



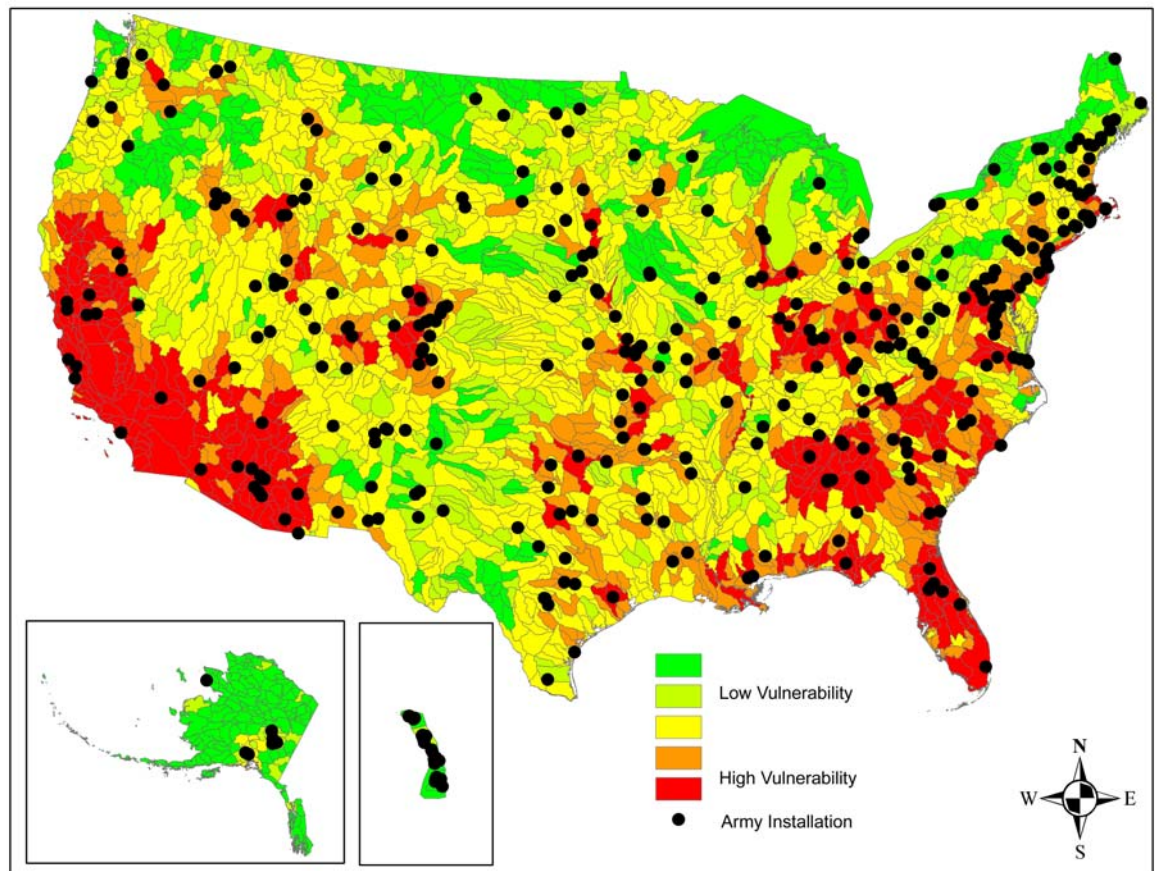
**US Army Corps
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Army Installations Water Sustainability Assessment

An Evaluation of Vulnerability to Water Supply

Elisabeth M. Jenicek, Natalie R.D. Myers, Donald F. Fournier,
Kevin Miller, MeLena Hessel, Rebecca Carroll, and Ryan Holmes

September 2009





**US Army Corps
of Engineers®**
Engineer Research and
Development Center



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An Evaluation of Vulnerability to Water Supply

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Final Report

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Abstract: A key concern for the U.S. Army is the vulnerability of military installations to critical resource issues. Water issues of concern—including adequate supply, increased cost of production per unit volume, quality, habitat degradation and salinity issues—already impact military installations and military operations in many locations within the nation and across the globe. There is a need to assess vulnerability of regions and installations to water supply and to develop strategies to ameliorate any adverse effects on the triple bottom line. This work employed methodologies developed by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) to conduct national screenings of watershed vulnerability, prepare regional water budgets documenting supply and demand in regions containing Army installations, and develop installation water demand projections. The methodologies look beyond the fenceline and 30 years into the future to identify the potential for water scarcity. Water law is described on a region-by-region basis and instructions are provided for developing a water conservation program. Recommendations are made for achieving Federal water conservation targets contained in Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*.

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Table of Contents

List of Figures and Tables	v
Preface	viii
Unit Conversion Factors.....	ix
1 Introduction.....	1
1.1 Background.....	1
1.2 Objective	2
1.3 Approach	2
1.4 Mode of technology transfer	3
2 Water Vulnerability Issues for Army Installations.....	4
2.1 Water trends of concern.....	4
2.1.1 Rising demand for water.....	4
2.1.2 Water quality.....	5
2.1.3 Climate change	5
2.1.4 Land Use Trends	6
2.1.5 Groundwater Depletion.....	7
2.1.6 The Energy/Water Nexus.....	8
2.2 Army water challenges	11
2.3 Federal and DOD water policy.....	12
2.3.1 Energy Independence and Security Act of 2007 (EISA) 2007	12
2.3.2 Executive Order 13423.....	13
2.3.3 Department of Energy (DoE) Supplemental Guidance.....	13
2.3.4 Historical Water Policy	15
3 Water Policy	16
3.1 Water policy impacts on Army installations.....	16
3.1.1 Regional and installation water trends.....	16
3.1.2 Federal water policy and the impacts to Army installations	18
3.1.3 State and regional water policies.....	22
3.2 Total Water Management (TWM)	29
4 National Screening for Watershed Sustainability	36
4.1 Regional resource assessment framework and metrics	38
4.2 Watershed assessment indicators	38
4.3 Analysis methodology.....	41
4.3.1 Concept.....	41
4.3.2 Methodology.....	41
4.4 Watershed sustainability scores results.....	43
4.5 Installation-Region Sustainability Scores.....	46
4.6 Interpreting the results.....	52

4.6.1	Framework limitations	53
4.6.2	Using Appendix B	55
5	Evaluating Regional Water Availability.....	56
5.1	Introduction.....	56
5.2	General methodology	56
5.2.1	Regional characterization.....	59
5.2.2	Developing the regional model.....	63
5.2.3	Projecting water supply and demand trends.....	69
5.2.4	Water sustainability assessment	71
5.3	Case Study: Fort Bragg, NC.....	71
5.3.1	Regional characterization of Fort Bragg.....	72
5.3.2	Developing the Fort Bragg regional model	80
5.3.3	Projecting water supply and demand trends in the Fort Bragg regional model	88
5.3.4	Water sustainability assessment of the Fort Bragg regional model.....	93
5.4	Case Study: Fort Bliss, TX.....	94
5.4.1	Regional characterization of Fort Bliss	94
5.4.2	Developing the Fort Bliss regional model	103
5.4.3	Projecting water supply and demand trends in the Fort Bliss regional model	113
6	Projection of Installation Water Demand.....	123
6.1	Introduction.....	123
6.2	Water demand model.....	123
6.2.1	Drivers for water demand	123
6.2.2	Water use data	123
6.2.3	Model development and testing.....	124
6.2.4	Model results	124
6.3	Case Study: Fort Bragg, NC.....	125
6.3.1	Establishing the baseline.....	125
6.3.2	Projecting Fort Bragg usage	125
6.4	Case Study: Fort Bliss, TX.....	127
6.4.1	Establishing the baseline.....	127
6.4.2	Projecting Fort Bliss usage	127
6.5	Conclusion	129
7	Water Efficiency Planning.....	130
7.1	Developing a Water Efficiency Plan	130
7.1.1	Analyze water use	131
7.1.2	Identify and analyze water efficiency measures	131
7.1.3	Water efficient measure selection	132
7.1.4	Create a formal plan	132
7.2	Water Conservation and Efficiency Measures	133
7.2.1	Water monitoring and loss programs.....	133
7.2.2	Residential buildings.....	137
7.2.3	Commercial, industrial, and institutional buildings.....	146
7.2.4	Landscaping.....	152
7.2.5	High water use facilities.....	157

7.2.6 Alternate water sources.....	160
8 Conclusions.....	164
8.1 Summary.....	164
8.2 Issues Affecting Water Availability on Army Installations	165
8.3 Recommendations	167
8.3.1 Emphasize Water Manager Staffing and Centralize Data Collection	167
8.3.2 Include Water Efficiency Measures in all Projects	167
8.3.3 Adopt a Program of Total Water Management (TWM).....	167
8.3.4 Continue to Emphasize Metering/Infrastructure Upgrades	168
8.3.5 Conduct a Comprehensive Review of Installation Water Rates/Contracts	168
8.3.6 Engage the Local Community in Planning for Sustainable Water	168
References.....	170
Acronyms and Abbreviations	181
Appendix A: Indicator Metadata	185
Appendix B: Indicator Data Values	229
Appendix C: Indicator Maps.....	230
Appendix D: State Agencies Pertaining to Water	241
Appendix E: Modeling Stream Flows.....	244
Appendix F: Modeling Installation Demand	247
Report Documentation Page.....	260

List of Figures and Tables

Figures

1. Vulnerability to groundwater depletion	8
2 Thermoelectric power energy withdrawals, 10-year change	9
3 Water basin regions of the United States (source: USGS <i>1990 Water Rights of the Fifty States and Territories</i>)	17
4 State surface water doctrines.....	23
5 State groundwater doctrines	24
6 Watershed indicator level reporting methodology.....	42
7 Distribution of vulnerability scores for watersheds and installations.....	44
8 Watershed vulnerability scores	45
9 Army installation watershed vulnerability scores.....	46
10 Watershed vulnerability scores	51
11 Army installation watershed vulnerability scores.....	52
12 The hydrologic cycle (Shultz 2009)	57
13 Surface-groundwater interaction (Winter et al. 1998)	58
14 National HUC and aquifer maps (source: USGS, National Atlas)	59
15 Regional water demand model	67
16 Fort Bragg region political boundaries (USGS, U.S. Census, DOD)	74
17. Fort Bragg hydrologic features (USGS, U.S. Census, DOD).....	75
18 Fort Bragg soil types (USGS, U.S. Census, DOD).....	77
19 Fort Bragg regional land use summary (USGS)	78
20 Annual and 10-year lowest 7-day average flow (USGS)	81
21 Dam release ratio vs. flow in Haw River (USGS)	85
22 Average annual flows in Cape Fear watershed (USGS).....	85
23 Little River at gage 02103500, 7Q1 flow (USGS).....	86
24 Fort Bragg upstream region projected withdrawals (ibid).....	87
25. Fort Bragg Water Supply Model.....	88
26 Fort Bragg water availability base case (ibid).....	91
27 Fort Bragg water availability with climate change (ibid).....	91
28 Fort Bragg water availability worst case (ibid).....	92
29 Fort Bliss regional population growth projections (U.S. Census).....	95
30 Fort Bliss political boundaries map (U.S. Census, National Atlas, USGS, Google Earth orthophotos).....	96
31 Regulations affecting the Rio Grande include International treaty requirements (Texas Water Development Board (TWDB), The Watercourse, USGS, U.S. Census).....	97
32 1944 International treaty allocations (TWDB)	97

33	Agencies supervise and allocate Rio Grande Project water (Turner et. al, TWDB, USGS, U.S. Census, The Watercourse)	98
34	Fort Bliss regional land use (USGS)	102
35	Annual flows in the Rio Grande River (USGS)	105
36	Long term historical flows at the El Paso gage showing variability (USGS).....	105
37	Hueco Bolson aquifer depletion trend – Gage JL-49-06-702 (USGS)	107
38	Fort Bliss hydrologic features map (groundwater sources) (U.S. Census, National Atlas, USGS, El Paso Water Utilities)	108
39	Mesilla Bolson aquifer depletion trend – Gage JL-49-04-418 (USGS)	110
40	Allotment of water rights during low flow years (IBWC)	111
41	Fort Bliss region projected withdrawals (includes irrigation) (ibid.).....	112
42	Projected municipal and industrial water demand (no irrigation) (ibid.)	112
43	Fort Bliss water supply model.....	113
44	Projected reduction in West Texas runoff (Global Climate Change Impacts in the United States 2009)	119
45	Potential for West Texas and New Mexico Water Supply Conflict (Global Climate Change Impacts in the United States 2009).....	120
46	Fort Bragg historical water consumption (Fort Bragg DPW)	125
47	Projected Fort Bragg water consumption	127
48	Fort Bliss historical water consumption (AEWRS).....	128
49	Projected Fort Bliss water consumption	129

Tables

1	State water policy and administering agencies	25
2	Water-related interstate compacts.....	30
3	Indicators for assessing watershed sustainability.....	40
4	Statistics of scores.....	44
5	Vulnerability ranges	44
6	Army installation average vulnerability scores by basin.....	47
7	Highly vulnerable Army installation watersheds by basin	48
8	Very low vulnerability ranked installations.....	50
9	Vulnerable basins and installations at high vulnerability.....	53
10	Total upstream County water consumption (MGD), CY2000 (USGS)	79
11	Proposed Jordan Lake drought operating rules (NCDWR 2008)	82
12	Projected upstream water withdrawals (USGS, NC Demographer, U.S. Census)	87
13	Summary of Fort Bragg Regional Scenarios (MGD) (derived from USGS data).....	90
14	Year 2000 water use in the Fort Bliss region (MGD) (USGS).....	103
15	Hueco Bolson groundwater storage per chloride level (Hutchison 2004)	107
16	Projected water withdrawals for El Paso County in MGD (Hutchison 2004).....	111
17	Projected water withdrawals for Ciudad Juarez in MGD (Hutchison 2004)	111
18	Summary of Fort Bliss scenario projections (Hutchison 2004)	117
19	Population and infrastructure data used for Fort Bragg (Fort Bragg).....	125

20	Initial installation baseline projected consumption for Fort Bragg	126
21	Population and infrastructure data used for Fort Bliss (Fort Bliss).....	128
22	Initial installation baseline projected consumption for Fort Bliss	128
23	Average daily uses of toilet types per capita	144
24	Average daily uses of fixtures and washers per capita	144
25	Water use amounts and average retail cost of various water appliances	144

Preface

This study was conducted for the Army Environmental Policy Institute under project “Army Installations Water Sustainability Study,” Work Unit LGD638. The technical monitor was Mr. David Sheets, Senior Fellow, Army Environmental Policy Institute (AEPI).

The work was performed by the Energy Branch (CF-E) of the Facilities Division (CF), and the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Elisabeth M. Jenicek (CF-E). Part of this work was done by Donald F. Fournier of the University of Illinois at Urbana-Champaign under Cooperative Agreement number W9132T-07-2-0001 and by Kevin Miller, MeLena Hessel, Rebecca Carroll, and Ryan Holmes of UIUC under Contract W9132T-06-C-0025. Special appreciation is owed to Dr. Katherine White (ERDC-CRREL) for technical review and input into the content of this document, and to Mr. Keith Landreth and Mr. Dave Heins, the study contacts at Fort Bliss and Fort Bragg, respectively. Franklin H. Holcomb is Acting Chief, CF-E. Alan Anderson is Chief, CN-N. L. Michael Golish is Chief, CF, and Dr. John Bandy is Chief, CN. The associated Technical Director is Martin J. Savoie, CEERD-CV-T and the director of CASI is William Goran. The Director of CERL is Dr. Ilker R. Adiguzel.

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Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32)$	degrees Celsius
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32) + 273.15$	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

Water is generally considered a renewable resource, but a host of widespread changes (population growth; surface and groundwater contamination from human activities; globally increased water usage for agricultural, industrial, and personal uses; rising global and regional temperatures; and rising water demands for alternative energy production options such as bio-fuels and tar sands) are contributing to growing problems that are beginning to limit access to adequate, sustainable supplies of high quality water. Over the past decade, about 50 percent of the United States has been experiencing drought and/or severe drought conditions (NOAA 2005). While problems with access to adequate fresh water supplies vary spatially and temporally, they are growing in extent and duration and will contribute towards political strife and regional instability in many parts of the world. The historic water rights systems of Riparian Rights of Landowners and Prior Appropriation Doctrine are leaving insufficient supplies for users experiencing water scarcity due to drought, population growth, or declining aquifers. In the United States, Georgia, Alabama, and Florida have been quarrelling over water rights for many years.

Water issues of concern—including adequate supply, increased cost of production per unit volume, quality, habitat degradation and salinity issues—already impact military installations and military operations in many locations within the nation and across the globe. A high priority Army environmental research requirement identifies water “reuse” as a concern in addressing water supply and cost problems. This requirement cites examples where water supply, water price, and/or water quality currently impact military installations. In addition, regional competition for water due to urban growth threatens continued availability of adequate water both on and off-post.

These impacts will grow in scale and severity in the near and mid terms, requiring better understanding and forecasting of how limited water supplies and increasing water costs could impact Army installations over the next few decades. This understanding will inform the Army’s water use policies and help coordinate these policies with stakeholders. It will also

enable better planning and application of system upgrades, including the implementation of Best Management Practices (BMPs) (water reuse technologies, conservation measures, leak detection and repair), water treatment, and improved water delivery infrastructure. In addition, future Army water sustainability measures will have to be coordinated with municipalities and districts that are using the same watershed or aquifer.

Although individual studies have been completed as a result of localized threats to water supply, a comprehensive review of water sustainability at Army installations in all regions has not been completed. National watershed assessments provide classes of installations based on the “health” of the associated watersheds. This allows prioritization of regions for detailed analysis. Regional assessments provide the specific information necessary to formulate policy measures that support a sustainable water future and attainment of the triple bottom line.

1.2 Objective

The objective of this study is to provide an assessment of regional water scarcity as it affects Army installations to ensure continued viability and sustainability of Army operations. Results of the assessment were used to formulate strategies for achieving water efficiency goals and to present recommendations for changes to Army policy to plan for a secure water future.

1.3 Approach

The national watershed-level screening identified Army installations in regions vulnerable to issues of water supply and demand. This work uses the Sustainable Installations Regional Resource Assessment (SIRRA) methodology to identify watersheds with potential sustainment problems, rank watersheds by their relative vulnerability to such problems, and refer those watersheds containing critical Army installations and flagged as “at risk” during screening for further study. While screening by itself does not provide a diagnosis of “at risk” watersheds, it is the first key step in the process that may identify additional recommended studies, planning, and actions.

Installation water scarcity was assessed by developing and applying methods for conducting a regional water balance (or budget) at two installa-

tions. Regional water budgets identify sources of water supply and demand for the water resources used by Army installations. The product is an input-output model of regional water supply and demand. Model variables were altered to produce alternate future scenarios and evaluate the potential impact on availability of water for Army installations.

The Installation Water Demand Model was used to develop water use estimates projecting 30 years into the future. The model uses installation-specific data about historic water use and existing and planned building stock to project future demand. Regional water demand is calculated using historic regional water data, existing and planned water conservation measures, and projected population changes.

Water policy affecting Army installations is characterized on a region-by-region basis. Creation, definition, and control of private water rights rests at the state level. Three doctrines for surface water allocation are appropriation, reasonable use, and absolute ownership. Groundwater allocation is determined using the appropriation doctrine, riparian doctrine, or mixed doctrine. The key Federal policies regarding Army water use are contained in the Energy Independence and Security Act of 2007 (EISA 2007) and Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*.

This report includes guidance on water efficiency planning--including recommendations for BMPs for different water use categories--and makes recommendations as to how installations can meet the water conservation targets established in E.O. 13423.

1.4 Mode of technology transfer

This report will be made accessible through the World Wide Web (WWW) at URL:

<http://www.cecer.Army.mil>

2 Water Vulnerability Issues for Army Installations

2.1 Water trends of concern

Water scarcity may be the most underestimated resource issue facing the world today. World water use has tripled in the last 50 years. Current global water usage breaks down into three general categories: 70 percent for irrigation, 22 percent for industry, and 8 percent for residential purposes. The fact that 40 percent of the world's food supply now comes from irrigated land shows the increased reliance on irrigation in the world food economy. While the demand for fresh water continues to increase, the basic supply of fresh water in the global hydrological cycle remains static.

“Humans already appropriate over 50 percent of all renewable and accessible freshwater flows ...” And yet, about one-third of the world's population lives under moderate-to high water stress, that is, consumption exceeding supply by an excess of ten percent (Gleick et al. 2008). Two principal signs of stress indicate that the demand for water is outrunning supply: rivers run dry and water tables fall (Brown 2001). In fact, many of the world's major rivers either fail to make it to the sea, or have very little water left in them when they do reach their mouths. For example, the Colorado River rarely reaches the Gulf of California; it is drained dry to satisfy the agricultural needs in Colorado, Arizona, and California. The Nile River has little water left in it when it reaches the Mediterranean. The Ganges, which is shared by India and Bangladesh, is almost dry when it reaches the Bay of Bengal. China's Yellow River, the cradle of Chinese civilization, first ran dry in 1972; beginning in 1985 it has run dry for part of each year.

2.1.1 Rising demand for water

Water tables are falling on every continent. Aquifer depletion is a global problem that has emerged in the last half century. This occurred because it is only during this time period that the pumping capacity has existed to deplete aquifers. The size of the world water deficit—the amount of over-pumping in the world—using data for India, China, the Middle East, North

Africa, and the United States, is estimated to be 160 billion tons of water, which equals 160 billion cubic meters (Postel 1999). The United State's portion of the water shortfall is about 2,700 billion gal/yr, about 7 percent of the total.

The U.S. Army is also experiencing unprecedented growth, undergoing the largest organizational change since World War II. It is expected that fully one-third of the forces will be restationed by 2011 impacting 380,000 soldiers and family members. In addition, total Army strength is growing by 74,200 troops. This transformation is triggering 743 new building construction projects at a cost of \$66.4B. These projects include twenty brigade complexes, 690,000 barracks spaces, 4,100 family housing units, and 66 child development centers (Balocki 2008).

2.1.2 Water quality

Water quality is inextricably connected to water supply. The extent and condition of water can affect human health, ecosystems, and critical environmental processes. Even small changes in quality can render water supplies useless for their intended use or hazardous to life. In addition to meeting direct human needs, water provides vital ecosystem services. Among these services are recycling of nutrients, infiltration of storm water, maintenance of base flow, aquifer recharge, sediment transport, flood mitigation, and maintenance of productive aquatic and riparian habitat. Degrading freshwater sources through pollution or inadequate source protection diminishes the supply of adequate water for environmental and human use. Sources of water pollution include runoff from urban areas, farmland, and animal feedlots. Contamination of surface and groundwater in agricultural and urban areas is characterized by a complex mix of nutrients, trace elements, pesticides, VOCs, and their chemical breakdown products. Pollutants include pesticides and fecal matter from farms, chemicals from industrial processes, and fuel and organic compounds from vehicles and transportation routes. Other water quality issues include saltwater intrusion from drawdown of aquifers and interactions between surface and groundwater due to over pumping.

2.1.3 Climate change

One of the factors that make assessing future water scarcity difficult is climate change. The latest evaluations of global climate models anticipate the

following changes in the water cycle: changes in precipitation patterns and intensity, changes in the incidence of drought, widespread melting of snow and ice, increasing atmospheric water vapor, increasing evaporation, increasing water temperatures, reductions in lake and river ice, and changes in soil moisture and runoff. Regional differences are projected and it is expected that extreme events will precede changes in the mean (Karl et al 2009). That is, in regions where average amounts of precipitation will remain the same, moisture will be delivered in larger storm events. This will reduce the usable amount of water due to the inability of the ground to absorb the water for later release or for recharge of ground water.

Temperature rise will affect water supply, particularly for agriculture. A rise in average temperature in mountainous regions of 1 or 2 °C can substantially alter the precipitation mix between rainfall and snowfall, with substantial increases in the amount of rain precipitation and a reduction in the amount of snow precipitation. This change translates into more runoff and more flooding during the rainy season and less water that is stored as snow and ice in the mountains for use in the dry season. The snow pack acts as a reservoir which is slowly draining. Earlier peak streamflow due to earlier warming-driven snowmelt is already occurring. This provides greater river flows earlier in the growing season when it is not needed by agriculture, and consequently provides lesser flows later in the growing season when it is needed. Higher temperatures also increase evaporation of surface waters leaving less available for human or environmental purposes.

2.1.4 Land Use Trends

In the United States, the per capita water consumption has lessened over the past 20 years; yet, 16 million people face water rationing (Glenn and Gordon 2004). Over the next decade, the United States is expected to move from a high water availability nation to an average water availability nation (CIA 2000). In addition to issues related to climate change and the overpumping of aquifers for irrigation and domestic water supply, another major contributor to water problems in the United States is the way that land is developed. Sprawling growth paves over increasing areas of wetlands and forests, which contributes to the depletion of water supplies (Otto, Ransel, et al. 2002).

Critical water shortages are not isolated to the arid West. The rapidly suburbanizing Southeast is now in serious trouble, as are many other formerly water-rich regions of the country. Over the last decade, studies have linked suburban sprawl to increased traffic and air pollution and also to the rapid loss of farmland and open space. Sprawl both pollutes and reduces water supplies. Impervious surfaces (roads, parking lots, driveways, and roofs) replace meadows and forests so that rain can no longer seep into the ground to replenish aquifers. Rainwater is swept away by gutters and storm sewer systems. The sprawling of America has translated into a significant loss of valuable natural resources. Undeveloped land is valuable not just for recreation and wildlife, but also because of its natural filtering function. Wetlands act like sponges that absorb precipitation and runoff, and then slowly release it into the ground.

2.1.5 Groundwater Depletion

More than one-third of Americans get their drinking water directly from groundwater, and the remaining two-thirds depend on surface water. Groundwater conditions also impact surface water because, typically, about half of a stream's volume comes from groundwater. These streams and the lakes are then the source of drinking water for the other two-thirds of the population. Groundwater depletion characterizes the extent to which rates of groundwater withdrawals are exceeding long-term average recharge rates resulting in overdraft. Overdraft, or groundwater withdrawals in excess of natural baseflows, indicates an unsustainable rate of groundwater use. Where groundwater withdrawals are high relative to baseflows, water users may be vulnerable to climatic changes that reduce runoff and aquifer recharge. This suggests that increased groundwater use may not be a viable adaptation to changes in surface water supply or increases in water demand accompanying climate change.

The SIRRA indicator, Groundwater Depletion (Figure 1), illustrates the ratio of withdrawals from recharge. Groundwater withdrawals in excess of natural groundwater recharge rates indicate an unsustainable rate of groundwater use (Hurd, Leary et al. 1999). Groundwater depletion was determined by the percent change in total groundwater withdrawals between 1995 and 2000.

The groundwater depletion ratings were grouped into the following classifications based on statistical classification around the mean (83.17 percent) and standard deviation (323.17).

Very Low Vulnerability	(1):	≤ 0 percent change
Low Vulnerability	(2):	0 – 25 percent change
Moderate Vulnerability	(3):	0 – 25 percent change
Vulnerable	(4):	26 – 83 percent change
High Vulnerability	(5):	>150 percent change

High depletion rates are vulnerable to long-run changes in hydrology and future lack of supply. Much of the U.S. West, Southwest, central plains, and Florida are highly vulnerable.

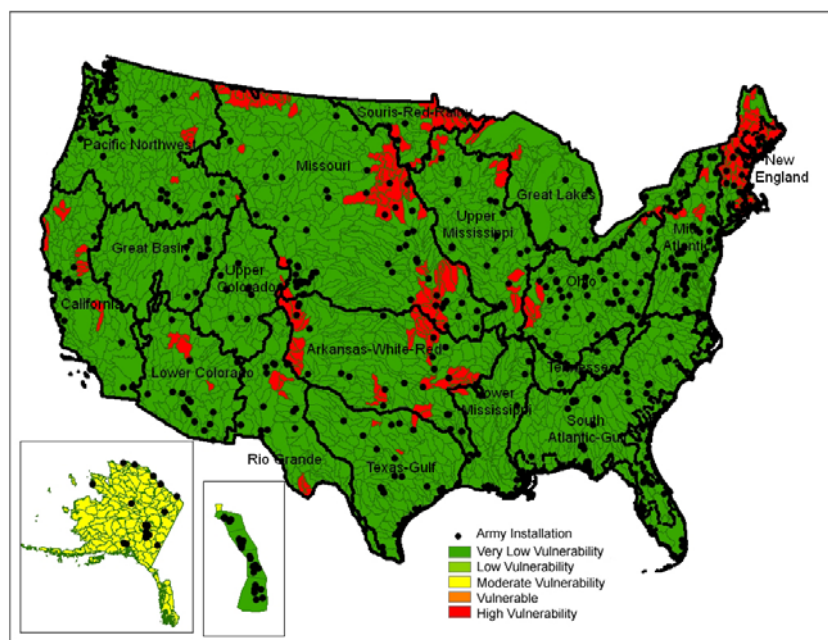


Figure 1. Vulnerability to groundwater depletion.

2.1.6 The Energy/Water Nexus

The Energy/Water nexus is an important issue that has taken on new urgency as concerns have grown about competing demands for this limited resource (WEF 2008). Energy can account for 60 to 80 percent of water transportation and treatment costs and 14 percent of total water utility costs. Much of water resources development took place during the 20th century in an era of both low energy and water prices. Subsidized rural electricity increased agricultural production in irrigated areas and encour-

aged the use of irrigation in areas without direct access to surface water. Energy-related uses of water include thermoelectric cooling, hydropower, minerals extraction and mining, fuel production (fossil, non-fossil, and biofuels), and emission controls. Energy demands in potable water systems include that required for pumping, transport, treatment, and desalination of water (UN 2009).

In the United States, the use of water for power generation is the number two use behind agriculture. Electric power plants are among the greatest users of water nationally, especially in the northern and eastern parts of the country, though only 5 percent is consumptive use. Water for thermoelectric power is used in generating electricity with steam-driven turbine generators. Thermoelectric-power withdrawals accounted for 48 percent of total water use, 39 percent of total freshwater withdrawals for all categories, and 52 percent of fresh surface-water withdrawals. Construction of new power plants has been flat for 20 years, but that is changing.

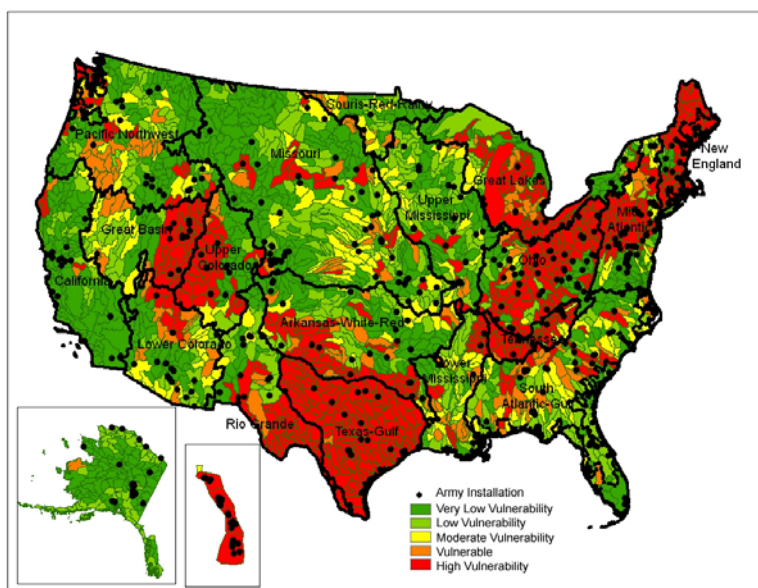


Figure 2. Thermoelectric power energy withdrawals, 10-year change.

The SIRRA indicator, Water for Energy Production 10-year Change, highlights regions where water withdrawals for energy production are increasing. While climate change will have a number of adverse effects on water cycles, increased temperatures will also increase the demand for air conditioning. Combined with increased power needs for expected population growth, and planned construction of biofuel production facilities, overall

water requirements for energy production will continue to increase. Figure 2 shows the 10-year change in water use by thermoelectric power. The data used covers the 10-year period between 1990 and 2000. This indicator measures areas where 50 percent or more of the water withdrawals go towards energy production. (Note that 5 percent of this is consumptive use.) The consumption ratings were defined as:

Very Low Vulnerability	(1):	=0%
Low Vulnerability	(2):	>0 – 25%
Moderate Vulnerability	(3):	>25 – 50%
Vulnerable	(4):	>50 – 75%
High Vulnerability	(5):	>75%

At the time of this writing, twenty new commercial nuclear reactors were in planning stages (EIA 2009). The EIA's Annual Energy Outlook projects a net increase of approximately 12 gigawatts of nuclear capacity coming on line through 2030. In addition, approximately 100 coal-fired power generation plants are also in planning stages, although coal plants use about twenty percent less water for cooling purposes than nuclear. If new power plants are constructed with today's technologies, water use for power generation could more than double by 2030, from 3.3 billion gallons per day (BGD) in 1995 to 7.3 BGD. Water required for power generation may compete with other demands such as agriculture and sanitation. The August 2007 drought in the Southeastern United States caused several nuclear power plants to reduce their output by up to 50 percent due to low river levels (IEEE 2009).

Biofuels also carry a heavy water footprint. The demand for ethanol-based fuels varies with the price of oil. At the peak price in 2008, many new ethanol production plants were in planning stages. Not all of those plants were constructed with the drop in oil price since then. The water demand of ethanol production varies among crops and regions. Another variable is regional, whether crop irrigation is required. For Midwest corn-based ethanol, it takes approximately four gallons of water to produce a gallon of ethanol. Researchers recommend seeking optimal production regions for each crop based on water consumption and climate data (PNAS 2009).

Changing fuels to minimize greenhouse emissions should be done in ways that minimize the strain placed on water resources. Renewable energy technologies have varying water footprints. There are also concerns about

the water requirements of carbon capture technologies, being employed to address concerns over climate change. Without careful selection of technologies, solving a problem in one sector will exacerbate a problem in another (IEEE 2009). A Senate bill, S. 531 the Energy and Water Integration Act of 2009, was introduced to help deal more effectively with this issue.

2.2 Army water challenges

The greatest water challenge for the Army is that the resource supply and demand act across a multiple of scales. Watersheds and aquifers cross political boundaries and require Federal, state, and local agencies to work cooperatively in addressing water problems. Army installations represent just a fraction of regional water demand, and yet, the negative impacts of water scarcity and degradation will be borne equally by all users.

The complexity of water compacts, treaties, and agreements is another challenge for Army installations. Each installation is subject to a regionally-unique set of rules that determine availability of water. The question of who owns the water--or, if water belongs to the public, who has the right to use it--is an issue of great contention. Laws, customs, and traditions form the agreements that are the basis for water allocation law. They were developed during times of water abundance. The Pacific Institute chronicled a 5000-year long history of water conflicts and it is oft repeated that future wars will be fought for the right to use water (Gleick 2008).

Like its neighbors outside the fence, Army installations are facing huge challenges due to aging infrastructure. The historic lack of water meters makes water loss assessment a difficult task. Two Army public works initiatives, utility contract operations and the utility metering program, have the potential to support water conservation efforts by reducing water loss and identifying end-uses. It is critical to understand where water is being used when formulating a comprehensive water management plan.

Army facilities within the United States currently enjoy relatively low water costs. Throughout the United States, water is priced, not according to its value as a precious resource, but to recover the costs incurred to extract and pump. The Army is not eligible for any special rate structure and trends toward increases in pricing are being seen. According to the American Water Works Association *2008 Water and Wastewater Rate Survey*,

the average monthly water bill for an “average” customer increased by 4.8 percent annually since January 2006. * For those communities with block rate structures for residential users, the shift since 2006 has been toward increasing block rates, that is, greater water use incurs a higher rate (AWWA 2009). There are also examples of decoupling water rates, that is, where reducing water consumption does not necessarily result in lower cost. This ensures that utilities can continue to pay the operations and maintenance costs of the water supply system.

2.3 Federal and DOD water policy

The following section describes policy related to installation water management. More detailed information about the evolution of Federal water policy is contained in Chapter 3.

2.3.1 Energy Independence and Security Act of 2007 (EISA) 2007

The latest water efficiency requirements related to water consumption of Army facilities is found in the Energy Independence and Security Act of 2007 (EISA) and Executive Order 13423. Section 432 of EISA establishes a framework for facility project management and benchmarking. Under this new requirement, Federal agencies must identify all “covered facilities” that constitute at least 75 percent of the agency’s facility energy/water use. Implementing guidance was promulgated through DODI 4170.11 dated September 9, 2009, echoing the requirements of the EISA 2007 and EAct 2005. A “covered facility” may be a group of facilities at a single location, or multiple locations managed as an integrated operation. An energy manager must be designated for each covered facility. Each facility energy manager will be responsible for:

1. Completing comprehensive energy *and water* evaluations (including re-/retrocommissioning) of 25 percent of covered facilities each year.
2. Implementing of identified energy *and water* efficiency measures, where bundling of individual measures of varying paybacks into combined projects is permitted.
3. Following up on implemented measures, including fully commissioning equipment, putting in place operations and maintenance (O&M) plans, and measuring and verifying energy *and water* savings.

* The “average” customer uses 7,480 gallons per month, or 249 gallons per day.

2.3.2 Executive Order 13423

E.O. 13423, *Strengthening Federal Environmental, Energy and Transportation Management*, directs each agency to reduce water consumption intensity, through life-cycle cost effective measures, by 2 percent annually through the end of the FY15 relative to the baseline of the agency's water consumption in FY07. Total water reduction is 16 percent by the end of FY15.

2.3.3 Department of Energy (DoE) Supplemental Guidance

The Federal Energy Management Program (FEMP) of DOE developed supplemental guidance to help achieve the water goals and to meet the reporting requirements of E.O. 13423 and the Instructions for Implementing Executive Order 13423. This guidance, *Establishing Baseline and Meeting Water Conservation Goals of Executive Order 13423* was developed to assist in the interpretation of, and ultimate compliance with, E.O. 13423. Specifically, three key elements of compliance were identified and presented:

1. *Water Use Intensity Baseline Development.* Agencies must develop a water use intensity baseline (defined as gallons per gross square foot of facility space) for water consumed in FY07. All future reduction goals will be measured relative to this baseline.
2. *Reduction of Water Use Intensity.* Agencies must identify and implement life-cycle cost-effective water savings measures to achieve, at minimum, a 2 percent annual reduction or 16 percent overall reduction of water use intensity (gallons per total gross square footage of facility space) in agency facilities by the end of FY15.
3. *Reporting.* The primary requirement is to report to the Chairman of the Council on Environmental Quality according to a schedule and format as the chairman requires. Until that has been issued, reporting procedures in place as of 24 January 2007 shall be continued. Therefore, agencies are required to continue to report annual water use in million gallons and facility gross square feet (as defined below) to the Department of Energy that will show the agency's progress towards the water use intensity reduction goal. (Beginning in the 2008 report, DOE is amending its energy data report to include guidance on accurate reporting of water consumption and water use intensity reduction data.)

This document provides an interpretation of E.O. 13423, suggestions for a path forward, and resources for additional information for each key area contained in the E.O.

FEMP also includes the following definitions to be used in interpreting the policy of E.O. 13423:

- *Water Use.* Water use is defined as that water classified as “potable” or permitted for human consumption. This includes water obtained from public water systems or from natural freshwater sources such as lakes, streams, and aquifers for example. Water use may include potable water used for drinking, bathing, toilet flushing, laundry, cleaning/food services, landscape watering, irrigation, and process applications such as cooling towers, boilers, and fire suppression systems.
- *Facility Gross Square Footage.* The facility gross square footage is the same value used to determine the energy use intensity related to the agencies’ energy reduction goals. The facility gross square footage is used to calculate the water use intensity (defined below).
- *Irrigated Landscape.* Potable water used for landscape irrigation is to be reported in the agency total water use, but the square footage of landscape area is not included in the facility gross square footage, which is used to calculate water use intensity.
- *Water Use Intensity.* Water use intensity calculated for each individual agency is defined as annual water use divided by total gross square footage of facility space (as defined above) reported in gallons per square foot. Agencies are required to report both water use (in million gallons) and facility gross square footage (in thousand square feet) in the Department of Energy’s energy management data report. Note that the water use intensity will be used to assess each agency’s progress toward meeting the water reduction goal; it will not be suitable to make comparisons with other agencies water use or published standards.
- *Exemptions.* Exemptions will be handled on a case-by-case basis. The head of a Federal agency may request an exemption for specific facilities or processes using the procedures outlined in Section 8 of E.O. 13423. The request should document efforts already taken to reduce water consumption and/or to substitute non-potable water for potable water uses for the specified facilities or processes. All cost-effective measures should have been considered and implemented and appropriately documented as part of the request. The request for an exemp-

tion must be renewed annually. A copy of the current exemption is to be submitted with the annual data report.

Additionally, best management practices (BMPs) were originally developed by the FEMP Program in response to the requirements set forth in previous E.O. 13123, which required Federal agencies to reduce water use through cost-effective water efficiency improvements. In response to E.O. 13423 and to account for recent changes in technology in water use patterns, the U.S. Environmental Protection Agency's (USEPA's) Water Sense Office updated the original BMPs. The updated BMPs were developed to help agency personnel achieve water conservation goals of E.O. 13423

Additional Army guidance is found in Memorandum DAIM-ZA, Assistant Chief of Staff for Installation Management (ACSIM), 18 March 2003, on the Army adoption of DOE's 10 BMPs for developing water management plans, increasing public awareness, and implementing conservation practices. The Air Force Water Conservation Handbook, the handbook referenced in the memo, is available on the ACSIM water policy web site, http://army-energy.hqda.pentagon.mil/policies/water_con.asp.

2.3.4 Historical Water Policy

The requirements in the ACSIM memo, and in Memorandum HQ IMCOM SFIM-OP-P, 21 Apr 2004, "Army Water Conservation Policy", direct Army installations to develop water management plans. These plans must be reviewed and updated periodically. A template is available from ACSIM for help with developing or revising a water management plan. The goal is no longer for installations to develop and submit four of the 10 BMPs, as stated in the IMCOM memo, but to use as many BMPs as are required to achieve the mandatory water conservation intensity goal of 2 percent annually.

The Pacific Northwest National Laboratory (PNNL) report, *Update of Market Assessment for Capturing Water Conservation Opportunities in the Federal Sector*, was completed for FEMP in 2005. This report assesses the water conservation potential in the Federal sector. The analysis looks at savings potential across the Federal sector based on a life cycle cost analysis of basic domestic fixtures.

3 Water Policy

A key factor affecting the availability of water for Army installations is the complex set of laws, agreements, and policies that regulate water rights. Often historic in origin, water rights can prevent access to local water by local users. Equally challenging is the regional nature of water as a resource coupled with the extra-regional influences. For example, the recharge zone of an aquifer can be hundreds of miles from the aquifer itself. Likewise, headwaters of major tributaries are far removed from the users hundreds of miles downstream. And yet, laws, actions, and conditions outside of the withdrawal zone have a direct impact on availability of water to local users.

The following section describes water policy and law as it affects Army installations. Policy is discussed as it applies to water basins and to states. There is a listing of relevant policies by basin and state in several tables. There is also a discussion of the concept of Total Water Management (TWM), a systems approach to achieving water sustainability. TWM considers drinking, sanitary, and stormwater systems together to work toward a sustainable water supply.

3.1 Water policy impacts on Army installations

3.1.1 Regional and installation water trends

Disputes over water have long been common. The Colorado River was the first apportioned in 1922, after years of interstate battling. In recent decades, as populations have risen, similar conflicts have developed in the East. Maryland and Virginia fight over the Potomac; South Carolina squares off against North Carolina over the Pee Dee River; and against Georgia over the Savannah River; and, in what is perhaps the most contentious of these battles, Alabama, Florida, and Georgia clash over the waters of the Apalachicola-Chattahoochee-Flint river basin. Competing demands include booming cities, agriculture, industry, environmental protection, fisheries, power generation, navigation, and a host of other human and non-human uses. The management of water resources requires systems thinking, is increasingly complex, and faces numerous obstacles.

As conflicts continue to grow, installations are likely to find themselves faced with situations in which their water needs cannot be met by the local water supply. Thus, managers are searching for integrated solutions to sustainably manage water resources.

Today's water conditions are far from these 19th century's characterizations where water policy entailed cooperative irrigation compacts in the arid West that were unnecessary in the East. Today, water scarcity and interstate conflicts have become major challenges for both the East and West. Growing populations, agriculture, and industry have pumped so much water that now even the water-rich states face shortages and conflicts.

Today's water policy is locally unique. States and local governments dominate water control. It is appropriate to characterize national water policy at the basin level because basins tend to share common concerns and trends (Figure 3). This section highlights the national history of water policy, generalizes state policies, and discusses basin-level compacts. (Caution—any decision relevant to a specific watershed or location should always be informed by local jurisdictions.)

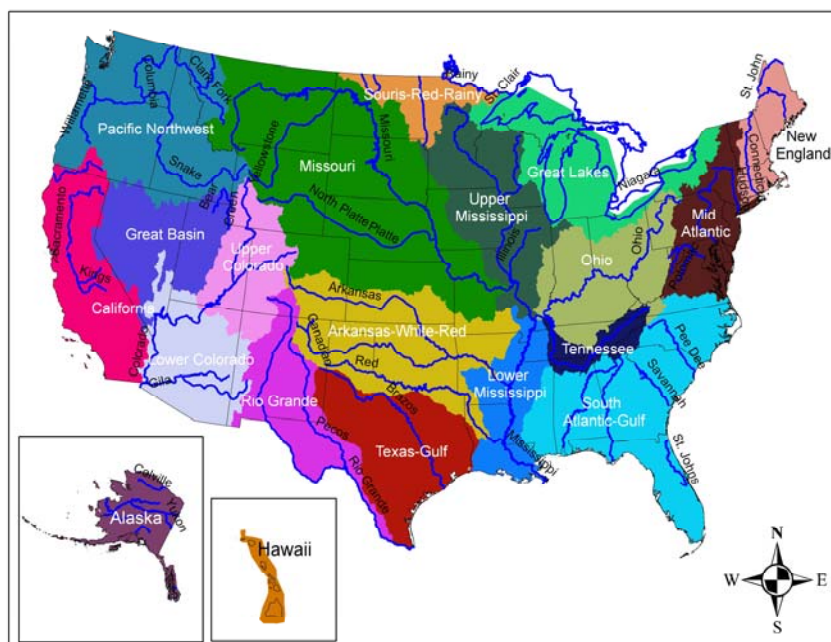


Figure 3. Water basin regions of the United States (source: USGS 1990 *Water Rights of the Fifty States and Territories*).

3.1.2 Federal water policy and the impacts to Army installations

For the most part, water rights are a matter of state (not Federal) law. The Federal government has left the creation, definition, and control of private water rights to the states. Nevertheless, the Federal government has considerable power over water through its power to regulate water, and through the Federal reserved water rights doctrine.

Through its power to regulate navigation and interstate commerce under the commerce clause of the Constitution, the Federal government has paramount and virtually limitless control over surface and groundwater* use. By direct application of this power, Congress could, if it chose, apportion the waters of interstate streams among states. Congress has apportioned interstate waters only twice. In the Boulder Canyon Project Act of 1928, Congress divided half of the flow of the Colorado River among Arizona, California, and Nevada (Public-No. 642-70th Congress, H.R. 5773). In 1990, Congress apportioned the waters of the Truckee and Carson rivers and Lake Tahoe between California and Nevada (Public Law 101-618).

The more frequently used power is the Federal reserved water rights doctrine, which holds that when the United States sets aside or reserves public land for uses such as Indian reservations, military reservations, national parks, forests, or monuments, it also implicitly reserves sufficient water to satisfy the purpose for which the reservation was created. Furthermore, Federal reserved water rights exist outside of the state water rights system. They need not fulfill the beneficial use requirement and are not subject to forfeiture or abandonment for nonuse. The precedent-setting case for the Federal reserved water rights doctrine is *Winters v. United States* (1908). In this case, the U.S. Supreme Court found that when the Federal government created Indian reservations, water rights were reserved in sufficient quantity to meet the purposes for which the reservation was established.

When *Winters* was decided at the turn of the century, no one paid much attention. By the 1960s everyone was paying attention. The *Winters* deci-

* The U.S. Supreme Court asserted a Federal interest in state groundwater management in *Sporhase v. Nebraska ex rel. Douglas* (1983). The Supreme Court held groundwater to be an article and commerce so that state statutes prohibiting the interstate transport of groundwater were illegal because they violated the commerce clause. Prior to *Sporhase*, it was assumed that states had absolute ownership and control over their groundwater. In its decision, the Court called state ownership of groundwater "legal fiction."

sion threatened to drastically reorder the existing priority system on many western streams. Indian reservations had effectively moved to the front of the seniority line, with a right to potentially large amounts of water. Consequently, much conflict arose regarding the quantification and use of such rights. The decision that made established water users stand up and take notice was *Arizona v. California* (1963). This case reaffirmed the U.S. Supreme Court's decision in *Winters* and expanded the reserved-rights doctrine in two ways. First, it allowed for reserved rights to apply to other Federal lands including water uses in national forests, national parks and monuments, and military reservations. Second, it allowed for a change of the uses, as long as the new use was not more consumptive than the original use for which the reserved rights were made.

Meanwhile, Congress and the Federal courts have limited Federal reserved water rights and returned substantial water management power to the states. The McCarren Amendment (1952) requires that the Federal government waive its sovereign immunity in cases involving the general adjudication of water rights—recognizing that the exemption of the Federal government from these adjudications would undermine the state's water allocation systems. Therefore, any Federal agency claiming a Federal reserved water right must participate in the state's adjudication process. In *Cappaert v. United States* (1976), the Court ruled that Federal reserved water rights were limited to the primary purpose of the reservation and only to the minimum amount of water necessary to fulfill the purpose of the reservation. In *United States v. New Mexico* (1978), the Court found that the reserved water rights on national forests apply only to the preservation of timber resources and water flows. National forests are not reserved for aesthetic, environmental, recreation, or wildlife preservation and any claimed water needs for these purposes would have to obtain the rights like any other appropriator under state law.

These rulings have narrowed the scope of the *Winter's* Doctrine. Yet there are still many other Federal statutes and activities that directly and indirectly affect water resources. For example, the U.S. Energy Independence and Security Act of 2007, H.R. 6 (EISA 2007) and Executive Order 13423 are the latest water efficiency requirements that Army facilities must meet. The Wild and Scenic Rivers Act (1962) is intended to preserve streams in their pristine condition. The Coastal Zone Management Act (1972) manages the densely populated coasts. The Endangered Species Act (1973) ap-

plies to water habitats. The Federal government has also passed important environmental legislation dealing with water quality, drinking water standards, and the handling of toxic and hazardous waste—all of which affect water resources.

The amount of water reserved for military installations is not unlimited. Rather, Federal reservations are guaranteed only that amount of water necessary to fulfill the purpose of the reservation. To determine the amount of water reserved, courts examine the asserted water rights and the specific purposes for which the land was reserved. In other words, how much water is being sought, for what purpose, and is that purpose consistent with the reason the reservation was created?

In November 1995, the Deputy Assistant Secretary of the Army (Installations and Housing) and Deputy General Counsel (Civil Works and Environment) issued policy guidance for maintaining water rights at Army installations (Johnson and Stockdale 1995). This guidance provides a logical framework for responsible staff elements to track water rights issues. According to the introductory memorandum, the guidance was badly needed because attorneys and engineers at some Federal installations were woefully ignorant of the importance of maintaining records to protect water rights. Under the guidance:

... the Army will comply with the applicable laws of the States pertaining to the use of water when they are consistent with Federal law and military requirements. The guidance also emphasizes close coordination with major commands and the Environmental Law Division. Installations are directed to notify states when new uses of water are pursued under Federal reserved rights and to apply for water rights when water in excess of a judicially quantified Federal water right is required. On acquired land, installations are urged to apply for water rights under state law unless the process will adversely affect the Army's ability to perform its mission or the state fails to recognize valid existing water rights. In emergencies, the guidance suggests that purchase of water rights or condemnation is options to explore. The guidance also urges commanders to ensure that detailed and accurate water rights records are kept by the responsible officers on the installations.

Dept. of the Army Pamphlet 27-50-287,

Maintaining Federal Water Rights in the Western United States

In general, the guidance emphasizes an approach that accounts for the needs of states and other appropriators, but recognizes that the needs of national defense must be superior. The military's needs for water should always be met. However, the success of the military's water maintenance programs depends on careful management. Western neighbors jealously view the Army's abundant supplies of water. Close coordination and careful recordkeeping within the Army, as urged in the Army's recent policy guidance, can be the key to long-term success. Availability of water must not be taken for granted. Thus, the Army has set forth policy to reduce water use through cost-effective water efficiency improvements.

All Army installations are required to prepare comprehensive water management plans which must be reviewed and updated periodically. EISA 2007 and EAct 2005/EO 13423 are the latest water efficiency requirements that Army facilities must meet. EISA establishes a framework for facility project management and benchmarking. Under this new requirement, Federal agencies must identify all "covered facilities" that constitute at least 75 percent of the agency's facility energy/water use and identify an energy manager for each. Each facility energy manager will be responsible for:

1. Completing comprehensive energy *and water* evaluations of 25 percent of covered facilities each year;
2. Implementing identified energy *and water* efficiency measures; bundling of individual measures of varying paybacks into combined projects is permitted; and,
3. Following up on implemented measures, including fully commissioning equipment, putting in place O&M plans, and measuring and verifying energy *and water* savings.

EAct 2005/EO 13423 directs each agency to use as many BMPs required to achieve the mandatory water conservation intensity (efficiency) goal of 2 percent annually beginning in FY08 through FY15 or 16 percent total by FY15. BMPs were originally developed by the Department of Energy FEMP in response to EO 13123. Today FEMP funds a series of reports (PNNL 2005) that assess the water conservation potential in the Federal sector. These analyses look at the savings potential across the Federal sector based on a life cycle cost analysis.

Additionally, the Army Water Conservation Plan identifies metering as critical to monitoring the impact of attempted improvements. All new military projects are provided with water meters. Faucets, flush valves, showerheads, toilets and urinals in new projects are the low flow type and used at appropriate locations, in accordance with Army standards.

This and additional material concerning Army water policy may be extracted from the ACSIM web site:

http://www.Army-energy.hqda.pentagon.mil/policies/water_con.asp

and the FEMP web site:

http://www1.eere.energy.gov/femp/water/water_fedrequire.html

3.1.3 State and regional water policies

For the most part, water rights are a matter of state law. The Federal government has left the creation, definition, and control of private water rights to the states. This accounts for the great diversity of water rights systems—each of the 50 states and each territory is free to develop its own system of water rights. Generally, states have adopted either a riparian or appropriation doctrine to address surface waters and rely on a doctrine of absolute ownership, reasonable use, or appropriations for groundwater regulation.

3.1.3.1 State water law

While riparian and appropriation are the basic surface water doctrines, they should be viewed as templates from which each state has fashioned its own laws. Riparian law developed in the humid eastern states where water was abundant. The appropriation doctrine is found in western states and developed in response to the dry conditions. Some states (California, Iowa, Mississippi, Florida, and Hawaii) have mixed doctrines.

The origin of riparian law is English common law brought over with the colonists to America. The riparian doctrine says that the right to water belongs to those who own land that touches the stream or lake. It does not matter how much of the land touches the water body, nor is it necessary to own any portion of the bed, stream, or lake—just that a property is adjacent to it. Since the water right is incident to the ownership of land, a land

owner can never lose the right so long as they own the land. The use of water by a non-riparian land owner is illegal (USGS 1990).

Appropriation doctrine is the water law in 17 states. The appropriations doctrine originated in the mining camps of California. Two fundamental rules developed by the miners were “first in time, first in right,” and “use it or lose it.” The first rule says if you are the first person to stake a claim, the claim is yours alone to work. The second rule limited speculation. A miner had to actively work his claim (USGS 1990). The appropriation doctrine allocates water rights on a temporal basis—first in time, first in right. The first person to appropriate water from a stream has the most senior water right. The next person to make an appropriation has the next-most senior right, and so on. When water supply is limited, appropriators are cut off from the stream in inverse order of priority. This means the most junior right is cut off first. Appropriators obtain a right to a fixed quantity of water through a permit.

Figure 4 details state surface water doctrines. The mixture of legal doctrines in the Plains reflects the transitional climate, whereas in the remaining mixed doctrine states, riparian rights are the older rights and the states have transitioned to an appropriations doctrine within the last century. The flow of groundwater, on the other hand, is difficult, if not impossible, to observe—making it more challenging to understand and manage than surface water. This is evident in the number of state groundwater laws that completely ignore the reality of hydrologic interconnections between groundwater and surface water (Thompson 1999).

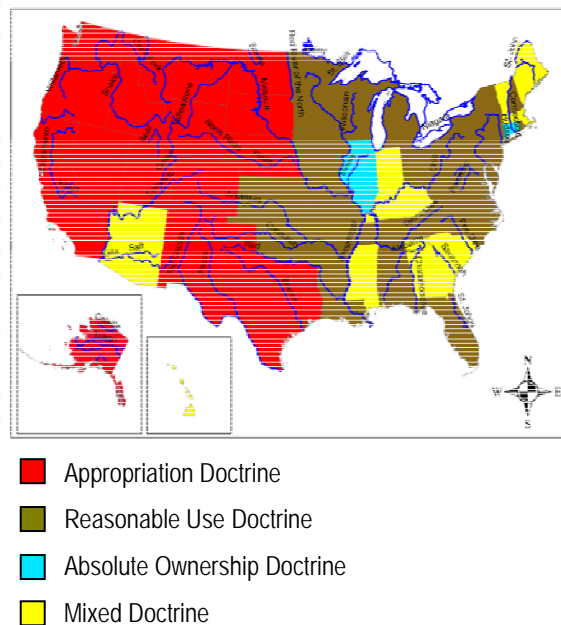


Figure 4. State surface water doctrines.

Within the three basic groundwater doctrines, absolute ownership means each landowner has unlimited right to pump and use groundwater. The water can be used anywhere and is not restricted to the overlying land. In other words, the biggest pump wins. Landowners have an unlimited right to interfere with their neighbor's use of the resource and vice versa. The doctrine of reasonable use developed in response to the excesses of absolute ownership. Here, the landowner is viewed as having the right to make any reasonable use of groundwater on the overlying land, even if it causes injury to others. Finally, appropriation for groundwater operates the same as for surface water, and as with surface water it is mainly a western doctrine. It is the seniority-based system or permitting system (USGS 1990).

Figure 5 details state groundwater doctrines. Mixed doctrine states have typically developed different regulations for percolating groundwater and underground streams. The data in Table 1 were adopted from the USGS report *Water Rights of the Fifty States and Territories* published in 1990. This updated table summarizes water policy and administering agencies.

Today, states increasingly establish commissions and agencies to address specific water issues and influence new policy decisions. For example, the Ohio Lake Erie Commission is a coalition of state agencies established in 1990 to preserve Lake Erie's natural resources, enhance the quality of its waters and ecosystem, and promote economic development. In 2007, the Maryland general assembly appointed the Oyster Advisory Commission to work jointly with other state agencies on an aggressive oyster restoration plan. In 2008, the North Carolina general assembly filed a water conservation bill (*S1879 Drought/Water Management Recommendations*). Many examples exist. Yet difficulty arises from the fact that waters are not contained within state boundaries. Interstate conflicts are a major challenge. For this, states have entered into agreements with each other and private organizations have formed to help address the problems.

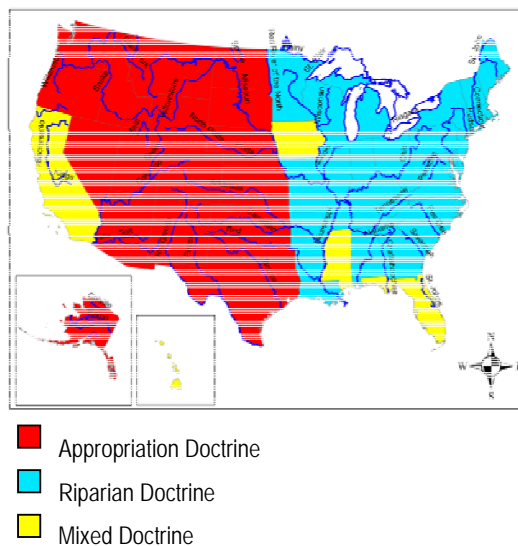


Figure 5. State groundwater doctrines.

Table 1. State water policy and administering agencies.

State	Surface Water Right System	Groundwater Right System	Permit Required		Court Approval		Buying/Selling	Disputes	Administering Agency	Number of Compacts or Treaties
			Surface Water	Groundwater	Surface Water	Groundwater				
Alabama	R	U	No	No	No	No	No	Gc	None	0
Alaska	A	A	Yes	Yes	No	No	Yes	Wa, Gc	Dept. Of Natural Resources	0
Arizona	A	Mixed	Yes	Yes	No	No	Yes	Wa, Gc	Dept. Of Water Resources	3
Arkansas	R	U	No	No	No	No	Yes	Gc	None	0
California	Mixed	A	Yes	No	No	No	Yes	Gc	Water Resources Control Board	4
Colorado	A	A	No	Yes	No	No	Yes	Sc	Div. Of Water Resources	12
Connecticut	R	O	Yes	Yes	No	No	No	Gc	Dept. Of Environmental Protection	2
Delaware	R	U	Yes	Yes	No	No	No	Wa, Gc	Dept. Of Natural Resources	4
Florida	Mixed	U	Yes	Yes	No	No	No	Wa	Regional Water Management Districts	0
Georgia	R	Mixed	Yes	Yes	No	No	No	Gc	Dept. Of Natural Resources	0
Hawaii	Mixed	Mixed	No	Yes	No	No	No	Wa, Sc	State Water Commission	0
Idaho	A	A	Yes	Yes	No	No	No	Gc	Dept. Of Natural Resources	2
Illinois	R	O	No	No	No	No	No	Gc	Div. Of Water Resources	1
Indiana	R	Mixed	No	No	Yes	No	No	Wa, Gc	Dept. Of Natural Resources	1
Iowa	Mixed	U	Yes	Yes	No	No	No	Wa, Gc	Dept. Of Natural Resources	0
Kansas	A	U	Yes	Yes	No	No	No	Gc	Div. Of Water Resources	4
Kentucky	R	Mixed	Yes	Yes	No	No	No	Wa, Gc	Div. Of Water	2
Louisiana	R	U	No	No	No	No	No	Gc	None	2
Maine	R	Mixed	No	No	No	No	No	Sc	None	1

State	Surface Water Right System	Groundwater Right System	Permit Required		Court Approval		Buying/Selling	Disputes	Administering Agency	Number of Compacts or Treaties
			Surface Water	Groundwater	Surface Water	Groundwater				
Maryland	R	U	Yes	Yes	No	No	No	Wa, Gc	Water Resources Administration	3
Massachusetts	R	O	Yes	Yes	No	No	No	Gc	Div. Of Water Supply	0
Michigan	R	U	No	No	No	No	No	Gc	Dept. Of Natural Resources	2
Minnesota	R	U	Yes	Yes	No	No	No	Wa, Gc	Dept. Of Natural Resources	2
Mississippi	Mixed	Mixed	Yes	Yes	No	No	No	Wa, Gc	Dept. Of Natural Resources	0
Missouri	R	U	No	No	No	No	No	Gc	None	0
Montana	A	A	Yes	Yes	No	No	No	Wa	Water Resources Div.	4
Nebraska	A	A	Yes	No	No	No	Yes	Wa, Sc	Dept. Of Water Resources	5
Nevada	A	A	Yes	Yes	No	No	Yes	Wa, Gc	Div. Of Water Resources	1
New Hampshire	R	U	No	No	No	No	Yes	Gc	Water Resource Div.	0
New Jersey	R	U	Yes	Yes	No	No	No	Wa, Gc	Div. Of Water Resources	1
New Mexico	A	A	Yes	Yes	No	No	Yes	Gc	State Engineer's Office	11
New York	R	U	Yes	Yes	No	No	Yes	Gc	Dept. Of Environmental Conservation	4
North Carolina	R	U	Yes	Yes	No	No	Yes	Gc	Div. Of Water Resources	0
North Dakota	A	A	Yes	Yes	No	No	Yes	Gc	State Water Commission	2
Ohio	R	U	Yes	Yes	No	No	No	Gc	Dept. Of Natural Resources	4
Oklahoma	A	U	Yes	Yes	No	No	Yes	Wa, Gc	Water Resources Board	3
Oregon	A	A	Yes	Yes	Yes	Yes	Yes	Wa, Sc	Dept. Of Natural Resources	2
Pennsylvania	R	U	Yes	No	No	No	No	Gc	Dept. Of Environmental Resources	7
Rhode Island	R	U	No	No	No	No	No	Gc	Water Resources Board	0

State	Surface Water Right System	Groundwater Right System	Permit Required		Court Approval		Buying/Selling	Disputes	Administering Agency	Number of Compacts or Treaties	
			Surface Water	Groundwater	Surface Water	Groundwater					
South Carolina	R	Mixed	Yes	Yes	No	No	No	Gc	Water Resources Commission	0	
South Dakota	A	A	Yes	Yes	No	No	Yes	Wa, Gc	Dept. Of Water And Natural Resources	1	
Tennessee	R	U	No	No	No	No	Yes	Gc	Dept. Of Health And Environment	2	
Texas	A	A	Yes	No	No	No	Yes	Wa, Gc	State Water Commission	8	
Utah	A	A	Yes	Yes	No	No	Yes	Wa, Gc, Sc	Dept. Of Natural Resources	4	
Vermont	R	Mixed	No	No	No	No	Yes	Gc	None	2	
Virginia	R	U	No	Yes	No	No	No	Gc	State Water Control Board	4	
Washington	A	A	Yes	Yes	No	No	Yes	Wa, Gc	Dept. Of Ecology	2	
West Virginia	R	U	No	No	No	No	Yes	Gc	Div. Of Natural Resources	3	
Wisconsin	R	U	Yes	Yes	No	No	Yes	Wa, Gc	Dept. Of Natural Resources	5	
Wyoming	A	A	Yes	Yes	No	No	Yes	Gc	State Engineer's Office	10	
A–Appropriation; R–Riparian							Source: USGS 1990 Water Rights Of The Fifty States And Territories				
A–Appropriation; O–Absolute Ownership; U–Reasonable Use											
Wa–Water Agency; Gc–General Courts; Sc–Special Courts											

3.1.3.2 *Interstate compacts*

The most common way that states address water problems that extend beyond state lines is through interstate compacts. The authority of states to compact with one another comes from the Compact Clause of the Constitution. When an interstate agreement implicates Federal interest, the Compact Clause requires Congressional approval. Congressional approval is required because interstate water conflicts invariably affect Federal interests. The compact process typically begins with Congressional approval for the states to negotiate. After negotiating, the participating states pass identical legislation signifying their agreement on the compact's terms, purpose, and policies. The compact takes effect and becomes Federal law when Congress ratifies it by statute. As such, it takes precedence over contrary Federal common law or state law. Apart from requiring congressional consent, the Constitution places no limits on what may be done through an interstate compact.

Currently, there are 23 water allocation compacts on Western streams, 17 pollution/regulatory compacts within the Eastern states, and 5 planning/flood control compacts on Eastern rivers (USGS 1990; Thompson 1999). Compacts in the West are often created in response to water shortages in particular interstate basins and are generally focused on water allocation issues. A different experience has governed the Eastern states' development of interstate water compacts. Many assume a rather restrictive view of the functions sought to be accomplished and require only the exchange of information or state-to-state consultations on common problems such as pollution, flood, and urban development.

Water allocation compacts divide the waters using either storage allocation or flow allocation procedures. Storage allocation allows the upper basin state(s) to store a certain amount of water for later use. This type of allocation is easy to monitor and enforce because reservoir storage is open and visible. Flow allocation is more complex. States have used hydrologic models, percentage of total flow, and guaranteed quantities of flow as methods for dividing the waters. Each method has limitations in terms of enforcement, and they differ in how the risk of shortage is shared between the states.

Before passage of Federal water quality legislation, interstate water quality disputes were resolved in court through nuisance lawsuits or by interstate compacts. There are five interstate pollution control compacts between Eastern states. While the purposes of pollution control compacts have largely been superseded by the Federal Clean Water Act (1972), they still provide useful examples of how states coordinate and manage waters on a basin-wide scale.

Table 2 lists the water-related interstate compacts in the United States. Note that each state has a number of active organizations addressing water in a research and advisory capacity. A number of private organizations that aid and advise interstate compacts will often support basin-wide water resource management, for example:

- American Water Works Association (AWWA) Water Rights Committee, www.awwa.org/
- American Water Resources Association (AWRA), www.awra.org/
- American Rivers, www.americanrivers.org/
- Instate Council on Water Policy, www.icwp.org/
- Western Governor's Association, www.westgov.org/
- Western Progress, www.westernprogress.org/
- U.S. Commission on Ocean Policy, www.oceancommission.gov/
- Great Lakes Environmental Law Center, www.greatlakeslaw.org/
- Association of Metropolitan Water Agencies, www.amwa.net/
- National Association of Clean Water Agencies, www.amsa-cleanwater.org/
- Water Utility Climate Alliance
- Pacific Institute, www.pacinst.org/
- Oasis Design, www.oasisdesign.net/
- Chesapeake Bay Foundation, www.cbf.org/

3.2 Total Water Management (TWM)*

Total water management (TWM) takes a systems approach to the management of water resources. Traditional approaches to water management tend towards segmentation: supply and demand-side issues are considered in complete isolation; drinking, sanitary, and stormwater systems are wholly separate; water districts within the same watershed operate entirely independently; and, land use decisions are made without any consideration of water resources. Compartmentalization leads to inefficient water management that cannot address the challenges faced by the water industry. The TWM approach responds to these inadequacies by developing a highly integrated water management system. This approach to managing water resources can help Army installations to economically meet their own water needs and the requirements of E.O. 13423.

* Unless otherwise noted, this section interprets information regarding total water management and integrated water resources management (a highly similar approach) from Chesnutt et al. 2007; Global Water Partnership 2009; Grigg, 2008; and Patwardhan et al. 2007.

Table 2. Water-related interstate compacts.

Water Basin Region	Compact/Treaty	Water Body	States	Year	Regulation
Pacific Northwest	Snake River Compact	Snake River	ID, WY	1949	Apportions percentage of flow for postcompact uses
California	Klamath River Compact	Klamath River	CA, OR	1956	Apportions postcompact uses by prioritization of type
Great Basin	Bear River Compact	Bear River	ID, UT, WY	1955, 1978	Apportions percentage of flow; Limits storage
	California-Nevada Interstate Compact	Lake Tahoe; Carson, Truckee, and Walker River	CA, NV	pending	Establishes commission to apportion waters
Missouri	Belle Fourche River Compact	Belle Fourche River	SD, WY	1943	Apportions percentage of flow for postcompact uses
	Big Blue River Compact	Big Blue River	KS, NE	1971	Apportions postcompact use in NE to provide minimum flow to KS
	Yellowstone River Compact	Yellowstone River	MT, ND, WY	1950	Apportions percentage of flow for postcompact uses
	Republican River Compact	Republican River	CO, KS, NE	1943	Establishes commission to apportion waters
	South Platte River Compact	South Platte River	CO, NE	1923	Apportions fixed quantity
	Upper Niobrara River Compact	Upper Niobrara River	NE, WY	1962	Apportions storage limitations
Upper Colorado	Upper Colorado River Basin Compact	Colorado River	CO, NM, UT, WY	1948	Establishes commission to apportion waters
	Upper Colorado River Basin Compact	Animas River and La Plata River	CO, NM	1968	Apportions storage rights to Colorado and New Mexico from the La Plata and Animas river systems
	La Plata River Compact	La Plata River	CO, NM	1922	Equitable apportionment
Lower Colorado					
Rio Grande	Pecos River Compact	Pecos River	NM, TX	1949	Apportions flow based on hydrologic model
	Rio Grande Interstate Compact	Rio Grande River	CO, NM, TX	1938	Apportions flow based on hydrologic model
Texas-Gulf	Sabine River Compact	Sabine River	LA, TX	1953, 1992	Apportions flow
Arkansas-White-Red	Red River Compact	Red River	LA, AR, OK, TX	1978	Divided into five reaches; Apportions percentage within each reach

Water Basin Region	Compact/Treaty	Water Body	States	Year	Regulation
	Arkansas River Compact	Arkansas River	KS, CO	1949	Apportion maximum draws from the John Martin Reservoir
	(Kansas-Oklahoma) Arkansas River Compact	Arkansas River	KS, OK	1965	Apportions storage limitations
	(Arkansas-Oklahoma) Arkansas River Compact	Arkansas River	AR, OK	1970, 1972	Apportions percentage of flow
	Canadian River Compact	Canadian River	OK, NM, TX	1950	Apportions storage limitations
	Costilla Creek Compact	Costilla Creek	CO, NM	1944, 1963	Detailed priority of individual water rights
Souris-Red-Rainy					
Upper Mississippi	Minnesota-Wisconsin Boundary Waters Compact	Mississippi River and St. Croix River	MN, WI	1965	Withdrawn in 1999
	Upper Mississippi River Basin Association	Mississippi River	WI, MO, MN, IA, IL, IN	1981	-
Lower Mississippi	Alabama-Coosa-Tallapoosa River Basin Compact	Alabama-Coosa-Tallapoosa Basin	AL, GA	1997	Equitable apportionment
Great Lakes	Great Lakes Basin Compact	Great Lakes	IL, IN, MI, NY, OH, PA, WI, MN	1968	Establishes commission to advise policy
Ohio	Ohio River Basin Commission	Ohio River	KY, MD, VA, WV	1981	Establishes commission to coordinate activities
	Wabash Valley Compact	Wabash River	IN, IL	1959	Establishes commission to coordinate activities and costs
	Wheeling Creek Watershed Protection and Flood Prevention District Compact	Wheeling Creek	PA, WV	1967	Establishes commission to coordinate activities and costs
	Ohio River Valley Water Sanitation Compact	Ohio River	NY, IL, KY, IN, OH, WV	1940	Establishes commission to advise pollution policy
	Pymatuning Reservoir Compact	Pymatuning Lake	OH, PA	2004	Established commission to regulate use
Water Basin Region	Compact/Treaty	Water Body	States	Year	Regulation
Tennessee	Tennessee River Basin Water Pollution Control Compact	Tennessee River	KY, TN	1958, 2000	Establishes commission to advise pollution policy
	Tennessee-Tombigbee Waterway Development Compact	Tennessee River; Tombigbee River	AL, KY, MS, TN	1984	Established commission to promote economic and trade potential

Water Basin Region	Compact/Treaty	Water Body	States	Year	Regulation
South Atlantic-Gulf	Apalachicola-Chattahoochee-Flint	Apalachicola-Chattahoochee-Flint Basin	AL, GA, FL	1997	Equitable apportionment
Mid Atlantic	Delaware River Basin Compact	Delaware River	DE, NJ, NY, PA	1961	Establishes commission to coordinate activities and apportion waters
	Delaware-New Jersey Compact	Delaware River	DE, NY		
	Susquehanna River Basin Compact	Susquehanna River	MD, NY, PA	1970	Establishes commission to coordinate activities and apportion waters
	Potomac River Basin Compact	Potomac River	MD, PA, VA, WV, DC	1970	Establishes commission to coordinate regulations and standards
	Potomac River Low Flow Allocation Agreement	Potomac River	VA, MD, DC	1978	Established commission to insure adequate potable water supplies
	Chesapeake Bay Basin Compact	Chesapeake Bay	MD, VA, PA, DC	1980, 1987	Establishes commission to coordinate activities and apportion nutrient loading
	New York Harbor Interstate Sanitation Compact	New York Harbor	NY, NJ, CN	1935	Establishes commission to restrict the release of contaminants
	Appalachian States Low-Level Radioactive Waste Compact		PA, WV, DE, MD	1985, 1986	Established commission to regulate equitable waste disposal
New England	Connecticut River Compact	Connecticut River	CT, MA, NH, VT	1983	Establishes commission to apportion waters
	Merrimack River Flood Control Compact	Merrimack River	MA, NH	1957	Establishes commission to coordinate activities and costs
	Thames River Flood Control Compact	Thames River	CT, MA	1958	Establishes commission to coordinate activities and costs
	Connecticut River Flood Control Compact	Connecticut River	CT, MA, NH, VT	1953	Establishes commission to coordinate activities and costs
	New England Interstate Water Pollution Control Compact	--	CT, MA, RI	1947	Establishes commission to coordinate regulations and standards
Alaska					
Hawaii					
Multi-Basin					
Upper and Lower Colorado	Colorado River Compact	Colorado River	AZ, CA, CO, NM, NV, UT, WY	1922, 1944	Apportioned fixed quantity from Upper Basin to Lower Basin

Water Basin Region	Compact/Treaty	Water Body	States	Year	Regulation
New England, Mid Atlantic, South Atlantic-Gulf	Atlantic States Marine Fisheries Commission	–	ME, NH, MA, RI, CT, NY, NJ, PA, DE, MD, VA, NC, SC, GA, FL	1942	Establishes commission to coordinate regulations and standards addressing fishery resources
	Western States Water Council	–	AK, AZ, CA, CO, ID, KS, MT, NE, NV, NM, ND, OK, SD, TX, UT, WA, WY	1965	Establishes commission to coordinate regulations and standards addressing water resources
Source: Thompson 1999 Water Use, Management, and Planning in the United States					

TWM is defined as “stewardship of water resources for the greatest good of society and the environment” (as cited in Grigg 2008, p 56). The broad scope of this definition is key to the effectiveness of TWM. Planning with regard to *all* the aspects of water use allows water managers to deliver the most efficient allocation of water resources. TWM is the practice of making decisions and taking actions while considering multiple viewpoints and activities. Seven principles lay the foundation for TWM planning:

1. Consider all sources of water (wastewater, stormwater, seawater, and others).
2. Apply sustainability and equity in allocating water resources.
3. Account for all end users of water.
4. Consider water quantity and quality.
5. Include stakeholder participation in the planning process.
6. Ensure TWM decisions made at local and river basin levels are in-line with broader national objectives.
7. Integrate social, economical, and environmental goals into TWM strategies.

The central focus of TWM is integration (Grigg 2008). TWM implements three coequal processes: the integration of economic, social, and environmental goals, the integration of all actors and decision making processes that affect water in a single watershed, and the integration of different aspects of water management.

1. *Integration of Economic, Social, and Environmental Goals.* TWM suggests that an integrated perspective, which considers budgets, health, equity, and natural systems in the long term, will lead to greater efficiency than traditional management. This approach necessitates an awareness of the full cost of water. * A participatory process that facilitates public input is central to achieving this broad perspective. This ensures that all of the varied impacts of water are considered before decisions are made.
2. *Integration of Water Actors/Decisions within a Single Watershed or River Basin.* Water use in any one part of a watershed impacts water use in all other parts of the watershed. Thus, water planning and management are most efficient when they occur at the watershed level. TWM calls for

*“Full cost” means the full long-term marginal cost or the full societal cost. For more information on full cost, see the USEPA definition and conceptual model of full cost pricing (Office of Water, 2006), at: http://www.epa.gov/waterinfrastructure/pdfs/workshop_si_fullcostpricing.pdf#page=15

- different jurisdictions in a single watershed to work with one another, with other water actors, and with the public to make unified decisions regarding water resources. This level of coordination will require the Army to work in close partnerships with the civil institutions that share installations' watersheds. Furthermore, while TWM advocates for water decisions made at the local level, these decisions must play into the larger, regional water management plan.
3. *Integration of All Aspects of Water Management.* TWM recommends the active planning of a single system for water management that:
 - a. Integrates water supply, wastewater, and stormwater systems;
 - b. Considers demand control alongside supply expansion;
 - c. Keeps all potential sources and end uses of water in mind;
 - d. Manages all storage, diversions, discharges, and hydrologic modifications;
 - e. Is designed in concert with the hydrologic cycle; and,
 - f. Coordinates water resource planning with land use planning.

When optimizing for the system as a whole instead of each component individually, the effect of one component on the other is no longer a given that must be dealt with, but rather a variable that can be changed. Thus, the synergies of TWM are best realized through an iterative and constantly updated planning and management process.

Water supply utilities developed TWM and are the most common TWM users. However, the ideas that underlie TWM serve as a general guideline for all actors in the water resource arena. Army installations are in a unique position to implement and benefit from TWM given their on-site control over so many aspects of the water management system (Hatcher et al.).

The linkages between drinking water, and sanitary and stormwater systems are not just local; they exist at a watershed level. Total water management and regional water conservation plans are emerging challenges that must be met if water resources are to be planned and managed on an integrated, comprehensive basis (ENN 2008, IWR 2006).

4 National Screening for Watershed Sustainability

The national screening for watershed sustainability seeks to identify those watersheds containing Army installations for which additional studies, planning, and actions may be recommended to ensure continued viability and sustainability of Army operations. Screening by itself does not provide a diagnosis of “at risk” watersheds, but is the first key step in the process. Through application of the Sustainable Installations Regional Resource Assessment (SIRRA) methodology, this work aims to identify watersheds with potential sustainment problems, rank watersheds by their relative vulnerability to such problems, and refer those watersheds containing critical Army installations and flagged as “at risk” during screening for further study. National screening allows comparisons between regions through the use of national color-coded maps for each sustainability indicator, for the set of water supply indicators, for the set of water demand indicators, and for overall watershed health.

SIRRA is a web-based sustainability assessment tool that characterizes installation-regions based on a set of 54 indicators grouped into ten sustainability issue areas. SIRRA uses uniform assessments with a broad set of indicators covering the range of issues that may affect military installations and their locality. The indicator(s) may be used to express the relative ranking of installation-regions based on single measures (or groups of measures) that define a theme. This standardized approach enables the use of national level data to evaluate the regional aspects of the installation setting. This provides a heightened awareness of long-term issues that could threaten mission sustainment.

The SIRRA watershed screening application utilizes an area-based weighting scheme to combine many indicators into three composite indices: water supply, water demand, and watershed health. There is a great demand from high-level decision-makers for a manageable number of easily understood indices. Examples of indices outside of sustainability are the Consumer Price Index and the Dow-Jones Industrial Average. However, indices face the challenges of weighting, standardizing, aggregating, and eclipsing because of differing units

and scales (Maclaren, 1996). Simplified methods of aggregation may ignore the problem of compensation; that is, where acceptable values in one indicator or index can hide unacceptable values in another. Selecting an aggregation technique requires evaluating the ability of each to meet established project requirements. Some available multicriteria decision techniques include weighted sum, analytical hierarchies, PRES II, Promethee, TOPSIS, CODASID, Electre TRI, and Fuzzy WS (Cloquell-Ballester 2005). SIRRA aggregation methods are currently under review and will, in future versions, offer the user a choice of aggregation methods.

The SIRRA methodology was first developed and presented in *An Assessment of Encroachment Mitigation Techniques for Army Lands*, ERDC/CERL TR-02-27. It was further developed in *Sustainable Installation Risk Assessment and Stationing Implications*, ERDC/CERL SR-02-12. SIRRA version 1a was released in July 2004. Its capabilities are described in *The Sustainable Installations Regional Resource Assessment (SIRRA) Capability: Version*, ERDC/CERL TR-04-9.

SIRRA version 2 was released in October 2008. Version 2 incorporates additional applications including the evaluation of DOD testing and training ranges based on primary military mission, the analysis of watersheds for relative sustainability, and guidance in applying SIRRA for National Environmental Policy Act (NEPA) investigation screening. The current update sought to identify existing regulatory requirements that SIRRA could support, and documented the findings in a Public Works Technical Bulletin. SIRRA version 2 may be accessed through URL:

<http://datacenter.leadgroup.com/sirra/>

SIRRA's regional resource framework provides the opportunity to incorporate the broader perspective of regional issues into the concept of sustainability and its implications to mission performance and sustainment. Accordingly, such a framework can be incorporated into U.S. Army projects to allow for more effective watershed-systems management. The Army is aimed at balancing the water system to help meet environmental, social, and economic goals; to increase scientific knowledge; and to reduce tensions among stakeholders.

4.1 Regional resource assessment framework and metrics

Assessing watershed sustainability is complex and requires the evaluation of a combination of indicators that are related to factors present both on and off Army installations. These factors may not readily lend themselves to prioritization, but present an indication of issues that may need to be addressed in watershed planning and management. Demographic change, community growth and sprawl, and regional economic vitality present a range of resource issues outside the fence line that may be a threat to continued Army operations or watershed vitality. Issues associated with operations, management, and cultural and natural histories define on-post risk. Assessing levels of regional resource and environmental stress or demands entails developing a set of indicators or indices that can provide reliable information about the level and type of a given resource. The resource can vary from availability of clean water to the amount of vehicular traffic congestion in the region, the latter being an indicator of potential air pollution and water from non-point sources.

4.2 Watershed assessment indicators

An “indicator” is a piece of information that reflects what is happening in a larger system. It allows observers to see the big picture by looking at a smaller part of it. Indicators are often quantitative measures such as physical or economic data. For example, traditional indicators such as inflation and unemployment rates are used for making economic decisions. Indicators are widely used as tools that monitor progress and that simplify, quantify, and communicate complex issues. Multiple indicators are sometimes aggregated into an index, usually for comparison across locations or to assess change over time. Indicators are often used as the feedback mechanism to inform policy changes intended to improve the situation being measured. Their intent in the SIRRA applications is to provide baseline information about the region in which the installation resides and illuminate key issues that may be a current or future threat to mission sustainment, mission realignments, or regional environmental health. These provide the starting point for regional planning and impact mitigation.

A watershed is the area of land that drains all of the water either under it or on it through the same geographic point. The USGS delineates watersheds using a nationwide system based on surface hydrologic features, which divides the country into 21 regions, 222 subregions, 352 accounting

units, and 2262 cataloguing units. A hierarchical hydrologic unit code (HUC) consisting of two digits for each level in the hydrologic unit system is used to identify any hydrologic area. The 6-digit accounting units and the 8-digit cataloguing units are generally referred to as basin and sub-basin. Many states have defined hydrologic units to 16-digit HUCs.

The national water sustainability analysis application of SIRRA strives to identify “at risk” watersheds in terms of water supply and demand characteristics. The intent is to supply Army field personnel, policy makers, planners, researchers, and business partners with a tool for improved decision-making and communication with stakeholders. Indicators with the potential for measuring watershed sustainment in terms of water supply and water demand were selected from the overall SIRRA list of 54 based on specific requirements:

- whether they are available at a uniform scale nation-wide to ensure consistency in comparisons;
- whether they were recorded for multiple time periods to enable the evaluation of change;
- whether they were prepared by a reputable source, such as a government agency or professional data vendor, and accompanied by metadata for quality assurance;
- whether they were provided in a digital format, to accelerate data gathering and preparation for analysis; and,
- whether they can be converted to geographic information system (GIS) format.

Sustainability indicators related to watershed health include fourteen water supply indicators and ten water demand indicators. The selected indicators represent a broad spectrum of issues related to resource availability and development. Table 3 lists the selected indicators, and shows the data source and the geographic scale. The 24 indicators provide a wide variety of information about population, land development and usage, watershed quantity and health, natural disasters, infrastructure, and regional energy. Indicators come from a variety of sources such as the USGS for water use information, the U.S. Fish and Wildlife Service (USFWS) for endangered species data, and the U.S. Census Bureau for population statistics. Appendix A includes the metadata documentation for each indicator, and provides the logic for indicator selection along with data sources, method of calculation, and assessment criteria. Since most of these are national data

sets and were chosen due to the availability of national data, mapping provides a ready pictorial view of the sustainability issues. Appendix C includes national maps for each indicator.

Table 3. Indicators for assessing watershed sustainability.

		Indicator	Source	Year	Scale
Water Supply*	A1	Streamflow	USGS	2007	HUC 8
	A2	Local Water Production	USGS	2007	HUC 8
	A3	Presence of Groundwater	USGS	2006	region
	A4	Low Flow Sensitivity	USGS	2002-2007	HUC 8
	A5	Groundwater Depletion	USGS	1995-2000	County
	A6	Drought Sensitivity	National Oceanic and Atmospheric Administration (NOAA)	2007	region
	A7	Federally Declared Disasters	Federal Emergency Management Agency (FEMA)	1964-2007	State
	A8	Seismic Zones	USGS	2002	region
	A9	Federally Declared Floods	FEMA	1964-2004	County
	A10	Flood Risk	Journal of American Water Resources Association (JAWRA)	1990	HUC 4
	A11	TES Richness	NatureServe	2005	HUC 8
	A12	TES Hotspot	NatureServe	2006	HUC 8
	A13	Criteria Pollutant Non-Attainment	U.S. Environmental Protection Agency (USEPA)	2007	County
	A14	Water Quality	JAWRA	1999	HUC 8
Water Demand**	D1	Total Withdrawals	USGS	2000	County
	D2	Consumption Rate	USGS	1995-2000	County
	D3	Energy Withdrawals	USGS	2000	County
	D4	Regional Population Density	U.S. Census Bureau	2007	County
	D5	Regional Population Growth	U.S. Census Bureau	2000-2007	County
	D6	Population Growth Projection	U.S. Census Bureau	2000-2030	State
	D7	State Smart Growth Plans	American Planning Association	2002	State
	D8	Proximity to Metropolitan Statistical Areas (MSA)	U.S. Census Bureau	2000	region
	D9	Proximity to Interstate	Environmental Systems Research Institute, Inc. (ESRI)	2002	region
	D10	Traffic Volume	Federal Highway Administration (FHWA)	2006	State
* Water supply refers to water availability for use.					
** Water demand refers to water withdrawal, consumption, and depletion.					

4.3 Analysis methodology

4.3.1 Concept

SIRRA has proven to be a useful and successful sustainability screening tool and has been used in the past to assess installations in a decision support function. The SIRRA methodology was reviewed by the individual DOD services before release. SIRRA's data framework is derived from validated national sources, compiled in a consistent format, and covers a wide array of sustainability topics. SIRRA quantifies the state or condition of sustainability indicators and provides sustainability ratings for single indicators. However, it does not currently provide sustainability ratings based on an index—that is, a group of indicators. This is left to the user for specialized applications. To meet the objective to rank the general sustainability of all the HUC8 watersheds in the nation, the methodology of this analysis must generate a sustainability rating based on multiple indicators and must be able to illustrate minor differences between watersheds and regions.

SIRRA sustainment ratings categorize indicator measures in five categories:

1. Very low vulnerability
2. Low vulnerability
3. Moderate vulnerability
4. Vulnerable
5. High vulnerability.

The process of setting these thresholds is described in step 2 of section 4.3.2. Note that these ratings are not absolute in all cases; some are relative to a norm or mean.

4.3.2 Methodology

The analysis methodology consists of characterizing watershed supply and demand indicators at the HUC8 watershed level using the SIRRA issue-based indicator framework. Each indicator was linked to the watershed boundary file. For each watershed, indicators were combined to form an overall vulnerability score.

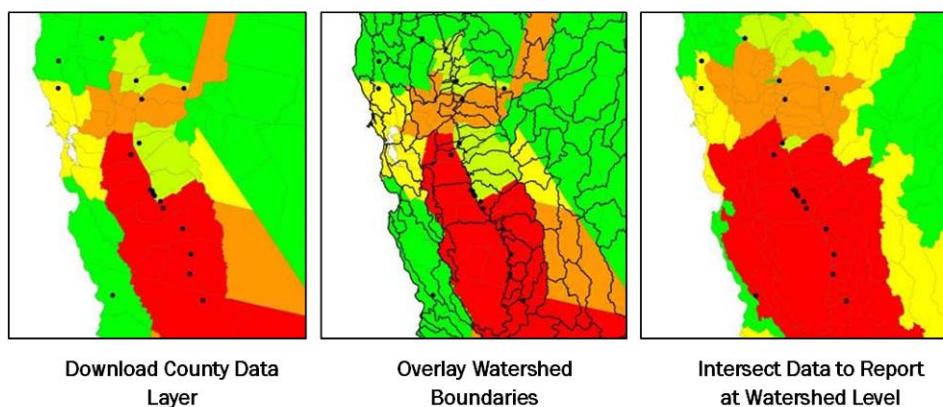


Figure 6. Watershed indicator level reporting methodology.

The analysis methodology consists of characterizing watershed supply and demand issues at HUC8 watersheds using the SIRRA issue-based indicator framework. Twenty-four indicators in all were selected for this evaluation. These indicators are listed in Table 3 (and also in Appendix A).

The following steps were followed to accomplish this:

1. Compile data for 24 indicators for all the HUC8 watersheds in the nation.
2. Divide the 24 indicators into five categories of sustainability—where 1 represents very low vulnerability and 5 represents high vulnerability—using SIRRA threshold definitions as a guide.
3. Sum the sustainability ratings to arrive at an overall sustainability score that characterizes a potential for sustainment jeopardy.

A more detailed description of each step follows.

1. Collect indicator data from national sources. This data is reported at various scales. For example, the USGS reports withdrawals at the county level, the USCB reports population projections at the state level, and Nature-Serve reports threatened and endangered species at the ecoregion level. Intersect each indicator level with HUC8 watershed boundaries (Figure 6) and determine an overall indicator score for each 2,252 HUC8 watersheds. Rules to accomplish this change in reporting level vary based on the indicator. Watershed values may be based on a weighted average, “worst” rating, or most common value. The metadata in Appendix A define the method used for each indicator.
2. Establish the vulnerability rating levels for indicator data. The metadata in Appendix A includes the sustainment rating thresholds and the selection

logic for the 24 indicators used in this study. Once sustainment ratings were determined, they were assigned numbers. This allows an indicator to be weighted and scored based on its criticality to watershed sustainment:

- very low vulnerability = 1
- low vulnerability = 2
- moderate vulnerability = 3
- vulnerable = 4
- high vulnerability = 5.

Indicator sets often include “not-available” data values—specifically for water sustainment indicators in Alaska and Hawaii where the data source does not report conditions in these areas. To ensure that these “not-available” data values neither hurt nor help watersheds, these values were either entered as “moderately sustainable,” or the rating was interpolated from the surrounding nearby regions. Appendix B gives all data values for the indicators by watershed used in the analysis.

3. Sum the individual indicator ratings for each watershed to arrive at an overall score. To arrive at a final sustainment/vulnerability score for the watershed, simply add the indicator rating values (i.e., 1, 2, 3, 4, or 5). The higher the score, the more vulnerable the watershed is considered to be or the more stress it incurs due to development and encroachment issues. The lower the score, the less vulnerable the watershed is to environmental and key issue stresses. Appendix B provides the indicator vulnerability score and final sustainment score for each watershed. The indicators are not weighted and each is treated equally. There could be some locational weighting applied for certain indicators, but this was not attempted for the current study.

Users are advised to review the indicators that lead to a high or low sustainability score and interpret the score based on specific local data sources and stakeholder knowledge.

4.4 Watershed sustainability scores results

Figure 7 shows the resulting rankings of all 2,252 HUC8 sustainability scores along with the corresponding Army installations. Army installation scores are assigned based on the score of the watershed in which the installation resides. The sustainability scores for the watersheds ranged from 50 to 103. Vulnerability ratings were determined by subjecting the data to statistical analysis.

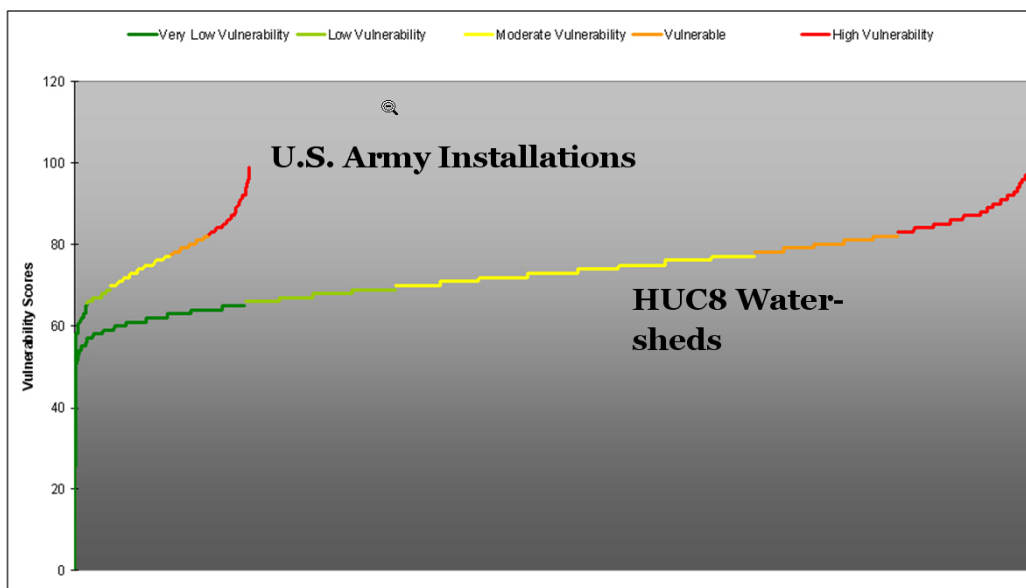


Figure 7. Distribution of vulnerability scores for watersheds and installations.

Possible overall sustainability scores range from 24 to 120, where the lowest score represents the lowest potential vulnerability and the highest score represents the maximum potential vulnerability. Table 5 lists the range of scores and their statistics, and Table 5 lists the ranges for the various vulnerability classifications.

Table 4. Statistics of scores.

Statistical Analysis of Vulnerability Scores	Watershed	Army Installation
Median	73	76
Mean	73.4	76.5
Standard Deviation	8.5	8.1
Lowest Score	50	58
Highest Score	103	99

Table 5. Vulnerability ranges.

Ranges of Vulnerability Based on Statistics	
<i>Very Low Vulnerability</i>	Less than 1 Std Dev below Mean (≤ 65)
<i>Low Vulnerability</i>	Between 1/2 and 1 Std Dev below Mean (66 - 69)
<i>Moderate Vulnerability</i>	Between 1/2 Std Dev above Mean and below Mean (70 - 77)
<i>Vulnerable</i>	Between 1/2 and 1 Std Dev above Mean (78 - 82)
<i>High Vulnerability</i>	Above 1.5 Std Dev above Mean (≥ 83)

Watersheds with the highest vulnerability tended to be in areas with high levels of urban development or near large metropolitan areas. Regions showing the highest vulnerability were in California, Florida, the southeastern states, and the New Jersey/New York City area. Watersheds in areas rated the least vulnerable tended to be located in rural areas or settings with low population. Figure 8 shows a map of the United States that consolidates the results.

All locations have some vulnerability to sustainability problems, as evidenced by the fact that the lowest rating score was still significantly higher than the lowest possible score. The highest scored watershed was much closer to the highest possible score. This indicates that watersheds do vary and that not all of the indicators are low for any given location. The range of scores was fairly linear across the range except for either extreme. The watersheds with the highest vulnerability have a fairly steep rise in scores. The same is true for regions rated least vulnerable.

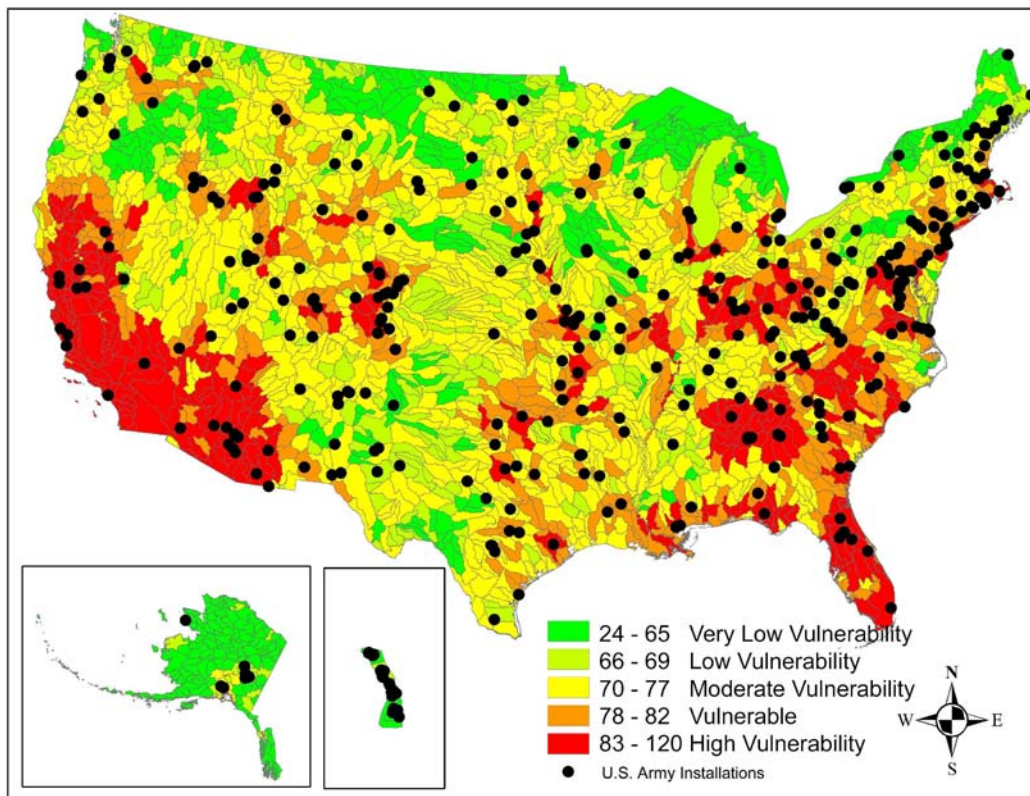


Figure 8. Watershed vulnerability scores.

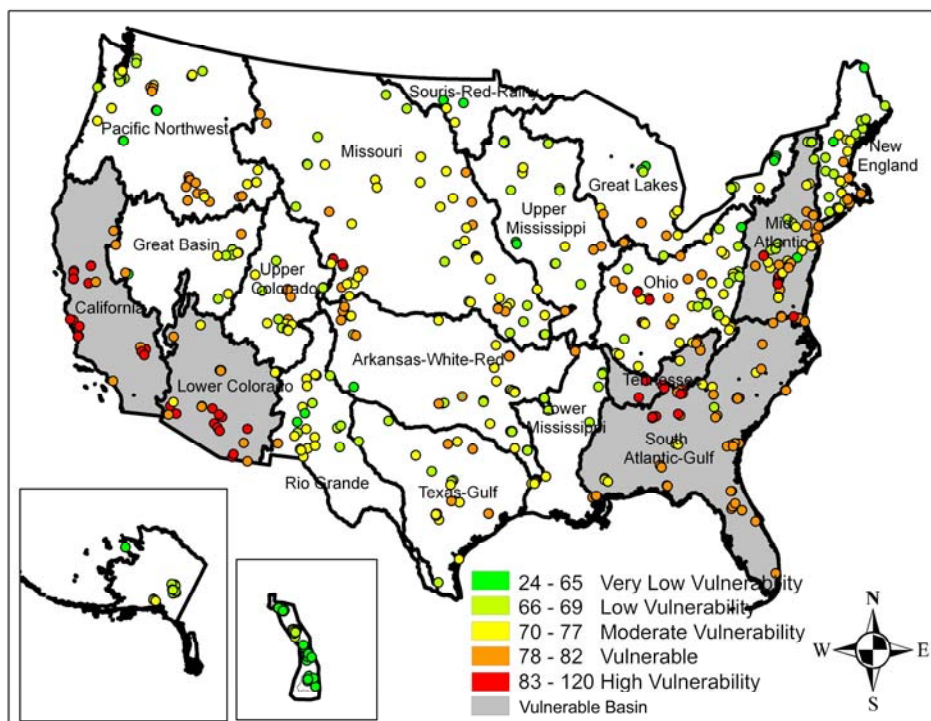


Figure 9. Army installation watershed vulnerability scores.

4.5 Installation-Region Sustainability Scores

Figure 9 maps Army installations in relation to Basin Region vulnerability scores. Nearly 100 of the 411 installation studied (23 percent) lie within watersheds that are highly vulnerable to water crisis situations. Twenty-eight installations (6.8 percent) are unlikely to face severe water shortages (i.e., they lie within low vulnerability watersheds). Highly vulnerable installations tend to be in the South Atlantic-Gulf, Lower Colorado, Mid-Atlantic, and California basin regions. Very low vulnerable installations tend to be within the Hawaii and Upper Mississippi basin regions (Tables 6, 7, and 8).

Table 6 summarizes the strengths and weaknesses of Army installations by basin. Most Army installations are threatened by high traffic, growth, and urbanization. However, the most endangered watersheds show additional vulnerabilities to natural disasters and species habitat preservation (Figure 10). Even the least vulnerable installations are threatened by low regional streamflow and high regional water runoff (in Appendix A, see Indicator: Local Water Production (A2), p 187). The most vulnerable installations gain points in the consumption factors.

Table 6. Army installation average vulnerability scores by basin.

Basin Region	Army Installation Average Total Vulnerability Score	Streamflow	Local Water Production	Presence of Groundwater	Low Flow Sensitivity	Groundwater Depletion	Drought Sensitivity	Federally Declared Disasters	Seismic Zones	Federally Declared Floods	Flood Risk	TES Richness	TES Hotspot	Criteria Pollutant Non-Attainment	Water Quality	Total Withdrawals	Consumption Rate	Energy Withdrawals	Regional Population Density	Regional Population Growth	Population Growth Projection	State Smart Growth Plans	Proximity to MSA	Proximity to Interstate	Traffic Volume	
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	
		Army Installation Average Vulnerability Score																								
Hawaii	63.2	5	5	1	1	1	3	1	5	3	3	5	5	1	3	2	1	1	3	3	2	3	3	3	1	
Souris-Red-Rainy	68.3	5	5	3	3	3	3	3	1	5	3	1	2	1	3	1	2	1	5	1	1	5	4	5	5	
Alaska	68.3	3	5	5	1	3	3	3	5	2	3	1	2	1	3	1	1	3	4	4	4	5	2	2	1	
Upper Mississippi	73.3	3	3	1	2	3	3	4	2	5	3	2	2	1	3	3	2	4	3	3	3	3	4	5	5	
New England	73.4	4	1	5	2	2	3	2	5	5	4	2	2	2	3	4	3	3	3	3	3	3	4	5	3	
Rio Grande	73.6	5	5	1	2	2	2	2	5	2	3	4	4	2	4	3	1	1	3	3	3	3	4	4	5	
Great Basin	73.9	5	5	1	2	1	3	1	5	3	3	4	4	2	2	3	1	1	4	4	4	3	4	5	5	
Lower Mississippi	74.0	4	3	1	1	3	3	4	4	5	4	2	3	1	3	3	3	2	3	2	3	3	4	5	5	
Great Lakes	74.4	4	2	1	1	2	3	3	4	5	4	2	2	2	4	3	2	4	3	2	3	3	5	5	5	
Upper Colorado	75.4	3	5	1	3	2	3	1	5	3	5	5	4	1	2	4	2	2	4	4	4	3	3	4	5	
Pacific Northwest	75.6	3	3	1	2	3	3	3	5	4	3	3	3	2	3	4	2	1	3	4	4	2	4	5	5	
Ohio	75.8	2	2	1	2	2	3	4	4	5	3	3	3	4	3	3	3	3	2	2	4	5	5	5		
Arkansas-White-Red	76.4	4	4	2	3	3	3	4	4	5	3	3	3	1	2	3	2	3	3	3	3	4	4	5	5	
Missouri	76.4	3	4	2	2	3	3	2	3	5	3	2	2	1	3	3	2	3	3	3	3	4	4	5	5	
Texas-Gulf	77.0	4	4	1	2	1	3	5	3	5	5	3	3	2	2	3	3	1	2	4	5	3	5	5	5	
Mid Atlantic	79.4	4	2	1	3	3	3	3	4	5	5	3	3	3	3	4	2	4	2	4	3	3	5	5	4	
South Atlantic-Gulf	83.5	4	4	1	2	3	3	3	4	3	5	5	4	2	3	3	3	4	3	4	4	3	5	5	5	
Tennessee	84.7	4	3	1	1	2	3	3	5	5	3	5	5	4	2	3	3	3	3	3	4	3	5	5	5	
Lower Colorado	87.1	5	5	1	3	2	3	2	5	4	5	4	4	3	3	4	2	2	3	5	5	3	4	5	5	
California	91.3	5	5	1	2	3	4	5	5	5	5	5	4	4	3	5	2	3	3	4	4	3	4	5	5	
United States	76.5																									

Table 7. Highly vulnerable Army installation watersheds by basin.

Army Installation		Watershed Region	Vulnerability Score
1	Camp Roberts	California	99
2	Florence Military Reservation	Lower Colorado	96
3	Rittenhouse Training Site	Lower Colorado	96
4	Redstone Arsenal	Tennessee	96
5	Camp San Luis Obispo	California	95
6	Hunter Liggett	California	95
7	Catoosa	Tennessee	94
8	VAAP Logistics Transformation Agency (LTA)	Tennessee	94
9	Camp Parks	California	92
10	Concord	California	92
11	Parks RFTA	California	92
12	Riverbank Army Ammunition Plant (AAP)	California	92
13	Papago Park Military Reservation	Lower Colorado	92
14	Fort Belvoir	Mid Atlantic	92
15	Fort Lesley J McNair	Mid Atlantic	92
16	Fort Myer	Mid Atlantic	92
17	U.S. Army Adelphi Laboratory Center	Mid Atlantic	92
18	Walter Reed Army Medical Center	Mid Atlantic	92
19	Los Alamitos Joint Forces Training Base (JFTB)	California	92
20	Van Vleck Ranch	California	91
21	Anniston Army Depot	South Atlantic-Gulf	91
22	Fort McClellan	South Atlantic-Gulf	91
23	Henry H. Cobb Jr. - Pelham	South Atlantic-Gulf	91
24	National Training Center (NTC) and Fort Irwin	California	91
25	Safford Training Site	Lower Colorado	90
26	Horsetooth Reservoir	Missouri	90
27	Jefferson Proving Grounds	Ohio	90
28	Fort McPherson	South Atlantic-Gulf	90
29	Fort Huachuca	Lower Colorado	89
30	Casa Grande Training Site	Lower Colorado	89
31	Picacho Training Site	Lower Colorado	89
32	Western Army National Guard Aviation Training Site (WAATS) Silverbell	Lower Colorado	89
33	Buckeye Training Site	Lower Colorado	88
34	Fort Eustis	Mid Atlantic	88
35	Lexington	Arkansas-White-Red	87
36	Sierra Army Depot	California	87
37	Stead FAC MTA	California	87
38	Camp Navajo	Lower Colorado	87
39	Navajo	Lower Colorado	87

Army Installation		Watershed Region	Vulnerability Score
40	Fort Hamilton	Mid Atlantic	87
41	Wally Eagle DZ	Missouri	87
42	Felicity	Ohio	87
43	Tarleton LTA	Ohio	87
44	Military Ocean Tml Sunny Point	South Atlantic-Gulf	87
45	Camp Merrill	South Atlantic-Gulf	87
46	Yuma Proving Ground	Lower Colorado	86
47	Camp Fretterd	Mid Atlantic	86
48	Gunpowder Military Reservation	Mid Atlantic	86
49	Camp Curtis Guild	New England	86
50	Fort Gillem	South Atlantic-Gulf	86
51	Paisley LTA	South Atlantic-Gulf	86
52	Snake Creek Training Site	South Atlantic-Gulf	86
53	Tosohatchee LTA	South Atlantic-Gulf	86
54	Camp Crowder	Arkansas-White-Red	86
55	Sunny Hills LTA	South Atlantic-Gulf	86
56	Goodpasture DZ	Arkansas-White-Red	85
57	Douglas Training Site	Lower Colorado	85
58	Chatfield Reservoir	Missouri	85
59	Marion LTA	Ohio	85
60	Pocatello Airport LTA	Pacific Northwest	85
61	Buckman	South Atlantic-Gulf	85
62	Camp Blanding	South Atlantic-Gulf	85
63	Fort Lee	South Atlantic-Gulf	85
64	Ocala Armory	South Atlantic-Gulf	85
65	Swift Acres LTA	South Atlantic-Gulf	85
66	Camp Villere	Lower Mississippi	84
67	BG Thomas Baker Training Site	Mid Atlantic	84
68	Pendleton MTA SMR CP	Mid Atlantic	84
69	89th RSC Sunflower Wet Site	Missouri	84
70	Sunflower AAP	Missouri	84
71	Camp Atterbury	Ohio	84
72	Newport Chemical Depot	Ohio	84
73	Hodges Training Site	South Atlantic-Gulf	84
74	Haws Crossroads Wet Site	Tennessee	84
75	Barker Dam LTA	Texas-Gulf	84
76	Barker Dam Training Site	Texas-Gulf	84
77	Fort Wolters	Texas-Gulf	84
78	Wells Gulch	Upper Colorado	84
79	Joliet Training Center	Upper Mississippi	84
80	Fort Gordon	South Atlantic-Gulf	84

Army Installation		Watershed Region	Vulnerability Score
81	Fort Stewart	South Atlantic-Gulf	84
82	Fort Carson	Arkansas-White-Red	83
83	Fort Ritchie	Mid Atlantic	83
84	Sioux Falls Airport Training Area	Missouri	83
85	Weldon Spring	Missouri	83
86	Camp Edwards	New England	83
87	Massachusetts Military Reservation	New England	83
88	Blue Grass Army Depot	Ohio	83
89	Hunter Army Airfield	South Atlantic-Gulf	83
90	McCrary Training Center	South Atlantic-Gulf	83
91	Duffield Industrial Park	Tennessee	83
92	Mabe Range LTA	Tennessee	83
93	Kingsbury LTA	Upper Mississippi	83
94	Pocatello Training Site	Pacific Northwest	83
95	Fort Jackson	South Atlantic-Gulf	83
96	Tulahoma Military Reservation	Tennessee	83

Table 8. Very low vulnerability ranked installations.

Army Installation		Watershed Region	Vulnerability Score
1	Aahoaka LTA	Hawaii	58
2	Anahola LTA	Hawaii	58
3	Kalepa LTA	Hawaii	58
4	Kekaha	Hawaii	58
5	Kekaha LTA	Hawaii	58
6	Nounou LTA	Hawaii	58
7	Ridgeway	Ohio	60
8	Stewart River	Alaska	61
9	Tucumcari Training Site	Arkansas-White-Red	61
10	Puu Kapele LTA	Hawaii	61
11	Puu Luahine (Red Hill) LTA	Hawaii	61
12	Caswell Training Site	New England	61
13	Fort Drum	Great Lakes	62
14	Keamuku LTA	Hawaii	62
15	Keaukhana Military Reservation	Hawaii	62
16	Pau'Uilo LTA	Hawaii	62
17	Pohakulua Training Area	Hawaii	62
18	Puu Pa LTA	Hawaii	62
19	Honopou LTA	Hawaii	63
20	Kanaio Training Center	Hawaii	63
21	Maluhia LTA	Hawaii	63
22	Pu'Unene LTA	Hawaii	63

Army Installation		Watershed Region	Vulnerability Score
23	Ukumehame Firing Range	Hawaii	63
24	Brettons Wood Biathlon Range	New England	63
25	Mickelsen Stanley R SFG MSR	Souris-Red-Rainy	63
26	Camp Dodge	Upper Mississippi	65
27	Camp Dodge MTA	Upper Mississippi	65
28	Camp Grayling	Great Lakes	65

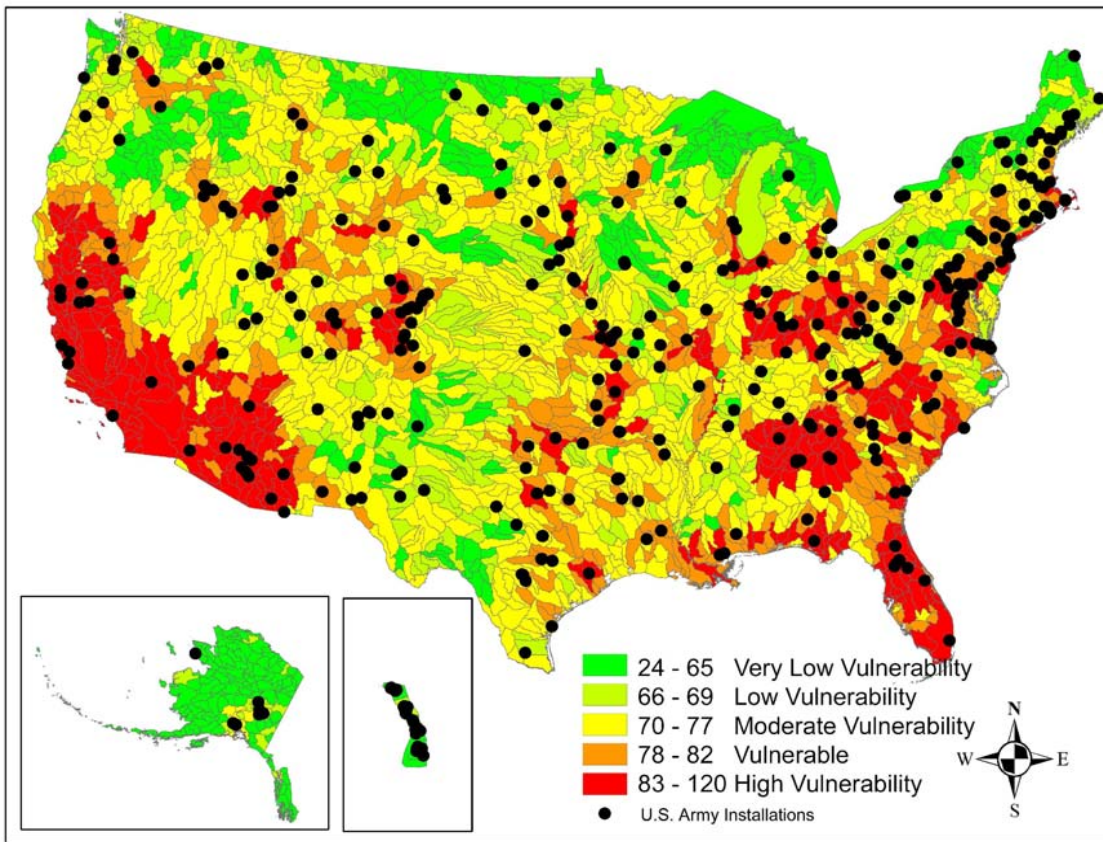


Figure 10. Watershed vulnerability scores.

While these basins tend to have abundant water supplies and seldom experience drought, they also have lower withdrawals per capita and overall. Vulnerable installations have the same threats as low-vulnerable, but increasing consumption rates coupled with high population growth as well as more drastic weather events causes a higher stress level in a number of watersheds (Figure 11). These stresses are further evident in the high presence of threatened and endangered species and low water quality in vulnerable watersheds.

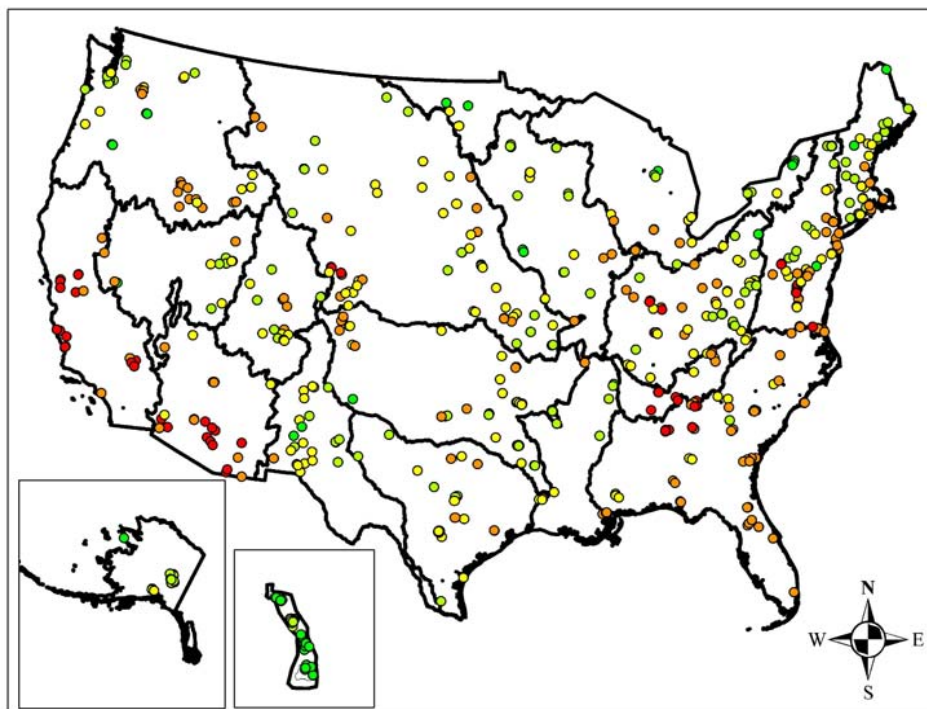


Figure 11. Army installation watershed vulnerability scores.

Not surprisingly, installations located within vulnerable watersheds also tend to have more Base Realignment and Closure (BRAC) measures identified. Planned growth within the fence line is a factor that merits serious consideration when assessing the vulnerability of installations to water supply and demand. Table 9 lists vulnerable Army installations by basin, with an arrow indicating whether it will gain or lose population due to various Army transformation actions. Although new building design standards require that new Army facilities achieve a LEED silver rating, overall water use is expected to increase. Installations located within “high-risk” basins (South Atlantic-Gulf, Lower Colorado, Mid-Atlantic, and California) have a need to better identify key issues and challenges to water supplies. These are areas where the Army might provide enhanced support to installations, state, and regional integrated water resource planning and management.

4.6 Interpreting the results

The watershed vulnerability scores underpin the global water concerns previously discussed—available supply is shrinking, demand is growing, and quality is being degraded. Although regions and installations may not currently encounter the effects, watersheds within their basin are. Given the interconnectedness of watersheds, the threats are real. Installations may not be subject to local resource constraints but supply, demand, quality, and water rights issues are threatening the system.

Table 9. Vulnerable basins and installations at high vulnerability.

State/Basin	Installation	State/Basin	Installation
Hawaii	(none)	Tennessee	Haws Crossroads Wet Site Catoosa VAAP LTA Redstone Arsenal ▲
Rio Grande	(none)	Upper Mississippi	Joliet Training Center
Pacific Northwest	Pocatello Airport LTA	Great Lakes	(none)
Mid Atlantic	BG Thomas Baker Training Site Pendleton MTA ▼ Camp Fretterd Gunpowder Military Reservation Fort Hamilton Fort Eustis ▼ Fort Belvoir ▲ Fort Lesley J McNair Fort Myer U.S. Army Adelphi Laboratory Center ▼ Walter Reed Army Medical Center ▼	Missouri	89th RSC Sunflower Wet Site Sunflower AAP Chatfield Reservoir Wally Eagle DZ Horsetooth Reservoir
Souris-Red-Rainy	(none)	Lower Colorado	Douglas Training Site ▼ Yuma Proving Ground Camp Navajo Navajo Buckeye Training Site Casa Grande Training Site Picacho Training Site Western ARNG Aviation (WAATS) Silverbell Fort Huachuca ▼ Safford Training Site Papago Park Military Reservation Florence Military Reservation Rittenhouse Training Site
Great Basin	(none)	New England	Camp Curtis Guild
Ohio	Camp Atterbury Newport Chemical Depot Marion LTA Felicity Tarlton LTA Jefferson Proving Grounds	Upper Colorado	Wells Gulch
South Atlantic-Gulf	Fort Gordon Fort Stewart Hodges Training Site Buckman Camp Blanding Fort Lee ▲ Ocala Armory Swift Acres LTA Sunny Hills LTA Fort Gillem ▼ Paisley LTA Nake Creek Training Site Tosohatchee LTA Camp Merrill Military Ocean Tml Sunny Point Fort McPherson ▼ Anniston Army Depot ▲ Fort McClellan Henry H. Cobb Jr. - Pelham	Texas-Gulf	Barker Dam LTA Barker Dam Training Site Fort Wolters
Alaska	(none)	California	Sierra Army Depot Stead FAC MTA NTC and Fort Irwin Van Vleck Ranch Los Alamitos JFTB ▼ Camp Parks ▼ Concord ▼ Parks RFTA Riverbank AAP ▼ Camp San Luis Obispo Hunter Liggett ▲ Camp Roberts
Lower Mississippi	Camp Villere	▲ BRAC 2005 Gain ▼ BRAC 2005 Close/Realign	
Arkansas-White-Red	Goodpasture DZ Camp Crowder Lexington		

4.6.1 Framework limitations

Users are encouraged to use the national screening as an initial step in a series of increasingly localized studies. The national screening can help to prioritize local studies for regions with more critical water quantity and quality problems. It is also advised to examine the individual indicator ratings when assessing a region’s water sustainability, rather than roll-up scores. High and

low ratings can balance each other and result in a satisfactory overall rating. Some indicators are critical to regional water sustainability and may outweigh all others, though they only comprise 1/24th of the roll-up score.

Vulnerability scores presented here represent a generic evaluation of the potential for environmental problems and general sustainability of any given watershed. The ranking methodology is meant to provide a screening tool—not a final, definitive evaluation of the sustainability of a watershed or U.S. Army installations. The screened information requires further detailed studies specific to a watershed and its region. In other words, this methodology screens for certain issues and identifies watersheds considered to have potential problems as determined by the chosen set of indicators. A watershed may score high on an indicator that is state-wide in scope, yet the score could be wrong for that particular location.

The methodology of this analysis is based on national data sets and does not factor in unique or site-specific conditions. As a national level screening tool, the information represents entire counties, states, or ecoregions, such that this data will not always agree with local data sources for specific watersheds or managed units within a county, watershed, or ecoregion. There are trade-offs between using this standardized approach, which allows the use of national-level data to evaluate regional aspects of the watershed, and using an approach that considers solely watershed specific data. The best recommendation is to examine the scores to judge the numbers that are most important, and to determine what they mean. Any decision relevant to a specific watershed or location should always be informed by more than this analysis alone.

Vulnerability scores offer a view of watershed health at a given moment in time. Scores are a snapshot view. Additional guidance would be to provide historical snapshots and track watershed ratings over time. This would illustrate watersheds as worsening or improving over time and/or project life spans, i.e., whether moderately vulnerable regions tend to become highly vulnerable or less vulnerable; whether policy choices or project implementation plans alter the vulnerability trend; or whether vulnerabilities tend to differ in different regions.

Time comparisons could significantly expand the depth of these vulnerability scores. These scores could potentially be improved by weighting specific indicators relative to their potential impact on mission sustainment. For example, streamflow levels may not be as critical to an installation with low water demands vs. an installation with high water demands. In this situation, the low demand installation would put less emphasis on highly vulnerable stream-

flows when summing indicator vulnerability scores. Therefore, the regional sustainability ranking approach could provide a weighted summary of assessment indicators that determine an overall mission sustainment or vulnerability rating for each watershed. Both time comparisons and weighting applications are viewed as additional capabilities that may be added to this initial screening tool to assess installations where additional studies, planning, and actions are recommended to ensure continued mission accomplishment.

4.6.2 Using Appendix B

The product of the SIRRA watershed screening application is a spreadsheet (located in Appendix B of this report—AppendixB.xls). The workspace provides the 24 individual indicator vulnerability scores, average issue area vulnerability score for water supply and water demand, and the final sustainment scores for all HUC8 watersheds and 411 U.S. Army installations. From this, analytical graphics—tables, maps, and charts—may be generated. As previously stated, the higher the score the more vulnerable the watershed is considered to be or the more stress it incurs due to system conditions. The lower the score, the less vulnerable the watershed is to environmental and key issue stresses. The Appendix B workspace contains five worksheets—*Main Page*, *Watershed Indicators*, *Raw Watershed Data*, *Watershed Vulnerabilities*, and *Installation Watersheds*. These are identifiable by tabs located in the bottom, left corner of the workspace. *Main Page* holds all vulnerability and final sustainment scores. *Watershed Indicators* is a reference worksheet. Users may refer to this worksheet for a quick reference of indicator identifiers, source, and data level (i.e., users may recollect that A1 represents 2007 streamflow data from the USGS). *Raw Watershed Data* provides the indicator value for each HUC8 watersheds. This is the value used to determine the vulnerability classification. Users may refer to this worksheet for a clearer understanding of the vulnerability rating used if the rating was the result of “no data” reported from the source. For an understanding of which watershed an installation resides in, refer to the *Installation Watershed* worksheet. *Watershed Vulnerabilities* provide the vulnerability ratings for each HUC8 watershed.

Appendix B provides users the ability to identify potential environmental problems for any Army installation and to view vulnerability ratings in relation to other installations. Data columns include installation name and final vulnerability scores. Users may sort the *Main Page* columns using the Microsoft Excel sort function to employ several analyses, including ranking all Army installations by sustainment score, distinguishing critical issues and regions for water resources, and identifying the regional constraints in adding mission requirements within a given installation.

5 Evaluating Regional Water Availability

5.1 Introduction

In this study, a regional water budget was used to evaluate the vulnerability of Army installations to potential water shortages over the next 30 years. This study defines water scarcity as that condition where demand for water exceeds its supply by at least 10 percent. This chapter provides methods for projecting the regional supply and demand, and for evaluating water scarcity. This chapter also explains how population growth, policy changes, climate change, and other important criteria affect the projected supply and demand of water for a region. The potential for water scarcity over a 30-year time frame is reviewed under a number of alternate scenarios. After introducing the methodology, water scarcity projections are formulated for the Fort Bragg, NC and Fort Bliss, TX regions.

5.2 General methodology

The hydrologic cycle (Figure 12) is the movement of water through three distinct spheres: the atmosphere, land surface, and subsurface. The natural processes contained in the hydrologic cycle are precipitation, infiltration, and evapotranspiration. These processes influence the storage and movement of water between these spheres. The atmosphere delivers water to the land surface through precipitation, while the land surface transfers a fraction of this water to the subsurface through infiltration. The land surface and subsurface convey water to the atmosphere through evapotranspiration. Evapotranspiration is the combination of evaporation from land surface and subsurface, and the transpiration of water through plants from the subsurface. Water on the surface is simply called surface water, while water in the subsurface is generally termed groundwater.

A water budget generally considers water only on the land surface and subsurface. Hydrologists study the movement and distribution of water on or near the land surface and work on developing techniques for determining water budgets. The basic concept of a water budget is the mass balance, or accounting, of water coming into and leaving a system. These budgets or balances work on a spatial and temporal scale, both of which are defined depending on the level of detail required by the study. The spatial scale of water balance studies is regionally unique and is determined during the regional characterization.

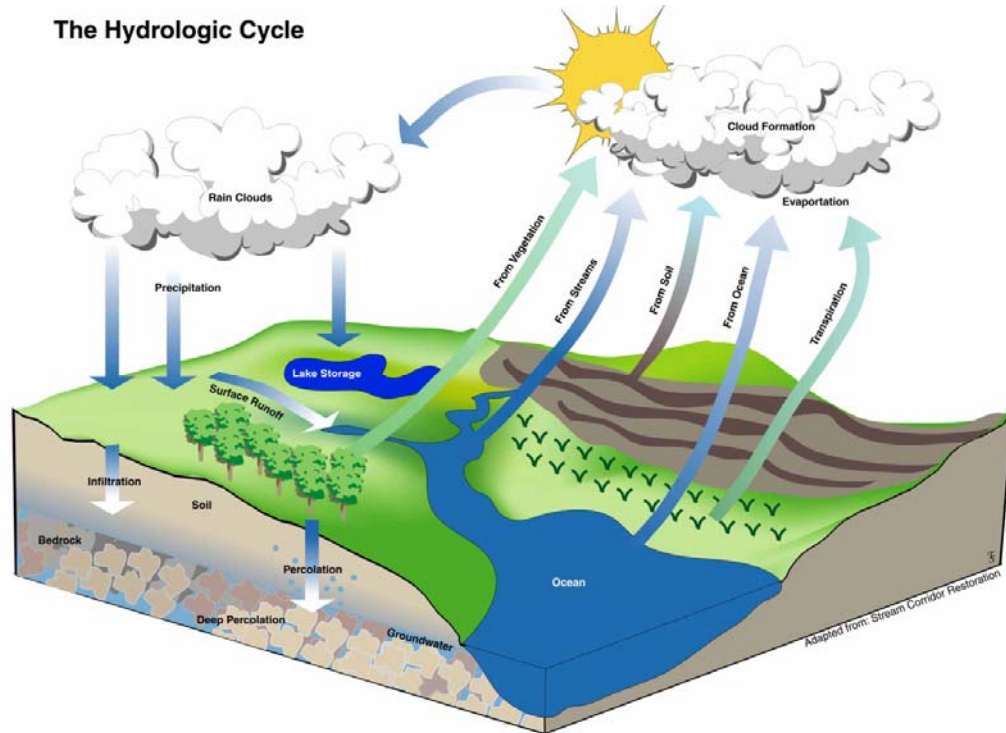


Figure 12. The hydrologic cycle (Shultz 2009).

Land surface and subsurface water systems are connected via water transport mechanisms. If the stored water in an aquifer provides a source of flow for the river, the river is called a *gaining stream* (Figure 13 on the right). The flow experienced during drought conditions is called *base flow*, and is usually provided solely by an aquifer. A river is called a *losing stream* if it provides water to the aquifer as seen in Figure 13 on the left. This is called *recharge*. The term recharge is also used when water infiltrates down to the aquifer from precipitation.

These types of interactions happen with any type of land surface and subsurface water source. The interactions seen in a region may change due to seasonal variations, human-induced conditions, or other scenarios. An aquifer may provide water during summer months when rainfall is low and be recharged during the winter months. Alternately, a surface source may lose flow to recharge an aquifer if there is an increase in pumping rates from the nearby aquifer (Winter et al. 1998). Various aquifer characteristics can also drastically affect the interaction of the surface and subsurface layers. A *confined aquifer* is sandwiched between layers of impermeable rock that pressurizes the water within. These generally have lower recharge rates than *unconfined aquifers* that are more open to receive water from the surface. Such interactions are identified when developing the regional water balance.

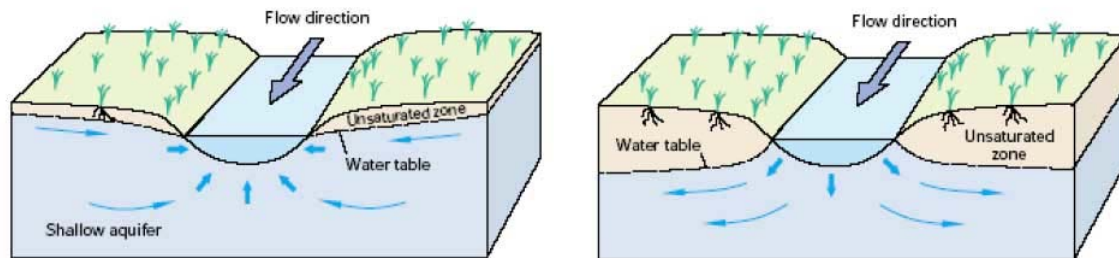


Figure 13. Surface-groundwater interaction (Winter et al. 1998).

Hydrologic systems are complex in their interactions and therefore difficult to quantify. Each part of the hydrologic cycle interacts with the other parts, and a change to one affects all. Changes that affect regional water budgets include land use, climate patterns, and water management practices (Lettenmaier 2008). Increases in development due to population growth and urban sprawl leads to increased amounts of impervious surface. This diminishes groundwater recharge and increases not only surface water volume, but also peak flow events. This can lead to increased flooding and lower flows during drought conditions due to decreased groundwater availability. The expected impacts of climate change include altered magnitudes of evapotranspiration and precipitation, both impacting regional water budgets. Finally, water management practices, such as dam operations and inter-basin transfers, alter stream flow patterns, which in turn impact the water budget. The impact of these changes is evaluated during the model projection phase.

The process for assessing regional water availability is completed in four steps:

1. *Regional Characterization.* This requires reviewing previous regional studies, gathering historical data, defining the hydrologic sector boundaries (spatial and temporal scale), and characterizing the region.
2. *Developing the Regional Model.* The major hydrologic components of the water balance are spatially identified and a baseline for the water budget is defined. The water balance consists of a supply model and a separate demand model.
3. *Projecting Water Supply and Demand Trends.* This uses information from historical trends, regional water plans, population projections, and current climate change models to develop alternate supply scenarios for the supply and demand models.
4. *Water Sustainability Assessment.* A comparison of the projected supply and demand models is used to evaluate the sustainability of adequate water supplies and determine whether there is the potential for water scarcity in the region.

5.2.1 Regional characterization

Regional characteristics that are important when evaluating potential changes to the water budget include military mission, demographic trends, water sources, climate, topography, land use, and historic water demand. Other region-specific characteristics may also be identified as important. These characteristics are defined in their historical and current context during the literature review so that potential changes to these characteristics may be evaluated when projecting future trends. Suggested information and data sources that may help characterize the region are discussed later in this chapter.

Another important step is determining the geophysical boundaries for preparing the water budget. The boundaries may follow natural divisions, political lines, municipality coverage areas, or other methods (Hayes et al. 1980). A simple way to define supply boundaries is by using naturally defined watershed and aquifer boundaries, also termed hydrologic boundaries. A watershed represents the entire land area that drains to a particular point and may be composed of a single stream or an entire river network. The USGS has defined the boundaries of every watershed in the country at various scales through a standard hydrologic unit hierarchy. Each watershed has its own name and HUC. An aquifer is a subsurface layer that stores groundwater. Aquifers are found at various depths, and can have widely varying characteristics that define its water bearing capacity. Figure 14 shows the 20 regions of the HUC naming system on the left and the major aquifers of the United States on the right. Thus, a water budget depends on the scale of both space and time. The water budget may have different spatial scales for the subsurface and land surface sectors, but they should operate on the same temporal scale. A time scale that uses annual figures is appropriate for identifying long-term trends in supply, and has thus been chosen as the standard time scale for this study (Hayes et al. 1980).

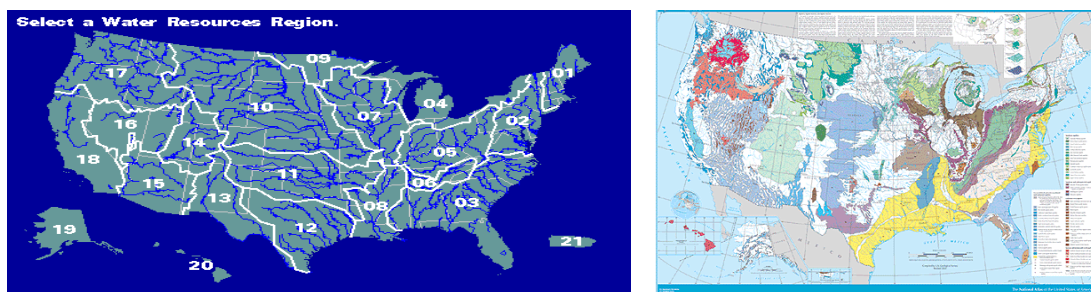


Figure 14. National HUC and aquifer maps (source: USGS, National Atlas).

5.2.1.1 *National Atlas*

The *National Atlas* (<http://www.nationalatlas.gov>) is a U.S. Department of Interior web-based mapping tool that provides a wide variety of geospatial data. This data is accessible to the public, and can be downloaded and integrated in GIS software. These map layers can be used to aide in visualizing the region and defining the water budget boundaries. The *National Atlas* provides GIS layers of watersheds, major aquifers, streams, political boundaries, and more. Similarly the National Geospatial-Intelligence Agency, as an agency of the U.S. Department of Defense, provides imagery and geospatial information for diverse government users.

5.2.1.2 *Installation Research*

Preparation of regional water budgets and installation water demand projections requires several categories of data unique to the Army installations. This data falls into the general categories of historic water demand, existing water infrastructure, planned increases in both effective population and buildings, and water conservation policies. Other information that may be available includes special studies, water supply contracts, information on the sewage and stormwater systems, system condition reports, and any details of water-consuming appliances and fixtures. Installation sources include the Environmental, Utilities, and Master Planning offices of the Directorate of Public Works; the Base Housing Office; the Operations or Transformation/BRAC Office; and, the water system contract operator.

5.2.1.3 *State Government*

States regulate water use and collect a variety of data and reports to formulate policies that maintain sustainable supplies of clean water. Comprehensive state water supply plans provide information regarding available sources of water and consumers of those sources. These plans are informed by reports submitted by water suppliers within each state. State water offices may also provide information regarding restrictions imposed by the Endangered Species Act. Other state offices may provide region specific information concerning climate, topography, land use, population growth, and water use. Appendix D to this report contains a list of agencies that may oversee some aspect of each state's water supply.

5.2.1.4 *Water Utility Providers*

Water utility companies may be able to provide historic water use and information regarding how they plan to provide adequate supply for the projected future demand. This should include current sources, capacity of treatment

plants, and expansion plans for facilities or number of water sources. The water utility providers should have current water use figures and estimates for future water use projections. In addition to individual utilities, trade organizations such as the American Water Works Association (AWWA) are additional sources of information related to water demand and supply issues.

5.2.1.5 U.S. Geological Survey (USGS)

The USGS monitors the nation's water systems in a variety of ways. The USGS defines the boundaries of the watersheds using an 8-digit HUC, where the first two numbers represent the region, the next two are the sub-region, the fifth and sixth numbers denote the river basin, and the final two denote the sub-basin (<http://water.usgs.gov/GIS/regions.html>). Maps and descriptions of various types of aquifers may also be obtained from the USGS (<http://capp.water.usgs.gov/aquiferBasics/>). The National Water Information System (NWIS, <http://waterdata.usgs.gov/nwis/>) provides historical surface water, groundwater, and water quality information, and some real-time measurements. The National Water Quality Assessment (NAWQA) program is administered by the USGS and monitors the condition of the nation's streams, rivers, and groundwater over time while evaluating the effects of natural and human impacts on these conditions. The USGS has also provided state water use data every 5 years since 1950 and water use data at the county and watershed level every 5 years since 1985. The data for 2005 is not yet available, so 2000 is used as the baseline for water demand projections. USGS offices also produce National Land Cover Data (NLCD): <http://landcover.usgs.gov/index.php>

Recent initiatives such as Water for America, jointly sponsored with the U.S. Bureau of Reclamation, seek to conduct a broad national assessment of changing water availability, and to work to improve water management and water resource monitoring. The USGS has offices in each state.

5.2.1.6 Environmental Protection Agency (USEPA)

The USEPA's mission is to protect human health and preserve the environment through research and monitoring of the natural environment including the land, air, and water. They are also charged with setting and enforcing standards for environmental protection. Such standards may work to directly improve human health by ensuring safe drinking water, or may protect habitats in which humans obtain food such as wetlands and oceans. The USEPA has 10 regional offices that are each responsible for executing the agency's goals within the states it is responsible for. The USEPA manages STORET, the largest computerized environmental data system. This database includes water quality, biological, and physical data. The Surf Your Watershed feature on

their website enables the public to locate, use, and share environmental information about the watershed in which they live. The USEPA's Office of Water released the *National Water Program Strategy: Response to Climate Change* in late 2008. This document provides an overview of the likely effects of climate change on water resources and the nation's clean water and safe drinking water programs. The WaterSense program works with the public to increase water use efficiency and has an appliance labeling program similar to the Energy Star program.

5.2.1.7 National Oceanic and Atmospheric Administration (NOAA)

NOAA collects and evaluates a wide array of historical and current weather data including temperature, precipitation, and drought monitoring. This information is disseminated through the National Climatic Data Center (NCDC, <http://www.ncdc.noaa.gov/oa/ncdc.html>). Historical data can generally be obtained as daily records or as statistical averages at daily, monthly, and annual intervals. Data is collected at reporting stations and may be available at the climate division level (344). Historic climate data may also be obtained through the U.S. Air Force at <http://www.afcc.af.mil> for government users.

5.2.1.8 Population and Economic Forecasts

The United States Census bureau designs and implements the Decennial Census, which counts the nation's entire population every 10 years using both "long form" and "short form" questionnaires mailed to dwellings, preceding a door-to-door survey. The bureau makes specialized efforts to achieve comprehensive population counts, including homeless and transient people. In addition to the 10-year complete census, the agency produces other intermediary products: "intercensal" population estimates, the sample-based American Community Survey (released yearly), the 5-year Economic Census, the Puerto Rican Community Survey, Agricultural Census, etc.

The public may freely download the complete Decennial Census data, along with the array of other Census products and demographic analyses, at <http://factfinder.census.gov>.

5.2.1.9 Other

A literature review should be conducted for the study region including the Army installation. Sources include non-governmental organizations (NGOs), research organizations, and universities. The References list provides a starting point for potential sources. A thorough review may turn up information not provided by the listed sources such as information regarding surface and

groundwater interaction, future availability, and other appropriate information. For installations near national borders, projections for other countries, such as Mexico, should also be attained.

5.2.2 Developing the regional model

The regional characterization provides information required to define the region boundaries and characterize the relevant properties associated with water supply and demand. Models are derived separately for the regional supply and the regional demand. Together these models create a water budget. Developing the regional model consists of spatially identifying the major water balance components, defining the interactions at the boundaries, and defining the current balance components and their associated driving factors. The basic relationship of a water budget is that the change in storage over time is equal to the inflow minus the outflow:

$$\text{Storage} = \text{Inflow} - \text{Outflows}$$

The significant components of inflow and outflow must be spatially identified to formulate a water balance model. Inflow parameters may include precipitation, stream flow, and return flow from withdrawals. Outflows include stream flow, evapotranspiration, and human uses such as agricultural, municipal, residential, and industrial among others. A regional water balance is a simplified representation of the interactions occurring within the defined boundaries. The location of these inflow and outflow components in relation to each other greatly affects the availability of water at the installation in question. A spatial representation of the system components such as location of municipal withdrawals, river tributaries, and stream gauging stations are all vital to understanding the water balance. Some type of flow chart or schematic of the water balance components should be formed to identify such a spatial representation of the region.

Certain legal and physical human systems may alter how the water balance is set up. These often occur at the regional boundaries, but may be present elsewhere as well. The interactions at the boundaries are dependent on how the boundaries were defined. The transfer of water outside of the defined boundaries, whether through a natural stream or human systems, represents a boundary interaction. Such human systems may include the presence of a dam that regulates the flow according to a predetermined rules set, environmental requirements, or interstate and international agreements that designate downstream flow requirements. Inter-basin transfers of water into or out

of the defined boundaries also affect the water budget of each basin. All of these must be defined, especially at the water budget boundaries.

Once the major system components affecting the region are spatially identified, a baseline is set to define availability. Historical water data should be evaluated to establish the baseline water budget scenario. This may be determined by using a representative year, or some sort of average figure over a certain range of years for each component. Each model component has varying degrees of information available, and each is developed using different methods. The driving factors for each component are given a baseline value that is altered when projecting future trends. The model outputs are total annual supply and demand, respectively, which are used to evaluate water scarcity in section 5.2.4, Water Sustainability Assessment.

5.2.2.1 Regional water supply model

Even the most detailed water budget studies contain uncertainty due to their complex nature (Healy et al. 2007). A water balance can not be expected to contain a detailed description of the surface and groundwater system nor be a precise accounting of water supply (Hayes et al. 1980).

A review of the national stream gage network states that 77 percent of the nation's basins are adequately monitored for water budget purposes, and the number of eco-regions that have been adequately monitored for long-term trends has dropped to 76 percent from 86 percent since 1976 (USGS 1998). The loss of gages that provide long-term data is a concern when trying to assess impacts due to changes in climate and land use patterns affecting future supply. Further, the USGS notes that no nationwide, systematic groundwater level monitoring program exists (USGS 2002), and the data available on groundwater levels and rates of change are "not adequate for national reporting" (Heinz Center 2008). This indicates that the level of detail possible for a water balance may vary significantly from region to region. Statewide or regional estimates for certain components may not represent actual conditions, but are often the only available information (Hayes et al. 1980). The challenge is to define the hydrologic system components so that a simplified representation of their interactions may be determined. The best available knowledge of the system should be used to define the current balance. Once the system is defined, the inputs and outputs can be modified to represent alternate future scenarios. The supply model components can be broken into three general classifications: stream flow, surface storage, and groundwater.

5.2.2.1.1 Stream flow

The storage term for a river or stream is zero, and thus the inflow equals the outflow. Driving factors for inflow include precipitation, aquifer base flow, and flows into the defined region boundaries. Outflows include evaporation, and flows out of the defined region boundaries. If there are adequate stream flow records for the region, the precipitation and evaporation factors may be neglected as the stream flow measurements reflect the results of these two processes (Hayes et al. 1980). This reasoning may also be applied to the aquifer base flow in some cases. Stream flow records can thus be directly used to determine the available water supply at that location. If adequate stream flow records are not available, some sort of rainfall-runoff model may need to be developed. One simple method is to develop a regression model using data from nearby stream gauging stations and climatic data for the region in question. Appendix E to this report contains further details on regression models. Calibrating such models can be a very time intensive process.

5.2.2.1.2 Surface storage

The inflows and outflows of surface storage systems such as lakes may include streams, runoff from the land, seepage into the ground, and evaporation. If surface storage is fed by streams then similar methods as discussed above may be used, otherwise inflows may have to be evaluated using precipitation values, and general runoff ratios. The effects of evaporation are greater with lakes than with flowing streams, and should be estimated using the best available data. Seepage rates may be difficult to obtain, or may be an insignificant factor affecting surface water. The most common measurement provided for lakes is the elevation or level of the water surface. Unfortunately this measurement does not directly translate to the volume of water available without knowing more about the geometry of the source. This provides information regarding sustainable use of the source. If the level is dropping, there is more outflow from the system than inflow to the system. This may indicate unsustainable use. A surface storage system that is not managed in a sustainable fashion has a limited supply. The length of time the source is available may not be directly determined if the volume of water is unknown. Yet the effect of changes in parameters on the storage capacity of the system can be determined. This indicates whether an improvement in the system should be expected or not. Further, there may be restrictions on minimum water levels for surface storage systems due to cooling requirements for power plants, ecosystem requirements, or other human needs.

5.2.2.1.3 Groundwater

Recharge represents the inflow of water to groundwater systems, while pumping withdrawals and evapotranspiration are the main source of outflows. In-

teractions with streams should also be considered. These driving factors are not well monitored and present a challenge when estimating groundwater availability. A rudimentary infiltration rate may be determined from precipitation values to simulate aquifer recharge, but this depends on information available concerning the aquifer.

The recharge zone may also be outside of the defined boundaries, and would alternately be represented by groundwater flows into the region. Yet, groundwater flows at a much slower pace than that of surface water, so recharge may be a negligible term. The level of detail available may vary drastically from one region to another. Much like surface storage sources, aquifer measurements are provided as a level measured in distance from the land surface. This level indicates a relative measurement of water availability over time unless the geometry of the aquifer is known. Only the sustainability of the source may be evaluated without the availability of in depth studies concerning the aquifer.

5.2.2.2 Regional water demand model

Figure 15 shows a model of the relationships between land-use change and water availability in a region. The factors influencing these connections provide the framework for analysis of water demand and consumption. Both water replenishment and water extraction are influenced by land use and demographic change. The focus for this section is on water extraction. Water extraction is divided into several sectors. These sectors are public supply, domestic, industrial, agricultural, and water losses. The figure shows how water demand is related to land use and demographic-driven change factors such as household units, commercial/industrial buildings, and agricultural land.

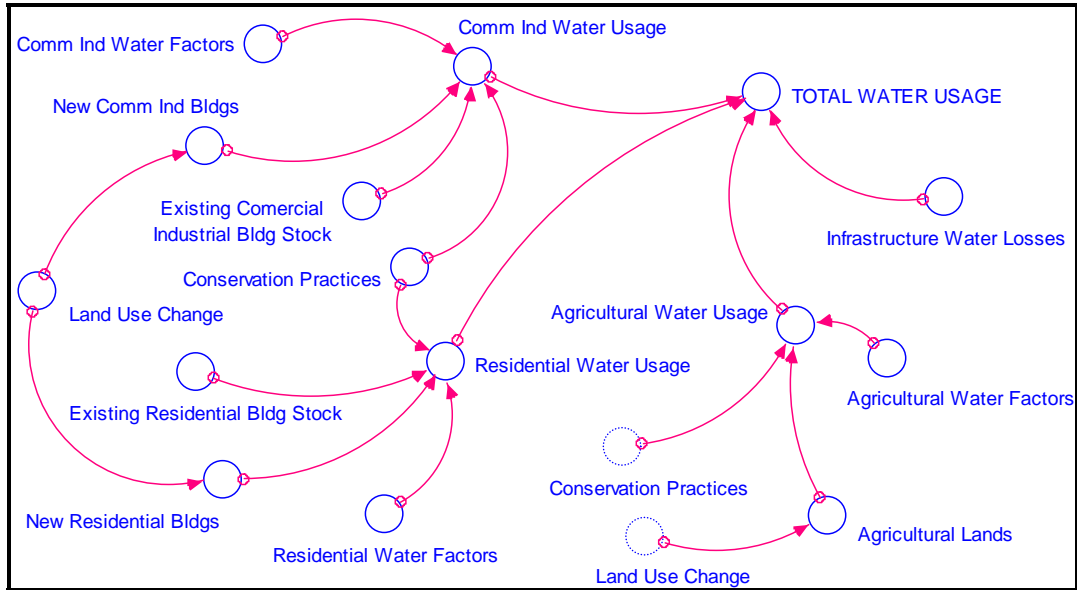


Figure 15. Regional water demand model.

5.2.2.2.1 Drivers for regional water demand

The USEPA and the USGS are national leaders in gathering water data. USGS publishes circulars on estimated use of water in the United States at 5-year intervals, currently available from 1950. The 2000 Estimated Water Use Report was used as the base for the model (USGS 2005). The data is provided by county and by water use category. These categories include:

- *Domestic Water*, defined here as self supplied water used for all indoor household purposes as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and also outdoor purposes as watering lawns and gardens.
- *Industrial Water*, defined here as water used for fabrication, processing, washing, and cooling, and includes such industries as chemical and related products, food, mining, paper and allied products, petroleum refining, and steel.
- *Irrigation Water*, defined here as water that is applied by an irrigation system to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands such as parks and golf courses. Irrigation includes water that is applied for pre-irrigation, frost protection, chemical application, weed control, field preparation, crop cooling, harvesting, dust suppression, the leaching of salts from the root zone, and water lost in conveyance.
- *Public-Supply Water*, defined here as water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public suppliers provide water for a variety of uses, such as domestic, commercial, industrial, thermoelectric power, and public water use.

- *Livestock Water*, defined here as water for livestock watering, feedlots, dairy operations, and other on-farm needs. Types of livestock include dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses and poultry.

These categories represent varying levels of consumptive water use. Not all of the water that is withdrawn from the source is returned after use. For example, industrial processes may heat the water causing steam that is lost to the atmosphere. Consumptive water use is thus the amount of water that is not returned to the source it was withdrawn from. This can also be expressed as a fraction or percent. A public water supply having 15 percent consumptive use means that 15 percent of the water withdrawn is not returned. Alternatively, a non-consumptive use implies that nearly all of the water withdrawn is returned.

5.2.2.2.2 Water demand model development

The model was developed based on the calendar year (CY) 2000 consumption and projecting forward using demographic change (population growth), local water utility projections, and an estimated achievable projection of water conservation trends. The projection methodology varies for different regions depending on the data available. Utility projections are the preferred methods for estimating future usage, but lacking that information, population projections with per capita demands are used to project future demand.

Estimates of per capita consumption are based on data from the public systems for the years 2000 through 2007. A trend line is developed from these and is used in conjunction with population projections to predict future consumption demands. Other demands in the public systems are assumed to follow population trends. For the baseline projection, agricultural demands are expected to remain stable or to decline slightly as land is converted away from agriculture to residential or commercial/industrial. Domestic usage from wells is expected to follow population trends. The impact of power generating plants accounts for their consumptive use only.

The model of demand in the region is not expected to provide a perfect projection, but to provide an indication of demand trends and a range of expected consumption. The base case can be then modified by introducing potential for water savings due to implementation of conservation programs. Total regional demand is a combination of self-supplied demand, agricultural demands such as irrigation and livestock watering, industrial demand, and public system demand. Water reuse, to the extent that it is in use or planned, is also added into the total as a negative demand.

5.2.3 Projecting water supply and demand trends

A number of possible methods are available to project future water supply and demand. Physical modeling of natural systems requires large amounts of data, and tends to be very time intensive. For example, it took a 6-year effort to improve the understanding of the recharge and river interaction of the Middle Rio Grande Basin Aquifer so that a water management strategy could be implemented (Alley 2006). Therefore simple methods must be developed to evaluate potential changes within a reasonable time frame at multiple locations. The major water balance components and their driving factors as identified when developing the regional model shall be systematically altered using the best information available to create a number of water scarcity scenarios. The task of accurately projecting future water budgets is difficult, because each component and driving factor has a level of uncertainty.

5.2.3.1 *Regional water supply model*

A number of issues arise when projecting future water availability. Among these are: uncertainty in how the components respond to future changes, uncertainty in predicting the changes themselves, and the possibility that changes outside of the defined region may impact the budget. Simplified linear projections are used to assess potential changes in water availability. As was previously noted the major factors affecting water availability are changing climate patterns, water management practices, and land use. The projected changes in these factors should be developed based on input from a range of sources as described below.

5.2.3.1.1 Climate patterns

Changes in climate could be associated with natural cycles or human influence. Various natural cycles have been observed that affect the climate across North America. Such patterns include the El Nino/ Southern Oscillation, Pacific Decadal Oscillation, and Arctic Oscillation/North Atlantic Oscillation. These patterns lead to a change in climatic conditions that last for decades at a time (Mantua 1999). Thus the water balance should be evaluated under historically significant drought cycles. Yet, this approach represents climatic stationarity, which assumes that natural systems fluctuate within a known range of conditions based on historical occurrence. However, former climate conditions may not provide an appropriate basis for future planning (National Science and Technology Council 2004). Therefore, results from the current global circulation models (GCMs) and climatic projections and impacts are used to assess future climate conditions as well.

5.2.3.1.2 Water management practices

Projected inter-basin transfers, dam operations, and other water management strategies are very important when evaluating changes to the water balance. Humans directly affect the water balance when they attempt to manage water, thereby overriding natural processes. Inter-basin transfers alter the volume of flow in a river, which may also affect the groundwater interaction of each basin. Dam operations could either increase or decrease downstream flows. Alternatively, a dam may not change the volume of water provided, but the timing of its delivery may affect natural ecological systems and available supply for downstream users. Information concerning proposed changes in dam operations, inter-basin transfers, or other human systems should be evaluated if such information is available. These may be obtained from state water plans, utility providers, or other such sources.

5.2.3.1.3 Land use

The effects of land use are varied, especially among the types of hydrologic sources. Land use may alter the timing and volume of runoff. This may or may not be a desired effect depending on surface and sub-surface interactions, dam operations, and other driving factors of the balance. Increasing amounts of impervious surfaces from land development decreases rates of groundwater recharge. Current recharge rates may be an insignificant factor in the model though, considering that many aquifers are a result of thousands of years of collecting water. "Groundwater from the middle Rio Grande aquifer is as old as 30,000 years, indicating that some recharge to the aquifer occurred when the Southwestern United States was experiencing a much wetter climate" (Healy et al. 2007). Yet decreasing recharge rates not only affect the groundwater storage, but also the base flows available to streams provided by groundwater systems. Greater amounts of impervious area may also increase the amount of water that is evaporated. Therefore, state water plans, census projections, and current land use patterns may be used to evaluate the potential impact of proposed population growth and subsequent land use change.

5.2.3.2 Regional water demand model

The regional demand model, as described above, provides the water demands for the period of interest. The demand provided by the model shows the change over time of the requirement for water resources. The demands are based on land use change and demographic projections. The impact of water conservation programs is also incorporated into the model.

5.2.4 Water sustainability assessment

The purpose of the effort described in this section is to evaluate the possibility of water scarcity on a regional scale. The potential for scarcity issues, their overall likelihood, and worst case scenarios are discussed in this section. Since water scarcity has been defined as demand exceeding supply by at least 10 percent, the following equation may be developed, where an installation is considered to have a water scarcity issue if the equation produces a value equal to or greater than zero:

$$WS_Y = D_Y - 1.1 * S_Y$$

where:

WS_Y = Water Scarcity during year, Y
 D_Y = Regional Demand during year, Y
 S_Y = Regional Supply during year, Y

5.2.4.1 Regional water supply model

The available water from each hydrologic source for each year is summed to determine the Regional Supply for a year:

$$S_Y = (S_{1,y} + S_{2,y} + \dots)$$

where:

S_Y = Regional supply during year, Y
 $s_{x,y}$ = Available supply from source, x, during year, y

5.2.4.2 Regional water demand model

The demand for water for each consuming sector for each year is summed to determine the Regional Demand for a year:

$$D_Y = (d_{1,y} + d_{2,y} + \dots)$$

where:

D_Y = Regional supply during year, Y
 $d_{x,y}$ = Demand for sector, x, during year, y

5.3 Case Study: Fort Bragg, NC

Fort Bragg, North Carolina was established in 1918 as a field artillery base on 127,000 acres with fewer than 5,000 people. During World War II Fort Bragg's population grew to over 100,000 soldiers as it served as the training ground for all five Airborne Divisions. Today the installation covers approximately 161,000 acres located in portions of Harnett, Hoke, and Cumberland Counties and is the largest U.S. Army installation by population with military population of nearly 50,000 and a total base population of over 68,000. It is the home for the XVIII Airborne Corps and the 82nd Airborne Division. The

U.S. Army Special Operations Command and the U.S. Army Parachute Team (the Golden Knights) also call Fort Bragg home. The installation experiences large shifts in the number of troops in residence, as it houses a strategic crisis response force manned and trained to deploy rapidly by air, sea, and land anywhere in the world. Due to the Base Realignment and Closure (BRAC) objectives and other transformation initiatives Fort Bragg will be expanding its operations to a projected population of over 56,000 by 2013. The region surrounding Fort Bragg continues to grow in population as well creating the need for an analysis of the water available in this region now and in the future. This study reviewed the potential for water scarcity using a regional water balance and suggested policies that may help to ensure a sustainable supply of water to this growing region.

5.3.1 Regional characterization of Fort Bragg

The following is a description of the natural and human systems that define the Fort Bragg region and influence development and outcomes of the regional water balance.

5.3.1.1 Demographic trends

The Southeastern United States is expected to continue growing in population at an overall rate higher than most of the rest of the Nation. In the nine-county region directly upstream from the sources of water providing Fort Bragg its supply, the population is expected to grow about 62 percent from 2000 to 2035. Some of this is driven by expected population growth associated with Fort Bragg's military transformation initiatives and some from regional growth.

North Carolina's State Demographer's Office produces population forecasts on the county level using a detailed cohort component analysis modified to accommodate human agency in determining group quarters population (Song 2009). This model involves segmenting the population into distinct "cohorts" by sex and age, applying known birth and death rates for each cohort, accounting for in- and out-migration, and allocating the surviving population by age given a simulated passage of 10 years in repeated iterations until it reaches the time horizon (Isserman 1993, and Song 2009). North Carolina appears to employ a "net migration" approach, which would introduce inaccuracy, but also innovates by using exponential smoothing/Auto-Regressive Integrated Moving Average (ARIMA) time series trend calculations, and other methods as controls. The state also updates its models annually, making its forecasts the most timely and accurate ones readily available, especially given

the time constraints often present in making a water balance in which they play a very important, but not central, role.

As the official forecasts did not reach as far into the future as the water balance time horizon, simple linear equations describing the best line fits for the population forecasts and North Carolina's official intercensal estimates for 1991-2008 enabled further projection of the trends.

Figure 16 shows a map of county and municipality boundaries in the area around and to the north of Fort Bragg. The Upper Cape Fear Region includes the rapidly growing urban areas of Greensborough, Burlington, Durham, and Chapel Hill and their associated suburban and exurban areas. The major cities shown on the map are those with populations greater than 45,000, with the cities Fayetteville, Greensboro, and Durham boasting over 100,000 residents in 2000.

5.3.1.2 Water sources

The region surrounding Fort Bragg relies primarily on water withdrawals from the Cape Fear River and its tributaries. The region immediately surrounding Fort Bragg contains groundwater, but the yields from these aquifers would be insignificant amounts when compared to the current demand. Typical yields are 0.25 to 0.5 Million Gallons per Day (MGD), but may be as high as just over 1 MGD. Yet Fort Bragg currently consumes on the order of 5 MGD. A few groundwater wells do serve the installation's ranges and golf course, but are inadequate for supplying the entire installation. These groundwater sources also provide much needed base flow in the surrounding rivers and streams in the region during drought conditions.

The Cape Fear River is formed at the confluence of the Deep River and the Haw River in Chatham County. The river is located within the Cape Fear Sub-Region, which is part of the South Atlantic-Gulf Region. This sub-region only contains the Cape Fear Basin, which is composed of seven sub-basins. Figure 17 shows the sub-basin boundaries for the Haw, Deep, and Upper Cape Fear Rivers. The B. Everett Jordan Dam on the Haw River just north of this confluence significantly alters the natural flow of the Cape Fear River. The operating procedures associated with this dam are a major factor in determining available supply for Fort Bragg.

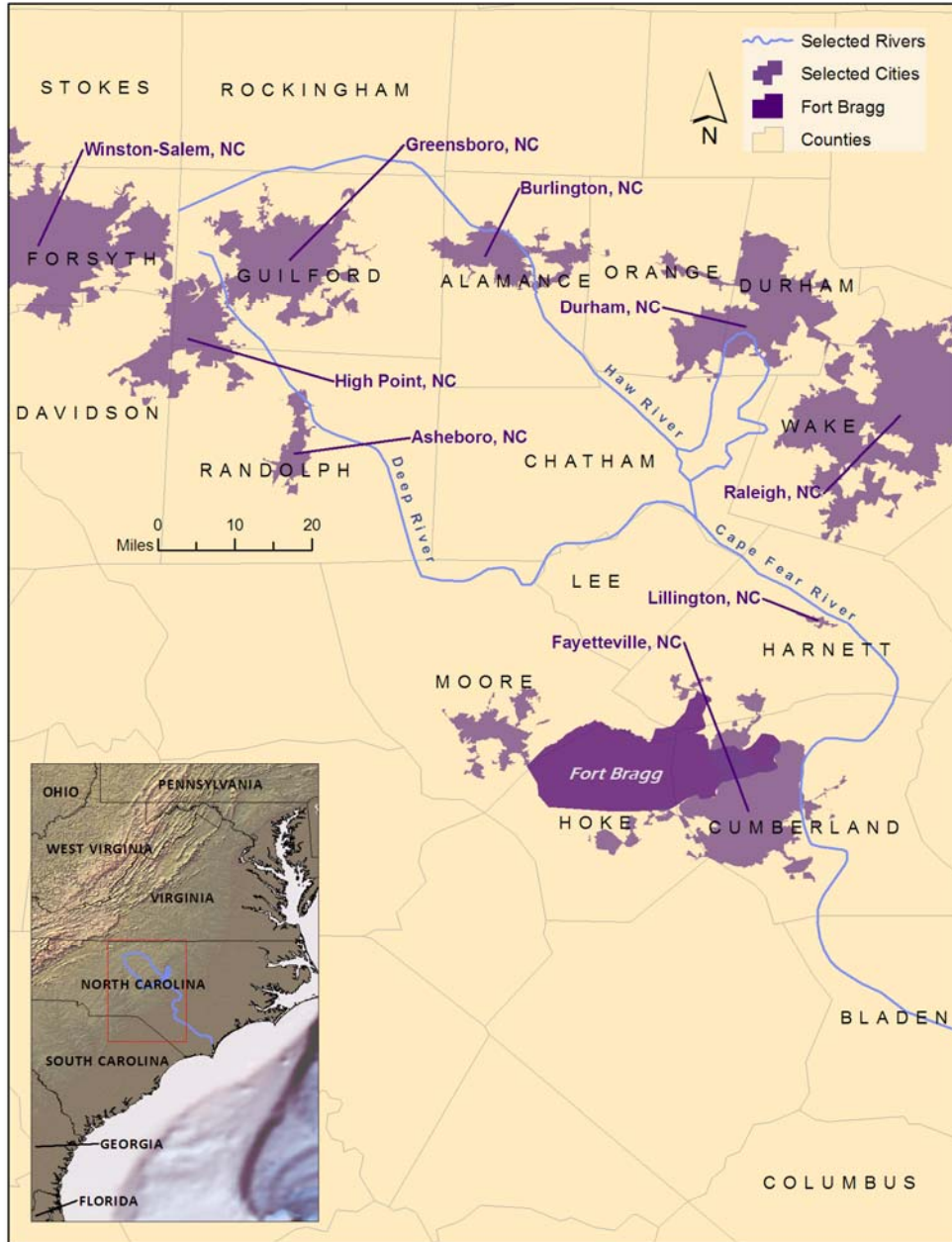


Figure 16. Fort Bragg region political boundaries (USGS, U.S. Census, DOD).

Major tributaries between the confluence and the installation are the Upper Little River and the Little River. The Little River runs along the northern border of Fort Bragg and is the installation’s current source of water. The Lillington and Fayetteville stream gauges also represent the withdrawal locations for the municipalities of Harnett County and Fayetteville respectively. Fort Bragg has plans to obtain their water from these two suppliers starting late 2009/early 2010.

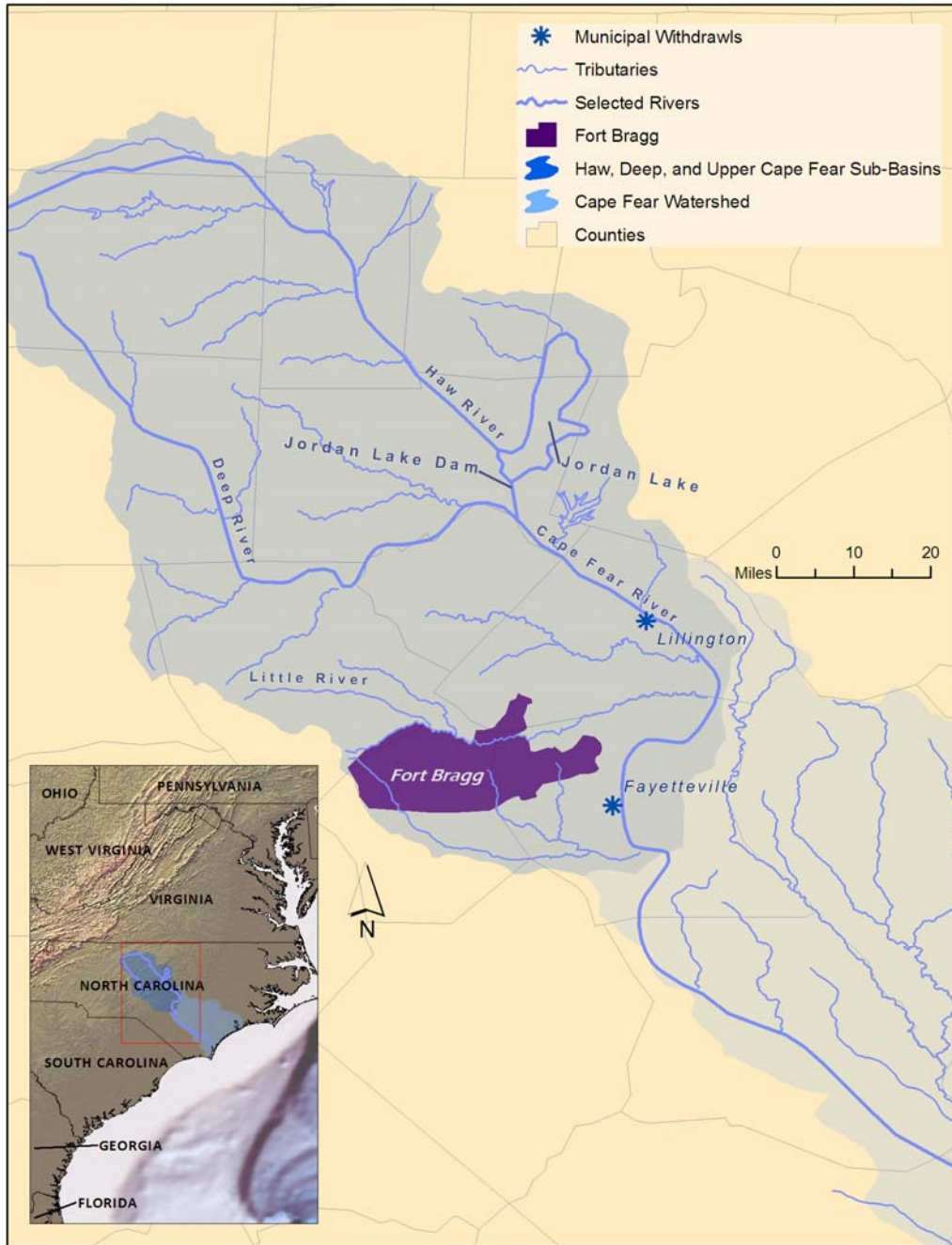


Figure 17. Fort Bragg hydrologic features (USGS, U.S. Census, DOD).

Dams along the rivers impact fish habitats by flooding shoal and marsh habitats. Further, dams hinder some fish from reaching spawning grounds, which have diminished shad and striped bass populations. Some agricultural practices release excess nutrients in the river, which lead to algal blooms. The algae use oxygen that is crucial to the livelihood of the fish. The Cape Fear shiner has been on the endangered species list since 1987, and has been affected by dams in the basin. Chatham County’s Carbonton Dam was removed in 2005. Shiner habitat was reclaimed and the fish subsequently returned.

5.3.1.3 *Climate*

The North Carolina climate can be described as having long, hot, and humid summers with short and mild winters. The average annual temperature and precipitation (1961 – 1990) in the basin is 58 °F and 42.5 in., respectively (Owenby et al. 2001). The highest rainfall generally occurs during July and August, with the lowest values generally seen during October and November (in the Fort Bragg region). Lillington, NC is located in Harnett County along the Cape Fear River about 20 miles northeast of Fort Bragg. The average annual stream flow at the Lillington gage site since 1982 has been 2,070 MGD, with the lowest annual average occurring in 2002 at just over 645 MGD.

Seven major droughts occurred between 1900 and 1990, including the years from 1950-1957, 1966-1971, and 1985-1988. The regularity of droughts in the Fort Bragg region has not ceased as major droughts have occurred over the past 6 years as well. The Cape Fear River basin experienced extreme drought conditions in 2002, while 2007 and 2008 brought exceptional drought conditions according to the North Carolina Drought Management Advisory Council. The droughts of 2007 and 2008 were the all-time worst since 1887 (NCDPPEA 2008). Yet tree rings dating back to the 12th century have shown periods of even more intense droughts (Marstel Day 2008). During these recent droughts, Fort Bragg was required to purchase water from Fayetteville, its backup source. This recent experience led Fort Bragg to pursue water supplies other than the Little River.

5.3.1.4 *Topography*

Fort Bragg is located within the Cape Fear River Watershed at the southernmost point of the Upper Cape Fear Sub-basin. The entire basin is composed of 33 percent moderately drained soils, and 51 percent poorly drained soils. Such soils are not desirable for sustained flows in drought periods. The geology of the upper Cape Fear Watershed can be characterized into two general regions: the Piedmont and the Coastal Plains, or Southeastern Plains (Figure 18).

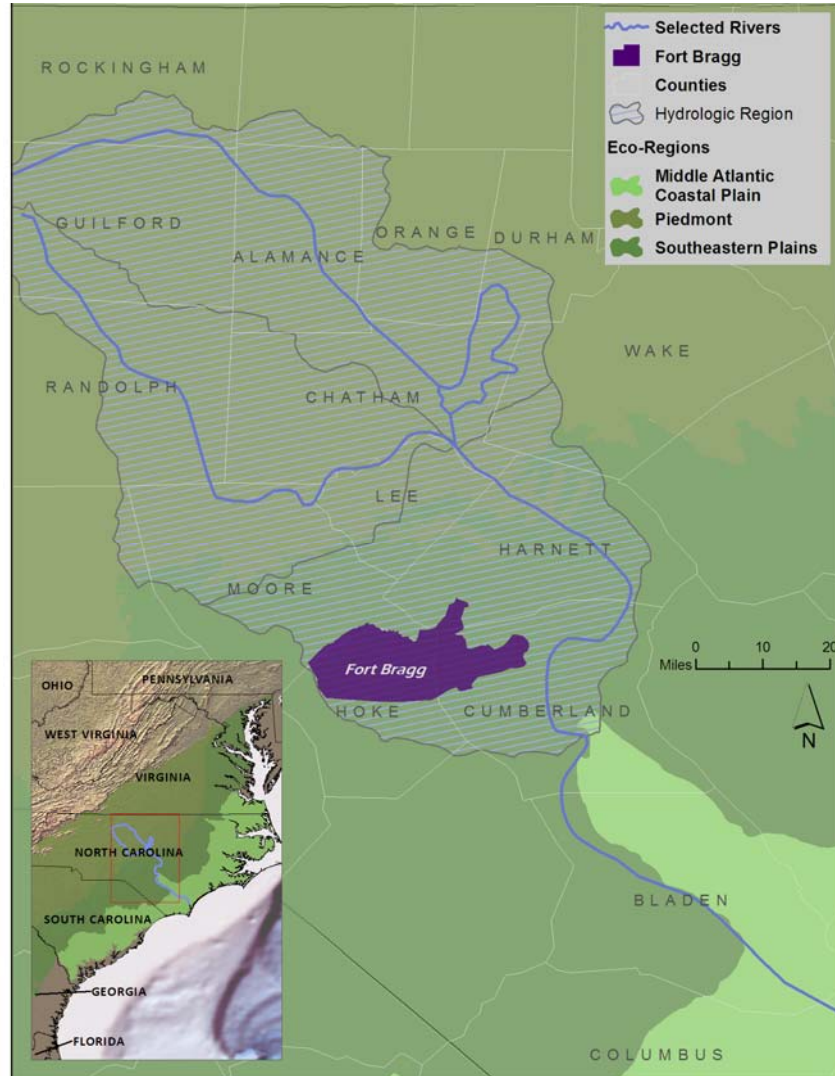


Figure 18. Fort Bragg soil types (USGS, U.S. Census, DOD).

The Piedmont area is described as having rolling hills and is composed of slate, granite and other similar rocks making it a well drained area. The properties of these impervious rocks do not allow for much storage of water, and thus lead to very low base flows during drought conditions. The coastal plains formation is primarily composed of layers of sands, silts, and clays that can hold more water, providing more base flow that allows for higher flows during drought conditions. The high permeability of the coastal plains also means that contaminants seep more easily into groundwater sources. This is of greatest concern during droughts and low flow periods when most of the water in the river is supplied by groundwater sources. The Coastal Plains province includes the Sand Hills Regions of portions of Moore, Harnett, Hoke, and Cumberland counties. This area is considered to have some of the best base flow characteristics in all of North Carolina. This means that the Coastal Plains Region and, to a greater degree, the Sand Hills Region present more reliable flows during drought conditions.

5.3.1.5 Land Use

The study area is dominated by forest, agriculture, and urban areas, which compose almost 84 percent of the land use in the region according to 2001 land use data from the USGS Land Cover Analysis Tool (<http://lcat.usgs.gov>). Figure 19 shows that forests have been reduced since 1992 and are being replaced by urbanized areas and rangeland. This type of change is expected to continue. These land use changes may impact the rate of runoff from storm events leading to higher likelihood of flooding and lower flows during periods of drought, but probably do not affect water availability on an annual scale.

Fort Bragg is located in the Sand Hills ecoregion, which supports a number of endangered species. Five Federally protected species have been identified in the rare longleaf pine habitats on the installation: the American chaffseed (*Schwalbea americana*), Michaux’s sumac (*Rhusmichauxii*), Rough-leaved loosestrife (*Lysimachia asperulifolia*), the Saint Francis Satyr butterfly (*Neonympha mitchellii francisci*), and the Red-cockaded woodpecker (*Picoides borealis*). The installation works cooperatively with other agencies towards the protection of longleaf pine habitat and the species it sustains off site in a program widely viewed as a success story (Marstel Day 2008). Further, the Army has identified five species at risk (SAR) on Fort Bragg, which are not currently identified on a national level.

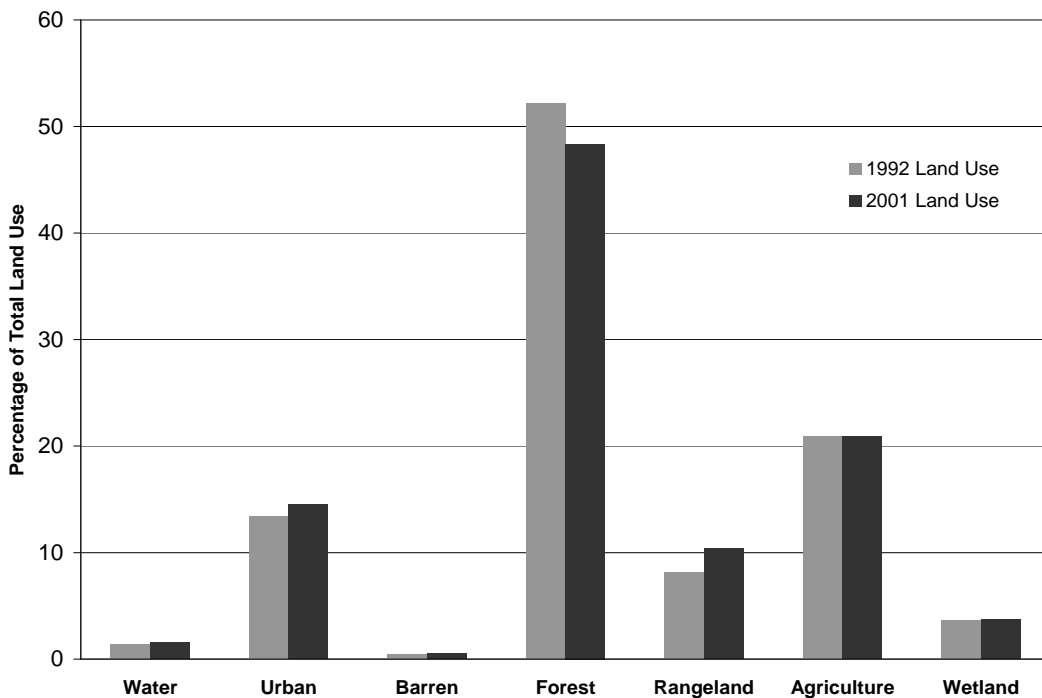


Figure 19. Fort Bragg regional land use summary (USGS).

All five species are plants and include the Sandhills bean (*Astragalus michauxii*), Sandhills Pyxie-moss (*Pyxidantha brevifolia*), Georgia lead-plant (*Amorpha georgiana var georgiana*), Pickerings dawnflower (*Stylisma pickeringii*), and Sandhills Lily (*Lillium pyrophyllum*). The Army is working to implement proactive measures for the protection of these species as well. Such ecological protection should also help to maintain the quality of water that the rivers supply especially during drought periods.

5.3.1.6 Historic water demand

Currently, the nine counties of significance that draw water from the same basin as Fort Bragg and that are upstream consume about 282 MGD as compared to Fort Bragg's consumption of about 5 MGD. Fort Bragg's consumption at times does reach the 10 MGD that it is permitted to use. Power plants in the upstream basin also have a non-consumptive use of about 352 MGD for once-through cooling. These counties have a 2000 population of ~1.5 million people. About 78 percent of the water consumption in these counties is surface water, which affects the flows in the basin upstream from Fort Bragg. The counties of interest are Alamance, Chatham, Cumberland, Durham, Guilford, Harnett, Lee, Moore, and Randolph. Table 10 lists the total water consumption in CY2000 for the various counties. Since some of the counties are not completely in the watersheds of concern, the demand model area weights these demands.

The North Carolina Division of Water Resources has set a standard for the amount of water that can be drawn from the Cape Fear River. The 7Q10 flow is the lowest 7-day average flow in the last 10 years. Pending a site-specific study, North Carolina has stated that river withdrawals must not exceed 20 percent of the 7Q10, so as not to affect aquatic habitat during droughts (NCDWR, March 2002). The 7Q10 figure is thus used by water utility companies as the basis for water availability. Most municipalities are using 7Q10 figures from a report generated by the USGS, which uses data up to 1998 (Weaver 2001).

Table 10. Total upstream County water consumption (MGD), CY2000 (USGS).

County	Water Uses						Water Sources		Consumption		
	Public Supply	Domestic	Industrial	Irrigation	Livestock	Thermo-electric	Ground Water	Surface Water	Total	% in Basin	Basin Consumption
Alamance	18.2	4.4	0.2	3.6	0.7	0.0	5.0	22.1	27.1	100	27.14
Chatham	4.7	1.9	0.5	1.5	4.0	3.0	5.2	10.4	15.6	100	15.63
Cumberland	39.7	3.1	0.0	5.0	0.6	0.0	9.5	38.9	48.4	63	30.35
Durham	30.5	4.0	0.0	3.2	0.0	0.0	4.8	32.8	37.7	27	10.13
Guilford	56.7	10.9	1.3	10.0	0.3	0.0	12.7	66.4	79.1	98	77.09
Harnett	10.0	0.4	1.1	4.1	2.5	0.0	3.8	14.3	18.0	86	15.54
Lee	7.2	1.4	0.0	2.1	0.7	0.0	2.6	8.8	11.4	100	11.37
Moore	7.0	2.2	0.0	13.7	3.6	0.0	10.6	15.9	26.5	80	21.18
Randolph	7.5	4.7	0.0	3.6	5.7	0.0	9.3	12.3	21.6	56	12.14
Total	181.5	32.9	3.1	46.7	18.2	3.0	63.4	221.9	285.4	N/A	220.58

5.3.2 Developing the Fort Bragg regional model

Although there are many aquifers in the region, none currently provide enough water for Fort Bragg's demand. Fort Bragg currently obtains water from the Old North Utility Services, Inc. (ONUS), of which the installation is its only consumer. ONUS currently operates the existing historic Bragg water plant, which is located on the installation and draws water from the Little River, which runs adjacent to the Northern boundaries of the installation. The Little River is fed by James Creek, Crane Creek, and other smaller tributaries.

Most users upstream on the Little River draw their water from ground sources (not from the river). Thus Fort Bragg is the major consumer on the Little River. Fort Bragg maintains an emergency backup supply from the Fayetteville Public Works Commission (Fayetteville PWC).

The installation has plans to shut down the ONUS facilities in the summer of 2010. Fort Bragg will then purchase water from the Harnett County Department of Public Utilities (Harnett DPU) and the Fayetteville PWC, both of which draw water from the Cape Fear River. Harnett DPU withdraws its water near Lillington upstream of where the Little River meets the Cape Fear River, while Fayetteville PWC draws its water supply from the Cape Fear River downstream of where the Little River joins the Cape Fear River.

5.3.2.1 Water supply model

This study focuses on the long-term supply—out to 2040—provided by the Cape Fear River. The year 2000 is used as the baseline to match the demand model baseline. The Cape Fear River Basin Water Supply Plan (NCDWR 2002) divided Cape Fear municipalities into groups of common water systems according to water withdrawal and discharge locations. Additionally, some groups execute inter-basin transfers and water withdrawal and discharge to separate basins within the Cape Fear watershed. Water availability is comprised of a combination of surface and groundwater sources for each group. Drawing on this, the water balance is analyzed at the sub-basin scale and includes the Deep, Haw, and Upper Cape Fear Sub-Basins.

Most municipalities base their surface water availability figures on a report published by the USGS (Weaver 2001). This report uses data through 1997 to support the conclusion that the 7Q10* flow at the Lillington gage site is approximately 340 MGD, and approximately 390 MGD at Fayetteville. Only 20

* The 7Q1 is the lowest 7-day average stream flow for a given year, while the 7Q10 is the lowest 7Q1 over the past ten years.

percent of the 7Q10 value may be withdrawn from the river without a detailed study of ecological impacts (NCDWR, March 2002). Therefore Harnett is allowed 68 MGD, and Fayetteville may withdraw 78 MGD according to this study. Unfortunately, the 7Q10 flow declined the year after data collection for this study was completed, and declined again in 2002 and 2007 (Figure 20).

5.3.2.1.1 Deep sub-basin

The Deep River is approximately 125 miles long and contains a number of human systems that regulate its flow. An increase in demand from the municipalities should increase the consumptive use of the available water in the Deep River. Further, a number of basin transfers occur that affect the flows of the river. Randleman Dam was completed in 2002 for the purpose of water supply for the Greensboro group. The dam diverts up to 30 MGD and has minimum release requirements ranging from 5 to 20 MGD depending on the reservoir levels. This could decrease average annual flows, but may increase low flows in the Haw River, which would increase water available to downstream users. Some of the diverted water is discharged to the Haw River Sub-Basin, which may not significantly impact the overall budget, but the effects of this dam have not been fully reviewed by the North Carolina Division of Water Resources. Water withdrawn from this reservoir may also be discharged to the Yadkin River Basin. Other transfers include the Greensboro group's importation of water from the Yadkin River basin. The Moncure stream gage, which is located on the Deep River just upstream of where it meets the Cape Fear River, recorded an average annual stream flow of 740 MGD in 2000.

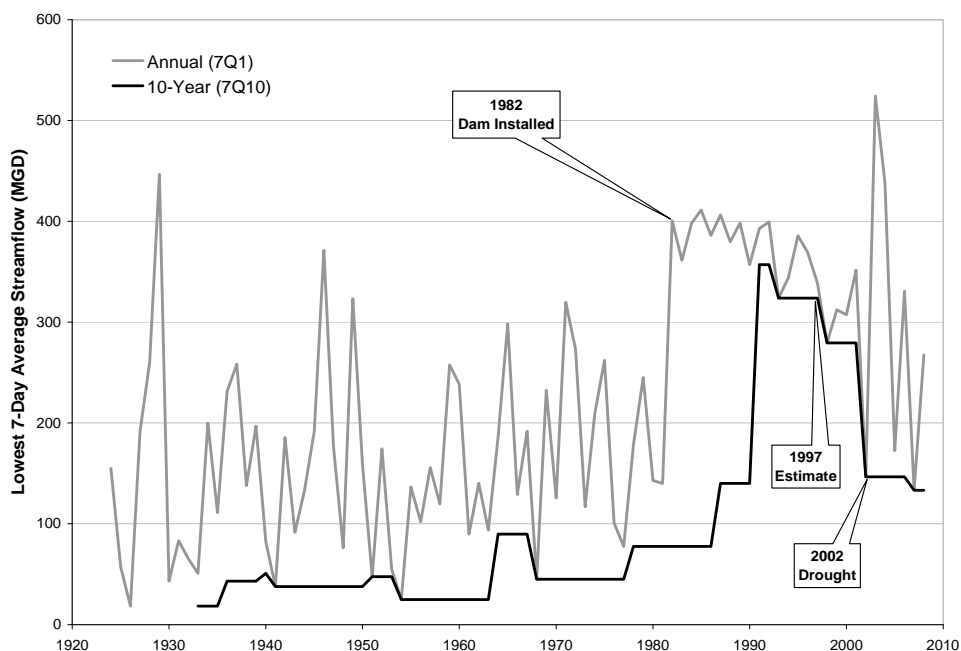


Figure 20. Annual and 10-year lowest 7-day average flow (USGS).

Table 11. Proposed Jordan Lake drought operating rules (NCDWR 2008).

Drought Stage	Percent Remaining in Water Quality Account	Minimum Release (MGD)	Lillington Target (MGD)
-1	100	25	390
0	80-100	25	390
1	60-80	25	290-390
2	40-60	25	190-290
3	20-40	130	None
4	0-20	70	None

5.3.2.1.2 Haw sub-basin

The Haw River is approximately 110 miles long and is dammed near its outlet by the B. Everett Jordan Dam (Jordan Dam) operated by the Army Corps of Engineers. The primary goal of this dam is to ensure minimum flows in the Cape Fear River, with secondary goals of flood control, water supply, recreation, and fish and wildlife conservation. The dam is operated to maintain about 390 MGD flowing at the Lillington stream gage during most times. In extreme drought situations, the Lillington gauge has no target. Minimum release of 25 MGD is specified at all times (USACE 1992). It has been proposed that under extreme circumstances, the dam release at least 70-130 MGD depending on the percent remaining in the Water Quality Account (Table 11).

The lake consists of a *water supply account* and a *water quality account*. This is intended to minimize disputes during extreme drought situations. Sixty-seven percent of the water that flows into the lake is applied to the water quality account while the rest goes to the water supply account (USACE 1992). The purpose of the water quality account is to maintain water quality in the lake and maintain target flows downstream. The storage volume of the dam is 538,400 acre feet (AF) for flood control and conservation storage of 140,400 AF. The conservation storage consists of 45,800 AF for the water supply account and 94,600 acre feet for water quality account (low flow augmentation). The proposed drought operating rules would decrease the target flow at Lillington as the water quality account decreases. An increase in demand from the upstream municipalities could increase the consumptive use of the available water in the Haw and Deep Rivers, and thus decrease the amount of water being added to the water quality account. The potential for increased low flow volumes in the Deep River due to the Randleman Dam may help the Jordan Dam operations achieve minimum flow targets at Lillington.

The Burlington and Durham systems currently import water to the Haw River Sub-Basin from the Neuse River Basin, while Cary, Durham, and Harnett groups transfer water to the Neuse Basin. The Bynum stream gage is located just upstream of Lake Jordan and recorded an average annual stream flow of 690 MGD in 2000, and the dam released on average 877 MGD. Historically,

releases from the dam have been 140 percent higher than flow at the Bynum gage, but they have been as low as 85 percent and as high as 330 percent. This shows that the other small streams feeding into Lake Jordan, such as New Hope Creek, provide a substantial volume of water.

5.3.2.1.3 Upper Cape Fear sub-basin

As stated previously, the Cape Fear River is formed at the confluence of the Deep River and the Haw River. The Fayetteville and Carthage Groups transfer water from the Upper Cape Fear Sub-Basin to the Lumber River Basin, but these transfers should not affect the availability of water to the installation. Harnett County estimates that their water supply intake could not function if flows at the Lillington gage drop below 123 MGD. When the low-flow target is reduced to 194 MGD due to drought conditions, systems withdrawing from the Cape Fear River are to reduce the quantity of water they withdraw by 20 percent (NCDWR, December 2002). The Lillington gage recorded an average annual stream flow of 1800 MGD in 2000. This means that another 183 MGD is unaccounted for between the Deep River and the releases from Jordan Dam. This difference in flow is most likely due to a combination of precipitation running off the land, evaporation processes, and base flow from aquifers. From 1982 – 2008, this difference in flow ranged from negative 390 MGD to positive 600 MGD. This indicates that evaporation and whether the river is gaining or losing plays a significant role in some years.

The 7Q1 flow from tributaries downstream of Lillington shall be added to the Lillington estimate to obtain the 7Q1 flow estimate at Fayetteville. There is no gage data available for the Upper Little River, and thus only flow from the Little River shall be added for the Fayetteville estimate. This simplification seems reasonable when compared to the low flow profile of the Cape Fear River, as it shows that the Upper Little River provides a proportionally insignificant volume of water compared to the Little River and the Cape Fear River during low flow scenarios (Weaver 2001 p 73). USGS gage 02103500 located near Linden, NC on the Little River provides discharge measurements closest to the river's confluence with the Cape Fear River. Unfortunately this gage was only operational from 1928 to 1971. The next closest gage (02103000) is located just upstream of Fort Bragg near Manchester, NC and was operational from 1939 to 1950, and 2002 to the present; thus a 2000 baseline figure cannot be obtained from this gage either. The only gage along the Little River or any tributary of the Little River that was in operation during 2000 is gage 02102908 located on Flat Creek, upstream of the Linden gage, near Inverness, NC. This gage has been operated continuously from 1968 to the present.

A comparison of flows at the Flat Creek gage and the Linden gage during which they were both operational was used to determine that on average 2.1 percent of the Little River flow at the Linden gage originates from Flat Creek. This figure was used to determine the flow at the Linden gage by scaling up the 2000 flow at Flat Creek. The resulting flow was estimated to be 347 MGD. Similar methodology determined that 2.7 percent of the flow at the Manchester gage is explained by Flat Creek, and 77 percent of the flow at the Manchester gage is found at the Linden gage. These figures were used to estimate the flow at the Linden gage between 2003 and 2008 to check the validity of this method. The results showed that scaling the flows up from either Flat Creek or Linden were within an average of 6 percent of each other when the scaled flow was between about 250 MGD and 350 MGD, but were not accurate for higher flows. Therefore, this methodology is acceptable to prepare an estimate for the 2000 baseline annual flow of 347 MGD.

5.3.2.1.4 Drivers for water supply

Each component of the regional water supply is driven by a number of factors. The Haw and Deep Rivers are driven by variations in runoff, basin transfers, and consumptive use; the Upper Cape Fear River is driven by dam operations, runoff, consumptive use, and 7Q10 requirements. Dam operations and 7Q10 requirements for the Upper Cape Fear River and the 7Q1 flow for the Little River are pre-defined as follows using historical data, while the other driving factors require further analysis when projecting water supply trends.

Releases of water from the Jordan Lake Dam are accomplished under a set of operational guidelines, sometimes called a rules set. Historical data may be used to estimate future operational patterns. Figure 21 shows a relative consistency in annual Jordan Lake Dam releases as a function of annual water flowing in from the Haw River. The average release is 140 percent of the flow coming in from the Haw River. This average decreases to 133.5 percent if the outlier of 331 percent is removed. Therefore, dam releases are assumed to be 133.5 percent of the flow from the Haw River in a given year unless the flow in the Cape Fear River drops below 390 MGD. It is assumed that the levels in the dam will remain constant when the outflow is kept at 133.5 percent of the inflow from the Haw River.

Annual water availability is determined as a function of the 7Q10 flow and not annual flow. A linear trend can be seen in the plot of 7Q1 as a percentage of average annual flow at Lillington (Figure 22). This linear trend is used to estimate the 7Q1 flow for the projected Cape Fear Flows so a 7Q10 flow may be incorporated for available water supply. Therefore the amount of water available shall be 20 percent of the estimated 7Q10 flow instead of the annual flow.

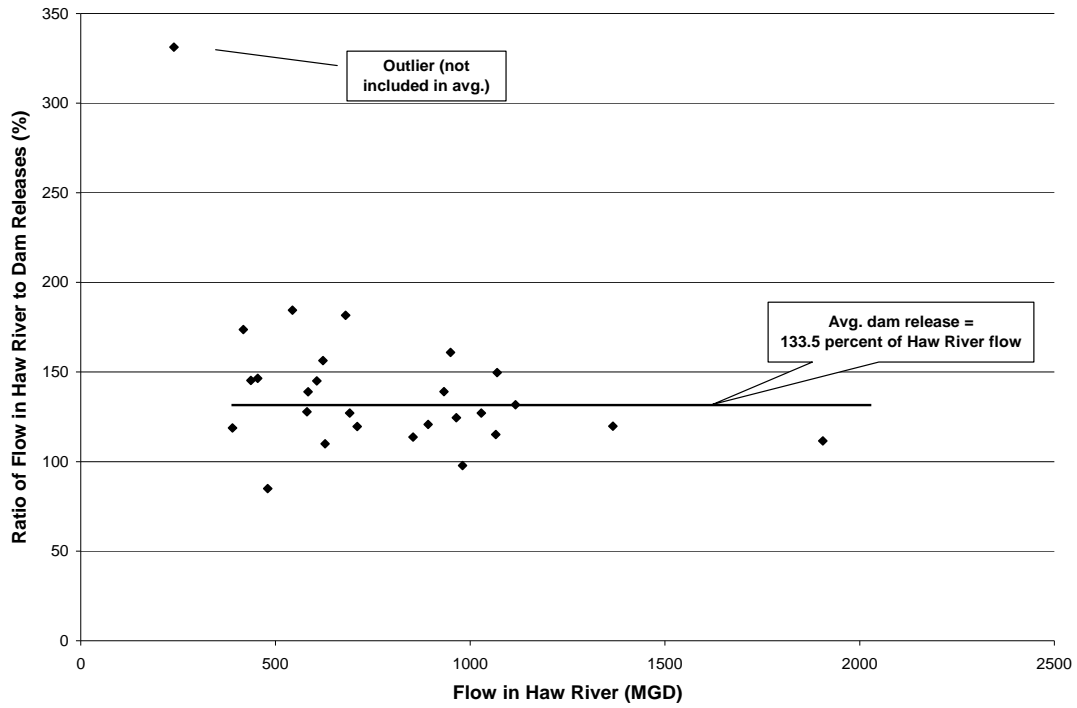


Figure 21. Dam release ratio vs. flow in Haw River (USGS).

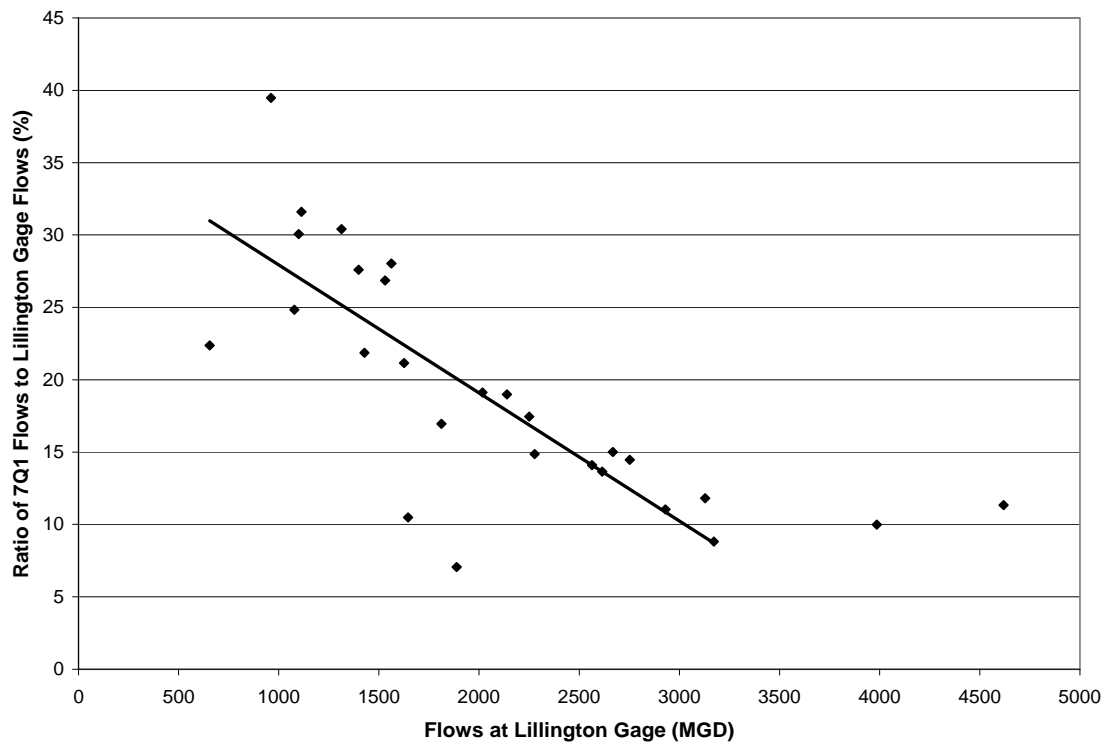


Figure 22. Average annual flows in Cape Fear watershed (USGS).

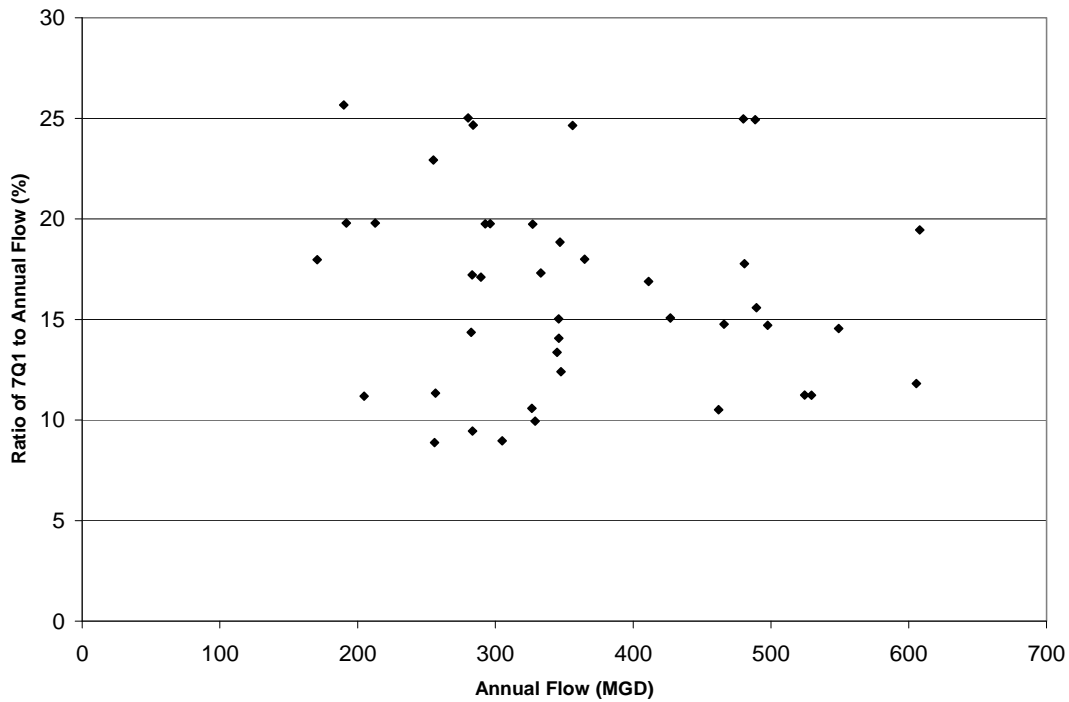


Figure 23. Little River at gage 02103500, 7Q1 flow (USGS).

Historically the 7Q1 flow for the Little River has consistently been between 10 and 25 percent of the flow at all flow levels (Figure 23). Therefore the 7Q1 flow from the Little River will be set at 17.5 percent and will not vary with flow level, resulting in a 7Q1 flow of 60.7 MGD. This value lies between the 7Q2 and 7Q10 estimate of Weaver (2001), and therefore seems a reasonable estimate. Although the 7Q10 flow of the Cape Fear River has dropped significantly since Weaver’s study in 2001, the same expectation may not be appropriate for the Little River. This is due to the topography of the Sand Hills area previously discussed, which provides more consistent and higher base flows during times of drought. The annual flows from 1998 to 2008 of the Haw, Deep, and Cape Fear Rivers are an average of approximately 38 percent lower than pre-1998 flows. Flat Creek has only seen a 24 percent decrease in flows, which is only 63 percent of the decrease experienced by these major rivers. Therefore the change in runoff for the Little River will only be 63 percent of the change for all other rivers in this study.

5.3.2.2 *Water demand model*

The water demand for the nine county region upstream from the sources for Fort Bragg is based on the initial 2000 consumption (Table 12) and incorporates population projections for the selected counties. The number of households in the upstream region is expected to grow at the same rate as the population. It is also assumed that the total public system residential and

commercial consumption will grow with the population. Industrial uses are projected to remain constant and agricultural uses are adjusted downward each year at half the percentage of the growth rate. This is to reflect loss of agricultural land to residential construction.

5.3.2.3 Model results

Table 12 lists the baseline projection for the region. The growth in consumption expected without intensive demand management is projected to be about 45 percent by 2040. Figure 24 shows the withdrawal projection to year 2040.

Consumptive usage in the basin is expected to be in the range of 55 MGD by 2040. This is calculated from the baseline projection of total withdrawals of about 321 MGD by 2040. A factor of about 17 percent for consumptive usage versus total withdrawals is used for the South Atlantic-Gulf region (USGS 1995). If best management practices were put into effect for the entire upstream region, the total withdrawals and consumptive usage could be reduced by approximately 50 percent.

Table 12. Projected upstream water withdrawals (USGS, NC Demographer, U.S. Census).

Projected upstream water withdrawals in MGD, to 2040									
	2000	2005	2010	2015	2020	2025	2030	2035	2040
Alamance	27.3	28.3	30.7	33.4	36.1	38.8	41.1	43.0	45.3
Chatham	15.7	16.2	17.0	17.8	18.6	19.5	20.3	21.5	21.5
Cumberland	46.3	49.7	51.8	54.2	54.2	54.8	55.1	56.7	57.7
Durham	10.2	10.8	12.1	13.5	15.0	16.4	17.8	19.1	20.5
Guildford	77.6	80.3	86.8	93.0	99.2	105.5	111.9	119.0	126.7
Harnett	15.5	15.9	16.6	17.2	17.8	18.3	18.7	19.3	19.8
Lee	11.4	11.6	12.0	12.4	12.6	12.8	13.0	13.5	14.0
Moore	21.3	21.3	21.3	21.4	21.4	21.5	21.5	21.6	21.8
Randolph	12.4	12.5	12.9	13.2	13.6	13.9	14.2	14.6	15.0
Totals	221.9	230.5	244.2	257.4	269.9	282.0	293.2	306.6	320.7

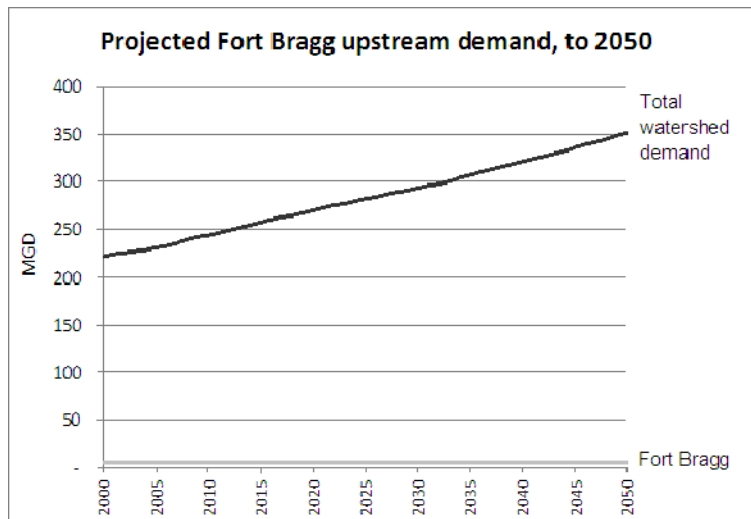


Figure 24. Fort Bragg upstream region projected withdrawals (ibid).

5.3.3 Projecting water supply and demand trends in the Fort Bragg regional model

The objective of this section is to project water availability 30 years into the future. Therefore the 2000 baseline is projected to the year 2040 for both the supply and demand models.

5.3.3.1 Water supply model

Figure 25 shows a number of driving factors that affect the components of regional water supply. The available supply is directly linked to the change in flows in the rivers upstream, and to the in-stream flow requirements. The dam release and 7Q10 have been defined using historical data. Therefore the following scenarios alter the runoff, basin transfers, and consumptive use of each sub-basin.

5.3.3.1.1 Scenario 1 – Basin transfers

This scenario represents the most likely outcome for future water supply. Projections in climate change for the North Carolina region vary widely from less rain to more rain, but they all show an increase in temperature. A weighted average of 17 different Global Circulation Models (GCMs) shows that an increase in both rain and temperature for the region should be expected (Cai et al. 2008). Increased rain would suggest more river flow, while increased temperature would indicate less flow in rivers due to increased evaporation. This makes predicting the impact on river flows extremely difficult. Therefore, Scenario 1 assumes no change in runoff within the river. The North Carolina Division of Water Resources 2002 Draft of the Cape Fear River Basin Water Supply Plan projects changes in basin transfers out to the year 2050. It suggests that the Deep River Sub-Basin may expect transfers into the basin to increase by 0.5 MGD by 2040, while the Haw River Sub-Basin should expect to see a net change in transfers of approximately 8 MGD leaving the basin.

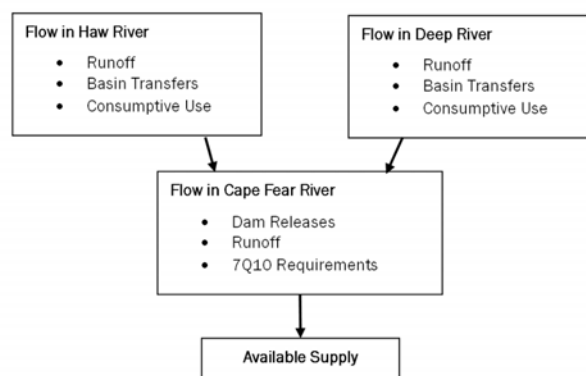


Figure 25. Fort Bragg Water Supply Model.

The demand model projects the withdrawals in the basin to be approximately 320 MGD by 2040 with a consumptive use of about 55 MGD. With increased temperatures of climate change leading to increased evaporation, consumptive use would be expected to increase. This would be due to increased irrigation in the agricultural and public use sectors. For this scenario, no change in the consumptive percentage was assumed.

5.3.3.1.2 Scenario 2 - Climate change

This scenario builds on the basin transfers from the previous scenario, and evaluates the effects of less rain and more evaporation, which some models have suggested for this region. The 2007 droughts were the worst in over 100 years, and could have been caused by various climate cycles such as the Pacific Decadal Oscillation, El Nino, and the North Atlantic Oscillation coinciding with one another. Scenario 2 analyzes the effects if this type of climate scenario becomes the norm. During the 2007 droughts, streams were characterized as having 10–24 percent of their historical average flow (Marstel Day 2008). Flows have already decreased about 38 percent from pre-1998 flows. Therefore another 37 percent decrease from the 2000 baseline is applied in this scenario, and the basin transfers from Scenario 1 are retained. The demand model projects the withdrawals in the basin to be approximately 320 MGD by 2040 with a consumptive use of about 55 MGD. With climate change and increased evaporation, consumptive use would be expected to increase from 17 percent to 25 percent.

5.3.3.1.3 Scenario 3 - Worst case

This scenario represents a worst case scenario that inflates the effects of all of the scenarios. This scenario assumes that the Deep River basin experiences no transfers into the basin, while the transfers out of the Haw River basin continue to increase. It is possible that Haw River Basin transfers could increase significantly if cities such as Raleigh located outside of the Cape Fear Watershed are to obtain water from Lake Jordan as proposed in a recent *Raleigh News and Observer* editorial (Marstel Day 2008). Here again the demand model projects the withdrawals in the basin to be approximately 320 MGD by 2040 with a consumptive use of about 55 MGD. With climate change and increased evaporation, consumptive use would be expected to increase to 25 percent of withdrawals or about 80 MGD. This scenario assumes a change in runoff from Scenario 2 to a 50 percent decrease.

5.3.3.1.4 Model results of the Fort Bragg regional water supply model

The basin transfers described in Scenario 1 play a small role in water availability when compared to the climate change of Scenario 2 (Table 13).

Table 13. Summary of Fort Bragg Regional Scenarios (MGD) (derived from USGS data).

Fort Bragg Region	2000	2040	2040	2040
	Baseline	Scenario 1	Scenario 2	Scenario 3
Flow at Moncure (Deep River Sub-basin)	740	737	462	365
Flow at Bynum (Haw River Sub-basin)	690	670	410	288
Flow at Lillington (Upper Cape Fear Sub-basin)	1800	1815	1124	841
Estimated 7Q1	371	371	300	246
Harnett County Availability	74	74	60	49
Little River 7Q1	61	61	47	42
Fayetteville Availability	86	86	68	56

Although the most likely scenario shows no major impacts from climate change due to the annual offset between increased precipitation and temperature, another expected effect of climate change will likely be shorter and more intense storms. This could pose higher day-to-day or even month-to-month water availability risks than currently experienced in the region.

The Fort Bragg region's water situation will remain essentially viable for continued civic life and installation operation if leaders pursue sound TWM practices, and implement forward-thinking, conservation best practices. However, increasingly variable hydrologic peaks and lows threaten higher storm flows that alternate with more severe droughts. Planning should account for these extremes.

In fact, North Carolina's drought management policy mandates increasingly stringent conservation measures whenever the region descends deeper into drought. The state government has also recently moved towards more stringent regulation governed by central authority, and future movements in the same direction might be anticipated if extreme water events increase. The state assembly recently passed legislation (Session Law 2008-143, H 2499 Drought/Water Management Recommendations), signed into law by Governor Easley, that seals a gap in prior legislation. The new law requires implementation within 10 days of drought response indicators where previous measures required "water systems to develop water shortage response measures, but left decisions about implementation to the [local] water system" (Session Law 2008-143 Summary). The legislation also gives the Department of Environment and Natural Resources the authority to "require a water system to begin implementing the first tier of water conservation in its water shortage plan" given further conditions, moving to the second tier given additional prerequisites, etc., amounting to a forceful basis of requirements.

5.3.3.1.5 Fort Bragg summary

This study has only evaluated the *overall* annual availability of water (Figures 26, 27, and 28). Further work may be necessary to assess the full day-to-day

impacts of the dry season. Average annual flow from 1982-1998 is over 30 percent higher than 1999-2008 for all three rivers. The recent extreme drought conditions experienced in this region could be cyclical in nature due to a multi-decadal climate pattern. Tree rings dating back to the 12th century have shown periods of even more intense droughts experienced in this region (Marstel Day 2008). Therefore measures should be taken to prepare for such extreme events.

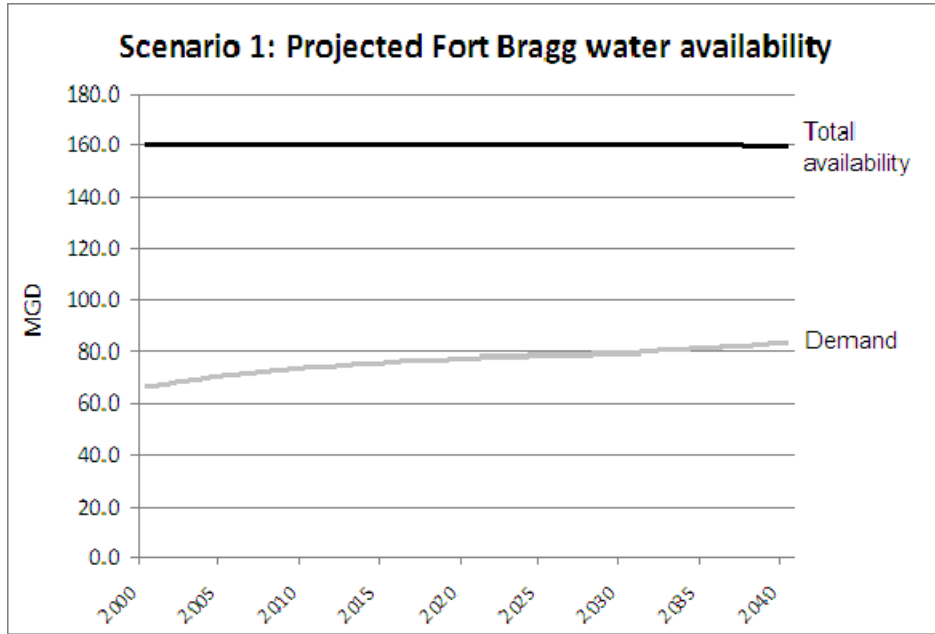


Figure 26. Fort Bragg water availability base case (ibid).

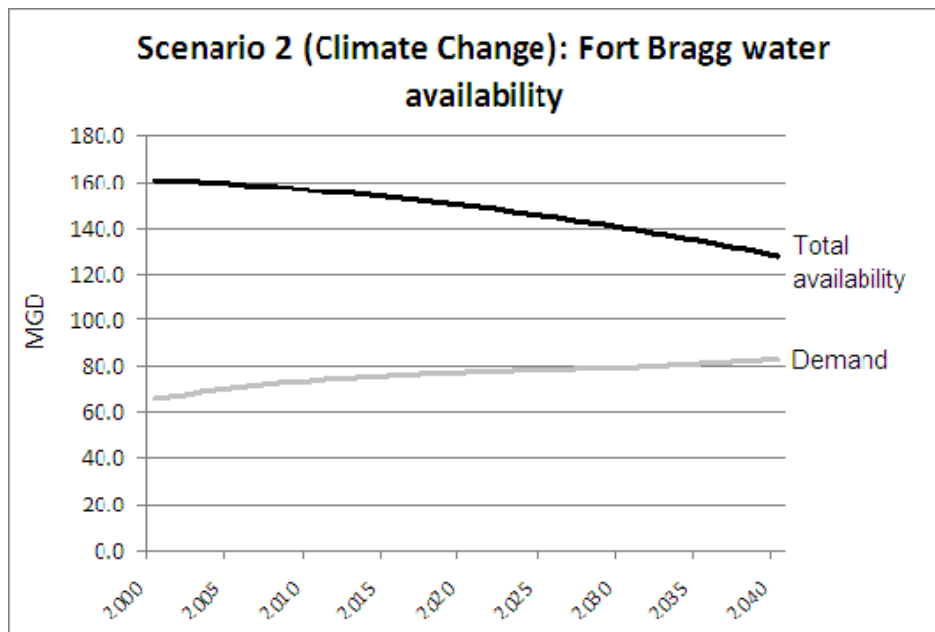


Figure 27. Fort Bragg water availability with climate change (ibid).

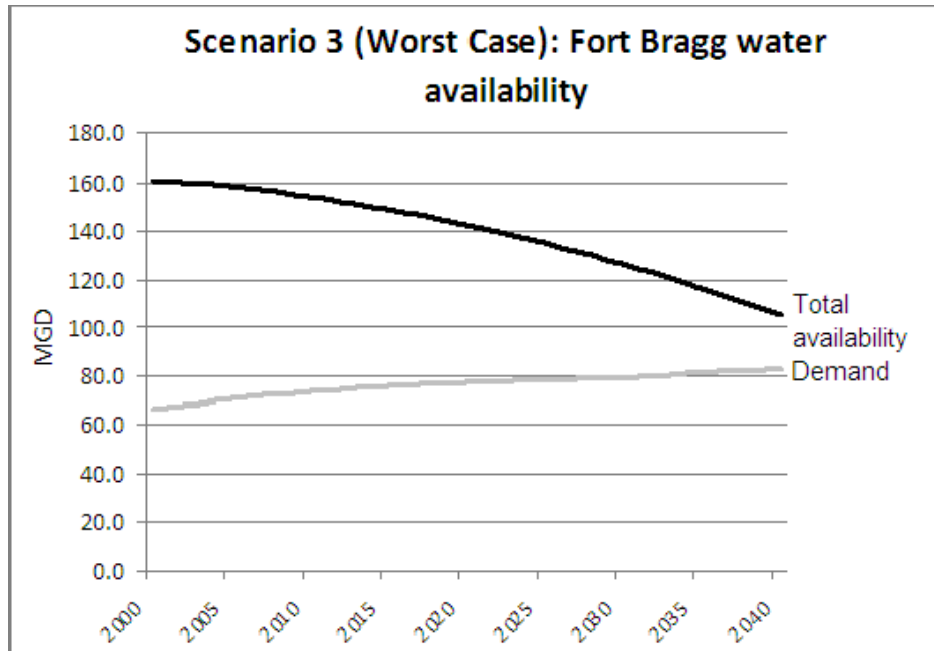


Figure 28. Fort Bragg water availability worst case (ibid).

Runoff was the greatest contributor to available water in the river system, and more intense storms lead to greater peak runoff flows in the river, followed by more marked periods of low flow.

A study of land use changes in the region projected a 1 percent increase in impervious surfaces by the year 2030 (Jenicek et al. 2006). This produced only a 0.01 percent increase in the annual volume of runoff water. Another probable result of increased impervious surfaces would be a decreased runoff time, which leads to lower flows during drought periods, because there is less natural storage. This is consistent with most theories of the effects of expanding urban areas on river flows. Therefore both changes in climate and land use, could lead to relatively the same volume of water in the river each year, but decreased base flows during drought periods. This could create more extreme events such as flooding and droughts, instead of a constant water supply. These conditions make it difficult for the Jordan Dam operators to maintain the target flows at Lillington as seen during the recent droughts (also see Figure 22, p 85). Land development policy that includes stormwater conservation can help mitigate the negative effects of increased storm flow and decreased runoff time. Such policy can be designed to encourage construction and use of building-level water systems that increase conservation of water designated for human use. Installations that gradually phase in such land systems alongside in-building conservation practices take one step further onto high ground.

While groundwater only makes up about 20 percent of the water usage in the Fort Bragg region, domestic water and water used for irrigation and livestock comes from aquifers. If the region's major cities develop in sprawling "ex-urbs"--a danger in Fayetteville, as in other cities nationwide--a time may come when outskirt landowners are driven to drill wells and rely further on groundwater to see them through drought conditions, especially in places where municipal infrastructure does not extend. The river system draws significant base flow from the groundwater system ("gaining streams") as surface water recharges from well water, because groundwater pumping is not currently taking place. With increased well pumping, however, the beginning stages of groundwater depletion could cause a decrease in base flow. Examples of this effect can be found elsewhere in the nation. In the Southwest, the Rio Grande is just such a "losing stream." Groundwater pumping gave rise to this situation. In the Bragg region, such a shift would represent a major shift in water supply, or lack thereof.

Harnett County DPU's current treatment capacity of 18 MGD is being upgraded to 36 MGD. Fayetteville PWC's current treatment capacity is 57.5 MGD and an upgrade is being considered that would raise their total treatment capacity from 57.5 to 88 MGD. Fort Bragg agreements allow up to 8 MGD from each municipality (Marstel Day 2008). The projected water withdrawal for Harnett County in 2040 is about 20 MGD (not considering Fort Bragg's demand). Fort Bragg's demand is expected to be about 6 MGD with peaks up to about 10-11 MGD.

The projected capacity of the water plants in Harnett County and Fayetteville are within the projected demands on an annual basis. There may be times when peak demands become problematic when stream flows are at a minimum. Harnett County estimates that their water supply intake could not operate when the flow at Lillington is less than 123 MGD. This point is not reached in any of the scenarios. It has been proposed that all municipalities reduce their withdrawal by 20 percent if the target flow at Lillington is dropped to around 194 MGD (NCDWR, December 2002).

5.3.4 Water sustainability assessment of the Fort Bragg regional model

Because of these strict requirements, this report recommends that planning for increasingly extreme drought-flood cycles should involve the gradual implementation of best management water conservation practices, discussed in detail in a later section, beginning as soon as feasible. Installations that begin to implement these measures, and thus build a strong basis for future drought management rapid response (now becoming a state requirement), will lead

the way to environmental sustainability in the region and safeguard mission sustainment. Fort Bragg's aggressive water conservation program at the turn of this century may make additional gains in efficiency more difficult to achieve. Anticipated increases in water pricing nation wide will improve monetary payback for water conservation projects. Implementing a program of total water management can prepare an installation for fluctuations in water availability while easing the affects of extreme storm events and increasing water security and independence through retention and reuse of both storm-water and gray water where applicable.

5.4 Case Study: Fort Bliss, TX

In 1848, the War Department established an installation by the name of The Post opposite of El Paso. Relocated in 1854 and renamed Fort Bliss, the installation now covers 1.1 million acres of land stretching across the far western tip of Texas north into New Mexico. With 9,330 soldiers stationed at Fort Bliss in 2005, an additional 28,000 are planned in response to several Army transformation initiatives. The installation is home to the regional military community units of the 32nd Army Air and Missile Defense Command, 11th Air Defense Artillery Brigade, the 108th Air Defense Artillery Brigade, 31st Air Defense Artillery Brigade, 4-1 Cavalry, the 204th MI Battalion, and the 978th Military Police Company. Fort Bliss represents the Army's center for the education and training of Air Defense Artillery soldiers and units. It also hosts the Army's Sergeants Major Academy. The Base Realignment and Closure (BRAC), Army Modular Force (AMF), Global Defense Posture Realignment (GDPR), and Army Campaign Plan (ACP)/Grow the Army initiatives will triple Fort Bliss' active duty population by 2013. This will result in a net increase of nearly 38,000 family members (Fort Bliss Transformation Brief Jan 2009). There is \$4.6B in planned construction on-post alone. The area surrounding Fort Bliss is also experiencing rapid growth, as is the adjacent region across the international border in Mexico, which suggests the need for a review of current and future regional water sources. This study reviews the potential for water scarcity using a regional water balance and suggests policies that may aide in maintaining a sustainable supply of water to this growing region.

5.4.1 Regional characterization of Fort Bliss

The following paragraphs describe the natural and human systems that define the Fort Bliss region and influence development and outcomes of the regional water balance.

5.4.1.1 Demographic trends

El Paso is the cultural center of the Southwest, enriched for more than four centuries by contributions from Native Americans, Spanish settlers, and European and Asian immigrants. The first decennial Federal Census that included El Paso was in 1890, and listed 10,000 residents. El Paso now has a population of over 700,000, and its sister city of Ciudad Juarez south of the border boasts 1.4 million residents. El Paso is the fourth most populous city in Texas. Combined with Ciudad Juarez, the metropolitan area forms the largest population center on any international border in the world. About 2.2 million live in the area. El Paso is the nation's third fastest growing metropolitan area and has been a focal point of trade and development in the region. The projected population for El Paso County is about 1.5 million by 2050 (FWTWPG 2006). For Ciudad Juarez, which draws on the same water sources, the population for 2050 is expected to be over 3.2 million (Peach 2003). This increase puts tremendous long-term stress on the water supplies, both currently and for the future. Figure 29 shows the population trends for the region. Figure 30 shows a map of the political boundaries in the Fort Bliss region. Note that the shape of Juarez was derived from Google Earth orthophotography and represents notional (not official) bounds, which is provided for context. Inaccuracies should not be construed as a statement of intent or representation of current or future planning motivations.

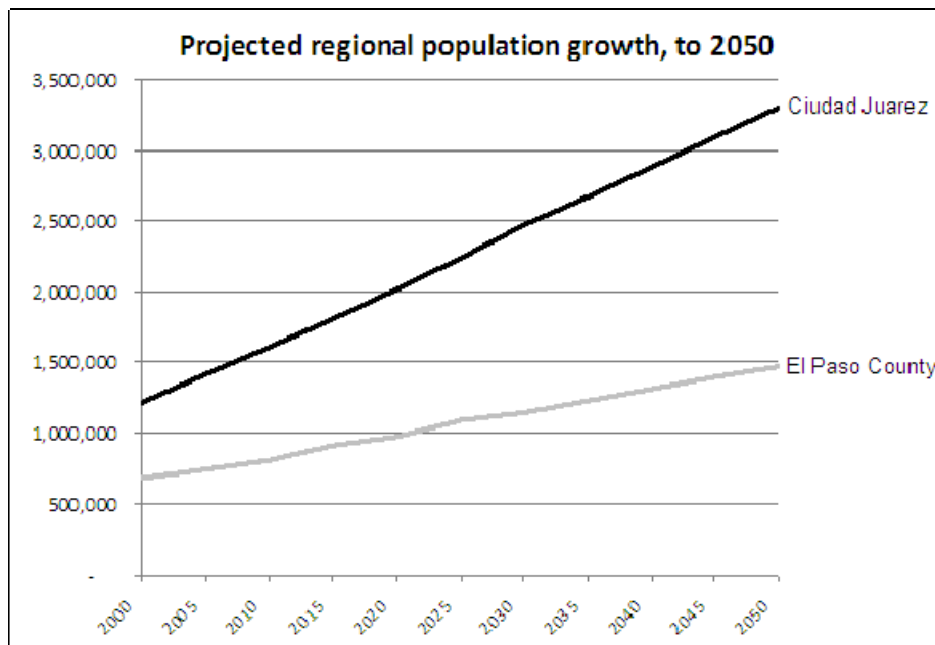


Figure 29. Fort Bliss regional population growth projections (U.S. Census).



Figure 30. Fort Bliss political boundaries map (U.S. Census, National Atlas, USGS, Google Earth orthophotos).

5.4.1.2 Water sources

The region surrounding Fort Bliss relies on water withdrawals from the Mesilla Bolson and Hueco Bolson Aquifers and the Rio Grande River. The Rio Grande River is the fourth longest river in the United States. It originates in Colorado, travels through New Mexico, and acts as the border between Texas and Mexico before discharging into the Gulf of Mexico. The river's origin is in the snow fields of the San Juan Mountains of southern Colorado and the Sangre de Cristo Mountains of northern New Mexico. It flows through the Chihuahuan Desert and through the cities of Albuquerque, Las Cruces, El Paso, and Juarez. Flow is augmented by diversions from the Colorado River Basin via the San Juan-Chama Project and by groundwater and available surface water pumped out of the San Luis Valley Basin. The Rio Grande's flow is a highly sought after commodity and has been appropriated through International Treaties and State Compacts (Figure 31).



Figure 31. Regulations affecting the Rio Grande include International treaty requirements (Texas Water Development Board (TWDB), The Watercourse, USGS, U.S. Census).

1944 International Treaty: Allocations

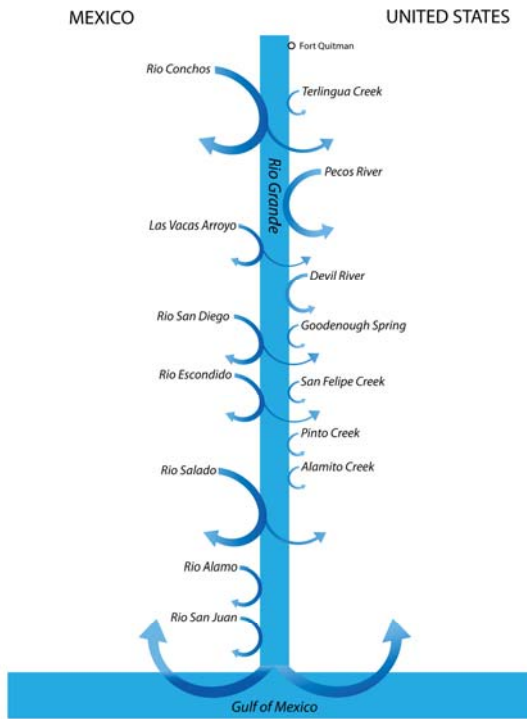


Figure 32. 1944 International treaty allocations (TWDB).

The Treaty of 1906 with Mexico cedes that country 60,000 acre-feet (53.6 MGD) of water during non-drought years. The Rio Grande Compact was signed in 1939 between Colorado, New Mexico, and Texas and apportions water between the states based on the amount of flow present at certain gages along the river. The 1944 International Treaty “addresses the waters in the international segment of the Rio Grande from Fort Quitman, TX to the Gulf of Mexico” (FWTWPG 2006). “The Treaty allocated water in the river based on percentage of flows in the River from each county’s tributaries to the Rio Grande” (Figure 32).

The control point for providing water to Mexico and Texas is at the Caballo Dam in New Mexico approximately 120 miles north of El Paso (Figure 33). There are no major tributaries between this dam and the city of El Paso. The Rio Grande is often a dry river bed south of El Paso due to the restriction of natural flow and heavy use. In the past, the river was a gaining stream, as the aquifers provided water to the Rio Grande River. Due to substantial pumping and declining aquifer levels in the Fort Bliss region, the Rio Grande is now a losing stream, as water seeps from the river bed into the aquifers.

Rio Grande Project Area



Figure 33. Agencies supervise and allocate Rio Grande Project water (Turner et. al, TWDB, USGS, U.S. Census, The Watercourse).

Although the entire Rio Grande aquifer system stretches from the north in Colorado to the south into Mexico, it is composed of many different aquifers. These aquifers may have all been hydraulically connected at some point in the past, but this is not necessarily the case anymore. While the Mesilla Bolson Aquifer (Mesilla) and Hueco Bolson Aquifers (Hueco) are connected at what is termed “The Narrows,” it is estimated that less than 26 MGD of water is transported from the Hueco to the Mesilla (Heywood 2003). The Mesilla lies mostly in New Mexico and Mexico, but also extends into El Paso County, Texas, which lies between the Rio Grande River and the Franklin Mountain Range. The flows in the Mesilla Bolson are generally to the southeast, parallel to the flow of the Rio Grande River.

The aquifer is recharged by infiltration of water around the basin edges and seepage from the Rio Grande River. It is estimated in 1996 that over 267 billion gallons of freshwater were available, and another 98 billion gallons of slightly saline water were available in the Mesilla (Ryder 1996). The Hueco is situated in parts of New Mexico, Texas, and Mexico as well, but lies to the East of the Mesilla Bolson Aquifer between the Franklin and Hueco Mountain Ranges. The aquifer most likely obtains much of its recharge from the Tularosa Aquifer to the north. The aquifer is recharged at the base of the Franklin Mountain Range. The Hueco Bolson naturally flows from North to South, but pumping has caused localized shifts in this flow. It is estimated that just between the Texas-New Mexico Border and the City of El Paso approximately 2.9 to 3.3 trillion gallons of freshwater is available, with vast amounts of slightly saline water also available.

5.4.1.3 Western water rights upstream – New Mexico

Fort Bliss is affected by water rights in New Mexico in several ways. The training ranges associated with the installation extend northward into New Mexico and obtain water based on the local set of water compacts, treaties, and agreements. In addition, there is increasing interest among cities in New Mexico to gain access to additional waters from the Rio Grande River. The following summary of the water rights of upstream users in New Mexico largely summarizes the narrative in *Discover a Watershed: Rio Grande/Rio Bravo* (2001) except where otherwise noted. This synopsis is important in that it enables users and managers to think of water systems' interconnectedness and the potential for upstream conflict affecting downstream supply.

In most years New Mexico is allowed to use 393,000 acre-feet (AF) of water between Otowi, a stream flow gage that measures New Mexico's compliance with the Rio Grande Compact, and Elephant Butte Dam, which lies less than 50 miles south of Bosque del Apache, where New Mexico delivers water to Texas under the Rio Grande Compact.

Upstream locations have developed water policy and facilities that will impact downstream availability to a greater extent than in the past. According to the terms of an agreement (the San Juan-Chama Project), each year the cities have a right to 50,000 acre-feet of water that has been diverted from the Colorado River to the Rio Grande. In the San Juan-Chama Project, water flows through tunnels under the Continental Divide from the San Juan River to the Chama River, where it is stored at Abiquiu Lake.

Albuquerque completed its San Juan-Chama drinking water project in 2008. On completion, the city "[made] surface water in to the area's primary drinking water source for the first time" through treatment at a new surface water plant to provide an eventual 70 to 90 percent of the 520,000 person city's potable demand (Albuquerque Bernalillo County Water Utility Authority (WUA), <http://www.abcwua.org/content/view/31/24/>). The project also entails provisions and systems for the silvery minnow habitat protection.

From Cochiti to Bosque del Apache, a protected refuge with 7,000 acres of flood plain, the Middle Rio Grande Conservancy District extracts water for irrigation, diverts it to farms, and returns water that is unused or collected from a drainage system and puts it back into the river. State law authorizes them to do this.

Water rights in New Mexico are governed by the doctrine of prior appropriation, which regulates water use based on water users' priority of rights*. A state engineer, appointed by the governor and confirmed by the state senate, assumes broad authority for the supervision, measurement, appropriation, and distribution of the state's water (Wolfe 1996, as cited in *Discover a Watershed*). Unlike El Paso's water law, New Mexico's regulates groundwater usage in many "declared groundwater basins" under the auspices of the state engineer. Recent state legislation has moved toward regulating deep underground basins as well, which has inspired purported efforts to submit well applications to the state engineer prior to the effectual period of such a law.

In drought times, the Office of the State Engineer issues a "priority call" as a last resort. At this point, those with most senior rights receive their needed allotment as determined by law, followed by those with more junior rights. Water cuts begin down the rights chain, with the most junior receiving cuts the earliest. "The state's surface water supply and most of the groundwater supply is fully or over appropriated. If all the water right permits, licenses, and declarations were fully exercised today, current supply would not meet demand" (New Mexico Office of the State Engineer, <http://www.ose.state.nm.us/faq/index.html>). Therefore, the state engineer encourages "voluntary agreements among water users" so that it does not have to implement "full priority administration," where water management is totally governed by regulated prior appropriation. These agreements can include water banking.

The obligation to deliver a certain amount of water downstream, particularly during low rainfall years, has become more concerning in recent years, as the Rio Grande Compact was drawn up at a time before most current land development and water use began. "Water users who were not represented in the past have been given a voice in the present," including water for the needs of native species and for sustaining riparian habitat that was not part of the 1938 Law [the Rio Grande Compact].

Federal reserved water rights also play a huge role in New Mexico water law, since 46 percent of New Mexico land is Federally owned. Landmark U.S. Supreme Court rulings established that Indian reservations

"may reserve water for future use in an amount necessary to fulfill the purpose of the reservation, with a priority [seniority] dating from the treaty that established the reservation" (Federal Bureau of Land Management, <http://www.blm.gov/nstc/WaterLaws/fedreservedwater.html>).

* See Chapter 3 for a detailed description of water rights.

More recent rulings established precedent that Federal rights holders must still enter the state adjudication process, although this process cannot deny rightful seniority. The court later extended this doctrine to other Federal lands, like Army installations, while curbing its powers to include “only the minimum amount of water necessary to fulfill the purpose of the reservation,” making metering and quantification measures for customers important if they are to attain their rights.

State water administrators and water rights holders fear that existing water allocation regimes will be disrupted once reserved rights are exercised. However, states cannot prevent the eventual exercise of these Federal property rights in water (Wolfe 1996 as cited *ibid*). The recently passed Omnibus Public Land Management Act of 2009 (H.R. 146) included portions sponsored by Senator Bingaman of New Mexico that authorized significant water supply delivery to the Navajo Nation as the result of litigation settlement between the tribe and the state.

Pueblo tribes can also secure water through litigation and negotiation. Non-Indian irrigators recognize that the Pueblos have senior rights and are concerned that in drought years – if the Indians choose to exercise their full right – they may not receive their appropriation (*Discover a Watershed*, 48). Two bills in the 2009 congressional session have made it to committee, encompassing rights claims by the Pueblos of Taos, Nambe, Pojoaque, San Ildefonso, and Tesuque (S. 965 and S. 1105).

5.4.1.4 Climate

The El Paso region is located in the Chihuahuan Desert ecosystem, which is characterized as arid and warm with very hot summers and mild, dry winters. The average annual temperature and precipitation (1961 – 1990) in the basin was around 60 °F and 10 inches, respectively in the El Paso area (Owenby et al. 2001). The highest rainfall generally occurs during July, August, and September with the lowest values generally seen during March and April in the Fort Bliss Region. The annual potential evaporation greatly exceeds the annual precipitation, which leads to the very dry conditions and high evaporation rates. The average annual stream flow just below the Caballo dam (1961-2006) has been 589 MGD, with the lowest annual average occurring in 1964 at just over 180 MGD.

5.4.1.5 Topography

Fort Bliss is located in the southeast portion of what is termed the *Basin and Range* physiographic province. This area is characterized by isolated, nearly

parallel mountain ranges separated by broad flat basins, or bolsóns, in Spanish. The Rio Grande formerly flowed between the Franklin and Hueco Mountain Ranges, but over the years has cut a pass through the Franklin Mountain Range. El Paso literally means “the pass” in Spanish and refers to the pass that the river cuts through mountains on either side. These mountain ranges generally consist of sedimentary rock with some igneous intrusions. The highest point in the Hueco Range is around 6800 feet and the Franklin Range tops out at 7200 feet. Both the Mesilla and Hueco basins below lie at around 4000 feet and are composed of fine sands, clays, silts, and gravels worn down from the mountains over the years. These materials are prime deposits for holding stores of water.

5.4.1.6 Land use

The El Paso-Las Cruces Sub-basin is dominated by rangeland, which composes over 86 percent of the land use in the region according to 2001 land use data from the USGS Land Cover Analysis Tool (<http://lcat.usgs.gov>). Figure 34 shows that the major land use change between 1992 and 2001 was due to urbanization of rangeland. The impacts of this change are very dependent on the location of urbanization, and could decrease aquifer recharge if development occurs in areas along the mountains and other high recharge areas. The croplands in the region are mainly located along either side of the Rio Grande River as this is the major source of irrigation water.

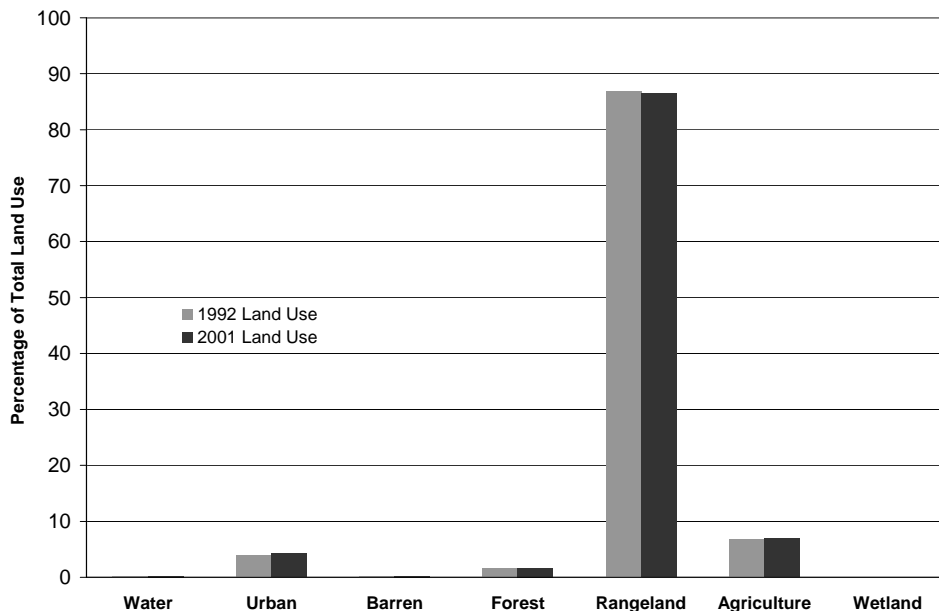


Figure 34. Fort Bliss regional land use (USGS).

Historic water demand

The water in the Rio Grande River that flows to Texas is apportioned according to the Rio Grande Compact, and further defined by the Operating Agreement for the Rio Grande Project signed in March 2008. This agreement was overseen by the Bureau of Reclamation, the Elephant Butte Irrigation District, and the El Paso County Water Improvement District No. 1 (EPCWID), which oversees water rights in El Paso County. Most of the Rio Grande is used for irrigation purposes, but some of these rights may not be exercised as farmers sell land to developers.

According to Texas state law, the Mesilla Bolson and Hueco Bolson aquifers may be pumped by anyone owning land over which the aquifers lie. The primary users of these aquifers are the municipalities of Ciudad Juarez and El Paso, and Fort Bliss. El Paso Water Utility (EPWU) pumping in the Hueco Bolson peaked 1989 at about 80,000 acre-feet per year. As the result of concerns about limited water availability in the aquifers, EPWU increased use of Rio Grande water by purchasing additional water rights. Table 14 lists the 2000 water consumption in the Fort Bliss Region by major user and end use.

5.4.2 Developing the Fort Bliss regional model

Fort Bliss currently supplies its own water from on-site wells that draw from the Hueco Bolson Aquifer and maintains an emergency supply connection from the EPWU. In 2007 the EPWU obtained approximately 23 percent of their water from the Hueco Bolson aquifer, 19 percent from the Mesilla Bolson aquifer, and 58 percent from the Rio Grande River (EPWU, accessed March 2009). Ciudad Juarez draws water from the Hueco and has plans to tap into the Mesilla and Bismarck's aquifers as well. The other major water user in the region is the city of Las Cruces, NM that withdraws water from the Mesilla and the Jornada del Muerto aquifers.

Table 14. Year 2000 water use in the Fort Bliss region (MGD) (USGS).

Regional Population and Water Consumption, 2000			
	El Paso County	Ciudad Juarez	Fort Bliss
Population	679,622	1,219,926	
Water Consumption (MGD)			
Municipal	111.0	129.2	4.8
Self-Supplied Domestic	9.0		
Self-Supplied Industrial	13.2		
Water Reuse	3.5	53.4	
Irrigation	235.2	154.5	
Total	360.1	230.3	4.8

Through a public-private partnership, Fort Bliss and EPWU constructed a desalination plant to tap into the tremendous stores of brackish water in the Hueco. This plant is rated to produce a maximum capacity of 27.5 MGD of fresh water. It accomplishes this by extracting 18.5 MGD of brackish water from which it produces 15.5 MGD of permeate, or desalted water, and 3 MGD of concentrated brackish water. The concentrate is pumped back into the aquifer at a location where it should not migrate into the freshwater storage. The permeate is blended with 12 MGD of fresh water before entering the water distribution system (EPWU, accessed March 2009). There is currently room for another 3.5 MGD expansion of the plant, for a total of 30.5 MGD plant capacity.

5.4.2.1 *Water supply model*

The year 2000 is used as the model baseline and supply is projected under several alternate future scenarios out to 2040. The model is analyzed at the sub-basin scale for the Rio Grande River. For simplification, the Texas portions of the Hueco Bolson and Mesilla Bolson Aquifers are considered as separate entities within the Rio Grande Aquifer System.

5.4.2.1.1 El Paso – Las Cruces sub-basin

This sub-basin extends from the Caballo Dam down to El Paso. The waters within this stretch of the Rio Grande River are highly managed, as flow from the dam is controlled by a number of political agreements. In 1906, the Convention for the Equitable Division of the Waters of the Rio Grande was signed between Mexico and the United States. In this international treaty, the United States agreed to provide Mexico 53.6 MGD of water during non-drought years. The water is provided in varying amounts on a monthly basis as described in the treaty. During drought years, this amount shall be proportioned in the same manner as the waters of the Rio Grande Compact. In 1939 the states of Colorado, New Mexico, and Texas signed the Rio Grande Compact for the distribution of 705 MGD of water below Elephant Butte Reservoir.

The interstate compact allots a specified amount of water to Texas based on flows at upstream gages. At times, this water is completely consumed by users in El Paso County, which often leads to a dry river bed south of the city of El Paso (Figures 35 and 36). The International Boundary and Water Commission maintains stream gages that track the amount of water delivered to Texas and Mexico. In some years the EPWU has managed to secure almost 52.6 MGD of water from the Rio Grande River by obtaining water rights through the EPCWID.

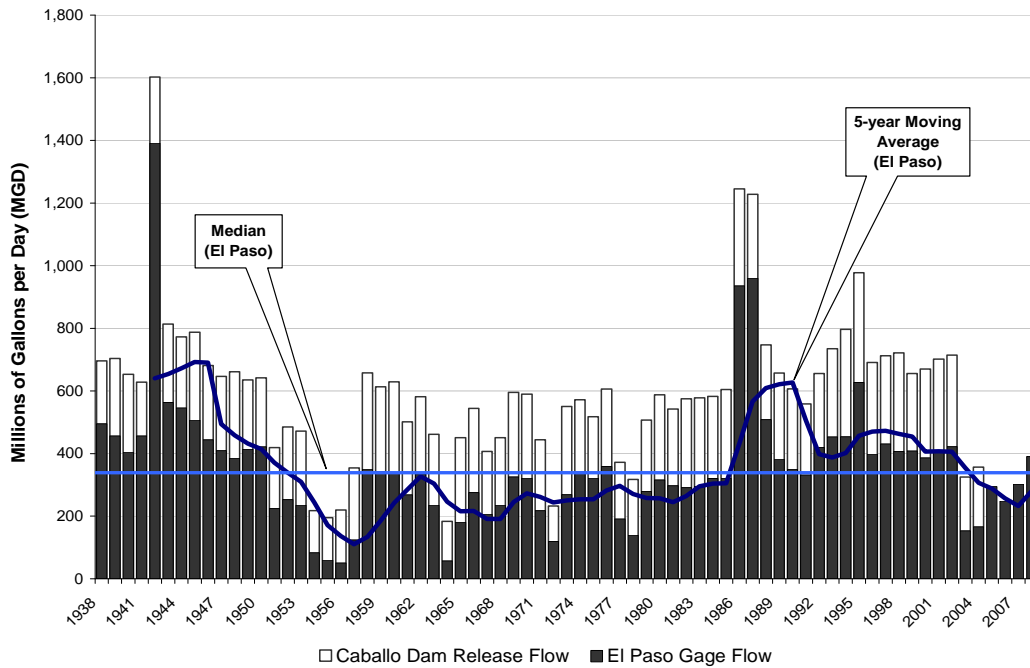


Figure 35. Annual flows in the Rio Grande River (USGS).

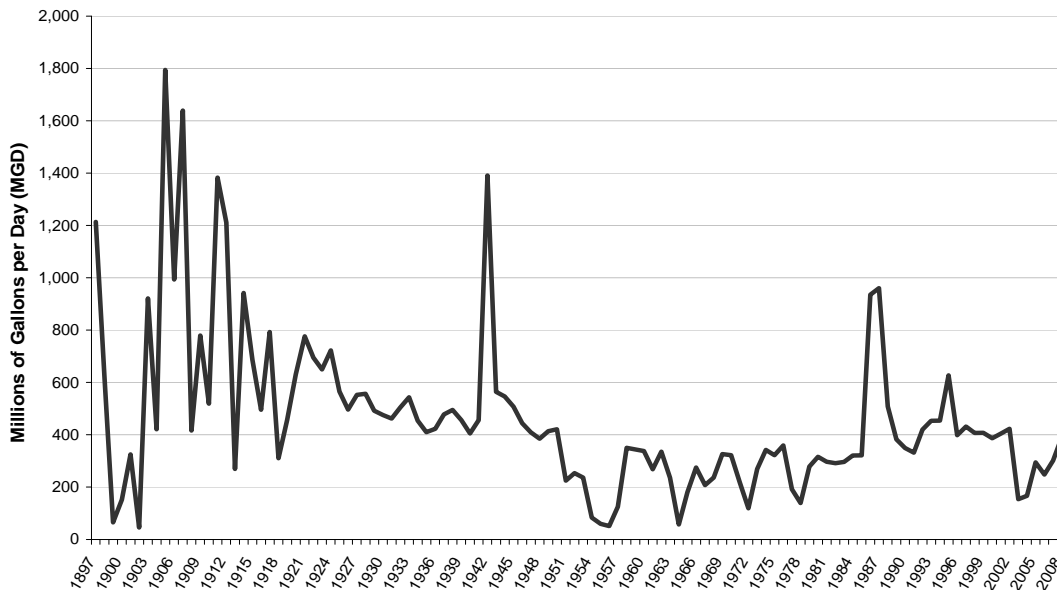


Figure 36. Long term historical flows at the El Paso gage showing variability (USGS).

The efforts of the EPWU to secure rights to the Rio Grande have increased over the past few decades. From 1993 to 2002, the EPWU on average secured 6.5 percent of the flow released from the Caballo Dam, while Mexico on average received about 7.4 percent of the flow. Evaporation and seepage into the

ground accounts for a large part of the water released from the Caballo Dam. Historically, these flow losses have averaged around 43 percent. In 2000 the amount of water released from the Caballo Dam Reservoir was 670 MGD, of which 386 MGD reached El Paso for a 42.3 percent flow loss. Fifty-four MGD of water reaching El Paso was diverted to the Acequia Madre to be used by Mexico, and the EPWU claims that it secured 37.8 MGD of water in 2000. Also, in 2000 the irrigation district in El Paso withdrew about 236 MGD.

5.4.2.1.2 Texas portion of Hueco Bolson aquifer

The municipalities of El Paso and Ciudad Juarez represent the majority of withdrawals from the Hueco Bolson, although anyone who owns land above the aquifer is entitled to pump from the aquifer. It has been estimated that the aquifer will run dry as soon as 2020 (Schoik undated) or remain in service over 70 years from now (Bredehoeft et al. 2004). Ciudad Juarez is attempting to maintain current pumping rates through water conservation measures and tapping other sources (Barreno 2005). Ciudad Juarez currently uses water from the Rio Grande for irrigation. The city has plans to provide treated waste water to farmers so that the Rio Grande water may be used for municipal purposes. This is how the city plans on capping the Hueco Bolson pumping rates. The EPWU reported pumping 53.0 MGD of water from the aquifer in 2000. EPWU has worked to secure increased access to waters from the Rio Grande River in an attempt to preserve waters in the Hueco Bolson.

Despite these efforts, the water table in the aquifer has steadily declined in many areas for more than 50 years. Figure 37 displays groundwater depth data from 1952 to 2007 of well JL-49-06-702. Units shown are in feet below land surface, with a decline of approximately 76 feet during this time period. This declining trend of water table levels is consistent with many gages for the Hueco Bolson aquifer (Figure 37). The recently constructed desalination plant is intended to aid in conservation of the aquifer. The aquifer is estimated to contain over 14.9 trillion gallons of water in the El Paso area, but only 3.1 trillion gallons of this is fresh water (Table 15). The Hueco is predominately composed of brackish water, defined as water with chloride levels exceeding 250 milligrams per liter (mg/L). The desalination plant is equipped to treat water with chloride levels as high as 2500 mg/L (Ruiz 2009). This significantly increases the amount of water that is recoverable from the aquifer. The blend of brackish and fresh water produced by the desalination plant could more than double the recoverable water from the Hueco Bolson aquifer.

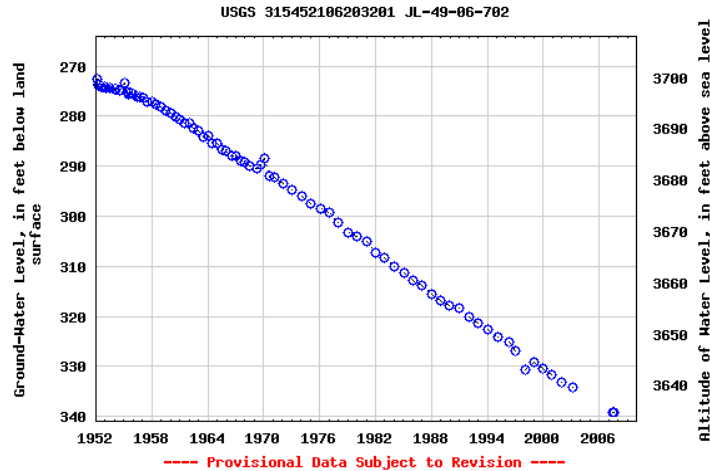


Figure 37. Hueco Bolson aquifer depletion trend – Gage JL-49-06-702 (USGS).

Table 15. Hueco Bolson groundwater storage per chloride level (Hutchison 2004).

Chloride (mg/ l)	Water Quality	El Paso Area Groundwater Storage (trillion gallons)
< 250	Fresh water	3.1
250 – 500	Desalination Source	2.3
500 – 750	Desalination Source	1.7
750 – 1000	Desalination Source	1.5
> 1000	Desalination Source/ Unusable	6.3
<i>Total</i>		<i>14.9</i>

Figure 38 shows the extent of the aquifers beneath El Paso County and the region, including the Mesilla and Hueco Bolson aquifers within the Rio Grande Aquifer system. Natural Recharge has been estimated to be anywhere from 5 to 13 MGD, with an average of 8.9 MGD, which shall be used as the baseline for natural recharge (Heywood et al. 2003). The model developed for the USGS report (Heywood et al. 2003) was used to produce a hydrogeology report (Hutchison 2004) and associated third party review (Bredehoeft et al. 2004) completed by the EPWU.

The following data was compiled from the three reports. The reports estimate that recharge through basin transfers is approximately 21.4 MGD. They also note that recharge from the river is between 26.7 and 44.6 MGD. An average of these values comes to 35.7 MGD, and this was used as the baseline for river recharge. Most of the river recharge is transferred to the Mexican portion of the Hueco Bolson. Estimates of flow to the Mexican portion range from 26.7 to 35.7 MGD. The average of these, 30.3 MGD, was used for this analysis. Finally the total change in storage represents the sum of all recharge, discharge, and withdrawals from the aquifer. The total average change in storage is estimated to range from a decline of 9.8 to a decline of 29.5 MGD, with an average of 18.4 MGD.



Figure 38. Fort Bliss hydrologic features map (groundwater sources) (U.S. Census, National Atlas, USGS, El Paso Water Utilities).

The sum of the terms used in the baseline figures for these recharges, discharges, and the 2000 EPWU withdrawal rate comes to a decline of 17.2 MGD, just under the estimated average decline of the aquifer. Other factors that have influenced the water budget of the Hueco Bolson since 2000 include induced recharge and desalination. The EPWU website notes that the Fred Hervey wastewater treatment plant artificially recharges the Hueco Bolson by pumping about 1.5 MGD of treated water into the aquifer. The joint EPWU/Fort Bliss desalination plant began operating in mid-2007. The plant has only been run at full capacity for a total of 1 week, and was running at 3.5 MGD in March 2009 (Williams 2009). The 3.5 MGD operating rate is used as the 2008 baseline with the rate increasing at the same rate as demand increases. Note: It may not be appropriate to assume that all of the water recharged from basin transfers is fresh water, or that all of the water within the aquifer is readily recoverable.

5.4.2.1.3 Texas portion of Mesilla Bolson aquifer

The municipalities of Las Cruces, NM, and El Paso, TX withdraw from the Mesilla Bolson aquifer. Ciudad Juarez has also recently entered a public-private partnership to construct a pipeline to pump water from this aquifer on the Mexican side (Sur 2007). The Conejos is projected to supply the city with approximately 23 MGD. The Las Cruces region has pumped from the Mesilla

for domestic water for over 50 years and also pumps from the Mesilla for about 13 percent of the irrigation water for a total of about 79 MGD in 2000 (PdNWTf 2001). The EPWU reported withdrawing 22 MGD in 2000 from the Mesilla aquifer. It is estimated that 6.5 trillion gallons of freshwater are available within the Mesilla aquifer north of Texas. It is unlikely that pumping in Las Cruces plays a large role in the amount of water stored in the Texas portion of the aquifer due to the large stores of water available in New Mexico. Similarly, the pumping in Mexico may not have a large impact on the stores in Texas unless pumping were to significantly increase.

The Texas portion of the Mesilla Bolson Aquifer has significantly less available water than the Texas portion of the Hueco. With just over 260 billion gallons of freshwater in the Texas portion of the Mesilla, this represents just 8 percent of the fresh water the Hueco holds. As previously noted, the Mesilla naturally discharges water through “the narrows” (the land between the two) to the Hueco at a rate less than 26 MGD. It is difficult to quantify total annual discharge for this aquifer due to its complex interaction with the Rio Grande River. The mountain front recharge in the New Mexico portion has been estimated to be 9.9 MGD with an error of minus 50 percent to plus 100 percent (Terracon et al. 2004).

This same source states that river recharge estimates range from 18.1 MGD to 86.9 MGD between Las Cruces and Anthony, NM. Information from the report was used to estimate stream recharge in the Texas portion to be on the order of 100 to 250 MGD. Such wide variances in recharge indicate the degree of uncertainty of recharge inherent with most aquifers due to a lack of spatial data and varying weather conditions from year to year. The estimated stream recharge does not support the trend of declining water table, unless there are losses other than merely EPWU withdrawals. Figure 39 shows data from 1961 to 2008 for well JL-49-04-418. The variation in the data is likely due to seasonal effects from flows in the river. A slight declining trend over time can still be picked up, especially over the past 30 years. This downward trend is similar to many other water table measurements for the Mesilla.

5.4.2.1.4 Drivers for water supply

The availability of water from each component of the regional water supply is driven by a number of factors in this study. The Rio Grande River is driven by Caballo Dam releases, flow losses, EPWU water rights, and rationing of Rio Grande Water during drought years. The aquifers are driven by the level of water recoverability, and the change in storage. The change in storage for the Hueco Bolson Aquifer is defined for freshwater and brackish water.

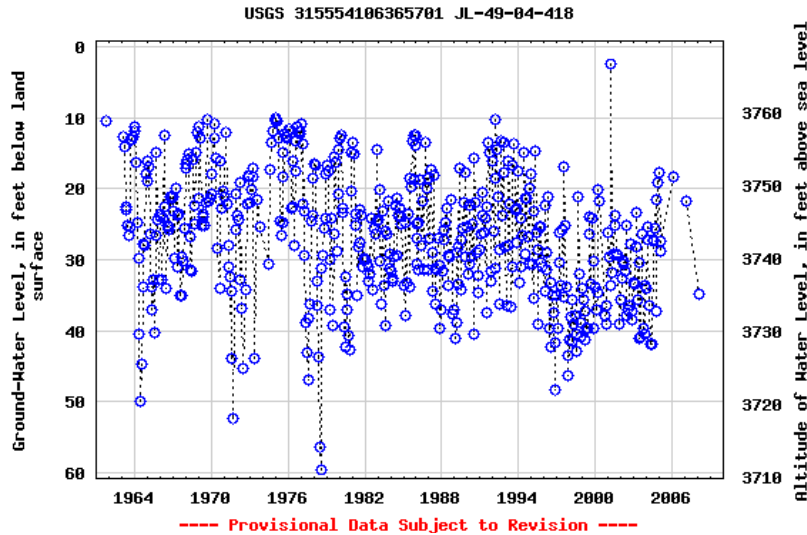


Figure 39. Mesilla Bolson aquifer depletion trend – Gage JL-49-04-418 (USGS).

Change in freshwater storage includes natural recharge, recharge from the Rio Grande River, recharge from the New Mexico portion of the aquifer, artificial recharge from the wastewater treatment plants, discharged flow to Mexico, and withdrawals by the EPWU and the desalination plant. The change in storage for the Mesilla Bolson Aquifer only includes a generic recharge term and EPWU withdrawals. The rationing of Rio Grande water during drought years is based on historic data, while the remaining driving factors require further analysis when projecting water supply trends.

The Treaty of 1906 requires the United States to provide Mexico with 53.6 MGD during non-drought years. Figure 40 shows that the full allotment was generally provided when annual flows in the Rio Grande at El Paso were at least 280 MGD. The water was generally proportioned according to the power function provided in the figure when flows were less than 280 MGD. This function was used to determine the allotment provided to EPWU as well. The maximum allotment available to the EPWU is set at 49.1 MGD (Turner 2008).

5.4.2.2 Water demand model

The water demand projection for the El Paso region around Fort Bliss is based on the initial 2000 consumption (Tables 16 and 17) and the population projections for El Paso county and Ciudad Juarez. The number of households in the region is expected to grow at the same rate as the population. It is also assumed that the total public system residential and commercial consumption provided by public supply will grow with the population. Industrial uses are projected to remain constant and agricultural uses are adjusted downward each year at one eighth of the percentage of the annual population growth rate. This is to reflect loss of agricultural land due to residential construction.

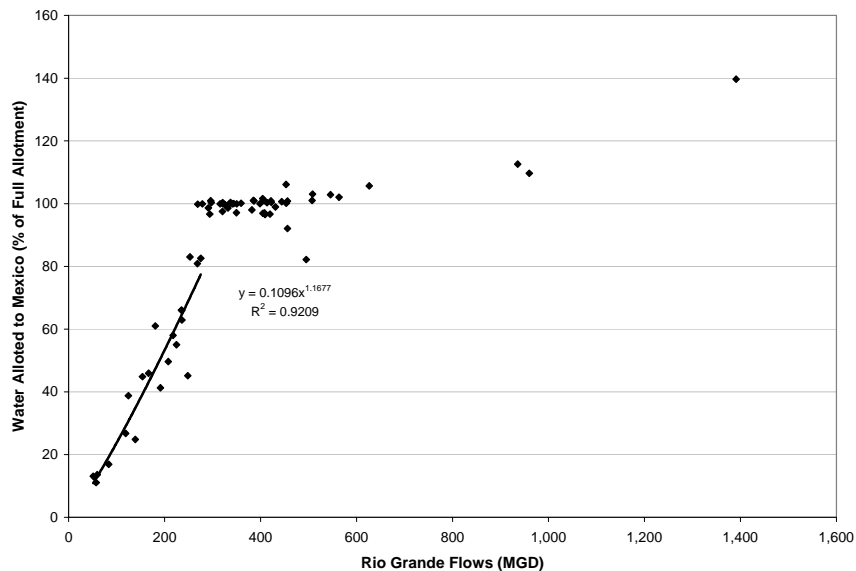


Figure 40. Allotment of water rights during low flow years (IBWC).

Table 16. Projected water withdrawals for El Paso County in MGD (Hutchison 2004).

El Paso County Projected Water Consumption, to 2040									
With use detail									
	2000	2005	2010	2015	2020	2025	2030	2035	2040
Population	679,622	742,416	812,525	909,993	978,315	1,092,494	1,144,105	1,227,000	1,309,895
Water Consumption (MGD)									
Municipal	111.0	96.4	103.0	109.8	113.7	123.1	125.7	131.8	137.9
Self-Supplied Domestic	9.0	7.8	8.3	8.9	9.2	10.0	10.2	10.7	11.2
Self-Supplied Industrial	13.2	13.7	14.1	14.6	15.1	15.6	16.0	16.5	17.0
Water Reuse	-3.5	-4.5	-6.6	-7.8	-9.4	-10.7	-12.2	-13.6	-15.0
Irrigation	235.2	232.6	229.9	226.7	224.6	221.5	220.2	218.2	216.5
Total	364.9	346.0	348.9	352.1	353.2	359.4	359.9	363.6	367.5
Fort Bliss	4.8	4.6	8.1	9.4	9.4	9.4	9.4	9.4	9.4

Table 17. Projected water withdrawals for Ciudad Juarez in MGD (Hutchison 2004).

Ciudad Juarez Projected Water Consumption, to 2040									
With use detail									
	2000	2005	2010	2015	2020	2025	2030	2035	2040
Population	1,219,926	1,421,447	1,612,249	1,812,448	2,019,855	2,236,799	2,465,487	2,673,270	2,881,048
Water Consumption (MGD)									
Municipal	129.2	108.2	111.6	125.5	139.8	154.8	170.7	185.0	199.4
Water Reuse	-53.4	-53.4	-54.8	-66.5	-66.5	-66.5	-66.5	-66.5	-66.5
Irrigation	154.5	153.8	153.2	152.6	152.0	151.5	150.9	150.4	149.8
Total (MGD)	230.3	208.6	210.0	211.5	225.3	239.8	255.0	268.9	282.7

5.4.2.3 Model results

Figures 41 and 42 show the baseline projection for the region. The growth in consumption with current trends in demand management is projected to grow by about ½ percent per year in El Paso County by 2040. (This assumes a robust program of water reuse.) The growth in consumption expected on the Mexico side of the border is about 23 percent through 2040. (Increased water reuse is expected.) Figures 41 and 42 show the results of the regional withdrawal projection to year 2040 and 2050, respectively.

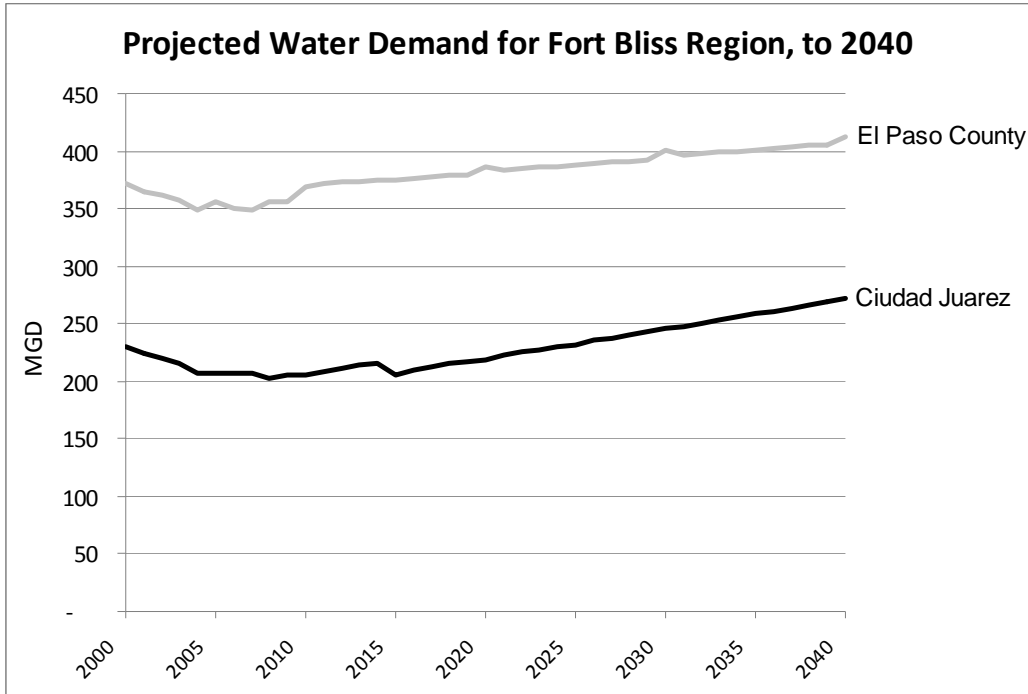


Figure 41. Fort Bliss region projected withdrawals (includes irrigation) (ibid.).

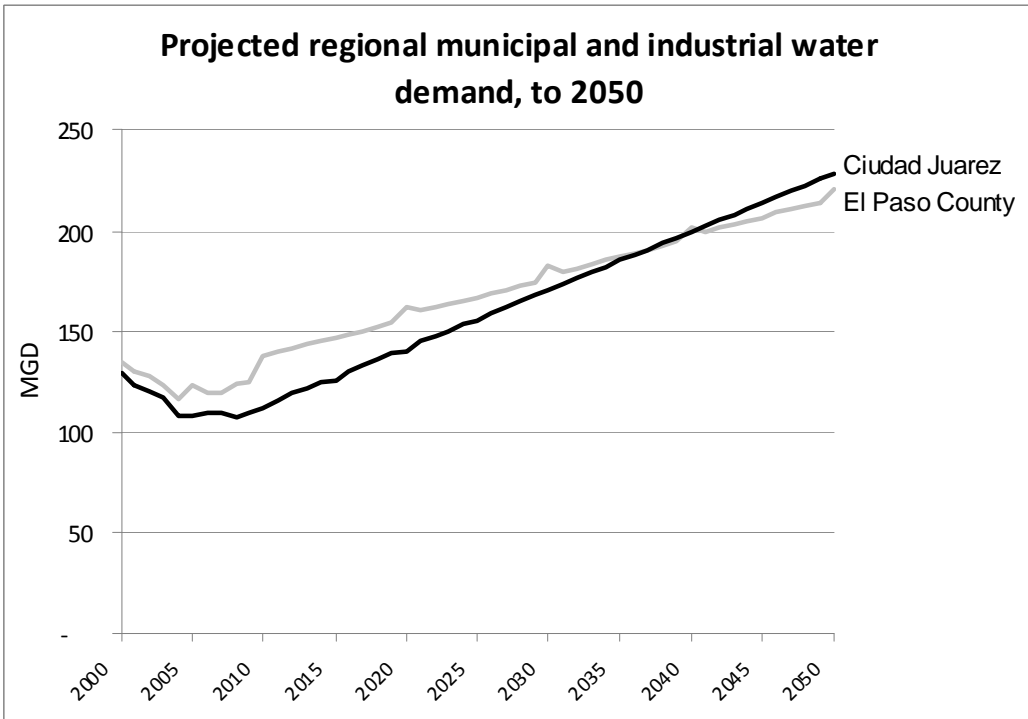


Figure 42. Projected municipal and industrial water demand (no irrigation) (ibid.).

Consumptive usage* in the region is expected to be in the range of 390 MGD by 2040. This is calculated from the baseline projection of total withdrawals equaling 650 MGD by 2040. A factor of about 60 percent for consumptive usage versus total withdrawals is used for the Southwest region (USGS 1995). The total withdrawals and consumptive usage could be reduced by approximately 20 percent if best management practices were adopted region-wide.

5.4.3 Projecting water supply and demand trends in the Fort Bliss regional model

The objective of the regional model is to project water availability 30 years into the future based on several alternate future scenarios. Therefore the 2000 baseline is projected to the year 2040 for both the supply and demand models.

5.4.3.1 Water supply model

Figure 43 shows a number of driving factors that affect the components discussed above. The available supply essentially comes from three sources. Yet the extraction of water from the aquifers is linked to the flow in the Rio Grande River since the EPWU uses all available water from the river first. The 2006 Regional Water Plan for Far West Texas includes six alternative integrated strategies to meet future demands after 2020. These alternatives include the use of differing amounts of local surface water, local groundwater, expansion of reclaimed water, and imported groundwater from properties owned by EPWU (FWTWPG 2006).

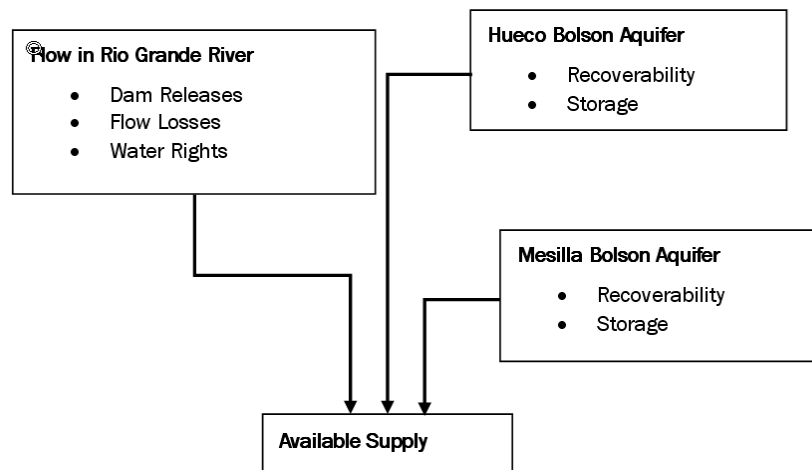


Figure 43. Fort Bliss water supply model.

* Consumptive usage includes water that does not return to the watershed, for example, evapotranspiration.

5.4.3.1.1 Scenario 1 – Climate change

Climate models of the southwestern United States show general agreement regarding projected climatic trends. As a result, more information is available regarding the impacts of climate change. The weighted average results of 17 GCMs (Cai et al. 2008) were analyzed to show a projected increase in temperature as well as an estimated 12 percent decrease in precipitation (although this may range from 10-20 percent for the region). This is consistent with many studies completed for the Rio Grande region. It is noted that the American “dust bowl” of the 1930s was associated with a decrease in rainfall of about 10 percent over a 10- to 20-year period (Solomon et al. 2009). The combination of a 12 percent decrease in precipitation, and an increase in temperature could produce river conditions worse than existed in the “dust bowl,” therefore a 20 percent decrease in releases from the Caballo Dam is assumed in this scenario. Scenario 1 also assumes that EPWU is able to retain the water rights it currently holds.

Typical estimates of the total amount of recoverable water from the Hueco Bolson range from 25 – 50 percent. Scenario 1 assumes that 37.5 percent of the water from each aquifer is recoverable. The amount of fresh water that flows underground from New Mexico and areas to the east is unknown. Therefore, Scenario 1 assumes that the ratio of fresh to brackish water from these basin transfers is equal to the ratio of fresh to brackish water already in storage. Some initial studies of climate effects on natural recharge in the Texas area have been performed. This research suggests that a 20 percent decrease in rainfall could lead to a 70 percent decrease in the recharge of local aquifers (Chandler 2008). Scenario 1 assumes a 35 percent decrease in natural recharge. The rate of river recharge is the result of complex interactions between the flow in the river, and the rate of aquifer pumping in the area. This study sets the river recharge at a constant 9.2 percent of flow in the river based on the baseline figures used. Furthermore, El Paso has been working to minimize pumping from the Hueco, and Ciudad Juarez is working to limit their pumping to current levels. Therefore this scenario assumes no change in river recharge. Since Mexico has pledged to not exceed current pumping rates, there is no change in the percentage of river recharge that flows to the Mexican portion of the aquifer for scenario 1. Similarly the change in recharge from basin transfers is driven by pumping rates and is set at zero for this first scenario.

The final factors for the Hueco Bolson Aquifer are that of artificial recharge and desalination. It is assumed that the 1.5 MGD that was artificially recharged in 2004 by the Fred Hervey treatment plant continues at the same rate. EPWU projects that the amount of water desalinated would increase as

demand increases (Williams 2009). A 3.5 MGD desalination rate represents 3.5 percent of the demand in 2008. Therefore this percent remains constant for Scenario 1.

The percent of water that is recoverable from the Mesilla Bolson is matched with that of the Hueco Bolson at 37.5 percent. According to the baseline figures, decline in storage totals 37 percent of the total discharges from the Hueco Bolson. The Mesilla Bolson is declining at one-third of the Hueco, based on the slope of a linear trend line of the data shown in Figure 37. Therefore, it is reasonable to assume that only the storage decline equals 12 percent of the total withdrawals from the Mesilla aquifer or, to put another way, 88 percent of the withdrawals are recharged. This is the recharge rate that is used for Scenario 1. From 1995 to 2002, the EPWU obtained an average of 32 percent of its groundwater from the Mesilla, supporting the use of this figure for Scenario 1.

5.4.3.1.2 Scenario 2 - Increased Juarez pumping

This scenario maintains the effects of climate change, and evaluates the effects of increased pumping in the region. The current Ciudad Juarez project to develop the Conejos-Medanos aquifer should supply approximately 23 MGD to the city, which is far less than the estimated increase in demand. Therefore, Ciudad Juarez may not be able to cap pumping from the Hueco Bolson through the various measures they have begun implementing. This is coupled with increased pumping by EPWU creating potential changes in the drawdown cones in the region. The effects of this are complicated. Without a detailed model, it is difficult to estimate the interactions of various system components. It is expected that, as the drawdown cones increase in size, there would be increased river recharge and the potential for an increased percentage of river recharge to be discharged to Mexico. A general increase of 3 percent river recharge was assumed, along with a 5 percent increase in flow to Mexico. Recharge from basin transfers could also increase, but it is probable that this would be a relatively small amount; therefore, a 1 percent increase was applied for this scenario.

5.4.3.1.3 Scenario 3 - Operational changes (induced recharge)

Scenario 3 again builds on all of the data from the previous two scenarios, and evaluates some of the mechanisms that are available to preserve the availability of water. As demand increases, there is the potential for increasing induced recharge of the aquifer that is recharging the aquifer with processed effluent. The volume of induced recharge is increased to 6 MGD in the year 2020 for this scenario.

EPWU recommends that, while the Hueco would benefit from an artificial recharge project, it is not critical that such a project begin in the next 20 to 40 years under the assumed level of pumping. “If pumping were to increase in either El Paso or Juarez substantially above the assumptions, an artificial recharge project should be considered sooner” (Hutchison 2006).

5.4.3.1.4 Scenario 4 – Operational changes (desalination)

Scenario 4 also retains the assumptions of the previous scenarios but also includes increased desalination. Desalination still uses fresh water, but over half of the water produced is originally brackish water. Therefore, if all water that was pumped from the aquifer was desalinated, the lifespan of the aquifer would more than double. This scenario assumes that in 2010 the desalination plant production is increased to 27.5 MGD, which represents the current maximum capacity.

5.4.3.1.5 Scenario 5 – Worst case

Scenario 5 evaluates more conservative estimates of each supply component. If there is a 25 percent decrease in flows of the Rio Grande by the year 2040, the flow at El Paso will fall below 280 MGD and the allotted water rights must be rationed. Therefore Scenario 5 applies a 25 percent decrease in river flow, yet maintains the EPWU water rights at their current level. Scenario 5 also uses an extreme estimate of a 70 percent decrease in natural recharge. Furthermore, the scenario retains the assumptions of increased river recharge, flow to Mexico, and basin transfers. The operation of the desalination plant is not maximized, and there is no increase of induced recharge either. The Mesilla aquifer may experience a decrease in recharge as the flow in the river declines, thus a recharge rate of only 50 percent is assumed.

5.4.3.1.6 Scenario 6 – Operational changes (desalination) absent climate change

Scenario 6 uses Scenario 4 as a baseline and subtracts the effects of climate change detailed in Scenario 1 to provide a view of a water supply situation, assuming that climate change will not affect the West Texas hydrologic system at all.

5.4.3.1.7 Model results of the Fort Bliss Regional water supply model

A summary of the projected regional water supply in 2040 as a result of the six scenarios is shown in (Table 18). The percent of recoverable water from the aquifers is an unknown but crucial factor in determining the availability of water. A relatively conservative value was chosen, but regardless of this factor the results show the impacts of various scenarios.

Table 18. Summary of Fort Bliss scenario projections (Hutchison 2004).

Fort Bliss Region	2000 Baseline	2040 Scenario 1	2040 Scenario 2	2040 Scenario 3	2040 Scenario 4	2040 Scenario 5	2040 Scenario 6
Rio Grande River (MGD)	38	49.1	49.1	49.1	49.1	36.0	49.1
Hueco Bolson Aquifer – Fresh (MG)	1,151,223	416,104	414,135	433,668	592,424	58,511	627,017
Hueco Bolson Aquifer – Brackish (MG)	2,067,499	2,235,874	2,236,899	2,251,859	2,093,103	2,236,899	2,093,103
Mesilla Bolson – Fresh (MG)	97,500	37,677	37,677	37,677	37,677	0	37,677
Total Fresh Water Availability (MG)	1,263,557	471,703	469,734	489,266	648,023	71,646	682,616

The difference in river flows decreasing from 20 percent in the first four scenarios to 25 percent in Scenario 5 was enough to cause the water rights of the EPWU to decline significantly (receiving only three-fourths of their current allotment). The impact of projected climate change on flows of the Rio Grande are crucial to regional planning for water supply. A decline in Rio Grande water means more stress on the aquifers, especially if it impacts the recharge to the Mesilla Bolson as seen in Scenario 5.

Fort Bliss is primarily supplied by the Hueco Bolson aquifer, which is estimated to be capable of providing adequate water supply for a minimum of 70 years (Bredehoeft et al. 2004). Although the 70-year estimate and this study show that the Army requirements are met within a 40-year scope, the aquifer remains a limited non-renewable supply under current pumping rates. Essentially the only naturally renewable supply available is the Rio Grande River and this too may decline due to changes in the amount and timing of snowpack in Colorado, the source of the river, and decreased precipitation across the entire basin. At the same time, demands for irrigation will increase due to rising evaporation rates resulting from higher temperatures (Karl et al 2009). This will also lead to an increase in the consumptive use fraction. Accordingly, efforts should be made to create a more renewable supply from the Hueco. Scenario 3 shows that increased artificial recharge aides in maintaining the Hueco Bolson, and Scenario 4 increased efforts to obtain water through desalination, which could increase the lifespan of the aquifer twofold.

The EPWU has plans to tap aquifers in other counties in which they have purchased land and to pipe the water to El Paso. The Bone Spring-Victorio Peak aquifer is one source, starting in 2030, and the Captain Reef aquifer is another, starting in 2040. The start dates of these plans are likely to be pushed back due to water demand not reaching the projections of the 2006 regional water plan (Combs 2009).

Note that issues of climate change and population growth in the region will become problematic in the future. Additionally, the use of the flows in the Rio Grande will become more contentious over time. Tribal water rights in the upper Rio Grande have not been resolved and increasing demands from Mex-

ico may result in requests for additional Rio Grande water to be allocated to them.

5.4.3.1.8 Issues of climate change and population growth

Former EPWU Water Resources Manager Bill Hutchison (now with the Texas Water Development Board) recently presented his research to the El Paso Geological Society in May 2009. He showed that groundwater decline in the Hueco Bolson Aquifer stabilized due to factors linked to the public water utility's management strategies and investments, including conservation practices, greater reliance on surface water with treatment, and the addition of desalination plant wells. He predicts that sufficient water supply will be available during this century.

Extensive studies of underground flows developed by Hutchison and others support his predictions. He asserts that enough water will be available over the next century or longer due to planning for the variability that can be seen in historic data and tree ring records, even without the effects of climate change: "...it can be seen that after 100 years of operation under the JDF [Joint Desalination Facility] scenario, 75 percent of the fresh groundwater currently in storage in the El Paso portion of the Hueco Bolson will remain in storage" (Hutchison 2006). His estimate is conservative, he proposes, given two assumptions. It accounts for lack of knowledge regarding the movement of brackish water within the aquifer by assuming all storage decline to be fresh water. It also assumes only 25 percent of the total fresh groundwater is "economically recoverable," while other, earlier research assumed a greater percentage.

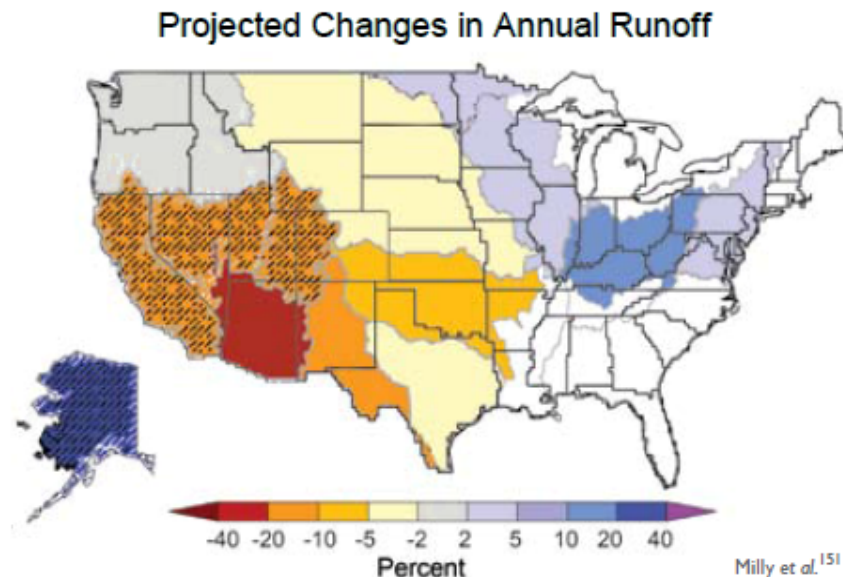
However, the most recent regional climate change research contains water findings that seem to contradict a sustainability conclusion. Human and non-human factors introduce uncertainty, although West Texas researchers make great efforts to internalize these into their models and conclusions. Most El Paso region supply comes from groundwater, an area opened to science recently and only partially understood. The same is true of the climate change science.

In the case of groundwater, managers currently supervise Hueco Bolson pumping without the benefit of a transport model, which would enable an understanding of underground brackish water movement. Hutchison and previous consultants highlighted the need for such a model to reduce uncertainty. "Managing the Hueco as a sustainable supply requires attention to both groundwater storage and groundwater quality. However, the completion of a solute (groundwater quality) model is needed to assess the effectiveness

of this effort further” (Hutchison 2006). Bredehoeft, et. al, recommended that EPWU develop a transport model, although “there is no question that [its calibration] is considerably more difficult than calibrating a flow model,” to the point where the USGS was unsuccessful in doing so (Bredehoeft 2004). The stakes are high enough to justify a conservative stance on water availability.

In the case of climate change, runoff decrease mapped in Figure 44 would likely lead not only to reduced flows in the Rio Grande, but reduced recharge to the aquifers. Talk of Rio Grande flow changes must acknowledge the potential for water supply conflicts highlighted in Figure 45 (Global Climate Change Impacts in the United States 2009). Albuquerque now withdraws surface water that would otherwise flow into the Rio Grande, a marked change from the past.

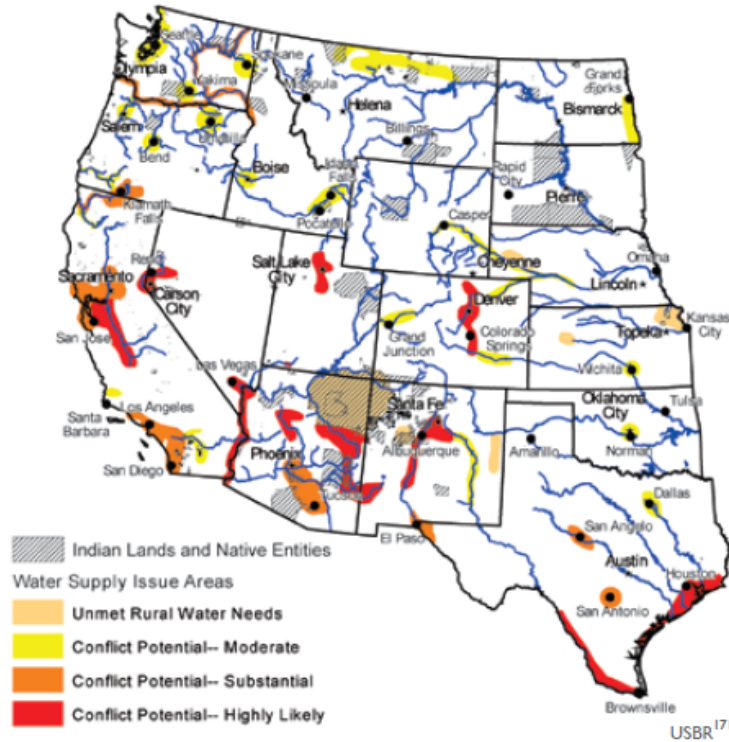
Juarez introduces another externality. Groundwater was the only municipal supply for Juarez in 2004. Accuracy in population forecasting more than 20 to 30 years into the future is dubious, and unforeseen changes in water use intensity can have transformative effects on likely scenarios. The river flows past both the largest border community *in the world*, and over 300 other municipalities that also require water (*Discover a Watershed* 2001).



Projected changes in median runoff for 2041-2060, relative to a 1901-1970 baseline, are mapped by water-resource region. Colors indicate percentage changes in runoff. Hatched areas indicate greater confidence due to strong agreement among model projections. White areas indicate divergence among model projections. Results are based on emissions in between the lower and higher emissions scenarios.⁹¹

Figure 44. Projected reduction in West Texas runoff (Global Climate Change Impacts in the United States 2009).

Potential Water Supply Conflicts by 2025



The map shows regions in the West where water supply conflicts are likely to occur by 2025 based on a combination of factors including population trends and potential endangered species' needs for water. The red zones are where the conflicts are most likely to occur. This analysis does not factor in the effects of climate change, which is expected to exacerbate many of these already-identified issues.¹⁷¹

Figure 45. Potential for West Texas and New Mexico Water Supply Conflict (Global Climate Change Impacts in the United States 2009).

Although delivery of flow downstream is governed by interstate compact, upstream neighbors like Albuquerque will likely seek to divert water in the shift from groundwater reliance. Rio Grande water supply to Texas sits amidst a complex compilation of treaties between states and nations whose largest cities are booming in population. Mexico chose not to deliver on regulated water promises in recent years, and as a consequence knowingly went into “water debt.” Its consumers took priority in drought times, irrespective of international violations. Increasingly severe droughts may only exacerbate conflict.

There is the potential for emerging factors to change the situation in unpredictable ways, true to a scenario planning process. Somewhat foreseeable anthropogenic natural systems changes will form less foreseeable feedback loops with human behavioral changes and decisions. The recent Climate Impacts Report from the U.S. Global Change program gives examples of unknown future variability sources, both use-reducing and -increasing: irrigation demand may increase from forecasted trends in response to higher temperatures and longer droughts; flora may use water more efficiently with rising CO₂ levels;

power plants will increase cooling water withdrawals in the heat; consumers will want more air-conditioning during more balmy summers, thus increasing electricity demand that necessitates even more power plant cooling water (Global Climate Change Impacts in the United States 2009). “There is also the possibility of even larger changes in climate than current scenarios and models project,” and “the long record of climate found in ice cores, tree rings, and other natural records show that Earth’s climate patterns have undergone rapid shifts from one stable state to another within as short a period as a decade.” Some of these also vary with population and economic change.

Human actors can offset some of these feedback loops through policy initiatives linked to behavioral and systems changes, given sufficient political will and organizing initiative. Regional governance can hinder or help these efforts. As the report’s scientists observe, “The past century is no longer a reasonable guide to the future for water management.”

5.4.3.1.9 Fort Bliss summary

This study has only evaluated the *overall* annual availability of water. Further work may be necessary to assess the full day-to-day impacts. This report recommends the implementation of best management water conservation practices, discussed in detail in a later section, beginning as soon as feasible. Installations that begin to implement these measures, and thus build a strong basis for future drought management rapid response, will lead the way to environmental sustainability in the region and safeguard mission sustainment. Anticipated increases in water pricing nation wide will improve monetary payback for water conservation projects.

Implementing a program of total water management can prepare an installation for fluctuations in water availability while easing the affects of extreme storm events and increasing water security and independence through retention and reuse of both stormwater and gray water where applicable.

Given uncertainties of groundwater and conclusions among respected water and climate change experts, the 25 percent recoverability discussed as conservative should be considered the norm, and EPWU should pursue artificial recharge sooner rather than later. Fort Bliss leadership should seek any opportunity to expedite such a project while rapidly phasing in conservation practices, to include metering. Many such practices are already part of the culture of conservation established by EPWU throughout broader El Paso. Decision-makers at Fort Bliss may readily draw on them as locally successful approaches. Furthermore, if Bliss can play a role in emphasizing the need for a saline water transport model to EPWU or other researchers, it should do so.

One school of forecasting internalizes incongruous opinions between experts by inviting them into a conference room where they hash out seeming differences and tend to drift towards a more moderate center, which then becomes the preferred scenario for planning. While such a process falls outside this study's scope, decision-makers for Army installations in vulnerable regions like Fort Bliss should take away the strong imperative to err on the side of conservation, caution in supply planning, and TWM.

6 Projection of Installation Water Demand

6.1 Introduction

The purpose of the water forecasting models used in this study was to predict over a 30-year time horizon the capacity, demand, and raw water supply requirements for a military installation.

6.2 Water demand model

The Installation Water Demand Model uses customer disaggregation* as the basis for projections. Customer classes are residential (family housing, Unaccompanied Personnel Housing (UPH)/barracks, and transient/lodging facilities), dependent schools, industrial and maintenance, medical, administrative and moderate users, community and commercial (food and non-food related), storage, high water use facilities, pools and vehicle wash facilities, irrigation and improved lands, and losses. Categories can be combined depending on the availability of installation data.

Sectoral demands were developed based on typical water consumption values and are calibrated to the installation footprint, population, and op-tempo.

6.2.1 Drivers for water demand

The key drivers for the water model are the installation real property data, installation permanent population (barracks, multifamily, single family, transient quarters), commuting population, industrial tempo, deployment tempo, rainfall and evapotranspiration data, and planned construction.

6.2.2 Water use data

Installation water use data is reported on a monthly basis by the utility contract operator. Data is available for the entire installation. Reimbursable customers are metered separately for billing purposes. This data is aggregated quarterly and entered into the Army Energy and Water Reporting System (AEWRS).

Initial per capita water usage is typically about 69.3 gallons per capita per day (gpcd) and applies to resident population (family housing, multifamily hous-

* Disaggregation is the process of separating water usage by customer class using the total installation consumption and estimating factors for end uses.

ing, and barracks). Indoor water usage for commuting population is 10 gpcd. Irrigation water usage is:

$$[\text{acreage} \times (\text{summer evapotranspiration rate})] - [.60 \times (\text{summer precipitation rate})]$$

The model assumes no restrictions on irrigation. The seasonal variation in installation consumption can also be used as a check on the irrigation rate.

Initial rough break-out by sector is 50-60 percent for residential, 25 percent for non-residential, and 10-15 percent for losses. These figures may need re-alignment based on the fact that many installations have a large population that commutes onto the installation so the non-residential sectors may exceed the typical city's profile ratio for commercial/industrial/institutional buildings and usage. Landscape irrigation may also be a much larger consumer than in a typical community due to large parade fields, commons, golf courses, etc.

The factors for the consuming sectors of the model were taken from Forecasting Urban Water Demand (Jennings and Jones 2008). The model works on the premise that there are several basic using categories of consumers on the installation. These are residents, commuters, and processes. The residential consumption is in the housing, barracks, and transient facilities. The commuting population is represented by the square footage of the different types of buildings and their consumption factors. The processes are represented by the irrigation loads, losses, and high water uses. These are more unique consumers and should be evaluated for each installation.

6.2.3 Model development and testing

The steps in developing the water model are: collect data on water use and drivers for water demand (10 years of monthly data and 20 years of annual data); analyze key drivers and disaggregate data; develop and test model; augment data if required; test and calibrate model for several installations; develop forecast for the drivers (independent variables); and develop water demand and consumption forecasts.

6.2.4 Model results

The model was developed for two installations—Fort Bragg and Fort Bliss. These installations are located in significantly different climate zones, Fort Bragg is in the Southeast and Fort Bliss is in the Southwest. They have significantly different evapotranspiration rates for exterior use of water.

6.3 Case Study: Fort Bragg, NC

6.3.1 Establishing the baseline

Fort Bragg is a large U.S. Army Forces Command (FORSCOM) installation located in Fayetteville, NC. Figure 46 shows Fort Bragg’s historical water consumption, using monthly data obtained from installation staff. Consumption has changed over the last several years, dropping from an average of 8 MGD to about 5 MGD. This has been the result of their aggressive water conservation program and also partly due to a high level of deployments. It should also be noted that their consumption is trending back up since the low point of 4.3 MGD in FY06. Using the last 5 years of data, the average was 4.84 MGD, but since this is trending up, 5 MGD was taken as the baseline for calibrating the model.

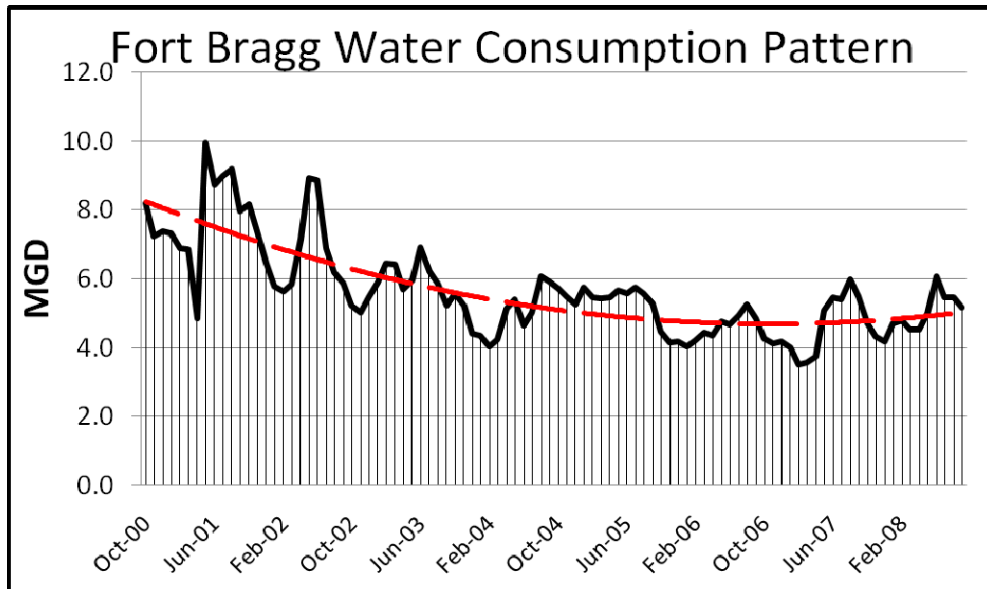


Figure 46. Fort Bragg historical water consumption (Fort Bragg DPW).

6.3.2 Projecting Fort Bragg usage

Table 19 lists the baseline population and input data used for Fort Bragg.

Table 19. Population and infrastructure data used for Fort Bragg (Fort Bragg).

Housing Units	5,580
Military Stationed	47,435
Transient Population	2,451
Dependents	72,101
Civilian Workforce	16,290
Deployment Factor: Family Housing	0.84
Deployment Factor: Barracks	0.67
ET (Moisture Deficit)	16.66
Losses Factor	0.10

Table 20 lists the initial installation baseline projected consumption. Note that this is an unconstrained baseline and assumes irrigation of improved lands is conducted according to the typical evapotranspiration requirements of the area. The initial calculation gives a projected baseline of about 5.6 MGD annualized demand. Note that the actual demand will fluctuate based on season and can be as much as 80-100 percent higher during high irrigation times.

The model is then adjusted for growth in consumption in the various sectors based on expected changes (growth or reduction) in the various inputs. The installation population is adjusted for future changes, the various consuming sectors are adjusted based on planned construction, and the mobility factors are adjusted based on the expected rates of deployment. The baseline projection makes no assumptions about water conservation projects or implementation of best management practices as defined in Chapter 8.

Figure 47 shows the 30-year projection for Fort Bragg. The model projects that the installation will increase its baseline water consumption about 0.5 MGD in the future due to several Army transformation initiatives. The graph in Figure 47 also provides a modified projection based on implementation of the water saving requirements of Executive Order 13423. EO 13423 requires a 2 percent reduction per year from FY08 through FY15. Implementing water efficiency best management practices would result in a long-term reduction of consumption to an annual average of about 5.2 MGD. Here, it is assumed irrigation requirements are met.

Table 20. Initial installation baseline projected consumption for Fort Bragg.

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 Users	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, Wash Racks, etc	0.100			
Losses	0.489			
Total	5.380			

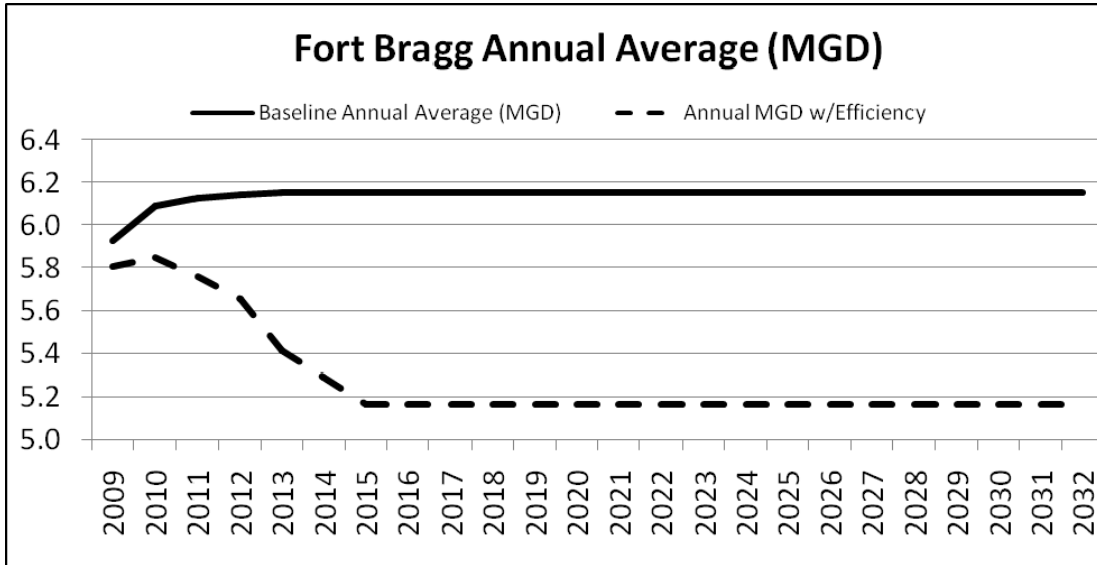


Figure 47. Projected Fort Bragg water consumption.

6.4 Case Study: Fort Bliss, TX

6.4.1 Establishing the baseline

Fort Bliss, located in El Paso, TX, is an installation in transition. It is growing from a medium sized training installation to a large troop type installation. Figure 48 shows Fort Bliss’ historical annual water consumption below. Data was obtained through the AEWRS system as quarterly consumption. Consumption has changed over the last several years, dropping from an average of 5 MGD to about 4 MGD. It should also be noted that their consumption is trend is somewhat erratic and is probably weather dependent. Using the last 8 years of data, the average was 4.4 MGD, which is fairly high for an installation of this size, but is an indicator of the demand due to climate. This was taken as the baseline for calibrating the model.

6.4.2 Projecting Fort Bliss usage

Table 21 lists the baseline population and input data used for Fort Bliss.

Table 22 lists the initial installation baseline projected consumption broken out by category. Note that this is an unconstrained baseline and assumes that irrigation of improved lands is conducted according to the typical evapotranspiration requirements of the area. This results in a projected baseline of about 4.6 MGD. The actual demand will fluctuation based on season and can be as much as 80-100 percent higher during high irrigation times. The number show is an annualized demand.

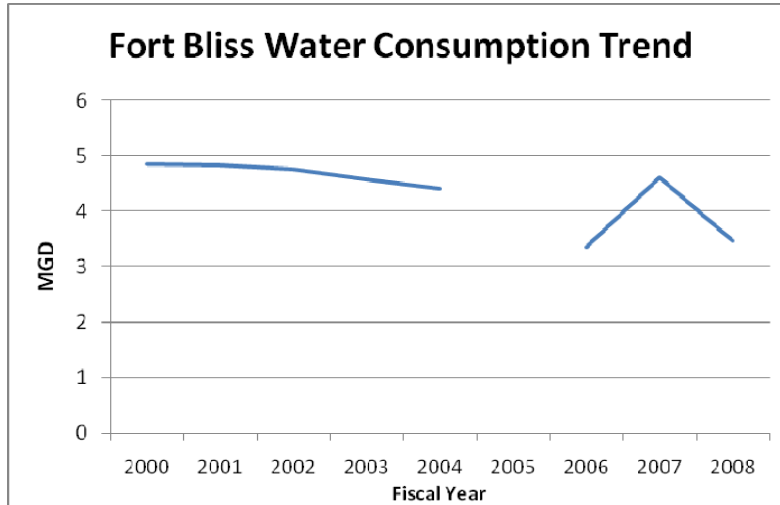


Figure 48. Fort Bliss historical water consumption (AEWRS).

Table 21. Population and infrastructure data used for Fort Bliss (Fort Bliss).

	Baseline
Housing Units	3,052
Military Stationed	9,330
Transient Population	2,132
Dependents	15,330
Civilian Workforce	3,621
Deployment Factor: Family Housing	0.90
Deployment Factor: Barracks	0.83
ET (Moisture Deficit)	30.00
Losses Factor	0.12

Table 22. Initial installation baseline projected consumption for Fort Bliss.

Using Sector	MGD (annual average)	Number	Units	Consumption (gpud)
Family Housing	1.21	13,499	Occupants	100
Barracks	0.68	8,211	Spaces	100
Dependent Schools	0.00	80	Students	20
Medical	0.09	76	Buildings	1,236
Industrial and Maintenance	0.12	176	Buildings	700
Transient Housing/Lodging	0.12	772	Spaces	150
Administrative/Moderate Users	0.18	146	Buildings	1,204
Community and Commercial: Non-food related (indoor)	0.07	106	Buildings	629
Community and Commercial: Food-related	0.02	17	Buildings	906
Storage	0.00	218	Buildings	10
High Water Use Facilities	0.01	28	Buildings	500
Irrigated/Improved Land	1.49	335	Acres	
Pools, Wash Racks, etc	0.50			
Losses	0.45			
Total	4.95			

The model is then adjusted for growth in consumption in the various sectors based on expected changes (growth or reduction) in the various inputs. The installation population is adjusted for future changes, the various consuming sectors are adjusted based on planned construction, and the mobility factors are adjusted based on the expected rates of deployment. The baseline projection makes no assumptions about water conservation projects or implementation of best management practices as defined in Chapter 8.

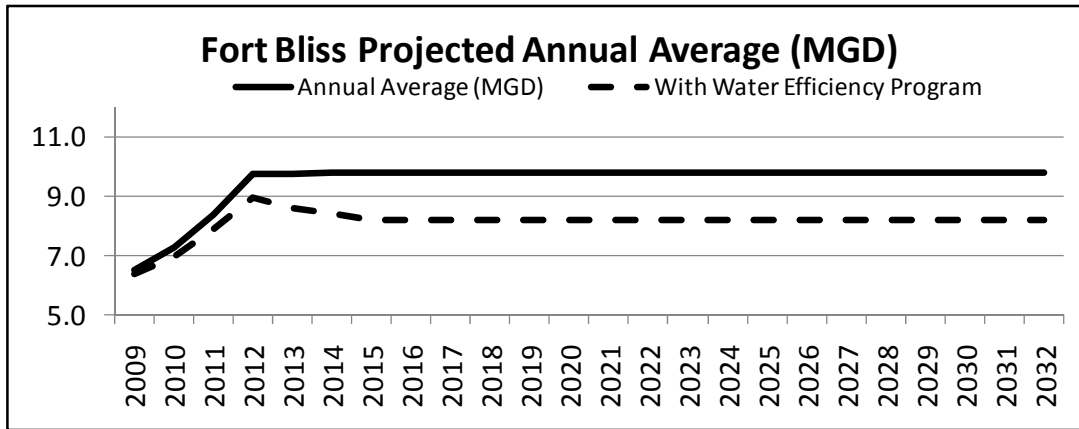


Figure 49. Projected Fort Bliss water consumption.

Figure 49 shows the 30-year projection for Fort Bliss. The model projects that the installation will increase its baseline water consumption by about 5.2 MGD to 9.8 MGD in the future due to the various Army transformation initiatives. The projection indicates that water consumption could more than double. Figure 49 also provides a modified projection based on implementation of the water saving requirements of EO13423, which requires a 2 percent reduction per year from FY08 through FY15. Implementing water efficiency best management practices would result in a long-term consumption trend at an annual average of about 8.2 MGD. Here the water efficiency improvements are going on at the same time so that increases in consumption are occurring due to the new construction and stationing activities. Again, it is assumed irrigation requirements are met. Also, new construction should be more water efficient than the existing buildings.

6.5 Conclusion

The Water Projection model provides an estimate of future water consumption based on current trends, future construction and stationing, and irrigation requirements. Projections are as accurate as the data that is used. The model is installation-specific and the baseline can be calibrated to the installation. The model also provides guidance in disaggregating the installation water consumption to several key using sectors. The sectors can provide insight in where to focus water efficiency improvement efforts on the installations. Appendix F provides instructions on using the model.

7 Water Efficiency Planning

7.1 Developing a Water Efficiency Plan

The likelihood of future water deficits is one faced by many communities across the United States (USGAO 2003). Traditional water management schemes normally deal with water deficits by pursuing and developing new water supply sources. For installations this often means either expanding existing on-post sources or procuring additional water supplies from off-post providers. TWM's focus on the entire water system allows a much broader range of strategies with which to address water deficits than those available in traditional schemes. Water conservation planning is central to the TWM approach to a balanced water budget (Grigg 2008).

Water conservation planning works to balance water supply and demand by promoting water conservation and efficient use by end-users (AWWA 2006). In effect, this ensures that the water supply is being used as efficiently as possible *before* new sources for potable water are sought. Conserved water is almost always less expensive to procure than are new water sources, and in some places, conservation and efficiency improvements can potentially eliminate the need for supply development all together (Gleick, et al. 2004).

Water conservation planning can help the Army to meet both Federal and DOD water policy requirements. The U.S. Energy Independence and Security Act of 2007 (EISA) stipulates that covered facilities must complete comprehensive water (and energy) evaluations once every 4 years.* This process must include the re- (or retro-) commissioning of each facility and the implementation of all water (and energy) efficiency measures that are cost-effective over the life-cycle of said measure. A water conservation planning process could easily be structured to fulfill all of the EISA water requirements.

The other major Federal water policy requirement is Executive Order 13423, which requires a reduction of water per square foot of building space (as compared to a 2007 baseline) by 2 percent per year or 16 percent in total between 2008 and 2015. To achieve this reduction, Federal facilities will have to implement a variety of water conservation and efficiency measures. Mooring these measures in a full water conservation plan will help to ensure that the

* The criteria for covered facilities are yet to be developed. However, at a minimum they will include Federal facilities that constitute at least 75 percent of energy use at each agency.

measures chosen are the most effective for a given site and that the implementation process is carried out fully.*

7.1.1 Analyze water use†

The first step in the creation of a water conservation plan is a careful analysis of present and future water usage. “Usage” includes water that is regularly accounted for within the system, and unmetered and unbilled water. An understanding of water usage is a large part of EISA-specified water evaluation. Furthermore, a detailed understanding of how much water is used by different classes of users (e.g., domestic versus industrial) and how that use varies over time (peak use, seasonal variation, etc.) is the base on which the remainder of the water conservation plan is constructed. It is impossible to calculate the benefit of various conservation measures without a clear picture of water demand throughout the implementation period and lifespan of those measures.

7.1.2 Identify and analyze water efficiency measures

Once water usage has been fully illustrated, potential water savings must be identified. Knowledge of water efficiency and conservation practices is important for this stage of the water conservation planning process. The Department of Energy has developed a wealth of information to aid in the implementation of E.O. 13423 that addresses water efficiency and conservation practices, including a list of best management practices (BMPs) that should be used to implement the executive order‡. A cursory introduction of some such practices appears below; however, many more resources exist on the topic. All potential methods for saving water should be identified and screened for appropriateness. AWWA (2006) suggests screening based on:

1. Cost-effectiveness;
2. Technology maturity;
3. Local conditions;
4. Customer acceptance; and,
5. The availability of substitutes.

Once a list of potential conservation/efficiency measures has been identified, future water savings can be calculated for each of the potential water conservation measures.

* For further guidance on E.O. 13423, including required Best Management Practices (BMPs), see http://Army-energy.hqda.pentagon.mil/policies/water_con.asp.

† The following draws in large part from AWWA (2006).

‡ See http://Army-energy.hqda.pentagon.mil/policies/water_con.asp.

7.1.3 Water efficient measure selection

Projected water demand and water savings calculations can be combined to create a series of alternative scenarios for meeting long-term water needs. These scenarios can include bundles of BMPs and supply development options. TWM takes a long-term perspective that considers social and environmental impacts in addition to economic ones. This approach means that the monetary implications of conservation measures – infrastructure and capital costs, operations and management budgets, energy and wastewater expenses – must be considered in the long term, and that impacts on equity and environmental health must be taken into consideration. AWWA (2006) suggests scenario selection based on the following criteria:

1. Ability to meet long-term water goals;
2. Cost-effectiveness;
3. Regulatory requirements;
4. Public input;
5. Environmental benefits;
6. Partnerships opportunities;
7. Budget/ staffing requirements; and,
8. Community impacts.

Compliance with EISA and E.O. 13423 should also be considered at the measure-selection phase of the planning process.

When evaluating a potential water conservation plan, it is useful to look at the sum advantages and disadvantages of the entire plan. A measure especially beneficial in only one area can sometimes offset another measure especially beneficial in another. Cost-benefit analyses are well understood tools for evaluating the cost-effectiveness of various scenarios while more qualitative analyses are often performed with regard to some of the other criteria. A useful source for both the technicalities of benefit-cost analysis and a framework for incorporating non-economic criteria into decision-making processes is *Water Efficiency Programs for Integrated Water Management* (AWWA-RF 2007).

7.1.4 Create a formal plan

Once a particular bundle of water conservation and efficiency measures has been chosen, a formal water conservation plan must be developed to ensure it is effectively implemented.* The public should be consulted for their input

* For a sample water conservation plan, see *Summary Report for WSMR Water Management Plan*.

and potential partnerships should be explored with other agencies (e.g., regional planning, wastewater and energy utilities) as part of the formal plan development. A detailed budget and schedule must be drawn up to support the implementation of the water conservation plan. Furthermore, programs to track the performance of the plan must be developed so that the program can be evaluated and modified, if necessary, to ensure that the measures implemented are achieving the water conservation needed to safeguard the water supply in the long-term. This data can provide a useful basis for knowledge sharing between programs and will also produce requisite documentation proving facility compliance with EISA and E.O. 13423.

7.2 Water Conservation and Efficiency Measures*

The following is a brief introduction to a variety of potential measures that can be employed by Army installations to achieve greater water efficiency. Water efficiency measures are grouped by facility type with the exception of water monitoring and loss programs which apply to all facilities. The efficiency measures listed here are in no way comprehensive and will not all be appropriate for every Army installation.

7.2.1 Water monitoring and loss programs

Understanding where, how, and how much water is used in the facilities at an installation is the prerequisite to the development of a water efficiency plan. This knowledge is both the key to knowing the water conservation and efficiency measures that will generate water savings and to maintaining those water savings. Water systems and fixtures require continuous attention and repairs to run at the optimum level of efficiency. Thus having a working knowledge of how water is used in a facility and monitoring that use is in some way the most important water conservation and efficiency measure that can be taken.

7.2.1.1 Water monitoring

Water monitoring requirements are:

- *E.O. 13423* requires baseline data be collected about water usage for all facilities.[†]
- *EISA* requires water evaluations be performed for 25 percent of “covered” facilities each year.*

* When not otherwise documented, the information used in the remainder of the chapter is drawn from Vickers, 2002, and the Alliance for Water Efficiency; information about product specification comes from WaterSense, Energy Star, FEMP, and CEE.

† Executive Order 13423, “Strengthening Federal Environmental, Energy, and Transportation Management.”

Some efficiency measures for water monitoring are:

- Perform a water audit that inventories all uses of water on-site and determines the amount of unaccounted for water.
- Update existing water audit regularly.
- Meter 100 percent of water use.

A water audit is an inventory of all water use on site. It is essentially an accounting of the water that flows through a site, much like the accounting of money that flows through an organization. Ideally, this information is gathered using water meters, but where usage is unmetered, engineering estimates can be used to help calculate water usage. In addition to flows of water through a site, it is useful to gather very specific information about the fixtures and appliances that use water such as the number of gallons flushed by each flush of a toilet onsite or the gallons of water a food steamer typically uses per hour. The Federal Energy Management Program (FEMP) has a useful tool for calculating cost savings from water conservation that includes this sort of careful water accounting. The tool, called Watergy, is available from the FEMP website. † At a minimum, this data should provide the baseline water use data required by E.O. 13423, the water evaluation data required by EISA, and also information regarding any unaccounted-for water (water that enters the site, but is not accounted for in any of the end-uses); however, the more detailed the data, the more useful the audit will be in support of water conservation programs immediately or in the future.

The data from a water audit is the backbone of any plan of action regarding water efficiency and conservation. Data makes it clear where the biggest water-users are and thereby where conservation and efficiency measures have the potential to make the biggest differences. It can be used to calculate the water savings from a proposed bundle of water efficiency measures, determine payback periods, and perform cost-effectiveness analyses. The data should also help identify areas of potential water loss and thereby help direct leak detection and repair resources. Regularly updating a water audit ensures its usefulness over the long term, allows it to be used as a measure of the pro-

* The Energy Independence and Security Act of 2007. Covered facilities are those which constitute at least 75 percent of the agency's facility energy use.

† FEMP's Watergy tool is available at: http://www1.eere.energy.gov/femp/information/download_watergy.html. The program also provides water use indices that allow for the estimation of water use by building type in conjunction with baseline data requirements for E.O. 13423 at http://www1.eere.energy.gov/femp/water/water_useindices.html.

gress of any water efficiency/conservation programs in place (a part of EISA requirements), and can help to identify emerging trends such as new leaks or new potential conservation areas.

Meters, as mentioned above, can provide important information regarding water use in a facility. This information informs the water audit, water efficiency calculations and analyses, and programs that monitor water loss. Information regarding water usage over time is particularly useful as it allows for the same kind of trend identification as does water auditing. Metered information is much preferable to engineering estimates as estimates are based on assumptions about typical water usage. Unfortunately if something about water usage is atypical at a particular site, such as a leak, engineering estimates may not always discern that abnormality. Comprehensive metering is part of the infrastructure that facilitates water conservation and efficiency.

Installation of water meters is required by EISA and DoD criteria and is currently managed by Huntsville Center of the Corps of Engineers. The priority for meter installation is for installation of electrical meters first (required by 30Sep2012) followed by natural gas, steam, and water (required by 30Sep2016). Installation of 7,000 water meters funded by IMCOM is programmed for FY13. Some garrisons are electing to install water meters earlier utilizing OMA funds or FY09 end-of-year IMCOM funding. These include Fort Gordon, Fort Leavenworth, Fort Sam Houston, and Fort Hamilton (utilizing ARRA*/stimulus funds). U.S. Army Reserve Centers and medical treatment centers are installing meters on a region by region basis as funded by their commands (Murrell 2009).

7.2.1.2 Water loss program

Some efficiency measures for Water loss programs are:

- Optimize the system water pressure.
- Perform regular maintenance for water fixtures and water-using appliances.
- Detect and fix any extant leaks.
- Fund a water loss program to detect and fix ongoing water loss issues.

The most water-efficient fixtures and practices can still waste large amounts of water when the water system to which they are attached is leaky. Pipes break, fixtures leak, and varying amounts of water disappear before ever reaching a tap. All water systems experience some amount of water loss. Typi-

* American Recovery and Reinvestment Act, February 2009

cally water systems are expected to strive toward the level of leakage at which the value of water lost is equal to the cost of intervention activities to control that loss. This is called the economic level of leakage and will vary from system to system (AWWA 2006).^{*} There are a number of water efficiency measures that can be taken to achieve this level of leakage.

Water pressure in a water distribution system must be high enough to keep the water flowing through the pipes and correctly discharging from water fixtures. However, the higher the pressure, the more wear and tear received by the pipes and the more water lost to any leaks in the system. Thus, optimizing water pressure is important for combating water loss and can help yield a more efficient water distribution system (Barry 2007).

Regular maintenance of water-using appliances, water fixtures and the water distribution system itself are also important to controlling water loss. Preventive maintenance for water-related equipment helps to prevent leaks before they spring and is often much less costly than are repairs. Thus, regular maintenance is an important water efficiency measure.

In addition to preventing leaks through pressure optimization and regular maintenance, actively working to detect and repair leaks will further limit water loss. Larger leaks in water fixtures and appliances are often visually or audibly noticeable, but seepage and smaller leaks should be checked for with a close visual examination (and in most toilets with tanks, a dye tablet) on a regular schedule. Likewise, pipes should be checked for leakage regularly. Common methods for detecting leaks in pipes include acoustic techniques and flow measurement. Acoustic techniques involve using tools that can detect differences in the sound of water flowing through pipes to discover leakage. Flow measurement techniques involve measuring the flow at two different points in a pipe to determine if there is leakage (AWWA 2007). Comprehensive metering, described above, can help to detect leakage by providing data about spikes in usage or by being used as a data point for flow measurement leak detection.

Finally, funding some sort of program to control water loss on an ongoing basis is an important step in achieving optimum water efficiency. Water loss is an ongoing problem and therefore needs proactive attention. Funding a mechanism to ensure that as few leaks occur as possible, and that when they do occur they are found out and repaired quickly will generate considerable water savings over the lifetime of the program.

^{*} While this standard is most often applied to water supply systems, the standard and the logic behind it are just as applicable to a site, facility, or even a single building.

7.2.2 Residential buildings

Potential water efficiency measures for residential buildings revolve around the water fixtures such as toilets, faucets, and clothes washers that are part of everyday life. Therefore these measures often extend to buildings in the industrial, commercial, and institutional sectors as well (making them useful tools for reaching the water conservation goal of E.O.13423). While behavior surrounding water usage can make a large difference in water use for all buildings, this section will focus largely on non-behavioral modifications that have the potential to save water. Therefore, for residential buildings, most water conservation measures involve the replacement or retrofit of inefficient water fixtures and appliances. Information gathered in the water audit should help with identification of inefficient fixtures/appliances that need replacement.

Whenever available, *WaterSense* specifications will be recommended as part of these efficiency measures. *WaterSense* is an USEPA program that helps consumers choose quality, water efficient products and services.* The USEPA works with manufacturers to develop water efficient specifications for various products and provides *WaterSense* labels to products that have been independently certified to meet specifications. The USEPA is still in the process of developing its full body of specifications. Thus, it is recommended that the *WaterSense* website (<http://www.epa.gov/watersense/>) be checked regularly to keep installations abreast of new specifications or updates to existing specifications.

The implementation instructions for E.O. 13423 direct Federal agencies to purchase *WaterSense* products whenever possible (DOE 2008). *WaterSense* products are thus both the water-efficient and E.O. 13423-compliant choice. EISA also limits Federal agency purchases of certain products to those that are designated by the FEMP or Energy Star qualified (Sissine 2007). Where *WaterSense*-labeled, FEMP-designated, or Energy Star-qualified products exist, they will be identified below. Other Federal regulations with regard to the water flow through specific fixtures will be outlined when *WaterSense*, FEMP, or Energy Star requirements are not in place.

* See the *WaterSense* website: <http://www.epa.gov/watersense/> for more information.

7.2.2.1 Toilets

Requirements for toilets are:

- *WaterSense*: tank-type toilets must have effective flush volumes of 1.28 gpf or less.*
- *U.S. Energy Policy Act of 1992 (EPAct)*: all toilets sold, imported, or installed in the United States must have flush volumes of 1.6 gpf or less.

Some efficiency measures for toilets are:

- Replacement – Replace older toilets with high-efficiency toilets (1.28 gpf).
- Replacement – Replace older toilets with composting toilets.
- Retrofit – Retrofit flushometer-valve toilets with a diaphragm-valve replacement kit (may require bowl replacement).
- Retrofit – Retrofit flushometer-valve toilets by turning the screw on the valve to increase water efficiency (not possible for all units).

The largest water users in the residential sector are toilets, typically accounting for more than a quarter of indoor usage (Vickers 2002). Using graywater for flushing toilets, discussed further below, holds great potential for saving water in residential buildings. Whether or not graywater is used, however, limiting the amount of water flushed down the toilet is an important efficiency measure that can be applied to these water-intensive fixtures. Savings are achieved in this arena by reducing the number of gallons of water used for every flush of the toilet, i.e., reducing the number of gallons per flush (gpf).

Tank-type toilets can earn the *WaterSense* label by having an effective flush volume of 1.28 gpf or less. These “high-efficiency toilets” (HETs) are commonly available and are able to flush waste just as effectively as older toilets with higher flush volumes (USEPA *WaterSense* 2007). Though no *WaterSense* label has yet been developed, valve-type HETs are available as well. Additionally, HETs are by no means the limit of toilet water efficiency; pressure-assisted 1.0 gpf toilets are commonly available and can achieve even higher water savings than can the HETs. Replacing older toilets – especially those installed before 1994 that have effective flush volumes of 3.5 gpf or greater – with toilets that flush at 1.28 gpf or less can save a great deal of water (information about gpf rating for existing toilets should be gathered on the water audit).

* Effective flush volume is generally considered to be the average flush volume for a single flush toilet or the average of one “full” flush and two “reduced” flushes for a dual flush toilet (EPA *WaterSense* 2007).

Another water saving option is to install a system of composting toilets in lieu of traditional flush toilets. Composting toilets use virtually no water and, if operated correctly, result in a safe odor-free end product that is easy to clean out. A composting system has different infrastructure needs than do traditional toilets and thus can sometimes be easier to incorporate into the plans for new construction than retrofitted into an extant building; however, designers of composting toilet systems can do both.

Finally, for flushometer-valve toilets (the kind of tankless toilet most often seen in non-residential applications) some water-conserving retrofit options exist for cases where replacement is not feasible. These include installing a valve-diaphragm replacement kit or turning a screw sometimes located on the flush valve to adjust the amount of water used for each flush. Valve replacement is only appropriate for toilets with an effective flush volume of 3.5 gpf or greater and can sometimes necessitate a replacement bowl to avoid clogging problems. Both adjustments result in a water use reduction of up to 1.0 gpf.

7.2.2.2 Urinals

Requirements for urinals are:

- *WaterSense*: (in development) urinals must have effective flush volumes of 0.5 gpf or less.
- *FEMP*: urinals must have effective flush volumes of 1.0 gpf or less.

Some efficiency measures for urinals are:

- Replacement – Replace older urinals with waterless urinals or with 0.5 gpf urinals in systems that cannot handle waterless urinals.
- Retrofit – Retrofit flushometer-valve urinals with a diaphragm-valve replacement kit.
- Retrofit – Retrofit flushometer-valve urinals by turning the screw on the valve to increase water efficiency (not possible for all units).
- Retrofit – Replace the valve on a higher water-using flushometer-valve urinal with a valve for a lower water-using urinal (not possible for all units).

Army Installation Design Standard requires that all new construction and major repair projects use waterless urinals (USACE 2006). At virtually no water usage, waterless urinals have the potential to provide significant water savings for high-traffic lavatories, especially when replacing older, more water-inefficient models. Waterless urinals require different, but generally no more, maintenance than water-using urinals. It is important to ensure that a sewer system can handle the reduced liquid volume and higher concentration of

waste resulting from the installation of waterless urinals, as these issues can sometimes cause problems in older sewer systems. Also in some retrofit applications, the sewer lines are not sloped enough to handle the reduced flows (Demiriz 2006). In these cases, high efficiency urinals that use a maximum of 0.5 gpf, though models using as little as a pint of water per flush are available, could be considered (Koeller 2005).

There is concern in the plumbing industry over the relatively new technical issue of “dry drains”. Concern for drainline transport efficacy has been voiced by members of the plumbing trade since low-flush toilets were first mandated in the United States in 1994. At the recent ISH, the world’s leading trade fair for the plumbing and heating industry, there was a special Dry Drains Forum. The Plumbing Efficiency Research Coalition (PERC), a coalition formed in February 2009 and comprised of five industry organizations*, has identified Drainline Transport as its first research project.

Traditional water-using flushometer valve urinals can also be retrofitted to use less water, as with flushometer valve toilets. Both the valve-diaphragm replacement kit and the screw adjustment mentioned above are potential retrofit options for urinals. Additionally, in some of the lower flush volume urinals (1.5 to 3.0 gpf), the flush valve itself can be replaced with an even newer 0.5 or 1.0 gpf flush valve to achieve water usage reductions.†

7.2.2.3 Showerheads

Requirements for showerheads are:

- *WaterSense*: (label in development) showerheads must have flow rates of 1.5 to 2.0 gpm or less at 80 psi.
- *FEMP*: showerheads must have flow rates of 2.2 gpm or less at 80 psi.

Some efficiency measures for showerheads are:

- **Replacement** – Replace older showerheads with high-efficiency showerheads (1.5 to 2.0 gpm at 80 psi or less).
- **Behavioral** – Use an on/off valve during showers.

* These organizations are the Alliance for Water Efficiency, International Association of Plumbing and Mechanical Officials, International Code Council, Plumbing-Heating-Cooling Contractors Association, and Plumbing Manufacturers Institute.

† For greater differences in flush volumes, e.g., retrofitting a from 3.5 gpf urinal to a 1.0 gpf model, urinals may run into problems fully evacuating liquid. Retrofits to pint-urinals should include a retrofit to the body of the urinal to ensure complete evacuation. (Conversation with Jamie Nobles, 22 July 2009)

WaterSense is in the process of developing specifications for high-efficiency showerheads, but it expects to require *WaterSense*-labeled showerheads to use no more than 1.5 to 2.0 gallons per minute (gpm) at a water pressure level of 80 pounds per square inch (psi). Such showerheads are already on the market and have price tags roughly equivalent to more water-inefficient models (Stoughton, et al. 2005). Additionally, some showerheads come with on/off valves – these features can save additional water, but only if actually used during showers.

7.2.2.4 Faucets

Requirements for faucets are:

- *WaterSense*: residential lavatory faucets must have flow rates of 1.5 gpm or less at 60 psi.
- *FEMP*: lavatory faucets must have flow rates of 2.0 gpm or less at 60 psi.
- *EPAct*: faucets must have flow rates of 2.2 gpm or less at 60 psi.

Some efficiency measures for faucets are:

- Replacement – Replace older faucets with low-flow and high-efficiency alternatives (2.2/1.5/0.5 gpm/0.25 gpc at 60 psi for kitchen/residential lavatory/public lavatory/metering uses respectively).
- Retrofit – Add an aerator to higher flow faucets to achieve lower flows.
- Behavioral – Switch from disposing of organic waste using a food waste disposal to composting.

The best practice for faucet water usage varies by faucet type. Generally, kitchen faucets require a relatively high water flow to fill pots and perform other kitchen-related tasks. Maximum water flows from the most recent Federal legislation, the U.S. Energy Policy Act of 1992 (EPAct), which specify maximum faucet water flow at 2.2 gpm at 60 psi, are still considered appropriate for kitchen faucets. A number of more water-efficient kitchen faucets are available for those willing to forego quickly filled kitchen sinks; some even have adjustable flow rates to allow for the higher flow when needed. These lower-flow kitchen faucets should be considered and installed where appropriate to achieve further kitchen water savings.

WaterSense has released a more stringent specification for non-public lavatory faucets. To warrant a *WaterSense* label, private residential lavatory faucets must have a flow rate no greater than 1.5 gpm at 60 psi. Best practice for public lavatory faucets comes from an American Society of Mechanical Engineers (ASME) code, which requires a flow rate of no greater than 0.5 gpm at 60 psi except for metering faucets that should flow at 25 gallons per cycle

(gpc) according to the Code of Federal Regulations.* Often, these levels of water flow are achieved as effectively with replacement fixtures as with faucet aerators. Faucet aerators restrict water flow while maintaining the feel of higher pressure by mixing air into the flowing water.

There are a variety of different mechanisms for activating faucets beyond the traditional manual method. These include sensors that turn faucets on when triggered by a person's presence and faucets that shut off after a certain amount of time has passed or water has flowed. In theory, many of these mechanisms have the potential to help conserve water. In fact that was the intention behind the development of some. However, a number of empirical studies contest the idea that manual water faucets are less efficient than their competitors; sensor-activated faucets in particular have been shown to use *more* water than their manual counterparts.† While more studies are certainly needed to clarify the most water-efficient faucet activation method, caution should be used when considering non-manual faucets, and especially sensor activated faucets, to ensure that these models are the most water efficient option.‡

Food waste disposers are another aspect of faucet water usage in the residential sector. From a pure water perspective, food waste disposers constitute an unnecessary use of water because organic waste can be disposed of in a number of other ways. This perspective is probably best applied in a drought situation. From a broader perspective, there are pros and cons to various methods of food disposal and sometimes using a food waste disposer is preferable to other forms of disposal. When possible, composting is always considered the most efficient and environmentally friendly way to dispose of organic wastes. When composting is not an option, disposal to the sewer via a food waste disposer is generally considered to be environmentally preferable to an incinerator; when choosing between a sewer system (via a disposer) and a landfill, whichever utility captures waste methane is considered the preferable option for organic waste (Liebenluft 2008).§

* ASME code from "Table 1 of ASME A112.12.1-Plumbing Supply Fittings"; Federal regulations code from "10 CFR Part 430," (EPA *WaterSense* 2007, p. 3).

† See for example Hills, et al. (2002) or Fanne, et al. (2002).

‡ Similarly, automatic flushing sensors for toilets should be used with careful attention given to their calibration as they can waste water when not set correctly (automatic flushing is generally intended to reduce the spread of germs, not save water) (Vickers, 2002).

§ See also Diggelman and Ham, 2003 and Lundie and Peters, 2005.

7.2.2.5 Clothes washer

Requirements for clothes washers are:

- *Energy Star*: clothes washers must have water factors of 7.5 or less; this maximum allowable water factor will be lowered to 6.0 on 11 January 2011.*
- *FEMP*: clothes washers must have water factors of 8.0 or less.

Some efficiency measures for clothes washers are:

- Replacement – Replace older clothes washer with *Energy Star* or Consortium for Energy Efficiency (CEE) clothes washer (15 gpc on average).
- Behavioral – Operate clothes washer only when full using low-water, short cycles.

While there are no *WaterSense* specifications for clothes washers, both *Energy Star* and the Consortium for Energy Efficiency (CEE) specify high-efficiency clothes washers that achieve both water *and* energy savings.† High efficiency washers are often front loading as opposed to top loading, as front loading washers can typically clean more effectively with less water. These high-efficiency washers have a maximum water factor of 7.5 (use a maximum of 7.5 gallons of water per cycle per cubic foot of washing space). However, the most water efficient washers have water factors of only 3.1. On average, *Energy Star* qualified washers use 15 gpc. Furthermore, if clothes washers are operated only when full on low-water, short cycles, additional water savings can be realized.

7.2.2.6 Dishwasher

Requirements for dishwashers for are:

- *Energy Star*: standard/compact dishwashers must respectively use 5.8/4.0 gpc or less; this maximum will be lowered to 5.0/3.5 gpc, respectively, on 1 July 2011.‡
- *FEMP* requirements exist, but do not directly take water into account.

Some efficiency measures for dishwashers are:

- Replacement – Replace older dishwasher with *Energy Star* dishwasher (5.8/4.0 gpc maximum for standard/compact models).

* Water factor is defined as gallons of water per cycle per cubic foot of washing space.

† For more information visit the *Energy Star* and CEE websites: <http://www.energystar.gov> and <http://www.cee1.org/>.

‡ Water factor is defined as gallons of water per cycle per cubit foot of washing space.

- Behavioral – Operate dishwasher only when full and on the shortest cycle possible.

Dishwashers also lack *WaterSense* specifications but, like clothes washers, have *Energy Star* criteria that include water use. *Energy Star*-labeled dishwashers come in two sizes – standard (capable of holding eight place settings and six serving implements) and compact (not capable of holding that much). Standard dishwashers currently use a maximum of 5.8 gpc, and compact dishwashers, a maximum of 4.0 gpc.* However, the most water efficient (standard) dishwashers use as little hot water as 1.6 gpc. Behavioral measures can also impact the water efficiency of dishwashers. Scraping food instead of pre-rinsing and washing full loads on the shortest cycle possible will ensure the most efficient dishwasher water use possible.

7.2.2.7 Cost effectiveness

Cost effectiveness should be calculated for the replacement and retrofit of inefficient water fixtures with the more water-efficient fixtures detailed above. Tables 23, 24, and 25 list product cost and water use information that can be used in combination with local information to calculate cost effectiveness.

Table 23. Average daily uses of toilet types per capita.

Product	Average Per Capita Daily Use		
	Day in Office		Day at Home
	Female	Male	Female or Male
Toilet - Office Building	3	1	5.1
Urinal - Office Building	0	2	5.1
Toilet - Home	2.1	2.1	5.1
Source: Vickers 2002			

Table 24. Average daily uses of fixtures and washers per capita.

Product	Average Per Capita Daily Use
Showerhead	5.3 min/day
Faucet	8.1 min/day
Clothes Washer	0.37 cycles/day
Dishwasher	0.1 cycles/day
Source: Vickers 2002	

Table 25. Water use amounts and average retail cost of various water appliances.

Product	Water Use	Average Retail Cost
Toilets – average replacement: 12.5 years***		
High-Efficiency	1.28 gpf	\$232
Composting System	0 gpf	\$5,000-\$20,000
Flush Valve Replacement Kit	2.5 gpf+	\$20-\$25**
Urinals – average replacement: 10 years***		
Waterless	0 gpf	\$338
New Flush Valve	0.5 – 1.0 gpf	\$100-\$150

* Starting July 1, 2011, these standards will change to 5.0 gpc for standard dishwashers and 3.5 gpc for compact dishwashers.

Product	Water Use	Average Retail Cost
Flush Valve Replacement Kit	0.5 gpf+	\$20-\$25
Showerheads – average replacement: 10 years		
High-Efficiency	1.5 – 2.0 gpm @ 80psi*	\$20
Faucets – average replacement: 10 years		
Kitchen: Low-Volume	2.2 gpm @ 60 psi	\$152
Lavatory (Residential/Public): High-Efficiency	1.5/0.5 gpm @ 60 psi	\$100
Aerator (Kitchen/Residential/Public Lavatory)	2.2/1.5/0.5 gpm @ 60 psi	\$6
Clothes Washers – average replacement: 13 years		
High-Efficiency	15 gpc (average)	\$924
Dishwasher – average replacement: 13 years		
High-Efficiency (Standard/Compact)	5.8/4.0 gpc (maximum)	\$475
Abbreviations: gpf = gallons per flush; gpm = gallons per minute; psi = pounds per square inch; gpc = gallons per cycle.		
* This should be changed to the final <i>WaterSense</i> specification when it is released by <i>WaterSense</i> .		
** Does not include cost of new bowl.		
*** While the average life of a urinal is 20 years, FEMP estimates urinals to be replaced on average at the midpoint of their useful life; this assumption is extended to toilets (which have an average life of 25 years).		
Sources: Email exchange with USEPA's <i>WaterSense</i> Helpline, 1 July 2009; Vickers 2002; General Services Administration (GSA) Advantage (price information was averaged); Wallander 2008; <i>Energy Star</i> (water usage).		

Local information needed includes population, water and wastewater rates, and current fixtures/appliances (the data for the latter two items should have been collected as part of the water audit). It is important to note that the prices listed above are for the purchase of a single, retail item – if the product in question is likely to be bought wholesale or in bulk, the listed price can typically be reduced by 15 to 20 percent. The installation cost of the product is not included in these prices. The price for installation will vary with the ability of in-house staff to perform the installation, the number of fixtures being installed, and location in the country.

FEMP has a number of tools to assist in cost-effectiveness calculations, including calculators for most of the products detailed above. FEMP's Watergy tool, mentioned above, is a useful and comprehensive tool for doing these calculations; FEMP also provides cost calculators for individual products.*

Per EISA, cost-effectiveness is calculated over the lifetime of the product in question. One advantage of the FEMP calculators is the inclusion of energy costs in the cost-effectiveness calculation. Reduced energy costs (due to reduced hot water use) will generally increase the likelihood that a conservation method will be cost-effective for all fixtures/appliances except for toilets and urinals.

7.2.3 Commercial, industrial, and institutional buildings

In addition to the kinds of water savings achievable via the replacement and/or retrofit of domestic water fixtures, commercial, industrial, and institutional (CII) buildings can often take a number of other steps to conserve water. Sometimes these measures involve the straightforward retrofit or replacement of a single fixture or appliance generally found in a facility to achieve water savings. Many times water efficiency measures will be very specific to the unique activities that take place in a given building.

As much as possible, general strategies for achieving water savings will be discussed below. However, researching specific strategies for water conservation for CII facilities found to have high water-use during the water audit can often yield significant savings. The more detailed the water audit with regard to the specific water-using activities going on in a building, the easier identifying areas of potential water savings will be. It is recommended that both general and facility-specific water-saving strategies be explored to most effectively achieve the water-efficiency goals of E.O. 13423.

* Both tools are available from FEMP's website: <http://www1.eere.energy.gov/femp/index.html>.

7.2.3.1 Heating and cooling systems

Energy Star and FEMP requirements exist for a number of products that regulate temperature and climate, but none directly take water into account.

Some efficiency measures for heating and cooling systems are:

- Ensure climate-control system is shut down when not in use.
- Retrofit or replace climate systems that use water in a once-through (single pass) manner so that the system recirculates water (is a closed loop).
- Minimize blowdown (bleed-off) for all water-using systems.
- Retrofit or replace boilers and steam generators that dispose of condensate so that the model in use has a condensate return system.

CII buildings and the equipment inside them are often heated and cooled with systems that use water.* The simplest and probably least expensive way to achieve water savings for all the equipment discussed in this section is to shut the equipment down when the building is empty and/or climate control is not needed. Often, heating and cooling systems come with or can be retrofitted with auto-shutoff devices that perform this task without requiring any behavior changes on the part of building inhabitants.

Once-through (single pass) cooling systems are some of the most blatant users of unnecessary water. Once through systems cool a piece of equipment by cycling cold water through the equipment once and then disposing of it (normally into the sewer system). Retrofitting these types of cooling systems to recirculate the water through the cooling process multiple times or replacing these systems with air-cooled systems can generate significant water savings.†

Two other forms of climate control, evaporative coolers and humidifiers, are also sometimes users of once-through water systems. Evaporative coolers (also called swamp coolers or desert coolers) cool spaces by circulating air over a wet pad. The water cools and humidifies the air that passes over it. The water used for the pad can be part of a once-through or recirculating system. If once-through, retrofitting or replacing the cooler to be recirculating will conserve water. Likewise, recirculating the water used in humidifiers in a

* Single-family residential buildings and residential equipment do not use water as often for heating and cooling; however, in cases where a residential use does involve the equipment described in this section, the same conservation measures apply.

† Air cooled systems are generally more energy-intensive than water cooled systems. When considering a switch to air-cooled systems, it is important to consider the added energy usage. In some cases, as with commercial icemakers discussed below, the added energy usage will be more than offset by the water reduction savings. In other cases, as can be so for evaporative coolers, also discussed below, the significantly lower energy usage can make a more water-intense system the better choice (especially when the water used in energy production is considered).

closed loop (through retrofit or replacement) can conserve water that previously would have been sent down the drain.

Some amount of water does have to be disposed of in humidifiers and other climate control systems to limit the build up of dissolved solids in water. The process of disposing of water to avoid overly-high levels of dissolved solids is called blowdown (or sometimes, bleed-off). While blowdown is necessary to keep a variety of equipment, including humidifiers, cooling towers, and boilers/steam generators working correctly, a number of steps can be taken to ensure that the minimum amount of water is lost to blowdown. These include preventive maintenance, adjusting the machinery so it operates at the highest efficient concentration of dissolved solids, and chemical treatment and mechanical adjustments. Equipment adjustments and proper operation can also help cooling towers--which take water heated from a cooling process and cool it down so it can be used to cool again--avoid water loss to evaporation and drift (mist).

In addition to blowdown, boilers and steam generators can lose water when their steam condensate is not captured for reuse. Boilers and steam generators work by creating steam that is sent through the distribution system of a large building or facility to warm spaces. If condensate from steam is discarded after use instead of recycled through the system, water savings can be achieved by adding a condensate return system. Condensate return systems in large district heating networks can be problematic unless proper water chemistry treatment is used to ensure that the condensate remains non-acidic (Drew Chemical Corporation 1985).^{*} Further water savings can be achieved for boilers/steam generators, and also cooling towers and once through cooling systems, if graywater is used instead of potable water (discussed below).

7.2.3.2 Commercial kitchen

Requirements for commercial kitchens are:

- *WaterSense*: (in development) pre-rinse spray valves must flow at 20 percent below Federal standard (of 1.6 gpm) or less, i.e., at 1.28 gpm or less.
- *Energy Star*: icemakers must be air-cooled and commercial dishwashers must use 1.00/0.95/0.70/0.54 gallons of water per dish rack depending on whether they are (respectively) under-counter/stationary single tank door/single tank conveyor/multiple tank conveyor-type dishwashers.

^{*} Without proper water chemistry, condensate receivers start to leak and condensate is sent to building drains. This results in the loss of not only the heat in the return, but the return mass itself. The boiler plant must make up the lost water costing more chemical treatment and energy. If the make-up system cannot keep up, then the system endures even more damage due to untreated make-up entering the system.

- *FEMP*: pre-rinse spray valves must flow at 1.25 gpm or less.
- *Energy Star* has requirements for steamers, but they do not directly consider water.
- *FEMP* has requirements for both icemakers and steamers, but they do not directly consider water.

Some efficiency measures for commercial kitchens are:

- Water-Cooled Once-Through Icemakers
 - Replacement – Replace with air-cooled *Energy Star* labeled icemakers
 - Retrofit – Retrofit into recirculating water-cooled or air-cooled system
- Boiler-Based Steamers
 - Replacement – Replace with boilerless (connectionless) or CEE Tier 1b steamer*
- Cafeteria trays
 - Elimination – Eliminate cafeteria trays altogether
- Pre-Rinse Spray Valves (PRSVs)
 - Replacement – Replace older PRSVs with 1.25 gpm PRSVs
 - Behavioral – Scrape dishes rather than pre-rinsing whenever possible
- Commercial Dishwasher
 - Replacement – Replace with *Energy Star* labeled dishwasher
 - Behavioral – Wash only full loads of dishes
- Garbage Disposer/Scrapping Trough
 - Elimination – Eliminate garbage disposers/scrapping troughs
 - Replacement – Use garbage strainers in the place of disposers

Commercial kitchens are one type of CII facility for which water efficiency measures are unlikely to vary by facility. These measures usually involve the straightforward retrofit, replacement, or, occasionally, elimination of an appliance or fixture. Most, though not all, of these potential savings exist in the dishwashing arena. Water efficiency measures not related to dishwashing involve the retrofit or replacement of outdated icemakers and steamers.

Commercial icemakers generally come in two types – water-cooled and air-cooled. Water-cooled icemakers run water through the machine, generally without recirculation, to remove the rejected heat. Replacement of once-through water-cooled icemakers with air-cooled *Energy Star* icemakers will generate water savings. While air-cooled units generally use marginally more energy than water-cooled units, the difference is not enough to offset the

* CEE Tier 1b steamers have all the same energy efficiency requirements as *Energy Star* steamers but use only 4 gallons of water per hour or less; (111 of the 136 *Energy Star* steamers report water usage; of those 111, 91 report using 1.5 gph or less and only 12 have water usage figures greater than 4 gph.)

higher initial cost and water-use of once-through units (USEPA 2008). Additionally, recent research suggests that air-cooled icemakers actually are more energy efficient when embedded energy is taken into consideration (in addition to direct energy) (Koeller and Company 2008). When replacement is not an option or is expensive, it is sometimes possible to retrofit a water-cooled icemaker into an air-cooled or recirculating water-cooled machine.

Traditional boiler-based steamers cook food by running a constant stream of steam and regularly draining the resultant water out, a process that takes relatively large amounts of both water and energy. Replacing traditional boiler-based steamers with boilerless steamers or steamers that qualify for CEE Tier 1b can result in significant water savings. These steamers use an average of 2 gallons per hour (gph), 22 to 32 gph below the average usage of boiler-based steamers.

Dishwashing is one of the most water-intensive activities in commercial kitchens. One way to save water on dishwashing is to reduce the number of dishes to be washed. In cafeteria settings, some colleges have reported success with reducing water usage by eliminating cafeteria trays (with concurrent food waste reductions).*

Training workers to scrape soiled dishes instead of pre-rinsing them before putting them in the dishwasher will help commercial kitchens conserve water. When dishes must be pre-rinsed, water savings can be realized through the replacement of older pre-rinse spray valves with newer low-flow ones that use no more than 1.25 gpm at 60 psi. FEMP guidelines restrict the usage of PRSVs with a flow greater than this 1.25 gpm flow and *WaterSense* is in the process of developing specifications for these valves. New PRSVs cost around \$50, making replacement cost-effective over the short-term. Likewise, replacing older dishwashers with new, *Energy Star* models – a water conservation method for commercial kitchens – is often cost-effective. This is due to the combination of water and energy savings that can be achieved from such a replacement. Using dishwashers only with full loads can save additional water.

Finally, water can be saved in the process of disposing of leftover food. Simply eliminating scraping troughs, which use water to move waste to food waste disposers, will result in water savings. Replacing food waste disposers with food waste strainers or eliminating them altogether can result in water savings as well. Other more water efficient methods of food disposal are readily available. As in the residential sector, there are pros and cons to eliminating

* See for example Foderaro, 2009 and Newhouse, 2008.

food waste disposers; however, when possible, composting is always considered an environmentally preferable option.

7.2.3.3 Medical/laboratory facilities

Some efficiency measures for medical/laboratory facilities are:

- Autoclaves/steam sterilizers.
 - Replacement – Replace models that keep water flowing constantly with ones that shut water off when in standby mode.
 - Retrofit – Retrofit once-through models into recirculating ones.
 - Behavioral – Use the smallest model available for the load being sterilized and operate only with full loads.
- X-ray film processing.
 - Retrofit – Retrofit film processing machines to flow at reduced rates.

Medical facilities contain a couple items for which simple retrofit or replacement is the most important type of conservation measure: the process of sterilization and of x-ray film development. Film processing of all types requires water for chemical reactions, washing, and rinsing to develop film. Often, water savings can be achieved by retrofitting these units to flow at 2 gpm or less. This can sometimes be achieved through adjusting an inlet valve already installed on the unit, installing a new flow meter and adjustable valve, and/or installing pressure reducing devices on water lines.

Steam sterilizers and autoclaves are used for sterilization in medical and laboratory settings. While only steam sterilizers use water as the medium for sterilization, both machines use water for other parts of the sterilization process. Replacing or retrofitting older sterilizers and autoclaves so that the models do not keep water flowing when in standby mode and recirculate rather than dispose of cooling water will help facilities conserve water. Additionally, using the smallest possible model for the instruments being sterilized and sanitizing only full loads can save even more water.

7.2.3.4 Industrial Processes

Some efficiency measures for industrial processes are:

- Optimize the process to use the minimum amount of water necessary.
- Reuse water within the same process.
- Recycle used water for another process that does not require pristine water.

With the exception of some high-water use facilities described below, most of the remaining commercial/industrial/institutional sector water uses are unique to the specific industrial processes through which they occur. While this section will not attempt a full description of the many water efficiency measures that have been developed for very specific industrial processes, it gives some general direction for water conservation in industrial processes.

Industrial processes should be thoroughly investigated during the water audit to ensure that the minimum amount of water is being used at each stage of the process, that the lowest effective flows are being used when water is necessary, and that water is not being used for any process for which there is a ready and cost-effective substitute. Furthermore, water should be reused within a single process whenever possible. For instance, water is often used for transport in industrial processes; often a closed loop system through which transport water cycles again and again can result in water savings without any detriment to the industrial process. Finally water can be recycled from one part of an industrial process to another. Different process stages will have different requirements regarding the quality of the water used; water can be used for parts of the process that have the most stringent requirements first and then cycled through processes with less stringent requirements. This method of water conservation, whereby water is used repeatedly in a succession of stages, each having less stringent water quality requirements than the last, is known as cascade reuse (Scholze et al. 2009).

7.2.4 Landscaping

Water Efficiency Measures for landscaping center mostly on the plants selected for a landscape area and the irrigation of those plants. One water efficiency measure with huge potential for generating water savings is to irrigate landscape plants with non-potable water – either graywater or harvested rain/stormwater. Irrigating with non-potable water is discussed further below. Both the management practices discussed in this section and those discussed in relation to non-potable water usage can help installations make significant strides in cutting outdoor usage, which accounts for as much as 50 percent of water use in some places, and achieving the water conservation goal of E.O. 13423.

7.2.4.1 Plant selection

Some efficiency measures for plant selection are:

- Use turfgrass as sparingly as possible.
- Xeriscape or engage in “water-wise” planting whenever possible.

Plant selection for a water-efficient landscape sometimes calls for a departure from traditional turfgrass. Although it is widely used, turfgrass takes a relatively large amount of water to grow and maintain and can therefore require levels of irrigation that are simply not practical in some drier areas. For places that expend large amounts of water on irrigation, limiting the amount of turfgrass on site can yield significant water savings.* While there are some landscaped areas for which turf grass is truly central to the purpose of the space – golf courses, parade grounds, etc. – turfgrass used purely for decoration is likely an inefficient use of scarce water resources. For places that do need significant irrigation, water can be conserved by surveying all turfgrass areas and replacing those that do not serve a practical purpose with other types of plantings.

Non-turf areas are most water efficient when planted with species that thrive in the climate conditions that naturally occur on site. There are a number of different terms for this planting strategy, but two commonly used are Xeriscaping and “water-wise” planting. Xeriscaped or water-wise landscapes combine site-specific design with water efficient maintenance practices to create landscapes that need little to no irrigation. The key to this strategy is selecting plants that will thrive in the conditions they experience on site, both on a macro (rainfall, temperature, etc.) and micro (shade, grading, etc.) level. Plants should be grouped together in zones according to the amount of water they will require. Additionally, soil quality should be improved as needed and mulch should be used to maximize the soil’s ability to retain water.

7.2.4.2 Irrigation

Requirements for irrigation are:

- *WaterSense*: irrigation contractors should be WaterSense certified and weather- and sensor-based irrigation controllers should be *WaterSense* labeled (the latter is in development).

Some efficiency measures for irrigation are:

- Manage irrigation systems to use water as efficiently as possible:
 - Water only in the early morning or at night.
 - Water different irrigation zones on different days.
 - Irrigate with the minimum amount of water necessary.
 - Reduce irrigation during droughts.
 - Incorporate “cycling” into the irrigation schedule.

* In wetter areas that do not depend on irrigation for turfgrass maintenance, there is no (water conservation) reason to reduce turfgrass cover.

- Tailor irrigation to daily and seasonal water needs.
- Match irrigation system components to the irrigation needs on-site.
- Choose irrigation technologies that use water as efficiently as possible:
 - Use drip or micro-spray irrigation for non-turf areas.
 - Consider choosing irrigation systems that use current and historical weather information for the local area to determine watering.
- Use non-misting sprinkler heads with adjustable trajectories:
 - Use *WaterSense*-labeled irrigation technologies/services whenever possible.
 - Use *WaterSense*-certified landscape irrigation services.
 - Once specifications have been fully developed, use *Water-Sense* labeled weather- or sensor-based irrigation controls.

Unlike installing the proper plumbing fixture in a home or even installing the proper water-wise plant in a landscape, water-efficient irrigation requires active management throughout the lifetime of the landscape. Incorporating the following management practices into a system of irrigation will help achieve water-efficient irrigation:

- *Water only in the early morning or at night.* This reduces water lost to evaporation.
- *Water different irrigation zones on different days.* Dividing a landscape area into zones and watering different zones on different days reduces peak water usage. While this tactic will not change the amount of water used, it will reduce the maximum amount of water needed on any given day.
- *Irrigate with only the minimum amount of water necessary.* While watering with the minimum amount of water necessary may seem obvious, determining that minimum is not. In theory, irrigated water should replenish the amount of water lost through evapotranspiration, and not made up by rainfall, by that particular plant (State of California 2008).^{*} When performing the full calculation for water needs for different zones on a particular site is not feasible, basing the amount of water used for irrigation on local evapotranspiration rates (normally available from a water station), can yield marked reductions in irrigation water usage (Mayer, et al., 2009).[†]

^{*} For more information on calculating landscape water needs, see the California Irrigation Management System website (<http://www.cimis.water.ca.gov/cimis/welcome.jsp>) and University of California Cooperative Extension, (2000).

[†] Studies have actually found no discernable difference between water at eighty percent of evapotranspiration and one hundred percent of evapotranspiration (Gibeault, 1985). The former has therefore become best practice for water conservation.

- *Reduce irrigation during droughts.* When water supplies are at drought levels, reducing water use for irrigation to conserve water for more critical purposes can be important. Irrigation can be reduced to levels that keep plants alive while not allowing them to enter growth stages until water supply is more stable (Scholze, no date). Some regions of the United States mandate these sorts of practices during droughts.
- *Incorporate “cycling” into the irrigation schedule.* In irrigation, “cycling” means irrigating a zone for a period of time less than the full time needed for irrigation, stopping, and then starting again in a short while (and possibly repeating this process). This tactic facilitates effective infiltration by giving soil time to absorb water before adding more; it is intended for soils in which water infiltrates more slowly than sprinklers irrigate.
- *Tailor irrigation to daily and seasonal water needs.* Water needs change on a seasonal basis (plants need more water in July than in September) and also on a daily basis (plants need more water on dry days than on rainy days). Altering a water schedule to fit these changing needs achieves higher levels of water efficiency.
- *Match irrigation system components to the irrigation needs on-site.* Make sure that hoses and sprinkler heads are the right sizes and in the right places for the plants they are supposed to water.

In addition to management practices, the technology used in a particular irrigation system can also have a strong impact on the efficiency of outdoor water-use. For non-turf areas, drip and micro-spray irrigation systems are usually far more water-efficient than traditional surface spray irrigation. Drip irrigation systems use tubing, often buried, to deliver water directly to plant roots at very low pressures. Micro-spray systems are a cross between drip irrigation and traditional surface spray irrigation. Water is delivered through tubing to miniature spray heads that irrigate at low pressures. Micro-spray systems can water more area than can drip irrigation systems, but are more subject to water loss through evaporation. Both systems will generate water savings in the long term when replacing a traditional surface spray system.

For turf areas, choosing the proper sprinkler head and using it correctly is an important part of maximizing water efficiency. Misting sprinkler heads should be avoided as they are subject to heavy water losses due to evaporation. Furthermore, the trajectories of sprinkler heads should be adjustable. Adjusting sprinkler head trajectories to match the landscaped area needing water can ensure maximum water efficiency from surface-spray irrigation systems.

Finally, both turf and non-turf irrigation systems can conserve water by using technologies that irrigate based on local weather conditions. One simple example of this technology is a rain sensor that shuts off an irrigation system when it detects a certain amount of rain. On the more complicated end of the spectrum, some irrigation systems allow for all watering to be controlled by local weather. This can be done through on-site sensing of weather conditions, remote communication with a local weather station, or a combination of the two. These weather- or sensor-based irrigation controllers, known as “smart” controllers, are generally more effective at tailoring water to site needs than other automatic irrigation systems.

The *WaterSense* program is currently developing specifications for weather- and sensor-based smart controllers. Once developed, *WaterSense* smart controllers should be sourced when switching to this technology. The *WaterSense* program also certifies a variety of irrigation professionals. These irrigation professionals can be relied on to prioritize water efficiency in their work and should be used when contracting out irrigation work.

7.2.4.3 Other outdoor water uses

Some efficiency measures for other outdoor water uses are:

- Avoid water features if at all possible. When necessary use ones that recirculate water and shut them off when not in use.
- Avoid water brooms if at all possible. When necessary use the lowest flows possible.
- Add nozzles to hoses.

Outside of plants and irrigation, water is sometimes used outdoors as a decoration (a water feature) or for cleaning. Water features lose water to evaporation, maintenance, and leakage. Thus, decorating with features that do not use water is more effective from a water-efficiency standpoint. If water features must be used, ensuring that they recirculate water (instead of releasing it to the environment or a drain after one use) and shutting them off when they are not needed will generate water savings. Similarly, eliminating the use of water brooms whenever possible will generate water savings. While convenient, the work done by these instruments can often be done just as effectively with other equipment that require less water. In cases where water is needed for outdoor cleaning (or other uses), water brooms or other nozzles set to the lowest flow possible use less water than uncovered hoses.

7.2.5 High water use facilities

Facilities that are especially high water-users are also potentially especially high water-savers. Small inefficiencies in areas where water use is high often yield high levels of water waste simply due to the frequency of water-use. Therefore, high water-use facilities merit close scrutiny to ensure water is being used as efficiently as possible and to assure compliance with E.O. 13423.

7.2.5.1 *Swimming pools*

Some efficiency measures for swimming pools are:

- Refill pools as infrequently as possible given health and safety requirements.
- Optimize the backwashing schedule so that backwashing occurs as infrequently as possible without compromising health or equipment.
- Use an insulated cover whenever pool is not in use.
- Lower pool temperature when not in use.
- Keep water level at one inch below the top of the pool.

Swimming pools lose water due to pool cleaning, evaporation, and splash out. Choosing a cleaning schedule that minimizes water use while maintaining chemical levels safe enough for swimming is a key step in attaining efficient pool water use. Thus, filter backwashing and pool refilling should be minimized as much as possible without putting health or safety at risk. Water from backwashing can also be reused in some cases (see graywater section below). Evaporation can be combated by covering the pool with an insulated cover when not in use (which also saves energy by combating heat loss). Lowering the temperature in swimming pools, especially when not in use, can also make dents in water loss due to evaporation. Finally, lowering the water level to one inch below the top of the pool can help pools avoid water loss due to splash out.

7.2.5.2 *Golf courses*

Some efficiency measures for golf courses are:

- Design the course to include the minimum amount of irrigated land possible.
- Naturalize the maximum amount of area possible.
- Choose turf that is best suited to local soil, climate, and pests.
- Follow the irrigation management practices outlined above.
- Where appropriate, design ponds for stormwater retention and reuse during peak (and possibly other) irrigation instances.

The primary use of water on golf courses is for turf irrigation. Irrigation needs for golf courses vary greatly with the design of the course, irrigation, and (when appropriate) stormwater retention and drainage. The layout of the golf course itself can be designed specifically to minimize irrigation water use. Layouts that include narrower fairways and use native plants that need little to no water in roughs can greatly help reduce the amount of necessary irrigation on a given course. In fact, limiting turf grass as much as possible by naturalizing or other means is a very simple way to reduce water usage on a course. Furthermore, ensuring that where turf is used, it is the best match for the particular soil and climate (and pests) of a given course site will yield even more efficient water use (Delaware River Basin Commission, 2002).

Choosing the proper irrigation system and managing it correctly is an important part of efficient water usage for golf courses. The landscape irrigation principles outlined above apply as easily to golf courses as to more general landscape and should be assiduously applied. Additionally, golf courses can often conserve even more water by using non-potable water for irrigation. In places that experience significant amounts of rain, stormwater management systems can be designed to funnel water into on-course ponds; this water can then be used during times of peak irrigation (or more regularly if water is available) to reduce pressure on the water supply (Connecticut Department of Environmental Protection, 2006).

7.2.5.3 *Commercial laundry*

Some efficiency measures for commercial laundries are:

- Follow the clothes washer water efficiency measures detailed above for domestic or coin-operated washers.
- Install a water reclamation system for conventional washer-extractors.
- Install a tunnel (continuous batch) washer.
- Install an ozone laundry system.

Commercial laundries that operate machines roughly on the same scale as residential machines can optimize water efficiency by following the technical and behavioral efficiency measures detailed above. Laundries that wash significantly larger amounts of fabric in bigger machines have the potential to conserve water in different ways. Traditional washer-extractors (which operate similarly to residential clothes washers and are the norm in commercial laundry facilities) can conserve water by installing a water reclamation system that recycles wash and rinse water for additional uses. Some newer washer-extractors come with water reclamation systems.

Another potential water efficiency measure for commercial laundries is to install a tunnel (or continuous batch) washer. These washers cycle soiled clothes in one direction through a series of washing chambers while water is cycled through in the other direction. Through this water reuse, tunnel washers are able to achieve considerable water savings. These washers are limited by their relatively high initial cost and inability to use more than one wash formula per batch. Nonetheless, these washers can be both cost-effective and water efficient for facilities that wash high amounts of similar fabrics (such as linens) (Water Energy Laundry Consulting, 2009).

Finally, ozone laundry systems can generate considerable water (and energy) savings when replacing more conventional laundry systems. Ozone laundry systems work through the oxidation of ozone to both clean and soften clothes in smaller amounts of cooler water and with lower amounts of chemicals than do traditional laundry systems. These systems differ significantly from traditional washers (for instance, because of its instability, ozone must be made on site). However, given the right situation and the proper information and care, ozone laundry systems are cost-effective over relatively short time periods (Riesenberger, 2005).

7.2.5.4 *Car/vehicle wash*

Some efficiency measures for car/vehicle wash facilities are:

- Reclaim and reuse as much wash and rinse water as possible.
- Optimize the number, position, and flow rate of all spray nozzles.
- Consider dry-washing vehicles.

The car wash industry has invested both time and money into developing water efficiency measures for individual car washes. As a result automatic car washes are often more water-efficient than hand washing. A number of systems have been developed to reclaim and filter water from all types of automatic car and vehicle washes for reuse. In fact, some vehicle washes can even reuse graywater from other uses for washing. These water reclamation systems can help vehicle washes to achieve relatively high levels of water savings. Additionally, optimizing the system of spray nozzles that apply water during vehicle washes by adjusting their number, position, and flow facilitates further water efficiency for car and vehicle washing. Finally, the potential of using a dry-vehicle washing product should be investigated, especially in water-scarce areas.

7.2.6 Alternate water sources

Thus far, most water efficiency measures discussed have focused on using less water to meet human and landscape needs. However, another strategy for achieving efficient water use and E.O. 13423 compliance is to tap into alternate water sources, especially for uses that do not require potable water. There are many water-uses that do not require drinking-quality water. Landscape irrigation, for instance, is a very popular choice for non-potable water application as water quality for landscape irrigation can be lower than for many other uses. While these uses are typically consumptive and should be done only at maximum efficiency, using water from alternate sources for the minimum amounts of water still needed reduces pressure on water supply and wastewater systems and frees up potable water for other uses. These sources include graywater, treated wastewater, and rainwater.

While irrigation and toilet-flushing are two of the most common re-uses of water, a variety of other possibilities exist for the use of alternate sources. These sources have the potential to be used for groundwater/aquifer recharge, heating/cooling (cooling towers, water-cooled equipment, and boilers), vehicle washing, and some industrial processes. Careful attention must be paid to the water quality necessitated for processes using alternate water sources; and, in some cases, some amount of treatment may need to be applied before use to protect human health, equipment, or both. As with the reuse of water in industrial facilities, cascade reuse should be employed so that the water users with the most stringent water quality needs use water first and those with the least stringent water quality needs use water last (Scholze, et al., 2009). Local regulations often limit the types of water re-use allowed and should be checked before any serious investigation into alternate sources. Other regulations on the usage of alternate sources include EPA regulations on drinking water and backflow prevention and IAPMO's codes regarding non-potable water reuse systems (Hoffman, 2008).*

Water-efficiency measures for non-potable water sources are:

- Install a graywater system to capture and possibly treat washwater for reuse.
- Reuse treated wastewater effluent for irrigation or other appropriate uses.
- Gather rainwater, stormwater, and air-conditioning condensate for use.

* The International Association of Plumbing and Mechanical Officials. Chapter sixteen of IAPMO uniform plumbing code is devoted to non-potable water reuse systems.

7.2.6.1 Graywater

The general definition for graywater is used washwater – the byproduct of most indoor water uses including showers, clothes washers, and most sinks, but excluding toilets, and sometimes kitchen sinks and dishwashers (which produce wastewater containing food particles). Graywater needs some amount of treatment before reuse except when being used for subsurface irrigation; even then, however, it needs to be used relatively quickly (if not treated) otherwise it will become septic (Hoffman, 2008).

Systems for graywater reuse generally have to be tailored to the facility from which the water will be collected. For new construction, washwater can simply be collected separately from other water, whereas in existing construction, graywater is typically run through the same pipes and sewerage as other waste water, so a separate collection system would generally have to be retrofitted to the facility.* Nonetheless a variety of graywater systems, with and without water treatment, are available for both new and existing buildings. The amount of graywater generated in a building will decrease as other water usage becomes more efficient. Even so, a significant portion of waste water on site is typically gray water (Madungwe and Sakuringwa, 2007). Thus, especially for larger sites (such as Army installations), graywater has the potential to play an important role in water use efficiency.

7.2.6.2 Treated wastewater

The effluent from water treatment plants is another type of non-potable water that has some use left in it. The effluent released by sewage treatment plants into the environment is normally treated to a relatively high quality – local state and Federal environmental regulations ensure this.† Such water can then be put to a variety of non-potable uses (directly or sometimes with additional treatment), though many U.S. communities limit the use of treated effluent to landscape irrigation (EPA, 2004). Some communities facilitate the use of treated wastewater by installing purple pipes to redistribute effluent for landscape or other uses. Both graywater and treated wastewater have the advantage of not drying up during droughts, although as water fixtures themselves become more efficient, the amount of wastewater available for reuse, like graywater, will diminish.‡

* In accordance with local regulations and code requirements.

† El Paso boasts that its treated wastewater meets drinking water standards.

‡ Cooling tower blowdown is another potential source of reusable water. Though not necessarily considered gray water, blowdown can sometimes be reclaimed for use without the full menu of treatments provided by a wastewater treatment plant (Hoffman, 2008).

7.2.6.3 Atmospheric water

Naturally occurring water in the form of rainwater, stormwater, and condensate from water vapor are all also available for non-potable use. Rainwater is typically collected from roof runoff into gutters and stored in rain barrels, cisterns, or tanks. A number of rainwater collection systems are commercially available, and there is plenty of information on how to design a rainwater harvesting system for a facility.*

While relatively clean on falling, rainwater can pick up roof debris and organic material en route that should be filtered before entering storage. Bacteria levels in untreated rainwater should be tested routinely, and if too high, the water should be tested before being put to (even non-potable) use. If organic material and bacteria do enter the storage area, rainwater has the potential to become unusable (although on a slower time scale than does graywater). Additional treatment of rainwater, using ultraviolet (UV) radiation or ozone for example, can actually achieve levels of water quality high enough to be potable (TCEQ 2007).

Stormwater is differentiated from rainwater because it is collected out of storm drains or other areas set aside to collect stormwater as opposed to directly from the roofs on which the water falls. This results in important differences with regard to the amount and types of pollutants and debris stormwater is likely to pick up. Stormwater tends to gather more debris and is exposed to different and more pollutants than is rainwater (such as oil from roadways, pesticides, trash, etc) (Hoffman, 2008). Due to these potential pollutants, stormwater is more likely to need treatment before use than is rainwater. Stormwater can be relatively easy to collect, treat, and distribute in places with separate sewer systems; however, in places with combined sewer systems, the potential of wastewater contamination makes this process more difficult.

Condensate from water vapor is regularly collected in air-conditioning and refrigeration units that operate in warm, moist places. This water has the advantage of being reliably available in humid places over the hottest months when landscape irrigation and/or cooling tower make-up water is most needed and generally clean enough to be put to either of these uses without treatment. In larger commercial and industrial buildings, the amount of condensate produced can be in the thousands of gallons. Retrofits for the collection of condensate water are normally relatively simple as most air-

* For more information, see *Texas Manual on Rainwater Harvesting*, available at http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf.

conditioning systems collect and/or discharge condensate at a single location. While condensate reuse and recovery systems do not generate a great deal of water in dry locations, such systems can save considerable amounts of potable water in humid areas (Hoffman, 2008 and Wilson, 2008).

8 Conclusions

8.1 Summary

This study evaluated issues of water availability as they affect the U.S. Army. The national watershed screening used a set of 24 sustainability indicators to screen HUC8 watersheds for vulnerability to water supply, water demand, and watershed health. The results are a series of color-coded maps depicting at-risk watersheds and an ordered list of Army installations located in those watersheds. The regional water budgets created a “checkbook” of water supply and demand in regions containing installations. This study developed the water budget method and applied it to the Fort Bragg and Fort Bliss water regions. One component of the method is the Installation Water Demand Model. This tool calculates water required by the installation based on effective population, building stock, and projected changes of both over time. Regional supply and regional and installation demand is projected out to 2040.

Water availability is an increasing domestic and international problem; it may even be more important than energy since it is one of only two Earth resources that are absolutely essential to human existence—fresh water and soil (Youngquist 1997). From this reality comes the imperative to use water resources effectively and efficiently and to consider water issues in long-term sustainability planning.

Army installations are vulnerable to the same issues of water supply and demand that jeopardize the national and indeed the global water supply. Providing the required amount of clean fresh water in the location where it is needed is increasingly difficult. The complexity of water compacts, treaties, and agreements is another challenge for Army installations. In the coming years the impacts of water scarcity will be more severe and this will be reflected in increasing costs. Increased privatization of water systems, motivated in part by the profit motive, will be another stimulus for increases in water cost.

The conditions that exacerbate water availability are the aging condition of water infrastructure, generalized population growth especially in regions containing key Army installations, increased demand for power generation plants, and uncertain but generally agreed upon regional impacts of global climate change.

Another complicating factor is that water is a resource that recognizes no boundaries—installation, municipal, county, region, state, and national—

other than its own, that of watershed or sub-surface aquifer. Man intervenes in the natural hydraulic systems through inter-basin transfers, the movement of “virtual water” from one water region to another in products, and the increase in water bottling plants. Planning for water sustainability is a regional issue requiring cooperation among a host of players whose decisions affect long-term scarcity.

At Fort Bragg, regional water scarcity will not be an issue through 2040. In the past, reliance on the Little River has proved unsustainable in times of local drought. New water supply contracts with Fayetteville Public Works Commission and Harnett County Department of Public Utilities should provide the required water without interruption. It is important for Fort Bragg to maintain their water conservation ethic to best prepare for the extreme drought-flood cycles anticipated due to the effects of global climate change. Adopting a program of total water management will decrease the amount of fresh water required, increase water system security, and provide beneficial synergies between fresh, storm, and sanitary water systems.

The climate change scenarios for the Fort Bliss region are not as positive. Already subject to an arid regime, the Bliss region is anticipated to receive even less precipitation under global climate change. While scientific estimates of aquifer longevity differ, the aquifers are declining and represent a limited non-renewable supply of water. Existing El Paso Water Utility (EPWU) wells in the Hueco Bolson (Fort Bliss’ source for self-supplied water) have been capped due to salinity and, the effect of pumping from new wells is unknown due to the complex subterranean structure of the aquifer. Fort Bliss’ back-up water sources (through EPWU) are the Mesilla Bolson, which is also declining, and the Rio Grande River, which presently ends in a dry stream bed in Mexico. Fort Bliss is encouraged to establish an aggressive water conservation program to reduce the demand on existing wells and the back-up supply. A program of total water management could include a “purple pipeline” on post, as EPWU has done in El Paso proper, to utilize processed sewage for select installation water uses.

8.2 Issues Affecting Water Availability on Army Installations

Staffing water conservation positions is a key requirement for having an effective water conservation program. Installation staffing is often based on a benefit/cost relationship or regulatory requirements. Also, the pricing of water currently does not reflect its importance and/or potential scarcity, nor the anticipated changes in the supply/demand relationship due to the factors described in this report. Therefore, dedicated water staff may be perceived as a

nice-to-have rather than a critical need to attain water sustainability. This lack of dedicated staff affects the ability to effectively plan for the water future, since it requires centralized collection of data, as well as information related to water usage, infrastructure assessment, planned facilities upgrades and new construction, regional factors that affect water, and the array of BMPs available to work toward sustainable use.

Understanding current usage patterns is a key to developing a water management program. Army installations do not currently have individual building meters for water supply, but rather one meter at the gate and perhaps a few individual meters that are used to monitor reimbursable utility customers (e.g., Non-Appropriated Fund (NAF) activities or Army Family Housing (AFH)). Lack of metering makes it difficult to establish accountability for water use. It is also difficult to isolate a leak or break in water piping. System condition is an unknown factor, though it is thought that infrastructure on-post is in the same condition as that off-post, especially if the age of the pipes is the same. The out-sourcing of installation utility operations and maintenance can also be a factor affecting system condition.

Simply meeting the requirements of E.O. 13423 will not prepare Army installations for regional water scarcity, nor will compliance with Leadership in Energy and Environmental Design (LEED), which is required only for MILCON new construction. Safeguarding water availability can best be accomplished by taking a systems approach to water management by instituting a program of total water management (TWM). TWM should include a hierarchy of water use and decentralized treatment coupled to multiple distribution systems, as well as a cascade of reuse. TWM saves water and chemicals, is more responsive to customers, and is resilient to natural disasters. Embracing TWM will require taking a holistic view of the array of laws, regulations, design guidelines, and SOPs that affect drinking, storm, and sanitary water systems on installations. While instituting TWM will be easiest when constructing new facilities from the ground up, working toward sustainable water use requires applying TWM principles to the over 900 MSF of existing facilities.

Conditions are ripe in the United States for a rethinking of traditional water rights. "Who owns the water" is a question that is voiced more and more by states, cities, tribes, and individuals. The answer is critical for residents in California and the southeast United States, the latest domestic victims of water scarcity. Laws, customs, and traditions ("using 20th century rules to solve 21st century water problems, " according to Peter Gleick*) form the agree-

* In www.circleofblue.org/waternews/2009/world/peter-gleick-whose-water-is-it-water-rights-in-the-age-of-scarcity/#more-5004

ments that are the basis for water allocation law, however, the notion of water being part of the commons is being given increased consideration. The Army will need to be an active participant in development of new water use doctrines.

8.3 Recommendations

Water availability is a critical issue for sustaining military readiness. The impacts of water scarcity are regional in nature and mitigation efforts should be focused on installations where sustainability issues are projected to be most vulnerable. The following recommendations are made to increase water efficiency and to prepare Army installations for an era of water scarcity.

8.3.1 Emphasize Water Manager Staffing and Centralize Data Collection

An increased emphasis should be placed on maintaining a dedicated individual to manage the water conservation program on installations. This position should be given the emphasis that the Installation Environmental Manager position was given during the height of Superfund projects and that energy managers received during the 1990s after signing of the first Energy Policy Act. Wherever possible, continuity should be maintained through either personnel or a centralized system of managing information that supports an installation's water conservation program.

8.3.2 Include Water Efficiency Measures in all Projects

Water efficiency measures should be included in all O&M, minor construction, and MILCON projects. Rather than planning for dedicated "water conservation projects," every project should consider the possibility of including conservation measures as well as the project's impact on installation water use. Activities such as the recent energy Tiger Team at Fort Bliss, that examined MILCON construction projects for energy efficiency, should also include water efficiency measures. Other actions that should be taken include stocking only WaterSense products in the supply system.

8.3.3 Adopt a Program of Total Water Management (TWM)

The Army should adopt a program of TWM on installations. The drinking water, storm water, and sanitary programs are currently managed separately. Taking a systems approach to these will optimize efficiencies and costs. Elements of TWM are more easily incorporated in new construction but should be considered for renovation projects and even in instances where no projects are planned.

8.3.4 Continue to Emphasize Metering/Infrastructure Upgrades

The Army should continue to seek alternate means of funding installation of building-level water meters prior to the EISA deadline of 30 September 2016 (for example OMA, ARRA, etc.). Where meters are already installed or scheduled for installation prior to 2016, installations should be encouraged to monitor water usage both to establish baselines for estimating future water demand and for identifying any system leaks.

8.3.5 Conduct a Comprehensive Review of Installation Water Rates/Contracts

The Army should examine current installation water rate structures and trends. Knowing the true cost of water will raise the visibility of water conservation and help to prioritize execution of water efficiency projects. Army facilities within the United States currently enjoy relatively low water rates however, this is likely to change. The use of block rate structures and decoupling rates, along with supply exceeding demand, are conditions that point to increasing costs for water. USACE developed a prototype Army Commercial Utilities Program Oversight/Management (ACUPOM) Web application designed to help administer utilities contracts, manage utility rate cases, and oversee the Commercial Utilities Program. The Army should expedite fielding of this system to provide full information about water rates and contracts.

8.3.6 Engage the Local Community in Planning for Sustainable Water

The Army should be an active participant in regional negotiations over water rights. Water rights exist on the state level and need to be debated on that level. The State Military Affairs Committees are an important voice in state government. This is the avenue that Army installations should take when addressing issues of present or future water rights. Though Army installations retain rights to any required water through the Federal reserved water rights doctrine, it is important to engage regional partners when issues regarding best use of this critical resource are raised.

Judge Paul Magnuson perhaps stated this best in his finding regarding the city of Atlanta's use of the water of the Apalachicola-Chattahoochee-Flint (ACF) system:

Too often, state, local, and even national government actors do not consider the long-term consequences of their decisions. Local governments allow unchecked growth because it increases tax revenue, but these same governments do not sufficiently plan for the resources such unchecked growth will

*require. Nor do individual citizens consider frequently enough their consumption of our scarce resources, absent a crisis situation such as that experienced in the ACF basin in the last few years. The problems faced in the ACF basin will continue to be repeated throughout this country, as the population grows and more undeveloped land is developed. Only by cooperating, planning, and conserving can we avoid the situations that gave rise to this litigation.**

* United States District Court Middle District of Florida, Case No. 3:07-md-01 (PAM/JRK), In re Tri-State Water Rights Litigation, Memorandum and Order, Filed 07/17/2009

References

- Aamodt Litigation Settlement Act. 2009. S. 1105.
- Albuquerque Bernalillo County Water Utility Authority. 2009. San Juan-Chama drinking water project. Accessed 08 July 2009, <http://www.abcwua.org/content/view/31/24/>
- Alley, William M. 2006. Tracking U.S. ground water: reserves for the future. *Environment*. 48(3):10-25.
- Alliance for Water Efficiency. 2009. *Alliance for Water Efficiency*. Accessed 22 July 2009, <http://www.allianceforwaterefficiency.org/>
- American Water Works Association. 2006. *Water Conservation Programs: A Planning Manual*. AWWA Manual (1st ed.). Denver CO: American Water Works Association.
- Arizona v. California. 1963. 373 U.S. 546.
- Assistant Secretary of the Army for Installations & Environment (ASAIE). 2004. *The Army Strategy for the Environment*. Washington DC: Office of the Assistant Secretary of the Army for Installations and Environment. Vol. 12.
- Balocki, Col James. Army Growth and BRAC Update. Society of American Military Engineers Conference. May 22, 2008.
- Barreno, Dr. Rene Franco. 2005. Binational Challenges and Opportunities for the Municipal Board of Water and Wastewater of the City of Juarez, Chihuahua. Presented at the Legislative Border Conference: 12th Legislative Forum.
- Boulder Canyon Project Act of 1928. 1928. Public-No. 642-70th Congress, H.R. 5773.
- Bredehoeft, John, Jon Ford, Bob Harden, Robert Mace, and James Rumbaugh III. 2004. *Review and Interpretation of the Hueco Bolson Groundwater Model*. Prepared for El Paso Water Utilities.
- Cai, Ximing, Dingbao Wang, Tingju Zhu, and Claudia Ringler. 2009. Assessing the regional variability of GCM simulations. *Geophysical Research Letters* 36(L02706), <http://www.agu.org/journals/gl/gl0902/2008GL036443/>
- Cappaert v. United States. 1976. 426 U.S. 128.
- Chandler, David. 2008. *Water Supplies Could Be Strongly Affected by Climate Change: Changes in Rainfall Can Be Amplified, up or down, in Changes to Aquifers*. Massachusetts Institute of Technology (MIT) News Office, <http://web.mit.edu/newsoffice/2008/print/agu-groundwater-1218-print.html>
- Clean Water Act. 1972. Public-No. 92-500, 33 U.S.C. 1251-1376.
- Clemons, Josh. 2004. Interstate water disputes: A road map for states. *Southeastern Environmental Law Journal*, 12(2), Spring 2004.

- Cloquell-Ballester, Vicente-Agustin, Victor-Andres Cloquell-Ballester, Rafael Monterde-Diaz, and Maria-Cristina Santamarina-Siurana. (2006) "Indicators validation for the improvement of environmental and social impact quantitative assessment." *Environmental Impact Assessment Review*. 26(2006)79-105.
- Coastal Zone Management Act. 1972. Public-No. 92-583, 16 U.S.C. 1451-1456.
- Combs, Susan. 2009. *Liquid Assets: the State of Texas' Water Resources*. Texas Water Development Board. Texas Comptroller of Public Accounts.
- Connecticut Department of Environmental Protection. (2006, July). Best Management Practices for Golf Course Water Use. CT DEP. Retrieved July 22, 2009, from http://www.ct.gov/dep/lib/dep/water_inland/diversions/golfcoursewaterusebmp.pdf.
- Consortium for Energy Efficiency. 2009. CEE—Consortium for energy efficiency. Accessed 22 July 2009, <http://www.cee1.org/>
- Current requirements in EO 13423 and Energy Policy Act 2005, formerly EO 13123, Memorandum HQ SFIM-OP-P, and Memorandum DAIM-ZA.
- Deal, Brian M., Donald F. Fournier, Diane M. Timlin, and Elisabeth M. Jenicek. 2002. *An Assessment of Encroachment Mitigation Techniques for Army Lands*. [Technical Report] ERDC/CERL TR-02-27/ADA409139. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). Accessed 22 July 2009, http://www.cecer.army.mil/techreports/Jenicek_AssessmentOfEncroachment/Jenicek_AssessmentOfEncroachment.pdf
- Delaware River Basin Commission. (2002, October). Water Conservation Guidelines for Golf Courses. DRBC. Retrieved July 22, 2009, from <http://www.state.nj.us/drbc/golfcourses.pdf>.
- Demiriz, M. 2006. *Application of Dry Urinals Study Report*. Gelsenkirchen University of Applied Sciences.
- Department of the Army. 1996. Maintaining Federal water rights in the western United States. Department of the Army Pamphlet 27-50-287. October 1996, http://www.loc.gov/rr/frd/Military_Law/pdf/10-1996.pdf
- Department of the Army. 2007. Army energy and water campaign plan for installations. December 2007.
- Department of the Army. 2008. Water efficiency. Army Energy Program, http://Army-energy.hqda.pentagon.mil/policies/water_con.asp
- Diggelman, C., and R. Ham, 2003. Household food waste to wastewater or to solid waste? That is the question. *Waste Management & Research*. 21:501-514.
- Drew Chemical Corporation. 1985). *Principles of Industrial Water Treatment*. 8th ed. Boonton NJ: Drew Chemical Corp.
- El Paso Water Utilities. (2007). Reclaimed Water. *El Paso Water Utilities*. Retrieved July 24, 2009, from http://www.epwu.org/reclaimed_water/rwater.html.

- Endangered Species Act. 1973. Public-No. 93-205, 16 U.S.C. 1531-1544.
- Eng, William F. 2008. "Everything You Need To Know About Water Conservation Program." Public Works Digest, vol. XX, no.5, September/October 2008.
- Environmental News Network (ENN). 2008. Water seen as the new oil for U.S. Army, <http://www.enn.com/ecosystems/article/38361>
- EPFD. 2008. Desert blooms: *A Sunscape Guide to Plants for a Water-Scarce Region, Regional Water Sources Overview*. U.S. Department of the Interior, U.S. Bureau of Reclamation, El Paso Field Division, <http://www.usbr.gov/uc/dblooms/index.jsp>
- EPWU. 2008. Water: Past and present water supplies. *El Paso Water Utilities*. Accessed March 2009, http://www.epwu.org/water/water_resources.html
- EPWU. 2008. Water: Setting the stage for the future. *El Paso Water Utilities*. Accessed March 2009. http://www.epwu.org/water/desal_info.html
- ERG for EPA's WaterSense Helpline. 2009. *Average Prices for Watersense Labeled Products*.
- Executive Order (EO) 13423 Strengthening Federal environmental, energy, and transportation management. *Federal Register* 72(17):3919-3923.
- Fanney, A., B. Dougherty, and J. Richardson. 2002. Field test of a photovoltaic water heater. *Transactions- American Society of Heating Refrigerating and Air-Conditioning Engineers*. 108:780-792.
- Far West Texas Water Planning Group. 2006. Far West Texas Water Plan. Prepared for the Texas Water Development Board. January 2006.
- Federal Bureau of Land Management. 2009. Federal reserved water rights. *Western States Water Laws*. Accessed 15 July 2009, <http://www.blm.gov/nstc/WaterLaws/fedreservedwater.html>
- Federal Register, Executive Order 13423. 2007. Strengthening federal environmental, energy, and transportation management.
- Foderaro, L. W. 2009. Without cafeteria trays, colleges find savings. *The New York Times*. Accessed 22 July 2009, <http://www.nytimes.com/2009/04/29/nyregion/29tray.html>
- Fort Bliss Transformation Brief. January 2009.
- Fournier, Donald, Elisabeth Jenicek, and Natalie Downs. 2005. *Watershed Application of the Sustainable Installations Regional Resource Assessment Tool*. ERDC/CERL TR-05-24, Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).
- Gerbens-Leenes, Arjen Y. Hoekstra, and Theo H. van der Meer. The water footprint of bioenergy. *Proceedings of the National Academy of Sciences*. V. 106 , No. 25. 10219-10223.

- Gibeault, V., Meyer, J., Younger, V., & Cockerham, S. (1985). Irrigation of Turfgrass below Replacement of Evapotranspiration as a Means of Water Conservation: Performance of Commonly Used Turfgrasses (pp. 340-356). INRA Publ.
- Gleick, Peter H. 2008. Water Conflict Chronology. Data from the Pacific Institute for Studies in Development, Environment, and Security database on Water and Conflict (Water Brief). March 5, 2008.
- Gleick, Peter H. Heather Cooley, Michael Cohen, Mari Morakawa, Jason Morrison, and Meena Palaniappan. The Worlds Water 2008-2009: The Biennial Report on Freshwater Resources. Washington D.C.: Island Press. 2008.
- Gleick, Peter H., et al. 2004. Waste not, want not: The potential for urban water conservation in California. Oakland: Pacific Institute. November 2003. 176 pp.
- Global Climate Change Impacts in the United States*. Thomas R. Karl, Gary M. Melillo, and Thomas C. Peterson (eds.). New York: Cambridge University Press. 2009.
<http://www.globalchange.gov/usimpacts>
- Global Water Partnership; International Network of Basin Organizations. 2009. *A Handbook for Integrated Water Resources Management in Basins*. Global Water Partnership and the International Network of Basin Organizations.
- Griggs, N. 2008. *Total Water Management: Practices for a Sustainable Future*. American Waterworks Association.
- Hayes, Richard J., Katherine A. Popko, and William K. Johnson. 1980. *Guide Manual for Preparation of Water Balances*. U.S. Army Corps of Engineers, Hydrologic Engineering Center.
- Healy, Richard W., Thomas C. Winter, James W. LaBaugh, and O. Lehn Franke. 2007. Water budgets: *Foundations for Effective Water-Resources and Environmental Management*. Circular 1308. U.S. Department of the Interior, U.S. Geological Survey.
- Heinz Center, The. 2008. The State of the Nation's Ecosystems 2008: *Measuring the Lands, Waters, and Living Resources of the United States*. The H. John Heinz III Center for Science, Economics and the Environment.
- Heywood, Charles E., and Richard M. Yeager. 2003. *Simulated Ground-Water Flow in the Hueco Bolson, an Alluvial-Basin Aquifer System near El Paso, Texas*. Water Resources Investigations Report 02-4108. U.S. Department of the Interior, U.S. Geological Survey. Prepared in Cooperation with El Paso Water Utilities and U.S. Army – Fort Bliss.
- Hills, S., R. Birks, and B. McKenzie. 2002. The Millennium Dome “Watercycle” experiment: to evaluate water efficiency and customer perception at a recycling scheme for 6 million visitors. *Water Science and Technology*, 46(6-7): 233-40.
- Hoffman, H. (2008). Capturing the water you already have: Using alternate onsite sources. *JOURNAL - AMERICAN WATER WORKS ASSOCIATION*, 100(5), 112-116.
- Hutchison, William R. 2004. *Hueco Bolson Groundwater Conditions and Management in the El Paso Area*. EPWU Hydrogeology Report 04-01.
- Hutchison, William R. 2006. *Groundwater Management in El Paso, Texas*. University of Texas at El Paso. Boca Raton: Dissertation.com.

- Hutchison, William R. 2008. *Climate Change Impacts on Municipal Water Management in El Paso, Texas*. Presentation slides from lecture to El Paso Geological Society.
- Hutchison, William R. 27 May 2009. Lecture to El Paso Geological Society.
- Hutchison, William R. *Climate Change Impacts on Municipal Water Management in El Paso, Texas*. El Paso: El Paso Water Utilities.
- Hutson, Susan, et al. 2004. *Estimated Use of Water in the United States in 2000*. U.S. Geological Circular 1268. Reston: U.S. Department of the Interior, U.S. Geological Survey. 52 pp.
- Institute for Water Resources (IWR). 2006. Managing watersheds holistically, http://www.iwr.usace.Army.mil/waterresources/docs_wr/ManagingWatersheds.pdf
- Institute of Electrical and Electronic Engineers (IEEE). 2009. *Congress and DOE Focusing Intensified Attention on Energy-Water Nexus*. IEEE-USA Today's Engineer online. September 2009. <http://www.todaysengineer.org/2009/Sep/energy-water.asp>
- Isserman, Andy. 1993. The right people, the right rates: Making population estimates and projections with an interregional cohort-component method. *Journal of the American Planning Association* 59,1: 45-64.
- Jenicek, Elisabeth M., Natalie R.D. Myers, Brad Boesdorfer, and Donald F. Fourier. 2006. *Strategic Sustainability Assessment Pilot Study: Fall Line Region of the Southeast*. ERDC/ CERL TR-06-32, Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).
- Jennings, R. B., and C. V. Jones. 2008. *Forecasting Urban Water Demand*. Denver, Colorado: American Water Works Association.
- Karl, Thomas R., Jerry M. Melillo, and Thomas C. Peterson (eds.). 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press.
- Karl, Thomas R., Jerry M. Melillo, and Thomas C. Peterson (eds.). *Global Climate Change Impacts in the United States*. New York: Cambridge University Press. 2009.
- Koeller and Company. 2008. *A Report on Potential Best Management Practices — Prepared for California Urban Water Conservation Council*. California Urban Water Conservation Council.
- Koeller, J. 2005. *Potential Best Management Practice Report HETS and HEUS*. Koeller and Company, <http://www.allianceforwaterefficiency.org/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=956>
- Leibenluft, J. 2008. Should we dispose of disposals? The best way to get rid of your leftover food. *Slate*. Accessed 22 July 2009, <http://www.slate.com/id/2201176/>
- Lettenmaier, D. P. 2008. Water Resources. Ch 4 in *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity*. The U.S. Climate Change Science Program.
- Lundie, S., and G. Peters. 2005. Life cycle assessment of food waste management options. *Journal of Cleaner Production*, 13(3):275-286.

- Maclaren, V., *Developing Indicators of Urban Sustainability* (Intergovernmental Committee on Urban and Regional Research, Toronto, 1996).
- Madungwe, E., & Sakuringwa, S. (2007). Greywater reuse: A strategy for water demand management in Harare? *PHYSICS AND CHEMISTRY OF THE EARTH PARTS A B C*, 32(15-18), 1231-1236.
- Mantua, N. J. 1999: The Pacific decadal oscillation and climate forecasting for North America. To appear in premiere issue of "Climate Risk Solutions" newsletter.
- Marstel Day. 2008. *Water Demand Forecasts for Sustainable Water Management Strategies at Fort Bragg, North Carolina*. Final Report.
- Mayer, P., DeOreo, W., Hayden, M., Davis, R., Caldwell, E., Miller, T., et al. (2009, July 1). Evaluation of California Weather-Based "Smar" Irrigation Controller Programs. Aquacraft, Inc. Water Engineering and Management.
- Murrell, Jefferey. U.S. Army Corps of Engineers, Huntsville Division. Personal Communication. 17 September 2009. Jefferey.B.Murrell@usace.army.mil.
- National Science and Technology Council Committee on Environment and Natural Resources: Subcommittee on Water Availability and Quality. September 2007. *A Strategy for Federal Science and Technology to Support Water Availability and Quality in the United States*.
- National Science and Technology Council. 2004. *Science and Technology to Support Fresh Water Availability in the United States*. Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality.
- NCDPPEA. 2008. *Drought: A Missed Opportunity for Water Conservation?* Presentation at the Fort Bragg Military Reservation 7 March 2008, www.p2pays.org/webshare/DoD/Drought_03_07_08.PPT
- NCDWR. 2008. *Cape Fear River Basin Surface Water Assessment: Modeling of Future Water Use Scenarios*. North Carolina Department of Environment and Natural Resource. North Carolina Division of Water Resources.
- NCDWR. December 2002. *State of North Carolina B. Everett Jordan Lake Drought Management Plan (DRAFT)*. North Carolina Department of Environment and Natural Resource, North Carolina Division of Water Resources.
- NCDWR. March 2002. *Cape Fear River Basin Water Supply Plan: Second Draft*. North Carolina Department of Environment and Natural Resource, North Carolina Division of Water Resources.
- New Mexico Office of the State Engineer. 2009. Frequently asked questions. Accessed 15 July 2009, http://www.ose.state.nm.us/faq_index.html
- Newhouse, R. 2008. Students have their hands full saving food, energy, and water. *Campus Ecology - National Wildlife Association*. Accessed 22 July 2009, <http://www.nwf.org/campusEcology/climateedu/articleView.cfm?iArticleID=18>
- Nobles, J. 2009. Phone Conversation with Commercial Brass - Aquaflush Flush Valve Products Employee.

- North Carolina State Demographer. 2009. *Population Projections Description*. Accessed 15 July 2009, http://www.osbm.state.nc.us/ncosbm/facts_and_figures/socioeconomic_data/population_estimates/demog/projinet.html
- Omnibus Public Land Management Act of 2009. 2009. H.R. 146.
- Owenby, J., R. Heim, Jr., M. Burgin, and D. Ezell. 2001. *Climatology of the U.S. No. 81 – Supplemental #3: Maps of Annual 1961 – 1990 Normal Temperature, Precipitation and Degree Days*.
- Pacific Northwest National Laboratory (PNNL). 2005. Update of market assessment for capturing water conservation opportunities in the Federal sector. PNNO-15320. August 2005. U.S. Department of Energy Federal Energy Management Program.
- Pacific Northwest National Laboratory. 2005. Update of Market Assessment for Capturing Water Conservation Opportunities in the Federal Sector. Prepared for the U.S. Department of Energy, Federal Energy Management Program. PNNL-15320. August 2005.
- Paso del Norte Water Task Force. Water Planning in the Paso del Norte: Toward Regional Coordination. March 2001. <http://www.sharedwater.org>. El Paso.
- Patwardhan, A., D. Baughman, A. Tyagi, A., and J. Thorpe. 2007. Developing and implementing a TWM strategy-approaches and examples. *Journal - American Water Works Association*. 99(2):64-75.
- Paul Johnson and Earl Stockdale. 1995. Memorandum, subject: Policy Guidance on Water Rights at Army Installations in the United States. 25 November 1995.
- Peach, J., and J. Williams. 2003. *Population Dynamics of the U.S.-Mexican Border Region*. Unpublished, forthcoming SCERP Monograph. San Diego.
- Public Law 109-58. 2005. Energy Policy Act of 2005. United States Congress. 29 July 2005.
- Riesenberger, J. (2005, November 4). Potential Best Management Practices - Commercial Laundry Facilities. Koeller and Company.
- Ruiz, Art. February 2009. Phone Conversation between Plant Supervisor and Kevin Miller, ERDC-CERL.
- Ryder, Paul D. 1996. Groundwater atlas of the United States: Oklahoma, Texas, HA 730-E. Department of the Interior, U.S. Geological Survey, http://pubs.usgs.gov/ha/ha730/ch_e/index.html
- Schoik, D. Rick Van, Erik Lee, and Thomas McGuckin. Undated. *Border Water: Sovereignty, Scarcity, and Security in the U.S. – Mexican Binational Region*. Southwest Center for Environmental Research and Policy, www.iadb.org/IDBDocs.cfm?docnum=967353.
- Scholze, R. (n.d.). Smart Landscaping Practices Save Water. *Engineer Research and Development Center*. Retrieved July 22, 2009, from http://www.erd.usace.army.mil/pls/erdcpub/www_org_info.show_page?f_id=54736&f_parent=55174.

- Scholze, R., G. Gerdes, W. Goran, J. Hall, K. Preston, M. McLeod, et al. 2009. *Proceedings of the Military Applications for Emerging Water Use Technologies Workshop*. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). Accessed 22 July 2009, http://www.cecer.Army.mil/techreports/ERDC-CERL_TR-09-12/ERDC-CERL_TR-09-12.pdf
- Shultz, Tom. 2009. Department of Natural Resource Ecology and Management (NREM) at Iowa State University, <http://www.buffer.forestry.iastate.edu/Photogallery/illustrations/illustrations-1.htm>
- Sissine, F. 2007. *Energy Independence and Security Act of 2007: A Summary of Major Provisions*. Congressional Research Service. Accessed 22 July 2009, <http://energy.senate.gov/public/files/RL342941.pdf>
- Society of American Military Engineers Annual Conference. 2008. Army Growth and BRAC Update. Col Jim Balocki, ACSIM. 22May2008.
- Solomon, Susan, Gian-Kasper Plattner, Reto Knutti, and Pierre Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences* 106(6):1704-1709, <http://www.pnas.org/content/106/6/1704.full.pdf>
- Song, Jennifer (NC State Demographer). 3 June 2009. Email correspondence. jennifer.song@osbm.nc.gov
- Sporhase v. Nebraska ex rel. Douglas. 1982. 458 U.S. 941.
- State of California. 2008a. *California Irrigation Management Information System (CIMIS)*. Accessed 22 July 2009, <http://wwwcimis.water.ca.gov/cimis/welcome.jsp>
- State of California. 2008b. ET overview. *California Irrigation Management Information System*. Accessed 22 July 2009, <http://wwwcimis.water.ca.gov/cimis/infoEtoOverview.jsp>
- Stoughton, K. L. M., A. E. Solana, D. B. Elliot, G. P. Sullivan, and G. B. Parker. 2005. *Update of Market Assessment for Capturing Water Conservation Opportunities in the Federal Sector*. Pacific Northwest National Laboratory.
- Sur, Frontera Norte. 2007. Carlos Slim's border water project. *Newspaper Tree*, November 2007, Features section, <http://newspapertree.com/features/1839-carlos-slim-s-border-water-project>
- Taos Pueblo Indian Water Rights Settlement Act. 2009. (S. 965).
- Terracon, John Shomaker & Associates, Inc., Livingston Associates, LLC, Inc., Zia Engineering and Environmental, Inc., and Sites Southwest. 2004. *The New Mexico Lower Rio Grande Regional Water Plan*. Prepared for The Lower Rio Grande Water Users Organization, Anthony Water and Sanitation District, City of Las Cruces, Dona Ana County, Dona Ana Mutual Domestic Water Consumers Association, Elephant Butte Irrigation District, New Mexico State University, Town of Mesilla, and Village of Hatch.
- Texas Commission on Environmental Quailtiy. (2007). *Harvesting, Storing, and Treating Rainwater for Domestic Indoor Use*. TCEQ. Retrieved July 24, 2009, from http://www.tceq.state.tx.us/files/gi-366.pdf_4445350.pdf

- Texas Water Development Board. (2005). The Texas Manual on Rainwater Harvesting. Texas Water Development Board. Retrieved July 24, 2009, from [http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rd edition.pdf](http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf).
- Texas Water Development Board. 2006. *Far West Texas Water Plan*.
- The McCarren Amendment. 1952. 43 U.S.C. § 666.
- Thompson, Stephen A. 1999. *Water Use, Management, and Planning in the United States*. Academic Press, San Diego, CA.
- Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1991. 1991. Public-No. 101-618.
- Turner, Charles D. and Jahagirdar, Abhijeet B. Undated paper. *Water Markets Features for Rio Grande Water in El Paso County, Texas*. El Paso: University of Texas at El Paso.
- Turner, Charles D. January 23, 2009. Email Correspondence. cturner@utep.edu
- U.S. Army Corps of Engineers (USACE). 1992. Excerpts from the approved *1992 Water Control Manual for B. Everatt Jordan Project*. U.S. Department of Defense, U.S. Army Corps of Engineers, Wilmington District, <http://epec.saw.usace.Army.mil/jwcplan.txt>
- U.S. Department of Energy, and U.S. Environmental Protection Agency. Undated. *Energy*. Accessed 22 July 2009, <http://www.energystar.gov/>
- U.S. Department of Energy. 2006. *EERE: Federal Energy Management Program Home Page*. Accessed 22 July 2009, <http://www1.eere.energy.gov/femp/>
- U.S. Department of the Interior. Undated. National Atlas of the United States, <http://nationalatlas.gov/asp/popups.asp?imgFile=../images/wall/aquifers.gif&imgw=528&imggh=451>
- U.S. Energy Independence and Security Act of 2007 (EISA 2007), H.R. 6.
- U.S. Energy Independence and Security Act of 2007. 2007. Public-No. 110-140, H.R. 6>
- U.S. Environmental Protection Agency (USEPA), Office of Water. 2006. Expert workshop on full cost pricing of water and wastewater service. USEPA. Accessed 11 June 2009, http://www.epa.gov/waterinfrastructure/pdfs/workshop_si_fullcostpricing.pdf
- U.S. Environmental Protection Agency. 2008. *Summary of Rationale for ENERGY STAR Ice Machine Specification*. USEPA. Accessed 22 July 2009, http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/ice_machines/Ice_Machine_Decision_Memo.pdf
- U.S. Environmental Protection Agency. 2009. *WaterSense / USEPA*. Accessed 22 July 2009, <http://www.epa.gov/watersense/>
- United States District Court Middle District of Florida. Case No. 3:07-md-01. In re Tri-State Water Rights Litigation. 17 July 2009. 97 pages.

- United States v. New Mexico. 1978. 438 U.S. 696.
- University of California Cooperative Extension, and California Department of Water Resources. 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California: The Landscape Coefficient Method and WUCOLS III*. California Department of Water Resources. Accessed 22 July 2009, <http://www.owue.water.ca.gov/docs/wucols00.pdf>
- US Environmental Protection Agency. (2004, September). Guidelines for Water Reuse. EPA. Retrieved July 24, 2009, from <http://www.epa.gov/NRMRL/pubs/625r04108/625r04108.pdf>.
- USACE. 2006. *Engineering and Construction Bulletin: The Army Standard for Urinals*. USACE. Accessed July 22, 2009, http://www.wbdg.org/ccb/ARMYCOE/COEECB/ecb_2006_7.pdf
- USEPA WaterSense. 2007. *Tank-Type High-Efficiency Toilet Specification*. USEPA. Accessed 22 July 2009, http://www.epa.gov/watersense/docs/spec_het508.pdf
- USGS. 1990. *Water Rights of the Fifty States and Territories*. American Water Works Association, Denver, CO
- USGS. 1998. *A New Evaluation of the USGS Streamgaging Network*. A Report to Congress. U.S. Department of the Interior, U.S. Geological Survey.
- USGS. 1998. *Estimated Water Use in the United States in 1995*. U.S. Department of the Interior, U.S. Geological Survey, Circular 1200.
- USGS. 2002. *Concepts for National Assessment of Water Availability and Use*. Report to Congress. U.S. Department of the Interior, U.S. Geological Survey, Circular 1223.
- USGS. 2005. *Estimated Water Use in the United States in 2000*. U.S. Department of the Interior, U.S. Geological Survey, Circular 1268.
- USGS. 2008. Hydrologic units (watersheds), National Atlas, <http://www.nationalatlas.gov/>
- USGS. Undated. *Hydrologic Unit Map*. (Based on data from USGS water-supply paper 2294). U.S. Department of the Interior, U.S. Geological Survey, <http://water.usgs.gov/GIS/regions.html>
- Vickers, A. 2001. *Handbook of Water Use and Conservation*. Waterplow Press.
- Wallander, S. 2008. *Price Impacts of the Energy Star Label - A Case of Redundant Information*. University of California Santa Barbara. Accessed 22 July 2009, <http://www.econ.ucsb.edu/~grainger/wallander.pdf>
- Water Energy Laundry Consulting. (2009). Continuous Batch Washers. *Laundry Consulting*. Retrieved July 23, 2009, from <http://laundryconsulting.com/equipment/washers/continuous-batch-washers/>
- Watercourse, The. 2001. *Discover a Watershed: Rio Grande/Rio Bravo*. Montana: Montana State University. pp 30-75.

- Weaver, J. Curtis, and Benjamin F. Pope. 2001. *Low-Flow Characteristics and Discharge Profiles for Selected Streams in the Cape Fear River Basin, North Carolina, through 1998*. Water Resources Investigations Report 01-4094. U.S. Department of the Interior, U.S. Geological Survey. Prepared in Cooperation with the Division of Water Quality of the North Carolina Department of Environment and Natural Resources.
- Wild and Scenic Rivers Act. 1968. Public-No. 90-542, 16 U.S.C. 1271-1287.
- Wilkinson, Robert, Ph.D. 2008. *Water Supply Challenges for the 21st Century*. Congressional Hearing. Committee on Science and Technology, U.S. House of Representatives, Subcommittee on Energy and the Environment. 13 August 2008.
- Williams, Jim. March 2009. Phone Conversation between Assistant Plant Supervisor and Kevin Miller, ERDC-CERL.
- Wilson, A. (2008, May 1). Alternative Water Sources: Supply-Side Solutions for Green Buildings. *Environmental Building News*. Retrieved July 24, 2009, from <http://www.buildinggreen.com/auth/article.cfm/ID/3903/>. Chesnutt, T., Fiske, G., and Feecher, J. 2007. *Water Efficiency Programs for Integrated Water Management*. American Water Works Association.
- Winter, Thomas C., Judson W. Harvey, O. Lehn Franke, and William M. Alley. 1998. *Ground Water and Surface Water: A Single Resource*. USGS Circular 1139. U.S. Department of the Interior, U.S. Geological Survey.
- Winters v. United States. 1908. 207 U.S. 564.
- Woodley, John P., Jr. 2008. Proposals for a water resources development act of 2008. Subcommittee on Water Resources and Environment, Committee on Transportation and Infrastructure, U.S. House of Representatives. 30 April 2008.
- World Economic Forum. 2008. *Thirsty Energy: Water and Energy in the 21st Century*. WEA in partnership with Cambridge Energy Research Associates. Geneva: WEF. 2008.
- United Nations. 2009. *Water in a Changing World, The United Nations World Water Development Report 3*. London: UNESCO. 2009.
- Youngquist, Walter. 1997. *GeoDestinies: The inevitable control of Earth resources over nations and individuals*. National Book Company.

Acronyms and Abbreviations

Term	Spellout
AADT	Annual Average Daily Traffic per Lane
AAP	Army Ammunition Plant
ACP	Army Campaign Plan
ACSIM	Assistant Chief of Staff for Installation Management
ACUPOM	Army Commercial Utilities Program Oversight/Management
AEC	Army Environmental Command
AEPI	Army Environmental Policy Institute
AEWRS	Army Energy and Water Reporting System
AFCEE	Air Force Center for Engineering and the Environment
AMF	Army Modular Force
APA	American Planning Association
AR	Army Regulation
ARIMA	Auto-Regressive Integrated Moving Average
ARNG	Army National Guard
ARRA	American Recovery and Reinvestment Act
ASAIE	Assistant Secretary of the Army for Installations & Environment
ASME	American Society of Mechanical Engineers
AWRA	American Water Resources Association
AWWA	American Water Works Association
AWWA-RF	American Water Works Association Research Foundation
BG	Brigadier General
BRAC	Base Realignment and Closure
CEE	Consortium for Energy Efficiency
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CIA	Central Intelligence Agency
CII	commercial, industrial, and institutional
CIMIS	California Irrigation Management Information System
CO	carbon monoxide
COEECB	Corps of Engineers Engineer and Construction Bulletin
CRREL	Cold Regions Research and Engineering Laboratory
CY	calendar year
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DPU	Department of Public Utilities
DZ	drop zone
EERE	[U.S. DOE] Energy Efficiency and Renewable Energy
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order

Term	Spellout
EPCWID	El Paso County Water Improvement District
EPFD	El Paso Field Division
EPWU	El Paso Water Utilities
ERDC	Engineer Research and Development Center
ERG	Eastern Research Group
ESA	U.S. Endangered Species Act
ESRI	Environmental Systems Research Institute, Inc.
ET	evapotranspiration
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FHWA	Federal Highway Administration
FORSCOM	U.S. Army Forces Command
FWTWPG	Far West Texas Water Planning Group
FY	fiscal year
GCM	Global Climate Model
GDPR	Global Defense Posture Realignment
GIS	geographic information system
GOES	Geostationary Operational Environmental Satellite
GSA	General Services Administration
HQ	headquarters
HUC	hydrologic unit code
IBWC	International Boundary and Water Commission
IFRCRCS	International Federation of Red Cross and Red Crescent Societies (IFRCRCS)
IMCOM	Installation Management Command
IWI	Index of Watershed Indicators
IWR	Institute for Water Resources
JAWRA	Journal of American Water Resources Association
JDF	Joint Desalination Facility
JFTB	Joint Forces Training Base
LEED	Leadership in Energy and Environmental Design
LTA	Logistics Transformation Agency
MGD	million gal/day
MIT	Massachusetts Institute of Technology
MSA	Metropolitan Statistical Areas
NAAQS	National Ambient Air Quality Standards
NAVFAC	Naval Facilities Engineering Command
NAWQA	National Water Quality Assessment
NCDC	National Climatic Data Center
NCDPPEA	North Carolina Division of Pollution Prevention and Environmental Assistance
NCDWR	North Carolina Division of Water Resources
NEMIS	National Emergency Management Information System
NEPA	National Environmental Policy Act
NLCD	National Land Cover Data

Term	Spellout
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NREM	Natural Resource Ecology and Management
NTC	National Training Center
NWIS	National Water Information System
O&M	operations and maintenance
ONUS	Old North Utility Services, Inc.
OSD	Office of the Secretary of Defense
PDF	Portable Document Format
PdNWTf	Paso del Norte Water Task Force
PM	particulate matter
PNNL	Pacific Northwest National Laboratory
PWC	Public Works Commission
PWD	
RFTA	
RSC	Regional Support Center
RWRI	rarity-weighted richness index
SAR	Species at risk
SCERP	Southwest Center for Environmental Research and Policy
SDSU	San Diego State University
SERM	Sustainability, Environment, and Room to Maneuver
SIRRA	Sustainable Installations Regional Resource Assessment
SR	Special Report
TES	threatened and endangered species
TR	Technical Report
TTI	Travel Time Index
TWDB	Texas Water Development Board
TWM	total water management
UIUC	University of Illinois at Urbana-Champaign
UM	units of measurement
UPH	Unaccompanied Personnel Housing
URL	Universal Resource Locator
USACE	U.S. Army Corps of Engineers
USC	United States Code
USCB	U.S. Census Bureau
USDOD	U.S. Department of Defense
USDoHS	U.S. Department of Homeland Security (USDoHS)
USDOI	U.S. Department of the Interior
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGAO	U.S. General Accounting Office
USGS	U.S. Geological Survey

Term	Spellout
UV	Ultraviolet
VAAP	Vulnerability Assessment Action Plan
WAATS	Western Army National Guard Aviation Training Site
WUA	Water Utility Authority
WUCOLS	Water Use Classifications of Landscape Species (WUCOLS)
WWW	World Wide Web

Appendix A: Indicator Metadata

Contents

Contents	185
Sustainability Issue: Water Availability	185
Indicator: Federally Declared Floods (A9)	198
Sustainability Issue: Water Demand.....	212
Indicator: Water for Energy Production (D3).....	215
Indicator: Regional Population Density (D4)	216
Description of each worksheet, with selected screenshots.....	247
Water Proj Summary.....	248
Cost Projection.....	250
Instructions for using the demand model	252

Sustainability Issue: Water Availability

Indicator: Streamflow (A1)

Variables: Velocity, cubic feet per second

Scale: Watershed, HUC 8

Year: Water Year 2007 (a water year runs from October 1st to September 30th)

Data Source:

U.S. Environmental Protection Agency (USEPA). 1997. *The Index of Watershed Indicators, EPA-841-R-97-010*. Office of Water. Washington, DC,
<http://www.epa.gov/wateratlas/geo/maplist.html>

Hurd, B., N. Leary, R. Jones, and J. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association*, 35(6): 1399-1409,
<http://www.awra.org>

U.S. Geological Survey (USGS). 2007. *National Water Information System (NWIS): Surface-Water Data for the Nation, Daily Streamflow for the Nation*. Washington, DC,
<http://nwis.waterdata.usgs.gov/usa/nwis/discharge>

Logic: Streamflows are critical to many riparian areas. If they fall below safe threshold levels, it can threaten individual species or potentially endanger entire aquatic ecosystems. Riparian ecosystems where seasonal periods of extreme low flow occur are the most vulnerable to climatic and hydrologic

changes (B. Hurd et al. 1999).

Impacts to the military mission would include diminished or stressed threatened and endangered species (TES) habitat and population, which in turn could negatively impact the ability for certain training and other missions. Diminished carrying capacity across training may result due to the increased erosion, as a result. Finally, the availability of water would significantly decrease resulting in overall resource vulnerability.

Replicable: USGS surface-water data includes more than 850,000 stations recording time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. The data is collected by automatic recorders and manual measurements by field personnel and is relayed through telephones or satellites to offices where it is stored and processed. The data relayed through the Geostationary Operational Environmental Satellite (GOES) system are processed automatically in near real time, and in many cases, real-time data are available online within minutes. Annually, the USGS finalizes and publishes the daily data in a series of water-data reports. Daily streamflow data and peak data are updated annually following publication of the reports. Due to extensive downloading and numerous calculations of streamflow data to create the Streamflow indicator, it is recommended that this indicator be updated annually or every other year.

Directions: Download average annual streamflow by hydrologic region for water year 2007 from USGS NWIS at: <http://nwis.waterdata.usgs.gov/usa/nwis/discharge>. Save files as tab-separated data. Import and join all files into a spreadsheet program. Group all data stations by HUC. Since not all basin and sub-basin HUC have data stations, compute averages for the largest HUC units first then for smaller HUC units as data allows. Import the HUC streamflow 2007 annual averages into a GIS program and join them with HUC 8 watershed boundary files to create a GIS Streamflow indicator layer.

Note, downloading average annual streamflow measurements for over 850,000 stations results in millions of data points. Due to query limitation of the NWIS web server, it is recommended to contact USGS Surface-Water Data Department for assistance in these queries.

Indicator Measure: Streamflow was defined as the mean value of velocity (cubic feet per second) that originates from groundwater outflow (base flow). This measurement is mostly independent of levels and changes in surface runoff. The streamflow ratings were grouped into the following classifications

based on statistical analyses around the average (3,125.93) and the standard deviation (13,140.38):

Very Low Vulnerability	(1):	>6,000 cft/sec
Low Vulnerability	(2):	3,001 – 6,000 cft/sec
Moderate Vulnerability	(3):	501 – 3,000 cf/sec
Vulnerable	(4):	201 – 500 cft/sec
High Vulnerability	(5):	0 – 200 cft/sec.

Rules: No rules necessary for relating data to the HUC 8 watershed level.

Indicator: Local Water Production (A2)

Variables: Annual Runoff, millimeters per year

Scale: Watershed, HUC 8

Year: Water Year 2007 (a water year runs from October 1st to September 30th)

Data Source:

U.S. Geological Survey (USGS). 2007. *National Water Information System (NWIS): Surface-Water Data for the Nation, Daily Streamflow for the Nation*. Washington, DC, <http://nwis.waterdata.usgs.gov/usa/nwis/discharge>

Logic: Runoff is the portion of precipitation that flows over land surfaces into streams and lakes. The runoff is also a spatially distributed quantity and has been calculated by USGS as the stream flow divided by the drainage area or watershed area. The result is an estimation of the amount of water generated from with-in a watershed and contributing to local water supplies.

Local precipitation (primarily in the form of rainfall or snow melt) is not the only source of water supply for populations. Often, streams and waterways carry water supplies across watershed boundaries. However, if local production is low, supplies must depend on outside sources. Impacts to military missions could include diminished water supplies and result in overall resource vulnerability.

It is important to also note that when runoff flows along the ground, it can pick up man-made or soil contaminants such as petroleum, pesticides, or fertilizers that become source pollutants. In other words, a watershed may supply sufficient water supplies, but land development may deteriorate the quality of the supplies. Because of this concern, this indicator should be taken in context and used in conjunction with other land development and water quality indicators.

Replicable: USGS surface-water data includes more than 850,000 stations recording time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. The data is collected by automatic recorders and manual measurements by field personnel and relayed through telephones or satellites to offices where it is stored and processed. The data relayed through the GOES system are processed automatically in near real time, and in many cases, real-time data are available online within minutes. Annually, the USGS finalizes and publishes the daily data in a series of water-data reports. runoff data is updated annually following publication of the reports. Due to extensive downloading of runoff data to create the Local Water Production indicator, it is recommended that this indicator be updated annually or every other year.

Directions: Download average annual runoff by hydrologic region for 2007 from USGS NWIS at: <http://nwis.waterdata.usgs.gov/usa/nwis>. Save files as tab-separated data. Import and join all files into a spreadsheet program. Group all data stations by HUC 8 watershed level. Import runoff values into a GIS program and join them with HUC 8 watershed boundary files to create a GIS Local Water Production indicator layer.

Indicator Measure: Local water production was defined as the average value of precipitation that originates from a watershed during a typical year. This measurement is approximated with surface runoff. The local water production ratings were grouped into the following classifications based on statistical analysis around the mean (259.18) and the standard deviation (338.12):

Very Low Vulnerability	(1):	>600 mm/yr
Low Vulnerability	(2):	431 – 600 mm/yr
Moderate Vulnerability	(3):	261 – 430 mm/yr
Vulnerable	(4):	90 – 260 mm/yr
High Vulnerability	(5):	<90 mm/yr.

Rules: No rules necessary for relating data to the HUC 8 watershed level.

Indicator: Presence of Groundwater (A3)

Variables: Principal Aquifer

Scale: National

Year: 2006

Data Source:

U.S. Geological Survey (USGS). November 2006. *National Atlas: Water*. Washington, DC, <http://www.nationalatlas.gov/atlasftp.html#aquifrp>

Logic: Principal aquifers are the uppermost aquifer typically supplying groundwater. This indicator illustrates the areas where groundwater sources yield significant quantities of water to wells and springs. This information is often used by Federal, State, and local agencies for water-resource planning and management. Impacts to the military mission include secure water availability, but may also include activity restriction on possible source contaminations.

Not tied to this data is the current level of available groundwater, recharge rates, or water qualities. Thus, it is important to use local knowledge in interpreting the presence of groundwater indicator.

Replicable: This indicator could be replicated regularly as long as the USGS continues to monitor groundwater aquifers. However, the presence of groundwater aquifers is unlikely to change. It is recommended that this indicator be replicated only once a decade. The GIS compatible layer containing aquifer boundaries (USGS 2006) can be found at:

<http://www.nationalatlas.gov/atlasftp.html#aquifrp>

Directions: Download “aquifers” from the USGS National Atlas at URL:

<http://www.nationalatlas.gov/atlasftp.html#aquifrp>.

Import the data into a GIS program to create the Presence of Groundwater indicator layer.

Indicator Measure: Presence of groundwater was defined as the existence of a principal aquifer:

Very Low Vulnerability	(1):	Groundwater Supply Present
Low Vulnerability	(2):	Not Applicable
Moderate Vulnerability	(3):	Not Applicable
Vulnerable	(4):	Not Applicable
High Vulnerability	(5):	No Groundwater Supply Present.

Rules: Watershed may have multiple or partial aquifers within its boundaries. If any part of the HUC 8 watershed has an aquifer boundary present, the entire watershed is characterized as “groundwater present.”

Indicator: Low Flow Sensitivity (A4)

Variables: Velocity, cubic feet per second

Scale: Watershed, HUC 8

Year: Water Year 2002 and Water Year 2007 (a water year runs from October 1st to September 30th)

Data Source:

U.S. Environmental Protection Agency (USEPA). 1997. *The Index of Watershed Indicators*, EPA-841-R-97-010. Office of Water. Washington, DC, <http://www.epa.gov/wateratlas/geo/maplist.html>

Hurd, B., N. Leary, R. Jones, and J. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association*, 35(6): 1399-1409, <http://www.awra.org>

U.S. Geological Survey (USGS). 2007. *National Water Information System (NWIS): Surface-Water Data for the Nation, Daily Streamflow for the Nation*. Washington, DC, <http://nwis.waterdata.usgs.gov/usa/nwis/discharge>

Logic: Streamflows are critical to many riparian areas, and falling below safe threshold levels can threaten individual species or potentially endanger entire aquatic ecosystems. Riparian ecosystems where seasonal periods of extreme low flow occur are the most vulnerable to climatic and hydrologic changes. Changes in annual streamflows can further diminish streamflows during the low flow seasons, since there is less capacity for enduring additional stresses (B. Hurd et al. 1999).

Impacts to the military mission would include diminished or stressed TES habitat and population, which in turn could negatively impact the ability for certain training and other missions. Additional diminished carrying capacity across training may result due to the increased erosion. Finally, the availability of water would significantly decrease resulting in overall resource vulnerability.

Replicable: USGS surface-water data includes more than 850,000 stations recording time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. The data is collected by automatic recorders and manual measurements by field personnel and relayed through telephones or satellites to offices where it is stored and processed. The data relayed through the GOES system are proc-

essed automatically in near real time, and in many cases, real-time data are available online within minutes. Annually, the USGS finalizes and publishes the daily data in a series of water-data reports. Daily streamflow data and peak data are updated annually following publication of the reports. Due to extensive downloading and numerous calculations of streamflow data to create the Streamflow indicator, it is recommended that this indicator be updated annually or every other year.

Directions: Download average annual streamflow by hydrologic region for water year 2002 and 2007 from USGS NWIS at:

<http://nwis.waterdata.usgs.gov/usa/nwis/discharge>

Save files as tab-separated data. Import and join all files into a spreadsheet program. Group all data stations by HUC 8 watershed level. Since not all basin and sub-basin HUC have data stations, compute averages for the largest HUC units first then for smaller HUC units as data allows. Calculate the percent change in streamflow from 2002 to 2007:

$$[(\text{streamflow 2007} - \text{streamflow 2002})/\text{streamflow 2002}]*100].$$

Import the percent change in streamflow into a GIS program and join them with HUC 8 watershed boundary files to create a GIS Low Flow Sensitivity indicator layer.

Note, downloading average annual streamflow measurements for over 850,000 stations results in millions of data points. Due to query limitation of the NWIS web server, it is recommended to contact USGS Surface-Water Data Department for assistance in these queries.

Indicator Measure: Streamflow sensitivity was defined as the percent change in velocity (cubic feet per second) from water year 2002 to water year 2007. This measurement is mostly independent of levels and changes in surface runoff over a 5-year timeframe. The low flow sensitivity ratings were grouped into the following classifications based on statistical analysis around the average (169.98) and the standard deviation (13,140.38):

Very Low Vulnerability	(1):	<0%
Low Vulnerability	(2):	0 – 85%
Moderate Vulnerability	(3):	86 – 170%
Vulnerable	(4):	171 – 255%
High Vulnerability	(5):	>255%.

Rules: No rules necessary for relating data to the HUC 8 watershed level.

Indicator: Groundwater Depletion (A5)

Variables: Groundwater Withdrawals (annual)

Scale: County

Year: 1995 and 2000

Data Source:

USEPA. 1997. *The Index of Watershed Indicators*, EPA-841-R-97-010. Office of Water, Washington, DC, <http://www.epa.gov/wateratlas/geo/maplist.html>

USGS. 2002. *Estimated Use of Water in the United States in 2000*. U.S. Department of the Interior, Washington, DC, <http://water.usgs.gov/watuse/>

USGS. 1997. *Estimated Use of Water in the United States in 1995*. U.S. Department of the Interior, Washington, DC, <http://water.usgs.gov/watuse/>

Hurd, B., N. Leary, R. Jones, and J. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association*, 35(6): 1399-1409, <http://www.awra.org>

Logic: Groundwater depletion is a measure of groundwater withdrawals. Groundwater withdrawals can affect both ground and surface water supplies and quality. Intensive withdrawals have led to cases where wells, springs, and wetlands have gone dry; lake levels have dropped; stream flow has been reduced with great harm to wildlife; and contamination has prevented installation of new wells.

Excessive groundwater withdrawals suggest that increased groundwater use may not be a viable adaptation to changes in surface water supply or increases in water demand (B. Hurd et al. 1999). The drop in the water table known as groundwater mining is one problem. It occurs when water is withdrawn from an aquifer more rapidly than it is replenished. As the water table drops, water pumping costs increase. Eventually, the users run out of water. Extensive groundwater mining also may cause subsidence, a lowering of the land surface. Subsidence occurs when the removal of water levels underground spaces that collapse or when underlying clay shrinks from lack of moisture. The result looks like a cone of depression on the land. Lowered water tables can also lead to greater contamination of groundwater. The reduction in surface water lowers the ability of a region's waterways to filter pollutants from water before

it flows in to recharge an aquifer. Average groundwater withdrawals in excess of natural base flows indicate an unsustainable rate of groundwater use.

Replicable: This indicator can be replicated every 5 years based on USGS updates.

Directions: Download 1995 and 2000 data for counties from the USGS *Water Use in the United States* available through URL: <http://water.usgs.gov/watuse/>.

Import the data into a spreadsheet program and calculate the percent change in water withdrawals from 1995 to 2000:

$$[(\text{Total Withdrawals 2000} - \text{Total Withdrawals 1995}) / \text{Total Withdrawals 1995}] * 100$$

Import the percent change in withdrawal values into a GIS program and join them with the county boundary files to create the Groundwater Depletion indicator layer.

Indicator Measure: Groundwater depletion was determined by the percent change in total groundwater withdrawals between 1995 and 2000. The groundwater depletion ratings were grouped into the following classifications based on statistical classification around the mean (83.17 percent) and standard deviation (323.17):

Very Low Vulnerability	(1):	<= 0 percent change
Low Vulnerability	(2):	0 – 25 percent change
Moderate Vulnerability	(3):	0 – 25 percent change
Vulnerable	(4):	26 – 83 percent change
High Vulnerability	(5):	>150 percent change.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Drought Sensitivity (A6)

Variables: 12-month percent of average precipitation

Scale: National

Year: 2007

Data Source:

NOAA Satellite and Information Service. 2007. North American drought monitor drought indices and data. National Climatic Data Center,
<http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/nadm/indices.php>

Logic: The percent of long-term average precipitation is a viable indicator of drought conditions. Long-term average precipitation has been calculated over a 1951 to 2001 base period. The drought sensitivity indicator shows the percentage of these averages that has fallen during the July 2006 to June 2007 period.

Drought impacts military mission and the overall ability to produce goods and provide services. Direct impacts included reduced crop, rangeland, and forest productivity; increased fire hazard; reduced water levels; increased livestock and wildlife mortality rates; and damage to wildlife and fish habitat.

Replicable: This indicator could be replicated every month based on data gathered by the National Climatic Data Center.

Directions: Download “long-term average precipitation, 12-month percent of average” from the National Climatic Data Center at URL:

<http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/nadm/indices.php?mdf=map&divstn=stn&indicator=pctpcp&submitted=Submit>

Import the data into a GIS program to create the Drought Sensitivity indicator layer.

Indicator Measure: This indicator measures hydrological drought to characterize potential decreases in water supplies. The drought sensitivity ratings were grouped into the following classifications based on definitions created by the NCDC (NOAA 2007):

Very Low Vulnerability	(1):	>160% (change from long-term average)
Low Vulnerability	(2):	131 – 160%
Moderate Vulnerability	(3):	74 - 130%
Vulnerable	(4):	45 – 73%
High Vulnerability	(5):	<45%

A complete explanation of the NCDC ranges is available at URL:

<http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/nadm/indices.php>

Note, no data available for Alaska or Hawaii.

Rules: Watersheds often cover two or more drought regions. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each drought region and multiplies that percentage for each region by that region's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Federally Declared Disasters (A7)

Variables: Number of Federally declared natural disasters in the categories of tsunami, coastal storm, drought, earthquake, flood, freezing, hurricane, typhoon, dam/levee break, mud/landslide, severe ice storm, fire, snow, tornado, volcano, and severe storm per square mile

Scale: State

Year: 1964 through 2007, totaled

Data Source:

Federal Emergency Management Agency U.S. Department of Homeland Security. 2007. *Federally Declared Disasters by Calendar Year*. FEMA GIS and Data Solutions Branch. Washington, DC, <http://www.fema.gov/library/drcys.shtm>

International Federation of Red Cross and Red Crescent Societies (IFRCRCS). 2002. World disasters report: Focus on reducing risk 2002, <http://www.ifrc.org/publicat/wdr2002/>

Logic: This indicator measures the number of Federally Declared Disasters occurring between 1964 and 2002. Federally declared disasters are those disasters declared by communities to the Federal government. Often times on declaration, the Federal government offers some form of relief to the community (IFRCRCS 2002). Thus whether or not a disaster is declared depends largely on the resources of the community and the aggressiveness of community leaders. Many disasters of significant consequences are not declared while some of relatively little consequences are declared. In other words, declaration may have little to do with severity. Nonetheless, Federally declared disasters offer the best indication of a community's disaster vulnerability reduction efforts. It is simply vital to use local knowledge in interpreting the Federally Declared Disasters classifications.

Disasters impact local infrastructure, water supplies, and drainage and sanitation. Direct damages to the water supply include repairs or reconstruction costs in water collection works, water processing plants, distribution pipes, and leakages in water distribution network; repair costs of sanitary sewage network; and rehabilitation costs of served water treatment plants.

Replicable: This indicator can be updated annually based on Federally Declared Disasters by Calendar Year data, as collected in the National Emergency Management Information System (NEMIS) maintained by FEMA.

Directions: The database, “declarations by type,” is sorted by disaster type (USDoHS. FEMA 2007). Those disasters that are not in the categories of tsunami, coastal storm, drought, earthquake, flood freezing, hurricane, typhoon, dam/levee break, mud/landslide, severe ice storm, fire, snow, tornado, volcano, or severe storm are eliminated. Data is then sorted by state. Import the data into a GIS program and join it with the state shape files to create a Federally Declared Disasters indicator layer.

Indicator Measure: The number of Federally declared natural disasters in the categories of tsunami, coastal storm, drought, earthquake, flood, freezing, hurricane, typhoon, dam/levee break, mud/landslide, severe ice storm, fire, snow, tornado, volcano, and severe storm for each state was summed to obtain a 38-year total for natural disasters. Statistical analysis resulted in a mean of 32 disasters per state. Fitting the data around the mean created the following classifications:

Very Low Vulnerability	(1):	<20 disasters
Low Vulnerability	(2):	20 - 30 disasters
Moderate Vulnerability	(3):	31 - 40 disasters
Vulnerable	(4):	41 - 50 disasters
High Vulnerability	(5):	>50 disasters.

Rules: Watersheds often cover two or more states. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each state and multiplies that percentage for each state by that state’s classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Seismic Zones (A8)

Variables: Spectral acceleration for 0.2 second period with 2 percent probability of exceedance in 50 years

ability of exceedance in 50 years

Scale: National

Year: 2002

Data Sources:

Frankel, Arthur, Charles Mueller, Theodore Barnhard, David Perkins, E.V. Leyendecker, Nancy Dickman, Margaret Hanson, and Stanley Hopper. 1997. *Seismic-Hazard Maps for the Conterminous United States*, U.S. Geological Survey Open-File Report 97-131-F. U.S. Geological Survey Bureau, U.S. Department of the Interior (USDOI), Reston, VA. Map F - Horizontal spectral response acceleration for 0.2 second period (5% of critical damping) with 2% probability of exceedance in 50 years, <http://geohazards.cr.usgs.gov/eq/>

Personal communication with Steven Sweeney, Structural Engineer, ERDC-CERL, Champaign, IL and Adam Sagert, graduate student assistant associated with the project. 2002.

Logic: Earthquakes are a threat to built structures and human health and safety. The military must be sensitive to potential threats from the natural environment. The mission of the installation, local infrastructures, water supplies, and drainage and sanitation systems can be severely impacted by an earthquake. Direct damages to the water supply include repairs or reconstruction costs in water collection works, water processing plants, distribution pipes, and leakages in water distribution network; repair costs of sanitary sewage network; and rehabilitation costs of served water treatment plants.

Replicable: This indicator can be replicated as often as the USGS updates their Seismic Risk data. The trend seems to be to update these maps every 5 or 6 years.

Directions: Download the horizontal spectral response acceleration for 0.2 second period (5 percent of critical damping) with 2 percent probability of exceedance in 50 years. Import the data into a GIS program to create a seismicity risk area indicator layer. GIS data concerning seismicity (A. Frankel et al. 1997), <http://geohazards.cr.usgs.gov/eq/>

Indicator Measure: The values found on the map are the horizontal spectral response acceleration for 0.2 second period (5 percent of critical damping) with 2 percent probability of exceedance in 50 years. USGS documentation (A. Frankel et al. 1997) separates the data into various seismic classifications, which were then translated into a vulnerability scale with the assistance of

seismic expert and structural engineer (personal communication with Sweeney 2002):

Very Low Vulnerability	(1):	$\leq 7\%$	(gravity)
Low Vulnerability	(2):	$7 - \leq 8\%$	(gravity)
Moderate Vulnerability	(3):	$8 - \leq 16\%$	(gravity)
Vulnerable	(4):	$16 - \leq 24\%$	(gravity)
High Vulnerability	(5):	$> 24\%$	(gravity).

Rules: Watersheds often cover two or more seismic zone. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each seismic zone and multiplies that percentage for each zone by that zone's classification value. Those values for each zone of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Federally Declared Floods (A9)

Variable: Number of Federally declared floods per Square Mile

Scale: County

Year: 12/24/1964 through 6/15/2004, totaled

Data Sources:

Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security, *Federally Declared Disasters by Calendar Year* (FEMA GIS and Data Solutions Branch, Washington, DC, 2004),
<http://www.fema.gov/library/drcys.shtm>

International Federation of Red Cross and Red Crescent Societies (IFRC), *World Disasters Report: Focus on Reducing Risk 2002* (2002),
<http://www.ifrc.org/publicat/wdr2002/>

Logic: This indicator measures the number of Federally Declared Floods occurring between 1964 and 2002. Federally Declared Floods are those floods declared by communities to the Federal government. Often times on declaration, the Federal government offers some form of relief to the community (IFRC 2002). Thus whether or not a flood is declared depends largely on the resources of the community and the aggressiveness of community leaders. Many floods of significant consequences are not declared while some of relatively little consequences are declared. In other words, declaration may have little to do with severity. Nonetheless, Federally Declared Floods offer the best

indication of a community's flood risk reduction efforts. It is simply vital to use local knowledge in interpreting the Federally Declared Floods classifications.

Every year flood disasters cause damage amounting to billions of dollars world-wide. Floods inflict the greatest loss in money than any other Federally declared disaster in the United States. Floods are a threat to both built structures and human health and safety. Floods impact local infrastructure, water supplies, and drainage and sanitation. Direct damages to the water supply include repairs or reconstruction costs in water collection works, water processing plants, distribution pips, and leakages in water distribution network; repair costs of sanitary sewage network; and rehabilitation costs of served water treatment plants. Thus, the military must be sensitive to potential threats from the natural and built environment. The mission of the installation can be severely impacted by a flood if proper provisions are not in place.

Replicable: This indicator can be updated annually based on Federally Declared Disasters by Calendar Year data, as collected in the National Emergency Management Information System (NEMIS) maintained by FEMA.

Directions: The database, "Declarations by Type," is sorted by disaster type (USDoHS. FEMA 2004). Download data to a spreadsheet program and eliminate all disasters except flooding. Import the data into a GIS program and join it with the county shape files to create a Federally Declared Floods indicator layer.

Indicator Measure: The number of Federally declared floods for each county was summed to obtain a 38-year total for floods. This sum was then divided by its respective county area (square miles) resulting in Federally declared floods per square mile. This distributes the data by area. Distributing the data by area allows for an equal comparison between large and small-area counties. In other words, it protects against a large-area county from a more vulnerable classification because it naturally has more occurrences compared to a small-area county. Statistical analysis resulted in a mean of 0.000442 floods per square mile. Fitting the data around the mean created the following classifications:

Very Low Vulnerability	(1):	0 floods per square mile
Low Vulnerability	(2):	0 – 0.000441 floods per square mile
Moderate Vulnerability	(3):	0.000442 – 0.000662 floods per square mile
Vulnerable	(4):	0.000663 – 0.000884 floods per square mile
High Vulnerability	(5):	>0.000884 floods per square mile.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Flood Risk (A10)

Variable: Population

Scale: Watershed, HUC 4

Year: 1990

Data Source:

USEPA. 1997. *The Index of Watershed Indicators*, EPA-841-R-97-010. Office of Water, Washington, DC,
<http://www.epa.gov/wateratlas/geo/maplist.html>

Hurd, B., N. Leary, R. Jones, and J. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association*, 35(6): 1399-1409,
<http://www.awra.org>

Logic: This indicator is based on the current population living within a 500-Year flood plain. The flood risk indicator characterizes the extent to which lives and property are at risk of flood damages. The 500-Year Floodplain was selected over the more commonly used 100-Year standard because most, if not all, zoning standards and building practices have been based on the 100-Year standard (B. Hurd et al. 1999). This means that those living within the 100-Year Flood plain have generally taken the necessary precautions to mitigate flood risks. There is more concern and risk for populations and property that lie just beyond the margin of the 100-Year Floodplain, where people have not had regulations that have required modifications to properties to mitigate flood risks generally (B. Hurd et al. 1999). This takes into consideration the pressures on the future of negative impacts on water availability and quality. Floods impact local infrastructure, water supplies, and drainage and sanitation. Direct damages to the water supply include repairs or reconstruction costs in water collection works, water processing plants, distribution pips, and leakages in water distribution network; repair costs of sanitary sewage network; and rehabilitation costs of served water treatment plants. Training mis-

sion and carrying capacity would be negatively impacted as a result of a 500-Year flood. This would then place military activities in a vulnerable state, possibly affecting the type and intensity of training that would take place on an installation. Applicable laws and regulations can be found at URL:

<http://www.epa.gov/win/law.html>

Replicable: This indicator will be replaced by the analysis of an installation's proximity to the 100 and 500-Year Floodplain once that data is released in its entirety by FEMA.

Directions: Download "flood risk" from the USEPA *Index of Watershed Indicators* at URL: <http://www.epa.gov/wateratlas/geo/maplist.html>

Import the data into a GIS program and join it with the watershed shapefiles to create a GIS Flood Risk indicator layer.

Indicator Measure: Ranges were defined as estimated number of people within the 500-year floodplain. The flood vulnerability was grouped into the following classifications based on definitions created by the USEPA:

Very Low Vulnerability	(1):	Low Flood Vulnerability (defined by USEPA as less than 20,000 people)
Low Vulnerability	(2):	Not Applicable
Moderate Vulnerability	(3):	Average Flood Vulnerability (defined by USEPA as 20,000 to 200,000 people)
Vulnerable	(4):	Not Applicable
High Vulnerability	(5):	High Flood Vulnerability (defined by USEPA as greater than 200,000 people)

A complete explanation of the USEPA ranges (USEPA 1997) is available at URL:

<http://www.epa.gov/wateratlas/geo/maplist.html>

Note, no data available for Alaska or Hawaii.

Rules: *No rules necessary—HUC 4 classifications are assigned to the HUC 8 level.*

Indicator: TES Richness (A11)

Variable: ESA "Endangered," "Threatened," "Proposed," and "Candidate" Species; The Nature Conservancy G1 (critically imperiled) and G2 (imperiled) Species

Scale: Watershed, HUC 8

Year: 2005

Data Source:

Bak, J. M., S. Sekscienski, and B. Woodson. 2002. *FY 2000 Survey of Threatened and Endangered Species on Army Lands*. U.S. Army Environmental Center. Aberdeen Proving Ground, MD, <http://clients.emainc.com/navfac/>

Sikes Act. 1960. 16 United States Code (USC) 670a-670o, 74 Stat. 1052, <http://laws.fws.gov/lawsdigest/sikes.html>

U.S. Endangered Species Act. 1973. 16 USC 1531-1544, 87 Stat 884.

U.S. Department of Defense, and U.S. Fish and Wildlife Service, U.S. Department of the Interior. 2002. *Integrated Natural Resources Management Plans*. Washington, DC, <http://endangered.fws.gov/DOD/inrmp.pdf>

U.S. Fish and Wildlife Service, U.S. Department of the Interior. 2005. *Threatened and Endangered Species System*. The endangered species program. Washington, DC. (Species Information), <http://endangered.fws.gov>

NatureServe. NatureServe centralized database. 2005. Arlington, VA. <http://www.natureserve.org/explorer/index.htm>

Logic: This indicator characterizes the degree of relative stress that a watershed may be currently experiencing from a variety of sources, including habitat loss, pollution, predation, and disease by counting the number of “endangered,” “threatened,” “proposed,” “candidate,” G1, and G2 species within a watershed.

The presence of TES is highly sought after as a sustainability indicator, since it may possibly put limitations on certain land use actions, military or otherwise, in time or in space. The presence of TES may also possibly indicate water and habitat vulnerabilities. Changes in water supplies and qualities, small or large, will often significantly impact species viability. The sustainability severity or type of limitations (e.g., restrictions, reductions, or change of training) resulting from the presence of TES varies greatly with the species and location. However, for screening purposes, it is practical to characterize regions with a greater presence of TES as more vulnerable to changing water supplies and quantities and to legal and other requirements regarding the conservation and management of those species—possibly affecting the type and intensity of training that would take place on an installation (USDOD et al. 2002).

Replicable: This information could be replicated annually based on updates from the United States Fish and Wildlife Service, Endangered Species Pro-

gram and NatureServe (2005). However, changes in numbers can be anticipated to be relatively small and replication every year should not be universally necessary.

Directions: Use the NatureServe Explorer: <http://www.natureserve.org/explorer/index.htm> to download the number of “endangered,” “threatened,” “proposed,” “candidate,” G1, and G2 species by watershed. Or, contact NatureServe directly to compile the requested datasets. Import the resulting data into a GIS program and join it with HUC 8 watershed boundary files to create a TES Richness indicator layer.

Indicator Measure: This indicator measures the quantity of TES species (“endangered,” “threatened,” “proposed,” “candidate,” G1 and/or G2) present within a watershed. The existence of TES species means consultation with USFWS or the National Marine Fisheries Service (NMFS) is necessary to ensure actions are not likely to jeopardize the continued existence of any TES or result in the destruction or adverse modifications of critical habitat. Whether or not TES presence is a result of water supply/quality conditions or impacts mission activities requires further investigation. The relationship between number of species and current or potential sustainability issues is often unclear—making it difficult to apply criteria based on number of present species without specific knowledge of species or training information. Because of this concern, it is important to use local knowledge in interpreting this indicator.

The number of TES species per watershed was classified as follows using thresholds defined by NatureServe:

Very Low Vulnerability	(1):	0 – 5 TES species
Low Vulnerability	(2):	6 – 12 TES species
Moderate Vulnerability	(3):	13 – 24 TES species
Vulnerable	(4):	25 – 50 TES species
High Vulnerability	(5):	51 or more TES species

Note Missing Data: Species data at the watershed scale was not available for Massachusetts and New Hampshire for this analysis. Additionally, The Nature Conservancy collects species occurrence data from local Natural Heritage Programs across the United States. It is important to note that the following Nature Conservancy data is missing in the NatureServe Central Databases and the dataset used for this analysis:

- *Most Washington animal data.* With the exception of some select species, animal data in Washington is tracked by an agency outside the Washing-

ton Natural Heritage Program and the methodology of that animal location data is not currently compatible with Heritage EO Methodology.

- *Alaska animal data.* NatureServe is unable to provide Alaska animal data until they complete their next data exchange with their Heritage program in the coming year.
- *Arizona data.* NatureServe does not currently store the coordinates for Arizona species location data in their Central Database. The crosstab tallies for watersheds that intersect with Arizona do not include counts of species locations within the state of Arizona.

Note Category Definitions: The U.S. Endangered Species Act (ESA) enacted in 1973 recognized two principal status categories, “endangered” and “threatened.” As defined in the act, endangered refers to species that are “in danger of extinction within the foreseeable future throughout all or a significant portion of its range,” while threatened refers to “those animals and plants likely to become endangered within the foreseeable future throughout all or a significant portion of their ranges.” As a part of the listing process, two additional categories exist, “proposed” and “candidate” species. “Proposed” species are those for which listing rules have been published in the Federal Register, but formal listing still awaits administrative action. “Candidate” species are those for which the implementing agency (either the USFWS or the NMFS) has sufficient information about vulnerability and threats to support listing.

Furthermore, The Nature Conservancy has established the NatureServe conservation status ranks. Here the conservation status of a species or community is designated by a number from 1 to 5, preceded by a letter reflecting the appropriate geographic scale of the assessment (G=Global, N=National, and S=Subnational). The numbers have the following meaning: 1=critically imperiled; 2=imperiled; 3=vulnerable to extirpation or extinction; 4=apparently secure; and 5=demonstrably widespread, abundant, and secure. For example, G1 would indicate that a species is critically imperiled across its entire range (i.e., globally). In this sense, the species as a whole is regarded as being at very high risk of extinction. A rank of S3 would indicate the species is vulnerable and at moderate risk within a particular state or province, even though it may be more secure elsewhere.

Criteria in assessing conservation status for both systems include: occurrence, condition, population size, area of occupancy, range, trends, threats, fragility, and protected occurrences. The ESA or The Nature Conservancy listings en-

sues cooperation with Federal agencies for the planning, management, and maintenance of fish and wildlife populations and their associated habitat.

Rules: *No rules necessary for relating data to the HUC 8 watershed level.*

Indicator: TES Hotspot (A12)

Variable: Presence of Species, The Nature Conservancy Rarity-Weighted Index

Scale: Watershed, HUC 8

Year: 2005

Data Source:

Bak, J. M., S. Sekscienski, and B. Woodson. 2002. *FY 2000 Survey of Threatened and Endangered Species on Army Lands*. U.S. Army Environmental Center. Aberdeen Proving Ground, MD, <http://clients.emainc.com/navfac/>

Nature Conservancy, The. 2003. Bruce A. Stein, Lynn S. Kutner, and Jonathan S. Adams (eds.) *Precious Heritage: The Status of Biodiversity in the United States*. Oxford University Press.

Sikes Act. 1960. 16 USC 670a-670o, 74 Stat. 1052, <http://laws.fws.gov/lawsdigest/sikes.html>

U.S. Endangered Species Act. 1973. 16 USC 1531-1544, 87 Stat 884.

U.S. Department of Defense, U.S. Fish and Wildlife Service, and U.S. Department of the Interior. 2002. *Integrated Natural Resources Management Plans*. Washington, DC, <http://endangered.fws.gov/DOD/inrmp.pdf>

U.S. Fish and Wildlife Service, and U.S. Department of the Interior. 2005. *Threatened and Endangered Species System*. The endangered species program. Washington, DC. (Species Information), <http://endangered.fws.gov>

NatureServe. NatureServe centralized database. 2005. Arlington, VA. <http://www.natureserve.org/explorer/index.htm>

Logic: This indicator characterizes the degree of relative stress that a Watershed may be currently experiencing from a variety of sources, including habitat loss, pollution, predation, and disease by counting the number of “rare” species within a watershed. The logic behind TES Hotspots is that a watershed assumes increased conservation significance if a number of species occur only in that watershed, since protection of these unique species cannot be accomplished elsewhere. At least with regard to those species, the watershed is “irreplaceable” from a conservation perspective. On the other

“irreplaceable” from a conservation perspective. On the other hand, if a watershed contains a high diversity of species, all of which can be found in other watersheds as well, that watershed would not be irreplaceable to the protection of those species (although it might still be extremely important in their conservation). Employing this concept of irreplaceability, two watersheds with the same number of imperiled species may differ considerably in their conservation significance. This approach has been characterized as the “rarity-weighted richness index” by The Nature Conservancy. Rarity in this context refers to species with restricted distributions.

Identification of relatively rare species is highly sought after as a sustainability indicator due to the possible limitations rare species may put on certain land use actions, military or otherwise, in time or in space. The severity or type of limitations resulting from the presence of rare species, however, varies greatly with the species and location. For example, one region may house a regionally rare species, of which the presence has resulted in significant restrictions on water supplies, water quality, and/or military training. Another region may house a differing regionally rare species, of which the presence has no direct impacts on water or military missions. It is not guaranteed that a region with one or more rare species will significantly increase regulatory restrictions. Nor is it guaranteed that a region with multiple rare species will experience increased regulatory restrictions compared to a region with a single rare species. However, for screening purposes, it is practical to characterize regions with a greater presence of rare species as more vulnerable to water and mission sustainability requirements (USDOD et al. 2002).

Replicable: This information could be replicated annually based on updates from the United States Fish and Wildlife Service, Endangered Species Program and NatureServe (2005). However, changes in numbers can be anticipated to be relatively small and replication every year should not be universally necessary.

Directions: Access NatureServe: <http://www.natureserve.org/explorer/index.htm> to download species by watershed. Or, contact NatureServe directly to compile the requested datasets. Calculate rarity-weighted richness index (RWRI) by first assigning a score—or weight—based on the inverse of the number of watersheds in which it occurs. For instance, if a species is found in only a single watershed, that species receives the maximum possible score of 1/1 or 1.0. The score for a species that occurs in 20 watersheds would be 1/20 or 0.05. The individual scores of all species in a watershed are then summed to yield a rarity-weighted index for the watershed. This can be expressed mathematically as:

$$RWRI = \sum_{i=1}^n 1/h_i$$

where:

h_i = the number of watershed that species I occupies

n = the number of species found within a watershed.

In the case of a watershed containing two species, one of which is restricted to that watershed and the other occurs in 19 other watersheds, the RWRI for the watershed would equal 1.05. This score may be thought of as the watershed's index of irreplaceability.

Import the resulting data into a GIS program and join it with HUC 8 watershed boundary files to create a TES Hotspots indicator layer.

Indicator Measure: This indicator measures the quantity of species with restricted distributions present within a watershed. This 'rarity-weighted richness' approach tends to favor the identification of hotspot clusters that represent concentrations of limited-range species, and high turnover species between adjacent watersheds. As previously discussed, whether or not a TES hotspot impacts water and mission sustainment activities requires further investigation. Because of this concern, it is important to use local knowledge in interpreting this indicator.

The number of restricted distribution species per watershed was statistically classified around the average (1.8252 RWRI):

Very Low Vulnerability	(1):	0 RWRI
Low Vulnerability	(2):	>0 – 0.3503 RWRI
Moderate Vulnerability	(3):	>0.3506 - <=1.9211 RWRI
Vulnerable	(4):	>1.9211 - <=8 RWRI
High Vulnerability	(5):	>8 RWRI.

Note Missing Data: Species data at the watershed scale was not available for Massachusetts and New Hampshire for this analysis. Additionally, The Nature Conservancy collects species occurrence data from local Natural Heritage Programs across the United States. It is important to note that the following Nature Conservancy data is missing in the NatureServe Central Databases and the dataset used for this analysis:

- *Most Washington animal data:* With the exception of some select species, animal data in Washington is tracked by an agency outside the Washing-

ton Natural Heritage Program and the methodology of that animal location data is not currently compatible with Heritage EO Methodology.

- *Alaska animal data*: NatureServe is unable to provide Alaska animal data until they complete their next data exchange with their Heritage program in the coming year.
- *Arizona data*: NatureServe does not currently store the coordinates for Arizona species location data in their Central Database. The crosstab tallies for watersheds that intersect with Arizona do not include counts of species locations within the state of Arizona.

Rules: No rules necessary for relating data to the HUC 8 watershed level.

Indicator: Criteria Pollutant Non-Attainment (A13)

Variables: Six Principal Air Pollutants (also referred to as criteria pollutants): Nitrogen Dioxide (NO₂), Ozone (O₃), Sulfur Dioxide (SO₂), Particulate Matter (PM), Carbon Monoxide (CO), and Lead (Pb)

Scale: County

Year: 2007

Data Sources:

USEPA. 2007. *Green Book Non-Attainment Areas for Criteria Pollutants*. (Non-attainment Status for Each County by Year). Office of Air and Radiation/Office of Air Quality Planning and Standards. Washington, DC, <http://www.epa.gov/oar/oaqps/greenbk/anay.html>

USEPA. 2004. *The Particle Pollution Report: Current Understanding of Air Quality and Emissions through 2003*. Office of Air Quality Planning and Standards, Emissions, Monitoring, and Analysis Division. Washington, DC, <http://www.epa.gov/airtrends/>

Logic: The Clean Air Act provides the principal framework for national, state, tribal, and local efforts to protect air quality. Under the Clean Air Act, USEPA establishes air quality standards to protect public health by setting National Attainment Air Quality Standards (NAAQS) for the six principal pollutants that are considered harmful to public health and the environment: nitrogen dioxide (NO₂), ozone (O₃), sulfur dioxide (SO₂), particulate matter (PM), CO, and lead (Pb), and ensures that these air quality standards are met. USEPA tracks trends in air quality based on actual measurements of pollutant concentrations in the ambient (outside) air at monitoring sites across the country. State, tribal, and local government agencies and also some Federal agencies, including the USEPA, operate monitoring stations.

Air quality is important to both water sustainability and military operations. Being located in a non-attainment zone is a strong indicator that the military may face restrictions on the amounts of certain emissions they can release (including mobility emissions) as part of the region's plan for coming into attainment. It may also be a strong indicator of water supply and quality vulnerabilities. For example, as water supplies diminish so may plant species critical to filtering air pollutants.

Information concerning what affects each criterion is available from the USEPA at <http://www.epa.gov>. Moreover, each criterion is vulnerable to change. Thus, the data should be updated regularly and the age of the data should be carefully noted in any analysis. Additionally, the data reflects county level data where different values are reported for the same county in the same year in some cases. Thus, knowledge of the local area and its efforts need to be considered especially in large acreage counties.

Replicable: Each year USEPA examines changes in levels of these ambient pollutants and their precursor emissions. This indicator could be replicated annually based on USEPA updates.

Directions: Download *Non-Attainment Status for Each County by Year* for all U.S. counties from the USEPA Green Book at <http://www.epa.gov/air/oaqps/greenbk/anay.html> (USEPA 2007). Import the *Classification* data into a GIS program and join it with county boundary files to create a Criteria Pollutant Non-Attainment indicator layer.

Indicator Measure: Emission status indicates whether or not a U.S. County is in attainment of USEPA air quality emission standards for the six criteria pollutants. The USEPA designates a classification rating for each criteria depending on the non-attainment status—extreme, severe, serious, moderate, marginal, primary, subpart 1, and section 185A (USEPA 2007). Different values may be reported for the same county in the same year in some cases. In this case, the worst value is indicated (USEPA 2004). The emission ratings were grouped into the following classifications:

Very Low Vulnerability	(1):	Attainment
Low Vulnerability	(2):	Primary Violations
Moderate Vulnerability	(3):	Marginal and Moderate Violations
Vulnerable	(4):	Serious and Severe Violations
High Vulnerability	(5):	Non-attainment and Extreme Violations.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by the highest vulnerability rating present

within the watershed.

Indicator: Water Quality (A14)

Variables: Waters meeting designated uses, Source water condition for drinking water systems, Fish & wildlife consumption advisories, Indicators of source water condition, Contaminated sediments, Ambient water quality – toxics, Water quality – conventional, Wetlands loss, Aquatic and wetlands species at risk, Loads over limits – toxics, over limits – conventional, Urban runoff potential, Agriculture runoff potential, Population change, Hydrologic modification caused by dams, Estuarine pollution susceptibility, Deposition

Scale: Watershed, HUC 8

Year: 1999

Data Source:

USEPA. 1997. *The Index of Watershed Indicators*, EPA-841-R-97-010. Office of Water, Washington, DC,
<http://www.epa.gov/wateratlas/geo/maplist.html>

USEPA. 1999. *EPA Overall Watershed Characterization: September 1999 IWI Release*. Office of Water, Washington, DC,
<http://www.epa.gov/iwi/1999sept/catalog.html>

Logic: The Index of Watershed Indicators (IWI) characterizes the condition and vulnerability of aquatic systems in each of the 2,262 watersheds in the 50 states and Puerto Rico (USEPA 1999). This involves an assessment of condition, vulnerability, and data sufficiency. All variables taken into consideration are strong indicators of pressures in the future on water quality and vulnerability, leading to greater demands and risks to water supplies (USEPA 1999). This would then place the military installation in a vulnerable state, possibly affecting the type and intensity of training that would take place on the installation. (Supplementary applicable laws and regulations, available through URL: <http://www.epa.gov/win/law.html>)

A watershed is the area of land where all of the water that is under it or drains off of it is routed to a specific waterway. Watersheds are delineated by USGS using a nationwide system based on surface hydrologic features. This system divides the country into 21 regions, 222 subregions, 352 accounting units, and 2,262 cataloguing units. An HUC consisting of two digits for each level in the hydrologic unit system is used to identify any hydrologic area. The 6-digit accounting units and the 8-digit cataloguing units are generally referred to as

basin and sub-basin. There are many states that have defined down to 16-digit HUCs (USEPA 1997).

Replicable: This indicator could be replicated every 2-4 years based on Regional inputs and monitoring programs. The Index of Watershed Indicators results are based on monitoring programs established within USEPA Regions; monitoring programs vary across the country (USEPA 1999). Areas with strong monitoring programs may show more problems than those with weaker programs and replicability of these indicators depends heavily on current and future monitoring programs.

Directions: Download “water quality” from the USEPA *Overall Watershed Characterization: September 1999 IWI Release* (USEPA 1999), available through URL: <http://www.epa.gov/iwi/1999sept/catalog.html>

Import the data into a GIS program and join it with the watershed shapefiles to create a GIS Water Quality indicator layer.

Indicator Measure: This map combines 17 disparate data layers as listed above; layers were weighted and then combined by the USEPA. The approach taken by the USEPA (1999) can be found at:

http://oaspub.epa.gov/eims/direnrpt.report?p_deid=9996&p_chk=9186

Indicators of the condition of the watershed were scored and assigned to one of three categories: better water quality, water quality with less serious problems, and water quality with more serious problems (USEPA 1999). It is important to note that the strength of monitoring programs varies across the country and is reflected in the map. Areas with strong monitoring programs may show more problems than those with weaker programs. The water quality IWI ratings were defined as follows by the USEPA (1999):

Very Low Vulnerability	(1):	Good Water Quality
Low Vulnerability	(2):	Better Water Quality
Moderate Vulnerability	(3):	Less Serious Water Quality Problems
Vulnerable	(4):	More Serious Water Quality Problems
High Vulnerability	(5):	Serious Water Quality Problems

Note, no data available for Alaska or Hawaii.

Rules: No rules necessary for relating data to the HUC 8 watershed level.

Sustainability Issue: Water Demand

Indicator: Total Withdrawals (D1)

Variables: Total Withdrawals (groundwater and surface water, all uses), gal/year

Scale: County

Year: 2000

Data Sources:

USGS. (2002). Estimated Use of Water in the United States in 2000. U.S. Department of the Interior: <http://water.usgs.gov/watuse/>

Logic: Groundwater depletion is a measure of groundwater withdrawals. Groundwater withdrawals can affect both ground and surface water supplies and quality. Intensive withdrawals have led to cases where wells, springs, and wetlands have gone dry; lake levels have dropped; stream flow has been reduced with great harm to wildlife; and contamination has prevented installation of new wells.

Excessive groundwater withdrawals suggest that increased groundwater use may not be a viable adaptation to changes in surface water supply or increases in water demand (B. Hurd et al. 1999). The drop in the water table known as groundwater mining is one problem. It occurs when water is withdrawn from an aquifer more rapidly than it is replenished. As the water table drops, water pumping costs increase. Eventually, the users run out of water. Extensive groundwater mining also may cause subsidence, a lowering of the land surface. Subsidence occurs when the removal of water levels underground spaces that collapse or when underlying clay shrinks from lack of moisture. The result looks like a cone of depression on the land. Lowered water tables can also lead to greater contamination of groundwater. The reduction in surface water lowers the ability of a region's waterways to filter pollutants from water before it flows in to recharge an aquifer. Average groundwater withdrawals in excess of natural base flows indicate an unsustainable rate of groundwater use.

Replicable: This indicator could be replicated every 5 years based on USGS updates.

Directions: Download "2000 data for counties" from the USGS *Water Use in*

the United States (USGS 2000), available through URL:

<http://water.usgs.gov/watuse/>

Import the total withdrawals data into a GIS program joined with the county shapefile to create a Total Withdrawals indicator layer.

Indicator Measure: This indicator identifies areas of high water demand. The total withdrawal ratings were defined as follows around the statistical mean (35,451,064) and standard deviation (177,860,039):

Very Low Vulnerability	(1):	<17,725,532 gal/yr
Low Vulnerability	(2):	17,725,532 - 35,451,064 gal/yr
Moderate Vulnerability	(3):	35,451,064 - 213,311,103 gal/yr
Vulnerable	(4):	213,311,103 - 231,036,635 gal/yr
High Vulnerability	(5):	>231,036,635 gal/yr.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Consumption Rate (D2)

Variables: Total public supply per capita consumption rate (Mgal/d)

Scale: County

Year: 1995-2000

Data Sources:

USGS. 2002. Estimated use of water in the United States in 2000. U.S. Department of the Interior, Washington, DC,
<http://water.usgs.gov/watuse/>

USGS. 1995. Estimated use of water in the united states in 1995. U.S. Department of the Interior, Washington, DC,
<http://water.usgs.gov/watuse/>

Logic: Public water consumption is a measure of water demand. Growing demand can affect both ground and surface water supplies and quality. Intensive withdrawals have led to cases where wells, springs, and wetlands have gone dry; lake levels have dropped; steam flow has been reduced with great

harm to wildlife; and contamination has prevented installation of new wells.

It is particularly important for high growth regions to reduce per capita consumption to avoid excessive increases in water withdrawals and non-viable changes in surface water supply (B. Hurd et al. 1999). The drop in the water table known as groundwater mining is one problem. It occurs when water is withdrawn from an aquifer more rapidly than it is replenished. As the water table drops, water pumping costs increase. Eventually, the users run out of water. Extensive groundwater mining also may cause subsidence, a lowering of the land surface. Subsidence occurs when the removal of water levels underground spaces that collapse or when underlying clay shrinks from lack of moisture. The result looks like a cone of depression on the land. Lowered water tables can also lead to greater contamination of water supplies. The reduction in surface water lowers the ability of a region's waterways to filter pollutants from water before it flows in to recharge an aquifer. Average water withdrawals in excess of natural base flows indicate an unsustainable rate of groundwater use.

Replicable: This indicator could be replicated every 5 years based on USGS updates.

Directions: Download "2000 data for counties" and "1995 data for counties" from the USGS *Water Use in the United States* (USGS 2002), available through URL: <http://water.usgs.gov/watuse/> in a spreadsheet program. Calculate the percent change from 1995 to 2000 total per capita use from public supply:

$$\left[\frac{(\text{Consumption Rate} = (\text{Per capita consumption 2000} - \text{Per capita consumption 1995}) / \text{Per capita consumption 1995}) * 100 \right]$$

Import the data into a GIS program and join it with the county shapefile to create a Total Withdrawals indicator layer.

Indicator Measure: This indicator measures areas of growing water demand. The consumption ratings were defined as follows around the statistical mean (9%) and standard deviation (175):

Very Low Vulnerability	(1):	<0%
Low Vulnerability	(2):	0 – 9%
Moderate Vulnerability	(3):	9 – 184%
Vulnerable	(4):	184 – 359%
High Vulnerability	(5):	>359%.

Rules: Watersheds often cover two or more counties. Therefore, watershed

classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Water for Energy Production (D3)

Variables: Thermoelectric power, total withdrawals (Mgal/day)

Scale: County

Year: 2000

Data Sources: USGS. (2002). Estimated Use of Water in the United States in 2000. U.S. Department of the Interior: <http://water.usgs.gov/watuse/>

Logic: Electric power plants are among the greatest users of water in the United States, especially in the northern and eastern parts of the country. Water for thermoelectric power is used in generating electricity with steam-driven turbine generators. In 2000, about 195,000 million gallons of water each day (Mgal/d) were used to produce electricity (excluding hydroelectric power). Surface water was the source for more than 99 percent of total thermoelectric-power withdrawals. In coastal areas, the use of saline water instead of freshwater expands the overall available water supply. Saline withdrawals from surface water sources accounted for 96 percent of the National total saline withdrawals. Thermoelectric-power withdrawals accounted for 48 percent of total water use, 39 percent of total freshwater withdrawals for all categories, and 52 percent of fresh surface-water withdrawals.

One of the main uses of water in the power industry is to cool the power-producing equipment. Water used for this purpose does cool the equipment, but at the same time, the hot equipment heats up the cooling water. Overly hot water cannot be released back into the environment. It would be detrimental to fish downstream from a power plant releasing the hot water. So, the used water must first be cooled. One way to do this is to build very large cooling towers and to spray the water inside the towers. Evaporation occurs and water is cooled. That is why large power-production facilities are often located near rivers, lakes, and the ocean. Overall, large portions of the water supply used for power generation is linked to unsustainable withdrawals of water resources.

Replicable: This indicator could be replicated every 5 years based on USGS updates.

Directions: Download “2000 data for counties” from the USGS *Water Use in the United States* (USGS 2002), available through URL:

<http://water.usgs.gov/watuse/>

Import *Thermoelectric power, total withdrawals* data into a GIS program and join it with the county shapefile to create a Water for Energy Production indicator layer.

Indicator Measure: This indicator measures areas where 50 percent or more of the water withdrawals go towards energy production. The consumption ratings were defined as follows:

Very Low Vulnerability	(1):	=0%
Low Vulnerability	(2):	>0 – 25%
Moderate Vulnerability	(3):	>25 – 50%
Vulnerable	(4):	>50 – 75%
High Vulnerability	(5):	>75%.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county’s classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Regional Population Density (D4)

Variables: Population, Land Area (square mile)

Scale: County

Year: 2007

Data Source:

Bureau of the Census, U.S. Department of Commerce. 2007. *County Population Estimates and Estimated Components of Change, April 1, 2000 to July 1, 2007*. Population Estimates Program, Washington, DC,
http://eire.census.gov/popest/estimates_dataset.php

Bureau of the Census, U.S. Department of Commerce. 2001. Summary file 1: GCT-PH1-R population, housing units, area, and density. *American FactFinder*. Washington, DC, <http://factfinder.census.gov>

Craig, John. 1984. Averaging population density, *Demography*, 21(3):405-412, <http://www.jstor.org/>

Logic: This indicator provides a measure of the population density for all U.S. counties. A high regional population density can have both negative and positive impacts on water and mission sustainability vulnerabilities. For example, high density means lower costs associated with the development and maintenance of sewer and water lines. Yet, higher density also means greater concentrations of pollutants entering and withdrawals taken from water systems at specific locations and greater probabilities for restrictions on military activities. Thus, it is important to understand the implications and limitation of the Regional Population Density indicator.

For purposes of water supply, higher densities are assumed to reduce resource vulnerabilities. In other words, greater density is viewed as lowering infrastructure costs and increasing efficiency. In contrast, sprawling development patterns tend to require long stretches of sewer and water lines with intense pressures to move water through the pipes. This is often associated with large energy costs and higher probabilities of water leaks. Here, higher densities are linked to lower vulnerabilities. But because of potential risks associated with higher densities, it is important to use local knowledge in interpreting the Regional Population Density classification. The most important idea is to direct development to locations where the environment can handle it in a way that does not create damage to surrounding environments.

Replicable: This indicator could be replicated every year based on Census population estimates, or every decade based on actual, verifiable counts.

Directions: Download county population from the U.S. Census Bureau, *County Population Estimates and Estimated Components of Change, April 1, 2000 to July 1, 2007*,

http://eire.census.gov/popest/estimates_dataset.php

Download land area from U.S. Census Bureau,

<http://factfinder.census.gov>

Import the data into a spreadsheet program and divide the total population for each county in the United States by the land area (not total area, which includes water bodies) in that county to reach a population density figure:

[Regional Population Density = total population / land area].

Import the resulting math into a GIS program and join it with the county shape files to create a GIS Regional Population Density indicator layer.

Indicator Measure: This indicator measures potential efficiency in water supply systems. The average population density for the entire United States is 79.6 people per square mile according to the 2000 U.S. Census. The mean density for U.S. counties is 247 people per square mile. The results were then subjected to a normal statistical distribution (19%/62%/19%) to determine vulnerability classifications:

Very Low Vulnerability	(1):	$\geq 2,000$ people per square mile
Low Vulnerability	(2):	$\geq 247 - < 2,000$ people per square mile
Moderate Vulnerability	(3):	$\geq 12 - < 247$ people per square mile
Vulnerable	(4):	$\geq 6 - < 12$ people per square mile
High Vulnerability	(5):	< 6 people per square mile.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Regional Population Growth (D5)

Variables: Total Population 1993 and 2003

Scale: County

Year: 2000 and 2007

Data Source:

Bureau of the Census, U.S. Department of Commerce, *County Population Estimates and Estimated Components of Change, April 1, 2000 to July 1, 2007* (Population Estimates Program. Washington, DC, 2004),
http://eire.census.gov/popest/estimates_dataset.php

Logic: This indicator measures the population growth over the last 7 years for each U.S. county. Population growth is one of the leading causes of environmental degradation, because more people use more resources including water, energy, and waste disposal, and other problems. This indicator assumes that fast growing human populations are less sustainable—particularly to water resources and military mission related activities. The degree of regional population growth is a strong indicator of the demand for services, access, resources, and land in competition with the military installation. This can affect water availability and quality and also the type and intensity of training that can take place on military facilities.

Additionally, it is important to note this data is site specific and may be skewed by local “hotspots.” In other words, if a region (e.g., watershed) has one community with relatively high regional population growth, the entire region is classified as high regional population growth regardless of the characteristics of the remaining majority of the region. Because of this concern, it is important to use local knowledge in interpreting the Regional Population Growth classifications.

Replicable: This indicator could be replicated every year based on U.S. Census Bureau population estimates, or every decade based on actual, verifiable counts.

Directions: Download population for all U.S. counties for 2000 and estimates for 2007 from the U.S. Census Bureau Population Estimates Program, *County Population Estimates and Estimated Components of Change, 1 April 2000 to 1 July 2007*. Import data into a spreadsheet program and calculate the 2000 to 2007 population growth rate as follows:

$$\text{Regional Growth Rate} = ((\text{Population 2007} - \text{Population 2000}) / \text{Population 2000}) * 100.$$

Import the resulting math into a GIS program and join it with the county shape files to create a GIS Regional Growth Rate indicator layer.

Indicator Measure: Regional Growth Rate is a measure of how fast a county has grown during the previous decade. The population growth rate is measured from 2000 to 2007. This data is available from the U.S. Census at URL: http://eire.census.gov/popest/estimates_dataset.php

The data illustrates a county average growth rate of 2.9 percent. The results were statistically classified based on the mean and standard deviation (9.3) values:

Very Low Vulnerability	(1):	>0% growth
Low Vulnerability	(2):	0 – 0.5%
Moderate Vulnerability	(3):	0.5 – 4 % growth
Vulnerable	(4):	4 – 8% growth
High Vulnerability	(5):	>8% growth.

Rules: Watersheds often cover two or more counties. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each county and multiplies that percentage for each county by that county's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: Regional Population Projection (D6)

Variables: Total Population 2000, Total Population Projection 2030

Scale: State

Year: 2000 and 2030

Data Source: Bureau of the Census, U.S. Department of Commerce, Population Projections.

Logic: This indicator measures the likely population count in 2030 for each U.S. county. Population growth is one of the leading causes of environmental degradation, because more people use more resources including water, energy, and waste disposal, and other problems. This indicator assumes that large human populations are less sustainable—particularly to water resources and military mission related activities. The amount of population within a region is a strong indicator of the demand for services, access, resources, and land in competition with the both the environment and military facilities. This can affect water availability and quality and also the type and intensity of training that can take place on military facilities.

Additionally, it is important to note this data is collected at the state level and may be both overly general. State data may be skewed by local “hotspots.” In other words, if a state has one community with relatively high regional population growth, the entire region received a higher classified regardless of the

characteristics of the remaining majority of the state. Because of this concern, it is important to use local knowledge in interpreting the Regional Population Projection classifications.

Replicable: This indicator could be replicated every decade based on U.S. Census Bureau population projections.

Directions: Download population projection for all U.S. states from the U.S. Census Bureau. Import the data into a spreadsheet program and calculate projected population growth rate using 2000 population counts and 2030 population projections:

$$\text{[Regional Population Projection Growth Rate} = ((\text{Population 2030} - \text{Population 2000}) / \text{Population 2000}) * 100\text{].}$$

Import the resulting math into a GIS program and join it with the state shape files to create a GIS Regional Population Projection indicator layer.

Indicator Measure: This indicator measures potential future regional population concentrations. Range classifications were based on statistical analysis around the mean (31.37 percent growth) and standard deviation

Very Low Vulnerability	(1):	<0% growth
Low Vulnerability	(2):	0 – 5%
Moderate Vulnerability	(3):	5 – 31%
Vulnerable	(4):	31 – 58%
High Vulnerability	(5):	>58%

Rules: Watersheds often cover two or more states. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each state and multiplies that percentage for each state by that state's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual counties.

Indicator: State Smart Growth Plans (D7)

Variables: Presence of State Smart Growth Plan

Scale: State

Year: 2002

Data Source:

American Planning Association (APA), *Planning for Smart Growth: 2002 State of the States* (Smart Growth Network, Chicago, IL, 2002), available through URL: <http://www.planning.org/growingsmart/states2002.htm>

Logic: This indicator shows the status of State Smart Growth Initiatives across the United States. Smart growth is the planning, design, development, and revitalization of cities, towns, suburbs, and rural areas to create and promote social equity, a sense of place and community, and to preserve natural and cultural resources. Smart growth enhances ecological integrity over both the short- and long-term, and improves quality of life for all by expanding—in a fiscally responsible manner—the range of transportation, employment, and housing choices available to a region (APA 2002).

The presence of a state smart growth plan is important because smart growth legislation can reduce sprawl and decrease the growth of urbanized land within a region. This in turn decreases water resource and military mission vulnerabilities. The logic is that regions pursuing smart growth legislation are also addressing water and mission sustainability.

Replicable: This indicator could be replicated regularly as long as the APA continues to monitor Smart Growth (which is likely considering that one of the main tenants of the APA currently is to get smart growth passed in every state). It is recommended that this indicator be updated annually.

Directions: APA constructed a map to chart the progress of smart growth reform. That map is available at URL:

<http://www.planning.org/growingsmart/states2002.htm>

Import the map data into a GIS program state shapefile to create a GIS State Smart Growth Plans indicator layer.

Indicator Measure: Substantial Reforms means that smart growth legislation has been passed in the state. Moderate reforms or pursuing additional reforms means that some form of land use laws resembling smart growth have been passed or legislation has been proposed. No reforms mean that no legislation has been passed or proposed (APA 2002):

Very Low Vulnerability	(1):	Substantial Reforms
Low Vulnerability	(2):	Not Applicable
Moderate Vulnerability	(3):	Moderate (or Pursuing Additional) Reforms
Vulnerable	(4):	Not Applicable

High Vulnerability (5): No Reforms

Rules: Watershed boundaries do cross state boundaries. In this case, the watershed takes on the highest vulnerability rating located within its boundaries.

Indicator: Proximity to MSA (D8)

Variables: MSA, Mile Buffers

Scale: National

Year: 2003

Data Source:

Bureau of the Census, U.S. Department of Commerce, *About Metropolitan and Micropolitan Statistical Areas* (Office of Management and Budget, Washington, DC, 2003),
<http://www.census.gov/population/www/estimates/aboutmetro.html>

Logic: This indicator measures the presence of an MSA in a HUC 8 watershed, which indicates the potential for resource sustainment vulnerabilities. MSAs are a geographic entity designated by the Federal Office of Management and Budget for use by Federal statistical agencies. An MSA consists of one or more counties, except in New England, where MSAs are defined in terms of county subdivisions (primarily cities and towns) (USDOC, Bureau of the Census 2003). MSAs are defined by intense urban development. The logic is that large expanses of population centers are a strong indicator of pressures on the use and vulnerability of resources. Particularly, water resources where intensive withdrawals have led to cases where wells, springs, and wetlands have gone dry; lake levels have dropped; stream flow has been reduced with great harm to wildlife; and contamination has prevented installation of new wells.

Additionally, it is important to note that HUC 8 watersheds are relatively large areas. The likelihood of an MSA present within its boundaries is high. Thus, data may be skewed local 'hotspots.' In other words, if a watershed has contains a small portion of an MSA, the entire watershed received an MSA present classification regardless of the characteristics of the remaining majority of the watershed. Because of this concern, it is important to use local knowledge in interpreting the Proximity to MSA classifications.

Replicable: This indicator could be replicated every 10 years based on U.S. Census Bureau population counts. Following each decadal census, the U.S.

Census Bureau finalized and publishes MSA classifications.

Directions: Download the GIS layer containing MSAs from the U.S. Census Bureau. Import the data into a GIS program and create buffers at a predetermined distance from the edge of each MSA to show a level of risk.

Indicator Measure: Proximity to MSA is defined as the distance from the nearest MSA. All watersheds with an MSA were classified as highly vulnerable, while all watersheds not within an MSA, but within 20 miles of an MSA were classified as moderately vulnerable. All watersheds outside of the 20-mile buffer were considered not vulnerable. Proximity to MSA classifications were defined as follows:

Very Low Vulnerability	(1): Areas greater than 20 miles from any MSA
Low Vulnerability	(2): Not Applicable
Moderate Vulnerability	(3): Areas not within an MSA, but within 20 miles of one or more MSAs
Vulnerable	(4): Not Applicable
High Vulnerability	(5): Areas within a designated MSA

Rules: This indicator measures a watershed's proximity to an MSA. If only part of a watershed is located within an MSA, then that watershed takes on the highly vulnerable classification. The same follows if a watershed straddles the 20 mile buffer—half of the watershed within 20 miles the other half greater than 20 miles, the watershed takes on the 'moderate' vulnerability classification.

Indicator: Proximity to Interstate (D9)

Variables: Interstate Highways, Mile Buffers

Scale: National

Year: 2003

Data Sources:

ESRI, GIS Data Layers, available through URL: <http://www.esri.com>

Logic: This indicator provides a measurement of the presence of interstate highways within a watershed. The proximity of an interstate to a watershed is an indicator of availability of full transportation access, but also an indicator of development and a gauge of the health of natural resources.

Urban uses (or removal of natural land cover) change the local water balance. Imperviousness changes the routing and timing for water to reach a lake or stream. Trees, shrubs and grasses are natural land covers. They shelter the soil surfaces from rain, wind, and surface erosion; intercept precipitation; and filter rainwater. When rain reaches the ground, leaf litter and shallow roots are there to absorb it and recycle rainwater. Natural land covers encourage the lateral movement of shallow infiltrated precipitation into wetlands, lakes and streams. Development of interstate highways requires the removal of some natural land cover to create a reliable hard surface. Unintended results may include: removal of natural storage, retention, and recycling of precipitation; significant increases in overland runoff into surface waters; decreases in stream base flow and groundwater recharge; widening or morphology of stream channels; increases in floodwater velocities; and increases in the magnitude and frequency of flooding.

Replicable: This indicator could be replicated every year based on updated interstate highway maps as new construction occurs.

Directions: Obtain and open an interstates shapefiles from ESRI in a GIS program. Create “buffers” around these interstates at pre-determined distances to develop a Proximity to Interstate indicator layer.

Indicator Measure: Proximity to interstates is defined as the distance from the nearest interstate highway. All watersheds within 20 miles of an interstate were considered to be areas of development (high vulnerability), while all watersheds more than 20 miles, but less than 50 miles from an interstate were considered to be moderately developed (moderate vulnerability). All watersheds outside of these buffers are considered undeveloped (very low vulnerability). Proximity to Interstate classifications are defined as follows:

- | | |
|-----------------------------|---|
| Very Low Vulnerability (1): | Greater than 50 miles from an interstate |
| Low Vulnerability (2): | Not Applicable |
| Moderate Vulnerability (3): | Within 50 miles, but greater than 20 miles from an interstate |
| Vulnerable (4): | Not Applicable |
| High Vulnerability (5): | Within 20 miles of an interstate |

Rules: This indicator rates watersheds by evaluating its proximity to interstate highways. The watershed takes on the highest vulnerability classification depending on its proximity to an interstate. For instance, if an watershed straddles the 20 mile buffer—half of the installation within 20 miles the other half greater than 20 miles, the region resource takes on the ‘moderate vulnerability’ classification.

Indicator: Traffic Volume (D10)

Variables: Annual Average Daily Traffic per Lane (AADT)

Scale: State

Year: 2006

Data Sources:

Chen, Ciao, Zhanfeng Jia, and Pravin Varaiya, *Causes and Cures of Highway Congestion* (University of California at Berkeley, Berkeley, CA, 2001), http://paleale.eecs.berkeley.edu/~varaiya/papers_ps.dir/csmppaperv3.pdf

Federal Highway Administration, U.S. Department of Transportation, *Highway Statistics 2001* (Table HM-62, Average Daily Traffic per Lane on Principal Arterials; Appendix B, Methodology for 2006 Annual Report) (Office of Highway Policy Information, Washington, DC, 2006), available through URL: <http://www.fhwa.dot.gov/ohim/hs01/aspublished/hm62.htm>
http://mobility.tamu.edu/ums/study/methods/entire_methodology.pdf

TTI, *Urban Mobility Study* (Appendix A Exhibit A-17, 2000 Roadway Congestion Index) (Texas A&M University, College Station, TX, 2002), available through URL: http://mobility.tamu.edu/ums/study/appendix_A/exhibit_A-17.pdf

TTI, *The Keys to Estimating Mobility* (Chapter 5: Recommended Mobility Measures) (Texas A&M University, College Station, TX, 2003), available through URL: http://mobility.tamu.edu/ums/estimating_mobility/chapter5.pdf

Logic: This indicator provides a measurement of the congestion of the local road network in the region surrounding a military installation in terms of annual average daily traffic per lane. Traffic volume is an indicator of not only potential problems using the local roads, but also of high levels of development. From the military operations standpoint, congestion problems would place military activities in a vulnerable state, affecting the type and intensity of training that could take place on a facility. For instance, commute times for work related travel for the local community surrounding and including the installation would be extended longer than normally expected as a result of congestion problems (TTI 2003).

Heavy to severe congestion areas also impacts water supply and quality. These areas often contain large extents of impervious surfaces. Imperviousness changes the routing and timing for water to reach a lake or stream. When rain reaches impervious surfaces, any pollutants (such as automobile fuel) are collected by the water and carried into neighboring water systems. Other unintended results may include: removal of natural storage, retention, and recycling of precipitation; significant increases in overland runoff into surface wa-

ters; decreases in stream base flow and groundwater recharge; widening or morphology of stream channels; increases in floodwater velocities; and increases in the magnitude and frequency of flooding.

Additionally, it is important to note this data is on the state level and may be skewed by local “hotspots.” In other words, if a state has one area with high local traffic volumes, it could skew the data for the entire state causing it to be classified as high traffic volumes regardless of the characteristics of the remaining majority of the state. Because of this concern, it is important to use local knowledge in interpreting the traffic volume classifications.

Replicable: This indicator could be replicated every year based on information updated annually in Federal Highway Administration’s Highway Statistics (USDOT, FHWA 2006).

Directions: Road access is defined by AADT, which is the number of vehicles passing through a particular road segment. The U.S. Department of Transportation’s (USDOT’s) Federal Highway Administration provides annual highway statistics containing urban and rural data by state on AADT. The traffic volume levels were determined by information obtained from Appendix B of the 2002 Urban Mobility Study by the Texas Transportation Institute (TTI 2002). Download the Highway Statistics data into a GIS program and join it with the state shapefiles to create a Traffic Volume indicator layer.

Indicator Measure: Traffic Volume classifications were defined as follows based on definitions provided in the Texas Transportation Institute's *2002 Urban Mobility Study* (TTI 2002):

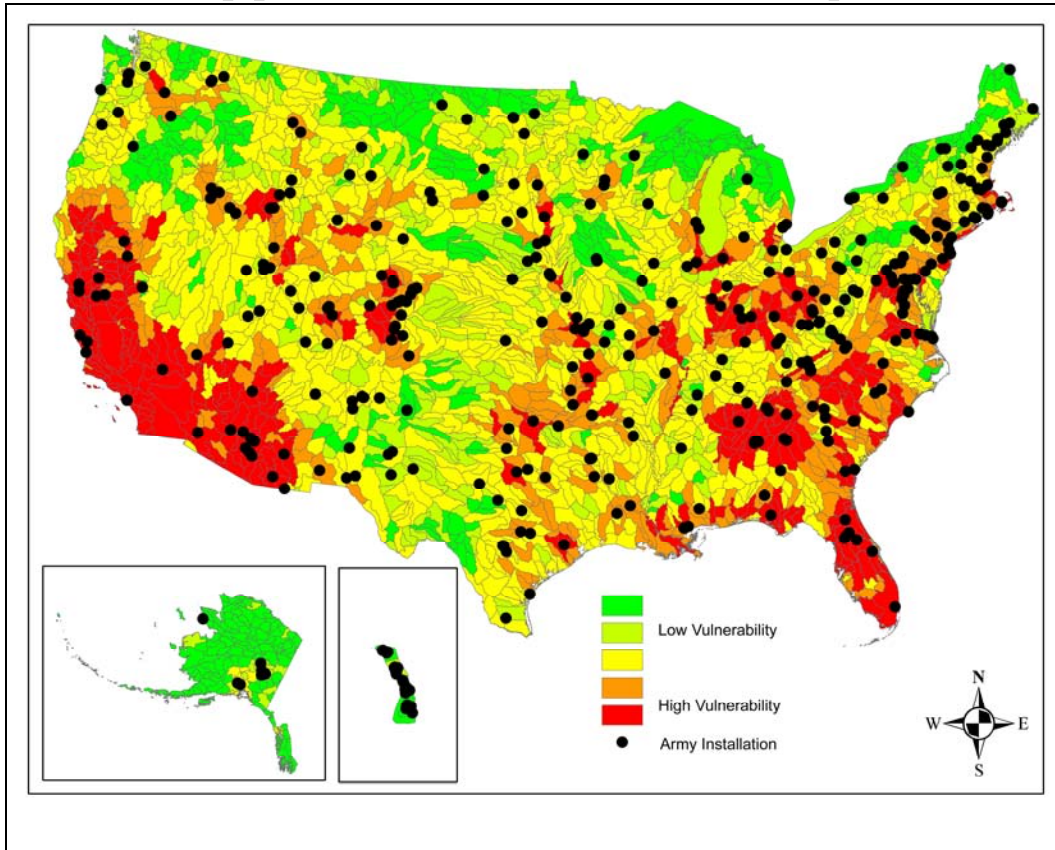
Very Low Vulnerability (1): ≤ 5500 AADT (Low Traffic Volume)
Low Vulnerability (2): Not Applicable
Moderate Vulnerability (3): $> 5500 - \leq 7000$ AADT (Medium Traffic Volume)
Vulnerable (4): Not Applicable
High Vulnerability (5): > 7000 AADT (High Traffic Volume)





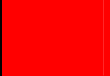
Rules: Watersheds often cover two or more states. Therefore, watershed classifications are determined by a weighted average. The weighted average calculation determines what percentage of the watershed is in each state and multiplies that percentage for each state by that state's classification value. Those values for each region of the watershed are then totaled to arrive at a value for the watershed. This value is subjected to the same ranking metric that determined the classifications for the individual county.

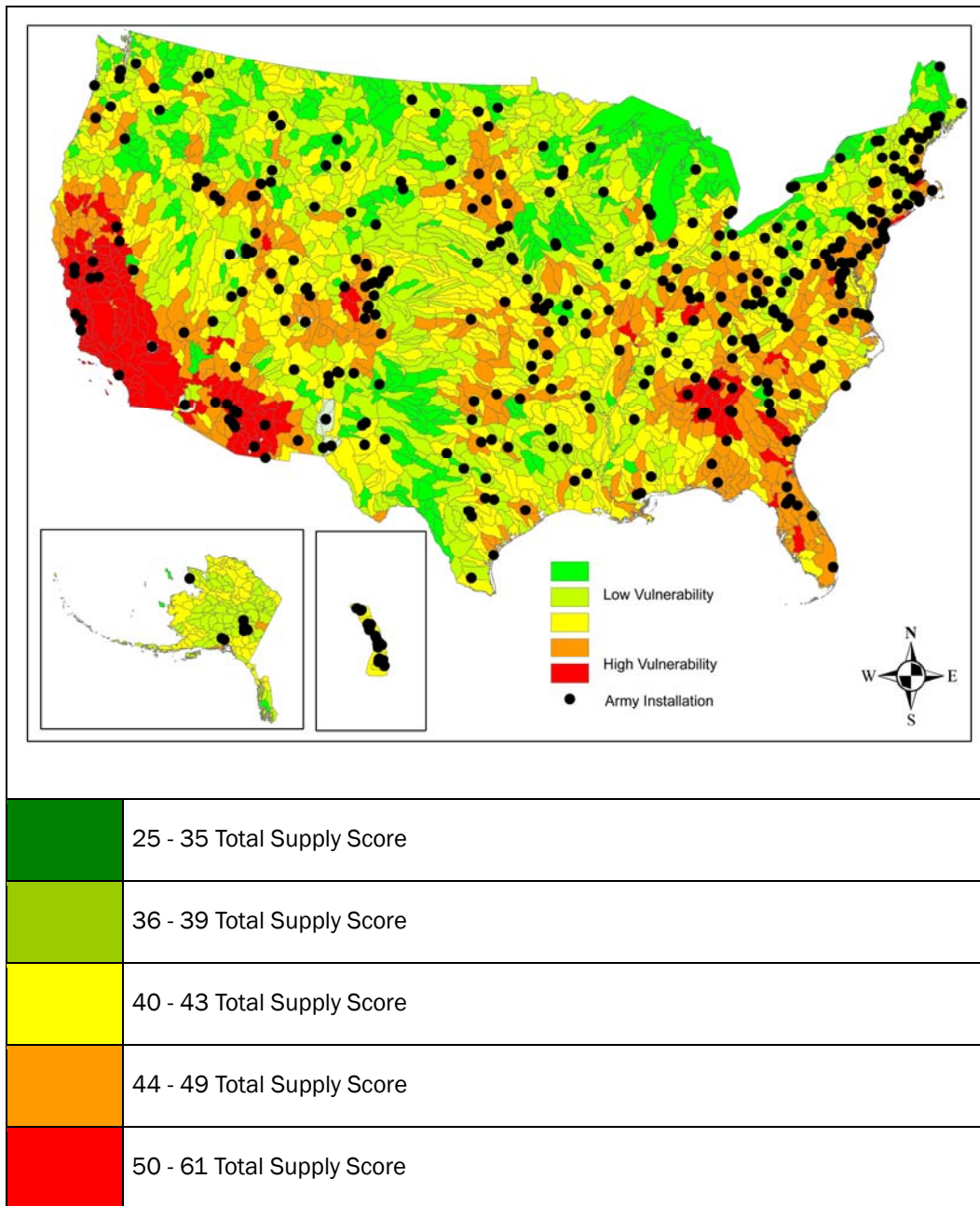
Appendix B: Indicator Data Values

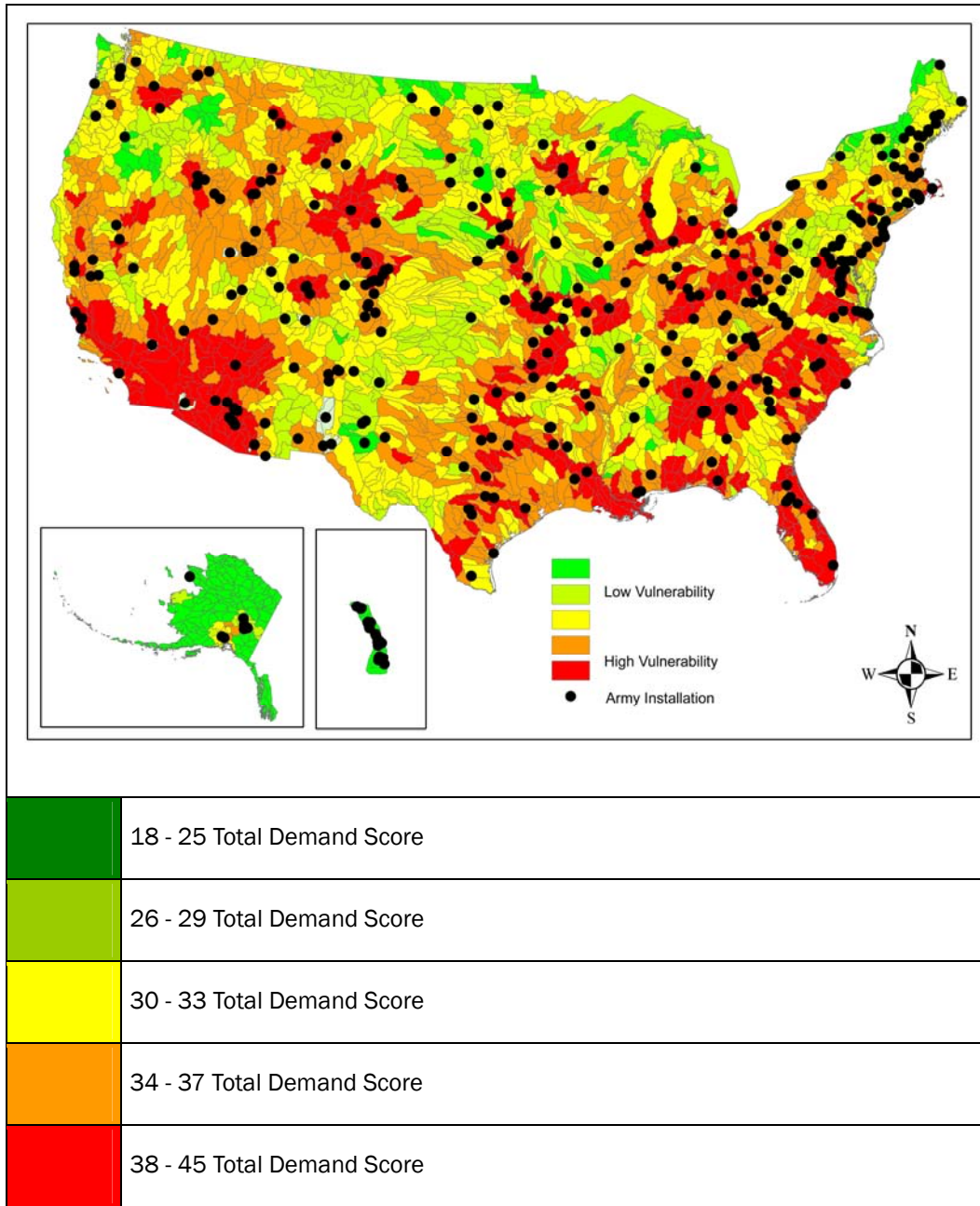
(see attached Excel Spreadsheet)

Appendix C: Indicator Maps

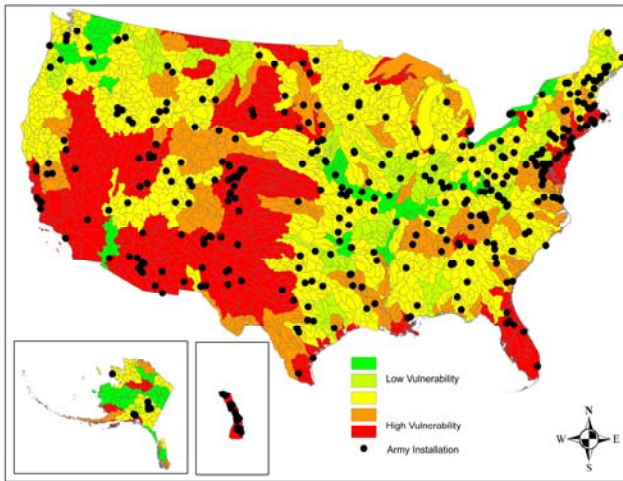


	24 - 65 Total Vulnerability Score
	66 - 69 Total Vulnerability Score
	70 - 77 Total Vulnerability Score
	79 - 82 Total Vulnerability Score
	83 - 120 Total Vulnerability Score

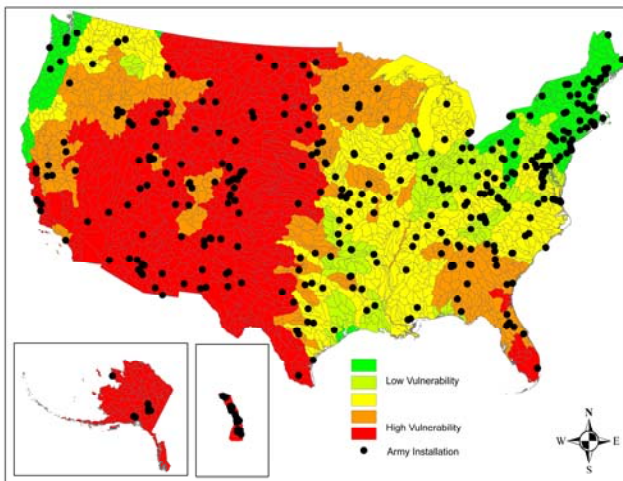




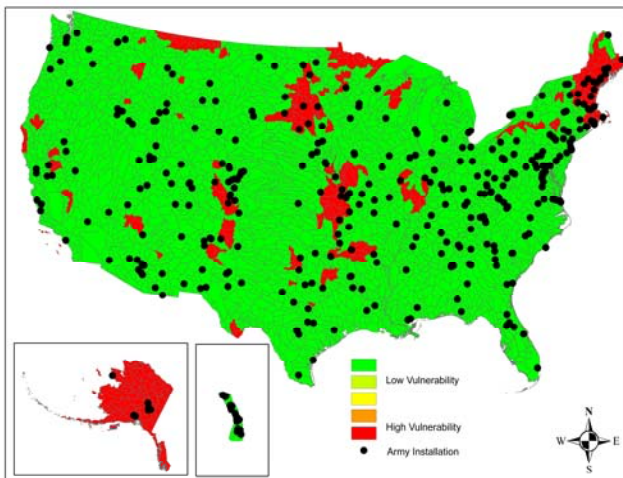
Water Supply Indicators



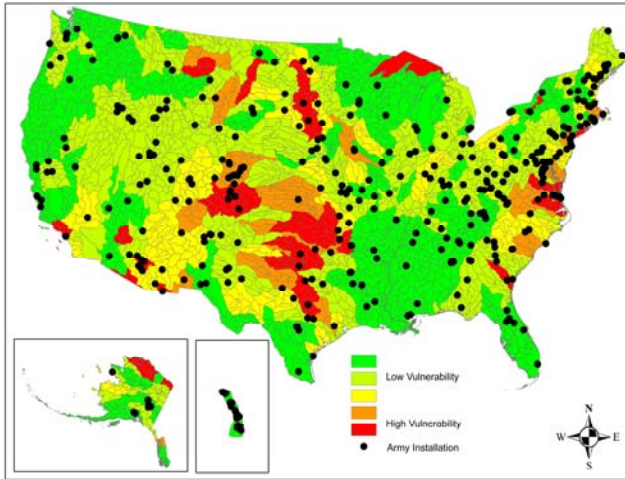
A1 Streamflow



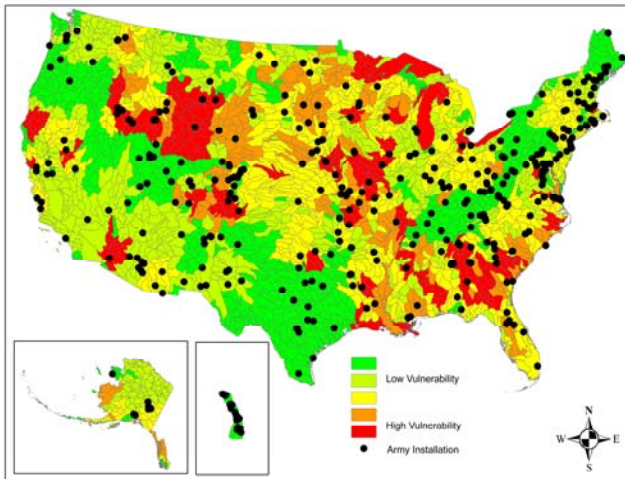
A2 Local Water Production



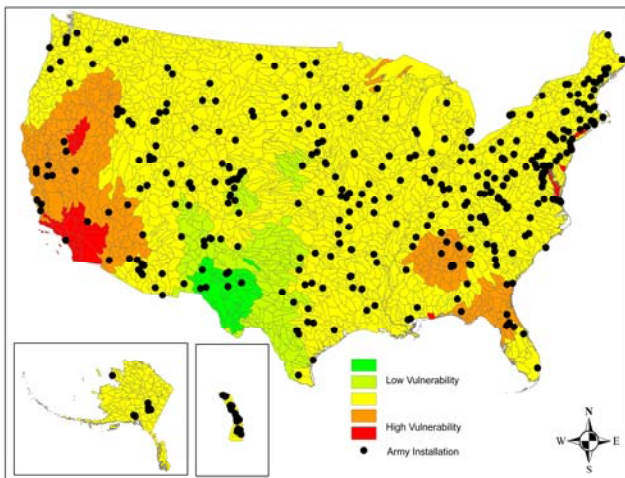
A3 Presence of Groundwater



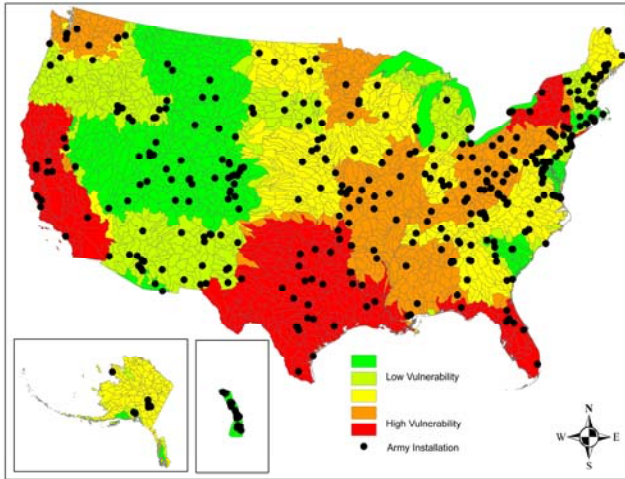
A4 Low Flow Sensitivity



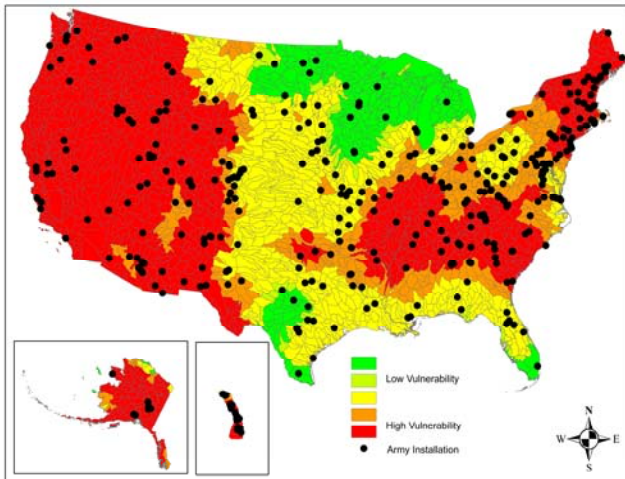
A5 Groundwater Depletion



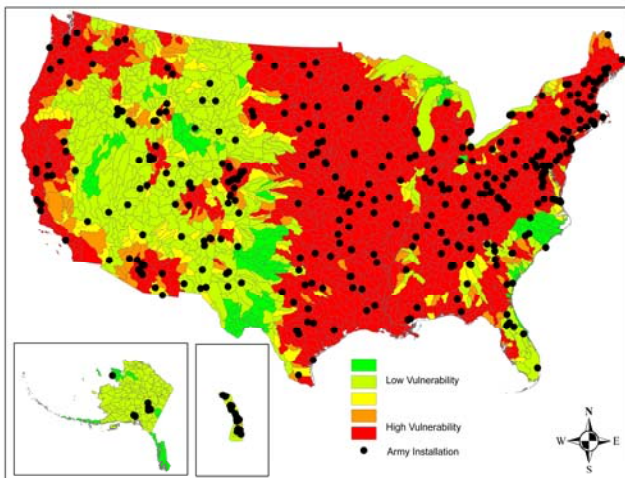
A6 Drought Sensitivity



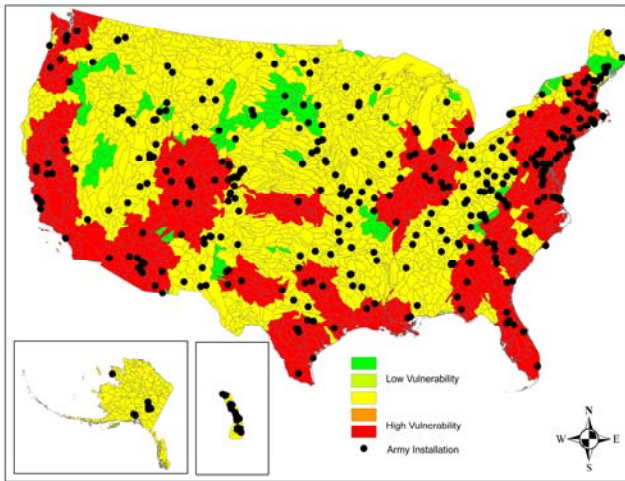
A7 Federally Declared Disasters



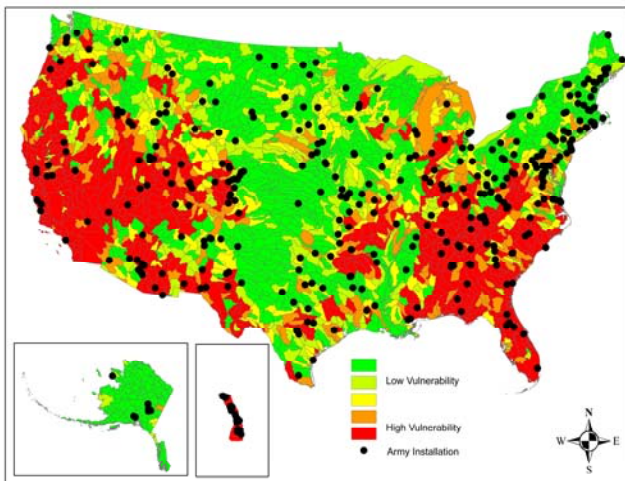
A8 Seismic Zones



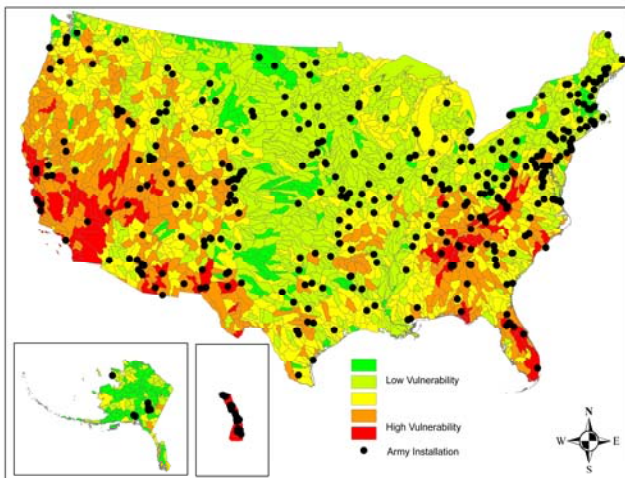
A9 Federally Declared Floods



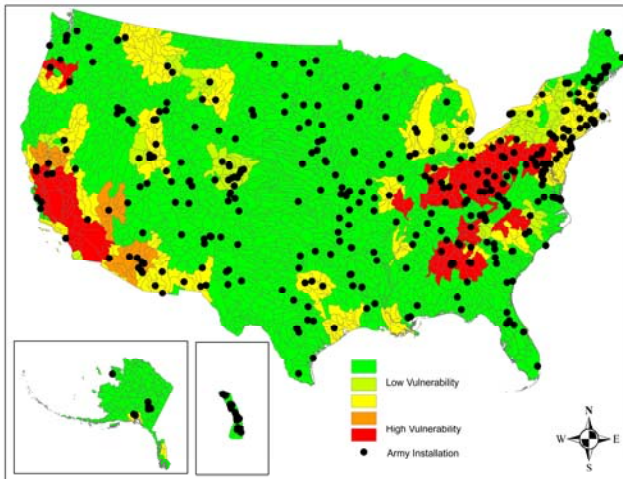
A10 Flood Risk



A11 TES Richness

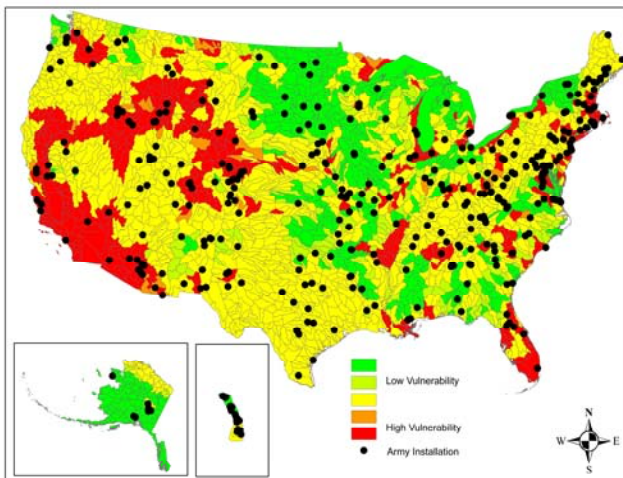


A12 TES Hotspot

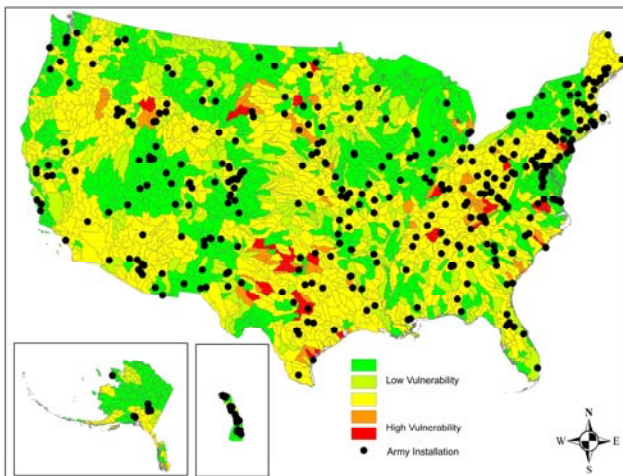


A13 Criteria Air Pollutant

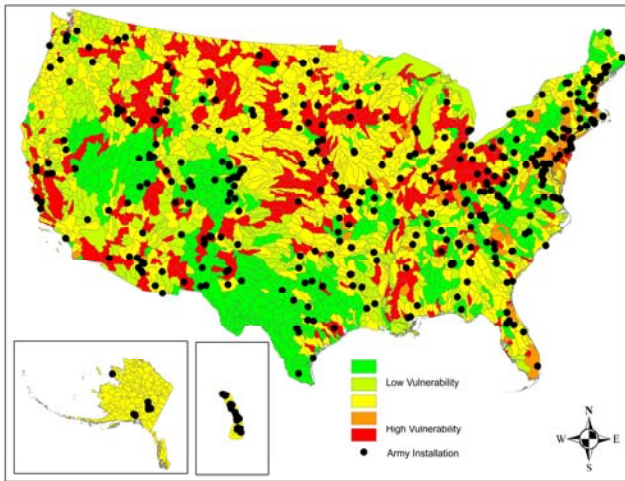
Water Demand Indicators



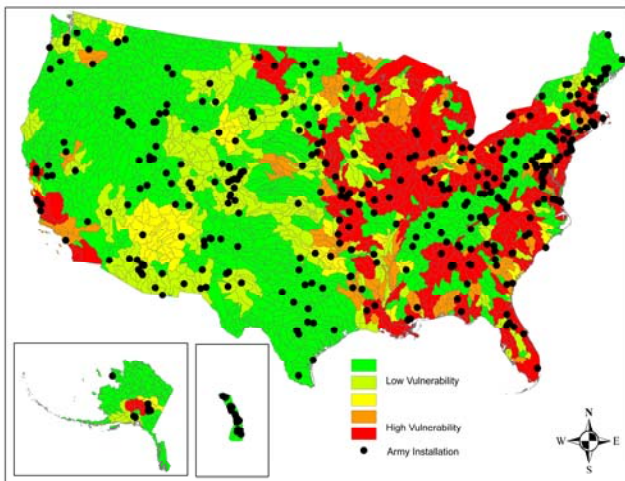
D1 Total Withdrawals



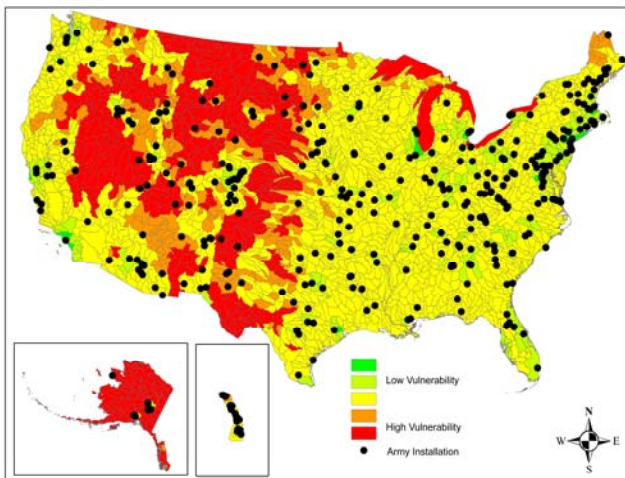
D2 Consumption Rate



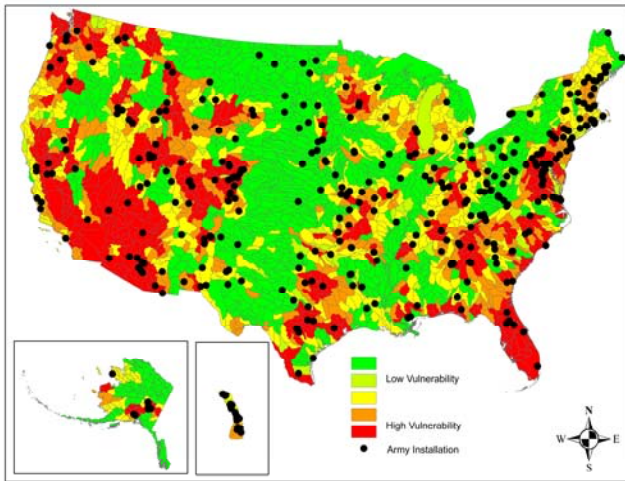
A14 Water Quality



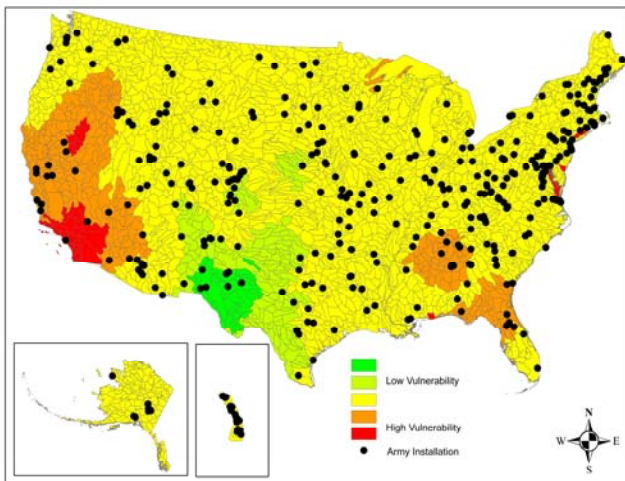
D3 Energy Withdrawals



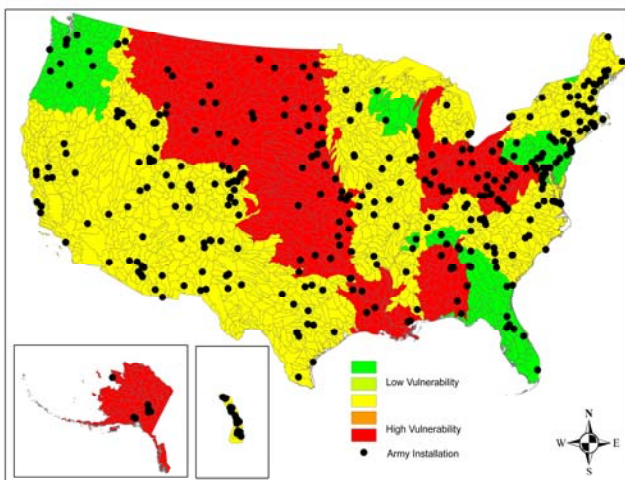
D4 Regional Population Density



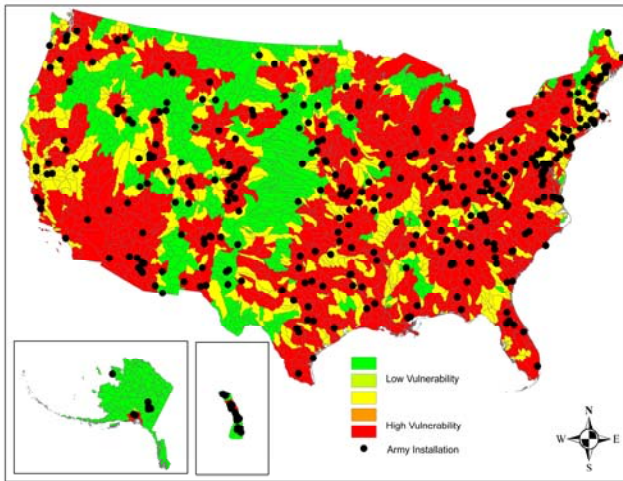
D5 Regional Population Growth



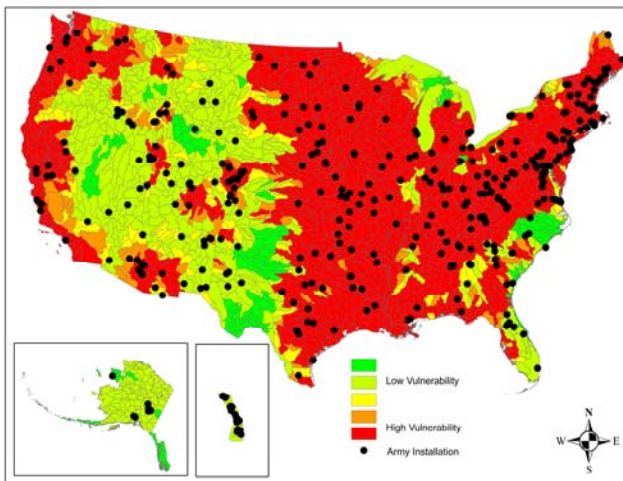
D6 Population Growth Projection



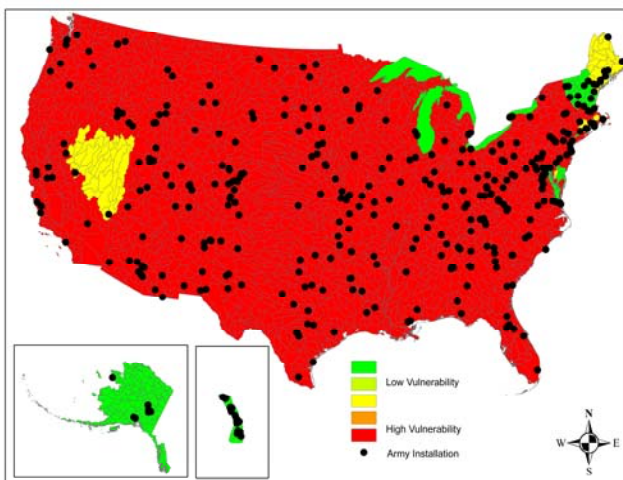
D7 State Smart Growth Plans



D8 Proximity to MSA



D9 Proximity to Interstate



D10 Traffic Volume

Appendix D: State Agencies Pertaining to Water

State	Water Related Agencies
Alabama	Department of Conservation and Natural Resources
	Department of Environmental Management
	Department of Economic and Community Affairs: Office of Water Resources
Alaska	Department of Natural Resources
	Department of Environmental Conservation
Arizona	Department of Water Resources
	Department of Environmental Quality
Arkansas	Department of Environmental Quality
California	Department of Water Resources
	Department of Conservation
	Environmental Protection Agency
Colorado	Department of Natural Resources
	Department of Public Health and Environment
Connecticut	Department of Environmental Protection
Delaware	Department of Natural Resources and Environmental Control
Florida	Department of Environmental Protection
Georgia	Department of Natural Resources
Hawaii	Department of Land and Natural Resources
	Department of Health
Idaho	Department of Water Resources
	Department of Environmental Quality
Illinois	Department of Natural Resources
	Environmental Protection Agency
Indiana	Department of Natural Resources
	Department of Environmental Management
Iowa	Department of Natural Resources
Kansas	Department of Health and Environment
Kentucky	Department for Natural Resources
	Department for Environmental Protection
Louisiana	Department of Natural Resources
	Department of Environmental Quality
Maine	Department of Environmental Protection
Maryland	Department of Natural Resources
	Department of the Environment

State	Water Related Agencies
Massachusetts	Department of Conservation and Recreation
	Department of Environmental Protection
Michigan	Department of Environmental Quality
Minnesota	Department of Natural Resources
	Department of Environmental Assistance
	Pollution Control Agency
Mississippi	Department of Environmental Quality
Missouri	Department of Natural Resources
	Department of Conservation
Montana	Department of Natural Resources and Conservation
	Department of Environmental Quality
	Natural Resource Information System
	GIS Data Library
Nebraska	Department of Natural Resources
	Department of Environmental Quality
Nevada	Department of Conservation and Natural Resources
	Division of Environmental Protection
New Hampshire	Department of Environmental Services
New Jersey	Department of Environmental Protection
New Mexico	Energy, Minerals, and Natural Resources Department
	Environmental Department
New York	Department of Environmental Conservation
North Carolina	North Carolina Department of Environment and Natural Resources
	GIS Database
North Dakota	Department of Health
	State Water Commission
Ohio	Department of Natural Resources
	Environmental Protection Agency
Oklahoma	Department of Environmental Quality
	Conservation Commission
Oregon	Water Resources Department
	Department of Environmental Quality
	Department of Fish and Wildlife
Pennsylvania	Department of Conservation and Natural Resources
	Department of Environmental Protection
Rhode Island	Department of Environmental Management
South Carolina	Department of Natural Resources
	Department of Health and Environmental Control
South Dakota	Department of Environment and Natural Resources
Tennessee	Department of Environment and Conservation

State	Water Related Agencies
Texas	Commission on Environmental Quality
	Texas Water Development Board
Utah	Department of Natural Resources
	Department of Environmental Quality
	Automated Geographic Reference Center
Vermont	Agency of Natural Resources
	Environmental Board
Virginia	Department of Environmental Quality
Washington	Department of Natural Resources
	Department of Ecology
	Department of Transportation's Environmental Services
West Virginia	Department of Commerce: Division of Natural Resources
	Department of Environmental Protection
Wisconsin	Department of Natural Resources
Wyoming	Department of Environmental Quality

Appendix E: Modeling Stream Flows

If stream flow records are inadequate or not recorded, there are a number of methods that may be developed to estimate the availability of water. These methods may include using historical precipitation and evaporation data, data from a similar river in a nearby basin, or other methods. Physical modeling of natural systems requires large amounts of data, and tends to be very time intensive to calibrate. It took a six-year effort to improve the understanding of the recharge and river interaction of the Middle Rio Grande Basin Aquifer, so that a water management strategy could be implemented (Alley 2006). A simple regression model may be the best choice to estimate available surface water supplies. A regression model is a statistically based approach to estimating a value from given inputs. Regression models can define stream flow with merely precipitation as an input, but other terms that may be used include temperature, impervious area, soil moisture content, and others. Generally, the more terms used to define the stream flow, the more accurate the model should be, yet a model is only as accurate as the data used. Since this model needs only to produce annual stream flow figures a less detailed model may be used. It is suggested that the inputs of precipitation and temperature be used due to their high correlation to annual stream flow amounts and wide availability.

Literature Review

Linear precipitation-runoff regression models have been successfully used in the past to represent seasonal runoff relationships (Dishkin 1970). Others have furthered the study of linear regression models for the purpose of evaluating seasonal runoff relationships (Raman 1995). Such studies show that regression models are adequate representations of watershed responses for monthly time scales. The models have experienced trouble accurately reflecting responses in arid areas when precipitation is the only input.

Many authors have addressed the inadequacies of regression models in arid regions by including temperature inputs to represent evapotranspiration rates. Such models perform well when simulating annual flows, but less well in simulating monthly flows (Alley 1984). Better models are available for estimating evapotranspiration, but are complex and require more parameters (Xu 1998). Models are to be developed and applied to a number of watersheds in a short time period. With this in mind a simple

temperature variable shall be used for evapotranspiration purposes, keeping in mind that monthly estimates may be misleading.

Developing the Model

Various authors have noted the complications presented with inadequate stream flow gauging (Xu 2004; Raman 1995). Parameters may be regionalized, or nearby watershed basins may be used to estimate rainfall runoff relationships. A nearby basin with similar land use characteristics and an adequate rainfall and stream flow record should be chosen.

Stream flow measurements may be obtained from the USGS. Precipitation and temperature data is obtained from the NOAA. The temperature data can be from a larger area than the watershed itself, because monthly temperature values are fairly constant over larger regions, while the precipitation data is quite varied in a spatial context. The precipitation figures should ideally be taken from gages within the watershed itself. Due to rainfall rates being spatially dependent, multiple gages may be needed to determine an average rate for a watershed through the use of geostatistics. The calibration process uses historical values of each of the inputs to determine the appropriate constants in the model through a least squares regression process. The model may be tested with a few different equation types (linear, power, sine, etc.) to find a model that appropriately defines the watershed response. The calibrated model may then be scaled using the watershed areas to represent expected flow in the un-gauged river.

The physical meanings of the inputs are lost when least square regression is used as an optimization tool. The operators with which the inputs are multiplied are only loose representations of physical processes such as infiltration and evaporation. Therefore in a normal water balance evaporation would be a negative term, the operator determined through least square regression may be a positive term. Least square regression methods are appropriate given the following conditions (Troutman 1985):

9. The errors are statistically independent of the predictions and are identically distributed.
10. The errors are statistically independent of each other.
11. The errors have a mean of zero and a finite variance.
12. The errors are normally distributed.

These assumptions are reviewed for validity to find an appropriate equation form (linear, power, sine, etc.) before projecting future trends. This model may be used to define the baseline stream flow available.

Projecting Future Trends

Once the baseline stream flow has been established, the normal procedures for projecting future trends may be followed. Alternatively, Global Circulation Models (GCMs) predict changes in temperature and precipitation on a global scale. A linear relation between the projected values and the current values may be used to evaluate the change in stream flow response to changing climate. A Monte Carlo simulation may be applied to the trended precipitation and temperature values to portray weather variability (Maidement 1993). This projection should be run a number of times to create a statistically significant dataset, since the Monte Carlo Simulation is a statistical process.

References

- Alley, William M. 1984. On the treatment of evapotranspiration, soil moisture accounting, and aquifer recharge in monthly water balance models. *Water Resources Research* 20(8):1137-1149.
- Alley, William M. 2006. Tracking U.S. ground water: Reserves for the future. *Environment* 48(3):10-25.
- Dishkin, M. H. 1970. Definition and uses of the linear regression model. *Water Resources Research* 6(6):1668-1673.
- Maidement, David. 1993. *Handbook of Hydrology*. McGraw Hill, NY.
- Raman, H., S. Mohan, and P. Padalinathan. 1995. Models for extending streamflow data: A case study. *Journal of Hydrological Sciences* 40(3): 381-393.
- Troutman, Brent M. 1985. Errors and parameter estimation in precipitation-runoff modeling: 1. Theory. *Water Resources Research* 21(8):1195-1213.
- Xu, C.-Y., and V. P. Singh. 1998. A review on monthly water balance models for water resources investigations. *Water Resources Management* 12:31-50.
- Xu, C.-Y., and V. P. Singh. 2004. Review on regional water resources assessment models under stationary and changing climate. *Water Resources Management* 18:591-612.

Appendix F: Modeling Installation Demand

The installation water demand model is an Excel spreadsheet application that projects water demand for most U.S. Army installations up to 2032, based on data input by the user. The model uses a macro to sort the installation's Real Property data, and then uses that and other data entered by the user to calculate water demand.

Description of each worksheet, with selected screenshots

Instructions

This provides instructions for using the demand model spreadsheet application. Do not attempt to use the demand model before reading these. An extended version of the instructions, with screenshots, is also found in the next section.

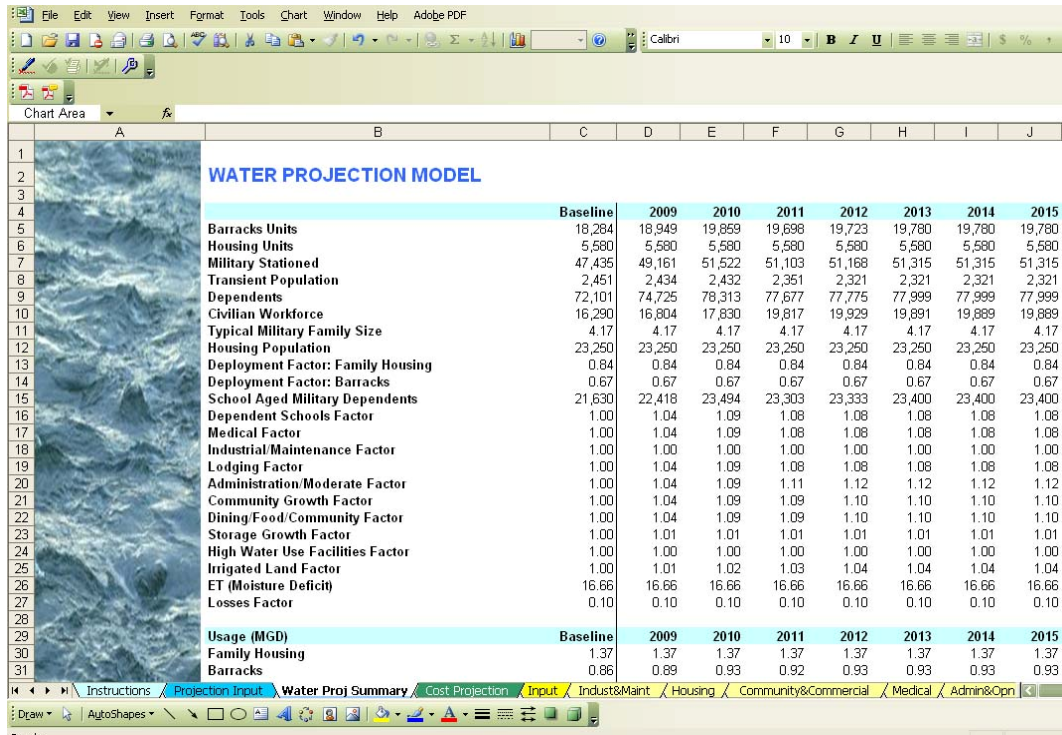
Projection Input

This is one of the two main worksheets in which data is entered. Here the user enters information about the installation, such as number of housing units, number of military stationed, and the estimated water consumption in gallons per unit per day (gpud) for certain use sectors. The bright yellow cells require data input, while the bright green cells contain default values that may be changed if the user wishes. Other cells should not be altered. At the bottom of the worksheet is a place to enter up to three possible water rates in the form of X price per thousand gallons of water, so that estimated future water costs can be calculated.

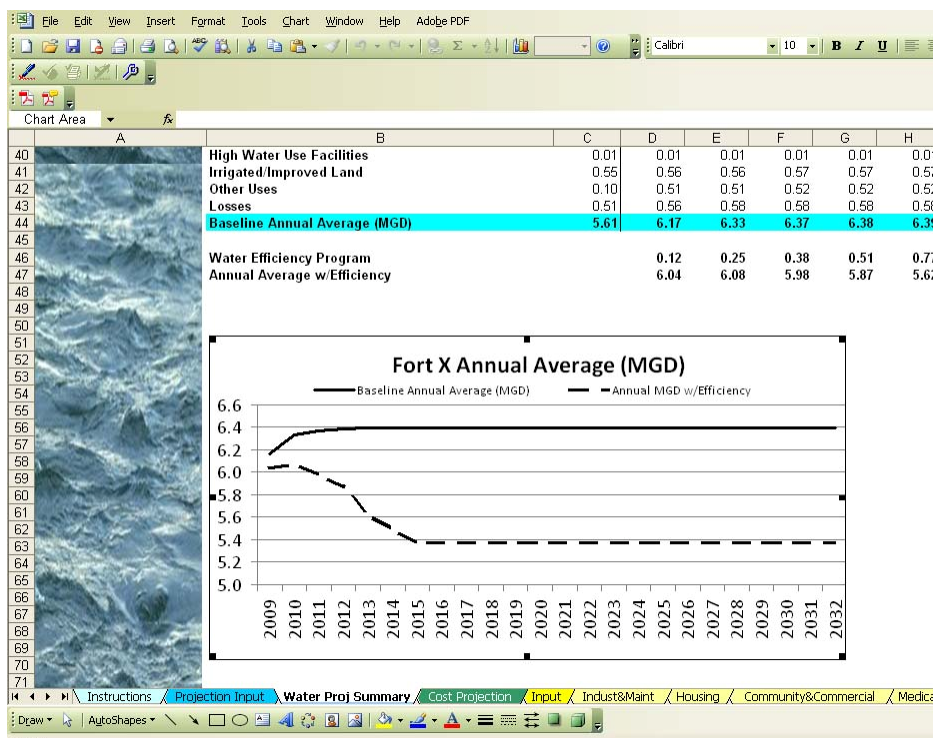
	Baseline	2009	2010	2011	2012	2013	2014	2015	2016	2017
Projection Input										
Barracks Units	18,284									
Housing Units	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580
Military Stationed	47,435	49,161	51,522	51,103	51,168	51,315	51,315	51,315	51,315	51,315
Transient Population	2,451	2,434	2,432	2,351	2,321	2,321	2,321	2,321	2,321	2,321
Dependents	72,101	74,725	78,313	77,677	77,775	77,989	77,989	77,989	77,989	77,989
Civilian Workforce	16,290	16,804	17,830	19,817	19,929	19,891	19,889	19,889	19,889	19,889
Typical Military Family Size	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Deployment Factor: Family Housing	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Deployment Factor: Barracks	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Industrial/Maintenance Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Storage Growth Factor	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
High Water Use Facilities Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Irrigated Land Factor	1.00	1.01	1.02	1.03	1.04	1.04	1.04	1.04	1.04	1.04
ET (Moisture Deficit)	16.66	16.66	16.66	16.66	16.66	16.66	16.66	16.66	16.66	16.66
Losses Factor	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Consumption (gpud)	Baseline	2009	2010	2011	2012	2013	2014	2015	2016	2017
Family Housing	70	70	70	70	70	70	70	70	70	70
Barracks	70	70	70	70	70	70	70	70	70	70
Dependent Schools	15	15	15	15	15	15	15	15	15	15
Medical	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236
Industrial/Maintenance	700	700	700	700	700	700	700	700	700	700
Lodging	150	150	150	150	150	150	150	150	150	150
Admin/Moderate Users	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204
Community and Commercial: Non-food related	629	629	629	629	629	629	629	629	629	629
Community and Commercial: Food-related	906	906	906	906	906	906	906	906	906	906

Water Proj Summary

This displays the results of the projection model. It summarizes the data entered in the Projection Input worksheet, and shows values calculated from that data, such as the number of school-aged dependents.



The bottom part of the worksheet shows the water demand projections out to 2032, in both table and chart form. There are two projections shown: 1) the baseline annual average in MGD, which assumes that unit water consumption rates (in gpcud) remain constant into the future, and 2) the water-efficient annual average in MGD, which assumes a 2 percent annual decrease in consumption beginning in 2009 in compliance with Executive Order 13124.



Cost Projection

This worksheet shows estimated water costs. In the Projection Input worksheet, the user is able to enter possible water rates. The water costs are calculated from the total projected water usage in MGD (in the Water Proj Summary worksheet) and the water rates entered in the Projection Input worksheet. Results are in terms of both water cost per day and water cost per year. A chart at the bottom of the worksheet is helpful for comparing costs between the baseline and water efficiency results.

Input

In this worksheet, the user enters the Real Property data for the installation. The worksheet is set up so that only the category code, primary and secondary quantities, and total number of that particular category code need to be entered. The other columns will automatically fill, as the worksheet is set up to search the full list of category codes (found in the Cat-Codes worksheet) for the category code value input by the user. A description of the various units of measurement (UM) is also found at the top of this worksheet.

Indust&Maint

Once the macro is run, this worksheet displays the industrial and maintenance buildings and structures at the installation.

Housing

Once the macro is run, this worksheet displays the housing buildings at the installation. There are three subcategories: family housing, transient housing/lodging, and barracks. Each of these subcategories has a different water consumption rate, so it is necessary to separate them.

Community&Commercial

Once the macro is run, this worksheet displays the community and commercial buildings and structures at the installation. There are three subcategories: non-food related indoor, non-food related outdoor, and food-related. Non-food related outdoor buildings and structures generally do not use water, and are not factored into the water demand projections. They are included for informational purposes.

Medical

Once the macro is run, this worksheet displays the medical buildings at the installation. The yellow cells at the bottom need to be filled in with specific values. See instructions for more details.

Admin&Opns

Once the macro is run, this worksheet displays the administration and operations buildings and structures at the installation.

Trng&Schools

Once the macro is run, this worksheet displays the training and school buildings and structures at the installation. There are two subcategories: dependent schools and other training and schools.

Storage

Once the macro is run, this worksheet displays the storage buildings and structures at the installation.

Special Category

Once the macro is run, this worksheet displays the “special category” buildings and structures at the installation, which are singled out for their water usage. There are three subcategories: high water use facilities, irrigated/improved land, and other land.

CatCodes

This worksheet displays the full list of all U.S. Army category codes, their primary and secondary quantity units of measurement, and the short and long code descriptions. It is included for informational purposes.

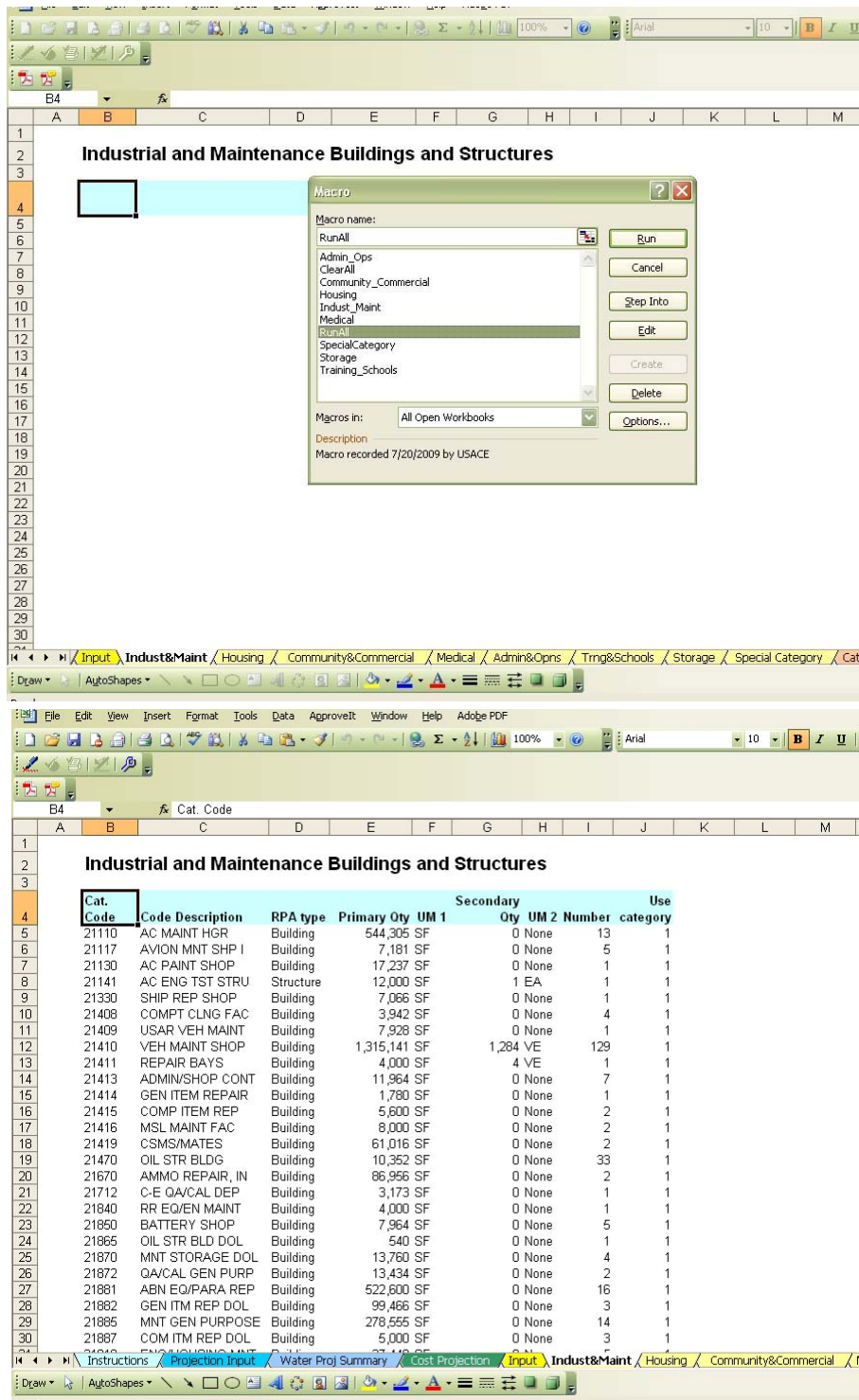
*A note about units: On some of the building/structure worksheets (Indust&Maint, Housing, etc.) the secondary quantities are summed at the bottom, while others are not. This is because the secondary quantity units are not always able to be added. Always check to make sure these can be added before doing so. For example, “spaces” and “persons” (as found in the Housing worksheet) may be added, but “vehicles” and “seats” (as found in the Community&Commercial tab) cannot. See the UM description at the top of the Input worksheet to determine whether two different UMs may be added.

Instructions for using the demand model

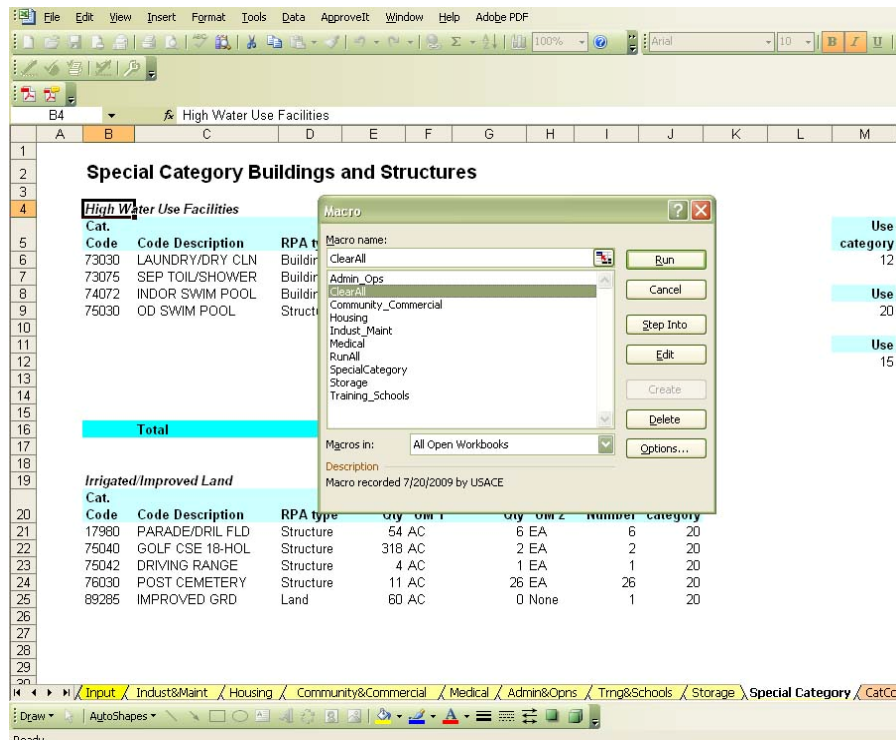
Before doing anything else, go to Save As and save the document under a name that reflects the installation you are studying (ex. Water_Demand_Model_FtBragg).

Tips

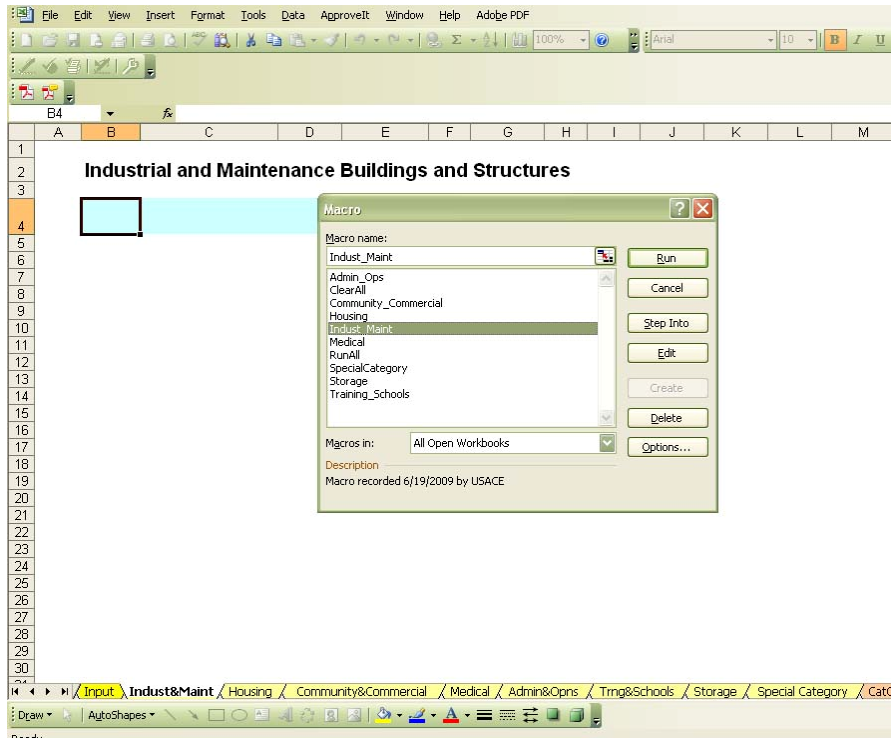
- Do not enter any data until you have read the instructions.
 - Make sure macros are enabled. If you did not enable the macros when you opened the document, close the document and open it again, this time enabling macros.
 - Do not rearrange the order of the worksheets or add new ones. Also do not insert new rows or columns anywhere in this workbook. These actions may cause the macros to malfunction.
 - Data may be entered only into cells that are bright yellow or bright green, found only in the Projection Input, Input, and Medical tabs.
1. Go to the Input tab. Enter the category codes for all uses on the installation, and the primary and secondary quantities and the total number of buildings or structures in each category code. **Only** the bright yellow columns should be filled. If you are copying and pasting from another spreadsheet, make sure you right click and select “Paste Special” and then select “Values” so that you are pasting the values only.



1. If the macro returns an error message, take the following steps. Otherwise, skip to Step 5. Go to the Special Category tab and select cell B4. Open the macro window and select "ClearAll" and click Run. The macro will clear all data from the light yellow tabs. Repeat Step 3.



1. If the macro still returns an error message, you may sort the data tab by tab by doing the following. Go to the Special Category tab and select cell B4 and run the ClearAll macro again. Go to the Indust&Maint tab and select cell B4. Open the macro window and select "Indust_Maint" and click Run. Repeat this step for all light yellow tabs, selecting cell B4 and running the macro with the corresponding name for each one.



1. Go to the Medical tab. Since the medical center is so much larger than the rest of the medical buildings, you will need to do a few calculations. Cell E18 is equal to the total square footage of the health clinics (category code 55010, column E) divided by the number of health clinics (column I).

Cat. Code	Code Description	RPA type	Primary Qty	UM 1	Secondary Qty	UM 2	Number	Use category	Use category
51010	MED CTR/HOSP	Building	1,947,453	SF	287	BD	1	8	8
53020	LABORATORY	Building	7,321	SF	0	None	2	8	
53025	PHARMACY	Building	1,630	SF	0	None	1	8	
53040	VET FACILITY	Building	8,738	SF	0	None	3	8	
54010	DENTAL CLINIC	Building	92,145	SF	188	OU	6	8	
55010	HEALTH CLINIC	Building	234,003	SF	0	BD	13	8	
Total			2,291,290		475		26		

Avg size of non-hospital medical Hospital equal to this many buildings =E10/I10
 Number of non-hospital buildings
Total

Cell E19 is equal to the total square footage of the medical center (category code 51010, column E) divided by the value in cell E18.

Cat. Code	Code Description	RPA type	Primary Qty	UM 1	Secondary Qty	UM 2	Number	Use category	Use category
51010	MED CTR/HOSP	Building	1,947,453	SF	287	BD	1	8	8
53020	LABORATORY	Building	7,321	SF	0	None	2	8	
53025	PHARMACY	Building	1,630	SF	0	None	1	8	
53040	VET FACILITY	Building	8,738	SF	0	None	3	8	
54010	DENTAL CLINIC	Building	92,145	SF	188	OU	6	8	
55010	HEALTH CLINIC	Building	234,003	SF	0	BD	13	8	
Total			2,291,290		475		26		

Avg size of non-hospital medical Hospital equal to this many buildings 19,000
 Number of non-hospital buildings =E5/E18
Total

Cell E20 is equal to the sum of all the buildings (cell I15) minus the number of medical centers. Cell E21 is equal to cell E19 plus cell E20.

1. In the Projection Input tab, enter the appropriate data into all of the bright yellow cells in Rows 5-10, 12-19, 23-25, and 33. Only bright yellow cells should be filled. White cells do not require any data input. For example, the typical military family size in row 11 is calculated from other values. If you do not have data beyond a specific year, you may drag the value for the last year you do have data over to the rest of the years. Use your best judgment. For example, if you know there will be an increase in the number of soldiers at your installation in 2011, you should enter data to reflect that.

The data in rows 5-10 and 12-19 will likely be given by the installation. The water consumption data in rows 23-25 and 33 are derived from the regional water consumption data.

	Baseline	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Barracks Units	18,284										
Housing Units	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580	5,580
Military Stationed	47,436	49,161	51,522	51,103	51,168	51,315	51,315	51,315	51,315	51,315	51,315
Transient Population	2,451	2,434	2,432	2,351	2,321	2,321	2,321	2,321	2,321	2,321	2,321
Dependents	72,101	74,725	78,313	77,677	77,775	77,999	77,999	77,999	77,999	77,999	77,999
Civilian Workforce	16,290	16,804	17,830	19,817	19,929	19,891	19,889	19,889	19,889	19,889	19,889
Typical Military Family Size	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Deployment Factor: Family Housing	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Deployment Factor: Barracks	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Industrial/Maintenance Factor	1.00										
Storage Growth Factor											
High Water Use Facilities Factor											
Irrigated Land Factor											
ET (Moisture Deficit)											
Losses Factor											
Consumption (gpcud)	Baseline	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Family Housing											
Barracks											
Dependent Schools											
Medical	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236
Industrial/Maintenance	700	700	700	700	700	700	700	700	700	700	700
Lodging	150	150	150	150	150	150	150	150	150	150	150
Admin/Moderate Users	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204
Community and Commercial: Non-food related	629	629	629	629	629	629	629	629	629	629	629
Community and Commercial: Food-related	906	906	906	906	906	906	906	906	906	906	906

1. In the bright yellow cells at the bottom of the page (rows 40-42), under “Costs”: Enter data for cost projections. Data will likely be in the form of a certain price per thousand gallons of water. You may enter a description of the pricing in the first column (e.g., Price A 2011 Price, etc.).

The screenshot shows a spreadsheet with the following data:

	A	B	C	D	E	F	G	H	I	J	K	L	M
25		Dependent Schools	15	15	15	15	15	15	15	15	15	15	15
26		Medical	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236	1,236
27		Industrial/Maintenance	700	700	700	700	700	700	700	700	700	700	700
28		Lodging	150	150	150	150	150	150	150	150	150	150	150
29		Admin/Moderate Users	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204	1,204
30		Community and Commercial: Non-food related	629	629	629	629	629	629	629	629	629	629	629
31		Community and Commercial: Food-related	906	906	906	906	906	906	906	906	906	906	906
32		Storage	10	10	10	10	10	10	10	10	10	10	10
33		High Water Use Facilities	200	200	200	200	200	200	200	200	200	200	200
34													
35		gpd=gallons per unit per day											
36													
37													
38		Costs											
39		Description	Scenario	Rate	#	UM							
40		Current price	1	\$1.00	per	1,000	gal						
41		Price A	2	\$1.25	per	1,000	gal						
42		Price B	3	\$1.11	per	1,000	gal						
43													
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14. ABSTRACT A key concern for the U.S. Army is the vulnerability of military installations to critical resource issues. Water issues of concern—including adequate supply, increased cost of production per unit volume, quality, habitat degradation and salinity issues—already impact military installations and military operations in many locations within the nation and across the globe. There is a need to assess vulnerability of regions and installations to water supply and to develop strategies to ameliorate any adverse effects on the triple bottom line. This work employed methodologies developed by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) to conduct national screenings of watershed vulnerability, prepare regional water budgets documenting supply and demand in regions containing Army installations, and develop installation water demand projections. The methodologies look beyond the fence line and 30 years into the future to identify the potential for water scarcity. Water law is described on a region-by-region basis and instructions are provided for developing a water conservation program. Recommendations are made for achieving Federal water conservation targets contained in Executive Order 13423, Strengthening Federal Environmental, Energy, and Transportation Management.					
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