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Water Use Intensity at U.S. Army Facilities

An Investigation into Factors That Influence Potable Water End Use

Elisabeth M. Jenicek, Noah W. Garfinkle, Andy Hur,
Nicholas Bartholomew, Sarah Buchhorn, Kelly Chen,
Lindsey Miller, Munira Mithaiwala, and Bjorn Oberg

June 2018

ARMY WATER USE INTENSITY PROJECT

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An Investigation into Factors That Influence Potable Water End Use

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Abstract

Water is a critical resource for the U.S. Army's global mission. Insufficient supplies will compromise readiness and mission sustainment, and affect the ability to train and support the force. Incorporation of water availability into the Army's stationing analysis framework is being considered; however, there is insufficient data to determine the critical amount of water required by installations, and insufficient guidance on how to achieve reductions in water directed to non-essential functions. The ability to quantify a minimum sustainable amount of required water for prioritizing allocation is invaluable to sustaining the mission. This work was undertaken to develop water use intensity factors for the range of facilities found at installations to determine: the range of water demand for an installation; how long an interruption in water supply can be tolerated; how water demand varies in relation to such "use factors" as square footage, population, etc.; and the correlation between water demand and climate zone.

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Contents

Abstract	ii
Figures and Tables.....	vi
Preface.....	x
1 Introduction.....	1
1.1 Background	1
1.2 Objectives.....	1
1.3 Approach	1
1.4 Scope.....	2
1.5 Mode of technology transfer	2
2 Drivers: The Army's Need To Understand Water Use Intensity	3
2.1 Background: Water in the U.S. Army	4
2.2 Drivers for WUI studies	6
2.2.1 Readiness	6
2.2.2 Policy	7
2.2.3 The price, cost, and value of water.....	8
2.3 Challenges to water resilience	10
2.3.1 Current end-use data are limited.....	10
2.3.2 Studies of WUI for the Army are lacking.....	11
2.3.3 Data and units of measure	12
2.3.4 Modeling water end use.....	13
2.3.5 Army-unique facilities	14
2.3.6 Privatization initiatives	15
2.4 Applications of WUI.....	15
3 Framework.....	16
3.1 Water uses	16
3.1.1 Criticality of water demand	17
3.1.2 Water users in this Study.....	17
3.2 WUI	20
3.3 Data processing.....	22
4 Previous Water Demand Efforts.....	26
4.1 Literature review	27
4.2 Installation water sustainability assessments	29
4.2.1 Pilot study.....	30
4.2.2 Assessment of 10 installations	30
4.2.3 Assessment of three outside continental United States (OCONUS) installations	32
4.2.4 Four Net Zero water installations	33
4.2.5 Eight AMC installations	34
4.2.6 Implications for WUI efforts.....	35

4.3	Pacific Northwest National Laboratory water balance analyses.....	35
4.3.1	Methods	36
4.3.2	Data sources.....	36
4.4	Results.....	37
4.4.1	Overview.....	37
4.4.2	Opportunities for further study	39
4.5	Installation water needs regression models	39
4.6	System Master Planning-Net Zero Planner Water Module	40
4.7	DoD Water Needs Assessment Tool	40
4.8	Large water use estimates at Fort Leonard Wood	40
5	Data Sources.....	42
5.1	Enterprise data	42
5.1.1	Army	42
5.1.2	Non-military national data.....	43
5.2	Installation data.....	45
5.2.1	Water demand data.....	45
5.2.2	End-use factors.....	49
6	Water Use Intensity	50
6.1	Approach	50
6.2	WUI by water user-level characteristics	50
6.2.1	Facility Group 1: Industrial and maintenance.....	52
6.2.2	Facility Group 2: Housing (family).....	55
6.2.3	Facility Group 3: Housing (transient).....	58
6.2.4	Facility Group 4: Housing (barracks)	62
6.2.5	Facility Group 5: Community and Commercial: Non-Food (indoor).....	69
6.2.6	Facility Group 6: Community and Commercial: Food	72
6.2.7	Facility Group 7: High energy use intensity.....	76
6.2.8	Facility Group 8: Medical facilities.....	80
6.2.9	Facility Group 9: Administration and operation	81
6.2.10	Facility Group 10: Other training and schools	84
6.2.11	Facility Group 11: Storage	86
6.2.12	Facility Group 12: High water use facilities	88
6.2.13	Facility Group 18: Community and Commercial: Non-Food (outdoor).....	90
6.2.14	Facility Group 19: Dependent schools.....	90
6.2.15	Facility Group 20: Irrigated land.....	93
6.2.16	Facility Group 21: Miscellaneous	96
6.3	WUI by installation-level characteristics	99
6.3.1	Fort Carson	99
6.3.2	Fort Hood	99
6.3.3	Fort Leonard Wood	100
6.3.4	Fort Gordon	100
6.3.5	Fort Campbell.....	102
6.3.6	Fort Knox.....	102
6.3.7	Presidio of Monterey	102

6.3.8 Fort Bragg	104
6.3.9 Fort Drum	104
6.3.10 WUI for climate zones	104
6.3.11 WUI by primary mission type	107
7 Conclusions and Recommendations	109
7.1 Summary	109
7.1.1 Determinating WUI	109
7.1.2 WUI values	110
7.2 Significance.....	110
7.2.1 Key conclusions	110
7.2.2 Contributions to knowledge base	111
7.3 Assumptions and limitations.....	112
7.3.1 Water meter data.....	112
7.3.2 End-use factor data	112
7.4 Applications for WUI data	113
7.5 Improving the model.....	113
7.5.1 Capturing enterprise data sources.....	113
7.5.2 Studying more installations and facilities	114
7.5.3 Introducing thresholds of supply	114
References	115
Acronyms and Abbreviations	124
Appendix A: Annotated Bibliography	127
Appendix B: Facility Type Fact Sheets	138
Appendix C: Real Property Breakdown for Each Installation	154
Report Documentation Page (SF 298)	157

Figures and Tables

Figures

2-1	USEPA Energy Star Portfolio Manager, water use tracking	12
3-1	Data validation process flow chart	23
3-2	Outcome of VEE	25
4-1	Data sources for PNNL water balance studies	37
5-1	ASHRAE climate zone map	44
5-2	Climate zone map showing installation locations	44
5-3	Summary of water users by climate zone	46
5-4	Count of water users by installation	46
5-5	Count of water users by facility group (all installations)	47
5-6	Installation property by facility group	48
6-1	Median WUI findings (post-VEE) per square foot	51
6-2	Industrial and maintenance WUI histogram. WUI	53
6-3	Industrial and maintenance WUI time series for Fort Bragg	53
6-4	Industrial and maintenance WUI time series for Fort Campbell	54
6-5	Industrial and maintenance WUI boxplot by catcode for Fort Bragg	54
6-6	Industrial and maintenance WUI boxplot by catcode for Fort Campbell	55
6-7	Family housing WUI by installation	56
6-8	Family housing WUI time series	56
6-9	Family housing WUI per occupant for Fort Leonard Wood	57
6-10	Family housing WUI by building and construction year	57
6-11	Family housing WUI boxplot by catcode	58
6-12	Distribution of transient housing area across all observations	59
6-13	Distribution of transient housing WUI across all observations	60
6-14	Comparison of housing (transient) WUI across installations	60
6-15	Housing (transient) WUI by catcode	61
6-16	Timeseries for Fort Campbell's housing (transient) WUI	62
6-17	Timeseries for the Presidio's housing (transient) WUI	62
6-18	Median barracks WUI by construction year	63
6-19	Time series of barracks WUI per installation	64
6-20	Presidio's time series for monthly barracks WUI	65
6-21	Fort Bragg's time series for monthly barracks WUI	65
6-22	Barracks WUI by installation	66
6-23	Barracks WUI by climate zone	67
6-24	WUI using occupancy for barracks for all installations	68
6-25	WUI using square footage for barracks for all installations	68
6-26	Distribution of indoor Community and Commercial WUI – all observations	69

Figures

6-27	Distribution of indoor Community and Commercial WUI less than five	69
6-28	Community and Commercial: Non-Food (indoor) WUI by catcode	70
6-29	Comparison of indoor Community and Commercial WUI across installations	71
6-30	Fort Campbell's indoor Community and Commercial WUI by category code	72
6-31	Fort Campbell's indoor Community and Commercial WUI by category code without three highest WUI groups	72
6-32	Community and Commercial: Food. WUI across all installations	73
6-33	Community and Commercial: Food. WUI boxplot by installation	73
6-34	Community and Commercial: Food time series – before data correction	74
6-35	Community and Commercial: Food time series – after data correction	75
6-36	Community and Commercial: Food – WUI boxplot by catcode	75
6-37	Dining facilities – distribution of WUI by meal	76
6-38	WUI by meal for independent DFAC buildings	77
6-39	Distribution of WUI for high energy facilities	77
6-40	Comparison of WUI for high energy facilities across installations	78
6-41	Monthly WUI for high energy facilities	79
6-42	Comparing WUI by category code for high energy facilities	79
6-43	Distribution of medical WUI across all installations	80
6-44	Medical facilities WUI by catcode	81
6-45	Admin and operations WUI by installation	82
6-46	Admin and operations WUI by catcode – before correction	83
6-47	Admin and operations WUI by catcode – after correction	83
6-48	Other training and schools: WUI by installation	85
6-49	Comparison of category codes for other training facilities and schools	86
6-50	Distribution of WUI for other training facilities and schools	87
6-51	Storage WUI by category code	87
6-52	Distribution of storage WUI across all observations	88
6-53	High water user facilities: WUI by catcode	89
6-54	High water user facilities: WUI by installation	89
6-55	Distribution of WUI	91
6-56	Community and Commercial; non-food (outdoor) facilities at the Presidio of Monterey	91
6-57	Monthly WUI for Community and Commercial; Non-food (outdoor) facilities for Presidio of Monterey	92
6-58	Comparison of dependent school WUI across installations	92
6-59	Dependent schools WUI time series	93
6-60	Dependent schools: WUI distribution	93
6-61	Irrigated land: WUI at Fort Campbell and the Presidio of Monterey	94

Figures

6-62	Time series for Fort Campbell and Presidio of Monterey on WUI for irrigated land	95
6-63	Time series for Fort Campbell on WUI for irrigated land	95
6-64	Distribution of WUI for irrigated land	96
6-65	Distribution of WUI	97
6-66	Miscellaneous: WUI by catcode	97
6-67	Miscellaneous: WUI by installation	98
6-68	Monthly water usage for miscellaneous facilities at Fort Campbell	98
6-69	Fort Carson WUI by facility group	99
6-70	Fort Hood WUI by facility group	100
6-71	Fort Leonard Wood WUI by facility group	101
6-72	Fort Gordon WUI by facility group	101
6-73	Fort Campbell WUI by facility group	102
6-74	Fort Knox WUI by facility group	103
6-75	Presidio of Monterey WUI by facility group	103
6-76	Fort Bragg WUI by facility group	104
6-77	Fort Drum WUI by facility group	105
6-78	WUI by climate zone	106
6-79	WUI by installation	106
6-80	Heat map of median WUI by facility group and climate zone	107
6-81	WUI by mission	108
6-82	Heat map of median WUI by facility group and mission	108

Tables

2-1	Major water mandates	8
2-2	Energy use intensity targets for pre- and post-2008 buildings	12
3-1	Study terms and definitions	16
3-2	Facility groups and category codes	18
3-3	Example end-use factors by facility type	22
3-4	Meter readings reported in differing units	22
3-5	Average percent unique values by installation	24
4-1	Summary of housing WUI values from prior studies	26
4-2	Summary of miscellaneous WUI values from prior studies	26
4-3	Water use ranges and medians from literature review	29
4-4	Installation water demand tool assumptions	30
4-5	Baseline water demand assumptions	31
4-6	Water end use data for four of 10 Army installations (gal/unit daily)	32
4-7	Water end use data for U.S. Army Garrison (USAG) Grafenwöhr (MGD)	33

Tables

4-8	Water end use data for four Net Zero Water Army installations (gal/unit daily)	34
4-9	Water end use data for eight AMC installations (gal/unit daily)	34
4-10	PNNL domestic plumbing metrics	37
4-11	PNNL motor pool vehicle washing flow rates	38
4-12	PNNL laundry metrics	38
4-13	PNNL kitchen and dining equipment flow rates	38
4-14	PNNL meal preparation metrics	38
4-15	Summary of estimated water use for large water users	41
5-1	Real property breakdown across study installations	48
5-2	End-use factors by facility type	49
6-1	WUI per square foot by facility group	51

Preface

This study was conducted for the Office of the Assistant Secretary of the Army, Installations, Energy, and Environment, under reimbursable project (OASA[IE&E]), “Water Intensity to Support Resilient Installations,” work unit 8951B3. The technical monitor was Dr. Marc Kodack, OASA(IE&E).

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COL Bryan S. Green was Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

For Army installations, water supply represents a critical resource for which there is no substitute. Any interruption in supply will result in degraded training, and will reduce readiness of Soldiers and their equipment, compromise force projection, disrupt the industrial base, and reduce the quality of life for Soldiers, military families, and civilians. To prioritize the allocation of water, there is a critical need to develop the capacity to quantify a minimum sustainable amount of water that an installation requires. Establishing these benchmarks for a range of water end uses will enable installation water managers to focus their efforts on the most cost-effective means of reducing water consumption to preserve this finite resource for mission-critical needs.

1.2 Objectives

The objective of this project was to develop water use intensity (WUI) factors for the range of facilities found at Army installations by performing an in-depth review and analysis of end use scale water demand that will answer the following questions:

- What is the range of water demand for an installation starting with the minimum of supplying mission-critical uses only to supporting all current water end uses?
- How long of an interruption in water supply can be tolerated, using available back-up sources, before mission-critical functions are affected and the level of desired risk is exceeded?
- How does water demand vary relative to such use factors as facility square footage, population, Soldiers trained, meals served at Dining Facilities (DFACs), or patients treated?
- What is the correlation, if any, between water demand and climate zone?

1.3 Approach

The objectives of this work were completed through the following steps:

1. A literature review was conducted (Appendix A contains an annotated bibliography of relevant documents pertaining to this subject matter.).

2. Subject installations and facility groups were identified.
3. Data were collected.
4. A model was developed.
5. The model was populated.
6. Model results were analyzed.
7. Project documentation was prepared.

1.4 Scope

This project was based on the outcomes of past water use studies and data disaggregation efforts identified by the sponsoring organization's representative. (Appendix B contains a number of fact sheets that summarize water use at Army installation facilities.) This work could be replicated elsewhere by taking into account unique aspects of each installation's water system.

1.5 Mode of technology transfer

Knowledge obtained from this project will support changes to policy and specifications and will enable more informed efforts at water resilience, security, and goal attainment efforts.

2 Drivers: The Army's Need To Understand Water Use Intensity

Water is a critical resource for execution of the Army's global mission; it affects every aspect of military operations. Insufficient water supplies on installations compromise military readiness and mission sustainment; affect the military's ability to train and support the force; and can cause training to be curtailed or canceled, and staff levels to be reduced. Planning for sufficient and secure water supply across a range of contingencies requires detailed knowledge of how installations and units use water, i.e., water's "end use." Prioritizing demands and securing critical levels of water supplies will support sustainable readiness. However, determining end use is difficult, especially given that there is limited metering of water use or data collection on how water is used, both within the Army and in comparable facilities outside the fence line. While incorporation of water availability into the Army's stationing analysis framework is being considered, there are insufficient data to determine the critical amount of water required by installations and to achieve reductions in water directed to non-essential functions.

Even when there is a limited determination of some end uses, water consumption can vary between users and even for the same user over time, due to variations in staffing levels, seasonal variations, or changes in operation tempo. Because of these common variations in water use, there is a need to formulate guidelines on how water use changes with measurable variables. Such guidelines, termed "water use intensity" (WUI), form the foundation and motivation for this study. WUI refers to the amount of water an end use is expected to consume per unit of a measured variable pertaining to that end use, e.g., the square footage of an office, the occupancy of a barracks, the meals served in a dining facility, the number of patients in a medical clinic, or the number of vehicles washed in a vehicle wash rack.

Such a detailed examination of WUI has never before been conducted for Army installations. This work developed a series of models (data-driven techniques) for deriving WUI factors from information available to the Army by tracking water data from a number of sample installations. These models require the development of new "Validation, Editing, and Estimating" (VEE) workflows to "clean" messy real-world data to perform statistical and exploratory analyses of millions of data points.

The remainder of this chapter describes how water is used by the U.S. Army, highlights the drivers that motivate the U.S. government to care about WUI, defines some of the challenges that must be taken into consideration and overcome, and concludes with a discussion of the various applications for an improved understanding of WUI.

2.1 Background: Water in the U.S. Army

Previous Army studies found that 23% of sites and 31% of active Army troops are contained within watersheds that are highly vulnerable to water crises. Army installations are vulnerable to the same issues of water supply and demand that jeopardize the U.S. water supply. Changing climate, coupled with population growth, aging infrastructure, and unsustainable water extraction rates make it increasingly difficult to provide the required amount and quality of water to the location. Water resource availability varies by region and by season. These variations intensify risks to the Army's mission in regions where water scarcity exists or will recur more often. Water scarcity is a critical issue in drier regions, even in areas where water has historically been in good supply, but where localized droughts are more prevalent and often last longer. Eighty percent of state water managers expect water shortages during the next 10 years under average conditions (Jenicek et al. 2009).

Over the past decade, Federal legislation and Executive Orders have required all Federal agencies to implement increasingly rigorous water efficiency and conservation actions. Army installations must meet mandatory water reduction requirements, such as those specified in Executive Order (EO) 13834, *Efficient Federal Operations* (White House 2018) and the Army's Net Zero Installation initiative (OACSIM 2017). The Army adopted these requirements through policy and regulation. The Army's *Energy Security and Sustainability (ES²) Strategy* (DA 2015) and *Army Installations 2025* (DA 2016) capture these policies and regulations and advance the concept even further by establishing challenging targets for fixed installations to achieve Net Zero Water.

The 156 Army installations are comprised of nearly a billion square feet of facilities; installations are small cities that support 2.1 million Soldiers and their families with a variety of building types and other infrastructure (DoD 2016). Some civilian building categories, such as offices and recreational fa-

cilities, correspond directly to Army buildings. However, most mission-critical facilities, including specialized training facilities, often have no off-installation counterparts; water benchmarking at these facilities is crucial.

Meeting water reduction targets can be especially difficult to achieve at installations that are often located in regions characterized by a broad spectrum of conditions that affect water availability, quality, security, and cost; and the applicability of water-efficient technologies. To achieve large reductions in water use, installations will require a holistic approach that includes policy, technology, behavior change, partnering, and a strong Command emphasis. There is a lack of installation-unique data regarding where and how much water is used on an installation, and also a lack of benchmarks for these values. Acquiring these types of data will support efforts to target non-essential water users to sustain mission-critical functions while reaching assigned water targets.

Installations document water use with data from meters located at points of water production or purchase. Although Federal policy requires the use of building-scale energy meters, the U.S. Department of Defense (DoD) establishes criteria for installation of building water meters based on the cost, not the scarcity, of water. There are few water meters beyond an installation's main supply point and, therefore, little building or end-use demand data are available to determine the water used by individual Army facility categories.

There is also a dearth of information about the amount of water that *should* be consumed by individual water end uses on an installation. Studies of water demand off-installation focus primarily on residential building classes, with little benchmark data available for commercial, industrial, and institutional facility groups. Some buildings in this inventory correspond well to civilian equivalents, e.g., offices and recreational facilities. Other buildings are unique to the military mission, e.g., tactical equipment maintenance facilities and buildings that support specialized training, such as chemical and biological protection. There are Army facilities that appear similar to civilian counterparts, but carry unique resource footprints corresponding with their use, e.g., barracks (which are very different from college dormitories) and family housing (which are smaller than off-installation equivalents, but which typically support larger families).

2.2 Drivers for WUI studies

Few functions of the Army can be sustained for any extended period without an adequate supply of water. Maintenance of critical functions ensures readiness of installations and units to complete essential tasks, and serves as a fundamental responsibility of the Army in the maintenance of its installations. The U.S. government maintains a series of policies (whether through legislation, executive orders, or mandates derived to meet policy objectives) to ensure that readiness is prioritized and that installations behave as good stewards of natural resources and taxpayer dollars.

The reliance on price in particular often poses a problematic tradeoff between stewardships of mission, resources, and finances. The price of water often seems to be very low, if one does not consider embedded costs such as infrastructure and energy, and if one neglects non-market values such as mission resilience. Resilience is the capacity to provide sufficient and uninterrupted water supply of sufficient quality and quantity for important missions.

2.2.1 Readiness

It is important to the Army to achieve water sustainability because it enables the Army to meet its responsibilities as a good neighbor by maintaining shared resources, as a good steward of Federal lands and resources, and as a good role model for other communities. However, financial and ecological sustainability is better conceptualized as a part of the Army's responsibility to ensure readiness. The Army needs to establish water resilience, in part to meet policy requirements and economic objectives, but more importantly (and fundamentally) to maintain readiness. Resilience in water resources helps to assure readiness by empowering installations to quickly adapt to and overcome diminishment of water supply. By better understanding how, where, and why they use water, installations will be better empowered to meet their responsibilities to the Army and to the American people by maintaining a condition of readiness.

In addition to considering capacity or continuity of supply, water suppliers must also weight the quality required for specific end uses. While water quantity is important to maintain readiness, water quality also needs to be considered because, even if sufficient supply may be available, poor quality will render that water unacceptable if the end use requires potable water. For example, the Elk River chemical spill incident in West Virginia in 2004 has been overshadowed in recent years by the quality disaster in

Flint, MI, the substantial disruptions in water quality due to Hurricane Harvey in Texas, and the loss of both water quality and quantity in Puerto Rico and the U.S. Virgin Islands during Hurricane Maria.

The Army also has been affected by readiness-diminishing losses of water resources. In 2017, both Fort Bragg, NC, and the City of Vicksburg, MS, have been forced to decrease military installation services due to water main breaks. Fort Leonard Wood, MO, has experienced two such events in the past decade. First, a December 2010 tornado damaged the installation's water treatment plant, causing significant diminishment of water service. Second, flooding in April 2017 caused the loss of the installation's main pumping station for 3 days, forcing the installation to operate on stored supplies.

By their very nature, disruptions often occur without any prior warning. As such the Army must attempt to understand the variety of disruptions that might reasonably occur, including short term (infrastructure damage) and long-term (drought) disruptions. The Army must prepare for supply crises (drought, contamination), infrastructure crises, demand increases (fire, mobilization), and long-term challenges, such as changing climate, population shift, aging infrastructure, unsustainable water extraction rates, and loss of water rights.

A better determination of how and why installations use water can support resilience planning by augmenting the current lack of data on water end use, in particular, on the criticality of end uses.

2.2.2 Policy

Army water policy derives from Federal legislation and Executive Orders. The main sustainability driver containing key water targets is Executive Order 13834, *Efficient Federal Operations*. (Table 2-1 summarizes other relevant water mandates.) Policies driving potable water use and targets emerged as components of broader energy policy. These includes public laws, Executive Orders, DoD and Army policy, and technical criteria and guidance. These documents establish guidelines for acceptable potable water use, criteria for reductions in demand, and technical guidance for both facilities and equipment.

Many of these policies, directives, and Executive Orders overlap in their requirements. Collectively, the requirements are:

- To reduce building water use by 36% by Fiscal Year 2025 (FY25) (relative to 2007)
- To reduce industrial, landscape, and irrigation water use by 30% by 2025 relative to 2013
- To reduce potable and non-potable water consumption
- To increase usage of alternate sources of water thereby improving water security
- To construct or renovate buildings in accordance with sustainability strategies, including potable water conservation and water reuse strategies
- To plan for a 14-day back-up supply for mission-critical water needs.

Table 2-1. Major water mandates.

Mandate	Area	Requirements
EISA 2007	Covered facilities	Evaluation, projects and follow-up
	Post-construction stormwater	Restore to pre-development hydrology
EO 13834, May 2018	Potable and non-potable water	Reduce potable and non-potable water consumption
	Industrial, landscape, agricultural	Reduce by 2%/year through 2025
	Metering	Install meters to improve management
	Stormwater management	Install Low Impact Development (LID) to improve Solid Waste (SW) management
DoD UFC 1-200-021/13	Indoor water	American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 189.1-2011 & WaterSense®
	Outdoor water	Reduce by 50%; ASHRAE if cost effective
	Heating and cooling water	ASHRAE when cost effective
	Measurement of water	Meter in accordance with Department of Defense Instruction (DoDI) 4170.11
Energy & Water Security Strategy	Security	For critical missions, assure a minimum of a 14-day supply

2.2.3 The price, cost, and value of water

Installation potable water supply is often undervalued when compared to higher cost energy. Low water pricing leads to long payback periods for water investments and can lead to waste and inefficiencies. The price of

water at an installation is determined either by the source utility, or where installations supply their own water, by governing Army policy for calculating utility resale rates. These rates, which are then used in billing reimbursable customers, vary by customer class.

On average, the price of potable water to Army installations is \$2.75 for every thousand gallons (kgal) for FY17. Water reuse and industrial, landscape and agricultural water categories are reported separately to the Army Energy and Water Reporting System (AEWRS). While total Army potable water use has declined since FY07, the unit cost of water rose by 92% through FY17, with a 5% increase over the past year. Water rates in the United States increased by 5.34% annually between 2004 and 2016 (DA 2017, Espinola 2017).

It is imperative that installations account for all of the operations and maintenance costs incurred by the water system. This requires that service orders and work orders are classified correctly when reported or completed.

There may be additional costs to the drinking water treatment and distribution system that are currently not incorporated into operations and maintenance costs. For example, the disposal of treatment by-products, such as sludge. At Fort Leonard Wood, this totaled \$23,333/year over 12 years.

Some customer classes are charged at a rate less than the full cost of water calculated in the “B” rate, that is, the rate that is charged only to non-Government customers. For example, the estimated water use by Residential Communities Initiative (RCI) housing at Fort Leonard Wood, MO, is 0.62 million gal/day (MGD). The difference between the “C” rate—the rate that is specified for RCI housing--and the “B” rate is \$409/day for total lost revenue of \$150,000/year.

In addition to the above costs, it is important that the energy used by the water system be fully accounted for. This requires careful attention to any changes in, for example, pump efficiencies or operating hours from year to year.

Understanding the true cost of water allows installation personnel to enhance how they budget for water. These costs are lowered when end use on an installation is as water-efficient as possible. Given that all non-Government tenant utilities are subsidized to some extent provides strong justification for engaging tenants in an active conservation program.

In contrast to cost, the value of water is influenced by the degree of availability. Water is typically undervalued when considering water stress, both seasonal and chronic, in many regions of the United States. In this context the cost of water is the sum cost of all inputs required for its provision. These costs are derived from summing inputs from each stage of the supply process: source, transport, treatment, provision to customer/user, recycling, and release back to the environment.

2.3 Challenges to water resilience

2.3.1 Current end-use data are limited

The lack of information about how water is used on installations falls at the intersection of low water cost and insufficient data. Installations document water use with data from meters located at points of water production or purchase. Although Federal policy requires the use of building-scale energy meters, DoD establishes criteria for installation of building water meters based on the cost, not the scarcity, of water. There are few water meters beyond the installations' main supply point. Therefore, little building or end-use demand data are available to determine the water used by individual Army facility categories.

Even where water intensity data are available for a broad range of building types, its usefulness may be impaired by the differences between civilian and military facilities. Some buildings in the Army's inventory correspond well to civilian equivalents, e.g., offices and recreational facilities. Other buildings are unique to the military mission, including tactical equipment maintenance facilities and buildings that support specialized training, such as chemical and biological protection. There are Army facilities that appear similar to civilian counterparts, but that carry unique resource footprints corresponding with their use, e.g., barracks (which are very different from college dormitories) and family housing (which is smaller than off-installation equivalents, but which typically supports larger families). Another way in which civilian and military facilities differ is in the gender distribution of occupants, which directly influences water use.

Benchmarking will help the Army to: identify the least efficient types of facilities and prioritize efforts for the best opportunities for savings; formulate and update goals for water use efficiency; identify clusters of facilities, and trends and commonalities; identify use trends more efficiently than

trying to audit each installation; and, once outliers are known, allow water managers to focus on the largest water uses by facility class.

2.3.2 Studies of WUI for the Army are lacking

The last evaluation of WUI across installations (Fort Bliss, TX, Fort Carson, CO, Fort Bragg, NC, and Fort Lewis, WA.) was documented in CERL Technical Report N-157, *Distribution of Water Use at Representative Fixed Army Installations* (Bandy and Scholze 1983). This report examined the implications of water use for mobilization planning, determined the proportion of potable water consumption to each major category of use, and, determined how these proportions changed during the year. Water end use estimates were prepared for the most part without the benefit of water meters (Bandy and Scholze 1983, Langowski et al. 1985).

A sampling of water use in Federal buildings can be found in water data that are voluntarily entered into the U.S. Environmental Protection Agency's (USEPA's) Portfolio Manager reporting system (e.g., see Figure 2-1). A roll-up of this water data was published in 2012, reflecting water use of 53,306 buildings in 11 facility groups (USEPA 2012). While Portfolio Manager has worked well with energy benchmarking, there are challenges with water. Many facilities have multiple meters; while the system is set up for different types of water (municipal versus reclaimed) it has not been as effective for multiple meters. Water is often used on a site/campus, not a single building. There are limited categories of end use, making it difficult to identify the inefficient segments at the site/campus. However, there are opportunities for it to be built up in the future.

Headquarters, U.S. Army Corps of Engineers (HQUSACE) commissioned the development of energy use intensity targets for five major building types in different climate zones across the United States: (1) Brigade Headquarters, (2) Tactical Equipment Maintenance Facilities, (3) Unaccompanied Enlisted Personnel Housing, (4) Company Operations Facilities, and (5) Dining Facilities. Meter Database Management System (MDMS) meter data were used to calibrate energy models, which were then used to develop baseline energy models. Calibrated baseline models were transferred to other climate zones that lacked sufficient data for calibration, preserving operational performance. Energy use intensity targets were developed for pre- and post-2008 constructed buildings (Table 2-2) and were intended as a reference against which measured energy consumption can be compared (Athalye et al. 2016).

Figure 2-1. USEPA Energy Star Portfolio Manager, water use tracking.

Table 2-2. Energy use intensity targets for pre- and post-2008 buildings.

Table ES.1. EUI Targets for Pre-2008 Buildings

Army Building Type	1A	2A	2B	3A	3B Coast	3B Other	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
COF	35	39	36	41	27	36	28	51	40	42	59	42	44	71	60	79	95
BdeHQ	74	72	69	71	63	68	63	76	69	66	82	73	66	93	82	99	112
DFAC	390	401	390	402	346	388	356	427	401	393	456	405	403	502	463	547	635
UEPH	65	67	70	68	53	65	54	68	62	57	73	69	58	83	74	89	107
TEMF	47	52	55	80	46	67	49	116	85	92	149	124	99	197	160	225	299

Table ES.2. EUI Targets for Post-2008 buildings

Army Building Type	1A	2A	2B	3A	3B Coast	3B Other	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
COF	28	31	29	33	22	29	23	41	32	33	47	34	35	57	48	63	76
BdeHQ	59	58	55	57	50	54	50	61	55	53	66	58	53	74	65	79	90
DFAC	351	361	351	362	311	350	321	384	361	354	410	365	362	452	417	492	571
UEPH	59	61	63	61	48	58	49	61	56	52	65	62	53	74	67	80	97
TEMF	37	41	44	64	37	54	39	92	68	74	119	99	79	158	128	180	239

2.3.3 Data and units of measure

One driver for this study is the limited availability of quality metering data throughout the Army. Rarely is water meter data, of any quantity, readily available. When water meter data are centrally available, validation and benchmarking are limited or non-existent. For the tens of thousands of data points collected over the course of this study, several challenges were encountered.

In metering, as in nearly all real-world data collection activities, data quality should be a concern. Broken meters will give fixed readings, measured as zero consumption, regardless of actual consumption by the user. Total consumption is typically reported rather than starting and ending values.

This calculation is likely captured in a spreadsheet in an office. Thus, transcription errors or missing data, e.g., the start and end values, will result in erroneous consumption for a period. If the end value is smaller than the starting value, e.g., a number is missing, consumption readings may include negative numbers. While zero values are feasible for an inactive water user, negative use numbers are not possible.

Outliers in data can occur from faulty meters, incorrect application of units, kilo-gallons instead of mega-gallons, or transcription errors. Outliers within a reasonable number of standard deviations from the mean are often challenging to diagnose, as leaks or changes in end-user water use behavior can result in higher values. An outlier nearing zero is possible, if a large water user is inactive due to maintenance or seasonal demand variations. Transcription errors can also result in non-numbers. From the point of view of computer parsing, even transcription non-errors, such as the inclusion of units in the same cell as the number can result in errors if not properly handled by a software parser. While the software can detect and address some of the above issues, no parser can handle all these sources of error.

2.3.4 Modeling water end use

Even when the data are correctly captured or entered, not all end uses across the organization will compare exactly with study data. Because of this, this report takes a data-driven approach to modeling water end uses, using statistics on large volumes of meter readings to determine likely ranges of WUI. Even so, some facilities will be legitimate outliers within the same facility type, consuming water in an unexpected way (for instance, leakage) or varying from otherwise similar facilities. For instance, facilities that are converted to an alternate use.

Some water users are so unique that they do not fit neatly into any category, including those that are specifically designed for irregular water consumers, such as large water users. Some water uses will support multiple uses. These multiple uses do not fit neatly into the discrete categories created for this study, which are introduced in Chapter 3.

Two approaches are available to installation personnel when multiple building uses are identified. First, in cases where the user is considered critical, users can be split into two separate groups, particularly if sufficient information is available to discriminate between intensity factors and

meter readings. Alternatively, installation personnel may choose to identify the facility as a single-use facility instead of a multiple use facility. While this will create some errors in the model, the analysis can continue. This choice to change the type of facility being modeled should be documented in the notes. If sufficient confidence is available for each potential single-use designation, installation personnel may choose to evaluate a multiple water use facility rather than evaluating each individual facility, by selecting the closest match.

Just as multiple water uses can exist in a single facility, a facility may contain multiple water meters. It would be ideal if each meter corresponded to a separate water use or water use category, but this is not always true. When multiple meters are available, installation personnel may discriminate between use factors, assigning a portion of the total water use, by type of use, to each meter.

2.3.5 Army-unique facilities

Existing civilian research on WUI primarily focuses on common civilian buildings like single-family housing, apartment complexes, hospitals, schools, and office buildings. While installations have similar buildings, such as houses, schools, and administrative offices, installations are also composed of unique facilities designed to support and conduct Army missions and operations.

Army-unique facilities include barracks, dining facilities, data centers, industrial plants, simulator buildings, and labs. Such facilities' water use intensities are unlike civilian facilities due to the volume and concentration of Soldiers in select buildings or the high energy use, and subsequent cooling, required for some Army facilities. Since modern WUI research is mostly limited to common civilian facilities, much of this project addresses the gap in methods for obtaining unique Army facilities' WUI.

Even in facilities that are similar in the civilian and military sectors, the gender composition differs starkly and is likely to affect water use patterns. In general, military facilities comprise a larger fraction of males than do many civilian industries. While gender ratio is not expected to affect many end uses, buildings in which water consumption is dominated by restroom use are likely to see an effect due to increased use of potentially higher efficiency urinals.

2.3.6 Privatization initiatives

Privatization of infrastructure (Utilities Privatization [UP]) and water users (RCI) may prove challenging for data collection and evaluation for two primary reasons. First, data from contractors may be more difficult to acquire. Second, contract-operated infrastructure and facilities may be subject to policies different from those that apply to Army-operated equivalents, which makes benchmarking and comparison difficult.

2.4 Applications of WUI

The WUI factors developed in this project will provide necessary information to plan and execute water conservation, water security, and emergency response initiatives. Installations can regulate water use by identifying and monitoring water consumption categories. Cutting back on water waste and improving efficiency will increase the resources available to installations and allow them to maintain mission-critical facilities during water emergencies. Maintaining a comprehensive database for the installation's water meter data is essential to identifying areas of non-essential consumption. Analyzing these data through the model developed for this project will allow users to determine the minimum use requirements during times of water scarcity.

3 Framework

This study leverages unique access to water meter and facility information for 13 Army installations, and nearly a decade of CERL research, modeling, and data collection efforts to study water uses throughout the U.S. Army. This section introduces the overarching concepts, terms, and approaches applied in this study. Table 3-1 lists study terms and their definitions. To build the models for assessing WUI (the main product of this research), it is first essential to understand Army water consumption by end use. These end uses are separated into water use, e.g., common facility types. Each water use/facility type may have unique use factors that help to explain how the user's water consumption varies. Better understanding these WUI metrics will help installation personnel focus investments toward achieving increased resilience.

Data for this work were obtained directly from installations, from centralized Army meter data repositories such as MDMS, and from previous ERDC-CERL studies. Chapter 4 gives further details on the inclusion of past studies and Chapter 5 provides a detailed discussion of the data sources. Incorporation of these data requires the model to integrate VEE business rules as introduced in Section 3.3.

Table 3-1. Study terms and definitions.

Term	Definition
Facility Group/ Use Category	One of 21 groups that water users are categorized into for the purposes of this study based on their category codes. See Table 3-2.
End Use Factor/ Use Factor	Quantities that describe some attribute associated with the water user and/or its end use(s). See Table 3-3.
Water User	The building or other facility/area/fixture associated with a given water meter and its meter readings.
End Use/Water Use	The way(s) in which water is used by a water user.

3.1 Water uses

The foundational assumption of this research is that water consumption for each installation, known here as “sites for flexibility,” can be separated and attributed to discrete water uses within the site. Many of the water uses in this study are in buildings, which are often the easiest to conceptualize. Many large water uses on military installations may not fit neatly into a building. For instance, even though a vehicle wash rack may have multiple buildings, each with a unique number assigned by the Directorate

of Public Works (DPW), and a unique RPAUID, such as control rooms, storage, and restrooms — much of the water use occurs as a result of composite “facility” operations that stem from the operation of the exterior wash rack. Better examples can also be found in bulk water points, often without any building or building number, and in irrigation, which is not tied to a specific building.

Additional water uses include leaks and loss in water distribution infrastructure. Leaks/losses may be correlated with installation-level factors including utility privatization, climate, and total water consumption.

3.1.1 Criticality of water demand

The advantage of disaggregating an installation into water uses is that it gives the installation the ability to correctly associate water use with the criticality of various installation missions, and to provide a frame of reference for benchmarking. As such, water use categories are defined by combining consumers with similar missions.

3.1.2 Water users in this Study

Each installation has a unique list of buildings with water meter data. To allow for analysis across installations, the project used category code (catcode) classifications to sort buildings into 21 facility groups. Catcodes, which are five-digit numerical codes assigned to each real property facility within the Army, are used to identify the function or use of a specific type of facility. Catcodes are universal across installations, so this method ensures consistent sorting.

The 21 facility groups and associated catcodes were drawn from the Installation Water Demand Model spreadsheet (HQUSACE 2010). These classifications were used for the WUI project because of their relevance to the current study. The Installation Water Demand Model uses customer disaggregation to project the capacity, demand, and raw water supply requirements of a given installation over 30 years. The catcode classifications that the model incorporates treats each catcode as a different water customer. This allows information to be aggregated as Residential Usage, High Water Usage, and more. This also allows for categories to be combined, if needed, depending on the type and amount of data provided.

The Installation Water Demand Model's classification flexibility aligned with the various formats in which data were received for the WUI project. While there were variations in the file formats and available data gathered from each installation in the study, the one constant was that each installation was able to provide a catcode for the facilities and/or equipment they owned. Additionally, the installation water demand classifications are directly related to water use and thus were able to highlight High Water Use Facilities, Non-Irrigated Lands, Irrigated Lands, and various housing types.

Table 3-2 lists building classifications and major category codes included in each classification. Groups 13-17 (paved surfaces, unpaved surfaces, other land: non-irrigated, fuel dispensing and storage, and utility lines) are omitted as there were no data provided for these groups.

Table 3-2. Facility groups and category codes.

No.	Classification Name	Major Category Codes and Subcategories	
1	Industrial and Maintenance	22	PRODUCTION
		212	MAINT - GUIDED MISSILES
		213	MAINT - SHIPS/SPARES
		214	MAINT - TANK/AUTOMOTIVE
		215	MAINT - WEAPONS, SPARES
		216	MAINT - AMMO/EXPLSV/TOXICS
		217	MAINT - ELEC/NX/COMM EQUIP
		218	MAINT - MISC MATL & EQUIPT
		219	MAINT - INSTAL REPAIR & OPER
		310	SCIENCE LABORATORIES
2	Housing (Family)	711	FAMILY HOUSING - DWELLINGS
		712	SUBSTNRD TRAILERS - FAM HSG
		713	FAMILY HOUSING - TRAILER SITE
3	Housing (Transient)	720	UNACOMP PERSONNEL HOUSING
4	Housing (Barracks)	721	UNACOMP PERS HOUS - ENL PERS
		724	UNACOMP PERS HOUS - OFF QTRS
5	Community and Commercial: Non-food (indoor)	730	COMMUNITY FAC-PERS SUPPORT
		740	COMM FAC - MOR, WEL & REC INTR
6	Community and Commercial: Food	722	UNACOMP PERS HOUS - MESS FAC
		740	COMM FAC - MOR, WEL & REC INTR
7	High Energy Use Intensity (High Energy)	131	COMMUNICATIONS - BUILDINGS
		172	SIMULATION FACILITIES
		317	ELECTRON, COMM & ELEC EQUIP
		318	PROPULSION
8	Medical	51	MEDICAL CENTER/HOSPITAL
		54	DENTAL CLINICS
		55	DISPENSARIES/CLINICS

No.	Classification Name	Major Category Codes and Subcategories	
9	Administration (Admin) and Operations	32	UNDERWATER EQUIPMENT
		37	RANGE FACILITIES
		39	RESEARCH, DEVELOPMENT, AND TEST OPERATIONS
		61	ADMIN BUILDINGS
		62	ADMIN FACILITIES UNDERGROUND
		131	COMMUNICATIONS – BUILDINGS
		133	NAV AND TRAFFIC AIDS – BUILDINGS
		137	SHIP NAV&TRAFFIC AIDS – BLDG
		138	SHIP NAV&TRAFFIC AIDS – OTHER
		143	SHIP & OTHER OPERTNL-BLDGS
		156	CARGO HANDLING FAC/BLDGS
		172	SIMULATION FACILITIES
		311	AIRCRAFT
		312	MISSILE AND SPACE
		314	TANK AND AUTOMOTIVE
		315	WEAPONS AND WEAPON SYSTEMS
		316	AMMO, EXPLOSIVES & TOXICS
		317	ELECTRON, COMM & ELEC EQUIP
		318	PROPULSION
10	Other Training and Schools	171	TRAINING BUILDINGS
11	Storage	43	COLD STORAGE
		44	GENERAL SUPPLY BUILDINGS
		142	OPERTNL HELIUM PLANTS&STRG
		421	AMMUNITION STRG DEP/INSTLN
		423	AMMUNITION STRG LIQ PRPLNT
		424	WPN – RELATED BATTERY STRG
12	High Water Use Facilities (High Water Users)	14	WASH BUILDINGS
		723,730	LAUNDRY BUILDINGS, SHOWER
		740	CAR WASH
		740,750	SWIMMING POOLS
		75031	AQUATIC REC CENTER
		75089	STEAM CLEANING
18	Community and Commercial: Non-food (outdoor)	750	COMMUNITY FAC-MW&R-EXTER
19	Dependent Schools	73046	DEPENDENT SCHOOL
20	Irrigated Land	179	PARADE FIELD
		7504	GOLF COURSE
		7603	CEMETERIES
		932	LANDSCAPE PLANTINGS, ETC.

No.	Classification Name	Major Category Codes and Subcategories	
21	Miscellaneous	16	HARBOR AND COASTAL FAC
		69	OTHER ADMINISTRATIVE FAC
		87	GROUND IMPROVEMENT STRUCTURE (DRAINAGE AND STORM SEWER)
		88	FIRE AND OTHER ALARM SYSTEMS
		132	COMMUNICATIONS – OTHER THAN BUILDINGS
		134	NAV AND TRAFFIC AIDS – OTHER
		136	AIRFIELD PAVEMENT LIGHTING
		151	PIERS
		152	WHARFS
		154	SEAWLS/BULKHDS/Q UAYWLS
		155	SMALL CRAFT BERTHING
		159	OTHER WATERFRONT OPERATION
		425	OPEN AMMUNITION STRG PAD
		811	ELECTRIC POWER – SOURCE
		813	ELECTRIC PWR – SUB/SWTH STA
		821	HEAT-SOURCE
		823	HEAT, GAS – SOURCE
		826	REFRIGERATION/AIR CONDNG
		831	SEWAGE-IND WASTE TRTMT&DSP
		832	SEWAGE/IND WASTE COLLECTION
		833	SOLID WASTE HANDLING FAC
		841	POTABLE WATER SUP/TMT/STRG
		843	WATER, FIRE PROTECTION
		844	WATER SUPPLY/STRG-NONPOTABLE

3.2 WUI

This research sought to create an improved understanding of WUI formulated for two distinct audiences: installation personnel, and policy makers and decision makers. WUI is defined as water consumption in terms of quantity per unit. For most applications, including Army policy, this intensity is expressed in gallons per square foot. However, in many applications square footage does correlate meaningfully with water consumption. In a dining facility, for example, water is likely related to the number of meals prepared and served, whereas in a home, water consumption is likely correlated to the number of residents. WUI, then, should compare and contrast each of these potential explanations when data are available. Future research will benefit significantly from the ability to directly connect to Army enterprise sources of data, such as systems designed to track meals served.

This report, along with the foundational research on which it was built, takes three mutually-reinforcing approaches to assessing WUI. Top-down

approaches attempt to determine water use data from enterprise wide data. A common example of top-down approaches are regression analysis, which seek out correlations between changing explanatory variables and overall installation or facility water use. Bottom-up approaches, roll-up high-resolution data, such as the water consumption of each fixture in a building. Data and simulation driven approaches rely on the direct observation or simulation of user water consumption.

3.2.1.1.1 Site-level intensity factors

Time-independent information about the installation serves as a powerful explanatory variable. For instance, two research questions that motivated this study are:

1. Does WUI for similar buildings vary based on the climate zone in which they are constructed?
2. Does the primary mission of an installation affect how water is used by a consumer, as opposed to a similar consumer with a different mission?

The second question is in some ways more of an oversimplification than the first, as mission may vary substantially between individual water uses within an installation. However, such micro-variation is difficult to detect with enterprise data. More interestingly, it is possible that use factors, e.g., occupancy or vehicles washed, may experience different patterns, magnitudes, and seasonality based on if the water user is located on a training base vs. to a power projection platform. Additionally, consideration of the primary mission of an installation may help to explain why similar water uses differ in criticality across installations.

3.2.1.1.2 Water use level intensity factors

A fundamental objective of this work is to incorporate explanatory data into the Army's understanding of water meter data, and in particular to seek out and integrate data with similar resolution to the meter readings themselves. While early analyses prioritize area, currently considered a time-invariant characteristic, and occupancy, considered time-variant, users can assign each facility time-stamped characteristics of their choosing. For instance, a hotel study might use the number of rooms, a hospital might use the number of patients, and a cooling tower might use heat flow. Table 3-3 lists some example end-use factors by facility type.

A current limitation of these water use characteristics is a lack of standardization. While flexibility is highly desirable, inconsistencies in terminology and spelling could make it difficult to compare facilities. To overcome these sources of variability, the current study standardizes water consumption by intensity factors such as square footage, ensuring that water end uses can be compared on a per-unit-factor bases.

Table 3-3. Example end-use factors by facility type.

Facility Type	End-Use Factor (reported for a given time period)
Administrative buildings, barracks, family housing, storage buildings, community buildings, physical fitness facilities	Occupancy
Wash facilities, vehicle maintenance shops	Number of vehicles
Classrooms, schools	Number of students/trainees
Medical facilities	Number of patients served, number of beds
Dining facilities	Number of meals served

3.3 Data processing

Data collection/manipulation for this project is divided into five stages: (1) ingestion, (2) standardization, (3) cleaning, (4) aggregating, and (5) analysis. Data ingestion incorporates scripts and user interfaces to enable installation personnel to add large amounts of meter and user data to the central database. Manual formatting and inputting of data are required for non-standardized sources, such as billing data in a portable document format (pdf) format.

Data standardization ensures that data are expressed in the same units and the same timescale. Table 3-4 presents two different water uses in Bldgs. 38 and 40, one with data collected in thousands of gallons, the other in gallons. While these data were both collected monthly, Bldg. 38's data are in kilo-gallons, whereas Bldg. 40's data are in gallons. This difference could be confusing for a reader and would be misinterpreted by the model without the standardization step.

Table 3-4. Meter readings reported in differing units.

Water User Identification (ID)	Timestamp	Use	Use Units	Use Interval
38	17-Mar	106	kgal	1 month
38	17-Apr	91	kgal	1 month
38	17-May	85	kgal	1 month

Water User Identification (ID)	Timestamp	Use	Use Units	Use Interval
38	17-Jun	689	kgal	1 month
40	16-Oct	73000	gal	1 month
40	16-Nov	73000	gal	1 month
40	16-Dec	73000	gal	1 month

Data cleaning occurs after data standardization. It is important to note that this study relies on self-reported data from throughout the Army; at this scale, errors are unavoidable. The cost of completely avoiding errors would likely discourage participation. The variable quality and quantity of real-world data necessitates the creation of VEE approaches to data analysis. Commonly, performing VEE includes looking for spikes in consumption, comparing use to schedules, analyzing flat consumption, and performing exploratory data analysis to look for trends and outliers. There is currently a lack of methods outlined in academia for integrating variable-resolution water data at the scale faced by the U.S. Army. Figure 3-1 shows the steps this study implemented to eliminate likely-faulty values, to flag suspicious items, and to perform further assessments.

Figure 3-1. Data validation process flow chart.

Negative, non-numeric, and duplicate entries are eliminated. Zeroes, outliers, values with missing or non-standard area units, and values with missing category codes are flagged. Outliers for this study are observations that differ substantially from the typical observation in a set, whether that set is for a specific user, a specific use type at an installation, or a specific use type across installations. In this demonstration, outliers are flagged by researcher-defined parameters, such as the interquartile range. For the results in discussed Chapter 6, outliers are defined as values falling plus or minus three times the interquartile range from the third and first quartile, respectively.

User involvement and judgment during the data cleaning process is key. When the computer flags data as suspect, users are encouraged to examine the suspect data in more detail to determine the anomalous cases and

causes. For instance, a statistical outlier may reflect a leaking pipe rather than a faulty meter. A consumption of zero may reflect a building without leaks that is unoccupied and unused during the time period data were collected by a meter. Likewise, large differences in water usage between seemingly similar buildings may be driven by differences in building usage, renovation status, or other factors not captured by the model.

Even data that are not flagged as outliers may be suspect. Data reported for Facility 40 (Table 3-4) are all identical, which is unlikely over three different months. Query capabilities within the model allow installation personnel to see that water use in Bldg. 40 is listed as “BN & CO HQS, ARMS STORAGE & BARRACKS,” a multi-purpose building at Fort Hood, TX. Because the building’s occupancy varies over time, it is likely that these data are unreliable. The uniqueness score was designed to help users understand the level of similarity between a given subset of data. After initial cleaning steps (zeroes, duplicate entries, negatives, etc.), each building’s meter readings are gathered and the number of unique usage values is divided by the total number of readings. If all meter readings were different, the uniqueness score would be 100%, and if all meter readings were the same, the score would approach 0% as the total number of readings increases. Table 3-5 lists the average percent unique values for each water user at each site.

Table 3-5. Average percent unique values by installation.

Site ID	Name	Average Percent Unique Readings for all Water Users
1	Fort Carson	60.1%
2	Fort Hood	31.0%
3	Fort Leonard Wood	92.8%
4	Fort Gordon	65.6%
5	Fort Campbell	93.5%
6	Fort Knox	44.3%
7	Presidio of Monterey	56.7%
8	Fort Bragg	93.8%
9	Fort Drum	43.9%

Implementation of VEE in this study significantly improves the quality of results, introduced in Chapter 6. After the validation methods, a total of 33,131 rows in the database out of 138,317 rows (Figure 3-2) were eliminated or flagged. A large share of these dropped rows were not due to errors or concerns with the meter data itself, but reflected differences in collection

methods (multiple meters for one building) and types of data received (not all end use factor data were useful, e.g., number of breakfast meals served in a day is not useful if the time scale of data collection was 1 month). “Blank” readings were typically rows where there was an end-use factor for a given building and time period, but no corresponding meter data.

Figure 3-2. Outcome of VEE.

Once data are edited and validated, aggregation builds linkages that will help in analyses and simulations. Some of these linkages occur on data ingestion, e.g., recognizing that two facilities are located on the same installation. Others are more flexible, with installation personnel-tweakable business rules sorting catcodes into use groups and converting the climate zone at an installation into heating degree day and cooling degree day information.

The data analysis phase provides installation with a framework to test facility water use assumptions using best-available statistical, machine learning, and data mining tools.

4 Previous Water Demand Efforts

The effort reported here to develop actual and benchmark WUI values used prior research as a foundation both to understand patterns of water consumption by end use, facility type, and by climate and other parameters; and to evaluate the usefulness of prior efforts to Army installation water use. The review included commercial, industry, and academic studies; and evaluations of Army water use. Several existing models were also examined to determine the usefulness of their assumptions to this effort. Tables 4-1 and 4-2 summarize WUI factors from the various groups of studies and models.

Table 4-1. Summary of housing WUI values from prior studies.

Source	Family	Barracks	Transient
Pacific Northwest National Laboratory (PNNL)	Flush rate: 1.5–3.5 gpf; 46.58–73.28 gal/day	Flush rate: 1.1–3.5 gpf	
	Bathroom faucet flow rates: 1.5–2.2 gpm	Bathroom faucet flow rates: 0.5–2.5 gpm	
	Kitchen faucet flow rates: 2–2.5 gpm	Kitchen faucet flow rates: 0.5–2.5 gpm	
	Showerhead faucet flow rates: 1–2.5 gpm	Showerhead faucet flow rates: 1.25–2.5 gpm	
DoD Water Needs Assessment (WNA) Tool	Daytime staff water use: 42.1 gsf/yr	Daytime staff water use: 36.1 gsf/yr	Daytime staff water use: 53.9 gsf/yr
	Cooling water at full load: 700 kgal/yr/100 tons	Cooling water at full load: 1700 kgal/yr/100 tons	Cooling water at full load: 1700 kgal/yr/100 tons
27 Sustainability Assessments	Baseline end use: 70 gal/occupant/day	Baseline end use: 70 gal/occupant/day	
Literature Review	46.58–73.28 gal/person/day ⁽¹⁾		Lodging: 3.5–7.7 gsf/month ⁽²⁾⁽³⁾ or 104–140 gal/room/day ⁽⁴⁾
1. Range derived from amalgamation of family housing water consumption sources. (See the annotated bibliography.) 2. U.S. Energy Information Administration (USEIA). 2017. 2012 Commercial Buildings Energy Consumption Survey: Water Consumption in Large Buildings Summary, https://www.eia.gov/consumption/commercial/reports/2012/water/ 3. Sterling Water Treatment. 2010. <i>Water Usage Estimating Charts for Water Treatment Equipment</i> . Churubusco, IN: Sterling Water Treatment. 4. U.S. Department of Energy (USDOE). 2012. <i>2011 Buildings Energy Data Book</i> . Washington, DC: U.S. Department of Energy (USDOE), https://ieer.org/resource/energy-issues/2011-buildings-energy-data-book/			

Table 4-2. Summary of miscellaneous WUI values from prior studies.

Source	Administration & Operations	C&C: Food	Medical
PNNL	Toilet flush rate: 0.5–3.5 gpf	Tobyhanna Army Depot (TYAD): 7900 kgal	
	Bathroom faucet flow rates: 0.5–2.5 gpm	Fort Carson: 9 Mgal	

Source	Administration & Operations	C&C: Food	Medical
	Urinal flush rate: 0.5–1.6 gpm	Fort Riley: 34.3 Mgal	
	Showerhead faucet flow rates: 1–2.5 gpm	Joint Base Lewis-McChord (JBLM): 17,900 kgal	
		Aberdeen Proving Ground (APG): 17 Mgal	
DoD WNA Tool	Daytime staff water use: 12.4 gsf/yr	Daytime staff water use: 8 gal/meal	Daytime staff water use: 51.2 gsf/yr
	Cooling water at full load: 1700 kgal/yr/100 tons	Cooling water at full load: 1700 kgal/yr/100 tons	Cooling water at full load: 1700 kgal/yr/100 tons
27 Sustainability Assessments	Baseline end use: 1204 gal/building/day	Baseline end use: 906 gal/building/day	Baseline end use: 1236 gal/building/day
Literature Review	1.8 gsf/month ⁽¹⁾	2.7–16.2 gal/meal ⁽³⁾	In-patient healthcare: 3.75 gsf/month
	20 gal/employee/day ⁽²⁾	8 gal/patron ⁽²⁾	
1. U.S. Energy Information Administration (USEIA). 2017. 2012 Commercial Buildings Energy Consumption Survey: Water Consumption in Large Buildings Summary, https://www.eia.gov/consumption/commercial/reports/2012/water/ 2. Sterling Water Treatment. 2010. <i>Water Usage Estimating Charts for Water Treatment Equipment</i> . Churubusco, IN: Sterling Water Treatment. 3. U.S. Department of Energy (USDOE). 2012. <i>2011 Buildings Energy Data Book</i> . Washington, DC: U.S. Department of Energy (USDOE), https://ieer.org/resource/energy-issues/2011-buildings-energy-data-book/			

4.1 Literature review

Studies of water use have historically focused on one of two distinct topics: the effect of a singular fixture type (toilets, pre-rinse spray valves), or the quantity of water used by one specific asset class (residential, office, commercial). In asset class based studies, the focus has been on determining the quantity of water used at the facilities. However, most of these studies failed to examine the other factors that could affect the amount of water used, such as the age and condition, e.g., tuberculation and leaks, of a facility's water infrastructure.

An assortment of metrics for quantifying water use have been used in previous research. Many studies attempt to reduce the overall quantity of water used into some form of unit cost. Examples of units used include square feet, population, meals, and patients. While these per-unit metrics allow for conclusions to be drawn about structure of varying sizes, they minimize the role that economies of scale play in a facility's water use.

The quantitative data for many of the previous efforts to understand water use have come from utility company records, and from field measurements for water flow rates conducted by researchers. While utility company data are often readily available and easy to understand, the data are

unstandardized across different utility providers and are infrequently updated. A limited number of studies used sub-meters to track water use within a building. Occupant surveys have also been used to gather qualitative data regarding occupants' water use.

Studies on water use have been conducted in a variety of locations throughout the United States and around the world. However, only a few studies consider their location and climate region as having a noteworthy effect when evaluating the amount of water used at a facility. Previous work has demonstrated the effect that location and climate can have on water use at Army installations (Jenicek et al. 2103). However, these studies did not consider rainfall, which can be an important factor for outdoor water use. Another study concluded that for every 0.2 in. of rainfall, there will be no water demand for irrigation for 5 days (TWDB 2004).

Nearly all previous work on the topic assumes an equal gender distribution among a facility's occupants. Studies show that water use differs significantly based on the gender of the users. Under the scenario that men always use the urinal (not the toilet) to urinate, males use about 60% less water than females in the bathroom.

A substantial portion of the literature available on water use predates the Federal government's increased emphasis on water conservation. The effects of water use requirements in Executive Order (EO) 13514 (White House 2009, which was replaced by EO 13834 [White House 2018]), EO 13423 (White House 2007, which was also replaced by EO 13834), USEPA's Water Efficiency Program in 2006 (Frace 2006), and the Energy Independence and Security Act (EISA 2007) remain understudied. Most discussions of facility water use ignore the role that such programs might impart on a facility's water use.

The majority of prior studies focused on single-family residential water use. These studies measured water use per capita and water flow rates of commonly used residential appliances. Single-family residential water use from these studies ranged from 46-73 gal/capita/day. With the exception of Energy Star's Portfolio Manager, studies and research did not report on water use for general commercial and industrial facilities since non-residential water use is dependent on business and building activity. In 2012, Energy Star's Portfolio Manager released an analysis on non-residential water use based on data from the Portfolio Manager database, which con-

tains over 53,000 properties across the United States. Their analysis indicated that senior care facilities, hotels, and hospitals had the highest WUI, 60 gal/ft², 55 gal/ft², and 52 gal/ft², respectively. These data (Table 4-3) show that hospitals used 315 gal/person/day, offices used 13 gal/person/day, and hotels used 102 gal/room/day (USEPA 2012).

Table 4-3. Water use ranges and medians from literature review.

Categories Relevant to WUI Study	Use Factor	Water Used (range or median)
Single-family residential	gal/person/day	46-73
Office	gal/person/day	13 or 127*
Hotel	gal/room/day	102
Hospital	gal/bed/day	315
School (K-8)	gal/ft ²	10
Supermarket	gal/ft ²	21
Retail	gal/ft ²	5
Residence Hall/Dormitory	gal/ft ²	36
Medical Office	gal/ft ²	19
Warehouse (Unrefrigerated)	gal/ft ²	3
* Includes building cooling, irrigation, and other water use not directly consumed by people		

4.2 Installation water sustainability assessments

While Portfolio Manager is the only other study that examined water use intensities for buildings, a tool to calculate building water demand was missing. The Army developed a water demand tool as part of the studies intended to examine regional water supply and demand. Installation Water Sustainability Assessments were conducted at 27 installations between 2009 and 2015. The intent of the research was to determine installation water vulnerability in both a national and regional context and to identify additional studies, planning, and actions that should be pursued to ensure that adequate supplies remain available.

The Installation Water Demand Tool was developed under the pilot project to enable a quick and standardized calculation of water demand across each installation. The tool used historical water use, real property data, planned construction, and population projections to project future water demand. Water intensity factors were developed based on historic Army efforts, Federal assumptions, installation data collection, and site surveys (Installation Water Resource Analysis and Planning System [IWRAPS] and Federal Energy Management Program [FEMP]). The macro-enabled

Excel spreadsheet allowed users to project future water demand by changing model assumptions (Table 4-4).

The factors used in this series of studies provide a framework for the WUI metrics of subsequent research. While the model default values remain those developed for Fort Bragg, NC, in the pilot study (Table 4-5), factors for subsequent installation studies were tailored based onsite surveys, installation-specific data, and interviews with installation personnel.

4.2.1 Pilot study

The 2009 pilot study developed the methods that were used for all subsequent projects and included analyses of Fort Bragg, NC, and Fort Bliss, TX/NM. Each analysis projected installation water demand for 30 years. In each instance, demand was calculated using real property data, a combination of the permanent and commuting population, industrial tempo, deployment tempo, rainfall and evapotranspiration data, and planned construction.

4.2.2 Assessment of 10 installations

This study examined water sustainability at 10 Army installations in the United States. Many of the installations have experienced or are experiencing the challenges that accompany transformation initiatives. In addition, each is subject to a unique set of regional stressors that affect water sustainability (Jenicek et al. 2011).

Table 4-4. Installation water demand tool assumptions.

Input Rows*	Explanation
Barracks Units	This represents the number of spaces total in the barracks on the installation and is populated directly from the real property data input by the user.
Housing Units	This represents the number of families that can be housed in the family housing on the installation. The data from the baseline year is populated directly from the real property data input by the user. However, information from future years must be obtained from other sources. The installation master planning office often has this data.
Military Stationed	This can be populated from current and future years using ASIP COP data. It is equivalent to the "Total Full Time Military" category for the installation from the ASIP.
Transient Population	This can be populated for current and future years using ASIP COP data. It is equivalent to the difference between the "Total Military" and the "Total Full Time Military" categories for the installation from the ASIP.
Dependents	This can be populated for current and future years using ASIP COP data. It is equivalent to the "Military Family Members" category for the installation from the ASIP.
Civilian Workforce	This can be populated for current and future years using ASIP COP data. It is equivalent to the "Total Full time Civilians" category for the installation from the ASIP.
Typical Military Family Size	This field is automatically populated with the average family size for the installation using ASIP data input in the above fields.
Deployment Factor: Family Housing	This is an occupancy rate for family housing units and must be obtained from an on-installation source, such as the RCI.
Deployment Factor: Barracks	This is an occupancy rate for family housing units and must be obtained from an on-installation source, such as DPW-housing.

Input Rows*	Explanation
Industrial/Maintenance Factor	These factors allow an upward or downward adjustment to the amount of water predicted to be used by any of the four categories of buildings/structures/irrigated fields types in any year. So a factor of "1.00" means that actual predicted water usage is 100% of that predicted by the combination of the other model inputs; a factor of "1.25" means that predicted water usage is 125% of that predicted by the combination of the other model inputs. . These factors are most commonly used to adjust for construction or demolition of buildings — for instance, if the storage building stock in 2015 will be 6% greater than that in the baseline year, then the "Storage Growth Factor" for 2015 can be set to "1.06." These factors can also be used when more water is used for irrigated land than is strictly needed to replace evaporated moisture.
Storage Growth Factor	
High Water Use Facilities Factor	
Irrigated Land Factor	
ET (Moisture Deficit)	This number represents the difference between annual evaporation and annual precipitation, in inches, during months when irrigation takes place.
Losses Factor	This factor represents the amount of water lost to leakage, etc. Thus, a factor of "0.10" would indicate that 10% of water is lost to leakage. As much as possible, this should be based on actual data on the installation's water system.
* Projection Input Explanation: This table lists different input rows from the top half of the input sheet, and provides an explanation of what goes into each.	

Table 4-5. Baseline water demand assumptions.

Using Sector*	MGD (Annual Average)	Number	Units	Consumption (gpud)
Family housing	1.367	23,250	Occupants	70
Barracks	0.858	18,284	Spaces	70
Dependent schools	0.102	6,812	Students	15
Medical	0.165	133	Buildings	1,236
Industrial and maintenance	0.321	459	Buildings	700
Transient housing/lodging	0.190	1,267	Spaces	150
Administrative/moderate use	1.271	1,056	Buildings	1,204
Community and commercial: non-food-related (indoor)	0.109	173	Buildings	629
Community and commercial: food-related	0.040	44	Buildings	906
Storage	0.012	1,188	Buildings	10
High water use facilities	0.025	49	Buildings	500
Irrigated/improved land	0.332	446	Acres	
Pools, washracks, etc.	0.100			
Losses	0.489			
Total	5.380			
*Source: U.S. Army Corps of Engineers (2010).				

Following the lead of the pilot study, the water demand calculations for this assessment used historical water use, real property, planned construction, and population projection data to predict future water use. Climate change, changes in demand, and changes in water flows were common threads in each installation study. Assumptions about these changes varied based on the water source for each installation. Population projections were then made. The most recently available data were used as the model baseline. The growth trend from the baseline year was then projected through 2040 (Table 4-6).

Table 4-6. Water end use data for four of 10 Army installations (gal/unit daily).

Factor	Benning	Carson	Hood	JBLM*
Family Housing	112	87	94	90
Barracks	77	87	94	90
Dependent Schools	23.7	5.8	31	20
Medical	1,236	1,236	7,936	900
Industrial & Maintenance	700	700	2,045	700
Lodging	150	150	150	150
Admin/Moderate Users	1,204	1,204	1204	800
Community and Commercial: Non-food	629	629	629	629
Community and Commercial: Food	906	906	906	906
Storage	10	10	10	10
High Water Use Facilities	900	621	500	400
*Joint Base Lewis-McChord (JBLM)				

The Water Sustainability Assessments for 10 Army Installations used the baseline figures and units established with Fort Bragg and Fort Bliss in the initial study. The data for each installation were tailored dependent on the available information. For instance, in Table 4-6, the Community & Commercial food and non-food categories were estimated to be the same value for each installation, but family housing data varied. This suggests that the pilot study values were used for the Community and Commercial values, but that Family Housing occupation data were available. Installations Benning, Carson, Hood, and the Joint Base Lewis-McChord all incorporated the assumptions of the pilot study in their analyses, but adjusted the data where they were available. The other seven installations followed the same process, but their specific end-use figures were not published.

4.2.3 Assessment of three outside continental United States (OCONUS) installations

The objective of this study was to provide an assessment of regional water scarcity as it affects Army installations in overseas locations to ensure continued viability and sustainability of Army operations. This study examined water sustainability at three enduring Army installations overseas, all of which have experienced or are experiencing the challenges that accompany transformation initiatives. In addition, each is subject to a unique set of regional stressors that affect water sustainability.

U.S. Army Garrison-Grafenwöhr, Germany, transformed from a population of 9,963 (2006) to 15,930 (2008) as the result of Efficient Basing

Grafenwöhr. U.S. Army Garrison-Vicenza, Italy, had a population of 12,814 (2009), and was to house 17,578 military, civilians, and family members as the 173rd Airborne Brigade was consolidated with the Dal Molin facility. U.S. Army Garrison Humphreys-Korea (USAG-H) is engaged in a series of transformation initiatives that will triple the installation's population for an end state of 53,943 (FY20).

Due to the limited amount of data available at the time of the study, U.S. Army Garrison-Grafenwöhr was the only installation with published end-use data in the Assessment of Three OCONUS Installations report (Table 4-7). The difference in values seen for this study may be attributed to the difference in units, but also to the difference in international measurements of end-use data.

Table 4-7. Water end use data for U.S. Army Garrison (USAG) Grafenwöhr (MGD).

Factor	USAG Grafenwöhr
Family Housing	0.3532
Barracks	0.0836
Dependent Schools	0.0009
Medical	0.0012
Commissary	0.0015
Ranges	0.0007
Other Installation Operations	0.1833
Irrigated/Improved Land	0.0072
Other Uses	0
Losses	0.0027
High Water Use Facilities	0

4.2.4 Four Net Zero water installations

The goal of this water sustainability study was to apply the methods developed in earlier assessments to four additional net zero water installations: Aberdeen Proving Ground, MD, Fort Buchanan, PR, Camp Rilea, OR, and Tobyhanna Army Depot, PA.

Each "X" in Table 4-8 represents data that were not published in the Four Net Zero Water Installations report. As in the other studies, the values were adjusted for each installation where information was available. If end-use data were not available, the baseline values as established in the pilot study were used.

Table 4-8. Water end use data for four Net Zero Water Army installations (gal/unit daily).

Factor	Aberdeen Proving Ground	Fort Buchanan	Camp Rilea	Tobyhanna Army Depot (AD)
Family Housing	X	133	0	65
Barracks	X	36	65	53
Dependent Schools	X	X	0	X
Medical	X	X	10	0
Industrial/Maintenance	X	X	300	1,000
Lodging	X	X	65	50
Admin/Moderate Users	X	X	20	42
Community and Commercial: Non-food	X	X	20	X
Community and Commercial: Food	X	X	20	3
Storage	X	X	8	X
High Water Use Facilities	X	X	80	767

4.2.5 Eight AMC installations

Assessments of AMC installations were conducted to examine water use at these unique set of installations where critical manufacturing and maintenance activities occur (Table 4-9). These analyses required modification of the Installation Water Demand Model to include water uses that are not typically associated with building area or population.

Table 4-9. Water end use data for eight AMC installations (gal/unit daily).

Factor	Anniston AD	Blue Grass AD	Radford Army Ammunition Plant (AAP)	Iowa AAP	Corpus Christi AD	Red River AD	Sierra AD	Lake City AAP
Family Housing	X	80	94	90	70	70	80	X
Barracks	X	80	94	90	0	0	80	X
Dependent Schools	X	0	31	20	0	0	0	X
Medical	1236	1236	7936	900	1236	1236	1236	X
Industrial & Maintenance	700	700	2045	700	700	700	700	700
Lodging	150	150	150	150	150	150	150	150
Admin/Moderate Users	1204	1204	1204	800	2408	1204	1204	1204
Community and Commercial: Non-food	629	629	629	629	629	1100	629	629
Community and Commercial: Food	906	906	906	906	906	1000	906	906
Storage	10	10	10	10	10	20	10	10
High Water Use Facilities	X	500	500	400	500	500	500	X

4.2.6 Implications for WUI efforts

Each of the water sustainability assessments varied slightly. This implies that the WUI studies also need to account for differences in installations even among similar facilities. Fortunately, the water sustainability assessments did provide a solid core group of water factors to consider when measuring intensity. These studies can be useful to compare water vulnerability across a set of installations of varying size, composition, mission; and that are located in different regions. The WUI factors contained in the Installation Water Demand Model were modified for each installation based in input from the site's water personnel; however, water meter data were not evaluated in detail, i.e., in comparison with end-use factors other than building area or population.

4.3 Pacific Northwest National Laboratory water balance analyses

The Pacific Northwest National Laboratory (PNNL) conducted a series of eight water balance analyses at the following Army installations between 2012 and 2013:

1. Aberdeen Proving Ground, MD (PNNL 2013)
2. Camp Rilea, OR (PNNL 2013)
3. Fort Bliss, TX/NM (PNNL 2012)
4. Fort Buchanan, PR (PNNL 2012)
5. Fort Carson, CO (PNNL 2012)
6. Fort Riley, KS (PNNL 2012)
7. Joint Base Lewis-McChord, WA (PNNL 2012)
8. Tobyhanna Army Depot, PA (PNNL 2012).

These studies were conducted to gather similar water use data for these Net Zero Water pilots. In addition, the analyses increased mission readiness by identifying water loss in an effort to neutralize vulnerabilities to installations.

4.3.1 Methods

PNNL used a three-phased approach to collecting data that was adapted from American Water Works Association methods:^{*}

1. Phase 1 was the pre-audit data analysis, in this phase PNNL gathered data from the installations and other sources to plot general trends in water use, population, and building inventory.[†]
2. Phase 2 was the water audit, which required collecting data via installation walk-throughs. During this phase, PNNL personnel collected information on equipment, conducted interviews, and made onsite observations to help estimate end-use water consumption.
3. Phase 3 was the water balance analysis. This consisted of analyzing the data collected in the previous two steps and estimating the total installation water use and the individual end-use demands.
4. The data were organized by end-use water consumption. Every installation had at the very least the following end uses listed:
 - a. Domestic plumbing
 - b. Administrative buildings and daytime plumbing
 - c. Commercial kitchen/dining facilities
 - d. Dishwashers
 - e. Laundry machines
 - f. Personnel groups
 - g. Vehicle washing stations
 - h. Morale, Welfare, and Recreation (MWR) pools
 - i. Irrigation.

Additional end-use categories were used for specific installations due to differing installation size or installation mission such as: aircraft washing, industrial shops and motor pools, laboratories, test tracts, fire preparedness, line flushing, central plants, and boiler/cooling towers.

4.3.2 Data sources

With respect to the data gathering process, PNNL first attempted to obtain metered data or population data directly from the base. If this was not possible, then assumptions were made using data from other sources (Figure 4-1).

^{*} The reports imply that the only adaptations made were to be used for a multi-building installation. They also described the use of best practices gained from past assessment for Federal installations.

[†] Table 4-1 lists "Other sources."

4.4 Results

4.4.1 Overview

Tables 4-10 to 4-14 summarize the WUI metrics presented in PNNL's reports. Note that in Figure 4-1, Joint Base Lewis-McChord (JBLM), Fort Bliss, and Fort Carson use the same values for domestic plumbing. Meanwhile Tobyhanna Army Depot (TYAD), Fort Riley, and Aberdeen Proving Ground (APG) use the same metrics. Similarly, Fort Buchanan and Camp Rilea use the same metrics. These three categories of differing flow rates are not based on climate zone or installation size. The data in Tables 4-11 to 4-14 clearly depict the variation in basic equipment and standard procedures, such as vehicle washing, laundry services, kitchen and dining, and meal preparation between installations.

Figure 4-1. Data sources for PNNL water balance studies.

Table 4-10. PNNL domestic plumbing metrics.

Location	Climate Zone	Toilet Flush Rate (gpf)	Urinal Flush Rate (gpf)	Lavatory Faucet Flow Rate (gpm)	Kitchenette Faucet Flow Rate (gpm)	Showerhead Flow Rate (gpm)
JBLM	4C	1.1–3.5	1.0–1.5	0.5–2.2	1.25–2.2	2.2–2.5
Fort Bliss	3B	1.1–3.5	1.0–1.5	0.5–2.2	1.25–2.2	2.2–2.5
Fort Carson	5B	1.1–3.5	1.0–1.5	0.5–2.2	1.25–2.2	2.2–2.5
TYAD	5A	1.28–4.5	1.0–2.3	0.5–2.2	2.0–2.2	1.5–3.0

Location	Climate Zone	Toilet Flush Rate (gpf)	Urinal Flush Rate (gpf)	Lavatory Faucet Flow Rate (gpm)	Kitchenette Faucet Flow Rate (gpm)	Showerhead Flow Rate (gpm)
Fort Riley	4A	1.28–4.5	1.0–2.3	0.5–2.2	2.0–2.2	1.5–3.0
APG	4A	1.28–4.5	1.0–2.3	0.5–2.2	2.0–2.2	1.5–3.0
Fort Buchanan	1	1.6–3.5	1.0–1.5	2.0–2.2	1.75–2.0	1.0–2.0
Camp Riley	4C	1.8–4.5	1.0–2.3	0.5–2.2	2.0–2.2	2.2–3.0

Table 4-11. PNNL motor pool vehicle washing flow rates.

Location	Climate Zone	Vehicle Washrack (gpm)
JBLM	4C	15.00
Fort Bliss	3B	—
Fort Carson	5B	15.00
TYAD	5A	8.00–11.50
Fort Riley	4A	2.50–5.00
APG	4A	13.13
Fort Buchanan	1	10.00–15.00
Camp Riley	4C	10.00

Table 4-12. PNNL laundry metrics.

Location	Climate Zone	Family Housing (gal/load)	Barracks (gal/load)	Misc. (gal/load)
TYAD	5A	30	18	18
Fort Riley	4A	25	24	23
APG	4A	35	27	35

Table 4-13. PNNL kitchen and dining equipment flow rates.

Location	Climate Zone	Convection Steamer (gpm)	Ice Machines (gal/cycle)	Pre-Rinse Sprayers (gpm)	Dish Washing (gpm)	Misc. Equipment (gpm)	Garbage Disposal (gpm)
TYAD	5A	0.02	318.9	2.50	2.20	2.20	5.80
Fort Riley	4A	0.33	51.3	3.25	3.25	4.95	6.00
APG	4A	—	205	0.70	0.70	0.90	—
Camp Rilea	4C	0.33	4.50	12.30 gal/cycle	12.30 gal/cycle	—	8.50

Table 4-14. PNNL meal preparation metrics.

Location	Climate Zone	Water Consumption per Meal (gal/meal)
JBLM	4C	5.0
Fort Bliss	3B	7.6–8.5

Location	Climate Zone	Water Consumption per Meal (gal/meal)
Fort Carson	5B	7.6–8.5
TYAD	5A	6.0–8.0
Fort Riley	4A	5.0
APG	4A	3.5
Fort Buchanan	1	6.0–8.0
Camp Riley	4C	7.6–8.5

4.4.2 Opportunities for further study

One limitation of PNNL’s methods is the lack of a comprehensive analysis. These studies focus on the largest end-use consumption, overall consumption, and scale. The limitation in this is that there are various factors that are ignored, which makes it difficult to compare water use among installations. Some of these factors include climate, mission type, and installation operation levels.* However, the metrics used in their analyses emphasize differing flow rates, which raises questions regarding why water infrastructure and standard procedures differ from installation to installation.

4.5 Installation water needs regression models

Between FY16 and FY17, CERL conducted preliminary research on WUI, which became the foundation of much of the research presented in this report. Termed the Installation Water Needs Regression Models (I-WNR), this research forms the basis of the top-down method for water needs assessment. Top-down methods are conceptualized in the products within this report as coarse, installation-aggregated assessments of water needs that do not require substantial information about individual users. The top-down approach is the opposite of bottom-up approaches, which sum the total water consumption of each user to create an aggregated picture. However, the top-down approach is shaped heavily by the knowledge created in the bottom-up approach, and at times the reverse is also true.

The I-WNR models relied on enterprise-level data discussed in Section 5.1. The study is built on higher fidelity information about installation consumption that could be used for validating (testing) the models, but not for training the models. As such, the study of water intensity at each installa-

* Here installation operation levels refer to the percent of the installation that is operating, and how much of the installation is being used.

tion was restricted to a study of the year, installation population, installation primary and secondary mission, climate zone of the installation, and total installation square footage as reported to (Army) Headquarters Installation Information System (HQIIS).

4.6 System Master Planning-Net Zero Planner Water Module

System Master Planner-Net Zero Planner (SMP-NZP) is a web-based tool providing installations and planners with integrated energy, water, solid waste, and low impact development modeling (EW2+LID). After an initial setup of an installation's facilities and infrastructure, SMP-NZP makes it easy to create scenarios for projecting integrated resource consumptions and flows. Additionally, scenarios allow for return on investment analysis for conservation measures. The entire package is designed to integrate within an installation's master planning process.

The WUI research will be invaluable for calibrating integrated planning-scale models such as the SMP-NZP. High-resolution meter and simulation data, can be substituted into models throughout the Army to provide best-available and constantly-improving data to decision makers.

4.7 DoD Water Needs Assessment Tool

The DoD WNA Tool was intended to support DoD installations' water resources planning by enabling estimates of how much water is required rather than how much is used. The tool is built on MS Excel software and contains a series of water use wizards to guide users through the most important questions for each facility type. The tool generates a "Water Needs Report" that contains total estimated and detailed annual water needs for nine real property categories, total installation water need, and WUI calculations. The tool was demonstrated at nine Army installations.

4.8 Large water use estimates at Fort Leonard Wood

Water demand of large water users was characterized in a previous study at Fort Leonard Wood, MO to support compliance with Army water reduction goals. Actual water use of the large water use activities (swimming pools, bulk water points, specialized training, potable water line flushing, water hydrant testing, vehicle washracks, heating, ventilating, and air-conditioning [HVAC], and laundries) is unknown since the water consump-

tion of the users was not metered. Flow rate, user type, operation frequency, and other activity specific data were collected from the installation estimate the level of current water demand for each end use (Jenicek et al. 2016). Table 4-15 summarizes estimated water use for large water users.

To compensate for the lack of long-term data, this analysis assumed that the large water users were in regular operation at average rates of demand. Based on this premise, the annual water consumption of large water users was estimated to be 78.22 million gallons in FY14. This accounted for 8.5% of total potable water consumption of 916 million gallons.

Table 4-15. Summary of estimated water use for large water users.

Large Water Users	Estimated Consumption	Unit*	Note
Swimming Pool	4.77	MG/yr	
Potable Water Line Flushing	0.37	MG/yr	
Fire Hydrant Flow Test	0.95	MG/yr	Regular operation
Old Vehicle Washrack (TA-244)	69.08	MG/yr	Rough estimate
HVAC-Boiler M/U	1.31	MG/yr	Average estimation
HVAC-Chiller M/U	0.47	MG/yr	Average estimation
Bulk Water Point (TA-206)	0.33	MG/yr	Training use only
Laundry (PAL)	0.94	MG/yr	Rough estimate
Total	78.22	MG/yr	8.5% of total installation use
*million gallons (MG)			

The most significant activity among the identified large water users is the centralized vehicle washrack. At 69.08 MG/year, this amounts to 7.2% of the installation's potable water use and approximately \$96,000 in water cost each year. The goal of the top-down and bottom-up models detailed in this report is to maximize usability, while also providing an easy workflow for new and more advanced knowledge to be added to the tool over time.

5 Data Sources

5.1 Enterprise data

5.1.1 Army

5.1.1.1 Army Energy and Water Reporting System (AEWRS)

Annual water consumption data (Mgal) and WUI (gallons per square foot [GSF]) for installations were obtained from the AEWRS, which is the automated system used by the Army to facilitate annual reporting of energy and water consumption and to progress toward goals set by the Office of the Secretary of Defense (OSD). Data are input in five water categories including potable, industrial, landscaping, agricultural, and alternative non-potable water.

Annual factors in AEWRS include building square footage, which is used to calculate potable water intensity, a key metric for conservation. Buildings square footage is imported into AEWRS from Headquarters Installation Information System (HQIIS). However, installations that do not report data into HQIIS must input building square footage data manually into AEWRS. Data imported from HQIIS excludes commissaries, leased buildings, buildings where Army does not pay for the utilities, privatized housing (RCI), and non-government (non-Federal) tenants. National Guard Federal support codes determine the percent of each building's square footage counted (DA 2012).

5.1.1.2 Army Stationing and Installation Plan (ASIP)

Population data for installations were obtained from ASIP, which is the official Army force structure database of populations on Army installations worldwide. ASIP is based on the Structure and Manpower Allocation System (SAMAS), The Army Authorization Document System (TAADS), and many other official Army data sources. Populations included in the report are: full-time military, student and transient military, full-time civilians, student and transient civilians, and reserve component military. ASIP data feed into Defense Enrollment Eligibility Reporting System (DEERS).

Population data can be used to calculate per capita water factors; however the limitations of the data should be noted. Data from ASIP must be combined with surrounding population data tracked by DEERS to create the best estimate of the population that uses the services in any one installation. The

problem is to provide a statistical level of confidence to support these sources since neither ASIP data nor DEERS account for persons who visit the installation, use the facilities, and then leave every day. In addition, ASIP and DEERS data are only as accurate as the existing reporting systems, and those processes are still subject to human error (Jenicek et al. 2013).

5.1.1.3 Headquarters Installation Information System (HQIIS)

Category codes, build dates, and area for buildings were obtained from HQIIS. HQIIS is the Army's enterprise-level comprehensive information repository and the Army's authoritative source for real property installation, site, and base data. It is populated from the following installation-level real property databases: Army Integrated Facilities System (IFS), Planning Resource Infrastructure Development and Evaluation (PRIDE), Real Estate Management Information System (REMIS), and Rental Facility Management Information System (RFMIS) (HQDA 2014).

5.1.2 Non-military national data

5.1.2.1 Climate

Climate is expected to affect water consumption due to heating/cooling degree day effects on space conditioning (cooling towers) and precipitation effects on irrigation. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) climate zone map (Figure 5-1) was used to classify each installation according to its climate zone (Figure 5-2). There are eight thermal climate zones (1 – 8) and three moisture regimes (A – C) for a total of 24 possible zones. Climate Zone 1 is the warmest, and Climate Zone 8 is the coldest. Moisture regime A is moist, B is dry, and C is marine (ASHRAE 2017).

Additional climate data were collected from the National Weather Service website; these data included 10 years of average monthly snow and rainfall, and the average monthly temperatures. The data also provided the average depth of a given weather phenomenon and average monthly wind speeds. The information gathered from the National Weather Services was used to provide the larger context for the installation data.

Figure 5-1. ASHRAE climate zone map.

Source: ASHRAE 2017.

Figure 5-2. Climate zone map showing installation locations.

5.2 Installation data

5.2.1 Water demand data

5.2.1.1 *Monthly water demand*

DPW personnel provided spreadsheets of total monthly water demand for an installation. These data reflect the consumption read by a master meter for the entire installation. In unique cases, such as Fort Drum, NY, which does not meter buildings individually, overall water demand was provided. For installations with their own water treatment plant—regardless of whether it is government owned or privatized—the monthly water demand reflects total potable water production of the plant. In many cases, monthly water demand may include several sources. For example, surface water is often mixed with well water pumped by an installation to increase drinking water quality.

5.2.1.2 *Meter Database Management System (MDMS)*

Where applicable, monthly water use data also were available through MDMS. MDMS is an enterprise system that contains raw utility meter data including potable water data consumption. The system also allows installations to track their utility consumption at the facility level. If an installation could not provide water meter data, MDMS data were used. MDMS does not contain every single water meter that an installation may have, which is why metered data were collected directly from installations, as discussed below.

5.2.1.3 *Building water meter data*

Monthly building water meter data were provided by contacts at installations, either as spreadsheets with readings tabulated for each building in each month or as billing records with meter readings. Meter data from 2007-present were requested. However, the majority of water meter readings are from 2012-2017. Metering time frame and metered building types vary from site-to-site based on the information provided by installation personnel.

Once meter data were collected, they were entered into a database. The database holds data for each meter reading, water user, and installation. At the time of this writing, there are 131,143 meter readings for 4,275 water users across nine installations (Figures 5-3 and 5-4). Note that Groups 13-17 have been excluded from Figure 5-5 as there were no meter data for buildings in these categories. Group 2 had a total of 2,488 facilities – much larger than any other group.

Figure 5-3. Summary of water users by climate zone.

Figure 5-4. Count of water users by installation.

Note: water Users are colored by climate zone.

Figure 5-5. Count of water users by facility group (all installations).

Facility and infrastructure data

Maps of buildings and water infrastructure networks at installations were collected either as geographic information system (GIS) shapefiles or as pdfs. Additional information on building renovations or water fixture upgrades was requested for each installation.

Figure 5-6 illustrates summary statistics of facility type breakdown for installations from HQIIS. Appendix C includes full tables of data. Across installations, buildings within the Family Housing group (Group 2) account for 44% of all listed property, and 26% to 59% of property at each installation. Other major groups across installations include Miscellaneous (Group 21, 9.6%), Storage (Group 11, 8.4%), and Administration and Operations (Group 9, 7.3%). Table 5-1 lists the real property breakdown across study installations.

Figure 5-6. Installation property by facility group.

Source: HQIIS (Downloaded Aug 2017).

Table 5-1. Real property breakdown across study installations.

Group	Number	Percent	Group	Number	Percent
1	1,432	4.2%	11	2,860	8.4%
2	15,055	44.0%	12	564	1.6%
3	162	0.5%	13	1,119	3.3%
4	874	2.6%	14	798	2.3%
5	845	2.5%	15	157	0.5%
6	140	0.4%	16	122	0.4%
7	252	0.7%	17	462	1.4%
8	173	0.5%	18	1,348	3.9%
9	2,489	7.3%	19	145	0.4%
10	1,570	4.6%	20	343	1.0%
			21	3,273	9.6%
			TOTAL	34,183	100.0%

Source: HQIIS (Downloaded Aug 2017)

5.2.2 End-use factors

End-use factors were requested for each building type for which meter data existed at a given installation (Table 5-2). End-use factors varied between building types by category code. A total of 10,289 end-use factors were collected. Most of these were dining hall counts from Fort Leonard Wood and Fort Campbell and monthly barracks occupancy data for Fort Campbell, KY and the Presidio of Monterey, CA.

Table 5-2. End-use factors by facility type.

Facility Type	End-Use Factor (reported for a given time period)
Administrative buildings, barracks, family housing, storage buildings, community buildings, physical fitness facilities	Occupancy
Wash facilities, vehicle maintenance shops	Number of vehicles served
Classrooms, schools	Number of students/trainees
Medical facilities	Number of patients served, number of beds
Dining facilities	Number of meals served

6 Water Use Intensity

This chapter presents results, analyses, and discussion regarding the WUI factors calculated from the datasets discussed previously.

6.1 Approach

Five primary data streams are integrated to assess WUI: (1) near-static site-level characteristics, such as mission and climate, (2) time-variant site-level characteristics, such as utility privatization and installation population, (3) near-static water user characteristics, such as area, (4) time-variant water user characteristics, such as meals served, and (5) meter data.

As shown in Figures 5-4 and 5-5, the amount of data from each site and each facility group is not consistent. This limitation should be kept in mind while viewing, interpreting, and applying the results of this study. Of particular note, family housing data (Facility Group 2) from Fort Campbell (Climate Zone 4) represent 51% of all data in the study.

6.2 WUI by water user-level characteristics

For each facility group, WUI is calculated using all available explanatory data. Table 6-1 provides median intensity data across all installations for each water user category, expressed in gallons of water consumption per square foot per month. Figure 6-1 gives a graphic representation of the same results.

The largest WUI is from the Miscellaneous category, followed closely by high water users. After this, the largest WUI is from Community Areas and Food Production Facilities, commonly consisting of DFACs. Figure 6-1 illustrates results both before and after the VEE process described in Section 3.3. The median slightly increases for most facility groups due to the removal of zeroes from meter readings and combining readings that were from the same building in the same month.

Table 6-1. WUI per square foot by facility group.

ID	Facility Group	Median WUI* no VEE w/VEE	
		no VEE	w/VEE
1	Industrial and Maintenance	0.16	0.19
2	Family Housing	1.22	1.41
3	Transient Housing	1.67	1.97
4	Barracks	2.25	2.41
5	Community and Commercial: Non-food (indoor)	0.88	1.05
6	Community and Commercial: Food	5.10	6.19
7	High Energy Use Intensity	0.24	0.36
8	Medical	0.83	1.0
9	Administrative and Operations	0.39	0.43
10	Training and Schools	0.37	0.39
11	Storage	0.16	0.15
12	High Water Users	17.6	24.39
18	Community and Commercial: Non-Food (Outdoor)	0.74	14.6
19	Dependent Schools	0.50	0.92
20	Irrigated Lands	0.26	0.50
21	Misc.	6.75	26.65

*WUI is expressed in gallons per square foot per month.

Figure 6-1. Median WUI findings (post-VEE) per square foot.

The remainder of this chapter breaks down the results for each water user category. First, the square footage derived WUI is broken down by each category code comprising the water user group. This step is designed to help installation personnel identify how closely similar facility types consume resources, from the perspective of water user categories. Second, results are adjusted for installation variables, such as climate zone and mission. Finally, any available explanatory data are used to propose alternate WUI metrics, and to help calibrate results when only square footage is available. For many

cases when installations are applying these tools, they will only have access to limited data such as square footage. It is still useful to use other factors in this study, because those factors can help inform how the Army considers square footage. For instance, if information is available about water consumption per Soldier in a barracks, for barracks without manning reports the installation could help to calibrate barracks water consumption based on assumptions about the number of square feet per Soldier.

6.2.1 Facility Group 1: Industrial and maintenance

Facility Group 1 had a median WUI of 0.19 GSF/month. The vast majority of data for this facility group come from Fort Campbell (70 buildings, 2,317 meter readings) and Fort Bragg (90 buildings, 1,282 meter readings). Ten additional buildings and 309 additional meter readings come from Presidio, Fort Leonard Wood, Fort Knox, Fort Drum, and Fort Carson combined (Figure 6-2).

Figures 6-3 and 6-4, respectively show time series for Fort Bragg and Fort Campbell. Most of the monthly WUI values are close to zero, with several large spikes. These spikes are driven by high WUI values associated with Category Code 89127 (Combined Air-Conditioning/Heat Plant Building) and 21850 (Battery Shop) at Fort Bragg, and 89131 (Sewage/Waste Treatment Building), 89121 (Heating Plant Building), and 21470 (Oil Storage Building) at Fort Campbell.

As illustrated by the sharp difference in WUI values between category codes in Figures 6-5 and 6-6, water use in this category is highly dependent on the specific function of the building. Because of this variation, the median WUI value for this facility group does not hold as much meaning as the WUI values for individual catcode groups.

Figure 6-2. Industrial and maintenance WUI histogram. WUI

Figure 6-3. Industrial and maintenance WUI time series for Fort Bragg.

Figure 6-4. Industrial and maintenance WUI time series for Fort Campbell.

Figure 6-5. Industrial and maintenance WUI boxplot by catcode for Fort Bragg.

Figure 6-6. Industrial and maintenance WUI boxplot by catcode for Fort Campbell.

6.2.2 Facility Group 2: Housing (family)

Installation family housing may resemble family housing in nearby civilian areas, with the exception that occupancy rates may vary. Privatization initiatives may also affect residential water consumption due to varying rate structures and responsibilities for water-consuming activities, such as outdoor irrigation.

Ninety-six percent of family housing meter observations were collected at a single installation, Fort Campbell, KY/TN; 3.9% of observations were collected at Fort Leonard Wood; and less than 0.1% of observations were from Fort Bragg. Substantial future data collection and analysis are advised to increase representation from different climate zones and installations.

Fort Leonard Wood and Fort Bragg have similar median WUI values – 2.37 and 2.43 GSF/month, respectively (Figure 6-7). The median WUI at Fort Campbell is lower, at 1.37 GSF/month. The time series in Figure 6-8 clearly show that Fort Campbell's WUI was not generally lower than Fort Bragg and Fort Leonard Wood's until the 2015-2017 recording period.

Figure 6-7. Family housing WUI by installation.

Figure 6-8. Family housing WUI time series.

Fort Leonard Wood provided occupancy data for family housing units, which allowed the WUI per occupant to be calculated (Figure 6-9). The median WUI per occupant is 1,323 gal/occupant/month, or 44.1 gal/occupant/day. The average of 1,592 gal/occupant/month equates to 53.1 gal/occupant/day. The average value is at the lower range of the values from the literature review of 46 – 73 gal/capita/day for single-family residences (Table 4-3). The value is significantly less than the 70 gal/occupant/day from the Fort Bragg and Fort Bliss 2009 Pilot Study (Table 4-5).

Figure 6-9. Family housing WUI per occupant for Fort Leonard Wood.

The family housing units at Fort Campbell were mostly built around 1960 and post-2000. As Figure 6-10 shows, there is no clear trend between median WUI and building age. Units built in the same year vary in their median WUI values within a ~3-6 GSF/month range.

Figure 6-10. Family housing WUI by building and construction year.

While all family housing building types are within the confidence interval for the facility group (shaded blue in Figure 6-11), three building types are within the higher range and three are lower. The buildings that have higher WUI are occupied by higher ranking Army members — General Officers (71111), Colonels (71112), and Lt Colonel and Major (71113). The

buildings that have lower WUI are occupied by lower-ranking Army members – Company Grade and Warrant Officer (71114), Senior non-commissioned officer (NCO) (71115), and Junior NCO/Enlisted (71116). Note that there are more data points for catcodes associated with lower-ranking members.

Figure 6-11. Family housing WUI boxplot by catcode.

6.2.3 Facility Group 3: Housing (transient)

These facilities are temporary living accommodations for installation visitors, transient personnel, families, or Soldiers awaiting quarter assignments. Examples of transient housing on installations include guest-houses, lodges, and hotels. WUI for transient housing has been measured using area. However, WUI would be more accurate if it were measured by room occupancy.

The database has 29 unique transient housing buildings. Building areas range from 1,314 to 177,983 sq ft. As represented by the red vertical line in Figure 6-12, the median area for a transient housing building is 29,382 sq ft. The average U.S. hotel is 48,000 sq ft (Fixr 2018). While the median transient housing building area is almost 40% smaller than the average hotel area, installations' average transient housing area is 44,107 sq ft.

The range of building area demonstrates the variety in transient housing building types at installations. According to the rug plot illustration at the bottom of Figure 6-12 that denotes each buildings' exact area by square feet, a majority of the installations' transient housing buildings are much smaller than a typical U.S. hotel. The smallest transient housing facilities are guesthouses.

Figure 6-12. Distribution of transient housing area across all observations.

The median WUI by square foot for transient housing across all installations is 1.97 gal. The median is shown by the red vertical line in Figure 6-13. The 2012 Commercial Buildings Energy Consumption Survey reports that lodging buildings (like hotels) average about 42 gal/sq ft (USEIA 2017). According to the USEPA's water data report, hotels are among the most intensive water users (Healthcare Facilities Today 2013). The significant difference between installation and U.S. average WUI might be due to differing types of lodging establishments and accommodations offered. This transient housing dataset includes guesthouses that are more akin to single-family residences in their water consumption characteristics.

Figure 6-13. Distribution of transient housing WUI across all observations.

Figure 6-14 displays transient housing WUI by square foot across installations color-coded by climate zone. Unlike some other facility groups, installations (aside from Fort Leonard Wood) provided similar amounts of water metering data for transient housing. Installation transient housing median water consumption ranges from 1.5 to 5.9 gal/sq ft/month.

Figure 6-14. Comparison of housing (transient) WUI across installations.

In Figure 6-15, the light purple background represents $\pm$ one standard deviation from average transient housing WUI across all installations. The first to third quartile ranges for all catcode groups fall within this range, which indicates that the average is a useful value for describing transient housing WUI in general. The median value of WUI for transient housing is relatively similar across category codes. The close-fitting average WUI interval and tight median range indicates that these catcode categories are in the appropriate facility group.

Figure 6-15. Housing (transient) WUI by catcode.*

Housing (Transient) WUI fluctuates monthly and seasonally as seen in the time series for Fort Campbell and Presidio (Figure 6-16 and Figure 6-17). Both installations' transient housing facilities use more water in the summer and less in the winter, but this pattern is most explicit with Fort Campbell.

* A single building from Fort Carson makes up Catcode 14113 in the figure. While Catcode 14113 represents an administration building – specifically, an access control facility for aircraft operations – Fort Carson converted this facility into a hotel. Army databases have not yet updated this building to an appropriate catcode.

Figure 6-16. Timeseries for Fort Campbell's housing (transient) WUI.

Figure 6-17. Timeseries for the Presidio's housing (transient) WUI.

6.2.4 Facility Group 4: Housing (barracks)

Barracks are buildings that house Soldiers. The number of military personnel living in barracks varies depending on the installation's size and mission. In barracks, water consumption is primarily for the building's cooling and Soldier toilet and shower use. Previous Army studies measured water use by area to extrapolate barrack water consumption on other installations. However, a more accurate measure of barrack water use is occupancy.

Contrary to popular assumption within the Army, the age of a building has little effect on WUI (gal/sq ft/month) for barracks. As Figure 6-18 shows, there is no clear distinction between older buildings and new buildings with respect to WUI. Over time an increase in the frequency of data points just before 2010 becomes apparent. This may be due to collective initiatives to adhere to the Net Zero Water policy, but there is no decline in intensity over the years.

Figure 6-18. Median barracks WUI by construction year.

When looking at Figure 6-18, bear in mind that renovations and increased efficiency in buildings are not recorded here. Buildings constructed in an earlier time period cannot be accurately compared to a newer construction due to the lack of consistent data collection for buildings over the years. These limitations are illustrated in Figure 6-19, in which inconsistent metering or lack of available data are apparent where there are non-continuous lines for individual installations.

Figure 6-19 demonstrates seasonal changes and overall trends in water consumption between installations. This figure also shows the installations that have consistent metering practices, the most available metering data, or questionable data. For example, the gap in Campbell's barracks data from 2013 to 2014 is due to the installation's inability to find those years' water metering data. Also, static median meter readings over time for Fort Hood's barracks are consistent with the installation's low uniqueness score on water meter readings (Table 3-5).

Figure 6-19. Time series of barracks WUI per installation.

Due to its relatively few data gaps and to its consistent, but cyclical, water usage, Presidio of Monterey is a leading example of dependable water meter tracking. Figure 6-20 provides a clear illustration of Presidio's barracks water usage over time. Extreme dips in water consumption occur at the end of every year, which is most likely due to the holiday season. Presidio's barracks median water consumption has clearly declined slightly between 2012 and 2017. Figure 6-21 shows that Fort Bragg also experienced a decline in barracks water consumption between 2014 and 2017. In general, other installations' median water usage fluctuates extensively and do not present a clear pattern. However, barracks water consumption patterns may become clear once occupation patterns are explained by the respective installations.

Figure 6-22 shows barracks WUI at individual installations. Recall that the median WUI for barracks across all installations is 2.41 GSF/month. The top two rows display the total number of barracks buildings and meter readings at each installation. There is only one installation in Climate Zones 2 (red) and 6 (blue). Between the two installations, only six water users and 73 monthly meter readings were provided. These installations' meter readings cover roughly 2 years of data, which do not provide a sufficient number of data points to make any significant conclusions regarding these climate zones.

Figure 6-20. Presidio's time series for monthly barracks WUI.

Figure 6-21. Fort Bragg's time series for monthly barracks WUI.

Figure 6-22. Barracks WUI by installation.

There are significant amounts of barracks data from Climate Zone 3 (orange) and 4 (yellow), but data from two climate zones are not enough to determine if there is a correlation between climate and barracks WUI. Median values between installations in Climate Zone 4, including Presidio and Fort Bragg from Zone 3, are comparable. However, Fort Gordon's WUI range is wide and its WUI median is considerably different from the other five installations.

Climate zone representation in Figure 6-23 for Climate Zones 2 (orange) and 4 (blue) is not meaningful since Fort Hood represents all of Climate Zone 2 and Fort Drum represents all of Climate Zone 6. The concept for Figure 4 is most valuable when there are more installations, buildings, and observations. In the future, with a robust water meter database, it may be possible to make better comparisons between barracks WUI in different climate zones. With these current water meter data, however, it is only possible to report the range and median barracks water consumption in Climate Zones 3 and 4.

Figure 6-23. Barracks WUI by climate zone.

Figure 6-24 shows WUI by occupant instead of area at Fort Campbell (no other installation provided occupancy data). Calculating WUI using square footage is the current Army standard when analyzing WUI, but this analyses demonstrate that water use by occupancy may be a more meaningful metric. The median value of 1,360 gal/occupant/month assumes that approximately 45 gal/occupant/day is being used within barracks. This is close to the 55 gal/occupant/day metric estimated by the baseline water demand for Fort Leonard Wood in a previous Net Zero Water Initiative (Stumpf et al. 2014).

Given that Soldiers are allotted either 90 or 135 sq ft within barracks, the median value of 2.4 gal/sq ft/month (according to results shown in Figure 6-25) equates to 7.2-10.8 gal/Soldier/day (Headquarters 1999). This is far less than both values estimated from the meter data shown in Figure 6-24 and the value of 55 gal/occupant/day reported by Fort Leonard Wood (Fort Leonard Wood Personnel, 2013). As seen in Figure 6-25, the median value for barracks WUI by occupancy across all installations is 1,361 gal/occupant/month. Using the median number, the median water consumption in barracks per Soldier per day was calculated to be 44 gal. WUI by occupant should provide a more accurate representation of the consumption than WUI by area since it is tied to the primary driver of water use in barracks, i.e., the Soldiers.

Figure 6-24. WUI using occupancy for barracks for all installations.

Notes:

- (1) All barracks occupancy data come from Fort Campbell;
- (2) One meter reading that had 48,571 WUI was removed from the illustration's dataset as it was clearly related to abnormally low occupancy numbers.

Figure 6-25. WUI using square footage for barracks for all installations.

6.2.5 Facility Group 5: Community and Commercial: Non-Food (indoor)

There are 5,933 observations in the Community and Commercial: Non-food (Indoor) group. The median WUI for Facility Group 5, as indicated by the red vertical line in Figure 6-24, is 1.04 GSF/month. Outliers represent a small proportion of end users – only 79 meter readings registered over 100 GSF/month (1% of total Community and Commercial: Non-food [Indoor]). Figure 6-26 shows the distribution of Community and Commercial: Non-Food (Indoor) WUI to be less than five. The number of readings in Figure 6-27 (5,933) accounts for 89% of the total readings.

Figure 6-26. Distribution of indoor Community and Commercial WUI – all observations.

Figure 6-27. Distribution of indoor Community and Commercial WUI less than five.

There are many types of purposes for buildings in the Community and Commercial Non-Food (Indoor) facility group. In this study, 39 category codes have been identified within the facility group. Examples of building titles include: bank (74006), commissary (74021), library (74040), community fitness center (74069), automotive service station (74052), and amusement/recreation center (74068). Despite the large array of category codes comprising this facility group's water end use, most WUI values are relatively close. Figure 6-28 highlights the category codes that have extremely high WUIs. The category codes that stand out are: miscellaneous detached facilities for Soldiers (72360), family life centers (73019), riding stables (74049), recreational equipment checkouts (74065), recreational support buildings (74075), and outdoor pool service buildings (74089).

Some of these high WUIs might be explained by water used for maintenance, cleaning, and cooling purposes. For example, Category Code 74049, horse stables, might use a considerable amount of water to clean facilities and horses, along with using water for the horses' sustenance.

Figure 6-28. Community and Commercial: Non-Food (indoor) WUI by catcode.

There are 39 category codes within Community and Commercial: Non-Food (Indoor). However, Figure 6-26 only displays 33 category codes so that it is easier to look at the visual information. Category Codes 73012, 74003, 73011, 74036, 74076, and 73072 were not included. The category codes had less than one building and 18 or fewer observations.

According to the data in Figure 6-29, all WUI outliers come from Fort Gordon, Fort Bragg, and Fort Campbell. These installations also contribute the most water meter reading data for this facility group (with the exception of Presidio).

Figure 6-29. Comparison of indoor Community and Commercial WUI across installations.

For planning or installations' purposes, it may be helpful to narrow down on this general visualization in Figure 6-29. Figure 6-30 takes a closer look at one of the installations, Fort Campbell. It appears that Category Codes 74065 (recreational equipment checkout), 74075 (recreational support building), and 74089 (outdoor pool service building) are the subset of buildings responsible for Fort Campbell's highest WUI.

Figure 6-30 might not be useful if the objective were to examine or understand WUI for Community and Commercial: Non-food (Indoors) buildings that are not purposed for high water consumption. Figure 6-31 shows a version of Figure 6-30 without the three highest WUI category codes.

Figure 6-30. Fort Campbell's indoor Community and Commercial WUI by category code.

Figure 6-31. Fort Campbell's indoor Community and Commercial WUI by category code without three highest WUI groups.

6.2.6 Facility Group 6: Community and Commercial: Food

The Community and Commercial: Food group includes DFACs, restaurants, and fast food/snack bars. DFACs provide breakfast, lunch, and dinner to military and civilian personnel. An installation's dining facilities can serve thousands of meals a day. Dining facilities use significant water for meal preparation and clean up. In this study, the water use factor for dining facilities is the number of meals served.

Across all installations, this category has a median WUI value of 6.19 GSF/month (Figure 6-32). This facility group had at least one water user from each installation. Facilities at Fort Hood have the highest median WUI value. Fort Campbell provided the most meter readings, and has the most outliers. No WUI pattern based on climate zone is discernable (Figure 6-33).

Figure 6-32. Community and Commercial: Food. WUI across all installations.

Figure 6-33. Community and Commercial: Food. WUI boxplot by installation.

Initially, Fort Leonard Wood's intensity values were noticeably lower than those of other installations. The time series in Figure 6-34 shows near-zero intensity values for Fort Leonard Wood from mid-2012 through the beginning of 2017. All of the readings from Fort Leonard Wood aside from the 2017 April, May, and June readings were for two buildings: a fast food/snack bar and an officer open dining facility.

Figure 6-34. Community and Commercial: Food time series – before data correction.

Upon inspection of the original meter data, the units of the low meter readings were called into question. Between May 2016 and June 2016, three additional zeroes were added to the meter reading values for Bldg. 4109. This implies that, before June 2016, true usage values were in kgal and as of June 2016, true usage values were in gallons. For Bldg. 491, the “true usage” column appears to be in mixture of hecto-gallons and kilo-gallons. This points to the importance of either consistency in meter usage reporting, or columns in the original dataset that explicitly define what unit is being used for each reading.

The usage values that were correctly labeled with the “gallons” unit in the database for Bldg. 4109 (June 2016 and onwards) were actually removed from the database during the VEE process since they were flagged as outliers from the other readings in this catcode group. This illustrates how the data cleaning process is limited by the integrity of the original dataset.

When the usage and intensity values were corrected for these buildings, the median WUI for the Community and Commercial: Food facility group increased by 0.1 GSF/month. After correction, the Fort Leonard Wood

WUI values are still low compared to other installations, but the median WUI value is similar to that of Fort Bragg (Figure 6-35).

Figure 6-35. Community and Commercial: Food time series – after data correction.

Meter data were provided for nine catcodes within this facility group. As seen in Figure 6-36, 74051 (exchange cafeteria), 74064 (installation restaurant), 72210 (dining facility), and 74062 (fast food/snack bar) had the highest median WUI values, and Catcodes 74048 (officer open dining facility), 74050 (exchange branch), 74058 (exchange concession), 74046 (consolidated open dining facility), and 74047 (enlisted open dining facility) had lower median values. Comparison is limited by the fact that most of these catcodes only had one data element from one facility.

Figure 6-36. Community and Commercial: Food – WUI boxplot by catcode.

Number of meals served at DFACs (Catcode 72210) was available for 107 months from Fort Campbell, and 3 months from Fort Leonard Wood (Figure 6-37). The median value was 11.0 gal/meal. This is higher than literature values from PNNL studies, which have ranges of 3.5-8.5 gal/meal for Climate Zone 4. As Figure 6-38 shows, there is wide variation between WUI by meal values for individual DFAC buildings, and buildings with more meter readings have narrower WUI ranges.

6.2.7 Facility Group 7: High energy use intensity

Depending on the installation and its mission, buildings that have high energy use intensity will vary in number and functionality. Some examples of high energy uses include information systems processing centers, printing plants, communications centers, and simulator buildings. WUI depends on the buildings' water use processes. As such, water intensity factors will depend on the building's function.

The data shown in Figure 6-39 demonstrate that the meter readings for high energy buildings are not necessarily high water use buildings. From the meter readings provided, it is clear that a majority of the readings do not surpass 10 (GSF/month).

Figure 6-37. Dining facilities – distribution of WUI by meal.

Figure 6-38. WUI by meal for independent DFAC buildings.

Figure 6-39. Distribution of WUI for high energy facilities.

The distribution of WUI across the study installations (Figure 6-40) shows that Fort Gordon has the largest range and median WUI whereas the rest remain below 5 (GSF/month).

A more detailed look at the water consumption for these installations over time (Figure 6-41) shows values close to zero for almost all of the installations besides Fort Gordon, Presidio of Monterey, and Fort Knox. Since data from Fort Knox do not vary between months, it is reasonable to assume that these values were estimated. Also note that there are no identifiable pattern overall for the time series, indicating that seasonality is not a factor in high energy water use.

Presidio of Monterey demonstrated a distinctive drop near 2012, which then remains relatively low for the rest of the time frame. This may be due to a switch in data collection processes, decrease in water use, or primary mission related activities.

Figure 6-42 shows that most of the category codes fall in between the confidence interval for the median WUI, except for 13131 and 14162.

Figure 6-40. Comparison of WUI for high energy facilities across installations.

Figure 6-41. Monthly WUI for high energy facilities.

Figure 6-42. Comparing WUI by category code for high energy facilities.

The importance of water security in ensuring energy security can be seen with Category Code 14162, a data center at Fort Gordon, GA. Water-cooled critical infrastructure such as data centers can account for substantial water consumption. Note that there is only one building reported by Fort Gordon and it is also the only one listed within its category code.

On the other hand, Category Code 13131, is reported by both by both Fort Carson (31 observations) and Fort Bragg (33 observations). Bldg. 1550 at Fort Carson is 68,096 sq ft with an average use of approximately 34,000

gal/month. Bldg. 82312 at Fort Bragg is 30,762 sq ft, roughly half the size of Bldg. 1550, yet it consumes approximately 922,000 gal/month.

These buildings have very different functions even though they are listed under the same category code. Bldg. 1550 conducts electronic content management, scanning and conversion, printing services, and office device management. Conversely, Bldg. 82312 is a Tier III data center that handles installation processes for Forces Command (FORSCOM), which has state of the art mechanical, electrical, and security systems. The building at Fort Carson acts more as an office building whereas the building at Fort Bragg functions as a data center.

6.2.8 Facility Group 8: Medical facilities

Medical facilities (hospitals, clinics, and laboratories) use high water-consuming equipment. The red vertical line in Figure 6-43 indicates that the median WUI for the medical facility group is 1.0 GSF/month. While this intensity may seem low – especially considering that hospitals are among the facilities with the highest WUI according to the USEPA’s data report – hospitals are just one of the many types of medical facilities in the Army (Healthcare Facilities Today 2013). Other Army medical facilities include health clinics, pharmacies, laboratories, ambulance garages, dental clinics, and veterinary kennels. Since the facilities’ purposes vary widely, installations might find it more useful to examine (median) water consumption of category code groups independent of one another.

Figure 6-43. Distribution of medical WUI across all installations.

As Figure 6-44 illustrates, with the exception of three category code groups—53025, 53045, and 51010—medical facilities consume water per square foot relatively consistently between category codes.

Category Code 53025 (pharmacies) has a high WUI range with little data between two buildings, warranting more data collection before additional analysis on this catcode group. Another deviation is Category Code 53045 (animal kennels). This suggests installations should consider human and animal medical care facilities separately for modeling and planning purposes. Veterinary clinics in this study are distributed relatively evenly between Fort Hood and Fort Campbell, helping to explain the greater variation in WUI for medical facilities at those installations. The third category code that has a higher median than most of the other category code groups is 51010 (hospitals). Like barracks or dining facilities, WUI in hospitals by patient or occupancy should be a more accurate measure of water consumption than area.

6.2.9 Facility Group 9: Administration and operation

Administrative buildings are facilities that assist military functions on installations. They provide working spaces for administration, intelligence, human resources, and facilities management. Water consumption will generally be for the building's cooling and plumbing. WUI should be measured by number of employees or occupants in the building.

Figure 6-44. Medical facilities WUI by catcode.

Note: Category code 53045 had eight meter readings that ranged from 50 to 110 GSF/month.

As the boxplot in Figure 6-45 shows, all installations have similar median and interquartile range values for this facility group. There are also many outliers, particularly for Fort Gordon, Fort Bragg, and Fort Campbell.

Initially the largest outlier was 426 GSF for a monthly reading from Fort Campbell in Catcode 13320. The fact that the 426 GSF/month value from Fort Campbell was not eliminated during the VEE process indicated that it was not an outlier within its catcode group. This suggests wide variation in common WUI values within different catcodes within this facility group, and this is confirmed by the boxplot in Figure 6-46. Catcodes 13320 (Air Navigation Building), 61070 (Red Cross Building), and 14161 (Emergency Operations Center) have particularly wide ranges.

As seen in Figure 6-46, there are three air navigation buildings within this study's database. Two of these buildings have average WUI values of 0.5 and 3 GSF/month, and the other building (6628) has an average WUI of 117. Comparison with GIS maps from Fort Campbell reveals that Bldg. 6628 appears to have an incorrect total area value of 157 sq ft. Dividing the meter readings by this small value results in large WUI values.

Figure 6-45. Admin and operations WUI by installation.

Figure 6-46. Admin and operations WUI by catcode – before correction.

There was no HQIIS entry for the actual Bldg. 6628, but the algorithm used here matched it to A6628, a shed near the air navigation building. The value was updated to 63,698 SF per the GIS attribute table, and this greatly narrowed the range of WUI values for Catcode 13320 as seen in Figure 6-47. There are also several catcodes (14165, 61055) that have the same usage value for each month that appear as flat lines in Figure 6-47.

Figure 6-47. Admin and operations WUI by catcode – after correction.

There were only five end-use factor data points collected (building occupants), and these were all for Company Headquarters Buildings at Fort Campbell. The WUI values ranged from 33.3 to 91.7 gal/person/day, with an average of 54.9 and a median of 41.9 gal/person/day. This is higher

than the literature value of 13 gal/person/day for a standard office building, but less than the value of 127 gal/person/day when building cooling, irrigation, and other water use is accounted for (Table 4-3). More information on the specific water uses measured by this meter would have to be gathered to know which value is a more appropriate comparison.

This analysis has demonstrated the variety of water users within the Administration and Operations category, and the need for better understanding of what is driving water use in each building type to develop more useful end-use factors. The median WUI value of 0.43 GSF/month does describe the majority of data points collected within this facility group.

6.2.10 Facility Group 10: Other training and schools

Training facilities and schools are education spaces for Soldiers and children. Buildings can vary from skill development centers to traditional elementary schools. These buildings generally use water for building cooling and plumbing. Some facilities in this category may have a cafeteria where water will be used to prepare meals and clean dishes. The preferred water intensity factor for these facilities is the number of employees and students on any given day/week/month.

There were a total of 4,490 observations reported to the database for Other Training and Schools. A majority of these were reported by Presidio of Monterey (2,844 observations) and Fort Campbell (717 observations), followed by a significant number of observations from Fort Bragg (383 observations) and Fort Gordon (292 observations).

Figure 6-48 demonstrates various characteristics regarding the relationship between climate zones and training/schooling facilities; and the differences between installations. Climate Zones 3 (orange) and 4 (yellow) do not demonstrate a strong enough relationship to indicate that climate zone is a factor in WUI.

A majority of the category codes fall within the confidence interval except for Category Code 74017, which is a Child Development Center for children under the age of 6 years old, and 17135, which is an instructional laboratory building (Figure 6-49). Even though these two category codes deviate from the confidence interval for the facility group, their median values still remain under 4 GSF/month.

Figure 6-48. Other training and schools: WUI by installation.

Figure 6-49. Comparison of category codes for other training facilities and schools.

Figure 6-50 shows the distribution of water use intensities across all installations; there is relatively low demand for water at training facilities and schools since the median WUI does not exceed 11 GSF/month.

6.2.11 Facility Group 11: Storage

Storage facilities can be highly varied in function as classified by category code. Category Code 44222 yields general purpose storage sheds, whereas Category Code 44288 yields buildings for hazardous material storage. Storage for hazardous material might require more water consumption (for cooling or cleaning) than typical storage due to required safety precautions. The two category codes with the highest number of buildings and observations, 44224 and 44220, are organizational storage buildings and general purpose storage buildings, respectively (Figure 6-51).

Figure 6-50. Distribution of WUI for other training facilities and schools.

Figure 6-51. Storage WUI by category code.

Figure 6-52 presents the distribution of storage facility WUI across all observations (2000 meter readings). The red vertical line indicates the median WUI, which is 0.15 GSF/month. The rug plot at the bottom of the histogram illustrates the exact WUI for each meter reading, providing a different visual understanding of the storage facilities' WUI distribution.

Figure 6-52. Distribution of storage WUI across all observations.

Note: 65 water use intensities ranging from 50 to 540 gal/SF/month were not included in this figure.

6.2.12 Facility Group 12: High water use facilities

Installation buildings and operations that use significant amounts of water are considered high water use facilities. The purpose of these facilities and operations typically cannot be implemented without large water consumption. Based on data drawn from ERDC/CERL TR-16-25 (Van Blaricum, Russell, and Broadwater 2016), a few large water users were selected as the prototype for installations: pools, irrigation, and centralized vehicle wash racks. WUI factors depend on the large water user's consumption processes.

Meter data in this facility group came from only three distinct catcodes: 74059 (Exchange Car Wash), 74019 (MWR Car Wash), and 73075 (Separate Toilet/Shower Building) (Figure 6-53). Water use for car washes and the toilet/shower building is expected to be associated with number of vehicles washed and the type of fixtures in the toilet/shower building, and with number of users. These data would likely provide a more useful metric than the intensity by area.

Figure 6-53. High water user facilities: WUI by catcode.

No pattern in WUI by climate zone is clear from Figure 6-54. Fort Carson had the highest median WUI value in this facility group, and Presidio had the lowest. Comparison across installations is limited as there was only one high water use facility at five of the six installations represented, and these facilities did not all have the same use.

Figure 6-54. High water user facilities: WUI by installation.

The median WUI for this group is the highest of any facility group at 24.4 GSF/month (red line in Figure 6-55). This is due to the function of these buildings and to their relatively small total areas (the highest building area in this facility group was 4,806 sq ft).

There were five buildings in two category codes in this group that did not have an associated area. These were three outdoor swimming pools and two centralized wash facilities with soaking capability at Fort Campbell. The swimming pools used an average of 243,593 gal/month, median of 105,930. The wash facilities used an average of 2,610,609 gal/month, median of 4,000.

6.2.13 Facility Group 18: Community and Commercial: Non-Food (outdoor)

The only installation to report metered data for the Community and Commercial: Non-Food (Outdoor) category was Presidio of Monterey. Since only two water users were reported, no significant conclusions can be made regarding the water use for this end-use category. The water users were in Category Codes 75022 and 75018. Category Code 75022, Hilltop Field, is a multi-purpose athletic field (133,682 SF) that is used for training and recreational activities and also has a court area (7,121 SF). Category Code 75018 is 369,662 sq ft and is being used as a playground.

There are a total of 55 observations with a median value of 14.6 GSF/month. As shown by Figure 6-56, a majority of the observations are made for Category Code 75022. Figure 6-57 shows a clearer illustration of the difference in WUI between the two sites over time. WUI for Hilltop Field increases during the summer months in 2012-2015, then remains constant in 2015, suggesting a change in meter data collection patterns.

6.2.14 Facility Group 19: Dependent schools

Dependent schools are expected to primarily consume water in relation to the population of students and teachers. There is only one category code (73046 – Dependent Schools) within this facility group. Figure 6-58 shows no distinct pattern between WUI and climate zone. Fort Gordon, Fort Bragg, Fort Campbell, and Fort Carson have median WUI values between 0.82 – 1.48 GSF/month, and Fort Knox has a median WUI value of 2.73 GSF/month.

Figure 6-55. Distribution of WUI.

Figure 6-56. Community and Commercial; non-food (outdoor) facilities at the Presidio of Monterey.

Figure 6-57. Monthly WUI for Community and Commercial; Non-food (outdoor) facilities for Presidio of Monterey.

Figure 6-58. Comparison of dependent school WUI across installations.

Seasonal variation in WUI is evident for this facility group, with lower WUI values during school breaks (Figure 6-59). Variation is observed for all installations except Fort Knox, which suggests that the data from Fort Knox were estimated. This should be kept in mind when interpreting the boxplot in Figure 6-58.

Figure 6-60 shows that WUI distribution for dependent schools skews right, with half of readings below 0.92 GSF/month and the other half extending up to 8.15 GSF/month. All meter readings above 4 GSF/month came from Fort Carson.

Figure 6-59. Dependent schools WUI time series.

Figure 6-60. Dependent schools: WUI distribution.

6.2.15 Facility Group 20: Irrigated land

Irrigated areas are rarely metered on installations, often because irrigation is combined with overall building water consumption. Typically, there are

no individual meters or pump stations solely for irrigation. Data were provided by two installations for two category codes and three buildings, for a total of 156 observations. Since a limited number of observations were available, no significant conclusions can be made; however, the data provided are discussed below.

Presidio of Monterey reported data for two irrigation meters used for Post Cemetery (Category Code 76030). This 91,476 SF piece of land on average uses 83,899 gal/month. Fort Campbell reported one irrigation meter for their Parade/Drill Field (Category Code 17980), which is 46 acres (2,004,196 SF) and uses 578.79 gal/month. The median values for Fort Campbell and Presidio of Monterey are 0.000120 and 0.80140 (GSF/month), respectively. It is likely that there is other irrigation for the Parade Field at Fort Campbell that was not reported, or that they only irrigate a small portion of the field.

The time series graph in Figure 6-62 shows that WUI at Presidio is highest during the summer months, as expected.

Figure 6-61. Irrigated land: WUI at Fort Campbell and the Presidio of Monterey.

Figure 6-62. Time series for Fort Campbell and Presidio of Monterey on WUI for irrigated land.

Compared to Presidio of Monterey, Fort Campbell has a significantly lower WUI. Because its data were reported inconsistently, no conclusions can be drawn regarding the seasonality of Fort Campbell's water use (Figure 6-63).

Figure 6-63. Time series for Fort Campbell on WUI for irrigated land.

Figure 6-64 shows the distribution of all data points collected for these two areas. Note that the WUI does not exceed 6 gallon/SF/month and the overall median value is close to zero.

Figure 6-64. Distribution of WUI for irrigated land.

Fort Gordon reported irrigation data for Gordon Lakes Golf Course, a 27-hole golf course upgraded in 2002. Because the area of this land was unknown, the WUI by area was not calculated. It used an average of 28,896 gal/month, and a median value of 16,000 gal/month.

6.2.16 Facility Group 21: Miscellaneous

Miscellaneous structures also require additional data collection. Included in this category are infrastructure components, such as facilities supporting water distribution systems.

The median WUI value for this facility group is 26.65 GSF/month, but WUI values are expected to vary greatly within this group since users do not share a common function. The histogram in Figure 6-65 shows that the upper half of data points have a much wider distribution than the lower half.

The boxplot in Figure 6-66 shows the catcodes that are associated with what range in the histogram. 81160 (standby generator), 69010 (flagpole), and 89148 (water storage building) have low values, 84125 (filter plant facility) has mid-range values, and 89141 (water supply/treatment building potable) and 89144 (water supply building, non-potable) have higher values.

Figure 6-65. Distribution of WUI.

Figure 6-66. Miscellaneous: WUI by catcode.

Figure 6-67 shows that the facilities with the highest WUI values are located at Fort Campbell. Fort Campbell also provides the most data for this group. Fort Campbell also has several water users in this category with no area and thus no WUI by area. These include: cable vault (13252), monuments/memorials (76020), non-potable pump station (84472), sewage lift station (83150), and waste petroleum, oil, and lubricants (POL) storage tank (89550). Figure 6-68 shows the monthly water usage for these facilities.

Figure 6-67. Miscellaneous: WUI by installation.

Figure 6-68. Monthly water usage for miscellaneous facilities at Fort Campbell.

6.3 WUI by installation-level characteristics

6.3.1 Fort Carson

Fort Carson is a maneuver installation located in Climate Zone 5. It reported 1608 observations to the database, most of which are in the Medical and Community and Commercial: Non-food (indoor) facility groups (57% combined). Facility groups with the highest median WUI are High Water Users (80.8 GSF/month) and Community and Commercial: Food (7.43 GSF/month) (Figure 6-69).

6.3.2 Fort Hood

Fort Hood is a maneuver installation located in Climate Zone 2. It reported 3177 observations to the database, most of which are in the Medical and Admin & Operations facility groups (88% combined). Facility groups with the highest median WUI are High Water Users (60.4 GSF/month) and Community and Commercial: Food (15.1 GSF/month) (Figure 6-70).

Figure 6-69. Fort Carson WUI by facility group.

Figure 6-70. Fort Hood WUI by facility group.

6.3.3 Fort Leonard Wood

Fort Leonard Wood is a Training Installation located in Climate Zone 4. It reported 5,876 observations to the database, most of which are in the Family Housing and Barracks facility groups (82.4% combined). Facility groups with the highest median WUI are Medical (2.62 GSF/month), Family Housing (2.37 GSF/month), and Community and Commercial: Food (2.18 GSF/month) (Figure 6-71).

6.3.4 Fort Gordon

Fort Gordon is a Training Installation located in Climate Zone 3. It reported 3545 observations to the database. Facility groups with the highest median WUI are High Water Use Facilities (35.2 GSF/month), Miscellaneous (15.3), and High Energy Use Intensity (13.9 GSF/month) (Figure 6-72).

Figure 6-71. Fort Leonard Wood WUI by facility group.

Figure 6-72. Fort Gordon WUI by facility group.

6.3.5 Fort Campbell

Fort Campbell is a maneuver installation located in Climate Zone 4. It reported 71803 observations to the database, most of which are in the Family Housing (74.9%). Facility groups with the highest median WUI are Miscellaneous (44.9 GSF/month) and High Water Users (17.7 GSF/month) (Figure 6-73).

Figure 6-73. Fort Campbell WUI by facility group.

6.3.6 Fort Knox

Fort Knox is a Training Installation located in Climate Zone 4. It reported 1194 observations to the database. Facility groups with the highest median WUI are High Energy Use Intensity (6.43 GSF/month), Transient Housing (5.88 GSF/month), and Community and Commercial: Food (5.31 GSF/month) (Figure 6-74).

6.3.7 Presidio of Monterey

Presidio of Monterey is a Professional Development Installation located in Climate Zone 3. It reported 8750 observations to the database. Facility groups with the highest median WUI are Community and Commercial: Non-food (outdoor) (14.6 GSF/month) and Community and Commercial: Food (14.1 GSF/month) (Figure 6-75).

Figure 6-74. Fort Knox WUI by facility group.

Figure 6-75. Presidio of Monterey WUI by facility group.

6.3.8 Fort Bragg

Fort Bragg is a maneuver installation located in Climate Zone 3. It reported 6696 observations to the database, most of which are in Admin & Operations and Industrial and Maintenance (61% combined). Its top water user was High Water Use Facilities (22.7 GSF/month) (Figure 6-76).

Figure 6-76. Fort Bragg WUI by facility group.

6.3.9 Fort Drum

Fort Drum is a maneuver installation located in Climate Zone 6. It reported 1089 observations to the database, most of which are in Community and Commercial: Non-food (indoor) (48%). Its top water users were Community and Commercial: Food (7.41), Barracks (4.68 GSF/month), and Transient Housing (3.12 GSF/month) (Figure 6-77).

6.3.10 WUI for climate zones

The ASHRAE climate zone map was used to classify each installation according to its climate zone (ASHRAE 2017). There are eight thermal climate zones (1 – 8) and three moisture regimes (A – C) for a total of 24 possible zones. Climate Zone 1 is the warmest, and Climate Zone 8 is the coldest. Moisture regime A is moist, B is dry, and C is marine.

Figure 6-77. Fort Drum WUI by facility group.

Figures 6-78 and 6-79 show one of the key challenges of assessing the relationship between climate and WUI. With the given data, no significant conclusions can be drawn regarding Climate Zones 2 (red) and 6 (blue) due to insufficient data. Only Climate Zone 3 (orange) and 4 (yellow) can be compared.

Looking across facility groups (Figure 6-80), there are no clear patterns of WUI and climate zone. Climate Zone 2 has the highest WUI for Groups 6, 7, and 9 and the second highest WUI for Groups 8 and 12, but there is only one installation in this climate zone (Fort Hood) and a limited number of readings. Climate Zone 6 has the highest WUI for Facility Groups 4, 5, and 8, but also only has one installation (Fort Drum) and even fewer buildings and meter readings than Climate Zone 2. Between Climate Zones 3 and 4, which have the most data, WUI values vary across groups and neither zone is consistently higher than the other.

Figure 6-78. WUI by climate zone.

Figure 6-79. WUI by installation.

Figure 6-80. Heat map of median WUI by facility group and climate zone.

6.3.11 WUI by primary mission type

Installation primary mission type determines the types of buildings that an installation requires and deems as mission-critical. An installation that focuses on training may have more fitness centers and health clinics, whereas an installation with research and information systems may have a higher number of High Energy Use Intensity buildings, which in turn affect the installation's WUI (Figure 6-81). Training installations (Fort Leonard Wood, Fort Gordon, and Fort Knox) have the highest median WUI in Facility Groups 1, 2, 3, 5, 7, 11, 12 and 19 (Figure 6-82).

Figure 6-81. WUI by mission.

Figure 6-82. Heat map of median WUI by facility group and mission.

7 Conclusions and Recommendations

7.1 Summary

7.1.1 Determinating WUI

This report has documented an effort to determine water use intensity (WUI) across a range of Army facilities based on existing water meter data and end-use factors. The WUI model developed for this work includes data from 14 installations with differing major missions that are located in six ASHRAE climate zones. Comparing and contrasting installations with diverse climate, mission, and facility types helps policy makers and installation planners to better plan for, secure, and use scarce water resources. This study sought to leverage enterprise-level data sources with information across the Army, such as real property assets at installations (HQIIS), installation and facility level resource consumption (AEWRS, MDMS), and population served (ASIP).

WUI values were determined for 21 unique facility groups based on related functions. The use of these rolled-up facility groups, as opposed to the hundreds of unique facility category codes they contain, is designed so that planners can customize the level of detail of their analyses and decrease time spent gathering building-level data inputs. While the use of facility square footage to measure water intensity is often not fully relevant to the actual end use, square footage was used in addition to, and in the absence of, other identifiable end-use factor data because square footage information for facilities is readily available across the Army.

The more than 130,000 monthly water meter readings that comprise the WUI model were subjected to VEE to increase the accuracy of this effort. Creation of VEE rules to account for common data errors, such as null data, repeated values, and outliers from defective equipment or transcription errors, will help the Army to incorporate more data from disparate sources into this and future efforts. Importantly, VEE rules, when coupled with data cleaning tools, assist people in analyzing datasets. Thus, more data can be incorporated into the model, at a lower cost, with better precision than is otherwise typically available.

7.1.2 WUI values

Over 130,000 meter readings from more than 4,000 distinct water users across the Army were used in the analysis. From these data, WUI is estimated to vary from 0.15 gal/sq ft/month (storage facilities) to 24.39 gal/sq ft/month (large water users). As expected, dining facilities (Community and Commercial: Food) consume a larger amount of water per square foot (6.14 gal/sq ft/month across the Army) than do billeting functions such as barracks (2.41 gal/sq ft/month) and family housing (1.41 gal/sq ft/month).

It is important to note here the value of WUI factors expressed in measures other than square footage. While square footage is widely reported across the Army, it provides less estimating precision than more relevant factors, such as occupancy. For family housing across all study installations, the median WUI per occupant is 1,323 gal/month, or 44.1 gal/occupant/day. This number compares closely to the median water consumption per occupants in barracks, at 44 gal/Soldier/day. It is important to note that while these water consumption values are almost identical, they reflect different water use patterns and are not comparable if evaluated on a per square foot basis.

The gap between occupancy and building area as a unit of WUI is important. Simply dividing barracks square footage by prescribed Soldier allocations, often varying from 72-135 sq ft per Soldier, appears to underestimate the water consumption of barracks, ranging from 7.2 to 10.8 gal/Soldier/day. This difference likely represents a divergence between conditioned building areas, reported to the Army, and occupied area, calculated based on planning factors. Better planning factors are needed in the absence of occupancy reporting, although occupancy reporting is strongly preferred for more precise estimations of billeting water consumption. Chapter 6 contains detailed tables, figures, and discussion of the range and variability of WUI.

7.2 Significance

7.2.1 Key conclusions

The data and metrics collected at installations and reported centrally to the Army are often inadequate for managing water programs that seek to ensure water supply resilience. In particular, the Army's reliance on the use of

square footage as the only metric for tracking and comparing water consumption masks the actual relative water use, makes it difficult to evaluate water use between water users, and thus decreases the ability of installations to prioritize allocation based on importance to mission and readiness.

In addition to metrics, Army water security would benefit substantially from increased and improved collection of water consumption data. This study has shown that many facilities across the Army are not metered at all, and even at installation that are metered, many water meters fail to collect reliable data. The lack of centralized utility collection likely leads to an increase in transcription and data errors, because people have to manually read meters resulting in higher costs and lower accuracy than could be achieved by building automation systems.

As more data are collected, the importance of VEE likewise increases. The use of statistical and algorithmic approaches to decrease the cost of cleaning data from disparate sources will help the Army to incorporate more data at lower cost. It is likewise important that these VEE methods should be transparent, such that planners, policy makers, and researchers can better understand the data variability that is included in models.

7.2.2 Contributions to knowledge base

This research contributes to a better understanding of WUI throughout the Army in three ways. First, this study pulls together large quantities of data from diverse sources. The last broad water metering study for the Army was completed more than 3 decades ago. The results reported here provide the Army with a framework for more standardized integration of future data into planning and decision making. Second, this study assesses existing WUI metrics to identify other water use data that would be more useful to water managers. This study seeks to identify available data that would improve water management, and to identify gaps in currently collected data. Finally, this study provides processes and tools for integrating, validating, editing, estimating, and processing varied data inputs to provide the Army with a platform that can ideally grow in the future to encompass more information as it becomes available.

7.3 Assumptions and limitations

7.3.1 Water meter data

The use of water meters at Army installations is far less common than is the use of electrical, natural gas, and steam meters. This phenomenon is sometimes attributed to the relatively low cost of water relative to high energy costs, and to the cost of installing water meters. This limited number of installed and reporting water meters detracts from the Army's ability to account for the use of this resource. Where water meters are installed, they may reflect inherent biases in the types of facilities monitored. For instance, meters are more often installed for reimbursable customers, though this is not always the case, as estimated bills are also allowable by regulation. Likewise, some installations install more water meters than others, with installations such as Fort Campbell, KY/TN providing a disproportionate amount of data to this study due to the large number of water meters in family housing. Much of the meter data used in this study was captured manually by installation or contractor personnel; relative to automated data capture technologies, such manual data collection is expensive and prone to errors, and increases the time interval between readings (most often monthly). The reliance on existing personnel often does not allow sufficient time for installations to collect and analyze data.

Meter data from installations can be inaccurate. A portion of the reported meter data made available appeared to be estimates, e.g., reported water use was the same every month. Although most installations did not provide details, some installations provided detailed notes on the monthly billing process and individual meter readings, e.g., if there was an error with a certain meter or a meter replacement. Without these notes, it was unclear whether a given meter in a building was capturing all of the building's water use or only a portion of it, and if it was capturing outdoor uses as well, such as irrigation. The lack of consistency in data capture and collection injects increased uncertainty in models comparing facilities and installations across the Army.

7.3.2 End-use factor data

Although end-use factor data were requested from each installation, obtaining these data was a challenge. At most installations, occupancy data and other metrics were not readily available or were not being collected in a systematic way; rather, each building had its own records, or had no records at all. Building area was used when other end-use factors could not be

obtained. This limited the ability to fully understand water use drivers. The Army's efforts to understand and increase water security will benefit substantially from improved centralized collection, analysis, and distribution of enterprise-level end-use factor data, such as meals served, barracks occupancy, and medical patients served.

7.4 Applications for WUI data

Improved understanding and modeling of how the Army uses water will help both policy makers and installations to better evaluate and target investments in water security and mission resilience. By better understanding how and why water is used for various missions across the Army, planners can incorporate these data into water conservation and emergency response initiatives. In particular, the ability to prioritize certain uses over others will help installations to identify critical water demands, and will allow them to plan for secure water access and supply during times of need.

By identifying and monitoring water consumption, installations can prioritize and regulate water use, especially during shortages. Water conservation and water waste reduction will increase the resources available to installations, and will better prepare them to maintain mission-critical facilities in times of emergency. Maintaining a comprehensive database for an installation's water meter data is fundamental to identifying areas of essential and non-essential consumption. Analyzing these data through the model presented here will allow users to determine the minimum use requirements during times of water scarcity.

7.5 Improving the model

7.5.1 Capturing enterprise data sources

A serious challenge to data-intensive efforts, such as the WUI project, is the ability of installation personnel to support data collection efforts. Several enterprise data systems were identified through the course of this project that could ease data collection efforts for any future model updates and reduce the burden on installations. For example, existing Army programs already collect information on dining facility meals served, as reported to the Army Food Management Information System (AFMIS). It is possible for installation personnel to query the database down to the facility and meal level. However, such a query is time consuming to construct and produces unnecessarily large reports for analysis.

Likewise, it is expected that the Army maintains useful databases of barracks manning, hospital patients, and MWR use. Future work on the WUI model will benefit substantially from exploring the possibility of obtaining these enterprise data directly from the hosting organizations within the Army; researchers can then automate the data analysis to avoid placing this burden on installation personnel. This will also allow a far larger number of installations to be studied in the future, as the data are available across the enterprise.

7.5.2 Studying more installations and facilities

Incorporation of more installations and facilities into the study will improve the statistical accuracy of analyses, and emphasize differentiating factors available for installations looking to estimate more precisely or to compare facilities to comparable subsets. In particular, adding more data will help to identify climate relationships, such as heating degree days and cooling degree days, as well relationships between water consumption and different mission types, e.g., Guard and Reserve facilities.

Furthermore, extending the application of collected data used in the assessment of metered buildings to use in predictive approaches will enable the estimation of water consumption in unmetered facilities, and will help installations better plan for water security. The incorporation of additional data will help to improve the fidelity of these models, while the improvement of techniques for predicting applicable ranges of water consumption will provide installations with a powerful tool for identifying critical water demands and ensure resilient water access.

7.5.3 Introducing thresholds of supply

Installations are subject to important new policies related to the resilience of water supply, in particular, to their ability to provide adequate resources for mission assurance. Studies of WUI provide valuable data and tools for installations to identify critical demands, and to prioritize allocation of water in the event of a disruption. Planning for such disruptions is likely to prove challenging for installations that already lack personnel for water management. WUI research can support these personnel to identify thresholds of supply required to meet specific water demands, which is necessary to support their water resilience planning efforts.

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Acronyms and Abbreviations

Term	Definition
AAP	Army Ammunition Plant
AD	Army Depot
AEPI	Army Environmental Policy Institute
AEWRS	Army Energy and Water Reporting System
AFCEC	U.S. Air Force Civil Engineer Center
AFMIS	Army Food Management Information System
AMC	U.S. Army Materiel Command
ANSI	American National Standards Institute
APG	Aberdeen Proving Ground
APHC	U.S. Army Public Health Center
AR	Army Regulation
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASIP	Army Stationing and Installation Plan
ATSDR	Agency for Toxic Substances and Disease Registry
AWWA	American Water Works Association
BMP	Best Management Practice
CERL	Construction Engineering Research Laboratory
C/I	Mixed Water Usage <u>Commercial/Industrial</u> , Office, and Residential
CII	Commercial, Industrial, and Institutional
CSH	Code for Sustainable Homes
DA	Department of the Army
DEERS	Defense Enrollment Eligibility Reporting System
DFAC	Dining Facility
DoD	U.S. Department of Defense
DODI	Department of Defense Instruction
DPW	Directorate of Public Works
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
FDOR	Florida Department of Revenue
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FORSCOM	U.S. Army Forces Command
FSAWWA	Florida Section of the American Water Works Association
GIS	Geographic Information System

Term	Definition
GSF	Gallons per Square Foot
HEMTT	Heavy Expanded Mobility Tactical Truck
HHS	U.S. Department of Health and Human Services
HQDAF	Headquarters, Department of the Air Force
HQDA	Headquarters, Department of the Army
HQIIS	[Army] Headquarters Installation Information System
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HVAC	Heating, Ventilating, and Air-Conditioning
IBWA	International Bottled Water Association
ID	Identification
IFS	Army Integrated Facilities System
IMCOM	U.S. Army Installation Management Command
I-WNR	Installation Water Needs Regression Models
IWRAPS	Installation Water Resource Analysis and Planning System
JBLM	Joint Base Lewis-McChord
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
LLC	Limited Liability Corporation
MDMS	Meter Database Management System
MG	million gallons
MGD	million gal/day
MWR	Morale, Welfare, and Recreation
NAVFAC	Naval Facilities Engineering Command
NCO	non-commissioned officer
NFPA	National Fire Protection Association
NOAA	National Oceanic and Atmospheric Administration
NSN	National Supply Number
OACSIM	Office of the Assistant Chief of Staff for Installation Management
OASA(IE&E)	Office of the Assistant Secretary of the Army for Installations, Energy and Environment
OCONUS	Outside Continental United States
OMB	Office of Management and Budget
OSA	Office of the Secretary of the Army
OSD	Office of the Secretary of Defense
pdf	Portable Document Format
PNNL	Pacific Northwest National Laboratory
POL	Petroleum, Oil, and Lubricants
PRIDE	Planning Resource Infrastructure Development and Evaluation
PWS	Performance Work Statement
PWTB	Public Works Technical Bulletin
RCI	Residential Communities Initiative

Term	Definition
RDECOM	Research, Development, and Engineering Command
REMIS	Real Estate Management Information System
RFMIS	Rental Facilities Management Information System
ROWPU	Reverse Osmosis Water Purification Unit
SAMAS	Structure and Manpower Allocation System
SAR	Same As Report
SF	Standard Form
SMP-NZP	System Master Planner-Net Zero Planner
SW	Solid Waste
TAADS	The Army Authorization Document System
TR	Technical Report
TSHA	Texas State Historical Association
TWDB	Texas Water Development Board
TYAD	Tobyhanna Army Depot
UFC	Unified Facilities Criteria
UP	(Army) Utilities Privatization
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratory
USAG	U.S. Army Garrison
USAG-H	U.S. Army Garrison Humphreys
USDOE	U.S. Department of Energy
USEIA	U.S. Energy Information Administration
USEPA	U.S. Environmental Protection Agency
VEE	Validation, Editing, and Estimating
WUI	Water Use Intensity
WNA	Water Needs Assessment

Appendix A: Annotated Bibliography

This annotated bibliography is divided into five sections: residential, office, commercial/industry, mixed water usage, and other water usage information (research for military installations, history, methods, etc.)

A.1 Commercial/Industry

Arizona Municipal Water Users Association Regional Water Conservation Committee. 2003. *Facility Manager's Guide to Water Management*.

This guidebook resource assists owners and managers of commercial, industrial, and institutional facilities by improving their water use efficiency under reasonable economic parameters. The beginning of the guide discusses inventory and monitor the water plan. The document also describes how water-using equipment can be included in water conservation plans, specifically: domestic water uses (toilets, faucets, showerheads), cooling and heating systems, landscape water uses, kitchen and cafeteria water uses, laundry water uses, and x-ray and photo processing. The guidebook also gives advice to employers on how they can train their employees on water efficiency practices.

Axiom-Blair Engineering, Inc., Chris Brown Consulting, GDS Associates, Inc., and Tony Gregg. 2004. *Texas Water Development Board, Report 362*. Texas Water Development Board (TWDB).

Firms contracted by the TWDB created an extensive guide that informs municipal, industrial, and agricultural water users of water-efficient strategies and best management practices (BMPs). The document describes how to implement BMPs via water-efficient fixtures, appliances, systems, and programs. Every fixture, appliance, system, and program known to have significant water end-use has its own section in the guide. The BMP section for agricultural water users has more information regarding Texan land, water, and irrigation.

Cohen, Ronnie, Kristina Ortez, and Crossley Pinkstaff. 2009. *Increasing Water Efficiency in California's Commercial, Industrial, and Institutional (CII) Sector*. Natural Resources Defense Council.

This paper examines CII water efficiency successes and potential in California. Chapters highlight available technologies that increase water efficiency, the need and how-to for developing alternative sources of water-using LID and technologies that recycle water, and case studies of successful California water agency programs. Page 11 has a table of "Available Technologies and Potential Water and Energy Savings in the CII Sector" with a column specific to CII water use in California. Chapter three looks at industries and institutions that achieved success from implementing cost-effective, water-efficient technologies in California. Overall, the report gives comprehensive advice on how to improve California's CII water efficiency while describing the reasons that prohibit further improvements to CII water efficiency levels.

East Bay Municipal Utility District. 2008. *A Water-Use Efficiency Plan Review Guide for New Businesses*.

The guidebook helps businesses be more water-efficient. It provides information on water-saving technologies applicable in the CII sectors, and is intended for use by businesses, developers, consultants, planning agencies, and water providers. Thirteen water-using technologies (e.g., pools, restrooms, vehicle washes) were applied to 19 different business types (e.g., bakeries, paper manufacturers, laundries) in this guidebook. The authors urge water providers and planning agencies to consider adopting a plan-review program for better water use efficiency.

ENERGY STAR. 2007. *Putting Energy into Profits: ENERGY STAR Guide for Restaurants*. U.S. Environmental Protection Agency.

Most of the content in this guide was originally developed by the California Flex Your Power Program and was adopted for this reading material in the interest of normalizing energy efficiency practices. The information in the guide is intended for restaurant owners. It provides recommendations on how to conserve energy in the kitchen and advises switching to new energy efficient cooking appliances.

Table H8. *RSEs for Water Consumption Information for Large Hospitals, 2007*. U.S. Energy Information Administration.

The table's information provides large U.S. hospitals' water consumption information from 2007. The data are organized by area, year constructed, census region, climate zone, heating/cooling equipment, refrigeration, special equipment, and sewer use.

Table WD1. *Daily Water Consumption in Large Commercial Buildings, 2012*. U.S. Energy Information Administration.

This table provides WUI values from commercial buildings like: schools, health care facilities, hotels/motels, offices, churches, etc. The water consumption data come from approximately 45,000 buildings across the United States. These data are organized by total floor space, total consumption, consumption per building, consumption per area, and consumption per worker.

A.2 Residential

Bader, Hans-Peter, Steven J. Kenway, Paul Lant, Tove A. Larsen, and Ruth Scheidegger. 2012. *Water Related Energy in Households: A Model Designed to Understand the Current State and Simulate Possible Measures*. Energy and Buildings, 58: 378-389.

This paper looks at a case study of one family household in Brisbane, Australia to better understand energy use through water consumption in households. Implemented changes to behavioral and technical variables (e.g., change in appliances/fixtures and a switch from gas to solar-powered hot water system) were analyzed to assess energy reduction in the house. Using a material flow analysis to quantify the household flows of water and energy, the study found that the potential reduction for water use, greenhouse gas emissions, water-related energy consumption, water costs, and water-related energy costs were respectively 4-77%, 14-85%, 15-93%, 1-31%, and 13-90%. On technical improvement alone (without the solar hot water system), there was less than a 15% change in energy and gas emission reduction. Combined behavioral and technical changes have a much higher reduction potential.

Butler, D., A. Fidar, and F.A. Memon. 2010. *Environmental Implications of Water-Efficient Microcomponents in Residential Buildings*. Science of the Total Environment, 408: 5828-5835.

England's Code for Sustainable Homes (CSH), an English environmental standard, provides water efficiency benchmarks. This paper describes methods that assess energy consumption and carbon emissions using CSH's benchmarks. One of the key findings was that 96% and 87% of energy use and carbon emissions are attributable to in-house consumption (principally hot water). The findings also showed that defining water efficiency levels does not necessarily save energy or reduce carbon emissions (e.g., dishwashers can save water, but they are more likely to increase the carbon footprint.) However, carefully selected strategies do offer the potential to reduce both energy use and carbon emissions.

USEPA Watersense. 2013. *Version 1.1 WaterSense New Home Specification*. U.S. Environmental Protection Agency.

This document establishes the criteria for new water-efficient homes under the USEPA WaterSense Program. The specifications help reduce indoor and outdoor water usage in new residential homes. The USEPA aims to have new WaterSense Program homes use 20% less water than a typical new home. The document contains a long list of descriptions for fixtures/appliances and includes their performance metrics (e.g., flow pressures, flush volumes, and flow rates).

Lutz, James. 2005. *Estimating Energy and Water Losses in Residential Hot Water Distribution Systems*. eScholarship Repository, University of California.

The current design of hot water systems enables significant loss of energy and water from residential households. These losses include: wasted water while waiting for hot water to get to the point of use, wasted heat as water cools down in the water distribution system after a draw, and wasted energy needed to reheat water that has been heated before. By these processes, approximately 20% of hot water is wasted every day in residential households. The study found that average losses of water (i.e. runs down the drain without being used while consumer waits for hot water) were estimated to be 6.35 gal/day. The amount of wasted hot water was calculated to be 10.9 gal/day.

A.3 Office

Alliance for Water Efficiency. 2016. *Office Building Introduction*. Website. Accessed 23 January 2017, http://www.allianceforwaterefficiency.org/office_buildings.aspx

Office facilities are great places to implement water conservation and water use efficiency techniques. The webpage describes office building water use with consideration to work days per year, gender of workers, gendered facilities, office irrigation systems, and office cooling towers.

Chebaane, Mohamed, and Bill Hoffman. 2011. *Office Buildings Water Efficiency Guide*.

This is an introductory guide, from Jordan, to water efficiency in office buildings. The guide presents reasons for saving water and an account of current Jordanian water use. A list of tips and technologies for best indoor/outdoor water management practices is provided. The guide also informs the reader on how to manage and monitor existing water systems. It introduces potential alternative water sources: harvested rainwater, gray water, and treated wastewater. The document provides a cost-benefit analysis form to help the reader build a stronger argument for adopting a water use efficiency program in an office building.

D&R International, Ltd. 2012. *2011 Buildings Energy Data Book*. Silver Spring, MD: United States Department of Energy.

The Department of Energy's Office of Energy Efficiency and Renewable Energy created a book that provides an extensive set of buildings-related data. Water use data and summaries from residential, commercial, and industrial buildings can be found in chapter 8 of this book. Chapter 8's contents include residential water use by source, per capita residential water use, water billing rate structures, commercial water use by source, and water use amount by commercial industrial establishments (e.g., restaurants and supermarkets).

Proença, Lúcio Costa, and Enedir Ghisi. 2009. *Water End-Uses in Brazilian Office Buildings*. Resources Conservation and Recycling 54 (8): 12.

This paper presents the methods used to estimate the water end-uses of 10 office buildings in Florianópolis, southern Brazil for an evaluation of their potential potable water savings. Assessment of water end-uses is based on estimating water consumption, and this was done via interviews with the buildings' occupants and water flow rate measurements. Interviews confirmed the time and frequency of activities like toilet flushing, faucet use, and cleaning. Faucets and bowl-and-tank toilets were measured for water flow rates. The study confirmed that toilet flushing is responsible for 52-84% of total water consumption in the 10 buildings, followed by faucet water use in seven buildings. The paper concluded that programs for water conservation in office buildings should focus first on toilet flushing as it is responsible for a higher percentage of water consumption in such buildings.

A.4 Mixed Water Usage (Commercial/Industrial, Office, and Residential)

Aquacraft, Inc. 2011. *Embedded Energy in Water Studies, Studies 3: End-Use Water Demand Profiles*. California Institute for Energy and Environment.

In 2007, the California Public Utilities Commission authorized three studies that looked at the relationship between energy savings and water use efficiency. One of the studies, "End-Use Water Demand Profiles," looked at (cold) water use for six end-user categories. Flow trace analysis determined water use patterns, and the study's results included a 24-hour water use profile for each category. One of the studies was conducted during California's drought emergency declaration, and this may have affected studied water usage.

Avid Water Systems. 2011. *Water Usage Estimating Charts for Water Treatment Equipment*.

The information in these charts were prepared as a guide for estimating private and public buildings' maximum flow. The charts also help estimate daily water consumption where meter readings are not available. The assumed water use was calculated using flow rates and probability of use. Facilities included in the charts are include apartment buildings, barber shops, camps, country clubs, department stores, factories, hospitals, restaurants, motels, office buildings, schools, farms, trailer parks, etc.

Chanan, Vinita, Stuart White, Carol Howe, and Meenakshi Jha. 2003. *Sustainable Water Management in Commercial Office Buildings*. Perth, Australia: Innovations in Water: Ozwater Convention & Exhibition.

Although there are many programs in Australia that target efficiency in residential water use, less has been done on commercial office buildings' water use. The report examines the underlying principles and techniques used for sustainable water management practices in commercial office buildings. Alternative water source and technologies like water-efficient fixtures, rainfall capture and use, and treated roof garden effluent water are discussed. The report also reviews two commercial office building sustainable water management studies. The studies found that up to 80% of scheme water demand and 90% reduction of sewage discharge can be achieved in a sustainable commercial building through water capturing and recycling techniques.

GDS Associates, Inc. 2002. *Quantifying the Effectiveness of Various Water Conservation Techniques in Texas*. Austin, TX: TWDB.

The TWDB asked GDS Associates to quantify the effectiveness of water conservation tactics and provide an informed analysis on water conservation strategies' costs for select Texas regions. GDS Associates identified 16 residential and commercial efficiency measures for the study: commercial measures excluded manufacturing, steam electric, mining, agriculture irrigation, and livestock customers. The efficiency measure reports on expected customer participation rates, estimated costs, potential saving, and projected lifetime. The report's data were sensitive to different Texas regions as it had separate calculations and water use analysis for each respective region.

Morales, Miguel A., James P. Heaney, Jacqueline M. Martin. 2009. *Methods for Estimating Commercial, Industrial and Institutional Water Use*. Florida Section of the American Water Works Association (FSAWWA) Water Conference.

The Conserve Florida Water Clearinghouse developed new methods to estimate CII water use by combining billing records with parcel-level land use databases. These methods offer a significant improvement over traditional methods of calculating CII water use. The writers credit the Florida Department of Revenue for the extensive data provided. They also note that future refinements on the calculation tool can be made as/if more data become available. Future work should include a study to analyze the accuracy of the water use estimates described in this paper and the reliability of water and energy savings with conservation efforts. See *Estimating Commercial, Industrial, and Institutional Water Use on the Basis of Heated Building Area* by Friedman et al. (2011) for more recent information on this project.

Morales, Miguel A., James P. Heaney, Kenneth R. Friedman, Jacqueline M. Martin. 2011. *Estimating Commercial, Industrial, and Institutional Water Use on the Basis of Heated Building Area*. American Water Works Association, 103(6): 2-17.

CII users account for a significant proportion of total water withdrawn from water supplies. To estimate CII water use, utilities have historically relied on water use coefficients that use number of employees as the measure of size. However, it is difficult to obtain this information at a resolution fine enough to yield accurate results. The article presents a new method of estimating CII water consumption using water billing records and parcel-level land use databases, primarily from the Florida Department of Revenue (FDOR). Water use data for 3,172 CII parcels are linked with FDOR data to develop average and peak water use coefficients normalized by the heated building area. These new methods surpass previous water use estimate procedures, and thus provide more accurate observations for evaluating water conservation options. See *Methods for Estimating Commercial, Industrial, and Institutional Water Use* by Heaney et al. (2009) for the literature review and a comprehensive research report on the development of these new calculation methods.

South Florida Water Management District. 2013. *Water Efficiency and Self-Conducted Water Audits at Commercial and Institutional Facilities*.

This guidebook highlights common opportunities to improve water efficiency and lower operating costs in commercial and institutional facilities. Commercial and institutional facility managers, owners, and maintenance professionals in all geographic areas can find this guide useful, though it does contain information and resources specific to Florida (set apart from the rest of the text in orange boxes). The guide contains water system audit instructions accompanied by worksheets for managers and practitioners. There is also a section that outlines water efficiency improvement planning for facilities.

U.S. Environmental Protection Agency. 1998. *Water Conservation Plan Guidelines*. Washington, DC: USEPA, pp 163-168.

Appendix B of the guideline report from the U.S. Environmental Protection Agency provides several tables of data regarding water conservation benchmarks. The tables have information regarding: 1998 recent estimates of indoor water use with and without conservation, benchmarks for estimating residential end uses of water, sample calculation of water savings from showerhead replacement, benchmarks for savings from selected conservation measures, water efficiency standards established by the Energy Policy Act of 1992, and potential water savings from efficient fixtures.

U.S. Environmental Protection Agency. 2012. *WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities*. USEPA WaterSense.

WaterSense is a USEPA sponsored program that addresses the increasing strain on the Nation's water resources by supplying the market with water-efficient products and services. This document is WaterSense's compilation of BMPs for water efficiency to help commercial, industry, and institutional facility owners and managers better manage their water use. From x-ray machinery to showerheads to irrigation systems, the guide provides a comprehensive overview of domestic, commercial, and industrial equipment that typically sees significant water end use. The document highlighted operation, maintenance, and user education; retrofit options; replacement options; and savings potential for each of the equipment/practice. It also outlines and describes onsite alternative water sources.

A.5 Other Water Usage Information (Research for Military Installations, History, Methods)

Dziegielewski, Benedykt, and Jack C. Kiefer. 2010. *Appropriate Design and Evaluation of Water Use and Conservation Metrics and Benchmarks*. American Water Works Association, 102(6): 1-15.

Comparison and analysis across seven cities' water utility data resulted in findings that will be helpful when constructing metrics and benchmarks used for achieving higher water use efficiency. The current commonly used metric representing annual water use per capita is not a reliable measure of water use because measures of system size (like housing units, number of employees, etc.) are not updated frequently. The only accurate and regularly updated measure of system size is customer accounts. Metrics of water use should not be used for judging relative water use efficiencies from different geographic locations unless a standardized benchmark is more economically efficient than not having one. The authors suggest that the development of metrics, benchmarks, and efficiency goals should be further disaggregated into specific end uses. Unfortunately, highly disaggregated end-use data are not available for most water utilities. See Dziegielewski and Kiefer's *Water Conservation Measurement Metrics* (2010) for a lengthier analysis and discussion on this topic.

Dziegielewski, Benedykt, and Jack C. Kiefer. 2010. *Water Conservation Measurement Metrics*. American Water Works Association Conservation Division. Subcommittee Report.

This guidance report identifies and characterizes a set of water use and conservation metrics for public water supply utilities. The report's metrics can be used as measurement tools to evaluate the effects of water efficiency programs over time. Seven United States water utilities' data have been used for this project's case studies. This report was summarized in the *American Water Works Association Journal*; see Dziegielewski and Kiefer's *Appropriate Design and Evaluation of Water Use and Conservation Metrics and Benchmarks* (2010) for an article on reframing water measurement metrics.

Gleick, Peter H., Dana Haasz, Christine Henges-Jeck, Veena Srinivasan, Gary Wolff, Katherine Kao Cushing, and Amardip Mann. 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. Pacific Institute for Studies in Development, Environment, and Security.

The report explains California's potential and need for water conservation efforts. The report's seven appendixes numerically details water use, water use assumptions, and potential water savings for residential, commercial, and industrial buildings.

Gregg, Tony, Drema Gross, and Dan Strub. 2007. *Water Efficiency in Austin, Texas, 1983-2005: An Historical Perspective*. American Water Works Association, 99 (2): 79-86.

The article highlights Austin's water supply and historical conservation efforts. In the past few decades, the city of Austin created and implemented programs to improve a multitude of inefficient water end uses. Rebates for the installation of native plants in residents' irrigation systems, incentives for retrofitting inefficient toilets, distribution of free spray rinse valves, and subsidizing the sale of rain barrels are/were just a few of the programs that Austin has implemented in an effort to conserve water.

James J. Hirsch & Associates. 2007. *Water-Energy Measure Calculator*. California Public Utilities Commission Energy Division.

This document describes and explains a spreadsheet calculation tool used to estimate energy (electricity and natural gas) savings that come from water efficiency installations. The document does not clarify what type(s) of building the tool measures.

Jenicek, Elisabeth M., Rebecca A. Carroll, Laura E. Curvey, Melena S. Hessel, Ryan M. Holmes, and Elizabeth Pearson. 2011. *Water Sustainability Assessment for Ten Army Installations*. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory.

Assessment of water demand, supply, and vulnerability was conducted for 10 Army bases across the United States. Analyses were completed on a watershed level and projected over a 30-year time frame. The report's findings present a range of installation water sustainability conditions that reflect the larger picture of water sustainability across the United States.

Jenicek, Elisabeth M., Laura Curvey, Michael P. Case, Mike Follum, Mark Ginsberg, Matthew Hiett, James Valverde, Clint Wilson, Richard Scholze, Amy Allen, Marianne Choi, Yuki Cruz, Noah Garfinkle, Michelle Mehnert, and Justin Montgomery. 2013. *Considerations for Net Zero Water Installations*. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory.

The Army of the United States sets rigorous water conservation requirements for installations to achieve “Net Zero Water.” The achievement of “Net Zero Water” necessitates sustainable buildings that limit the consumption of freshwater resources and return water to the same watershed from which they draw from so as not to deplete the region’s natural ground and surface water. Analytic framework and background on policy relating to the Army’s Net Zero Water program were explained in the research writing. A variety of water models and tools, and conservation and efficiency measures, were evaluated and documented. Most of this document’s research was done for Fort Carson in Colorado, but the concepts apply to the development of all Army installations’ water conservation efforts.

Jenicek, Elisabeth M., Laura Curvey, Yuki Cruz, and Rachel Phillips. 2013. *Water Sustainability Assessments for Four Net Zero Water Installations*. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory.

The report evaluates the Army’s Net Zero Water Army installations for vulnerability to water and supply issues. By assessing regional hydrologic systems, projecting future water demand, and identifying plans to reduce installation demand for fresh water, the research expounds on strategies that enable the installations to be more resilient to water insecurities. The report also explores available data sources and existing data management systems that are used to facilitate and evaluate the installations. Research processes and data capturing methods for per capita water use metrics are also in the report.

Jenicek, Elisabeth M., Natalie R.D. Myer, Donald F. Fournier, Kevin Miller, MeLena Hessel, Rebecca Carroll, and Ryan Holmes. 2009. *Army Installations Water Sustainability Assessment: An Evaluation of Vulnerability to Water Supply*. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory conducted national screenings of watershed vulnerability, prepared regional water budgets for Army installations, and developed installation water demand projections. Section 7.2 of the document provides information on potential water measures that can be employed by Army installations to achieve greater water efficiency. Section 7.2.3 has information on water end use in commercial, industrial, and institutional buildings. Section 7.2.2.7 of the document presents civilian daily water use per capita.

Pacific Northwest National Laboratory. 2013. *Army Net Zero, Water Balance and Roadmap Programmatic Summary*. United States Army.

The document is a summary and evaluation of the Net Zero Water program's progress between 2011 and 2013. The source provides a comprehensive assessment of the eight Net Zero Water pilot installations: Aberdeen Proving Ground, Camp Rilea, Fort Bliss, Fort Buchanan, Fort Carson, Fort Riley, Joint Base Lewis-McChord, and Tobyhanna Army Depot. Details of the installations include water use, facility space, and major water uses.

United States Green Building Council. 2009. *Water Use Reduction Additional Guidance*.

This document was written to provide additional guidance to a series of Leadership in Energy and Environmental Design (LEED) 2009 reports. The contents include: description of fixture groups; examples of total daily use calculations for water closets, urinals, and other fixtures; clarifying information on dual flush toilets flush rates; clarifying information on blow-out fixtures; public metering lavatory faucet; non-potable water use calculations; and clarifying information on gender ratio modifications for water efficiency projects.

Vickers, Amy. 2001. *Handbook of Water Use and Conservation*. Waterflow Press.

The 18th page of Vickers' handbook is a table that presents the Federal maximum water use requirements for toilets, urinals, showerheads, and faucets as required by the U.S. Energy Policy Act (EPAAct). These fixture standards became effective between 1994 and 1997.

Vickers, Amy. 1993. *The Energy Policy Act: Accessing Its Impact on Utilities*. American Water Works Association.

Vickers' 1993 paper confirms that the Energy Policy Act of 1992 will make a significant contribution to the progress of water conservation in the United States. She states there will continuing and incremental reductions in water demand in the future as existing high-volume equipment will be replaced.

White, S., G. Milne, and C. Riedy. 2004. *End Use Analysis: Issues and Lessons*. Sydney, Australia: Institute for Sustainable Futures.

The paper describes methodologies to analyze energy and water end use. It provides insight as to how the methodologies and models may be improved. Furthermore, the paper reviews two case studies – the Sydney Water End Use Model and a study that demonstrates the linkages between end-use modeling of energy using and water-using appliances – to draw conclusions on further improvements for energy and water use analysis methods.

Whitehead, Camilla D. and Moya Melody. 2007. *Water Data Report, Annotated Bibliography*. Lawrence Berkeley National Laboratory.

This document is an annotated bibliography of the sources used to support the efforts of the Environmental Protection Agency's WaterSense program. There is a variety of data on water consumption, water supply, waste water, water quality, and watersheds that are organized by national, state, municipal, and local water classifications.

Appendix B: Facility Type Fact Sheets

Industrial & Maintenance

Database Overview

Number of I&M Facilities	179
Median WUI (GSF/month)	0.19
Average WUI (GSF/month)	24.16
Average Age (years)	26
Facility Area Range (SF)	151 - 118,275
Unique Facility Types	28

Installation Data Frequency

Water Use Intensity

Water users in this facility group have a wide range of monthly WUI values, from 0.000015 GSF to 2864 GSF. The median value is 0.19 GSF/month, and the third quartile value is 0.45 GSF/month. The higher average WUI of 24.16 is primarily due to four catcodes that have high WUI values. These are are labelled in the figure to the right above.

Climate Zone

Differences in WUI between intallations do not appear to be a function of climate zone, rather they are driven by the type of Industrial and Maintenance facilities that reported data at each installation. Fort Knox only has six facilities, three of which have WUI values consistently above 1, with the highest being a combined air-conditioning/heat plant building. Fort Campbell and Fort Bragg have many outliers extending far beyond the range shown to the right. Most of the facilities at these sites have low WUI values, but there are several mid to high WUI facilities at the sites as well such as sewage/waste treatment buildings and combined air-conditioning/heat plant buildings.

Family Housing

Database Overview

Number of Family Housing Units	2,488
Median WUI (GSF/month)	1.41
Average WUI (GSF/month)	1.71
Average Unit Age (years)	27
Facility Area Range (SF)	1,419 - 10,296
Unique Facility Types	6
Median WUI (gallons/occupant/day)	44.1

Installation Data Frequency

96% from Fort Campbell
0.1% from Fort Bragg
3.9% from FLW

WUI by Catcode

WUI Distribution

The median WUI value is 1.41 GSF/mo. The WUI by Catcode chart provides insight into values on each side of the distribution. Housing for Company Grade and Warrant Officers, Senior NCOs, and Junior NCOs/Enlisted had median WUI values less than 1.41 GSF/mo. Housing for General Officers, Colonels, and Lt. Colonels and Majors had median WUI values greater than 1.41 GSF/mo.

The median WUI per occupant based on data from FLW is 1,323 gallons/occupant/month, or 44.1 gallons/occupant/day. The average is 1,592 gal/occupant/month, or 53.1 gallons/occupant/day. This is at the lower range of the literature values of 46-73 gallons per capita per day for single family residences.

Climate Zone & Building Age

There is no clear pattern between WUI by area and climate zone or building age. Assessment is limited by the small amount of data from installations other than Fort Campbell.

Transient Housing

Database Overview

Number of Transient Housing Facilities	29
Average WUI (GSF/month)	2.5
Median WUI (GSF/month)	2
Average Facility Age (years)	32
Facility Area Range (SF)	1,314 – 177,983
Unique Facility Types	5

Installation Data Frequency

Installation (Climate Zone)	# of Water Users	# of Meter Readings
Fort Hood (2)	4	158
Fort Bragg (3)	3	27
Fort Gordon (3)	2	84
Presidio of Monterey (3)	6	287
Fort Campbell (4)	3	132
Fort Knox (4)	5	64
Fort Carson (5)	4	128
Fort Drum (6)	2	42

Eight installations in 5 climate zones have data for Transient Housing Installations. Unlike many other facility groups, installations provided a similar number of water users and meter readings.

WUI Distribution

The median WUI of 2 GSF/month is much less than the 2012 Commercial Buildings Energy Consumption Survey's report of 42 GSF/month for lodging buildings (like hotels). One factor in the difference between installation and U.S. average is the different types of lodging establishments offered on installations. Our transient housing dataset includes guesthouses, which are more akin to single-family residences in their water consumption characteristics.

Time Series Example

Transient Housing WUI fluctuates monthly and seasonally as seen in the above time series for Presidio of Monterey. Of the eight installations, Campbell and Presidio showed explicit seasonal water consumption patterns – using more water in the summer and less in the winter.

WUI by Catcode

The median value of water use intensity for transient housing is relatively similar across category codes. The close-fitting average water use intensity interval and tight median range indicates that these catcode categories are in the appropriate facility group.

Barracks

Database Overview

Number of Barracks Buildings	272
Average WUI (GSF/month)	2.8
Median WUI (GSF/month)	2.4
Median WUI (gal/occupant/day)	44
Average Building Age (years)	18
Facility Area Range (SF)	3,659 – 150,816
Unique Facility Types	6

Climate Zone

The figure above shows WUI for barracks across installations, colored by climate zone. There is not enough data from all the climate zones to draw conclusions about the effect of climate on barracks WUI. Fort Gordon's median WUI and wide WUI range is higher than the other five installations in climate zones 3 and 4.

WUI Distribution

The two figures above show WUI by area (left) and occupant (right). WUI by occupant should provide a more accurate representation of water consumption than WUI by area since it is tied to the primary driver of barracks water use – the soldiers. The WUI by occupant distribution only contains data from Fort Campbell, as occupancy data was not available for other sites. Using the median WUI by area and occupant, we calculated daily soldier water consumption. The median daily WUI by area came to be 7.2-10.8 gallons/soldier while the median daily WUI by occupant was 44 gallons/soldier. The WUI by occupant value is far closer to Net Zero Water Initiative estimate of 55 gallons/day for soldier water use in barracks.

WUI Time Series

The figure to the left shows seasonal trends in water use as well as which installations have consistent metering practices over time. Presidio of Monterey is an example of dependable water meter tracking in our database. Looking at Presidio's time series line, extreme dips in water consumption occur at the end of every year which is most likely due to low barracks occupancy during the holiday season.

Community & Commercial: Non-Food (Indoor)

Database Overview

Number of C&C: Non-Food Facilities	158
Average WUI (GSF/month)	6.3
Median WUI (GSF/month)	1
Average Facility Age (years)	32
Facility Area Range (SF)	659 – 387,338
Unique Facility Types	39

Installation Data Frequency

Installation (Climate Zone)	# of Water Users	# of Meter Readings
Fort Gordon (3)	11	589
Presidio of Monterey (3)	16	1044
Fort Bragg (3)	44	662
Fort Leonard Wood (4)	6	264
Fort Knox (4)	13	193
Fort Campbell (4)	51	2372
Fort Carson (5)	9	286
Fort Drum (6)	8	523

Eight installations in four climate zones have water meter data for facilities in the C&C: Non-Food (Indoor) group. Climate zones 3 and 4 have a similar amount of water users. While Campbell and Bragg have the most water users, Campbell and Presidio of Monterey contributed the most water meter readings.

WUI Distribution

WUI values over 100 GSF/month represent a small proportion of meter data – only 79 meter readings out of 5,933 total meter readings in the facility group (1%). The figure on the right shows the distribution of C&C: Non-Food (Indoor) meter readings with WUI values less than five; 89% of all meter readings are in this range.

WUI by Catcode

Despite the large number of catcodes in this facility group, most WUI values are relatively close. The catcodes with high WUIs are: miscellaneous detached facilities for soldiers (catcode 72360), family life centers (73019), riding stables (74049), recreational equipment checkouts (74065), recreational support buildings (74075), and outdoor pool service buildings (74089). These high WUIs might be explained by water used for maintenance, cleaning, and cooling purposes.

Community & Commercial: Food

Database Overview

Number of C&C: Food Facilities	42
Median WUI (GSF/month)	6.19
Average WUI (GSF/month)	7.91
Average Unit Age (years)	23
Facility Area Range (SF)	3,317 - 69,121
Unique Facility Types	9
Median WUI (gallons/meal)	11.0

Water Use Intensity

The median WUI value is 6.19 GSF/month. 35% of WUI values above 20 GSF are from two dining facilities at Fort Campbell.

The number of meals served at DFACs (catcode 72210) was available for 107 months from Fort Campbell, and 3 months from Fort Leonard Wood. The median WUI value was 11.0 gallons per meal. This is higher than literature values from PNNL studies, which have ranges of 3.5-8.5 gallons/meal for climate zone 4. There is wide variation between WUI by meal values for the 8 individual DFAC buildings that have meal data, from 0.89 gallons/meal to 69.5 gallons/meal.

Installation Data Frequency

This facility group had at least one water use at each installation, though comparison is limited by the small number of buildings at each installation and lack of overlap between building types.

WUI by Catcode

Catcodes 74051 (Exchange cafeteria), 74064 (post restaurant), 72210 (dining facility), and 74062 (fast food/snack bar) had the highest median WUI values. Catcodes 74048 (officer open dining facility), 74050 (Exchange branch), 74058 (Exchange concession), 74046 (consolidated open dining facility), and 74047 (enlisted open dining facility) had lower median WUI values.

Climate Zone

Facilities at Fort Hood have the highest median WUI value. Fort Campbell provided the most meter readings and has the most outliers. No WUI pattern based on climate zone is apparent.

High Energy Use Facilities

Database Overview

Number of High Energy Use Facilities	41
Average WUI (GSF/month)	2.19
Median WUI (GSF/month)	0.36
Average Age (years)	18
Facility Area Range (SF)	600-186,216
Unique Facility Types	13

Climate Zone

The boxplot of WUI by installation colored by climate zone above shows no discernable pattern between WUI and climate zone for High Energy Use Facilities. The median WUI value was close to zero for almost all of the installations besides Fort Gordon, Presidio of Monterey, and Fort Knox.

WUI Distribution

The WUI distribution is skewed to the right with a median WUI value of 0.36 GSF/month and an average WUI value of 2.19 GSF/month. Most high energy use facilities do not have high water use intensities.

In the time series graph below, Fort Knox does not vary between months so it is reasonable to assume that these values were estimated. There are regular patterns between traces in the time series, indicating that seasonality is not a factor in the water consumption for high energy use facilities.

Time Series

Medical

Database Overview

Number of Medical Facilities	153
Average WUI (GSF/month)	2.0
Median WUI (GSF/month)	1.0
Average Unit Age (years)	29
Facility Area Range (SF)	800 – 1,667,747
Unique Facility Types	10

WUI Distribution

The median WUI value for Medical facilities is 1.0 GSF/month. 59 WUI values ranging from 20–108 GSF/month were not included in the figure.

Installation Data Frequency

Climate Zone

All nine installations had meter data from the Medical facility group. Most of this data came from Fort Hood. While the amount of data received from installations varied, median WUI across installations was less than 3 GSF/month. There were 23 WUI values that ranged from 25 – 108 GSF/month from Hood, Gordon, FLW, and Campbell.

WUI by Catcode

Army medical facilities include health clinics, pharmacies, laboratories, ambulance garages, dental clinics, and veterinary clinics. For modeling and planning purposes, installations should consider different categorizing strategies for human and animal care facilities. Catcode 51010 is hospitals – according to the EPA, hospitals are among the facilities with the highest WUI. In our data, hospitals have the second highest median WUI, behind 53025 (pharmacies).

Administration & Operations

Database Overview

Number of Admin & Operations Facilities	412
Median WUI (GSF/month)	0.43
Average WUI (GSF/month)	0.64
Average Unit Age (years)	23
Facility Area Range (SF)	64 - 369,662
Unique Facility Types	25

Climate Zone

All installations have similar median and interquartile range values for this facility group. There are also many outliers, particularly for Fort Gordon, Fort Bragg, and Fort Campbell. There is no clear pattern based on climate zone.

Installation Data Frequency

This facility group had at least one water user at each installation, though comparison is limited by the small number of buildings at each installation and lack of overlap between building types.

WUI Distribution

The median WUI value is 0.43 GSF/month. 75% of values are below 0.76 GSF/month, and the maximum WUI value is 32.1 GSF/month.

33.3- 91.7 gallons/person/day

Five meter readings for Company Headquarters Buildings at Fort Campbell had corresponding occupancy data. The water use intensity values ranged from 33.3 to 91.7 gallons/person/day, with an average of 54.9 and a median of 41.9 gal/person/day.

WUI by Catcode

WUI values for most catcodes in this facility group are less than 2 GSF/month, but several catcodes have higher WUI values. These are: 61070- Red Cross Building, 14113 - Access Control Facility, 14161- Emergency Operations Center, 14177- Decontamination Building, and 61055 - Waiting Area/In-Out Processing. Note that aside from 14113, each of these high-WUI catcodes only had one facility, so these values are not representative of WUI values for these catcodes across all installations.

Other Training and Schools

Database Overview

Number of Other Training and Schools Facilities	109
Average WUI (GSF/month)	0.63
Median WUI (GSF/month)	0.39
Average Facility Age (years)	24
Facility Area Range (SF)	1139-187,128
Unique Facility Types	16

Climate Zones

The boxplot of WUI by installation colored by climate zone shows no distinct pattern between WUI and climate zone. There were a total of 4,490 observations reported to the database for Other Training and Schools, a majority of which were reported by Presidio of Monterey (2,844 observations).

WUI by Catcode

WUI Distribution

The majority of the category codes fall within the shaded confidence interval except for Category Code 74017, which is a Child Development Center for children under the age of 6 years old, and 71135, which is an instructional laboratory building. Even though these two category codes deviate from the confidence interval for the Facility Group, their median values still remain under 4 GSF/month.

The figure above shows the WUI distribution. The median WUI does not exceed 11 GSF/month. As the red line indicates, the median WUI value for the group is 0.39 GSF/month. Note that the graph is skewed right, and the average (0.63 GSF/month) is greater than the median due to the observations at the upper range of the distribution.

Storage

Database Overview

Number of Storage Facilities	62
Average WUI (GSF/month)	5
Median WUI (GSF/month)	0.15
Average Facility Age (years)	26
Facility Area Range (SF)	196-167,555
Unique Facility Types	8

WUI by Mission

Mission	Installation	Median WUI	# of Readings
Maneuver	Carson, Campbell, Bragg, Drum	0.14	1615
Professional Development	Presidio of Monterey	0.16	276
Training	Gordon, Knox	.39	109

The figure above shows WUI by mission type. Maneuver installations had the most meter readings collected and a higher WUI average.

WUI Distribution

The figure to the left shows the WUI distribution with a rug plot for all meter readings. A majority of buildings have a small monthly WUI – less than 10 GSF. 65 meter readings ranging from 50 to 540 GSF/Month were not included in the figure.

WUI by Category Code

Storage facilities can be highly varied in function. While some storage buildings are general purpose storage sheds (catcode 44222), others are buildings for hazardous material storage (catcode 44288). The difference in building purpose explains the difference in WUI. The two category codes with the highest number of buildings (44224 and 44220) are organizational storage and general purpose storage buildings.

High Water Use Facilities

Database Overview

Number of High Water Use Facilities	10
Median WUI (GSF/month)	24.4
Average WUI (GSF/month)	32.0
Average Unit Age (years)	30
Facility Area Range (SF)	733 - 4,806
Unique Facility Types	3

Installation Data Frequency

This facility group had at least one water user at six of the nine study installations. Five of these six installations (all but Presidio) reported data for a car wash.

Climate Zone

No pattern in WUI by climate zone is clear. Fort Carson had the highest median WUI value in this Facility Group, and Presidio had the lowest, though Presidio's data is for a separate toilet/shower building as opposed to a car wash.

WUI by Catcode

Meter data in this facility group came from only three distinct catcodes: 74059 (Exchange Car Wash), 74019 (MWR Car Wash), and 73075 (Separate Toilet/Shower Building). Water use for car washes and the toilet/shower building is expected to be tied to number of vehicles washed and the type of fixtures in the toilet/shower building, as well as number of users. This data would likely provide a more useful metric than the intensity by area.

WUI Distribution

The median WUI for this group is the highest of any facility group at 24.4 GSF/month. This is due to the function of these buildings as well as their relatively small total areas.

Water Usage

SWIMMING POOL

AVERAGE: 243,594

MEDIAN: 105,930

WASH FACILITY

2,610,609 gal./month

4,000 gal./month

There were five buildings in two category codes in this group that did not have an associated area, and thus no water use intensity by area was calculated. These were three outdoor swimming pools and two centralized wash facilities with soaking capability at Fort Campbell. Values for monthly water usage are shown above. Usage values for wash facilities were highly variable, spiking in the spring and summer.

Community and Commercial: Non-Food (Outdoor)

Database Overview

Number of C&C:Non-Food (Outdoor) Facilities	2
Average WUI (GSF/month)	18.89
Median WUI (GSF/month)	14.6
Average Facility Age (years)	7
Facility Area Range (SF)	7,121-369,662
Unique Facility Types	2

WUI by Catcode

The only installation to report meter data for the Community and Commercial: Non-Food (Outdoor) category was Presidio of Monterey (POM) in Climate Zone 3. There are a total of 55 observations collected from two buildings with a median value of 14.6 GSF/month. Since only two water users were reported, no significant conclusions can be made regarding water use for this Facility Group.

Time Series

Installation Name	Building #	Category Code	Average (GSF/month)	Median (GSF/month)	Observations
Presidio Of Monterey	701	75022	22.50	14.60	46
Presidio Of Monterey	400	75018	0.452	0.333	9

The water users reported were in Catcodes 75022 and 75018. Hilltop Field (Catcode 75022), is a multi-purpose athletic field (133,682 SF) that is used for training and recreational activities and also has a court area (7,121 SF). Category Code 75018 is 369,662 square feet and is being used as a playground. As shown by the table above, Hilltop Field reported 46 of the 55 total observations in this Facility Group, so the overall average and median WUI values primarily reflect usage at this field.

Dependent Schools

Database Overview

Number of Dependent Schools	30
Average WUI (GSF/month)	1.7
Median WUI (GSF/month)	0.9
Average Facility Age (years)	34
Facility Area Range (SF)	4,160-116,047
Unique Facility Types	1

Climate Zone

Three climate zones are represented in the Dependent Schools facility group: 3 (orange), 4 (yellow), and 5 (green). The boxplot above shows no distinct pattern between WUI and climate zone for Dependent Schools. Fort Campbell provided the most meter readings (737 out of 1,124) but has the lowest WUI (0.8 GSF/month).

WUI Distribution

The figure to the left shows the WUI distribution. The distribution skews right with a median WUI of 0.9 GSF/month and an average WUI of 1.7 GSF/month. The maximum WUI is 8.15 GSF/month.

The time series below illustrates seasonal variation in WUI, with lower WUI values during school breaks. WUI fluctuation is observed for all installations except Fort Knox, which suggests that data from Fort Knox was estimated.

Time Series

Irrigated Lands

Database Overview

Number of Irrigated Lands	3
Average WUI (GSF/month)	0.94
Median WUI (GSF/month)	0.5
Average Land Age (years)	51
Land Area Range (SF)	40,544-2,003,760
Unique Land Types	2

Installation WUI

Two installations reported 156 observations from three irrigated areas within two catcodes. As depicted by the figure above, the median and average for this Facility Group are largely driven by the data from Presidio of Monterey (POM). The two meters at POM are designated for the Post Cemetery and the meter at Fort Campbell is used for their Parade/Drill Field. The median values for Fort Campbell and Presidio of Monterey are 0.000120 and 0.80140 (GSF/month), respectively.

WUI Distribution

The figure to the left shows the WUI distribution for the two installations. The distribution skews right, does not exceed 6 GSF/month and the overall median value is 0.5 GSF/month.

The time series figure below illustrates that WUI at Presidio is highest during the summer months, as expected. Compared to Presidio of Monterey, Fort Campbell has a significantly lower WUI. Because its data was reported inconsistently, we cannot make any conclusion regarding the seasonality of its water use.

Time Series

Time Series: Fort Campbell

Miscellaneous

Database Overview

Number of Miscellaneous Facilities	8
Median WUI (GSF/month)	26.7
Average WUI (GSF/month)	80.3
Average Unit Age (years)	46
Facility Area Range (SF)	305 - 212,650
Unique Facility Types	6

Climate Zone

No pattern in WUI by climate zone is apparent. The facilities with the highest WUI values are located at Fort Campbell.

WUI Distribution

The median WUI value for this facility group is 26.65 GSF/month. WUI values are expected to vary widely since users in this group do not share a common function. The first quartile WUI value is 2.4, the third quartile value is 83.8, and the maximum WUI value is 818.1 (all values in GSF/month).

Installation Data Frequency

Only three installations in two climate zones had water users in the Miscellaneous facility group. Fort Campbell provides 69% of all meter readings in this group. Fort Campbell also has several water users in this category with no area and thus no water use intensity by area. Monthly usage for these facilities in gallons is shown in the boxplot below.

Water Usage

Facilities at Fort Campbell with no area are: cable vault (13252), monuments/memorials (76020), non-potable pump station (84472), sewage lift station (83150), and waste POL storage tank (89550).

WUI by Catcode

The boxplot above shows which catcodes are associated with different ranges in the histogram to the left. Catcodes 81160 (Standby generator), 69010 (Flagpole), and 89148 (Water storage building) have WUI medians of 1 GSF/mo. or less, and 28% of all data points are within these catcodes. 84125 (Filter plant facility) and 89141 (water supply/treatment building, potable) have WUI medians of 20 and 35 GSF/mo., respectively, and 37% of all readings are in these groups. Catcode 89144 (water supply building, non-potable) has a median WUI of 78 GSF/mo., and 35% of readings are in this group.

Appendix C: Real Property Breakdown for Each Installation

Group	Fort Leonard Wood		Fort Hood		Fort Bragg		Fort Gordon	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1	100	2.4%	289	4.5%	267	4.1%	24	5.2%
2	1,085	26.1%	3,372	52.2%	3,235	50.2%	271	58.5%
3	36	0.9%	4	0.1%	25	0.4%	-	0.0%
4	254	6.1%	141	2.2%	130	2.0%	6	1.3%
5	102	2.5%	180	2.8%	168	2.6%	8	1.7%
6	28	0.7%	18	0.3%	26	0.4%	2	0.4%
7	17	0.4%	65	1.0%	47	0.7%	7	1.5%
8	10	0.2%	47	0.7%	29	0.4%	1	0.2%
9	170	4.1%	637	9.9%	629	9.8%	24	5.2%
10	720	17.3%	139	2.2%	56	0.9%	9	1.9%
11	182	4.4%	80	1.2%	1,033	16.0%	28	6.0%
12	98	2.4%	91	1.4%	55	0.9%	4	0.9%
13	253	6.1%	159	2.5%	26	0.4%	-	0.0%
14	270	6.5%	204	3.2%	40	0.6%	1	0.2%
15	4	0.1%	4	0.1%	-	0.0%	-	0.0%
16	36	0.9%	11	0.2%	1	0.0%	-	0.0%
17	21	0.5%	14	0.2%	16	0.2%	2	0.4%
18	232	5.6%	213	3.3%	263	4.1%	24	5.2%
19	6	0.1%	9	0.1%	13	0.2%	—	0.0%
20	54	1.3%	25	0.4%	6	0.1%	—	0.0%
21	473	11.4%	761	11.8%	381	5.9%	52	11.2%
	4,151	100.0%	6,463	100.0%	6,446	100.0%	463	100.0%

Source: HQIIS (Downloaded August 2017)

Group	Presidio of Monterey		Fort Campbell		Fort Knox		Fort Carson	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1	132	6.7%	195	5.2%	109	3.6%	137	4.6%
2	944	47.8%	2,018	54.2%	1,392	45.4%	1,061	35.6%
3	8	0.4%	9	0.2%	24	0.8%	45	1.5%
4	21	1.1%	77	2.1%	59	1.9%	76	2.6%
5	33	1.7%	83	2.2%	108	3.5%	46	1.5%
6	7	0.4%	17	0.5%	14	0.5%	20	0.7%
7	18	0.9%	36	1.0%	16	0.5%	24	0.8%
8	5	0.3%	19	0.5%	12	0.4%	24	0.8%
9	42	2.1%	357	9.6%	113	3.7%	237	8.0%
10	50	2.5%	52	1.4%	161	5.2%	115	3.9%
11	114	5.8%	289	7.8%	138	4.5%	680	22.8%
12	3	0.2%	15	0.4%	85	2.8%	84	2.8%
13	53	2.7%	-	0.0%	-	0.0%	-	0.0%
14	13	0.7%	41	1.1%	34	1.1%	28	0.9%
15	147	7.4%	-	0.0%	-	0.0%	1	0.0%
16	33	1.7%	25	0.7%	4	0.1%	-	0.0%
17	56	2.8%	24	0.6%	121	3.9%	18	0.6%
18	40	2.0%	53	1.4%	71	2.3%	92	3.1%
19	-	0.0%	11	0.3%	101	3.3%	5	0.2%
20	3	0.2%	134	3.6%	109	3.6%	5	0.2%
21	252	12.8%	265	7.1%	396	12.9%	280	9.4%
	1,974	100.0%	3,720	100.0%	3,067	100.0%	2,978	100.0%

Source: HQIIS (Downloaded Aug 2017)

Group	Fort Drum		Combined	
	Number	Percent	Number	Percent
1	179	3.6%	1,432	4.2%
2	1,677	34.1%	15,055	44.0%
3	11	0.2%	162	0.5%
4	110	2.2%	874	2.6%
5	117	2.4%	845	2.5%
6	8	0.2%	140	0.4%
7	22	0.4%	252	0.7%
8	26	0.5%	173	0.5%
9	280	5.7%	2,489	7.3%
10	268	5.4%	1,570	4.6%
11	316	6.4%	2,860	8.4%
12	129	2.6%	564	1.6%
13	628	12.8%	1,119	3.3%
14	167	3.4%	798	2.3%
15	1	0.0%	157	0.5%
16	12	0.2%	122	0.4%
17	190	3.9%	462	1.4%
18	360	7.3%	1,348	3.9%
19	-	0.0%	145	0.4%
20	7	0.1%	343	1.0%
21	413	8.4%	3,273	9.6%
	4,921	100.0%	34,183	100.0%

Source: HQIIS (Downloaded Aug 2017)

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14. ABSTRACT Water is a critical resource for the U.S. Army's global mission. Insufficient supplies will compromise readiness and mission sustainment, and affect the ability to train and support the force. Incorporation of water availability into the Army's stationing analysis framework is being considered; however, there is insufficient data to determine the critical amount of water required by installations, and insufficient guidance on how to achieve reductions in water directed to non-essential functions. The ability to quantify a minimum sustainable amount of required water for prioritizing allocation is invaluable to sustaining the mission. This work was undertaken to develop water use intensity factors for the range of facilities found at installations to determine: the range of water demand for an installation; how long an interruption in water supply can be tolerated; how water demand varies in relation to such "use factors" as square footage, population, etc.; and the correlation between water demand and climate zone.					
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