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Statistical Analysis of Vegetation and Stormwater Runoff in an Urban Watershed During Summer and Winter Storms in Portland, Oregon, U.S.

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Abstract. Past research has examined the effect of urban trees, and other vegetation, on stormwater runoff using hydrological models or small-scale experiments. However, there has been no statistical analysis of the influence of vegetation on runoff in an intact urban watershed, and it is not clear how results from small-scale studies scale up to the city level. Researchers address this gap in the literature by estimating random-effects regression models of the effect of trees and other vegetation on total runoff and peak runoff for a summer (15–16 June 2010) and a winter (18–19 December 2010) storm in Portland, Oregon, U.S. Researchers found that additional tree canopy cover was associated with lower runoff in the summer storm, but the significance of the tree coefficient was sensitive to model structure. Researchers found that additional groundcover (grass and shrubs) associated with lower peak flow in the summer, and this result was robust to model structure. Neither trees nor groundcover were significantly associated with winter stormwater runoff. Results suggest that trees and other vegetation can be effective at moderating stormwater runoff. However, vegetation is not as effective in the winter, which is consistent with past modeling and experimental studies.

Key Words. Economics; Hydrology; Oregon; Portland; Runoff; Stormwater; Trees; Urban Forestry Vegetation.

In urban areas, trees, and other types of vegetation, are increasingly being used in stormwater management to supplement traditional gray infrastructure (Soltis 1997; Keating 2002; Villarreal et al. 2004; Day et al. 2008). Although there is a wealth of research in wildland settings showing trees can reduce and slow runoff (Heal et al. 2004; Link et al. 2004; Keim et al. 2005; Boegh et al. 2009), there has been less research in urban environments (Sanders 1986; Soltis 1997; Xiao et al. 1998; Xiao et al. 2000; Wang et al. 2008; Asadian and Weiler 2009). Furthermore, the research that has been done in urban environments has been based on small-scale experiments or hydrological models. There has been no statistical analysis of the influence of vegetation on runoff in an intact urban watershed. This is a significant gap in the literature, as wildland studies and small-scale experiments do not consider the built component of an urban watershed (e.g., impervious surfaces) and how this built component interacts with vegetation. Therefore, it's not clear how results from small-scale studies scale up to the city level, and it is important to understand the relationship between trees and stormwater runoff at the same scale as potential policy remedies. Researchers address this gap by quantifying the effect of vegetation on stormwater runoff in a combined-sewer system in Portland, Oregon, U.S.

Literature Review

Vegetation can affect stormwater runoff in three ways: interception, transpiration, and infiltration. Vegetation intercepts precipitation, which allows it to evaporate rather than landing on the ground and contributing to runoff. Transpiration occurs when vegetation draws water from the soil and releases it as water vapor from its leaves and stem. Finally, roots increase the infiltration of water through the soil.

In wildland settings, several studies have shown that trees intercept significant amounts of rain (Heal et al. 2004; Link et al. 2004), and that forest structure and tree age are important determinants of interception rates. Specifically, Pypker et al. (2005) found that a 25-year-old Douglas-fir plantation intercepted more rain than an old-growth stand of Douglas-fir, and Nadkarni and Sumera (2004) found that trees with a denser canopy intercepted more rain.

Interception rates are also influenced by weather. Rates are higher following a period of dry weather (McJannet et al. 2007) and decline as a storm progresses (Jetten 1996). Weather variation can also make it harder to draw general conclusions about interception by forest type (Crockford and Richardson 2000).

The findings of rain-interception studies in urban areas are generally consistent with those conducted in wildland settings. In Davis, California, U.S., Xiao et al. (2000) found that an open-grown deciduous tree intercepted less winter rain than an open-grown conifer. They also found that interception rates varied from 100% at the beginning of a storm to 3% at the end. Asadian and Weiler (2009) studied the interception rates of six trees (Douglas-fir and red cedar) in British Columbia, Canada, and they found that red cedar intercepted more rain than Douglas-fir, and interception was influenced by canopy structure and storm intensity. Guervara-Escobar et al. (2007) found that the mean interception rate of an open-grown evergreen was 60% across 19 summer storms.

Several studies have used models to estimate the interception rate of urban trees. Wang et al. (2008) used a hydrology model to estimate the interception rate of trees in Baltimore, Maryland, U.S. Their model showed that trees can significantly reduce runoff; however, results only held for low-intensity, short-duration storms. Sanders (1986) modeled the effect of urban development and vegetation on stormwater runoff in Dayton, Ohio, U.S. His model showed that development increased runoff, whereas vegetation reduced both total runoff and runoff rate.

This analysis explores the effect of vegetation on stormwater runoff in Portland, Oregon. Researchers analyzed two storms in 2010—a summertime (leaf on) and wintertime (leaf off) event—across 34 sewer monitoring sites. The objective is to quantify the effect of trees and other vegetation on total runoff and peak flow. The current study is the first to analyze this relation holistically in an intact urban watershed: researchers didn't rely on hydrological models and measured runoff in sewers as opposed to within or under trees. Therefore, the study is a useful complement to existing hydrological models and small-scale experiments, which have been used to justify significant investments in green infrastructure. In addition, the study is at the city scale, which matches the scale of likely policy interventions (e.g., tree planting programs).

MATERIALS AND METHODS

Study Area

Portland is a city in northwest Oregon with a population of 619,360 in 2014 (U.S. Census 2014). It has a maritime climate with a mean annual rainfall of 109 cm (National Oceanic and Atmospheric Administration 2011), which falls mainly in the winter and spring.

Approximately 70% of homes in Portland are connected to a combined-sewer system, in which sanitary flow and stormwater runoff share the same system of pipes. Approximately 772 communities in the U.S., serving 40 million people, have combined-sewer systems (U.S. Environmental Protection Agency 2008). When most combined-sewer systems were built, sanitary flow was not treated, so a combined system was viewed as an economical way of disposing of sanitary flow and stormwater runoff. Now that sanitary flow is treated before release, the management of combined-sewer flow presents challenges, because stormwater runoff is far more variable than sanitary flow, which can lead to the release of untreated sanitary flow into rivers and backup of sewer flow for residential customers.

In 1991, Northwest Environmental Advocates sued the City of Portland under the Clean Water Act because the City released untreated sanitary flow an average of 50 times a year into the Willamette River or the Columbia Slough. In response, the City built three storage tunnels, which became known as the big-pipe project. These tunnels were designed so that untreated flow would be released into the Willamette River an average of four times in the winter and once every three summers (based on 40-year development projections) and released into the Columbia Slough once every five winters and once every ten summers (Portland Bureau of Environmental Services 2012).

Although the big pipe reduced the discharge of untreated sanitary flow into the Willamette River, it did not affect sewer backup, which is a significant problem in older neighborhoods. Pipes that were big enough when a neighborhood was built are now unable to deal with the flow generated by additional development. Rather than replace undersized, but otherwise functional pipes, the City of Portland is using green infrastructure—trees and bioswales (Figure 1), for example—to supplement traditional gray infrastructure. Bioswales are landscape elements designed to filter and reduce surface runoff.

Data

The City of Portland maintains a series of permanent and temporary flow meters in the combined-sewer system. Flow data was obtained for two two-day storms: one in the winter (18–19 December 2010), in which 1.86 cm of rain fell, and one in the summer (15–16 June 2010), in which 0.97 cm of rain fell. Researchers chose storms that had significant precipitation and were preceded and followed by dry periods. Data were available from 34 monitors (flow monitors measure the total volume of runoff that flows through a pipe in a 15-minute increment). Data were used from all 34 sewer sheds in all subsequent models.

Each monitor measures runoff from a unique drainage, which shall be referred to as a sewer shed. An ArcGIS tool (developed by the City of Portland) was used to define the spatial extent of these sewer sheds. The tool traces all the pipes and associated surfaces that drain to a monitor. Researchers traced the sewer shed for each of the 34 monitors and combined them into a single GIS layer. Figure 2 shows an example sewer shed (E09), its associated pipes, and the location of its flow meter. Figure 3 shows the location of sewer shed E09 and the location of Portland's wastewater treatment plant. Table 1 provides summary statistics for these sewer sheds.

In a combined-sewer system, sanitary flow shares the same system of pipes as stormwater runoff. In the analysis, researchers chose not to

Figure 1. Bioswale in Portland, Oregon, U.S.

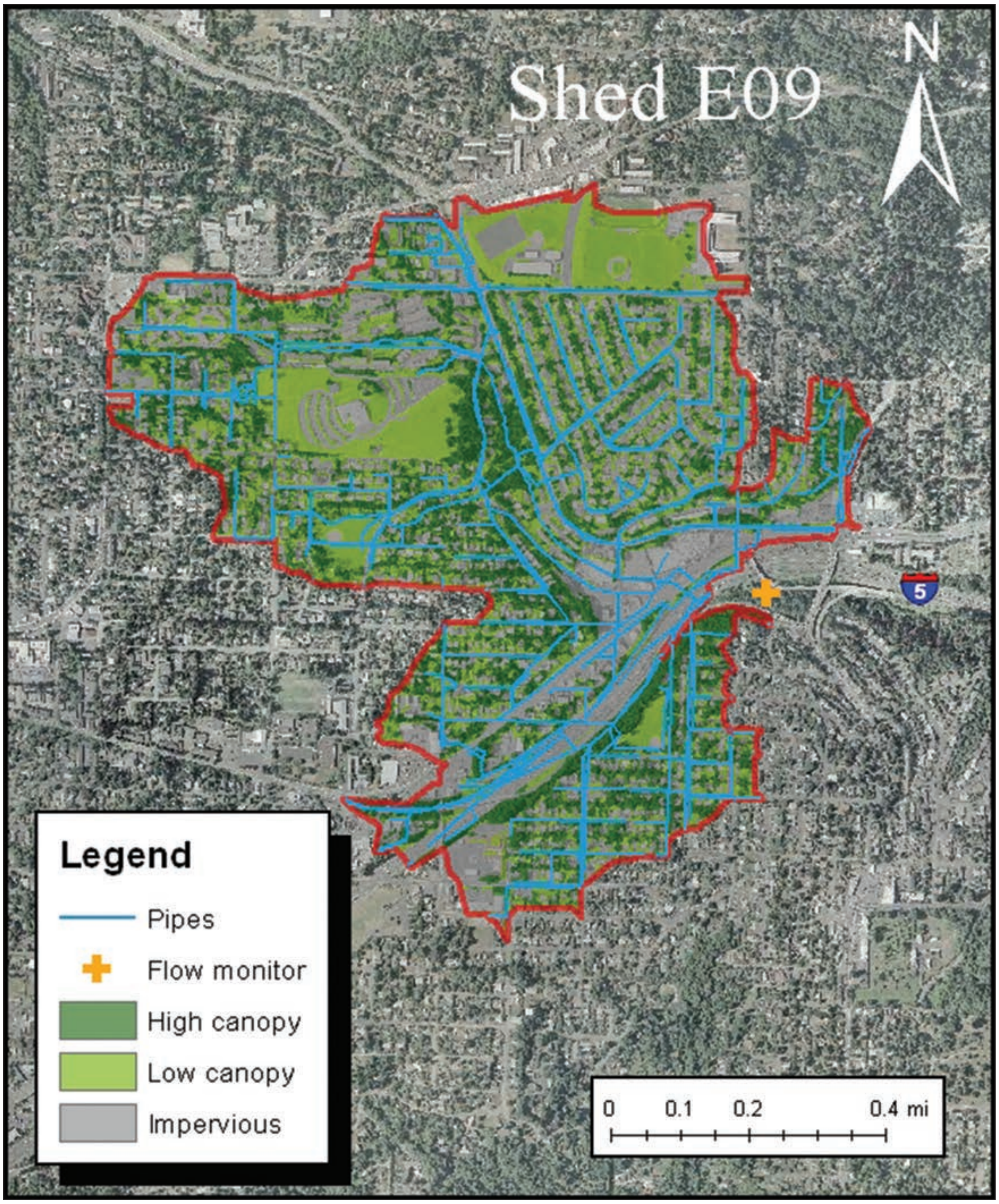

Figure 2. Sewer shed E09 showing tree cover, grass-and-shrub cover, major sewer pipes, and flow monitor in Portland, Oregon, U.S.

account for sanitary flow, because during the storms selected, stormwater runoff was several orders of magnitude larger than sanitary flow, and it was postulated that sanitary flows are uncorrelated with land cover and rainfall, all else equal. Indeed, many of the flow meters registered zero flow rates when it wasn't raining, which suggests the sanitary flow is typically too low to be detected.

Classified aerial imagery (metro land-cover classification 2007, 1 m resolution) was used to estimate the percentage of a sewer shed covered in three cover types: tree canopy, impervious surface, and low vegetation (grass and shrubs). Although the imagery could distinguish between trees and grass and shrubs, it could not distinguish between deciduous and evergreen trees.

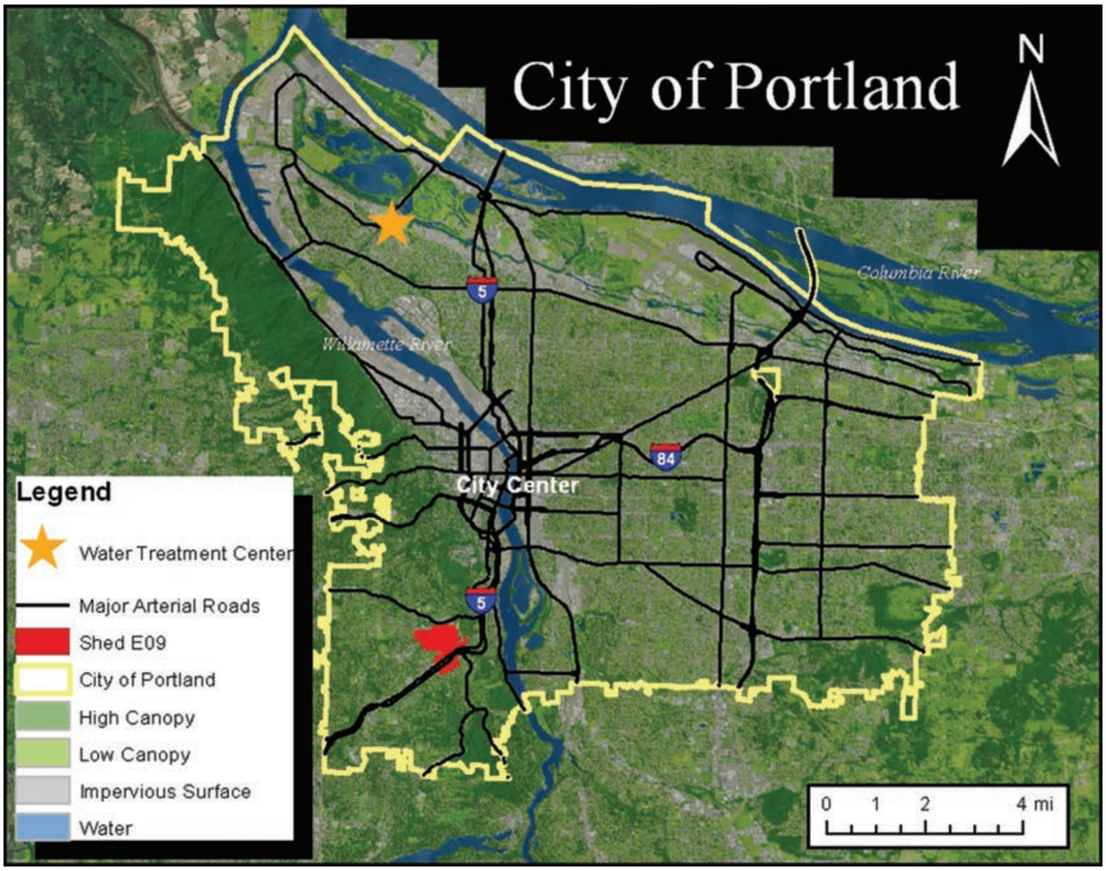

Figure 3. Location of sewer shed E09 and water-treatment center in Portland, Oregon, U.S.

Table 1. Summary statistics for 34 sewer sheds.

Variable	Mean [SD]	Minimum	Maximum
Sewer shed area (hectares)	1,113 [1,907]	1.70	5,756
Percent tree cover	29.1 [7.60]	6.75	42.2
Percent grass and shrubs	27.4 [9.49]	9.33	56.7
Percent impervious	43.1 [13.4]	12.2	78.2
Mean slope (%)	10.5 [4.07]	5.13	21.7

As the three cover types sum to 100%, an increase in one cover type necessarily means a decrease in one or both of the other two cover types. However, in reality, tree canopy can overhang grass and shrubs, as well as impervious surfaces.

There are 16 rain gauges within the combined-sewer catchment. If a sewer shed contained a single rain gauge, researchers assigned it to that sewer shed. If a sewer shed contained multiple rain gauges, then the mean of the gauges was assigned. If a sewer shed contained no rain gauge, then the gauge closest to the sewer shed's boundary was assigned. Finally, the mean slope in each sewer shed was estimated using a LIDAR-derived digital-elevation map.

Treatment Costs

The cost of stormwater management is affected by both total flow and peak flow. Total flow drives the variable costs of treatment, as each additional cubic meter of flow that reaches a treatment plant increases treatment costs (e.g., energy and chemical costs). Peak flow drives the fixed, infrastructure costs of stormwater treatment. For example, a system of pipes must be able to accommodate peak flow; otherwise, untreated flow may overflow into rivers or cause backups for commercial and residential customers. Variable treatment costs are essentially a linear function of total flow, whereas fixed costs are nonlinear and often have thresholds. For example, in one area, a small reduction in peak flow may significantly reduce the number of sewer backups. However, in an area that has pipes that are of sufficient diameter to accommodate peak flow, that same reduction in peak flow may have no effect on fixed costs. Therefore, the effects of vegetation on treatments costs are highly situational.

To investigate the influence of trees on fixed and variable treatment costs, researchers estimated a total flow model and a change-in-flow model. These two measures of flow are shown in Figure 4, which graphs sewer flow as a function of time. Total flow is the integral of this function between two points in time (in this case, these two points are 15 minutes apart). The change-in-flow model is the first differential of this function. The first differential was approximated using the slope of the ray connecting the two points $f(t_0)$ and $f(t_{15})$.

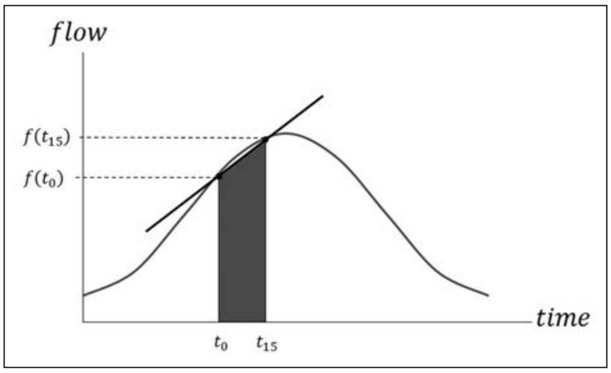

Figure 4. Total flow and change in flow.

Not all the sewer sheds are the same size, so total flow was normalized by sewer-shed area (units: cubic meters per hectare per 15 minute increment). To make the interpretation of model coefficients more intuitive, rainfall was measured in the same units. In the change-in-flow model, different sized sewer sheds were accommodated by using absolute percentage change in flow from one 15-minute increment to the next. Formally, normalized total flow (NF) and normalized change in flow (NCF) are defined as:

$$NF_{i,t} = \frac{Flow_{i,t}}{Area_i} \tag{1}$$

$$NCF_{i,t} = \left| \left\{ \frac{[Flow_{i,t+15} - Flow_{i,t}]}{Flow_{i,t}} \right\} * 100 \right| \tag{2}$$

where i indexes sewer shed and t indexes time.

Statistical Analysis

The data are structured as repeated measurements on the same observational unit (sewer shed). Data of this type can be analyzed using regression models of the following general form:

$$Y_{i,t} = \alpha + \boldsymbol{\beta} \boldsymbol{X}_{i,t} + \upsilon_i + \varepsilon_{i,t} \tag{3}$$

where $Y_{i,t}$ is either normalized flow or normalized change in flow for the ith sewer shed at time t, $\boldsymbol{X}_{i,t}$ is a vector of independent variables (including tree cover), $\varepsilon_{i,t}$ is an i.i.d. error term uncorrelated with the unit-specific residual υ_i, and α and $\boldsymbol{\beta}$ are coefficients to be estimated in the regression step. Typically, linear models of this form are estimated using either fixed-effects or random-effects estimators. The researchers chose between the two based on a Hausman specification test (Hausman 1978).

Variables were selected for inclusion in the final model using iterative backward selection. Variables were dropped from the model using progressively smaller p-value thresholds, with a final threshold of 0.1. The only exception to this selection criterion was rainfall. Table 2 shows a complete list of candidate variables. A variance-covariance matrix was used to avoid including highly collinear combinations of variables in the same model.

It takes time for rainfall to pass through a sewer system and reach a flow meter. Therefore, lagged rainfall were included in both models. For example, the variable rain denotes rainfall in the current 15-minute period, rain (15-minute lag) denotes rainfall in the previous 15-minute period, and so forth.

Several statistical issues can complicate the estimation of regression models using repeated-measurements data. Data are typically not independent. A random or fixed effect model addresses some of this dependence, but temporal autocorrelation can also be an issue. Autocorrelation was tested by using a Wooldridge test (Wooldridge 2002). As in simple linear regression, heteroskedasticity can also be an issue in repeated-measurements data. Heteroskedasticity was tested by comparing a model that assumes panel-level homoskedasticity (error-term variance is the same across sewer sheds) to one that assumes panel-level heteroskedasticity (error-term variance varies across sewer sheds) using a log-likelihood ratio test.

Table 2. Candidate variables for possible inclusion in total flow and change-in-flow models.

Variable	Definition
Total flow	Sewer flow in cubic meters per hectare per 15-minute increment
Flow (15 minute lag)	Total flow in previous 15-minute increment
Change in flow	Absolute percentage change in flow previous 15-minute increment
Sewer shed area	Area of sewer shed in hectares
Rain	Rainfall in cubic meters per hectare per 15-minute increment
Rain (15-minute lag)	Rainfall in previous 15-minute increment
Percent tree cover	Percent of sewer shed covered by tree canopy
Percent grass and shrubs	Percent of sewer shed covered by grass and shrubs
Percent impervious	Percent of sewer shed covered by impervious surface
Slope	Mean slope of a sewer shed

RESULTS

Hausman specification tests of all models found no statistically significant difference between coefficients estimated using random-effects estimators and those using fixed-effects estimators ($P < 0.01$). Under these conditions, both estimators are consistent, but only the random-effects estimators are efficient (Baum 2001). Therefore, all models were estimated using random-effects estimators.

In the flow model, researchers found evidence of autocorrelation ($P < 0.001$), so a 15-minute lag of sewer flow was included as an independent variable, which removed the autocorrelation ($P = 0.732$). In the change-in-flow model, researchers found no evidence of autocorrelation ($P = 0.149$). There was, however, evidence of heteroskedasticity in both models ($P < 0.001$). Therefore, standard errors were estimated with the usual model-based techniques and with sandwich estimators (Greene 2000), which are robust to some forms of misspecification including heteroskedasticity and non-normally distributed error terms.

Table 3 shows the results of the model of June sewer-flow rate. As expected, the coefficients on lagged sewer flow and rain are positive. Percentage tree cover is negatively associated with sewer flow, but the coefficient on trees is only significant with model-based standard errors. Standard errors were included using both estimators, as both estimators have shortcomings. Heteroskedasticity can lead to inefficient coefficient estimates when using model-based estimators. In contrast, sandwich estimators are robust to heteroskedasticity, but they are sensitive to misspecification of the likelihood function. In addition, the data have only 34 observational units, and sandwich estimators are only asymptotically efficient and consistent (Rabe-Hesketh and Skrondal 2012). Therefore, it is not clear which is the appropriate estimator, and readers should interpret results from this model cautiously.

To provide some context for coefficient on tree cover, if tree cover had been one percentage point higher (mean tree-canopy cover in the sample was 28%), then sewer flow would have been reduced by 4,550 cubic meters over the two-day storm.

Tree cover was not significant in the change-in-flow model (Table 4), but grass and shrubs were, which suggests that groundcover is more effective at slowing runoff than tree cover.

The coefficient on grass and shrubs is -0.5, which means that a one percentage point increase in grass and shrubs would result in a 0.5 percentage point decrease in absolute percentage flow. To provide some context for this number, the mean absolute percentage change in flow for the sample (including only those observations where absolute percentage change in flow is non-zero) is 19.5. A one percentage point increase in grass and shrubs would reduce this to 19. This is a modest change, but under the right circumstances, such a change might prevent a pipe from backing up. In addition, these results apply to all grass and shrubs. Groundcover specifically designed to slow runoff (e.g., bioswales) is likely to be more effective at moderating peak flow. The coefficient on trees and shrubs is significant for both estimators, so results are less ambiguous than the flow model.

When comparing the benefits of trees with the benefits of shrubs and grass, it is important to recall that increasing tree canopy does not require reducing the amount of impervious surface or grass and shrubs. Therefore, the coefficient on trees should be interpreted as the marginal effect of additional tree canopy. In contrast, increasing grass and shrubs necessarily requires reducing impervious surface, so the coefficient on grass and shrubs should be interpreted as the marginal effect of substituting grass and shrubs for impervious surface.

Results for the December flow and change-in-flow models are shown in Table 5 and Table 6. For comparison, researchers included the same variables as the corresponding June models. Neither trees nor grass and shrubs were significant in either model. In addition, both December models had lower explanatory power than their corresponding June models. This lack of significance may be because trees and

Table 3. Random-effects model of sewer-flow rate (cubic meters per hectare per 15 minutes) on 15–16 June 2010, in Portland, Oregon, U.S. (number of groups = 34, total number of observations = 6,375).

Variable	Coefficient	*P*-value (model based)	*P*-value (sandwich)
Intercept	0.042	0.075	0.296
Flow (15-minute lag)	0.992	<0.001	<0.001
Rain	0.064	<0.001	0.053
Percent tree cover	-0.0017	0.038	0.235
R-squared (within):	0.54		
R-squared (between):	1.00		
R-squared (overall):	0.985		

Table 4. Random-effects model of absolute, percentage change in sewer flow on 15–16 June 2010, in Portland, Oregon, U.S. (number of groups = 34, total number of observations = 6,341).

Variable	Coefficient	*P*-value (model based)	*P*-value (sandwich)
Intercept	25.7	<0.001	<0.001
Rain	3.61	<0.001	<0.001
Rain (15-minute lag)	1.03	0.167	0.172
Rain (30-minute lag)	3.33	<0.001	0.018
Rain (45-minute lag)	3.20	<0.001	0.020
Rain (60-minute lag)	6.91	<0.001	<0.001
Rain (75-minute lag)	3.14	<0.001	0.098
Percent grass and shrubs	-0.495	0.034	0.007
R-squared (within):	0.0739		
R-squared (between):	0.1260		
R-squared (overall):	0.0781		

Table 5. Random-effects model of sewer-flow rate (cubic meters per hectare per 15 minutes) on 18–19 December 2010, in Portland, Oregon, U.S. (number of groups = 30, total number of observations = 5,626).

Variable	Coefficient	*P*-value (model based)	*P*-value (sandwich)
Intercept	-0.00329	0.540	0.033
Flow (15-minute lag)	0.998	<0.001	<0.001
Rain	0.0112	<0.001	0.025
Percent tree cover	0.000631	0.973	0.665
R-squared (within):	0.57		
R-squared (between):	1.00		
R-squared (overall):	1.00		

Table 6. Random-effects model of absolute, percentage change in sewer flow on 18–19 December 2010, in Portland, Oregon, U.S. (number of groups = 30, total number of observations = 4,996)

Variable	Coefficient	*P*-value (model based)	*P*-value (sandwich)
Intercept	103.7	0.051	0.060
Rain	80.45	<0.001	0.322
Rain (15-minute lag)	34.42	0.094	0.025
Rain (30-minute lag)	-8.95	0.665	0.475
Rain (45-minute lag)	-28.71	0.164	0.240
Rain (60-minute lag)	-12.48	0.546	0.211
Rain (75-minute lag)	-7.47	0.701	0.328
Percent grass and shrubs	-2.690	0.120	0.122
R-squared (within):	0.0064		
R-squared (between):	0.0525		
R-squared (overall):	0.0069		

shrubs lose their leaves in winter, and therefore interception and transpiration rates are lower. In addition, colder, wetter winter weather reduces water loss from transpiration and infiltration.

DISCUSSION

The results suggest that, for summer storms in Portland, shrubs and grass reduce peak flow. The results for trees were more ambiguous. Using model-based estimators, the relationship between tree cover and total flow was significant. However, when sandwich estimators were used to correct for heteroskedasticity, the relationship between trees and total flow was no longer significant. In winter, neither total flow nor peak flow were affected by vegetation.

The results provide support for the use of bioswales and other ground-covering vegetation to augment traditional gray infrastructure. However, increasing groundcover was associated with relatively modest reductions in peak flow. Placing bioswales strategically, or combing them with other mitigation techniques, may have a significant effect on fixed infrastructure costs, but they shouldn't be considered a panacea. Future research could fruitfully focus on the impact of bioswales and bioswale structure on stormwater runoff.

The results do not provide definitive support for the use of trees in stormwater management. Some of this ambiguity may be a consequence of the study design—two-day storms were analyzed, and so tree cover was time invariant. However, the results suggest that wildland studies and single-tree experiments should not be blindly used to justify the use of trees in urban stormwater management. These studies do not consider the built component of urban watersheds, and it's far from clear how trees interact with built infrastructure. More than anything, this study emphasizes the need for more research in intact urban watersheds.

Determining how the hydrological effects of vegetation translate into changes in stormwater treatment costs is problematic because treatment costs are not simple linear functions of total flow. Rather, there are many threshold effects. For example, in some circumstances, a modest reduction in flow might stop a sewer pipe from backing up into people's basement, which would avoid significant short-term damage. In the long term, fewer backups may avoid the cost of replacing a small but otherwise functional pipe. However, in other situations, the same reduction in flow may have little effect on treatment costs.

Although it may be difficult to determine the effect of vegetation on stormwater treatment costs in a specific case, cost savings are likely to be higher in the following circumstances, all else equal: cities with combined-sewer systems, cities with high summer rainfall, and cities with undersized but otherwise functional pipes.

The study has several limitations. Researchers were only able to analyze two storms, so the results are, to some degree, an artifact of the idiosyncrasies of these storms. The coefficients of interest would, no doubt, have been different if different storms had been analyzed. How different, researchers are unable to say. Therefore, the results should be interpreted cautiously. However, analyzing more storms would not have added additional variability in vegetative cover, as both tree cover and grass-and-shrub cover were time invariant in the analysis. Therefore, additional storms may not have provided more insight into the relationship between vegetation and stormwater runoff.

The measures of vegetation cover are another source of uncertainty. Specifically, the imagery used is subject to classification error. In addition, tree canopy obscures underlying groundcover, so researchers couldn't determine how much of the area under tree canopy was covered by impervious surface or vegetation. Finally, imagery was used from 2007 to estimate canopy cover in 2010.

Despite these limitations, researchers believe the unique nature of the study provides useful support and caveats to past studies that have identified a relation between vegetation and stormwater runoff.

Although trees and other vegetation may be a useful complement to traditional stormwater infrastructure, it is important not to overstate their benefits. However, it is also important to consider the other benefits of trees, which include reduced energy consumption (Akbari et al. 1997; McPherson and Simpson 2003), increased sale price of homes (Anderson and Cordell 1988; Donovan and Butry 2010), reduced crime (Kuo and Sullivan 2001), and improved public health (Lovasi et al. 2008; Donovan et al. 2011; Donovan et al. 2013).

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Résumé. Des recherches antérieures ont examiné l'impact des arbres urbains et d'autres végétaux, sur le ruissellement des eaux pluviales à l'aide de modèles hydrologiques ou d'expériences à petite échelle. Cependant, il n'y a pas eu d'analyse statistique de l'influence de la végétation sur le ruissellement dans un bassin versant urbain intact, et on ne sait pas si les résultats des études à petite échelle peuvent s'appliquer à un grand territoire municipal. Les chercheurs tentent de combler cette lacune dans la littérature en utilisant des modèles de régression à effets aléatoires pour estimer l'impact des arbres et d'autres végétaux sur le ruissellement total et le ruissellement de pointe durant un orage estival (15 et 16 juin 2010) et une tempête hivernale (18 et 19 décembre 2010) à Portland, Oregon, aux États-Unis. Les chercheurs ont constaté qu'un plus grand couvert forestier était associé à un ruissellement plus faible durant l'orage estival, mais que la portée significative du coefficient de l'arbre était sensible à la structure du modèle. Les chercheurs ont cependant découvert qu'un couvre-sol végétal plus dense (herbacées et arbustes) était associé à un plus faible ruissellement de pointe durant l'été et que ce résultat était cohérent avec la structure du modèle. Ni les arbres, ni le couvre-sol végétal n'ont eu un impact significatif quant au ruissellement des eaux pluviales en hiver. Les résultats suggèrent que les arbres et les autres végétaux peuvent jouer un rôle efficace dans la modération du ruissellement des eaux pluviales. Cependant, la végétation n'est pas aussi efficace en hiver, ce qui est cohérent avec la modélisation antérieure et les études expérimentales.

Zusammenfassung. Die Forschung hat in der Vergangenheit den Einfluss von abfließendem Starkregen auf Strassenbäume und andere Vegetation in hydrologischen Modellen oder anderen kleinrahmigen Experimenten untersucht. Dennoch gibt es keine statistische Analyse über den Einfluss von Abfluss in einem intakten urbanen Wasserlauf und es ist nicht klar, wie die Ergebnisse aus klein angelegten Studien zur Beurteilung von größeren Objekten auf Stadtniveau herangezogen werden können. Die Forscher richten ihr Interesse auf diesen Spalt in der Literatur, indem sie Regressionsmodelle mit zufälligen Einflüssen hinsichtlich ihres Einflusses auf die Bäume und die andere Vegetation anwenden, um den Einfluss auf den gesamten Jahresabfluss sowie die Spitzenwerte für einen Sommer (15–16 June 2010) und einen Wintersturm (18–19 December 2010) in Portland, Oregon, U.S. untersuchen. Die Forscher fanden heraus, dass zusätzliche Kronenbedeckung mit weniger Wasserabfluss während des Sommerregens verbunden war, aber die Bedeutung des Baumkoeffizienten war sehr von der Modellstruktur abhängig. Weder Bäume noch Bodenbedeckung waren signifikant mit dem Wasserabfluss im Winter verbunden. Nichtsdestotrotz ist die Vegetation im Winter nicht so effektiv, was sich in den vergangenen Studien und Modellen gezeigt hat.

Resumen. Las investigaciones anteriores han examinado el efecto de los árboles urbanos y otros tipos de vegetación en el escurrimiento de aguas pluviales mediante modelos hidrológicos o experimentos a pequeña escala. Sin embargo, no ha habido un análisis estadístico de la influencia de la vegetación en la escorrentía en una cuenca urbana intacta, y no está claro cómo los resultados de estudios a pequeña escala pueden aplicarse hasta el nivel de ciudad. Los investigadores llenaron ese vacío en la literatura mediante la estimación de efectos aleatorios de modelos de regresión de los árboles y otra vegetación en la escorrentía total y la escorrentía pico para un verano (15-16 de junio de 2010) y una tormenta de invierno (18-19 diciembre 2010) en Portland, Oregon. Los investigadores encontraron que la cubierta de copa adicional se asoció con una menor escorrentía en la tormenta de verano, pero la significación del coeficiente árbol era sensible a la estructura del modelo. Los investigadores encontraron que la cobertura vegetal adicional (hierba y arbustos) estuvo asociada con el flujo pico más bajo en el verano, y este resultado fue coherente con la estructura del modelo. Sin embargo, ni árboles ni cobertura vegetal estuvieron significativamente asociados con la escorrentía de aguas pluviales en invierno. Los resultados sugieren que los árboles y otra vegetación pueden ser eficaces en la moderación de las aguas pluviales. Sin embargo, la vegetación no es tan eficaz en el invierno, lo cual es consistente con los modelos anteriores y los estudios experimentales.