A Comprehensive Assessment of the Delaware River Basin Commission's Water Audit Program (2012-2021)

Water Management Advisory Committee (WMAC)

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October 12, 2023

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Outline

1. Public water supply in the Delaware River
2. Water Loss Control: Context & Background
3. Data management and review
4. Water Audit Analysis (2021) and trends (2012-2021)
5. Real Loss Reduction Potential Analyses
6. UARL System Correction Factors (SCF)
7. Physiographic analyses
8. Conclusions

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1. Public Water Supply in the Delaware River Basin

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Population served by PWS (in-Basin)

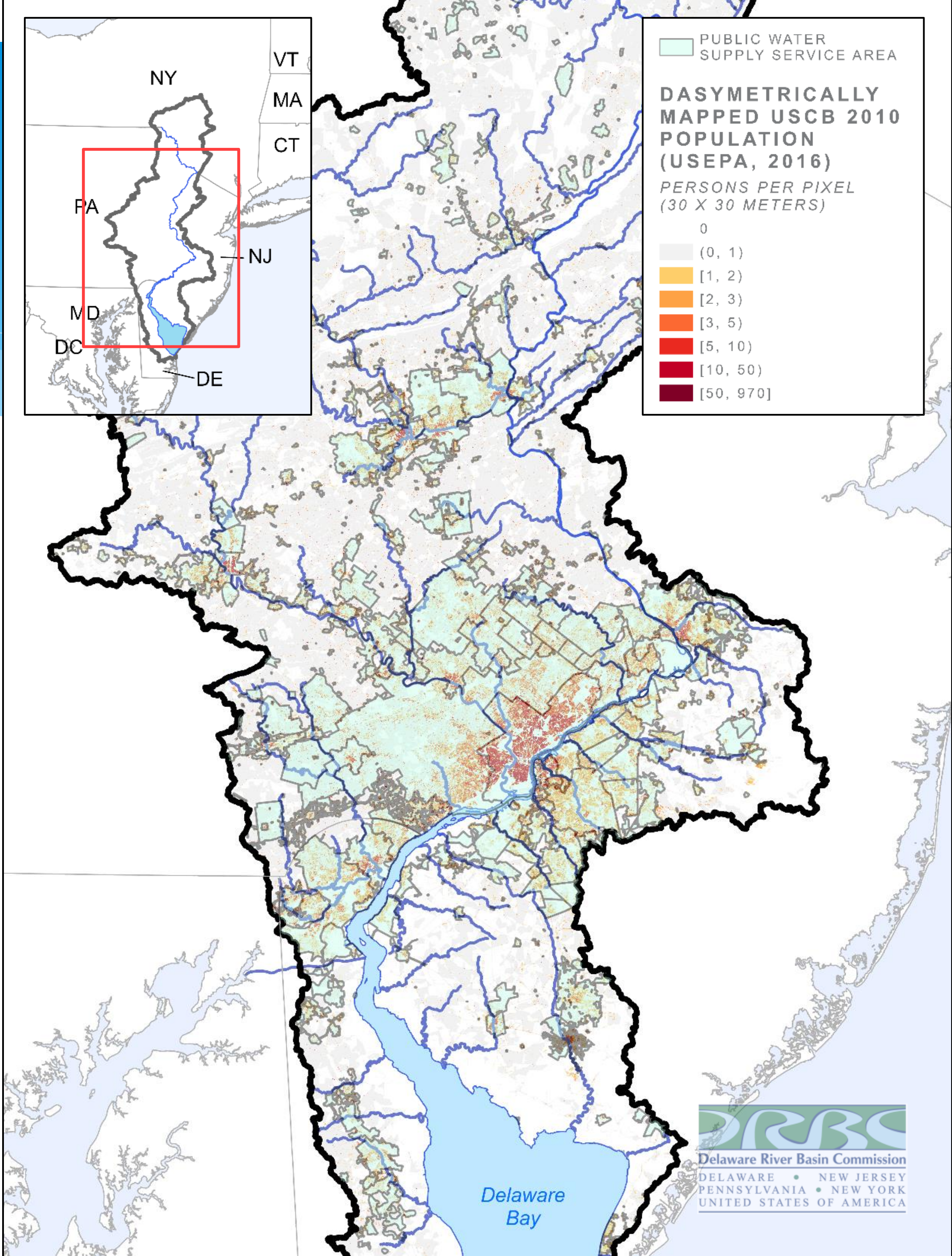
* Estimated about 900 public water supply service areas in the Delaware River Basin

2010

Using 2010 population data from the USEPA EnviroAtlas, it is estimated that 7.157 million people rely on public water supply
(87% of the estimated 8.252 million Basin residents)

2020

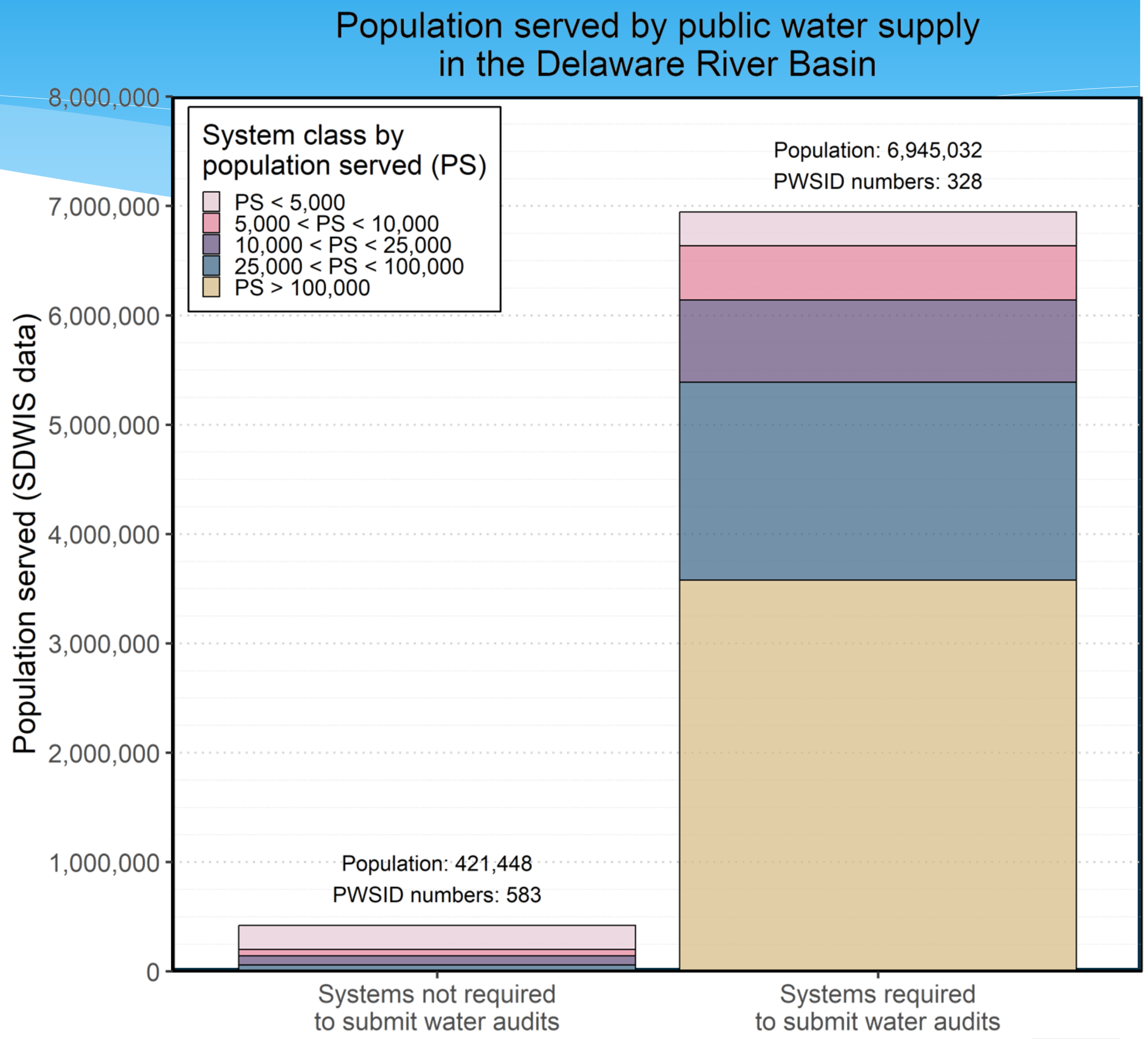
Using 2020 "population served" data from the USEPA SDWIS, it is estimated that 7.366 million people rely on public water supply
(85% of the estimated 8.629 million Basin residents)



Population served by PWS (in-Basin)

Looking more at the 2020 data:

- 7.336 million people within PWS service areas
- Approximately 300 systems are required to submit water audits (328 PWSIDs)
- These 300 account for most of the water withdrawn from the DRB for PWS (~99%) (Thompson & Pindar, 2021)
- This shows that audited systems account for most people served by PWS (6.945 million people, ~94%)

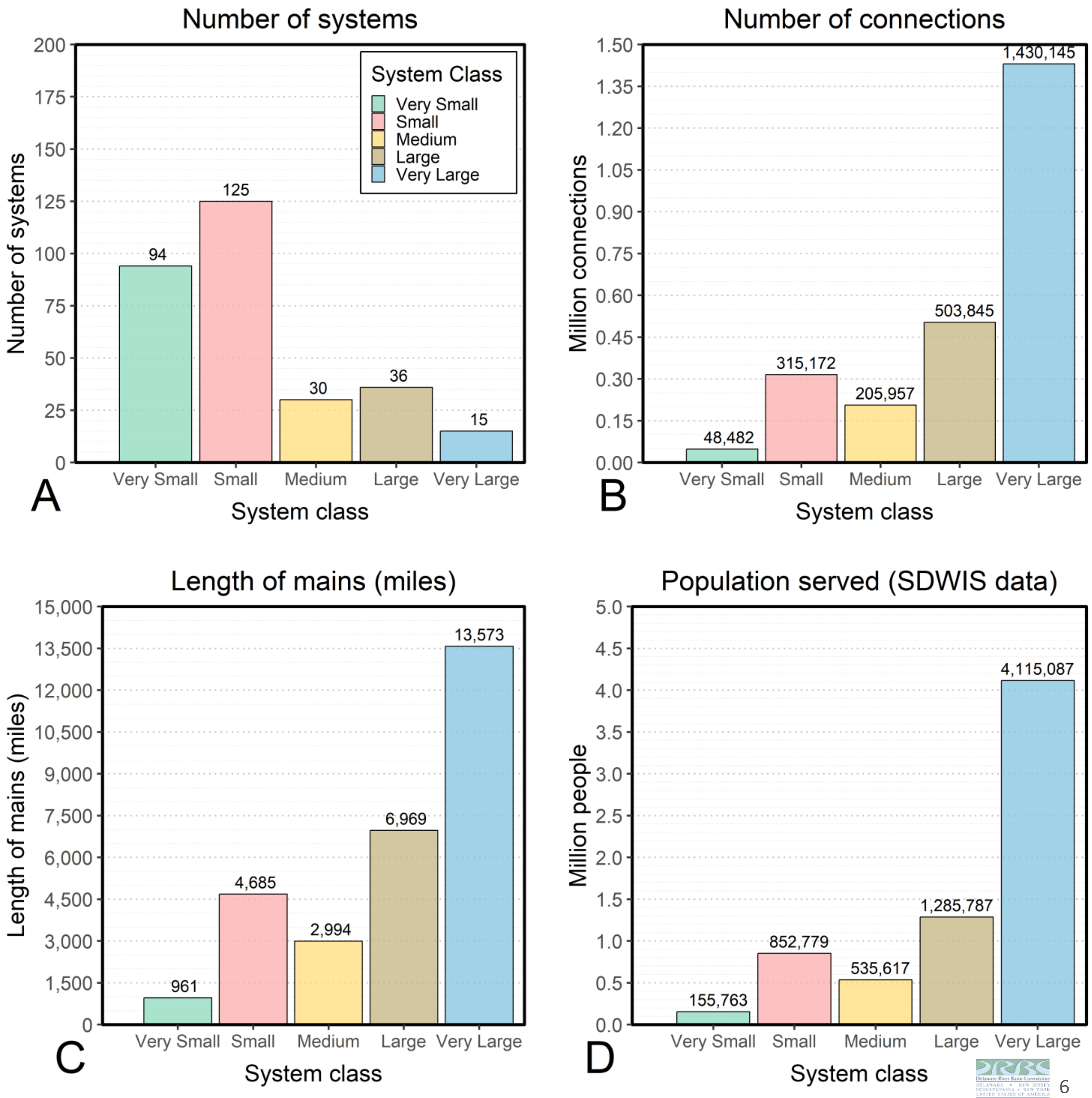


Extensive infrastructure

<u>Some notes:</u>

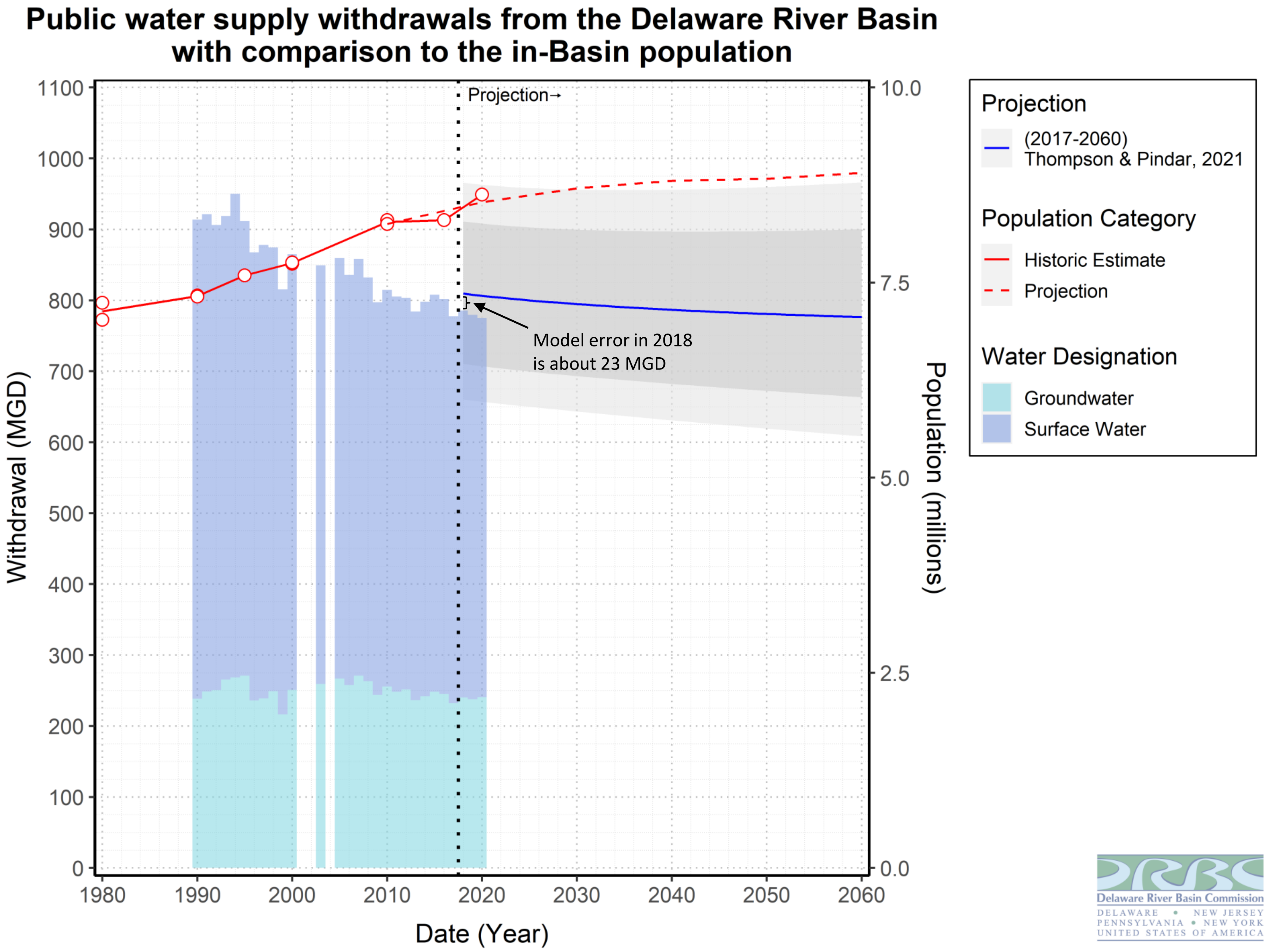
- The 300 systems have been classified by the number of connections.
- There are 29,000 miles of water mains in the Basin (enough to circle the Earth)
- There are 2.5 million service connections

System size class	Abbv.	Active/Inactive Connections
Very Small	VS	< 1,000
Small	S	[1,000, 5,000)
Medium	M	[5,000, 10,000)
Large	L	[10,000, 20,000)
Very Large	VL	≥ 20,000



This figure:

- Public water supply withdrawals from the DRB were projected by DRBC (Thompson & Pindar, 2021).
- While population has and is projected to increase, withdrawals have decreased.
    1. Plumbing standards
    2. Fewer industrial & commercial customers
    3. Lower per-capita rates
    4. Water conservation efforts (e.g. leak detection & repair)
- Can offset the projection by 2018 model error



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2. Water Loss Control: Context & Background

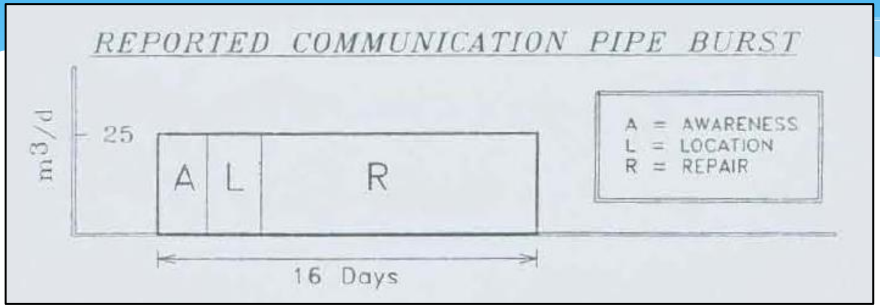
Standard water balance and terminology

Volume from Own Sources *(corrected for known errors)*	System Input Volume	Water Exported *(corrected for known errors)*	Billed Water Exported			Revenue Water
		Water Supplied	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
					Billed Unmetered Consumption	
				Unbilled Authorized Consumption	Unbilled Unmetered Consumption	Non-revenue Water
					Unbilled Metered Consumption	
			Water Losses	Apparent Losses	Customer Metering Inaccuracies	
					Unauthorized Consumption	
					Systematic Data Handling Errors	
				Real Losses	Leakage on Transmission and Distribution Mains	
					Leakage and Overflows at Utility's Storage Tanks	
Water Imported *(corrected for known errors)*					Leakage on Service Connections up to the point of Customer Metering	

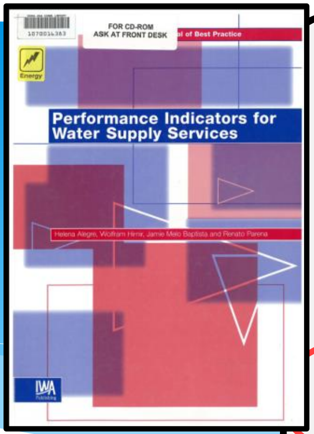
Master meter after treatment, i.e., what gets sent to customers

AWWA. (2016). The State of Water Loss Control in Drinking Water Utilities. A White Paper From the American Water Works Association. Denver, Colorado. American Water Works Association.

All systems leak…



Adopted from (Lambert, 1994)



(Algeres et al, 2000)

1996 IWA Operation and Maintenance Committee Task Force

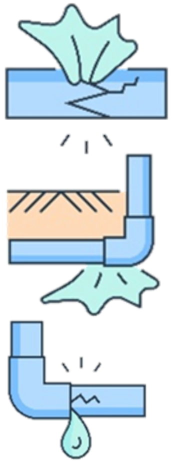
(1) prepare a recommended basic standard terminology for calculation of real and apparent losses

(2) review and recommend preferred performance indicators for international comparison of losses

<u>"Bursts and Background Estimate" (BABE)</u>

Conducted as part of research project for the National Leakage Control Initiative (NLCI) in 1994, resulting in "Managing Leakage" reports

Real Losses
- (1) Reported bursts
- (2) Un-reported bursts,
- (3) background leakage



"Leakage components"

Infrastructure component	Background losses		Reported bursts		Unreported bursts		UARL total	Units
Mains	9.6	+	5.8	+	2.6	=	18	L/km mains/ day/m of pressure
Service connections, meters at edge of street	0.60	+	0.04	+	0.16	=	0.80	L/conn/day/ m of pressure
Underground pipes between edge of street and customer meters	16.0	+	1.9*	+	7.1*	=	25	L/km u.g. pipe/ day/m of pressure

Adopted from (Lambert et al., 1999)

(1) $UARL = (18 * L_m + 0.80 * N_c + 25 * L_p) * P$

(2) $ILI = CARL / UARL$

"rational yet flexible basis… for a wide range of distribution systems."

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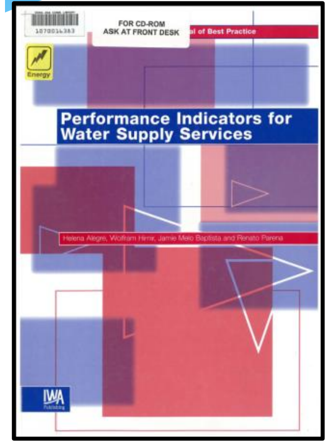
Free Water Audit Software (FWAS) & Performance Indicators

170 Performance Indicators
232 Variable definitions
(Algeres et al, 2000)

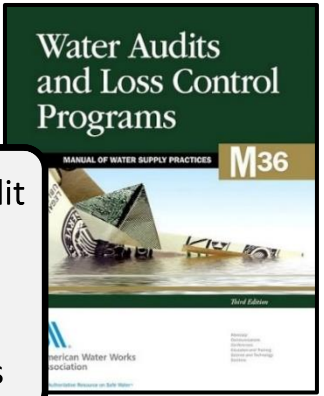


2003

"IWA methodology for the water audit (balance) and performance indicators should be recognized as the current BMP for quantitatively monitoring water use and water loss in drinking water systems"
(Kunkel, 2003)


COMMITTEE REPORT:
Applying worldwide BMPs in water loss control

2009



AWWA Free Water Audit Software & M36 adopt terminology and some recommended performance indicators

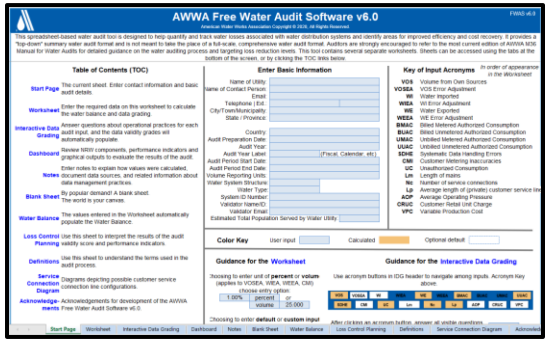
- ~~(Fi36) Volume of non-revenue water as a percentage of system input~~
- ~~(Fi37) Valuation of non-revenue water as a percentage of the annual cost of running the system~~
- (Op23) Apparent losses (gal/connection/day)
- (Op24) Real losses (gal/connection/day), (gal/connection/day/psi) or (gal/mi of mains/day/psi)
- UARL, Unavoidable Annual Real Losses, as in
- (Op25) ILI (dimensionless) = CARL / UARL

Codes used in
(Algeres et al, 2000)

"AWWA WLCC 2020 Position"
Recommended performance indicators incorporated into v6.0 of the AWWA FWAS
(Jernigan et al., 2019)

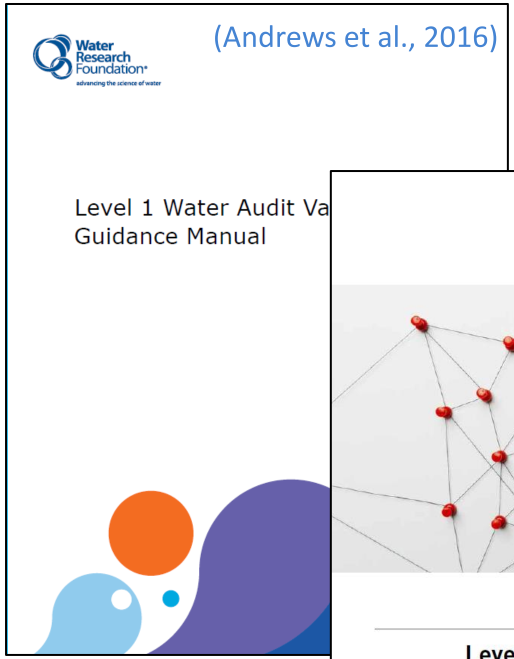
Type	Indicator	IWA Code (3rd Ed.)	Units
Attribute	Apparent Loss Volume	--	Volume
	Apparent Loss Cost	--	$
	Real Loss Volume	--	Volume
	Real Loss Cost	--	$
	Unavoidable Annual Real Loss (UARL)	--	Volume
Volume	Normalized Apparent Losses	--	volume / connection / day
	Normalized Real Losses	Op27	volume / connection / day
	Normalized Real Losses (pipe length)	Op28	volume / pipeline length / day
	Normalized Water Losses	Op23	volume / connection / day
	Real Losses by Pressure	--	volume / connection / day / pressure unit
	Infrastructure Leakage Index (ILI)	Op29	Dimensionless
Value	Apparent Loss Cost Rate	--	$ / connection / year
	Real Loss Cost Rate	--	$ / connection / year
Validity	Data Validity Tier (DVT)	--	Dimensionless

2020

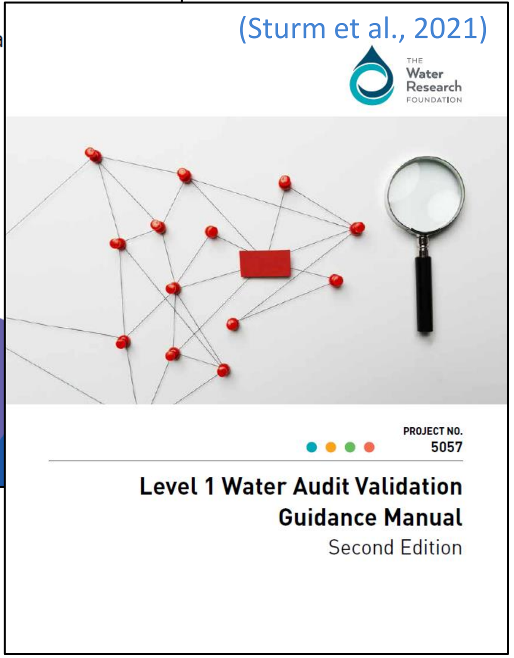


Data validation ≠ Data validity

This is where DRBC is currently operating, was defined in 1st edition but the 2nd edition does not really acknowledge “filtered”.



1st ed. (2016)



2nd ed. (2021)

Some states require this, and have “certified validators” – California, Georgia, Indiana

“Levels” of data validation

Self-reported audits............have not been subject to an in-depth review, and data grading has been completed by the reporting entity based on their best understanding.

Filtered audits...................have been checked for technical plausibility by a research team based on simple, broad criteria.

Level 1 validated audits.......have been subject to third-party “desktop review” of data that is immediately available (such as supply reports, consumption reports and testing reports). This level of validation is intended to (1) confirm the accurate application of the AWWA M36 water audit methodology to the utility-specific situation, (2) identify and correct inaccuracies where realistic, and (3) verify the answers selected to the Interactive Data Grading (v6.0).

Level 2 validated audits...... have been third-party reviewed with a deeper “desktop” analysis and may include the review of items such as a production database, SCADA system reports, billing system information, and meter test results. No field testing or new data gathering efforts are performed.

Level 3 validated audits...... have been third-party reviewed using both “desktop analysis” (as described in level 2 validation) and field investigations.

3. Data management and review

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Summary of reports and datasets

Statistics for the Delaware River Basin Commission's Water Audit Program (2012-2021)

Year	First Year	Last Year	Expected	Missing	v4.1	v4.2	v5.0	v6.0	Rec'd	Compliance	Filtered Dataset
2012	306	2	306	62	3	240	1	0	244	80%	174
2013	0	2	304	44	2	255	3	0	260	86%	182
2014	0	2	302	43	1	95	163	0	259	86%	191
2015	0	0	300	35	0	6	259	0	265	88%	192
2016	0	0	300	11	0	1	288	0	289	96%	202
2017	1	0	301	8	0	0	293	0	293	97%	202
2018	2	5	303	8	0	0	295	0	295	97%	168
2019	5	3	303	19	0	1	283	0	284	94%	187
2020	1	1	301	17	0	0	150	134	284	94%	199
2021	0	0	300	18	0	0	4	278	282	94%	209

Note: Data sets & usage

(1) Full "backfilled" data used for volumetric trend assessments

(2) Filtered data used for assessment of normalized metrics (representing the "most reliable" data points from a given year)

FILTER CRITERIA

1. Cannot be backfilled report data
2. Total Water Loss, Apparent Loss, Real Loss >= 0
3. Customer Metering Inaccuracy (CMI) < 25% of Total Water Loss
4. Infrastructure Leakage Index (ILI) 1 < ILI <20
5. Billed Metered Authorized Consumption (BMAC) > 1,000 gal/connection/month

So how does the DRBC filtered dataset look in comparison to validated data?

Example data backfilling for user inputs – calculations carried forward

YEAR	VOS
2012	121.000
2013	
2014	
2015	
2016	93.230
2017	75.545
2018	82.466
2019	
2020	80.712
2021	94.000

→

YEAR	VOS
2012	121.000
2013	93.230
2014	93.230
2015	93.230
2016	93.230
2017	75.545
2018	82.466
2019	80.712
2020	80.712
2021	94.000

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Water Audit Reference Dataset (WARD)

A product compiled by the AWWA Water Loss Control Committee which includes Level 1 validated water audits for calendar year 2018 from 1,124 utilities in:

- Quebec (Canada)
- California
- Georgia

Real Loss on y-axis in all plots

"Filtered" data from the Delaware River Basin aligns with Level 1 validated data fairly well

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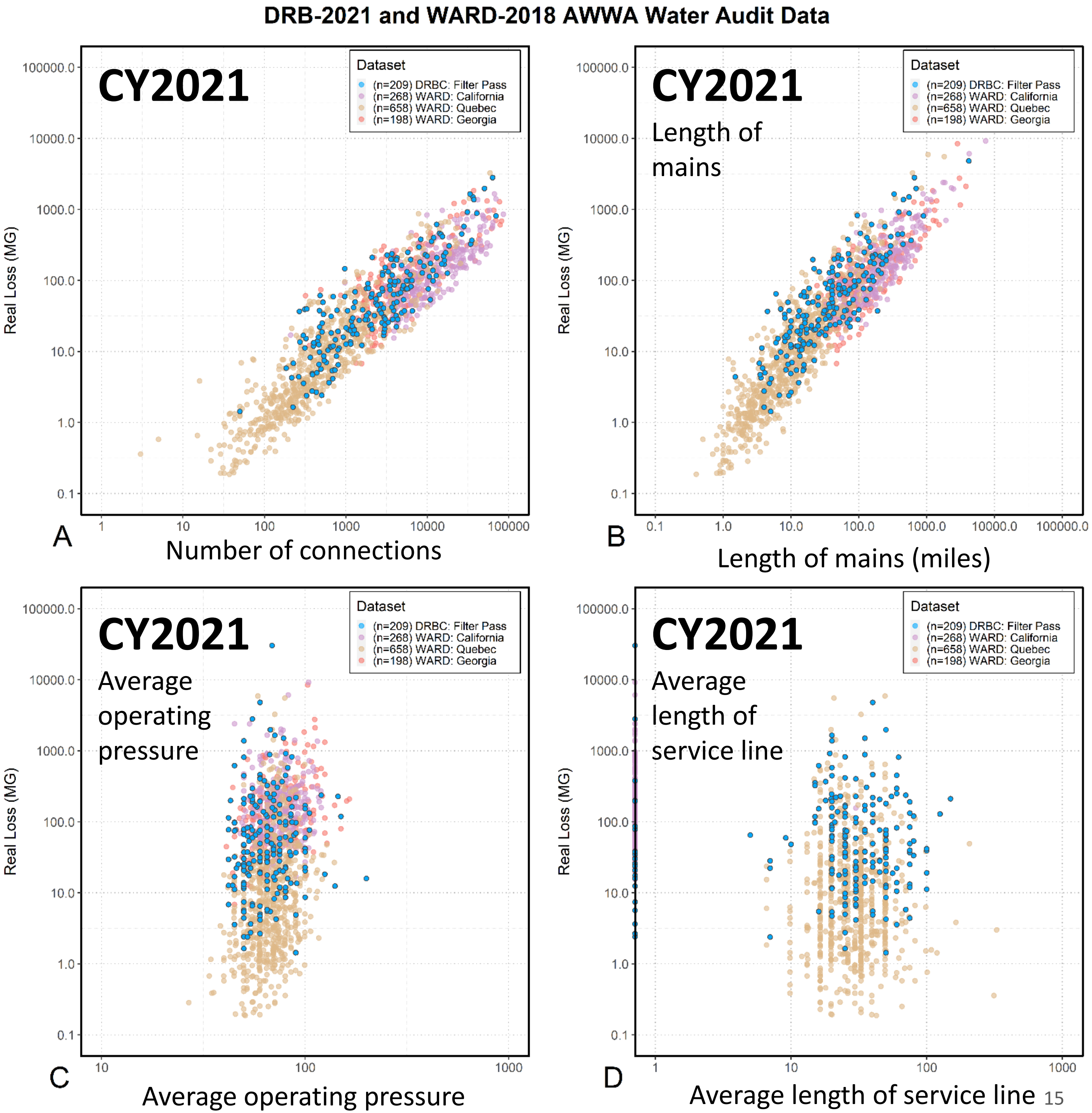

4. Water Audit Analysis (2021) and trends (2012-2021)

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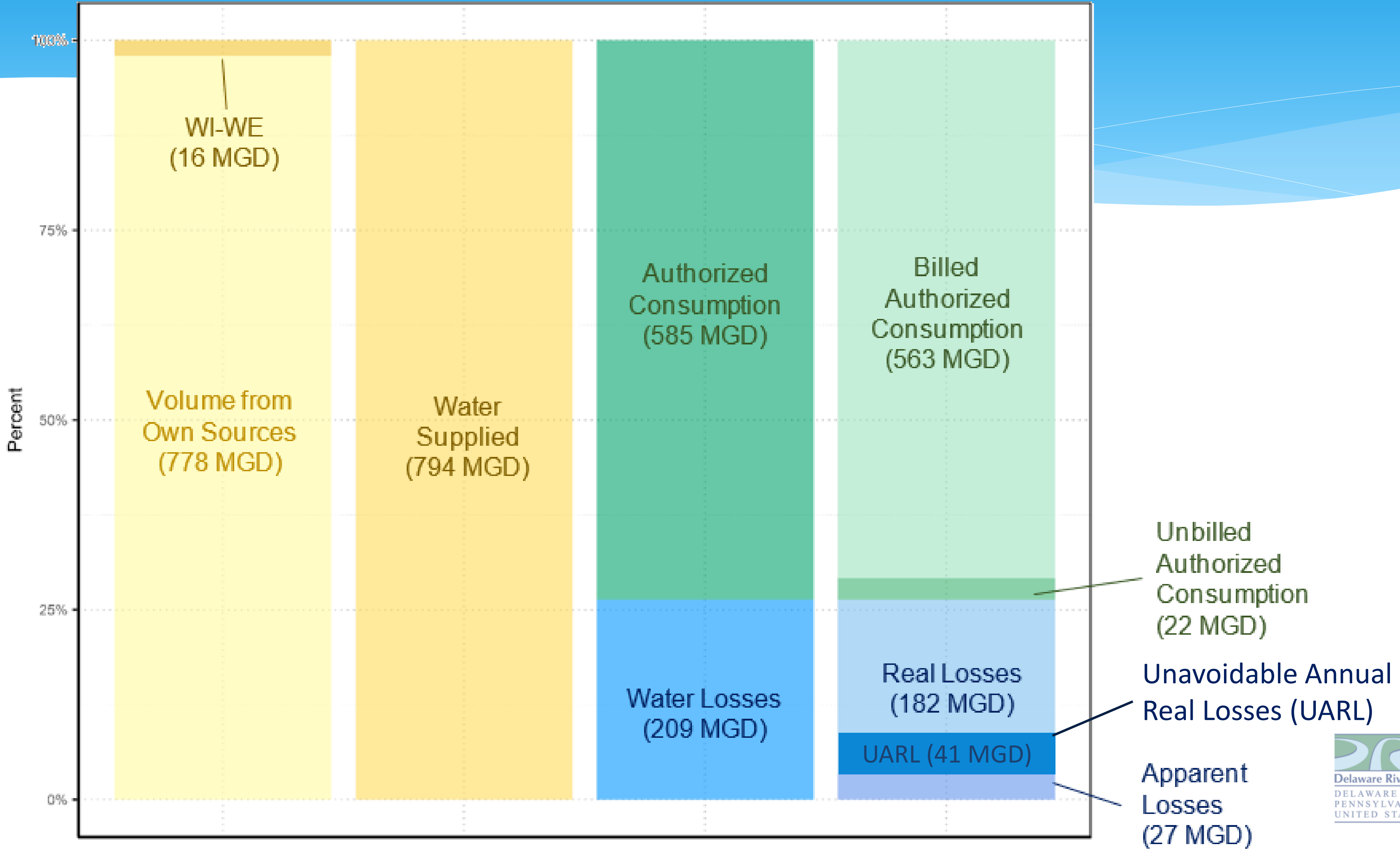
CY2021 Water Audits



Aggregate water balance for 300 systems reporting water audit data to DRBC in calendar year 2021.

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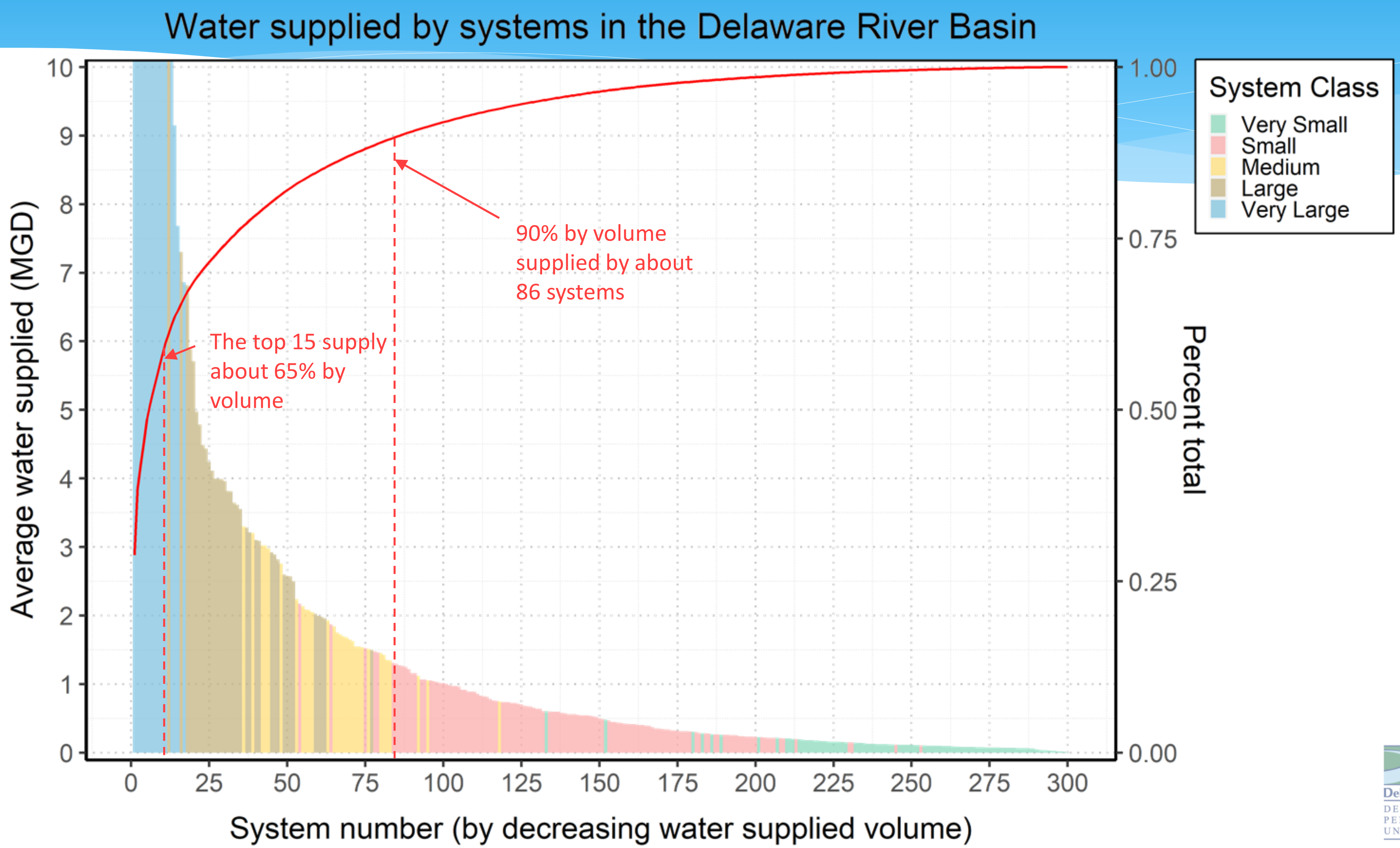
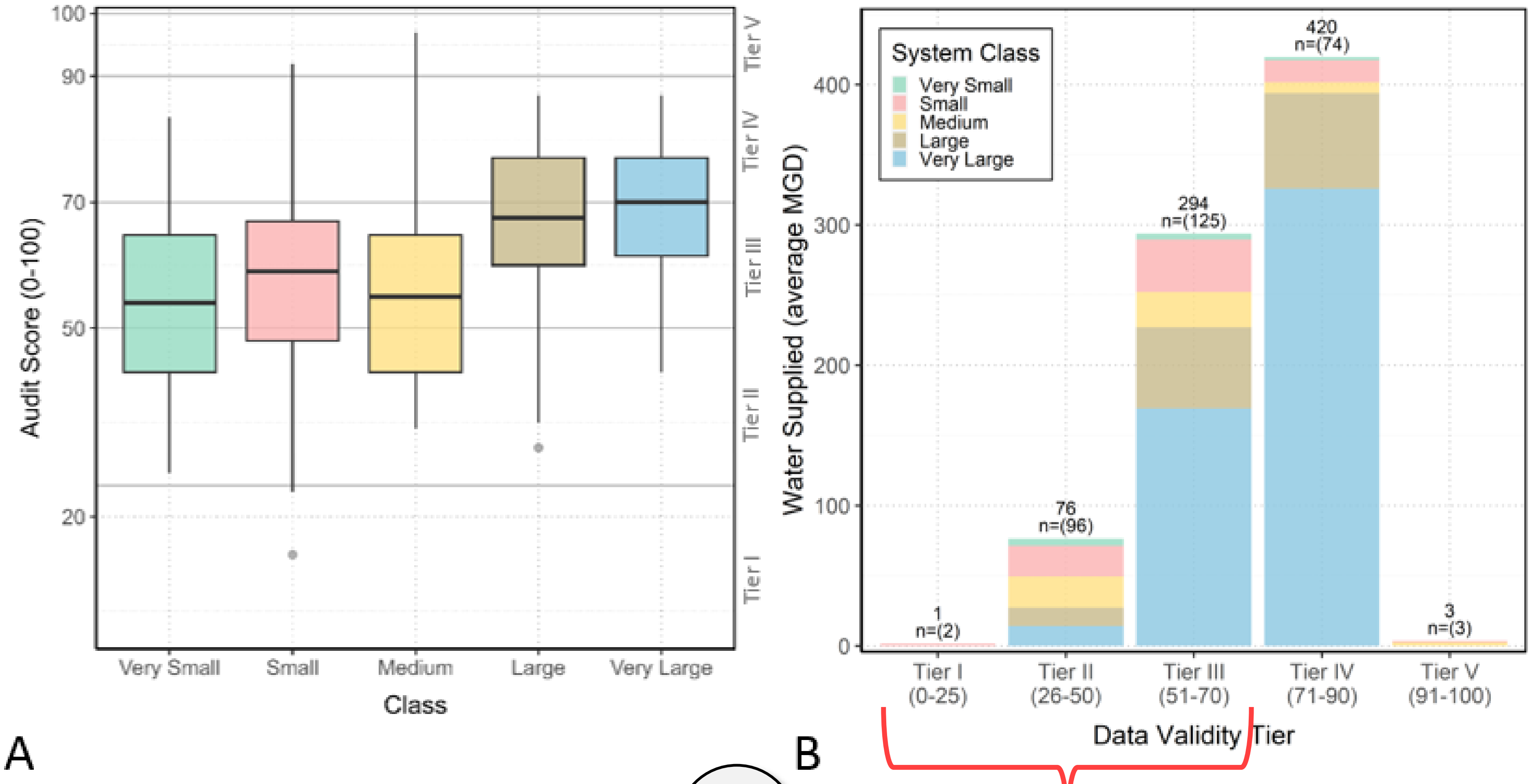
CY2021 Water Audits



CY2021 Water Audits



There is room for improvement here

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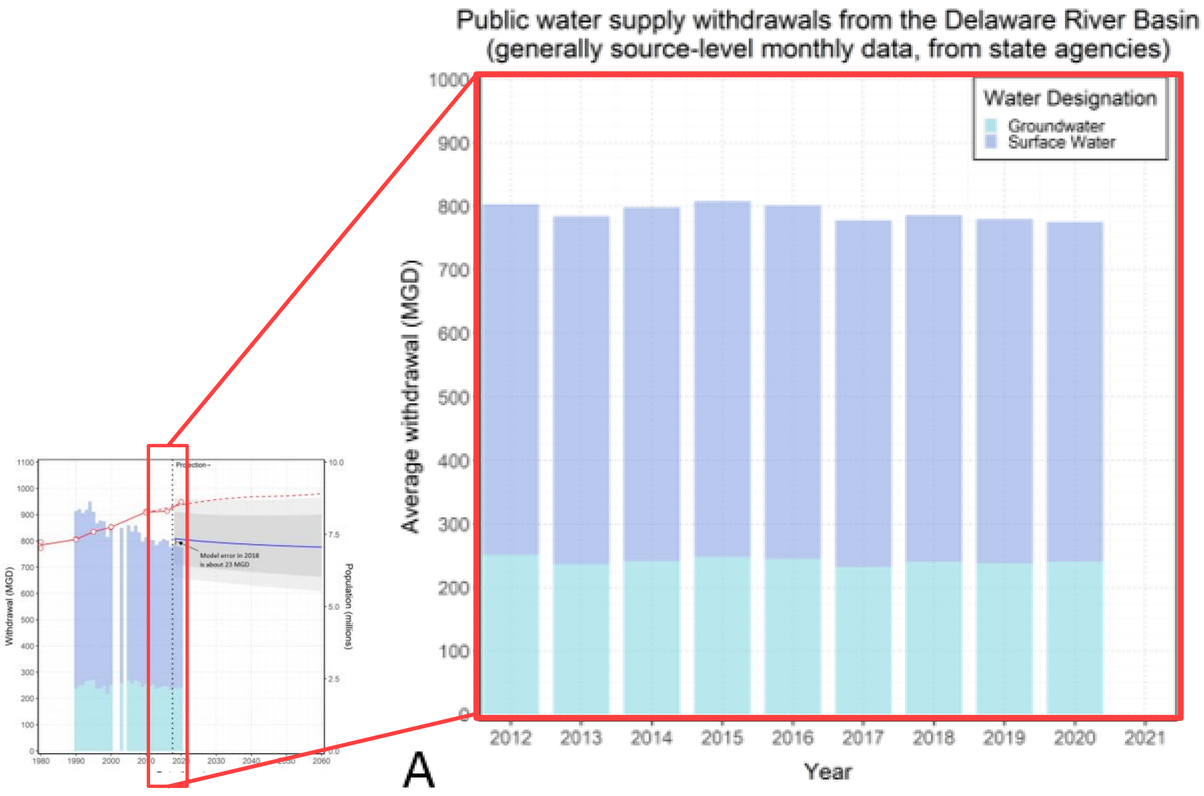
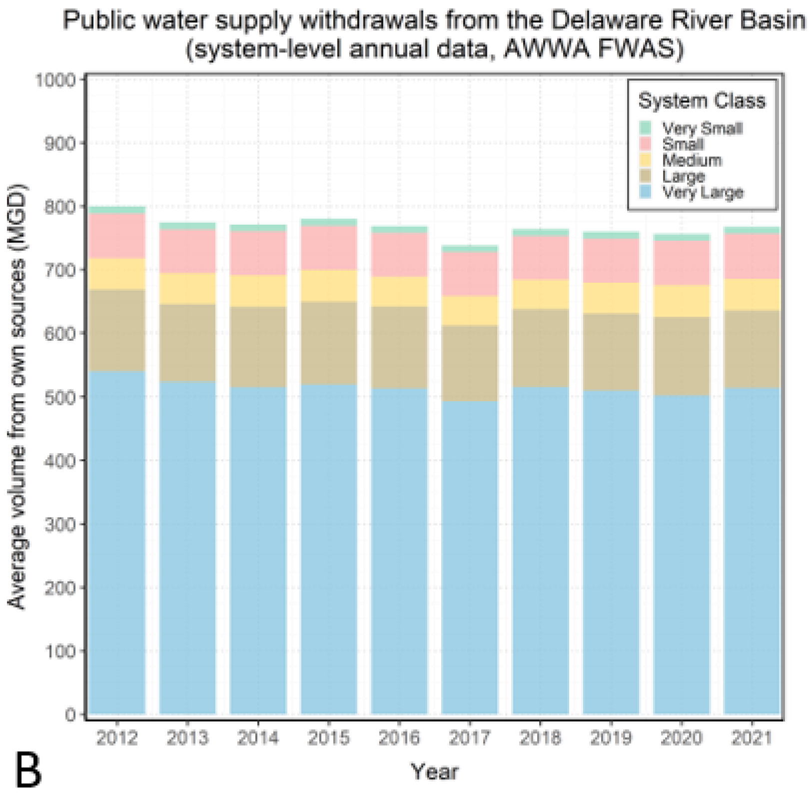
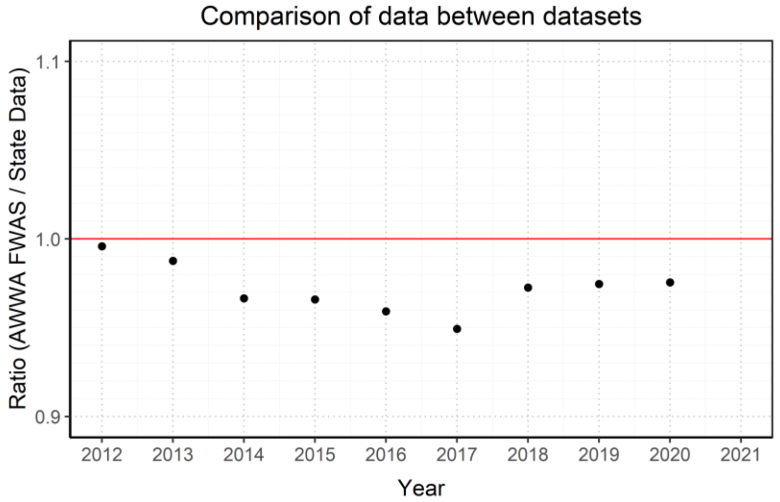




Zoom in on the period of study overlapping with "monthly source-level" data reported to state agencies, compiled by DRBC



The mean accuracy is 97%, state data is higher

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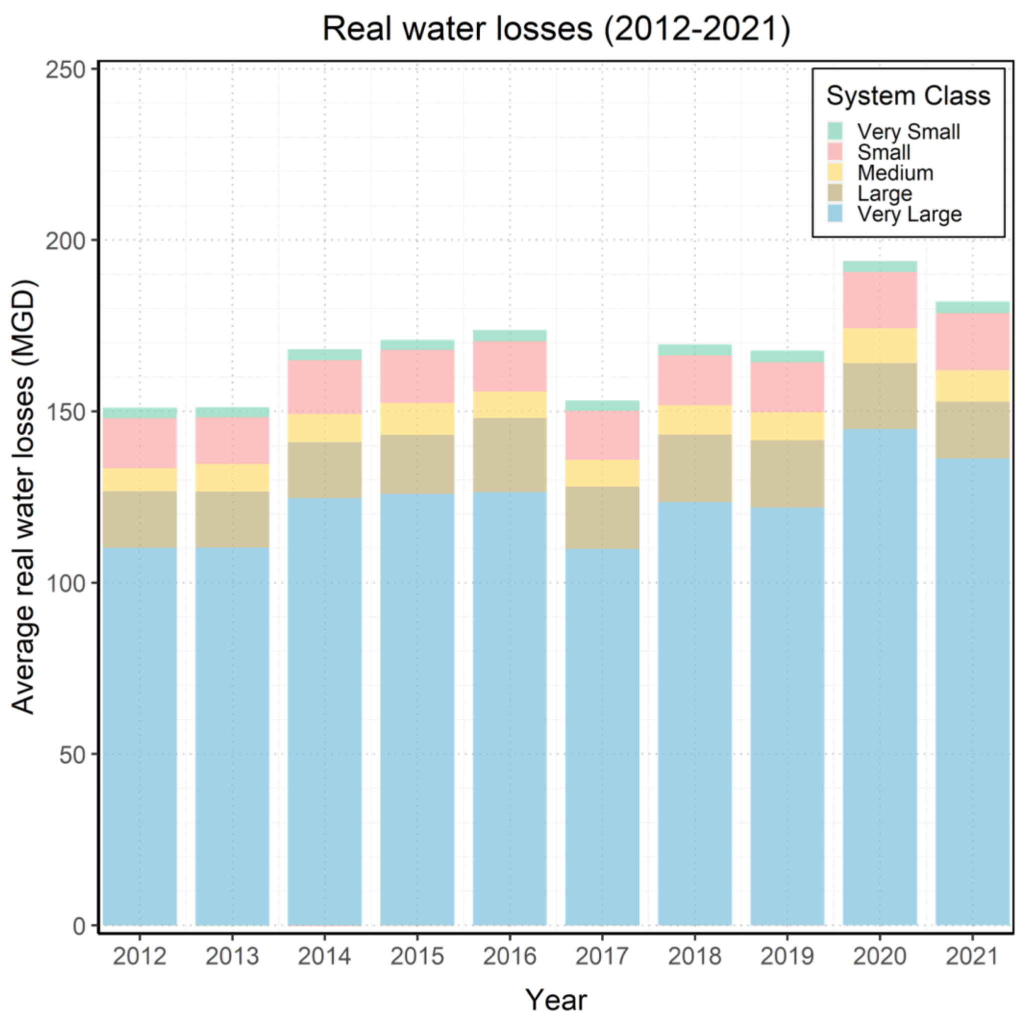

***Table 12:** The annual real water loss volumes by system class previously presented in Table 11, normalized by the 10-year mean and color coded such that values above the mean are red (>1), and values below the mean are blue (<1).*

Year	Very Small	Small	Medium	Large	Very Large	Total
2012	1.00	0.97	0.80	0.91	0.89	0.90
2013	0.92	0.91	0.96	0.90	0.89	0.90
2014	1.00	1.04	0.98	0.89	1.01	1.00
2015	0.92	1.03	1.11	0.95	1.02	1.02
2016	1.05	0.97	0.92	1.19	1.02	1.03
2017	0.93	0.95	0.93	1.00	0.89	0.91
2018	1.03	0.96	1.02	1.09	1.00	1.01
2019	1.07	0.97	0.97	1.09	0.99	1.00
2020	1.01	1.09	1.22	1.06	1.17	1.15
2021	1.07	1.11	1.09	0.91	1.10	1.08

The volume of real losses has remained relatively constant, with increases in the last two years (2020, 2021).

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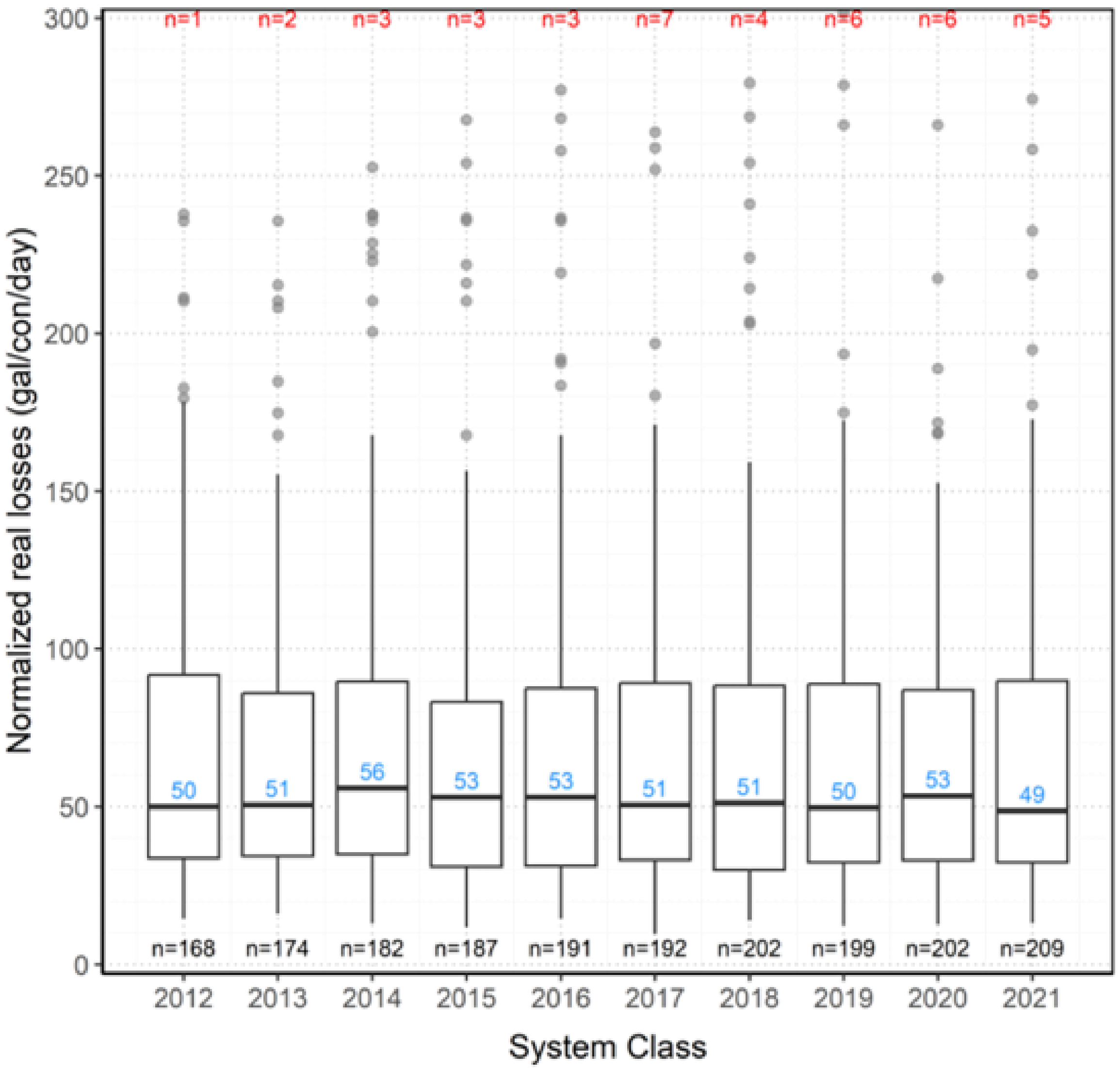
Normalized real loss rate



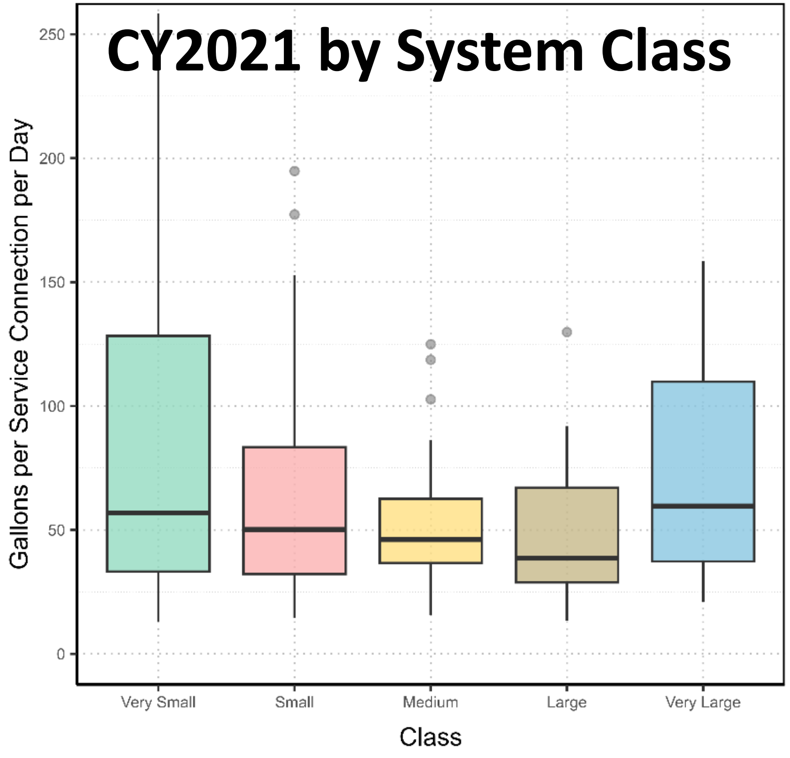
CY2021 statistics

min	13.1 gcd
p25	32.3 gcd
median	48.7 gcd
p50	72.1 gcd
p75	89.9 gcd
max	414 gcd

Figure 22: Normalized real water loss rate calculated using the filtered dataset for systems in the Delaware River Basin subject to water audit reporting requirements. The black "n=123" label at the bottom is the total data points for each bar, whereas the red "n=123" at the top of the frame is the total number of points plotting beyond the y-axis limit. The blue number in the middle of each box is the median value (normalized real loss rate).

Real losses

(gallons per service connection per day)



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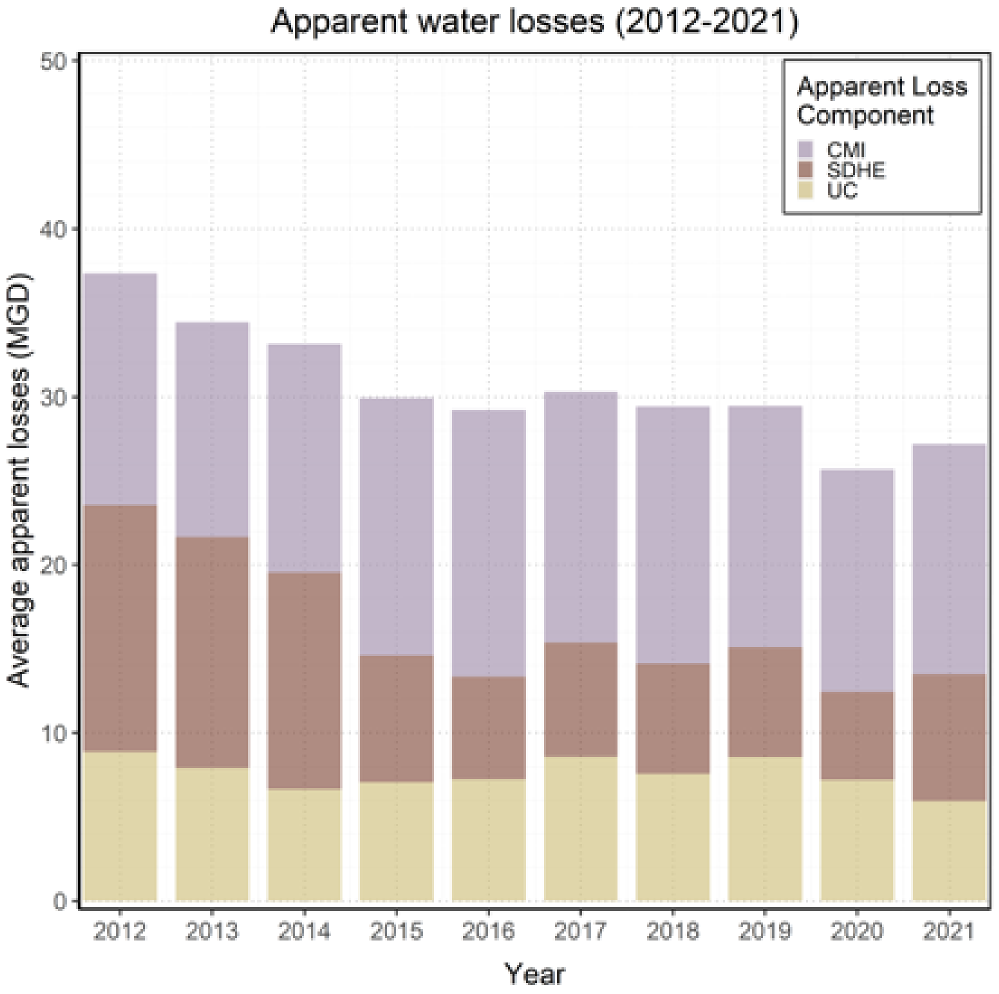
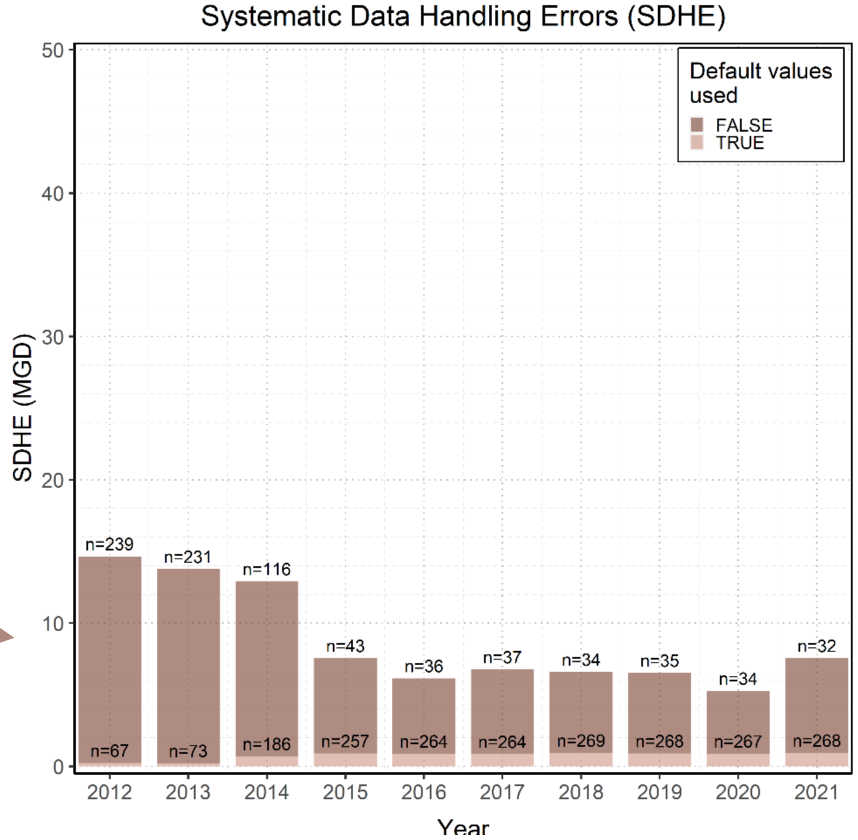
Apparent losses

Differing equations could easily be corrected to the most current method.

Without a default available, some input their own data at much higher rates.

Software Version	Unauthorized Consumption (UC)		Systematic Data Handling Errors (SDHE)		Customer Metering Inaccuracies (CMI)	
	Equation	Default	Equation	Default	Equation	Default
v4.1	WS * % [1]	0.25%	--	--	(BMAC+UMAC)/(1-%)-(BMAC+UMAC)	--
v4.2	WS * %	0.25%	--	--	(BMAC+UMAC)/(1-%)-(BMAC+UMAC)	--
v5.0	WS * %	0.25%	BMAC * %	0.25%	(BMAC+UMAC)/(1-%)-(BMAC+UMAC)	--
v6.0	BMAC+BUAC * %	0.25%	BMAC+BUAC * %	0.25%	(BMAC+UMAC)/(1-%)-(BMAC+UMAC)	--





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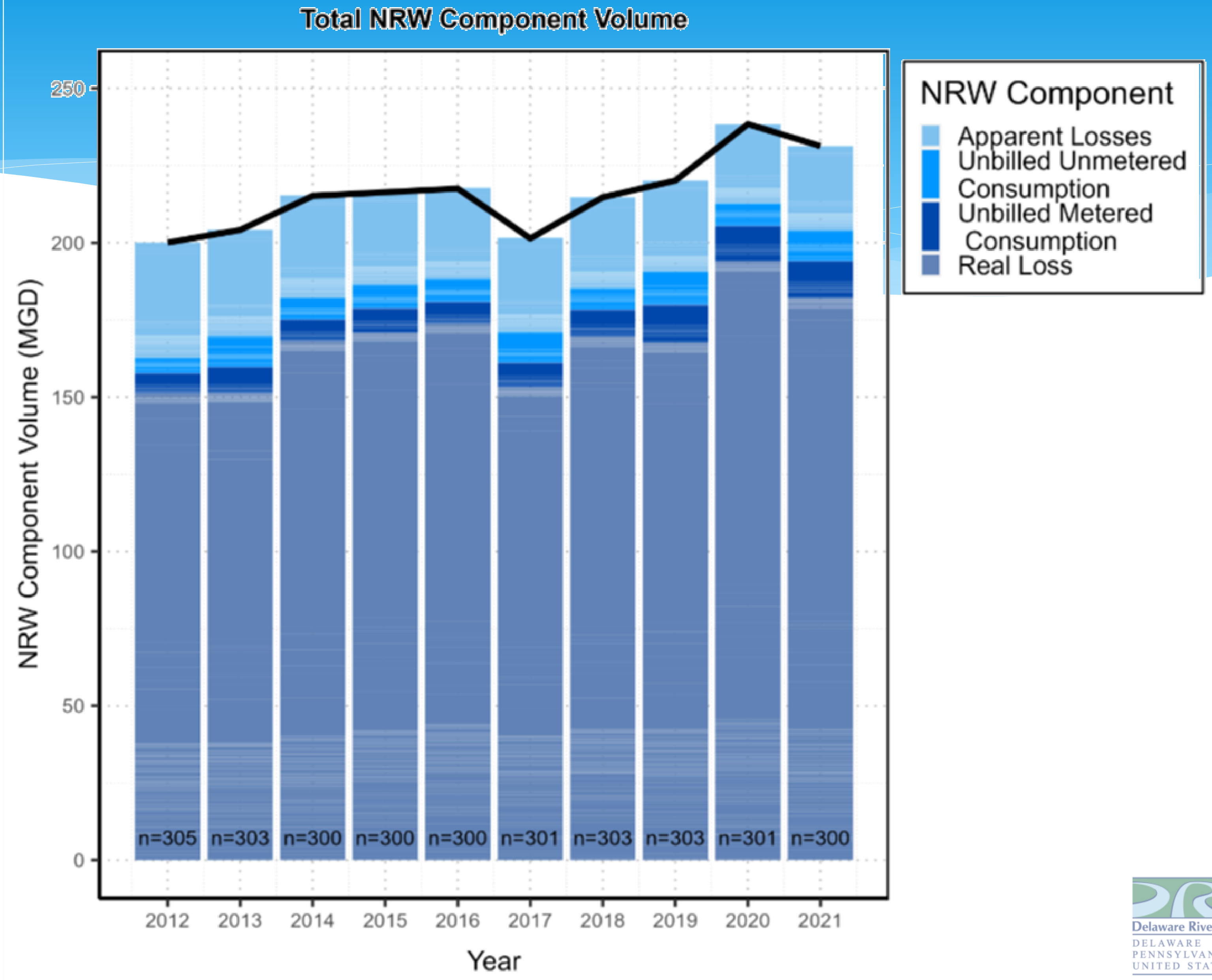
Non-revenue Water (NRW)



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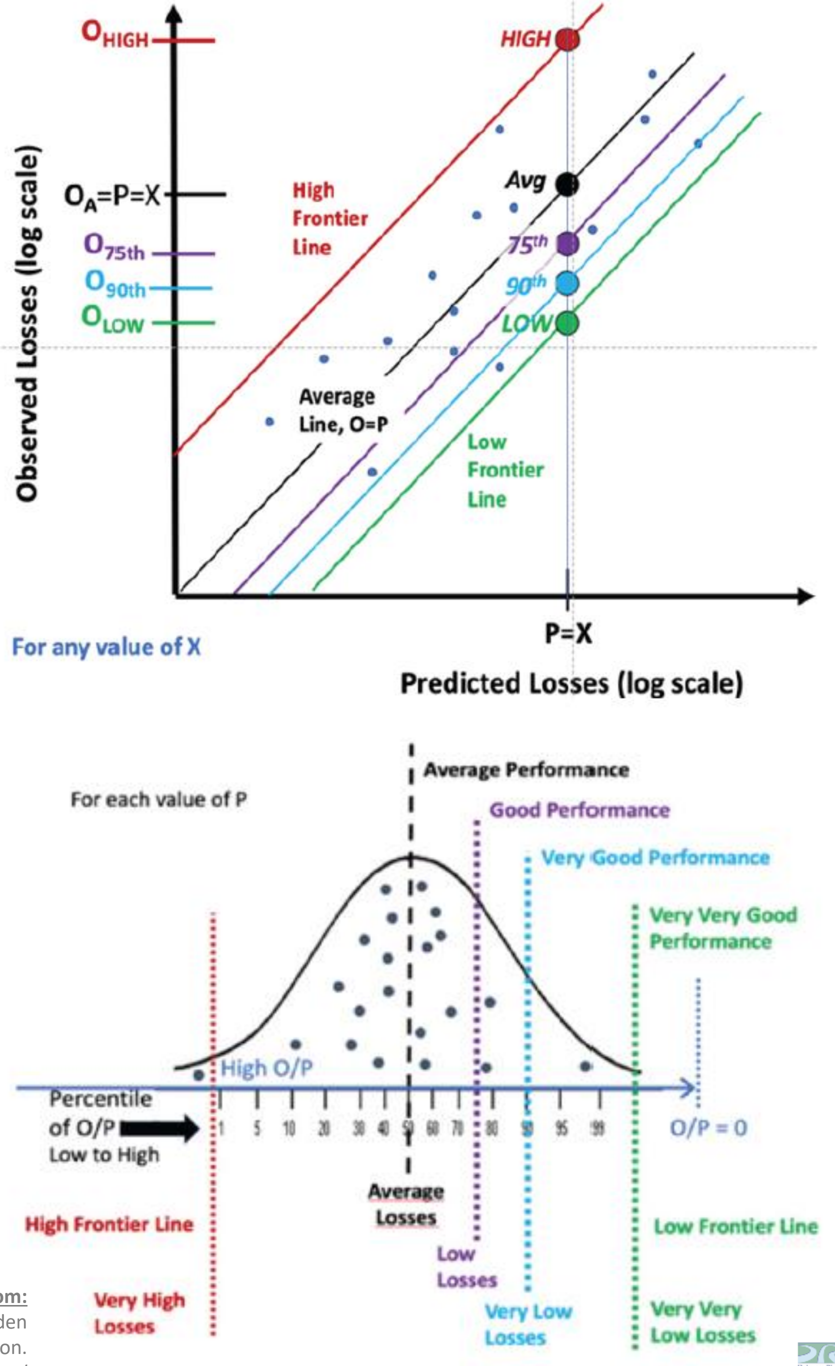
5. Real Loss Reduction Potential Analyses

Frontier Analysis

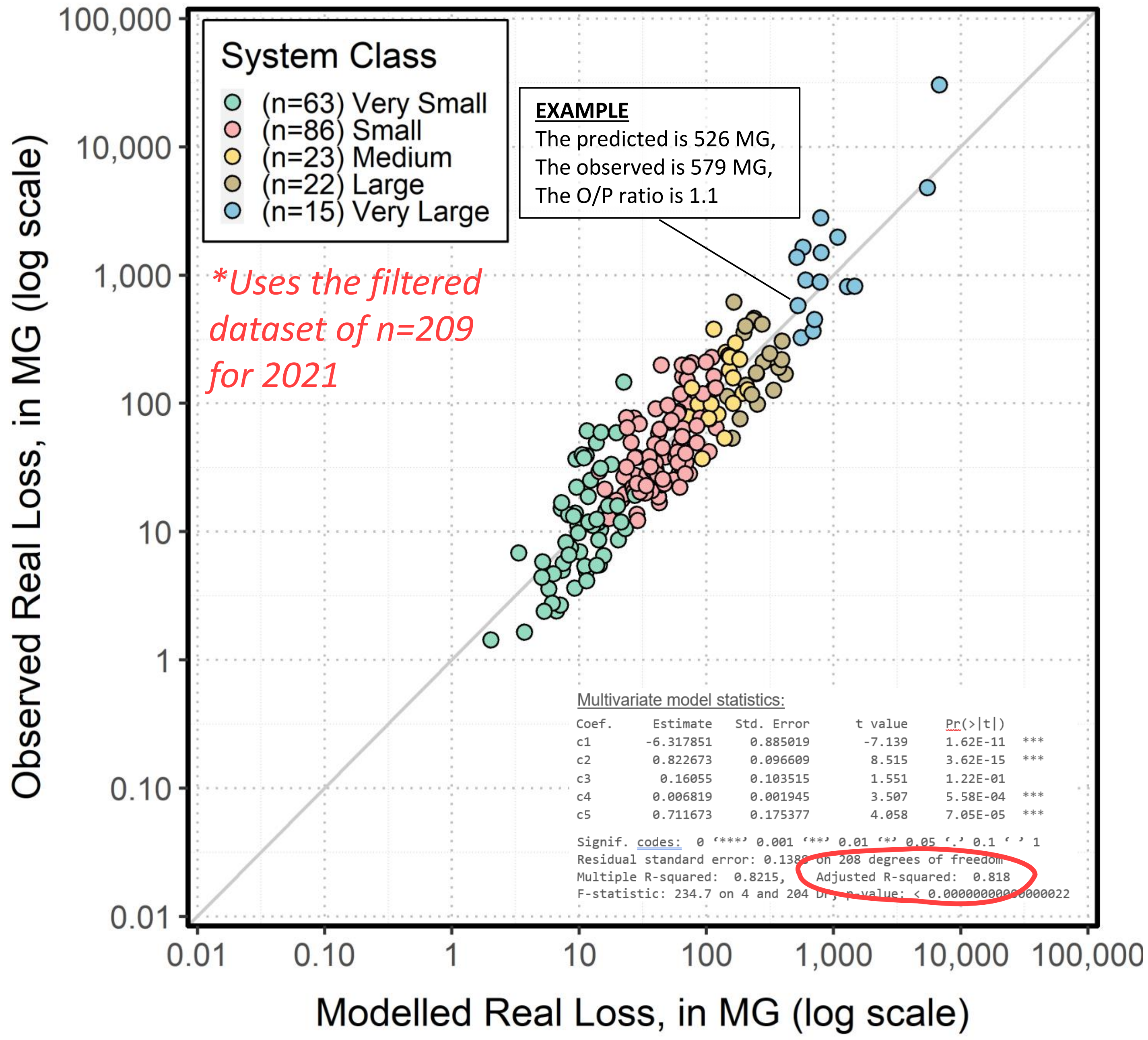
What is a frontier analysis as it relates to water loss?

1. Develop a multivariate model to predict real loss from a system
2. Look at how the ratios of $Rl_{observed}$ / $RL_{predicted}$ are distributed (i.e. the “O/P ratio”)
1. Calculate percentiles for O/P ratio based on distribution
   - **Average** systems performance = 50th percentile
   - **Good** system performance = 25th percentile
   - **Very Good** performance = 10th percentile
2. Calculate “Real Loss Reduction Potential” if systems worse than average improved performance to become average (etc.…)



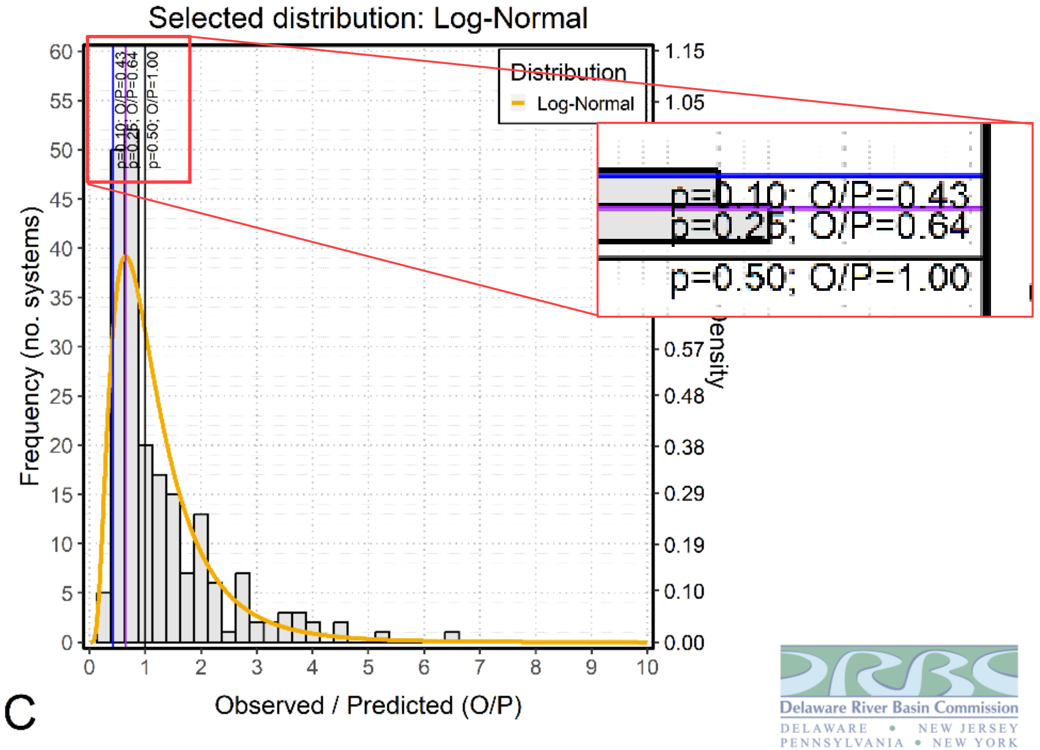
Figures adopted from:
Walker, J., Wyatt, A [Alan], Seefeldt, J., Goshen, D., Bock, M., Johnston, I., & Black, M. (2022). Hidden Reservoirs: Addressing Water Loss in Texas. Austin, Texas. National Wildlife Federation. https://texaslivingwaters.org/deeper-dive/water-loss/

Observed Real Losses v. Predicted Real Losses



The components of UARL

Dependent variable:	WL	Total Water Loss	MG / year
Independent variables:	N_c	Number of active and inactive service connections	count
	L_m	Length of mains	miles
	P_{AO}	Average operating pressure	psi
	L_p	Average length of customer service line	feet
Model Form	General form: $\ln(WL) = c_1 + c_2 * \ln(N_c) + c_3 * \ln(L_m) + c_4 * L_p + c_5 * \ln(P_{AO})$ Simplified form: $WL = \hat{c_1} * N_c^{c_2} * L_m^{c_3} * e^{(c_4 * L_p)} * P_{AO}^{c_5}$ where $\hat{c_1} = e^{c_1}$		



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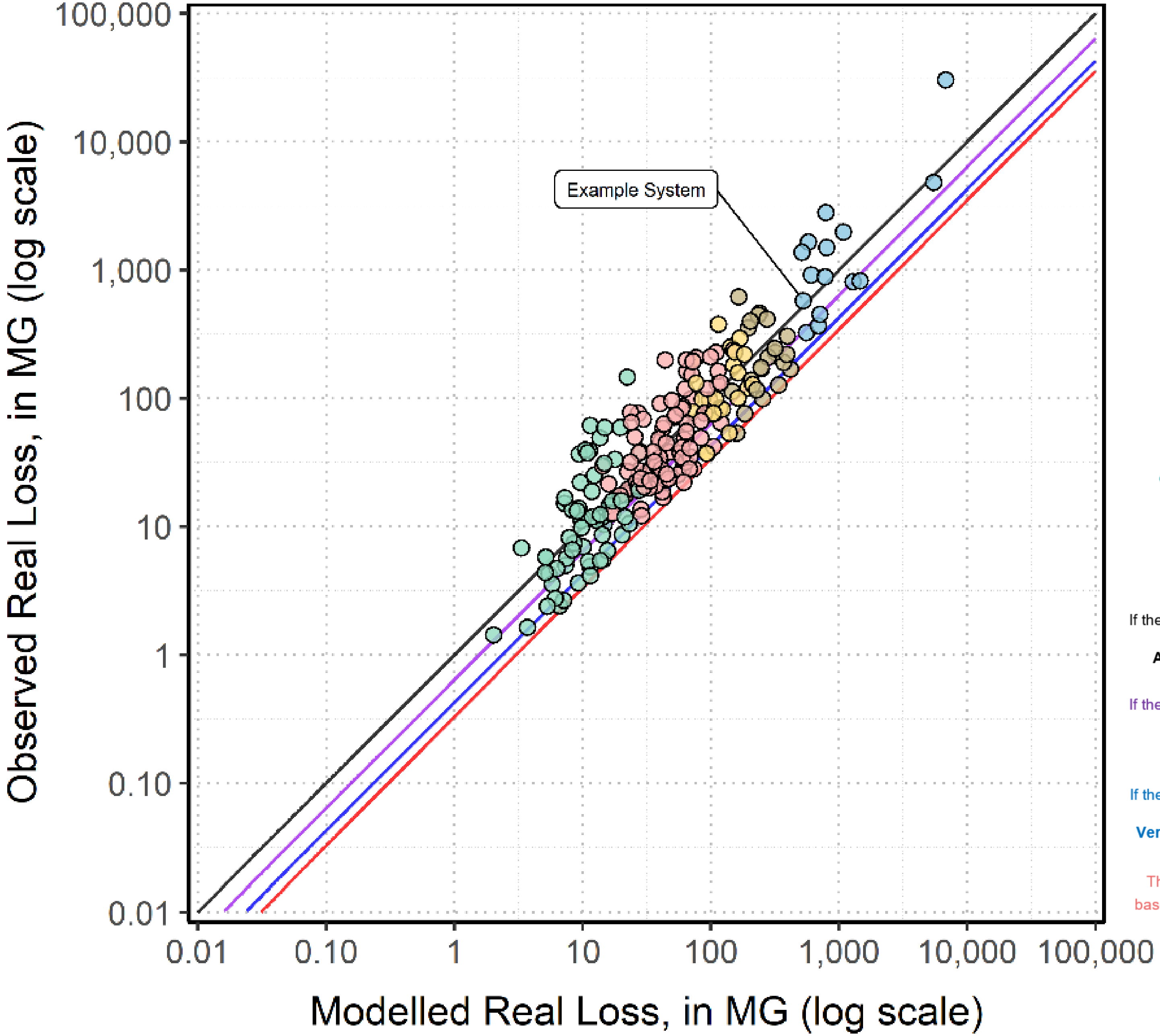
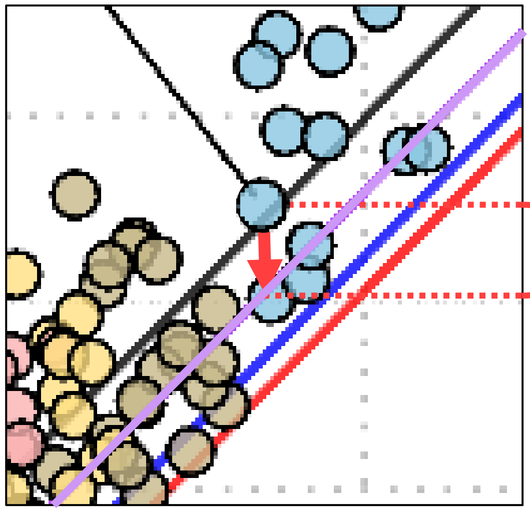
DRBC CY2021 AWWA FWAS data: Frontier Analysis





The vertical distance is the amount of real losses which could be mitigated by better performance

	Parameter	Value	Units	Calculation
Data reported on the AWWA FWAS	Reported real losses	579.041	MG	--
	Nc	28,171	conn.	--
	Lm	241.6	miles	--
	P	82.1	psi	--
	Lp	20	feet	--
	Predicted real losses	526.195	MG	$WL = \hat{c}_1 * N_c^{c_2} * L_m^{c_3} * P_{AO}^{c_4} * e^{c_5 * L_p}$
	O/P ratio	1.10	--	579.041 / 531.498
If the system were to improve to **Average (p50)** performance	p50 O/P ratio	1.00	--	--
	p50 predicted real losses	526.195	MG	1.00 * 526.195
	p50 reduction potential	52.846	MG	579.041 – 526.195
If the system were to improve to **Good (p25)** performance	p25 O/P ratio	0.64	--	--
	p25 predicted real losses	336.765	MG	0.64 * 526.195
	p25 reduction potential	242.276	MG	579.041 – 336.765
If the system were to improve to **Very Good (p10)** performance	p10 O/P ratio	0.43	--	--
	p10 predicted real losses	226.264	MG	0.43 * 526.195
	p10 reduction potential	352.777	MG	579.041 – 226.264
Theoretical limit based on UARL	UARL	189.778	MG	$(5.41\ L_m + 0.15\ N_c + 7.5\ N_c L_p) \times P_{AO} \times 365$
	UARL reduction potential	389.263	MG	579.041 – 189.778

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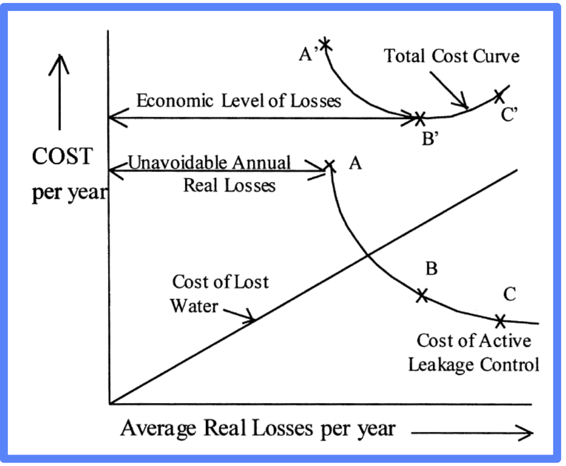
Frontier Analysis: Real Loss Reduction Potential

Aggregate results for the Basin:

1. Real losses could be reduced between about 34,000 – 52,000 million gallons per year (or about 95 - 144 MGD on average)
2. Can show the results as normalized gal / connection / day (average by class). (click to advance slide and change results)
3. Very Large systems account for the majority of the RLRP by volume, but not the highest when considering normalized
4. Incorporation of UARL brings in a component of "physical limits"

Challenges:

1. Reduction to UARL not realistic, should consider Economic Level of Leakage
2. Percentiles may change year to year if the analysis is redone



Economic Level of Leakage

Adopted from (Lambert et al., 1999)

Table 16: A summary of aggregate real loss reduction potentials in million gallons per year (MGY). These represent volumes of real water loss which could be mitigated should individual systems improve system efficiency to meet frontier predictions of real loss.

Dataset	Symbol	Count	System Class	Improvement to Average (p50) performance	Improvement to Good (p25) performance	Improvement to Very Good (p10) performance	Improvement to UARL performance
Filter Pass (n=210)	○	63	Very Small	521	673	796	844
	○	86	Small	1,730	2,718	3,521	3,903
	○	23	Medium	848	1,415	1,954	2,220
	○	22	Large	1,393	2,076	2,916	3,339
	○	15	Very Large	29,711	35,510	40,070	41,725
Subtotal		*209*	--	34,203	42,392	49,257	52,031
Filter Fail (n=090)	◇	31	Very Small	55	64	70	73
	◇	39	Small	272	301	332	340
	◇	7	Medium	0	0	0	0
	◇	14	Large	0	0	36	55
	◇	0	Very Large	0	0	0	0
Subtotal		*91*	--	327	366	438	468
Grand Total (MG)				34,530	42,758	49,694	52,499
Grand Total (MGD)				95	117	136	144

ILI Analysis: Real Loss Reduction Potential

What about using ILI?

ILI = Real Loss / UARL

Plot: Real Loss vs. UARL

- Strong technical basis for UARL
- "Frontiers" are based on physical characteristics of the system, not the group's performance
- "Frontiers" are not recalculated year after year
- Economic Level of Leakage (ELL) can often be indicated as an ILI value
- A Basin-wide RLRP can be calculated assuming that *"all systems above ILI=X were to reduce real losses to reach an ILI=X"*.

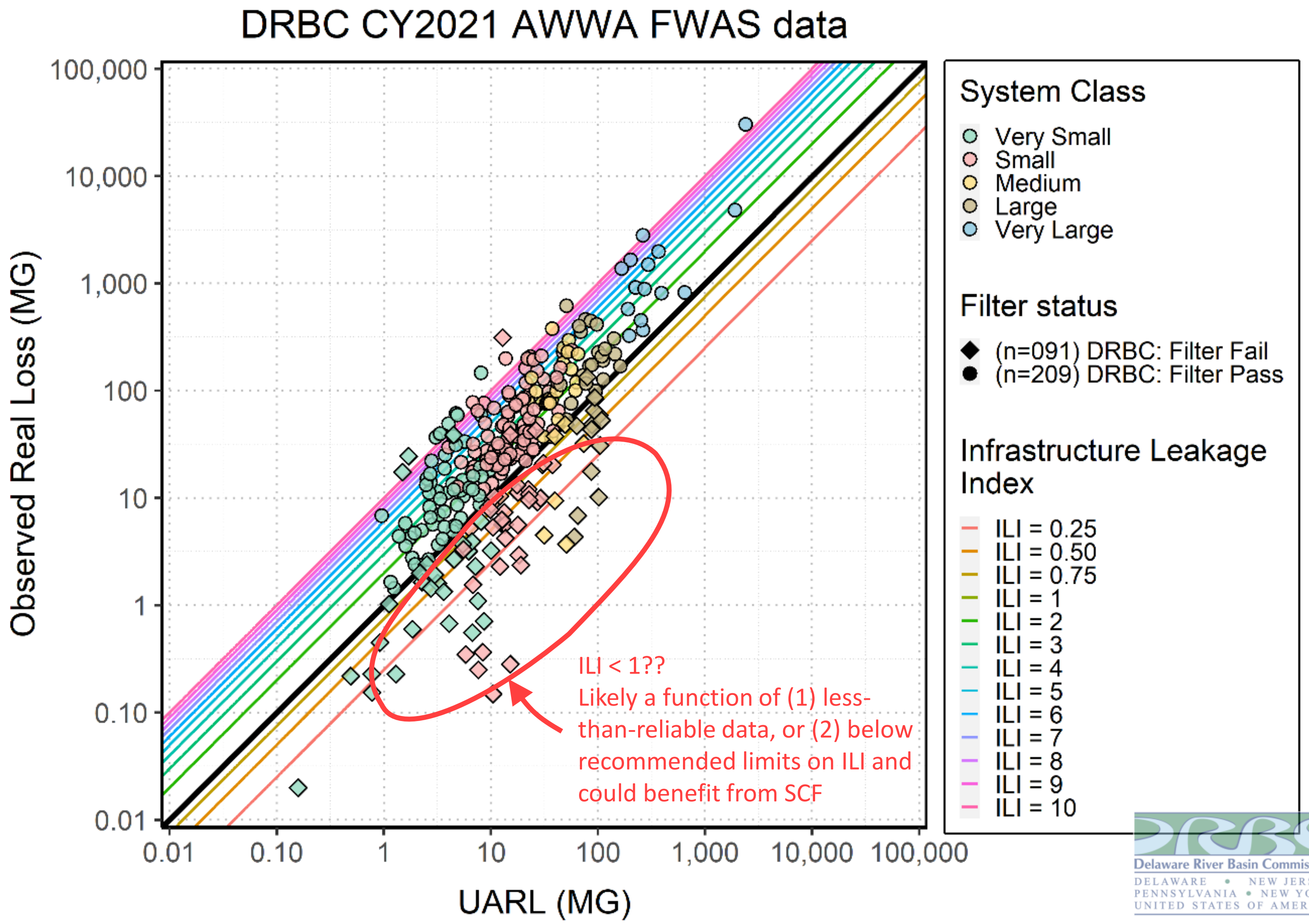


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***Table 18**: A summary of the real loss reduction potentials, based on an assessment of each system's performance increase to meet specified levels of ILI. Units are in million gallons.*

Data	Sy.	No.	System Class	ILI=10	ILI=9	ILI=8	ILI=7	ILI=6	ILI=5	ILI=4	ILI=3	ILI=2	ILI=1
Filter Pass (n=209)	○	63	Very Small	119	150	184	225	280	348	424	508	627	844
	○	86	Small	72	94	169	290	468	705	1,058	1,662	2,560	3,903
	○	23	Medium	7	44	94	154	215	330	536	871	1,389	2,220
	○	22	Large	112	163	213	264	324	550	924	1,369	1,906	3,339
	○	15	Very Large	6,650	9,308	12,065	15,091	18,116	21,313	25,025	29,018	34,450	41,725
Subtotal		*209*	--	6,960	9,760	12,725	16,024	19,403	23,245	27,967	33,428	40,932	52,031
Filter Fail (n=091)	◇	31	Very Small	10	13	19	27	35	42	50	58	65	73
	◇	39	Small	184	197	210	223	236	248	261	274	296	340
	◇	7	Medium	0	0	0	0	0	0	0	0	0	0
	◇	14	Large	0	0	0	0	0	0	0	0	0	55
	◇	0	Very Large	0	0	0	0	0	0	0	0	0	0
Subtotal		*91*	--	194	210	229	249	270	291	311	332	361	468
			Grand Total (MG)	7,154	9,970	12,954	16,273	19,673	23,536	28,278	33,760	41,293	52,499
			Grand Total (MGD)	20	27	35	45	54	64	77	92	113	144

Consider the results of the two methods:

- RLRP ≈ 34,000 MG (~93 MGD) → FA "Average" Performance, ... or ILI=3
- RLRP ≈ 43,000 MG (~118 MGD) → FA "Good" Performance, ... or ILI=2
- RLRP ≈ 50,000 MG (~137 MGD) → FA "Very Good" Performance
- RLRP ≈ 52,500 MG (~144 MGD) → FA "UARL" Performance, ... or ILI=1

Challenges:

- *"all systems above ILI=X were to reduce real losses to reach an ILI=X"*
- Changing the operating pressure (or system infrastructure) changes the UARL

This is an assumption. Many systems have different economic constraints on "how low they can go"

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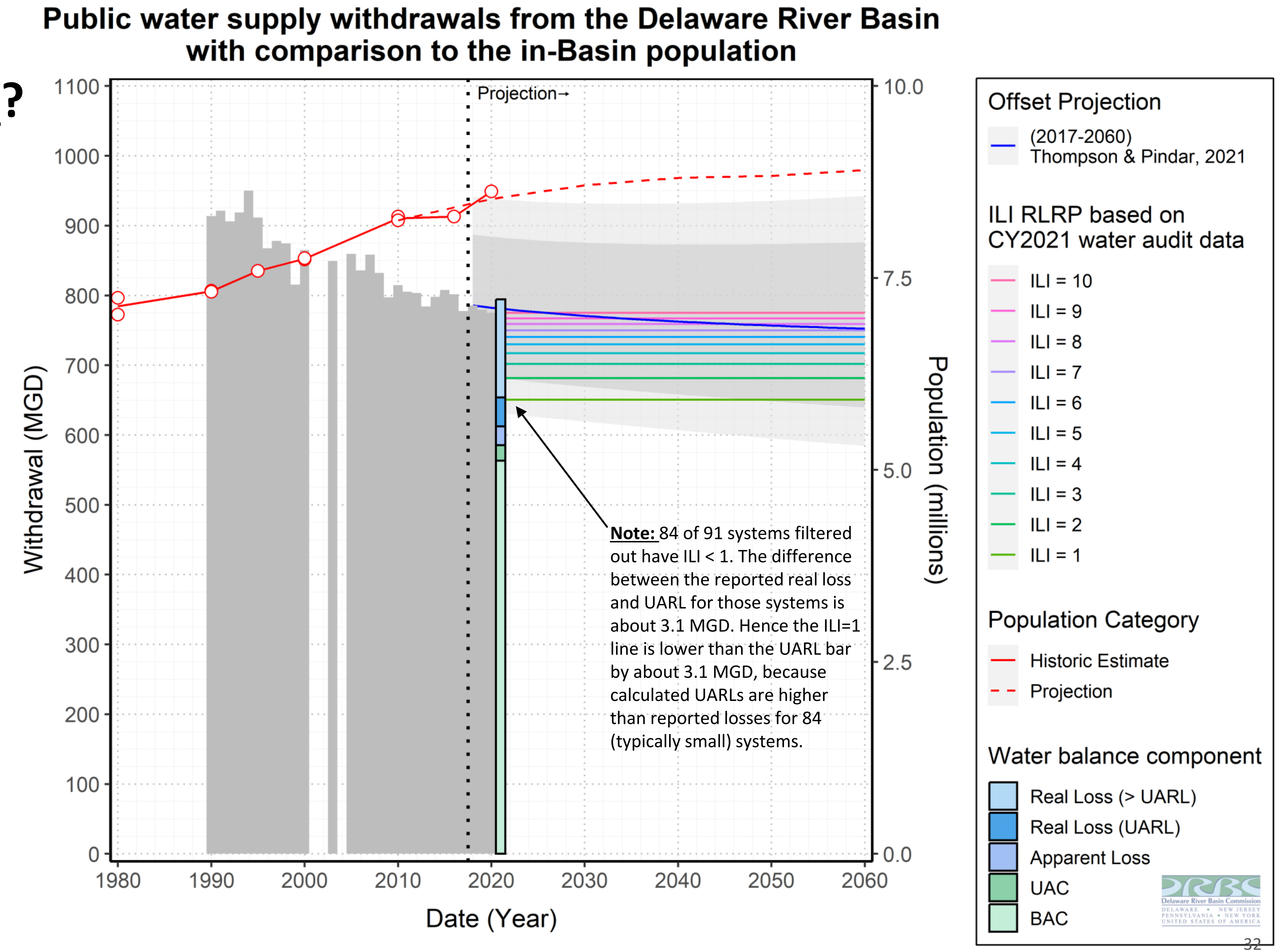
What does this mean?

- **The decrease in projected withdrawals (based on current operational trends) is equivalent in magnitude to systems above ILI=7 reducing to ILI≈7**
- There is room for improvement
  - Economic Levels of Leakage (ELL) are not included in assessment. ILI=1 not a realistic scenario and ELL analyses may help improve understanding.
- Is it possible the projection may reach an inflection point? Continued population growth outweighs reductions?



6. UARL System Correction Factors (SCF)

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UARL System Correction Factors (SCF)

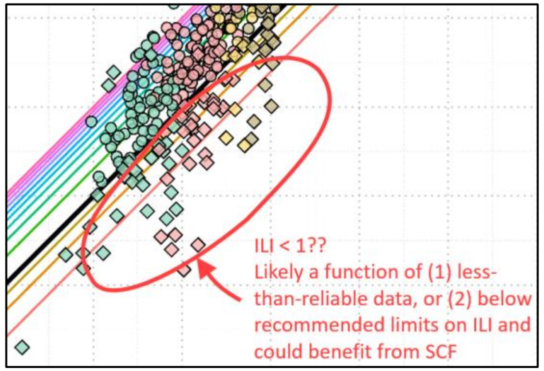
Recall: the equation for UARL uses three terms related to infrastructure, with coefficients based on three forms of leakage (all related to pressure).

$$UARL = (18*L_m + 0.80*N_c + 25*L_p) * P$$

Recommended limits based on data to generate coefficients:

$N_c > 5{,}000$

45m (64 psi) < P < 60m (85 psi)



Note that a lot of the points below ILI=1 are small systems (<5,000 connections)

Current research shows a dimensionless "system correction factor" can be applied to adjust UARL equation by modifying assumptions of the equation. (Lambert, 2020)

1. The relationship between pressure and leakage flow rate (P:Q), specifically as it related to the pipe material (rigid vs. flexible)
2. Low burst (leakage) frequencies in small systems
3. The relationship between pressure and burst frequency (P:BF)

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Pilot study using SCF

- DRBC worked with New Jersey American Water to gather the additional 3 parameters needed to calculate SCF.
- Water Loss Research & Analysis Ltd (WRA) performed the necessary calculations

Findings:

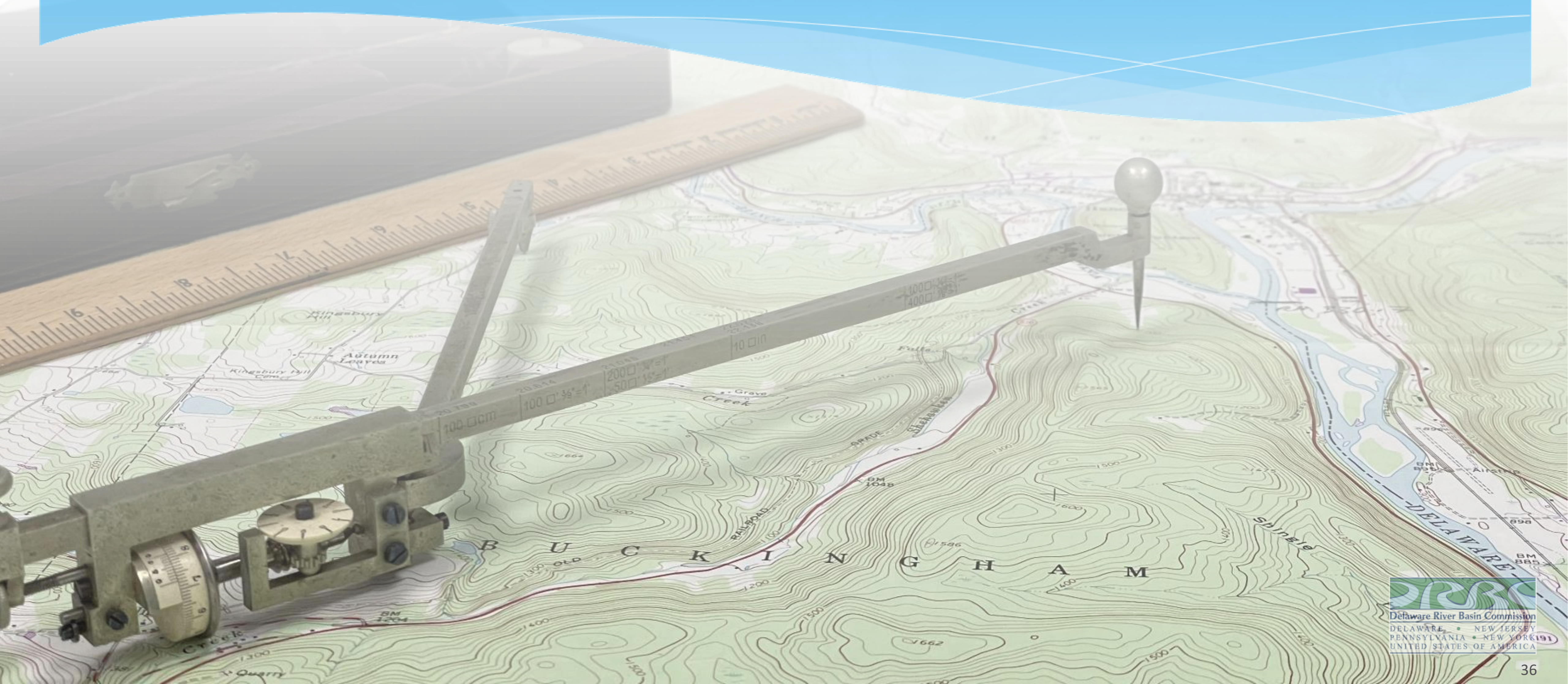
- FAVAD adjustments (based on pipe material) did not have much effect as would be expected, as the majority of piping is rigid.
- Adjusting the frequency of bursts for low systems had largest effect.
- One system went from un-realistic theoretical performance (ILI<1) to excellent performance (ILI>1)
- Only when pressure was on the high end of recommended range did that correct increase UARL.

Ultimately, beneficial pilot study and worth additional investigation.

***Table 20**: System data related to UARL for six small water public water supply systems in New Jersey, with supplemental data and calculations related to the System Correction Factors (SCF) as it applies to the UARL.*

Dataset	Parameter	Units	System 1	System 2	System 3	System 4	System 5
AWWA FWAS Data	N_c	--	473	1,293	2,582	3,902	4,850
	L_p	feet	25	25	25	25	25
	L_m	miles	7	12	52	72	95
	P	psi	73	57	52	50	86.1
	Real Loss	MG	9.821	5.172	63.225	47.827	163.405
	UARL	MG	3.347	6.341	14.431	20.319	44.427
	ILI	--	2.93	0.82	4.38	2.35	3.68
Supplemental data (% rigid pipes)	Service Connections (Main to Prop. Line)	%	65%	72%	98%	97%	96%
	Service Connections (Prop. Line to Meter)	%	80%	96%	77%	62%	77%
	Mains	%	100%	100%	99%	98%	100%
System Correction Factors	FAVAD	--	1.01	0.95	0.96	0.95	1.04
	FAVAD & POISSON	--	0.74	0.74	0.80	0.83	0.96
	FAVAD & POISSON & PRESSURE BURSTS	--	0.74	0.71	0.76	0.77	1.02
Modified based on FAVAD & POISSON & PRESSURE BURSTS	UARL (corrected)	MG	2.477	4.502	10.967	15.646	45.316
	ILI (corrected)	--	3.97	1.15	5.76	3.06	3.61

7. Physiographic analyses



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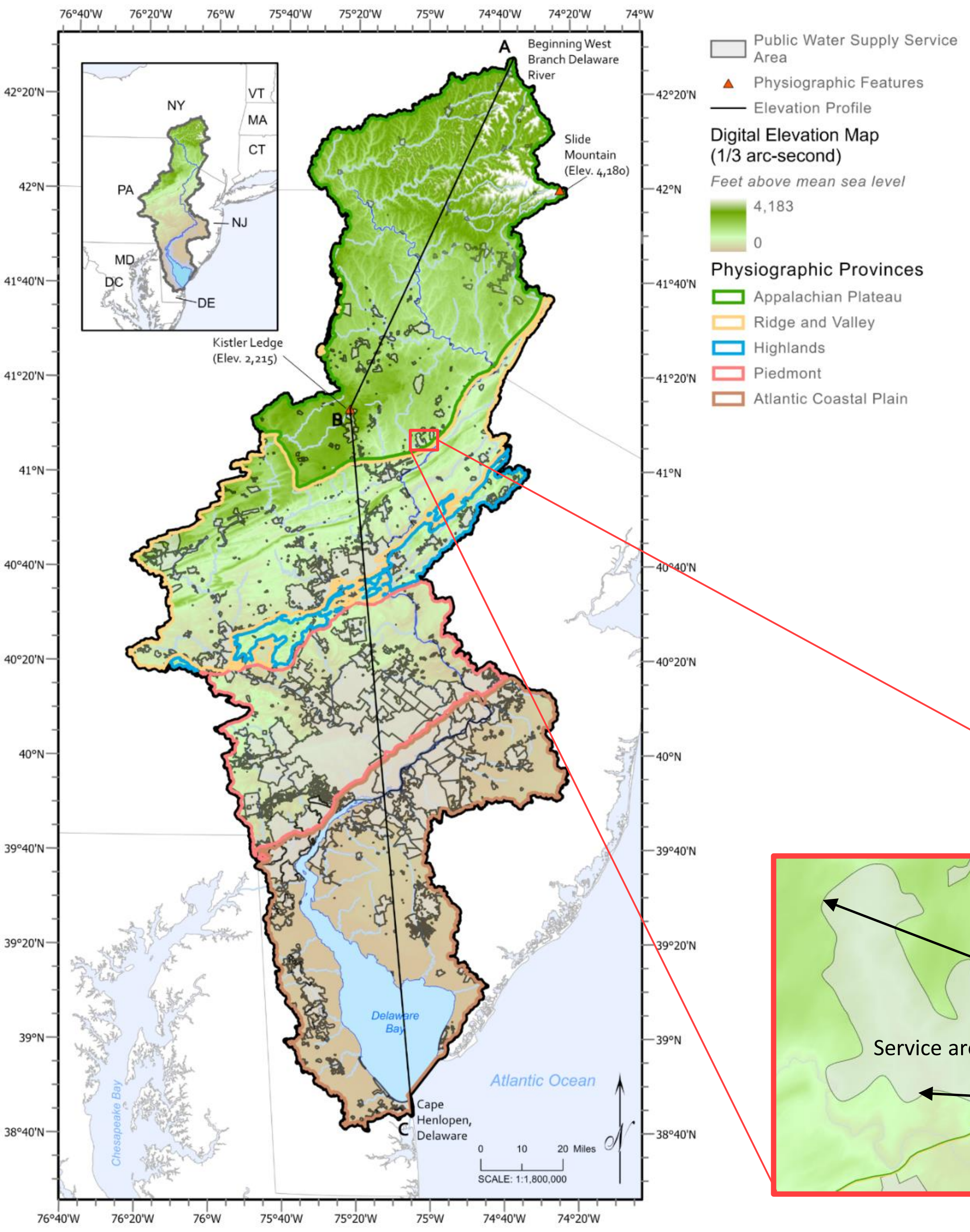

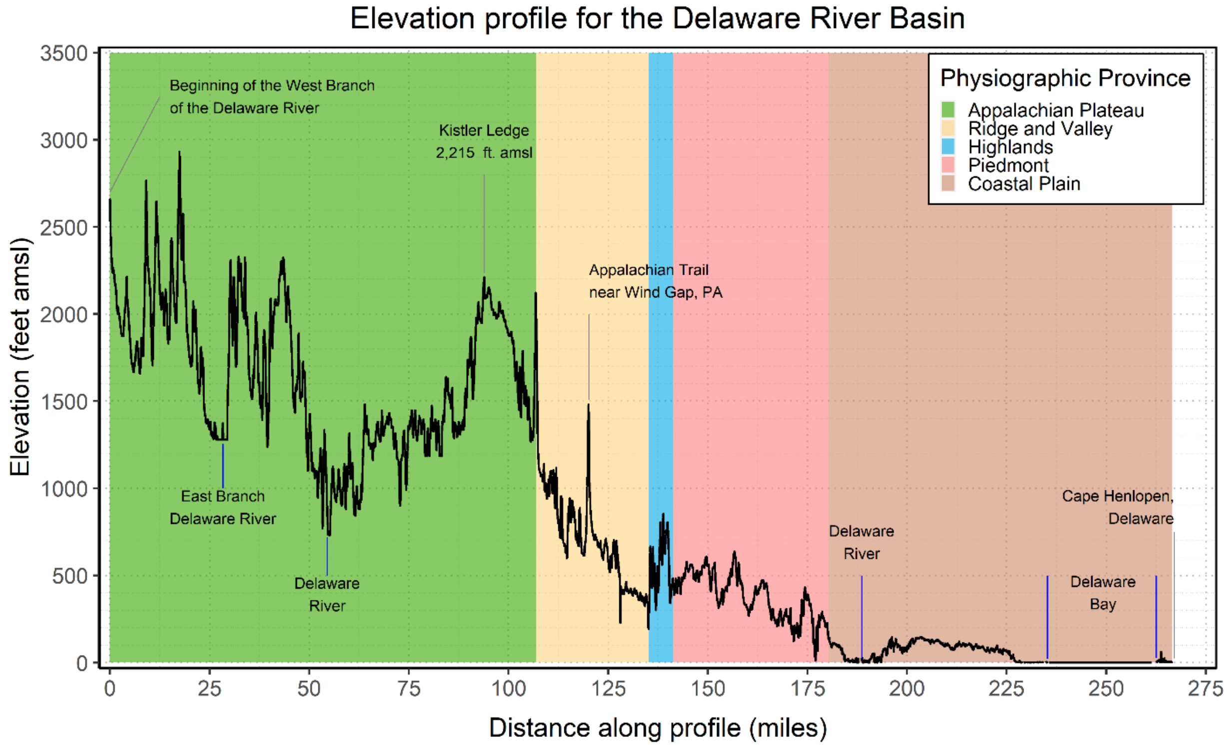

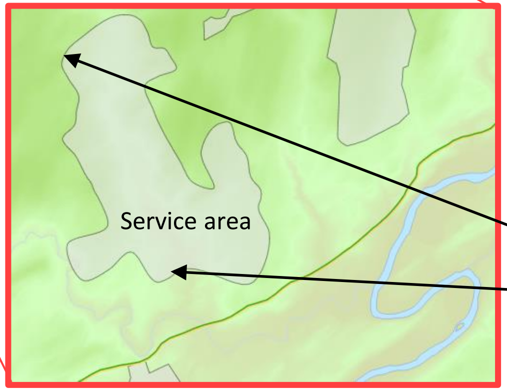

Is there some relationship between:

(1) Physiographic province

(2) Elevation differential of a service area

(3) Pressure or real losses

Highest elevation

Lowest elevation

Service Area Elevation Differential (SAED)

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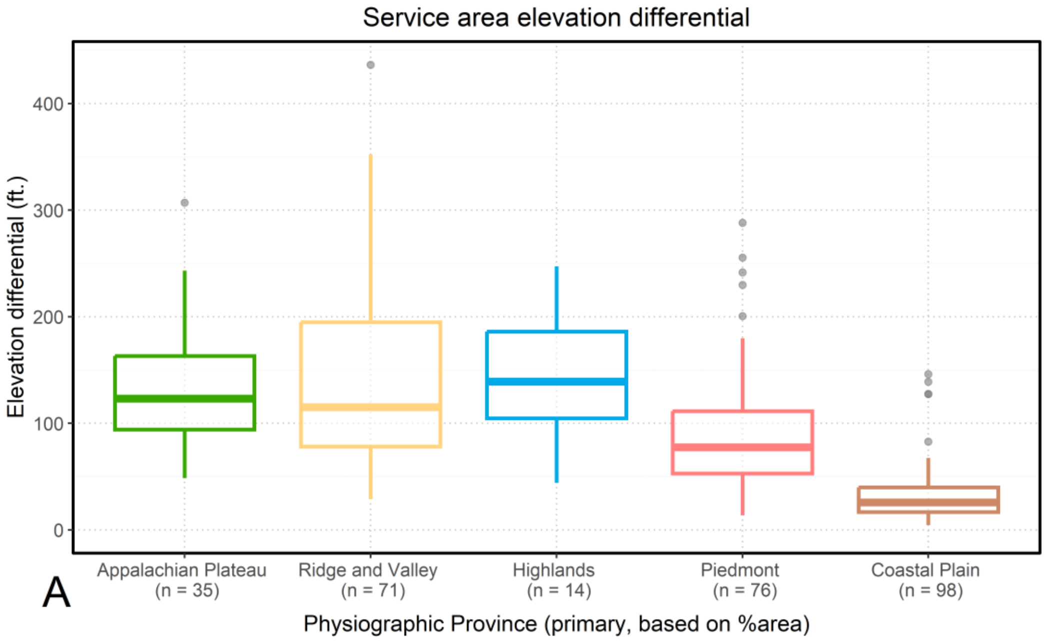


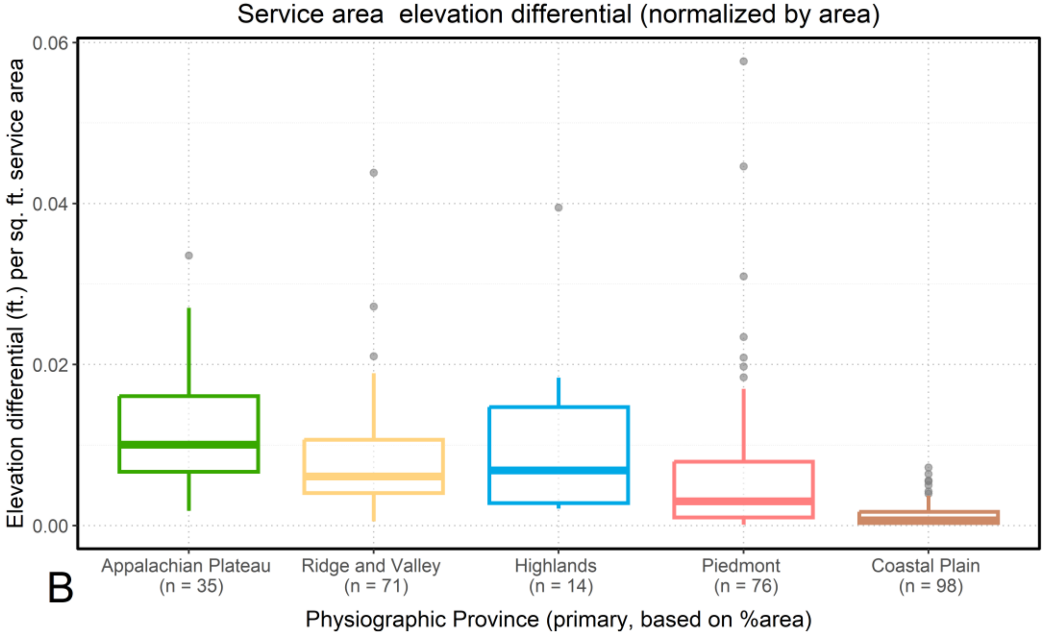
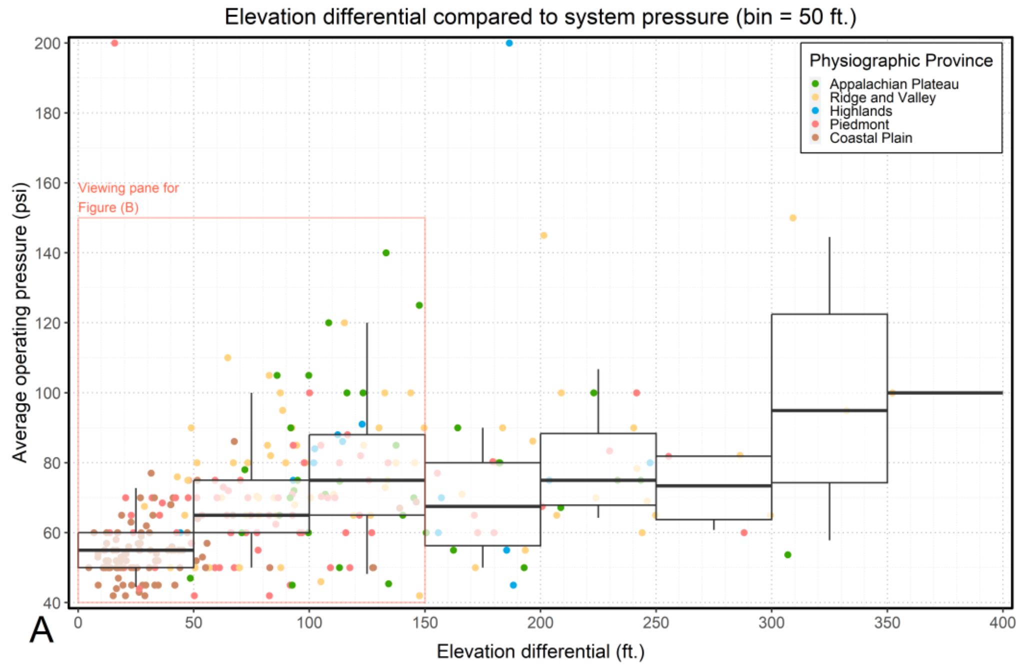
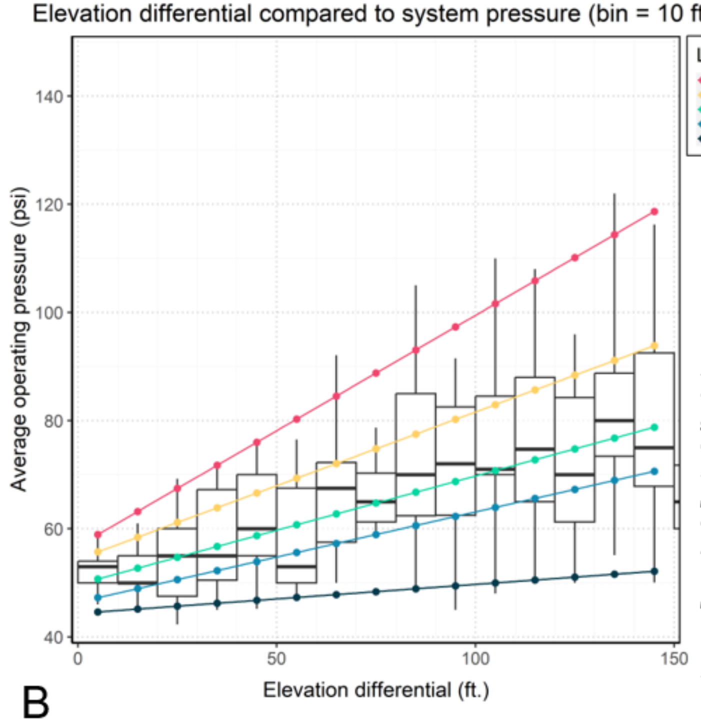


***Figure 50**: Elevation differentials within water supply service areas, grouped by physiographic province, which was assigned based on a percent area analysis. **(A)** Service area elevation differential, and **(B)** elevation differentials normalized by the size of the service area.*





Model	Adj. R^2	Equation
q = 0.95	0.87	P = 0.427*SAED + 56.798
q = 0.75	0.92	P = 0.272*SAED + 54.363
q = 0.50	0.86	P = 0.200*SAED + 49.712
q = 0.25	0.81	P = 0.167*SAED + 46.432
q = 0.05	0.28	P = 0.054*SAED + 44.354

***Figure 51**: Box plots relating the service area elevation differential (SAED) to the **average operating pressure** for the filtered dataset (n=209). Boxplots were created such that the whiskers represent the 95th and 5th percentiles, as opposed to 1.5 times the inter-quartile range. Outlier data points have not been plotted to avoid confusion with actual X-Y data points. (A) Individual system data plotted with large summary boxplots with a width of 50-ft. (B) Decreasing the box-size to 10-feet and performing linear regression analysis on each quartile statistic associated with the boxplot for SAED ≤ 150 feet.*

8. Conclusions

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KEY MESSAGES

1. This study is a comprehensive look at a decade of data from water audits, which has not been done before on this scale (multi-jurisdictional water basin)
2. Real losses remained relatively stable (2012-2019), showing possible slight increases over the past two years
3. In CY2021:
   - 794 MGD of water supplied
   - 182 MGD of real losses (41 MGD "unavoidable")
   - Real loss rate: ~ 49 gcd (median), ~ 72 gcd (mean)
4. There is improvement potential for real loss reduction. Current projections of continued operational trends suggest a reduction in withdrawal volume by 2060 *equivalent in magnitude* to all systems in 2021 above ILI=7 reducing to ILI≈7
5. Consistent high-quality data is important for accurate assessment of program success. Improved data quality and continued water audit program compliance will enhance water resource planning accuracy
6. Compliance is good, and there aren't many questions (in a given year) and not many requests for training (if any?). Even states where DRBC does not have regulatory primacy (NJ, DE) there is still good compliance rates. In past few years, have not had feedback from regulated community that it is burdensome.

RECOMMENDATIONS

1. Improve data validity
2. Improve quality of financial data
3. Improve water audit review process (at DRBC)
4. Perform analyses on the Economic Level of Leakage
5. Incorporate System Correction Factors for UARL calculations
6. Possible modifications to AWWA software
7. Investigate impacts on leakage due to COVID-19
8. Investigate the relationship between source water temperature and leakage
9. Update the national groundwater temperature map

NEXT STEPS

1. Incorporate comments from external review
    1. George Kunkel (Kunkel Water Efficiency)
    2. Allan Lambert (Water Loss Research & Analysis Ltd)
    3. Gary Trachtman (Arcadis)
2. Publish the report (Nov/Dec)
3. Presentation at AWWA North American Water Loss Conference & Exposition (NAWL)
    - WED02- THE MULTI-YEAR PROGRESS OF WATER LOSS PROGRAMS IN STATE & REGIONAL AGENCIES
    - 12/6/2023 @ 10:30 AM - 12:00 PM MDT
4. WMAC – review report and offer suggestions for the future (2024)

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REFERENCES

Alegre, H., Baptista, K., Cabrera Jr, E., Cubillo, F., Duarte, P., Hirner, W [Wolfram], Merkel, W., & Parena, R. (2000). Performance indicators for water supply services (1st ed.). Manual of best practice. IWA Publishing.

Andrews, L., Gasner, K., Sturm, R., Kunkel, G., Jernigan, W., & Cavanaugh, S. (2016). Level 1 Water Audit Validation: Guidance Manual. WRF Project No. 4639A. Denver, Colorado. Water Research Foundation.

AWWA. (2009). Water audits and loss control programs (3rd ed.). AWWA manual: M36. American Water Works Association. on.

AWWA. (2016a). The State of Water Loss Control in Drinking Water Utilities. A White Paper From the American Water Works Association. Denver, Colorado. American Water Works Association. https://www.awwa.org/Portals/0/AWWA/ETS/Resources/WLCWhitePaper.pdf?ver=2017-09-11-153507-487

AWWA. (2016b). Water audits and loss control programs (4th ed.). AWWA manual: M36. American Water Works Associati

Jernigan, W., Kunkel, G., Trachtman, G., & Wyatt, A [Alan]. (2019). Key Performance Indicators for Non-Revenue Water. Denver, Colorado. American Water Works Association. https://www.awwa.org/Portals/0/AWWA/ETS/Resources/WLCCKPIReport%202019.pdf?ver=2019-11-20-094638-933

Kunkel, G. (2003). Committee Report: Applying worldwide BMPs in water loss control. Journal - American Water Works Association, 95(8), 65–79. https://doi.org/10.1002/j.1551-8833.2003.tb10430.x

Lambert, A. (1994). Accounting for losses - the bursts and background estimates concepts. J. Institution Water Environ. Mngnt., 8(2), 205–214.

Lambert, A. (2020). System Correction Factor SCF can customise the standard UARL equation for pipe materials, small systems and pressure: bursts relationships. Water Loss Research & Analysis Ltd. https://www.leakssuitelibrary.com/low-ilis-and-small-systems/

Lambert, A., Brown, T. G., Takizawa, M., & Weimer, D. (1999). A review of performance indicators for real losses from water supply systems. Journal of Water Supply: Research and Technology—AQUA, 48(6), 227–237. https://doi.org/10.2166/aqua.1999.0025

Sturm, R., Gasner, K., & Andrews, L. (2015). Water Audits in the United States: A Review of Water Losses and Data Validity. WRF Project No. 4372b. Denver, Colorado. Water Research Foundation; U.S. Environmental Protection Agency

Sturm, R., Stief, C., Jernigan, W., & Blackwell, D. (2021). Level 1 Water Audit Validation Guidance Manual: Second Edition. Project 5057. Denver, Colorado. American Water Works Association.

Thompson, M. Y., & Pindar, C. E. (2021). Water Withdrawal and Consumptive Use Estimates for the Delaware River Basin (1990-2017) With Projections Through 2060. DRBC Report No: 2021-4. West Trenton, New Jersey. Delaware River Basin Commission. https://www.nj.gov/drbc/library/documents/water-use/DRBC_2021-4_Water2060_Final_101421.pdf

USEPA. (2016). EnviroAtlas - Dasymetric Population for the Conterminous United States. GIS Shapefile. U.S. Environmental Protection Agency. https://www.epa.gov/enviroatlas

Walker, J., Wyatt, A [Alan], Seefeldt, J., Goshen, D., Bock, M., Johnston, I., & Black, M. (2022). Hidden Reservoirs: Addressing Water Loss in Texas. Austin, Texas. National Wildlife Federation. https://texaslivingwaters.org/deeper-dive/water-loss/

Questions

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