Monitoring Stormwater Retrofits in the Echo Lake Drainage Basin – SAM Effectiveness Study – Final Report

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Department of Natural Resources and Parks
Water and Land Resources Division
Science and Technical Support Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
206-477-4800 TTY Relay: 711
www.kingcounty.gov/EnvironmentalScience

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Prepared for:

Washington State Department of Ecology
Washington Stormwater Workgroup

Submitted by:

Carly Greyell
King County Water and Land Resources Division
Department of Natural Resources and Parks

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All sample collections were led by Christopher Barnes of the King County Environmental Laboratory (KCEL) Field Science Unit (FSU), with assistance from other FSU personnel including Stephanie Hess, Dan Hutchens, Houston Flores, Jean Power, and Lyndsey Swanson. King County Science and Technical Support Section (STS) occasionally provided additional sampling assistance (Kate Macneale and Rory O'Rourke). Christopher Barnes (FSU) led the installation of the flow meters and additional assistance was provided by Marc Patten (FSU) and Dave Funke (STS). Laboratory project management was provided by Fritz Grothkopp of KCEL. PCB analysis was conducted by Pacific Rim Laboratories, and all other analyses were performed by the KCEL. PCB data validation was conducted by Laboratory Data Consultants. Tim Clark, Rachael Gravon, and Daniel Nidzgorski (STS limnologists) assisted with interpretation of water quality data from Echo Lake. Jenée Colton, Deb Lester, and Kate Macneale (STS) provided valuable guidance on the study design and document review.

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1.0 INTRODUCTION

This report presents an evaluation of the effectiveness of a stormwater retrofit along the Aurora Corridor (also known as Highway 99) in Shoreline, Washington, within the Echo Lake drainage basin (Figure 1). The study was designed to address data gaps identified by the Washington State Stormwater Work Group (SWG) in the effectiveness of stormwater treatment technologies used in the Puget Sound Region. Project funding was provided through the pooled resources of the Regional Stormwater Monitoring Program (RSMP), now called Stormwater Action Monitoring (SAM). This report is organized to provide a short summary of the study and its findings, with detailed methods and analyses included as appendices.

1.1 Study Design

The study was designed to evaluate the effectiveness of a stormwater retrofit at both the individual treatment installation level and system-wide in a 207-acre basin with primarily urban residential and commercial landuse (HDR 2011). The retrofit in the Echo Lake drainage basin included installation of various best management practices (BMPs) including Filterra® and bioretention planter boxes (BPBs) along the highway (Figure 2 and 3, respectively). A detention tank system (DTS) was also installed to provide flow control for the majority of the basin prior to discharge to Echo Lake (Figure A-1, Appendix A)[1]. This retrofit was selected for evaluation by this study because: (1) stormwater at the individual BMPs was accessible for sample collection both before and after treatment; (2) stormwater quality in this basin had been analyzed prior to the retrofit installations, providing a baseline for comparison; and (3) there is an ongoing, long-term water quality monitoring program for Echo Lake. These site qualities made it possible to address the following study objectives:

Individual BMPs

- *Objective 1:* Evaluate the effectiveness of individual enhanced stormwater treatment installations at reducing solids, nutrients, bacteria, metals, select organic contaminants and toxicity in highway runoff in Shoreline.

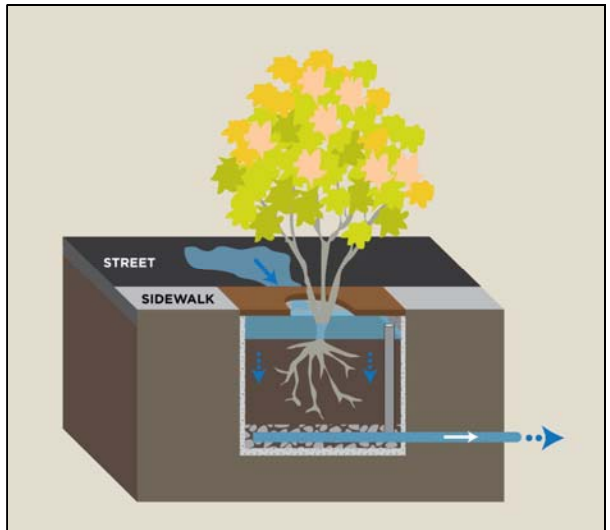
System-wide

- *Objective 2:* Evaluate the flow control benefits of the system-wide stormwater DTS, and any additional reduction of solids, nutrients, bacteria, metals and select organic contaminants that occur.
- *Objective 3:* Assess changes in stormwater quality in this system by comparing historical stormwater data to current stormwater quality before and after treatment.
- *Objective 4:* Identify if nutrient and bacteria levels have changed in Echo Lake over time, and how these changes correspond to changes in stormwater infrastructure in

[1] The Quality Assurance Project Plan (QAPP; King County 2015) and Appendix A of this report include additional site information, such as site history, basin characteristics, and retrofit design.

the contributing basin. The purpose of this analysis is to consider potential effects to the receiving water body for discussion, not to establish a causal relationship.

Figure 1. Echo Lake Drainage Basin Map



- Media = proprietary mix
- Designed for enhanced treatment *(i.e., basic and dissolved metals treatment)* and phosphorus treatment
- Concrete lined, no infiltration

Figure 2. Digram of Filterra

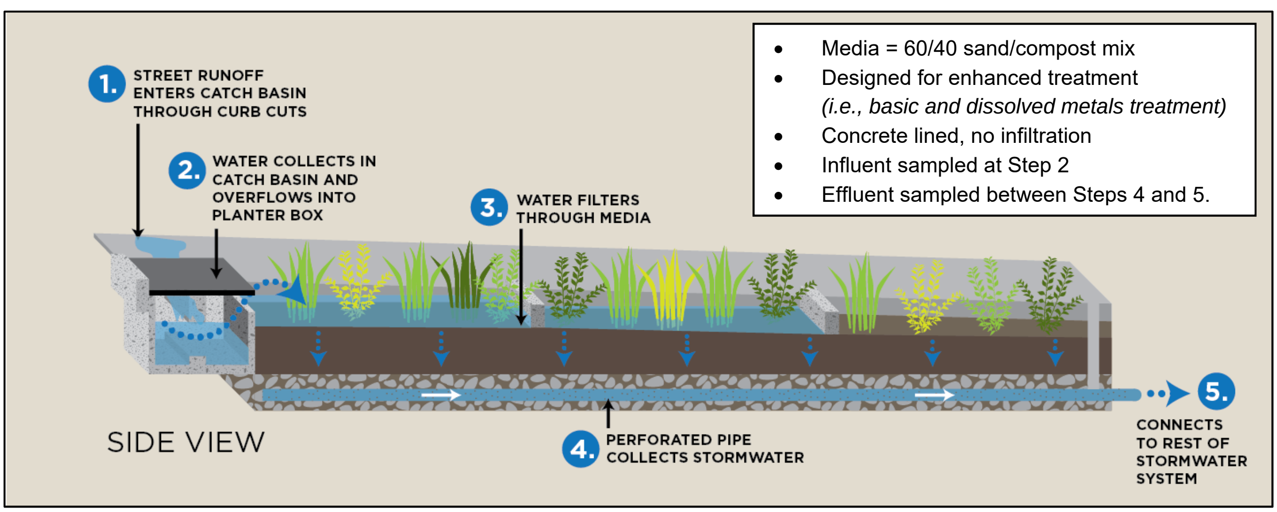


Figure 3. Diagram of Bioretention Planter Boxes

There are a number of particularly valuable aspects of this study. The study findings are regionally relevant, because the basin inputs are fairly typical for the region and include commercial and residential landuse along a busy roadway. Additionally, some of the BMPs were installed more than three years before the study began, allowing for assessment of performance of a more mature installation. Furthermore, the study evaluated the BMPs for their effectiveness to reduce not only the standard list of stormwater pollutants, but also a few chemicals that are rarely included in stormwater treatment studies (e.g., polychlorinated biphenyls [PCBs]).

Table 1 summarizes the information used to address each objective, including the sampling strategy for the study. More detailed information is available in the appendices to this report; site information (Appendix A), chain of custody forms for each sample collected (Appendix B), field sampling methods (Appendix C), laboratory methods (Appendix D), and data analysis methods and statistical results (Appendix E).

Table 1. Summary of samples and data used to address each study objective.

	Sample Locations	Sampling Timeframe	# of Storms Sampled	Notes
Objective 1:	Three BPBs installed in 2012 (inlet & outlet)	December 2015 to February 2017	7 to 8	Labelled BPB1, BPB2, BPB3
	One Filterra installed in 2012 (inlet & outlet)	December 2015 to February 2017	5	Labelled FLT1
	One BPB installed in 2016 (inlet & outlet)	October 2016 and January 2017	2	Labelled BPB4
Objective 2:	DTS (inlet & outlet)	September 2016 to October 2016	5	Flow monitoring was discontinued for this project (See Section 2.2)
Objective 3:	Stormwater outfall to lake	November 2010 to January 2011	5	Collected prior to the current study
	DTS (outlet)	Used data from samples collected for Objective 2		
Objective 4:	Mid-lake, surface and depth samples	May to October 2001, 2003-2016	Biweekly samples	Leveraged from long-term monitoring program
	Swimming beach	May to September 2004 - 2016	Weekly samples	Leveraged from long-term monitoring program

2.0 KEY FINDINGS/RESULTS

This section includes an overview of the key findings for each study objective and additional findings related to operations and maintenance (O&M). Detailed information about the study is available in the project Quality Assurance Project Plan (QAPP; King County 2015) and appendices to this report. Appendix F includes the validated, raw data generated for this study. Data quality was acceptable to meet the project objectives for most parameters[2] (Appendix G). Appendix H includes data summary tables, summary figures, and a deeper analysis of the results.

2.1 Individual BMPs

***Objective 1:* Evaluate the effectiveness of individual enhanced stormwater treatment installations at reducing solids, nutrients, bacteria, metals, select organic contaminants and toxicity in highway runoff in Shoreline.**

The effectiveness of the BMP installations was determined by a statistically significant reduction in concentration between influent and effluent, in addition to the average percent reduction in concentration with a 95% confidence interval generated through bootstrapping[3] (Table 2). The influence of concentration ranges is also discussed below. The Technology Assessment Protocol – Ecology (TAPE) also uses 95% confidence intervals for summarizing average reductions (Ecology 2011). Table E-3 in Appendix E compares results to TAPE performance goals.

BPBs Installed in 2012 (BPB1, BPB2, and BPB3):

The three BPBs all significantly reduced stormwater concentrations of total suspended solids (TSS), ammonia, total metals, dissolved zinc, total PAHs and TPH-Dx ($p<0.05$). Total nitrogen and dissolved copper concentrations were also significantly reduced in BPB1 effluent, as were dissolved lead concentrations at BPB2 ($p<0.05$). Toxicity was assessed at BPB1 and was always reduced in effluent when initially observed in the influent (Appendix H).

The average percent reduction in stormwater concentration was greater than 80% for total zinc, total polycyclic aromatic hydrocarbons (PAHs), total lube oil-/diesel-range petroleum hydrocarbons (TPH-Dx), and total PCBs at the three BPBs, and for TSS, ammonia, and total lead at BPB2 and BPB3. The average percent reduction in effluent concentration was between 60% and 80% for total copper and dissolved zinc at the three BPBs, and for TSS and ammonia at BPB1. Effluent concentrations of total phosphorus, orthophosphate

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[2] Data quality issues were encountered for bacteria results, and interferences on the growth media necessitated switching from analysis of fecal coliforms to *Escherichia coli* partway through the study. Bacteria results are discussed in Appendices G & H, but are not summarized in Section 2.0 due to these data quality issues.

[3] When parameters were not detected in a sample, the method detection limit (MDL) was used for statistical analyses. In most cases, the parameter was detected in the influent, but not the effluent; for which this method provides a conservative estimate of reduction. Appendix E provides detail on the statistical methods.

phosphorus, and nitrate/nitrite nitrogen consistently increased compared to influent at all three BPBs. Effluent concentrations of total nitrogen and dissolved copper sometimes increased relative to influent at BPB2 and BPB3, but generally decreased at BPB1. Dissolved cadmium and lead were infrequently detected in both influent and effluent samples. All other contaminant concentrations were more moderately reduced or had variable results (Appendices E and H).

Table 2. Summary of performance metrics for individual BMPs based on a comparison of effluent and influent concentrations.

Key: Average Concentration Reduction					
	Greater than 80%		Between 30% and 60%		Frequent increases in concentration
	Between 60% and 80%		Between 0% and 30%		

Site	Solids	Total Nutrients		Dissolved Nutrients			Total Metals				Dissolved Metals				Organic Contaminants		
	TSS	TP	TN	OP	NH3	NO3/2	Cd	Cu	Pb	Zn	Cd	Cu	Pb	Zn	PAHs	TPH-Dx	PCB
BPB1	***		**		***		***	***	***	***		**		***	***	***	
BPB2	***				***		***	***	***	***				***	***	***	
BPB3	***				***		NDs	***	***	***	NDs		NDs	***	***	***	
FLT1	***	***	***		***		***	***	***	***					***	***	
BPB4							NDs										

Notes:

The average is reported at the lower 95% confidence interval for all but BPB4, which was sampled for only two events. All analyses used the value of the method detection limits (MDL) for non-detects in effluent, which provides a conservative estimate of reduction.

Asterisks indicate statistically significant decreases in concentration: *** = $p<0.001$ and ** = $p<0.01$ (See Appendix E for methods and results). Due to limited sample size, statistical differences could not be determined for PCBs (n=4) or any parameter at BPB4 (n=2).

NDs = less than 75% frequency of detection at each site with non-detects in both influent and effluent samples. In these cases, all detects were less than the reporting detection limit (RDL).

Percent reduction in concentration is often used to evaluate stormwater treatment technology performance; however, without also considering the magnitude of influent and effluent concentrations, improper conclusions could be drawn. For example, percent reduction of dissolved copper at BPB1, 2 and 3 ranged from -258% to 54%, suggesting relatively poor treatment. However, both influent and effluent concentrations were very low, ranging from 1.1 to 7.93 µg/L. In fact, effluent concentrations were lower than presumed possible by previous research (Clark 2000 and Johnson et al. 2003).

Low influent and effluent concentrations can result in seemingly large differences based on percentages, even if the values are comparable[4]. These data highlight how performance goals based on effluent concentrations may be more informative than goals based on percent removal, especially when influent concentrations are relatively low. With the exception of nutrients, all effluent concentrations were fairly consistent at each of the BPBs, even when influent concentrations varied greatly between storm events. Appendix H includes figures illustrating these findings.

Flow was not measured for this study, but a substantial reduction in stormwater volume was visually observed at each BPB. During relatively light to moderate rain events, all influent flows were absorbed by the media; effluent was only observed during intense rainfall (i.e., sustained rainfall >0.03 inches per 15 minutes). The BPBs were very responsive to changes in rainfall intensity; as heavy rainfall began to subside, influent flow would lessen and effluent would cease to flow. Sample collection from these systems was challenging because only high intensity events resulted in sufficient effluent discharge. The sample collection timespans for many events were shortened to ensure sufficient sample volume was collected before effluent flow stopped. Due to the observed volume reduction, the reported concentration reductions likely substantially underestimate the reduction in loadings provided by these BPBs.

Filterra Installed in 2012, Media Replaced in 2015 (FLT1):

Similar to the BPBs installed in 2012, FLT1 also significantly reduced stormwater concentrations of TSS, total nitrogen, ammonia, total metals, total PAHs, and TPH-Dx ($p<0.05$). In contrast, FLT1 also significantly reduced concentrations of total phosphorus, and did not significantly reduce concentrations of any dissolved metals ($p<0.05$); rather effluent concentrations increased on average for dissolved copper and dissolved zinc compared to influent concentrations.

FLT1 performed better than the BPBs for removal of total phosphorus and total nitrogen (30 to 60 % reduction in concentration on average), but it was generally less effective than the BPBs at reducing concentrations of metals and TSS. FLT1 was still very effective at reducing concentrations of ammonia and organic contaminants (Table 2).

As described above, effluent concentrations should be evaluated in addition to percent reduction. With the exception of nutrients, effluent concentrations were generally comparable or higher at FLT1 compared to those in effluent from BPBs installed in 2012. Effluent phosphorus concentrations were always lowest at FLT1 (See Appendix H).

Unlike the BPBs, the Filterra design prevented visual inspection of the underdrain or effluent, impeding observed estimates of flow reduction. Based on sampling success, it was clear effluent was generally discharged at the Filterra before the BPBs during a given storm

[4] For example, results for BPB3 samples collected in the 2/9/2017 storm event consisted of 1.1 µg/L in the influent and 3.94 µg/L in the effluent, which results in a -258% reduction. These sample results are considered comparable, particularly because they are below the reporting detection limit.

event and flowed longer than BPB effluent. However, the volume reduction associated with the Filterra is unknown.

BPB Installed in 2016 (BPB4):

Samples at this site were successfully collected during only two storm events; therefore, statistically significant reductions could not be calculated. Percent reduction and effluent concentrations at BPB4 were generally within the range of other BPBs for most contaminants (Table 2).

Only two storms were sampled at this site for several reasons. First, installation of the BPB was delayed, and the feature did not come online until mid-2016. Second, effluent flows were rare at this site, which prevented sampling, even during relatively intense rainfall. The roadway adjacent to this installation is very flat, and it was clear the roadway runoff had a lower velocity at this site compared to the other BPBs. Additionally, the underdrain was a corrugated plastic tube rather than the smooth PVC pipe installed at the other BPBs. These factors may have limited effluent flow at this site.

2.2 System-wide

***Objective 2:* Evaluate the flow control benefits of the system-wide stormwater DTS, and any additional reduction of solids, nutrients, bacteria, metals and select organic contaminants that occur.**

The flow control structure at the DTS outlet caused significant obstacles to monitoring flow, which could not be resolved within the proposed project scope and budget. Because of this, the flow control component of this objective was dropped from the project (See Appendix I for details).

Influent and effluent DTS sample results were compared using the statistical methods described in Appendix E. The DTS provided significant reduction in concentration only for TSS and total zinc ($p<0.05$), but the magnitude of reduction was low (i.e., <20% on average). Overall, concentrations of other contaminants were comparable between influent and effluent for most events. Appendix F presents all DTS sample results.

***Objective 3:* Assess changes in stormwater quality in this system by comparing historical stormwater data to current stormwater quality before and after treatment.**

Prior to the retrofit installation, five water samples were collected at the main stormwater outfall to Echo Lake during storms between November 2010 and January 2011. The samples were analyzed for TSS, phosphorus, copper, zinc, PAHs, petroleum hydrocarbons, and field parameters. The intent was to compare the pre- and post-retrofit results to approximate changes in basin water quality since the stormwater retrofits were installed; however, several complications increased the uncertainty in this comparison. First, the retrofit included changes to the stormwater system that altered the comparability of the pre- and post-retrofit sample results (Appendix A and King County 2015). Additionally, most of the post-retrofit samples were collected in October 2016, which differed seasonally from the pre-retrofit samples collected in November and January. Differences in stormwater inputs due to drainage area and seasonal variations could obscure any differences attributable to the retrofit. Statistical comparisons were not included in this report due to the comparability issues described here. Appendix F presents the raw data.

***Objective 4:* Identify if nutrient and bacteria levels have changed in Echo Lake over time, and how these changes correspond to changes in stormwater infrastructure in the contributing basin. The purpose of this analysis is to consider potential effects to the receiving water body as a piece of the discussion, not to establish a causal relationship.**

The long-term water quality monitoring data for Echo Lake show seasonal increases in nutrient concentrations at depth, indicating that internal cycling from sediments may be a major source of nutrients to the lake. Surface nutrient concentrations were generally consistent over the summer months, with no observed correlation between rainfall events and nutrient concentrations. While this suggests that stormwater may not be a major source of nutrients during the summer months, it is not possible to characterize the proportion of nutrient loading to the lake due to stormwater versus internal cycling from lake sediments without additional information. Over the course of the monitoring period, water quality in Echo Lake consistently indicates mesotrophic or eutrophic conditions. A slight increasing trend in total phosphorus concentrations was observed; however, water quality data do not suggest substantial changes that correspond to retrofit installations in the basin (See Appendix H).

Patterns in summer fecal coliform levels at the Echo Lake swimming beach were consistent with other swimming beaches in the area in that high counts were more frequent in 2015 and 2016. These results are likely not associated with changes within the Echo Lake drainage basin, but rather to unseasonably hot and dry summers (See Appendix H).

There are several potential reasons that water quality improvements were not observed in Echo Lake. First, the retrofit included BPBs and Filterra that were designed to treat only 2.9 acres of impervious surface out of the 207-acre basin (with over 56% impervious surface; HDR 2011). Additionally, impervious surface area increased by 0.77 acres during the roadway improvements that corresponded with the retrofit. While the BPBs and Filterra target the most heavily trafficked impervious surfaces (i.e., Aurora Avenue North and North 185th Street), a higher density of BMPs may be required before water quality improvements are detected.

The assessment is also constrained by the parameters that have been included in the long-term monitoring effort (i.e., nutrients and bacteria). As described previously, bacteria removal by the individual BMPs could not be confidently assessed (See Appendix G) and nutrients were not efficiently reduced by the BPBs. Alternatively, the BPBs and Filterra were very effective at removing total metals and the analyzed organic contaminants from the highway runoff. Additionally, sources of these contaminants are more heavily concentrated on the busy roadways (e.g., automobiles), whereas nutrient sources could be more prevalent along the untreated residential streets (e.g., yard care products). Since metals and organic contaminants have not been included in long-term monitoring, it is uncertain if levels of these contaminants have changed in the lake over time. Finally, the individual BMPs may not have contributed to water quality improvements in the lake due to O&M issues, which are discussed in the following section.

2.3 Additional Findings (O&M)

A major finding of the study was not directly related to the study objectives, but to O&M. Site visits at the beginning of the study revealed the BPBs were not receiving stormwater because the inlets (curb cuts) had been blocked by debris (Figure 13). The curb cuts were relatively small, and the project field crew needed to make frequent maintenance visits to keep them clear over the wet season (as often as every two weeks).

The Filterra inlet was much larger than the BPB inlets, and was always clear of debris; however, media has needed replacement every two to three years since installation to address drainage issues. Trash was regularly observed in the Filterra, likely entering through the large curb cuts off the street (e.g., food wrappers, plastic bottles). However, the trash did not seem to impede stormwater flow into the media, instead observations suggest that the media may have been clogged by an accumulation of fine sediments.

The City of Shoreline has been monitoring BMP maintenance needs on an annual basis as part of their regional facility inspection. They are working to increase inspection frequencies to address these O&M findings. Appendix J includes an annotated summary of maintenance at the site and pictures of the installations that illustrate the above findings.

2.4 Conclusions/Recommendations

The BPBs installed in 2012 often increased effluent nutrient concentrations relative to influent levels, particularly for phosphorus, but significantly reduced concentrations of organic contaminants, total metals, and some dissolved metals. This is consistent with the effectiveness of new bioretention media, as reported in other local studies (Herrera 2016). The BPBs absorbed much of the influent flow, with effluent present only during periods of intense rainfall (i.e., roughly >0.1 inches per hour). This means contaminant loads were reduced more than contaminant concentrations. The Filterra significantly reduced phosphorus concentrations, but was slightly less effective for TSS and metals.

At each BMP site, effluent concentrations for most contaminants were fairly consistent, regardless of influent concentration. This suggests the effluent concentration is not dependent on the influent concentration (within the range evaluated), but could be influenced by the individual BMP capabilities. An evaluation of the limited historical data suggests water quality improvements at the individual BMP level may not yet be at a scale to influence system-wide water quality improvements (<3% of impervious surface treated by BPBs/Filterra).

Additionally, there were severe O&M issues at this site, which highlighted the need for regular site inspections to ensure treatment installations remain functional. Each BMP site is unique, and it is important for stormwater managers and city-wide programs to plan for inspections to ensure that the anticipated maintenance schedule truly meets the needs of the individual site. Additionally, changes in design could have mitigated the high maintenance requirements (e.g., larger curb cuts are not blocked as easily by roadway debris). Future studies should focus on optimizing the inlets to BPBs and other bioretention installations so that they receive an appropriate volume of stormwater that matches the capacity of the bioretention, while minimizing maintenance requirements.

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Additional references are cited in appendices.