water

Reducing High Flows and Sediment Loading through Increased Water Storage in an Agricultural Watershed of the Upper Midwest, USA

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Introduction

The supplementary information provided in this document includes: (1) maps detailing our contributing-area measurements (Figure S1) and contributing-area relationships (Figure S2); (2) graphs of parameters for the generalized flow-reduction equation (Equation (4)) with either water retention site (WRS) placement scenarios represented by color (Figure S3) or regression R^2 values represented by color (Figure S4); (3) examples showing the accuracy of the generalized flow-reduction equation for depths of 1 m and K = 0.36 or 0.036 mm/h (Figures S5 and S6); (4) projected reductions in sediment loading for scenarios with WRS design depths of 0.5 m (Figure S7) and 2 m (Figure S8); (5) Gauged and Soil and Water Assessment Tool (SWAT)-predicted daily flows used for the "2005–2009" sediment loads shown in Table 2 (Figure S9); (6) flow-reduction regressions for each exceedance probability bin, with WRS placement throughout the entire watershed (Tables S1–S5), in the upper watershed (Tables S6–S10), and in the lower watershed (Tables S11–S15); (7) baseline average normalized discharge values binned by exceedance probability (Table S16); and (8) generalized flow-reduction equation parameters (Equation (4); Tables S17–S19).

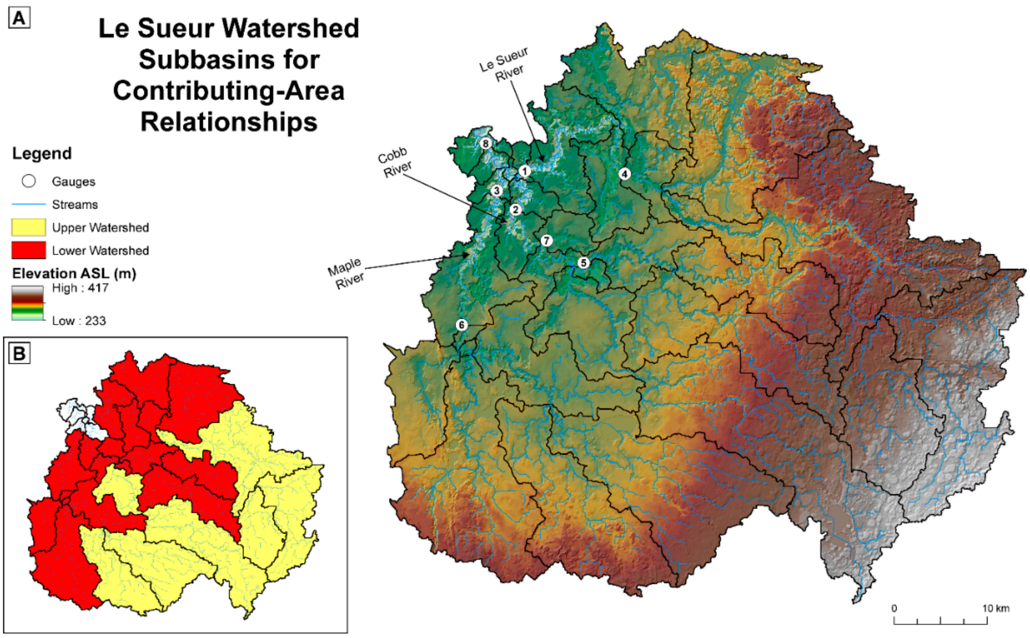

Figure S1. (**A**) Sub-basins used for our contributing-area relationship (Figure 3). Gauge numbers correspond with those in Table 1. (**B**) Selections of these sub-basins were used to define the water retention site (WRS) placement scenarios.

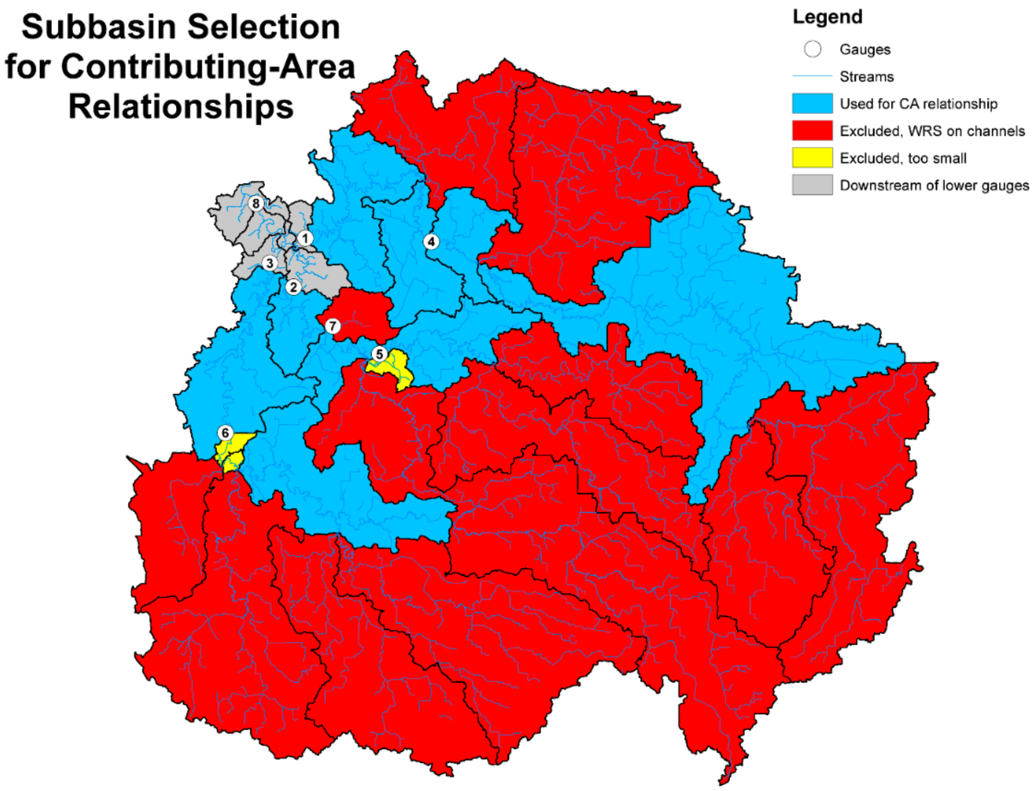

Figure S2. Sub-basin selection for our contributing-area relationship (Figure 3).

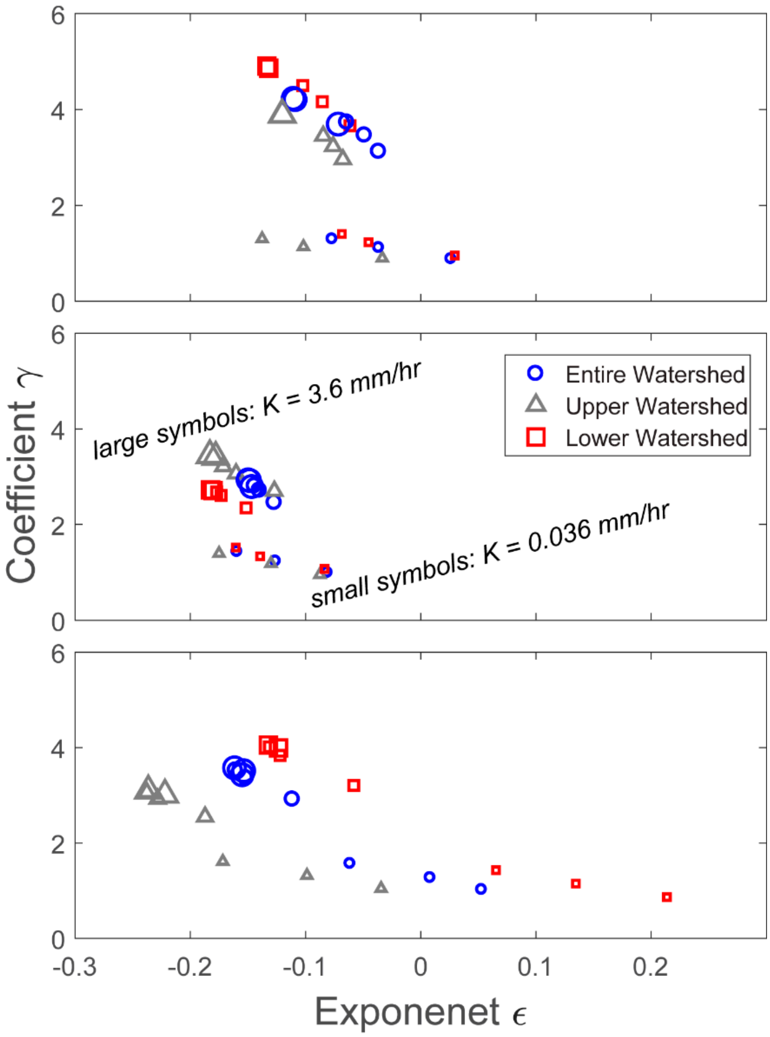

Figure S3. All values of coefficient γ and exponent ε (Equation (4)) for all rivers' WRS scenarios. Note that these regression parameters were creating with data for the probability bin of $10^{1.5}$% (~32%) to 10^{2}% excluded. Here, small, medium, and large symbols represent K = 0.036, 0.37, and 3.6 mm/h, respectively. All WRS depth scenarios are included. All Equation (4) parameters are available in Tables S17–S19.

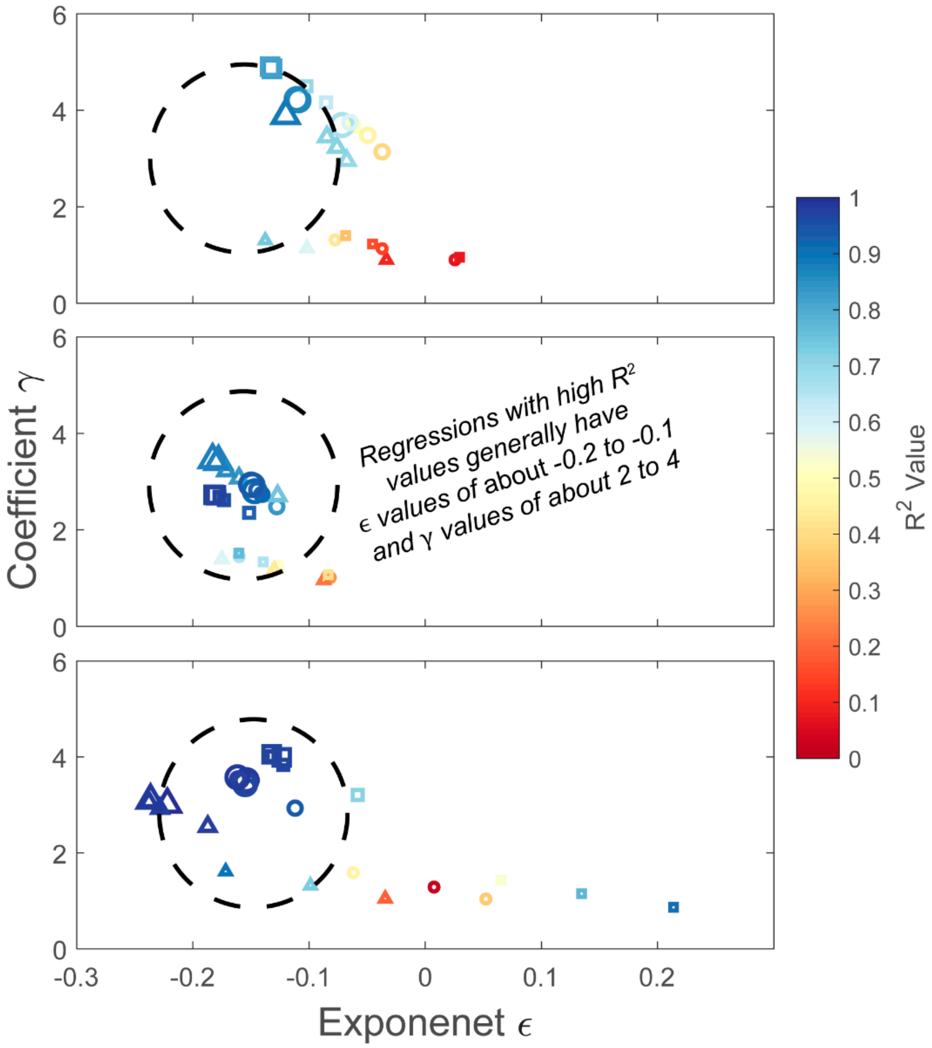

Figure S4. All values of coefficient γ and exponent ε values (Equation (4)) color labeled by the regression's R^2 value. Regressions with high R^2 values generally have ε values of about −0.2 to −0.1 and γ values of about 2–4, as shown on each graph. Note that these regression parameters were creating with data for the probability bin of $10^{1.5}$% (~32%) to 10^2% excluded. Here, small, medium, and large symbols represent $K = 0.036$, 0.36, and 3.6 mm/h, respectively. WRS placement scenarios are represented by symbol shape (see Figure S3). All WRS depth scenarios are included. All Equation (4) parameters are available in Tables S17–S19.

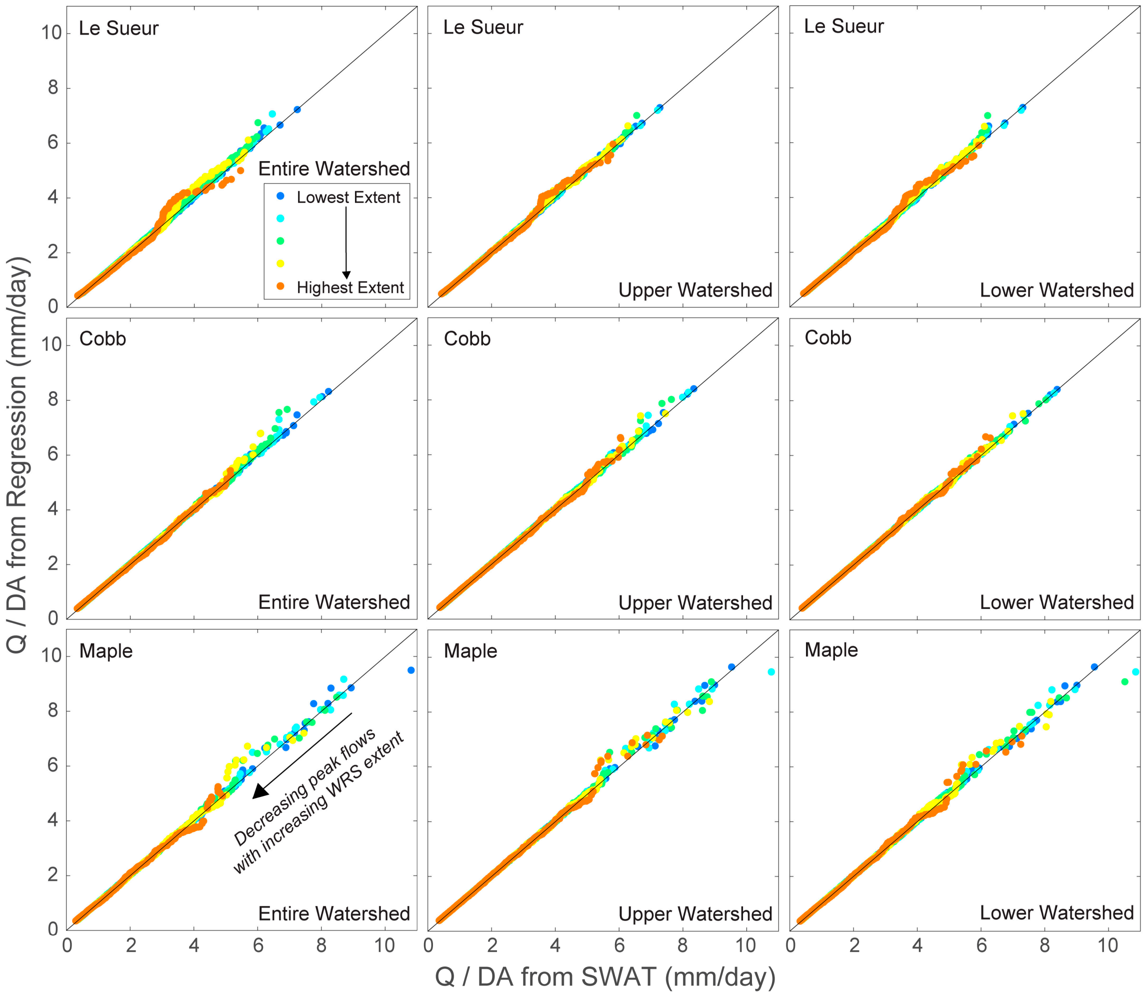

Figure S5. WRS implementation scenarios' normalized discharge values (*Q*/*DA*) created using Equation (4) relative to Soil and Water Assessment Tool (SWAT)-projected flows. Here, all scenarios use design depths of 1 m and *K* = 0.36 mm/h, the medium *K* value assessed here. Results are quite similar to those for *K* = 3.6 mm/h (Figure 8). The SWAT results from all nine of these scenarios are predicted almost perfectly, as shown by the 1:1 line in black. Compare with Figures 8 and S6.

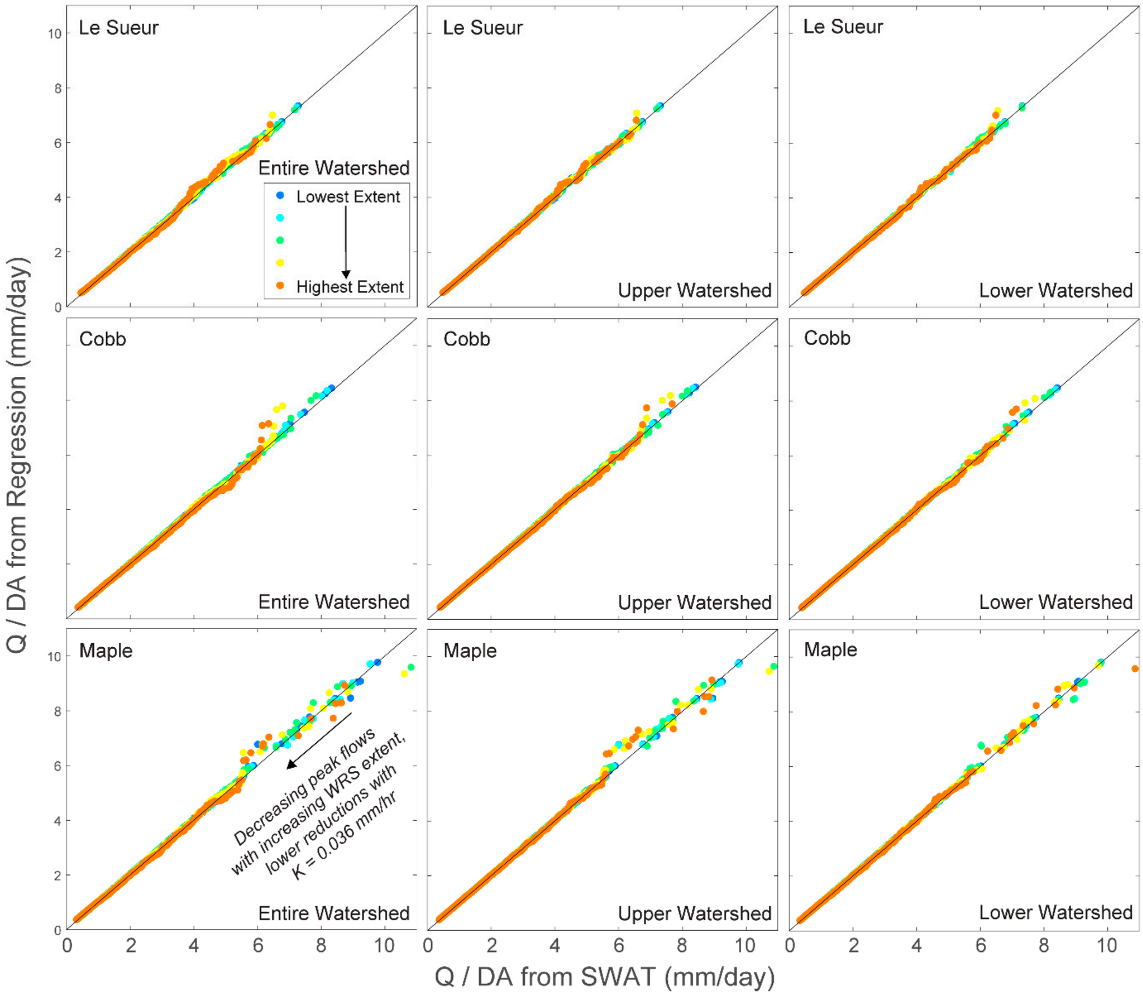

Figure S6. WRS implementation scenarios' normalized discharge values (*Q*/*DA*) created using Equation (4) relative to SWAT-projected flows. Here, all scenarios use design depths of 1 m and K = 0.036 mm/h, the lowest K value assessed here. Peak flow reductions are lower for these scenarios than for those using higher K values (Figures 8 and S5). Despite the lower R^2 values for regressions applied to scenarios using K = 0.036 mm/h (Figures 7 and S4), the SWAT results from all nine of these scenarios are still predicted almost perfectly, as shown by the 1:1 line in black. Compare with Figures 8 and S5.

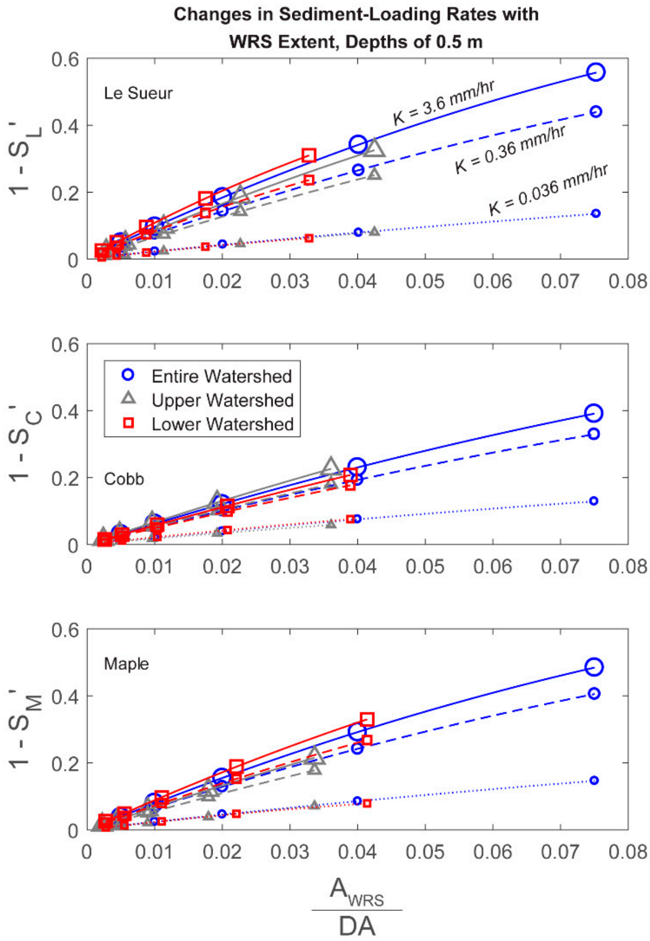

Figure S7. Sediment-loading reductions vs. WRS extent (A_{WRS}/DA) for design depths of 0.5 m. Polynomial regressions are shown for each scenario. Note that these sediment-loading rates only represents near-channel features in the knickzone (e.g., banks and bluffs). Small symbols and dotted lines are used for K = 0.036 mm/h, medium symbols and dashed lines are used for K = 0.36 mm/h, and large symbols and solid lines are used for K = 3.6 mm/h. Compare with Figures 9 and S8.

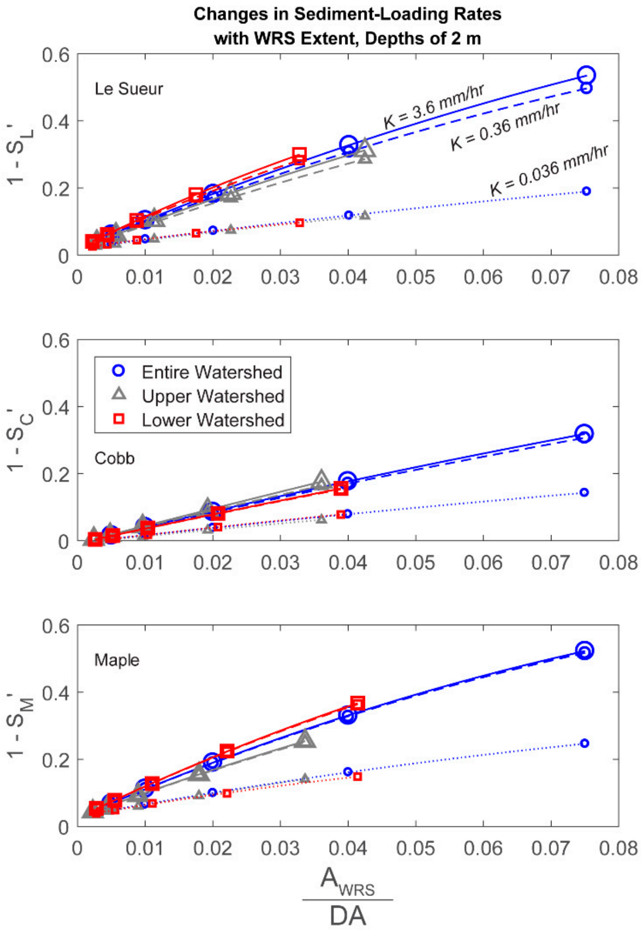

Figure S8. Sediment-loading reductions vs. WRS extent (A_{WRS}/DA) for design depths of 2 m. Note that these sediment-loading rates only represents near-channel features in the knickzone (e.g., banks and bluffs). Polynomial regressions are shown for each scenario. Small symbols and dotted lines are used for K = 0.036 mm/h, medium symbols and dashed lines are used for K = 0.36 mm/h, and large symbols and solid lines are used for K = 3.6 mm/h. Compare with Figures 9 and S7.

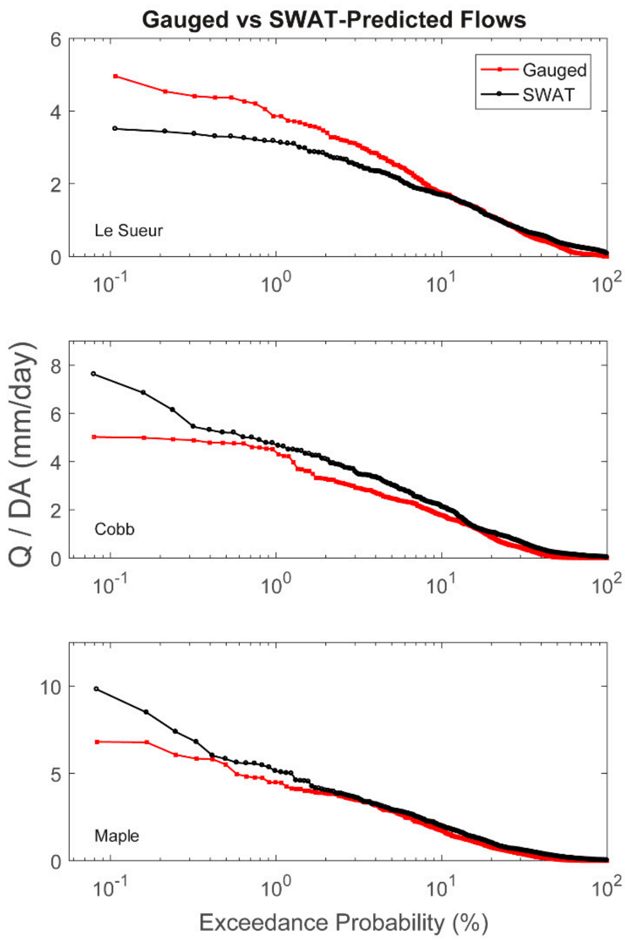

Figure S9. Gauged and SWAT-predicted flows normalized by drainage area (*Q*/*DA*) at gauges 1–3 (Figure 2) on the Le Sueur, Cobb, and Maple Rivers (**top**, **middle**, and **bottom**, respectively) used for the "2005–2009" sediment-loading rates in Table 2. Note, however, that the Cobb and Maple Rivers' data extends from 2005 to 2009, while the Le Sueur River's data extends from 2006 to 2009. Because of limited gauging records, average daily discharge values were selected only from days with gauged flows.

Table S1. Flow-reduction regressions for the top 0.1% of flows, WRS placement throughout the entire watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	4.95E+00	2.29E+01	3.97E+01	9.42E−01	9.36E−01	9.57E−01
	1	7.84E+00	2.51E+01	2.93E+01	9.84E−01	9.06E−01	7.37E−01
	2	1.05E+01	2.82E+01	4.01E+01	9.34E−01	9.18E−01	9.53E−01
Cobb	0.5	1.27E+01	3.12E+01	3.69E+01	9.75E−01	9.77E−01	9.39E−01
	1	1.78E+01	3.41E+01	3.57E+01	9.74E−01	9.54E−01	9.07E−01
	2	2.27E+01	3.54E+01	3.72E+01	9.61E−01	9.46E−01	9.32E−01
Maple	0.5	7.67E+00	3.77E+01	5.15E+01	9.51E−01	9.98E−01	9.94E−01
	1	1.08E+01	5.08E+01	5.15E+01	9.87E−01	9.90E−01	9.83E−01
	2	1.80E+01	5.38E+01	5.42E+01	9.87E−01	9.93E−01	9.93E−01

Table S2. Flow-reduction regressions for flows with exceedance probabilities of 0.1%–1%, WRS placement throughout the entire watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	4.86E+00	1.58E+01	2.26E+01	9.94E−01	9.91E−01	9.89E−01
	1	6.47E+00	1.93E+01	2.04E+01	9.90E−01	9.91E−01	9.51E−01
	2	7.77E+00	2.14E+01	2.28E+01	9.94E−01	9.87E−01	9.89E−01
Cobb	0.5	4.23E+00	1.35E+01	1.79E+01	9.70E−01	9.97E−01	9.99E−01
	1	5.83E+00	1.63E+01	1.67E+01	9.80E−01	9.99E−01	9.90E−01
	2	7.23E+00	1.72E+01	1.81E+01	9.92E−01	9.99E−01	9.99E−01
Maple	0.5	4.62E+00	1.54E+01	1.94E+01	9.75E−01	9.81E−01	9.85E−01
	1	6.27E+00	1.80E+01	1.85E+01	9.62E−01	9.85E−01	9.67E−01
	2	7.62E+00	1.95E+01	1.97E+01	9.63E−01	9.86E−01	9.87E−01

Table S3. Flow-reduction regressions for flows with exceedance probabilities of 1%–10%, WRS placement throughout the entire watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	1.28E+00	5.07E+00	6.35E+00	9.96E−01	1.00E+00	9.99E−01
	1	1.54E+00	5.57E+00	5.75E+00	9.97E−01	1.00E+00	9.94E−01
	2	1.72E+00	5.94E+00	6.38E+00	9.97E−01	1.00E+00	9.99E−01
Cobb	0.5	1.63E+00	4.56E+00	5.39E+00	9.98E−01	1.00E+00	1.00E+00
	1	1.94E+00	5.03E+00	5.11E+00	9.97E−01	1.00E+00	9.98E−01
	2	2.18E+00	5.21E+00	5.41E+00	9.96E−01	1.00E+00	1.00E+00
Maple	0.5	1.92E+00	5.42E+00	6.52E+00	9.96E−01	1.00E+00	1.00E+00
	1	2.33E+00	6.16E+00	6.25E+00	9.97E−01	1.00E+00	9.99E−01
	2	2.69E+00	6.45E+00	6.54E+00	9.97E−01	1.00E+00	1.00E+00

Table S4. Flow-reduction regressions for flows with exceedance probabilities of 10%–$10^{1.5}$ (~32)%, WRS placement throughout the entire watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	9.56E−01	2.62E+00	2.84E+00	9.96E−01	1.00E+00	1.00E+00
	1	1.00E+00	2.71E+00	2.74E+00	9.96E−01	1.00E+00	9.99E−01
	2	1.03E+00	2.77E+00	2.85E+00	9.96E−01	1.00E+00	1.00E+00
Cobb	0.5	1.00E+00	1.78E+00	1.87E+00	9.98E−01	1.00E+00	1.00E+00
	1	1.06E+00	1.82E+00	1.83E+00	9.98E−01	1.00E+00	1.00E+00
	2	1.10E+00	1.84E+00	1.88E+00	9.98E−01	1.00E+00	1.00E+00
Maple	0.5	1.10E+00	1.75E+00	1.79E+00	9.98E−01	1.00E+00	1.00E+00
	1	1.17E+00	1.78E+00	1.78E+00	9.98E−01	1.00E+00	1.00E+00
	2	1.21E+00	1.79E+00	1.80E+00	9.98E−01	1.00E+00	1.00E+00

Table S5. Flow-reduction regressions for flows with exceedance probabilities of $10^{1.5}$% (~32%) to 100%, WRS placement throughout the entire watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	6.41E−01	1.30E+00	1.34E+00	9.99E−01	1.00E+00	1.00E+00
	1	6.47E−01	1.31E+00	1.31E+00	9.99E−01	1.00E+00	1.00E+00
	2	6.52E−01	1.32E+00	1.34E+00	9.99E−01	1.00E+00	1.00E+00
Cobb	0.5	3.21E−01	5.10E−01	5.22E−01	1.00E+00	1.00E+00	1.00E+00
	1	3.24E−01	5.11E−01	5.13E−01	1.00E+00	1.00E+00	1.00E+00
	2	3.26E−01	5.14E−01	5.22E−01	1.00E+00	1.00E+00	1.00E+00
Maple	0.5	2.73E−01	3.78E−01	3.80E−01	1.00E+00	9.99E−01	9.99E−01
	1	2.76E−01	3.79E−01	3.79E−01	1.00E+00	9.99E−01	9.99E−01
	2	2.79E−01	3.79E−01	3.80E−01	1.00E+00	9.99E−01	9.99E−01

Table S6. Flow-reduction regressions for the top 0.1% of flows, WRS placement in the upper watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	6.09E+00	2.46E+01	3.75E+01	9.89E−01	9.80E−01	9.76E−01
	1	1.01E+01	2.63E+01	3.76E+01	9.98E−01	9.69E−01	9.76E−01
	2	1.31E+01	2.82E+01	3.76E+01	9.74E−01	9.61E−01	9.76E−01
Cobb	0.5	1.32E+01	3.52E+01	5.23E+01	9.94E−01	9.72E−01	9.91E−01
	1	1.78E+01	4.45E+01	5.41E+01	9.47E−01	9.83E−01	9.91E−01
	2	2.48E+01	4.85E+01	5.41E+01	9.75E−01	9.89E−01	9.91E−01
Maple	0.5	9.46E+00	4.28E+01	5.55E+01	9.23E−01	9.86E−01	9.90E−01
	1	1.54E+01	5.73E+01	6.12E+01	9.37E−01	9.93E−01	9.94E−01
	2	2.61E+01	6.10E+01	6.12E+01	9.78E−01	9.94E−01	9.94E−01

Table S7. Flow-reduction regressions for flows with exceedance probabilities of 0.1%–1%, WRS placement in the upper watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	5.43E+00	1.50E+01	2.19E+01	9.93E−01	9.98E−01	9.99E−01
	1	6.92E+00	1.79E+01	2.20E+01	9.87E−01	9.98E−01	9.99E−01
	2	8.18E+00	2.01E+01	2.20E+01	9.94E−01	9.99E−01	9.99E−01
Cobb	0.5	3.95E+00	1.45E+01	1.96E+01	9.76E−01	9.99E−01	9.99E−01
	1	5.63E+00	1.72E+01	1.98E+01	9.80E−01	9.99E−01	9.99E−01
	2	6.79E+00	1.83E+01	1.98E+01	9.93E−01	9.99E−01	9.99E−01
Maple	0.5	6.29E+00	1.47E+01	1.85E+01	9.93E−01	9.92E−01	9.93E−01
	1	7.96E+00	1.72E+01	1.88E+01	9.74E−01	9.92E−01	9.94E−01
	2	9.40E+00	1.86E+01	1.88E+01	9.83E−01	9.94E−01	9.94E−01

Table S8. Flow-reduction regressions for flows with exceedance probabilities of 1%–10%, WRS placement in the upper watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	1.24E+00	4.64E+00	5.84E+00	9.99E−01	1.00E+00	1.00E+00
	1	1.50E+00	5.05E+00	5.85E+00	1.00E+00	1.00E+00	1.00E+00
	2	1.66E+00	5.35E+00	5.85E+00	1.00E+00	1.00E+00	1.00E+00
Cobb	0.5	1.39E+00	4.76E+00	5.74E+00	9.98E−01	1.00E+00	1.00E+00
	1	1.67E+00	5.23E+00	5.75E+00	9.97E−01	1.00E+00	1.00E+00
	2	1.90E+00	5.43E+00	5.75E+00	9.96E−01	1.00E+00	1.00E+00
Maple	0.5	1.78E+00	4.33E+00	5.16E+00	9.98E−01	1.00E+00	1.00E+00
	1	2.16E+00	4.84E+00	5.19E+00	9.98E−01	1.00E+00	1.00E+00
	2	2.46E+00	5.06E+00	5.19E+00	9.98E−01	1.00E+00	1.00E+00

Table S9. Flow-reduction regressions for flows with exceedance probabilities of 10%–$10^{1.5}$ (~32)%, WRS placement in the upper watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	8.07E−01	2.29E+00	2.51E+00	9.96E−01	9.99E−01	1.00E+00
	1	8.39E−01	2.36E+00	2.51E+00	9.96E−01	1.00E+00	1.00E+00
	2	8.61E−01	2.42E+00	2.51E+00	9.96E−01	1.00E+00	1.00E+00
Cobb	0.5	1.03E+00	2.05E+00	2.20E+00	9.98E−01	1.00E+00	1.00E+00
	1	1.09E+00	2.09E+00	2.20E+00	9.98E−01	1.00E+00	1.00E+00
	2	1.12E+00	2.12E+00	2.20E+00	9.98E−01	1.00E+00	1.00E+00
Maple	0.5	8.21E−01	1.23E+00	1.26E+00	9.99E−01	1.00E+00	1.00E+00
	1	8.61E−01	1.25E+00	1.26E+00	9.99E−01	1.00E+00	1.00E+00
	2	8.84E−01	1.25E+00	1.26E+00	9.99E−01	1.00E+00	1.00E+00

Table S10. Flow-reduction regressions for flows with exceedance probabilities of $10^{1.5}$% (~32%) to 100%, WRS placement in the upper watershed.

River	Depth (m)	Q_{reduc} / A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	5.88E−01	1.24E+00	1.28E+00	9.98E−01	1.00E+00	1.00E+00
	1	5.92E−01	1.25E+00	1.28E+00	9.98E−01	1.00E+00	1.00E+00
	2	5.95E−01	1.25E+00	1.28E+00	9.98E−01	1.00E+00	1.00E+00
Cobb	0.5	3.93E−01	7.06E−01	7.32E−01	9.99E−01	1.00E+00	1.00E+00
	1	3.95E−01	7.09E−01	7.32E−01	9.99E−01	1.00E+00	1.00E+00
	2	3.97E−01	7.15E−01	7.32E−01	9.99E−01	1.00E+00	1.00E+00
Maple	0.5	2.42E−01	3.49E−01	3.50E−01	1.00E+00	1.00E+00	1.00E+00
	1	2.44E−01	3.49E−01	3.50E−01	1.00E+00	1.00E+00	1.00E+00
	2	2.45E−01	3.49E−01	3.50E−01	1.00E+00	1.00E+00	1.00E+00

Table S11. Flow-reduction regressions for the top 0.1% of flows, WRS placement in the lower watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	6.09E+00	2.99E+01	4.94E+01	8.98E−01	9.09E−01	9.25E−01
	1	1.05E+01	3.50E+01	4.98E+01	9.16E−01	8.78E−01	9.22E−01
	2	1.26E+01	3.94E+01	4.98E+01	9.21E−01	8.91E−01	9.22E−01
Cobb	0.5	1.24E+01	3.12E+01	3.77E+01	9.90E−01	9.97E−01	9.98E−01
	1	1.91E+01	3.62E+01	3.82E+01	9.97E−01	9.98E−01	9.98E−01
	2	2.24E+01	3.70E+01	3.82E+01	9.94E−01	9.98E−01	9.98E−01
Maple	0.5	3.22E+00	3.14E+01	5.01E+01	3.39E−01	9.84E−01	9.90E−01
	1	5.63E+00	4.96E+01	5.31E+01	5.48E−01	9.92E−01	9.91E−01
	2	9.26E+00	5.26E+01	5.31E+01	7.36E−01	9.91E−01	9.91E−01

Table S12. Flow-reduction regressions for flows with exceedance probabilities of 0.1%–1%, WRS placement in the lower watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	4.27E+00	1.89E+01	2.83E+01	9.99E−01	9.98E−01	9.97E−01
	1	5.71E+00	2.40E+01	2.89E+01	9.93E−01	9.97E−01	9.97E−01
	2	6.95E+00	2.72E+01	2.89E+01	9.91E−01	9.97E−01	9.97E−01
Cobb	0.5	5.36E+00	1.39E+01	1.78E+01	9.83E−01	9.94E−01	9.96E−01
	1	6.90E+00	1.65E+01	1.79E+01	9.86E−01	9.95E−01	9.96E−01
	2	8.53E+00	1.75E+01	1.79E+01	9.89E−01	9.96E−01	9.96E−01
Maple	0.5	4.04E+00	1.87E+01	2.38E+01	9.72E−01	9.88E−01	9.91E−01
	1	5.89E+00	2.18E+01	2.40E+01	9.56E−01	9.87E−01	9.91E−01
	2	7.42E+00	2.37E+01	2.40E+01	9.51E−01	9.90E−01	9.91E−01

Table S13. Flow-reduction regressions for flows with exceedance probabilities of 1%–10%, WRS placement in the lower watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	1.34E+00	5.44E+00	6.69E+00	9.94E−01	1.00E+00	1.00E+00
	1	1.60E+00	6.03E+00	6.71E+00	9.95E−01	1.00E+00	1.00E+00
	2	1.82E+00	6.40E+00	6.71E+00	9.95E−01	1.00E+00	1.00E+00
Cobb	0.5	1.81E+00	4.34E+00	4.94E+00	9.98E−01	1.00E+00	1.00E+00
	1	2.14E+00	4.78E+00	4.95E+00	9.97E−01	1.00E+00	1.00E+00
	2	2.39E+00	4.91E+00	4.95E+00	9.97E−01	1.00E+00	1.00E+00
Maple	0.5	2.04E+00	6.19E+00	7.39E+00	9.95E−01	1.00E+00	1.00E+00
	1	2.45E+00	7.03E+00	7.40E+00	9.94E−01	1.00E+00	1.00E+00
	2	2.84E+00	7.32E+00	7.40E+00	9.95E−01	1.00E+00	1.00E+00

Table S14. Flow-reduction regressions for flows with exceedance probabilities of 10%–$10^{1.5}$ (~32)%, WRS placement in the lower watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	1.15E+00	2.99E+00	3.19E+00	9.96E−01	1.00E+00	1.00E+00
	1	1.21E+00	3.07E+00	3.19E+00	9.96E−01	1.00E+00	1.00E+00
	2	1.26E+00	3.13E+00	3.19E+00	9.96E−01	1.00E+00	1.00E+00
Cobb	0.5	9.86E−01	1.53E+00	1.56E+00	9.99E−01	1.00E+00	1.00E+00
	1	1.05E+00	1.55E+00	1.56E+00	9.99E−01	1.00E+00	1.00E+00
	2	1.09E+00	1.56E+00	1.56E+00	9.99E−01	1.00E+00	1.00E+00
Maple	0.5	1.33E+00	2.16E+00	2.21E+00	9.98E−01	1.00E+00	1.00E+00
	1	1.42E+00	2.19E+00	2.21E+00	9.98E−01	1.00E+00	1.00E+00
	2	1.47E+00	2.20E+00	2.21E+00	9.98E−01	1.00E+00	1.00E+00

Table S15. Flow-reduction regressions for flows with exceedance probabilities of $10^{1.5}$% (~32%) to 100%, WRS placement in the lower watershed.

River	Depth (m)	Q_{reduc}/A_{WRS} (mm/day)			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	6.92E−01	1.35E+00	1.38E+00	9.99E−01	1.00E+00	1.00E+00
	1	7.01E−01	1.36E+00	1.38E+00	9.99E−01	1.00E+00	1.00E+00
	2	7.07E−01	1.36E+00	1.38E+00	9.99E−01	1.00E+00	1.00E+00
Cobb	0.5	2.43E−01	3.10E−01	3.10E−01	1.00E+00	1.00E+00	1.00E+00
	1	2.47E−01	3.10E−01	3.10E−01	1.00E+00	1.00E+00	1.00E+00
	2	2.49E−01	3.10E−01	3.10E−01	1.00E+00	1.00E+00	1.00E+00
Maple	0.5	2.89E−01	3.86E−01	3.89E−01	1.00E+00	9.99E−01	9.99E−01
	1	2.93E−01	3.87E−01	3.89E−01	1.00E+00	9.99E−01	9.99E−01
	2	2.96E−01	3.87E−01	3.89E−01	1.00E+00	9.99E−01	9.99E−01

Table S16. Baseline average normalized discharge values for each river and each exceedance probability group. Data are taken at gauges 1, 2, and 3 for the Le Sueur, Cobb, and Maple, respectively.

Exceedance Probability Range	<0.1%	≥0.1% and <1%	≥1% and <10%	≥10% and <$10^{1.5}$%	≥$10^{1.5}$%
Exceedance Probability of Bin Center	3.16E−02	3.16E−01	3.16E+00	1.78E+01	5.62E+01
Le Sueur's average $Q_{b\,avg}/DA$ (mm/day)	7.33E+00	5.20E+00	2.53E+00	8.91E−01	1.22E−01
Cobb's average $Q_{b\,avg}/DA$ (mm/day)	6.48E+00	4.47E+00	2.02E+00	8.42E−01	2.08E−01
Maple's average $Q_{b\,avg}/DA$ (mm/day)	8.38E+00	4.83E+00	2.31E+00	7.65E−01	1.06E−01

Table S17. Equation (4) parameters, WRS placement throughout the entire watershed with the $10^{1.5}$% (~32%) to 100% exceedance probability bin excluded. Data for the Le Sueur, Cobb, and Maple Rivers are taken at gauges 1, 2, and 3, respectively.

River	Depth (m)	Coefficient γ			Exponent ε			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	8.83E−01	3.12E+00	4.19E+00	2.63E−02	−3.65E−02	−1.08E−01	6.69E−02	3.87E−01	8.71E−01
	1	1.12E+00	3.46E+00	3.68E+00	−3.64E−02	−4.88E−02	−7.09E−02	1.35E−01	4.61E−01	6.69E−01
	2	1.30E+00	3.73E+00	4.22E+00	−7.68E−02	−6.41E−02	−1.10E−01	4.26E−01	5.89E−01	8.74E−01
Cobb	0.5	9.94E−01	2.46E+00	2.91E+00	−8.10E−02	−1.27E−01	−1.48E−01	2.68E−01	8.35E−01	9.41E−01
	1	1.23E+00	2.72E+00	2.78E+00	−1.26E−01	−1.40E−01	−1.46E−01	5.20E−01	9.17E−01	9.23E−01
	2	1.43E+00	2.81E+00	2.92E+00	−1.59E−01	−1.44E−01	−1.49E−01	6.62E−01	9.34E−01	9.42E−01
Maple	0.5	1.02E+00	2.91E+00	3.50E+00	5.29E−02	−1.11E−01	−1.53E−01	3.60E−01	9.39E−01	9.89E−01
	1	1.27E+00	3.37E+00	3.41E+00	8.28E−03	−1.52E−01	−1.54E−01	1.77E−02	9.68E−01	9.75E−01
	2	1.57E+00	3.52E+00	3.56E+00	−6.13E−02	−1.61E−01	−1.61E−01	4.62E−01	9.84E−01	9.86E−01

Table S18. Equation (4) parameters, WRS placement in the upper watershed with the $10^{1.5}$% (~32%) to 100% exceedance probability bin excluded. Data for the Le Sueur, Cobb, and Maple Rivers are taken at gauges 1, 2, and 3, respectively.

River	Depth (m)	Coefficient γ			Exponent ε			R^2 Value of Regression		
		K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h	K = 0.036 mm/h	K = 0.36 mm/h	K = 3.6 mm/h
Le Sueur	0.5	9.00E−01	2.96E+00	3.89E+00	−3.34E−02	−6.76E−02	−1.20E−01	1.04E−01	6.95E−01	8.89E−01
	1	1.14E+00	3.23E+00	3.89E+00	−1.02E−01	−7.61E−02	−1.20E−01	5.94E−01	7.17E−01	8.89E−01
	2	1.30E+00	3.45E+00	3.89E+00	−1.38E−01	−8.47E−02	−1.20E−01	7.44E−01	7.23E−01	8.89E−01
Cobb	0.5	9.53E−01	2.71E+00	3.41E+00	−8.76E−02	−1.27E−01	−1.78E−01	2.21E−01	7.54E−01	8.76E−01
	1	1.18E+00	3.07E+00	3.45E+00	−1.30E−01	−1.60E−01	−1.83E−01	4.44E−01	8.40E−01	8.76E−01
	2	1.39E+00	3.22E+00	3.45E+00	−1.75E−01	−1.71E−01	−1.83E−01	5.91E−01	8.61E−01	8.76E−01
Maple	0.5	1.05E+00	2.55E+00	3.01E+00	−3.44E−02	−1.87E−01	−2.22E−01	1.85E−01	9.77E−01	9.97E−01
	1	1.32E+00	2.92E+00	3.10E+00	−9.88E−02	−2.28E−01	−2.36E−01	7.34E−01	9.85E−01	9.93E−01
	2	1.61E+00	3.06E+00	3.10E+00	−1.72E−01	−2.38E−01	−2.36E−01	8.97E−01	9.92E−01	9.93E−01

Table S19. Equation (4) parameters, WRS placement in the lower watershed with the $10^{1.5}$% (~32%) to 100% exceedance probability bin excluded. Data for the Le Sueur, Cobb, and Maple Rivers are taken at gauges 1, 2, and 3, respectively.

River	Depth (m)	Coefficient γ			Exponent ε			R^2 Value of Regression		
		K = 0.036 mm/h	*K* = 0.36 mm/h	*K* = 3.6 mm/h	*K* = 0.036 mm/h	*K* = 0.36 mm/h	*K* = 3.6 mm/h	*K* = 0.036 mm/h	*K* = 0.36 mm/h	*K* = 3.6 mm/h
Le Sueur	0.5	9.55E−01	3.66E+00	4.86E+00	2.96E−02	−6.14E−02	−1.32E−01	7.62E−02	5.07E−01	8.26E−01
	1	1.23E+00	4.16E+00	4.91E+00	−4.54E−02	−8.54E−02	−1.34E−01	1.60E−01	6.42E−01	8.24E−01
	2	1.40E+00	4.50E+00	4.91E+00	−6.85E−02	−1.02E−01	−1.34E−01	3.40E−01	7.03E−01	8.24E−01
Cobb	0.5	1.07E+00	2.35E+00	2.72E+00	−8.34E−02	−1.52E−01	−1.80E−01	4.24E−01	9.28E−01	9.71E−01
	1	1.34E+00	2.62E+00	2.73E+00	−1.39E−01	−1.73E−01	−1.82E−01	6.61E−01	9.64E−01	9.71E−01
	2	1.52E+00	2.69E+00	2.73E+00	−1.61E−01	−1.77E−01	−1.82E−01	7.69E−01	9.71E−01	9.71E−01
Maple	0.5	8.65E−01	3.21E+00	3.99E+00	2.14E−01	−5.81E−02	−1.23E−01	9.06E−01	7.19E−01	9.65E−01
	1	1.15E+00	3.84E+00	4.05E+00	1.35E−01	−1.22E−01	−1.32E−01	7.83E−01	9.66E−01	9.73E−01
	2	1.43E+00	4.02E+00	4.05E+00	6.53E−02	−1.31E−01	−1.32E−01	5.34E−01	9.72E−01	9.73E−01