CADMUS

Introduction

Cadmus used two different techniques to measure fixture flow rates for the RBSA II study: a flow bag and a flow microweir. Technicians did not record which method was used at the time of data collection. The study results for water flow rate were higher than those recorded in the RBSA I study, raising understandable concerns about market trends and data reliability. To address these concerns and appropriately calibrate RBSA II results, Cadmus took these actions:

- Tested the accuracy of the two measurement methods (flow bag and microweir) and developed calibration factors for each method
- Contacted the field technicians who collected the RBSA II data to determine faucets and showerheads for which Cadmus could identify the measurement method with a high level of certainty

Our testing found that the measurements from both flow bags and microweirs were consistently higher than the actual flow rate of the faucets and showerheads. Based on this testing, applying a calibration factor for each method will produce results that more accurately represent RBSA II average flow rates. Therefore, we developed calibration factors for the two measurement methods, based on our testing, and applied it to flow rates where we were confident in the measurement method used by the field technician.

The following sections summarize how water flow rate data were collected for RBSA II and our calibration test methodology, findings, and conclusions. We also present tables showing adjusted RBSA II water flow rate results after applying the calibration factors for showerheads and faucets.

RBSA II Data Collection Approach

Cadmus field technicians collected flow rates for all kitchen faucets, bathroom faucets, and showerheads in each home, along with their location, rated flow (if available), and frequency of use. Technicians used either a flow bag or a microweir to measure the fixture's flow rate. Technicians were not required to record which method they used; however, several of the technicians used only flow bags.

Calibration Test Methodology

Cadmus tested a total of five faucets and five showerheads in its Waltham, Massachusetts, office. These devices were selected to cover the full range of actual flow rates of fixtures existing in homes. Two Cadmus staff measured each device's flow multiple times using each of the two measurement methods—flow bag and microweir. We compared the results from the testing to the actual fixture flow rate—determined through a mass flow calculation—to determine the calibration factors. Cadmus tested a range of faucet and showerhead flow rates, which are noted in Table 1 and Table 2. Cadmus also examined whether measured flow rates varied proportionately with actual flow rates.

Rated Fixture Flow Rate

Cadmus tested faucets with rated flow rates between 1.0 and 2.2 gallons per minute and showerheads with rated flow rates between 1.5 and 2.5 gallons per minute. We tested one faucet and two showerheads with unknown flow rates.

Actual Fixture Flow Rate

Cadmus determined the actual flow rate of each device using a mass flow calculation. Each tester filled a large bucket with water for 45-60 seconds depending on water flow, measured the weight and temperature of the water in the bucket, and then calculated the fixture flow. Each tester performed this process twice for each of the devices. Actual flow rates were less than rated flow rates for all tested devices.

Flow Bag and Microweir Flow Rates

After establishing the actual flow rate, the two testers measured each device's flow rate with the equipment used in the field. Testing resulted in 1,288 flow bag trials and 280 microweir trials in total.

For each flow bag test, we observed the water line in two ways—by holding the bag only by its handle or by resting the bag on a hard, level surface—matching the two ways field technicians reported using the flow bags during the RBSA II.

Test Findings

Table 1 shows the estimated mean flow rates for each measurement method, along with the difference between the mean measured and actual flow for each faucet. Table 2 show the same results for showerheads.

Table 1. Faucet Flow Testing Results

Measurement	Device ID	Rated Flow	Actual	Flow Bag	Flow Weir
Average GPM	1	1.00	0.85	1.04	0.88
	2	1.50	1.27	1.39	1.33
	3	2.20	1.80	2.23	1.95
	4	2.20	1.64	2.08	1.83
	5	Unknown	2.12	2.41	2.29
Measured Difference [(Method - Actual Flow)/Actual Flow]	1	-	-	23%	4%
	2	-	-	10%	4%
	3	-	-	24%	8%
	4	-	-	27%	12%
	5	-	-	14%	8%

Table 2. Showerhead Flow Testing Results

Measurement	Device ID	Rated Flow	Actual	Flow Bag	Flow Weir
Average GPM	1	1.50	1.28	1.39	1.35
	2	2.50	1.58	1.95	1.85
	3	Unknown	2.16	2.50	2.25
	4	1.75	1.41	1.50	1.48
	5	Unknown	2.50	2.93	2.57
Measured Difference [(Method - Actual Flow)/Actual Flow]	1	-	-	9%	5%
	2	-	-	23%	17%
	3	-	-	16%	4%
	4	-	-	6%	5%
	5	-	-	17%	3%

Key findings from testing were these:

- Test measurements using the flow bags resulted in the highest variability. Test measurements using flow bags were on average 6% to 27% greater than the actual flow.
- Test measurements using the microweir were more consistent than flow bags and were, on average, 3% to 17% greater than the actual flow.
- Variation in measurements between technicians was minimal.

Based on these findings, applying calibration factors to the flow data collected for the RBSA II will improve the accuracy of averaged results. Given the minimal variation in measurements between testers for each fixture, we are confident that a unique calibration factor is not required for different staff.

Calibration Factors

Table 3 shows the calibration factors we calculated.[1] Cadmus applied the calibration factors in Table 3 to the RBSA II faucet and showerhead flow rates for which the measurement method is known. Note that the calibration factors in Table 3 are equal one minus the weighted average of measured differences in Table 1 and Table 2, where weights are equal to the sample sizes. The calibration factors do not account for an individual home or its location characteristics and, therefore, are not intended to correct each faucet's observed flow rate exactly to its actual flow rate. Rather, the calibration adjusts the measured flow rates to provide more accurate summaries (means, proportions) of the aggregate data.

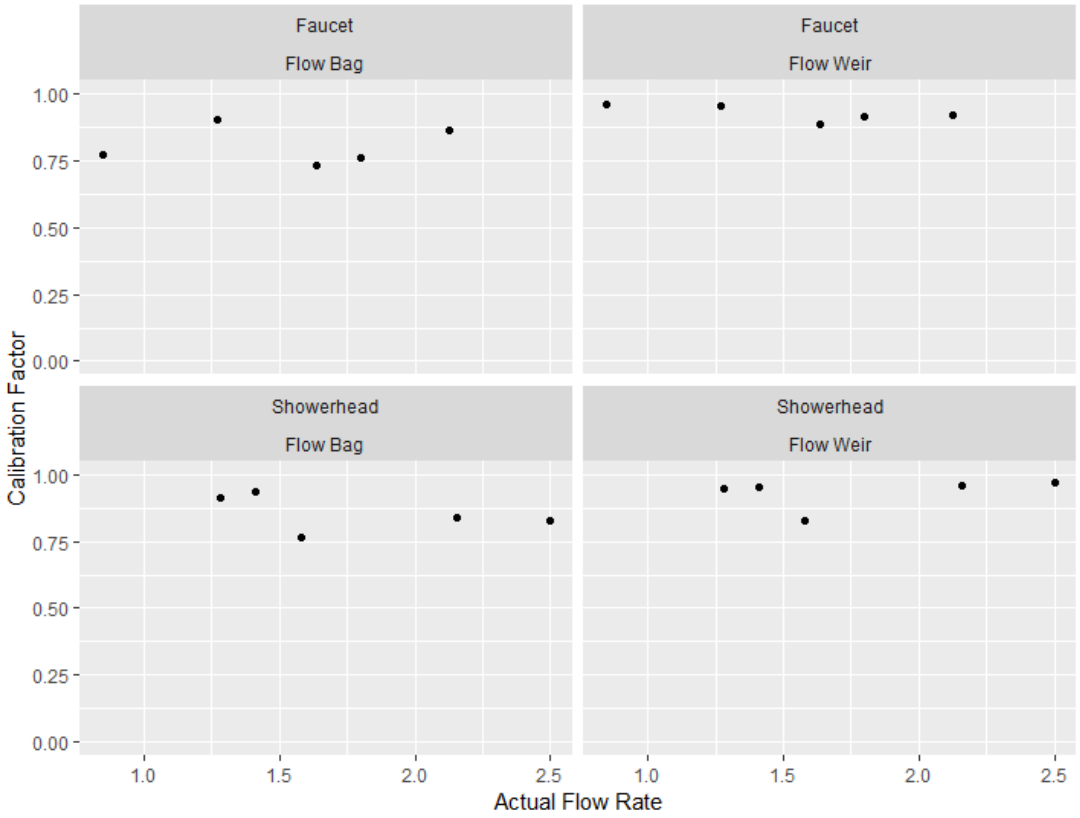
Table 3. Calculated Calibration Factors Per Fixture

Analysis	Method	Faucet	Showerhead
Calibration Factor	Flow Bag	0.80	0.85
	Microweir	0.93	0.93

Cadmus considered whether the calibration factor depends on the actual flow. We found no clear relationship between actual flow and calibration factors, as shown in Figure 1, which plots the calculated calibration factors against the actual flow measured for each fixture type.

[1] Cadmus used data from the laboratory study comparing actuals to measured data for each combination of fixture type and measurement device and calculated the calibration factors using the following equation: $mean\left(1-\frac{(GPM_{actual}-GPM_{measured})}{GPM_{actual}}\right)$.

Figure 1. Calibration for Different Actual Flow Rates



Identifying RBSA II Fixtures Suitable for Calibration

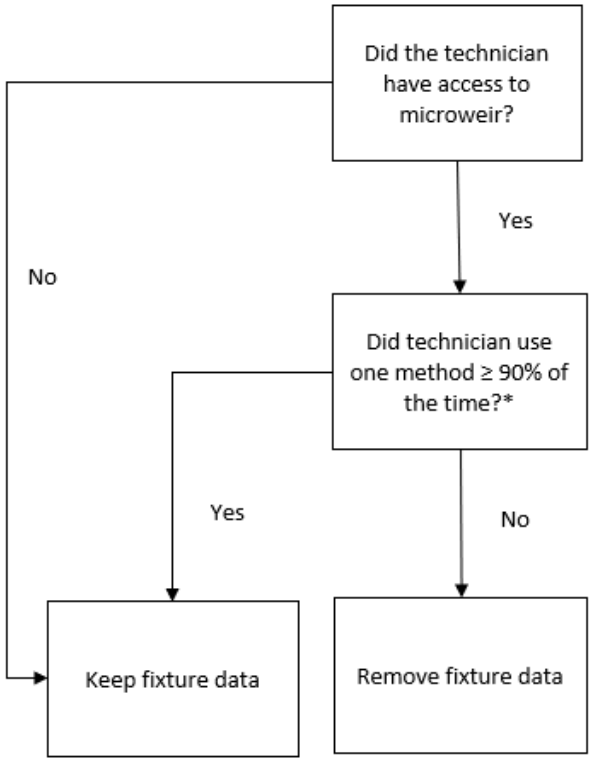
To properly apply a calibration factor to the flow rates collected during the RBSA II, the measurement method (microweir or flow bag) used for each fixture must be known. Although field technicians were not directed to note which method they used, the data collection software recorded which technician took each measurement. We attempted to question every technician who performed site visits and were able to reach 17 of 21 technicians.[2] Note that we asked technicians to recall field data collection they performed between April 2016 and September 2017.

We asked field technicians to recall what proportion of the time they used a flow bag or microweir by fixture type (bathroom faucet, kitchen faucet, and showerhead). In some instances, they did not have access to a microweir for known periods during the study and, therefore, used only flow bags. Based on this information and the technician identification data recorded in the software, we identified a subset

[2] The four technicians who could not be contacted account for 12% of total site visits. However, because two technicians were on each site visit, there are instances in which the second technician (who was contacted) collected data for some of the home fixtures. In these instances, the fixture may be eligible for an adjustment and would be captured in the fixture sample size.

of fixtures for which we could confidently determine the measurement method. See Figure 2 for the logic used to keep or remove fixtures from the dataset prior to applying calibration factors.

Figure 2. Logic for Keeping Fixture Data



* For fixtures kept in the sample, the average reported proportion of method usage ranged from 96% for showerheads to 99% for kitchen faucets. Many technicians reported using the flow bag 100% of the time.

Table 4 shows the number of homes (by home type) reported in the RBSA II reports, the number of homes that can have their flow rates adjusted with the calibration factor, and the percentage of homes remaining in the analysis for faucets and showerheads.

Table 4. Revised Dwelling Count by Housing Type

Fixture Type	Report	Single-Family	Manufactured	Multifamily
Showerheads	RBSA II Reported	961	379	473
	RBSA II Adjusted	613	255	331
	Percent Remaining in Analysis	**64%**	**67%**	**70%**
Bath Faucet	RBSA II Reported	1038	395	507
	RBSA II Adjusted	810	313	402
	Percent Remaining in Analysis	**78%**	**79%**	**79%**
Kitchen Faucet	RBSA II Reported	998	380	489
	RBSA II Adjusted	791	305	396
	Percent Remaining in Analysis	**79%**	**80%**	**81%**

Based on the logic explained above, we are confident of the measurement method used for showerheads and faucets in 64% to 81% of RBSA II homes and suggest that these homes be included in the final flow rate distribution analysis.

Table 5 shows the number of homes and fixtures with known measurement methods.

Table 5. Fixture and Home Count with Known Measurement Methods

Unit	Single-Family			Manufactured			Multifamily		
	Bathroom Faucet	Kitchen Faucet	Showerhead	Bathroom Faucet	Kitchen Faucet	Showerhead	Bathroom Faucet	Kitchen Faucet	Showerhead
Oregon									
Dwellings	196	201	139	97	92	85	100	103	84
Fixtures	483	216	226	211	94	144	138	103	96
Washington									
Dwellings	434	411	332	102	106	85	244	236	201
Fixtures	1,058	452	535	202	109	128	323	239	232
Idaho									
Dwellings	74	84	60	51	59	38	21	24	18
Fixtures	189	91	110	97	60	53	25	25	21
Montana									
Dwellings	106	95	82	63	48	47	37	33	28
Fixtures	245	109	145	124	52	70	50	33	32
Region									
Dwellings	810	791	613	313	305	255	402	396	331
Fixtures	1,975	868	1,016	634	315	395	536	400	381

Known Measurement Methods

Table 6 shows the known measurement method used by state, equipment (shower or faucet), and housing type. The flow bag was used for 98% of fixtures that remain in the analysis sample. Appendix A provides known measurements used compared to the RBSA II original sample design stratifications.

Table 6. Known Measurement Used

State	Equipment	Microweir or Flow Bag	Manufactured	Multifamily Residence	Single-Family	Grand Total
Oregon	Bathroom Faucet	Flow Bag	211	138	483	832
	Kitchen Faucet	Flow Bag	94	103	216	413
	Showerhead	Flow Bag	141	94	211	446
	Showerhead	Microweir	3	2	15	20
Washington	Bathroom Faucet	Flow Bag	202	323	1,058	1,583
	Kitchen Faucet	Flow Bag	109	239	452	800
	Showerhead	Flow Bag	122	216	490	828
	Showerhead	Microweir	6	16	45	67
Idaho *	Bathroom Faucet	Flow Bag	97	25	189	311
	Kitchen Faucet	Flow Bag	60	25	91	176
	Showerhead	Flow Bag	53	21	110	184
Montana	Bathroom Faucet	Flow Bag	124	50	245	419
	Kitchen Faucet	Flow Bag	52	33	109	194
	Showerhead	Flow Bag	59	30	126	215
	Showerhead	Microweir	11	2	19	32
Grand Total			**1,344**	**1,317**	**3,859**	**6,520**

* None of the showerhead flow rates in Idaho were measured using a microweir.

Results

See the RBSA II home reports for revised GPM flow rate tables.

Appendix A. Comparison Against Original RBSA II Stratification

The following tables compare the number of usable data points against the original RBSA stratification. Because the quantity of usable data varies from home-to-home, the tables break out the following information:

- The number of homes where it was possible to adjust all measured flow rates
- The number of homes with at least one adjusted faucet flow rate
- The number of homes with at least one adjusted shower flow rate

The number of homes eligible for adjustment (because we know the data collection method) to measured flow rates varies by stratum. Not including oversample data, the proportion of stratum target single-family homes achieved (for which we could adjust *all* fixture data) ranges from 19% in Western Oregon to 75% in Western Washington. If oversample data are included, the proportion of target achieved increases substantially, ranging from 51% in Idaho to 142% in Puget Sound. Including oversample homes increases achievement in Western Oregon to 56%. Tables 22 through 27 provide details on target achievement by stratum, for each home type.

Table 7. Distribution of Homes and Fixtures with Adjusted Flow Rates—Core Single-Family Homes

State	Sub-Region	Core Sites Only						
		Target Homes (Core Study)	Homes with All Faucets and Showers Adjusted		Homes with At Least One Faucet Adjusted		Homes with At Least One Shower Adjusted	
			Quantity	Percent	Quantity	Percent	Quantity	Percent
Idaho	Idaho	107	46	43.0%	81	75.7%	51	47.7%
Montana	Western Montana	107	63	58.9%	103	96.3%	68	63.6%
Oregon	Western Oregon	107	20	18.7%	67	62.6%	26	24.3%
	Eastern Oregon	107	78	72.9%	95	88.8%	73	68.2%
Washington	Western Washington	107	80	74.8%	103	96.3%	80	74.8%
	Puget Sound	107	46	43.0%	89	83.2%	57	53.3%
	Eastern Washington	107	74	69.2%	95	88.8%	69	64.5%
Total Homes		**749**	**407**	**54.3%**	**633**	**84.5%**	**424**	**56.6%**

Table 23. Distribution of Homes and Fixtures with Adjusted Flow Rates—All Single-Family Homes

State	Sub-Region	All Sites (Includes Oversamples)						
		Target Homes (Core Study)	Homes with All Faucets and Showers Adjusted		Homes with At Least One Faucet Adjusted		Homes with At Least One Shower Adjusted	
			Quantity	Percent	Quantity	Percent	Quantity	Percent
Idaho	Idaho	107	55	51.4%	93	86.9%	60	56.1%
Montana	Western Montana	107	79	73.8%	120	112.1%	82	76.6%
Oregon	Western Oregon	107	60	56.1%	122	114.0%	63	58.9%
	Eastern Oregon	107	81	75.7%	100	93.5%	76	71.0%
Washington	Western Washington	107	86	80.4%	113	105.6%	86	80.4%
	Puget Sound	107	152	142.1%	274	256.1%	169	157.9%
	Eastern Washington	107	82	76.6%	108	100.9%	77	72.0%
Total Homes		**749**	**595**	**79.4%**	**930**	**124.2%**	**613**	**81.8%**

Table 24. Distribution of Homes and Fixtures with Adjusted Flow Rates—Core Manufactured Homes

State	Sub-Region	Core Sites Only						
		Target Homes (Core Study)	Homes with All Faucets and Showers Adjusted		Homes with At Least One Faucet Adjusted		Homes with At Least One Shower Adjusted	
			Quantity	Percent	Quantity	Percent	Quantity	Percent
Idaho	Idaho	81	33	40.7%	65	80.2%	38	46.9%
Montana	Western Montana	81	32	39.5%	71	87.7%	46	56.8%
Oregon	Western Oregon	81	67	82.7%	81	100.0%	68	84.0%
	Eastern Oregon							
Washington	Western Washington	81	48	59.3%	81	100.0%	50	61.7%
	Puget Sound							
	Eastern Washington							
Total Homes		**324**	**180**	**55.6%**	**298**	**92.0%**	**202**	**62.3%**

Table 25. Distribution of Homes and Fixtures with Adjusted Flow Rates—All Manufactured Homes

State	Sub-Region	All Sites (Includes Oversamples)						
		Target Homes (Core Study)	Homes with All Faucets and Showers Adjusted		Homes with At Least One Faucet Adjusted		Homes with At Least One Shower Adjusted	
			Quantity	Percent	Quantity	Percent	Quantity	Percent
Idaho	Idaho	81	33	40.7%	66	81.5%	38	46.9%
Montana	Western Montana	81	33	40.7%	72	88.9%	47	58.0%
Oregon	Western Oregon	81	85	104.9%	103	127.2%	85	104.9%
	Eastern Oregon							
Washington	Western Washington	81	77	95.1%	122	150.6%	85	104.9%
	Puget Sound							
	Eastern Washington							
Total Homes		**324**	**228**	**70.4%**	**363**	**112.0%**	**255**	**78.7%**

Table 26. Distribution of Homes and Fixtures with Adjusted Flow Rates—Core Multifamily Buildings

State	Sub-Region	Core Sites Only						
		Target Homes (Core Study)	Homes with All Faucets and Showers Adjusted		Homes with At Least One Faucet Adjusted		Homes with At Least One Shower Adjusted	
			Quantity	Percent	Quantity	Percent	Quantity	Percent
Idaho	Idaho	15	11	73.3%	14	93.3%	12	80.0%
Montana	Western Montana	9	11	122.2%	15	166.7%	10	111.1%
Oregon	Western Oregon	76	44	57.9%	62	81.6%	42	55.3%
	Eastern Oregon							
Washington	Western Washington	158	84	53.2%	141	89.2%	87	55.1%
	Puget Sound							
	Eastern Washington							
Total Homes		**258**	**150**	**58.1%**	**232**	**89.9%**	**151**	**58.5%**

Table 27. Distribution of Homes and Fixtures with Adjusted Flow Rates—All Multifamily Buildings

State	Sub-Region	All Sites (Includes Oversamples)						
		Target Homes (Core Study)	Homes with All Faucets and Showers Adjusted		Homes with At Least One Faucet Adjusted		Homes with At Least One Shower Adjusted	
			Quantity	Percent	Quantity	Percent	Quantity	Percent
Idaho	Idaho	15	19	126.7%	25	166.7%	18	120.0%
Montana	Western Montana	9	32	355.6%	37	411.1%	28	311.1%
Oregon	Western Oregon	76	89	117.1%	113	148.7%	84	110.5%
	Eastern Oregon							
Washington	Western Washington	158	195	123.4%	290	183.5%	201	127.2%
	Puget Sound							
	Eastern Washington							
Total Homes		**258**	**335**	**129.8%**	**465**	**180.2%**	**331**	**128.3%**