SUPPLEMENTAL MATERIALS

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Climate-Resilient Sanitary Sewers through Minimized Inflow

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S.1. Application

S.1.1. Design Guidelines Considerations

We reviewed three design codes and guidelines to construct the sanitary sewer model: Brazil (ABNT 1986), South Africa (Department of Human Settlements 2019) and Toronto (Qazi 2021). Two of them, Brazil and South Africa, are country-level documents. However, the third one, Toronto (Canada), is a city-level guideline. Brazil has two different design codes, one for the collection network design and another only for interceptors' pipes. This study only analyzed the guideline for designing the sanitary sewer collection network.

In all three guidelines, the sanitary sewage flow is a function of the projected population at the end of the infrastructure lifetime, g(T), and the peak sewage production, $S_{p.p}$. The peak sewage production is the average sewage production per capita, S_p, magnified by a peak factor, p_f. The peak factor, p_f, is a fixed value in Brazil and South Africa guidelines. However, in Toronto's guideline, the peak factor is a function of the final population calculated using the Harmon equation to estimate the peak flow to average flow (see Table S1).

The approach for considering inflow and infiltration is different in each guideline. Brazilian guideline for collector sewers does not mention the contribution of stormwater inflow; the groundwater infiltration is the product of the total upstream length of the network and an infiltration load, μ (ABNT 1986). South Africa considers inflow and infiltration separately (Department of Human Settlements 2019). The stormwater inflow is a percentage of the pipe's total required capacity when flowing full. The groundwater infiltration flow is estimated as the product of the total upstream pipe's lengths, the designed pipe diameter, and an infiltration load, μ. For Toronto, inflow and infiltration are considered together: the infiltration and inflow combined flow rate is a function of the upstream area served by the sewer (Qazi 2021). See Table S1 for each guideline's infiltration load, μ.

To understand the influence of our use of three guidelines instead of only Brazil’s we repeated our analysis using only Brazil’s guidelines. The result is shown in Fig. S1.

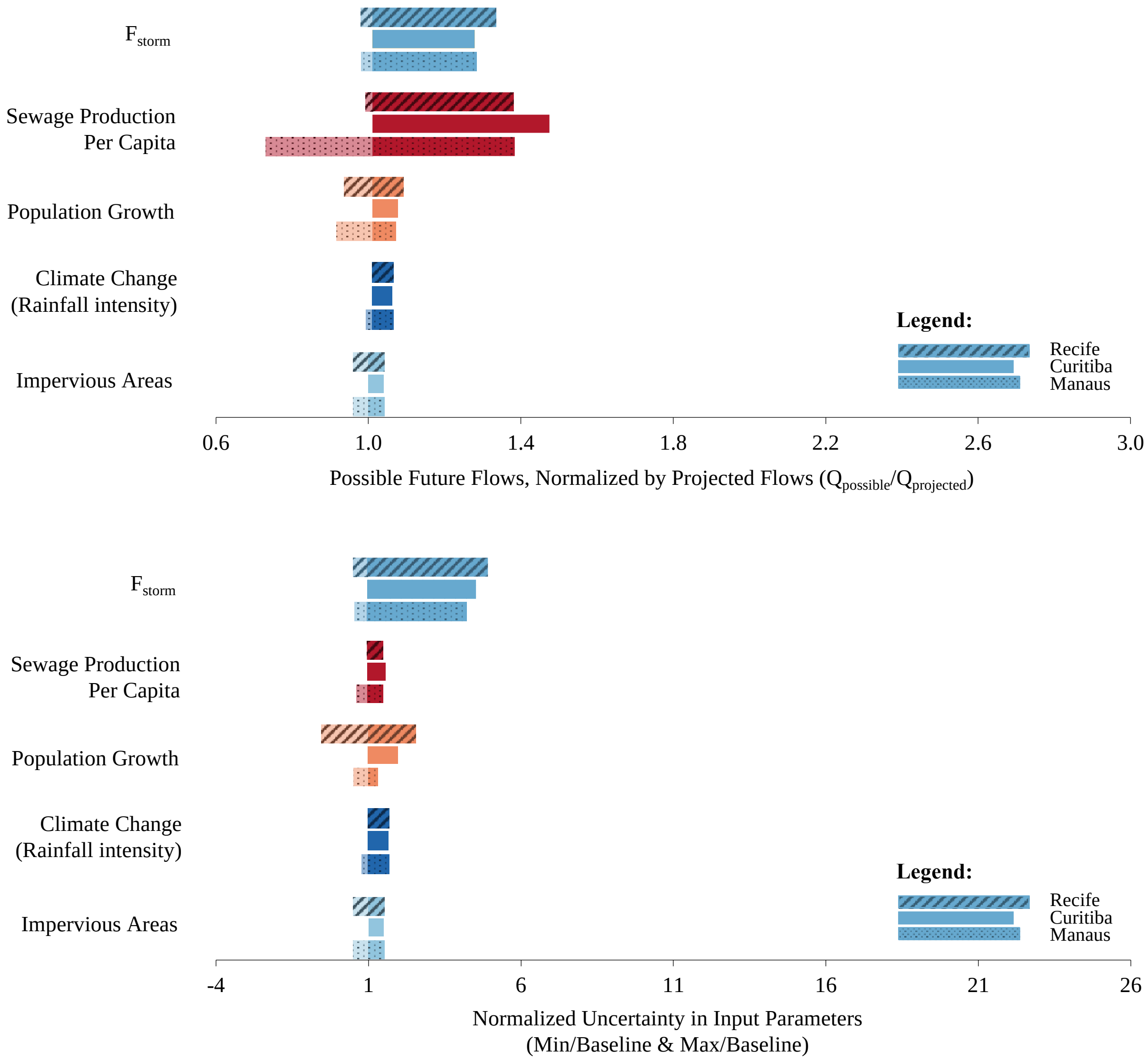


Fig. S1.The effects of uncertain input parameters on possible future flows using only Brazilian guidelines to calculate the min-max range of potential $F_{\text{storm-projected}}$. Similar to Fig. 3 in the main text: (a) One-way sensitivity analysis depicts the range of possible future flows that would result if each input parameter took on its maximum or minimum, normalized by the projected flows in the baseline case for Curitiba (top), Manaus (middle), and Recife (bottom) in 2050; (b) normalized uncertainty in each input parameter, normalized by the baseline estimate for Curitiba (top), Manaus (middle), and Recife (bottom). Darker colours (right) correspond to the upper bound (maximum value), and lighter colours to the lower bound (minimum value). Shades of blue correspond to the uncertainties that impact the inflow, and shades of red are the uncertainties that affect the sewage flow (Eq. 1 in the main text).

Table S1. Summary of main differences from the three design guidelines reviewed.

	Brazil	**South Africa**	**Toronto**
Peak Factor (p_f)	1.8	1.8 – 2.5	Using Harmon's formula for the peak factor $1+\frac{14}{4+\sqrt{\frac{P^*}{1000}}}$
Infiltration coefficient (μ)	0.05 - 1 [$L.s^{-1}.km^{-1}$]	0.03 - 0.04 [$L.min^{-1}.m$ $pipe^{-1}$. m $diameter^{-1}$]	0.26 [$L.s^{-1}$.gross ha^{-1}]
Inflow (Q_{inflow})	Not mentioned	30% of the flow of the total full capacity	
Spare Capacity (r)	0.08	0.3	0.2

[*] where P is the final population served by the network

S.1.2. Parameters estimation

Table S2. Intensity-Duration-Frequency (IDF) curve for Recife, Curitiba, Manaus

	IDF	Rainfall intensity[1] (Baseline)	Reference
Recife	$\frac{1423.97\ T_r^{0.1124}}{(t + 21^{0.7721})}$	88	(Weschenfelder et al. 2014)
Curitiba	$\frac{3221.07\ T_r^{0.258}}{(t + 26^{1.01})}$	81	(Fendrich 1989)
Manaus	$\frac{1102.28\ T_r^{0.115}}{(t + 9.8^{0.724})}$	102	(Monteiro and Braga 2018)

[1] Using a Return Period (T_r) of 2 years, and the duration (t) of 20 min.

Table S3. Justification of ranges of values for the five uncertainties considered for Recife

	Min. value (% Change from baseline)	Baseline Projections	Max. value (% Change from baseline)	Justification and Reference
Sewage production per capita ($L.capita^{-1}.day$)	80	82	122	SNIS: Brazilian's National Sanitation Information System (SNIS 2023)for water consumption. Return rate = 0.8 as recommended by Brazilian guidelines (ABNT 1986)
Total Population Growth rate (%)	- 4	+ 7	+ 18	*Baseline:* IBGE (IBGE 2023). *Minimum and Maximum value:* United Nation's World Population Prospects 2019 (United Nations 2019).
F_{storm} (%)	0.005	0.009	0.21	Assumption using different design guidelines (Figure 2a)
Impervious areas (-)	0.3	0.6	0.9	Authors' assumption
Climate change ($mm.h^{-1}$)	88	88	148	*Baseline:* Using the city's IDF (Assuming a t_c = 23.2 min and a return period of 2 years; Weschenfelder et al. 2014). *Minimum value:* assuming a possible decrease of -20% in 2050. *Maximum value:* assuming a possible increase of 68% in 2050.

Table S4. Justification of ranges of values for the five uncertainties considered for Curitiba

	Min. value (% Change from baseline)	**Baseline Projections**	**Max. value (% Change from baseline)**	**Justification and Reference**
Sewage production per capita (L.capita^{-1}.day)	77	108	172	SNIS: Brazilian's National Sanitation Information System (SNIS 2023)for water consumption. Return rate = 0.8 as recommended by Brazilian guidelines (ABNT 1986).
Total Population Growth rate (%)	- 4	+ 9	+ 18	*Baseline:* IBGE (IBGE 2023). *Minimum and Maximum value:* United Nation's World Population Prospects 2019 (United Nations 2019).
F_{storm} (%)	0.008	0.012	0.26	Assumption using different design guidelines (Figure 2b)
Impervious areas (-)	0.3	0.6	0.9	Authors' assumption
Climate change (mm.h^{-1})	65	81	136	*Baseline:* Using the city's IDF (Assuming a t_c = 23.2 min and a return period of 2 years; Fendrich 1989) *Minimum value:* assuming a possible decrease of -20% in 2050. *Maximum value:* assuming a possible increase of 68% in 2050.

Table S5. Justification of ranges of values for the five uncertainties considered for Manaus

	Min. value (% Change from baseline)	Baseline Projections	Max. value (% Change from baseline)	Justification and Reference
Sewage production per capita ($L.capita^{-1}.day$)	56	87	128	SNIS: Brazilian's National Sanitation Information System for water consumption (SNIS 2023). Return rate = 0.8 as recommended by Brazilian guidelines (ABNT 1986).
Total Population Growth rate (%)	+ 17	+ 33	+ 43	*Baseline:* IBGE (IBGE 2023). *Minimum and Maximum value:* United Nation's World Population Prospects 2019 (United Nations 2019).
F_{storm} (%)	0.006	0.010	0.20	Assumption using different design guidelines (Figure 2c)
Impervious areas (-)	0.3	0.6	0.9	Authors' assumption
Climate change ($mm.h^{-1}$)	82	102	171	*Baseline:* Using the city's IDF (Assuming a t_c = 23.2 min and a return period of 2 years; Monteiro and Braga 2018). *Minimum value:* assuming a possible decrease of -20% in 2050. *Maximum value:* assuming a possible increase of 68% in 2050.

S.1.3. Temporal Uncertainty

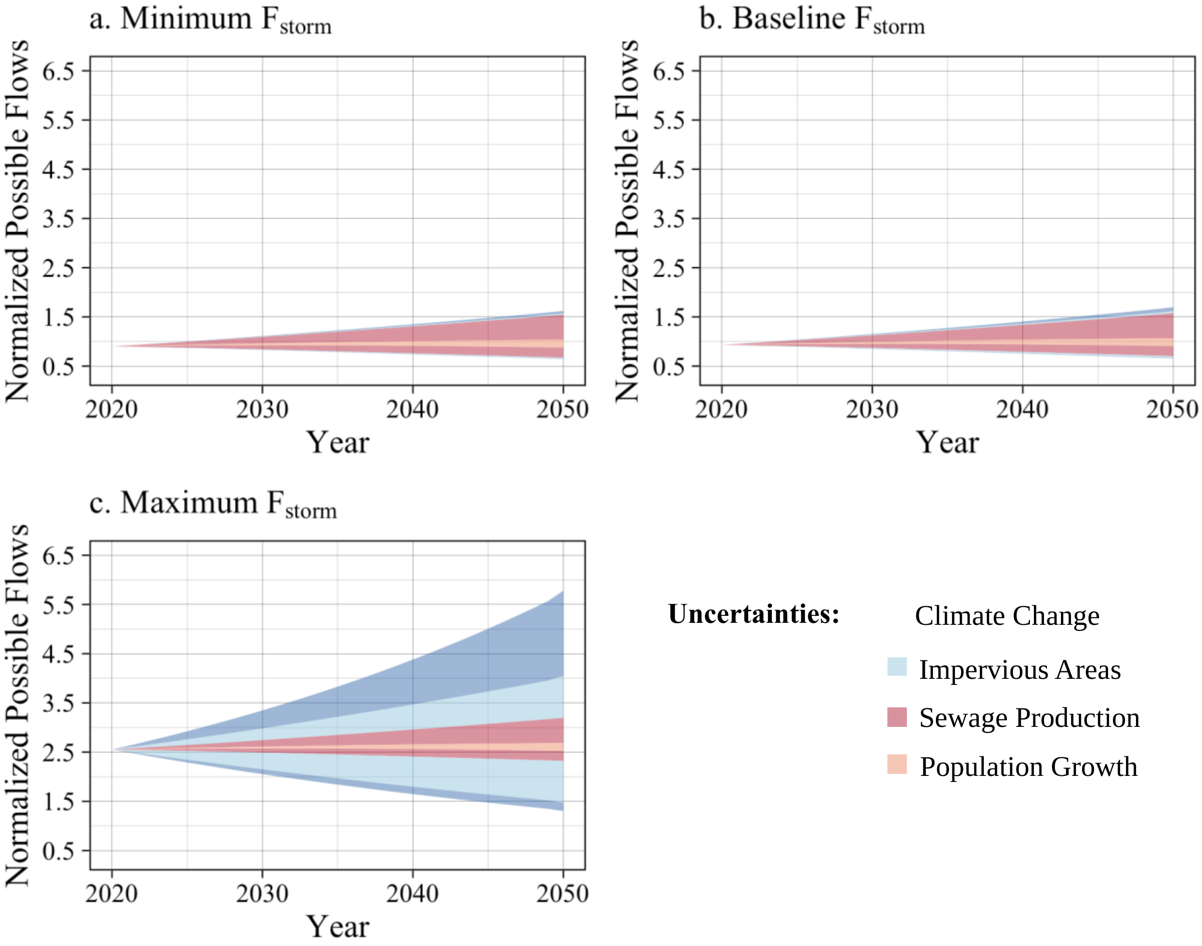
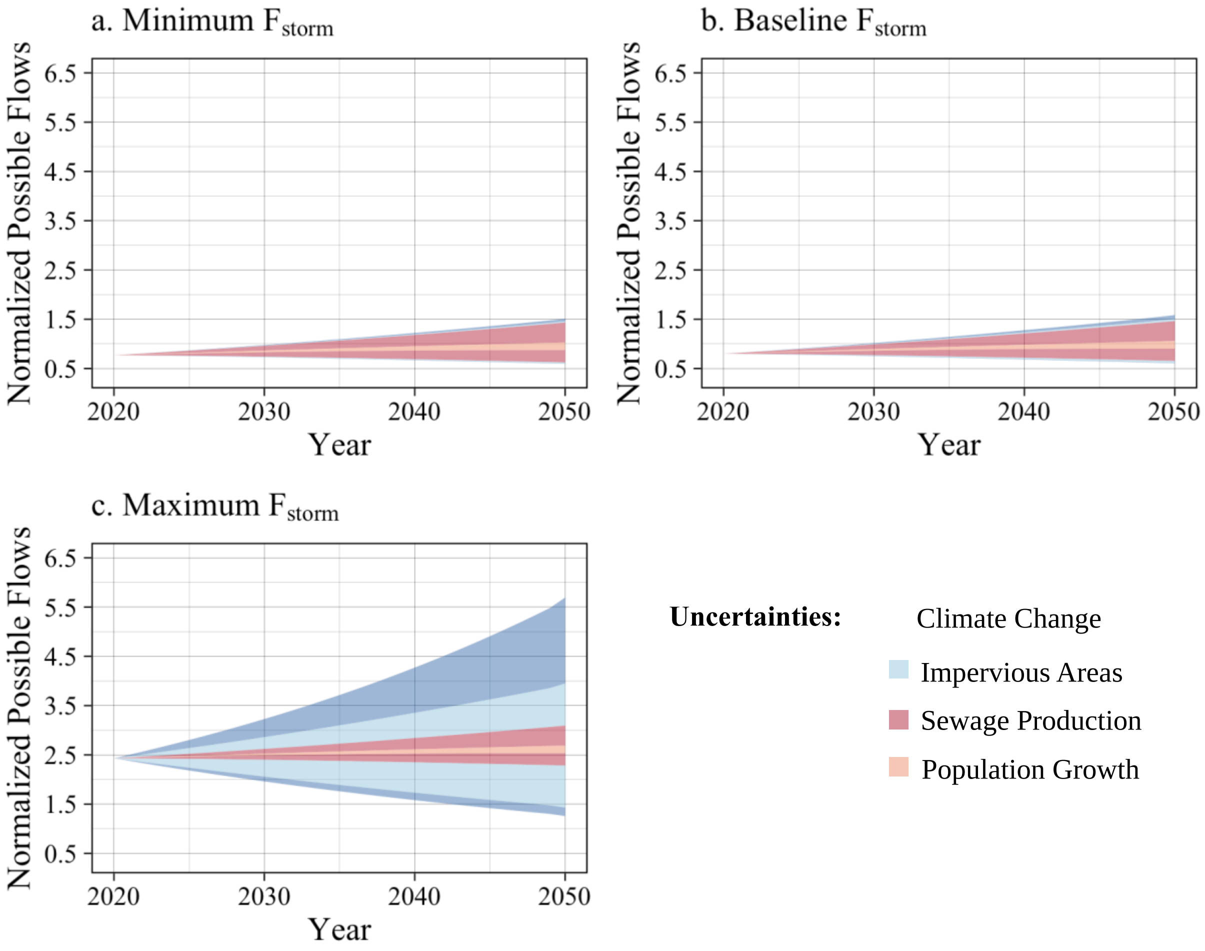


Fig. S2. The value of F_{storm} mediates the effects of other uncertainties over time. For the minimum (a), baseline (b), and maximum (c) possible values of F_{storm}, the results of a one-way sensitivity analysis in each year are superimposed. Uncertainties are shaded: population growth (light orange), sewage production (darker red), impervious areas (light blue) and climate change (dark blue). The time evolution is shown for Curitiba (from 2020- 2050).



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