent methods in monitoring. This procedure combines flow velocity data during storm events with periodic grab samples of runoff, which are subsequently tested for copper concentration. Ideally, multiple samples are pulled for each discrete storm event. Due to the limitations of this study, however, only one sample was pulled per storm event. For each storm event, the concentration of copper was divided by the volume of runoff for that storm event. This calculation, the event mean concentration (EMC) will then be determined by an equation that divides the concentration (M(t)) by the flow volume (Q(t)) during the interval of sampling (t), in this case the EMC is composed of a single sample per event.

$$EMC(mg/l) = \frac{\text{captured litter mass}}{\text{Discharged runoff volume}} = \frac{M(t)dt}{Q(t)dt}$$

This event mean concentration is then said to be flow weighted, and provides normalization of data. EMCs are meant to represent the average concentration of the constituent in question during a given storm event. The efficiency ratio (or percent removal) of the swale was then determined by dividing the average outlet EMC/average inlet EMC (for the Dwinelle swale) and subtracting the result from 1. Regression analysis was then used to determine the relationship, if any, between precipitation and the removal efficiency of the swale. Regression was also used to check for a relationship between the timing of a storm (in relation to other storm events) and removal efficiency. This test determined whether the efficiency of the swale decreased over a period of time characterized by distinct events separated by no more than 1-2 days.

Results

The low flow samples both showed no evidence of copper. The test for effectiveness did not yield a significant result (p=.27). Instead, to determine whether the Dwinelle swale effectively removed copper from runoff, a qualitative look at the data from A+E and the output of the Dwinelle swale confirms that copper concentrations at the swale output were either non-existent or well below those at A+E (Figure 2). For most events, there was no flow through the swale; meaning 100% of the copper was trapped by the swale.

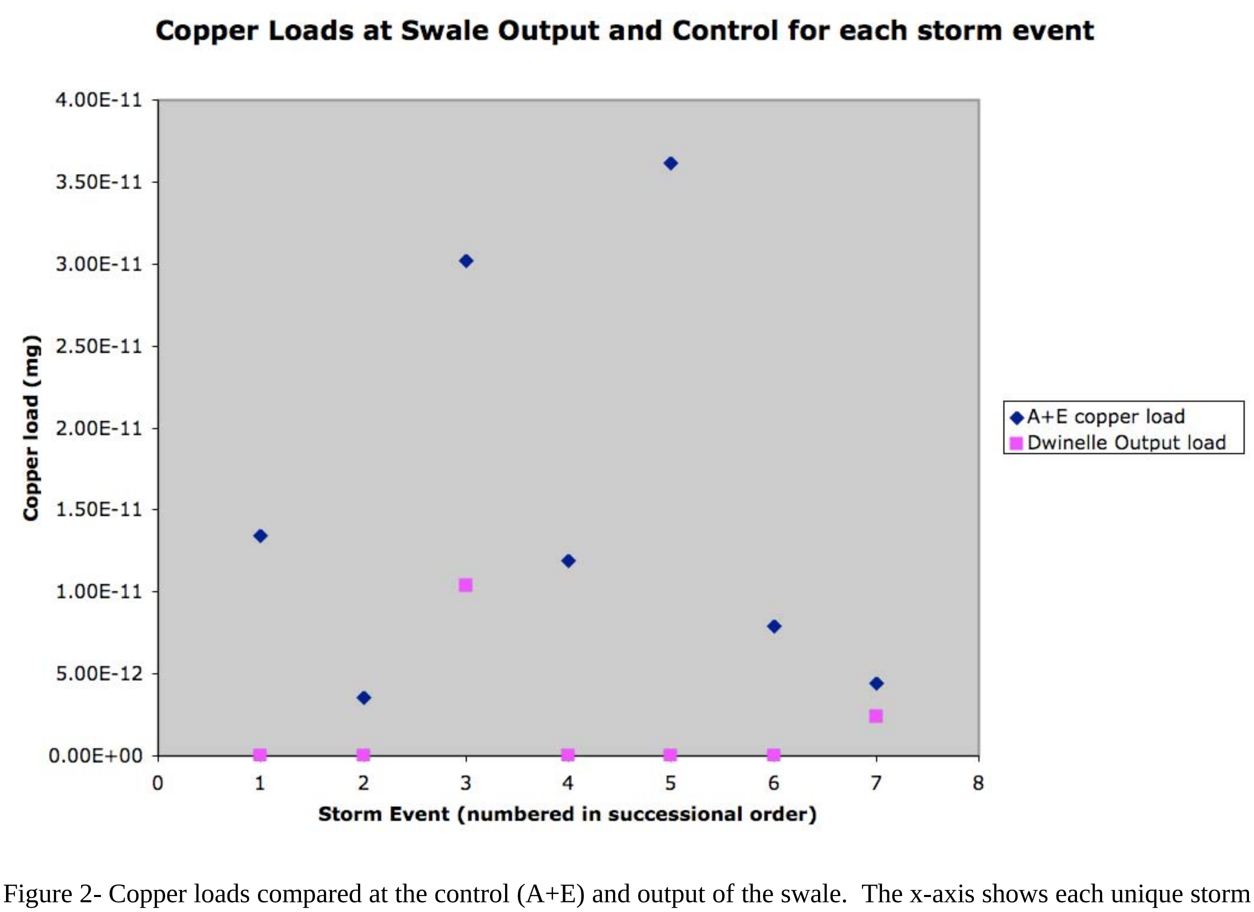

Figure 2- Copper loads compared at the control (A+E) and output of the swale. The x-axis shows each unique storm event, with 1 being the first and 7 the last. 0 values indicate that all copper was trapped by the swale.

A similar problem was encountered when comparing removal efficiencies to precipitation amounts. The result was insignificant (p=.8, r^2=.01) and is therefore not shown. To compare removal efficiency to precipitation, Figure 3 shows the removal efficiencies for each storm event. Again, storms are numbered sequentially 1-7, 1 representing the initial storm recorded and 7 representing the final storm recorded. In this case, the ANOVA also failed to yield a significant result (Chi Squared=.42) and displays clearly how removal efficiency changes throughout a rainy period. The average removal efficiency for all storms was 93%.

Removal Efficiency of Copper vs. Storm Event (sequential, 1=first, 7=last)

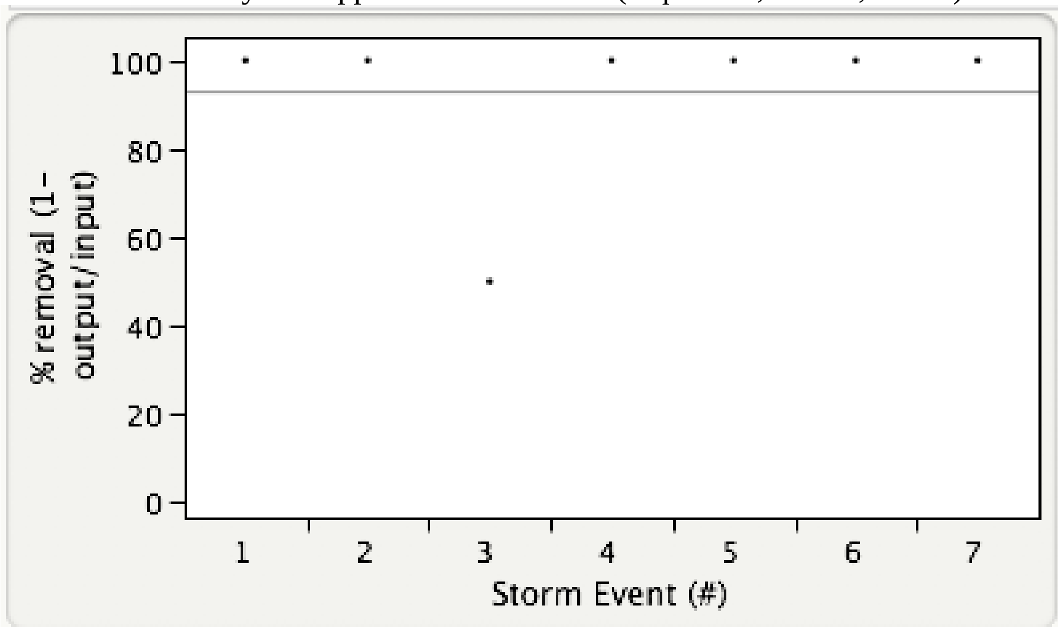

Figure 3- Removal Efficiency of copper over a period of sequential storm events with no intermediary dry period

Discussion

As the low flow samples registered no measurable copper in the water, it is reasonable to assume that stormwater runoff is the primary contributor of copper entering Strawberry Creek, and that such contributions occur during storm events. The statistical tests to establish efficiency of the swale and to compare removal efficiency with amount of precipitation both yielded insignificant ANOVA results. A qualitative look at the data was used instead and showed a surprising number of the storm events sampled failed to result in any flow through the swale, meaning all pollutants were 100% removed from the runoff and deposited in the swale during those events. The swale can be considered both effective and highly efficient based on the number of samples with no flow exiting the swale. Furthermore, there seemed to be no negative effect on removal efficiency as the rainy period progressed. Thus, the hypotheses in this study were refuted by the data, this particular swale is highly effective and efficient at removing copper, and that efficiency does not decrease over a rainy period. High removal efficiencies contribute greatly to the health of a stream, by limiting both the volume of runoff entering the stream and the amount of pollutants in that runoff that does reach the stream (Strecker et al. 2000). The highest copper concentrations, both at the control location and the input to the swale, were measured in the first 2 storm events, followed by a steady concentration for all subsequent events. This effect of a first flush, in which storms early in the rainy season contribute higher concentrations of pollutants to the stream, has been documented (Ackerman and Stein 2008).

The average removal efficiency documented in this study (93%) is higher, but not dramatically so, than similar studies of grassy swales and copper concentrations. Dorman et al. (1989) recorded 65% removal, while Harper and Herr (1993) documented 56% and 89%. Wang et al. (1981) recorded 70% removal, while Ackerman and Stein (2008) reported an average removal of 73%. The results of this study would likely be somewhat lower given additional sampling both within individual storm events and of more unique events. This study was limited by funding and personnel to adequately address these shortcomings.

Assuming these findings are accurate, the implications of this study are drastic, both for the University of California and stormwater managers everywhere. For the University, this result should indicate that all parking lots, and areas of high impervious surface, should be accompanied by a grassy swale. This would effectively minimize the effect of the parking lot on Strawberry Creek, improving its health dramatically. For stormwater managers, this result would indicate that there is a special aspect to this specific grassy swale that should be studied further and applied to similar projects. Thus, further studies should be done to determine what makes this swale so effective and efficient at removing pollutants.

This study has disproved its hypotheses, 1) that the swale would be only moderately effective, and 2) that its effectiveness would decrease over the course of a rainy period. The implications of this suggest further the University make similar installations and that additional study is needed on this swale to determine what makes it so effective. There is a possibility, however, that this study was too small in scale and scope to truly capture the effectiveness and efficiency of the swale in question, and that further studies would record a lower effectiveness at removing pollutants, especially metals. Still, the results of this study suggest great efficiency at removing pollutants. The lack of flow through the swale for most events, also suggests that peak flows during storm events are lowered as a result of this swale.

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