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Baseline Data to Establish The Current Amount Of Resource Recovery from WRRFs

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Preparation of Baseline Data to ESTABLISH THE CURRENT AMOUNT OF RESOURCE RECOVERY

September 2018

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Abbreviations

ADEQ	Arizona Department of Environmental Quality
BTU	British Thermal Units
CASA	California Association of Sanitation Agencies
CHP	Combined heat power
CSWRCB	California State Water Resources Control Board
CWNS	Clean Water Needs Survey database
DECNYS	Department of Environmental Conservation New York State
ECHO	Enforcement and Compliance History Online
EPA	Environmental Protection Agency
FDEP	Florida Department of Environmental Protection
GEP	Georgia Environment Partnership
kW	kilowatts
MDE	Maryland Department of Environment
MDEQ	Michigan Department of Environmental Quality Water Sources Division
mg/L	milligram per liter
mgd	million gallons per day
MW	Mega Watt
N	Nitrogen
NRC	National Research Council
MMBTU/day	million British thermal units (BTU) per day
NACWA	National Association of Clean Water Agencies
NJDEP	State of New Jersey Department of Environmental Protection
NRC	National Research Council
NYSDEC	New York State Department of Environmental Conservation
P	Phosphorus
SNWA	Southern Nevada Water Authority
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
UNR	State of Utah Natural Resources
USDA	U.S. Department of Agriculture
USEPA	United States Environmental Protection Agency
VDEC	Vermont Department of Environmental Conservation
WE&RF	Water Environment & Research Foundation
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRRFs	Water resource recovery facilities

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We also want to express our appreciation for the 17 Canadian and 109 U.S. facilities that took time to complete the survey for this project. The information in the surveys complemented our database review by providing up-to-date 2018 industry data on resource recovery practices in WRRFs.

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EXECUTIVE SUMMARY

Population pressures, climate change, aging infrastructure, and funding limitations strain water resources and call for sustainable resource management solutions and circular economy over the next century. Wastewater treatment plants cannot operate merely as disposal facilities any longer. Instead, water resource recovery must become a cornerstone of facility operation, producing water fit for purpose, recovering nutrients, and reducing fossil fuel consumption by recovering the energy inherent in wastewater.

One of WEF's objective is to develop a program to set strategic resource recovery goals for the U.S. and Canadian water sector. The first step of this effort is to establish a baseline for current resource recovery practices in the North American water sector, followed by quantifying and publicizing progress toward stated goals.

The following figures summarize the results of the current status quo of resource recovery at Water Resource Recovery Facilities (WRRFs) in the U.S. for water, biosolids, nutrient (phosphorus and nitrogen), and energy recovery.

In parallel to the database summary, a utility survey was conducted for this study to collect data on resource recovery practices. The results of this survey allow to quantify the recovery practices of WRRFs in more detail and compare practices by facility size across the U.S.

Of the WRRFs petitioned for the WRRF resource recovery survey, 109 participated from the U.S., and 17 participated from Canada. The U.S. facilities covered about 22% of nationally treated municipal wastewater flow and about 20% of the total mass of biosolids produced in the U.S. The survey data is generally in agreement with the aggregated resource recovery trends summarized in Figure ES.1 through Figure ES.5. Survey results allow for a refined mass balance evaluation on current resource recovery practices for water, biosolids, phosphorus, and energy (electricity).

The report finishes with specific recommendations on future work to help advance resource recovery practices in North America. Briefly these are summarized as follows:

1. **Databases.** Existing databases do not capture information on phosphorus, nitrogen, and energy (other than that captured in biogas) resource availability, recovery practices, and recovery potential.
2. **Recoverable Resources.** This data summary forms a basis for estimating resources that can be feasibly recovered by WRRFs. This needs to consider technological limitations as well as financial cost-effectiveness. In order to further advance resource recovery implementation it would be useful to conduct analysis on the techno-economic factors of different recovery options and geographical and policy related differences.
3. **Energy Resource Data.** Little to no information is available on other forms of energy content in wastewater than biogas, such as thermal, hydraulic, compressed national gas injection, and fuel generation, which would allow for developing aggregate baseline data at the state and national level.

4. **Carbon Recovery.** Organic carbon in wastewater is closely related to its chemical energy content. Future utility survey efforts on resource recovery should include carbon mass balances.
5. **Updated Biosolids Database.** The most comprehensive data for biosolids production and uses dates back to 2007. Since then, several states have issued updated reports, information that would be useful if it could be standardized and captured in an updated national database.
6. **Peer Facility Benchmarking.** It would help to have current water reuse data by utility and state compiled into an up-to-date national database.
7. **Peer Facility Benchmarking.** It is useful to differentiate resource recovery performance, not only by facility size as done in this study, but also by process type and the level of treatment employed at WRRFs. This could be achieved by combining several large existing databases and developing transparent and user-friendly query options to retrieve the necessary information.
8. **Canadian Resource Recovery Baseline.** We recommend adopting the approach developed in this study to develop national aggregates for resource recovery baseline performance in Canada. We also recommend combining the surveys conducted for Canada and the U.S. into a single database tool to expand the benchmarking value for WRRFs.
9. **Institutionalize Survey.** The utility survey collected valuable information allowing for resource recovery mass balances for individual utilities. In the future, we recommend institutionalizing this survey for broader participation and repeating it every 2-5 years. Combining the survey with a reporting tool of results could benefit participating utilities with a visual evaluation of relevant facility-specific statistics (e.g., performance benchmarking to other pier WRRFs, progress made towards goals since last data entries).
10. **Small Facility Potential.** Capturing information on the group of smallest facilities in North America (less than 1 mgd) is inherently challenging. Efforts should continue to complete the necessary information for small WRRFs to help reach their full resource recovery potential.

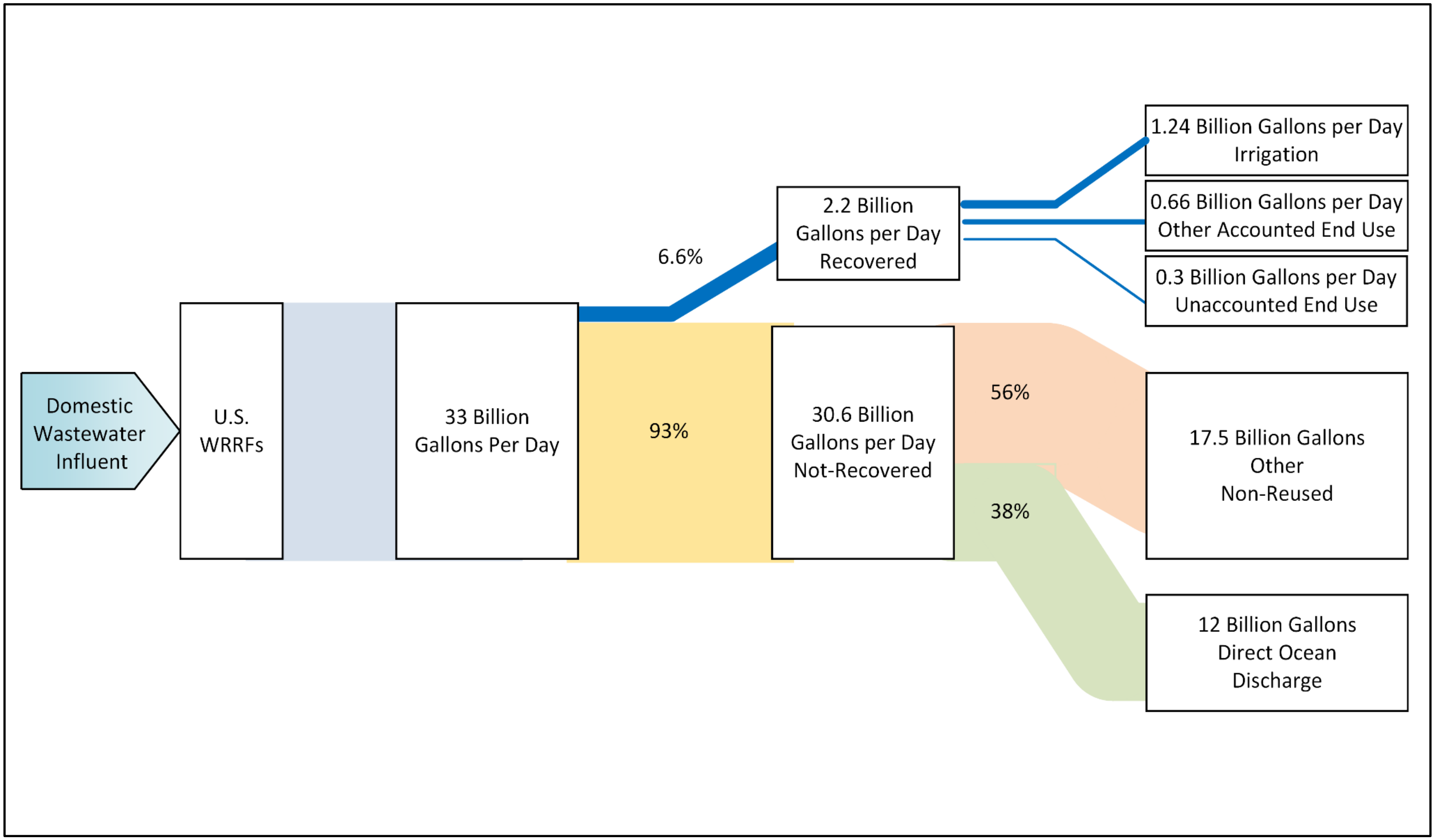

Figure ES.1 Summary of Aggregated Water Flows to WRRFs by End Use in the U.S.

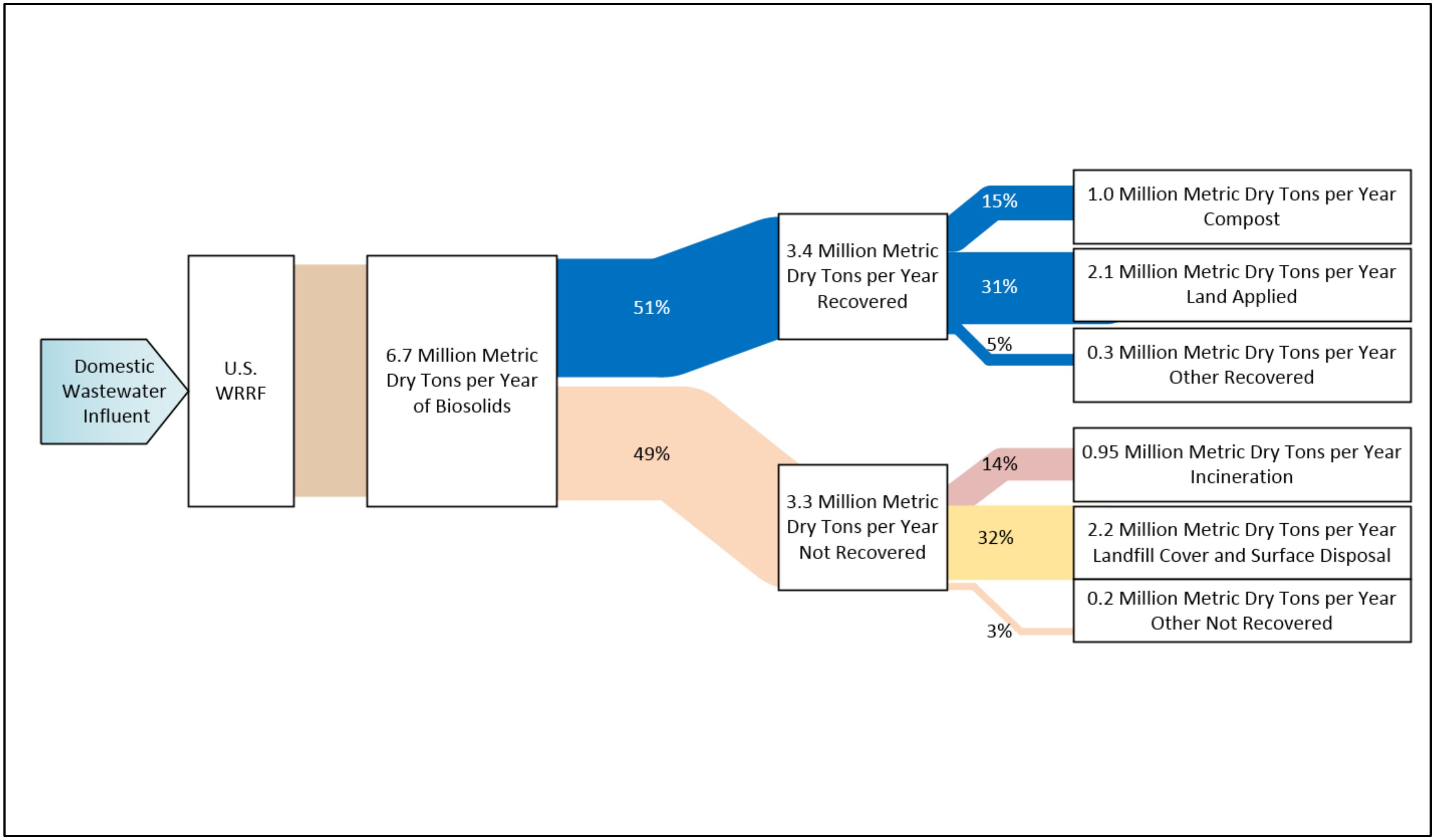

Figure ES.2 Summary of Aggregated Biosolids Mass from WRRFs by End Use in the U.S.

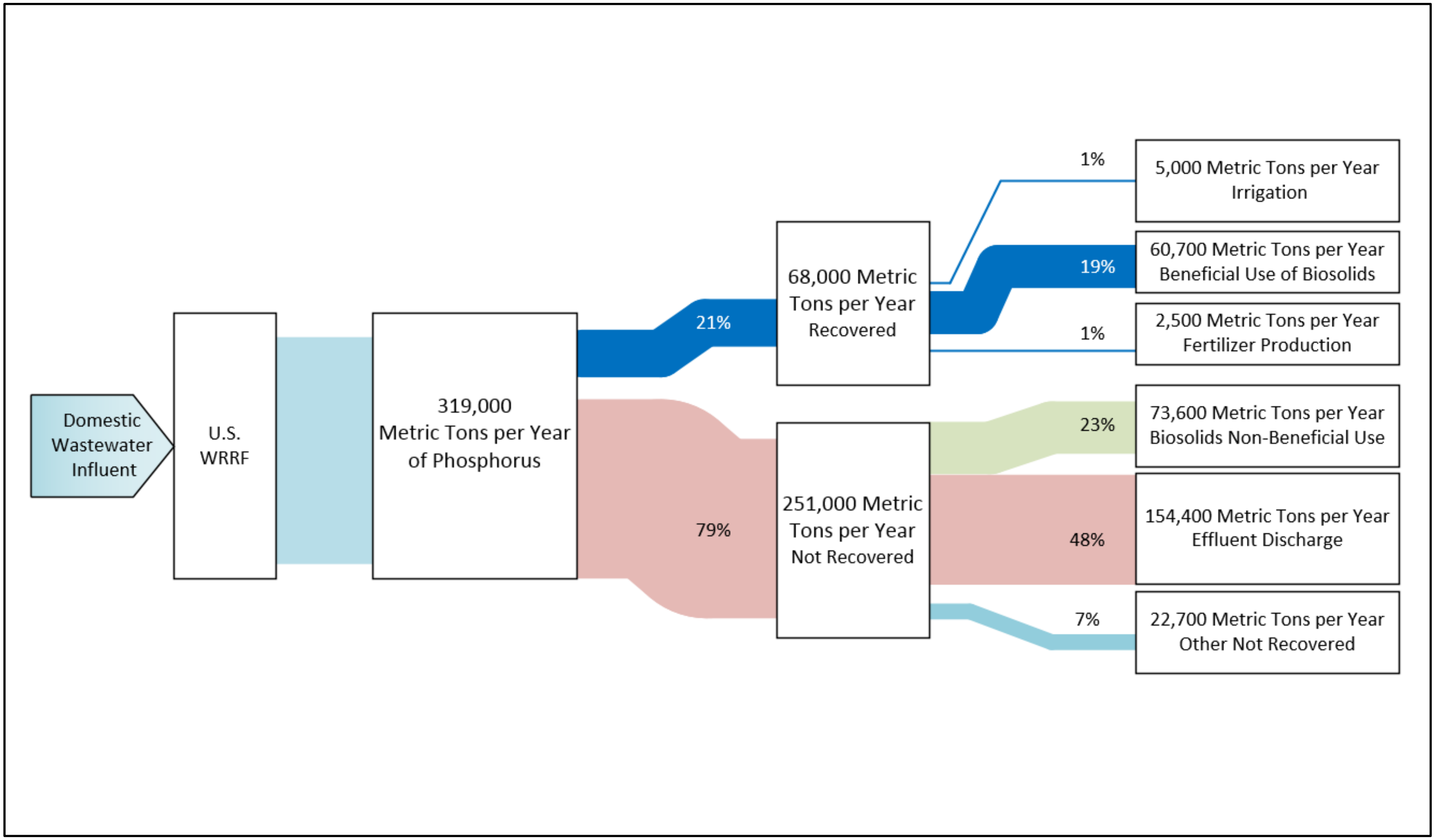

Figure ES.3 Summary of Aggregated Phosphorus Mass to WRRFs by End Use in the U.S.

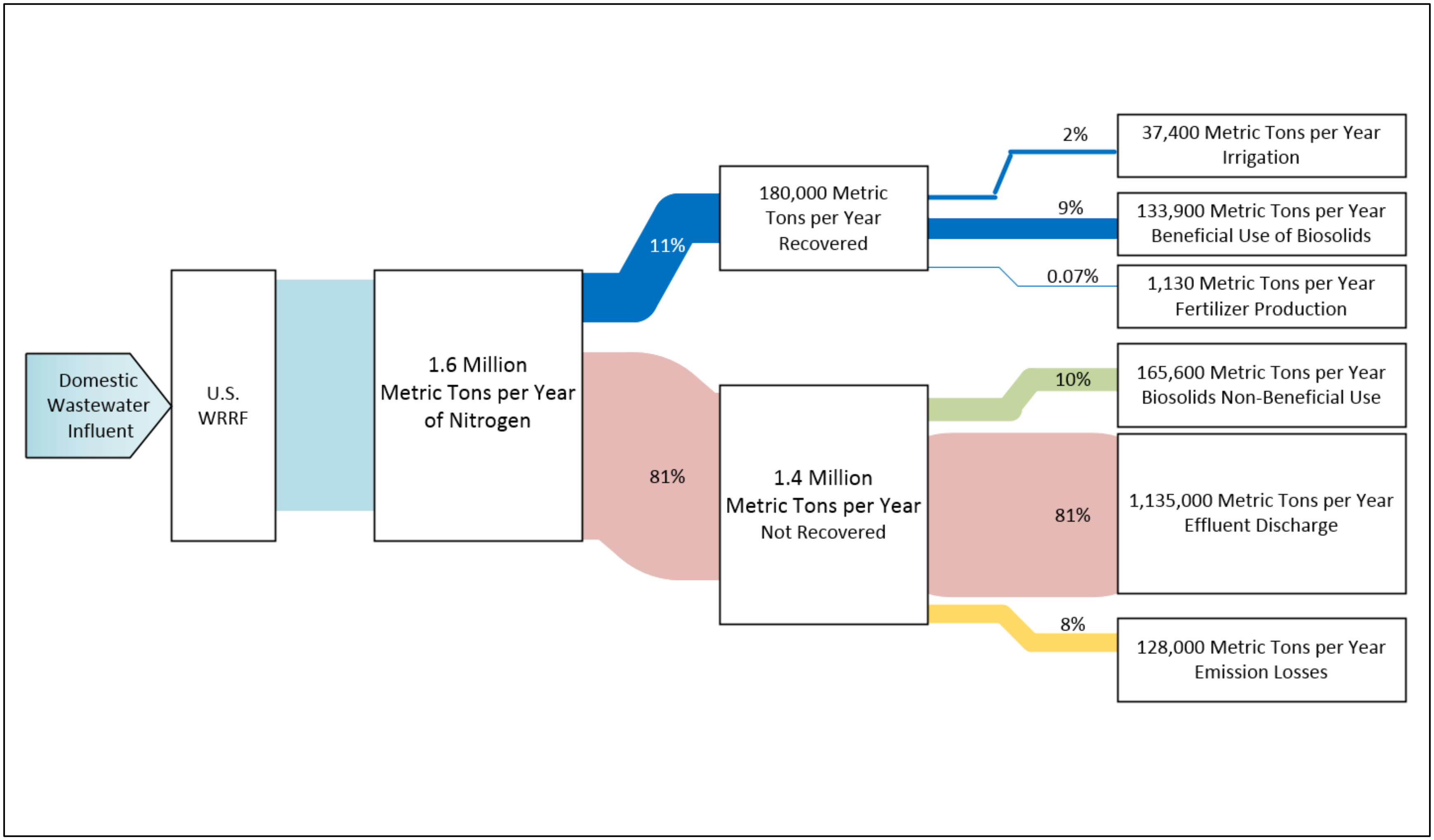

Figure ES.4 Summary of Aggregated Nitrogen Mass to WRRFs by End Use in the U.S.

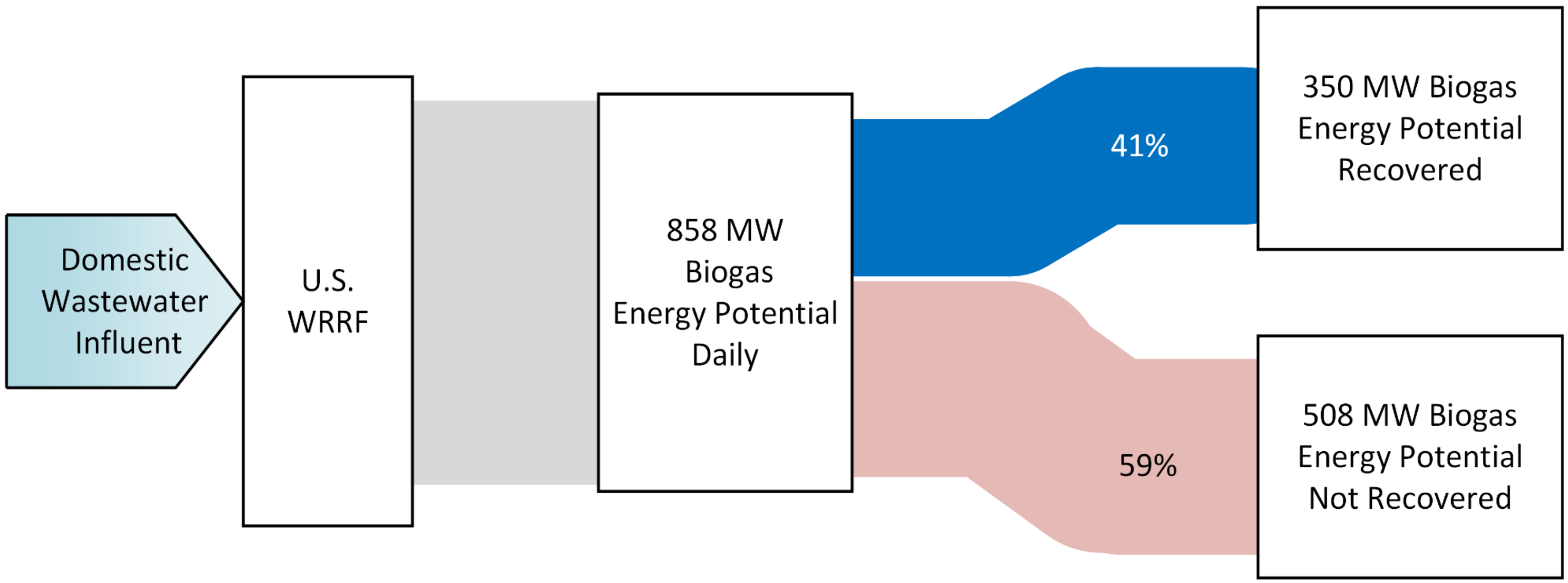

Figure ES.5 Summary of Aggregated Biogas Energy Potential to WRRFs by End Use in the U.S.

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Chapter 1
INTRODUCTION

1.1 Background

Five years ago, the National Association of Clean Water Agencies (NACWA), the Water Environment Federation (WEF), and the Water Environment & Research Foundation (WE&RF) published "Water Resources Utility of the Future … A Blueprint for Action," which described the progression of wastewater utilities into resource recovery facilities (NACWA, WERF, WEF, 2013). These "utilities of the future" follow the "N-E-W" paradigm for water management, recovering three key resources in wastewater: nutrients, energy, and water.

Many facilities in North America have taken the steps to become utilities of the future. However, as more facilities invest in the necessary infrastructure for resource recovery, utilities across the U.S. continue to struggle with balancing investments in N-E-W infrastructure and competing financial investments. Thus, utility managers and other planners would benefit from a better defined industry standard for a "utility of the future" or "resource recovery facility" to guide them with decisions and funding justifications.

This project is one important part of developing this new standard. The information in this report will help water resource recovery facilities (WRRFs) improve the way they benchmark utility achievements, track progress over time, and set achievable and defensible goals for resource recovery in the future.

1.2 Objectives

This project was implemented to compile baseline data on the state of resource recovery in North American WRRFs. Specifically, resource recovery industry metrics were developed for the following resources:

- Water.
- Nutrients.
- Energy.

As a first step, this study quantified recovery metrics for water, biosolids, and phosphorus (P); additional information was collected on nitrogen and energy recovery. This baseline is the first comprehensive data collection to understand the current status of resource recovery and help develop nationwide and utility-specific feasible resource recovery targets.

Beyond this, the data compiled in this study provides the following benefits to the industry:

1. **Justify a standard level of resource recovery.** With quantitative metrics on resource recovery in North America, this database can help utility managers justify recovery goals and funding requests.
2. **Benchmark resource recovery achievements among WRRFs.** The database allows WRRFs to compare their operation to the performance of other peer facilities and

resource recovery industry leaders. This information can help set defensible quantitative facility objectives.

3. **Track the progress of resource recovery objectives each year.** By documenting resource recovery metrics in the study's survey spreadsheet, WEF, policy makers, regulators, and WRRFs can track progress over time through regular updates.

1.3 Study Approach

The study was completed in the following two phases:

- **Phase 1:** The existing databases and literature were evaluated to compile information on the current state of resource recovery at WRRFs. At the time this study was performed, limited information for Canada was available. As a result, the first step involved evaluating resource recovery in the U.S. to establish an analytical and data collection framework helpful in expanding the effort to Canada in the future. Available U.S. databases provided data on the current state of water reuse, biosolids recovery, and parts of energy recovery at WRRFs (i.e. beneficial biogas use).

- **Phase 2:** An industry survey was developed for WRRFs throughout the U.S. and Canada to collect information that can be used to develop facility-wide balances for water, biosolids, and phosphorus, as well as nitrogen and energy as available. Data from the survey complemented the database review in Phase 1 with up-to-date 2018 facility information and allowed for a comparison of resource recovery trends between facilities of different sizes.

1.4 Report Overview

The report is organized into the following eight chapters:

- **Chapter 1** provides a brief background of the study and its objectives.
- **Chapters 2 through 6** summarize the status of resource recovery at WRRFs in the U.S. based on an evaluation of existing databases and literature for water reuse, biosolids, phosphorus, nitrogen, and energy (in terms of beneficial biogas use). To make referencing easier, each chapter includes references and appendices with raw data used to generate summary graphs.
- **Chapter 7** summarizes the results from the 2018 WEF Resource Recovery Utility Survey conducted for this study.
- **Chapter 8** provides a final summary combining the findings of the database review and the 2018 survey results; it also offers some final recommendations for next steps.

1.5 References

National Association of Clean Water Agencies (NACWA), Water Environment Research Foundation (WERF), Water Environment Federation (WEF) (2013).

Water Resources Utility of the Future - A Blueprint for Action. https://www.wef.org/globalassets/assets-wef/direct-download-library/public/03---resources/waterresourcesutilityofthefuture_blueprintforaction_final.pdf

Chapter 2

CURRENT STATUS OF WATER REUSE AT WRRFS IN THE U.S.

2.1 Methodology for Developing National Aggregates for Water Reuse and Recovery

The EPA estimated the total quantity of municipal wastewater produced in each U.S. state in the EPA Clean Water Needs Survey Database (CWNS, USEPA 2012a). For this study, all facilities that reported flow data in the database were included. In the database, 14,555 total facilities were located in the 50 states and the District of Columbia.

The total quantity of wastewater produced was also cross-checked with independent estimates published by the Metropolitan Council (2017), the National Research Council (NRC, 2012), and Seiple et al. (2017).

2.2 Wastewater Production in the United States

According to the American Society of Civil Engineers (2017), the total number of wastewater facilities estimated in the U.S. in 2017 was 14,748, which is close to the number of facilities captured in the 2012 EPA CWNS Database. In the U.S., an estimated 94% of urban population is connected to piped sewer systems (EPA 2012).

According to National Research Council (NRC, 2012), the total municipal wastewater flow estimated in the U.S. is 33 billion gallons per day. The Metropolitan Council (2017) also cited this figure, and Seiple et al. (2017) estimated a similar figure (34.5 billion gallons per day) for publicly owned treatment works in the U.S. Based on the 2012 CWNS, the total quantity of wastewater production by U.S. municipal facilities is 33 billion gallons a day, which is in close agreement with the other numbers.

This flow represents the total amount of wastewater flow from WRRFs in the U.S. theoretically available for recovery. Figure 1 shows the amount of municipal wastewater production by state based on information from the CWNS.

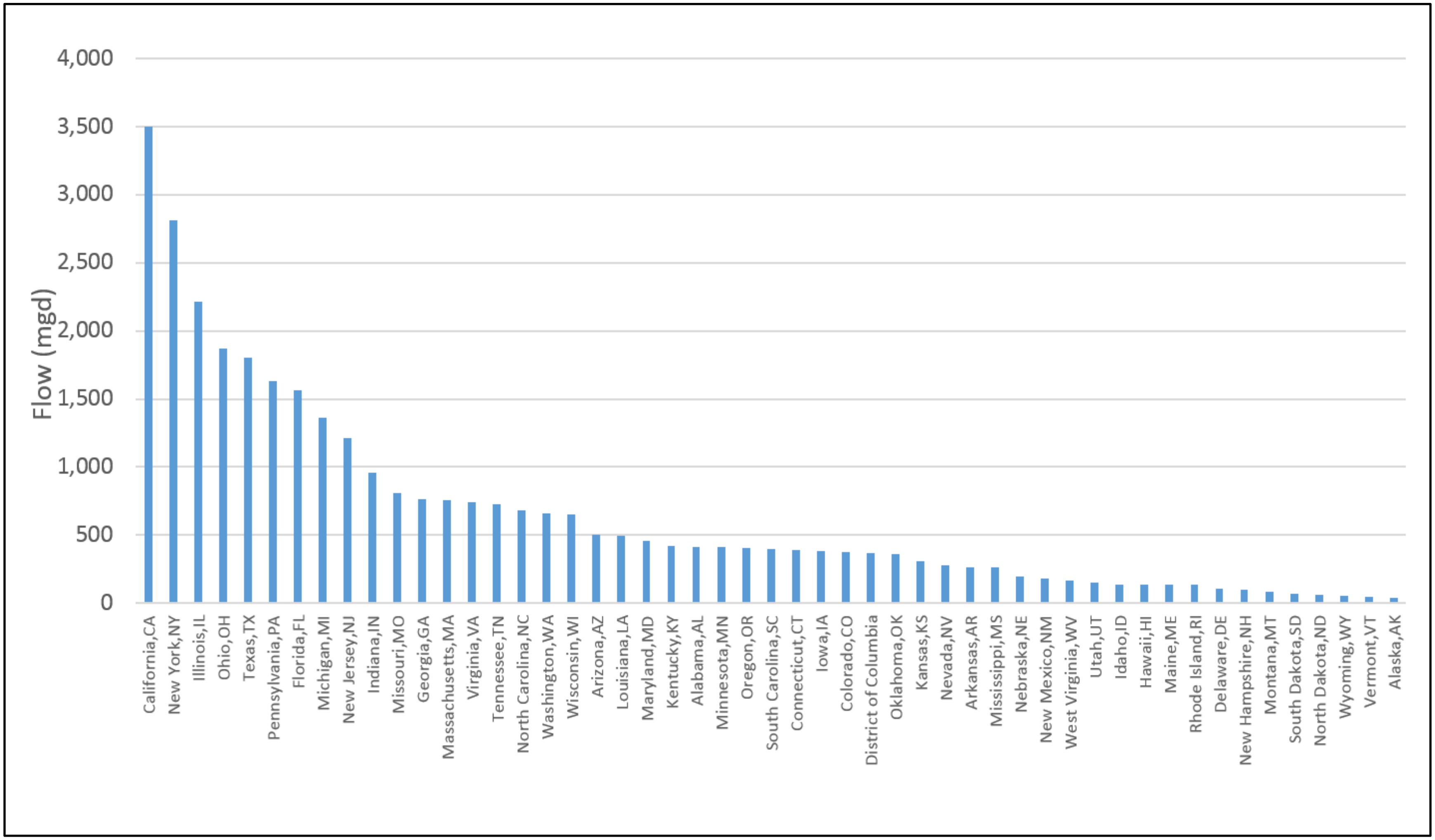

Figure 1 Wastewater Production Estimated per State in the U.S. (adapted from USEPA 2012a)

2.3 Total Water Currently Recovered at WRRFs

2.3.1 Definition of Water Resources Recovery

For this study, water from WRRFs was defined as "recovered" if it was used for potable or non-potable reuse or groundwater replenishment. Water contained in biosolids used for beneficial land application, although comprising a small quantity, was also considered recovered. Effluent discharged to surface waters (other than oceans) can be important for downstream uses such as environmental flow augmentation, aquatic life, or downstream drinking water or agricultural uses. This portion of effluent discharge was also considered recovered.

The evaporation of wastewater during treatment or as a discharge method (such as in small lagoon facilities) was not considered for the study. According to National Research Council (NRC, 2012) estimates, 12 billion gallons per day of municipal wastewater are discharged directly into an ocean or estuary, which this study does not consider recovered. Ocean discharge amounts to approximately 38% of total effluent in the U.S. and is considered by the National Research Council as potentially available to "directly augment available water resources," since it is not used by another facility downstream (NRC, 2012).

Figure 2 provides an overview of the recovered and disposed water streams defined for this study.

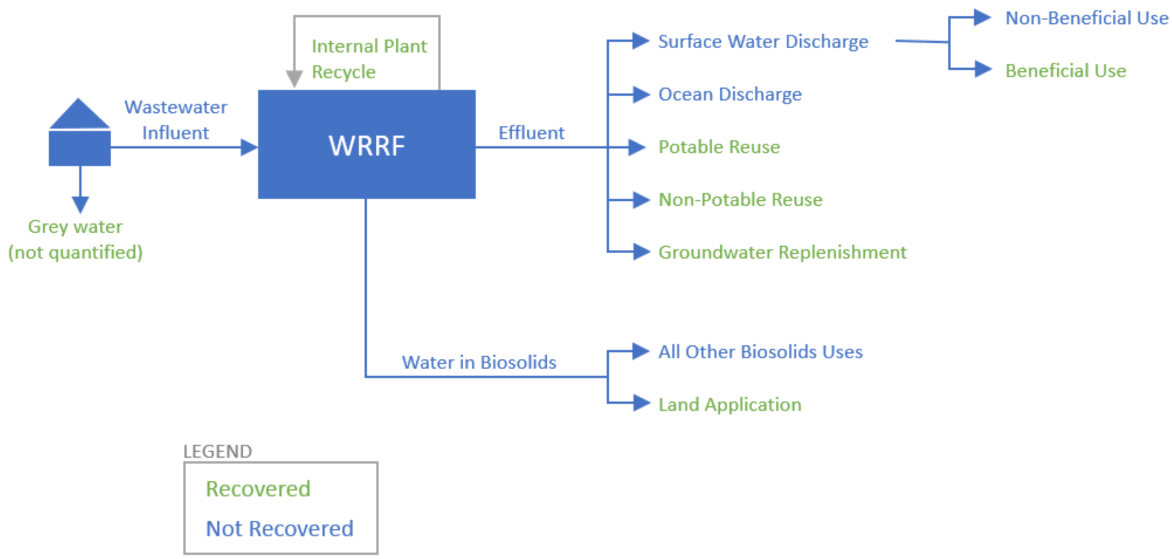

Figure 2 Definition of Recovered and Not Recovered Water in this Study

2.4 Current National Water Reuse and End Use Estimates for the U.S.

According to the USEPA (2012b), approximately 7-8% of all wastewater is currently being reused in the U.S. (Figure 3). The Metropolitan Council (2017) estimates that 2.5 billion gallons per day out of the 32 billion gallons per day of wastewater generated are currently reused in the U.S. Of that amount, approximately 90% is reused in California, Arizona, Texas, and Florida.

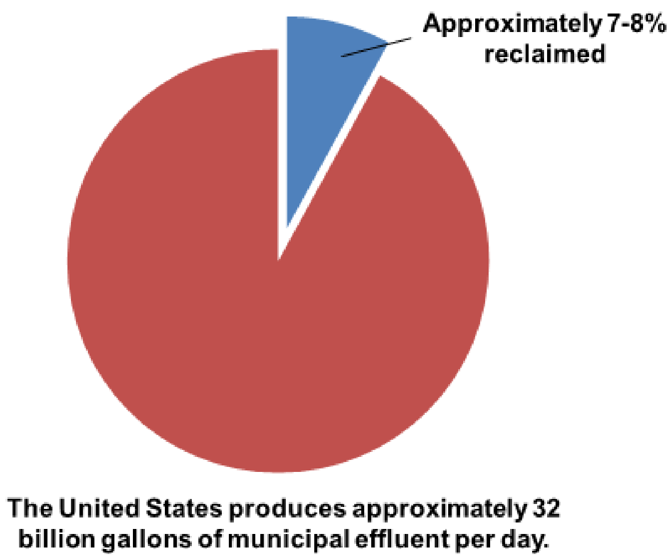

Figure 3 Reclaimed Water in the U.S. (USEPA 2012b)

According to the EPA (2012b), the additional advanced water reuse capacity for the U.S. is approximately 2.8 billion gallons per day, increasing the total projected water reuse fraction for the U.S. to 17%. This estimate originates from a 2010 study conducted by the Global Water Intelligence (2010), which assessed the regulatory, financial, and water demand and supply conditions in the U.S. to develop a water reuse market forecast. This study's definition of water reuse does not include water discharged to surface water used for environmental benefits, such as for habitat protection.

Figure 4 provides an estimated breakdown of beneficial uses for reclaimed water in the U.S. in 2011, according to the EPA (2012b). Among the largest uses are agricultural and landscape/golf course irrigation.

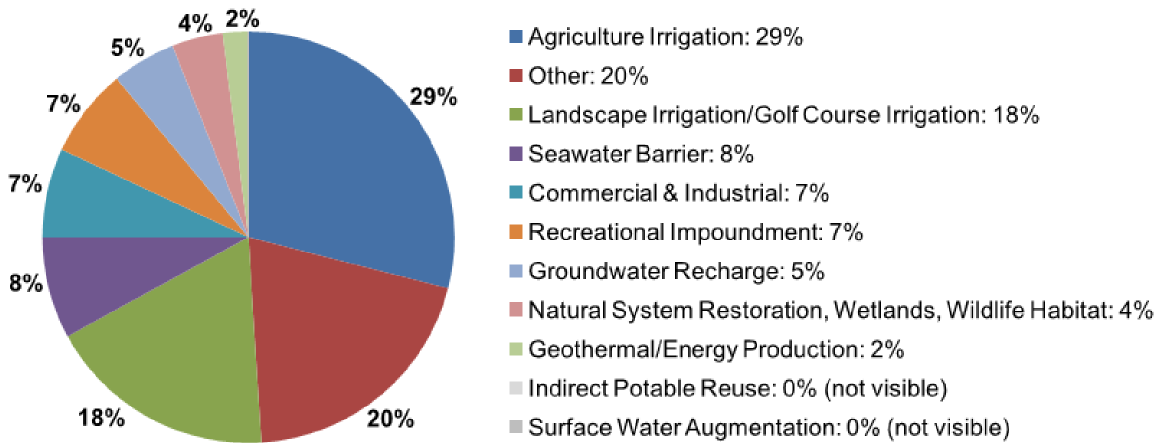

Figure 4 End Uses for Water Reuse in the U.S. (USEPA 2012b)

Using data from the last comprehensive national Biosolids Database Summary published in 2007 (Beecher, 2007), an estimated 17 million gallons per day (mgd) of water is contained within biosolids produced in the U.S. each day, assuming an average 20% dry mass solids in biosolids is produced. The estimated amount of water recovered via land application of biosolids is thus approximately 5 mgd. This value is not a significant fraction of the total daily national wastewater effluent flow (33 billion gallons).

2.5 Current Water Recovery Estimates by State

At this time, a complete database that quantifies water reuse and recovery in every state by facility size and end use does not exist. This is for several reasons: only a few states have established water reuse databases in recent years, and other states collect this information as part of surveys and permitting but have not yet synthesized the data and made it publicly available. For other states water reuse may not be a relevant consideration at this time.

The estimates in this study are based on the databases published for 17 of the 50 U.S. states that had made detailed information accessible (Appendix 2A). Of the remaining states, 8 reportedly do not have reuse programs, and 24 U.S. states and the District of Columbia do not have accessible water reuse information. The total percentage of water reuse in these 18 states totals 6% (or 1.9 billion gallons per day) of the total municipal wastewater production in the U.S. This data is therefore estimated to be approximately 75 to 85% complete (Figure 5).

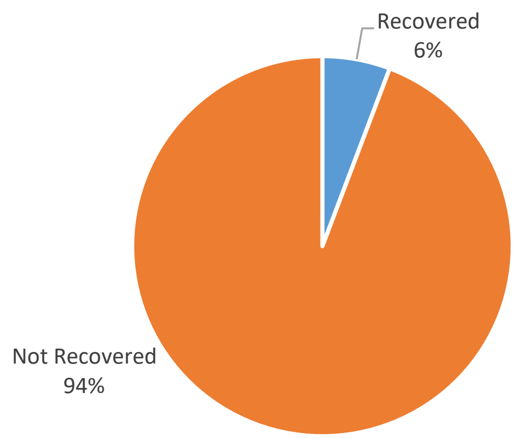

Figure 5 Percentage of Municipal Water Reuse (Recovered) in U.S. (Source: see Appendix 2A)

The water reuse estimates are shown by state in Figure 6, and the estimated percentage of water recovered by state is shown in Figure 7.

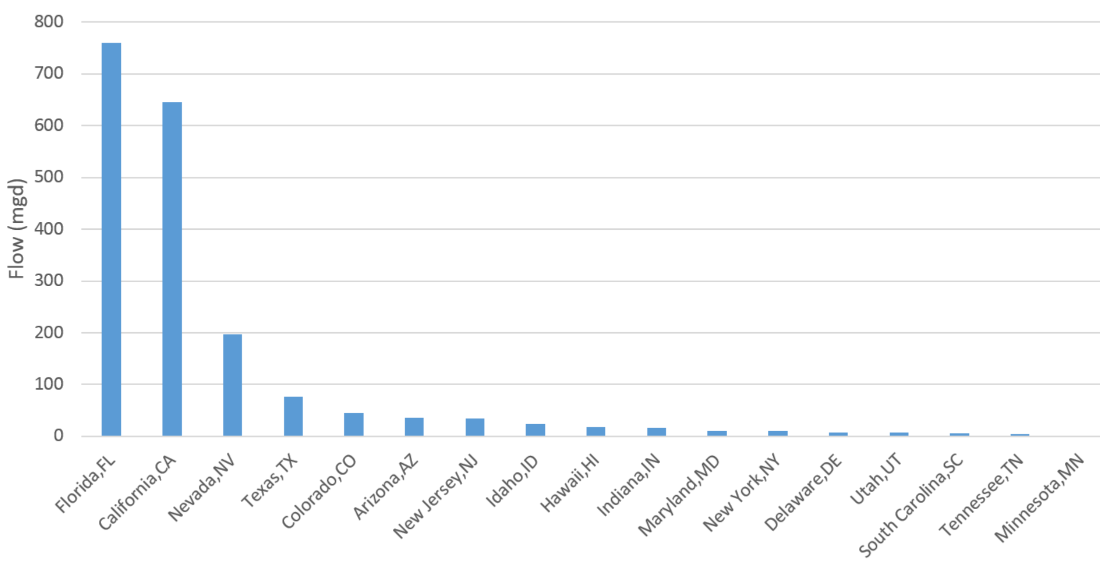

Figure 6 Reuse Flows by U.S. State

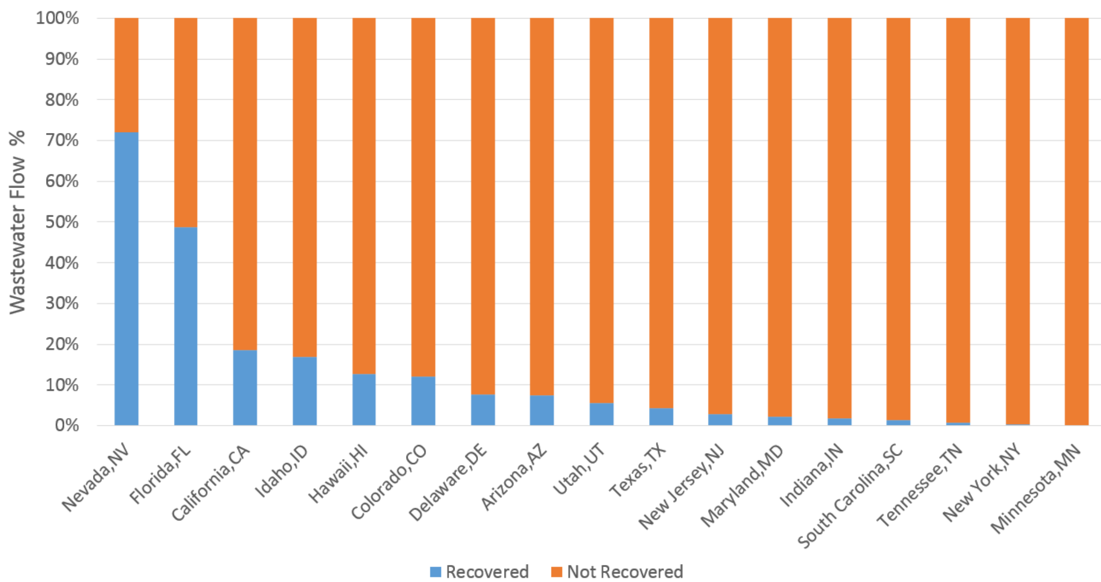

Figure 7 Water Recovery as Percentage of Total Wastewater Flow by State

Figure 8 shows the water flows currently being reused and not recovered by state.

2.6 Water Recovery Trends

2.6.1 United States

Over the past few decades, diminishing water resources from climate change, drought, population growth, and water quality impairments have led to increased water reuse in the U.S., a trend projected to continue. Although there is significant potential for increased future water reuse from municipal water resource recovery facilities throughout the United States, the demand for new sources of potable and non-potable water is growing especially more rapidly in the western and southern states, where the climate is drier and the population is growing. In particular, EPA projects involving water recovery are expected to occur more frequently in Nevada, Colorado, Washington, Virginia, and Georgia (EPA, 2012b), in addition to Florida, California, Texas, and Arizona. Demand is growing in the private industry sector as well.

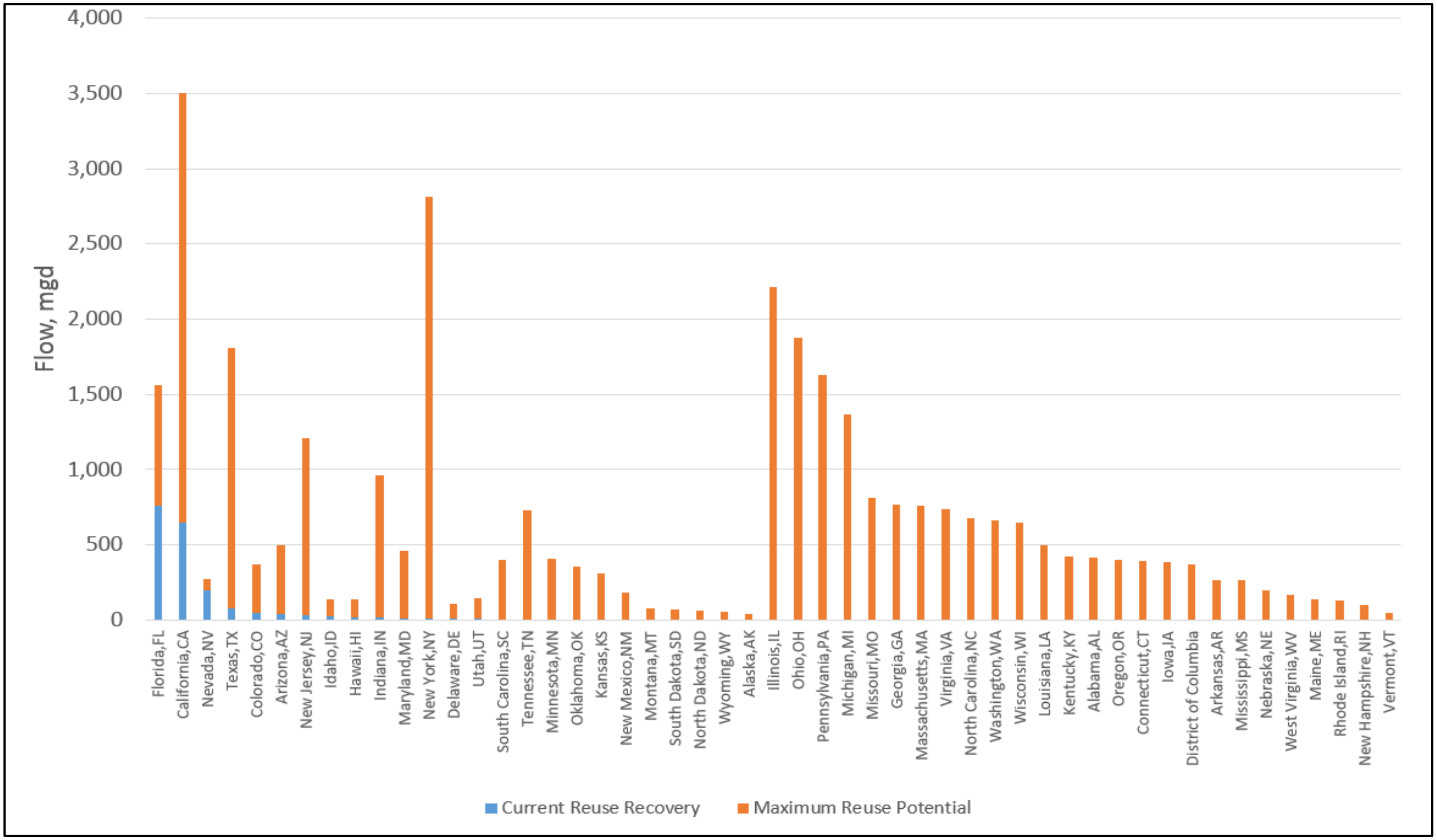

Figure 8 Total and Recovered Water Flows by State

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Appendix 2A

DATABASE SUMMARY ON WATER REUSE BY U.S. STATE

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State	WW Produced mgd	WW Reused mgd	% Reuse Statewide	Reference (where available)
California,CA	3,503	646	18%	CSWRCB, 2015
New York,NY	2,815	10	0%	NYSDEC, 2010
Illinois,IL	2,215			
Ohio,OH	1,873			
Texas,TX	1,805	77	4%	USEPA, 2012b
Pennsylvania,PA	1,631			
Florida,FL	1,561	760	49%	FDEP, 2016
Michigan,MI	1,364			
New Jersey,NJ	1,212	35	3%	NJDEP, 2017
Indiana,IN	961	16	2%	Dare, 2015
Missouri,MO	810			
Georgia,GA	767			
Massachusetts,MA	757			
Virginia,VA	740			
Tennessee,TN	726	5	1%	WateReuse, 2018
North Carolina,NC	679			
Washington,WA	662			
Wisconsin,WI	650			
Arizona,AZ	499	37	7%	*ADEQ, 2010*
Louisiana,LA	497			
Maryland,MD	457	10.17	2%	MDE, 2018
Kentucky,KY	423			
Alabama,AL	412			
Minnesota,MN	409	1	0.15%	MPCA, 2018
Oregon,OR	402			
South Carolina,SC	397	5	1%	BJWSA, 2018
Connecticut,CT	388			
Iowa,IA	380			
Colorado,CO	372	45	12%	Estimated
District of Columbia	370			
Oklahoma,OK	357	0		Bracken, 2012
Kansas,KS	309	0		Bracken, 2012
Nevada,NV	274	197	72%	SNWA, 2017
Arkansas,AR	266			
Mississippi,MS	263			
Nebraska,NE	193			
New Mexico,NM	184	0		Bracken, 2012
West Virginia,WV	167			
Utah,UT	147	8	5%	*UNR, 2005*
Idaho,ID	139	23	17%	Bracken, 2012
Hawaii,HI	138	17	13%	*DLNR, 2013*
Maine,ME	136			
Rhode Island,RI	132			
Delaware,DE	104	8	8%	Various irrigation projects
New Hampshire,NH	98			
Montana,MT	80	0		Bracken 2012
South Dakota,SD	69	0		Bracken 2012
North Dakota,ND	60	0		Bracken, 2012
Wyoming,WY	52	0		Bracken, 2012
Vermont,VT	46			
Alaska,AK	38	0		Bracken 2012
Sum	32,992	1,900		

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Chapter 3

CURRENT STATUS OF BIOSOLIDS RECOVERY AT WRRFS IN THE U.S.

3.1 Methodology for Developing National Aggregates for Biosolids Resource Recovery

The annual biosolids production from domestic U.S. WRRFs per state (in dry tons) is estimated from two sources: the most recent comprehensive database published in in the U.S. in 2007 and state-by-state data on biosolids regulation quality, treatment, end use, and disposal (Beecher, 2007). States issuing more recent data on biosolids production were researched, and the data was adopted as available (see Appendix 3A).

3.2 Biosolids Production in the United States

The aggregate total mass of biosolids by state totaled 6.71 million metric dry tons per year, which is close to independent estimates cited by Seiple et al. (2017) for tons of biosolids produced in the U.S. after solids treatment. This value represents the mass of biosolids theoretically available for recovery in the U.S.

Figure 9 shows the biosolids production by state.

3.3 Total Biosolids Resources Currently Recovered at WRRF

3.3.1 Definition of Biosolids Recovery

For this study, biosolids used for composting (Class A biosolids or equivalent) and land application (agriculture, ranch land, forest, reclamation, or landscaping) were defined as recovered. Biosolids routed to incineration, landfilling, landfill cover, or other non-beneficial uses were not defined as recovered (Figure 10).

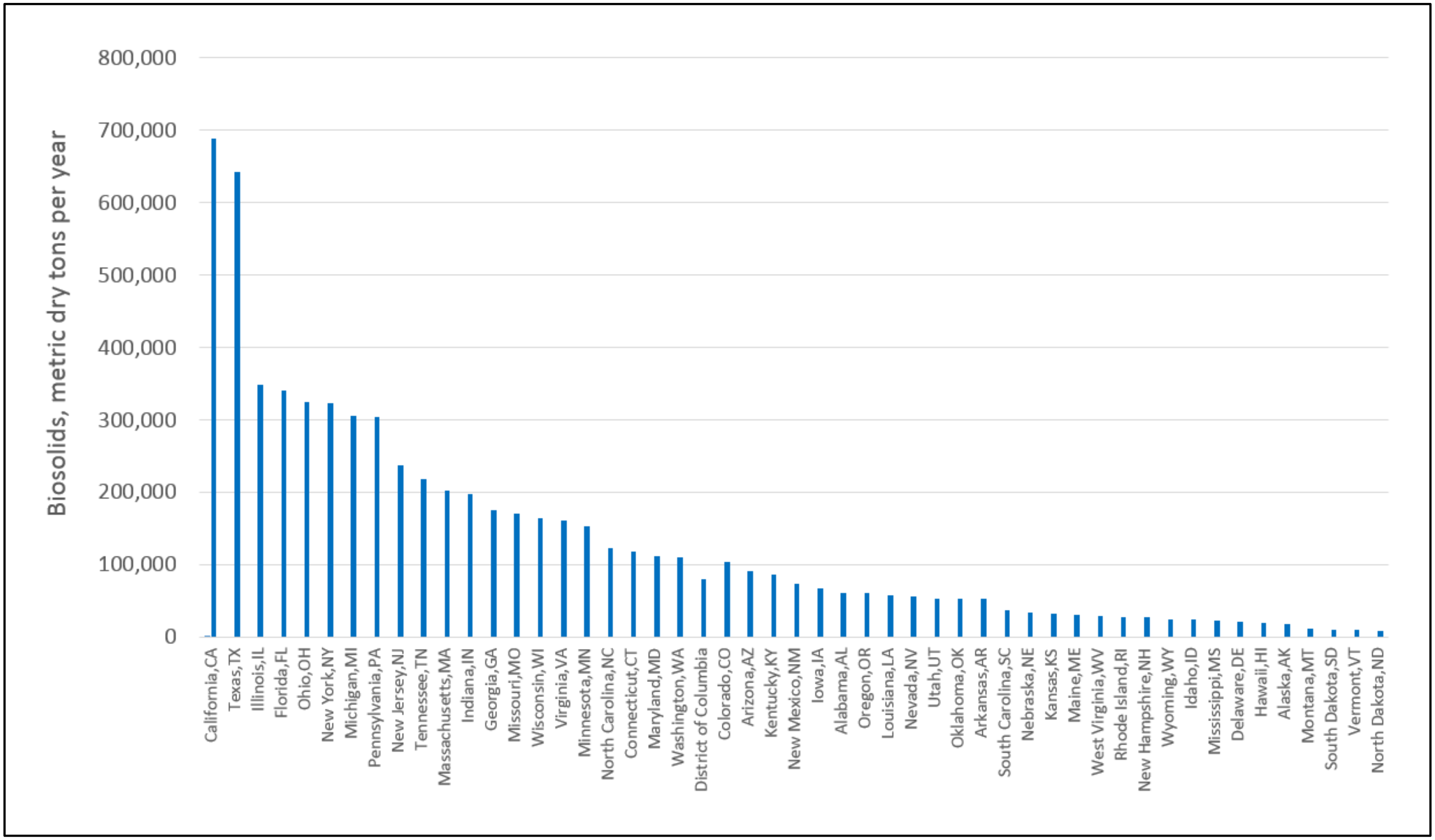

Figure 9 Annual Biosolids Production by State

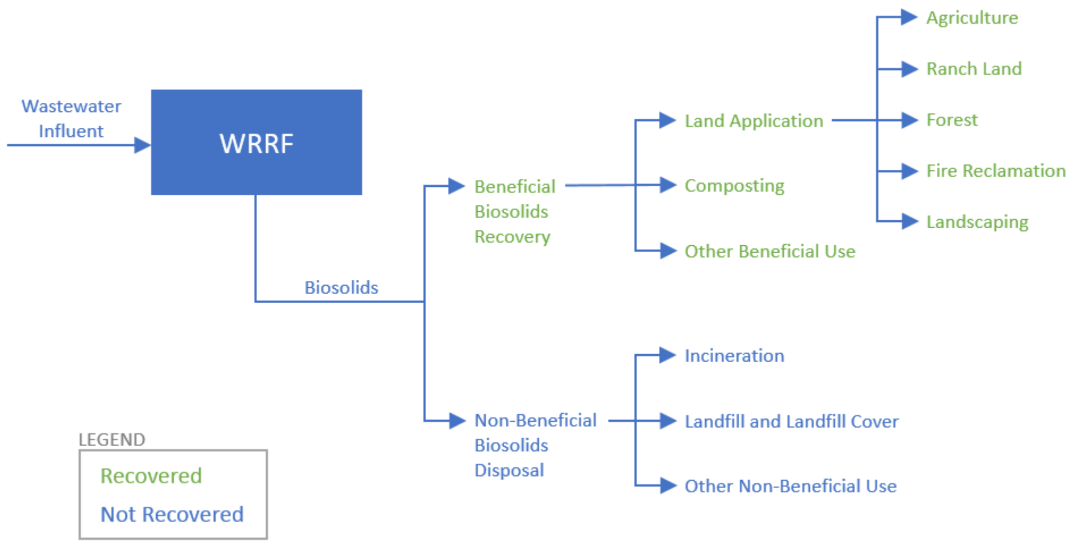

Figure 10 Definition of Recovered and Not Recovered Biosolids in this Study

3.3.2 Current National Biosolids Recovery and End Use Estimates For the U.S.

The estimated aggregated amount of recovered biosolids for all 50 states in the U.S. is 3.4 million dry tons, or 51% of the total biosolids produced in the U.S. Figure 11 shows the distribution of biosolids recovery by state as a percent, and Figure 12 shows the same value as metric dry tons.

Appendix 3A lists the biosolids end uses by state in tabular format.

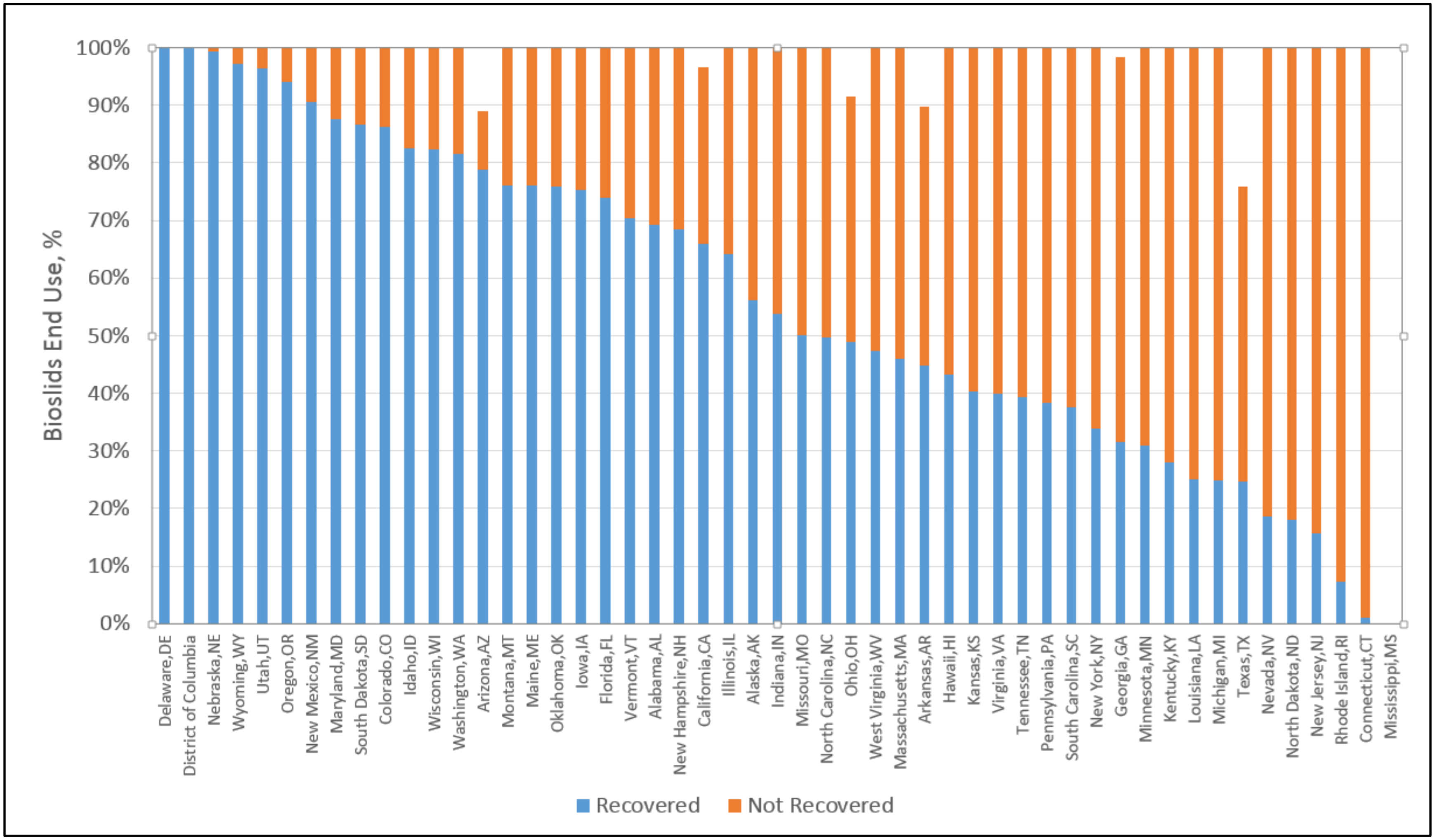

Figure 11 Annual Recovered and Not Recovered Biosolids Production by State as a Percentage

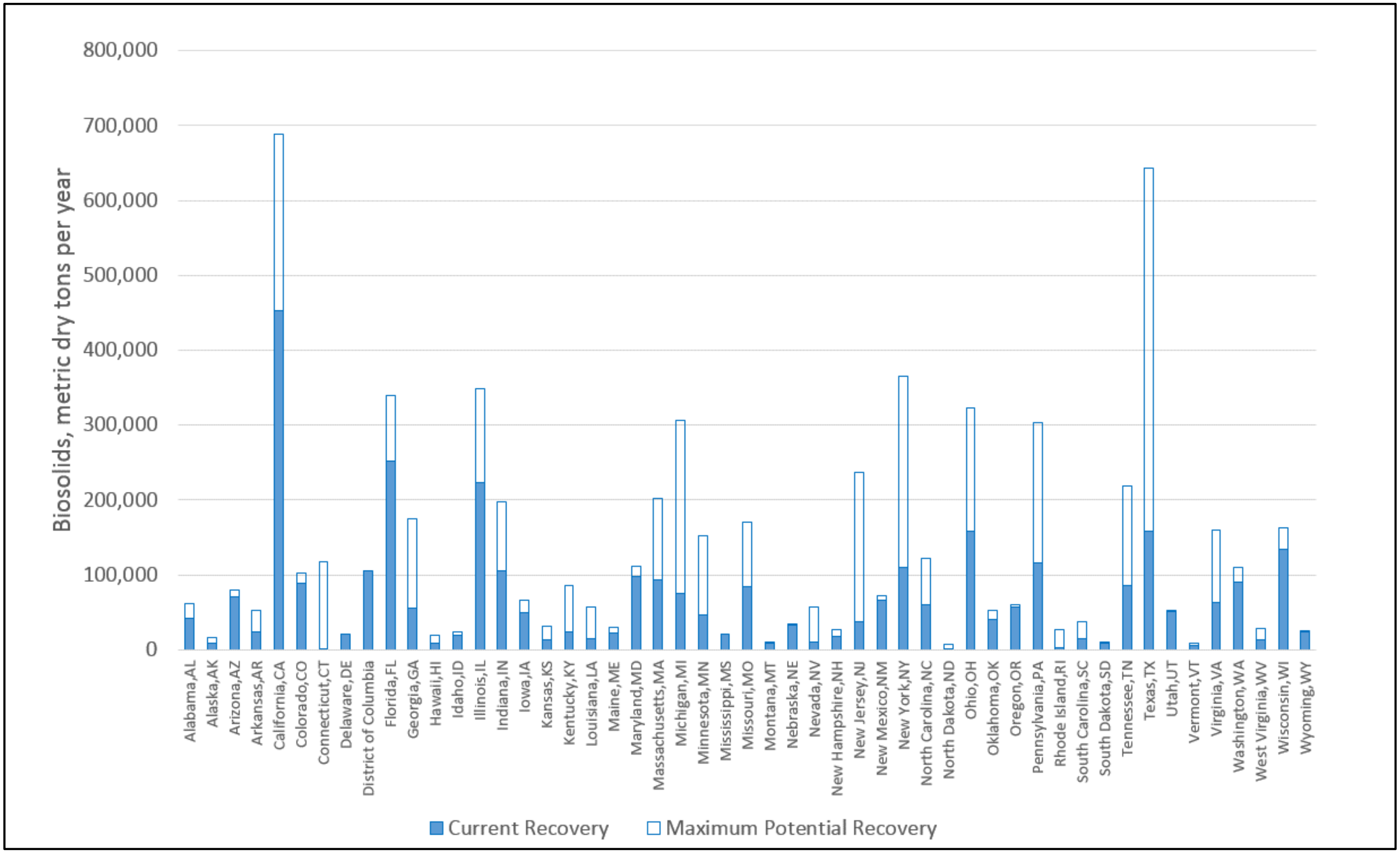

Figure 12 Annual Biosolids Recovery and Total Biosolids Recovery Potential by State

Figure 13 summarizes the average national distribution of biosolids end uses. Figure 14 shows the biosolids end use for biosolids produced in each state in the U.S.

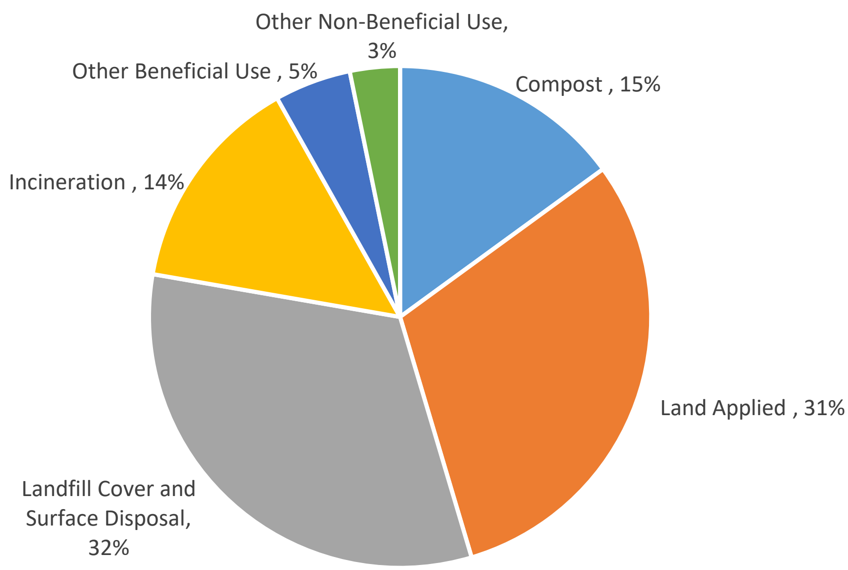

Figure 13 National Distribution of Biosolids End Use

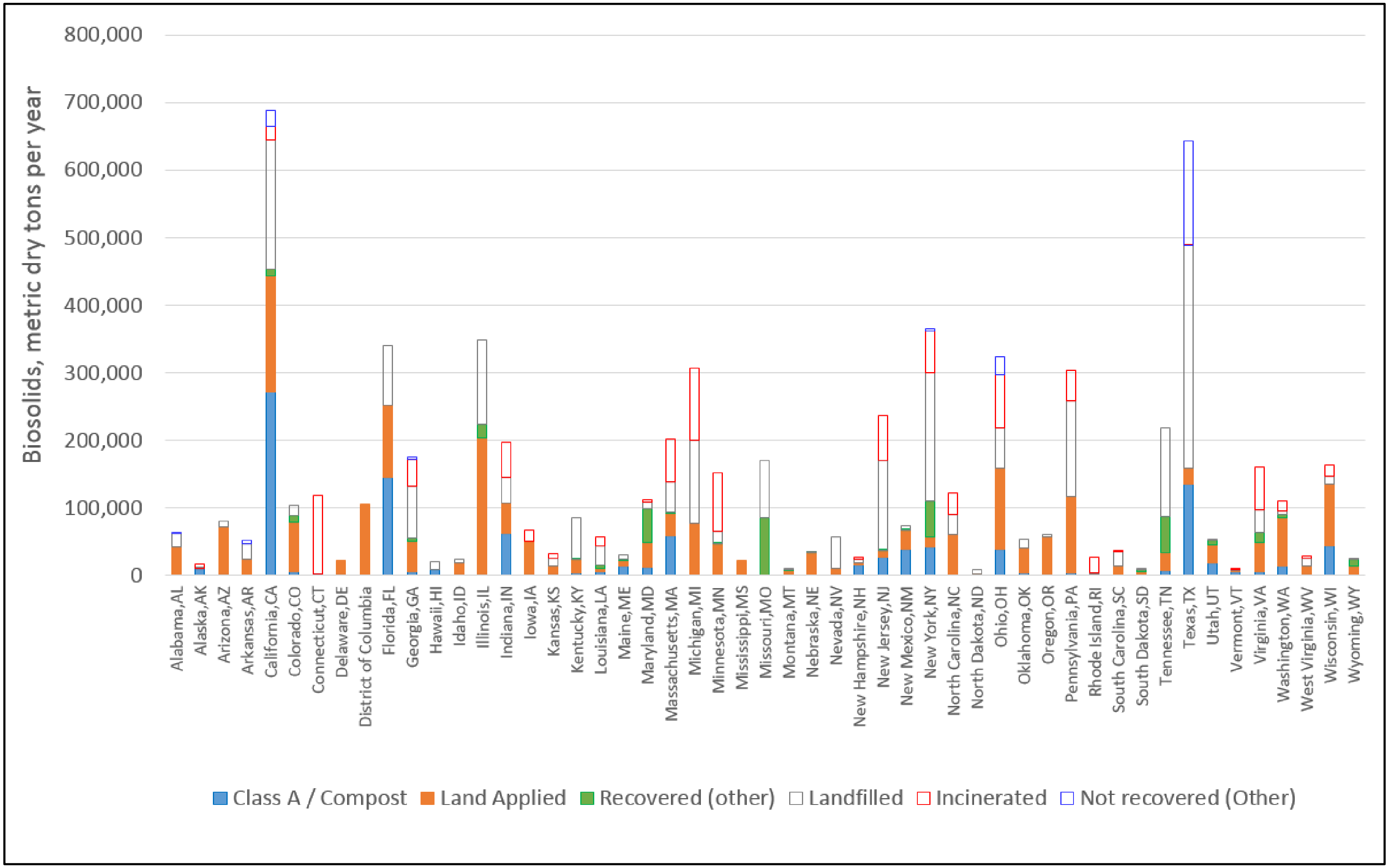

Figure 14 Annual Biosolids End Use by State (recovery shown as solid bar segments, disposal end uses with white fill)

3.4 Biosolids Resources Recovery Trends

In recent years, the paradigm shift from wastewater to resource recovery has changed the way biosolids are employed for end uses (Beecher, 2016). As technology develops, higher quality biosolids products such as compost, soil amendments, and fertilizers can be generated, and more energy from biosolids can be recovered through drying, gasification, and incineration.

In addition, diversifying markets open up new end uses for biosolids in agriculture, horticulture, soil reclamation, or carbon sequestration. Other organic co-substrates are entering the marketplace as well, creating new resource recovery opportunities for WRRFs. These opportunities include programs for fat, oil, and grease separation and for diverting organic food waste from landfills.

Over the last thirty years, the amount of landfilled biosolids has consistently decreased while the amount of land applied and composted biosolids has increased. Figure 15 compares specific data from the EPA's Enforcement and Compliance History Online (ECHO) database for the United States' biosolids use in 2016 and 2017. As shown, the ECHO data base covers a total of 4.26 million metric dry tons in 2017, representing 64 % of all biosolids estimated to be produced in the U.S. (EPA, accessed 2018).

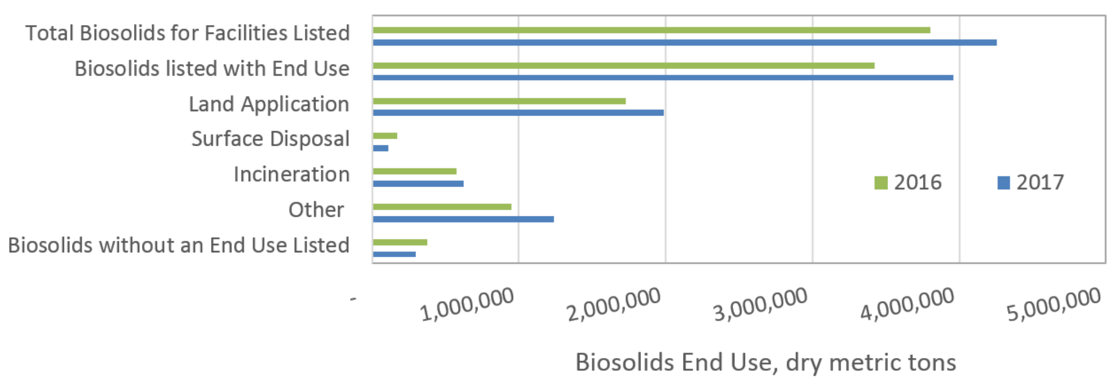

Figure 15 Comparison of 2016 and 2017 Biosolids End Uses in the U.S. (ECHO database, 2018)

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Appendix 3A

BIOSOLIDS PRODUCTION AND END USE BY U.S. STATE

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US State (dry metric tons per year)	Total amount of Biosolids produced	Class A / Composting (recovered)	Land Applied (recovered)	Landfilled and Cover, Surface Disposal (not recovered)	Incinerated (not recovered)	Other (not recovered)	Other (recovered)	Recovered Total	Not recovered Total	% Recovered	% Not Recovered	Reference
Alabama,AL	61,243	-	42,402	18,784		57		42,402	18,841	69%	31%	Beecher et al. 2007
Alaska,AK	16,921	9,497	-	10	7,414	-	-	9497	7,424	56%	44%	Beecher et al. 2007
Arizona,AZ	90,000	1,000	70,000	9,000	-			71000	9,000	79%	10%	Beecher et al. 2007
Arkansas,AR	52,178	-	23,391	23,485		5,302		23391	28,787	45%	55%	Beecher et al. 2007
California,CA	688,000	271,000	172,000	192,000	20,000	23,000	10,000	453000	235,000	66%	34%	CASA, 2016
Colorado,CO	102,912	4,271	74,229	14,109			10,303	88803	14,109	86%	14%	Beecher et al. 2007
Connecticut,CT	118,000	1,180		-	116,820			1180	116,820	1%	99%	Beecher et al. 2007
Delaware,DE	21,000	1,500	19,500					21000	-	100%	0%	Beecher et al. 2007
District of Columbia	105,787		105,787					105787	-	100%	0%	Beecher et al. 2007
Florida,FL	340,000	145,277	106,323	88,400				251600	88,400	74%	26%	Unknown, 2018
Georgia,GA	175,000	5,660	44,166	75,750	41,359	3,040	5,246	55072.66	120,149	31%	69%	GEP, 2002
Hawaii,HI	19,601	8,491		11,110				8491	11,110	43%	57%	Beecher et al. 2007
Idaho,ID	23,209	1,685	17,454	4,070				19139	4,070	82%	18%	Beecher et al. 2007
Illinois,IL	348,063	1,879	201,739	124,877			19,568	223186	124,877	64%	36%	Beecher et al. 2007
Indiana,IN	196,963	62,122	43,977	39,041	51,823			106099	90,864	54%	46%	Beecher et al. 2007
Iowa,IA	66,660	2,000	48,200		16,460			50200	16,460	75%	25%	Beecher et al. 2007
Kansas,KS	31,957	894	11,992	11,417	7,654			12886	19,071	40%	60%	Beecher et al. 2007
Kentucky,KY	85,484	3,233	19,961	61,480			810	24004	61,480	28%	72%	Beecher et al. 2007
Louisiana,LA	57,235	4,909	4,909	29,636	13,300		4,481	14299	42,936	25%	75%	Beecher et al. 2007
Maine,ME	29,900	13,050	9,178	7,774			490	22717.63	7,774	76%	26%	VDEC, 2016
Maryland,MD	111,456	11,052	37,973	10,199	3,575		48,657	97682.4	13,774	88%	12%	Beecher et al. 2007
Massachusetts,MA	201,700	58,207	33,820	45,738	63,301		633	92661.02399	109,039	46%	54%	VDEC, 2016
Michigan,MI	305,979		75,845	123,681	106,453			75845	230,134	25%	75%	MDEQ, 2017
Minnesota,MN	151,942		46,800	18,802	86,280		60	46860	105,082	31%	69%	Beecher et al. 2007
Mississippi,MS	21,561		21,561					21561	-			
Missouri,MO	170,000			85,000			85,000	85000	85,000	50%	50%	Beecher et al. 2007
Montana,MT	10,699	1,254	5,827	2,569			1,049	8130	2,569	76%	24%	Beecher et al. 2007
Nebraska,NE	33,902	325	32,850	227			500	33675	227	99%	1%	Beecher et al. 2007
Nevada,NV	56,478	938	9,614	45,926				10552	45,926	19%	81%	Beecher et al. 2007
New Hampshire,NH	27,021	14,421	4,088	4,032	4,480			18509	8,512	68%	32%	Beecher et al. 2007
New Jersey,NJ	236,960	26,510	10,126	133,151	66,830		344	36980	199,981	16%	84%	Beecher et al. 2007
New Mexico,NM	72,935	37,576	28,304	6,874			182	66062	6,874	91%	9%	Beecher et al. 2007
New York,NY	323,025	41,975	14,600	189,800	62,050	3,650	52,925	109500	255,500	34%	78%	DECNYS, N572018
North Carolina,NC	122,384	220	60,567	29,952	31,645			60787	61,597	50%	50%	Beecher et al. 2007
North Dakota,ND	7,797		1,400	6,397				1400	6,397	18%	82%	Beecher et al. 2007
Ohio,OH	323,695	37,576	120,480	59,744	78,548	27,347		158056	165,639	49%	43%	Beecher et al. 2007
Oklahoma,OK	52,753	3,761	36,282	12,710				40043	12,710	76%	24%	Beecher et al. 2007
Oregon,OR	60,677	2,103	55,000	3,574				57103	3,574	94%	6%	Beecher et al. 2007
Pennsylvania,PA	304,000	3,000	113,736	141,056	46,208			116736	187,264	38%	62%	Beecher et al. 2007
Rhode Island,RI	27,433	2,001		1,016	24,416			2001	25,432	7%	93%	Beecher et al. 2007
South Carolina,SC	37,364		14,063	20,423	2,878			14063	23,301	38%	62%	Beecher et al. 2007
South Dakota,SD	9,419	507	5,325	1,259			2,328	8160	1,259	87%	13%	Beecher et al. 2007
Tennessee,TN	218,668	7,467	25,703	132,515			52,983	86153	132,515	39%	61%	Beecher et al. 2007
Texas,TX	642,578	134,557	24,304	328,555	594	154,568		158861	483,717	25%	51%	Beecher et al. 2007
Utah,UT	52,940	19,091	25,436	1,859			6,554	51081	1,859	96%	4%	Beecher et al. 2007
Vermont,VT	8,973	5,503	813	2,323	334			6316	2,657	70%	30%	Beecher et al. 2007
Virginia,VA	159,995	4,835	44,250	32,024	64,116		14,770	63855	96,140	40%	60%	Beecher et al. 2007
Washington,WA	110,567	13,220	71,386	4,688	15,709		5,564	90170	20,397	82%	18%	Beecher et al. 2007
West Virginia,WV	28,315	2,300	11,100	11,515	3,400			13400	14,915	47%	53%	Beecher et al. 2007
Wisconsin,WI	163,107	42,526	91,846	12,153	16,582			134372	28,735	82%	18%	Beecher et al. 2007
Wyoming,WY	24,224	865	12,927	698			9,734	23,526	698	97%	3%	Beecher et al. 2007
Total	**6,708,660**	**1,009,439**	**2,051,234**	**2,179,402**	**952,230**	**216,964**	**332,182**	**3,392,855**	**3,348,596**			

Figures in red fond indicate that the values deviate from the cited references and were adopted from other sources.

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Chapter 4

CURRENT STATUS OF PHOSPHORUS RECOVERY AT WRRFS IN THE U.S.

4.1 Methodology for Developing National Aggregates for Phosphorus Resource Recovery

The annual total phosphorus (TP) load that can be recovered from domestic WRRF was estimated using the total quantity of wastewater produced from the CWNS, typical phosphorus wastewater influent concentrations in the U.S., and typical per capita phosphorus loads in wastewater. For more information on the CWNS, refer to Chapter 2.

Phosphorus recovery from biosolids and effluent reuse for irrigation was estimated from the biosolids database sources discussed in Chapter 3. All phosphorus in biosolids used for land application and effluent used for irrigation was assumed recovered regardless of site specific agronomical rates. . Water reuse data used for irrigation was also used, as available by state.

Phosphorus recovery for fertilizer production was estimated for WRRFs in the U.S. that currently produce struvite fertilizer full scale. This data was in part derived from the 2018 WEF Resource Recovery Survey conducted for this study and discussed in Chapter 7; other publications were used as well. All raw data is included in the appendices of this chapter.

4.2 Phosphorus Mass in Domestic Wastewater in the U.S.

As mentioned in Chapter 2, the estimated municipal wastewater generated in the U.S. is approximately 33 billion gallons per day. For this study, approximately 862 metric tons of phosphorus was estimated to enter WRRFs every day (319,000 metric tons P per year). This assumes that the average phosphorus wastewater influent concentration is about 7 milligrams per liter (mg/L) in the U.S.

With a total U.S. population of about 326 million in 2017, the average TP wastewater influent concentration corresponds to an average per capita loading of 2.6 gram per day phosphorus (0.006 lbs P per capita per day), which is comparable to the average per capita load referenced by Metcalf and Eddie (2003) for the U.S. (0.007 lbs P per capita per day). (Note this neglects the year-round population not connected to public sewer systems).

Figure 16 summarizes the phosphorus mass in domestic wastewater influent by state, based on these assumptions.

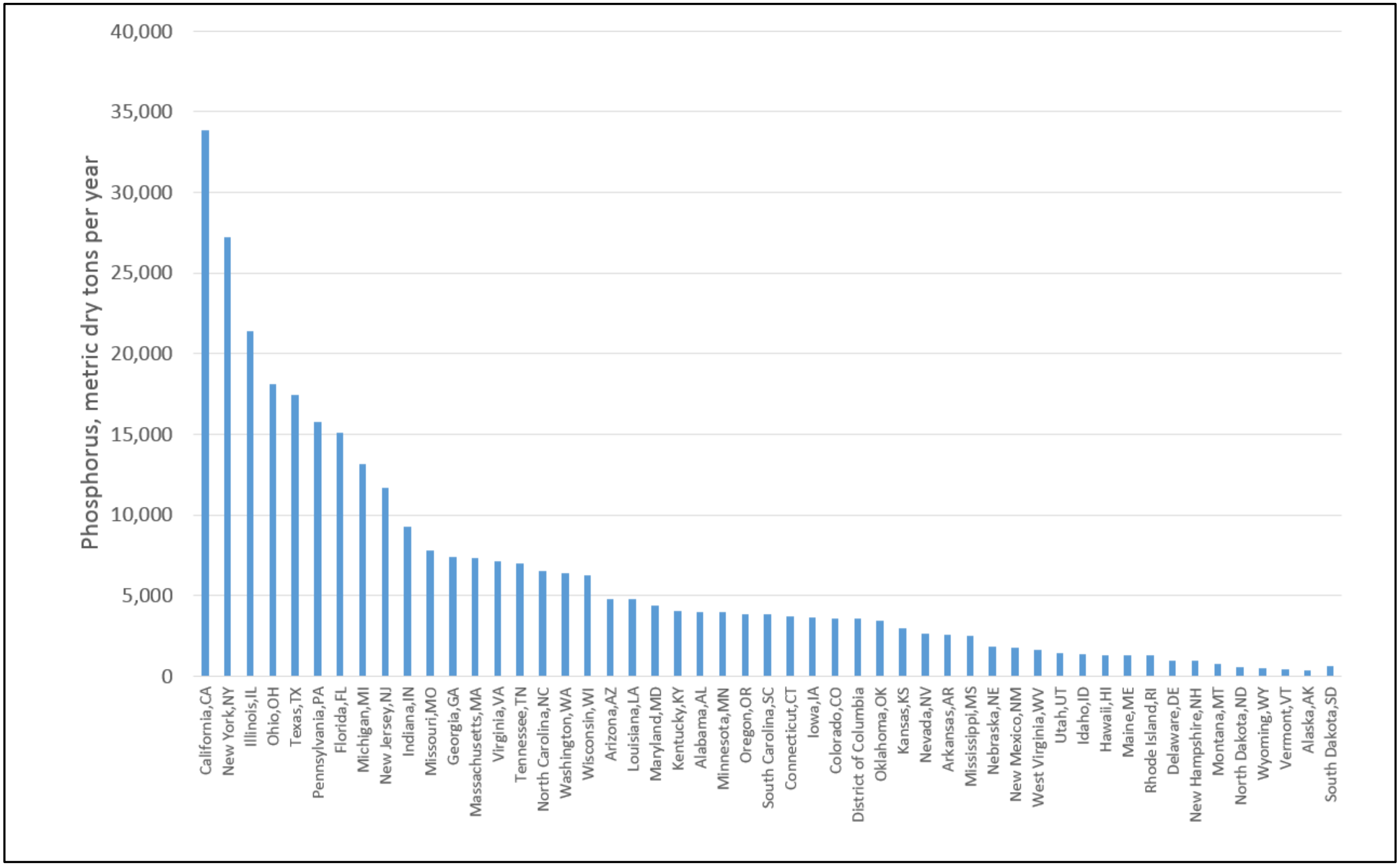

Figure 16 Annual Phosphorus Load in Wastewater Influent by State

4.3 Total Phosphorus Resources Currently Recovered at WRRF

4.3.1 Definition of Phosphorus Recovery

For this study, phosphorus in wastewater is defined as recovered for the following uses: urine source separation, water reused for irrigation, biosolids applied to land applications, and fertilizer production (struvite, vivianite, brushite, berlinite, etc.) from biosolids (Figure 17). The phosphorus content in effluent discharged to surface or groundwater, or used for potable reuse, was not defined as recovered. Likewise, phosphorus in biosolids disposed of in landfills or used in other ways than for land application or composting did not qualify as recovered.

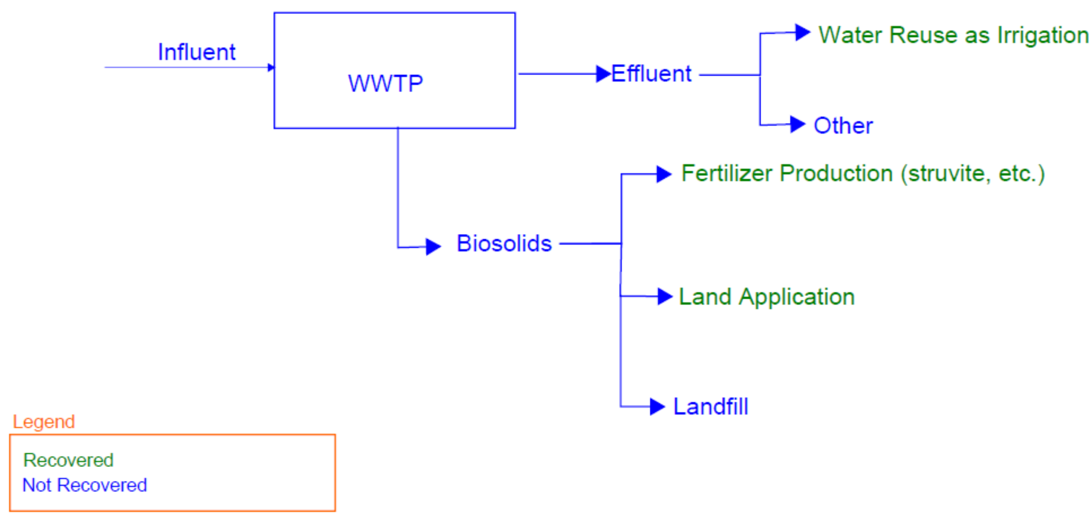

Figure 17 Definition of Recovered and Not Recovered Phosphorus Mass Streams in this Study

The most current and complete dataset was adopted from the EPA's CWNS (EPA 2012). According to this report, phosphorus removal has noticeably increased over past years in parts of the U.S. watersheds.

Using CWNS data, Figure 18 shows the wastewater flows treated for phosphorus removal by state. As shown, an average 20% of all wastewater produced in the U.S. was treated for phosphorus removal in 2012. Figure 19shows the percent wastewater in each state that is treated for phosphorus removal (EPA 2012).

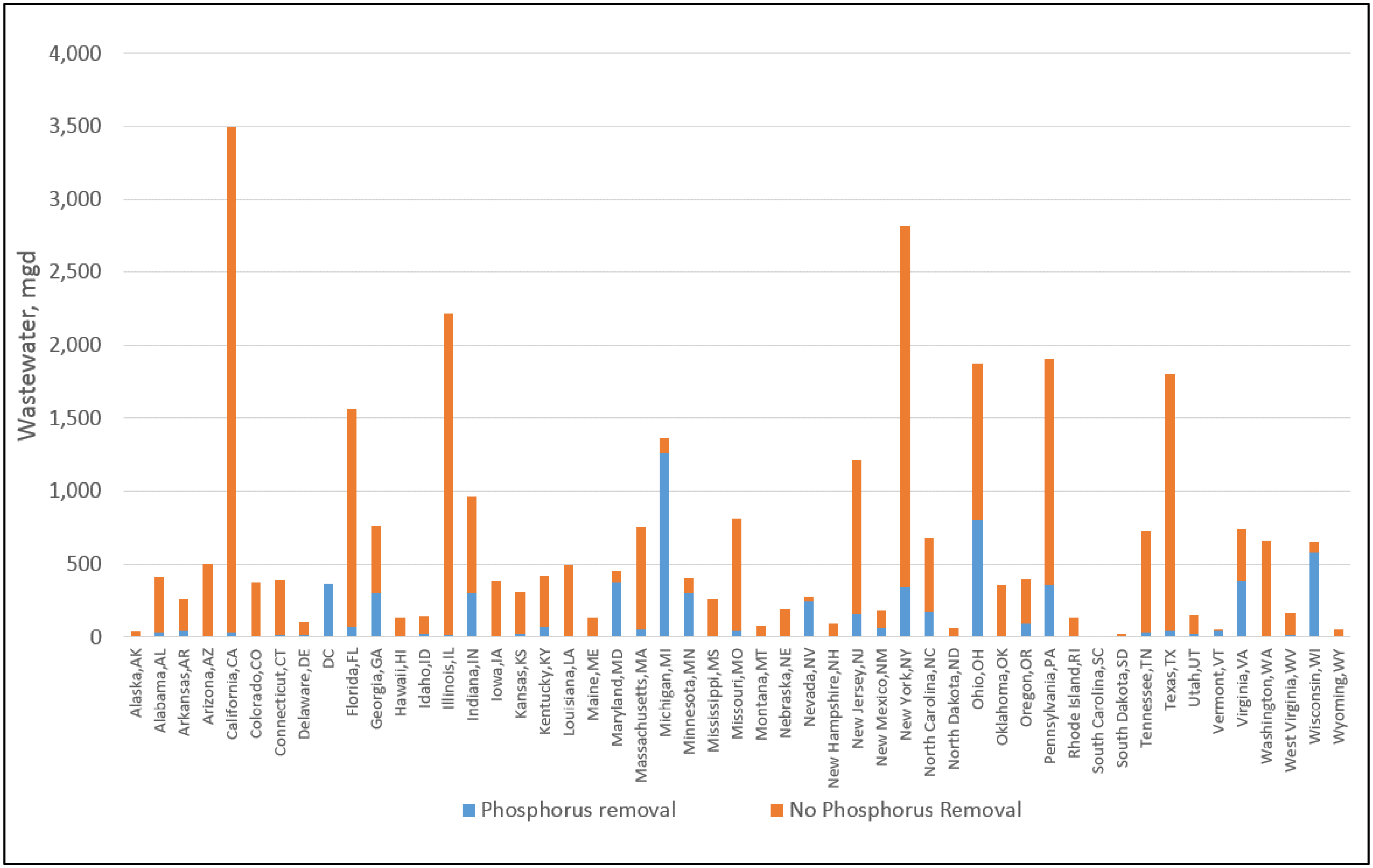

Figure 18 Wastewater Treated with Phosphorus Removal by State

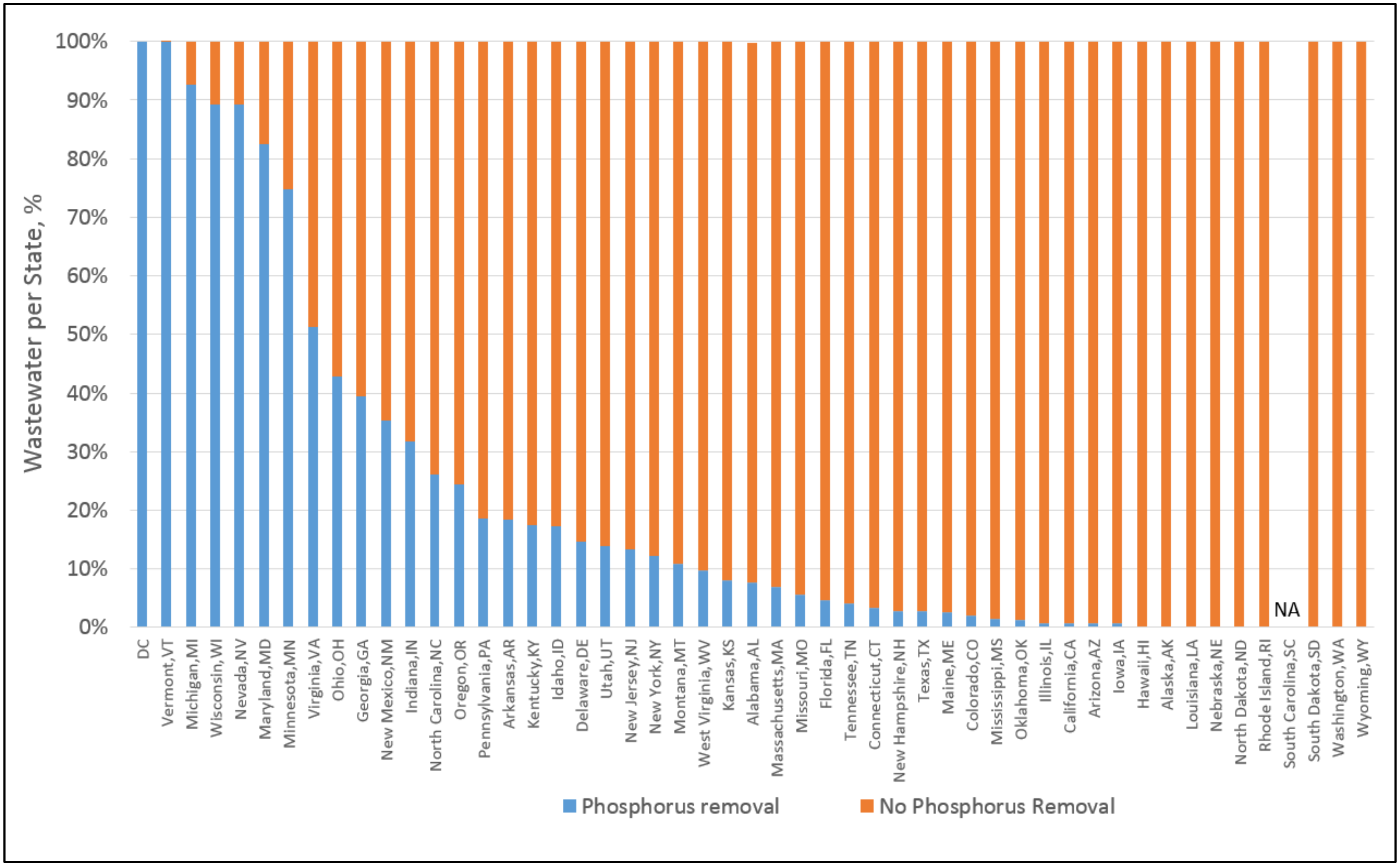

Figure 19 Percent Wastewater by State Treated with and without Phosphorus Removal

4.3.2 Current Status of Phosphorus Recovery in the U.S.

The current status of phosphorus recovery in the U.S. was estimated by aggregating the amount of phosphorus in water nationally reused for irrigation, biosolids used for land application and composting, and struvite production.

4.3.3 Phosphorus Recovery through Water Reuse for Irrigation

The water reused for landscape or crop irrigation was estimated for states with known reuse programs (Appendix 4A). For agricultural or landscape irrigation, the total estimated reclaimed water use in the U.S. per year was approximately 1,040 mgd. This value equates to about 54% of the estimated total annual water reuse (1.9 billion gallons per day) in the U.S.

According to EPA estimates, 29% of all reclaimed water in the U.S. is used for agricultural irrigation, and 18% is used for landscape and golf course irrigation (USEPA 2012). This totals 47%, which agrees strongly with state-by-state estimates developed for this study. According to other estimates, the average total phosphorus concentration in secondary treated effluent is approximately 3.3 mg/L across all states.

Given these estimates, the amount of phosphorus estimated to be beneficially recovered through effluent irrigation in the U.S. is 5,000 metric tons per year. This value corresponds to about 1.6% of the total mass of P entering wastewater facilities in the U.S. (319,000 metric tons per year).

4.3.4 Phosphorus Recovery through Biosolids Land Application and Composting

The estimated total of potentially recoverable mass of phosphorus in biosolids was approximately 2% of the solids dry mass in biosolids in the U.S. Facilities that operate enhanced biological phosphorus removal processes will typically have a phosphorus content in their biosolids closer to 4-5% as dry mass.

The total mass of biosolids produced in the U.S. to date is approximately 6.71 million metric dry tons per year (Chapter 3). Consequently, the estimated amount of phosphorus in biosolids is 121,700 metric tons per year, which is about 38% of the total phosphorus entering WRRFs (318,488 metric tons per year). Nationally, 51% of all biosolids is recovered for beneficial use (see Chapter 3), including 31% for land application, 15% for Class A production and composting, and 5% for other beneficial uses. This means that, as a national average, approximately 60,700 metric tons of phosphorus are currently recovered beneficially with biosolids each year (about 20% of the total available phosphorus for recovery).

In a separate evaluation, Seiple et al. estimated the aggregate total mass of phosphorus recovered in the U.S. with biosolids (2017). Their estimate was 51,281 metric tons per year, which is relatively close to the estimate provided above, with a difference of 18%.

4.3.5 Phosphorus Recovery through Fertilizer Production

As of 2017, an estimated twelve WRRFs were on line in the U.S. recovering phosphorus full-scale to produce commercial struvite fertilizer. These facilities are listed in Appendix 4B, along with their estimated current average daily flows and annual recovery mass. In 2017, these facilities recovered an estimated ~ 5,499,000 pound of phosphorus for fertilizer production (2,500 dry metric tons), which is about 0.8% of the total recoverable P available.

Figure 20 summarizes the aggregated percentage of phosphorus recovered by state. Figure 21 shows current phosphorous mass recovered from wastewater by state.

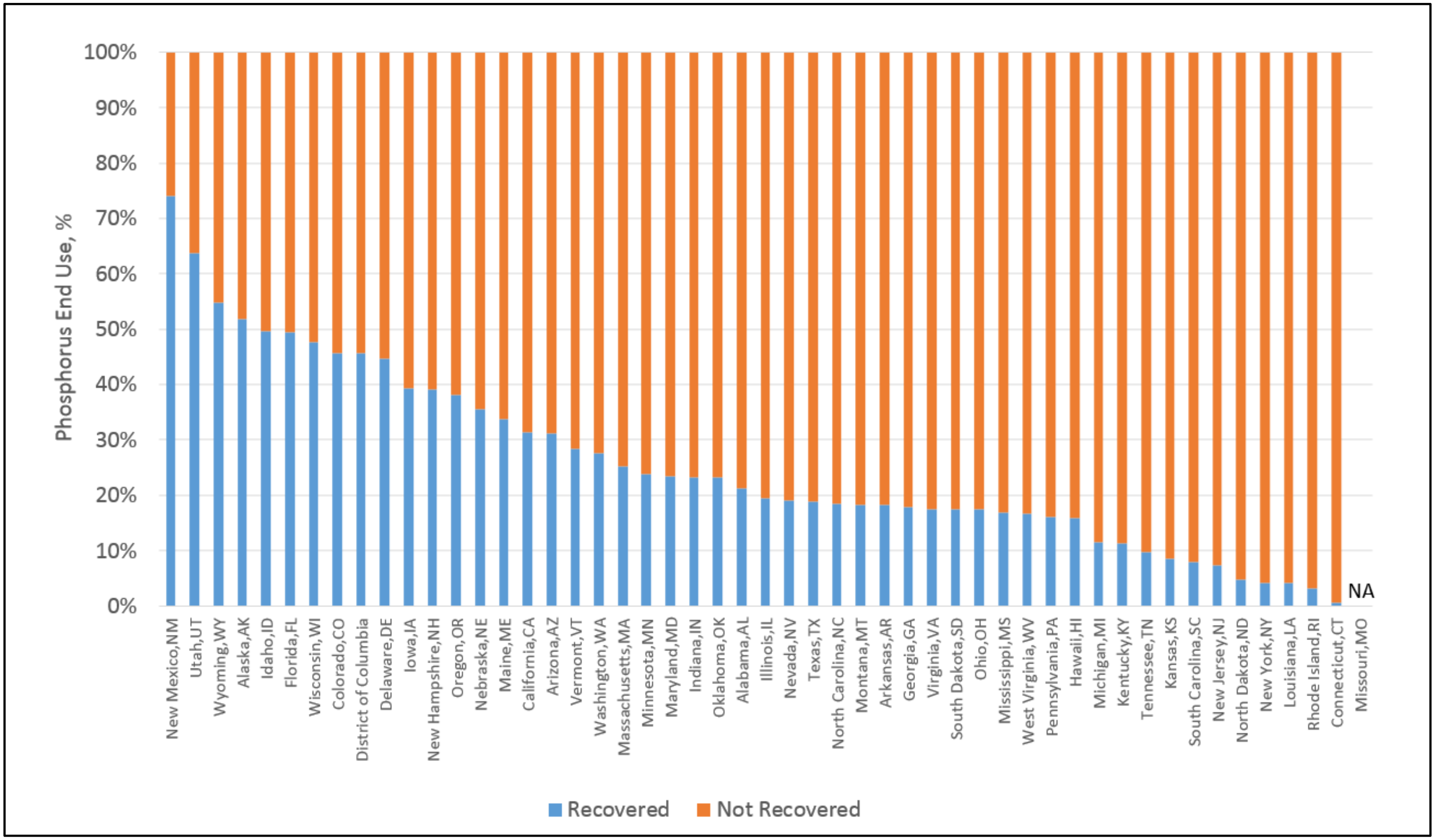

Figure 20 Recovered and Not Recovered Phosphorus by State as a Percentage

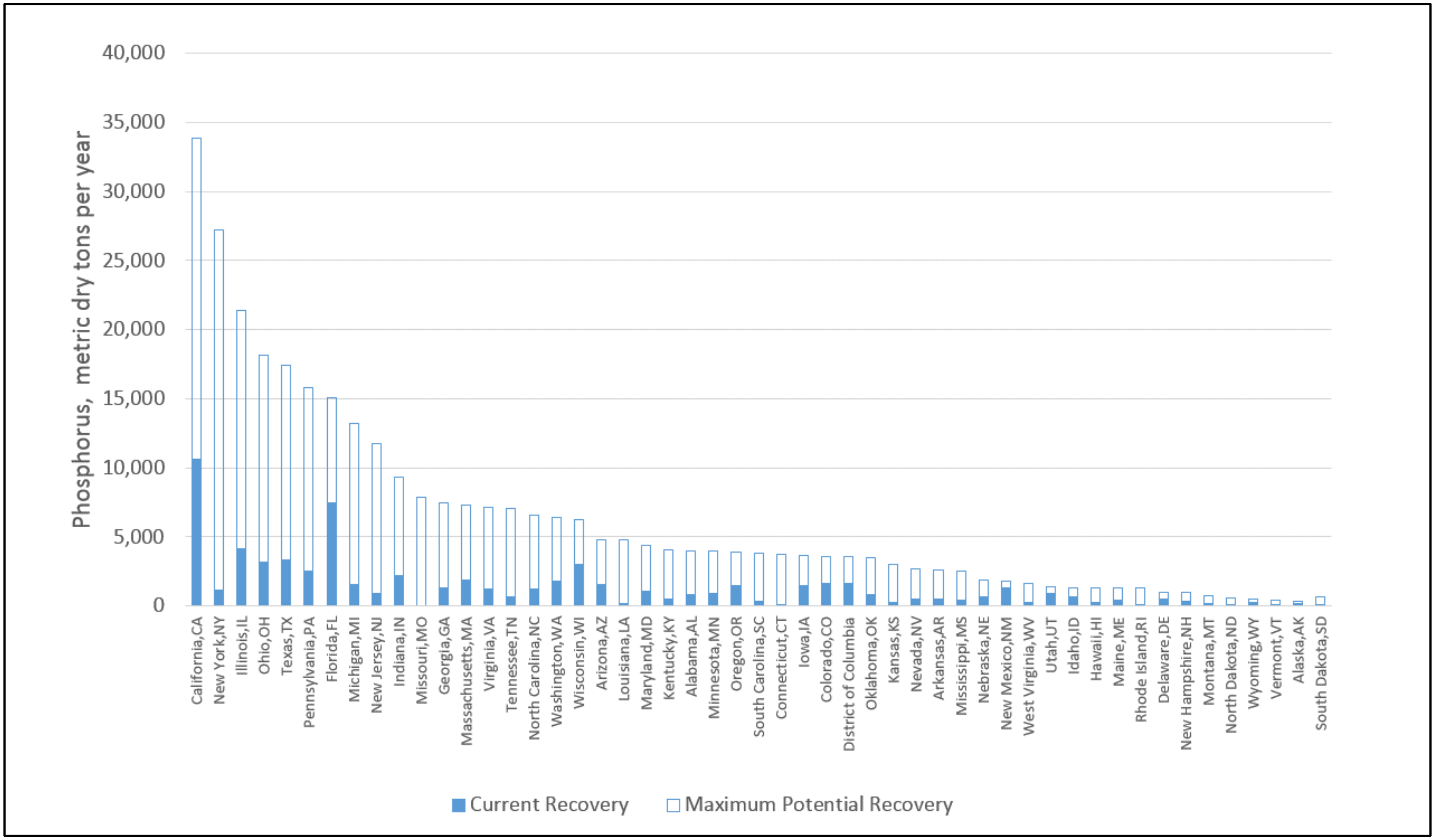

Figure 21 Phosphorus Recovery and Total Recovery Potential by State

Figure 22 summarizes the national average distribution of phosphorus end use.

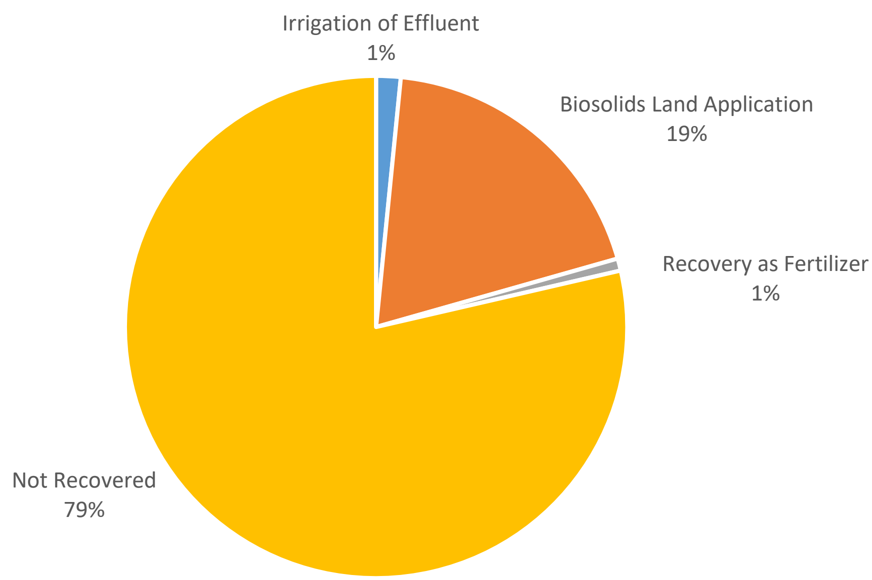

Figure 22 National Distribution of Wastewater Derived Phosphorus

Figure 23 shows the phosphorus end uses recovered by state. Figure 24 shows the recovered mass of wastewater derived phosphorus and its end uses by state.

Figure 25 shows the mass balance check between the estimated influent phosphorus mass in wastewater by state and the sum of all estimates of phosphorus end points, both recovered and not recovered. Generally, the agreement is very good and within 10% error.

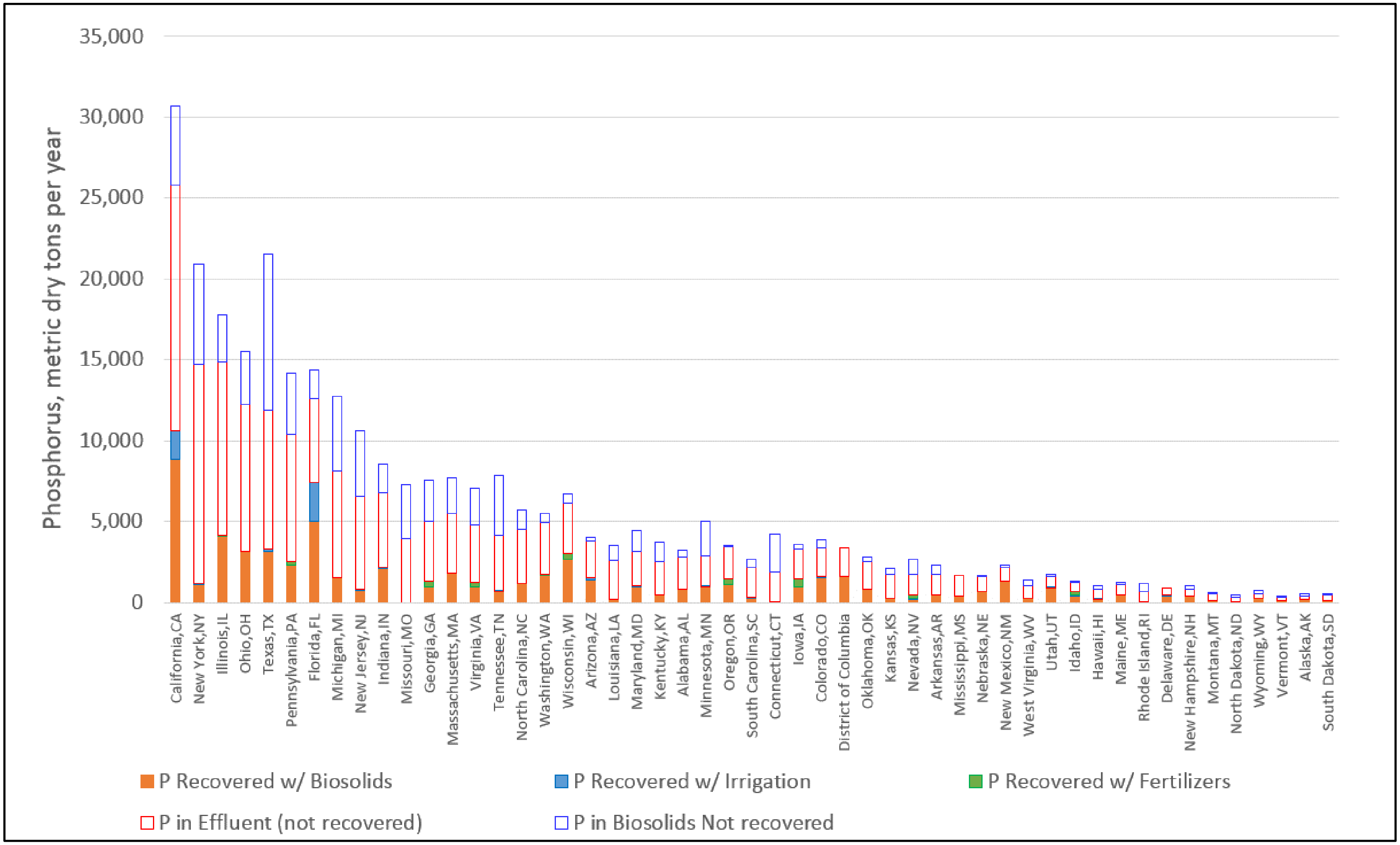

Figure 23 Wastewater Derived Phosphorus End Use by State (Recovered fractions shown as solid bar segments, not-recovered fractions with white fill)

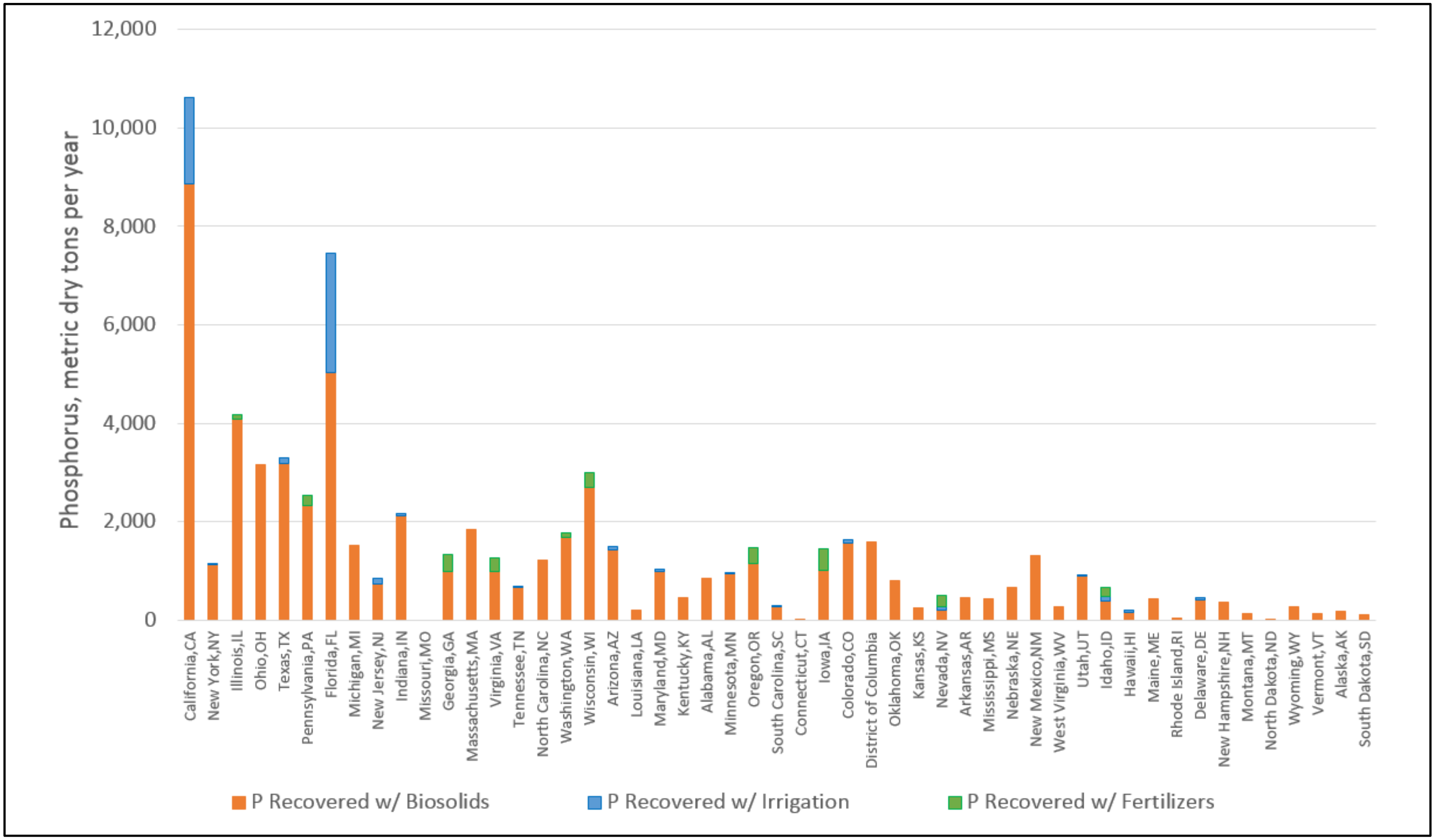

Figure 24 Wastewater Derived Phosphorus Recovery End Uses by State

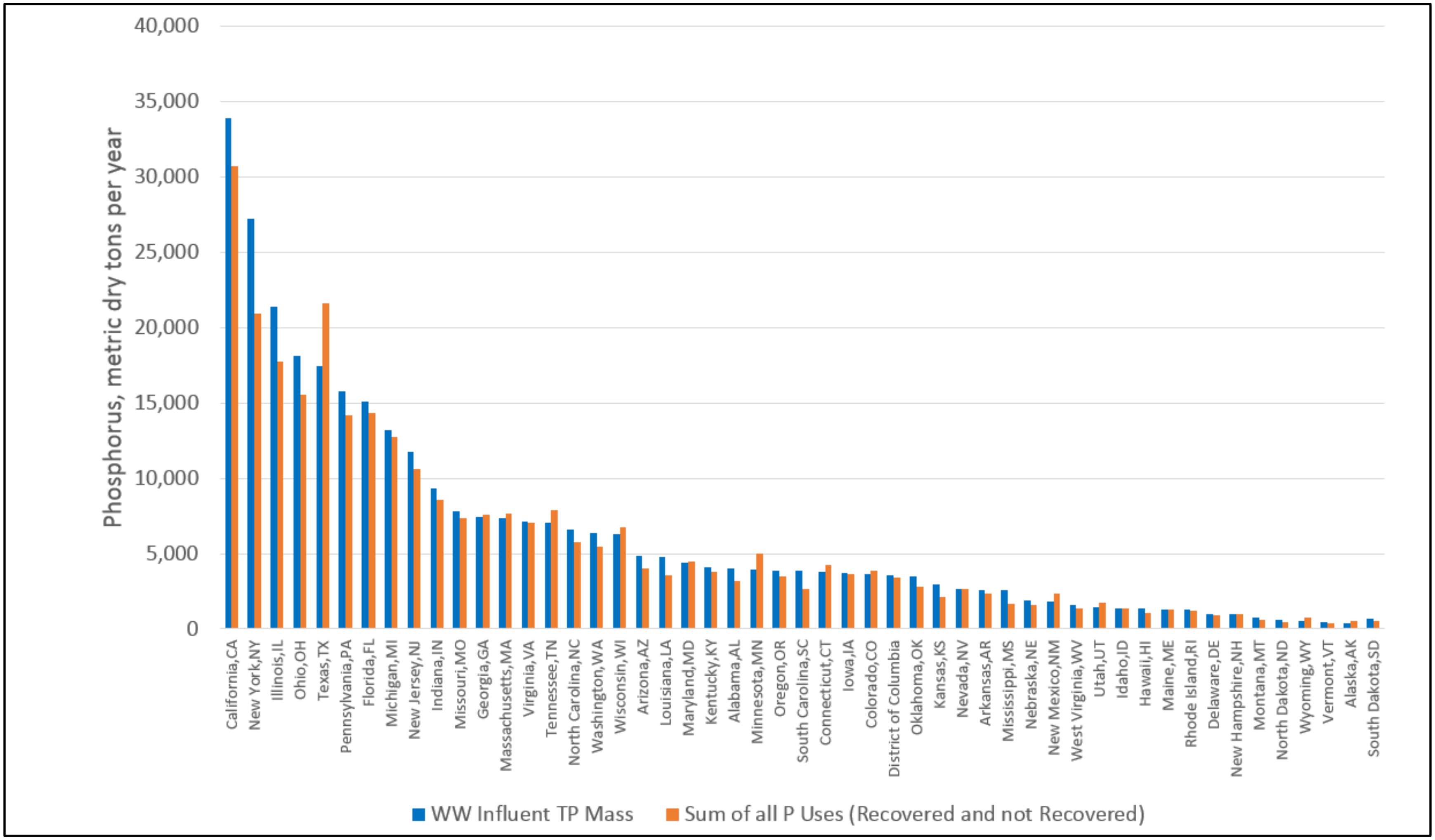

Figure 25 Mass Balance Check between Phosphorus Entering WRRFs and the Sum of all Phosphorus End Uses by State (recovered and not recovered)

4.4 Phosphorus Resource Recovery Trends

Most of the phosphorus available in wastewater influent is not yet recovered. Of all phosphorus currently recovered in the U.S. (21% of the total phosphorus mass available to WRRFs), almost 90% is estimated to be recovered through biosolids land application and composting programs. About 8% is recovered through reusing effluent for irrigation, and 4% is reused through struvite fertilizer production.

Given the continuous shift towards struvite recovery, phosphorus recovery is expected to continue to increase in the U.S. As a result, more U.S. WRRFs will need to convert their liquid stream treatment process to phosphorus removal and will be more likely to implement phosphorus sequestration. Many of these facilities are anticipated to implement phosphorus sequestration technologies for possible struvite, brushite, vivianite, or other fertilizer crystal recovery.

4.5 References

Mayer, B., Baker, L., Boyer, T., Drechsel, P., Gifford, M., Hanjra, M, Parameswaran, P., Stoltzfus, J., Westerhoff, P., Rittmann, B. (2016). Total Value of Phosphorus Recovery. Environmental Science & Technology, 50 (13), 6606-6620. DOI: 10.1021/acs.est.6b01239 https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b01239

Metcalf L, Eddy H, Tchobanoglous G: Wastewater engineering: treatment, disposal, and reuse.New York: McGraw-Hill; 2003

Seiple, T., Coleman, A.M., Skaggs, R. L. (2017). Municipal wastewater sludge as a sustainable bioresource in the United States. Journal of Environmental Management, 197, p. 673-680.

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Appendix 4A

WATER REUSE FOR IRRIGATION BY U.S. STATE

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State	Average Annual Reuse Flow	Reuse for irrigation	Average annual reuse for irrigation
	mgd	%	mgd
California	646	56%	363.7
Florida	760	66%	501.6
Texas	76.9	35%	26.8
Idaho	23.3	80%	18.6
Illinois	350	estimated	0.0
Hawai	17.2	estimated	8.6
Arizona	36.6	estimated	18.3
Nevada	197.4	8%	15.0
Utah	7.6	estimated	3.8
New Jersey	35	estimated	26.3
Indiana	16.4	estimated	8.2
Colorado	45	estimated	15.0
New York, NY	10	estimated	5.0
Maryland, MD	10.7	100%	10.7
Delaware	8	100%	8
South Carolina	5.3	100%	5.3
Tennessee, TN	4.7	100%	4.7
Minnesota, MN	0.62	100%	0.62
	2008.9		**1240.8**
For references see Chapter 2.			

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Appendix 4B

CURRENT STATUS OF STRUVITE RECOVERY BY U.S. STATE

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Vendor	Installation Country	Installation Location	ADAF Current, mgd	lbs P recovered as fertilizer per year	Reference
AirPrex	USA	Medina County, OH	Not yet online	-	
AirPrex	USA	Howard County, MD	Not yet online	-	
Multiform Harvest	USA	Boise, ID	26	425,531	Estimate
Multiform Harvest	USA	City of Yakima , WA	10	163,666	Estimate
Multiform Harvest	USA	Green Bay . WI	No long-term data yet.	-	
Ostara	USA	Rock Creek, Portland, OR	29	296,000	WEF 2018 RR Survey
Ostara	USA	Madison, WI	42	687,396	Estimate
Ostara	USA	Suffolk Nansemond River Treatment Plant, VI	18.24	400,000	WEF 2018 RR Survey
Ostara	USA	City of York, PA	26	425,531	Estimate
Ostara	USA	Durham Facility, Portland OR	27	458,000	WEF 2018 RR Survey
Ostara	USA	TMWRF, Reno NV	30	490,997	Estimate
Ostara	USA	Gwinnett, GA	34	732,000	WEF 2018 RR Survey
Ostara	USA	Chicago, IL	689	232,000	WEF 2018 RR Survey
Ostara	USA	Opequon Water Reclamation Facility, Winchester, VA	12.6	206,219	Estimate
Ostara	USA	Des Moines Wastewater Reclamation Authority, IA	60	981,994	Estimate
			Total	**5,499,332**	

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Appendix 4C

PHOSPHORUS MASS RECOVERED AND NOT RECOVERED BY U.S. STATE

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State	WW Produced (mgd)	P in Influent (metric tons per year)	P Recovered w/ Irrigation (metric tons per year)	Biosolids recovered (comp + land (dry tons per year)	P Recovered w/ Biosolids (metric tons per year)	P Recovered w/ Fertilizers (metric tons per year)	Total P Recovered (metric tons per year)	Total P Not Recovered (metric tons per year)	TP in Effluent Not Recovered (metric tons per year)	Other (recovered)	Biosolids not recovered (Not recovered)	TP in Biosolids Not Recovered (metric tons per year)	Mass balanace Check Sum of (metric tons per year)	P Mass Balance Error (%)
California,CA	3503	33,867	1,758	443000	8,860		10,618	23,249	15,175	10000	235000	4,900	30,694	91%
New York,NY	2815	27,218	24	56575	1,132		1,156	26,062	13,585	52925	255500	6,169	20,909	77%
Illinois,IL	2215	21,419		203618	4,072	105	4,178	17,241	10,709	19568	124877	2,889	17,776	83%
Ohio,OH	1873	18,109		158056	3,161		3,161	14,948	9,054		165639	3,313	15,528	86%
Texas,TX	1805	17,450	129	158861	3,177		3,307	14,144	8,596		483717	9,674	21,577	124%
Pennsylvania,PA	1631	15,772		116736	2,335	193	2,528	13,245	7,886		187264	3,745	14,159	90%
Florida,FL	1561	15,092	2,425	251600	5,032		7,457	7,635	5,121		88400	1,768	14,346	95%
Michigan,MI	1364	13,190		75845	1,517		1,517	11,673	6,595		230134	4,603	12,715	96%
New Jersey,NJ	1212	11,721	127	36636	733		860	10,861	5,734	344	199981	4,007	10,600	90%
Indiana,IN	961	9,295	40	106099	2,122		2,162	7,133	4,608		90864	1,817	8,587	92%
Missouri,MO	810	7,834		0	-		-	7,834	3,917	85000	85000	3,400	7,317	93%
Georgia,GA	767	7,419		49827	997	332	1,329	6,090	3,709	5245.96	120148.88	2,508	7,546	102%
Massachusetts,MA	757	7,316		92028	1,841		1,841	5,476	3,658	633.474373	109038.976	2,193	7,692	105%
Virginia,VA	740	7,150		49085	982	275	1,257	5,894	3,575	14770	96140	2,218	7,050	99%
Tennessee,TN	726	7,020	23	33170	663		686	6,334	3,487	52983	132515	3,710	7,884	112%
North Carolina,NC	679	6,566		60787	1,216		1,216	5,350	3,283		61597	1,232	5,731	87%
Washington,WA	662	6,400		84606	1,692	74	1,766	4,634	3,200	5564	20397	519	5,486	86%
Wisconsin,WI	650	6,281		134372	2,687	312	2,999	3,281	3,140		28735	575	6,714	107%
Arizona,AZ	499	4,822	88	71000	1,420		1,508	3,314	2,323		9000	180	4,011	83%
Louisiana,LA	497	4,805		9818	196		196	4,609	2,403	4481	42936	948	3,547	74%
Maryland,MD	457	4,416	52	49025	981		1,032	3,384	2,156	48657.24	13773.78	1,249	4,437	100%
Kentucky,KY	423	4,088		23194	464		464	3,624	2,044	810	61480	1,246	3,754	92%
Alabama,AL	412	3,986		42402	848		848	3,138	1,993		18841	377	3,218	81%
Minnesota,MN	409	3,954	3	46800	936		939	3,015	1,974	60	105082	2,103	5,016	127%
Oregon,OR	402	3,882		57103	1,142	342	1,484	2,398	1,941		3574	71	3,497	90%
South Carolina,SC	397	3,838	26	14063	281		307	3,531	1,894		23301	466	2,666	69%
Connecticut,CT	388	3,751		1180	24		24	3,728	1,876		116820	2,336	4,236	113%
Iowa,IA	380	3,677		50200	1,004	446	1,450	2,228	1,839		16460	329	3,617	98%
Colorado,CO	372	3,600	73	78500	1,570		1,643	1,958	1,728	10303	14109	488	3,858	107%
District of Columbia	370	3,577		80000	1,600		1,600	1,977	1,789		0	-	3,389	95%
Oklahoma,OK	357	3,456		40043	801		801	2,655	1,728		12710	254	2,783	81%
Kansas,KS	309	2,990		12886	258		258	2,732	1,495		19071	381	2,134	71%
Nevada,NV	274	2,654	73	10552	211	223	506	2,147	1,254		45926	919	2,679	101%
Arkansas,AR	266	2,571		23391	468		468	2,103	1,286		28787	576	2,329	91%
Mississippi,MS	263	2,543		21561	431		431	2,112	1,272		0	-	1,703	67%
Nebraska,NE	193	1,865		33175	664		664	1,201	932	500	227	15	1,610	86%
New Mexico,NM	184	1,780		65880	1,318		1,318	462	890	182	6874	141	2,349	132%
West Virginia,WV	167	1,615		13400	268		268	1,347	807		14915	298	1,374	85%
Utah,UT	147	1,425	18	44527	891		909	516	694	6554	1859	168	1,771	124%
Idaho,ID	139	1,344	90	19139	383	193	666	678	582		4070	81	1,329	99%
Hawaii,HI	138	1,331	41	8491	170		211	1,120	624		11110	222	1,058	79%
Maine,ME	136	1,315		22228	445		445	870	657	490	7774	165	1,267	96%
Rhode Island,RI	132	1,278		2001	40		40	1,238	639		25432	509	1,188	93%
Delaware,DE	104	1,005	39	21000	420		459	547	464		0	-	923	92%
New Hampshire,NH	98	948		18509	370		370	578	474		8512	170	1,014	107%
Montana,MT	80	776		7081	142		142	634	388	1049	2569	72	602	78%
North Dakota,ND	60	577		1400	28		28	549	289		6397	128	445	77%
Wyoming,WY	52	503		13792	276		276	227	251	9734	698	209	736	146%
Vermont,VT	46	444		6316	126		126	318	222		2657	53	401	90%
Alaska,AK	38	366		9497	190		190	176	183	0	7424	148	522	142%
South Dakota,SD	69	667		5832	117		117	550	334	2328	1259	72	522	78%
SUM	32,992	**318,972**	**5,028**	3,034,886	**60,698**	**2,495**	**68,221**	**250,750**						

Assumptions

TP influent (ave)	7	mg/L
TP effluent (ave)	3.5	mg/L
Biosolids P content	2	%

Figures in red fond indicate that the values deviate from the cited references and were adopted from other sources.

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Chapter 5

CURRENT STATUS OF NITROGEN RECOVERY AT WRRFS IN THE U.S.

5.1 Methodology for Developing National Aggregates for Nitrogen Resource Recovery

The annual total nitrogen (TN) load in domestic wastewater was estimated from the following: the total quantity of wastewater produced by the CWNS (see Chapter 2), typical nitrogen wastewater influent concentrations in the U.S., and typical per capita nitrogen loads in wastewater. For simplicity we assumed that all nitrogen present in biosolids used for composting or land application, and all nitrogen in effluent used for irrigation is recovered regardless of site specific agronomical rates. Nitrogen recovery from biosolids and effluent reuse for irrigation was also estimated from the biosolids database summary (Chapter 3) and reuse data (Chapter 2).

5.2 Nitrogen Mass in Domestic Wastewater in the United States

Approximately 4,360 metric tons of nitrogen (as total Kjeldahl, TKN) is estimated to enter WRRFs every day with domestic wastewater influent (1.6 million metric dry tons per year). This value assumes an average daily per capita TKN load of 0.029 pounds (Metcalf and Eddie, 2003) and a total population of about 326 million in the U.S. in 2017. (Note this neglects the year-round population not connected to public sewer systems). Neglecting industrial nitrogen production in wastewater, the average wastewater influent TKN concentration across all states is approximately 35 mg/L.

Figure 26 summarizes the TKN mass in domestic wastewater influent by state. This value was estimated using the wastewater flow by state (see Chapter 2) and the assumed average TKN wastewater influent concentration in the U.S. of 35 mg/L. The TKN mass represents the total amount of wastewater derived from nitrogen available for recovery, recognizing that not all of this nitrogen can be feasibly recovered.

Note that the total mass by state is expressed as nitrogen rather than TKN. This is because the majority of wastewater influent total nitrogen is TKN. Nitrate and nitrite are typically not detectable in wastewater influent.

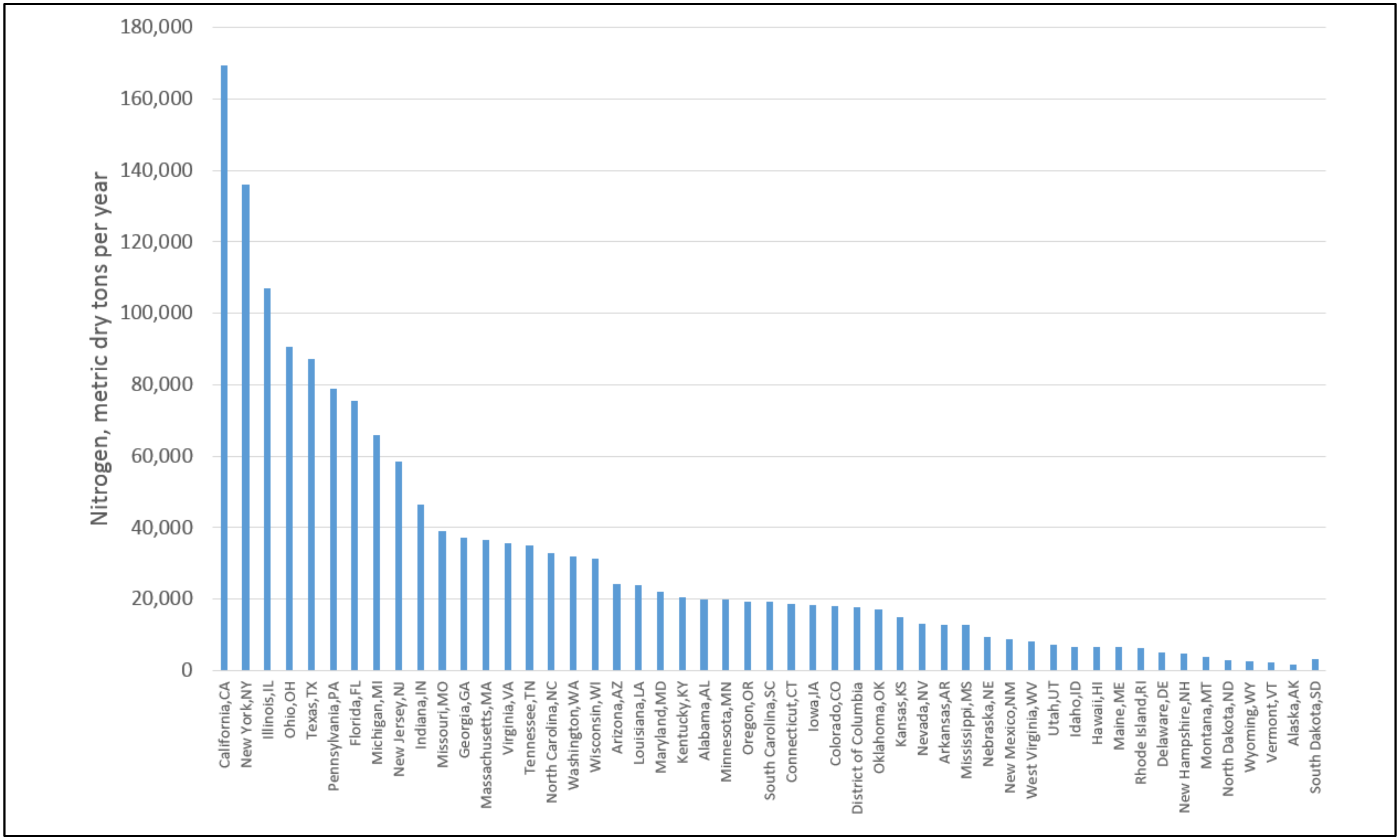

Figure 26 Annual Nitrogen Load in Wastewater Influent by State

5.3 Total Nitrogen Resources Currently Recovered at WRRF

5.3.1 Definition of Nitrogen Recovery

For this study, wastewater nitrogen was defined as recovered for the following uses: urine source separation, effluent water reused for irrigation, biosolids applied to land, and ammonia fertilizer production from concentrated recycle streams generated after anaerobic digestion and solids dewatering (see Figure 27). Nitrogen in effluent discharged to surface or groundwater or used for potable reuse was not defined as recovered, nor was nitrogen in biosolids disposed of in landfills or used in any way other than for land application or composting. WRRFs that remove nitrogen biologically through conventional nitrification and denitrification lose a significant portion of nitrogen through gaseous emissions.

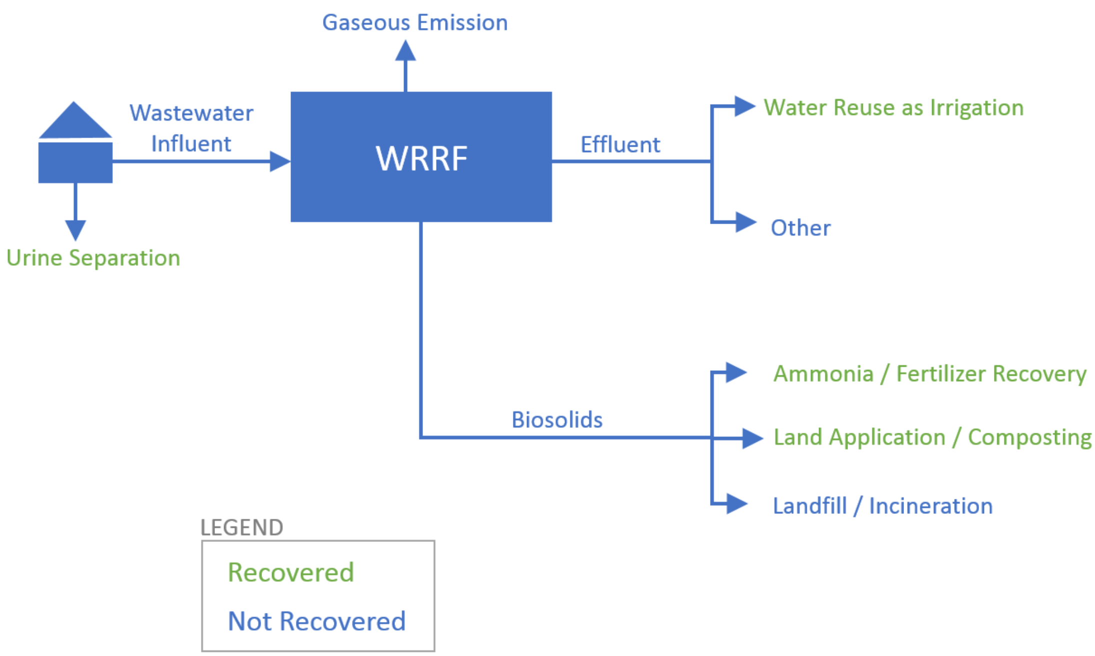

Figure 27 Definition of Recovered and Not Recovered Nitrogen Mass streams

5.3.2 Current National Nitrogen Recovery and End Use Estimates for U.S.

For an accurate estimate of nitrogen mass flows in WRRFs, one must have data on the amount of wastewater treated for nitrogen removal. Facilities that practice conventional nitrification and denitrification for nitrogen removal release approximately 50-65% of the influent nitrogen load as gaseous emissions from the aeration basins. Conversely, approximately 20% of the influent nitrogen load remains in the dewatered sludge and 15-30% remains in the treated effluent, mostly as nitrate. For WRRFs that do not remove nitrogen, approximately 80% of the influent nitrogen load remains in the liquid stream and is discharged in the effluent, mostly as ammonia. The remaining 20% of nitrogen resides in the dewatered sludge (WEF 2014).

Complete and current data on the number of facilities in the U.S. practicing nitrogen removal is not available. However, the EPA is compiling this information from various sources to make it available in the coming years (EPA, accessed 2018).

The most current and complete dataset was adopted from the EPA's CWNS (EPA 2012). According to this report, nitrogen and phosphorus removal noticeably increased over past years in parts of the U.S. watersheds.

Using CWNS data, Figure 28 shows the wastewater flows treated for nitrogen removal by state. As shown, an average 15% of all wastewater produced in the U.S. was nitrified and partially denitrified in 2012. Figure 29 shows the percent wastewater in each state that is nitrified and partially denitrified (EPA 2012).

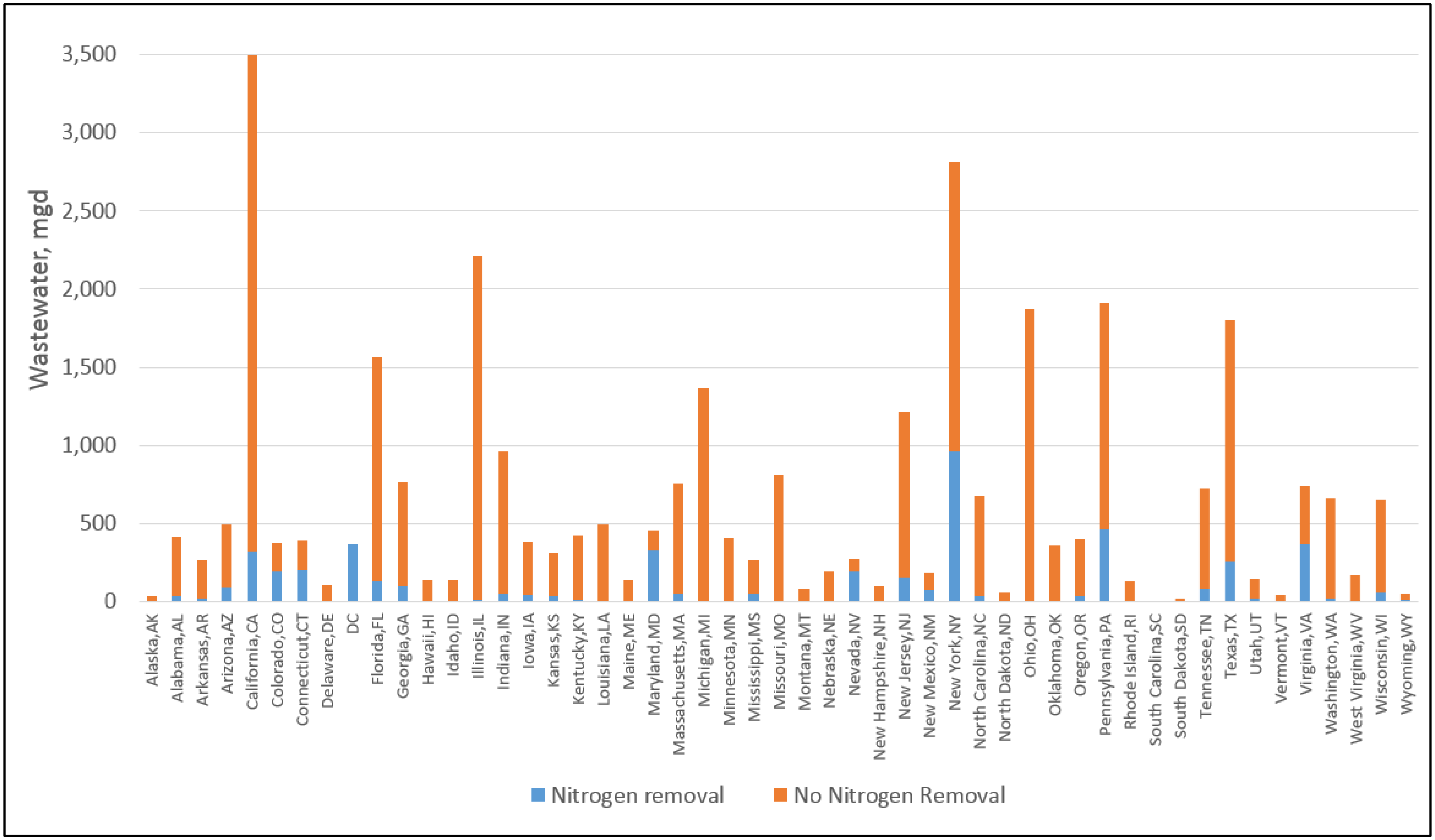

Figure 28 Wastewater Treated with Nitrogen Removal by State

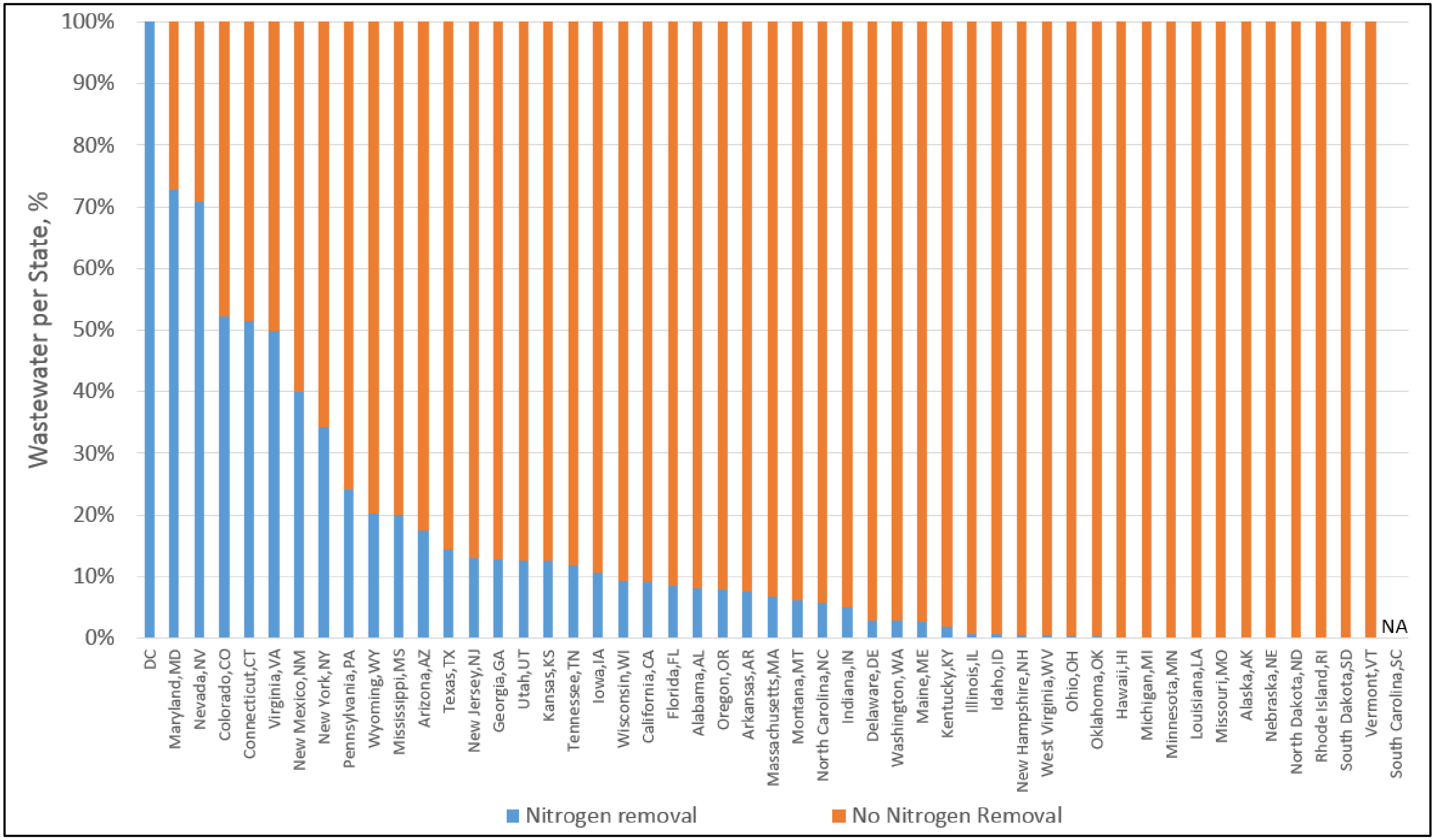

Figure 29 Percent Wastewater by State Treated with and without Nitrogen Removal

The current status of nitrogen recovery in the U.S. was estimated by aggregating the estimated amount of nitrogen in water reused for irrigation, biosolids used for land application and composting for each state, and ammonia-N sequestered in fertilizer production. Although ammonia recovery as a standalone fertilizer product is technologically feasible, it is not yet commercially practiced in the U.S. at WRRFs.

Ammonia is recovered at WRRFs commercially producing struvite, which was accounted for in this study. Nitrogen recovery with urine separation is currently only practiced at the demonstration-scale level and was thus not quantifiable nationally. It was therefore not included in the mass balance calculations.

5.3.3 Nitrogen Recovery through Water Reuse for Irrigation

The annual volume of effluent irrigation water used per state in the U.S. was developed from Chapter 4.

Based on a blend of WRRFs that remove and do not remove N with their treatment process (see Section 3.2), a flow-weighted average effluent TN concentration was calculated for each state. This estimate assumed an average effluent TN concentration of 28 mg/L in facilities without N removal (80% of influent concentration) and 11 mg/L in facilities with N removal (30% of wastewater influent concentration). For more information on this topic, see Appendix 5B.

Consequently, the amount of nitrogen estimated to be beneficially recovered through effluent irrigation in the U.S. is 37,400 metric tons per year (2.3% of the total estimated nitrogen load in wastewater influent.).

5.3.4 Nitrogen Recovery through Biosolids Land Application and Composting

The estimated total theoretically recoverable mass of nitrogen in biosolids was about 4.5% of the solids dry mass in biosolids in the U.S.

The total mass of biosolids produced in the U.S. after liquid and solids treatment was adopted from data developed in Chapter 3 (6.71 million metric dry tons per year). Consequently, the estimated amount of nitrogen in biosolids is 302,000 metric tons per year, approximately 19% of the total nitrogen estimated to enter WRRFs (1,600,000 metric tons per year). On a national scale, a total of 51% of all biosolids was recovered for beneficial used (Chapter 3). Therefore, as a national average, approximately 113,900 metric tons of nitrogen is recovered beneficially with biosolids (about 7% of the total nitrogen entering WRRFs).

5.3.5 Nitrogen Recovery through Fertilizer (Struvite) Production

Chapter 4 described the approach to quantifying the current amount of struvite recovery from wastewater nutrients by state. The facilities recovering struvite are listed in Appendix 4A, along with their estimated current average daily flows and current annual phosphorus recovery mass. Based on this information, the estimated mass of ammonia-nitrogen recovered with struvite was 1,130 metric tons per year, about 0.07% of the total nitrogen entering WRRFs every year.

Figure 30 summarizes the aggregated current nitrogen recovered and not recovered by state as a percentage.

Figure 31 shows the current nitrogen mass recovered and not recovered by state.

The combined nitrogen recovered with water reuse for irrigation, land application and composting, and fertilizer production is therefore estimated to be 172,400 metric dry tons per year, about 11% of the total nitrogen estimated to enter WRRFs.

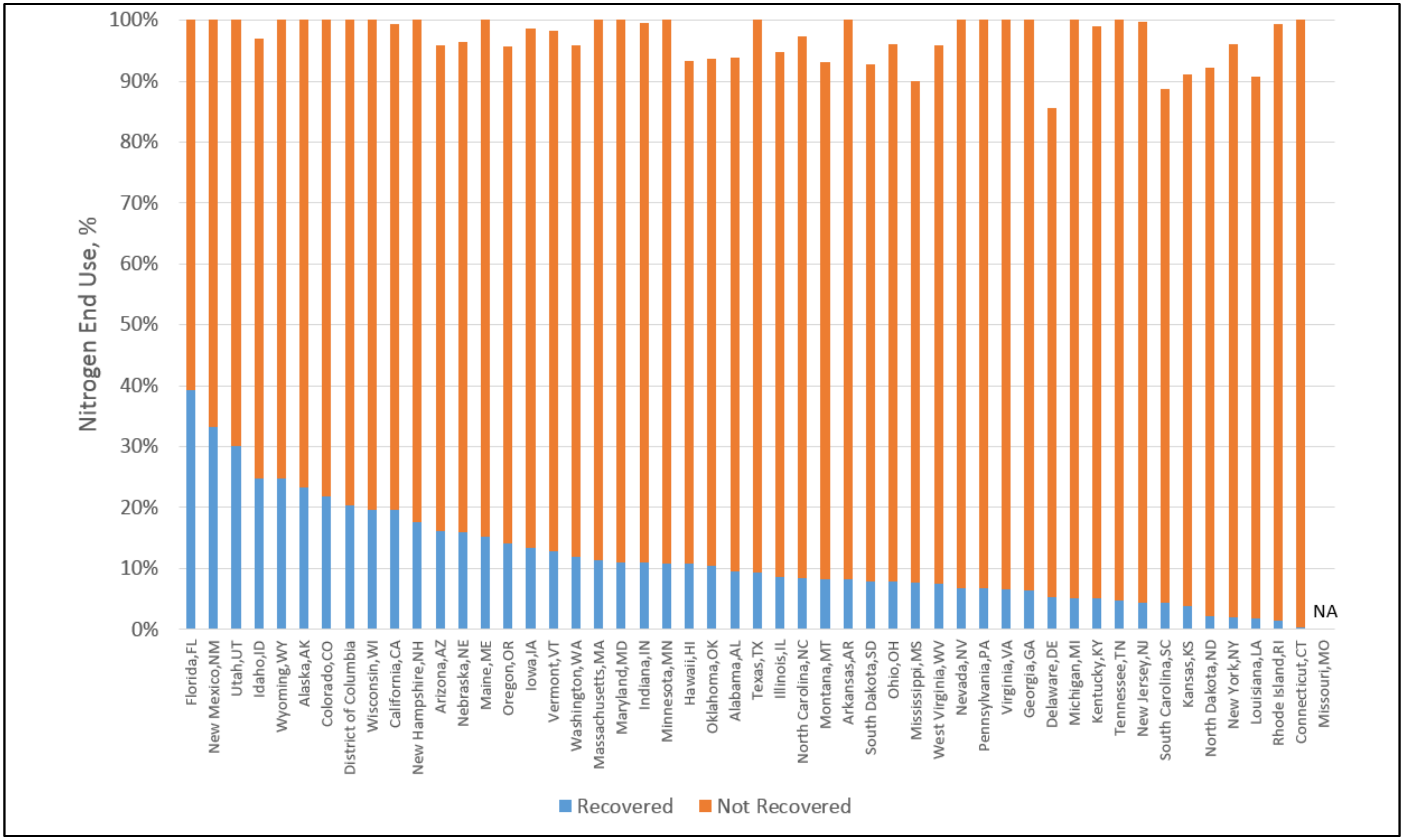

Figure 30 Nitrogen Mass Recovered and Not Recovered by State as a Percentage

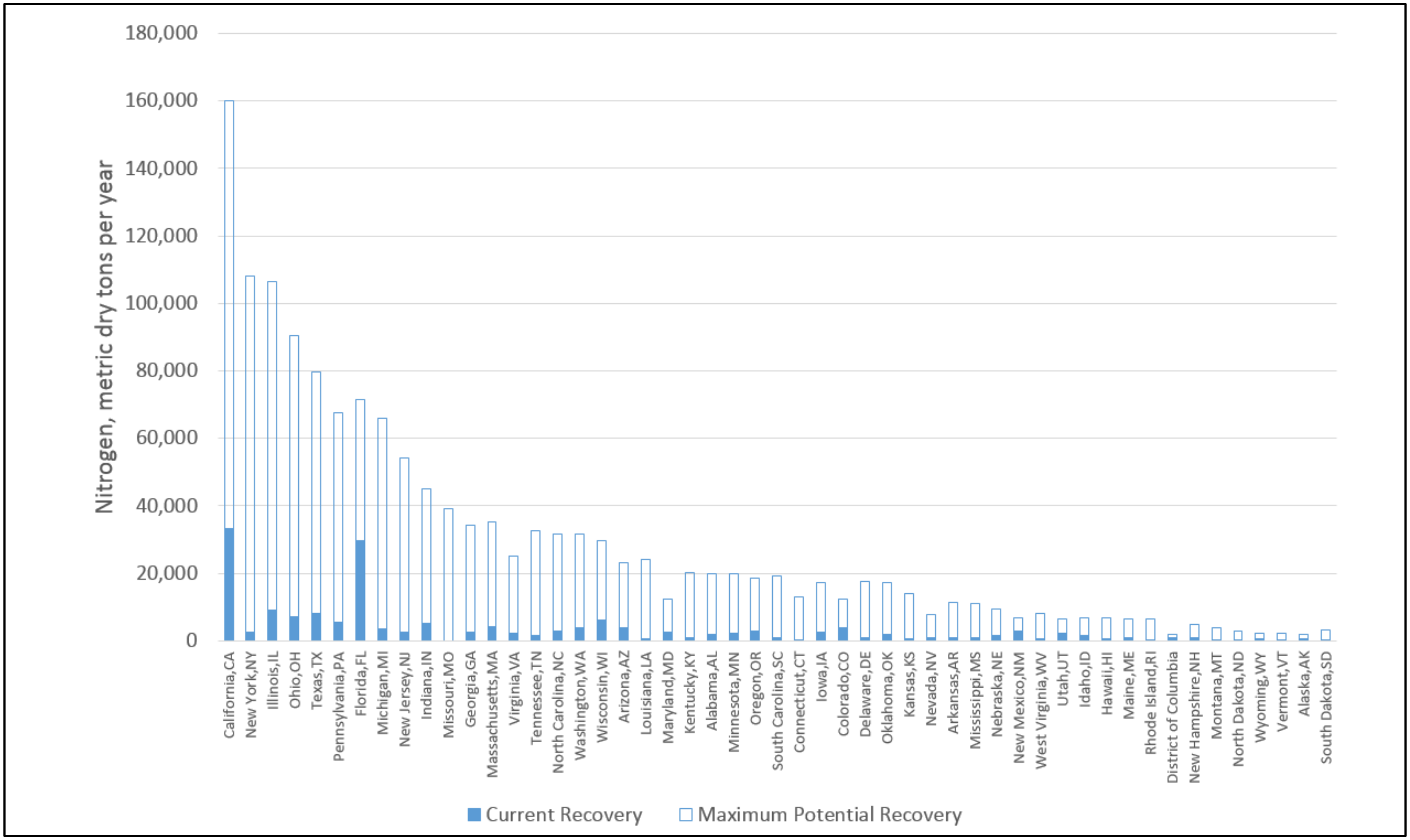

Figure 31 Annual Nitrogen Recovery and Theoretical Recovery Potential by State

Figure 32 summarizes the national average distribution of nitrogen end uses. Figure 33 shows the nitrogen end uses by state.

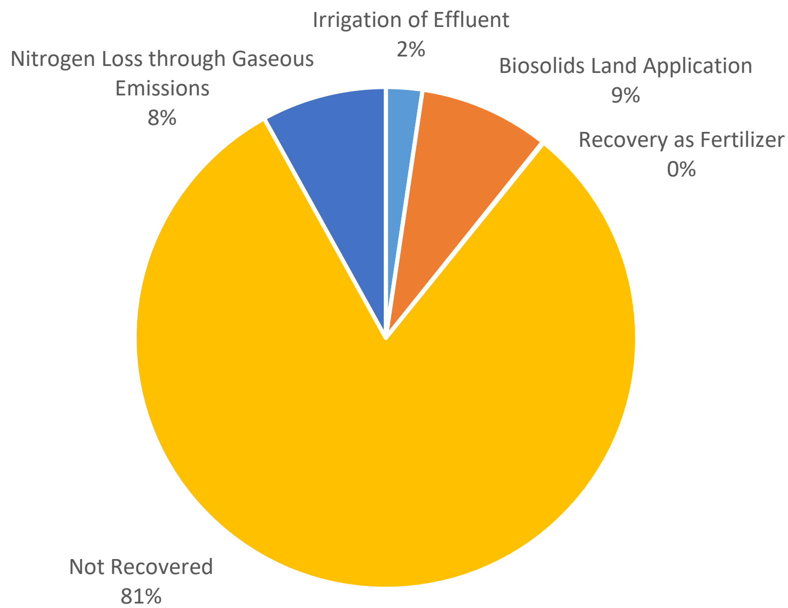

Figure 32 National Distribution of Wastewater Derived Nitrogen End Uses

Figure 34 shows the current mass of nitrogen recovered by state and by end use.

shows the mass balance check between the estimate influent nitrogen mass in wastewater per state and the sum of all individual estimates of nitrogen end uses (recovered and not recovered). Generally, the agreement is very good, with less than a 5% error.

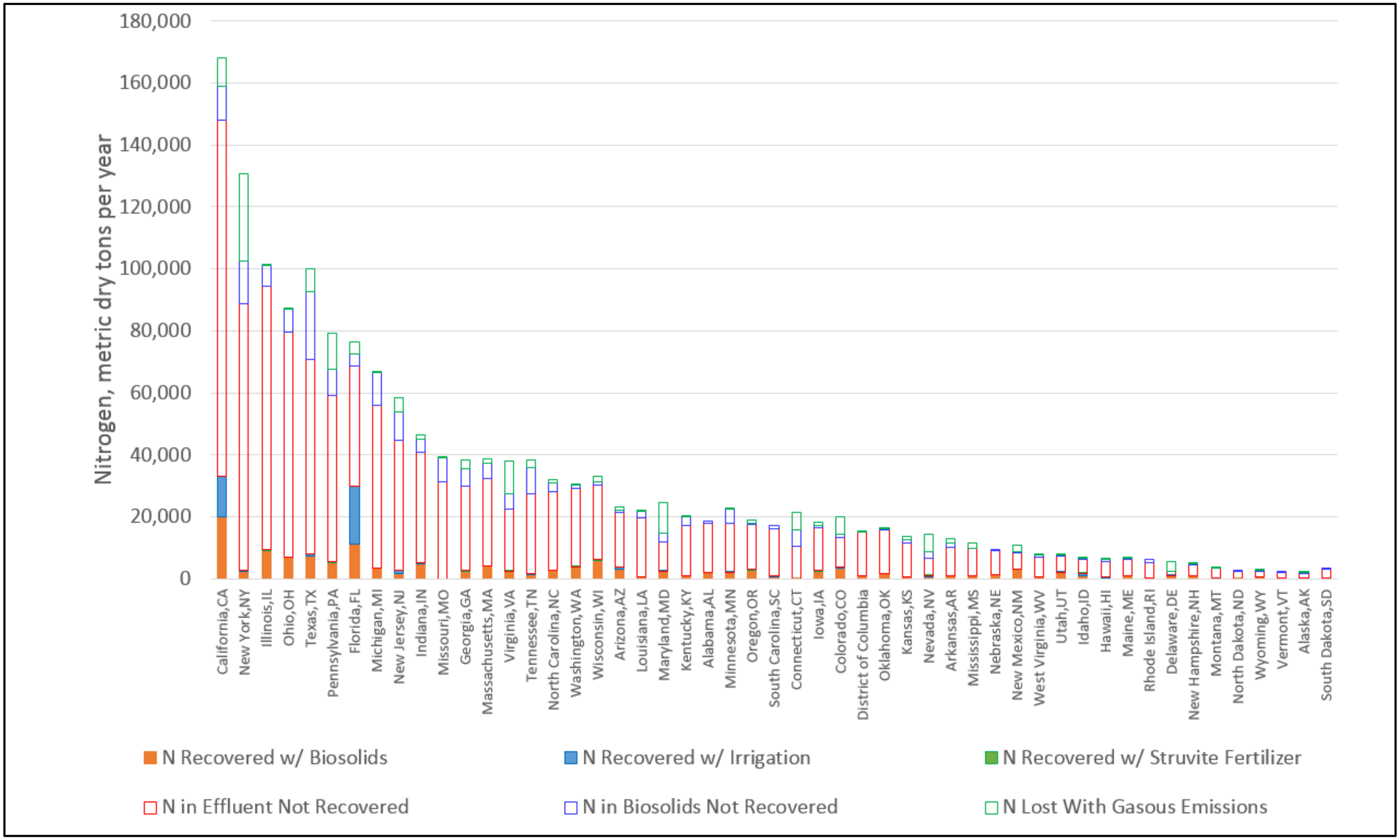

Figure 33 Annual Nitrogen End Use by State (recovery shown as solid bar segments, disposal end uses with white fill)

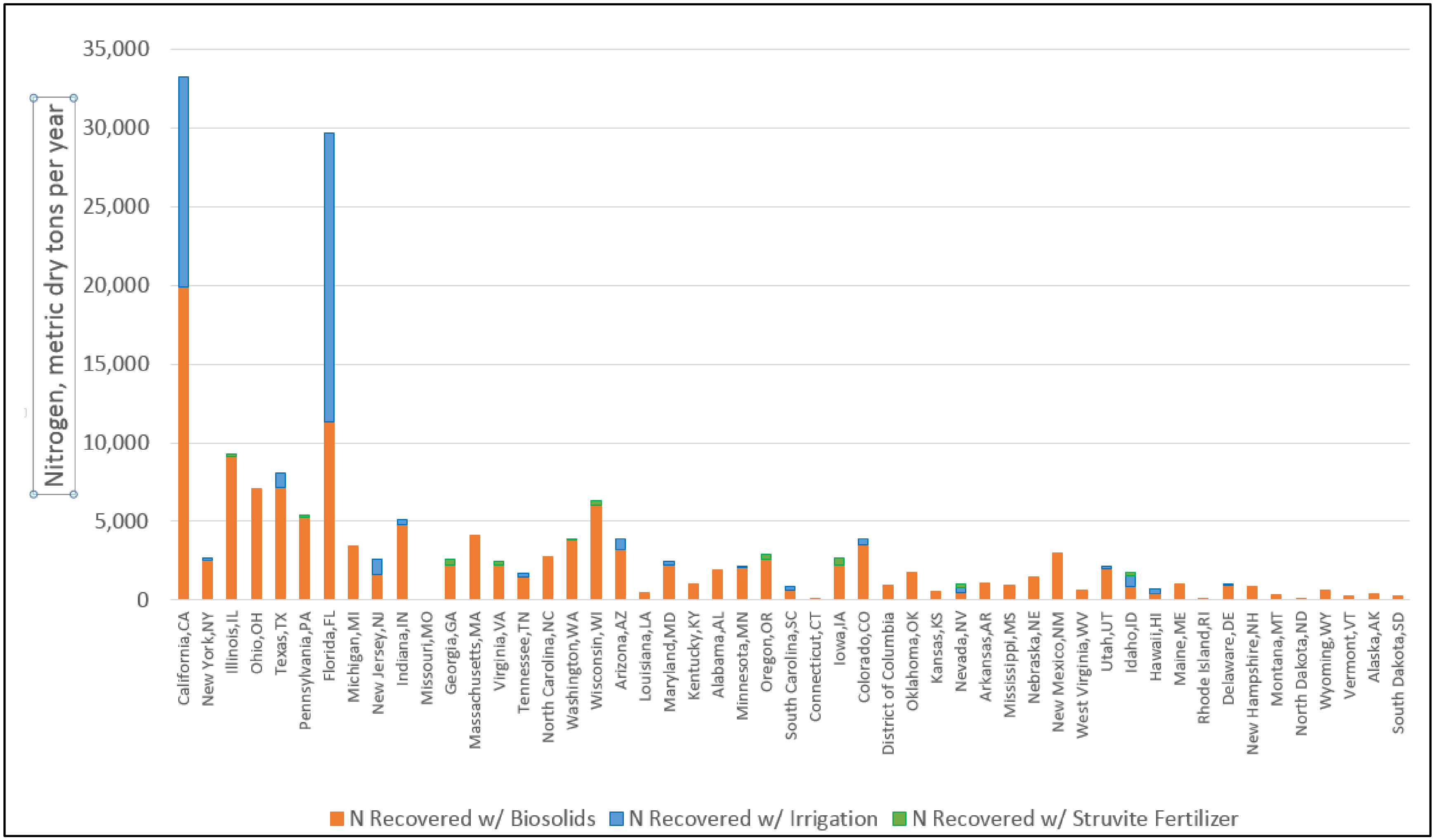

Figure 34 Wastewater Derived Nitrogen Recovery End Use by State

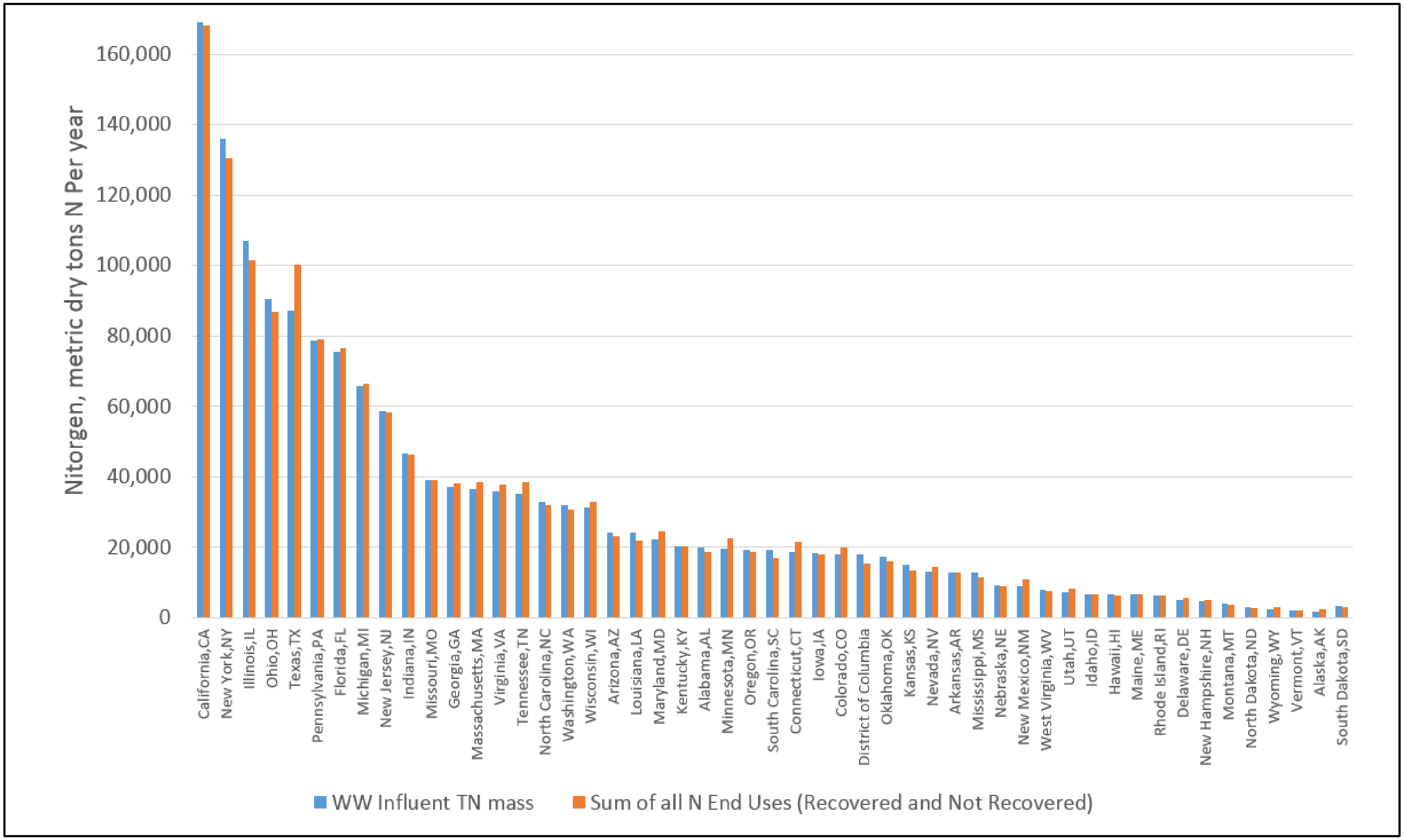

Figure 35 Mass Balance Check between Nitrogen Mass Entering WRRFs and the Sum of all Nitrogen Mass End Uses by State (recovered and not recovered)

5.4 Nitrogen Resource Recovery Trends

The majority of nitrogen in wastewater influent is not yet recovered and is instead diverted for non-beneficial uses (about 90% as a national average). Of all nitrogen recovered for beneficial use in the U.S., 74% is estimated to be recovered through biosolids land application and composting programs. About 25% is recovered through effluent reclamation for irrigation, and only about 1% is reused as struvite fertilizer production.

Given the ongoing shift from landfilling biosolids to land application and struvite recovery, nitrogen recovery is expected to continue increasing in the U.S. Furthermore, technologies that recover ammonia directly from wastewater concentrated streams or urine sources as fertilizer have shown to be technologically feasible and may gain traction in the future.

5.5 References

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Appendix 5A

NITROGEN MASS RECOVERED AND NOT RECOVERED BY U.S. STATE

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State	WW Produced	N (TKN) in Influent	% of Effluent w/ N Removal	Average N Concentration in Effluent (State)	N Recovered w/ Irrigation	Biosolids Recovered (comp + land appl)	N Recovered w/ Biosolids	N Recovered w/ Struvite Fertilizer	Total N Recovered	Total N Not Recovered	N in Effluent Not Recovered	Biosolids Other (Recovered)	Biosolids not Recovered	N in Biosolids Not Recovered	N Lost With Gasous Emissions	Mass Balanace Check (Sum of Recovered and Not Recovered Items)	N Mass Balance Error
	mgd	metric tons per year	%	mg/L	metric tons per year	dry tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	metric tons per year	%
California,CA	3503	169,336	9%	26.45	13,289	443000	19,935		33,224	134,965	114,699	10000	235000	11,025	9,241	168,189	99%
New York,NY	2815	136,090	34%	22.19	153	56575	2,546		2,699	127,913	86,129	52925	255500	13,879	27,905	130,612	96%
Illinois,IL	2215	107,093	1%	27.88		203618	9,163	48	9,210	92,261	85,308	19568	124877	6,500	454	101,472	95%
Ohio,OH	1873	90,544	0%	27.96		158056	7,113		7,113	79,914	72,332		165639	7,454	128	87,026	96%
Texas,TX	1805	87,252	14%	25.55	945	158861	7,149		8,093	92,062	62,746		483717	21,767	7,550	100,156	115%
Pennsylvania,PA	1631	78,862	24%	23.90		116736	5,253	87	5,340	73,690	53,854		187264	8,427	11,409	79,030	100%
Florida,FL	1561	75,460	9%	26.55	18,393	251600	11,322		29,715	46,690	38,846		88400	3,978	3,866	76,404	101%
Michigan,MI	1364	65,950	0%	27.98		75845	3,413		3,413	63,127	52,717		230134	10,356	54	66,540	101%
New Jersey,NJ	1212	58,606	13%	25.79	936	36636	1,649		2,584	55,833	42,253	344	199981	9,015	4,565	58,417	100%
Indiana,IN	961	46,473	5%	27.15	308	106099	4,774		5,082	41,225	35,744		90864	4,089	1,392	46,307	100%
Missouri,MO	810	39,168	0%	27.99		0	-		-	38,987	31,325	85000	85000	7,650	12	38,987	100%
Georgia,GA	767	37,094	13%	25.83		49827	2,242	150	2,392	35,860	27,372	5245.96	120148.88	5,643	2,845	38,252	103%
Massachusetts,MA	757	36,582	7%	26.87		92028	4,141		4,141	34,480	28,080	633.474373	109038.976	4,935	1,465	38,621	106%
Virginia,VA	740	35,752	50%	19.53		49085	2,209	124	2,333	35,629	19,949	14770	96140	4,991	10,688	37,962	106%
Tennessee,TN	726	35,102	12%	26.00	169	33170	1,493		1,661	36,732	25,906	52983	132515	8,347	2,479	38,394	109%
North Carolina,NC	679	32,829	6%	27.02		60787	2,735		2,735	29,251	25,343		61597	2,772	1,136	31,987	97%
Washington,WA	662	32,002	3%	27.53		84606	3,807	34	3,841	26,870	25,176	5564	20397	1,168	526	30,711	96%
Wisconsin,WI	650	31,403	9%	26.43		134372	6,047	141	6,188	26,747	23,714		28735	1,293	1,739	32,934	105%
Arizona,AZ	499	24,111	8%	26.71	675	71000	3,195		3,870	19,228	17,726		9000	405	1,097	23,098	96%
Louisiana,LA	497	24,027	0%	27.99		9818	442		442	21,357	19,214	4481	42936	2,134	9	21,799	91%
Maryland,MD	457	22,080	73%	15.64	231	49025	2,206		2,437	22,078	9,634	48657.24	13773.78	2,809	9,634	24,515	111%
Kentucky,KY	423	20,439	2%	27.68		23194	1,044		1,044	19,199	16,164	810	61480	2,803	232	20,242	99%
Alabama,AL	412	19,929	0%	28.00		42402	1,908		1,908	16,791	15,943		18841	848	-	18,699	94%
Minnesota,MN	409	19,772	0%	27.98	24	46800	2,106		2,130	20,528	15,783	60	105082	4,731	14	22,658	115%
Oregon,OR	402	19,411	8%	26.64		57103	2,570	155	2,724	15,867	14,777		3574	161	929	18,591	96%
South Carolina,SC	397	19,191		28.00	205	14063	633		838	16,197	15,148		23301	1,049	-	17,034	89%
Connecticut,CT	388	18,757	51%	19.25		1180	53		53	21,365	10,317		116820	5,257	5,791	21,419	114%
Iowa,IA	380	18,386	11%	26.18		50200	2,259	201	2,460	15,675	13,753		16460	741	1,182	18,135	99%
Colorado,CO	372	18,001	52%	19.12	396	78500	3,533		3,929	16,178	9,436	10303	14109	1,099	5,644	20,107	112%
District of Columbia	370	17,886	3%	27.50		21000	945		945	14,369	14,055		0	-	313	15,314	86%
Oklahoma,OK	357	17,280	0%	27.96		40043	1,802		1,802	14,400	13,805		12710	572	23	16,202	94%
Kansas,KS	309	14,951	13%	25.87		12886	580		580	13,033	11,050		19071	858	1,125	13,613	91%
Nevada,NV	274	13,268	71%	15.97	331	10552	475	101	906	13,423	5,724		45926	2,067	5,632	14,329	108%
Arkansas,AR	266	12,855	18%	25.02		23391	1,053		1,053	11,838	9,188		28787	1,295	1,354	12,890	100%
Mississippi,MS	263	12,716	20%	24.60		21561	970		970	10,464	8,938		0	-	1,526	11,434	90%
Nebraska,NE	193	9,325	0%	28.00		33175	1,493		1,493	7,492	7,460	500	227	33	-	8,985	96%
New Mexico,NM	184	8,900	40%	21.21		65880	2,965		2,965	7,844	5,393	182	6874	318	2,133	10,809	121%
West Virginia,WV	167	8,074	0%	27.92		13400	603		603	7,135	6,441		14915	671	23	7,738	96%
Utah,UT	147	7,126	13%	25.86	136	44527	2,004		2,140	6,046	5,129	6554	1859	379	539	8,186	115%
Idaho,ID	139	6,718	1%	27.89	718	19139	861	87	1,666	4,845	4,637		4070	183	25	6,511	97%
Hawaii,HI	138	6,656	0%	27.97	331	8491	382		714	5,495	4,988		11110	500	7	6,208	93%
Maine,ME	136	6,574	3%	27.56		22228	1,000		1,000	5,650	5,177	490	7774	372	102	6,651	101%
Rhode Island,RI	132	6,391	0%	28.00		2001	90		90	6,257	5,113		25432	1,144	-	6,347	99%
Delaware,DE	104	5,033	100%	11.00	122	20000	900		1,022	4,480	1,460		0	-	3,020	5,501	109%
New Hampshire,NH	98	4,739	1%	27.90		18509	833		833	4,177	3,778		8512	383	16	5,010	106%
Montana,MT	80	3,878	6%	26.94		7081	319		319	3,293	2,985	1049	2569	163	145	3,612	93%
North Dakota,ND	60	2,887	0%	28.00		1400	63		63	2,598	2,310		6397	288	-	2,661	92%
Wyoming,WY	52	2,513	20%	24.55		13792	621		621	2,538	1,763	9734	698	469	306	3,159	126%
Vermont,VT	46	2,220	0%	28.00		6316	284		284	1,896	1,776		2657	120	-	2,180	98%
Alaska,AK	38	1,831	8%	26.62		9497	427		427	1,816	1,393	0	7424	334	89	2,244	123%
South Dakota,SD	69	3,336	0%	28.00		5832	262		262	2,830	2,668	2328	1259	161	-	3,092	93%
SUM	32,992	**1,594,863**			**37,360**		**133,870**	**1,128**	**172,358**	**1,428,615**	**1,134,617**			**165,635**	**128,364**		

Assumptions

TKN influent (ave)	35	mg/L
TN effluent (ave) w/ N removal	11	mg/L
Biosolids N content	4.5	%
N emissions in WRRFs w/ N removal	60.00	%
TN effluent (ave) w/ N removal	28	mg/L

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Chapter 6

CURRENT STATUS OF BIOGAS ENERGY RECOVERY AT WRRFS IN THE U.S.

6.1 Methodology for Developing National Aggregates for Energy Resource Recovery

Wastewater contains chemical, thermal, and hydraulic (potential) energy (Figure 36). With today's technology, a portion of these energy forms can be recovered at WWRFs. Most commonly, a portion of the chemical energy in wastewater is recovered after anaerobic digestion as electric and thermal energy at WRRF operation biogas energy recovery systems.

This study's database evaluation focused on this portion of energy recovery in WRRFs. The data was compiled mainly from the BioGas System Database (USDA, 2016), state profiles of the American Biogas Council (accessed 2018), and the EPA's CWNS (2012).

Other forms of energy recovery besides biogas, such as direct pipeline injection and fuel conversion, are available and should be considered and evaluated for WRRFs in the future. Nonetheless, they were not covered in this database review for lack of national information. Recovery of hydraulic and thermal energy from wastewater also has potential, but it is not yet commonly practiced in the U.S. and should thus be evaluated in the future.

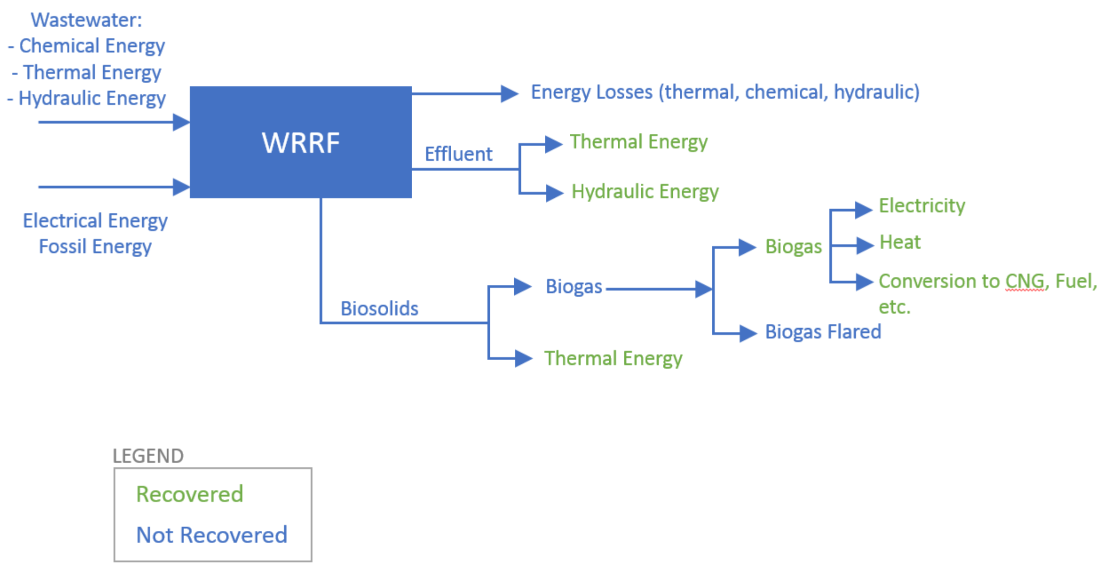

Figure 36 Definition of Recovered and Not Recovered Energy at WRRFs

6.2 Biogas Energy Potential in Wastewater

According to the EPA, every million gallons per day of wastewater flow can produce enough biogas in an anaerobic digester to produce 26 kilowatts (kW) of electric capacity and 2.4 million BTU per day (MMBTU/day) of thermal energy in a combined heat power (CHP) system (EPA 2011). Thus, these two values were used to estimate the electrical capacity and thermal energy content in wastewater based on the wastewater flows by state (Figure 37 and Figure 38). The aggregated electric capacity for all U.S. states based on these figures totals 858 MW electric capacity and 79,200 MMBTU per day.

In a previous evaluation, the EPA estimated that 1,351 WRRFs in the U.S. have a capacity larger than 1 mgd and have anaerobic digestion, but do not have a CHP system (EPA 2011). The combined wastewater flow from these facilities totals 15,795 mgd, resulting in an electric potential of about 400 MW. The thermal potential was estimated to be 37,908 MMBTU/day. According to this calculation, about half of the total electric and thermal potential in wastewater is available at facilities larger than 1 mgd with anaerobic digestion already in place.

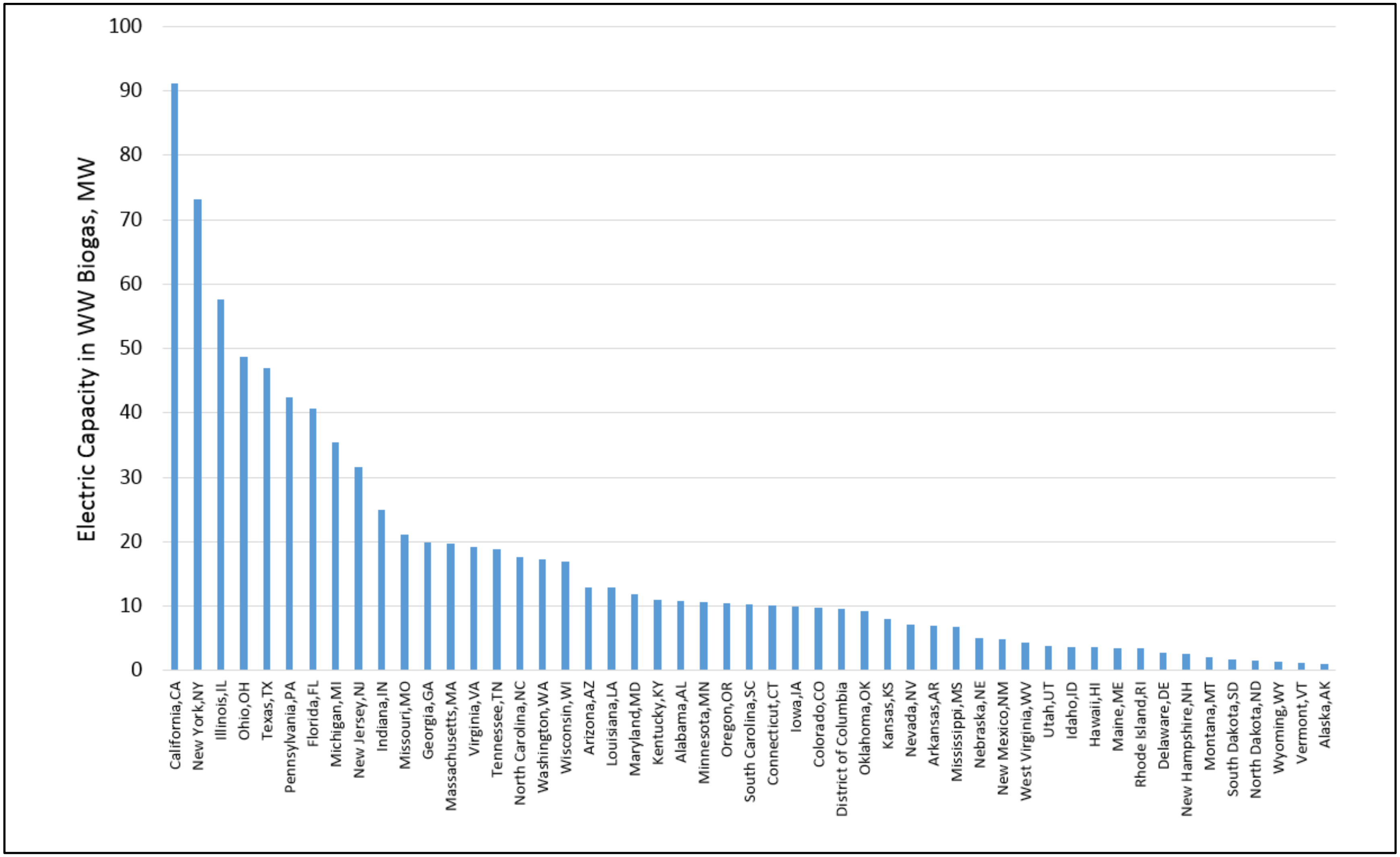

Figure 37 Electric Capacity of Wastewater Biogas Potential by State

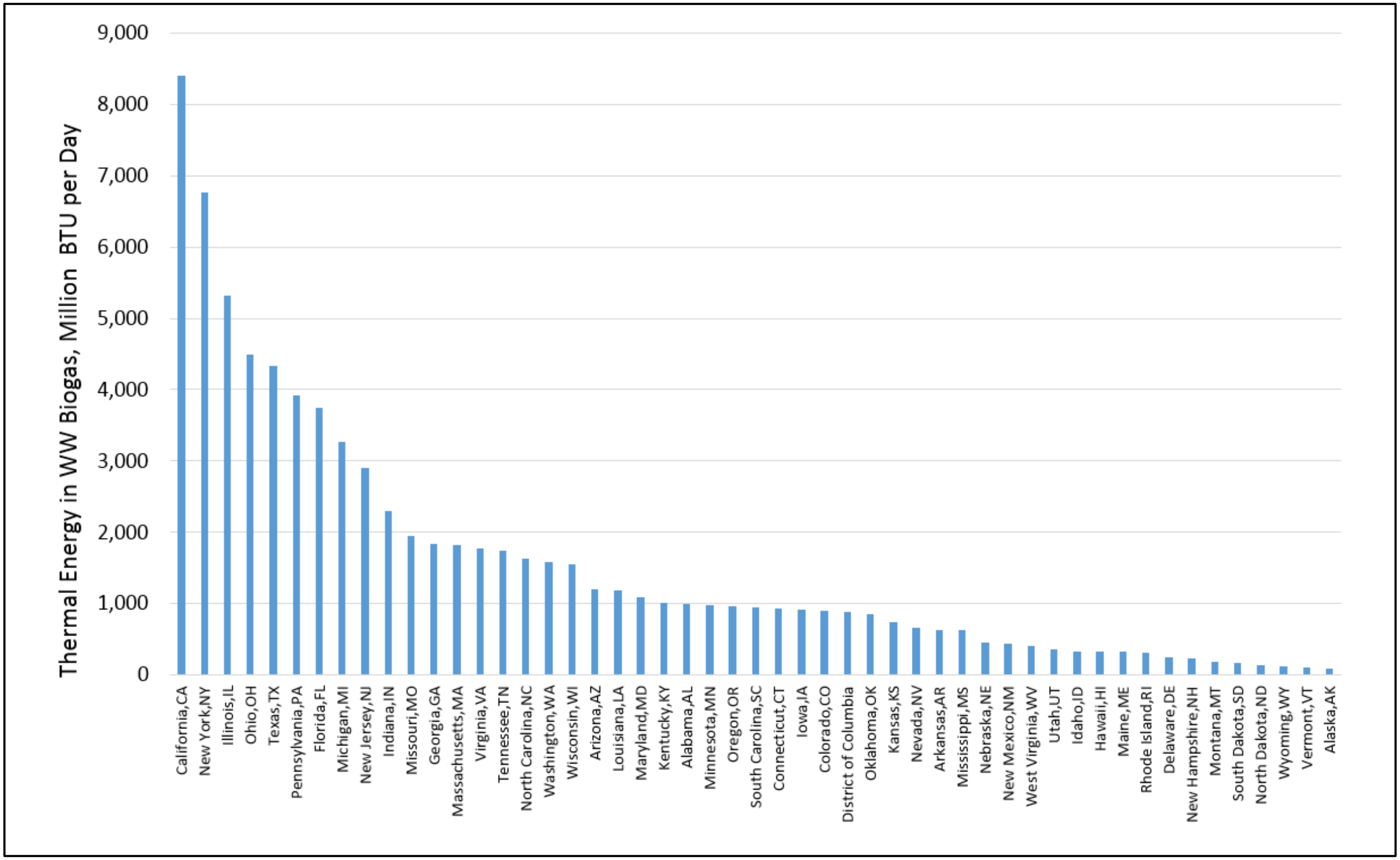

Figure 38 Thermal Energy in Wastewater Biogas Potential by State

6.3 Energy Currently Recovered through Biogas at WRRFs

Figure 39 summarizes data from the Wastewater BioGas Database (USDA, 2016). This database contains detailed information on WRRFs in the U.S. that contain biogas systems and the type of energy recovery they employ, if any. The database included a total of 1191 WRRFs (about 7% of all WRRFs in the U.S.), covering a total wastewater flow of 15,260 mgd (about 50% of all national wastewater flow).

Figure 39 splits the wastewater flow treated by WRRFs included in this database into two groups:

- **Group 1:** wastewater flow from facilities operating advanced biogas energy recovery systems. These systems include direct pipeline injection or power generation through ICE, turbines, microturbines, fuel cells, or direct drive of process machines.
- **Group 2:** wastewater flow from facilities operating either no energy recovery from biogas or only limited recovery systems, such as digester or building heating.

The combined flow treated by the facilities in group 1 is 13,400 mgd or 40% of the total wastewater flow in the U.S. The equivalent electric capacity for these facilities is estimated to be 350 MW.

Figure 40 shows the capacity distribution for facilities listed in the USDA database that operate advanced energy recovery systems (Group 1). Interestingly, more than 50% of all facilities have a rated capacity of less than 10 mgd.

Figure 41 summarizes the number of existing and potential WRRFs with biogas energy recovery systems by state, based on 27 state profiles published to date by the American Biogas Council (2018). Although some states have already achieved their recognized potential, others still show significant opportunities for growth.

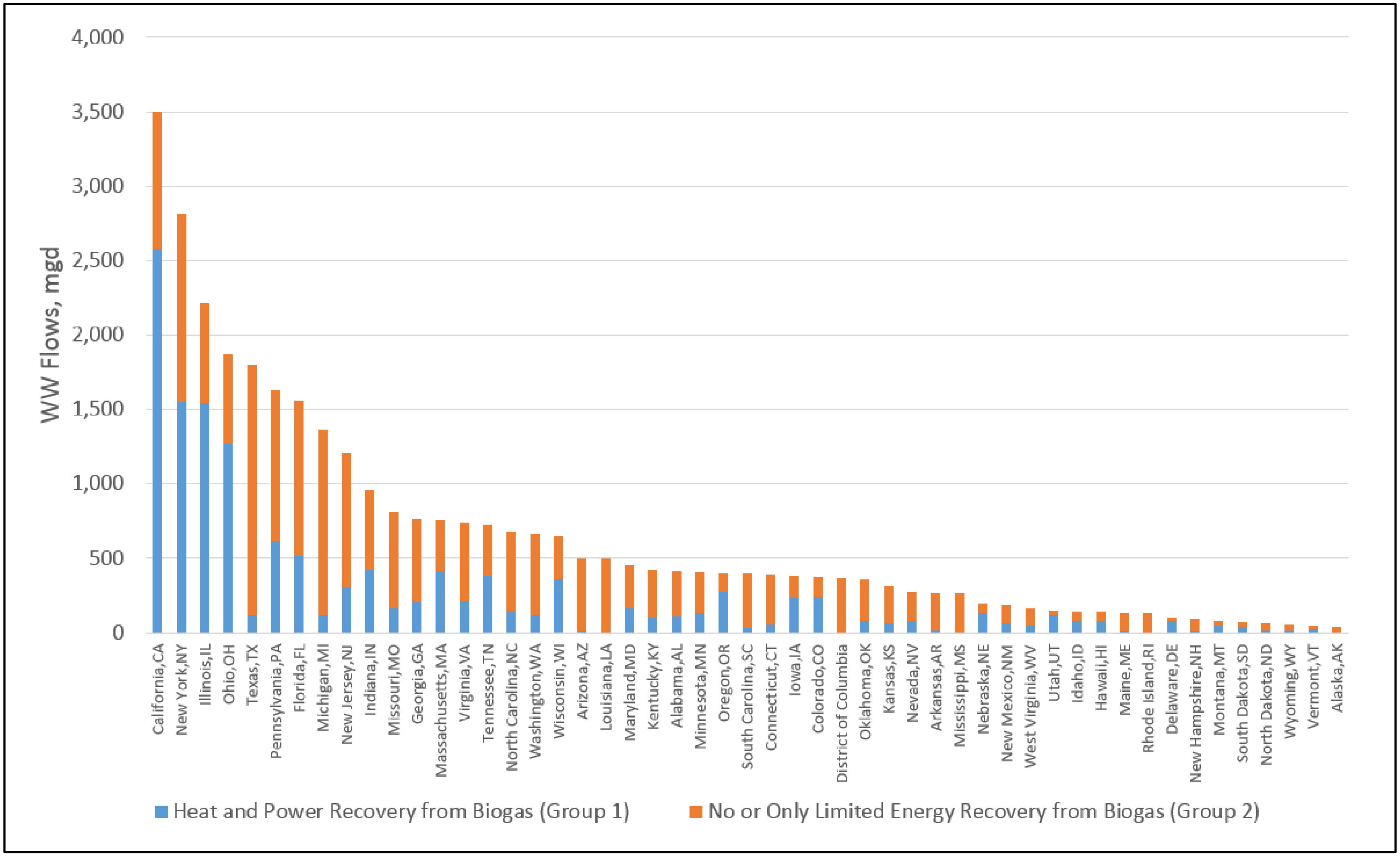

Figure 39 Wastewater Flows by State with and without Biogas Heat and Power Recovery (USDS 2016 BioGas Database)

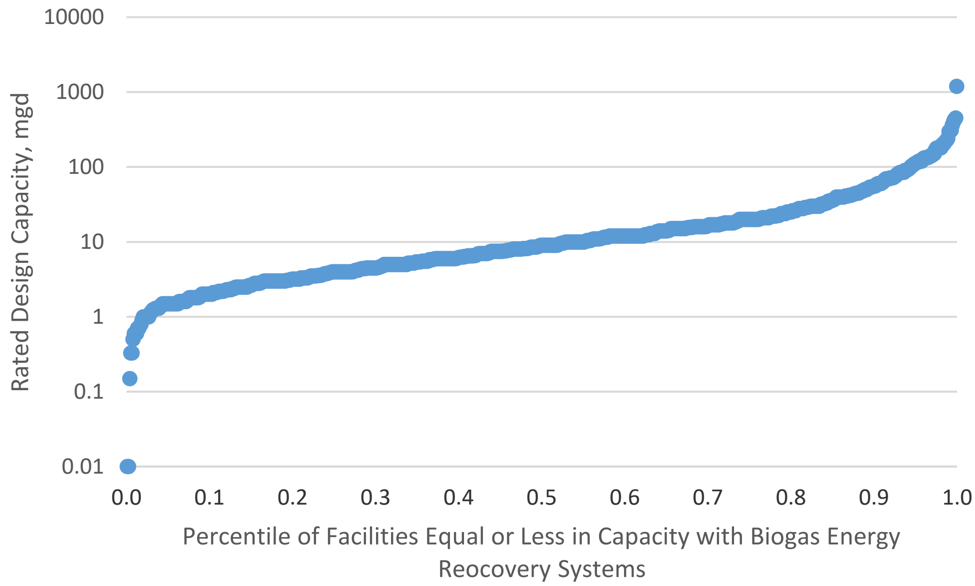

Figure 40 Treatment Capacity Distribution among WRRFs Operating Advanced Biogas Energy Recovery Systems (Group 1) (USDS 2016 BioGas Database)

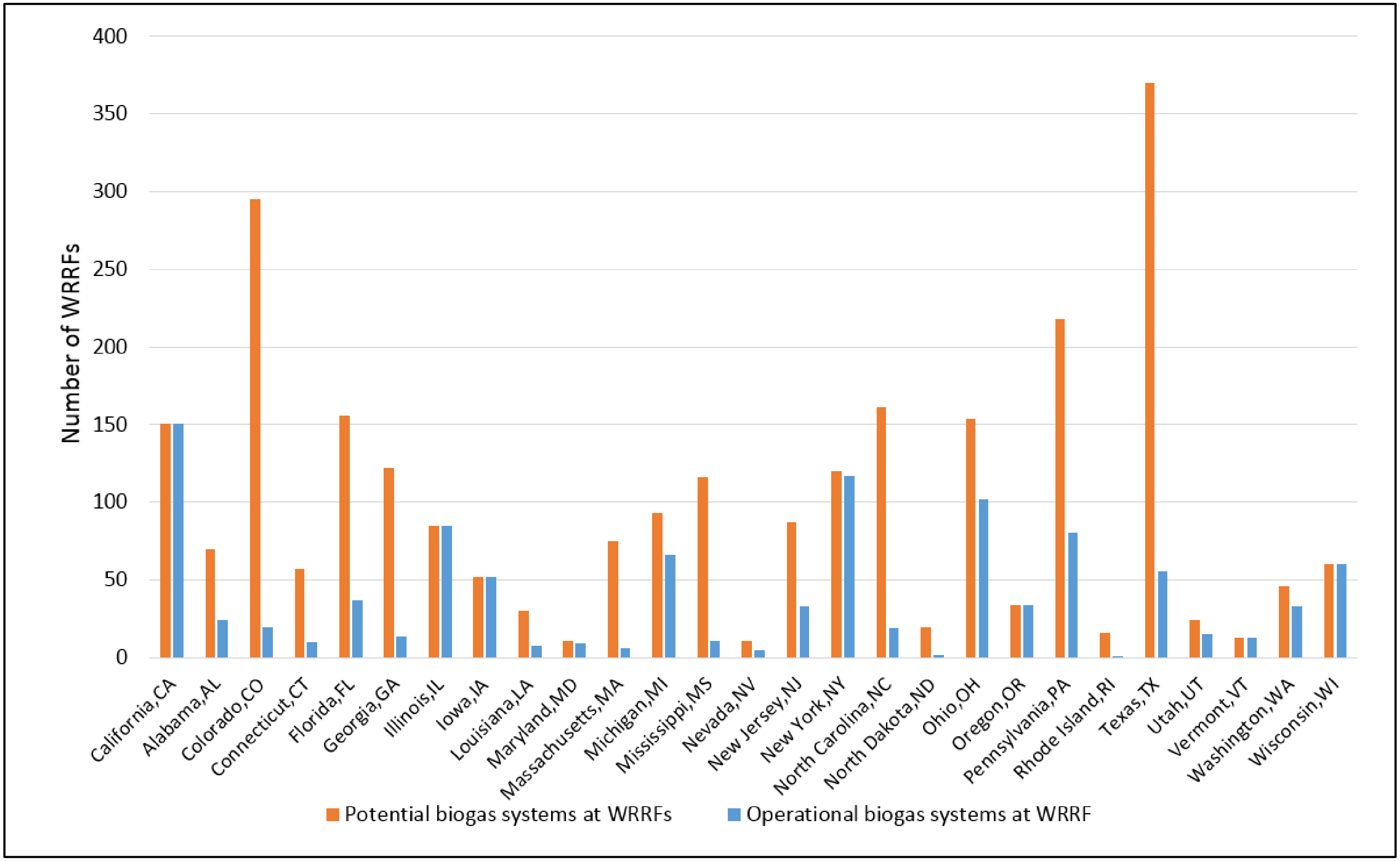

Figure 41 Potential and Actual Number of Biogas Systems at WRRFs by State (American Biogas Council, 2018)

6.4 References

American Biogas Council (accessed 2018). Biogas State Profiles. https://www.americanbiogascouncil.org/stateprofiles.asp

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Appendix 6A

USDA BIOSOLIDS DATABASE SUMMARY BY U.S. STATE

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	# of Facilities With Advanced Beneficial Use of Biogas	# of Facilities with Limited or No Beneficial Use of Biogas	Facilities with Advanced Beneficial Use of Biogas, mgd	Flows Treated at Facilities with Limited or No Benefical Use of Biogas, mgd	mgd	Estimated National WW Flows Without Beneficial Use of Biogas, mgd	National Potential Power Capacity from Biogas (26 kW/mgd), MW	National Potential Thermal Energy from Biogas (2.4 MM BTU/mgd), MMBTU/day	Energy Potential Used Today, Electric Power Equivalent (26 kW/mgd), MW
Alabama,AL	11	6	111.50	58.89	412	300.75	11	989	2.90
Alaska,AK	0	1	0	0.4	38	37.89	1	91	-
Arizona,AZ	1	1	9.00	31.00	499	489.77	13	1,197	0.23
Arkansas,AR	2	0	16.00	-	266	249.93	7	638	0.42
California,CA	106	41	2,583.09	145.32	3503	919.86	91	8,407	67.16
Colorado,CO	19	0	245.46	-	372	126.92	10	894	6.38
Connecticut,CT	10	0	55.35	-	388	332.66	10	931	1.44
Delaware,DE	1	0	78.00	-	104	26.00	3	250	2.03
District of Columbia					370	370.00	10	888	-
Florida,FL	17	15	518.70	58.34	1561	1,042.30	41	3,746	13.49
Georgia,GA	12	2	200.60	3.10	767	566.74	20	1,842	5.22
Hawaii,HI	5	4	77.40	34.36	138	60.29	4	330	2.01
Idaho,ID	10	3	77.34	11.80	139	61.64	4	334	2.01
Illinois,IL	49	21	1,546.35	273.55	2215	669.03	58	5,317	40.21
Indiana,IN	25	7	422.31	43.00	961	539.05	25	2,307	10.98
Iowa,IA	42	9	232.63	11.65	380	147.72	10	913	6.05
Kansas,KS	8	8	64.60	42.87	309	244.68	8	742	1.68
Kentucky,KY	2	1	104.05	19.85	423	318.77	11	1,015	2.71
Louisiana,LA	1	5	1.80	34.20	497	495.23	13	1,193	0.05
Maine,ME	1	0	12.00	-	136	123.99	4	326	0.31
Maryland,MD	4	4	166.80	165.03	457	289.96	12	1,096	4.34
Massachusetts,MA	5	0	410.20	-	757	346.56	20	1,816	10.67
Michigan,MI	39	14	116.21	16.51	1364	1,248.07	35	3,274	3.02
Minnesota,MN	22	3	133.88	-	409	275.13	11	982	3.48
Mississippi,MS	0	2	-	10.25	263	263.06	7	631	-
Missouri,MO	7	3	165.65	3.90	810	644.60	21	1,945	4.31
Montana,MT	6	2	44.89	2.50	80	35.34	2	193	1.17
Nebraska,NE	7	0	129.71	-	193	63.18	5	463	3.37
Nevada,NV	5	0	80.40	-	274	194.07	7	659	2.09
New Hampshire,NH	1	1	5.50	1.50	98	92.53	3	235	0.14
New Jersey,NJ	25	5	302.70	6.64	1212	909.64	32	2,910	7.87
New Mexico,NM	4	2	66.80	8.53	184	117.31	5	442	1.74
New York,NY	60	16	1,547.98	117.31	2815	1,267.22	73	6,756	40.25
North Carolina,NC	12	4	152.52	22.03	679	526.59	18	1,630	3.97
North Dakota,ND	2	0	19.00	-	60	40.73	2	143	0.49
Ohio,OH	102	24	1,274.62	232.08	1873	598.42	49	4,495	33.14
Oklahoma,OK	16	8	76.89	0.75	357	280.57	9	858	2.00
Oregon,OR	25	5	274.89	20.48	402	126.65	10	964	7.15
Pennsylvania,PA	46	27	620.05	72.82	1631	1,011.32	42	3,915	16.12
Rhode Island,RI					132	132.20	3	317	-
South Carolina,SC	5	4	33.00	58.00	397	364.00	10	953	0.86
South Dakota,SD	9	0	39.21	-	69	29.79	2	166	1.02
Tennessee,TN	9	2	379.59	4.50	726	346.54	19	1,743	9.87
Texas,TX	3	30	116.30	734.22	1805	1,688.63	47	4,332	3.02
Utah,UT	11	3	121.15	13.00	147	26.26	4	354	3.15
Vermont,VT	11	1	21.05	0.40	46	24.88	1	110	0.55
Virginia,VA	11	4	213.00	93.64	740	526.58	19	1,775	5.54
Washington,WA	19	7	117.81	23.31	662	544.20	17	1,589	3.06
West Virginia,WV	6	0	46.50	-	167	120.53	4	401	1.21
Wisconsin,WI	54	1	358.49	0.60	650	291.12	17	1,559	9.32
Wyoming,WY	3	0	20.20	-	52	31.78	1	125	0.53
SUM	**851**	**296**	**13,411**	**2,376**			**858**	**79,180**	349

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Chapter 7

2018 WEF RESOURCE RECOVERY SURVEY RESULTS SUMMARY

7.1 Survey Design

The survey conducted for this study requested the following information from WRRFs in the U.S.:

1. General facility information.
    a. Influent flows.
    b. Rated design capacity.
    c. Services area.
    d. Type and level of treatment.
2. Information about process streams.
    a. Influent.
    b. Effluent.
    c. Biosolids.
3. Types of resource use.
    a. Basic: Water, biosolids, and phosphorus.
    b. As available: Nitrogen, and energy.

The data was requested as 2017 annual average values. Brief explanations were included with the survey to explain the data requested and its use in the study, and terms that required explanations were defined as well. The survey was conducted between May and August 2018.

The following pathways were used to advertise and encourage participation in the survey:

- WEF webpage announcement (https://www.wef.org/resources/topics/browse-topics-o-z/resource-recovery-roadmaps/resource-recovery-data-collection-survey/).
- WEF press release
- Publicity through WateReuse Association, NACWA, and WEF.
- Advertisement through WEF Committees.
- Utility contacts of Carollo and Stantec.
- Announcements at conferences.

The survey results were then combined in a master spreadsheet, and mass balance calculations were completed to quantify each facility resource recovered and not recovered. Aggregate summaries were prepared for the U.S. as a whole by facility size. For this analysis, the four rated capacity size brackets defined were <5 mgd, 5-20 mgd, 20-50 mgd, and > 50 mgd.

7.2 Survey Participation Statistics

A total of 109 US WRRFs participated in the survey. The combined 2017 annual average flow from these facilities equaled 7, 220 mgd, representing about 22% of the total estimated wastewater flow production in the U.S. (33 billion gallons a day, see Chapter 2). Figure 42 provides an overview of the geographical distribution of WRRFs participating in the survey and breaks down each facility by treatment capacity.

The survey was customized for distribution in the U.S. and Canada. The Canadian response was notable, but ultimately limited (a total of 17 WRRFs participated). While this response does not allow for a statistical evaluation of resource recovery in Canada, integrating the evaluation of Canadian WRRFs with U.S. facilities in the future is recommended.

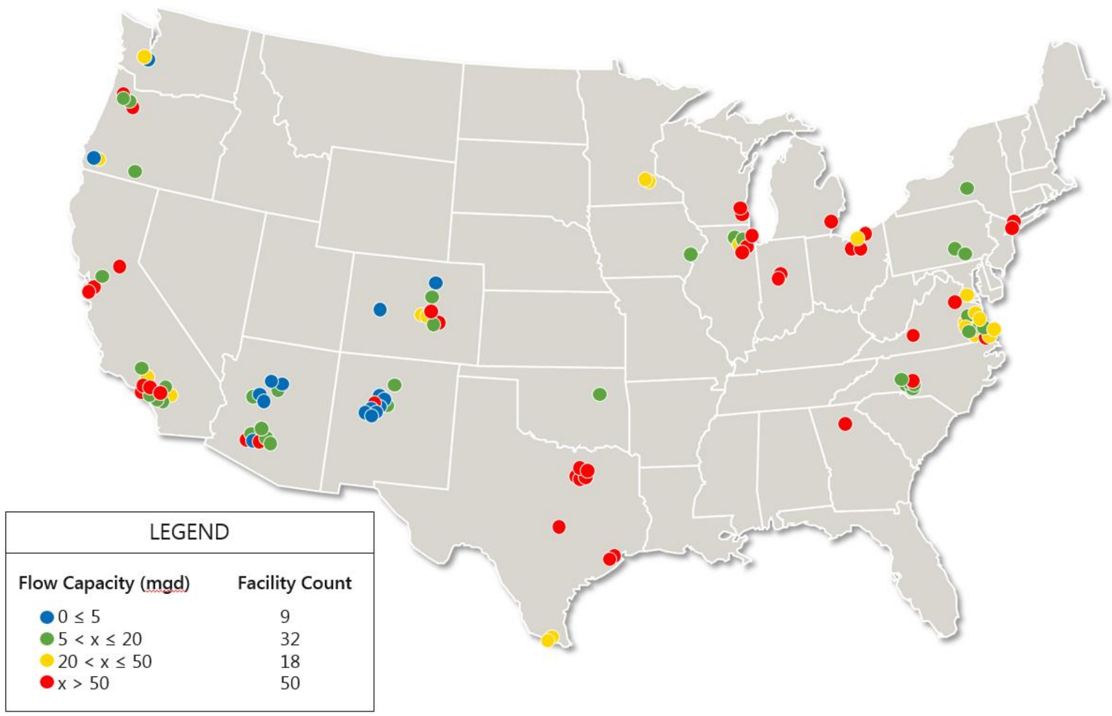

Figure 42 Geographical Distribution of Survey Participants

7.3 Survey Data Quality and Resource Recovery Mass Balance Accuracy

For most of the 109 U.S. facilities that participated in the survey, mass balances for water, biosolids, and phosphorus closed with less than a 10% mass balance error. Facilities with a higher mass balance error than 15% were removed from the analysis unless the cause of the error could be identified and the underlying data entries corrected.

7.4 Survey Results

7.4.1 Water Resource Recovery

Figure 43 shows the average percent distribution of water end uses for all participating utilities in the survey. About three-quarters of water from these WRRFs is discharged into surface waters. No environmental benefit was reported to be associated with this discharge, and there were no requirements for minimum return flow obligations. As a result, this category was not considered recovered.

Approximately 20% of the water discharged into surface waters reportedly satisfied an environmental benefit or was dedicated to downstream use. A total of 9% of all WRRF influent is used for potable or non-potable reuse, which is only slightly higher than the national wastewater reuse average identified based on state database reviews (see Chapter 2).

For this study, effluent discharged to streams or rivers was assumed to be recovered if the effluent flow constituted more than 50% of the annual average in-stream flow. Effluent discharged to surface waters was defined as a "disposal" if the annual average effluent flow was smaller than 50% of the annual average stream flow. The 50% threshold was selected as an arbitrarily criteria, however representing a significant flow contribution to the surface water. .

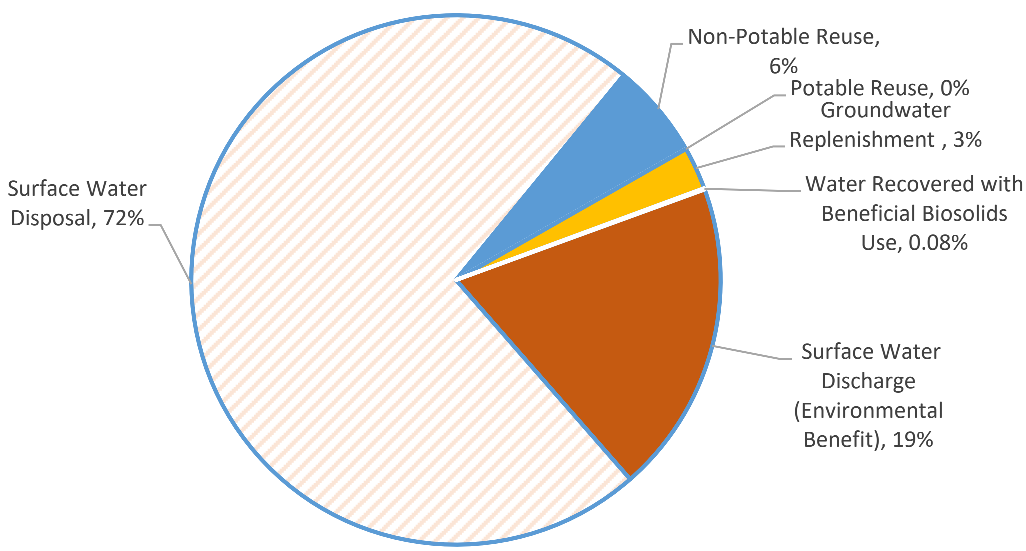

Figure 43 Distribution of Water End Uses for all Survey Participants

Figure 44 breaks down water end uses by facility size (rated capacity). All facilities larger than 5 mgd recovered a similar fraction of water and showed a similar distribution of recovery end uses. Notably, smaller sized facilities showed a slight trend toward higher water recovery. For larger facilities, surface water discharged for environmental benefits was the major water recovery end use. Smaller facilities showed a more even distribution among recovery end uses.

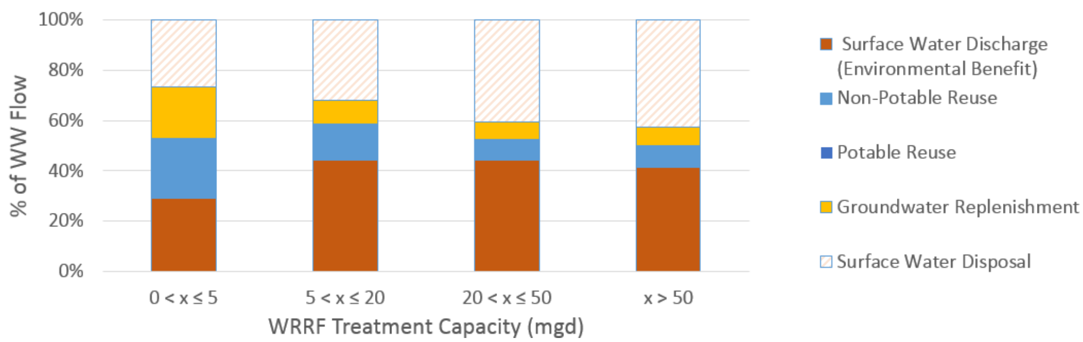

Figure 44 Distribution of Water End Uses by Facility Size for Survey Participants

7.4.2 Biosolids Recovery

The total itemized solids mass of all facilities participating in the survey totaled 1.32 million metric dry tons year. This amount covers about 20% of the national biosolids generation at WRRFs (6.71 million metric dry tons per year, as detailed in Chapter 3).

Figure 45 shows the average distribution of biosolids end uses among all surveyed facilities. Of all biosolids, 64% are being recovered (solid filled segments in Figure 4). Land application accounts for almost half of all generated biosolids, which is more than what was estimated given the 2007 national database results from Chapter 3. Composting and incineration fractions coincide well with the 2007 data. Landfill cover and surface disposal account for approximately 21% in our 2018 survey, which is less than what was calculated from the 2007 data. In part, this may reflect the continued shift over the past 10 years from biosolids landfill disposal to land application.

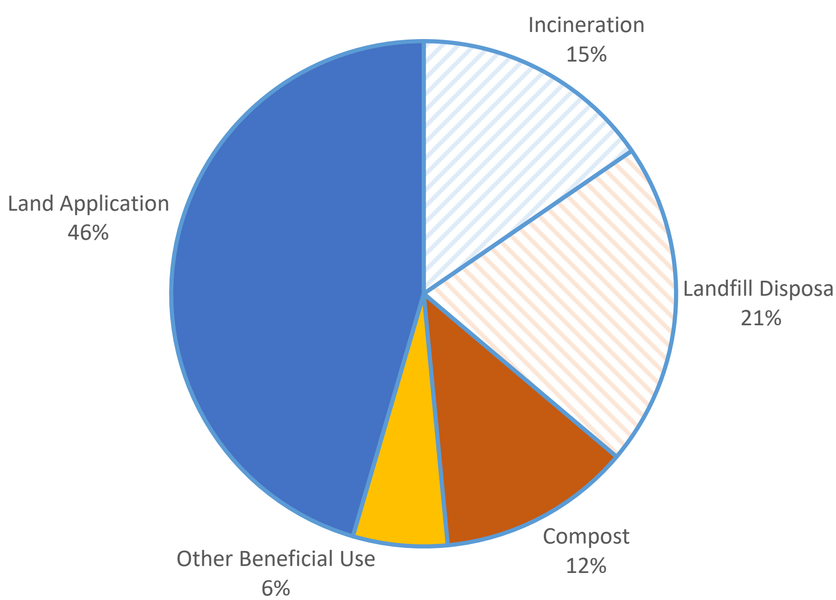

Figure 45 Distribution of Biosolids End Uses for all Survey Participants

Figure 46 breaks down biosolids end uses by facility size. Facilities larger than 50 mgd in capacity have a more diverse split among different biosolids end uses. Larger facilities (> 20 mgd) generally recover about 10-20% more biosolids than smaller facilities. Composting is more prevalent in facilities larger than 20 mgd in size. The fact that many facilities in the 20 to 50 mgd range use incineration for biosolids disposal may be an artefact of the small number of surveyed facilities in this category as well as their specific geographical location in the U.S.

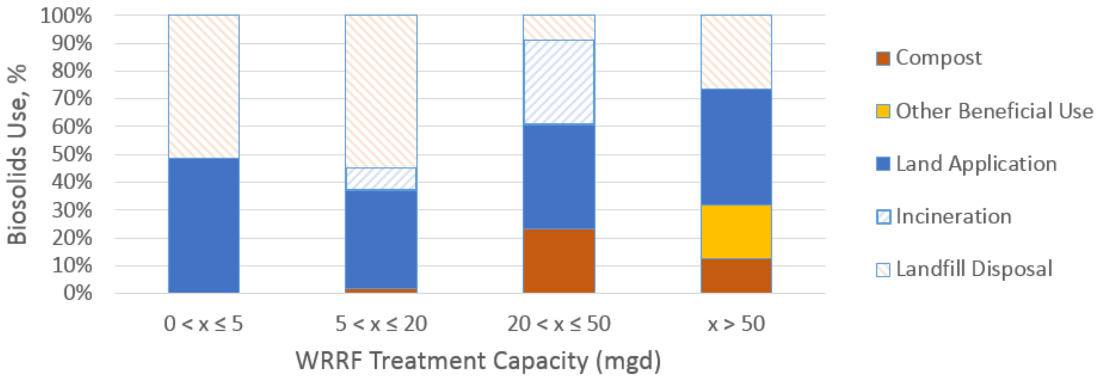

Figure 46 Distribution of Biosolids End Uses by Facility Size for Survey Participants

7.4.3 Phosphorus Recovery

The total itemized phosphorus mass of all facilities participating in the survey amounted to 66,683 metric tons per year. This amount covers approximately 21% of the estimated national biosolids generation at WRRFs (318,488 metric tons per year, see Chapter 3).

Figure 47 shows the average distribution of phosphorus end uses among all participating facilities. Of all phosphorus in wastewater influent, approximately 45% is being recovered (solid areas in Figure 43), primarily though biosolids land application.

Among survey participants, struvite recovery and phosphorus recovery with effluent reused for irrigation play a minor, but quantifiable role. Compared to the national estimate of phosphorus recovery from Chapter 4, the survey results reflect a larger fraction of phosphorus recovery in biosolids used for land application (41% compared to 18%).

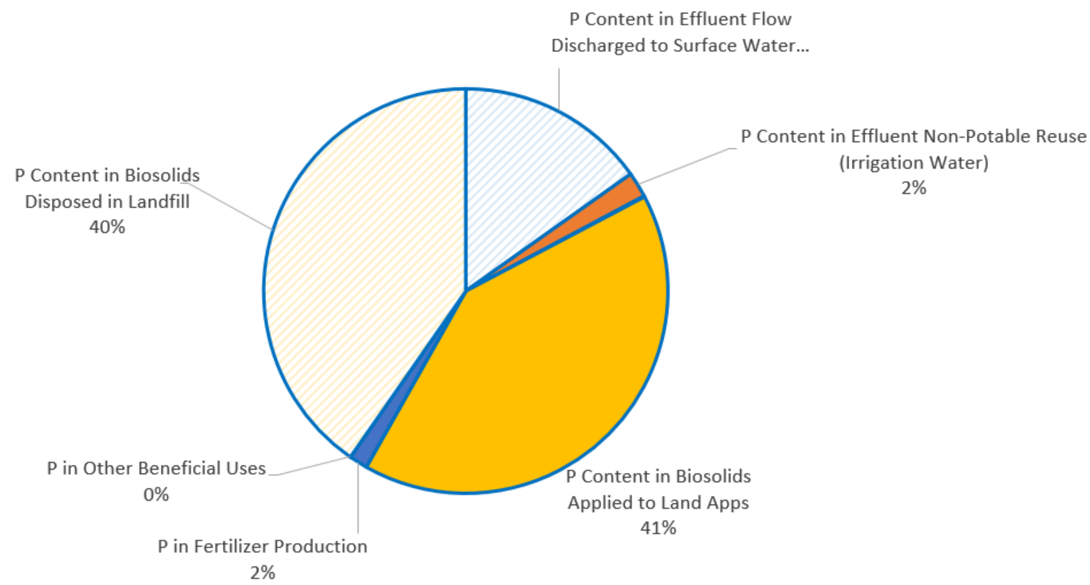

Figure 47 Distribution of Phosphorus End Uses for all Survey Participants

Figure 48 breaks down phosphorus end uses by facility size. Facilities larger than 20 mgd in capacity that participated in this survey recovered approximately 60% phosphorus on average, mainly through biosolids land application and struvite recovery. Smaller sized facilities recovered almost 40% phosphorus on average through biosolids land application and non-potable water reuse for irrigation.

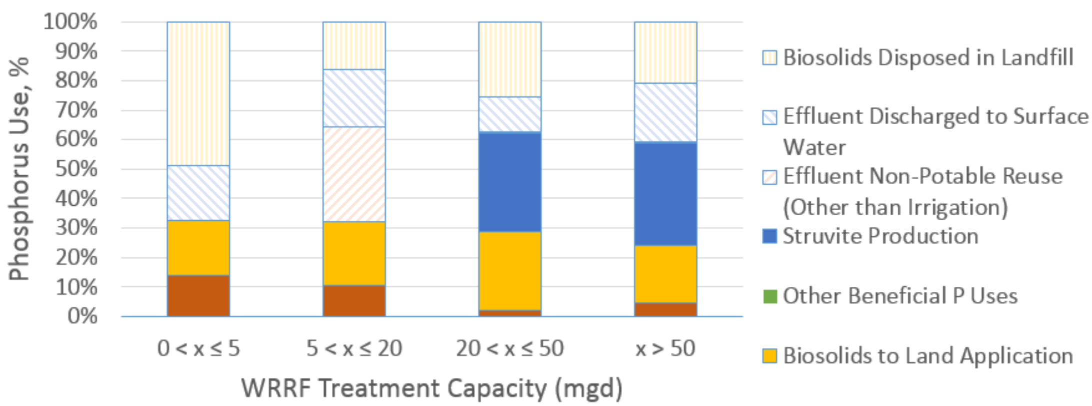

Figure 48 Distribution of Phosphorus End Uses by Facility Size for Survey Participants

Figure 49 shows the box-and-whisker plot of the phosphorus recovery distribution among the surveyed utilities. While all size classes showed a large spread, the overall phosphorus recovery performance was best in the medium sized facilities between 5 and 50 mgd as indicated by the median (60-70%) which is significantly higher than for the smaller or larger facilities.

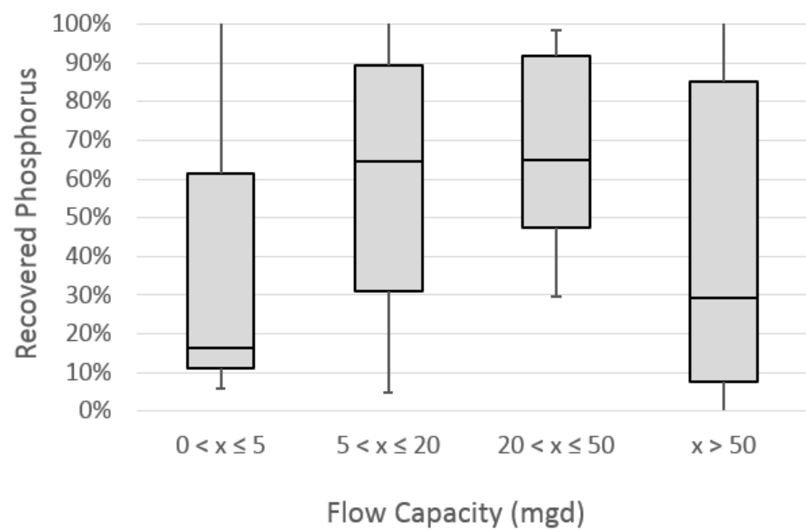

Figure 49 Box and Whisker Plot for Phosphorus Recovery by Facility Size

7.4.4 Nitrogen Recovery

About half of the utilities did not have influent and/or effluent nitrogen data available so that mass balance calculations could not be conducted. For most of the surveyed utilities, the nitrogen mass balances showed significant errors when evaluating the survey data (greater than 50%). One contributing cause was likely the unknown nitrogen concentrations in the biosolids another one the unknown amount of nitrogen off-gassing from the process. These difficulties should be considered when continuing the survey application. It is recommended to add mass balance data checks at the time of data entry to assure the data collected is consistent.

7.4.5 Energy Recovery

The survey data included information on annual average electric consumption and production at participating WRRFs. Figure 50 shows the specific electric consumption per wastewater flow treated by facility size. The economy of scale is clear: larger facilities are able to treat the same amount of wastewater flow at a specific smaller energy input. This type of data allows to rate the energy performance for facility size against peer facilities. A larger survey basis in the future would allow to differentiate and benchmark energy performance also by process type and treatment level.

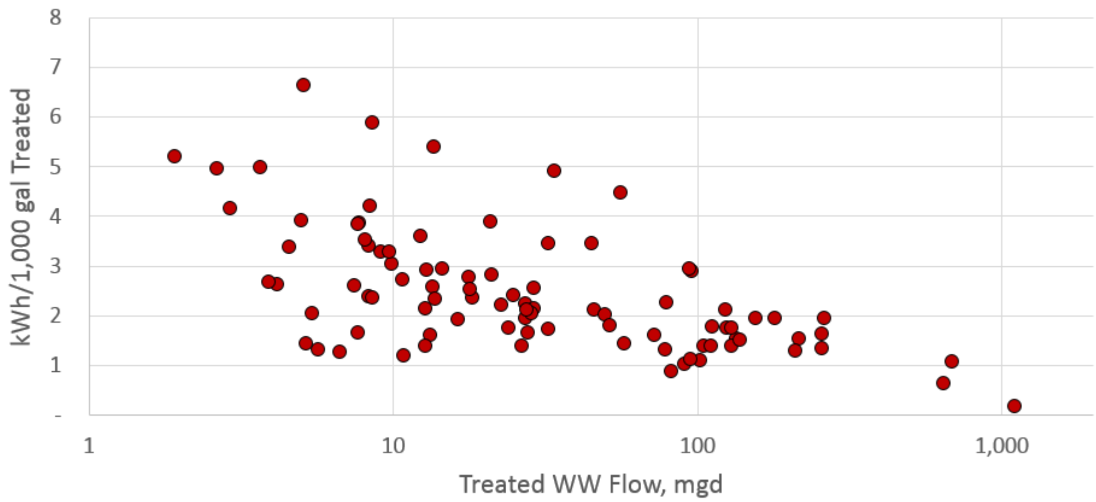

Figure 50 Specific Electric Consumption at Surveyed Utilities per Treated Wastewater Flows (Annual Average)

Of the 109 surveyed facilities

- 48 produce biogas.
- 32 recover heat from their process (18 able to quantify heat recovery).
- 28 produce electricity.
- 0 recover kinetic energy.
- 0 produce biofuels.

Table 1 summarizes the statistics for the degree of electric self-sufficiency among the participating WRRFs. Generally, surveyed facilities smaller than 5 mgd do not produce electricity onsite. About 10-25% of the larger utilities produce electricity and are able to cover 11 to 99% of their annual electrical demand. 10% of the surveyed facilities with treatment capacities larger than 50 mgd are approaching electric energy self-sufficiency.

Table 1 Degree of Electric Self-sufficiency among Survey Participants

Facility Size, mgd	0 < x ≤ 5	5 < x ≤ 20	20 < x ≤ 50	x > 50
Minimum	0%	0%	0%	0%
25th Percentile	0%	0%	0%	0%
Median	0%	0%	0%	0%
75th Percentile	0%	0%	11%	37%
90th Percentile	0%	17%	37%	82%
Maximum	0%	55%	50%	99%

Chapter 8

STUDY SUMMARY AND RECOMMENDATIONS FOR NEXT STEPS

8.1 Study Summary

Population pressures, climate change, aging infrastructure, and funding limitations strain water resources and call for sustainable resource management solutions and circular economy over the next century. Wastewater treatment plants cannot operate merely as disposal facilities any longer. Instead, water resource recovery must become a cornerstone of facility operation, producing water fit for purpose, recovering nutrients, and reducing fossil fuel consumption by recovering the energy inherent in wastewater.

One of WEF's strategic objective is to "collaborate with water sector partners to define and create a bold, aspirational, and public call to action to accelerate resource recovery." To help achieve this objective, WEF is developing a program to set strategic resource recovery goals for the U.S. and Canadian water sector. The first step of this effort is to establish a baseline for current resource recovery practices in the North American water sector, followed by quantifying and publicizing progress toward stated goals.

This report establishes this baseline data to help develop resource recovery targets for water reuse, nutrients, and energy in the future. The current status of resource recovery was quantified through a mass-balance approach for water, nutrient (phosphorus and nitrogen), and energy recovery at WRRFs in the U.S.

Note that insufficient data was available to expand the analysis to Canada. As a result, the report discusses only U.S. WRRFs. For this study, data was collected from available national and state agency databases, other publications, and a utility survey conducted among North American WRRFs between May and August of 2018.

Table 2 summarizes the aggregate annual U.S. baseline of resource recovery performance by the wastewater sector.

Table 2 Aggregate Annual U.S. Baseline of Resource Recovery Performance by the U.S. Wastewater Sector

Resource	Total Amount of Resource Available to WRRFs	Total Amount Currently Recovered by WRRFs	% of Resource Currently Recovered by WRRFs
Water, mgd	33,000	1,900 (Accountable Reuse) + 15% unknown reuse	6.3%
Biosolids, million dry metric tons per year	6.71	3.4	51%
Phosphorus, dry metric tons per year	319,000	68,220	21%
Nitrogen, dry metric tons per year	1,600,000	172,400	11%
Biogas Energy Potential in Wastewater, MW	858	350	41%

Of the WRRFs petitioned for the WRRF resource recovery survey, 109 participated from the U.S., and 17 participated from Canada. The U.S. facilities covered about 22% of nationally treated municipal wastewater flow and about 20% of the total mass of biosolids produced in the U.S.

With the data collected from the surveys, the recovery practices of different facility sizes across the U.S. were compared. For example, facilities with a capacity larger than 20 mgd recovered 20% more biosolids and phosphorus on average compared to smaller sized facilities. Still, percentage-wise, larger facilities recovered less effluent water for potable, non-potable, or other beneficial uses (e.g., environmental support of aquatic life habitats in receiving streams) compared to small facilities. Electric self-sufficiency through on-site energy production is generally pioneered by larger facilities in the U.S.

8.2 Data Needs and Recommended Next Steps

Today, several state and national agencies are developing and updating databases that will help fill key data needs in the future when updating resource recovery statistics. The following are some data needs that became apparent during this study:

1. **Databases.** In general, existing databases cover water and biosolids end uses at WRRFs, but do not explicitly capture information on phosphorus, nitrogen, and energy (other than that captured in biogas).
2. **Recoverable Resources.** This study quantified the total amount of resources entering WRRFs but did not differentiate between the "total amount of resource available to WRRFs" and the "amount of resources available for recovery". This needs to consider technological limitations as well as financial cost-effectiveness. Although this analysis was not in the scope of this project, it is a critical step in setting achievable and defensible recovery goals at the federal, state, and facility level. In order to further advance resource recovery implementation it would be useful to conduct analysis on the techno-economic factors of different recovery options and geographical and policy related differences.

3. Energy **Resource Data.** While database information is available on the power and heat energy content of biogas that can be produced from wastewater after anaerobic digestion, little or no information is available on other forms of energy content in wastewater and their status of recovery, such as thermal, hydraulic, compressed national gas injection, and fuel generation, which would allow for developing aggregate baseline data at the state and national level.
4. **Updated Biosolids Database.** Nationally, the best information was available for biosolids production and uses. However, the most comprehensive data dated back to 2007. Since then, several states have issued updated reports, information that would be useful if it could be standardized and captured in an updated national database.
5. **Peer Facility Benchmarking.** No complete national database on water reuse exists. Some states are collecting information on reuse practices informally, and a few comprehensively. However, it would help to have data compiled into a national database and made available to the public.
6. **Peer Facility Benchmarking.** It is useful to differentiate resource recovery performance, not only by facility size as done in this study, but also by process type and the level of treatment employed at WRRFs. This could be achieved by combining several large existing databases and developing transparent and user-friendly query options to retrieve the desired information.
7. **Canadian Resource Recovery Baseline.** Few databases were accessible to this project team for Canada. Thus, we recommend adopting the approach developed in this study to develop corresponding national aggregates for resource recovery baseline performance in Canada. We also recommend combining the surveys conducted for Canada and the U.S. into a single database tool to increase the statistical value as a benchmarking tool for WRRFs.
8. **Institutionalize Survey.** The utility survey collected valuable information allowing for resource recovery mass balances for individual utilities. In the future, we recommend institutionalizing this survey for broader participation and repeating it every 2-5 years. Combining the survey with a reporting tool of results could benefit participating utilities with a visual evaluation of relevant facility-specific statistics (e.g., performance benchmarking to other pier WRRFs, progress made towards goals since last data entries).
9. **Small Facility Potential.** Capturing information on the group of smallest facilities in North America (less than 1 mgd) is inherently challenging. As a result, this group is generally underrepresented in national databases and survey results collected in this study. However, a substantial number of WRRFs in North America falls within this group of facilities often located in environmentally sensitive areas. As such, efforts should continue to complete the necessary information for small WRRFs to reach their resource recovery potential.

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