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Stormwater utility fees and household affordability of urban water services

Erik Porse[a,b,*], Maureen Kerner[a], Joel Shinneman[a], Jonathan Kaplan[c], Samuel Stone[d] and Mary L. Cadenasso[e]

[a] Office of Water Programs, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819-6025, USA
[b] Institute of the Environment and Sustainability, University of California, Los Angeles, 619 Charles E. Young Dr East, La Kretz Hall, Suite 300, Los Angeles, CA 90095-1496, USA
[c] Department of Economics, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819-6025, USA
[d] Division of Politics, Administration & Justice, California State University, Fullerton, 800 N State College Blvd, Fullerton, CA 92834, USA
[e] Department of Plant Sciences, University of California, One Shields Ave, Davis, CA 95616, USA
*Corresponding author. E-mail: erik.porse@gmail.com

EP, 0000-0002-6691-2104

ABSTRACT

Stormwater utility fees provide dedicated revenues for managing stormwater. In setting fees, household-level affordability should be considered. Existing research does not address methods to evaluate the affordability of stormwater utility fees, especially alongside other household water costs. This paper aims to fill that gap. We present a scenario-based approach to evaluate household affordability of stormwater utility fees in a municipality, which considers other essential household water service charges. We estimate the relative contribution of stormwater utility fees to total household water costs and evaluate affordability across income brackets by integrating data for socioeconomic status, land use, water utility charges, and impervious surface cover. Using data for a case study region, results indicate that stormwater utility fees are small contributors to overall household urban water costs and comprise no more than 2% of the median household income across nearly all income quintiles. For low-income households, stormwater charges only exceed 1% of the household income for the lowest-income brackets (<$20,000) and still represent a small portion of household water costs. The analysis demonstrates a generalizable approach that can be applied everywhere when evaluating a stormwater utility fee as a funding strategy.

Key words: California, Drainage, Finance, One Water, Urban ecology, Urban water management

HIGHLIGHTS

- Stormwater utility fees provide a source of potential revenue.
- Utility fee revenues can be linked with land-use patterns.
- The affordability of stormwater fees should be considered alongside other water services.
- Stormwater fees are small contributors to overall costs of water services but may still impact low-income residents.
- Cities should examine the affordability of fees across the range of household incomes.

INTRODUCTION

Cities in the 21st century manage stormwater to meet multiple goals, including flood control, water quality, and benefits such as enhanced landscapes. Stormwater (urban drainage) systems were traditionally built to mitigate flooding by conveying runoff from developed areas. In the U.S., starting several decades ago, policymakers recognized the need to reduce urban pollution in local watersheds by revamping stormwater systems. These goals became codified through regulations (33U.S.C. 1251–1376; Chapter 758; Amended February 4, 1987). Contemporary stormwater management approaches evolved to include not only drainage and water quality improvements, but also other goals such as beautifying urban spaces, reducing water and energy consumption, and improving land management (Grigg, 2013; Hopkins *et al.*, 2018). The growing complexity of stormwater program goals, along with a lack of revenue in many places, has spurred greater interest in developing dedicated, diversified, and sufficient funding sources, which can provide a more consistent source of revenue for programmatic and infrastructure costs (Fedorchak *et al.*, 2017; EPA, 2020).

Municipalities use a variety of methods to pay for stormwater management, including general funds, dedicated fees and taxes, grants, bonds, loans, and other mechanisms (Grigg, 2013; CASQA, 2019; EPA, 2020). In North America, the establishment of stormwater utilities and funding structures has often lagged behind other urban water sectors (Grigg, 2013). As municipalities in the U.S. grew in the 19th century, they first developed centralized water supply and then wastewater treatment systems, managed by public and private utilities, to promote public health (Tarr, 1984; Tarr *et al.*, 1984). Not until the latter part of the 20th century did the U.S. invest in dedicated approaches to manage and fund stormwater quality. A primary motivation for this shift was the 1987 Amendments to the U.S. Clean Water Act, which enacted regulations for contaminants from sources such as stormwater (33U.S.C. 1251–1376; Chapter 758; Amended February 4, 1987). Through these amendments, federal and state regulators developed program requirements to manage stormwater runoff for key pollutants through the National Pollutant Discharge and Elimination System (NPDES). Continued funding challenges associated with meeting NPDES requirements have driven an interest in more innovative approaches to stormwater system designs, which achieve additional goals such as urban landscape enhancement, groundwater recharge, and even transit planning (Ellis, 1995; Lawrence *et al.*, 1999; Chocat *et al.*, 2001; Brown, 2005; Brown *et al.*, 2009; Heaney & Sansalone, 2009; BenDor *et al.*, 2018). Extreme precipitation from climate change is also driving a need to upgrade and enhance existing systems (Saraswat *et al.*, 2016; Cook *et al.*, 2019).

Ensuring sufficient revenue from funding streams is a critical goal when pursuing revenue options such as utility fees. This consideration, however, must be weighed against the affordability of such fees and taxes for residents and businesses. When enacting fees, utilities may evaluate the ability-to-pay for various affected groups. Household affordability has been a prominent consideration in the drinking water and wastewater sectors, and more recently, studies have advocated that household affordability should be considered across all water sectors (EPA, 1997; Teodoro, 2018; Raucher *et al.*, 2019). Yet, sparse research has explored how to assess the effects of combined drinking water, wastewater, flood control, and stormwater charges on household affordability across income groups or neighborhoods within a city.

In this paper, we present a method to evaluate how stormwater utility fees influence household affordability costs, given the costs of other urban water services. We address two main questions. First, what is the relative contribution of stormwater fees to household-level affordability of all municipal water services? Second, how do stormwater-related fee structures affect affordability of water services for residents across socioeconomic groups? To answer these questions, we present an approach to assess household affordability for stormwater fees alongside other typical urban water sector charges. We evaluate the relative contribution of potential stormwater fee structures using actual data for a case study (Sacramento County, CA) where, through 2021, no countywide fee currently existed. We evaluate the household-level impacts of potential stormwater fee assessments given available data and assumptions from industry and literature. We present results to show how fees affect affordability across household income strata and land-use types. The analysis provides an example of a method to estimate impacts through large-scale data integration. Finally, we describe limitations of the method and offer insights for applying it to other municipalities.

METHODS

We developed a methodology for estimating the affordability of stormwater utility fees that incorporated key inputs, which influence the likely distribution of fees across parcels, as well as the marginal impact of fees in relation to other household urban water bills. The sections below present details on the approach, including the case study region and steps used to implement the approach. The Supplementary Data section provides a detailed mathematical formulation for the calculation procedures.

Study area

We used data for the metropolitan Sacramento area within Sacramento County as a case study. Sacramento County is located in the Central Valley of California. While Sacramento County spans approximately 994 square miles and has a population of 1.5 million people, the majority of residents live in the metropolitan statistical area (MSA), which is displayed in Figure 1. The Sacramento MSA spans multiple cities and unincorporated areas and is the 26th largest metropolitan area in the country (Census, 2019). The reported median household

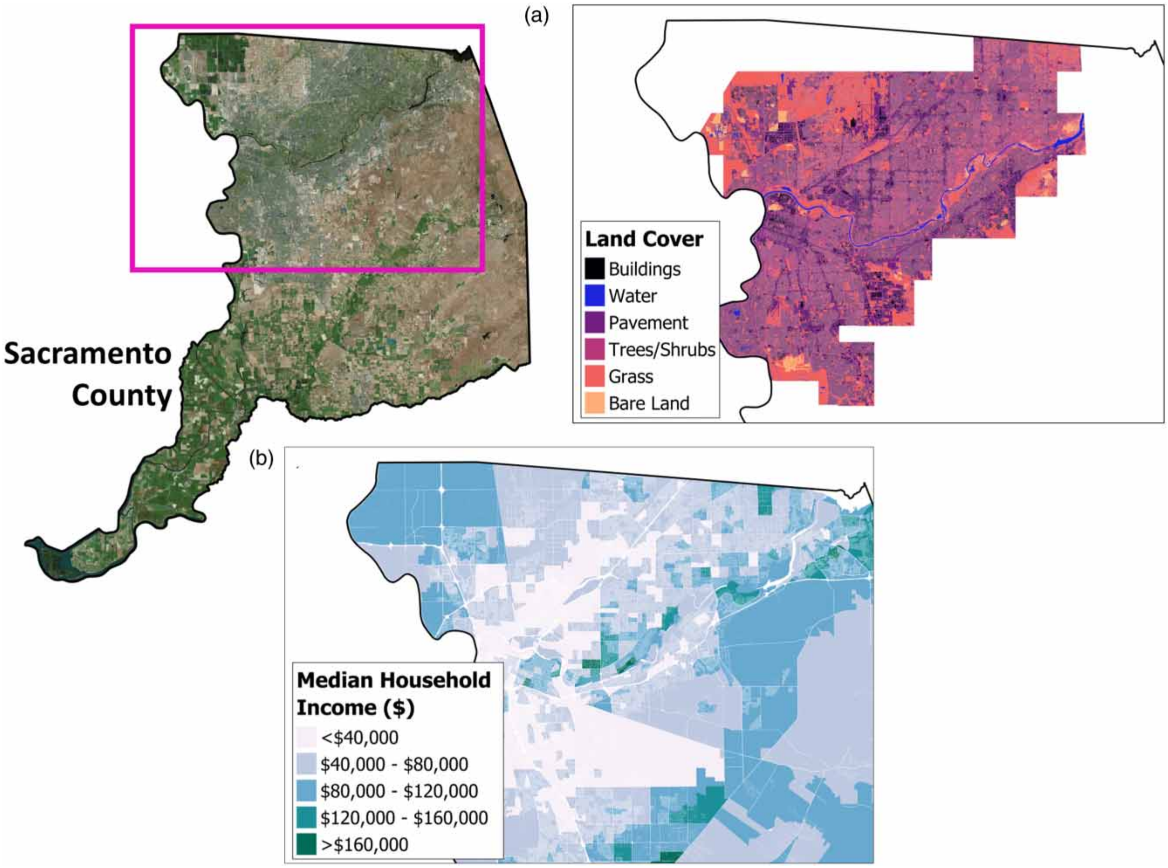

Fig. 1 | Case study region of metropolitan Sacramento within Sacramento County. (a) Land-cover categories used to evaluate impervious and pervious surface cover for parcels (Cadenasso *et al.*, 2007). The extent of imagery defines the study area. (b) MHI in U.S. Census Block Groups (U.S. Census 2014). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wp.2022.024.

income (MHI) of census block groups within the MSA ranges from $0 to $213,000, while 72% of the parcels across the county are in block groups with the MHI less than $80,000.

The county has nearly 453,600 parcels within available tax assessor records (Sacramento County, 2019). The metropolitan area included in the study has 298,220 parcels that could be correlated with data for land cover and impervious surface cover. Parcel sizes in the study area vary significantly, ranging up to 390 ha (963 acres), with the median lot size of 0.176 ha (0.43 acres). High density areas, indicated by more lots per acre, are located predominantly in the northern and western parts of the county.

The county is bordered by two rivers, the Sacramento River and the American River, which are fed by runoff from mountain snowmelt. The county receives an average of 43 cm of rain annually (WRCC, 2020). Like many areas of California, it has a Mediterranean Climate, with precipitation as rainfall primarily occurring in winter months (October through March).

Identifying municipal stormwater funding options and household affordability metrics

Funding for stormwater management may come from a variety of sources, including (a) general fund appropriations from central municipal budgets, (b) dedicated stormwater fees administered through a municipal utility and assessed on properties, (c) development fees on new properties and neighborhoods, (d) debt-based funding such as municipal bonds and subsidized loans that are used for infrastructure and equipment, (e) reapportioning or leveraging funds from other municipal sectors, (f) grants, and (g) emerging funding sources such as purpose-specific bonds, public–private partnerships, or market-based mechanisms (Thurston *et al.*, 2003, 2010; Parikh *et al.*, 2005; Cutter & Hodge, 2012; CASQA, 2019; EFC at Sacramento State, 2019). Table 1 describes these types of funding sources in detail.

Each funding source has advantages and drawbacks. For instance, while general fund revenue provides a flexible funding source, stormwater infrastructure needs often compete with other municipal services, such as libraries or roads, especially during times of fiscal hardship. Dedicated utility fees are a more secure source of funding (Zhao *et al.*, 2019). Instituting a dedicated utility fee for stormwater typically requires the creation of a stormwater utility.

Of the various funding sources, stormwater utility fees provide a dedicated revenue stream that is administered by a recognized administrative entity within the municipality. Many communities throughout the U.S. have dedicated stormwater funding (Kea *et al.*, 2016; Campbell *et al.*, 2018). When creating a stormwater utility, several methods are currently used to develop utility fees (EPA, 2009). First, each parcel or property in a municipality can be assessed the same fee. Second, rate structures based on *Equivalent Residential Units* (ERUs) can apply fees to properties based on average imperviousness, which is typically calculated using a sample of properties across land uses. Third, rate structures can be based on assessments of the amount of impervious surface cover on each property, with a unit charge per area assessed to each property accordingly. Finally, a combination of these rate structures can be applied across the metropolitan area, with some types of properties subject to fees through one method and other properties subject to fees originating from another (NEEFC, 2005).

In developing a rate structure for services, water utilities may assess whether proposed rates are sufficient for the long-term operation, maintenance, expansion, and eventual replacement needs of infrastructure. They can also evaluate the financial impact the rates will have on households and businesses (NAPA, 2017). This is particularly important for lower-income residents, whose expenses for housing, food, healthcare, and utilities are often disproportionately large in relation to household income.

In evaluating the affordability (referred to as ability-to-pay) for urban water services, a common benchmark has been the EPA's guidance for fees related to combined sewer systems (EPA, 1997). Through this framework, the residential indicator (RI), which is the percentage of total household income devoted to a bill for a given utility

Table 1 | Funding and financing options for municipal stormwater management programs (CASQA, 2019; Zhao *et al*., 2019; EFAB, 2020).

Funding options	Type	Description
Revenue sources	General funds	Funds from general revenues, such as property and sales taxes, which are combined and allocated to various municipal needs such as roads, parks, and emergency services. These funds are used for many purposes that may compete, especially during economic downturns that decrease tax revenue.
	Stormwater utility fees	Charges adopted by a municipality as part of establishing a separate utility through a public process with specific duties for managing stormwater. Revenues from these fees must be spent on specific purposes and are managed through an enterprise fund, which is a contained financial structure for a utility mission (enterprises).
	Development and realignment fees	Charges assigned to developers for connecting newly developed properties to existing storm sewer systems, inspection and permitting activities, reviewing site plans, mitigation and impact assessments, and other activities.
	State and federal government grant programs	Funding provided for specific tasks, often capital for projects, related to stormwater management. For instance, in California, the Integrated Regional Water Management Grant program offers grants for watershed management activities, and the Stormwater Grant Program offers grants to municipalities for municipal stormwater infrastructure. Some programs fund specific tasks related to stormwater permit compliance or environmental cleanup. Others, such as the Clean Water Act's 319(h) Nonpoint Source (NPS) Grant Program funds activities, monitoring, and outreach for NPSs.
	Special purpose sales taxes	It can be enacted with revenues earmarked for a specific task such as developing the stormwater infrastructure. For example, in 2016, the Los Angeles region of California passed Measure M designating $860 million of annual revenue from a $0.05 sales tax to transportation projects.
	Designated special district fees	Approved to fulfill a designated purpose, such as managing the stormwater infrastructure, and have taxable authority within a jurisdiction. The advantage of these types of fees is that costs and responsibilities are spread over the entire area where the management need exists, not just within existing jurisdictions and cities.
Financing sources	Bonds	Used by municipalities and states to finance infrastructure development. Through the sale of municipal bonds, governments raise revenue and agree to pay back the fronted cost of capital over time with interest. Bonds do not fill funding gaps. Instead, they spread the costs and finance charges over the life of the project. A variety of bonds are relevant for the stormwater infrastructure development, including general obligation bonds, popularly-approved bonds, 'green bonds', that are designated specifically for projects with environmental benefits and 'environmental impact bonds.'
	Federal and state loan programs	The Clean Water State Revolving Fund is an example that provides an application-based source of capital for building projects. Loans must be paid back over time, with a relatively low interest rate.
Other sources	Public–private partnerships	An emerging set of arrangements provide public entities with opportunities to contract or engage with private sector entities for purposes of financing, building, operating, and potentially owning projects related to stormwater management. At the time of publication, examples of successful partnerships are limited, such as in Philadelphia where the city offers substantial fee reductions for private property owners (Valderrama *et al*., 2013).

(*Continued*.)

Table 1 | Continued

Funding options	Type	Description
	Market solutions	Financial arrangements that introduce private capital to fund the construction and/or operation of infrastructure. Common market-based solutions include credits, which offer an entity needing to meet a regulatory target the opportunity to fund infrastructure or actions at other sites, which can help achieve the target at an overall lower cost, with examples available for urban stormwater such as Washington, D.C., but more examples available in watershed-scale programs focused on nutrients (Kertesz *et al.*, 2014; DC DEE, 2020).
	Volunteer efforts	In-kind donations of actions or infrastructure that promotes stormwater management goals. These can be beneficial at community engagement but often have limited outcomes and cannot be ensured over the long term.
	Inter-departmental cooperation	Leveraging funding or resources from multiple municipal departments to promote outcomes that merge stormwater management needs with other sectors such as transportation or water supply.

sector, was used to assess a range of affordable charges for bills associated with combined sewer services (1–4% of the household income). In 2014, the EPA reevaluated that document and determined the methodology could also be used to evaluate bills assessed for separate stormwater and wastewater systems (EPA, 2014).

The use of MHI as a factor in the analysis of ability-to-pay has since been reconsidered (EPA, 2014; NAPA, 2017). In particular, using community-wide MHI to determine whether a proposed fee will cause financial hardship has drawbacks. MHI for areas throughout a municipality can vary widely. It is also an inconsistent indicator of household income and poverty, since most available sources of MHI data evaluate income at household aggregations of hundreds or thousands of residences, which could mask differences in neighborhoods or even households (USCM, 2014). Alternative methods to assess affordability, deemed more equitable, include estimating the disposable income of urban residents based on economic surveys or judging the cost of water services in relation to hours of the minimum wage (Gawel *et al.*, 2013; Teodoro, 2018). In addition, the assumed affordable percentage (i.e., RI of 1–4%) does not necessarily consider differences in geography, climate, urban density, or utility operations.

Analytical steps

To evaluate the marginal fiscal impact of stormwater utility fees on a household, we collected and integrated high-detail geospatial data for land cover and impervious surface cover, property boundaries, land uses, and socioeconomic data. The method followed a multi-step procedure. We used high-resolution spatial data to assess trends in impervious surface cover and evaluate household stormwater fees associated with various rate structures. We also used socioeconomic and demographic data to estimate household fiscal charges for water services across income groups. These were combined to evaluate marginal household impacts of stormwater utility fees. The steps included:

(1) Formulate marginal household impacts of stormwater utility fees across socioeconomic strata: We assumed that utility revenue is generated from utility fees and charges that pay for water supply, wastewater, stormwater, and flood control requirements in a municipal area. Assuming that all funding needs are met by municipal utility revenue, the total revenue for municipality's water-related services is equal to the sum of revenue of these sub-sectors.

We estimated the household stormwater charges as the product of the stormwater utility fee rate (in dollars per square-foot of impervious surface cover) and the impervious surface cover area on a property (in square-feet). Summing these values across all properties yields the total municipal revenue from stormwater fees. The marginal household impact of the stormwater utility fee in relation to other charges is the relative portion of household water costs from stormwater fees. The Supplementary Data section includes a detailed description of the mathematical formulation.

(2) Develop a GIS database with property boundaries, land uses, and municipal jurisdictions: We developed a spatial database in GIS that included multiple scales of spatial data needed to evaluate stormwater fee impacts. Property boundaries and land uses were derived from the Sacramento County Tax Assessor's dataset (Sacramento County, 2019).

(3) Evaluate household income distribution: We used 2014 U.S. Census data from the American Community Survey (ACS) at the block-group level, which was available at the time of performing the analysis (U.S. Census, 2014). Each block group contains between 800 and 4000 households. Average MHI values in each block group of the study area were mapped. The MHI data from the associated block group were joined to the collection of properties located within the block group.

(4) Analyze geographic dispersion of income, land use, and lot size: We calculated summary statistics of land use and lot size, broken down by land-use categories (single-family residential, multi-family residential, commercial, and industrial) and recorded property-level attributes for these characteristics within the GIS database.

(5) Estimate impervious surface cover: We used an existing spatial dataset of high-resolution land cover for the Sacramento metropolitan region within Sacramento County, which is shown in Figure 1(a) (McConaghie & Cadenasso, 2016; Zhou *et al.*, 2017). We estimated impervious surface cover for properties using data that were generated from 1 meter resolution imagery from the National Agriculture Imagery Program (NAIP) in 2010 and an object-based classification approach (Zhou & Troy, 2008; MacFaden *et al.*, 2012). Six classes were included in the classification map: trees (i.e., tree canopy), grasses, pavement, buildings, water, and bare soil. For each property in Sacramento County, we summed the total area of impervious surface cover and building footprints for each land-cover type using GIS to estimate and summarize impervious surface cover across properties and land-use types. Table 2 details the statistics of land cover throughout the study area.

Table 2 | Land-cover statistics in the study area.

			Area per parcel		
Land cover	Total area, sq-ft, millions (sq-m, millions)	Percentage of total	Average, sq-ft/parcel (sq-m/parcel)	SD, sq-ft/parcel (sq-m/parcel)	Median, sq-ft/parcel (sq-m/parcel)
Buildings	870 (81)	16	3290 (306)	13360 (1242)	2110 (196)
Water	70 (7)	1	4750 (442)	57560 (5353)	404 (38)
Pavement	1329 (124)	24	4580 (426)	38051 (3539)	1540 (143)
Trees and shrubs	1126 (105)	21	4040 (376)	30500 (2837)	1980 (184)
Grass	1977 (184)	36	6830 (635)	116500 (10835)	1430 (133)
Bare dirt	99 (9)	2	37000 (3441)	267100 (24840)	3880 (361)
Total area	5474 (509)	100	4800 (446)	65600 (6101)	1760 (164)

Sq-ft square-feet; sq-m, square-meters.

(6) Select a range of stormwater utility fee structures: We used a rate structure based on the impervious surface cover area of a property. This type of rate structure is the most detailed and data intensive method for implementing stormwater utility fees, but it best aligns fees with the drivers of runoff on a property. The property-specific value of impervious surface cover was multiplied by the rate. We evaluated utility rates ranging from \$0.01 to \$0.05/sq-ft (\$0.11–\$0.52/sq-m), which represents current rate structures in California (CASQA, 2019). We assumed that all property types received the same rate per unit of impervious surface cover.

(7) Collect local drinking water and wastewater management data: We used data on existing water rates for drinking water and wastewater fees to estimate water and sewer bills. We used data from the City of Sacramento's current water rates and assumed a daily amount of 55 gallons per capita per day (gpcd) that is associated with indoor 'health and safety' needs. This value is part of the current regulatory standards in California. We also included an additional minimum amount for seasonal outdoor use (15 gpcd) as outdoor use is typically not viewed as essential for health and safety in arid and semi-arid climates. We also assumed household wastewater service charges based on an existing wastewater rate structure with service fees fixed based on the size or number of rooms in a building. Typical service fees range from \$20 to \$40/month (City of Sacramento, 2019). For wastewater and essential water services related to indoor health and safety and minimal outdoor irrigation, monthly bills range from \$95 to 100/month.

(8) Estimate total revenues and property-level bills across land-use types and utility fee rates: After identifying the land-use type and quantifying impervious surface cover for each property, the total and land-use–specific revenues for stormwater services were calculated. Estimates of average annual billing charges were developed for a range of stormwater utility fee rates across land-use types. Likewise, the total revenue from all properties was compared with the estimated stormwater management costs to identify whether the rates provide sufficient funds. Estimates of existing spending were derived from a separate multi-year study for recent published expenditures normalized to 2018 dollars (EFC at Sacramento State, 2020). These represent the best available estimates from known data. The report expenditures are not necessarily sufficient for required programs and infrastructure. Existing spending on municipal stormwater is challenging to estimate in California since it spans many levels of local government. No reliable data exist to evaluate funding gaps.

(9) Estimate household affordability: We estimated household affordability for all water services using a RI approach that calculated the total average household water bill (stormwater, wastewater, drinking water, and flood management through assessed fees) and compared it to the estimated MHI from ACS data using threshold indicators ranging from 1 to 5%.

(10) Adjust revenues based on fee reductions: To alleviate financial burdens posed by costs of water services for low-income residents, many utilities provide income-based assistance programs. For stormwater, rebates and credits are also common. These programs offer property owners monetary incentives to undertake actions that reduce runoff through on-site practices (Thurston *et al.*, 2003; Thurston, 2006; Cutter *et al.*, 2008; Kertesz *et al.*, 2014; SWRCB, 2018; Zhao *et al.*, 2019). For this analysis, however, we focused on potential fee reductions that targeted low-income households by assuming that 20% of the single and multi-family households in communities below the income assistance thresholds (i.e., block-group median income <80% of an average household income) would apply for financial assistance, with assistance applied as a credit for 100% of the household stormwater utility fees. We did not identify any compiled data for participation rates in income-based fee reduction programs for stormwater. Instead, we used data from the California Public Utilities Commission (CPUC) as the basis for assumptions. Data for water-related low-income assistance programs in investor-owned utilities in California indicated rates of the participation of 15–16%, with this rate being the number of enrolled eligible customers in the program divided by the total number of eligible customers in the service territory (Kahlon *et al.*, 2018).

Summary of data sources

Table 3 summarizes data sources used in the analysis and their sources.

RESULTS

For all the stormwater rates we assumed, the largest portions of total revenue were generated through residential properties (Figure 2(a)). This is due to the relative proportion of impervious surface cover devoted to residential land uses, as well as the larger amount of land area covered by residential properties as compared to commercial and industrial properties. Factoring in a prescribed 20% fee deductions for lower-income households, total revenue drops by approximately 7% (Figure 2(b), Tables S2–S4 in the Supplementary Data). This only affects revenues from the residential sector, with revenue from the single-family sector reduced by 38% and from the multi-family sector reduced by 25%. These percentages are similar across all fee scenarios, since the analysis estimates consistent fee deductions across the same set of properties based on a fee rate that is applied equally. In this scenario, commercial and industrial properties become a larger percentage of total revenue as the deduction is applied solely for residential properties.

The average annual stormwater management bill incurred by industrial and commercial properties is significantly larger than by residential properties (Figure 2(c)). This is due to the larger impervious square footage associated with these properties. Industrial and commercial properties tend to have a greater percentage of their parcels dedicated to parking lots, rooftops, and sidewalks, which increases the percent cover of impervious surfaces.

For total water bills in single-family and multi-family residences, adding assumed water and sewer fees to calculate average total bills across stormwater utility fee rates shows that stormwater fees are not generally a large contributor to total water bills. However, there is a significant difference between the lowest ($0.01/sq-ft) and highest ($0.05/sq-ft) rates. Average annual bills increase noticeably without considering any fee reductions, especially for multi-family properties (Figure 2(d)).

Both the RI and the utility fee rate affect the estimated number of households with affordable water services (Figures 3 and 4). Figure 3 illustrates the effect of the stormwater fee on the number of households and the associated stormwater fee as a percent of MHI. In a scenario with the highest utility fee rate ($0.05/sq-ft) and the lowest RI (1%), households with annual incomes below $30,000 would be deemed to have an unaffordable stormwater utility fee. This equates to approximately 164,000 households (55% of the properties in the study area). Considering the same utility fee rate ($0.05/sq-ft) but the highest RI (5%), however, only households with incomes

Table 3 | Summary of data and sources used in the analysis.

Parameter	Description and purpose	Source
Parcel maps	Provides property boundaries and land-use types	Sacramento County Tax Assessor's office
Drinking water and wastewater fees	Used in calculating the total water utility bill	Reported on city and county websites
Census data	Contains household income data for calculating MHI across income brackets	U.S. Census Bureau ACS
High-resolution imagery	Used for determining impervious area at the property level	USDA Farm Service Agency NAIP

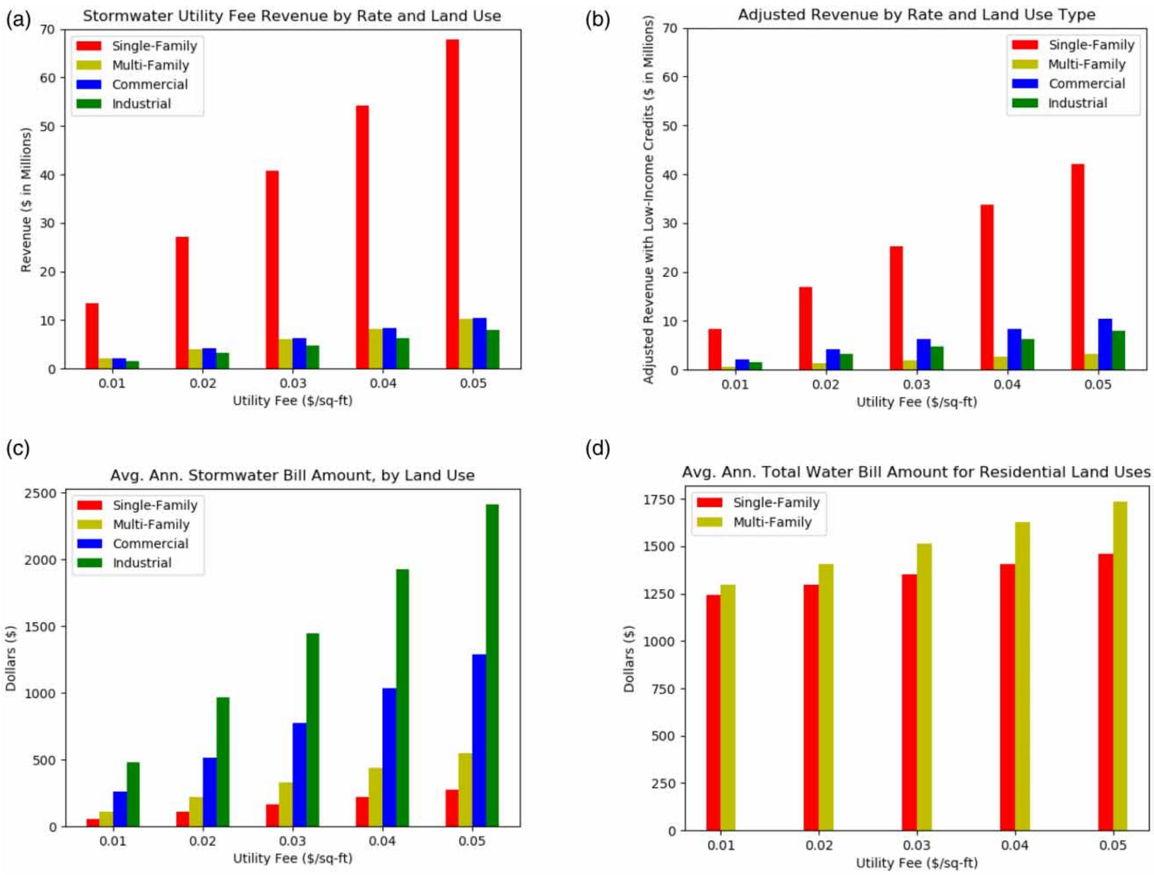

Fig. 2 | Utility revenues and household affordability. (a) Total utility revenue from stormwater utility fees by land-use type and stormwater utility fee rate, (b) adjusted revenue from stormwater utility fees after incorporating low-income fee reductions, (c) average annual stormwater bill amount by land-use type, not including any low-income fee reductions, and (d) average total water bills of residential properties (not including any low-income fee reductions) for varying stormwater utility fee rates. Data for these graphs are provided in Tables S2–S4 in the Supplementary Data section.

significantly below $10,000 would be deemed as having an unaffordable stormwater utility fee, which equates to approximately 5000 households.

Figure 4 illustrates total water bills across income groups. Bills for drinking water and sewer services are the main drivers of household affordability. This is evidenced by the relatively small difference in the RI between the highest and lowest stormwater utility fee rates. For all stormwater fee rates, lower-income communities with an MHI of approximately $25,000 would exceed the 5% RI threshold. The majority of households exceed the 1% RI threshold. Tables S5 and S6 in the Supplementary Data section provide more detailed reporting of values associated with Figures 3 and 4.

The total annual revenue from stormwater utility fees ranges from $18 million to 90 million after adjusting for assumed low-income assistance grants (Figure 2(b)). By comparison, recent stormwater spending by local governments in the region was estimated to be $62 million. This value was based on best available data compiled from reporting over several years, which was normalized to 2018 dollars (EFC at Sacramento State, 2020). Based on this total, local governments would need a utility fee rate of at least $0.03/sq-ft to generate revenues in the range

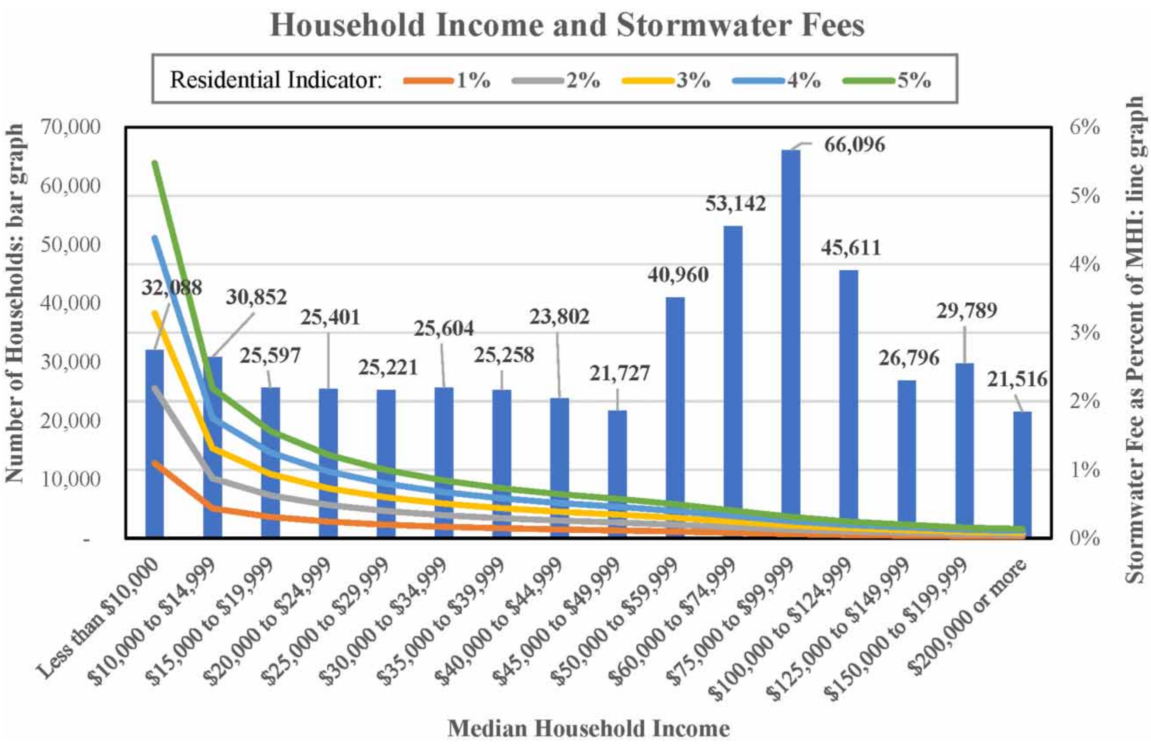

Fig. 3 | Evaluating stormwater bills by RI thresholds across the distribution of MHIs. Drinking water and sewer bills are the main drivers of household affordability, especially low-income residents.

of reported costs. The reported expenditures do not necessarily represent fully funded municipal programs. Such estimates are not available.

DISCUSSION

The analysis answered two key research questions. First, the financial burden of stormwater fees in relation to MHI is relatively small in comparison to water supply and wastewater charges. It does not exceed 4–5% in all but the lowest-income groups (Figure 3). Changing the stormwater utility fee rate does not change the RI significantly. Water and wastewater fees have a greater impact on affordability across income brackets (Figure 4). Given that the stormwater utility fee rates were based on rates typical in many U.S. communities, this finding is a reasonable estimate of effects. Second, household affordability impacts are most substantial for households with incomes less than $20,000. This value is significantly below median income levels (approximately $65,000) in the case study area. For households making over $30,000 annually, any of the modeled stormwater utility fee rates ($0.01–0.05/sq-ft) would consistently represent less than 1% of the total household income. For those below the $20,000 income threshold, however, stormwater utility fees can exceed 2% of the MHI depending upon the income bracket.

Implementation strategies for income-based assistance programs in stormwater is a topic that needs further research. Income-based assistance programs are common in other resource sectors such as electricity and sometimes found in the water management sector. For example, the California Water Service low-income credit assistance program for household water supply provides a discounted fee to households meeting income

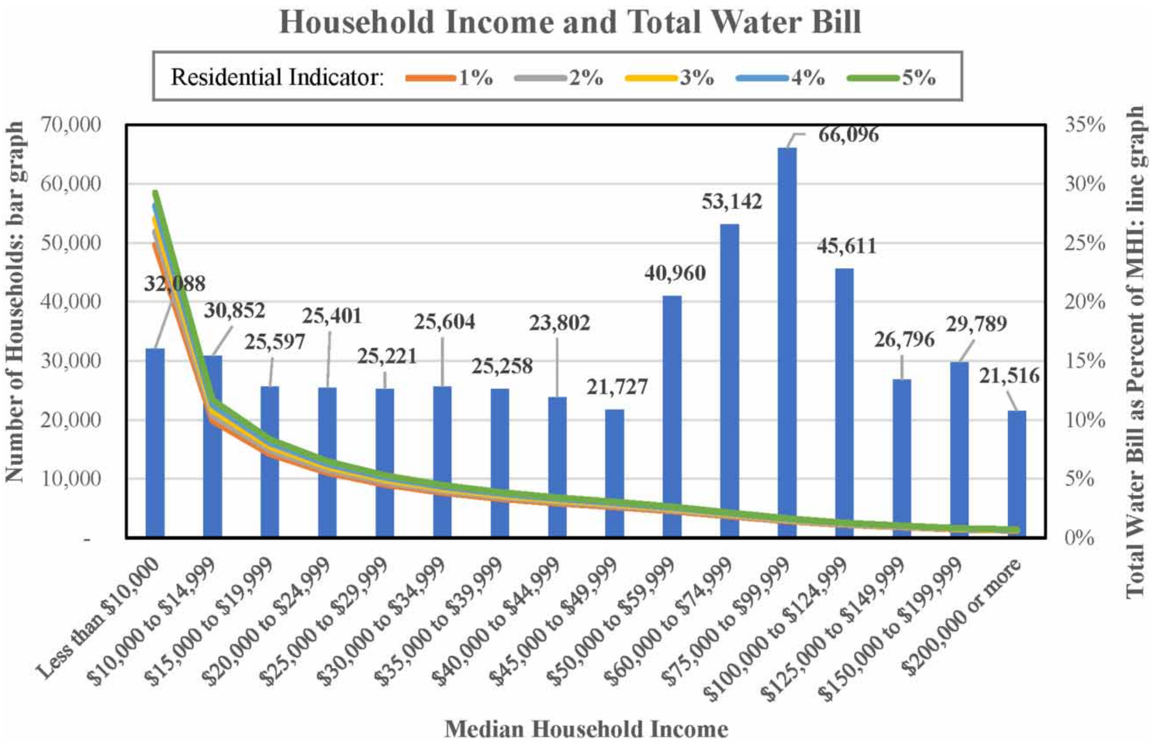

Fig. 4 | Evaluating total water bills by RI thresholds across the distribution of MHIs. Drinking water and sewer bills are the main drivers of household affordability, especially low-income residents.

eligibility requirements based on the household size (Table 4). Income-based assistance programs typically use a variety of approaches. Lower bills could come through exemptions from certain charges, a discount on a fixed rate charge on a bill, or a lump-sum credit (monthly or annually) provided to households to offset the billed cost-of-services. Another option for providing income-based relief is to include a 'zero-rate' style exemption (EFC at Sacramento State, 2019). In this structure, a tier or specific type of customer or property is charged at a zero rate.

Table 4 | Example of a Low-Income Credit Program Eligibility Scale from a water supply utility (*Source*: California Water Service Company 2018).

Household size	Total combined annual income cannot exceed
1–2	$32,920
3	$41,560
4	$50,200
5	$58,840
6	$67,480
7	$76,480
8	$84,760

In contrast, for stormwater management, many existing discounts tend to be rebates that incentivize desired actions, such as disconnecting downspouts or installing rain barrels. To adopt assistance programs that target low-income households related to stormwater utility fees, a rate structure could adopt a zero-rate tier with some threshold of impervious surface cover being assessed as no charge, or offer residents the opportunity to apply for income-qualifying fee assistance if they can provide documentation illustrating financial need. Multi-family properties also present a particular case, as residents share equally in the benefits provided by the stormwater infrastructure. Residents located in a multi-family residence within an area with qualifying income might share an income deduction based on a standard rate or amount. However, mixed use and central business districts with residents could present challenges in applying this approach.

The analysis is subject to several limitations. First, while the analysis uses high-resolution data, the method does not capture how household incomes change within census block groups. Second, the high-resolution imagery used to evaluate property-level impervious surface cover captures land-cover trends at a particular period in time. It would not necessarily capture rapid changes such as new development in expanding areas. Third, the analysis does not use individual utility bills for other water services (drinking water and wastewater). Instead, it uses average charges for a household based on published rates and, when necessary, assumptions of essential drinking water supply. In some households that, for instance, pay bills based on a variable rate structure, the relative contribution of stormwater fees to overall water service charges could be inaccurate. Households with lower water and sewer service charges based on efficient use would have a higher percentage of the total water bill comprised by stormwater fees, while households with more consumption (such as large families) would have stormwater fees comprise a lower percentage of total water bills. Thus, the analysis does not entirely capture household-level effects using the procedure with averages.

CONCLUSIONS

In this paper, we presented a systematic method to evaluate socioeconomic effects of stormwater utility fees alongside other urban water service charges (from drinking water, wastewater, and flood control) by integrating high-resolution data for a metropolitan area. The evaluation involved large-scale data integration with socioeconomic data, imagery data for land-use and land-cover types, and parcel-level tax assessor data. It ultimately evaluated potential household-level effects of various fees.

In the case study area of Sacramento, total water bills as a percentage of block-group–specific MHI exceed RI thresholds of 2% for income levels below Sacramento's regional MHI of $65,000. Effects are most significant for lower-income residents. For instance, in households with incomes of less than $35,000, total water bills can encompass between 3 and 25% of the household income without any fee reductions. Considered alongside other water service charges, however, stormwater is a small contributor to the overall household-level affordability. In these lower-income groups, stormwater fees comprise no more than 2% of the total household income. Urban water supply and wastewater charges comprise much larger portions of household income. The method can be applied to other communities throughout the U.S. for evaluating the socioeconomic impacts of stormwater utility fees from an integrated perspective that aligns with contemporary 'One Water' goals for urban water management.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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