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STORMWATER NON-POTABLE BENEFICIAL USES AND EFFECTS ON URBAN INFRASTRUCTURE

By:
Robert Pitt, Ph.D., PE, BCEE, D.WRE
Leila Talebi, Ph.D. student
Ryan Bean, MSCE student
The University of Alabama

Shirley Clark, Ph.D., PE, D.WRE
Penn State Harrisburg

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For more information, contact:
Water Environment Research Foundation
635 Slaters Lane, Suite G-110
Alexandria, VA 22314-1177
Tel: (571) 384-2100
Fax: (703) 299-0742
www.werf.org
werf@werf.org

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Research Team

Principal Investigator:

Robert Pitt, Ph.D.
Department of Civil, Construction, and Environmental Engineering
University of Alabama, Tuscaloosa, AL 35487

Project Team:

Leila Talebi, MSCE
Ryan Bean
Department of Civil, Construction, and Environmental Engineering
University of Alabama,

Shirley Clark, Ph.D.
Environmental Engineering Program
Penn State Harrisburg

WERF Project Subcommittee

<Full Names and Degrees of All PSC Members>
<*Organizations of Project Subcommittee Members*>
Place Names in Alphabetical Order

Water Environment Research Foundation Staff

Director of Research: Daniel M. Woltering, Ph.D.
Program Director: Walter Graf

ABSTRACT AND BENEFITS

Abstract

This project shows that lessons learned and successes from a wide variety of international stormwater beneficial use projects cover a range of conditions that may be found in the U.S. Examined are case studies from developing countries in both arid and wet climates, case studies from developed countries in areas where future water conservation is necessary to support continued growth, and from developed countries where sustainable use of natural resources is of high priority. Also examined are typical water quality conditions from different stormwater sources in urban areas and desirable (or regulated) water quality requirements for the use of this water for different applications. Water quality degradation associated with different storage options is also reviewed along with different water treatment options to meet the needed "finished" water quality before use. Guidance is provided on how to determine the amount of supplemental landscape irrigation needed from stored stormwater, and how to calculate needed tankage volumes for many locations in the U.S. The report calculates the beneficial use opportunities of stormwater, especially landscaping irrigation, in different areas of the country, along with continuous modeling results for the development of production functions for tankage volume alternatives.

List of Benefits

- This report consolidates much information pertaining to beneficial uses of stormwater, an emerging topic not supported by much guidance.
- Case study summaries show how stormwater beneficial uses can be applied to various US conditions.
- Reviews of stormwater quality and use criteria high-light potential problems
- Summaries of available treatment approaches are presented to allow the reader to identify potential methods to meet the use criteria.
- Design methods are presented to allow the report user to size storage tank facilities reflecting regional conditions.
- Detailed evapotranspiration information is presented, along with discussions of how the various ET data sources can be used to develop specific designs for an area.

Keywords: Stormwater management, sustainable urban water design, beneficial uses of stormwater, rainfall harvesting.

LIST OF ACRONYMS

Acronym	**Description**
AEC	Anion Exchange Capacity
AgriMET	Pacific Northwest Cooperative Agricultural Weather Network
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
BDST	Bed Depth Surface Time
BOD	Biochemical Oxygen Demand
CBOD	Chemical Biological Oxygen Demand
CCA	Chromated Copper Arsenic
CEC	Cation Exchange Capacity
CFU	Colony Forming Unit
CIDRC	Canadian International Development Research Centre
CIMIS	California Irrigation Management Information System
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
DEM	Digital Elevation Model
DRI	Desert Research Institute
DRWH	Domestic Rainwater Harvesting
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FAWN	Florida Automated Weather Network
GAC	Granular Activated Carbon
GIS	Geographic Information Systems
gpcd	gallons per capita per day
GW	Grey Water
HDPE	High Density Polyethylene
K-P	Kimberly Penman
LEED	Leadership in Energy and Environmental Design
MCL	Maximum Contaminant Level
MLD	Million liters per day
MPN	Most Probable Number
NAS	National Academy of Science
NMNH	Natural Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NRDC	Natural Resources Defense Council
NSF	National Science Foundation
NSQD	National Stormwater Quality Database

Acronym	**Description**
NSW	New South Whales
NTU	Nephelometric Turbidity Units
PAH	Polycyclic Aromatics Hydrocarbons
PSU	Portal State University
PVC	Polyvinyl Chloride
RAWS	Remote Automated Weather Stations
RCC	Reinforced Cement Concrete
RRC	Rainwater Research Center
RWH	Rainwater Harvesting
SFPUC	San Francisco Public Utilities Commission
SMCL	Secondary Maximum Contaminant Level
SMURRF	Santa Monica Urban Runoff Recycling Facility
SOR	Surface Overflow Rate
SS	Suspended Solids
SSIM	Sustainable Systems Integration Model
STEM	Symbiosis of Technology, Environment and Management
TDS	Total Dissolved Solids
TMG	Tokyo Metropolitan
TSS	Total Suspended Solids
TUD	Technical University of Darmstadt
UM	University of Maryland
UNICEF	United Nations International Children’s Emergency Fund
U.S. EPA	U. S. Environmental Protection Agency
USDA	United States Department Agriculture
USGS	United States Geological Survey
UV	Ultra Violet
VOC	Volatile Organic Compounds
WHO	World Health Organization
WinSLAMM	Windows© Source Loading and Management Model
WRCC	Western Regional Climate Center
WUCOLS	Water Use Classification of Landscape Species

List of Contents

List of Figures

List of Tables

SUMMARY

NON-POTABLE BENEFICIAL USES OF STORMWATER

This WERF-supported project shows that lessons learned and successes from a wide variety of international stormwater beneficial use projects cover a range of conditions that may be found in the U.S. Examined are case studies from developing countries in both arid and wet climates, case studies from developed countries in areas where future water conservation is necessary to support continued growth, and from developed countries where sustainable use of natural resources is of high priority. Also examined are typical water quality conditions from different stormwater sources in urban areas and desirable (or regulated) water quality requirements for the use of this water for different applications. Water quality degradation associated with different storage options is also reviewed along with different water treatment options to meet the needed "finished" water quality before use. Guidance is provided on how to determine the amount of supplemental landscape irrigation needed from stored stormwater, and how to calculate needed tankage volumes for many locations in the US. The report calculates the beneficial use opportunities of stormwater, especially landscaping irrigation, in different areas of the country, along with continuous modeling results for the development of production functions for tankage volume alternatives.

Several important issues are seen from the case studies. As expected, the heavily urbanized developing countries in water stressed areas (such as in China and India) are most concerned with harvesting as much runoff as possible, with minimal concern related to water quality. Not only is roof runoff harvested (the likely cleanest water available), but also runoff from all urban areas. Usually, all paved areas are used to harvest runoff water, as maximum volumes are needed to augment the poor quality and poorly available local sources. The water is stored in large ponds, and sometimes injected to shallow aquifers. These efforts improve the water quality to some extent, greatly depending on the storage conditions.

In developing countries with large rural populations in water stressed areas (such as in Africa), most of the runoff harvesting schemes focus on collecting roof runoff for storage in tanks near the homes. The water is used for all domestic purposes and for irrigation of food subsistence crops during dry weather. The storage tanks are therefore relatively large to provide seasonal storage.

In developed countries with large urban population centers in water scarce regions (such as Australia), runoff harvesting has long been used to augment the water supplies. In most cases, the runoff is collected from roofs and stored in large tanks adjacent to homes where the water is used for non-potable uses. In some rural cases, the water is used for all domestic water uses. At large development water harvesting projects (such as at large apartment buildings in urban city centers), runoff is collected from all areas and undergoes some pretreatment before storage in large (usually underground) storage tanks. The water usually undergoes very sophisticated water treatment before use. In many cases, this highly treated harvested runoff is still restricted to non-potable uses.

Examples of runoff harvesting in developed countries that currently are not under-going water shortages (such as Germany) are similar to the processes used in Australia. The purposes are to develop “sustainable” urban environments, where water conservation is a key factor.

In the U.S., many of the recent stormwater harvesting projects are either part of a LEED® certified project, and/or are used to help reduce stormwater discharges to combined sewer systems. The collected water is not used for potable uses, but mostly for irrigation uses, and sometimes for toilet flushing or for fire suppression.

Water reuse regulations or guidelines vary with the type of application, the regional context, and the overall risk perception. Few water reuse regulations address stormwater source water and were mostly initially developed for the reuse of treated sanitary wastewaters. The regulations therefore usually apply to all water sources that are deemed to be “wastewaters,” including stormwater. Most of the general reuse guidelines have limits on quality objectives based on suspended solids, organic content (usually expressed as BOD5), bacteria indicator organisms and some pathogens (total or fecal coliforms, E. coli, helminth eggs, enteroviruses), nutrient levels (nitrogen and phosphorus) and, in some cases, chlorine residual, while the stormwater beneficial use regulations mostly focus on E. coli, chlorine, pH, and turbidity.

This research also compared stormwater quality with the regulations and criteria for beneficial uses. Constituents where the expected stormwater average values exceed the available criteria include: BOD5, COD, TSS, turbidity, total coliforms, fecal coliforms, and E. coli. Additional constituents may periodically exceed the criteria, as some of the reported maximum stormwater values can be high, including: pH, ammonia, nitrate plus nitrite, arsenic, cadmium, chromium, copper, iron, selenium, and zinc. The most potentially problematic constituents (where the exceedences are the greatest and likely most frequent), include the bacteria, followed by the solids and turbidity values. The metals having the potentially greatest exceedences include cadmium and zinc. As expected, roof runoff and landscaped areas have better water quality, but all stormwater source areas can exceed the numeric criteria for BOD5, COD, TSS, and fecal coliforms. Stormwater runoff at outfalls exceeded the bacteria objectives by the greatest amount, followed by TSS. The BOD5 and COD exceedences were not as great, but almost all samples from all land use areas exceeded these criteria Therefore, none of the stormwater or source waters would likely be able to meet the numeric criteria for stormwater beneficial uses without treatment, with the bacteria being the most problematic, and the solids and turbidity values also being an issue. Roof runoff is the preferred source water for beneficial stormwater uses, but treatment, especially for bacteria, will still be necessary in order to meet existing criteria.

Different materials are used in the collection and storage components of stormwater beneficial use systems. Some materials can degrade runoff water even with very short contact times, and would be a problem even if used for the collection surface. Other materials, however, require extended exposure periods to degrade the water, such as would be evident in storage tanks. The most significant potential problems are associated with galvanized metal roofs or gutters and tanks, plus copper pipes or other plumbing fixtures used in the systems. These materials can elevate the zinc and copper concentrations to problematic concentrations during rain events, while extended contact, such as with storage tanks, can cause very high concentrations of these metals.

Treatment of stormwater may therefore be needed to meet non-potable beneficial use criteria. For simple irrigation use, bacteria reductions would be necessary, along with the prevention of excessive metal concentrations through careful selection of materials. Extended cistern and water tank storage can reduce most bacteria levels to close to the regulation's numeric values, although some additional treatment may be needed. Roof runoff can have excessive bacteria levels, especially during the non-winter months and if trees are over the roofs, which provide inviting habitat for birds and squirrels (shown to cause very large bacteria levels in roof runoff). Depending on the water quality of the source stormwater and the intended beneficial use, different water quality treatment options can be used. There are a number of commercial treatment units available designed for treating wastewater for reuse that can also reduce stormwater solids, bacteria, and heavy metals to acceptable levels.

The report also presents a method to evaluate or size water storage tanks needed to optimize the beneficial uses of stormwater. Irrigation of land on the homeowner's property was considered the beneficial use of most interest. Production function curves were prepared for several locations in the U.S. showing the relationship between water tank size and roof runoff beneficial use. Irrigation calculations rely on good evapotranspiration (ET) data, which is rare for urban settings. The report therefore also reviews several ET data sources and describes their applicability and use. Guidance on plants that withstand a wide range of moisture conditions is also provided in order to increase the irrigation demands to maximize the use of the runoff water.

The following table summarizes the results of calculations indicating the effects of different sized storage tanks for residential areas for irrigation use of roof runoff. The irrigation demands on this table are only to meet the evapotranspiration (ET) requirements, after infiltration of the typical rainfall. The continuous model used a five year rain series and does not consider any "over" irrigation or other uses. It is quite likely that excessive irrigation would be suitable as a stormwater disposal option. As an example, the use of roof runoff rain gardens usually do not only consider the minimum irrigation requirements, but supply an excess of water based on the infiltration capabilities of the soils. These values are therefore the minimum quantities of roof runoff harvesting available. The Central U.S. area has the highest level of potential stormwater beneficial use because the ET demands best match the rainfall distributions throughout the year. The Great Lakes area also has a high level of stormwater beneficial use potential. The East Coast, Southeast, and Southwest regions all had moderate levels of stormwater beneficial use potential due to poorer matches of the ET and rainfall patterns, or greater amounts of rainfall compared to the available irrigation demand (or both). The Northwest region has the poorest likely potential use of stormwater beneficial use due to the small ET-infiltration deficits (larger tanks have little additional benefit; the irrigation area would have to be greatly expanded to utilize any extra stored stormwater, or excessive irrigation applications would be needed).

Maximum Roof Runoff Harvesting Benefits for Regional Conditions (Medium Density Residential Land Uses, silty soil conditions)

Region	total roof area (% of total residential area)	landscaped area (% or total residential area)	representative city	study period annual rain fall (inches per year) (1995 to 2000)	roof runoff control (%) for 0.025 ft^3 storage/ft^2 roof area (about 5 rain barrels per 1,000 ft^2 roof)	roof runoff control (%) for 0.25 ft^3 storage/ft^2 roof area (3 ft high by 6 ft diameter tank per 1,000 ft^2 roof)	roof runoff control (%) for 1.0 ft^3 storage/ft^2 roof area (two 6 ft high by 10 ft diameter tanks per 1,000 ft^2 roof)
Central	18.1	62.5	Kansas City, MO	33.5	40%	78%	90%
East Coast	15.9	54.5	Newark, NJ	53.0	24%	33%	42%
Southeast	8.8	81.1	Birmingham, AL	49.8	34%	41%	42%
Southwest	15.4	61.2	Los Angeles, CA	16.7	35%	44%	48%
Northwest	15.4	61.2	Seattle, WA	41.7	16%	16%	19%
Great Lakes	15.0	57.5	Madison, WI	28.7	46%	68%	72%

CHAPTER 1.0

THE BENEFICIAL USES OF STORMWATER IN URBAN AREAS AND THE NEED FOR CHANGE IN URBAN WATER MANAGEMENT

1.1 Introduction

The following chapter is mostly excerpted from: R. Pitt, M. Lilburn. S.R. Durrans, S. Burian, S. Nix, J. Voorhees, and J. Martinson, *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems)*, originally prepared for the U.S. Environmental Protection Agency, Urban Watershed Management Branch, Edison, New Jersey, December 1999. Through the last decades, many of these new approaches have been applied in several areas, serving as demonstrations for more widespread applications of these emerging approaches in urban water management.

Stormwater has classically been considered a nuisance, requiring rapid and complete drainage from areas of habitation. Unfortunately, this approach has caused severe alterations in the hydrological cycle in urban areas, with attendant changes in receiving water conditions and uses. This historical approach of “water as a common enemy” has radically affected how urban dwellers relate to water. For example, most residents are not willing to accept standing water near their homes for significant periods of time after rain has stopped. However, there are now many examples where landscape architects have very successfully integrated water in the urban landscape. In many cases, water has been used as a focal point in revitalizing downtown areas. Similarly, many arid areas are looking at stormwater as a potentially valuable resource, with stormwater being used for beneficial uses on-site, instead of being discharged as a waste. One of the earliest efforts investigating positive attributes of stormwater was a report prepared for the Storm and Combined Sewer Program of the U.S. Environmental Protection Agency by Hittman Associates in 1968. Only recently has additional literature appeared exploring beneficial uses of stormwater. This section discusses some of these progressive ideas.

1.2 Stormwater as an Aesthetic Element in Urban Areas

Dreiseitl (1998) states that “stormwater is a valuable resource and opportunity to provide an aesthetic experience for the city dweller while furthering environmental awareness and citizen interest and involvement.” He found that water flow patterns observed in nature can be duplicated in the urban environment to provide healthy water systems of potentially great beauty. Without reducing safety, urban drainage elements can utilize waters refractive characteristics and natural flow patterns to create very pleasing urban areas. Successful stormwater management is best achieved by using several measures together. Small open drainage channels placed across streets have been constructed of cobbles. These collect and direct the runoff, plus slow automobile traffic and provide dividing lines for diverse urban landscaping elements. The use of rooftop retention and evaporation reduce peak flows. Infiltration and retention ponds can also be used to great advantage by providing a visible and enjoyable design element in urban landscapes.

Dreiseitl (1998) described the use of stormwater as an important component of the Potsdamer Platz in the center of Berlin. Roof runoff is stored in large underground cisterns, with some filtered and used for toilet flushing and irrigation. The rest of the roof runoff flows into a 1.4 ha (3.8 acre) concrete lined lake in the center of the project area. The small lake provides an important natural element in the center of this massive development and regulates the stormwater discharge rate to the receiving water (Landwehrkanal). The project is also characterized by numerous fountains, including some located in underground parking garages.

Göransson (1998) also describes the aesthetic use of stormwater in Swedish urban areas. The main emphasis for this study was to retain the stormwater in surface drainages instead of rapidly diverting the stormwater to underground conveyances. Small, sculpturally formed rainwater channels are used to convey roof runoff downspouts to the drainage system. Some of these channels are spiral in form and provide much visual interest in areas dominated by the typically harsh urban environment. Some of these spirals are also formed in infiltration areas and are barely noticeable during dry weather. During rains, increasing water depths extenuate the patterns. Glazed tile, small channels having perforated covers, and geometrically placed bricks with large gaps to provide water passage slightly below the surface help urban dwellers better appreciate the beauty of flowing water.

Tokyo has instituted major efforts to restore historical urban rivers that have been badly polluted, buried or have had all of their flows diverted. Fujita (1998) describes how Tokyo residents place great value on surface waterways: “waterfront areas provide urban citizens with comfort and joy as a place to observe nature and to enjoy the landscape.” Unfortunately, the extensive urbanization that has taken place in Tokyo over the past several decades has resulted in severe stream degradation and disappearance of streams altogether. However, there has recently been a growing demand for the restoration of polluted urban watercourses in Tokyo. This has been accomplished in many areas by improved treatment of sanitary sewage, reductions in combined sewer overflows and by infiltration of stormwater.

The Meguro and Kitazawa streams have been recovered by adding sanitary wastewater (receiving secondary treatment, plus sand filtration and UV disinfection, with activated carbon filtration and ozone treatment to provide further odor control) to previously dry channels. The treated wastewater is being pumped 17 km from the treatment facilities to the upstream discharge location in Meguro Stream. The Nogawa Stream has been restored by adding springwater produced from stormwater infiltration. Increased firefly activity has been noted along the Nogawa Stream and the adjacent promenade, providing adequate justification for these projects to the local citizens.

The quality of the treated wastewater entering Meguro Stream (at 0.35 m^3/s) since 1995 is as follows: total BOD_5: 6 mg/L; carbonaceous BOD_5: 2 mg/L; suspended solids: 0.5 mg/L; and ammonia-nitrogen: 7 mg/L. The total coliform bacteria concentrations were initially high (5,000 MPN/100 mL), and UV disinfection was therefore later installed at the outlets of the treated wastewater to the stream. The receiving water biological uses (carp and crustaceans) require the following conditions: total BOD_5: <8 mg/L; a water depth of at least 10 cm, and a stream velocity of at least 0.1 m/s. The BOD_5 goals are being met and the Meguro Stream has a 20 cm depth and a velocity of about 0.3 m/s. When storm events occur, remote valves are operated to decrease the discharge of the treated wastewater into the stream. However, the physical habitat of the stream is currently severely degraded, being concrete lined. The local residents are appreciative of the small flow in the stream, and the Tokyo Metropolitan Government (TMG) plans to modify the stream walls to facilitate groundwater recharge of the stream, to create rapids and pools for fish, and to plant trees along its banks, to further enhance the value of the stream to the local population.

Kitazawa Stream is another example of a severely degraded urban stream in Tokyo that has undergone extensive modification. The stream watershed is 10.5 km^2 and has a population of about 150,000 people. The rapid urbanization in Tokyo since the 1950s has resulted in a severe decrease in groundwater infiltration during rains. This has caused decreased groundwater levels and decreased the associated natural recharge into urban streams. By the 1960s, there was almost no natural flow in Kitazawa Stream during dry weather. The only flows present in the stream was wastewater from homes. The stream was therefore of extremely poor quality, creating an unsafe and nuisance condition. In addition, the increased development caused frequent flooding. The TMG therefore diverted the stream into an underground culvert. The aboveground area was converted into a promenade with extensive plantings. Local residents have requested the addition of a steam along the promenade. A very small flow (0.02 m^3/s) of treated wastewater has been pumped from 11 km away to create this new stream (a “two-storied watercourse”). This new steam, however small, has created a very important element in the lives of the residents of this heavily urbanized city. Special community organizations have been established to plan and manage the area.

Another Tokyo example of urban stream rehabilitation has occurred in the Nogawa Stream watershed. The watershed is about 70 km^2 in area and has a population of about 700,000 people. Urbanization in this area also dramatically decreased the natural groundwater recharge to the stream. With development, household graywater, some sanitary wastewater, and stormwater were infiltrated into the ground and recharged the stream. When the sanitary wastewater collection and treatment system was improved in the 1980s, the stream flow was severely diminished, as a major source of groundwater recharge was eliminated. The headwater springs in the Nogawa area were of special importance to the local residents and they requested that TMG restore the dried springs. Artificial groundwater recharge, using stormwater, has been successfully used to restore the springs. Many private homes have installed stormwater infiltration devices in the area. In an example in Mitaka City, 4,000 infiltration “soakaways” were constructed during the three years from 1992 to 1995, allowing about 240,000 m^3/yr of stormwater to be infiltrated to revitalize the spring at Maruike. Koganei City residents installed more than 26,000 soakaways and 10.4 km of infiltration trenches at 5,700 homes (about 25% of all of the homes in the area). Other cities in the area have also helped residents install several thousand additional infiltration facilities. Spring flows have increased, although quantitative estimates are not yet available.

Fujita (1998) repeatedly stated the great importance that the Japanese place on nature, especially flowing water and the associated landscaping and attracted animals. They are therefore willing to perform what seems to be extraordinary efforts in urban stream recovery programs in the world’s largest city. The stream recovery program is but one element of the TMG’s efforts to provide a reasonably balanced urban water program. Water reuse and conservation are important elements in their efforts. Stormwater infiltration to recharge groundwaters and the use of treated wastewaters for beneficial uses (including the above described stream restoration, plus landscaping irrigation, train washing, sewer flushing, firefighting, etc.) are all important elements of these efforts, although this reuse currently only amounts to about 7% of the total annual water use in Tokyo.

1.3 Guidelines for the Reuse of Stormwater in Urban Areas

An obviously important consideration when examining the reuse of stormwater is the different quality requirements for the different reuse activities. Reuse guidelines are relatively rare, but Table 1-1 presents some guidance from Japan (Fujita, 1998). The most serious restrictions relate to ensuring the safety of the water during inadvertent human contact. The prevention of nuisance conditions is also of concern.

Table 1-1. Quality Standards for the Reuse of Treated Wastewater in Japan. (Fujita, 1998)[1]

	Toilet Flushing	Fire Sprinklers	Landscape Irrigation	Recreation Use
Total Coliforms (MPN/100 mL)	<1,000	<50	<1,000	<50
Residual Chlorine (mg/L)	present	>0.4		
Color (Pt units)	No unpleasant appearance	No unpleasant appearance	<40	<10
Turbidity (NTU)	No unpleasant appearance	No unpleasant appearance	<10	<5
BOD_5 (mg/L)	<20	<20	<10	<3
Odor	Not unpleasant	Not unpleasant	Not unpleasant	Not unpleasant
pH	5.8 – 8.6	5.8 – 8.6	5.8 – 8.6	5.8 – 8.6

[1] In addition, the objectives for carp and crustaceans in urban streams include the following: total BOD_5: <8 mg/L; a water depth of at least 10 cm, and a stream velocity of at least 0.1 m/s.

Table 1-2 shows an example of early Maryland's reuse guidelines, along with acceptable use categories and per capita requirements (Mallory, 1973). Only a small fraction (<10%) of the total residential water use requirements need to be of the highest quality water. Class AA water meets all U.S. Public Health Service Drinking Water Standards, class A water is very similar, except for taste and odor considerations, class B water has less restrictions, especially with respect to suspended solids, and class C water only has minimum requirements pertaining to corrosivity. All of these waters require disinfection by the state of Maryland. It is not likely that stormwater would be used for class AA uses without conventional water treatment, but lower levels of use may be feasible with less treatment. Table 1-3 shows the specific maximum concentrations allowed for each reuse category, as determined by the state of Maryland, in addition to typical residential area stormwater quality. Average stormwater concentrations are presented, as needed storage would provide equalization of concentrations over short periods of time.

Table 1-2. Distribution of Maryland Residential Water Use and Required Quality. (Mallory, 1973)

Class	Use	Rate of Use (gal/person/day)	Percentage of Total Water Use
AA	Consumption by humans, food preparation, general kitchen use	6.5	7
A	Bathing, laundering, auto washing	31.0	36
B	Lawn irrigation	518 gal/day/acre	29
C	Toilet flushing	24.0	28

Table 1-3. Maximum Concentrations Allowed by Maryland for Different Reuse Categories, Compared to Typical Residential Stormwater Runoff. (Mallory, 1973)

Constituent (mg/L)	AA	A	B	C	Typical average residential stormwater quality and highest use without treatment (various references)
Total solids	150	500	500	1500	250 (A)
Suspended solids	-	-	10	30	50 (none)
Turbidity (NTU)	0-3	3-8	8-15	15-20	25 (none)
Color (color units)	15	20	30	30	25 (B)
pH (pH units)	7	6	6	6	6 to 9 (AA)
Oxygen, dissolved (minimum)	5	5	4	4	Near saturation (AA)
Total coliform bacteria (MPN/100 mL)	1	70	240	240	>10,000 (none)
Nutrients					
Ammonia (as NH_3)	0.5	0.5	0.5	0.5	<0.1 (AA)
Nitrate (as NO_3)	45	50	50	50	1 (AA)
Phosphates	1	1	1	1	0.5 (AA)
Major Ions					
Calcium	0.5	75	75	75	10 (A)
Chloride	50	250	250	250	<50 (AA)
Fluoride	1.5	3	3	3	0.03 (AA)
Iron	0.1	0.3	0.3	0.3	
Magnesium	0.5	150	150	150	1 (A)
Manganese	0.05	0.1	0.5	0.5	
Sulfate	50	200	400	400	10 (AA)
Heavy Metals					
Arsenic	0.01	0.05	0.05	0.05	<0.05 (A)
Chromium (+6)	0.05	0.05	0.05	0.05	<0.05 (AA)
Copper	1.0	1	1.5	1.5	0.05 (AA)
Cyanide	0.01	0.2	0.2	0.2	0.05 (A)
Lead	0.05	0.1	0.1	0.1	0.05 (AA)
Zinc	5	15	15	15	0.5 (AA)

As shown on these tables, residential area stormwater can be used to meet at least class A water needs, except for suspended solids, turbidity, color, and coliform bacteria. The solids, turbidity and color levels are likely to be adequately reduced through storage and associated settling, plus possible post-settling filtration. The most serious impediment for the reuse of stormwater in residential areas are the bacteria levels. Unfortunately, stormwater is known to contain pathogens that can cause illness through various exposure mechanisms. However, it must be remembered that stormwater currently comes in contact with many people during rains and runoff from roofs and paved areas are encouraged to drain to landscaped areas to reduce runoff quantities. These practices are not considered hazardous and have not shown detrimental effects. Never-the-less, total coliform bacteria levels in stormwater can be very large, much greater than 10,000 MPN/100 mL and greatly exceed reuse criteria. The criteria for reuse shown on Table 1-3 requires a maximum total coliform level of 240 MPN/100 mL for class B and C water, and a level of 70 MPN/100 mL for class A water. Drinking water (class AA water) requires a maximum of 1 MPN/100 mL. Any of these levels would be impossible to meet without significant disinfection efforts.

Another set of reuse guidelines has been developed in California (CDPH, 2009) and are shown on Table 1-4. These guidelines were developed for the reuse of high quality secondary domestic wastewater effluent. The median total coliform bacteria criteria are very stringent (to product the public from likely associated pathogens) and would also not be possible to be met without very significant disinfection efforts. The only uses where primary treatment alone (similar to detention) is needed, and for which no total coliform bacteria criteria are given, are for the irrigation of selected crops when the recycled water does not come in contact with the edible portion of the crop, and for flushing sanitary sewers . As indicated in Table 1-4 (data from CDPH, Regulations Related to Recycled Water, 2009), irrigation in areas where public contact is likely requires disinfection and very low levels of total coliform bacteria.

Table 1-4. California Reuse Guidelines (CDPH, 2009).

Use of reclaimed water	Undisinfected secondary recycled water[1]	Disinfected secondary-23 recycled water[2]	Disinfected secondary-2.2 recycled water[3]	Disinfected tertiary recycled water[4]
Irrigation				
Food crops, including all edible root crops, where the recycled water comes into contact with the edible portion of the crop, parks and playgrounds, school yards, residential landscaping, unrestricted access golf courses.				required
Food crops where the edible portion is produced above ground and not contacted by the recycled water.			required	
Golf courses, cemeteries, freeways, ornamental nursery stock and sod farms where access by the general public is not restricted, pasture for animals producing milk for human consumption, and any nonedible vegetation where access is controlled so that the irrigated area cannot be used as if it were part of a park, playground or school yard.		required		
Orchards and vineyards where the recycled water does not come into contact with the edible portion of the crop, non food-bearing trees, fodder and fiber crops and pasture for animals not producing milk for human consumption, seed crops not eaten by humans, food crops that must undergo commercial pathogen-destroying processing before being consumed by humans, and ornamental nursery stock.	required			
Impoundments				
Supply for nonrestricted recreational impoundments.				required
Supply for restricted recreational impoundments and any publicly accessible impoundments at fish hatcheries.			required	
Supply for landscape impoundments that do not utilize decorative fountains.		required		
Cooling				
industrial or commercial cooling or air conditioning that involves the use of a cooling tower, evaporative condenser, spraying or any mechanism that creates a mist.				required
Industrial or commercial cooling or air conditioning that does not involve the use of a cooling tower, evaporative condenser, spraying, or any mechanism that creates a mist.		required		

Table 1-4. California Reuse Guidelines. (continued)

Other Purposes				
Flushing toilets and urinals, priming drain traps, industrial process water that may come into contact with workers, structural fire fighting, decorative fountains, commercial laundries, consolidation of backfill around potable water pipelines, artificial snow making for commercial outdoor use, and commercial car washes, including hand washes if the recycled water is not heated, where the general public is excluded from the washing process.				required
Industrial boiler feed, nonstructural fire fighting, backfill consolidation around nonpotable piping, soil compaction, mixing concrete, dust control on roads and streets, cleaning roads, sidewalks and outdoor work areas and industrial process water that will not come into contact with workers.		required		
Flushing sanitary sewers	required			

[1] "Undisinfected secondary recycled water" means oxidized wastewater.

[2] "Disinfected secondary-23 recycled water" means recycled water that has been oxidized and disinfected so that the median concentration of total coliform bacteria in the disinfected effluent does not exceed a most probable number (MPN) of 23 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed, and the number of total coliform.

[3] "Disinfected secondary-2.2 recycled water" means recycled water that has been oxidized and disinfected so that the median concentration of total coliform bacteria in the disinfected effluent does not exceed a most probable number (MPN) of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed, and the number of total coliform bacteria does not exceed an MPN of 23 per 100 milliliters in more than one sample in any 30 day period.

[4] "Disinfected tertiary recycled water" means a filtered and subsequently disinfected wastewater that the median concentration of total coliform bacteria measured in the disinfected effluent does not exceed an MPN of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed and the number of total coliform bacteria does not exceed an MPN of 23 per 100 milliliters in more than one sample in any 30 day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 milliliters.

Source : California Department of Public Health, Regulations Related to Recycled Water, January 2009. Available at: http://www.cdph.ca.gov/certlic/drinkingwater/Documents/Lawbook/RWregulations-01-2009.pdf

Because of the risks associated with potential pathogens, reuse of stormwater in residential areas should only be considered where consumption and contact is minimized, restricting on-site reuse to classifications B and C, and only after adequate disinfection and site specific study to ensure acceptable risks. To further minimize risks, only the best quality stormwater (from a pathogen perspective) should be considered for reuse. As an example, residential area roof runoff generally has lower fecal coliform concentrations than runoff from other source areas, although very high levels are periodically observed from this source area. Therefore, stormwater “harvesting” efforts could be limited to residential area rooftops to reduce risks associated with pathogens.

1.4 The Need for Change in Urban Water Management

As indicated above, stormwater has been considered a valuable resource in some urban areas for many years, not just a waste that must be rapidly discarded. The *Symposium on Water, the City, and Urban Planning* was held in Paris, France, on April 10 and 11, 1997. The 300 participants formulated the *Paris Statement* outlining needed changes in urban water management. Even though stormwater management is usually considered a luxury of the developed countries (especially North America, Western Europe, and a few major Asian cities), this symposium stressed the need for recognizing the important role that stormwater management can play in the developing countries. Some of the major points of the *Paris Statement* are briefly outlined below:

- The marked process of urbanization in most countries, and especially in the developing world, is causing very rapid increases in water demands, often far outstripping available resources. Water management needed for sustainable urban development, let alone long-term survival of cities, requires immediate attention.
- Water related problems are affected by all elements of the water cycle, including water, land, air, and energy. Social, cultural, political, institutional, and economic aspects are integral and may even be dominant components of urban water management issues. Therefore, an integrated approach for solving urban water resource problems is necessary.
- Each city has a unique set of conditions and problems that require site specific solutions. However, a great deal of information from cities throughout the world is available for helping to solve these local problems.
- Demand management measures to encourage water conservation needs to be implemented, along with the timely consideration of environmentally sound projects to increase the availability of water when and where it is needed. Water problems are recognized mostly as temporal and spatial distribution problems, not because there is a fundamental shortage of water.
- An integrated management approach to surface and groundwaters is needed. Groundwater contamination by urban wastes must be controlled and safe recharge of groundwaters by wastewater and stormwater needs to be investigated.
- Appropriate approaches for urban drainage must consider variations in local climate, types of problems, and economic and maintenance capabilities. In addition, non-structural solutions need to be implemented as part of an integral approach to flood control in urban areas.
- There is a great need to conceive and apply new innovative solutions to solve urban water resource problems. This is especially likely and needed in areas with little drainage and sanitation infrastructure currently in place.
- The symposium recommended the creation of a single and integrated entity for coordination and management of water resources in each urban area.

A paper presented by Geldof (1998) at the Malmo conference on *Sustaining Urban Water Resources in the 21st Century* described changes that are occurring in the Netherlands. He stated that Dutch urban surface waters tended to be neglected in the past because of their poor water quality. However, current thinking is stressing significant changes in urban water management that will decrease many current problems (such as leaking sanitary and combined sewerage, discharges caused by peak flows, groundwater elevation variations and subsidence, and eutrophic surface waters). Two main changes are being used: changes in the sewerage systems, and increased source controls with on-site reuse of stormwater. In the Netherlands, combined sewers serve about 75% of the urban areas and have a capacity for about 7 mm or rain. Overflows occur when the rainfall exceeds this amount (as often as ten times a year). Separate sewers have been mostly built since the 1970s and now serve most of the remaining urban land area. The separate sewers solved the combined sewer overflow problems, but surprisingly did little to improve the annual mass discharges of pollutants. With separate drainage systems, none of the stormwater is treated at the municipal wastewater treatment plant. In addition, inappropriate discharges of sanitary sewage to the storm sewers are periodically found from inadvertent connections. A new system, termed an “improved separate system,” was therefore developed. This drainage system consists of separate sanitary and storm drainage, but they are cross-connected with one-way gate valves enabling some stormwater to enter the sanitary drainage and be treated at the municipal wastewater treatment facility. The one-way gate values prevent sanitary sewage from entering the storm drainage. Pressurized sanitary sewerage is also sometimes used, with pumps used to discharge appropriate amounts of stormwater into the sanitary sewage system. An important aspect of the improved separate system is that only the most contaminated stormwater enters the stormwater drainage system and then the sanitary wastewater collection system for conveyance to the treatment facility. The least contaminated stormwater (typically just the roof runoff) is infiltrated on site, or potentially also used for toilet flushing, laundry, or irrigation purposes. The improved separate systems typically have a conveyance capacity to handle a 4 mm rain, which is capable of directing about 75 to 90% of the paved area stormwater runoff to the treatment facilities. Geldolf reported that a surprising side effect of source control is that it tends to upgrade people’s perception of stormwater: “it becomes a pleasure rather than a nuisance.” He also reports that residents have even become competitive about how they can most effectively use stormwater on site.

1.5 Content of Final Report

1.5.1 Residential Area Water Use

This report section reviews water consumption in several countries. Residential water usage is of the greatest interest. The water consumption is divided by use to identify consumptive and nonconsumptive uses. The main purpose of this section is to illustrate the range of per capita water consumption and how it has changed with time, and to identify the amount of water that can be supplied by harvested stormwater. Economic, social and environmental factors affect the domestic water consumption, thus the amount of household water used varies for different countries.

1.5.2 Case Studies

This report section reviews a selection of current examples of rainwater harvesting in several countries. This discussion is not intended to be comprehensive, but to briefly illustrate the range of technologies being used in developing and in developed countries. The range of approaches is vast, with some situations simply concerned with capturing any available runoff possible to augment scarce local supplies, while other examples are in water-rich areas and the runoff is being harvested for beneficial uses to conserve already abundant water supplies. The methods used for storage and treatment are also seen to vary greatly, from local clay jars to vast underground reservoirs, and with many recharging aquifers for later withdrawal. Treatment also is seen to vary from virtually none to very sophisticated water treatment systems. The uses of the harvested runoff also vary from irrigation and toilet flushing only to all domestic water uses. This report section provides a short description of these features for the case studies, and also includes a summary table describing the range of features for each example.

Locations of reviewed case studies include:

Asia (Singapore, Japan, Thailand, Indonesia, Philippines, Bangladesh, China, South Korea, and India)
Africa (South Africa, Kenya, and Tanzania)
Europe (Germany and Ireland)
Australia (South Australia, Queensland, Victoria, and New South Wales)
North America (US Virgin Islands, Florida, Hawaii, Washington, New York, Maryland, California, Missouri, Oregon, Washington, D.C., and North Carolina)

Information in all desired categories was not available (especially for costs and treatment) from the project documentation for all of the projects, but collectively, the information results in a good understanding of the range of stormwater harvesting opportunities.

Several important issues are seen from these case studies. As expected, the heavily urbanized developing countries in water stressed areas (such as in China and India) are most concerned with harvesting as much runoff as possible, with minimal concern related to water quality. Not only is roof runoff harvested (the likely cleanest water available, but still with some problems as described in the source water quality report section), but also runoff from all urban areas. Usually, all paved areas are used to harvest runoff water, as maximum volumes are needed to augment the poor quality and poorly available local sources. The water is stored in large ponds, and usually injected to shallow aquifers. These efforts improve the water quality to some extent, greatly depending on the storage conditions.

In developing countries with large rural populations in water stressed areas (such as in Africa), most of the runoff harvesting schemes focus on collecting roof runoff for storage in tanks near the homes. The water is used for all domestic purposes and for irrigation of food subsistence crops during dry weather. The storage tanks are therefore relatively large to provide seasonal storage.

In developed countries with large urban population centers in water scarce regions (such as Australia), runoff harvesting has long been used to augment the water supplies. In most cases, the runoff is collected from roofs and stored in large tanks adjacent to homes where the water is used for non-potable uses. In some rural cases, the water is used for all domestic water uses. At large development water harvesting projects (such as for urban city centers for large apartment buildings), runoff is collected from all areas and undergoes some pretreatment before storage in large (usually underground) storage tanks. The water then undergoes very sophisticated water treatment before use. In many cases, this highly treated harvested runoff is still restricted to non-potable uses.

Examples of runoff harvesting in developed countries that currently are not under-going water shortages (such as Germany) are similar to the processes used in Australia. The purposes are to develop “sustainable” urban environments, where water conservation is a key factor.

1.5.3 Stormwater Beneficial Use Regulations and Guidelines

This section reviews regulations and guidelines addressing stormwater beneficial uses in different states and also in some other countries. Water reuse regulations or guidelines vary with the type of application, the regional context, and the overall risk perception. Few regulations address stormwater source water and were mostly initially developed for the reuse of treated sanitary wastewaters. The regulations therefore usually apply to all water sources that are deemed to be “wastewaters,” including stormwater. However, this section shows some of the regulations that do specifically relate to beneficial uses of stormwater. Depending on the application, water quality requirements, treatment process requirements, and criteria for operation and reliability are considered. Most of the general reuse guidelines have limits on quality objectives based on suspended solids, organic content (expressed by BOD as an indicator of organic content), bacteria indicator organisms and some pathogens (total or fecal coliforms, *E. coli*, helminth eggs, enteroviruses), nutrient levels (nitrogen and phosphorus) and, in some cases, chlorine residual, while the stormwater use regulations mostly focus on *E. coli*, chlorine, pH, and turbidity.

1.5.4 Treatment Needs of Stormwater before Beneficial Use

This section focuses on the more common treatment processes found in stormwater reuse systems, and also discusses general small scale point-of-use water treatment options. While distillation and air stripping are technologies that potentially could be applied to stormwater systems, they are not common and are likely not needed. Distillation requires a large energy input. Air stripping is only likely viable as a potential technology if the water contains substantial amounts of volatile organic compounds that need to be removed before they enter a containment system that would reduce volatilization. Therefore, this discussion stresses sedimentation, filtration (both physical and chemical since they often occur jointly in the same media), and only briefly disinfection, since this report does not address potable stormwater consumption.

1.5.5 Calculating the Benefits of Rainwater Harvesting Systems and Sizing Systems

This last report section describes calculation procedures in detail and presents much information on available evapotranspiration data and how to apply ET in urban areas. Production functions are also provided that show the needed size of water storage tanks to meet different levels of roof runoff control.

CHAPTER 2.0

WATER USE AND TRENDS

2.1 Introduction

This report section reviews water consumption rates in some countries around the world, with the main focus on residential water use. Water consumption by separate household activities, such as toilet flushing and laundry is also provided for some countries. The main purpose of this section is to briefly illustrate the range of per capita water consumption and how much is used for non-consumptive vs. consumptive uses to estimate the amount of indoor water demand that can be substituted by stormwater. This is not intended to be a comprehensive evaluation of these uses, but summarizes trends and uses of domestic water. This discussion shows that economic, social and environmental factors affect domestic water consumption; thus, the amount of household water varies from country to country. Many of the European examples discussed in this section are for developed countries having stable populations with minimal water shortages, while the Asian, African, and Middle Eastern examples have more stressful population and water supply situations. Per capita water use changes over time is also presented in some examples.

2.2 Europe

2.2.1 Germany

The typical German household uses about 39% of its total water use for personal hygiene including bathing and showering, 30% for toilet flushing, 13% for cloth washing, 7% for dishwashing, 7% for room cleaning, washing cars and gardening and 4% for cooking and drinking. Schleich, et al. in 2009 studied residential water consumption in Germany from 1975 to 2004. They concluded that residential water usage has changed significantly from 1983 to 2004. Although previous forecasts made in the early 1970s estimated an increase in water consumption to over 200 L per capita per day, the water usage per capita dropped about 13% between 1991 and 2004. In 2004, domestic water use was 126 Liter per capita per day, while water consumption in the new states was only 93 L/c/d compared to 132 L/c/d in the old states. As shown in Figure 2-1, by 1995 there was a 34% and 9% reduction in the new states and the old states, respectively, since the reunification of Germany in the early 1990s. This change was most likely associated with an increased awareness of water conservation and associated overall sustainability objectives.

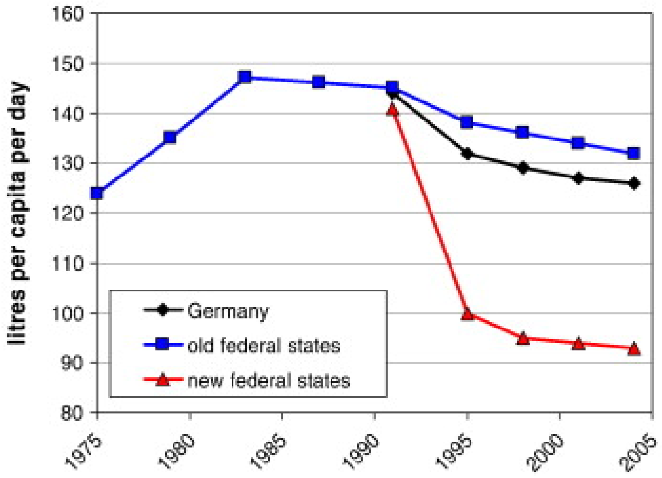


Figure 2-1. Water Consumption in Germany (in liters per capita per day). (Reprinted from Ecological Economics, Vol. 68, Schleich, J., Hillenbrand T., Determinants of residential water demand in Germany, pp.1756-1769, 2009, with permission from Elsevier)

2.2.2 Ireland

The residential water consumption sector in Ireland is a considerable portion of the total publicly-supplied water. In 2006, residential water usage accounted for about 60% of the total water demand, while the other 40% of the water supply was for agricultural, commercial, and industrial demand. (Li, et al., 2010). Among the European countries, Ireland's domestic water consumption per capita per day is one of the highest, after France and Spain, as shown in Figure 2-2 (data from Desalination, Vol. 260, Li, Z., , Boyle, F., Reynolds, A., Rainwater harvesting and greywater treatment systems for domestic application in Ireland, pp. 1-8, 2010, with permission from Elsevier). In Ireland, there was about a 10% increased per capita usage of residential water between 1997 and 2006, from about 135 L in 1997 to 148 L in 2006.

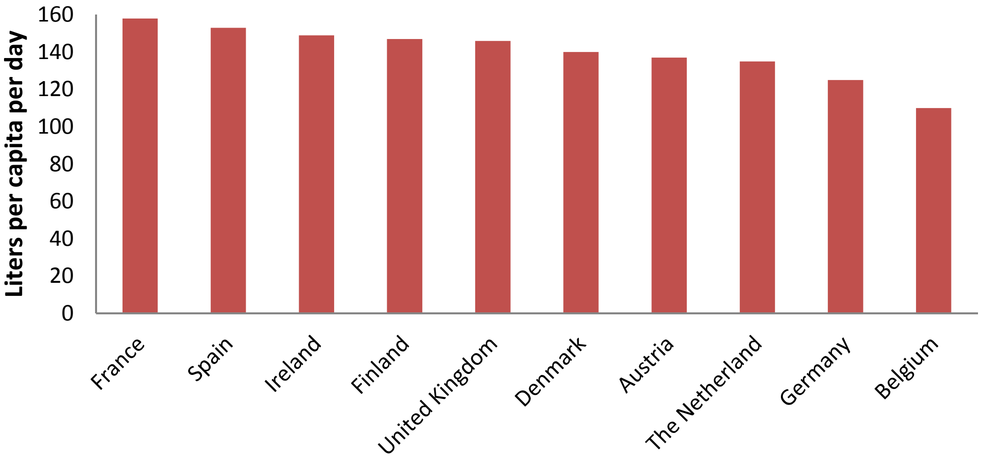


Figure 2-2. Average Domestic Water Consumption Per Capita Per Day in Selected EU Countries in 2006.

Although population growth and climate change could be significant reasons for increased overall domestic water use, the rise in the standard of living is one of the main factors that affect individual water consumption, especially for personal hygiene. In a typical house, the water consumption for toilet flushing, showering and bathing, washing machines and dishwashers is much more than 80% of total domestic water consumption. The breakdown of domestic water use per capita per day in an average household in Ireland in 2006 is represented in Figure 2-3 (data from Desalination, Vol. 260, Li, Z., , Boyle, F., Reynolds, A., Rainwater harvesting and greywater treatment systems for domestic application in Ireland, pp. 1-8, 2010, with permission from Elsevier)

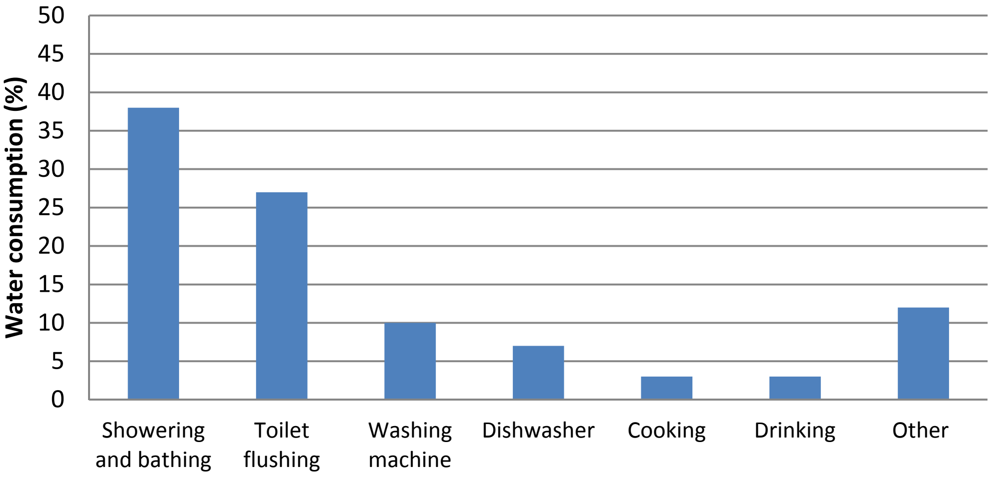


Figure 2-3. Breakdown of Indoor Domestic Water Use Per Capita Per Day for Various Uses in Ireland in 2006.

2.2.3 Poland

"One of the most dramatic trends in the Polish water sector since 1990 has been the 50% drop in water consumption, with contributions from both industry (due to industrial decline and more modern technology) and consumers (with the widespread introduction of metering, and price rises)" (de la Motte, 2007). In 1990, the normal water usage for a typical apartment was 250 L per day. In Gdan´sk, the average water use had dropped from 208 liters per capita per day in 1992 to 110 L per capita per day in 2003 (Figure 2-4, data from Utilities Policy, Vol. 15, de la Motte, R., A Tale of Two Cities: Public participation and sustainability in decision-making on water systems in two Polish cities, pp. 134-142, 2007, with permission from Elsevier)

Meter installation along with tariff increases resulted in a drop of 15% in average household water usage in a single year of 1995. A reduction of 52% in total per capita water consumption in the period of 1992 to 2003 was the most significant annual reduction in water consumption over the period.

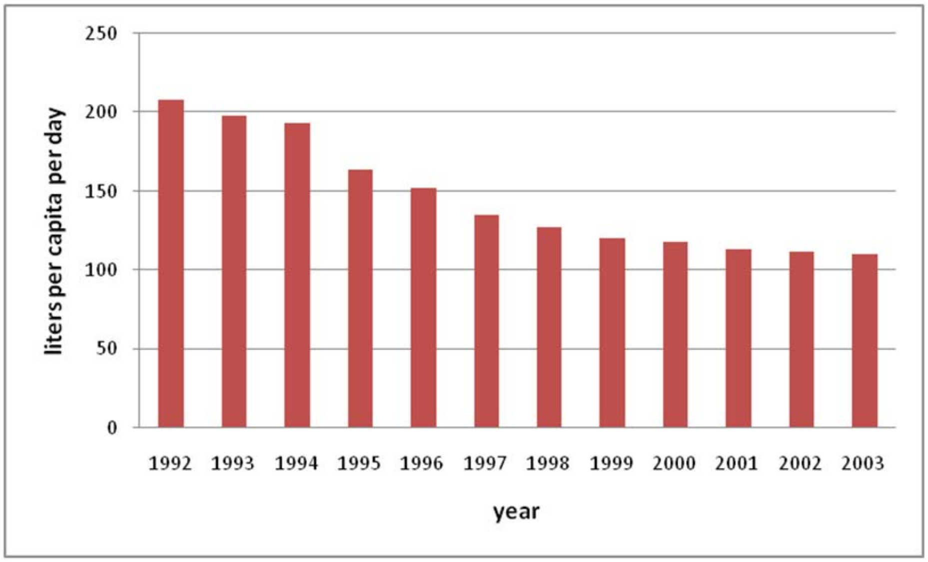


Figure 2-4. Gdan´sk Average Household Water Consumption.

Figure 2-5 (data from Utilities Policy, Vol. 15, de la Motte, R., A Tale of Two Cities: Public participation and sustainability in decision-making on water systems in two Polish cities, pp. 134-142, 2007, with permission from Elsevier) shows household water consumption in Lo´dz´´. In Lo´dz´´, the household water usage has dropped 95 L/c/d over the ten year period (from 236 L per capita per day in 1990 to 141 L per capita per day in 2000). In addition, Lo´dz´'s population has been decreasing since 1990 (from 850,000 in 1990, to 780,000 in 2003). Falling household water usage resulted in a noticeable decrease of 26.7 million m^3 in annual water supplies from 71.5 million m^3 in 1989 to 44.8 million m^3 in 2000 (Figure 2-6. data from Utilities Policy, Vol. 15, de la Motte, R., A Tale of Two Cities: Public participation and sustainability in decision-making on water systems in two Polish cities, pp. 134-142, 2007, with permission from Elsevier)

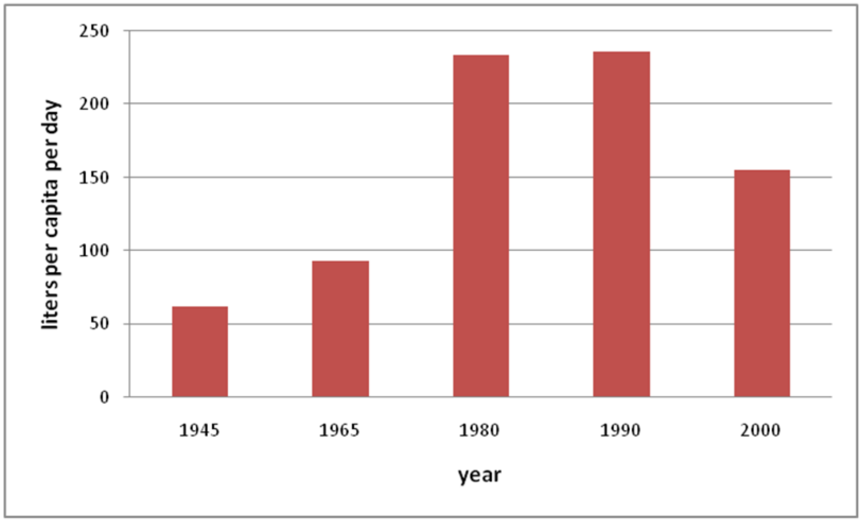


Figure 2-5. Lo´dz´ Average Residential Water Usage.

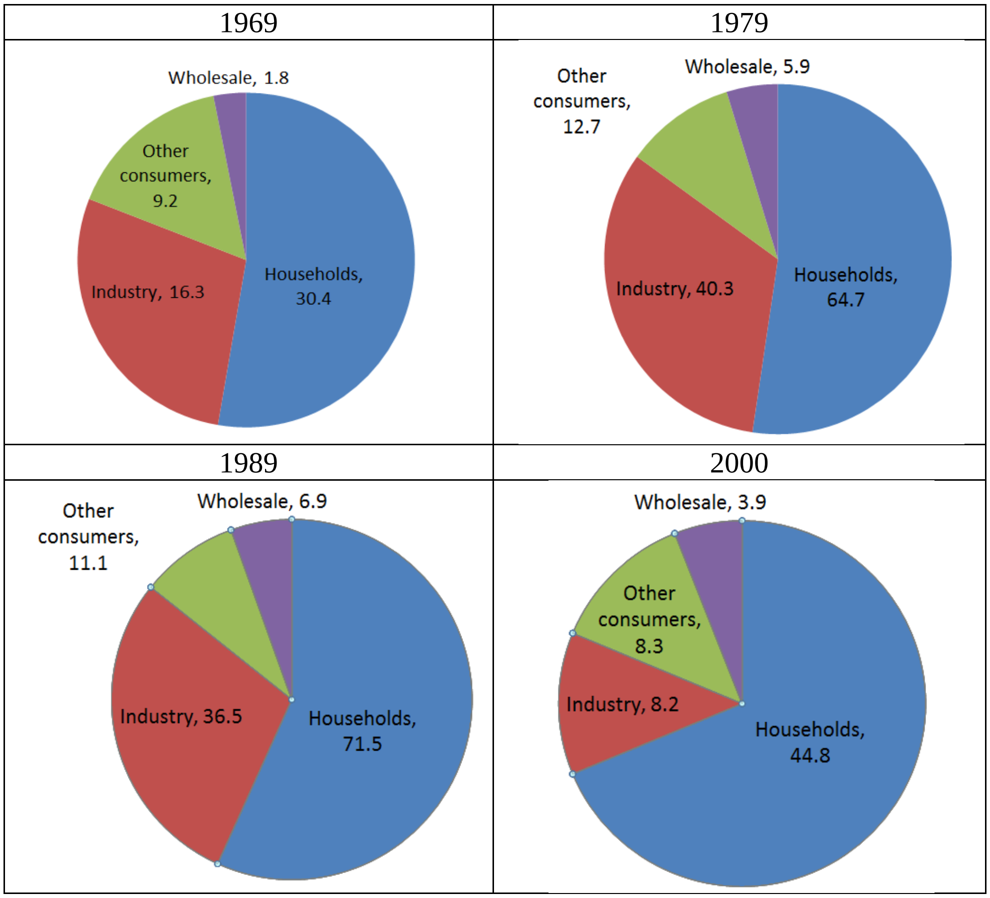


Figure 2-6. Lo´dz´Annual Water Usage.

2.2.4 Denmark

Figure 2-7 (data from Pramod Seth of Lyngby Tarbaek Council) shows that the typical Denmark household uses about 37% (48.5 liters) of its total water use for baths and showers (including wash basin use), 23% (30.1 liters) for flushing toilets, 19% (24.9 liters) for cloth washing, 12% (15.7 liters) for dish washing, 5% (6.6 liters) for drinking and food preparation, and 4% (5.2 liters) for outdoor usage.

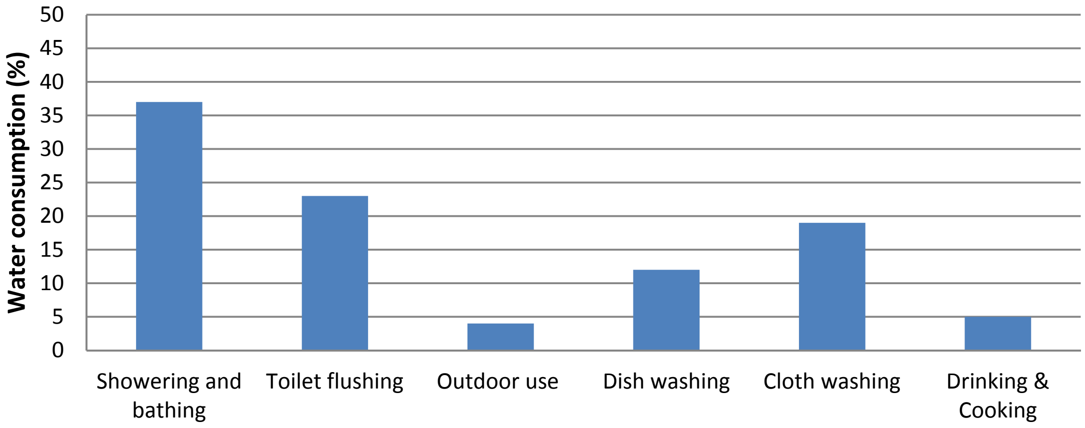


Figure 2-7. Breakdown of Domestic per capita Usage of Water in Denmark (131 l/h/d) into Various Categories.

The domestic per capita water usage in Denmark is 131 liters per day. Copenhagen Water supplies water to about 1.21 million customers in the Greater Copenhagen Area. In 1989, Copenhagen Water started a comprehensive water conservation program. This program focused on education campaigns, consultancy services, leak detection and repair. A part of the mentioned program made changes to the water price and taxation structure. As a result of these efforts, a reduction in the domestic per capita water usage of 22% occurred over the ten year period of 1989 to 1998, dropping from 168 L/c/d in 1989 to 131 L/c/d in 1998 (Environment Agency, 2008).

2.2.5 Finland

The typical household in Finland uses about 49% of its household water for personal hygiene, 19% for food preparation including dish washing, 14% for flushing toilets, 14% for washing clothes, 1% for drinking and 3% for other purposes, as shown in Figure 2-8. (data from Environment Agency, 2008).

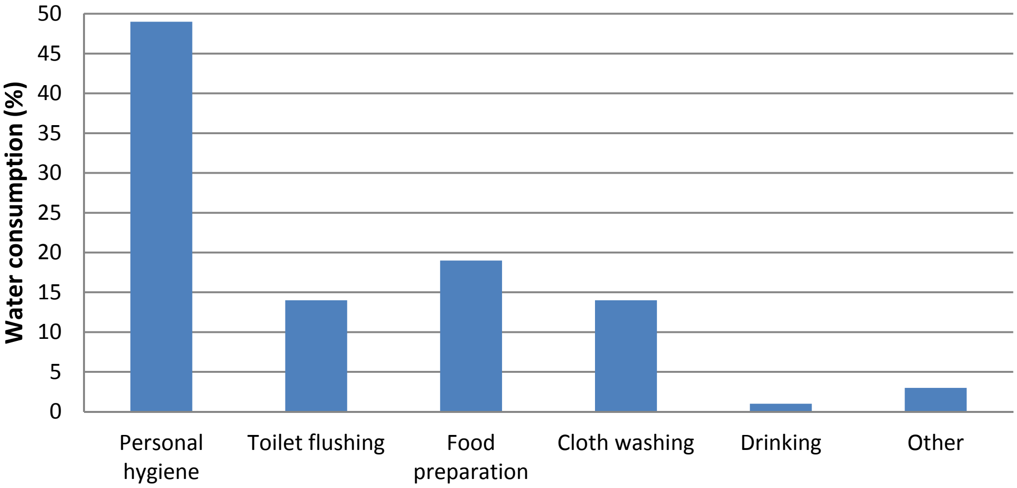


Figure 2-8. Breakdown of Finnish Domestic per capita Water Usage.

Rajala and Katko (2004) studied 185 cases at 37 different locations in Finland. They studied different types of housing including flats, terraced houses, semi-detached houses, and occupier status, as well as various metering arrangements which could be shared or by individual household. The result of study showed that per capita consumption for properties with a shared water meter was about 150 L/c/d and reduced to about 120 L/c/d for individually metered properties. Rajala and Katko (2004) concluded that water consumption of 120 L/c/d could be achieved for all housing categories, with appropriate management.

2.2.6 The Netherlands

Figure 2-9 (data from Environment Agency, 2008) shows the typical household in the Netherlands uses about 39% (49.8 liters) of its total domestic water use for showers, 29% (37.1 liters) for flushing toilets, 12% (15.5 liters) for washing machines, 4% (5.3 liters) for wash basins, 3% (3.8 liters) for dish washing by hand, 3% for drinking, 2% (3 liters) for dishwashers, 2% for bath, 1% (1.7 liters) for cloths washing by hand, and 4% for other purposes.

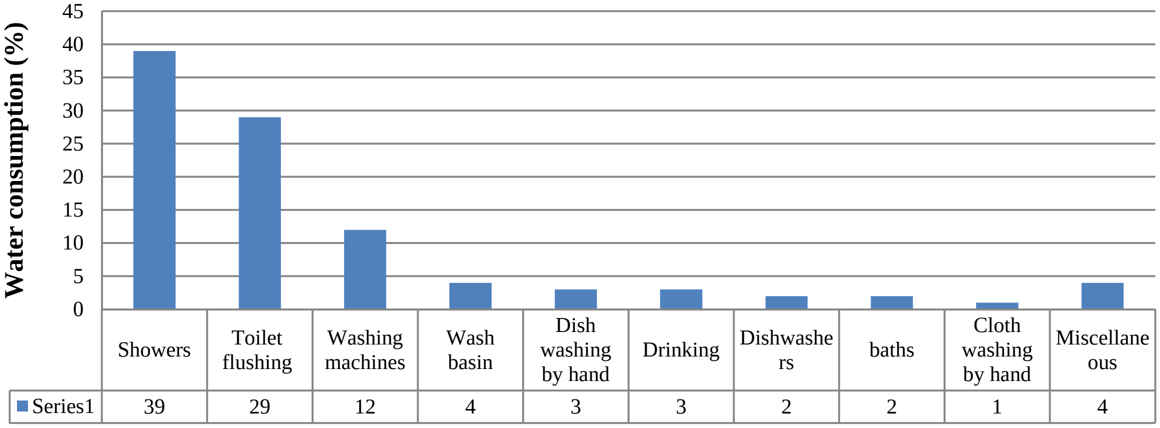


Figure 2-9. Breakdown of Domestic per capita Water Usage in Dutch Households..

Since 1995, there has been a drop in per household water use for baths (6.5 L/c/d), whereas there has been a noticeable increase (11.5 L/c/d) in shower use, in the same time. This could be a result of using showers more than baths for personal washing, over time. However, the increase in per household shower volume is much more than the reduction in bath volumes (about 5 L/h/d). Generally, in the Netherlands, there has been a seven percent drop in domestic per capita consumption since 1995 when the estimate was 137 L/c/d, to about 127 L/c/d in 2006 (Environment Agency, 2008).

2.2.7 Austria

As shown on Figure 2-10 (data from Environment Agency, 2008), a typical household in Austria uses about 34% (45.9 liters) of its total water use for baths and showers, 22% (29.7 liters) for flushing toilets, 17% (22.9 liters) for clothes washing, 7% (9.5 liters) for personal hygiene, 6% (8.1 liters) for dish washing, 3% (4 liters) for cooking and drinking and 11% (14.9 liters) for other purposes.

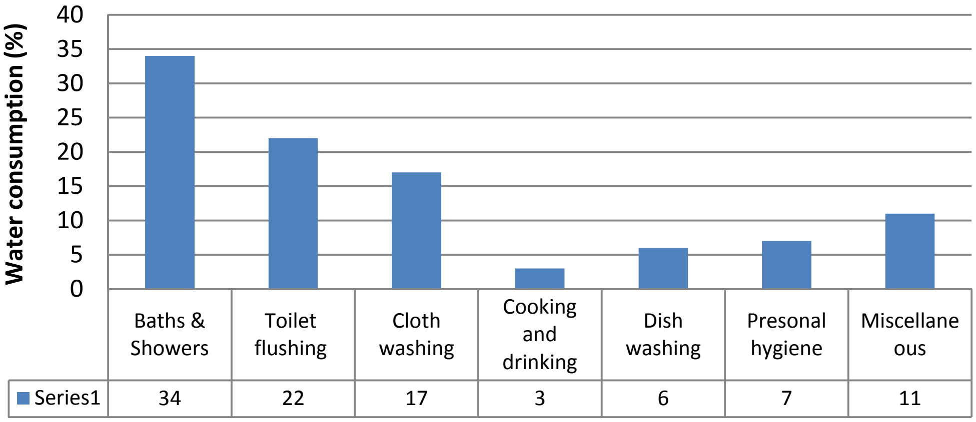


Figure 2-10. Breakdown of Domestic Water Consumption (per capita) in Austrian Households into Various Usages

2.3 Asia, Africa, and Middle East

2.3.1 Hong Kong

In Hong Kong, over 40% of the total water supply is for domestic freshwater demand. Figure 2-11 shows the increasing deliveries of annual freshwater for domestic use in Hong Kong from 1989 to 2003. This trend is approximately proportional to the population growth in that period (Wong, et al. 2008). The estimated daily per capita domestic water use was between 210 to 230 L per capita per day in the period 1991 to 2004 (Water Services Department Annual Report 2003–2004).

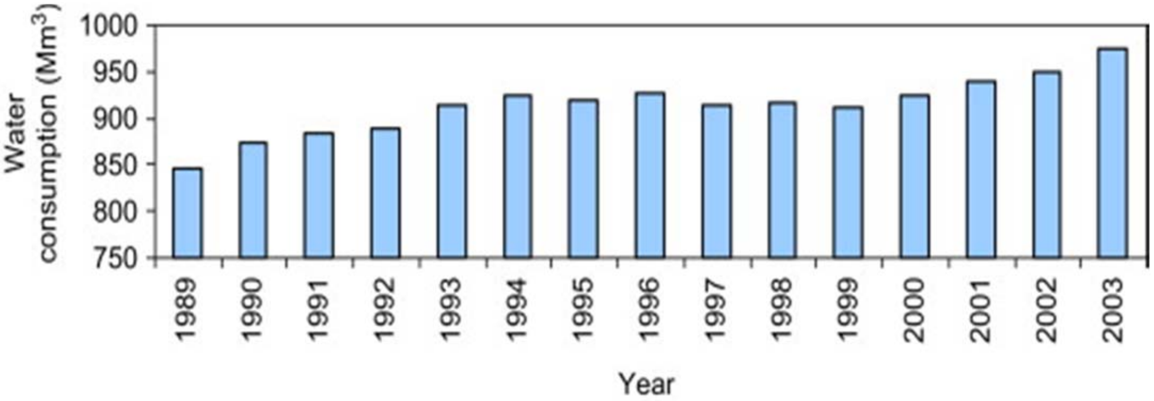


Figure 2-11. Average Yearly Freshwater Use in Hong Kong from 1989 to 2003. (Reprinted from Building and Environment, 43, Wong L. T., Mui, K. W., Epistemic water consumption benchmarks for residential buildings, pp. 1031–1035, 2008, with permission from Elsevier)

2.3.2 Nigeria

Adekalu, et al. (2002) studied 5,000 households in each of four cities (Lagos, Ibadan, Ife, and Ilesa) in South Western Nigeria to determine their household water use practices and the available water supply. The total water usage was calculated by quantifying the amount of water use based on the number of 8-litre buckets used per day. Table 2-1 shows the water use for different purposes in dry and rainy seasons. Lagos has the highest water consumption among four cities. In all four cities, more water was used in the dry season for drinking/cooking and washing/bathing than in the wet season (except for Ilesa which has a lower bathing/washing water usage in dry seasons in comparison to wet seasons).

Table 2-1. Water Consumption in Different Parts of South Western Nigeria. (L/capita/day) (Reprinted from Technovation, 22 (12), Adekalu, K. O., Osunbitan, J. A., Ojo, O. E., Water sources and demand in South Western Nigeria: implications for water development planners and scientists, pp. 799-805, 2002, with permission from Elsevier)

Town	Wet season		Dry season	
	Cooking/drinking	Bathing/washing	Cooking/drinking	Bathing/washing
Lagos	19.2	33.9	23.0	43.5
Ibadan	14.2	32.5	19.8	35.2
Ife	9.2	21.3	9.2	22.6
Ilesa	10.5	31.5	15.5	29.7

2.3.3 Israel

Due to rapid growth of the country's population (2.4-2.6% per year), water consumption in Israel had an increasing trend from 1991 to 1998 (Portnov and Meir, 2008). For example, there was an increase of about 26.5%, from 88 m^3 to 111 m^3, in the per capita annual water use between 1991 and 1998.. The per capita daily domestic water use was about 300 L/c/d in 1998, as shown in Figure 2-12 (data from Water in Israel, Consumption and Production, 2001).

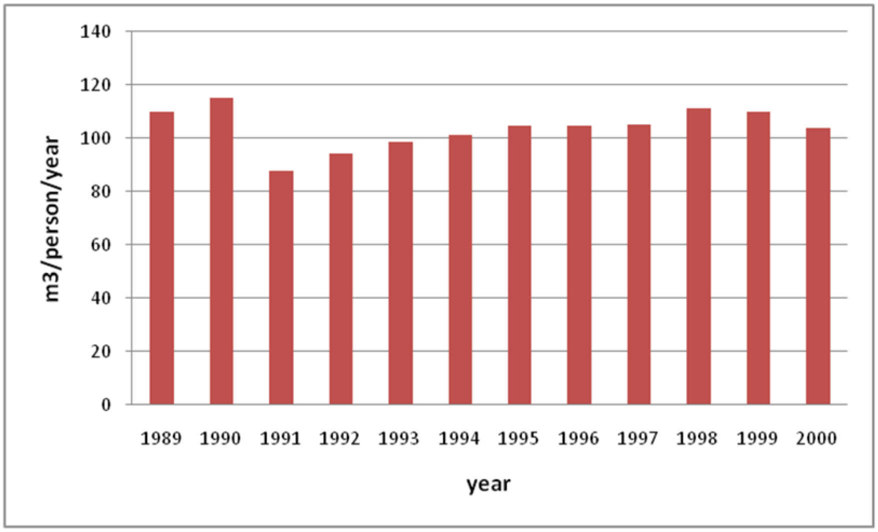


Figure 2-12. Per capita Water Consumption in the Domestic and the Municipal Sector.

2.4 North America

2.4.1 Millburn, New Jersey and Kansas City, Missouri

As noted in the above international examples, demographic information is needed when evaluating beneficial stormwater use potential for an area. As will be described in later sections of this report, household evaluations can be conducted and are useful. However, when examining the overall benefit for a region, population information, along with changes in water use with time, are both needed. In the U.S., information concerning population and household social-economic conditions are available from the U.S. Census Bureau, based on the most recent census. This data is available by zip code. As an example, current study sites in Millburn, NJ (a dry-well recharge project being conducted for the U.S. EPA) and Kansas City, MO, were examined. The zip codes of the monitored cistern locations were used to obtain information, as shown in Table 2-2.

Table 2-2. Summary of Census 2000 Information for Millburn, NJ, Zip Codes 07078 and 7041. (U.S. Census Bureau)

Zip Code	Population	Total Housing Units	Occupied Housing Units	Average Household Size	Average Family Size
7078	12,849	4,337	4,256	3.02	3.26
7041	6,880	2,809	2,747	2.5	3.07
Total	19,729	7,146	7,003	2.81	3.17

Domestic water use information is also available from the USGS (Water use in the United States, available at: http://water.usgs.gov/watuse/), by county. These water use values are available for domestic uses and for several dates in recent years. Figures 2-13 and 2-14 are example plots of how these domestic water use values have changed in Millburn, NJ, and in Kansas City (another current U.S. EPA study area).

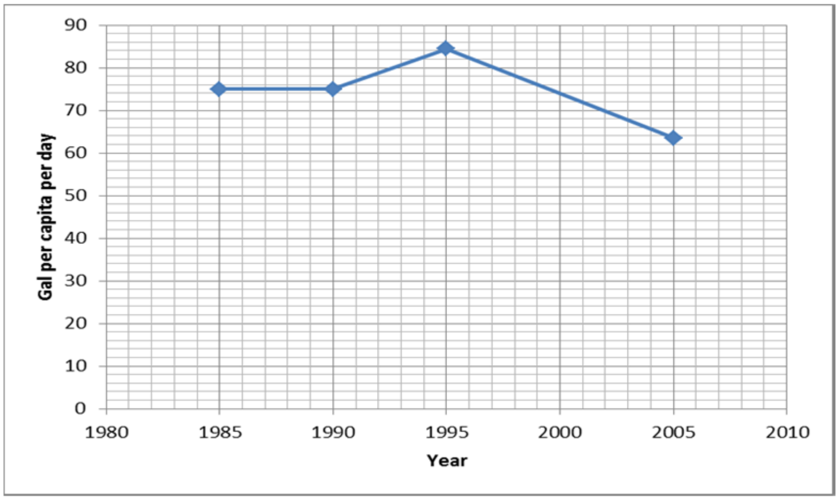


Figure 2-13. Essex County NJ daily per capita Water Use.

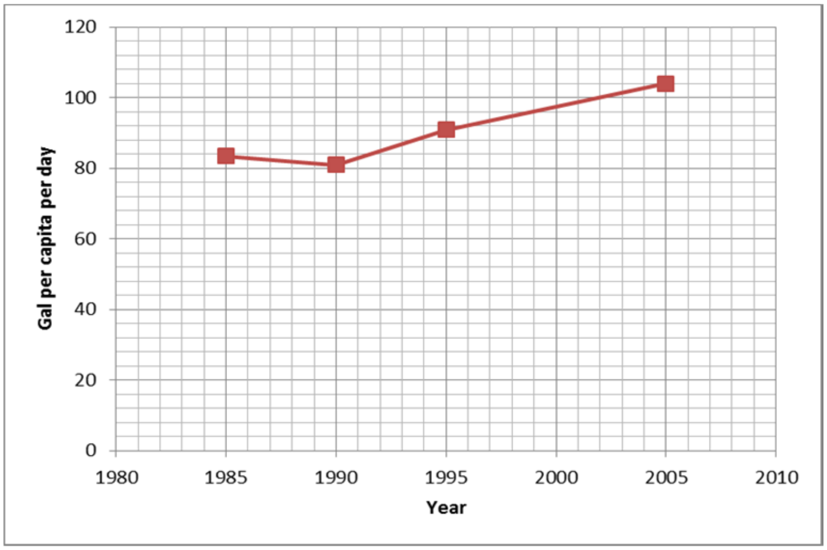


Figure 2-14. Per capita daily Water Usage in the Kansas City MO Metropolitan Area.
***1 gallon = 3.7854 Liter**

In these US examples, the per capita daily usage trends are different between 1985 and 2005. In Millburn, the rate is seen to be relatively steady, but with a recent decrease to about 63 gal/capita/day (240 L/capita/day). In Kansas City, there has been an increasing trend, to about 104 gal/capita/day (393 L/capita/day) in 2005. These data are available from the Census Bureau and the USGS for all counties in the US as a valuable resource for studying trends in populations and water use.

2.5 Summary of Domestic Water Usage

The previous discussions of some domestic water usage trends indicated several conclusions:

- Economic conditions (especially metering and charging for water usage) results in decreasing water usage, especially during financially troubling times.
- Increases in living standards had the expected opposite effect, with increasing water usage.
- Increasing efforts in water conservation did have the desired effect in reducing the domestic water usage.

Table 2-3 summarizes the per capita domestic water usage rates for the countries described previously and shows the amounts used for toilet flushing (the obvious indoor non-potable use that may safely be substituted with water of impaired quality). The European water use rates are all fairly consistent at about 120 to 150 L/capita/day. The toilet flushing usage was also fairly consistent at about 14 to 30% of this total domestic use (or 19 to 39 L/c/day). The European water usage values had no outside water usage (irrigation of landscaping areas) included in their values, while the two North American examples did (and had substantially greater household usage rates at about 250 to 400 L/c/day). The Nigerian example also had no outside use, or toilet flushing use, but only basic cooking and washing uses and was therefore much less.

Table 2-3. Summary of Reported Household Water Use and Amounts used for Toilet Flushing

Location	Per Capita Domestic Water Use per Day (L/c/d and date)	Toilet Usage of Indoor Water Supply (% of total supply and L/c/day)
Germany	126 (2004)	30% (38 L/c/day)
Ireland	148 (2006)	22% (33)
Poland	110 (2003) (Gdansk)	n/a
Denmark	131 (2005)	22% (29)
Finland	120 to 150 (2004)	14% (19)
The Netherlands	127 (2006)	29% (37)
Austria	125 to 135 (2007)	22% (29)
Hong Kong	230 (2004)	n/a
Nigeria	30 to 67 (cooking, drinking, bathing and washing only) (2002)	n/a
Israel	300 (1998)	n/a
Millburn, NJ	240 (2005)	n/a
Kansas City, MO	393 (2005)	n/a

2.6 The Urban Water Budget and Stormwater Reuse in U.S. Residential Areas

Developing an urban water budget is the initial step needed when examining potential beneficial uses of stormwater. The urban water budget comprises many elements, stormwater being just one. As an example, it is possible to determine the likelihood of supplying needed irrigation water and toilet flushing water (reuse classifications B and C in many states) from the stormwater generated from roof runoff by conducting an urban water budget, as will be shown later in this report. This budget requires knowledge of all water sources and uses, and the associated quality requirements. Another important element is understanding the timing of the water needs and supplies. For example, the following lists household water use (no irrigation) for a typical home (Two working adults and one child) in the U.S. southeast, where the rainfall averages about 50 inches per year:

♦ bathing	42%
♦ laundry	11%
♦ kitchen sink	15%
♦ dishwasher	8%
♦ bath sinks	12%
♦ toilet flushing	12%

Because this was a working family and the child was in school, bathing water use was relatively high, while the toilet flushing water use was relatively low, as the household residents are away from home much of the day. There were also wide variations in water use for different days of the week, with weekday water use (especially toilet flushing and laundry) being substantially less than for weekend water use. The household water use was relatively constant throughout the year and averaged about 90 gpcd (gal/capita/day), or 340 L/c/day, ranging from 77 to 106 gpcd, or 290 to 400 L/c/day (substantially greater than the European examples presented previously). There were no water conservation efforts employed during the two year observation period. Outside irrigation water use during the dry months averaged about 50 gallons per day, or 200 L/day (for a ½ acre landscaped area) above the inside water uses listed above. Landscape irrigation may occur for about 2 months at this level of use in this area.

The estimated roof runoff for a typical 2,000 ft^2 (or 200 m^2), 1- ½ level, house (roof area of about 1300 ft^2 (or 120 m^2)) would be about 40,000 gallons (or 150 m^3) per year, for this area having about 50 inches of rain a year. The total water use for this household is about 100,000 gallons (or 400 m^3) per year, with the amount used for toilet flushing being about 12,000 gallons (or 45 m^3), with another 3,000 gallons (or 10 m^3) used for landscaping irrigation. For this example, the roof runoff would supply almost three times the amount of water needed for toilet flushing and landscape irrigation. None of the other household water uses would be suitable for supply by roof runoff. The rainfall varies between about 3 to 5 inches per month, with a rain occurring about twice a week on the average. Rainfall only once every two weeks can occur during the most unusual conditions (the driest months when landscaping irrigation is most needed). Therefore, a simple estimate for required roof runoff storage would be two weeks for average toilet flushing (450 gallons or 1.7 m^3), plus two weeks for maximum landscaping irrigation (700 gallons or 3 m^3). A total storage tank of 1250 gallons or 4.7 m^3 (a typical septic tank size) would therefore be needed. Of course, a factor-of-safety multiplier can be applied, depending on the availability of alternative water sources.

For a typical 0.5 acre residential lot in the southeast, the annual stormwater generated would be about 170,000 gallons (or 650 m^3) per year. The roof would produce about 25% of this total, pavement would produce another 25%, and the landscaped area would produce about 50% of this total. Therefore, the amount of stormwater used on-site for toilet flushing and irrigation of landscaped areas would be only about 10% of the total generated. Therefore, most of the runoff would still have to be infiltrated on-site, or safely conveyed and discharged.

Other locations would obviously result in different water needs that could be supplied by runoff, depending on rainfall, soil conditions, and household water use patterns. Mitchell, et al. (1996) reported that on-site graywater and rain storage for re-use resulted in about 45% reductions in imported water needs, about 50% reductions in stormwater runoff, and about 10% reductions in wastewater discharges at two test developments in Australia. In most areas, Heaney, et al. (1998) reports that indoor water use is relatively constant at about 60 gpcd, with conservation practices, especially the use of low-flush toilets, possibly reducing this need to about 35 to 40 gpcd. Toilet flushing is about 30% of this use. In the arid parts of the U.S., landscaping irrigation can be the most important use of domestic water.

Heaney, et al. (1998) also reported the results of using water demand models to estimate the fraction of typical household irrigation water needs that could be satisfied by storing and using stormwater. Most eastern and west coast areas were able to satisfy their irrigation needs by storing stormwater for use on-site. Over 90% of the irrigation needs could be satisfied by stormwater re-use in the Rocky Mountain area and in the semi-arid southwest. The desert southwest was only able to supply about 25% of their irrigation needs with stormwater. Either supplemental irrigation, or the more appropriate selection of landscaping plants, would therefore be needed in these desert areas. Storage tank sizes varied widely and were quite large. Central Texas (San Antonio) required the largest tank size (25,000 gallons or 95 m^3), while most of the eastern areas of the U.S. required less than 5,000 gallon (or 20 m^3) tanks.

There are many areas that benefit from using poor quality water. A review by Paret and Elsner (1993) reported that some Florida golf courses use about 2,000 gal per acre per day of reclaimed sanitary wastewater. Other major Florida users of reclaimed sanitary wastewater include agricultural, horticultural and commercial users at about 1,500 gal per acre per day, and multifamily residential developments using about 3,000 gal per acre per day. The service fees for this reclaimed water ranged from about \$0.05 to \$0.64 per 1,000 gallons. Obviously, stormwater could be used for similar purposes, if stored and adequately treated. As an example, several new Veterans Affairs hospitals in the Los Angeles area are heavily landscaped using wet detention ponds holding stormwater tied into their firefighting systems.

Besides on-site beneficial uses of stormwater, dual distribution systems may be a feasible choice for some conditions. A dual water supply system includes a conventional domestic water supply system carrying class AA water for human consumption and bathing. Another water supply system is also used in a dual system carrying water of a lesser quality. This water is typically used for B and C uses, plus firefighting. In areas having dual distribution systems, the poorer quality water is typically secondary sewage effluent that has received additional treatment. Okun (1990) states that “throughout the world, dual distribution systems are proliferating, speeded up by policies adopted by states in the U.S. and governments elsewhere.” He points out that a common feature of these water reuse/dual distribution systems is that customers pay for the reclaimed water, but at a significantly reduced price, compared to typical domestic water. He concluded that a sustainable wastewater reclamation program can only exist with cost recovery.

Even though most of the examples of dual distribution systems and wastewater reclamation are for sanitary wastewater, stormwater may be a much preferable degraded water source for reclamation (NAS, 1994). Stormwater does not require nearly as high of a level of treatment, but it is not conveniently collected at one location such as at a wastewater treatment plant, nor is it available at such a constant and predicable flow as sanitary wastewater. However, the large volumes available and its generally better quality may make stormwater a more feasible water for dual distribution systems in many situations.

Other sections of this report discuss many features and considerations for the beneficial use of stormwater. Reuse of domestic sanitary wastewaters has grown substantially in many areas of the world and US, mainly for non-consumptive uses, but sometimes to recharge groundwaters. Stormwater beneficial uses have been used since household developments existed in many arid countries, and have been investigated and examined for many years and is also gaining in popularity in developed nations.

The following section presents a range of case study examples of stormwater beneficial uses throughout the world, briefly describing the scale of the projects and special considerations. Later report sections follow-up with detailed discussions on water quality and public health considerations, and calculating irrigation demands that can be satisfied by stormwater use.

CHAPTER 3.0

CASE STUDIES OF STORMWATER REUSE

3.1 Introduction

This report section reviews a selection of current examples of rainwater harvesting systems in several countries, organized by region. This discussion is not intended to be comprehensive, but to briefly illustrate the range of stormwater beneficial use technologies being used in developing and in developed countries. The range of approaches is vast, with some situations simply concerned with capturing any available runoff possible to augment scarce local supplies, while other examples are in water-rich areas and the runoff is being harvested for beneficial uses to conserve already abundant water supplies. The methods used for storage and treatment are also seen to vary greatly, from local clay jars to vast underground reservoirs for later withdrawal. Treatment also is seen to vary from virtually none to very sophisticated water treatment systems. The uses of the harvested runoff also vary from irrigation and toilet flushing only, to all domestic water uses. This section provides a short description of these features for the case studies, and also includes a summary table describing the range of features for each example.

3.2 International Case Studies

3.2.1 Asia

3.2.1.1 Singapore

Alternative sources and innovative methods of harvesting water is a critical water management issue in Singapore due to population growth and limited land resources. Almost all buildings in Singapore are fitted with gutters to collect the roof runoff for later beneficial use. Also, the surface runoff water from streets and parking lots flows into storm drains which flows to reservoirs. The collected stormwater is then filtered prior to reuse. Many roofs are also constructed to act as catchments to collect roof runoff water in cisterns for non-potable on-site uses. A recent study (http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp) of a 742 ha urban residential area determined the optimal storage volumes for rooftop cisterns using long-term rain records in order to meet a portion of the non-potable demands. This study indicated a saving of 4% of the total water used that otherwise would have had to be pumped from lower elevations. The total cost of the collected roof runoff was calculated to be S\$0.96/m^3 (US\$ 0.74/m^3), compared to S\$1.17/m^3 (US\$0.9/m^3) for the regular domestic water supply.

Changi Airport, Singapore, has a large rainwater harvesting and utilization system. The system is designed in a way that diverts runoff from the runways and the surrounding landscape areas to two impounding reservoirs. One of the reservoirs is for balancing the flows during periods of high runoff and incoming tides, while the other reservoir is used to store the runoff for beneficial uses. The water is used for non-potable purposes such as firefighting drills and toilet flushing. The treated harvested water is 28% to 33% of the total water used at the airport which could save about S$ 390,000 (US$ 300,300) annually. (http://www.rainwaterharvesting.org/international/singapore.htm).

Currently, very large-scale stormwater beneficial use projects, including using the Singapore harbor as a collection reservoir, are being proposed for the city-state that will supply both potable and non-potable water needs.

3.2.1.2 Japan

Tokyo has applied different approaches to increase water availability beyond its limited natural supplies to help meet the needs of its vast population. Their objectives are to mitigate water shortages, control floods, and secure water for emergencies. Table 3-1 shows characteristics of three runoff harvesting projects in Tokyo. (Furumai, 2008)

Table 3-1. Large-Scale Rainwater Storage Facilities in Tokyo. (Reprinted from Physics and Chemistry of the Earth, 33 (2008), Furumai, H., Rainwater and reclaimed wastewater for sustainable urban water use, pp. 340-346, 2008, with permission from Elsevier)

Place (year)	Effective capacity (m^3)	Purposes
Kokugikan (1985)	750	Toilet flushing, cooling water
Sumida-ward office (1988)	1,000	Toilet flushing
Tokyo dome (1988)	1,000	Toilet flushing

The Ryogoku Kokugikan Sumo-Wrestling Arena collects runoff from the 8,400 m^2 (91,000 ft^2) rooftop catchment surface and stores it in a 1,000 m^3 (35,000 ft^3) underground storage tank. The collected water is then used for toilet flushing and air conditioning. An example of a simple rainwater utilization system is the “Rojison” (literally meaning “roadside respect”) which has been installed by local residents in the Mukojima district of Tokyo to harvest runoff from rooftops of private properties. The water is used for various non-potable purposes such as garden watering and fire-fighting, but is also used as an emergency potable drinking water source. Figure 3-1 shows a typical Rojison facility. (http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp)

As of March 2002, there were 850 facilities (566 public buildings and 284 private buildings) practicing rainwater harvesting in Tokyo. (Furumai, 2008)

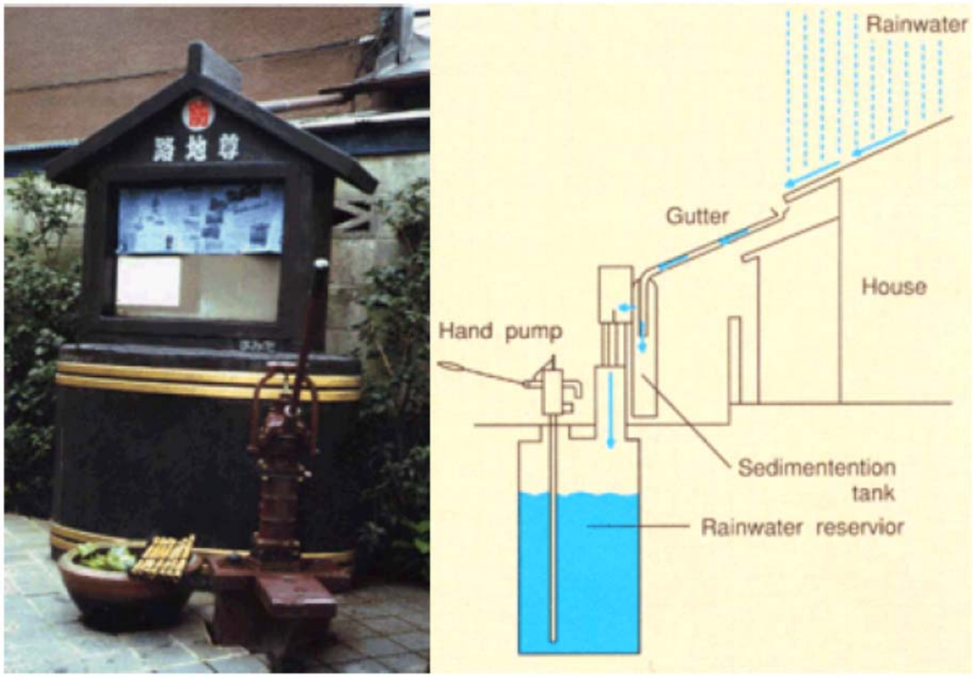


Figure 3-1. Rojison is a Simple and Unique Rainwater Utilization Facility Located at the Community Level in Tokyo, Japan (http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp).

3.2.1.3 Thailand

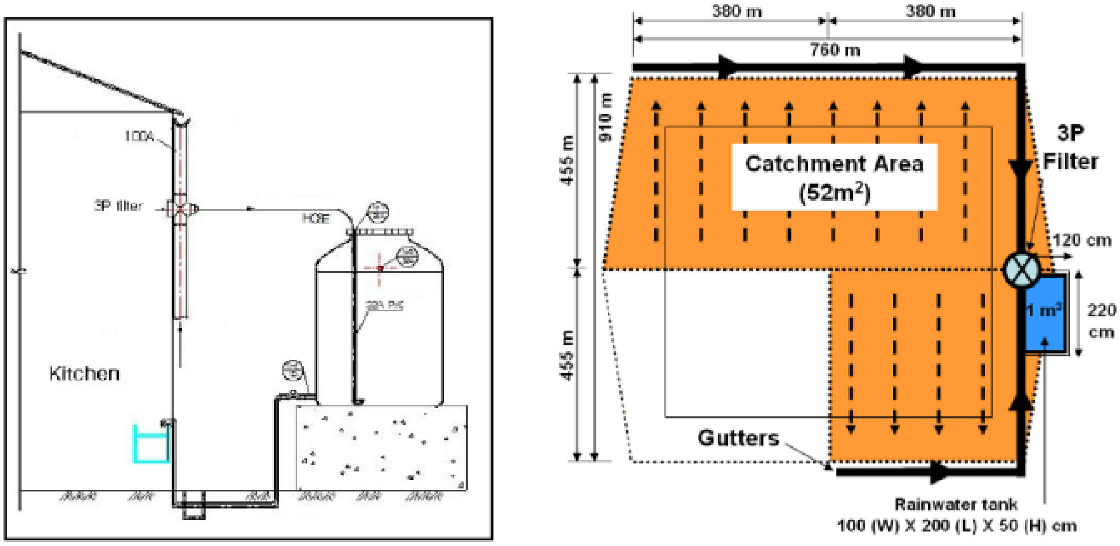
There are two types of Thai rainwater harvesting systems: one is comprised of individual household jars (actually relatively large units), while the other (rarer) uses much larger community-wide storage tanks. Those houses that have both tanks and jars usually use the tank water for potable purposes (drinking and cooking), and the jar water for non-potable usage. (http://www.rainwater-toolkit.net/fileadmin/rwh-material/documents/jar_programme.pdf)

The most common size of the jars is 2,000 liters, costs 750 Baht (US$25), and is equipped with lids, faucets, and drains. Jar sizes can range from 100 to 3,000 liters. The 2,000 liters common jar is appropriate to supply water for household with the size of six persons during the dry season. Two approaches are used to encourage people to install the harvested water systems. The first approach supports technical assistance and training villagers on water jar construction, while the second approach involves financial support. (http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp).

3.2.1.4 Indonesia

In Indonesia, groundwater, which historically has been one of the main sources of water, is now becoming scarcer in large urban areas. This was caused by the gradual reduction in water infiltration as a result of increasing pavement and roof areas. Recently, the Indonesian government identified stormwater beneficial use as a potential source of water in many parts of Indonesia, including the Special Province of Yogyakarta, the Capital Special Province of Jakarta, West Java, and Central Java Province.

In 2007, a team from the Seoul National University developed and installed several rainwater harvesting systems in Banda Aceh, Indonesia. Banda Aceh was damaged by the 2004 tsunami. Due to economic reasons, technical and geographical factors, about 16% of residents incomes are spent on the purchase of water. Therefore rainwater harvesting is an urgent concern in Banda Aceh, Indonesia (Song, et al., 2008). In 2007, Song, et al., described the recently installed rainwater harvesting systems and concluded that rainwater harvesting can be best achieved by an increase in public awareness and appropriate education. Figure 3-2 is a diagram of the conventional rainwater harvesting systems. Note that the roof runoff is treated by a filter before storage in the tank.



(a) at UNICEF health care center (2007)   (b) at Gano village (2008)

Figure 3-2. Diagram of the Rainwater Harvesting Systems (a) at UNICEF Health Care Center (2007) and (b) at Gano Village (2008) (Song, et al, 2009). (Reprinted from Desalination, 248 (2009), Song, J., Han, M., Kim, T., Song, J., Rainwater harvesting as a sustainable water supply option in Banda Aceh, pp. 233-240, 2009, with permission from Elsevier)

3.2.1.5 Philippines

A rainwater harvesting program was initiated in 1989 in Capiz Province, the Philippines, with the assistance of the Canadian International Development Research Centre (CIDRC). As part of this program, 500 roof runoff storage tanks (2-10 m^3 (500-2500 gallons)) were constructed using wire-framed ferro-cement. “The construction of the tanks involved building a frame of steel reinforcing bars (rebar) and wire mesh on a sturdy reinforced concrete foundation. The tanks were then plastered both inside and outside, thereby reducing their susceptibility to corrosion relative to metal storage tanks” (http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp). To cover financial problems and encourage the use of this system, loans were provided to fund the capital cost of the tanks.

3.2.1.6 Bangladesh

In 1998, the World Health Organization (WHO) proposed rainwater harvesting as a potential replacement water supply while looking for alternative solutions for people who were affected by contamination of their wells with arsenic. Since then, about 1,000 rainwater harvesting systems have been installed in the country with assistance of the non-governmental organization (NGO) Forum for Drinking Water Supply & Sanitation. The main focus of this program is to provide better access to safe, sustainable, affordable water and sanitation services and facilities in Bangladesh. “The materials and structures of the tanks vary, and include ferro-cement tanks, brick tanks, reinforced concrete ring tanks, and sub-surface tanks”. The capacity of the tanks varies from 500 liters to 3,200 liters, with costs ranging from Tk. 3000 to Tk.8000 (US$50 to US$150 – year for currency exchange is 2011). The harvested rainwater in Bangladesh is used for toilet flushing, drinking, and cooking. Although this system is new in Bangladesh, its acceptance as an accessible source of safe water is increasing.(http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp).

3.2.1.7 China

Gansu is one of the provinces in China which is considered arid due to its low annual precipitation (300 mm) and high evaporation potential (1,500mm-2,000 mm). From 1995 to 1996, the '121' Rainwater Catchment Project implemented by the Gansu Provincial Government solved the drinking water problem by building *one* rainwater collection catchment, *two* underground water storage tanks and providing *one* piece of land to be irrigated by stored rainwater. This project helped about 1.97 million people to supply drinking water and to irrigate lands in the first five years (from 1995 to 2000). Today, rainwater harvesting is applied in seventeen provinces in China, and includes 5.6 million tanks with a total capacity of 1.8 billion m^3, providing drinking water for 15 million people and supplemental irrigation for 1.2 million ha of land (http://www.gdrc.org/uem/water/rainwater/rainwaterguide.pdf).

3.2.1.8 South Korea

The Rainwater Research Center (RRC) at Seoul National University, South Korea, played an important role in implementing the rainwater collecting system at Star City. "Star City is a major residential development project including over 1,300 apartment units in Gwangjin-gu." The main purpose of the Star City rainwater harvesting system was to harvest stormwater from up to the first 100 mm of rainfall over the complex. Collected stormwater is then used to irrigate landscape and for flushing public toilets. Three tanks, having a total volume of 3,000 m^3, are located in the fourth underground floor in Building B of the complex. The first tank is used to collect rainwater from the rooftop, while the second tank is used to harvest runoff from the ground. The third tank is for storing domestic drinking water in case of an emergency. It is expected that stormwater harvesting will capture and use about 40,000 m^3 of water annually, equal to 67% of the annual rainfall over the Star City complex. Using harvested stormwater will result in significant savings to the city of about US$ 80,000 annually in reduced payments for water. The construction cost of the rainwater harvest system was approximately US$ 450,000 (http://www.fbr.de/fileadmin/user_upload/files/Englische_Seite/Han_WS_1_2009_engl_webseite.pdf).

3.2.1.9 India

Delhi

The national capital territory, (NCT) of Delhi receives an average of 611 mm of rainfall per year. The potential roof runoff water availability in the National Capital Territory of Delhi varies from 18,330 liters for a roof with area of 50 m^2 to 366,600 liters for a roof of 1000 m^2. Analysis represent that if 50% of the roof runoff was harvested, significant gaps in demand minus supply could be closed. The Janki Devi Memorial College's stormwater harvesting system uses runoff from a total rooftop and surface area of 32,170 m^2 (346,300 ft^2) area and was implemented in June 2001. The total annual volume of stormwater harvested was 6,880 m^3 which represents about 35% of the total stormwater harvesting potential. Three on-campus recharge borewells provide the total water requirements of the college. The runoff from the terrace of the college building is channelized into the recharge wells. The cost of the Janki Devi Memorial College's stormwater harvesting system was Rs 0.70 lakh (US$1400). Records show that the water level in the college premises was 35.8 m below ground level in May 2002. After implementing the stormwater harvesting system on the campus, groundwater levels rose, and by September 2002, was 22.1m below the ground level and in May 2003 was 25.0m below ground level. This represents a drop of 10.8m during a peak summer month. Another successful project in Delhi is the Delhi gymkhana club's stormwater harvesting system which was completed in May 2004. This site has a total rooftop and surface area of 113,000 m^2 (27.9 acre), and the total volume of stormwater harvested of 28,800 m^3 which is almost half of the total rooftop and surface runoff. In the project area, five tube wells located in the premises are coupled with the municipal supply. "On an average, 4 lakh liters (400,000 L) of water is used daily for potable and non-potable purposes." The rooftop runoff from the main club building, library, committee room, secretary office and cottages is collected by the stormwater drainage system and then directed to recharge wells. The cost of the stormwater harvesting system was Rs 0.8 lakh (US$1,800 - year for currency exchange is 2011). (http://www.rainwaterharvesting.org/urban/Practices-and-practitioners.htm)

Bangalore

Approximately 40% of the Bangalore population uses groundwater as the source of water, while the remaining use surface water (pumped from the Cauvery River through a distance of 95 km and a head of 1000 m). The annual rainfall in Bangalore is approximately 970 mm. There are several rainwater harvesting systems in Bangalore which store rainwater to use for non-potable purposes. Total proposed area for the year 2011 is 1,279 km^2 including 597 km^2 of development area and 682 km^2 of green belt area with total potential of 1,240 billion liters for annual rainwater harvesting.

Rainwater harvesting at Escorts-Mahle-Goetze is a well-known project in Bangalore. The industrial unit of Escorts-Mahle-Goetze is located on a 20 hectare campus at Yelanka, a suburb of Bangalore. The total rooftop area is 30,000 m^2 (7.4 acre).The total rainwater harvesting potential of the site is 185 million liters. In May 2000, a pilot project was initiated, covering about 1,280 m^2 (13,800 ft^2) of roof area for the administrative block and the canteen building. With a storage capacity of 4,200 liters, the unit collects about 1.1 million liters per year. (http://www.rainwaterharvesting.org/urban/Practices-and-practitioners.htm).

Chennai

The city of Chennai had a serious water shortage in the late 1980s. Rapid seawater intrusion extended from 3 km inshore in 1969, to 7 km inshore in 1983, and to 9 km inshore in 1987. The quality of the groundwater also started to decline during this time. Chennai has an average annual rainfall of 1,200 mm. Although harvested rainwater is mostly used for recharging of aquifers, in some places it is directly used for non-potable purposes. Normally, the runoff is collected from paved areas and infiltrated through percolation pits, trenches and recharge wells. Groundwater levels have recovered with time since recharge has started. Throughout the city, the average water level increased from 6.8 m in 1987 to 4.6m in 1998.

An example of rainwater harvesting in Chennai is at the Kones Elevator Factory, a project in which a combination of recharge and storage has been used. A major roof leader collects the roof runoff on both sides of the building. It is then diverted into the existing service storage sump having about 7,000 L capacity. The overflow is diverted to a percolation pit for groundwater recharge. "Four roof runoff harvesting percolation bore pits are also proposed at a car park where runoff water stagnates after rains." The total estimated cost of construction is around Rs 75,000 (about US$1700- year for currency exchange is 2011) (http://www.rainwaterharvesting.org/urban/Practices-and-practitioners.htm).

3.2.2 Africa

Rainwater harvesting is becoming more widespread in Africa, with projects currently in Botswana, Togo, Mali, Malawi, South Africa, Namibia, Zimbabwe, Mozambique, Sierra Leone and Tanzania, among others. In South Africa, with its mix of developed and developing regions, 20% of the population (about 9.7 million people) do not have access to a safe and clean water supply and 33% of the population (approximately 16 million people) suffer from lack of proper sanitation services. In many areas in Africa, including rural parts of South Africa, the financial assistance is provided by government. A typical tank for residential houses is 30 m^3, collecting water from mostly roofs and landscapes. (Mwenge Kahinda, et al. 2007).

3.2.2.1 South Africa

The City of Atlantis, located 50 km north of Cape Town South Africa, utilizes an urban stormwater harvesting system using artificial aquifer recharge within filtration basins. Atlantis is located along the semiarid west coast of South Africa and receives an annual average rainfall of 450 mm, mostly between April and September. There are only a few surface water resources available in the region. Stormwater is regarded as a valuable water source for augmenting freshwater supplies in this semiarid region (Tredoux, et al. 2002).

Storm event discharges can reach up to 72,000 m^3/d at Atlantis. Construction of this urban stormwater recharge system began in 1982. In this system, treated domestic wastewater and urban stormwater are being infiltrated into a sandy aquifer. The collection system has12 detention and retention basins as well as interconnecting pipelines with peak flow reduction features. All basins have depth ranges from 1 to 4 m to prevent excessive growth of algae and water plants. "The system was designed with the flexibility to control water flows of differing salinity and to collect the best quality water for infiltration into the aquifer" (Tredoux, et al. 2002).

3.2.2.2 Kenya

Kenya is another water scarce country in Africa. Since the late 1970s, many rainwater harvesting projects having different designs and implementation strategies have emerged in different parts of the country. These water harvesting projects use a simple roof runoff storage tank (locally termed a "fundis"). Ferro-cement tanks have been used for both surface and sub-surface storage tanks in the absence of locally available less expensive construction materials. (http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp)

Most current roof runoff harvesting systems in Kenya contain three basic sub-systems: a collection area (usually a roof covered with corrugated galvanized iron sheets), a gutter system, and a storage reservoir. Additional components can also be included, such as water gauges, filters, and first flush diversion devices (http://kwaho.org/t-rain-harvest.html).

3.2.2.3 Tanzania

There are several areas in Tanzania where beneficial uses of stormwater are being used to supplement insufficient water supplies. As an example, a study was undertaken in the Makanya catchment of rural Tanzania to assess sustainability of storage type of rainwater harvesting systems, including microdams, dug out ponds, sub-surface runoff harvesting tanks and rooftop rainwater harvesting (RWH) systems.

Microdams in the Makanya catchment are the stone masonry structures which are usually constructing close to ephemeral or perennial streams. The storage capacities of these structures vary from 200 to 2,000 m^3 (53,000-530,000 gallons). Runoff diverted to microdams is used for crops irrigation. Sub-surface rainwater harvesting tanks are made of different materials than the surface RWH tanks, being mostly built of reinforced cement concrete (RCC) material with a silt trap. They have smaller storage capacities, varying from 30 to 50 m^3 (8,000-13,000 gallons). (Pachpute, et al., 2009)

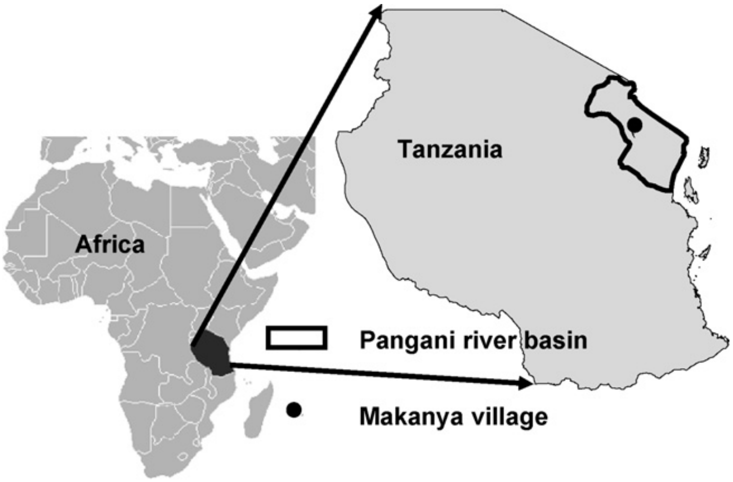


Figure 3-3. Location of the Makanya Catchment in Tanzania. (Reprinted from Agricultural Water Management, 9 (2010), Pachpute, J. S., A package of water management practices for sustainable growth and improved production of vegetable crop in labour and water scarce Sub-Saharan Africa, pp. 1251-1258, 2010, with permission from Elsevier)

Rooftop rainwater harvesting systems are also used in this region. Sheet metal roofing, gutters, collection pipe and storage tank (having capacities ranging from 2 to 10 m^3 (500-2,500 gallons)) are the main components of rooftop rainwater harvesting systems. Rainwater collected from the sheet-roof is stored in above ground tanks (plastic/RCC) and is re-used for domestic purposes or other non-potable purposes including landscape irrigation.(Pachpute, et. al, 2009). The sizes of the sheet metal roofs range from 15 to 40 m^2 (150-430 ft^2). The average values of the vegetable gardens per year were estimated to be US$ 322. Figure 3-4 shows rooftop water harvesting systems constructed in Makanya, Tanzania. (Pachpute, et al., 2009)

Figure 3-4. Rooftop Rainwater Harvesting Tank. (Reprinted from Agricultural Water Management, 9 (2010), Pachpute, J. S., A package of water management practices for sustainable growth and improved production of vegetable crop in labour and water scarce Sub-Saharan Africa, pp. 1251-1258, 2010, with permission from Elsevier)

3.2.3 Europe

3.2.3.1 Germany

Rain water harvesting has become widespread, since the 1980s. The main function of rain water harvesting facilities in Germany is collecting roof runoff which is then filtered and stored. The primarily uses of this water are for toilet flushing, garden watering, and household laundry (Nolde, 2007).

A well-known German stormwater harvesting project is located in Berlin-Lankwitz and has been operating since 2000. About 12,000 m^2 (3 acres) of impervious areas (63% roof, 35% courtyards and sidewalks and 12% roads) are connected to a storage tank located in the cellar of a new building. Stormwater from this area is collected and transported by the existing stormwater drainage system of the Berlin water company to the storage tank. Figure 3-5 is a flow diagram of the stormwater use facilities (Nolde, 2007).

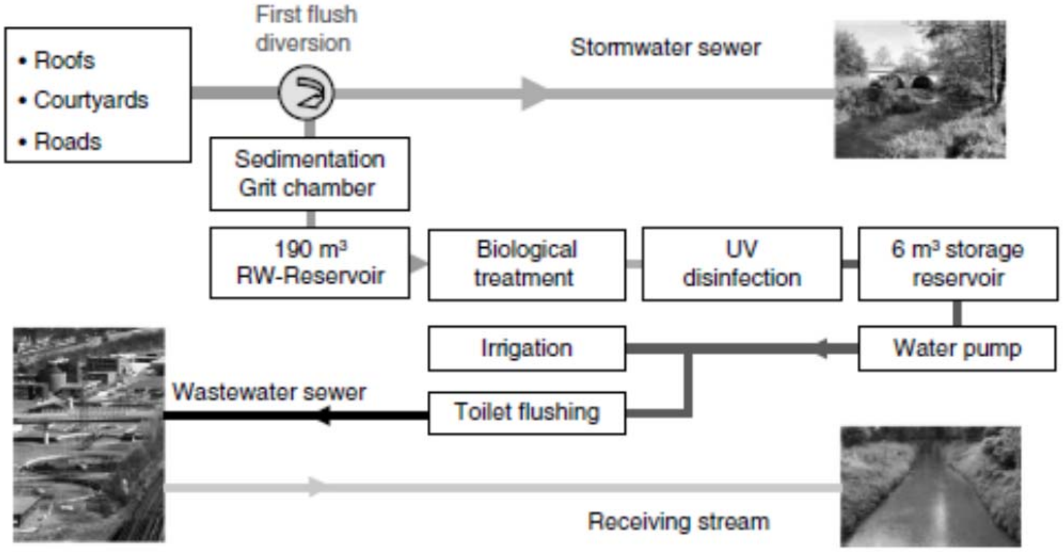


Figure 3-5. A Flow Diagram of the Rainwater Plant in Berlin-Lankwitz with First-Flush Diversion into the Reservoir. (Nolde, 2007) (Reprinted from Desalination, 215 (2007), Nolde, E., Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces, pp. 1–11. 2007, with permission from Elsevier)

As Figure 3-5 shows, the 190 m^3 (50,000 gallons) rainwater reservoir is filled with rainwater up to the sewer level. After biological treatment and UV disinfection, the treated water discharges to the small service water reservoir (6 m^3 (1,600 gallons)) which also acts as a system buffer during periods of peak water consumption. This stormwater harvesting facility supplies 80 apartments (serving a total population of 200 persons) and 6 small trade units with high-quality service water for toilet flushing and garden watering (Nolde, 2007).

Another city in Germany that uses harvested stormwater as a water source is Frankfurt. At the Frankfurt Airport and the Technical University Darmstadt, stormwater is being harvested in large facilities. In 1993, a stormwater harvesting system was constructed simultaneously with a new airport terminal building. The system collects runoff from the 26,800 m^2 roof of the new terminal. There are six tanks in the basement of the airport each have a storage capacity of 100 m^3. The harvested water is used mainly for flushing toilets, watering plants, and cleaning the air conditioning system. This roof runoff harvesting system is one of the largest in Germany and save about 100,000 m^3 of water per year. "The costs of the system were 1.5 million DM (US$63,000)." The Technical University of Darmstadt (TUD) has another large rainwater harvesting system. The harvested rainwater of TUD is used for "toilet flushing and is also supplied to the laboratories of the University for cooling and cleaning purposes." The water is treated prior to be used in laboratories. "Ever since this system has been installed, only 20% of the water demand is covered by drinking water, amounting to a saving of 80,000 m^3 of drinking water per year" (UN rainwater harvested manual, book 3 available online at: http://www.scribd.com/doc/35811018/UN-Rainwater-Harvesting-Manual).

3.2.3.2 Ireland

Potential water shortages in Ireland are the key issue for its current focus on sustainable future development. "Domestic rainwater harvesting (DRWH) and grey water (GW) treatment systems have been used in different parts of the country, but their use is not yet widespread." In Ireland, roof runoff collection is the most commonly used rainwater harvesting method. Harvested roof runoff water is generally less contaminated compared with other impervious catchment types (e.g. paved parking and storage areas, road surfaces, etc.). A typical roof runoff rainwater harvesting system in Ireland is shown in Figure 3-6 (Li, et al., 2010).

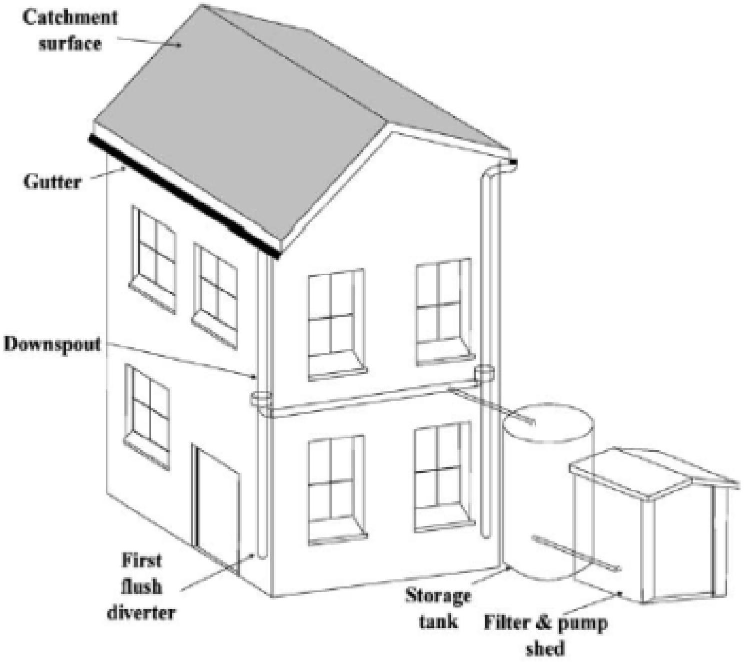


Figure 3-6. A Typical Roof Rainwater Harvesting System in Ireland (reprinted from Desalination, Vol. 260, Li, Z., , Boyle, F., Reynolds, A., Rainwater harvesting and greywater treatment systems for domestic application in Ireland, pp. 1-8, 2010, with permission from Elsevier)

Tanks ranging from 4,000 and 16,000 L are appropriate for most Irish homes. Selecting the size of tanks depends on various parameters depending on its intended use, such as the roof area, the amount of rainfall, the number of occupants in the house, and the amount of land to be irrigated. High levels of rainfall (from 750 mm to1,250 mm) occur in Ireland. The target is to replace 55% of publicly supplied water by using harvested roof runoff water to reduce the amount of stormwater runoff and to reduce the use of domestic water. The harvested roof runoff can be used for toilet flushing and/or garden watering (Li, et al. 2010).

3.2.4 Australia

3.2.4.1 South Australia

The Parafield stormwater harvesting project in the City of Salisbury, South Australia, is a recent project that supports the City Council's overall water strategy that recognizes stormwater harvesting as a critical component. Salisbury has been developed from a pioneering farming community into a developing residential area with retail and commercial business, industry, technology enterprise, recreational activity and environmental endeavors, over the past century (http://cweb.salisbury.sa.gov.au/manifest/servlet/binaries?img=1440&stypen=html).

The City of Salisbury committed to reduce the discharges of contaminated waters into the Barker Inlet of the Gulf St. Vincent, an important marine ecological area. The Parafield project diverts stormwater from the main drainage system to a storage basin with a capacity of 50 million liters. It is then pumped to another holding basin with similar capacity, where it flows by gravity to a 2 ha reed bed wetland. The system is designed to hold stormwater for about 10 days to provide a high level of treatment. Reported nutrient and other pollutant load reductions are 90% using this sedimentation and wetland treatment system. The effluent is finally discharged to an aquifer storage area to ensure a continuous water supply among dry weather (Frost, 2010). Table 3-2 shows the characteristics of the Parafield Stormwater Harvesting Facility.

Table 3-2. Characteristics of the Parafield Stormwater Harvesting Facility.
(http://cweb.salisbury.sa.gov.au/manifest/servlet/binaries?img=1440&stypen=html).

Catchment	1600 hectares
Cost	Aus $3.7 million USD $3.5 million (year 2011)
Land Area	11.2 hectares
Aquifer storage/recovery wells	2
Depth	160 to 180 m
Yield	1.1 Mm^3/year
Detention time	10 days
Flood Protection	1 in 10 years
Online Monitoring	pH, TDS, SS
Injection Rate	35 L/s
Supply Water Salinity	150 to 250 mg/L

3.2.4.2 Coomera Waterfuture, Queensland

The Gold Coast City Council developed the Waterfuture Strategy in December 2005 after investigating different water supply sources. The planning process of the Coomera Waters Development project required more than five years. The area is near a number of important aquatic ecosystems, including Moreton Bay Marine Park, Noosa River, Maroochy River and McCoys Creek, on the Queensland Gold Coast. The protection of mentioned ecosystems as well as flood control were main focus of the project which has been achieved through the principles of Water Sensitive Urban Design (WSUD) (Urban Water Security Research Alliance Technical

Report No. 13. Available at: http://www.urbanwateralliance.org.au/publications/UWSRA-tr13.pdf)

Another important objective of this project is to preserve “the pre-developed hydrologic and hydrogeological regime by recharging groundwater and to minimize the hydrological change induced by the increased impervious surfaces created by the development.”

The master plan for this project includes stormwater harvesting systems, wastewater systems and household water supply through the use of bioretention systems, bioretention rain gardens, a constructed wetland, smart sewers, dual reticulation systems, rainwater tanks and demand management measures. In terms of stormwater harvesting, the objective of the master plan is to treat stormwater runoff to a standard level. The treated stormwater is used for domestic uses and irrigation of public open space areas. (http://waterbydesign.com.au/coomera-waters/)

3.2.4.3 Docklands Park, Melbourne, Victoria

Docklands Park is a downtown green public open space with an area of 2.7 ha located in Melbourne. It has three wetlands with the maximum possible storage volume of 1,475m^3 for each. Docklands Park does not have adequate catchment area for stormwater harvesting to meet its irrigation demand. The park therefore also collects stormwater from the adjacent ultra-urban catchment of downtown Melbourne, providing sufficient opportunities for irrigation. Stormwater is collected from the NAB building roof and forecourt, Harbour Esplanade, Grand Plaza, and a portion of the Bourke St extension. The water is directed by gravity or pumped to Docklands Park. The three wetlands are capable of treating approximately 80% of the possible runoff generated from the catchment area of 4.8 ha. Treated stormwater is stored in underground storage tanks. Three underground storage tanks with a combined capacity of 500 m^3 are located adjacent to the wetlands. The stored and treated stormwater is used for park irrigation (Philp, et. al., 2008). The Docklands website explains that the captured stormwater is also treated using UV treatment process prior to use. (www.docklands.com.au)

Figure 3-7. Docklands, Downtown Melbourne, Australia Showing Public Sculpture Garden in Wetland Area near Underground Tanks (Pitt, R., photos).

3.2.4.4 New South Wales (NSW)

Bexley Municipal Golf Course, NSW

This stormwater harvesting project on a golf course in the Sydney suburb of Bexley was implemented mainly to reduce the mains water demand at Bexley Golf Course by using treated stormwater for irrigation. It also helps to reduce stormwater pollution loads entering the Cooks River. (Philp, et al., 2008)

A diversion weir was constructed in the concrete lined stormwater channel and the area upstream excavated to create an initial storage area of 5,300 m^3. In 2003, as a result of cleaning out the accumulated sediment the initial capacity increased to 7,000 m^3. An additional 1,400 m^3 storage dam was constructed on the golf course. The treatment system includes a trash rack (upstream of the weir in the concrete channel), sedimentation and mechanical aeration in the storage area. Treated stormwater is used to irrigate an area of 12.4 ha. The project had a capital cost of approximately AU$594,197 (USD $633,632 – year of conversion 2011), recurrent cost of AU$18,000 (USD $19,195 – year of conversion 2011) and life-cycle cost of AU$728,000 (USD $776,340 – year of conversion 2011) (Philp, et. al., 2008) (Department of Environment and Conservation NSW, 2006).

Figure 3-8. Bexley Stormwater Harvesting Project. (Source: 2006 NSW Metropolitan Water Plan) (Used by permission of www.environment.nsw.gov.au)

Black Beach Foreshore Park, Kiama, NSW

The main objectives of this project are to reduce stormwater pollution to Kiama Harbour and also to irrigate two parks with stormwater to reduce domestic water consumption. This project was completed in 2004. The harvested stormwater is used to irrigate the two parks (about 2 ha of parkland). The collected water is pre-treated to a holding tank using sand filtration technique. Then pre-treated stormwater is pumped from the holding tank to a 45 m^3 underground storage tank and then pumped through a UV disinfection unit into the irrigation network. The project had a capital cost of approximately AU$175,000, recurrent cost of AU$17,000 and a total life-cycle cost of AU$332,000 (Philp, et. al., 2008) (Department of Environment and Conservation NSW, 2006).

3.2.5 North America

3.2.5.1 St. Thomas, U.S. Virgin Islands

St. Thomas, U.S. Virgin Islands, is an island in the Caribbean Sea and constituent district of the United States Virgin Islands (USVI) that is 4.8 km wide and 19 km long. Annual rainfall in this area ranges from 1,020 mm to 1,520 mm. Based on water management strategies, “a rainwater utilization system is a mandatory requirement for a residential building permit in St.

Thomas" as a part of the construction review. A catchment area of 112 m^2 (1210 ft^2) and a storage tank of 45 m^3 (12,000 gallons) capacity is needed for a single family house. Typically, rainwater is collected from the roof and is stored in tanks located within or below the homes. According to water quality results of samples collected from the rainwater utilization systems in St. Thomas, fecal coliform and Hg concentrations were higher than U.S. EPA water quality standards. The collected water is therefore used for non-potable purposes due to poor quality. (http://www.gdrc.org/uem/water/rainwater/rainwaterguide.pdf).

3.2.5.2 Renaissance Project, West Palm Beach, Florida

The Renaissance Project, in operation since September 2002, collects stormwater runoff from different parts of the Convention Center and Pineapple Park Neighborhood to the Stub Canal and from there to a 0.02 km² settling basin. The Renaissance Project has different benefits including providing pre-treated water discharge to Lake Worth Lagoon, providing approximately 300 million gallons of treated stormwater, and reducing flood levels and duration.

The treatment process starts with passing water through traditional bar screens to remove heavy debris. Alum and polymers are also added for the control of heavy metals, nutrients, oils and grease. The treated water is then pumped into the South end of Clear Lake, where it is further cleaned through natural processes including interaction with wetland plant materials. To have potable and more safety water, the water can be pumped into the West Palm Beach Water Treatment Plant. The total cost of the completed project was about US$17.6 million. Overall, more than 1,140,000 m^3 of treated stormwater is added to the City's water supplies each year and over 800 million gallons per year of seepage losses are eliminated (Philp, et. al., 2008) (City of West Palm Beach 2005, available at: http://www.cityofwpb.com/utilities/cwmrp/renaissance.htm).

3.2.5.3 Island of Hawaii, U.S.

Stormwater harvesting systems have been constructed at the U.S. National Volcano Park in Hawaii. The main purpose of this system is to provide water for "1,000 workers and residents of the park and 10,000 visitors per day." The stormwater harvesting system collects the runoff from a 0.4 ha rooftop and 2 ha of ground surface areas. Two reinforced concrete water storage tanks, each having 3,800 m^3 (1 million gallons) capacity, and 18 redwood water storage tanks, each having 95 m^3 (25,000 gallons) capacity, are also parts of the stormwater harvesting system in the park. To meet water quality standards, a water treatment system along with a pumping plant was also built (http://www.gdrc.org/uem/water/rainwater/rainwaterguide.pdf).

3.2.5.4 King Street Center, Seattle, WA

The King Street Center, a typical office building in downtown of Seattle, was completed in 1999.The 30,400 m^2 (327,000 square-foot) building houses 1,600 employees of the county's Department of Natural Resources and Parks and Department of Transportation. There are three cisterns of 20 m^3 (5,400 gallons) capacity each for collecting rainwater from the Center's roofs. The collected water is used for toilet flushing and landscape irrigation. Collected stormwater from the tanks is filtered prior to being pumped to the building's toilets or irrigation system through a separate piping system. "When needed, potable makeup water is added to the cisterns" (Kloss, 2008). This system saves over 60% of the building's estimated annual water needs by providing 5.3 million liters (1.4 million gallons) of water annually. (http://www.psparchives.com/publications/our_work/stormwater/lid/LID_studies/rooftop_rainwater.htm)

3.2.5.5 The Solaire, Battery Park City, New York City, NY

Battery Park City is a multi-use community of residential, commercial, and institutional properties constructed on 37 ha (92 acres) of land. This “27 floor building was the first high-rise residential structure to receive LEED® Gold certification.” The Solaire was designed in accord with Battery Park City’s progressive water and stormwater standards. The system has a 38 m^3 (10,000 gallon) cistern in the building’s basement which acts as a reservoir for collected stormwater from the roofs. The tanks include varying degrees of sand filtration and disinfection to meet the New York City standards prior to being used for irrigating. (Kloss, 2008) The treated water is also used for toilet flushing, laundry, and cooling tower make-up. The capacity of the stormwater reuse system is about 95 m^3/d (25,000 gpd) providing approximately 30% of the total water use of the building per year. When all of the buildings are complete, it is estimated to have totally 660 m^3/d (175,000 gpd) reclaimed water flow from six separate systems. (http://www.werf.org/AM/Template.cfm?Section=Home&Template=/CM/ContentDisplay.cfm&ContentID=13317).

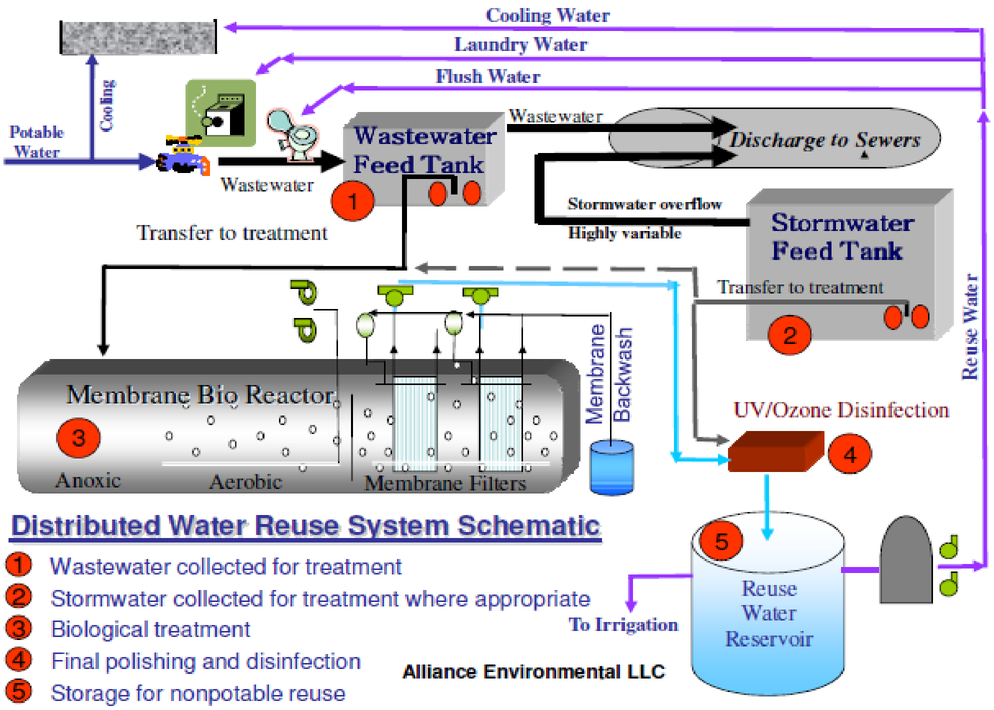


Figure 3-9. Scheme of Distributed Water Reuse System of Solaire, Battery Park City, New York. (http://www.werf.org/AM/Template.cfm?Section=Home&Template=/CM/ContentDisplay.cfm&ContentID=13317)

3.2.5.6 Philip Merrill Building, Annapolis, MD

“The Chesapeake Bay Foundation’s headquarters is a LEED® Version 1 Platinum certified building.” (Kloss, 2008) The building is a commercial office with about 2,900 m^2 (32,000 ft^2) of floor area which was completed in 2000. Runoff from the approximately 930 m^2 (10,000 ft^2) roof is collected in three exposed cisterns located above the entrance (Figure 3-10). A rain gutter drains the water through filters and into the cisterns, following by sand filtering treatment process. Filtered rainwater is used for mop sinks, laundry, irrigation, and fire suppression. Also, stormwater passes through a bioretention stormwater treatment system to treat oils and grease and to enhance water quality prior to entering the adjacent Black Walnut Creek. The building's design allows for a 90% reduction in water use over an otherwise comparable conventional office building. (http://www.nrel.gov/docs/fy02osti/29500.pdf and http://www.cbe.berkeley.edu/mixedmode/chesapeake.html).

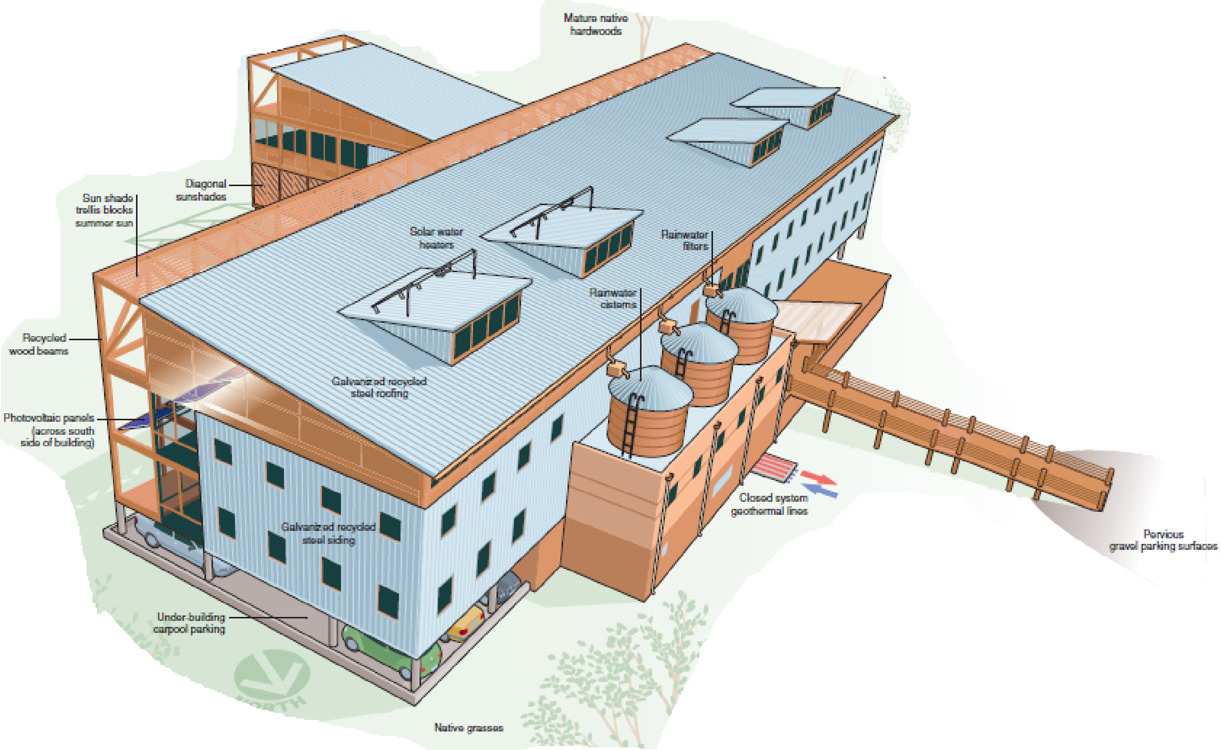


Figure 3-10. Schematic Picture of the Chesapeake Bay Foundation. (http://www.nrel.gov/docs/fy02osti/29500.pdf)

Figure 3-11. Exterior North view and Rainwater Harvesting Tanks in Philip Merrill Building, Annapolis. (http://www.nrel.gov/buildings/pdfs/34830.pdf)

3.2.5.7 SMURRF, Santa Monica

In February 2001, the Santa Monica Urban Runoff Recycling Facility (SMURRF) was constructed. The main focus of the facility was to eliminate pollution of Santa Monica Bay caused by urban runoff during the dry season. However, the project had other goals such as providing cost-effective treatment and producing high-quality water for reuse in landscape irrigation. The city of Santa Monica has two main stormwater drains from which the SMURRF harvests urban runoff. It has been estimated that these two stormwater drains contribute about 90% of the City's total daily dry weather runoff and drain an area of 20.6 km². The SMURRF is able to harvest and reuse up to 1,900 m^3 (500,000 gallons) of runoff per day which is approximately 4% of the City of Santa Monica's daily water use. SMURRF uses a 5-stage treatment train (Figure 3-12) The preliminary treatment is a fine screening to remove particles greater than 0.1 cm (0.04 in) in size. In the second stage grit and sand is removed. Then pre-treated water is stored in a tank to be pumped to the dissolved air floatation unit for oil and grease removal. The last stages include microfiltration and UV disinfection.. The treated SMURRF water is being used for landscape irrigation and for indoor commercial building use. Landscape irrigation customers include the Olympic Boulevard center median, the City of Santa Monica parks, and the Woodlawn Cemetery. The SMURRF system cost about US$12 million, including the distribution system for the recycled water (City of Santa Monica 2007 available at: http://www.smgov.net/uploadedFiles/Departments/OSE/Categories/Urban_Runoff/UR_SMURRF_Info_Sheets.pdf?n=5722).

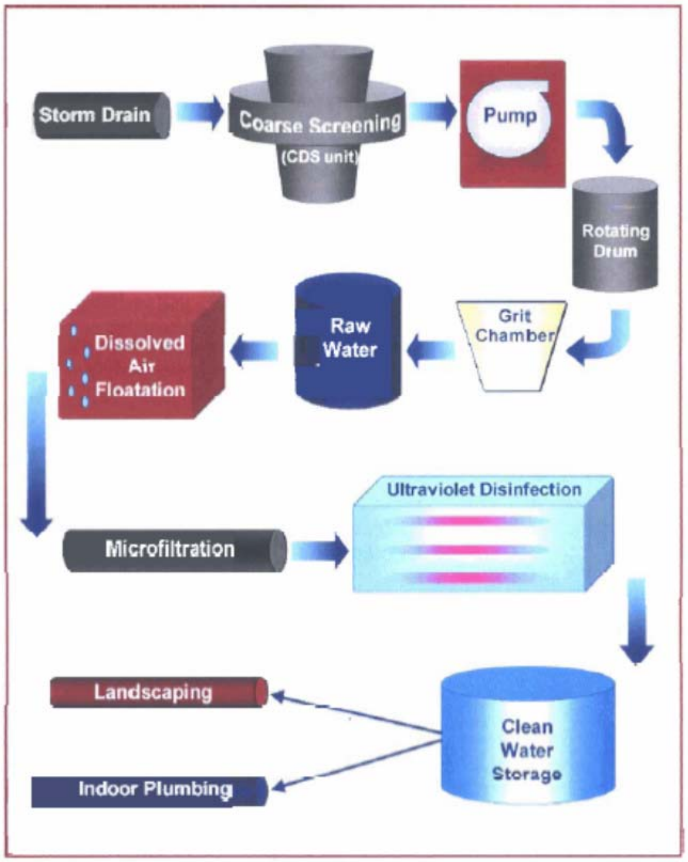


Figure 3-12. SMURFF Treatment Process (City of Santa Monica, 2007, http://www.smgov.net).

3.2.5.8 Natural Resources Defense Council's Robert Redford Building, Santa Monica

The building with an area of 1,400 m^2 (15,000 square foot) uses 60% less water than a standard building of its size by capturing and filtering rainwater, shower and sink water, resulting in an annual water savings of around 230 m^3 (60,000 gallons).(http://www.grist.org/article/of6/).

The combination of captured water from rainwater, shower and sink water is run through an Equaris Infinity disinfection and filtration treatment system before being used for irrigation and flushing toilets. The system has two cisterns with a capacity of about 11,400 liters (3,000 gallons) located beneath large planters. There is a porous paving system and landscaping that filter the water that is not captured by the cisterns (http://www.nrdc.org/cities/building/smoffice/guides/water.pdf).

Figure 3-13. NRDC Santa Monica Building's Gray-Water System (Photo: http://www.documents.dgs.ca.gov/bsc/Newsletter/Fall2010/NRDC.pdf)

Figure 3-14. Rainwater Cistern at NRDC's Santa Monica Office. (Photo: NRDC) (Used by permission of NRDC)

3.2.5.9 Alberici Corporate Headquarters, Overland, Missouri

In 2004, Alberici Corporation, a construction company, relocated its corporate headquarters to a 56,600 square meter (14 acre) site in the St. Louis suburbs (Kloss, 2008). The building design includes a rainwater collection and reuse system. The system is designed to collect water from 3,920 square meters (42,200 ft^2) of the garage rooftop and to store the harvested water in a 117 cubic meters (30,900 gallon) cistern. The collected water is filtered and chlorinated, held in a secondary 1,900-liter (500-gallon) tank, and used for all of the building toilet flushing demand and the building's cooling tower. Designing the size of the cistern was based on 27 years of local rainfall records. The cistern's overflow drains into a pond. The stormwater reuse system collects 1,900 cubic meters (500,000 gallons) of water annually which is equal to 70% reduction in potable water usage. (http://www.epa.gov/greenkit/stormwater_studies/Alberici_MO.pdf).

3.2.5.10 Stephen Epler Hall, Portland State University, Oregon

Portland State University's 5,800 m^2 (62,500 ft^2) mixed-use student housing facility is LEED® Silver Certified. The rainwater is collected from about 2,700 m^2 (29,000 ft^2) of rooftops, impervious pavement areas, and landscapes. After initial filtration through stormwater planters, the collected rainwater is stored in a tank of 33,000 liters (8,700 gallons) capacity. The collected stormwater is further treated with UV light prior to be used for toilet flushing and irrigation of about 280 square meters of surrounding landscapes (3,000 square feet). "However, in addition to serving as a demonstration project for a supplementary water source, the system delays and filters potentially polluted quick runoff that would otherwise flow through the city's stormwater pipes directly into the Willamette River" (Turner, 2005).

3.2.5.11 City of San Francisco Water Reuse and Living Machine©, California

This 13-story (25,800 square meters building) headquarters office building was designed to achieve LEED Silver certification and generates its own energy through "integrated solar panels and wind turbines, and treats and recycles all wastewater for re-use with an on-site Living Machine® system." This system will gather and treat about 19,000 liters/day (5,000 gallons/day) of blackwater, graywater, and cooling tower water to be reused for toilet flushing and irrigation. The SFPUC projects results in saving of about 2,800 cubic meters (750,000 gallons) of potable water, with an additional of approximately 3,400 cubic meters (900,000 gallons) for non-potable uses per year. (Sources: AECOM, 2011; and www.businesswire.com).

3.2.5.12 Mall-Wide Water Reclamation Initiatives, Washington, D.C.

"The Smithsonian Institution is the world's largest museum complex and research organization comprised of nineteen museums, nine research centers, and the National Zoological Park." The potential of water reclamation and stormwater harvesting strategies was investigated at the National Museum of Natural History (NMNH) in Washington, D.C. as a pilot study. In this pilot study different aspects of water management (e.g. water sources, consumption, usage) were examined. Finally this study recommended 13 potential scenarios for rainwater harvesting and water reuse opportunities. Four recommendations out of 13 strategies (Table 3-3) were proposed to reduce the building's potable water consumption by about 24% annually. "AECOM used a self-developed interactive modeling program, Sustainable Systems Integration Model (SSIM) to evaluate the effects of the proposed water conserving strategies accordingly." Table 3-3 shows a summary of four recommended scenarios. Recommendation number 2 has the second highest initial cost (after recommendation 2), but results in highest saving of potable water per year (13.1%) (AECOM, 2011).

Table 3-3. Recommendations Summary Table. (Source: AECOM, 2011)

Recommendation	Initial Cost	Gallons of Potable Water Saved Annually	Percentage of Total Potable Water Saved Annually	Cost per 1000 Gallons Saved
#1 – Implement additional monitoring and/or metering of individual building components to refine building management plans at the Better performance measure Collect and treat rooftop rainfall and surface runoff for use to meet irrigation demand and supplement cooling tower make-up water.	$61,233	NA	NA	NA
#2 - Replace existing plumbing fixtures with new more water efficient plumbing fixtures at the Best performance measure	$1,162,290	6,289,314	13.1%	$185
#3 – Collect and treat rooftop rainfall and surface runoff for use to meet irrigation demand and cooling tower make-up water at the Good performance measure. Collect and treat A/C condensate for use to meet irrigation demand at the Best performance measure. Evaluate the irrigation system for possible improvements in efficiency and management at the Best performance measure	$2,156,746	5,136,360	10.7%	$420
#4 – Conduct a study to determine the viability of implementing a vegetated roof on the East and West Wings Fifth and Sixth floor roofs	$4,168,831	NA	NA	NA
Total - Combined total if all four recommendations are implemented	$7,549,100	11,425,674	23.8%	$661

* 1 gallon = 3.785 liters

3.2.5.13 Tryon Palace Historic Sites, North Carolina

"Tryon Palace Historic Sites and Gardens is a collection of historic homes and gardens, including the colonial palace and gardens located in New Bern, North Carolina and the old Barbour Boatworks property adjacent to the palace." (AECOM 2011) In Tryon Palace, a rainwater harvesting system is collecting water from a about 80,000 square meters (20 acre) area. North Carolina History Education Center is a new part of this site. In the History Center runoff is collected from New Bern Historic District with an area of approximately 200,000 square meters (50 acre) and is stored in an underground storage system. The harvested runoff is treated to be used to irrigate and provide water for the wetlands. (http://news.ncdcr.gov/2011/02/22/tryon-palace-and-nc-state-university-partner-to-build-rainwater-harvesting-system/)

3.2.5.14 Washington University - University Center, St. Louis, Missouri

The Danforth University Center, which is a Gold LEED® certified building, has been designed as the major pedestrian linkage to campus. There is a 190 cubic meter (50,000 gallon) rainwater storage tank below the building that collects excess rainwater. The water is then used to irrigate the building's landscaping. The system is able to provide 100% of native planting irrigation demand in the project area. (AECOM, 2011) For instance, Brauer Hall has an underground cistern that stores captured rainwater from the building for irrigating landscapes around the building. (http://eece.wustl.edu/ContentFiles/PageContent/EECE_newsletter_WINTER_2010.pdf).

Also, the Tyson Living Learning Center at the university's Tyson Research Center, is a 270 m^2 (2,900 ft^2) facility that is designed to be a "zero net energy and zero wastewater building". It harvests rainwater and treats it for drinking water. The rainwater that falls on the building passes through a filter to be treated prior to being stored in a 3,000 gallon underground cistern (http://news.wustl.edu/news/Pages/14205.aspx).

Figure 3-15. A cistern is pictured alongside the Tyson Living Learning Center before being placed underground at Washington University in St. Louis, Missouri (http://www.solaripedia.com/13/275/2954/tyson_living_learning_center_cistern.html). (Used by permission of Washington University ©2010)

3.2.5.15 University of Maryland, Maryland

Stormwater runoff is harvested in ponds from campus land, rooftops, roads, and parking lots. Campus Creek is one of the most important environmental features of the campus. This water feature is "completely contained on the campus from its headwaters on the UM Golf Course to its confluence with the Paint Branch near the University View apartment complex." Northeast Branch is another important drainage basin for the campus which collects a large amount of university property drainage. In a 2007 report, the campus was separated into 23 subwatersheds to optimize the design of the stormwater drainage systems.

There is an underground cistern at Knight Hall building which is estimated to reduce stormwater runoff by 27 percent as a result of converting an impervious parking lot to a green building with a large landscaped area. This system collects rainwater from rooftops. Plants are only watered efficiently as needed with existence of a drip irrigation system which detects the amount of moisture in the soil. The stormwater runoff is treated by filtering through the mechanical filtering and the natural filtering. (http://www.sustainability.umd.edu/content/campus/stormwater.php)

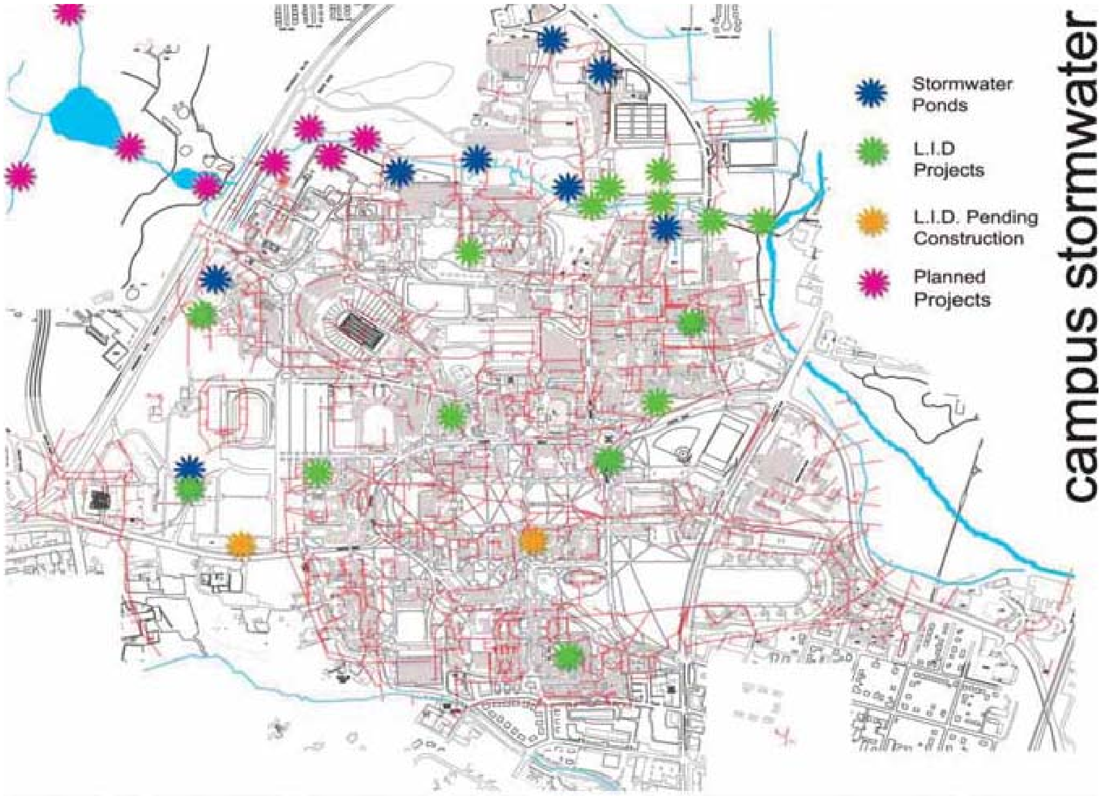


Figure 3-16. Maryland University Campus Stormwater Map.
(http://www.sustainability.umd.edu/content/campus/stormwater.php#GreenRoof).

3.2.5.16 Hearst Tower in Midtown Manhattan, New York

Hearst Tower's roof has been designed to collect rainwater for beneficial uses. This will reduce the amount of water discharged into the City’s combined sewer system during rainfall by 25 percent. The harvested rainwater is stored in a 53 m^3 (14,000 gallons) reclamation tank located in the basement of the Hearst Tower. The captured water is used for different non potable purposes, such as replacing water lost to evaporation in the office air-conditioning system, as well as irrigated landscaped areas . It is estimated that the harvested rainwater will provide about 50 percent of the watering needs (http://www.hearst.com/real-estate/hearst-tower.php). “The harvested water also will be utilized for "Icefall," a three-story, sculpted water feature within the building's grand atrium. In addition to serving as a stunning entrance to the building, Icefall, which is believed to be the nation’s largest sustainable water feature, will also serve an environmental function by serving to humidify and chill the atrium lobby as necessary” (http://www.saveandconserve.com/2007/08/tall_faceted_and_green_in_new_york.html).

Figure 3-17. Hearst Tower in Midtown Manhattan. (http://www.nyc.gov/html/hpd/downloads/pdf/Catherine-Barton-presentation.pdf)

3.2.5.17 REACH’s Station Place Tower, Portland, Oregon

REACH’s station place tower has 176 units with a total living area of about 14,300 m^2 (154,000 ft^2) and was completed in 2004. Rainwater is collected from all roofs except those that are covered by an eco-roof. The collection area is 1,100 m^2 (12,000 ft^2) from the three towers, with estimated rainwater harvesting of about 950 cubic meters (250,000 gallons) annually. The captured water is stored in a 68 cubic meters (18,000 gallon) concrete storage tank on each tower and is used for flushing 80 toilets in the building (35 m^3 or 9,500 gallons) and irrigating the on-site landscaped areas. “Rainwater plumbed to 41 percent of project water closets, which have locking-type lids. This is the first project to use tank-type locking covers in the City of Portland, which hasn’t previously allowed rainwater use in water closets..” (http://www.starkenvironmental.com/downloads/Interface_Engineering.pdf and http://www.homedepotfoundation.org/pdfs/reach_3.pdf).

3.3 Summary

Table 3-4 summarizes the features and noted problems indicated from the briefly described case studies. Several important issues are seen from these case studies. As expected, the heavily urbanized developing countries in water stressed areas (such as China and India) are most concerned with harvesting as much runoff as possible, with minimal concern related to water quality. Not only is roof runoff harvested (the likely cleanest water available, but still with some problems as described in the source water quality report section), but also runoff from all urban areas. Usually, all paved areas are used to harvest runoff water, as maximum volumes are needed to augment the poor quality and poorly available local sources. The water is stored in large ponds, and usually injected to shallow aquifers. These improve the water quality to some extent, greatly depending on these storage conditions.

In developing countries with large rural populations in water stressed areas (such as in Africa), most of the runoff harvesting schemes focus on collecting roof runoff for storage in tanks near the homes. The water is used for all domestic purposes and for irrigation of food subsistence crops during dry weather. The storage tanks are therefore relatively large to provide seasonal storage.

In developed countries with large urban population centers in water scarce regions (such as Australia), runoff harvesting has long been used to augment the water supplies. In most cases, the runoff is collected from roofs and stored in large tanks adjacent to homes where the water is used for non-potable uses. In some rural cases, the water is used for all domestic water uses. Large development water harvesting projects (such as for urban city centers for large apartment buildings), runoff is collected from all areas and undergoes some pretreatment before storage in large (usually underground) storage tanks. The water then undergoes very sophisticated water treatment before use. In many cases, this highly treated harvested runoff is still restricted to non-potable uses.

Examples of runoff harvesting in developed countries that currently are not under-going water shortages (such as Germany) are similar to the processes used in Australia. The purposes are to develop "sustainable" urban environments, where water conservation is a key factor.

In the U.S., many of the stormwater harvesting projects are either a port of a LEED® certified project, and/or to help reduce stormwater discharges to combined sewer systems. The collected water is not used for potable uses, but mostly for irrigation uses, and sometimes for toilet flushing or for fire suppression.

Later discussions in this report will address some of these features as illustrated in these case studies, including:

1) Regulations concerning water reuse quality
2) Quality of runoff from different source areas where harvested water may originate
3) Effects of different storage tank materials on harvested water quality
4) Groundwater contamination potential with recharging using waters of impaired quality
5) Water treatment benefits of aquifer storage/treatment and small scale water treatment units for harvested runoff

Later report sections will also address modeling results on runoff harvesting potential for several US locations, including water needs and storage requirements.

Table 3-4. Summary of Some Stormwater Beneficial Use Case Studies

Place	Project name	Stormwater type	Study area (catchment)	Storage capacity	Purposes	Benefits	Cost	Annual saving	Treatment
Singapore	Residential area	Rooftop cisterns	742 ha (7,420,000 m^2)		Non-potable	Saving 4% of total water used	$0.74/$m^3$		
Singapore	Changi Airport	Runoff from the runways and the surrounding green areas is diverted to two impounding reservoirs			fire-fighting drills and toilet flushing	Saving 28%-33% of total water used		$300,300	Treating before reusing
Japan	RyogokuKokugikan	Collecting runoff from rooftop	8,400 m^2	1000 m^3 (underground tank)	toilet flushing and air conditioning				Sedimentation tank prior to storage tank
South Korea	Star City (Seoul)	Collecting runoff from rooftop and ground	6.25 ha (62,500 m^2)	3000 m^3 (three 1000 m^3 tanks)	to irrigate gardens and for flushing public toilets		US$ 450,000	$80,000	
India	Delhi	Rooftop and surface runoff harvesting	113,000 m^2		Potable and non-potable		$1800		
Tanzania	Makanya	Water is collected from the sheet-roof and stored in above ground plastic/RCC tanks		Ranges from 2 to 10 m^3	Domestic purposes or other productive activities such as small vegetable garden.	Irrigation potential increases by 39%.			

Table 3-4. Summary of Some Stormwater Beneficial Use Case Studies (continued)

Place	Project name	Stormwater type	Study area	Storage capacity	Purposes	Benefits	Cost	Annual saving	Treatment
Germany	Berlin; Belss-Luedecke-Strasse building	Collecting runoff from roofs and surface.	7,000 m^2 of roofs & 4,200 m^2 of streets, parking spaces	160 m^3 cistern	toilet flushing, garden watering	2,430 m^3 per year saving of potable water			Treated in several stages
Germany	Berlin-Lankwitz	Collecting runoff from roofs and surface.	12,000 m^2 (63% roof, 35% courtyards and sidewalks and 12% roads)	190m^3	for toilet flushing and garden watering				Biological treatment and UV disinfection
Germany	Frankfurt Airport	Rooftop cisterns	26,800 m^2	Six tanks, each is 100 m^3	flushing toilets, watering plants, and cleaning the air conditioning system	and save about 100,000 m^3 of water per year	$63,000		
Ireland	Queens University in Belfast	The roof runoff is collected from roof, is filtered, and stored in an underground tank.	3000m^2		toilet flushing			£13,000 For installing	Filtering prior to be storing in underground tank

Table 3-4. Summary of Some Stormwater Beneficial Use Case Studies (continued)

Place	Project name	Stormwater type	Study area	Storage capacity	Purposes	Benefits	Cost	Annual saving	Treatment
South Australia	Salisbury; Parafield	Diverts stormwater from drainage system to a storage basin. pumped to a holding basin, flows by gravity to a reed bed wetland	1600 ha		effluent is then discharged to an aquifer storage area, ensuring a continuous water supply during dry weather	nutrient and other pollutant load reductions are 90%	Aus $3.7 million		Sedimentation and wetland treatment system
NSW	Black Beach Foreshore Park, Kiama	Stormwater is collected, treated and pumped to offline storage			to irrigate the two parks		$175,000	$80,000	Sand filter
Florida	West Palm Beach; Renaissance	collects stormwater runoff from different parts of the Convention Center and Pineapple Park Neighborhood to the Stub Canal, and to a settling basin			potable drinking water	more than 1,140,000 m^3 of treated stormwater is added to the City's water supplies each year	$17.6 million		Traditional bar screens to remove heavy debris / Alum and polymers for the control of heavy metals, oils and grease.

Table 3-4. Summary of Some Stormwater Beneficial Use Case Studies (continued)

Place	Project name	Stormwater type	Study area	Storage capacity	Purposes	Benefits	Cost	Annual saving	Treatment
Hawaii	U.S. National Volcano Park	Collecting runoff from roofs and ground	0.4 ha (4000 m^2) rooftop & 2 ha (20000 m^2) of ground catchment area	2 reinforced tanks each having 3,800 m^3 and 18 redwood tanks having 95 m^3 each	provide water for 1,000 workers and residents of the park and 10,000 visitors per day				
Washington	Seattle, King Street Center	collect stormwater from the building's roof	30,400 m^2 building houses	three 21 m^3 (5,400 gallon) cisterns	toilet flushing and landscape irrigation	saves an estimated 5300 m^3 (1.4 million gallons) of water per year, meeting over 60% of the building's estimated annual water needs			Filtering prior to being pumped to the building's toilets or irrigation system through a separate piping system
New York	Battery Park City; Solaire	Collecting stormwater from roof.		40 m^3 (10,000 gallon) cistern	Cooling, laundry, toilet flushing, irrigation	Stormwater reuse system is sized for 95 m^3/d (25,000 gpd) and provides approximately 30% of the total water use in the building.			Sand filtration and disinfection
New York	Hearst Tower, Midtown Manhatan	Collecting stormwater from roof.		53 m3 (14,000 gallon)	Replacing water lost to evaporation in the office air-conditioning system, and irrigation	reduce the amount of water discharged into the City's combined sewer system during rainfall by 25 percent.			

Table 3-4. Summary of Some Stormwater Beneficial Use Case Studies (continued)

Place	Project name	Stormwater type	Study area	Storage capacity	Purposes	Benefits	Cost	Annual saving	Treatment
Maryland	Annapolis; Philip Merrill Building	Collecting runoff from roof			Washing hands, laundry, irrigation, and fire suppression	The building's design allows for a 90% reduction in water use over an otherwise comparable conventional office building.			Sand filters/ chlorination and bioretention
California	Santa Monica; SMURFF	Collect runoff from roofs and surfaces			Landscape irrigation and indoor commercial building use.	Provides approximately 4% of the City of Santa Monica's daily water use	$12 million including the distribution system for the recycled water		5-stage treatment train, consisting of bar screens, flow equalization, air floatation, microfiltration, and UV disinfection
California	Santa Monica; Robert Redford Building	Collect runoff from the building roof		11 m^3 (3,000 gallons)	Irrigation and flushing toilets.	The building uses 60 percent less water than a standard building of its size, resulting in an annual water savings of over 230 m^3 (60,000 gallons)			porous paving system and landscaping planters

Table 3-4. Summary of Some Stormwater Beneficial Use Case Studies (continued)

Place	Project name	Stormwater type	Study area	Storage capacity	Purposes	Benefits	Cost	Annual saving	Treatment
Missouri	Overland, Alberici Corporate Headquarters		42,200 ft^2 (3,920 m^2)	120 m^3 (30,900 gallon) cistern	toilet flushing and the building's cooling tower	The stormwater reuse system saves 1893 m^3 (500,000 gallons) of water each year, reducing potable water demand by 70%			Filtering and chlorinating prior to reuse
Oregon	Portland University, Stephen Epler Hall		1988 m^2 (21,400 ft^2) roofs & (706 m^2 7,600 ft^2) turf and landscape plantings	33 m^3 (8700 gallons)	first floor restroom toilets and drip irrigation of 300 m^2 (3,000 ft^2) of native landscaping	in addition to serving as a demonstration project for a supplementary water source, the system delays and filters potentially polluted quick run-off that would otherwise flow through the city's stormwater pipes directly into the Willamette River	$71,800 initial, $310/year	$680	stormwater planters/ UV light
Oregon	REACH's station place tower	all roofs except those that are covered by an eco-roof	1,100 m2 (12,000 ft2)	68 cubic meters (18,000 gallon) on each tower	flushing 80 toilets in the building	harvesting of about 950 cubic meters (250,000 gallons) annually			

CHAPTER 4.0

WATER REUSE REGULATIONS AND OTHER GUIDANCE

4.1 Introduction

This section reviews water reuse regulations and guidelines in different parts of the U.S. and in some other areas. Water reuse regulations or guidelines vary with the type of application, the regional context, and the overall risk perception. Depending on the application, water quality requirements, treatment process requirements, and criteria for operation and reliability will be specified. Most of guidelines have limits on quality objectives based on total suspended solids (TSS) or turbidity, biochemical oxygen demand (BOD), biological indicators (total or fecal coliforms, *E. coli*, helminth eggs, enteroviruses), nutrient levels (nitrogen and phosphorus) and, in some cases, chlorine residual. Most of these regulations pertain to reusing treated sanitary wastewaters, but most are not specific as to their source. Some regulations, however, do specifically address beneficial uses of stormwater, of most relevance to the topic of this report.

4.2 Water Reuse Regulations in the U.S.

4.2.1 State Regulations of Wastewater Reuse

Many states in the U.S. have water reuse regulations and guidelines. Regulations refer to actual rules that have been enacted and are enforceable by government agencies. Guidelines, on the other hand, are not enforceable but can be used in the development of a reuse program. Currently, there are no federal regulations directly governing water reuse practices in the U.S. However, water reuse regulations and guidelines have been developed by many individual states. During the review by the U.S. EPA (2004), 26 states were found that had adopted regulations regarding the reuse of reclaimed water, 16 states had guidelines or design standards, and eight states had no regulations or guidelines. Some states have developed regulations for water reuse specifying water quality requirements for some parameters, as well as treatment processes to derive the maximum resource benefits of reclaimed water with respect to public health and protecting the environment. These states have set standards for reclaimed water quality and/or specified minimum treatment requirements. Generally, where unrestricted public exposure is likely in the reuse application, wastewater must be treated to a high degree prior to its application. Where exposure is not likely, however, a lower level of treatment is usually accepted. The most common parameters for which water quality limits are imposed are BOD_5, TSS, turbidity, and total or fecal coliform bacteria counts.

Most states do not have regulations that cover all potential uses of reclaimed water. There is a wide range of uses of the reclaimed water. Current regulations and guidelines may be divided into the following reuse categories (U.S.EPA, 2004):

- Unrestricted urban reuse – irrigation of areas in which public access is not restricted, such as parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments.

- Restricted urban reuse – irrigation of areas in which public access can be controlled, such as golf courses, cemeteries, and highway medians.
- Agricultural reuse on food crops – irrigation of food crops which are intended for direct human consumption, often further classified as to whether the food crop is to be processed or consumed raw.
- Agricultural reuse on non-food crops – irrigation of fodder, fiber, and seed crops, pasture land, commercial nurseries, and sod farms.
- Unrestricted recreational reuse – an impoundment of water in which no limitations are imposed on body-contact water recreation activities.
- Restricted recreational reuse – an impoundment of reclaimed water in which recreation is limited to fishing, boating, and other non-contact recreational activities.

This summary on reclaimed water quality and treatment requirements is based on water reuse regulations from 26 states and focuses on “unrestricted urban reuse” and “restricted urban reuse.” Applications of reclaimed water vary from state to state. Generally, reused water could be applied in irrigation (irrigation of golf courses and parks), washing yards, lots and sidewalks, toilet flushing, fire protection systems, etc. Table 4-1 shows different unrestricted and restricted allowable urban water usage for some of the reviewed States pertaining to reclaimed water.

Table 4-1. Allowable Uses of Reclaimed Waters for Beneficial Uses

	Arizona	California	Florida	Hawaii	Idaho	Kansas	Massachusetts	Montana	Nevada	New Mexico	North Carolina	North Dakota	Ohio	South Carolina	Tennessee	Texas	Utah	Washington
Residential landscape irrigation	*	*	*	*					*	*	*			*		*	*	*
Irrigation of parks		*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*
School ground landscape irrigation	*	*	*	*	*			*			*			*		*		*
Irrigation of golf courses		*	*	*		*		*	*	*	*	*	*			*	*	*
Decorative fountains		*		*							*							*
Washing yards, lots and sidewalks				*							*		*	*				*
Toilet and urinal flushing,	*	*	*	*			*				*					*	*	*
Fire protection systems,	*	*	*								*					*	*	*
Commercial closed-loop air conditioning systems	*																	
Vehicle and equipment washing	*	*	*								*							
Snowmaking	*																	
Construction site dust control			*								*							*
Tank trucks			*															

4.2.2 Unrestricted Urban Reuse

Unrestricted urban water reuse involves irrigation of areas in which public access is not restricted, such as parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments. Thus, the water needs a high degree of treatment. “In general, all states that specify a treatment process require a minimum of secondary treatment and treatment with disinfection prior to unrestricted urban reuse.” (U.S.EPA, 2004). These requirements obviously pertain to sanitary wastewaters, with minimal relevance to other waters, such as stormwater. Some of other states require higher levels of treatment such as filtration, and oxidation. Table 4-2 shows the reclaimed water quality and treatment requirements for unrestricted urban reuse for the states that have specified regulations for water reuse.

Limits on BOD_5 range from 5 to 30 mg/L. Texas and Georgia require a BOD_5 limit of 5 mg/L where Massachusetts, Nevada, Tennessee and Washington require a BOD_5 limit of 30 mg/L. Some states have different ranges of BOD_5 for different time ranges. For example, North Carolina requires that BOD_5 not exceed 10 mg/L (monthly average), while the daily average of BOD_5 should not exceed 15 mg/L. Some States such as Florida and Ohio specify limits on CBOD which is respectively 20 mg/L and 25 mg/L. Limits on TSS vary from 5 to 30 mg/L. Florida, Georgia, Indiana, and New Jersey require a TSS limit of 5.0 mg/L prior to disinfection, while North Dakota, Tennessee, and Washington require that TSS not exceed 30 mg/L. South Carolina and North Carolina have different limits of TSS for daily and monthly averages.

Limits on turbidity range from 1 to 10 NTU, but most of the states require an average turbidity limit of 2 NTU and a not-to-exceed limit of 5 NTU. Average fecal and total coliform limits range from non-detectable to 23 counts per 100 mL. Higher single sample fecal and total coliform limits are allowed in several state regulations. Florida requires that 75% of the fecal coliform samples taken over a 30 day period be below detectable levels, with no single sample in excess of 25 counts per 100 mL, while Massachusetts requires a median of no detectable fecal coliform per 100 mL over continuous seven-day sampling periods, and not to exceed 14 counts per 100 mL in any one sample.

Table 4-2. Unrestricted Urban Reuse Regulations

	Arizona	Arkansas	California	Colorado	Delaware	Florida	Georgia	Hawaii	Indiana	Idaho
Specified Treatment	Secondary treatment, filtration, and disinfection	Secondary treatment and disinfection	Oxidized, coagulated, filtered, and disinfected	Oxidized, coagulated, filtered, and disinfected	Oxidized, clarified, coagulated, flocculated, filtered, and disinfected	Secondary treatment with filtration and high-level disinfection	Secondary treatment, coagulated, filtration and disinfection	Oxidized, and disinfected	Secondary treatment, and disinfection	Oxidized, coagulated, clarified, filtered, and disinfected
BOD_5	NS	NS	NS	NS	10 mg/L	$CBOD_5$: 20 mg/L	5 mg/L	NS	10 mg/L	NS
TSS	NS	NS	NS	NS	10 mg/L	5 mg/L	5 mg/L	NS	5 mg/L	NS
Turbidity	- 2 NTU (24 hr average) - 5 NTU (not to exceed at any time)	NS	NS	- 3 NTU (monthly average) - 5 NTU (in more than 5 percent of any month)	5 NTU	NS	- not to exceed 3 NTU prior to disinfection	- not to exceed 2 NTU	NS	NS
Coliform bacteria	Fecal: -none detectable in 4 of last 7 daily samples - 23/100 mL (single sample maximum)	NS	Total: - 2.2/100 mL (7-day median) - 23/100 mL (not to exceed in more than one sample in any 30 days)	Total: - 2.2/100 mL (7-day median) - 23/100 mL (any sample)	Fecal: 20/100 mL	Fecal: - over 30 day period 75% of samples below detection limits - 25/100 mL (single sample)	Fecal: -23/100 mL (monthly average) -100/100 mL (maximum any sample)	Fecal: - 23/100 mL (7-day median) - 200/100 mL (not to exceed in more than one sample in any 30-day period)	Fecal: -no detectable (7-day median) - 14/100 mL (single sample)	Total: - 2.2/100 mL (7-day median)

Table 4-2. Unrestricted Urban Reuse Regulations (continued)

	Massachusetts	Montana	Nevada	New Jersey	New Mexico	North Carolina	North Dakota	Ohio
Treatment	(Toilet flushing) Secondary treatment with filtration and disinfection	Oxidized, clarified, coagulated, filtered, and disinfected	Minimum secondary treatment with disinfection	Secondary treatment, filtered (chemical addition before filtration)	Adequately treated and disinfected	Tertiary quality effluent (filtered or equivalent)	Minimum Secondary treatment with chlorination	Biological treatment and disinfection
BOD_5	30 mg/L	NS	30 mg/L	NS	NS	- 10 mg/L (monthly average) - 15mg/L (daily maximum)	25 mg/L	COD_5: 25 mg/L
TSS	10 mg/L	NS	NS	5 mg/L (not to exceed before disinfection)	NS	- 5 mg/L (monthly average) - 10 mg/L (daily maximum)	30 mg/L	NS
Turbidity	5 NTU (not to exceed at any time)	- 2 NTU (average) - 5 NTU (not to exceed more than 5% of 24 hr)	NS	- not to exceed 2 NTU	NS	- not to exceed 10 NTU at any time	NS	NS
Coliform	Fecal: -no detectable (7-day median) - 14/100 mL (any single sample)	Fecal: - 2.2/100 mL (7-day median) - 23/100 mL (single sample)	Fecal: - 2.2/100 mL (30-day geometric mean) - 23/100 ml (maximum daily number)	Fecal: - 2.2/100 mL (7-day median) - 14/100 mL (maximum any one sample)	Fecal: - 100/100 mL	Fecal: - 14/100 mL (monthly geometric mean) - 25/100 mL (maximum daily number)	Fecal: -200/100 mL	Fecal: (30-day average) - 23/100 mL with no public access buffer area or night application

Table 4-2. Unrestricted Urban Reuse Regulations (continued)

	South Carolina	South Dakota	Tennessee	Texas	Utah	Virginia	Washington	Wyoming
Treatment	Advanced wastewater treatment	Secondary treatment and disinfection	Biological treatment and disinfection	NS	Secondary treatment with filtration and disinfection	Secondary treatment with filtration and higher- level disinfection	oxidized, coagulated, filtered, and disinfected	advanced treatment and/or secondary treatment and disinfection
BOD_5	- 5 mg/L (monthly average) - 7.5 mg/L (weekly average)	NS	30 mg/L (monthly average)	5 mg/L	- 10 mg/L (monthly average)	- 10 mg/L (monthly average) CBOD5: - 8 mg/L (monthly average)	30 mg/L	NS
TSS	- 5 mg/L (monthly average) - 7.5 mg/L (weekly average)	NS	30 mg/L (monthly average)	NS	NS	NS	30 mg/L	NS
Turbidity	1 NTU (monthly average) - 5 NTU (not to exceed based on an average for 2 consecutive days	NS	NS	3 NTU	- not to exceed 2 NTU (daily average) - not to exceed 5 NTU at any time	- 2 NTU (daily average) - 5 NTU (not to exceed at any time)	- 2 NTU (monthly average) - 5 NTU (not to exceed at any time)	NS
Coliform	Total: - Similar to standards in State Primary Regulations	Total: - 200/100 mL (geometric mean)	Fecal: - 200/100 mL	Fecal: - 20/100 mL (geometric mean) - 75/100 mL (not to exceed in any sample)	Fecal: - none detected (weekly median - 14/100 mL (in any sample)	Fecal: - 14/100 mL (monthly geometric mean) - 49/100 mL (not to exceed in any sample)	Total: - 2.2/100 mL (7-day mean) - 23/100 mL (single sample)	Fecal: - 2.2/100 mL or less

4.2.3 Restricted Urban Reuse

Restricted urban reuse involves: irrigation of areas in which public access can be controlled, such as golf courses, cemeteries, and highway medians. Thus, restricted reuse may require less treatment than unrestricted reuse. Some States impose the same requirements on both unrestricted and restricted urban access reuse, while others adjusted different requirements for the restricted and unrestricted categories. Table 4-3 shows the reclaimed water quality and treatment requirements for restricted urban reuse.

Limits on BOD_5 range from 5 mg/L to 70 mg/L. Georgia requires a BOD_5 limit of 5 mg/L where Maryland requires a BOD_5 limit of 70 mg/L. Some states have different ranges of BOD_5 for different time ranges. For example South Carolina requires that BOD_5 not to exceed 30 mg/L (monthly average) where the daily average of BOD_5 should not exceed 45 mg/L. Some States such as Ohio specify limits on CBOD which is 40mg/L. Limits on TSS vary from 5 mg/L to 90 mg/L. Georgia and Massachusetts require a TSS limit of 5.0 mg/L prior to disinfection and Maryland requires that TSS not exceed 90 mg/L. South Carolina and North Carolina have different limits of TSS for daily and monthly averages.

Limits on turbidity range from 2 to 10 NTU, but most of the states require an average turbidity limit of 2 NTU and a not-to-exceed limit of 5 NTU. Average fecal and total coliform limits range from 2.2 counts per 100 mL to 200 counts per 100 ml. Higher single sample fecal and total coliform limits are allowed in several state regulations.

Table 4-3. Restricted Urban Water Reuse Regulations.

	Arizona	Arkansas	California	Colorado	Delaware	Florida	Georgia	Hawaii	Idaho
Treatment requirements	Secondary treatment and disinfection	Secondary treatment and disinfection	Secondary – 23, oxidized, and disinfected	Secondary treatment, and disinfection	Biological treatment and disinfection	Secondary treatment, filtration, and high-level disinfection	Secondary treatment, coagulated, Filtration and disinfection	Oxidized and disinfected	Oxidized and disinfected
BOD_5	NS	NS	NS	NS	30 mg/L	20 mg/L CBOD5	5 mg/L	NS	NS
TSS	NS	NS	NS	30 mg/L (maximum daily)	30 mg/L	5 mg/L	5 mg/L	NS	NS
Turbidity	NS	NS	NS	NS	NS	NS	- not to exceed 3 NTU prior to disinfection	2 NTU (Max)	NS
Coliform	Fecal: - 200/100 mL (not to exceed in 4 of the last 7 daily samples) - 800/100 mL (single sample maximum)	NS	Total: -23/100 mL (Avg) - 240/100 mL (Max in 30 days)	*E. coli*: - 126/100 mL (monthly average) - 235/100 mL (single sample maximum)	Fecal: 200/100 mL	Fecal: - 75% of samples below detection -25/100 mL (Max)	Fecal: -23/100 (monthly average) -100/100 mL (maximum any sample)	Fecal: - 23/100 mL (Avg) - 200/100 mL (Max)	Total: - 23/100 mL (7-day median)

Table 4-3. Restricted Urban Water Reuse Regulations. (continued)

	Indiana	Maryland	Massachusetts	Missouri	Montana	Nevada	New Jersey	New Mexico	North Carolina
Treatment	Secondary treatment and disinfection		Secondary treatment with filtration and disinfection	Secondary treatment with disinfection	Oxidized and disinfected	Minimum secondary treatment with disinfection	Secondary treatment, filtered (chemical addition before filtration)	Adequately treated and disinfected	Tertiary quality effluent (filtered or equivalent)
BOD_5	30 mg/L	70 mg/L	10 mg/L	NS	NS	30 mg/L	NS	NS	- 10 mg/L (monthly average) - 15mg/L (daily maximum)
TSS	30 mg/L	90 mg/L	5 mg/L	NS	NS	NS	5 mg/L (not to exceed before disinfection)	NS	- 5 mg/L (monthly average) - 10 mg/L (daily maximum)
Turbidity	NS		- 2 NTU (average over 24 hr) - 5 NTU (not to exceed at any time)	NS	NS	NS	NS	NS	- not to exceed 10 NTU at any time
Coliform	Fecal: - 200/100 mL (7-day median) - 800/100 mL (single sample)	Fecal: - 3/100 mL	Fecal: - no detectable colonies (7-day median) - 14/100 mL (single sample)	Fecal: - 200/100 mLI	Fecal: - 200/100 mL (7-day median) - 400/100 mL (any two consecutive samples)	Fecal: - 2.2/100 mL (30-day geometric mean) - 23/100 ml (maximum daily number)	Fecal: - 2.2/100 mL (7-day median) - 14/100 mL (maximum any one sample)	Fecal: - 100/100 mL	Fecal: - 14/100 mL (monthly geometric mean) - 25/100 ml (maximum daily number)

Table 4-3. Restricted Urban Water Reuse Regulations. (continued)

	North Dakota	Ohio	Oregon	South Carolina	South Dakota	Tennessee	Texas	Utah
Treatment	Minimum Secondary treatment with chlorination	Biological treatment and disinfection	Biological treatment and disinfection	Secondary treatment and disinfection	Secondary treatment and disinfection	Biological treatment and disinfection	NS	Secondary treatment with disinfection
BOD_5	25 mg/L	$CBOD_5$: 40 mg/L	NS	- 30 mg/L (monthly average) - 45 mg/L (weekly average)	NS	30 mg/L (monthly average)	20 mg/L	- 25 mg/L (monthly average)
TSS	30 mg/L	NS	NS	- 30 mg/L (monthly average) - 45 mg/L (weekly average)	NS	30 mg/L (monthly average)	NS	- 25 mg/L (monthly average) - 35 mg/L (weekly mean)
Turbidity	NS	NS	NS	NS	NS	NS	3 NTU	- not to exceed 2 NTU (daily average) - not to exceed 5 NTU at any time
Coliform	Fecal: -200/100 mL	Fecal: (30-day average) - 23/100 mL with no public access buffer - 200/100 mL with 100-foot public access buffer	Total: - 240/100 mL (two consecutive samples) - 23/100 mL (7-day median)	Total: - 200/100 mL (monthly average) - 400/100 mL (daily maximum)	Total: - 200/100 mL (geometric mean)	Fecal: - 200/100 mL	Fecal: - 200/100 mL (geometric mean) - 800/100 mL (not to exceed in any sample)	Fecal: - 200/100 mL (weekly median) - 800/100 mL (not to exceed in any sample)

Table 4-3. Restricted Urban Water Reuse Regulations. (continued)

	Washington	Wyoming
Treatment	oxidized, coagulated, filtered, and disinfected	advanced treatment and/or secondary treatment and disinfection
BOD_5	30 mg/L	NS
TSS	30 mg/L	NS
Turbidity	- 2 NTU (monthly average) - 5 NTU (not to exceed at any time)	NS
Coliform	Total: - 23/100 mL (7-day mean) - 240/100 mL (single sample)	Fecal: - greater than 2.2/100 mL but less than 200/100 mL

4.3 Water Reuse Regulations in Other Countries

4.3.1 Canada

In some parts of Canada, water is reused for different purposes such as agricultural irrigation, golf course irrigation, and toilet flushing. As 2011, there are no federal regulations for water reuse in Canada. Only two provinces (Alberta and British Columbia) have published regulations addressing water reuse. British Colombia has adopted regulations for non-potable uses of reclaimed water with treatment and water quality criteria similar to those in U.S. states such as California and Florida. Water reuse regulation in Alberta requires a minimum of secondary treatment, less than 100 mg/L TSS, less than 1,000 total coliform counts per 100 mL, and less than 200 fecal coliform counts per 100 mL for both unrestricted and restricted urban and agricultural irrigation (Crook, et al. 2005). Table 4-4 represents water quality requirements for reclaimed water in British Columbia (data from British Columbia Ministry of Environment, Lands and Parks, 1999

Table 4-4. Permitted Uses and Standards for Reclaimed Water in British Columbia.

Permitted Uses	Treatment Requirements	Effluent Quality Requirements	Monitoring Requirements
Unrestricted Public Access – agricultural, recreational and urban uses	Secondary, with chemical addition, filtration, disinfection and emergency storage	- BOD5 ≤ 10 mg/L - Turbidity ≤ 2 NTU - Fecal coliform ≤ 2.2/100 mL - pH = 6-9 - plus general considerations	Weekly Continuously Daily Weekly
Restricted Public Access – agricultural, urban/recreational, construction, industrial and environmental uses	Secondary, with disinfection	BOD5 ≤ 45 mg/L - Total suspended solids ≤ 45 mg/L - Fecal coliform ≤ 200/100 mL - pH = 6-9 - plus general considerations	Weekly Daily Weekly Weekly

4.3.2 Europe

Reclaimed water is used for irrigation, industrial purposes, groundwater recharge, non-potable urban uses and indirect potable use in Europe. Most of the reuse projects are Southern European countries (Cyprus, France, Greece, Malta, Portugal, Spain,), however some reuse projects are implemented in central and northern countries of Europe (Belgium, Sweden, UK) (EWA, 2007).

Although some European countries have developed guidelines for water reuse, there are no standardized water reuse regulations for the entire Europe. Some of European countries use regulations and criteria similar to those in Australia and the U.S., whereas others adopts WHO guidelines for wastewater use in agriculture (Crook, et al. 2005). Table 4-5 summarizes some examples of European water reuse regulations. (data from Crook, et al. 2005)

Table 4-5. Examples of European Water Reuse Regulations and Guidelines. (Crook, et al. 2005) (Used by permission of author)

Country or Region	Parameter			Level of Regulation	Recommended Uses
	Total coliform CFU/100 mL	Fecal coliform CFU/100 mL	Helminth eggs No./L		
Spain		0 200 1000 10000	<1	National proposal	Domestic uses, GWR by injection Urban uses, unrestricted irrigation GWR, pastures Fodder & fiber crops, industrial cooling
Balearic Islands		1000		Regional	Unrestricted irrigation
Italy	2 20	Not set		National	Unrestricted irrigation Restricted irrigation
Sicily	3000	1000	1/L	Regional	Unrestricted irrigation
Puglia	2 10	2	0/L	Regional	Unrestricted irrigation Restricted irrigation
Emilia-Romagna	2 20	Not set		Regional	Unrestricted irrigation Restricted irrigation
France		1000 n.s.r. n.s.r.	1/L 1/L n.s.r.	National	A - unrestricted irrigation (crops, public greens) B – cereals, orchards; accessed by workers C – cereals, industrial crops, orchards
Cyprus		50 200 1000 3000	0/L	National	Restriction of crop and exposure
Greece		10 100 1000 10000	0.1/L 1/L 1/L 1/L	National proposal	Domestic uses Urban use with public contact Restricted irrigation, fodder crops, aquaculture Irrigation of areas with restricted access, industry
		5 5 5 200		National proposal	Unrestricted irrigation Recirculated cooling systems Nonpotable aquifers Restricted irrigation
Austria		Not detected 2000 n.s.r.		National proposal	Restriction of crop and exposure
UK		Not detected		National proposal	Unrestricted irrigation, toilet flushing, clothes washing, air conditioners
Germany (Berlin)	100	10/mL		Local	Irrigation and groundwater recharge are authorized in conformance with Water Law, Ordinance on manure use

* n.s.r: no standard recommended

4.3.3 Middle East

Some Middle Eastern countries have developed regulations and standards for reused water based on different types of usage. For instance, Saudi Arabia uses the reclaimed water for irrigation and industrial purposes (such as cooling at a refinery) and has standards for unrestricted irrigation which include reclaimed water limits of 10 mg/L BOD_5, 10 mg/L TSS, 6-8.4 pH, 2.2 total coliform counts per 100 mL, and 1 NTU. In Kuwait while the main reuse application is irrigation, reclaimed water is only allowed for "the irrigation of vegetables eaten cooked (potatoes and cauliflower), industrial crops, forage crops (alfalfa and barley), and irrigation of highway landscapes." Table 4-6 details the effluent quality standards established by the Ministry of Public Works for water reuse. (U.S. Environmental Protection Agency, 2004; Crook, et al., 2005).

Table 4-6. Reclaimed Water Standards in Kuwait. (U.S. Environmental Protection Agency, 2004)

Parameter	Irrigation of Fodder and Food Crops Not Eaten Raw, Forestland	Irrigation of Food Crops Eaten Raw
Level of Treatment	Advanced	Advanced
SS (mg/L)	10	10
BOD_5 (mg/L)	10	10
COD (mg/L)	40	40
Chlorine Residual (mg/L), After 12 hours at 20° C	1	1
Coliform Bacteria (counts per 100 mL)	10,000	100

4.3.4 Asia

In Japan, as of 2003 there has not been a specifc water reuse regulation, however water quality criteria for toilet flushing reuse was issued by the Ministries of Construction, Health and Welfare, International Trade and Industries. The Ministry of Construction (MOC) also set minimum water quality requirements for water reuse for landscape irrigation and recreational impoundment, as summarized in Table 4-7 (Suzuki, et al., 2003).

Table 4-7. Japanese Water Quality Targets for Wastewater Reuse. (Suzuki, et al., 2003)

Categories	Items	Toilet Flushing	Landscape irrigation with sprinkling or watering of	Recreational impoundment
Basic	Total Coliforms	≤ 10 CFU/mL	Not detected	Not detected
	Residual Cl	Detected	≥ 0.4mg/L	—
Additional	Aesthetics	Not unpleasant	Not unpleasant	Not unpleasant
	Turbidity	-	-	≤ 10 (unit)
	BOD_5	-	-	≤ 10 mg/L
	Odor	Not offensive	Not offensive	not offensive
	pH	5.8 to 8.6	5.8 to 8.6	5.8 to 8.6

Table 4-7. Japanese Water Quality Targets for Wastewater Reuse. (Suzuki, et al., 2003) (continued)

Parameters	without body contact	with possible body contact
Total Coliforms	≤ 1000CFU/100mL	≤ 50CFU/100mL
BOD_5	≤ 10mg/Ｌ	≤ 3mg/L
pH	5.8～8.6	5.8～8.6
Turbidity	≤ 10 (unit)	≤ 5 (unit)
Odor	Not offensive	Not offensive
Color	≤ 40 (unit)	≤ 10 (unit)

4.4 Regulations Specifically Addressing Stormwater Beneficial Uses

Table 4-8 summarizes a few regulations identified that specifically addressed stormwater beneficial uses (New South Wales, Australia; Berkeley, CA; Texas; and the United Kingdom). Bacteria standards are common, with *E. coli* limits ranging from 1 count per 100 mL for non-potable uses with public access to 1,000 counts per 100 mL for controlled access. Chlorine residuals imply chlorination as a disinfectant, usually with a concurrent turbidity limit to allow more efficient disinfection.

Table 4-8. Regulations Restricting Stormwater Beneficial Uses.

		Coliform	Chlorine	pH	Turbidity	Ammonia	Aluminum	Nitrate/Nitrite
WHO[1]	Roof water harvesting	*E. coli.* <10cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	Not relevant	<1.5 mg/L	Not relevant	Not relevant
	Surface Runoff	*E. coli*.<10cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	<15 NTU	<1.5 mg/L	<0.2 mg /l	<50 mg/L and <3 mg/L
	Sand dams	*E. coli*.<10cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	<5 NTU	<1.5 mg/L	<0.2 mg /l	<50 mg/L and <3 mg/L
NSW Australia	Level 1[2]	<1 cfu/100 mL	1 mg/L Cl_2 residual after 30 minutes or equivalent level of pathogen reduction	6.5–8.5	≤ 2 NTU			
	Level 2[3]	<10 cfu/100 mL	1 mg/L Cl_2 residual after 30 minutes or equivalent level of pathogen reduction	6.5–8.5	≤ 2 NTU			
	Level 3	<1000 cfu/100 mL		6.5–8.5	--------			
Berkeley[4] California	Non-potable indoor/outdoor uses	Total coliforms <500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL						

1- RAIN Water Quality Guidelines, 2008
2- Non-potable residential uses (e.g. garden watering, toilet flushing, car washing)
3- Public access public uses: -Spray or drip irrigation of open spaces, parks and sports grounds (no access controls), -Industrial uses – dust suppression, construction site use (human exposure possible), -Ornamental waterbodies (no access controls), -Fire-fighting
4- Guidelines for Rainwater Harvesting, Planning and Development Department Energy and Sustainable Development & Building and Safety Division, 2010

Table 4-8. Regulations Restricting Stormwater Beneficial Uses. (continued)

		E-Coli	Chlorine	pH	Turbidity	Ammonia	Aluminum	Nitrate/Nitrite
Texas[1]	Non-potable indoor uses	Total coliforms <500 cfu per 100mL Fecal coliforms <100 cfu per 100mL						
UK[2]	Non-potable indoor uses	Total coliforms 10/100 mL	<2 mg/L	6–8	≤ 10 NTU			
Virginia[3]	Non-potable indoor uses	Total coliforms < 500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL						

1- Rainwater Harvesting Potential and Guidelines for Texas, 2006
2- Draft British Standard on Rainwater Harvesting, 2008
3- Virginia Rainwater Harvesting Manual, Second Edition. 2009.

4.5 Criteria that May Affect Irrigation as a Beneficial Use of Stormwater

There are no regulations restricting irrigation use of stormwater in most areas (beyond the few examples presented in the above section). These existing irrigation regulations focus on public health and restrict bacteria levels in water that may be in contact with the public. However, water quality criteria have been in place for many years recommending water quality levels to prevent damage to the plants themselves. These are mostly for heavy metal concentrations. Several cooperative extension services provide suggested water quality guidelines. Table 4-9 is from the Texas Cooperative Extension Service, for example. In many cases, short-term use allows higher concentrations compared to long-term use.

This table also lists potable water MCLs for reference. Potable uses require that the harvested water be treated to drinking water standards. In many areas, stormwater is a significant water source for the local drinking water supplies. Many states set drinking water levels based on U.S. EPA Maximum Contaminant Levels; however, testing of the harvested water is based only on the likeliest contaminants. These would be issued typically by the state's department of health and would be reflected in testing requirements for well water. On this table, the irrigation criteria are less restrictive than the MCLs, with some exceptions, including: chromium, copper, fluoride, and zinc. No drinking water MCLs exist for several of the metals for which irrigation criteria are listed, including: cobalt, lithium, molybdenum, nickel, and vanadium. The copper and zinc are common stormwater contaminants that may hinder irrigation use. In addition, these two metals can be dramatically affected by the use of certain materials commonly used in the construction of storage and delivery facilities (galvanized metal roofs and storage tanks and copper pipes or other plumbing fittings). These potential effects are described in the following report section.

Table 4-9. Recommended Reuse Water Quality Criteria.
(Irrigation: http://lubbock.tamu.edu/irrigate/documents/2074410-B1667.pdf; Drinking Water: http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf)

Constituent	Irrigation			Potable Water	
	Short-Term Use (mg/L)	Long-Term Use (mg/L)	Remarks	MCLs (M)/ SMCLs (S)	Remarks
Aluminum (Al)	20	5.0	Can cause nonproductivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate Al and eliminate toxicity	0.05 – 2.0 (S)	
Arsenic (As)	2.0	0.10	Toxicity to plants varies widely	0.01 (M)	Circulatory system damage; skin damage; cancer
Beryllium (Be)	0.5	0.10	Toxicity to plants varies widely	0.004 (M)	Internal lesions
Boron (B)	2.0	0.75	Essential to plant growth. Toxic to many sensitive plants at 1 mg/L.		
Cadmium (Cd)	0.05	0.01	Toxic to beans, beets, and turnips at 0.1 mg/L.	0.005 (M)	Kidney damage
Chromium (Cr)	1.0	0.1	Lack of knowledge on plant toxicity.	0.1 (M)	Allergic dermatitis
Cobalt (Co)	5.0	0.05	Toxic to tomatoes at 0.1 mg/L. Tends to be inactivated by neutral and alkaline solutions.		
Copper (Cu)	5.0	0.2	Toxic to many plants at 0.1 to 1.0 mg/L.	1.3 (M)/1.0 (S)	Short-term: Gastrointestinal distress; Long-term: Liver and kidney damage
Fluoride (F^-)	15.0	1.0	Inactivated by neutral to alkaline soils.	4.0 (M)/2.0 (S)	Bone disease
Iron (Fe)	20.0	5.0	Not toxic to plants in aerated soils, but can contribute soil acidification and loss of P and Mo	0.3 (S)	
Lead (Pb)	10.0	5.0	Can inhibit plant cell growth.	0.015 (M)	Children: Physical/mental delays; Adults: Kidney damage
Lithium (Li)	2.5	2.5	Tolerated by most crops up to 5 mg/L; mobile in soils. Toxic at low doses to citrus.		
Manganese (Mn)	10.0	0.2	Toxic to number of crops at low concentrations.	0.05 (S)	

Table 4-9. Recommended Reuse Water Quality Criteria. (continued)
(Irrigation: http://lubbock.tamu.edu/irrigate/documents/2074410-B1667.pdf; Drinking Water: http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf)

Constituent	Irrigation			Potable Water	
	Short-Term Use (mg/L)	Long-Term Use (mg/L)	Remarks	MCLs (M)/ SMCLs (S)	Remarks
Mercury				0.002 (M)	Kidney damage
Molybdenum (Mo)	0.05	0.01	Nontoxic at normal concentrations. Toxic to livestock if forage grown in soils with high levels of available Mo.		
Nitrate-N				10.0 (M)	Methemoglobinemia
Nitrite-N				1.0 (M)	
Nickel (Ni)	2.0	0.2	Toxic to number of plants at 0.5 mg/L. Reduced toxicity at neutral to alkaline pH.		
Selenium (Se)	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage grown in soils with added Se.	0.05 (M)	Numbness; Circulatory problems
Vanadium (V)	1.0	0.1	Toxic to many plants at low concentrations.		
Zinc (Zn)	10.0	2.0	Toxic to many plants at wide concentration variation. Reduced toxicity at increased pH (> 6) and in fine-textured or organic soils.	5.0 (S)	

Original Source of Irrigation Water Quality Standards Data: Rowe, D.R. and I.M. Abdel-Magid. 1995. *Handbook of Wastewater Reclamation and Reuse*. CRC Press, Inc. 550pp.

4.6 Stormwater Infiltration and Recharge

Infiltrating groundwater through surface soils or infiltration stormwater controls (rain gardens, biofilters, percolation ponds, etc.) or more direct recharging of groundwater using stormwater (dry wells, injection wells, porous pavements, gravel trenches, etc.) are the two mechanisms used to discharge stormwater to the groundwater as a receiving water. The first mechanism is usually focused on removing stormwater from the immediate surface water regime as a stormwater management tool, while the second method is more to recharge local groundwater supplies for future use.

One of the earliest comprehensive reports investigating groundwater recharge was the committee report prepared for the National Research Council (1994; *Ground Water Recharge using Waters of Impaired Quality*). This report contained many international case studies, mostly examining treated sanitary wastewaters, but also some on stormwater. The main focus was groundwater recharge for later beneficial uses, including potable use. The case studies that addressed potable use were mainly associated with soil-aquifer treatment and had substantial subsurface residence times. Short residence times and little aquifer movement of the recharged water would be more similar to a storage tank, with reduced improvements in water quality.

The potential for infiltrating stormwaters to contaminate groundwaters is dependent on the concentrations of the contaminants in the infiltrating stormwater and how effective those contaminants may travel thru the soils and vadose zone to the groundwater. Source stormwaters from residential areas are not likely to be contaminated with compounds having significant groundwater contaminating potential (with the exception of high salinity snowmelt waters). In contrast, commercial and industrial areas are likely to have greater concentrations of contaminants of concern that may affect the groundwater adversely. Therefore, pretreatment of the stormwater before infiltration may be necessary, or treatment media can be used in a biofilter, or as a soil amendment, to hinder the migration of the stormwater contaminants of concern to the groundwater. Again, these concerns are usually more of a problem in industrial and commercial areas than in residential areas.

Pitt, et al. (2010) summarized prior research on potential groundwater contamination. Table 4-10 can be used for initial estimates of contamination potential of stormwater affecting groundwaters. This table includes likely worst case mobility conditions using sandy soils having low organic content. If the soil was clayey and/or had a high organic content, then most of the organic compounds would be less mobile than shown. The abundance and filterable fraction information is generally applicable for warm weather stormwater runoff at residential and commercial area outfalls. The concentrations and detection frequencies would likely be greater for critical source areas (especially vehicle service areas) and critical land uses (especially manufacturing industrial areas), with greater groundwater contamination potential.

Table 4-10. Groundwater Contamination Potential for Stormwater Pollutants Post-Treatment.

Compound Class	Compounds	Surface Infiltration and No Pretreatment*	Surface Infiltration with Sedimentation*	Subsurface Injection with Minimal Pretreatment
Nutrients	Nitrates	Low/moderate	Low/moderate	Low/moderate
Pesticides	2,4-D	Low	Low	Low
	γ-BHC (lindane)	Moderate	Low	Moderate
	Atrazine	Low	Low	Low
	Chlordane	Moderate	Low	Moderate
	Diazinon	Low	Low	Low
Other organics	VOCs	Low	Low	Low
	1,3-dichlorobenzene	Low	Low	High
	Benzo(a) anthracene	Moderate	Low	Moderate
	Bis (2-ethyl-hexyl) phthalate	Moderate	Low	Moderate
	Fluoranthene	Moderate	Moderate	High
	Naphthalene	Low	Low	Low
	Phenanthrene	Moderate	Low	Moderate
	Pyrene	Moderate	Moderate	High
Pathogens	Enteroviruses	High	High	High
	Shigella	Low/moderate	Low/moderate	High
	P. aeruginosa	Low/moderate	Low/moderate	High
	Protozoa	Low	Low	High
Heavy metals	Cadmium	Low	Low	Low
	Chromium	Low/moderate	Low	Moderate
	Lead	Low	Low	Moderate
	Zinc	Low	Low	High
Salts	Chloride	High	High	High

NOTE: Overall contamination potential (the combination of the subfactors of mobility, abundance, and filterable fraction) is the critical influencing factor in determining whether to use infiltration at a site. The ranking of these three subfactors in assessing contamination potential depends of the type of treatment planned, if any, prior to infiltration.

* Even for those compounds with low contamination potential from surface infiltration, the depth to the groundwater must be considered if it is shallow (1 m or less in a sandy soil). Infiltration may be appropriate in an area with a shallow groundwater table if maintenance is sufficiently frequent to replace contaminated vadose zone soils.

Modified from Pitt, et al. 1994

Therefore, groundwater contamination potential of infiltrating stormwater can be reduced by:

1) careful placement of the infiltrating devices and selection of the source waters. Most residential stormwater is not highly contaminated with the problematic contaminants, except for chlorides associated with snowmelt.

2) commercial and industrial area stormwater would likely need pretreatment of reduce the potential of groundwater contamination associated with stormwater. The use of specialized media in the biofilter, or external pre-treatment may be needed in these other areas.

4.7 Water Use Regulations and Water Law

In many arid areas, state water laws severely restrict how any runoff is used, even roof runoff to irrigate the property owner's landscaped areas. This topic is beyond the scope of this report, but obviously has significant detrimental effects on stormwater beneficial uses and water conservation. It is hoped that these water laws and regulations will be modified in areas to allow more efficient use of scarce water supplies.

4.8 Summary

This report section summarizes available regulations and guidance that may affect the beneficial uses of stormwater in an area. Most of these regulations were originally written to pertain to reuse of sanitary wastewaters and do not address stormwater as a source water. There are a few regulations, however, that were specifically prepared to regulate the beneficial uses of stormwater. All of these focus on public health issues and contain restrictive levels of bacteria, with lower allowable limits where the public access is not well controlled, and with higher allowable limits for water non-contact situations and where access can be well controlled. As will be shown in the following report section that addresses likely stormwater source water quality, these bacteria levels will be difficult to meet without further treatment. In addition, irrigation criteria may affect stormwater use for certain plants, especially if galvanized metals or copper is in contact with either the collection, storage, or distribution areas of the rain water harvesting systems. Situations where groundwater recharge is direct with injection wells, or other methods providing little treatment, may also result in adverse water quality. Also, water laws in certain (mainly arid) states severely restrict the beneficial uses of stormwater, even on the property owner's own land. A discussion of these water laws is beyond the scope of this report, but they certainly need to be reviewed in the planning stages of any planned beneficial stormwater use project.

CHAPTER 5.0

STORMWATER QUALITY AND SUITABILITY FOR BENEFICIAL USES

5.1 Introduction

Chapter 4 of the report summarized the water quality regulations and criteria pertaining to beneficial uses of stormwaters. This section compares those numeric objectives to observed stormwater quality to identify potential problems and required treatment. This report section examines stormwater quality as contained in the National Stormwater Quality Database (NSQD) (Maestre and Pitt 2007) for comparison with the water quality regulations and criteria previously presented. Different treatment options are then discussed as ways to meet the numeric water quality objectives.

5.2 Stormwater Quality and Source Area Sheetflow Quality Compared to Use Criteria

Table 5-1 shows the approximate critical values for each of the constituents from Section 4, along with the numeric averages and coefficients of variation from the National Stormwater Quality Database (NSQD) (version 3.1) (http://www.unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml). The NSQD contains data from throughout the nation obtained from many phase 1 MS4 communities. More than 8,000 stormwater events are represented in the NSQD covering the major land uses and most geographical areas of the country. This table indicates that many of the constituents would likely have most of their concentrations greater than the associated numeric criteria. Constituents where the reported NSQD average values exceed the criteria include: BOD_5, COD, TSS, turbidity, total coliforms, fecal coliforms, and *E. coli*. Additional constituents may periodically exceed the criteria, as the maximum values were high, including: pH, ammonia, nitrate plus nitrite, arsenic, cadmium, chromium, copper, iron, selenium, and zinc. The most potentially problematic constituents (where the exceedences are the greatest), include the bacteria, followed by the solids and turbidity values. The metals having the potentially greatest exceedences include cadmium and zinc.

Stormwater source area runoff data for many locations have been collected and summarized by Pitt, et al. (2005a and 2005b). These sheetflow data are compared to the numeric criteria in Tables 5-2 and 5-3. Table 5-2 shows the data from the 1980s, while Table 5-3 shows more recent data. They are general similar, except for some of the lead concentrations that were much higher during the earlier period. Generally, the roof runoff and landscaped areas have better water quality, but all areas are seen to exceed the numeric criteria for: BOD_5, COD, TSS, and fecal coliforms. Freeway data exceeded the cadmium values, while some of the paved parking and street data exceeded the copper values. As indicated for the outfall data as shown in the NSQD, the bacteria data exceed the objectives by the greatest amount, followed by the TSS. The BOD_5 and COD exceedences were not as great, but almost all samples from all areas exceeded these criteria (except for a few roof and landscaped area samples).

Therefore, roof runoff is the preferred source water for beneficial stormwater uses, but treatment, especially for bacteria, will still be necessary.

Table 5-1. Stormwater Quality Compared to Water Quality Regulations and Criteria Limits for Beneficial Uses, mg/L.

	BOD5	COD	TSS	pH	Turbidity (NTU)	total Coliform bacteria (#/100 mL)	fecal coliform bacteria (#/100 mL)	E coli bacteria (#/100 mL)	ammonia	Nitrate plus nitrite
Approx. Critical Value from Regulations and Criteria:	10	40	10	6.5 - 8.5	5	1000	400	10	1.5	50
Overall NSQD 3.1 average (COV)	14 (1.5)	77 (1.1)	137 (2.2)	7.4 (0.1)	94 (1.4)	39,000 (2.5)	48,000 (5.0)	5,000 (2.1)	0.7 (1.3)	0.9 (2.0)
Maximum observed	430	1,000	10,700	10.7	630	900,000	5,230,000	66,000	12	66

Table 5-1. Stormwater Quality Compared to Water Quality Regulations and Criteria Limits for Beneficial Uses, mg/L. (continued)

	arsenic	beryllium	cadmium	chromium	copper	iron	lead	nickel	selenium	zinc
Approx. Critical Value from Regulations and Criteria:	0.1	0.1	0.01	0.1	0.2	5	5	0.2	0.02	2
Overall NSQD 3.1 average (COV)	0.002 (1.0)	0.005 (2.5)	0.004 (4.0)	0.011 (1.5)	0.03 (2.1)	4.1 (1.3)	0.04 (2.0)	0.014 (1.2)	0.005 (1.4)	0.18 (3.3)
Maximum observed	0.3	0.06	0.33	0.22	1.4	24	1.2	0.12	0.054	23

Table 5-2. Stormwater Source Area Water Quality Compared to Regulations and Criteria Pertaining to Beneficial Uses, mg/L. (data from the 1980s) (Pitt, et al. 2005a)

	BOD_5	COD	TSS	fecal coliform bacteria (#/100 mL)	ammonia	cadmium	chromium	copper	lead	zinc
Approx. Critical Value from Regulations and Criteria:	10	40	10	400	1.5	0.01	0.1	0.2	5	2
Stormwater Sheetflow Data (1980s)										
landscaped area runoff		26	100	3,300	0.8	0.001	0.01		0.035	0.01
freeway paved land and shoulder areas		130	180	1,500		0.06	0.07		2	0.5
roofs - residential	3		20	800	0.8	0.001	0.03	0.005	0.03	0.5
roofs - commercial	7			10	1.1		0.002	0.1	0.03	0.25
roofs - industrial			4	1600	0.4	0.002	0.03	0.001	0.02	0.07
paved parking - residential	22		200	100,000	0.2	0.001	0.05	0.06	0.5	0.4
paved parking - commercial	8		300	10,000	0.6	0.003	0.02		0.5	0.3
paved parking/storage - industrial			300	9,000	0.3	0.002	0.03	0.3	0.25	0.5
driveways - residential			440	600	0.05	0.005	0.03	0.2	1.4	1
streets - residential	13		240	5,000	0.2	0.002	0.03	0.035	0.5	0.16
streets - commercial			240		0.05	0.002	0.03	0.04	0.18	0.18
streets - industrial			1300	100,000	0.05	0.002	0.03	0.2	0.56	0.9

Table 5-3. Stormwater Source Area Water Quality Compared to Regulations and Criteria Pertaining to Beneficial Uses, mg/L. (Data from the 2000s) (Pitt, et al. 2005b)

	BOD_5	COD	TSS	Nitrate plus nitrite	cadmium	chromium	copper	lead	zinc
Approx. Critical Value from Regulations and Criteria:	10	40	10	50	0.01	0.1	0.2	5	2
Stormwater Sheetflow Data (2000s)									
roofs - residential	20	78	30	0.5	0.001		0.03	0.04	0.19
roofs - commercial	25	170	32	0.8	0.001		0.02	0.06	0.32
roofs - industrial		23	12		0.001		0.01	0.01	0.32
paved parking - commercial	11	77	150	0.4	0.001	0.01	0.03	0.05	0.29
paved parking - industrial	18	120	300	0.4	0.002	0.01	0.03	0.05	0.23
driveways	16	150	150	0.5	0.001	0.002	0.04	0.06	0.16
landscaped areas	25	170	230	0.5	0.001	0.02	0.01	0.05	0.07
streets - commercial	14	88	175	0.5	0.001	0.02	0.03	0.04	0.3
streets - residential	7	46	180	0.4	0.001	0.006	0.02	0.02	0.15
streets - industrial			890		0.001	0.02	0.02	0.09	0.59
freeways			140	0.8	0.001		0.06	0.03	0.23
undeveloped areas	7	87	16	0.03			0.005	0.001	

5.3 Degradation of Water Quality due to Material Use

Different materials are used in the collection, drainage, and storage components of stormwater beneficial use systems. Some materials can degrade runoff water even with very short contact times, and would be a problem even if used for the collection surface. Other materials, however, require extended exposure periods to degrade the water, such as would be evident in storage tanks. The following is a summary of potential pollutant releases associated with different materials that may be used as components from a rainwater harvesting system.

5.3.1 Potential Materials and Alternatives Available for Stormwater Pollution Prevention

Based on the results of many source area monitoring activities, candidate urban surfaces having potential for pollution reductions through the appropriate selection of alternative materials include roofing and paving materials. Building siding is also of concern as it is also exposed to rain and may cause some of the same problems currently found for roofing. The use of treated wood is also a concern. The following list shows typical components used for roofs and pavement surfaces:

For Roofing Materials:

concrete (roofing tiles)
glass (sky lights)
clay (roofing tiles)
tar (flat roofing material)
gravel (flat roofing material)
asphalt/asbestos (roofing shingles)
wood (roofing shingles and shakes)
zinc (flashing and roofing panels)
copper (flashing, gutter and roofing panels)
aluminum (flashing, gutter, and drain material)
galvanized metal (flashing, gutter, and drain material)
plastic/rubber (membrane roofing)
roofing felt (under shingles)
roofing nails
plastic glue/mastic (patching compound)
PVC plastic (gutter and drain material)

For Paved Surfaces:

Asphaltic cement flexible pavement
Portland cement rigid pavement

5.3.2 Roofing and Paving Materials

Boller (1997) concluded that runoff from roofs and streets contribute 50-80% of cadmium, copper, lead and zinc to Swiss combined sewer systems. Roof runoff samples, from tile, polyester, and flat gravel roofs, were analyzed and metal concentrations were found to vary tremendously with roof type. First flush analyses showed polyester roofs contributing highest concentrations of copper (6,817µg/L), zinc (2,076 µg/L), cadmium (3.1 µg/L) and lead (510 µg/L). Concentrations in runoff from tile roofs were copper (1,905 µg/L), zinc (360 µg/L), cadmium (2.1 µg/L) and lead (172 µg/L). Runoff from flat gravel roofs also contributed copper

(140 μg/L), zinc (36 μg/L), cadmium (0.2 μg/L) and lead (22 μg/L). Runoff from roofs was found to contain not only heavy metals, but polycyclic aromatic hydrocarbons (PAHs) and organic halogens as well.

Mottier and Boller (1996), working in Zurich, measured metal concentrations in road runoff and found average values of 300 μg/L for lead, 4 μg/L for cadmium, 150 μg/L for copper and 500 μg/L for zinc. Information on pavement material type was not included. Averaged roof runoff concentrations (from tile and polyester roofs) were also measured at 16 μg/L for lead, 0.17 μg/L for cadmium, 225 μg/L for copper and 42 μg/L for zinc. Boller concluded that copper installations on buildings seem to represent the largest source for this metal into the environment. Stark, et al. (1995) arrived at a similar conclusion, estimating that stormwater from roofs may be responsible for more the 60% of the copper in Austria's combined sewers.

Researchers in Marquette, Michigan, collecting wet weather flow concurrently at 33 sites during 12 storms detected discernible differences in runoff quality between a variety of impervious source areas. Commercial and residential rooftops were found to produce the lowest concentration of suspended solids, but the highest concentration of dissolved metals such as lead, zinc, cadmium, and copper. Parking lots produced the highest concentrations for all PAH compounds and high concentrations of zinc, total cadmium and total copper. Low traffic streets were also identified as a major producer of total cadmium (Steuer, et al. 1997).

Forster (1996) sampled and analyzed roof runoff for heavy metals (Cd, Cu, Zn, Pb). Measurements were made with an experimental roof system situated on the Campus of the University of Bayreuth and at various locations in the urban area of Bayreuth, Northern Bavaria. The experimental roof systems allowed the influence of different roof materials (concrete tiles, zinc sheet, pantiles, fibrous cement) on runoff quality to be compared. Large differences in runoff pollutant concentrations from various roofs were interpreted to indicate that the pollutants were not only being transported to the surface via the atmosphere, but also originating from the material itself. Extremely high values of zinc and copper were measured when the roof system, or parts of it, were made of metal panels, flashing and gutters. For example, runoff concentrations from zinc sheet roofing started almost three orders of magnitude higher and remained more than twenty times above the values measured for the roofs affected only by atmospheric deposition. Forster concluded by advocating abandoning the use of exposed metal surfaces on roofs and walls of buildings.

Good (1993) reported the results of sampling of runoff from a rusty galvanized metal roof, a weathered metal roof, a built-up roof of plywood covered with roofing paper and tar, a flat tar-covered roof which had been painted with a fibrous reflective aluminum paint, and a relatively new anodized aluminum material at a sawmill facility on the coast of Washington . The research was carried out following the discovery that stormwater samples from the site were acutely toxic and contained high concentrations of zinc. Built-up roofing contributed the highest concentrations of dissolved copper (128 μg/L) and total copper (166 μg/L), approximately 10 times higher than levels detected in runoff from the other roofs sampled. Runoff from the rusty galvanized metal roof contained the highest concentrations of dissolved lead (35 μg/L) and total lead (302 μg/L), dissolved zinc (11,900 μg/L) and total zinc (12,200 μg/L). High concentrations of zinc were noted in runoff from each type of roof sampled at the site. Dissolved metals concentrations and toxicity remained high in roof runoff samples collected three hours after the beginning of the storm event, indicating metals leaching continued throughout storm events.

Gumbs and Dierberg (1985) also cited the corrosion of galvanized roofs in a coastal environment as a source of heavy metal pollution. Yaziz, et al. (1989) analyzed the zinc content of roof runoff during rainfall events in Malaysia and observed continued elevated zinc levels in roof runoff after the first flush, indicating that zinc was leaching from the galvanized roof surface during the storm.

5.3.3 Leaching of Various Construction Materials

Pitt, et al. (2000) tested the leaching potentials for many materials that may be used in bench-scale and pilot-scale treatment units, and some of these materials are likely exposed to stormwater during typical construction applications. Samples of each material were immersed for a period of 72 h in approximately 500 mL of laboratory grade 18 megohm water. A sample blank was also prepared. Analyses conducted on each of these samples, and the sample blank, were the same as performed for the pilot-scale treatment devices. Tables 5-4 and 5-5 present the contaminants that were found in the leaching water at the end of the test in high concentrations that may affect the test results. The most serious problems occur with plywood, including both treated and untreated wood. Attempting to seal the wood with Formica and caulking was partially successful, but toxicants were still leached. Covering of the Formica clad plywood with polyethylene plastic sheeting was finally used to eliminate any potential problem, for example. Fiberglass screening material, especially before cleaning, also causes a potential problem with plasticizers and other organics. PVC and aluminum may be acceptable materials, if phthalate esters and aluminum contamination can be tolerated. The most serious concern is associated with the use of galvanized metals, as expected, where the tests indicated extremely high zinc concentrations, or the exposure of treated woods to stormwater (its typical application).

Table 5-4. Potential Sample Contamination from Construction Materials. (Pitt, et al. 2000)

Material:	Contaminant observed:
untreated plywood	toxicity, chloride, sulfate, sodium, potassium, calcium, 2,4-dimethylphenol, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol, N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol, 2,4-dinitrotoluene, 4-nitrophenol, alpha BHC, gamma BHC, 4,4'-DDE, endosulfan II, methoxychlor, and endrin ketone
treated plywood (CCA)	toxicity, chloride, sulfate, sodium, potassium, hexachloroethane, 2,4-dimethylphenol, bis(2-chloroethoxyl) methane, 2,4-dichlorophenol, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol, 4-chloro-3-methylphenol, acenaphthene, 2,4-dinitrotoluene, 4-nitrophenol, alpha BHC, gamma BHC, beta BHC, 4,4'-DDE, 4,4'-DDD, endosulfan II, endosulfan sulfate, methoxychlor, endrin ketone, and copper (likely), chromium (likely), arsenic (likely)
treated plywood (CCA) and Formica	toxicity, chloride, sulfate, sodium, potassium, bis(2-chloroethyl) ether*, diethylphthalate, phenanthrene, anthracene, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol*, N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol*, 4-nitrophenol, pentachlorophenol, alpha BHC, 4,4'-DDE, endosulfan II, methoxychlor, endrin ketone, and copper (likely), chromium (likely), arsenic (likely)
treated plywood (CCA), Formica and silica caulk	lowered pH, toxicity, bis(2-chloroethyl) ether*, hexachlorocyclopentadiene, diethylphthalate, bis(2-ethylhexyl) phthalate, phenol*, N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol*, alpha BHC, heptachlor epoxide, 4,4'-DDE, endosulfan II, and copper (likely), chromium (likely), arsenic (likely)
Formica and silica caulk	lowered pH, toxicity, 4-chloro-3-methylphenol, aldrin, and endosulfan 1
silica caulk	lowered pH, toxicity, and heptachlor epoxide
PVC pipe	N-nitrosodiphenylamine, and 2,4-dinitrotoluene
PVC pipe with cemented joint	bis(2-ethylhexyl) phthalate*, acenaphthene, and endosulfan sulfate
plexiglass and plexiglass cement	naphthalene, benzylbutyl phthalate, and bis(2-ethylhexyl) phthalate, and endosulfan II
aluminum	toxicity, and aluminum (likely)
plastic aeration balls	2,6-dinitrotoluene
filter fabric material	acenaphthylene, diethylphthalate, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, and pentachlorophenol
sorbent pillows	diethylphthalate, and bis(2-ethylhexyl) phthalate
black plastic fittings	pentachlorophenol
reinforced PVC tubing	diethylphthalate, and benzylbutyl phthalate
fiberglass window screening	toxicity, dimethylphthalate, diethylphthalate*, bis(2-ethylhexyl) phthalate, di-n-octyl phthalate, phenol, 4-nitrophenol, pentachlorophenol, and 4,4'-DDD
Delrin™	benzylbutyl phthalate
Teflon™	nothing (likely)
glass	zinc (likely)

note: ***** signifies that the observed concentrations in the leaching solution were very large compared to the other materials.

Table 5-5. Analyses of Washoff from Various Construction Materials. (short-term exposures)

Sample	Copper (µg/L)	Cadmium (µg/L)	Lead (µg/L)	Zinc (µg/L)	Iron (µg/L)	Chromium (µg/L)	Magnesium (µg/L)	Calcium (µg/L)
silica caulk	29	<lod[1]	<lod	14	48	8	<lod	0.08
formica and silica caulk	54	<lod	<lod	26	110	8	<lod	0.38
metal roof runoff	41	<lod	32	10,200	440	11	0.13	1.2
treated plywood	1,300	<lod	33	93	110	2,800	0.02	0.67
untreated plywood	79	<lod	<lod	67	310	12	1.3	3.2
washed PVC and PVC cement	36	<lod	<lod	32	83	8	<lod	0.60
washed geotextile filter fabric	44	<lod	<lod	32	110	16	0.05	1.2
washed fiberglass window screen	32	17	<lod	88	47	8	<lod	0.10

[1] <lod: less than the limit of detection.

Clark, et al. (2005 and 2008) reported on a series of laboratory and pilot-scale tests examining water contaminating potential of commonly used building materials at Penn State Harrisburg (PSH). The project focused on roofing and subbase materials that are commonly used in the construction industry. The field testing evaluated the following materials:

- Plexiglass (as a control to quantify and background subtract atmospheric deposition)
- Plytanium plywood (untreated and pressure-treated [CCA])
- Severe-weather pressure treated/water sealed planks
- Cedar shakes
- Roofing felt/tar paper – 30 lb. (United Roofing Mfg.)
- Asphalt fiberglass shingles (Supreme Owens Corning)
- Rubberized roofing material (similar to the layer on a built-up roof)
- Galvanized aluminum, corrugated
- Galvanized steel (Galvalume$^{\circledR}$) – coated
- Asphalt panel (Ondura$^{\circledR}$), corrugated
- Corrugated polyvinyl chloride panel

The woods typically had higher concentrations than the metal-based or vinyl-type roofing for the monitored nutrients and heavy metals. The metal, rubber, and vinyl concentrations were closer to background levels with periodic spikes in the runoff. Similar trends were seen for ammonia, total nitrogen, and total phosphorus. In general, the highest concentrations of these nutrients were found in the runoff from the wood products, and in the case of the nitrate, the untreated wood. This is not unsurprising since the untreated wood was the first wood product to show visible degradation (a split in the wood), exposing the underlayers to the rain.

Preliminary results showed that copper releases were substantially higher than expected for many materials Rubberized roofing had the highest Cu concentration of the metal, rubber, and vinyl materials, < 70 µg/L at day 50. The remaining materials from this group showed concentrations near background levels and less than 20 µg/L. Runoff concentrations of copper for asphalt shingles and the two treated wood panels exceeded 500 µg/L during the first two weeks of exposure (with multiple storms during that period to wash off any remaining surface coating). Both pressure treated wood and waterproofed wood showed cause for concern well past the first month post-installation. These samples were above the limits of the instrumentation after dilution (above 5 mg/L). Only after 270 days post-installation did the copper concentrations from these woods approach the analytical range of the instrumentation. These results indicated that copper continues to be released from these wood products.

The laboratory leaching results (Table 5-6) showed that galvanized metal roofing contributed the greatest concentrations of many of the pollutants of interest – conductivity, cations, metals, and nutrients. In addition, the metals' analysis showed that the pressure treated and waterproofed wood contributed substantial metals' loads. The potential for nutrient release exists in many of these materials, such as from the galvanized metal (likely as a result of phosphate washes and binders used in the material's preparation) and wood products due to natural degradation. Tests conducted in the laboratory on the aged roofing panels indicated that this pollutant release may occur for an extended period of time. The field testing has documented low-level, long-term releases of many pollutants from these materials.

Table 5-6. Laboratory Leaching of Building Materials.[1] (Clark, et al. 2008)

MATERIAL	PO_4 (mg/kg)	NO_3 (mg/kg)	NH_3-N (mg/kg)	COD (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Fe (mg/kg)
Asphalt/Tar Shingles	29.4 (0.5)	1.52 (0.4)	0.83 (0.8)	2698 (0.4)	0.66 (1.1)	0.34 (0.5)	1.22 (0.3)	46.7 (0.2)
Roofing Felt	44.6 (0.245)	4.2 (1.7)	108 (0.9)	26367 (0.9)	0.026 (2.4)	0.11 (0.2)	0 (0.05)	1.87 (0.4)
Ondura®Red Vinyl Roofing	0 (na[2])	2.44 (2.4)	1.44 (0.4)	13161 (0.6)	0 (na)	0 (na)	0 (na)	0 (na)
Fiberglass Roofing	0.86 (1.7)	0 (na)	0 (na)	0 (0.9)	0.017 (2.0)	0.005 (4.2)	0.53 (0.9)	0 (na)
White Plastic Roofing	0 (na)	0.99 (1.7)	0 (na)	6842 (0.5)	0.076 (0.4)	0 (na)	1.42 (0.1)	2 (0.7)
Cedar Roofing Shingles	1.23 (1.0)	0 (na)	0 (0.7)	18852 (0.6)	0.033 (1.1)	0.11 (0.4)	0.64 (1.2)	1.64 (0.3)
Galvanized Metal Roofing	53.8 (1.2)	58.4 (0.3)	12.1 (0.2)	20471 (0.1)	0.44 (0.5)	0.16 (1.2)	16500 (0.03)	9400 (0.4)
Galvanized Metal Roofing (replicate)	30.8 (1.5)	na (na)	1.14 (0.7)	0 (0.3)	0 (0.09)	1.61 (0.3)	11900 (0.01)	3300 (0.4)
Waterproofed Wood	0 (na)	9.12 (0.2)	0 (na)	0 (0.5)	161 (0.2)	0.29 (0.3)	3.72 (0.8)	3.22 (3.1)
Pressure Treated Wood	62.2 (0.06)	6.47 (0.2)	0.38 (0.8)	53002 (0.2)	191 (0.05)	0 (na)	1.35 (0.02)	2.69 (0.5)
Fake Slate Roofing Shingle	0.07 (1.7)	2.71 (0.4)	0 (na)	0 (0.3)	0.2 (0.1)	0.42 (0.07)	1.81 (0.3)	20.1 (1.1)
Leak Stopper™ Rubberized Roof Patch	0.05 (1.7)	9.43 (0.5)	0 (na)	726 (15.4)	0.13 (0.5)	3.78 (0.8)	2.61 (0.9)	2.25 (1.0)
Kool Seal™ Acrylic Patching Cement	21.6 (1.7)	0 (na)	0 (na)	2297 (1.2)	0.15 (1.4)	0.65 (0.9)	2.94 (1.5)	229 (0.9)
Gardner Wet-R-Dri™ Roofing Patch	203 (0.6)	0 (na)	0 (na)	0 (2.7)	0 (11.1)	0.094 (1.3)	0 (na)	1.39 (5.1)
Silver Dollar Aluminum Roof Coating	0 (na)	na (na)	na (na)	21520 (1.1)	1.14 (1.0)	0.3 (6.1)	0 (na)	151 (0.5)

[1] Table value equals average concentration (coefficient of variation [std. dev./avg.] in parenthesis).

[2] na = not available. Coefficient of variation cannot be calculated because none of the triplicate samples was indistinguishable from the background (material contribution was zero).

5.3.4 Leaching of Heavy Metals under Varying pH and Exposure Conditions

Ogburn and Pitt (2011) reported how different pipe, gutter, and storage tank materials affect water quality through a series of controlled laboratory experiments. The tests were conducted for a period of up to three months by immersing test materials in large quantities of pH buffer solutions made using locally collected roof runoff. The tests were conducted at pH 5 and pH 8. Water samples were periodically collected and then analyzed for a broad range of nutrients and heavy metals. The gutter materials that were tested included vinyl, aluminum, copper, and galvanized steel. The pipe materials tested were concrete, PVC, HDPE, and galvanized steel. Materials that are also commonly used in water tank construction included: aluminum, galvanized steel, concrete, PVC, and HDPE. All of the test materials were obtained as new specimens for these tests.

The samples were analyzed at 0 time (water with adjusted pH without the materials), 0.5 hour, 1 hour, 27 hours, 1 month, 2 months, and 3 months for the total metal concentrations of cadmium, chromium, lead, copper, zinc, aluminum, iron, as well as for the filterable metal concentrations of lead, copper, zinc, and aluminum, and Microtox toxicity, COD, and nitrogen compounds. The total cadmium and chromium concentrations were always below the detection limits.

5.3.4.1 Lead

As shown in Figure 5-1, during short exposure times, lead was not detected for any of galvanized steel samples at pH 5, but was detected for the galvanized steel gutter sample at pH 8 (a lead concentration of 8 µg/L after 27 hrs of exposure was observed). The steel pipe and gutter samples exposed at pH 5 had lead released at 1 month of exposure, while lead was detected after two months for the steel pipe sample exposed at pH 8.

The highest lead concentrations were found from the steel pipe sample at pH 8 which reached lead concentrations of 600 to700 µg/L after extended exposure periods (25-30 mg per surface pipe area). Aluminum, copper, and plastic materials did not have any detected lead releases.

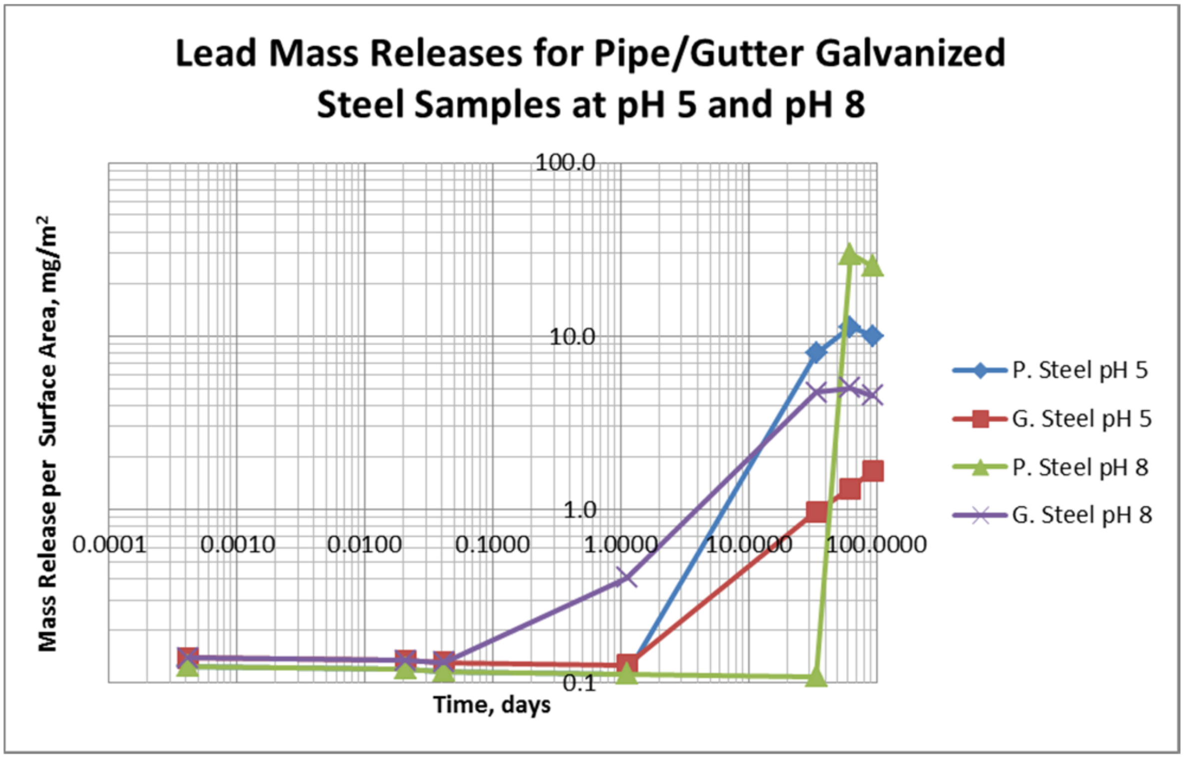


Figure 5-1. Releases of Lead from Pipe and Gutter Materials. (Ogburn and Pitt 2011)

5.3.4.2 Copper

During short-term exposure periods, copper was detected only for the copper gutters samples (at both low and high pH conditions. Copper releases from most of the other materials were observed after one or two months of exposure (Figure 5-2). Copper materials resulted in very high levels of copper concentrations (1 to more than 6 mg/L) (up to 960 mg/m^2 of copper released) during the first day of exposure. Greater and faster leaching occurred at lower pH conditions. As an example, long-term exposures (after one month) of the copper gutters resulted in copper concentrations at pH 5 that were greater than 5 mg/L (650 mg/m^2), in comparison with 2 mg/L (270 mg/m^2) values for the pH 8 exposures. The highest copper concentrations (6.8 mg/L equivalent to 970 mg/m^2) were reached after 27 hours of exposure before they started to level off. Some of the aluminum, galvanized steel, and plastic materials also showed leaching of copper, but with much lower resultant concentrations. Aluminum, PVC, and vinyl materials had the highest copper release (besides the copper materials) on the order of 5 mg/m^2 after the long time exposures. Steel pipes and gutters had copper releases at pH 8, but at pH 5, the copper release was detected for steel pipes only at one month of exposure. The lowest releases of copper were for HDPE and galvanized steel materials.

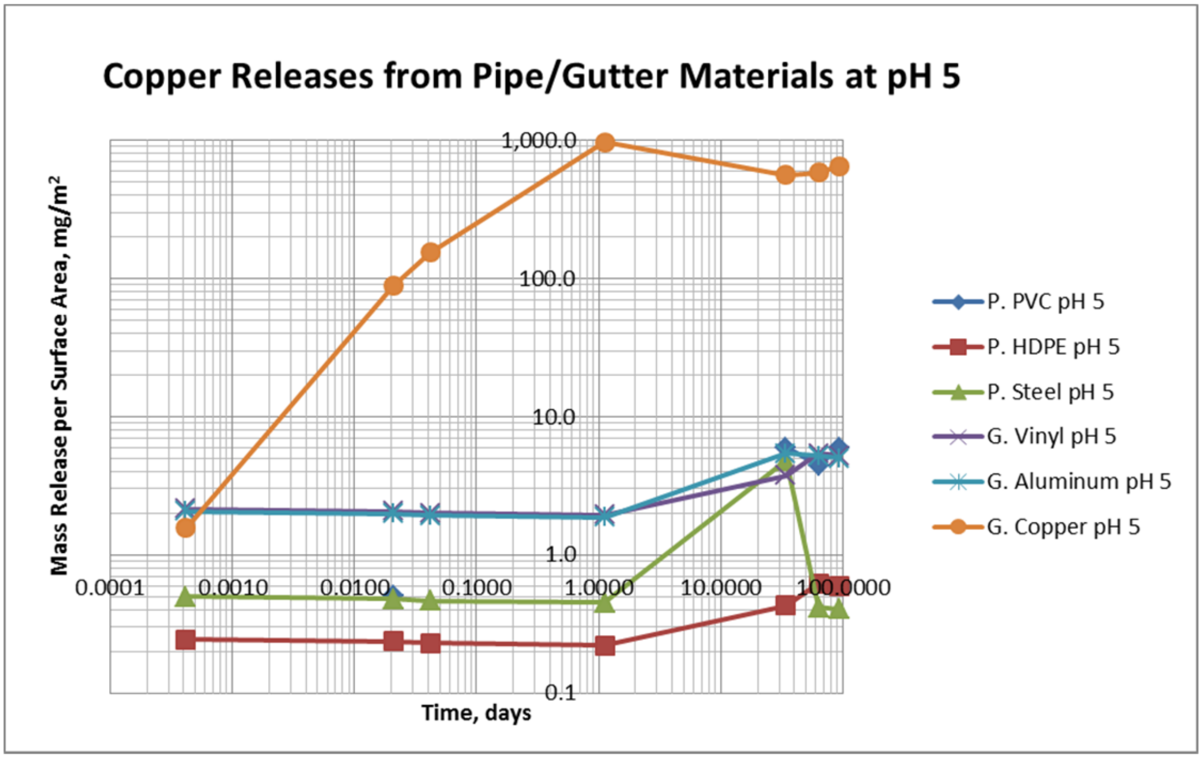


Figure 5-2. Releases of Copper from Pipe and Gutter Materials. (Ogburn and Pitt 2011)

5.3.4.3 Zinc

During short-term exposures, zinc was detected for the galvanized steel pipe and gutter samples at both low and high pHs, as well as for vinyl and aluminum gutter samples at pH 8, and for the copper and HDPE gutter samples at pH 5. Zinc releases for the other materials were observed after one or two months of exposure (Figure 5-3). The galvanized steel materials had very high levels of zinc concentrations (1 to more than 14 mg/L) during the first day of exposure, with greater and faster leaching occurring for the lower pH conditions. Long-term exposures (after one month) of galvanized metals resulted in zinc concentrations for pH 8 that were greater than 90 mg/L, in comparison with 14 mg/L values for the pH 5 tests. Copper pipes had the second highest zinc releases with higher concentrations at pH 5 (exceeding 0.13 mg/L; 17 mg/m^2). Some of the plastic materials also had zinc losses, but at much lower resultant concentrations. The lowest source zinc releases were for HDPE pipes at pH 8.

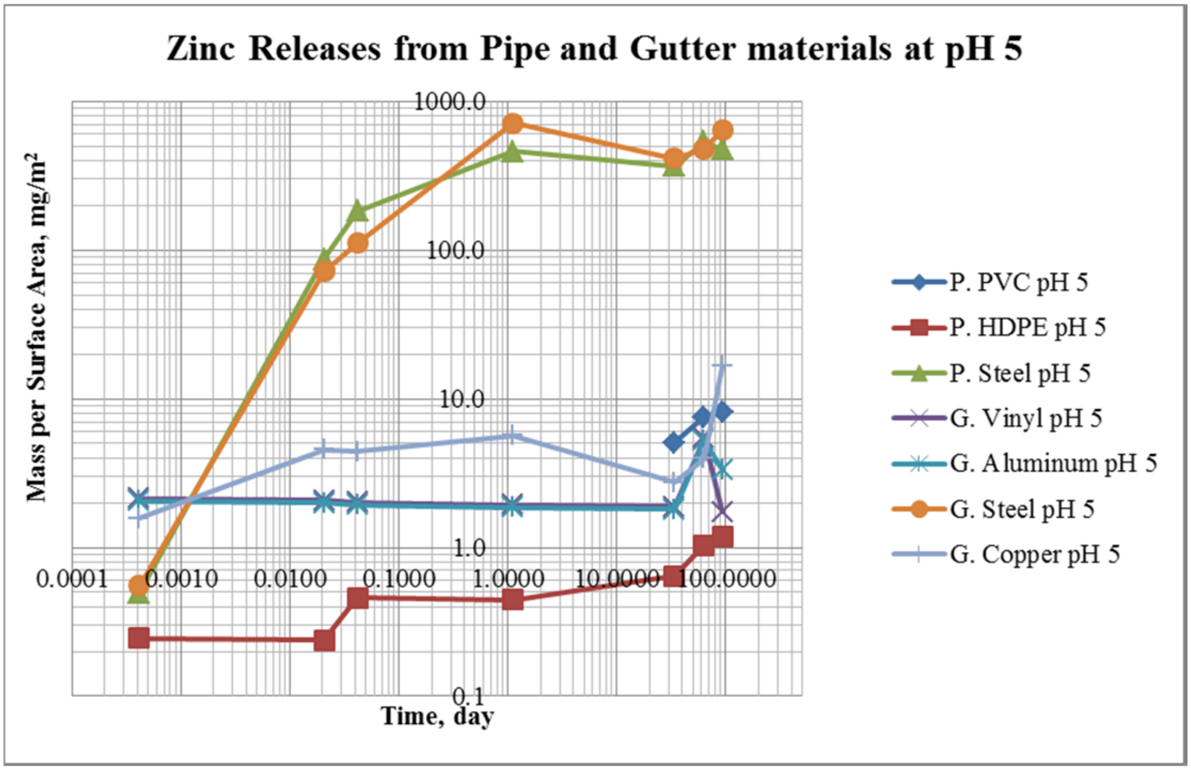


Figure 5-3. Releases of Zinc from Pipe and Gutter Materials. (Ogburn and Pitt 2011)

5.4 Treatment Methods to Enhance Stormwater Quality for Beneficial Uses

5.4.1 Selection and Design of Treatment Systems

This section will focus on the more common processes found in stormwater reuse systems. This discussion will focus on sedimentation (also occurs in water storage tanks), filtration (both physical and chemical since they often occur jointly in the same media), and, briefly since this report does not focus on potable reuse, disinfection.

5.4.1.1 Sedimentation Design

Because many pollutants are either substantially or somewhat associated with the particulate matter in runoff, sedimentation also provides removal of particulate-bound pollutants in addition to settleable solids. Sedimentation can also be used as a pretreatment process to prevent damage and increase the operating life of other treatment systems, such as filters and disinfection units. Sedimentation occurs in specially designed sedimentation facilities optimized for the control of these particulate solids, and also secondarily in water storage tanks.

Sedimentation may be required as a pretreatment step in the treatment of stormwater runoff for beneficial reuse, depending on the surface from which the runoff is collected. The smallest particle for which 100% sedimentation will occur, assuming discrete particle settling, can be calculated by setting the surface overflow rate (the ratio of the outlet discharge rate to the surface rate, or SOR) equal to the settling velocity of the critical particle size ($V_{particle}$), with the diameter calculated from Stoke's Law (assuming laminar flow which is suitable for most small particles of interest). Particles whose settling velocities are less than the SOR will not completely settle out before the water exits the device. For enhanced sedimentation using coagulation/flocculation, testing will be required since floc settling cannot be predicted theoretically.

For stormwater reuse systems using large cisterns or water storage tanks, sedimentation should be encouraged, especially if the water is not further treated. Therefore, the spigot or other connection to the tank to remove water for use should not be placed at the bottom of the tank, but instead should be about a foot above the bottom of the tank to prevent the withdrawal of sediment with the water. Periodically the tank should be drained and the captured solids removed. Cisterns also should be deep enough, or protected, so that the entering water does not scour previously captured sediment from the bottom. For pressurized uses, pumping may be required (unless the tank is elevated). The pumps should also not be placed on the bottom of the tank and should not draw water from the bottom of the tank. The captured solids likely will eventually abrade the pump components, which could result in the need for more frequent maintenance, besides discharging captured sediment with the water.

Bacteria reductions also occur when stormwater is stored in detention ponds, or in cisterns/water tanks. A method used to predict the "dieoff" of bacteria is Chick's law which can be used to predict the dieoff of bacteria (Chick, 1908). It is usually expressed as:

percent of bacteria remaining = e^{-Ket}

therefore, the fraction of bacteria removed (in time t) = 1 - e^{-Ket}

where K_e is the dieoff rate (units per day) and t is the time (days). K_e is 2.3 times larger than the commonly reported K_{10} values. Since detention ponds (or water storage tanks) can hold stormwater for a substantial period of time, significant bacteria reductions may be due because of natural dieoff. The average detention time of a storage tank is determined by dividing the tank volume by the average withdrawal rate. It is likely that observed "dieoff" is partly associated with particulate-bound bacteria settling with the larger particulates. These sediment-bound bacteria can be relatively easily re-suspended with scour. In addition, under certain conditions, bacteria regrowth may occur. Therefore, scour in storage tanks needs to be prevented and dark tanks, which seem to hinder regrowth, should be used. Fecal coliform bacteria dieoff rates (K_e) of about 2.3 per day are reasonable for stormwater, based on field investigations.

Figure 5-4 indicates the percentage dieoff of bacteria, based on differing K_e rate constants and detention times. This figure indicates that fecal coliform dieoff should be quite complete (99% dieoff) after about two days of detention (assuming a typical K_e value of 2.3/day). However, very high bacteria removals are seldom observed in stormwater detention ponds, possibly due to scour or regrowth, or continued dry weather contamination. A current project in Milburn, NJ, being conducted for the U.S. EPA includes monitoring of bacteria levels within a large underground plastic storage tank used to store stormwater for later irrigation. Typical bacteria levels in this tank are in the range of 10 to 100 *E. coli*/100 mL, mostly being in a suitable range for irrigation use. This is much lower than typical *E. coli* levels found in most stormwater (about 5,000 counts/100 mL), so 99% reductions may not be unreasonable to expect with just simple long-term storage in cisterns/water tanks.

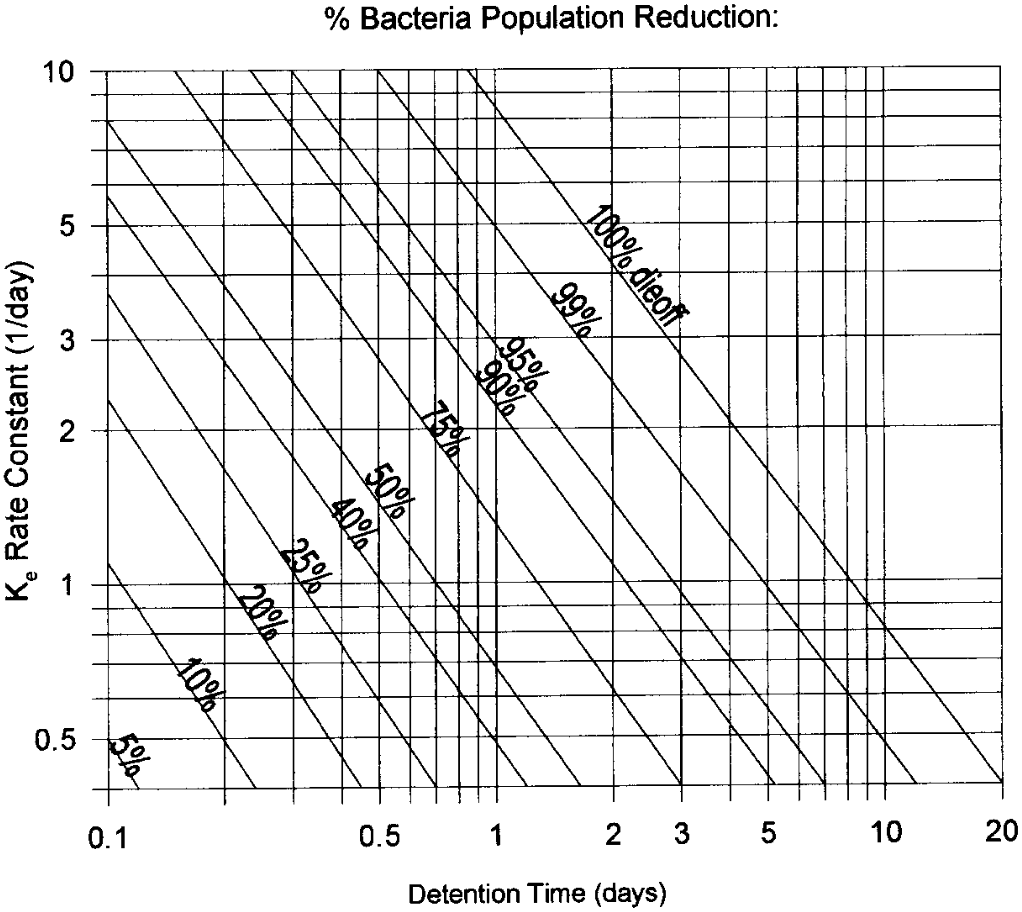


Figure 5-4. Chick's Law for Bacterial Die Off. (DETPOND documentation)

5.4.1.2 Physical and Chemical Removal using Filters

Filtration and sorption/ion-exchange are combined in a single design discussion since these treatment technologies usually occur simultaneously. The first step in the selecting of an appropriate filter medium is to determine what pollutants require removal. Solids removal, assuming the size of the solids is greater than colloids/clays, can be accomplished using sand filters. Sand is considered relatively inert compared to many media. Sand removal efficiencies increase as the media size decreases, and as the media/filter ages because the trapping of particles typically decreases the pore opening sizes, especially on the surface, allowing smaller particles to be captured. In addition, bacterial capture enhances removal because of the organic compounds that many bacteria excrete. These polymers improve the capture efficiency of many other pollutants, including organics.

For many organic and organo-metallic pollutants, media filters such as those containing activated carbon are considered the most efficient. This assumes that the organics are dissolved or emulsified in the water. Free-floating oils may need to be separated from the water based on density differences, such as by using an oil-water separator. Once any free organic that can be separated by density differences has been removed, many organic pollutants have dipole moments that can be exploited using the available weak bonding sites available on carbon, resulting in these substances being retarded/retained in the carbon column. Ion-exchange resins are very effective for metals that exist as free ions, i.e., do not participate substantially in complexation reactions, in water. Past research (Pitt and Clark, 2010) has shown that zeolites can be effective for the removal of the fraction of copper in solution that exists as Cu^{2+}. However, the overall effectiveness of the zeolites was reduced because much of the copper likely existed in valence forms other than the favored +2. The effectiveness of ion exchange decreases as the valence charge approaches zero. The other limitation of ion exchange resins is that they are advertised as being specific for anions and cations. Many natural zeolites typically can exchange both anions and cations, but preferentially remove one due to the preponderance of exchange sites for either anions or cations; synthetic resins may be tailored to the removal of specific ion types and sizes. The ability of any media to remove anions or cations through ion exchange is called the anion or cation exchange capacity (AEC or CEC, respectively). The media (either carbon or an ion-exchanger) is regenerated before a substantial amount of the pollutant escapes the column.

The capacity of adsorbing/ion-exchange media can be determined using batch isotherm testing with the resultant data fit to a model. Two specific models of pollutant capacity are the Langmuir and Freundlich isotherms. These isotherms are commonly used by the hazardous waste industry. The lifetime of the filter media then is predicted using an equation such as the Bed-Depth-Service-Time (BDST) model. The challenge of applying laboratory testing to stormwater is the chemical complexity of the runoff water. As noted above, rarely do these pollutants exist in runoff as pure compounds, and they occur in mixtures with many competing major ions and other metals. Metals may be complexed with anions or attached to solids. Organics may be attached to solids. In addition, none of these compounds exist in isolation in solution. The interaction and competition of these pollutants in the water for reaction sites on the media make the use of traditional models for sorption and ion-exchange problematic. In addition, the low concentrations of many of these pollutants reduces the driving force for removal (these reactions are reversible in many media) and reduces the likelihood of a successful interaction between the media and the pollutant since there are few pollutant molecules in the water.

Therefore, the selection of an appropriate media requires a determination of the pollutants to be removed. For example, for uncoated galvanized roof runoff containing large amounts of zinc (Clark et al., 2008), much of which passes through a 0.45-µm filter; treatment will require media filters with an active surface and/or a size-exclusion filter/membrane. Because zinc is an ion, the use of an ion-exchange resin (or suitable organic amendment) may be appropriate, assuming that zinc is primarily in the form of Zn^{2+}. The limitation of ion-exchange resins is that zinc forms complexes with anions commonly found in stormwater runoff, especially hydroxides and chlorides. These complexes change both the zinc's valence state and likely increase the molecular size. The changes in valence charge to ones closer to zero or negative reduce the likelihood that the exchange with the lattice-trapped ion is favorable. Increases in molecular size reduce the likelihood that the lattice-structure opening is large enough to accommodate the complex.

One anion of particular concern in stormwater runoff is chloride, especially during snowmelt periods in areas where salts are used for ice control. Chloride is very difficult to remove from stormwater runoff since it primarily exists as a free ion or in complexes with metals. Most media, including activated carbon and zeolites, have limited capacity to remove anions with a -1 valence charge. It does not form many precipitates. Therefore, it is considered a conservative tracer in many studies. For this reason, the primary method for removing chloride from water is through reverse osmosis (or distillation, which is not cost-effective for dispersed stormwater treatment. Reverse osmosis is the principle behind the large desalination plants found in the U.S. and around the world.

5.4.1.3 Disinfection

Pathogenic species can be removed from water using filtration. Many bacteria and viruses have surface charges and/or generate exopolymers that enable their removal in media filters through both physical straining and chemical interaction with the media. Cyst species typically are larger and can be more readily removed by these physical means. Filtration, however, does not permanently destroy pathogens. Reducing/removing the activity of pathogenic species requires disinfection. Three common means of disinfecting are the application of chlorine, ozone, or UV light. Chlorine is toxic and affects cell reactions at both the cell membrane and inside the cell, reducing or eliminating the ability of the cell to perform essential reactions. Ozone interferes with the cell membrane function also through oxidation-reduction of compounds on the membrane. Ozone also can penetrate the membrane and oxidize cell components, including DNA. UV light interacts with the DNA of the cell, rendering it incapable of reproducing.

As noted in Chapter 4 of this report, although many beneficial uses of stormwater runoff may not involve human contact, bacteria limits are still in place. Obviously, potable beneficial uses require greater levels of disinfection. Several pre-fabricated roof runoff harvesting systems either include or offer a disinfection system. Most of these systems use UV light as the disinfection technique for several reasons. First, the system requires no chemicals, a potential cost savings. In addition, the use of chlorine requires special training, given chlorine’s hazardous nature. UV light systems are designed to pass water over or around the lights, with the anticipated depth of light penetration being less than 2.5 cm. UV light efficiency decreases with increasing pollutant load in water, especially in waters having high turbidity. In turbid water, UV light cannot penetrate deeply into the water column, plus many pathogens attach to the solids and avoid contact with the ultraviolet rays. UV light efficiency also decreases if a coating develops on the light tubes because the UV light cannot penetrate the precipitate/film.

5.4.2 Off-the-Shelf Treatment Systems

Many small-scale, rapid treatment systems have been developed that could be used to treat stormwater runoff for beneficial uses. Example industries/locations where these point-of-use systems are common include the following:

- Rainwater Harvesting Treatment Systems
- Aquaculture Water Treatment Systems
- Well Water Treatment for Indoor Potable Use
- Swimming Pool Water Treatment Systems

5.4.2.1 Rainwater Harvesting Treatment Systems

Rainwater harvesting systems typically are designed to capture relatively-clean runoff from roofs. The website www.harvesth2o.com specializes in information relevant to the rainwater harvesting industry and they have a tab on their website for vendor links. This website also may contain press releases from vendors advertising new products available for rainwater harvesting. The focus of many of these systems is nonpotable reuse such as landscape irrigation.

Rainwater harvesting systems consist of piping or gutters to concentrate and collect the runoff in a cistern or water tank. Cisterns range in size from 35 gallons "rain barrels" to several thousand gallons underground storage tanks. Depending on the size and visibility of the cistern, tank materials can include plastic (typically opaque HDPE), wood, or galvanized metal. The interior of the tank should be constructed from materials that are relatively unreactive with water, even during long-term storage, and that do not allow light into the system to minimize algae growth (Virginia Rainwater Harvesting Manual, 2009 available at: http://dcr.virginia.gov/documents/stmrainharv.pdf . Screens often are used either at the gutter, in the piping system, or at the entry to the cistern to capture leaves and other large debris. For example, Rainwater Management Solutions (www.rainwatermanagement.com) sells mesh screen filters (having aperture sizes ranging from 280 to 1,000 micrometers) that are placed in the gutter system. Mesh sizes in this range are not likely to provide removal of pollutants other than leaves and other large debris. Meshes that are not cleaned regularly are likely to have a buildup of leaves and, as the leaves degrade, nutrients likely will leach from the leaves and end up in the cistern. The leaching of nutrients into the system from degrading leaves is why the rainwater harvesting guidance suggest that tanks be opaque – to prevent algae buildup. It can be estimated that these screens will provide close to 100% removals for particles greater than the mesh size and partial removal for smaller particles. Leaf and large solids capture, with resultant partial or complete blockage of mesh openings, would be expected to improve the capture efficiency for particles smaller than the mesh size, but this efficiency cannot be predicted.

Many water harvesting system vendors also sell water purification systems that can be attached to the cistern outlet. These systems usually consist of a membrane filter and a UV light cartridge. They are very similar, or in some cases identical, to point-of-use drinking water systems used in homes connected to private wells. The nominal pore size of the filters used in these units can range from < 1 to several hundred micrometers. Filtration efficiency will be based on the pore size. As with the mesh screens, filtration efficiency will increase as the filter ages, but the filter will fail at some point due to clogging.

For runoff sources that may be dirtier than is assumed for roofing systems, or for roofing systems in urban areas where airborne deposits may further degrade runoff quality (as described in the previous subsections), systems such as the SkyHarvester (Watertronics, Inc., www.watertronics.com/?gclid=CPPt1KrT7KgCFYXd4Aod5XfuCg#/skyharvester) allow the purchaser to incorporate more treatability into the system than the systems listed above. SkyHarvester, which is marketed to commercial water harvesters, has the ability to incorporate an oil-water separator into the system. The system includes filtration components that remove particles >75 µm for drip irrigation systems, plus the system can be accessorized with reverse osmosis or ultrafiltration units. A similar system, the UrbanGreen Rainwater Harvesting System, is sold by Contech Construction Products, Inc. (www.contech-cpi.com/Products/Stormwater-Management/Rainwater-Harvesting.aspx?gclid=CJXpuZjV7KgCFcTd4AodyhZtEw). Because Contech is the vendor for several proprietary treatment systems, including the Downspout Filter and the CDS solids separation unit, this system has more options for pretreatment based on anticipated pollutant concentrations. Post-collection treatment consisting of filtration down to 2-5 µm and disinfection can be attached to the tank and operated in-line prior to use. The vendor, however, does not list the option of reverse osmosis or nanofiltration, indicating that these treatment units may not be standard accessories. For disinfection, the system can add chlorination or UV light components.

As noted above, sediment filters can remove solids greater than the pore size opening and those pollutants that are associated with the solids. However, these filters do not remove dissolved pollutants effectively unless a chemically-active media is included. For example, the Contech Downspout Filters contain a compost-based media to provide removal of many dissolved constituents, including zinc. The Rainwater Store (http://therainwaterstore.com/index.php/) provides products from several manufacturers. On the Filtration page, this vendor sells a range of cartridge inserts for filter units, such as those described above by Rainwater Management Solutions. These cartridges may be designed for sediment removal only, with pore size openings of 5 µm and greater. Some cartridges also contain activated carbon to enhance pollutant removal.

In general, rainwater harvesting system vendors do not report treatment information. However, because these systems are similar to those used in the aquaculture and drinking water industry, their efficiencies and effluent quality can be estimated.

5.4.2.2 Aquaculture Water Treatment Systems

The aquaculture industry has developed small-scale treatment systems to address the needs of fish farmers of various operational sizes. These units typically consist of filters (sometimes optimized for specific contaminants, such as ammonia), optionally followed by disinfection. Pollutants of concern are waste products from fish, plus algae and other microorganisms.

Aquaculture Systems Technologies LLC (www.beadfilters.com/products.php) sells several bead filter units with a nominal pore size of 5 µm. Because one of the waste products from fish is ammonia, their filters also come with a media designed to enhance nitrification, e.g., convert ammonia to nitrate. The results of the research and development of these systems are not readily reported on the website.

Aquatic Eco-Systems (www.aquaticeco.com) also supplies filtration and disinfection systems to the aquaculture industry. Aquatic Eco-Systems segregates their filtration systems into chemical and biological categories. The chemical filtration systems include pleated cartridges of varying sizes (with nominal apertures of 30 µm) and several of the units have a filter column where chemical treatment media, such as activated carbon and/or an ion-exchange media, can be included. The biological filtration section consists primarily of growth substrates for treatment microorganisms. From the standpoint of selecting a treatment system, vendors such as Aquatic Eco-Systems offer not only the housing for treatment cartridges and media, they also sell the media. Filtration media can be selected based upon the anticipated pollutant concentrations and loadings. Media available from Aquatic Eco-Systems include the following:

- Lightweight Sand Filter Media: Removes particles down to 20 – 40 µm. The lightweight nature (25 lb/ft^3 compared to regular sand at about 100 lb/ft^3) of the media reduces the amount of water required for backflushing. This sand also is not spherical, which reduces pressure loss and improves particle trapping on the uneven surface. The media is made from anhydrous silicon dioxide.

- Mixed Media: Similar to the lightweight sand above, the mixed media is used primarily in physical filtration. The mixed media contains four sizes of media, including a top layer of carbonite with sizes between 2.0 and 2.2 mm and that can remove iron and manganese that adhere to the carbonite surface. Depending on the media component, the specific gravities range from lighter than sand to substantially heavier than sand, which will affect backwash rates, pressures and/or volumes.
- Schuran Nitrate Filter is designed to remove nitrate through denitrification. The filter uses sulfur-based balls as the growth and food substrate for the denitrifiers. If the ceramic balls are used as a substrate, alcohol must be added regularly to provide a food source for the denitrifiers.
- ProLine® Phosphate Remover: Removes silicates and phosphates down to concentrations of < 0.2 mg/L. The media description does not identify the chemical basis for this media. However, because iron and aluminum oxides are documented to remove phosphates, it is possible that this is sand coated with iron or aluminum oxide.
- Marineland Black Diamond® Carbon: Black Diamond® is a heat-activated, bituminous coal-based product. No additional performance information is given, although it could be anticipated that removals for many organic pollutants will be excellent at low flow rates and will decrease, as will the lifespan of the media, at higher flow rates.
- ProLine® Zeolite Ammonia Remover: This clinoptilolite zeolite is designed to remove ammonia through ion exchange. It also may provide a surface for the growth of nitrifiers which would convert captured ammonia into nitrate.
- Chemi-Pure®: This media takes advantage of the removal ability of both activated carbon and ion-exchange resins. At least one of the exchangeable ions, likely calcium and/or carbonate, is able to keep the pH at near-neutral conditions.

5.4.2.3 Point-of-Use Drinking Water Treatment Systems

Point of use drinking water treatment systems are typically installed in-line to either provide further treatment to municipal water sources or to provide treatment of private well water. These systems typically are not designed to treat highly-turbid water and do not include sedimentation as a treatment option. Solids removal is through filtration. If the stormwater runoff harvested for reuse is highly turbid, then pretreatment by sedimentation either in the cistern or prior to entering the cistern would be required.

Unlike rainwater harvesting treatment systems or aquaculture water treatment systems, many drinking water treatment systems for point-of-use have undergone testing and certification through NSF International’s technology verification program (www.nsf.org/business/drinking_water_treatment/index.asp?program=DrinkingWatTre). Testing standards for these devices include the following:

- NSF/ANSI Standard 42: Drinking Water Treatment Units - Aesthetic Effects: Addresses the ability of the systems to reduce specific aesthetic or non-health-related contaminants (chlorine, taste and odor, and particulates).
- NSF/ANSI Standard 53: Drinking Water Treatment Units - Health Effects: Addresses the ability of the systems to reduce specific health-related contaminants, such as *Cryptosporidium*, *Giardia*, lead, volatile organic chemicals (VOCs), and methyl tertiary-butyl ether (MTBE).

- NSF/ANSI Standard 58: Reverse Osmosis Drinking Water Treatment Systems: Addresses the ability of the RO systems to reduce contaminants such as fluoride, hexavalent and trivalent chromium, total dissolved solids, nitrates, etc.
- NSF/ANSI Standard 44: Cation Exchange Water Softeners: Addresses the ability of the water softeners to reduce hardness through cation exchange. It may also be used to evaluate the system's ability to reduce radium and barium.
- NSF/ANSI Standard 55: Ultraviolet Microbiological Water Treatment Systems: Addresses the ability of the systems to reduce microbiological contaminants through UV disinfection. Class A systems (40,000 µwsec/cm^2) are designed to disinfect and/or remove microorganisms from contaminated water, including bacteria and viruses. Class B systems (16,000 µwsec/cm^2) are designed for supplemental bactericidal treatment of public drinking water or other drinking water.
- NSF/ANSI Standard 62: Drinking Water Distillation Systems: Addresses the ability of the systems to reduce, through distillation, specific contaminants, including total arsenic, chromium, mercury, nitrate/nitrite, and microorganisms.
- NSF/ANSI Standard 177: Shower Filtration Systems - Aesthetic Effects: Addresses the ability of the systems to reduce free available chlorine.
- NSF Protocol P231: Microbiological Water Purifiers: Addresses the ability of the systems to filter and treat microorganisms in water.
- CSA B483.1: Drinking Water Treatment Systems: Addresses the system's ability to meet plumbing, mechanical and electrical requirements for drinking water components.

Since point-of-use systems are designed to treat water to drinking water standards, the maximum allowable effluent concentration for aesthetic contaminants under *NSF/ANSI 42* is based on U.S. EPA secondary maximum contaminant levels or other aesthetic thresholds. The maximum allowable effluent concentration for health contaminants under *NSF/ANSI 53* is set at regulated levels based on U.S. EPA or Health Canada requirements, or at other health effects concentrations when contaminants are not regulated by these agencies. Primary maximum contaminant levels (MCLs) can be found at http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf. Secondary MCLs, which are primarily designated for aesthetic reasons, can be found at http://water.epa.gov/drink/contaminants/#Secondary.

Products that have been tested and determined to meet these specifications can be found using the NSF International Drinking Water Treatment Unit Database (http://www.nsf.org/Certified/dwtu/). Products can be searched by vendor and by the protocol listed above. The reports generated through the database do not contain specific effluent concentrations; however, they are certified to have effluent water quality that meets or exceeds the maximum concentrations listed in the above standards. These products also may use the NSF seal on their advertising.

5.4.2.4 Swimming Pool Water Treatment Systems

Although not typically used to treat stormwater for beneficial uses, the technologies long used for treating swimming pool water (focusing on bacteria levels for safe water contact) could be used for maintaining acceptable water quality in water storage tanks. Most of these units use a recirculating pump system having a sand filter and a disinfection unit. Systems are now available that use ozone, reverse osmosis, and even chitosan to maintain bacteriological quality, but historically, chlorine (usually added as Trichloro-S-Triazinetrione, Sodium Dichloro-S-Triazinetrione, or calcium hypochlorite) was used. With recirculation, it is possible to maintain good bacteriological conditions in the storage tank, even without maintaining a high chlorine residual (such as specified by some of the water reuse standards described in Section 4 of this report).

5.4.3 Summary of Water Treatment Processes Suitable for Stormwater Beneficial Use Systems

Depending on the end application and the water quality, captured stormwater will likely require treatment, as described in Chapter 4 of this report. Potential beneficial uses include landscape irrigation, fire suppression water, cooling tower water, and some selective indoor uses mostly including toilet flushing. This project is not considering potable water uses, such as drinking/cooking or sanitation (bathing). Table 5-7 reviews some of the treatment unit processes that can be applied to stormwater collected for beneficial uses.

Table 5-7. Selecting Harvesting Treatment Technologies for Stormwater Pollutants.

Pollutant	Treatment Process	Design Notes
Solids		
Diameter > 5 – 10 µm	Sedimentation	• Do not install spigot or pump along bottom of tank. • Irrigation Use: Minimal sedimentation needed, except to prevent damage to pump and outlet piping. • Nonpotable Use: Aesthetic problem. Use bottom of tank as sedimentation area. • Potable Use: Use bottom of tank as sedimentation area. May prematurely clog membrane filters (needed for removal of smaller solids). • Sedimentation efficiency can be increased by using inclined plates and tubes or by using coagulation (drawback: cost, chemical storage and injection, and residuals management).
Diameter 1 – 5 µm	Physical filtration	• Physical filtration enhanced with media with smaller pore sizes; however, clogging and lifespan before maintenance must be considered. • Physical filtration enhanced with preceding coagulation and sedimentation, although chemical addition likely not attractive for stormwater (cost, maintenance, chemical storage, residuals).
Diameter < 1 µm	Membrane filtration Chemically-reactive filtration	• Membrane filtration typically best option since membranes can be purchased in various sizes and typically can be installed in pre-fabricated housing units. Commonly used in well-water treatment applications. • Small particles have surface charges and can be attracted electrostatically to chemically-reactive media such as GAC filters.

Table 5-7. Selecting Harvesting Treatment Technologies for Stormwater Pollutants. (continued)

Pollutant	Treatment Process	Design Notes
Nutrients (Irrigation Use: Treatment may not be necessary; Other Uses: Testing will determine level of required treatment)		
Ammonia	Ion-exchange Oxidation and plant uptake	• At pH of most runoff, majority of ammonia exists as ammonium ion (NH_4^+). Ion exchange possible but +1 is weak exchanger and ion-exchange may require zeolites with small lattice openings that exclude larger cations. Zeolites can be installed in pre-fabricated housing, but GAC also may remove ammonia.
Nitrate and Nitrite	Ion-exchange	• Ion-exchange possible, but anion exchange difficult (most zeolites have weak anion exchange capacity). • Some GACs have a limited but excellent capacity for nitrate as ion-exchange resin.
Phosphate	Chemically-active media filtration Plant uptake	• Phosphate is strong anion and could participate in ion-exchange, but difficult (weak anion exchange capacity of filter media). • Reacts strongly with iron and aluminum. Also reacts with these elements in stormwater-borne solids and may be removed by sedimentation/filtration.
Metals (Irrigation Use: Roofing material will affect runoff concentration with testing strongly suggested if metal roof used to capture rainwater; Other Uses: Treatment likely required)		
Lead	Ion-exchange Chemically-active media filtration	• Lead attaches strongly to particulate matter. Substantial removal may occur through sedimentation and/or physical filtration of solids to which lead is attached. • Lead < 0.45 µm may be ionic and could be removed using ion-exchange with zeolites, but filtered, ionic lead is usually at very low concentrations and it would be unusual to require treatment. • Removal preferential in media with multiple types of binding sites (peat, compost, GAC [less effective]).

Table 5-7. Selecting Harvesting Treatment Technologies for Stormwater Pollutants. (continued)

Pollutant	Treatment Process	Design Notes
Copper, Zinc, Cadmium	Chemically-active filtration	• These metals can attach to very small particles, with the attachments being a function of the particulate organic content, pH, and oxidation-reduction conditions (filterable fractions vary from 25 to 75+%). These metals complex with a variety of organic and inorganic ligands to create soluble complexes of varying valence charges (-2 to +2). Lack of ionic species (metal as +2 ion only) reduces effectiveness of ion-exchange resins. Complexes require multiple types of sorption/exchange sites. Organic complexes may be removed by GAC.
Mercury	Chemically-active filtration with organic media	• Mercury reacts with both organic and inorganic compounds to form complexes, plus it methylates to form methylmercury (log K_{OW} = 1.7 to 2.5), which is somewhat soluble in water. Complexes require multiple types of sorption/exchange sites. Organic complexes and methylmercury may be removed by GAC.
Organics and Pesticides (Irrigation Use: Testing strongly suggested if on-site or nearby uses of pesticides or if vehicular traffic prominent in area; Other Uses: Treatment likely required)		
Volatile Organic Compounds (VOCs)	Air stripping Chemically-active filtration	• Passive air stripping can be accomplished in the roofing gutters or by passing runoff over packing balls or other air entrainment mechanisms as the water enters the tank.
PAHs/Oil and Grease/Dioxin	Chemically-active filtration	• These compounds have high K_{OW} and low K_S and are strongly associated with particulates. Sedimentation's effectiveness is a function of particle size association. Preferential sorption to organic media, such as GAC.
Organic Acids and Bases	Chemically-active filtration	• Tend to be more soluble in water than PAHs. Need media with multiple types of sorption sites. GAC could be considered if nonpolar part of molecule interacts well with GAC or if GAC has stronger surface active reactions than just van der Waals strength forces.

Table 5-7. Selecting Harvesting Treatment Technologies for Stormwater Pollutants. (continued)

Pollutant	Treatment Process	Design Notes
Pesticides	Chemically-active filtration	- Tend to be soluble in water and need multiple reaction sites to be removed. Breakdown time in biologically-active filtration media is compound-dependent. Breakdown, though, has the potential to restore surface-active sites. Breakdown may result in more soluble daughter products, which may or may not be more toxic. Organic media such as GAC likely to be most effective since size of compound will exclude substantial removal in ion-exchange resins such as zeolites.
Microorganisms (Irrigation Use: May not need treatment if tank protected from creating conditions for regrowth, but most regulations require very low microorganism levels for even non-contact beneficial uses; Other Uses: Treatment likely required)		
Cysts and Large Pathogens (such as *Giardia* or *Cryptosporidium*)	Physical filtration	- Large enough to be physically strained from the water using membranes.
Bacteria	Physical filtration Organic media (chemically-active) filtration	- Membrane filtration and UV disinfection preferred treatment system for water contact use. - Membranes provide a location for captured bacteria to reside and grow. Challenge is encouraging capture and potential growth to create reactive sites, but without excessive growth that sloughs off the media and is washed out with successive storms.
Viruses	Chemically-active filtration	- Viruses in the environment are colloidal-sized particles (~0.01 μm) that are surface active. Viruses are not infectious unless they enter a suitable host and their removal may not need to be a focus of treatment efforts as the water will not be for potable uses.

5.5 Summary

This report section examines stormwater quality, both at outfalls, and at source areas, to identify water quality problems to meet the regulations and criteria for beneficial uses of the stormwater.

Many of the stormwater constituents would likely have most of their concentrations greater than the associated numeric criteria. Constituents where the reported NSQD average values exceed the criteria include: BOD_5, COD, TSS, turbidity, total coliforms, fecal coliforms, and *E. coli*. Additional constituents may periodically exceed the criteria, as the maximum values were high, including: pH, ammonia, nitrate plus nitrite, arsenic, cadmium, chromium, copper, iron, selenium, and zinc. The most potentially problematic constituents (where the exceedences are the greatest), include the bacteria, followed by the solids and turbidity values. The metals having the potentially greatest exceedences include cadmium and zinc. Generally, the roof runoff and landscaped areas have better water quality, but all areas are seen to exceed the numeric criteria for: BOD_5, COD, TSS, and fecal coliforms. Freeway data exceeded the cadmium values, while some of the paved parking and street data exceeded the copper values. As indicated for the outfall data as shown in the NSQD, the bacteria data exceed the objectives by the greatest amount, followed by the TSS. The BOD_5 and COD exceedences were not as great, but almost all samples from all areas exceeded these criteria (except for a few roof and landscaped area samples). Therefore, none of the stormwater or source waters would likely be able to meet the numeric criteria for stormwater beneficial uses, with the bacteria being the most problematic, and the solids and turbidity values also be an issue. Roof runoff is the preferred source water for beneficial stormwater uses, but treatment, especially for bacteria, will still be necessary.

Different materials are used in the collection, drainage, and storage components of stormwater beneficial use systems. Some materials can degrade runoff water even with very short contact times, and would be a problem even if used for the collection surface. Other materials, however, require extended exposure periods to degrade the water, such as would be evident in storage tanks. The most significant potential problems are associated with galvanized metal roofs or gutter and tanks, plus cupper piper or other plumbing fixtures used in the systems. These materials can elevate the zinc and copper concentrations to problematic concentrations during rain events, while extended contact, such as storage tanks, can cause very high concentrations.

Treatment of stormwater before most beneficial uses may therefore be needed. For simple irrigation use, bacteria reductions would be necessary, and the prevention of excessive metal concentrations through careful selection of materials. Cistern and water tank storage can reduce most bacteria levels to close to the regulation’s numeric values, although some additional treatment may be needed. Roof runoff typically has excessive bacteria levels, especially during the non-winter months and if trees are over the roofs. Depending on the water quality of the source stormwater and the intended beneficial use, different water quality treatment options can be examined. There are a number of commercial units available that would be suitable that can reduce the solids, bacteria, and heavy metals in the water before use.

Simple storage in cisterns and water tanks may approach the guideline values for roof and yard runoff (most which were developed for treated sanitary wastewater), and measures to minimize scour resuspension of deposited sediments, would likely be sufficient to protect public health. More contaminated source waters may require more sophisticated treatment options.

CHAPTER 6.0

CALCULATING THE BENEFITS OF RAINWATER HARVESTING SYSTEMS AND EVAPOTRANSPIRATION RATES

6.1 Introduction

This chapter presents a method to evaluate or size water tanks needed to optimize the beneficial uses of stormwater. Irrigation of land on the homeowner's property was considered the beneficial use of most interest. Production function curves were prepared for several locations in the U.S. showing the relationship between water tank size and roof runoff beneficial use. Irrigation calculations rely on good evapotranspiration (ET) data, which is rare for urban settings. This chapter (and associated appendices) reviews several ET data sources and describes its applicability and use. Guidance on plants that withstand a wide range of moisture conditions is also provided in order to increase the irrigation demands to maximize the use of the runoff water. Extensive appendices are given that present monthly ET values for several hundred locations near urban areas in the U.S.

6.2 Calculating the Benefits of Rainwater Harvesting Systems

Benefits associated with stormwater use for irrigation and other on-site use can be calculated based on site specific information. Specifically, source area characteristics describing where the flows will originate and how the water will be used, are needed. In the most direct case, this information is used in conjunction with the local rainfall information and storage tank sizes to determine how much of the water needs can be satisfied with the stormwater, and how the stormwater discharges can be reduced. The following section describes how WinSLAMM, the Source Loading and Management Model (Pitt, 1997), was used to calculate production functions that can be used to size storage water tanks to maximize irrigation use for residential locations throughout the U.S. The following is an example of how this was accomplished for Kansas City, MO, as part of a current U.S. EPA demonstration project on green infrastructure use to reduce the magnitude and volume of combined sewer overflows. Production functions for other regions are then shown.

6.2.1 WinSLAMM Background Information

WinSLAMM was developed to evaluate stormwater runoff volume and pollutant loadings in urban areas using continuous small storm hydrology, in contrast to single event hydrology methods that have been traditionally used for much larger drainage design events. WinSLAMM determines the runoff based on local rain records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain. Examples of source areas include: roofs, streets, small landscaped areas, large landscaped areas, sidewalks, and parking lots.

6.2.1.1 Regional Rainfall and Runoff Distributions

The model can use any length of rainfall record as determined by the user, from single rainfall events to several decades of rains. The rainfall file used in the calculations for Kansas City was developed from hourly data obtained from EarthInfo CDROMs, using the 27 years from 1972 through 1999, as shown on Figure 6-1. This period contained 2,537 rains, with an average of 0.40 inches and a maximum of 6.19 inches.

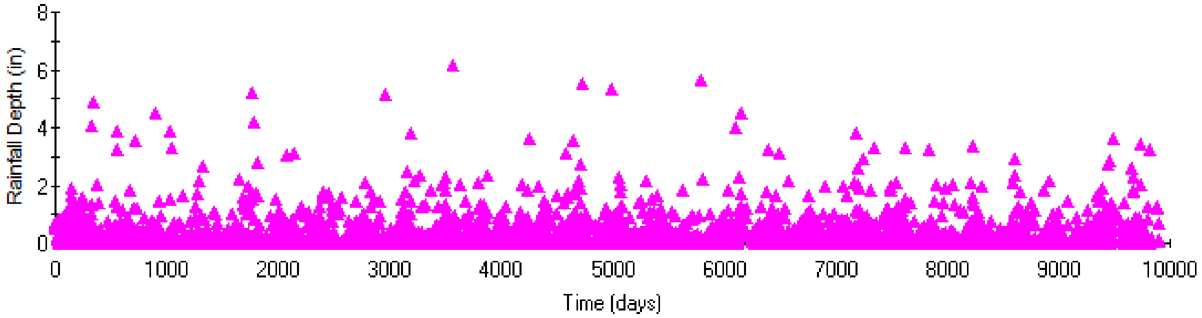


Figure 6-1. Long-Term Rain Depths for Individual Kansas City, MO, Rains. (1972 – 1999).

Figure 6-2 shows that the regional stormwater runoff is heavily influenced by the small to intermediate rains (data for the region shown for St. Louis, MO). Almost all of the runoff is associated with rains between about 0.3 to 2 inches, the events for which WinSLAMM is optimized. The rare drainage design events generally comprise a very small portion of the typical year's runoff. The 1.4 inch event used in Kansas City for the original sizing of distributed storage systems is close to the rain depth associated with the median runoff depth.

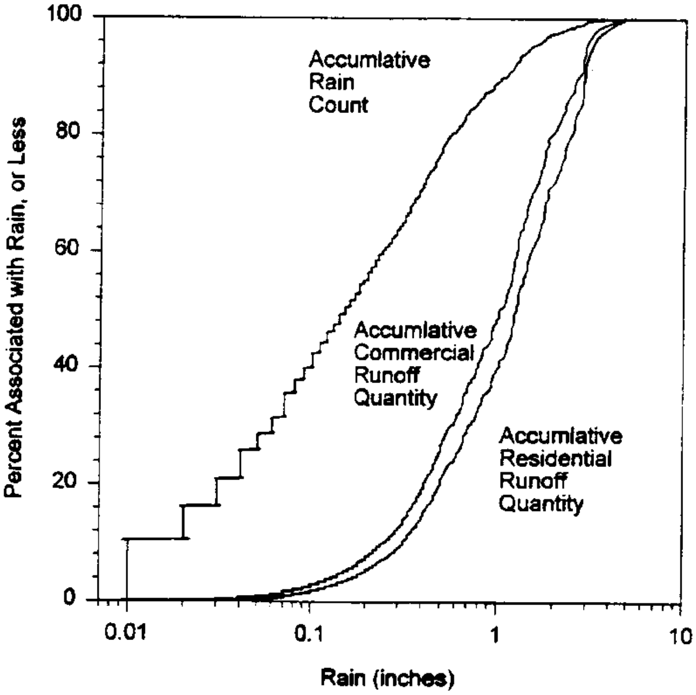


Figure 6-2. St. Louis, MO, Rain and Runoff Ristributions. (1984 through 1992 rains).

6.2.1.2 Stormwater Controls in WinSLAMM and Calculation Processes

WinSLAMM was used to examine a series of stormwater control practices, including rain barrels and water tanks for stormwater irrigation, pavement and roof disconnections, roof rain gardens, infiltration/biofiltration in parking lots and as curb-cut biofilters, street cleaning, wet detention ponds, grass swales, porous pavement, catchbasins, and selected combinations of these practices for the Kansas City regional land use conditions. The model evaluates the practices through engineering calculations of the unit processes based on the actual design and size of the controls specified and determines how effectively these practices remove runoff volume and pollutants. This summary only focuses on irrigation beneficial uses of stormwater and water storage tanks.

WinSLAMM does not use a percent imperviousness or a curve number to general runoff volume or pollutant loadings. The model applies runoff coefficients to each “source area” within a land use category. Each source area has a different runoff coefficient equation based on factors such as: slope, type and condition of surface, soil properties, etc., and calculates the runoff expected for each rain. The runoff coefficients were developed using monitoring data from typical examples of each site type under a broad range of conditions. The runoff coefficients are continuously updated as new research data becomes available.

For each rainfall in a data set, WinSLAMM calculates the runoff volume and pollutant load (EMC x runoff volume) for each source area. The model then sums the loads from the source areas to generate a land use or drainage basin subtotal load. The model continues this process for the entire rain series described in the rain file. It is important to note that WinSLAMM does not apply a “unit load” to a land use. Each rainfall produces a unique load from a modeled area based on the specific source areas in that modeled area.

The model was used to predict stormwater management practice effectiveness as presented in the Kansas City project report. The model replicates the physical processes occurring within the practice. For example, for a wet detention pond, the model incorporates the following information for each rain event:

1. Runoff hydrograph, pollution load, and sediment particle size distribution from the drainage basin to the pond,
2. Pond geometry (depth, area),
3. Hydraulics of the outlet structure,
4. Particle settling time and velocity within the pond based on retention time

Stokes Law and Newton’s settling equations are used in conjunction with conventional surface overflow rate calculations and modified Puls-storage indication hydraulic routing methods to determine the sediment amounts and characteristics that are trapped in the pond. Again, it is important to note that the model does not apply “default” percent efficiency values to a control practice. Each rainfall is analyzed and the pollutant control effectiveness will vary based on each rainfall and the pond’s antecedent condition. This report describes how each stormwater control practice examined in Antelope Creek is evaluated in WinSLAMM.

The model’s output is comprehensive and customizable, and typically includes:

1. Runoff volume, pollutant loadings and EMCs for a period of record and/or for each event.

2. The above data pre- and post- for each stormwater management practice.
3. Removal by particle size from stormwater management practices applying particle settling.
4. Other results can be selected related to flow-duration relationships for the study area, impervious cover model expected biological receiving water conditions, and life-cycle costs of the controls.

A full explanation of the model's capabilities, calibration, functions, and applications can be found at www.winslamm.com. For this project, the parameter files were calibrated using the local Lincoln MS4 monitoring data, supplemented by additional information from regional data from the National Stormwater Quality Database (NSQD), available at: http://www.unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

6.2.2 Evaluation of Performance of Stormwater Control Practices

The land development characteristics and the evaluation of flow and pollutant sources in the area determine the maximum effectiveness of different types of controls. The land survey found that most of the homes in the test watershed already have disconnected roofs (85% of all roof areas), and that the total roof areas comprise about 13% of the total area. The land survey also found that about 65% of the area is landscaped, with most being in turf grass in poor to good condition. This information was used in conjunction with regional evapotranspiration data to calculate the amount of supplemental irrigation needed to meet the ET requirements of typical turf grass, considering the long-term rainfall patterns. Most of the supplemental irrigation would be needed during the months of July and August, while excess rainfall occurs in October through December (compared to ET requirements during these relatively dormant months). Soil infiltration monitoring in the area, along with soil profile surveys, has indicated relatively poorly draining soil in the test area for the larger rains. Surface infiltration rates during several-hour rains may have infiltration rates of about 1 in/hr or greater, but these rates continue to decrease with increasing rain depths. For conservative modeling calculations, soil infiltration rates of 0.2 in/hr were used.

The expected major sources of runoff from the test area vary for different rain depth categories. Directly connected impervious areas are the major runoff sources only for rains less than about 0.25 inches in depth. The large landscaped areas contribute about half of the runoff for rains larger than about 0.5 inches in depth. The directly connected roofs, which make up only about 2% of the study area, contribute about 6% of the total annual flows. The disconnected roofs, which comprise about 11% of the area, contribute about 7% of the total flows. If all roofs were directly connected, they would comprise about 31% of the annual total runoff flows, most of which could be eliminated through the use of cisterns/water tanks and irrigation.

Performance plots were prepared comparing the size of the rain gardens to the size the roof vs. percent flow reductions. Rain gardens about 20% of the roof area are expected to result in about 90% reductions in total annual flow compared to directly connected roofs. This area is about 200 ft^2 per house which could be comprised of several smaller rain gardens so they can be located at each downspout. Fifty percent reductions in the total annual flows could be obtained if the total rain garden area per house was about seven percent of the roof area. The 200 ft^2 rain garden area per house is also expected to completely control the runoff from the regulatory design storm "D" of 1.4 inches.

Rain barrel effectiveness is related to the need for supplemental irrigation and how that matches the rains for each season. The continuous simulations used a typical one-year rain series and average monthly ET values for varying amounts of roof runoff storage. A single 35 gallon rain barrel is expected to reduce the total annual runoff by about 24%, if the water use could be closely regulated to match the irrigation requirements, such as with an automated irrigation system with soil moisture sensors (not likely to be used in conjunction with a few rain barrels, but more likely with a large tank than can be pressurizes). If four rain barrels were used (such as one on each corner of a house receiving runoff from separate roof downspouts), the total annual volume reductions from the roofs could be as high as about 40%. Larger storage quantities result in increased beneficial usage, but likely require larger water tanks. Water use from a single water tank is also easier to control through soil moisture sensors and can be integrated with landscaping irrigation systems for almost automatic operation. A small tank about 5 ft in diameter and 6 ft in height is expected to result in about 75% total annual runoff reductions from directly connected roofs, while a larger 10 ft diameter tank 6 ft tall could approach complete roof runoff control. The 5 ft diameter tank is also expected to provide almost complete control of runoff from the regulatory design storm "D."

The use of rain barrels and rain gardens together at a home is more robust than using either method alone: the rain barrels would overflow into the rain gardens, so their irrigation use is not quite as critical. In order to obtain reductions of about 90% in the total annual runoff, it is necessary to have at least one rain garden per house, unless the number of rain barrels exceeds about 25 (or 1 small water tank) per house.

Simple disconnections of the currently directly connected roofs can provide significant reductions in the annual flows from the roofs for expected less cost. A reduction of about 80% is expected in the total flows with disconnections, even with the site's clayey soils, with most occurring during small rains, and the benefits decreasing as the rains increase in depth. This flow volume reduction is enhanced due to the relatively small roof areas and large landscaped areas which provide long flow paths. With steep slopes and poor grass, this reduction will be less.

Caution is needed when comparing the amount of site runoff storage provided by these upland controls to the total storage goals to meet the objectives of the CSO control program (288,000 gallons). As an example, storage provided at directly connected roofs need to be discounted by factor of 1.3 to 1.4 as not all of the storage is available during all rains, and their drainage is controlled by low infiltration rates through the native soils, compared to flow controls directly connected to the combined sewers. In contrast, curb-cut biofilters have "access" to almost all of the flows in the area, so their storage volumes are more effectively utilized. More significantly, if storage was provided at roofs that are already disconnected, their storage volumes would need to be discounted by about 4.5X when compared to the total site storage goals, due to the existing infiltration occurring with the disconnected roof runoff.

6.2.3 Water Harvesting Potential

The water harvesting potential for water tank use was calculated based on supplemental irrigation requirements for the basic landscaped areas. The irrigation needs were determined to be the amount of water needed to satisfy the evapotranspiration needs of typical turf grasses, after the normal rainfall (a conservative calculation, as only a portion of the rainfall contributes to soil moisture).

Table 6-1 summarizes the monthly average rainfall for the 1973 through 1999 period at the Kansas City airport, a 26 year unbroken continuous rain record. The average total annual rainfall is typically about 37.5 inches, with most falling in the spring to early fall. A much smaller fraction of the annual rain occurs during December through February.

Table 6-1. 1973 through 1999 Kansas City Airport Rain Records.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average	1.13	1.24	2.54	3.48	5.41	4.27	4.15	3.63	4.63	3.32	2.08	1.60	37.49
COV	0.68	0.57	0.66	0.61	0.54	0.48	0.85	0.67	0.75	0.81	0.59	0.83	0.25
Minimum	0.02	0.20	0.32	0.34	1.18	1.73	0.25	0.65	0.57	0.00	0.00	0.00	21.60
Maximum	2.81	2.72	9.08	8.43	12.41	8.67	15.47	9.58	11.11	10.16	5.12	5.42	55.26

- 1 in = 25.4 mm = 2.54 cm

The total landscaped area in the 100 acre residential land use area is 65.1 acres, and with 576 homes, each has about 4,925 ft^2 of landscaped area that could potentially be irrigated.

Tables 6-2 and 6-3 along with Figures 6-3 through 6-5 show the monthly evapotranspiration requirements of typical turf grasses for a monitoring station near Kansas City (Ottawa, KS, at a University of Kansas field station). The total annual ET is about 52 inches a year, while the annual total rainfall is about 37 inches a year, resulting in a rainfall deficit of about 15 inches per year.

Table 6-2. Monthly Irrigation Requirements.

	in/day ET*	ET (in/month)	rainfall (in/month)	irrigation deficit (in/month)	irrigation deficit (gal/day/house)
Jan	0.05	1.55	1.13	0.42	42
Feb	0.10	2.83	1.24	1.59	172
Mar	0.10	3.10	2.54	0.56	55
Apr	0.15	4.50	3.48	1.02	104
May	0.20	6.20	5.41	0.79	78
Jun	0.20	6.00	4.27	1.73	177
Jul	0.25	7.75	4.15	3.60	357
Aug	0.25	7.75	3.63	4.12	408
Sep	0.20	6.00	4.63	1.37	140
Oct	0.10	3.10	3.32	n/a	0
Nov	0.05	1.50	2.08	n/a	0
Dec	0.05	1.55	1.60	n/a	0

* These ET values are for eastern Kansas (Ottawa, KS) and are for typical turf grasses.

- 1 in = 25.4 mm = 2.54 cm, 1 ft = 30.48 cm,1 gallon = 3.785 Liter

Table 6-3. Monthly Irrigation per Household.

month	irrigation needs per month (gal/house)	irrigation needs per month (ft³/house)	irrigation needs per month (ft depth/house)	irrigation needs per month (inches depth/month)	irrigation needs per month (inches depth/week)
Jan	1302	174	0.04	0.42	0.10
Feb	4859	650	0.13	1.58	0.39
Mar	1705	228	0.05	0.56	0.13
Apr	3120	417	0.08	1.02	0.24
May	2418	323	0.07	0.79	0.18
Jun	5310	710	0.14	1.73	0.40
Jul	11067	1480	0.30	3.60	0.81
Aug	12648	1691	0.34	4.12	0.93
Sep	4200	561	0.11	1.37	0.32
Oct	0	0	0.00	0.00	0.00
Nov	0	0	0.00	0.00	0.00
Dec	0	0	0.00	0.00	0.00
Totals:	46629	6234	1.27	15.19	

- 1 in = 25.4 mm = 2.54 cm, 1 ft = 30.48 cm,1 gallon = 3.785 Liter

Figures 6-3 through 6-5 plot the monthly ET, rainfall, and supplemental irrigation needs. Most of the supplemental irrigation is needed in July and August, while there is an excess of rainfall in October through December and therefore no supplemental irrigation needed during those months.

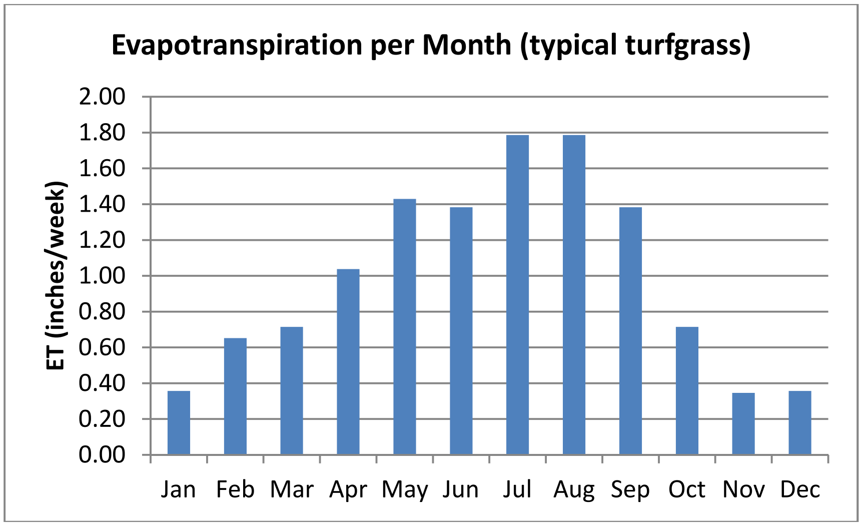


Figure 6-3. Evapotranspiration by Month.

- 1 in = 25.4 mm = 2.54 cm

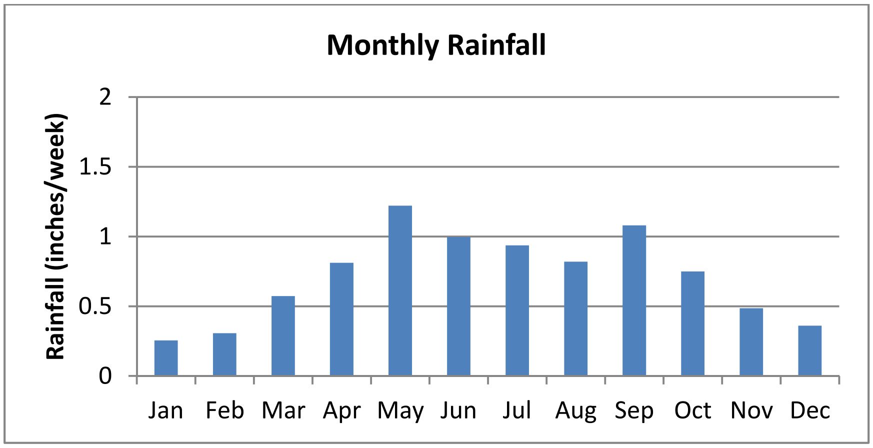


Figure 6-4. Monthly Rain Fall.

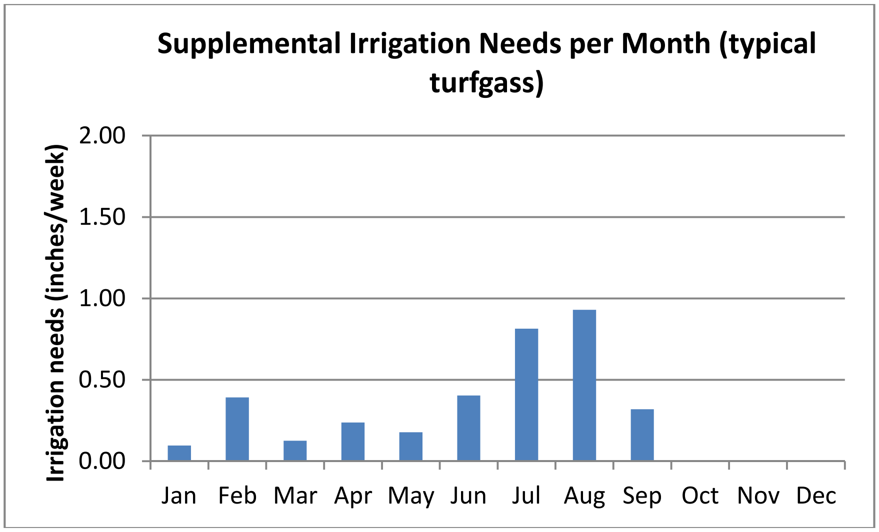


Figure 6-5. Monthly Irrigation Requirements to Meet ET.

- 1 in = 25.4 mm = 2.54 cm

The total amount of rainfall harvesting potential for irrigation (to match the ET) is about 46,600 gallons (6,230 ft^3) per household per year. With 4,925 ft^2 of landscaped area per household, the annual irrigation requirement is about 1.3 ft, or 15 inches, or an average of about half an inch of water applied per week during the 9 months when there is an irrigation need. With 576 homes in the watershed, this totals about 27 million gallons (3.6 million ft^3) per year for the 100 acre project area. Continuous simulations are used to see how much of this can actually be used based on the interevent conditions and rain patterns compared to the water need patterns and water storage volumes. It may also be possible to use a greater amount of this water for irrigation for certain plants. These irrigation values are for typical turf grasses. Any additional irrigation would not be used by the plants, but would be infiltrated into the soil. As noted, the long-term infiltration rates available through the soils at the project site are low.

6.2.4 WinSLAMM Modeling of Rain Gardens, Rain Barrel/Tanks, and Disconnection Roof Runoff Controls

Rain gardens, rain barrel/tanks, and disconnection of roof runoff are controls being used in the residential areas in the Kansas City Marlborough green infrastructure study area. They are located on private property and receive the runoff from directly connected roofs. Their maximum benefit is dependent on the amount of runoff that is contributed from the source areas where they would be located. Table 6-4 shows that the directly connected roofs only contribute about 5.8%, while the much greater area of disconnected roofs contribute about 7.2% of the annual runoff from the whole 100 acre area. The current flow contributions of all roofs in the area total about 13%. If all the roofs were directly connected, the roofs would contribute about 31% of the total area runoff, and the runoff from the total area would increase by about 25%, a significant increase. In contrast, if the currently directly connected roofs were disconnected through a downspout disconnection program, the total roof contribution would decrease to about 9%, and the total area runoff would decrease by about 5%. Since about 85% of the existing roofs in the area are already disconnected, the benefits of controlling the remaining directly connected roofs are therefore limited.

Table 6-4. Effectiveness of Roof Area Disconnections.

	roof 1 areas (currently directly connected) (1.9 acres)	roof 2 areas (currently disconnected) (10.6 acres)	land use total (100 acres)	Whole area Rv
base conditions (ft^3/year)	257,200	319,200	4,449,000	0.30
% contributions	5.8	7.2		
% roof contributions	13.0			
if all roofs connected (ft^3/year)	257,200	1,458,000	5,588,000	0.38
% contributions	4.6	26.1		
% roof contributions	30.7			
if all roofs disconnected (ft^3/year)	56,340	319,200	4,248,000	0.29
% contributions	1.3	7.5		
% roof contributions	8.8			

1 acre = 4,050 m^2

Table 6-5 shows that directly connected roofs in the study area contribute about 4.5 times the amount of runoff per unit area as the disconnected roofs. This indicates that about 78% of the annual runoff from the disconnected roofs is infiltrated as it passes over previous areas on the way to the drainage system. Therefore, it is much less cost-effective to use roof runoff controls for the runoff from the disconnected roofs compared to runoff controls for the directly connected roofs. If an infiltration or beneficial use control is used to control runoff from disconnected roofs, they would have to be about 4.5 times larger than if used for runoff control from directly connected roofs, in order to have the same benefit on the overall discharge volume from the area.

Table 6-5. Disconnected and Directly Roof Runoff Differences.

	area (acres)	annual runoff (ft^3)	runoff per area (ft^3/acre/year)
roof 1 areas (directly connected)	1.87	257,200	137,500
roof 2 areas (disconnected)	10.57	319,200	30,200
ratio of disconnected to directed connected:	5.65	1.24	0.220

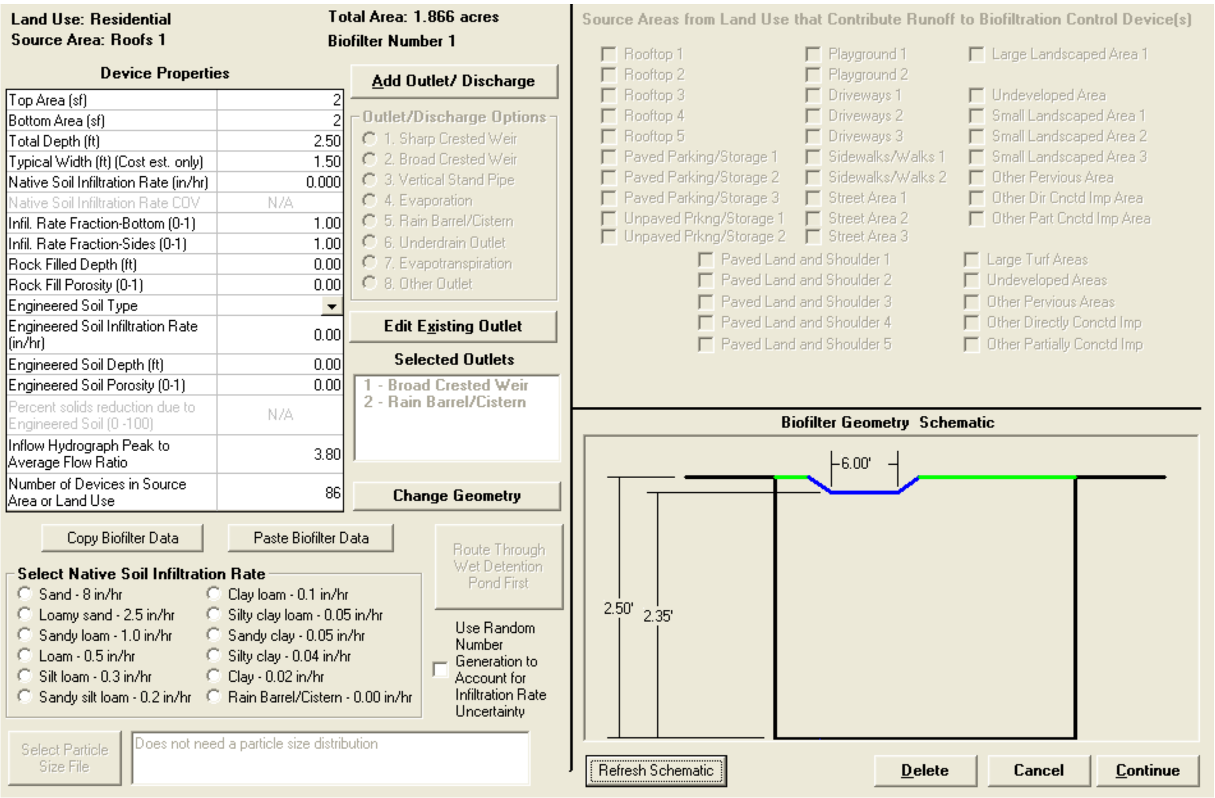
1 acre = 4,050 m^2, 1 ft = 0.305 m

6.2.4.1 Rain Barrels and Water Tanks

Rain barrels are a very simple method for collecting roof runoff for beneficial uses. In these analyses, irrigation of typical turf grass landscaping around the homes in the study area is the use being examined. This irrigation requirement was described previously and is the additional water needed to supplement the long-term monthly average rainfall in order to match the evapotranspiration requirements for the area. As will be shown in these analyses, small rain barrels provide limited direct benefits, so larger water tanks were also considered. Also, in order to be most beneficial, these calculations assume that the irrigation rates are controlled by soil moisture conditions in order to match the ET requirements closely. This level of control is usually most effectively achieved with a single large storage tank connected to an automatic irrigation system. Numerous smaller rain barrels are more difficult to control optimally.

For these calculations, each rain barrel is assumed to have 35 gallons of storage capacity (4.7 ft^3). Each roof has an average area of 945 ft^2 and receives a total of 3,100 ft^3 of rainfall. As noted above, these analyses are only for the directly connected roofs in the area, which only comprise about 15% of the total roof area in the study watershed.

Figures 6-6 and 6-7 are input screens used for rain barrels or cisterns in WinSLAMM version 9.5 (version 10 currently being completed has a more stream-lined water beneficial use/water barrels input screen). It is the same form used for the biofilters, but conditions relevant to rain barrels and water beneficial use are selected (top and bottom area the same, no native soil infiltration and no fill material needed. The two discharges include the required overflow (just the tank upper rim) and the monthly water use requirements (the irrigation demands).


Land Use: Residential
Source Area: Roofs 1

Total Area: 1.866 acres
Biofilter Number 1

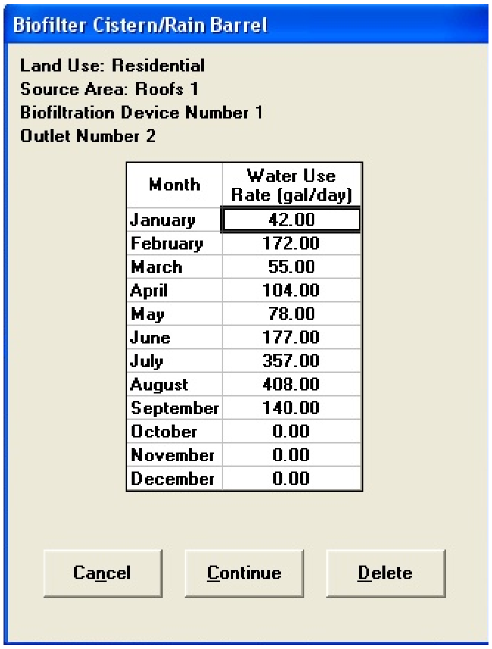
Device Properties

Top Area (sf)	2
Bottom Area (sf)	2
Total Depth (ft)	2.50
Typical Width (ft) (Cost est. only)	1.50
Native Soil Infiltration Rate (in/hr)	0.000
Native Soil Infiltration Rate COV	N/A
Infil. Rate Fraction-Bottom (0-1)	1.00
Infil. Rate Fraction-Sides (0-1)	1.00
Rock Filled Depth (ft)	0.00
Rock Fill Porosity (0-1)	0.00
Engineered Soil Type	
Engineered Soil Infiltration Rate (in/hr)	0.00
Engineered Soil Depth (ft)	0.00
Engineered Soil Porosity (0-1)	0.00
Percent solids reduction due to Engineered Soil (0 -100)	N/A
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Land Use	86

Selected Outlets
1 - Broad Crested Weir
2 - Rain Barrel/Cistern

Does not need a particle size distribution

Figure 6-6. Cistern/Water Tank Winslamm Input Screen.


Biofilter Cistern/Rain Barrel

Land Use: Residential
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 2

Month	Water Use Rate (gal/day)
January	42.00
February	172.00
March	55.00
April	104.00
May	78.00
June	177.00
July	357.00
August	408.00
September	140.00
October	0.00
November	0.00
December	0.00

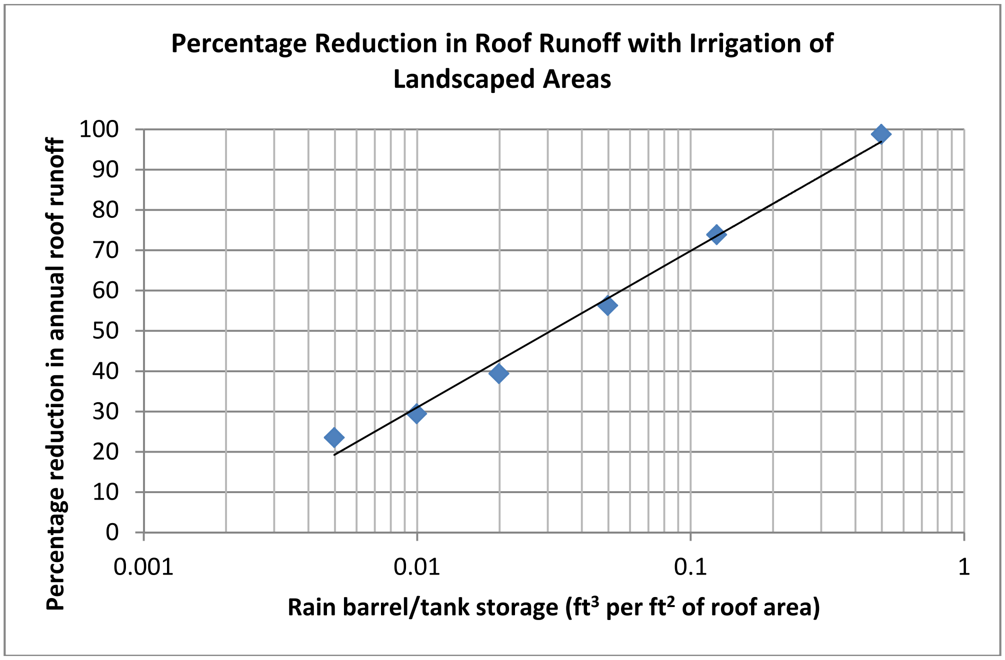
Figure 6-7. Water Use WinSLAMM Input Screen.

Tables 6-6 and 6-7 and Figure 6-8 summarize the benefits of storage and irrigation use of runoff collected from directly connected roofs. The use of a single rain barrel is expected to provide about a 24% reduction in runoff through irrigation to match ET. However, more than 25 rain barrels would be needed to reduce the roof's contributions by 90%. In order to match the benefits of disconnection of the connected downspouts (about 78% reductions), about 25 rain barrels would be needed. Twenty-five rain barrels correspond to a total storage quantity about equal to 0.12 ft (1.4 inches). The level of maximum performance for roof runoff storage in Kansas City is quite high because the excess rainfall occurs during times of the greatest ET needs (with some winter months not having ET needs). More importantly, the landscaped areas that can be irrigated are relatively large when compared to the small roof areas. These together results in substantial maximum benefits associated with irrigation beneficial uses. The next section describes expected performance of roof harvesting storage tanks in other areas, most which are not nearly as promising.

Table 6-6. Rain Barrel Use and Roof Runoff Reductions.

# of rain 35 gal. barrels per house	rain barrel storage per house (ft^3)	rain barrel storage per house (ft^3) per roof area (ft^2, or ft depth over the roof)	total annual roof runoff for 86 houses (ft^3)	total annual roof runoff per house (ft^3)	Rv for roof area	% reduction in roof runoff
0	0	0	257,200	2990	0.97	0
1	4.7	0.0050	196,700	2290	0.74	24
4	19	0.020	155,800	1810	0.58	39
10	47	0.050	112,400	1310	0.42	56
100	470	0.50	3,160	37	0.01	99

1 ft^3 = 28 Liter



1 ft = 30.5 cm

Figure 6-8. Irrigation Storage Requirements Production Function.

As the storage volume increases, it likely becomes impractical to meet the total storage volume with small rain barrels. Table 6-7 shows the equivalent size of larger water tanks or cisterns when the number of rain barrels is greater than four. As an example, a moderately-sized water tank 5 ft in diameter and 6 ft tall has a similar storage capacity as 25 rain barrels, and if the 6 ft tall tank was expanded to 10 ft in diameter, this larger tank would have a similar capacity as 100 rain barrels.

The use of about 25 rain barrels, or a small tank 5 ft in diameter and 6 ft tall, is the recommended amount of storage for the currently directly connected roofs in the study area. This would provide about 74% reductions in the total annual runoff discharges, and almost complete control for the 1.4 inch regulatory design storm "D."

Table 6-7. Rain Barrels and Water Tank Equivalents.

storage per house (ft depth over the roof)	storage per house having 945 ft^2 roof area (ft^3 and gallons)	Reduction in roof runoff for 1.4 inch rain (%)	Reduction in annual roof runoff (%)	# of 35 gal rain barrels	tank height size required if 5 ft D (ft)	tank height size required if 10 ft D (ft)
0	0 (0)	0	0	0	0	0
0.0050	4.7 (35)	16	24	1	0.24	0.060
0.010	9.4 (70)	19	29	2	0.45	0.12
0.020	19 (140)	27	39	4	0.96	0.24
0.050	47 (350)	46	56	10	2.4	0.60
0.12	118 (880)	96	74	25	6.0	1.5
0.50	470 (3,500)	100	99	100	24	6.0

- 1 in = 25.4 mm = 2.54 cm, 1 ft = 30.5 cm, 1 gallon = 3.785 Liter

6.2.5 Roof Harvesting and Water Tank Sizes for U.S. Regions

These same calculations were performed for typical medium density residential areas in all six of the major U.S. rain zones. Table 6-8 shows the calculations for the Great Lakes region, based on Madison, WI, rain data and regional evapotranspiration (ET) values. The monthly infiltration amounts in the landscaped areas, assuming silty soils, we calculated using the continuous WinSLAMM simulations. Those values were subtracted from the monthly ET values to obtain the monthly deficits per month, and the daily deficits per house per day.

Table 6-8. Calculations for Medium Density Area Irrigation Demands for Great Lakes Region.

Great Lakes		Silty				
	total rainfall (in/month)	ET (in/day)	ET (in/month)	total infiltration (in/month)	irrigation deficit (in/month)	irrigation deficit (gal/day/house)
Jan	1.49	0.00	0.00	1.43	n/a	0
Feb	0.83	0.00	0.00	0.79	n/a	0
Mar	1.81	0.00	0.00	1.73	n/a	0
Apr	3.46	0.11	3.30	2.42	0.88	114
May	3.13	0.15	4.65	3.03	1.62	204
Jun	4.55	0.16	4.80	3.81	0.99	129
Jul	4.07	0.16	4.96	3.95	1.01	127
Aug	3.74	0.13	4.03	3.69	0.34	43
Sep	1.78	0.11	3.30	1.75	1.55	202
Oct	2.60	0.08	2.48	2.54	n/a	0
Nov	1.32	0.04	1.20	1.25	n/a	0
Dec	0.61	0.00	0.00	0.57	n/a	0
	29.39		28.72	26.96	6.40	

1 in = 25.4 mm = 2.54 cm, 1 gallon = 3.785 Liter

Table 6-9 shows the results of the continuous simulations for different water tank volumes, and shows corresponding percentage roof runoff reductions. Figures 6-9 through 6-14 are plots of the roof runoff reductions vs. roof runoff storage tank volumes for the different areas and for sandy, silty, and clayey soil conditions.

Table 6-9. Calculated Benefits for Different Water Tank Volumes for Great Lakes Medium Density Residential Areas.

runoff water tank storage per house (ft^3)	rain barrel storage per house (ft^3) per roof area (ft^2, or ft depth over the roof)	total annual roof runoff per house (ft^3)	Rv for roof area	% reduction in roof runoff
0	0.0000	3683	0.91	
5	0.0007	3247	0.80	11.8
47	0.0072	2547	0.63	30.9
94	0.0144	2260	0.56	38.6
188	0.0288	1909	0.47	48.2
470	0.0719	1540	0.38	58.2
940	0.1439	1253	0.31	66.0
1880	0.2877	1195	0.30	67.6
2820	0.4316	1043	0.26	71.7
3760	0.5755	1043	0.26	71.7

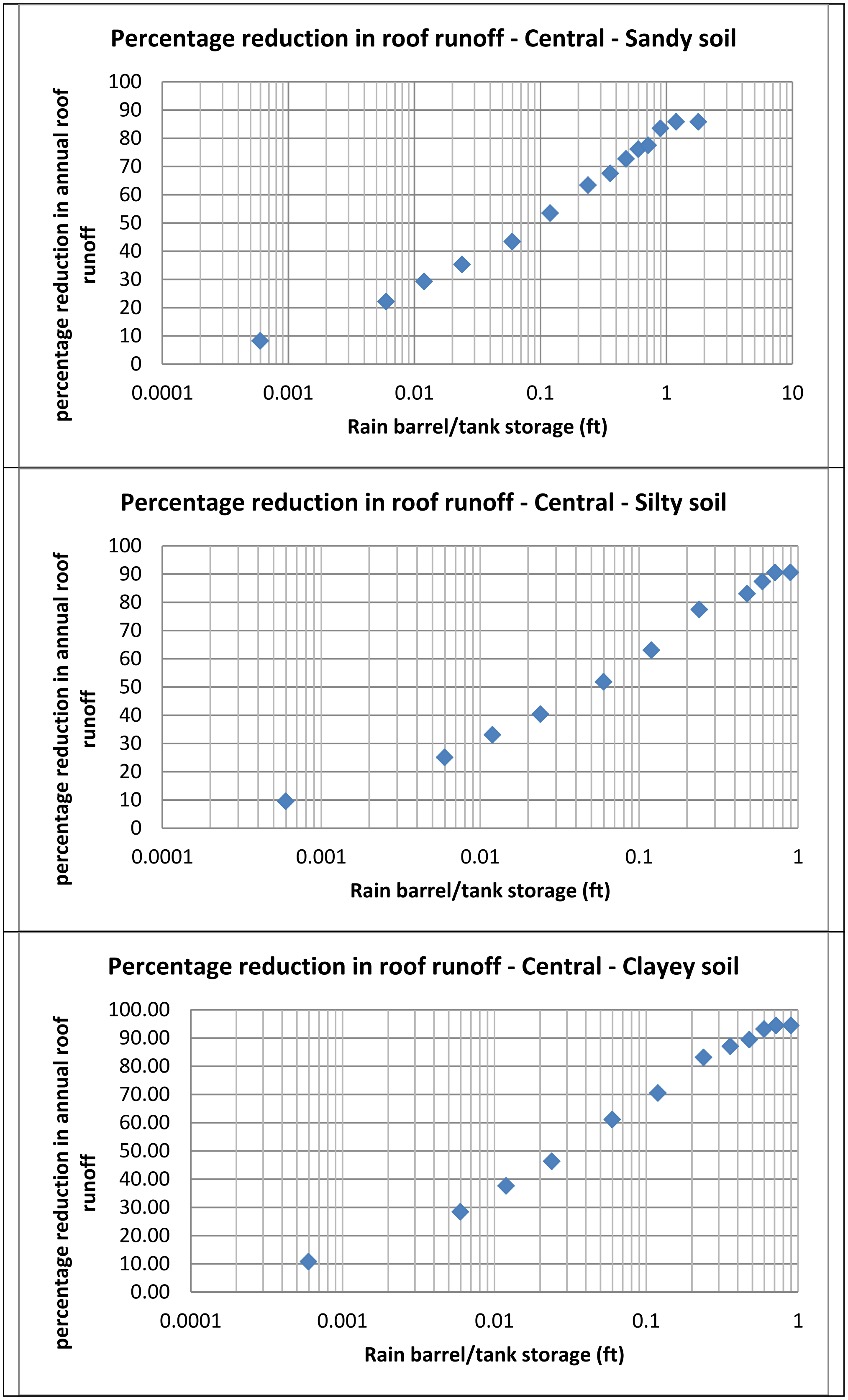


Figure 6-9. Roof Runoff and Water Tank Storage Production Functions for Medium Density Residential Areas in the Central Area of The U.S. (1 ft = 30.5 cm)

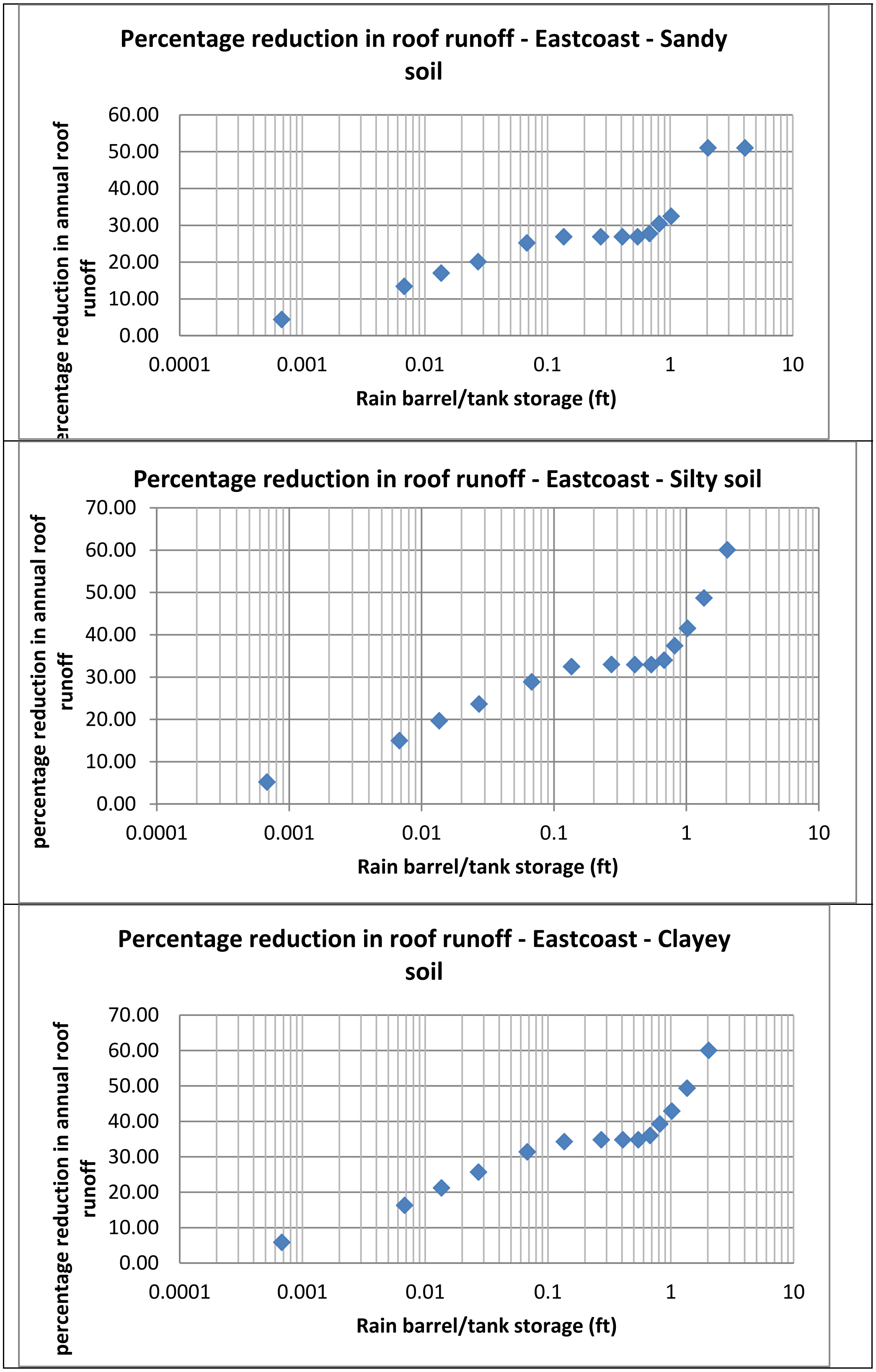


Figure 6-10. Roof Runoff and Water Tank Storage Production Functions for Medium Density Residential Areas in the East Coast Area of The U.S. (1 ft = 30.5 cm)

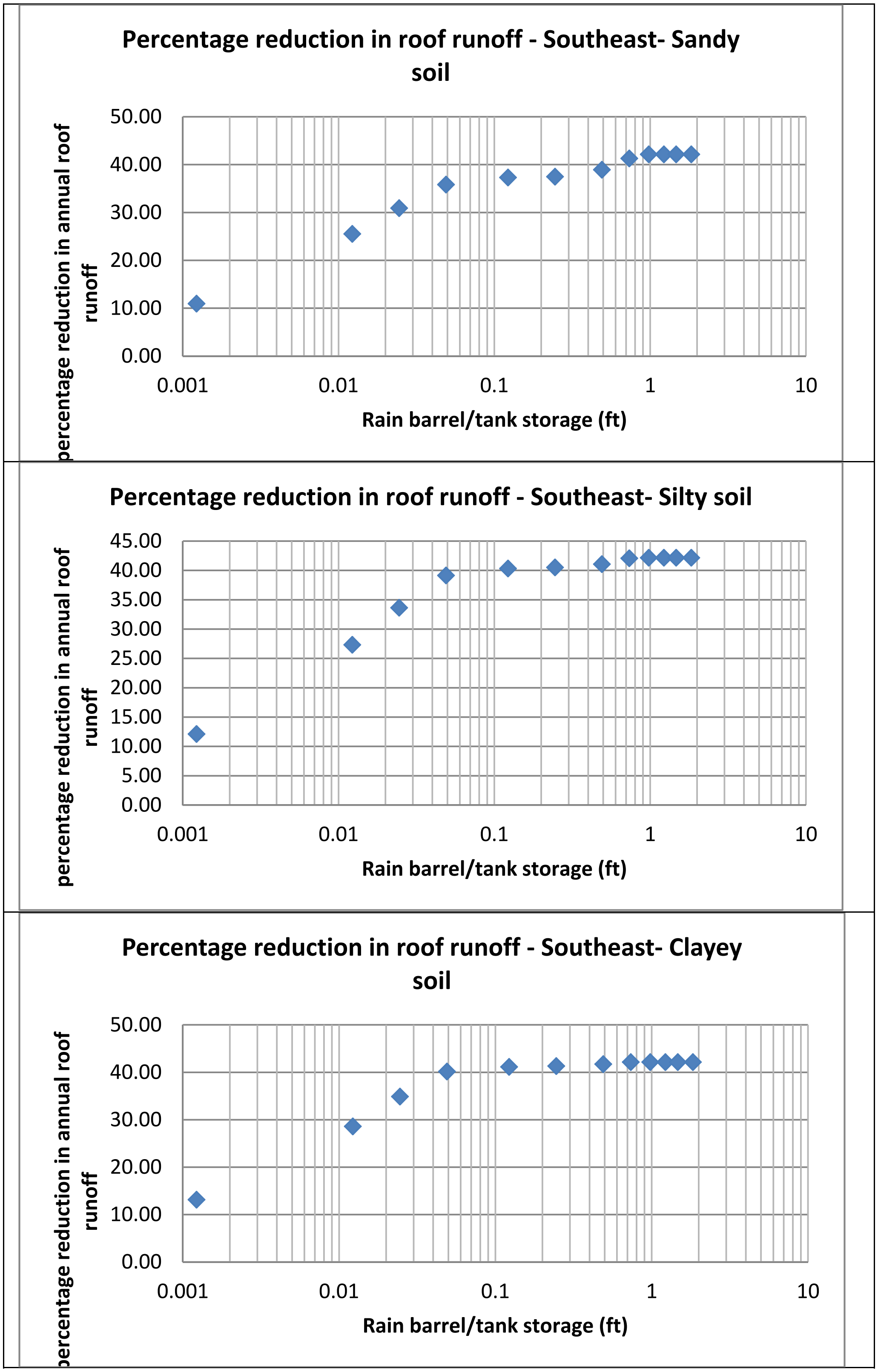


Figure 6-11. Roof Runoff and Water Tank Storage Production Functions for Medium Density Residential Areas in the South East Area of The U.S. (1 ft = 30.5 cm)

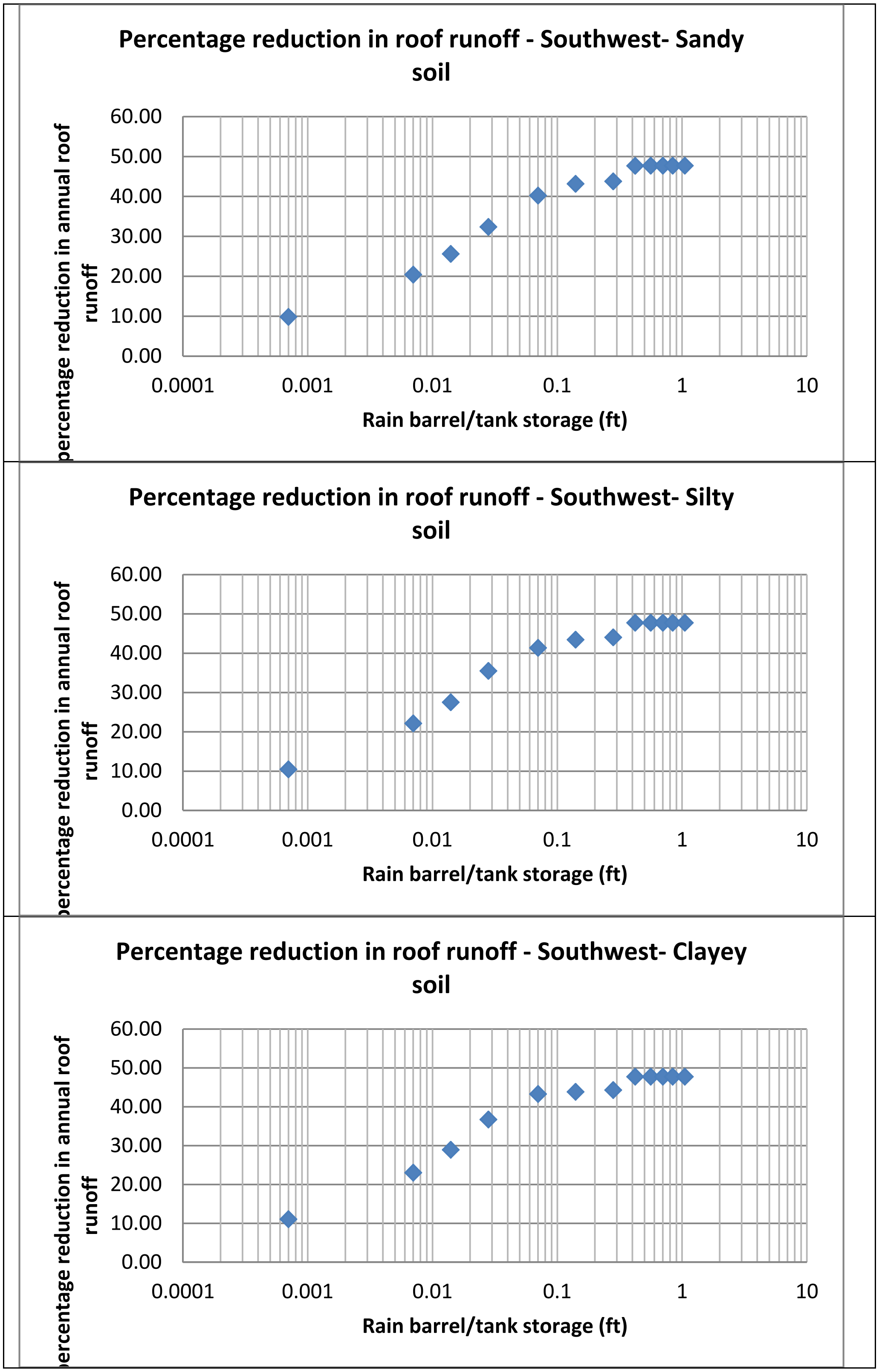


Figure 6-12. Roof Runoff and Water Tank Storage Production Functions For Medium Density Residential Areas in the South West Area of The U.S. (1 ft = 30.5 cm)

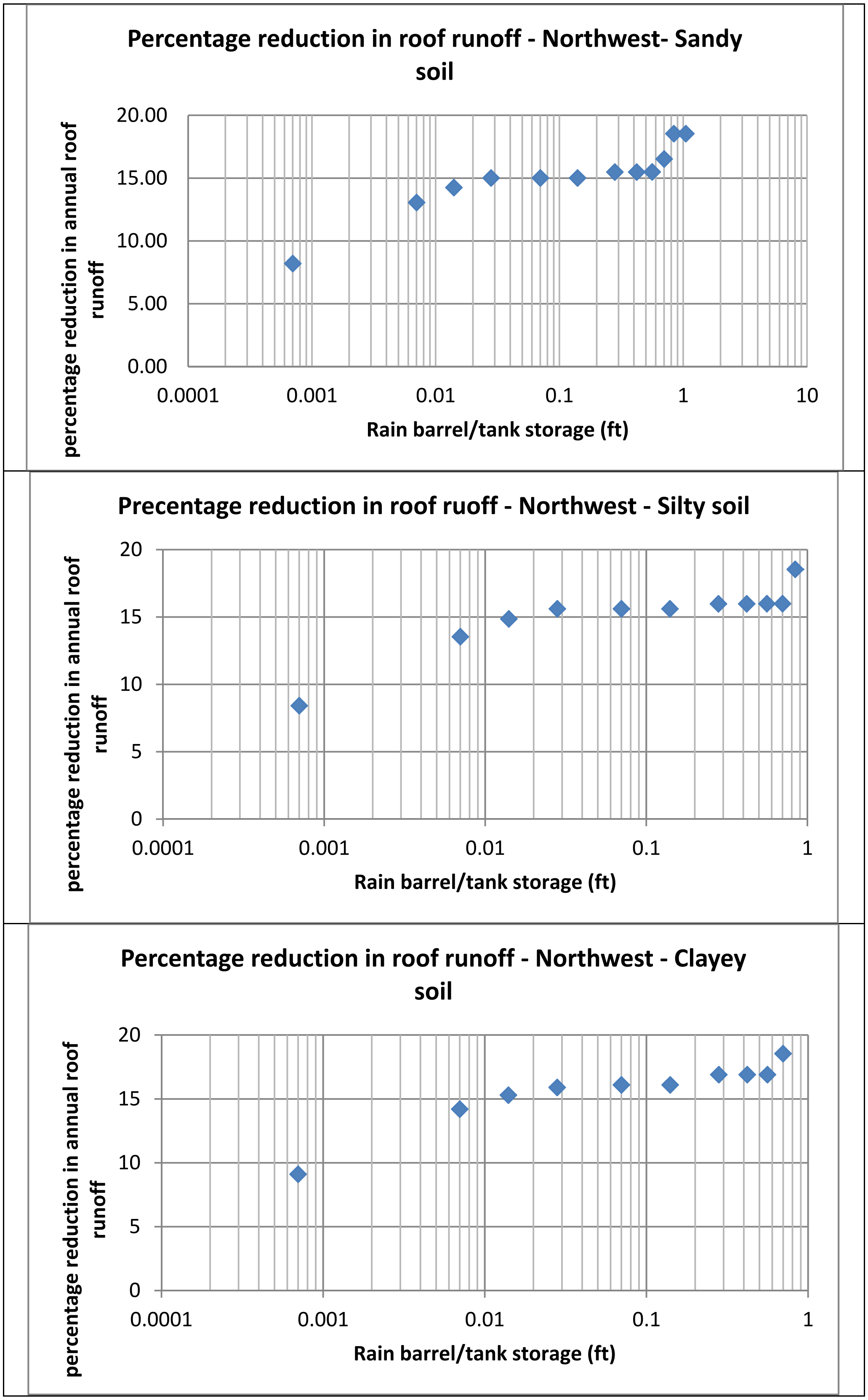


Figure 6-13. Roof Runoff and Water Tank Storage Production Functions for Medium Density Residential Areas in the North West Area of the U.S. (1 ft = 30.5 cm)

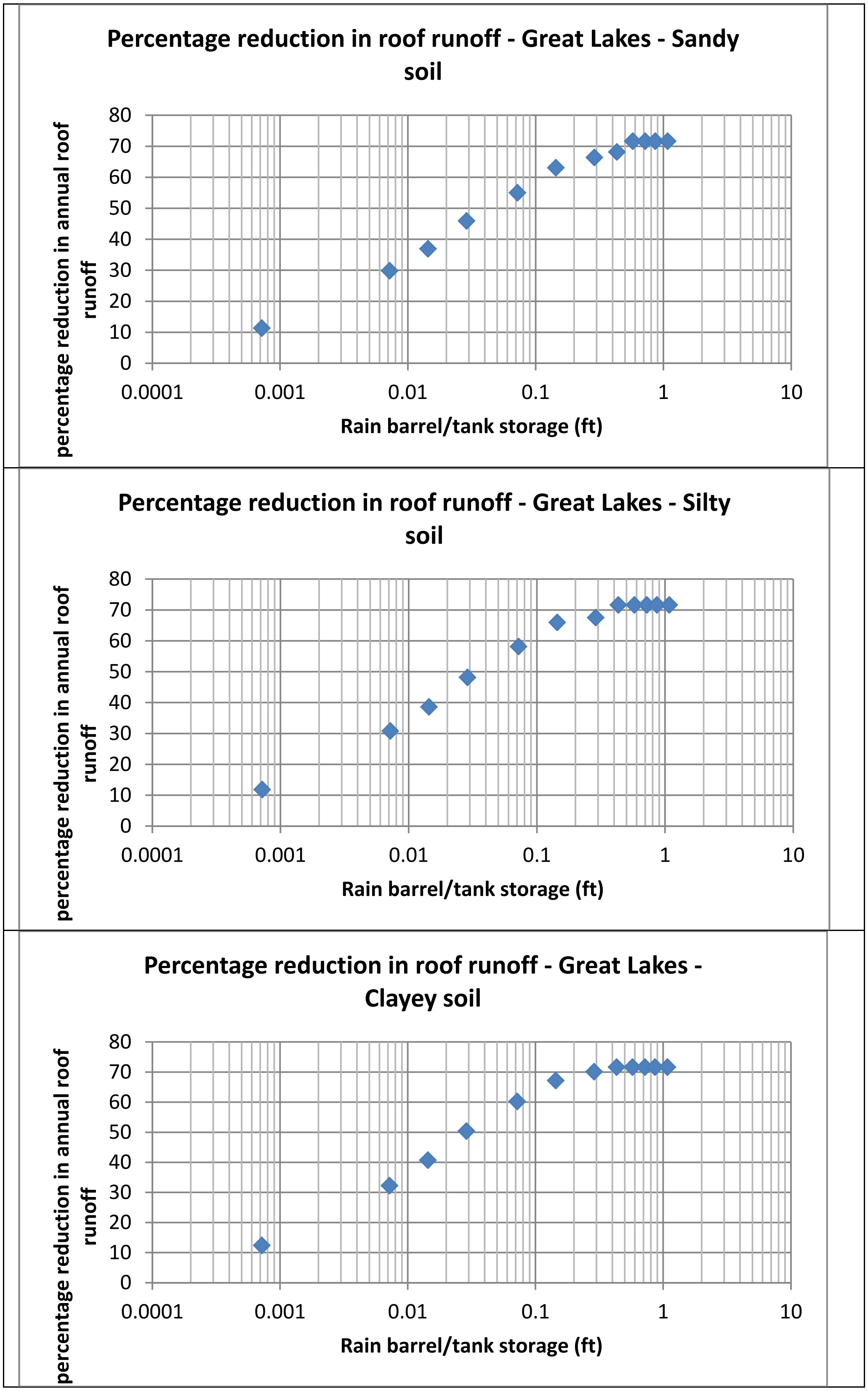


Figure 6-14. Roof Runoff and Water Tank Storage Production Functions for Medium Density Residential Areas in the Great Lakes Area of The U.S. (1 ft = 30.5 cm)

It is interesting to note that the sandy soil areas resulted in barely lower maximum levels of performance (very small difference) because more of the rainfall falling directly on the landscaped areas contributed to soil moisture, resulting in less of an irrigation demand to match the ET deficit. However, all three of the soil conditions were very similar, except for the extreme values where very minor differences are seen. Table 6-10 summarizes the results of these calculations (for the silty soil conditions). The Central U.S. area has the highest potential level of control because the ET demands best match the rain distributions. The Great Lakes area also had a high level of control. The East Coast, Southeast, and Southwest regions all had moderate levels of maximum control due to poorer matches of ET and rainfall, or greater amounts of rainfall. The Northwest region has the poorest maximum level of control, and large storage tanks are not likely very effective due to small ET-infiltration deficits.

Table 6-10. Maximum Roof Runoff Harvesting Benefits for Regional Conditions. (Medium Density Residential Land Uses)

Region	total roof area (%)	landscaped area (%)	ratio of roof area to landscaped area	representative city	study period annual rain fall (in) (5-year period, 1995 to 2000)	maximum roof runoff control (%), silty soil conditions	storage tank size for max roof runoff control (ft^3 storage/ft^2 roof area), silty soil conditions
Central	18.1	62.5	0.29	Kansas City, MO	33.46	90.6	0.72
East Coast	15.9	54.5	0.29	Newark, NJ	53.01	61.1	2.00
Southeast	8.81	81.08	0.11	Birmingham, AL	49.84	42.2	0.73
Southwest	15.4	61.2	0.25	Los Angeles, CA	16.73	47.7	0.42
Northwest	15.4	61.2	0.25	Seattle, WA	41.69	15.6	0.03
Great Lakes	15	57.5	0.26	Madison, WI	28.65	71.7	0.43

- 1 ft = 30.5 cm

The ratios of roof areas to landscaped areas for the medium density land uses range from 0.11 to 0.29 (0.25); the ratios for low density land uses range from 0.05 to 0.23 (most at 0.11); while the ratios for strip commercial areas range from 1.8 to 4.0 (most at 2.3). Low density residential area irrigation uses would therefore have a greater maximum benefit compared to the medium density areas, while the strip commercial areas would have much worse maximum benefits due to the lack of landscaped areas to irrigate and the relatively large roof areas.

6.3 Example Home Rainwater Harvesting Systems

Home rainwater harvesting systems can range from the simple rain barrel with an outlet spigot with a hose attachment to more complex and larger systems. The following website, http://www.builditsolar.com/Projects/Water/Water.htm#RainWaterHarvestSystems, contains descriptions of several rainwater harvesting systems constructed by homeowners. Many of these descriptions contain a list of parts, details on the piping and pumping system, plus costs. A summary of three projects/resources from the site is provided below.

#1: 2500 gallon rainwater tank, Bozeman, MT (http://www.builditsolar.com/Projects/Water/ShopRainCol/Collection.htm). The roof in question was a gambrel shop roof and an extension roof (both made of composition shingles), providing a total of 925 sq ft of collection area. Aluminum gutters are used to collect the roof runoff and transport it to PVC piping and a 2,500 gallon dark polyethylene tank. There is a first flush diverter just prior to the tank inlet to remove the first 3.5 gallons from the system. This homeowner chose a manual diverter mechanism made as a simple standpipe. On the last downflow pipe leading to the tank, the homeowner installed a tee fitting. Attached to the tee is a vertical pipe that is capped on the other end. The tee branches into the pipe leading to the tank. Therefore, when it first rains, the vertical pipe fills up (approximately 3.5 gallons, or 0.01 inches of roof storage) before any water is sent to the tank. At the bottom of the diverter pipe is a spigot that has to be opened and the pipe drained between storms, releasing the stored first 0.01 inch of roof runoff water.

The harvested rainwater is removed from the tank using a 120 VAC pump. An overflow pipe connects to the tank near the top and diverts water to an area for irrigation when the water volume exceeds the tank volume. The collection system page (found using the link above) has many photographs showing the installation of the entire system.

The estimated cost for the home-owner built project was slightly less than $1,400, broken down in Table 6-11.

Table 6-11. Estimated Costs for Home-Owner Built Rain Water Harvesting System.

Item	Cost	Notes
Tank (2,500 gal)	$800	Additional cost for shipping and gravel pad support (estimated at $300)
Gutters	$300 - $400	Owner chose to have gutters professionally installed
Pipes and fitting	$200	Hardware store
Electrical Supplies for Outlet (to operate pump)	$15	
Pump (0.5 hp from Northern Tool)	$50	

#2: Resource Guide from Humboldt State University, California (http://www.ccathsu.com/waterconservation/karlaFA2003/). This website was developed to provide guidance for people who want to set up and install a rainwater harvesting system. It includes sample calculations for the Humboldt, CA area, but the calculations can be adapted for other areas of the country.

The page starts out by asking questions about the project. Question 1 requires the user to identify the type of roof being used for harvesting. The website suggests that metal roofs be used. This site was developed prior to the newer published research on the pollutant release from uncoated galvanized metal (Clark et al. 2008). Question 2 addresses the volume of runoff that can be expected, while Question 3 addresses the size of the storage tank based on needs and potential reserve during drought conditions.

The next section of the page addresses the list of materials and estimated costs. These costs are out of date (2002/2003 costs), but can provide a first estimate for scaling up based on the relationship between those costs and current costs. The materials listed on the site include the tank, gutters (plus leaf guards), piping (pipes and fittings), and a base material for stabilizing the tank.

The final section of the page provides pointers/suggestions for laying out and installing the system. These include the need for the tank inlet to be lower than the gutter, the need to prevent leaves from entering the system (and potentially from being on the roof used for harvesting rainwater, piping size, and the pressure benefits of installing the tank on the highest ground available.

#3: Ersson Harvesting System (http://www.appropedia.org/Ersson_rainwater_harvest_and_purification_(original)), Portland, OR. This case study describes a residential rainwater harvesting installation. The water is captured from a 1,200 sq ft roof and is used for household purposes. The site has several pictures of the design and of the installation.

The section on maintenance describes how the greatest concerns were keeping the gutters and screens clean. The UV light must be replaced approximately once per year. The water is tested annually and the tank is cleaned every summer when it runs dry. Similar to the first case study, a vertical standpipe was used initially to collect the initial wash-off from the runoff. The standpipe must be manually emptied between storms. Several years into the operation, the owners installed a commercial roof washer.

The estimated cost for the home-owner built project was approximately $1,500, broken down as shown in Table 6-12.

Table 6-12. Cost Components for Home-Owner Built Rain Water Harvesting System.

Item	Cost	Notes
Tank (1,500 gal)	$800	Snyder Industries (suggested to price at agricultural or farm stores)
Gutters	No cost specified	
Pipes and fitting	No cost specified	
Electrical Supplies for Outlet (to operate pump)	$15	
Pump (0.5 hp from Jacuzzi)	$250	Adjustable pressure from 20 to 30 psi. Shallow-well pump.
Particulate filters (20 and 5 µm particle size)	$20 each	Replacement cartridges $3 - $5 each
UV light sterilizer (rated at 10 gpm)	$350	PURA model UV20-1. Uses about 40 W. Fluorescent bulb rates at 9,600 h (about 1 yr of continuous use). Replacement bulb $80.
Screening to cover cistern		
Roof washer to divert first 7.5 gal of captured water		
20 gal butyl rubber diaphragm pressure storage tank	$150	
Reduced pressure backflow prevention device	$120	Required by city to prevent backflow of water into city's piping system.
Water meter (optional)	$40	

6.3.1 Commercial and Industrial Rainwater Harvesting Systems

Similar to residential systems, commercial and industrial systems are sized based on both the anticipated water capture and on the needs of the site. The concerns over the water quality are the same for each use, with the potential exception of the quality of the atmospheric deposition on the roofs. In residential areas, the runoff likely will represent the air quality plus potentially local airborne pollutants, including very small grass clippings, bird fecal matter, etc. In commercial and industrial areas, bird fecal matter is still a concern. In addition, commercial roof runoff may have a higher concentration of petroleum-based hydrocarbons (from local vehicular traffic) and industrial roof runoff may reflect the airborne output of the industry, especially those stacks that are upwind of the roof.

Many companies provide commercially-sized rainwater harvesting systems. A sampling of the companies advertising their rainwater harvesting design and/or installation includes the following. Several company websites provide case studies to illustrate the types of systems they have installed. If case studies are provided, a sampling is provided below the company contact information.

- Water Harvesting Solutions WAHASO (304 South Lincoln St., Suite 100, Hinsdale, IL 60521, 800-580-5350) http://www.wahaso.com/
    - Valley Forge Field House, Chicago, IL
    - Panduit Corporation, Tinley Park, IL
    - Comfort Stations, City of Chicago, IL
    - University of South Florida, Patel Center for Global Solutions, Tampa, FL

- BRAE Home Office (550 E. 5th St, Oakboro, NC 28129-9019, 800-772-1958) http://www.braewater.com/home
  - AdvancED, Alpharetta, GA
  - Sam's Club #8209, Fayetteville, AR
  - North Carolina Arboretum, Asheville, NC
  - Lowe's Store #0031, Hendersonville, NC
  - Lowe's Store #2650, Belmont, NC
  - Public Works Yard (washout garbage trucks), Kinston, NC
  - Craven County Cooperative Extension, New Bern, NC
  - Cigas Machine, Pottstown, PA
  - Atlanta Public Safety Annex, Atlanta, GACHRIS Kids
- SARG Water Solutions (1627 N Stone Ave, Tucson, AZ 85716, (520) 299-7246) http://www.sargwatersolutions.com/
  - Naval Air Station, Jacksonville, FL
  - New Mexico Highlands University, Las Vegas, NM
  - The Sea Ranch, Sonoma County, CA
  - Tucson Community Food Bank, Tucson, AZ
- Pure Water LLC (9768 Maumelle Blvd, N. LIttle Rock, AR 72113, 800-324-1744) http://purewater2000.com/

6.4 Evapotranspiration (ET) Calculations and Mapping in Urban Areas as an Application for Beneficial Uses of Stormwater

As noted in the above example calculations, knowledge of local or regional ET conditions, at least on a monthly basis, is critical to determine the irrigation deficit that can be met by using harvested stormwater. The following discussion, along with Appendices A and B contain material describing ET applications in urban areas and typical ET values that can be applied to these calculations. There are several methods to calculate ET, and these are also described.

In the U.S., ET monitoring is primarily focused in agricultural and wild land environments. With educational advancements stressing water conservation in urban areas, there is a new desire to apply ET data as a part of wastewater reuse options for supplemental irrigation, and for more accurate modeling of rain garden and green roof controls for stormwater management. Climate-based methods are the most common method used to monitor ET. Evapotranspiration potential, ET_o, is only relevant for a standard condition that reflects normalized agricultural conditions. The ET_o value is therefore adjusted according to the soils, plants, and growing season conditions. Most of these adjustment factors were developed for agricultural situations and their use in highly disturbed urban environments has not been well-documented. The available ET_o values are also not located in urban areas. One of the tasks of this research is to examine these available ET_o values and map them for major urban areas. The product of mapping these locations will be used in conjunction with associated rainfall information to calculate irrigation requirements in urban areas as part of this project on the beneficial uses of stormwater.

The Desert Research Institute hosts a site called the Remote Automated Weather Stations (RAWS) Climate Archive that has served as the basis for the data used in this report. The site houses an array of climate data (including daily ET_o values) for all 50 states, and covers a large portion of the geographic area of the U.S. The archive currently houses historic data for more than 2,200 RAWS units across the U.S. This project uses the daily time series data recovered from the archive to obtain long-term average monthly ET_o values by location suitable for stormwater modeling applications. Users will then be able to choose ET_o values from tabulated data by regional maps that best fits their location.

Evapotranspiration (ET) can be an important aspect to complete a water balance in a bioretention device (Pitt, et al. 2008). ET represents the water loss from plant and soil surfaces. Evaporation, the first component in ET, is commonly understood because its effects can be measured and are in many cases clearly visible. Transpiration is the process by which plants expel water drawn from the soil. These elements combine to form ET which can be measured by a multitude of methods. The water, most of which is not retained in the plant, transports the essential nutrients plants need for growth. Therefore, monitoring water loss by ET, especially during a growing season, is critical in maintaining a suitable level of soil moisture. This report section looks at the current uses of ET and its applicability to stormwater management practices. The goal is to improve the beneficial uses of stormwater in urban areas.

In this report, most of the ET values were obtained from historic records collected by Remote Automated Weather Stations (RAWS). One of the products of this research is to examine these available ET_o values and map them for major urban areas. The product of mapping these locations could be used in conjunction with associated rainfall information to calculate irrigation requirements for alternative uses for stormwater. Users will then be able to choose ET_o values from tabulated data by regional maps that best fits their location.

6.4.1 Evapotranspiration Data Uses

In the United States, monitoring Evapotranspiration (ET) is primarily focused in agricultural and wild land environments. In agriculture, the growth potential of crops is dependent on a farmer’s ability to monitor soil moisture for use in irrigation. Their ability to determine irrigation requirements is based on potential ET for the crop planted. With each different crop, the estimated ET will change. An approximation of this water loss helps form an irrigation schedule for the duration of a crop’s growing season. Therefore, most available data and coefficients are developed for plant species associated with agriculture. One task of this project was to provide ET data for use in disturbed urban environments, which will vary from the ET used in agricultural or forested lands where this data has historically been used. The results from these agricultural-based methods in urban environments have not been well-documented.

The next major use of ET data is for, wildland and rangeland areas, which are common in most regions of the U.S. Most of these areas are sparsely populated, and are more vulnerable to natural disasters such as wildfires. In monitoring ET in these areas, the goal is not to recharge soil moisture as in agriculture, but instead monitor drought and land management. The difference between agricultural and wildland ET is primarily that, outside of forestry, these areas are not harvested. Wildland ET is determined by placing weather stations into rural locations that constantly monitor ambient conditions and communicate those conditions by satellite. These RAWS systems are an excellent source for ET and complete climate data for most of the United States. RAWS play a critical role in defending wildfires, especially in the western U.S. RAWS are also used extensively by researchers in monitoring air quality as well as climate change. Data collected by these stations is forwarded to many organizations that collect and store this data for later use. The data is available to the public over the internet at locations such as the RAWS Climate Archive.

Applying agricultural and wildland ET data resources to urban areas can be useful. Instead of creating a new weather station system, researchers can use existing archives for a specific region. One of the areas where these archives then become a valuable resource is stormwater management practices. Some of these emerging practices include wastewater reuse options for supplemental irrigation, and more accurate modeling of rain garden and green roof controls. Bioretention devices are a broad category of emerging stormwater that are being applied in many areas of the U.S., although they are most popular along the east coast (Pitt, et al. 2008). However, most ET data readily available does not cover the urban areas where these devices are being implemented. Researchers conducting experiments in stormwater management often use equipment similar to RAWS for monitoring ambient conditions during their monitoring activities. During a recent comparison of rain gardens in clay and sandy soils by the United States Geological Survey (USGS), ET was used extensively to compare infiltration rates for turf grasses to natural prairie vegetation (Selbig, 2010). The ET was calculated using data collected from an onsite weather station.

Alternatively, it may be viable to collect ET onsite. However, collecting time-series data onsite can be impractical for large scale management practices. There is a need for researchers and stormwater managers to estimate the ET portion in a water balance. The ET is used to calculate an irrigation requirement by subtracting the percent of precipitation used as soil recharge from the estimated ET, as described previously.

6.4.2 Example Alternative Irrigation Water Use Calculations

Tables 6-13 and 6-14 and Figures 6-15 and 6-16 are calculated supplemental irrigation requirements for residential areas in Millburn, NJ (Pitt and Talebi, 2012). These areas have roofs that are about 325 m^2 in area (3,500 ft^2) corresponding to about 13.5% of the land use, and landscaped areas about 1440 m^2 (15,500 ft^2) corresponding to about 61% of the land use, with a relatively high roof to landscaped area ratio of about 0.23 (large homes and small lots). Table 6-13 and Figure 6-15 show the irrigation needs that can be considered the minimum amount by barely meeting the landscaped area evapotranspiration requirements (assuming all of the rainfall contributes to soil moisture, which is true for rains less than about 25 mm (1 inch) in depth, but some of the rain flows to the storm drainage system for larger rains. The monthly rainfall compared to the monthly ET is shown in Figure 6-15 and illustrates how supplemental irrigation would be needed in the summer months, as expected. Table 6-13 shows there calculations, including the monthly irrigation needs in gallons per day per house. This rate would be used for barely meeting the ET needs with excessive irrigation. Excessive irrigation water would result in runoff (if applied at a rate greater than the infiltration rate of the surface soils), and recharge of the shallow groundwater. For a water conservation program, this irrigation amount is usually the target. However, for a stormwater management goal, maximum utilization of the roof runoff may be desired.

Table 6-13. Irrigation Needs to Satisfy Evapotranspiration Requirements for Essex County, NJ (Pitt and Talebi, 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual
Average monthly rain (in/mo)	3.42	3.11	4.16	3.71	3.99	2.88	4.21	4.04	3.61	3.06	3.70	3.47	43.37
Average monthly ET (in/mo)	0.47	0.85	3.26	3.90	4.81	4.65	4.81	4.19	3.60	3.57	3.00	1.40	38.47
deficit for ET needs (in/mo)	0.00	0.00	0.00	0.19	0.81	1.77	0.60	0.15	0.00	0.51	0.00	0.00	4.03
Deficit ET needed (gal/day/house) 0.36 acres	0	0	0	63	256	577	188	47	0	160	0	0	39,200 gal/year

(1 in/mo = 25 mm/mo)

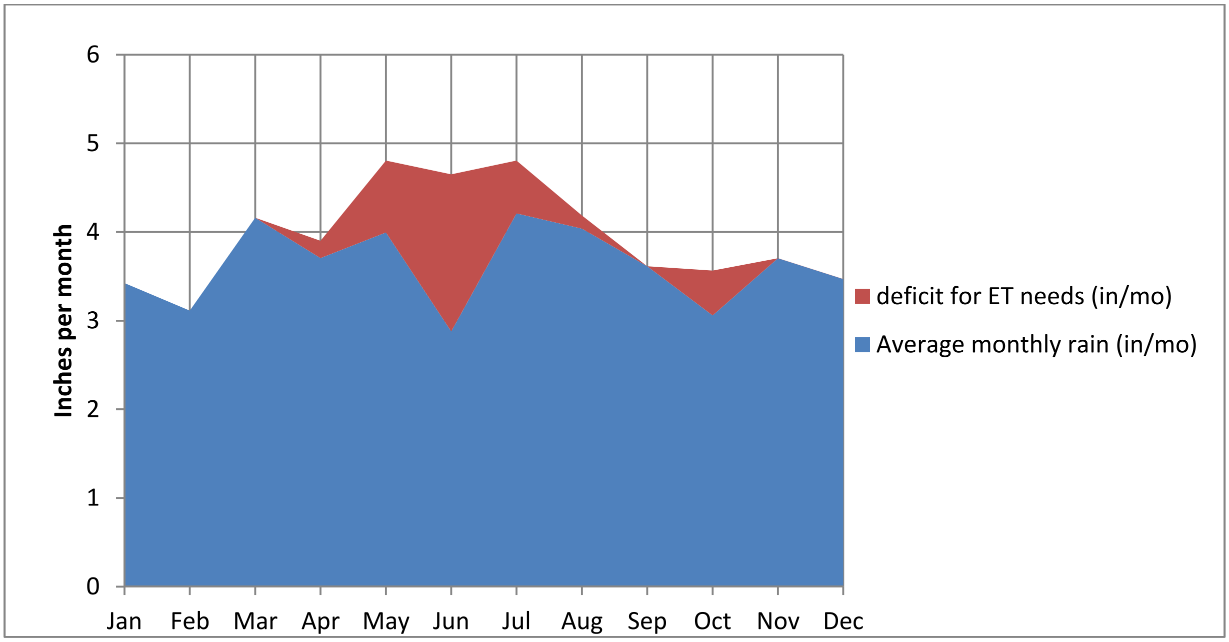


Figure 6-15. Plot of supplemental irrigation needs to match evapotranspiration deficit for Essex County, NJ. (1 in/mo = 25 mm/mo)

For maximum use of the roof runoff to decrease runoff volumes, it is desired to irrigate at the highest rate possible, without causing harm to the plants. Therefore, Table 6-14 and Figure 6-16 show an alternative corresponding to a possible maximum use of the roof runoff. For a "healthy" lawn, total water applied (including rain) is generally about 25 mm (1inch) of water per week, or 100 mm (4 inches) per month. Excessive watering is harmful to plants, so indiscriminate over-watering is to be avoided. Some plants can accommodate additional water. As an example, Kentucky Bluegrass, the most common lawn plant in the US, needs about 64 mm/week (2.5 in/week), or more, during the heat of the summer, and should receive some moisture during the winter. Table 6-14 therefore calculates supplemental irrigation for 12 mm (0.5 inches) per week in the dormant season and up to 64 mm/week (2.5 inches/week) in the hot months. Natural rains are expected to meet the cold season moisture requirements. The total irrigation needs for this moisture series is about 318,000 gallons (1,200 m^3) per year per home. This is about eight times the amount needed to barely satisfy the ET requirements noted above. However, the roofs in the Millburn study area are only expected to produce about 90,000 gallons (340 m^3) of roof runoff per year, or less than a third of the Bluegrass needs but more than twice the needs for the ET deficit. Therefore, it may be possible to use runoff from other areas, besides the roofs, for supplemental irrigation.

Table 6-14. Irrigation Needs to Satisfy Heavily Irrigated Lawn for Essex County, NJ (Pitt and Talebi, 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual
Average monthly rain (in/mo)	3.42	3.11	4.16	3.71	3.99	2.88	4.21	4.04	3.61	3.06	3.70	3.47	43.37
Lawn moisture needs (in/mo)	2.00	2.00	4.00	4.00	8.00	8.00	10.00	10.00	10.00	8.00	4.00	2.00	72.00
Deficit irrigation need (in/mo)	0.00	0.00	0.00	0.29	4.01	5.12	5.79	5.96	6.39	4.94	0.30	0.00	32.80
Deficit irrigation needed (gallons/day/house) 0.36 acres	0	0	0	96	1263	1669	1826	1880	2081	1558	96	0	318,000 gal/year

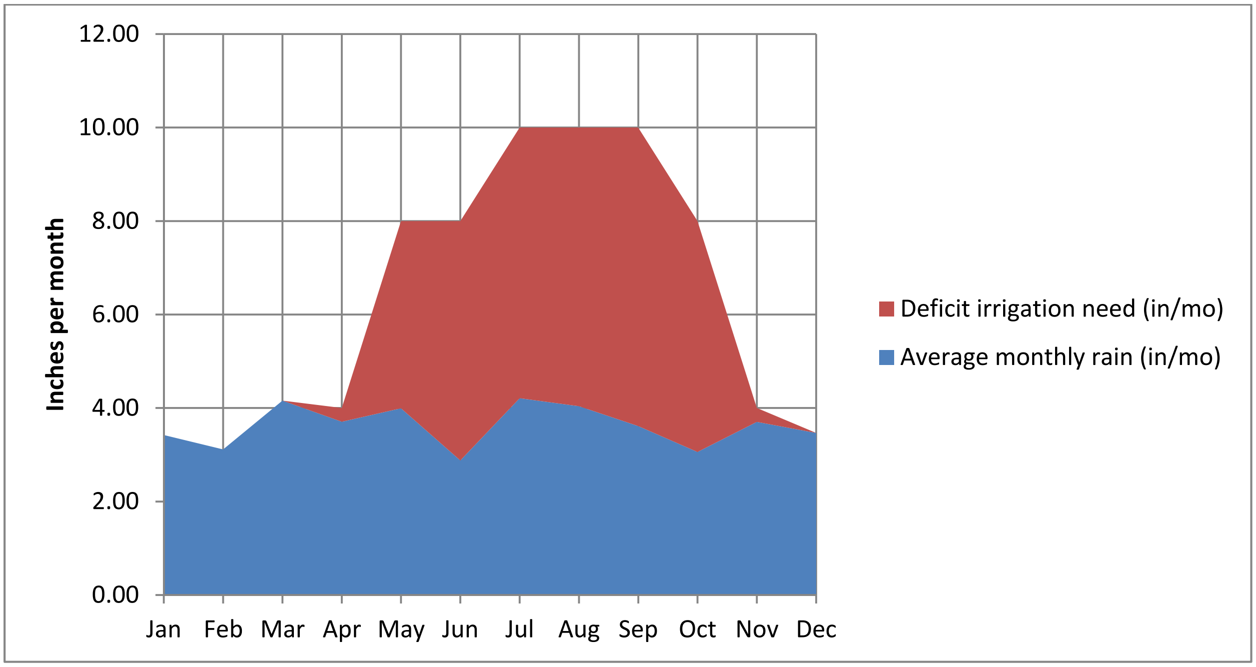


Figure 6-16. Plot of supplemental irrigation needs to match heavily watered lawn (0.5 to 2.5 inches/week) deficit for Essex County, NJ. (1 in/mo = 25 mm/mo)

6.5 Summary

This report section focuses on quantifying the benefits of rainwater harvesting systems, especially by providing guidance on sizing water storage tanks/cisterns and the selection of vegetation to optimize the system’s goals. Continuous simulations using about five years of rain data were used to calculate production functions to show the abilities of different sized rain tanks in reducing roof runoff quantities. In many areas, rainfall occurs out of synchronization with the ET requirements, requiring unusually large storage tanks, or limited performance. For other situations, the ratio of landscaped land available to irrigate was small compared to the roof areas, also leading to limited performance. In the Central and Great Lakes regions of the U.S., the greatest benefits of water storage tanks was observed, as these areas have rainfall that well match the ET deficits. In very wet (the South East or North West) areas of the U.S., performance was limited because of insufficient landscaped areas in medium density residential areas compared to roof areas to utilize most of the available roof runoff water. In the South West, the rainfall pattern was significantly out of sync with the ET deficit, also resulting in reduced benefits. In the Central and Great Lakes regions, water storage tanks of about 0.5 inches of storage can provide about 70-90% roof runoff reductions.

The costs of homeowner built rainwater harvesting systems can be modest, with most being less than a $2,000. Large systems with larger tanks and with water treatment systems are obviously more costly. Many commercial turn-key systems are also now available in many locations of the country, but these are more costly than the owner-built systems.

Evapotranspiration (ET) is a fundamental data need when sizing or evaluating stormwater beneficial use systems relying on irrigation. Good ET data applicable to urban settings is difficult to obtain from available sources. Conventional calculation methods, developed for agricultural or wild land areas, do not correspond well to measured ET values that have been obtained in the few urban projects. It is determined that the data recovered from the WRCC Climate Data Archive (the most comprehensive ET data source for the entire country), though not initially useful, could be post-processed for use in ET related projects in urban areas. Additional research should be conducted using these rates in urban experiments which are expected to aid in the development of a stronger relationship between the measured wildland ET and actual well watered conditions for a bioretention or other stormwater management-based project.

This report serves as a foundation for selecting biofilter and landscaping vegetation and helps to explain some characteristics necessary in implementing a good stormwater management landscape plan. As more research on the subject is conducted, and resources are compiled, many of these new practices should evolve into standard operating procedures for much of the U.S.

6.6 Useful Web-Based References

6.6.1 Greenroof Resources and Plant Lists

http://www.hrt.msu.edu/greenroof/PDF/08%20GetterRoweExtensionBulletin.pdf
http://www.bae.ncsu.edu/topic/raingarden/plants.htm
http://dnr.wi.gov/runoff/rg/index.htm#plant_lists
http://www.public.coe.edu/McLoud/RainGarden/plants.htm
http://www.umext.maine.edu/onlinepubs/pdfpubs/2702.pdf

6.6.2 Drought tolerant Plants, Trees, and Shrubs Plant Lists

http://www.bae.ncsu.edu/programs/extension/publicat/wqwm/ag508_3/
http://ohioline.osu.edu/hyg-fact/1000/1643.html
http://www.uri.edu/ce/factsheets/sheets/droughttolerant.html
http://www.umassgreeninfo.org/fact_sheets/plant_culture/drought_tolerant_plants.pdf
http://georgiafaces.caes.uga.edu/index.cfm?public=viewStory&pk_id=1063
http://bexar-tx.tamu.edu/HomeHort/F1Column/2006%20Articles/MAY21.htm
http://polkhort.ifas.ufl.edu/documents/publications/Drought%20Tolerant%20Plants.pdf

6.6.3 Raingarden Plant Lists

http://aswp.us/files/acnp/aswp_acnp_rain_garden_plants.pdf
http://www.uri.edu/ce/healthylandscapes/raingarden.htm
http://www.uvm.edu/~seagrant/communications/assets/VTRainGardenManualPlantList.pdf
http://www.extension.umn.edu/distribution/horticulture/components/08464-rain-garden.pdf
http://rainwaterharvesting.tamu.edu/files/2011/05/Rain-Garden-Plant-List-11-02-09.pdf
http://raingarden.wsu.edu/Plants.html
http://media.clemson.edu/public/restoration/carolina%20clear/toolbox/raingarden_trifoldkg031609.pdf
http://www.d.umn.edu/sustain/raingarden/scientificname.pdf
http://learningstore.uwex.edu/assets/pdfs/GWQ037.pdf

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APPENDIX A

EVAPOTRANSPIRATION DATA SOURCES AND MAP KEYS

A.1 ET Resources

There is no single system available for predicting average monthly ET rates for all locations in the U.S. that is readily available. However, there are several state and regional systems that provide rates for parts of the U.S. This leads to an overall lack of availability in approved ET rates for use by professionals in areas outside those zones. Those areas not covered include a majority of the U.S. (more specifically eastern states) and an even larger percent of urban areas, as most of the ET data available comes from states west of the Mississippi River. The following subsections highlight some of the features for these systems and their accessibility.

A.1.1 California Irrigation Management Information System (CIMIS)

CIMIS is probably the premier example for determining ET rates within a state. Their web services are capable of producing an array of useful information about most locations and regions in California. The stations monitored are not limited to traditional agricultural areas. In fact, stations can be found in urban zones (e.g. Hollywood Hills, Los Angeles County, California). The most useful product from CIMIS is the Reference ET Zone Map which covers the entire state of California. The map provides average rates for 18 regions within the state (Figure A-1).

Figure A-1. CIMIS Average ETo by Zone for California. http://wwwcimis.water.ca.gov/cimis/cimiSatEtoZones.jsp

A.1.2 Florida Automated Weather Network (FAWN)

Like the CIMIS program, the Florida Automated Weather Network (FAWN) provides a similar amount of data for most areas in Florida. The system is the best example available for the eastern U.S. Because of location and microclimate, the data offered by FAWN is only applicable within the state, but could be useful in comparing trends for areas of the lower southeastern states such as New Orleans, Louisiana. FAWN data is freely available online at: http://fawn.ifas.ufl.edu/

A.1.3 Texas ET Network

The Texas Agricultural Extension Service has well developed data sets that cover a long period of historical data. The service also provides a list of approved ET data that is referenced by the nearest major city. http://texaset.tamu.edu/pet.php

A.1.4 AgriMet

AgriMet is a satellite-based network of automated agricultural weather stations operated and maintained by the Bureau of Reclamation. The stations are located in irrigated agricultural areas throughout the Pacific Northwest and are dedicated to regional crop water use modeling, agricultural research, frost monitoring, and integrated pest and fertility management. http://www.usbr.gov/pn/agrimet/

A.1.5 Rainmaster

Rainmaster by Irritrol is the most complete and easiest to use resource for estimated average monthly ET rates for the U.S. The site only requires a nearby zip code to generate acceptable ET values for a site. This is a commercial site used as a resource for their irrigation equipment business. Because it is the only complete resource for the entire U.S., comparisons will be made with this data set with the other data from the state and regional systems. http://www.rainmaster.com/historicET.asp

A.1.6 Western Regional Climate Center

The two ET methods offered by the Western Regional Climate Data Center include Kimberly-Penman (K-P) equation and American Society of Civil Engineers Standardized Penman-Monteith equation (ASCE). When comparing these methods, the most notable distinction is that the K-P method is always slightly higher than the ASCE reference equation. This trend is continuous at each location considered in the study and is due to the reference crop (grass or alfalfa) that each equations models. Furthermore, the term Penman equation (which could represent either K-P or ASCE), is used for multiple versions of the original equation throughout literature and is often the subject of confusion (Howell et al, 2004). To reduce confusion about ET estimates, each equation will be defined separately.. http://www.raws.dri.edu/

A.1.7 ASCE Standardized Reference Equation

This equation is the most recent in a series of standards that have been adopted for reference ET. Both the ASCE and Food and Agriculture Organization (FAO-56) have approved versions of the equation with only minor differences (standard crop height being the major difference). ASCE reference ET can be calculated for only two specific crop heights, short (grasses) and tall (alfalfa). The data available in this report was calculated for a short reference crop. The result, ET_o or $\mathrm{ET_r}$, is the reference ET for a well-watered crop. It is calculated in millimeters per day$\left(\frac{mm}{day}\right)$, and converting inches per day$\left(\frac{in}{day}\right)$. The general form for the equation is shown below in Equation 5-1.

Equation 5-1. ASCE Standardized Reference Equation

$$ET_{ref} = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\frac{(\mathrm{C_n}\,)}{\mathrm{T} + 273}(\mathrm{e_s} - \mathrm{e_a})\mathrm{u_2}}{\Delta + \gamma(1 + \mathrm{c_d}\mathrm{u_2})}$$

A.1.8 Kimberly-Penman Equation

The 1982 Kimberly-Penman (K-P) equation, like the ASCE equation, is derived from the original Penman equation. It uses alfalfa as a reference crop with reference condition established as well-watered with 30-50 centimeters (approximately 12-20 inches) of top growth (Dockter, 1994). The general form of the K-P equation is shown below in Equation 5-2.

Equation5-2. Kimberly-Penman Equation

$$\lambda ET_r = \frac{\Delta}{\Delta + \gamma}(\mathrm{R}_n - \mathrm{G}) + \frac{\Delta}{\Delta + \gamma}6.43\mathrm{W}_f(\mathrm{e}_s - \mathrm{e}_a)$$

A.2 Issues with WRCC Data

After collecting data from the RAWS archive, several issues were noticed when comparing the data to approved rates from sources such as CIMIS, Rainmaster and other meteorological-based ET sites. In general, the trend for the RAWS data was lower in spring and summer months and higher in the fall and winter. This trend was the same for locations where approved rates could be compared to those available through the RAWS Archive. Most often rates differed by approximately 30-50%, but in some cases the differences could be in excess of 100% higher. Several factors could contribute to the deviation from data from an expected norm, but each factor considered is not solely responsible for the deviation. Instead they are most likely interrelated, and deviations for a single factor may alter one or more compounding the resulting difference.

A.2.1 Wind Speed

Wind speed affects the rate at which moisture is physically removed from the vicinity of the evaporative surface. The higher the wind, the faster the rate of evaporation can proceed at the surface. The standard height for measurement of wind speed at all RAWS locations is 20 feet above ground level. At most sites, as is common in wildland environments, the station is placed in a forested area in a clearing or open section of the woods. Under normal conditions, to properly monitor ET, a zone of clipped grass or crop fields would surround the weather station to standardize wind estimates for the site. In a best case scenario, the tree canopy surrounding the station is below the height of the wind instrument and is offset a suitable distance from the base of weather station. Under this condition, the wind measurement would be slightly reduced because of surface resistance from the upwind landscape. The ASCE Standardized reference equation recommends that wind speeds collected at heights other than 2 m above the ground be estimated using a logarithmic wind speed profile equation (ASCE 2005). If otherwise, the tree canopy would be higher than the instrument and any wind collected would first travel through the preceding forest. In this case, the wind speed estimate would be severely reduced, having a significant effect on accuracy of the Penman-Monteith equation. With the sheer number of stations associated with the program, it is difficult at best to evaluate each station to determine the correct vegetation height and the associated aerodynamic roughness coefficient required to complete wind speed adjustment to exact conditions. Either way, field standards outlined for the equation are not met, making wind speed a potential factor for lowered rates.

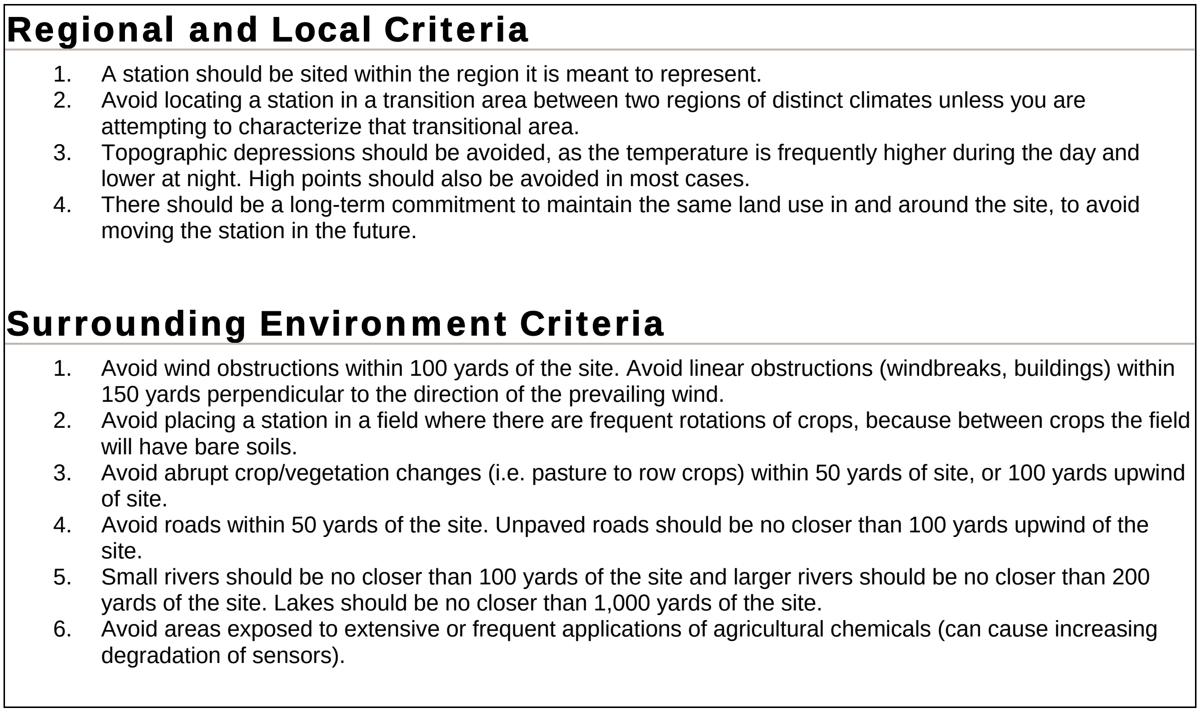
A.2.2 Mean Temperature

The second condition that may contribute to differences is mean daily temperature. During summer months, the shaded surface of a tree canopy could significantly reduce temperatures surrounding a weather station as well as lower potential evaporation. To reduce the likeliness of temperature effects on measurements, RAWS follow guidelines aimed at erecting stations in open areas that would reduce effects on temperature. However, these recommendations are not always met per the guidelines, and many of the sites could be erected in locations that could hinder climatic readings. A site visit to the Talladega National Forest’s Oakmulgee Division in Brent, Alabama inspected conditions for weather station monitoring. Although the site’s conditions mostly met the guidelines set by the National Wildfire Coordination Group, they differed significantly from a traditional agricultural weather station. The site was established in a lot approximately one acre in size and was surrounded by large trees. This scenario, although not indicative of every RAWS location in the U.S., shows the relative distinction of rates for these sites when compared to more conventional ET sources.

A.2.3 Elevation

Elevation is used to increase sunlight exposure on some sites as well as find open terrain in densely forested areas. Changes in elevation will have additional effects on ambient mean temperatures for a site. As elevation increases, temperature readings will drop linearly. In the case of hilly or mountainous terrain, extreme increases in elevation add to the other factors and further reduce ET estimates by reducing temperature and increasing wind potential. It is prescribed by CIMIS that depressions, hills, and ridges should be avoided if possible. Instead, stations should be placed in gentle terrain. In Figure A-2, a list for all CIMIS criteria clearly recommends conditions that differ from the expecting site conditions for RAWS locations.

However, in wildland environments, these conditions are sometimes unavoidable. The previous conditions as stated by CIMIS would rule out the usefulness of the data collected by the WRCC for traditional CIMIS stations because at many sites these conditions could not be met. Instead, the findings show that the data collected is typical for the conditions monitored by the WRCC. Rather than discredit a valuable resource for ET, an analysis of the relationship between these stations when compared to traditional ET rates is conducted in this report.



Regional and Local Criteria

1. A station should be sited within the region it is meant to represent.
2. Avoid locating a station in a transition area between two regions of distinct climates unless you are attempting to characterize that transitional area.
3. Topographic depressions should be avoided, as the temperature is frequently higher during the day and lower at night. High points should also be avoided in most cases.
4. There should be a long-term commitment to maintain the same land use in and around the site, to avoid moving the station in the future.

Surrounding Environment Criteria

1. Avoid wind obstructions within 100 yards of the site. Avoid linear obstructions (windbreaks, buildings) within 150 yards perpendicular to the direction of the prevailing wind.
2. Avoid placing a station in a field where there are frequent rotations of crops, because between crops the field will have bare soils.
3. Avoid abrupt crop/vegetation changes (i.e. pasture to row crops) within 50 yards of site, or 100 yards upwind of site.
4. Avoid roads within 50 yards of the site. Unpaved roads should be no closer than 100 yards upwind of the site.
5. Small rivers should be no closer than 100 yards of the site and larger rivers should be no closer than 200 yards of the site. Lakes should be no closer than 1,000 yards of the site.
6. Avoid areas exposed to extensive or frequent applications of agricultural chemicals (can cause increasing degradation of sensors).

Figure A-2. CIMIS Weather Station Criteria. http://wwwcimis.water.ca.gov/cimis/infoStnSiting.jsp

A.2.4 Humidity

Humidity is yet another very important factor that has strong effect on the water that physically transfers into the surrounding air. As ambient relative humidity increases, the eligible storage capacity of the air decreases. Relative humidity also increases as elevation rises and as temperature decreases. Both of which are expected conditions for many of the sites administered in wildland environments.

A.2.5 Seasonal Precipitation

Probably the most notable difference between the data collected from wildland environments and agricultural sites is that rates are higher than expected in winter months and lower during spring and summer when the growing season is active. During a normal twelve month period, a trend line for standardized grass reference monthly ET rates have a parabolic curve that peaks during the summer months of the growing season. The trend line for RAWS units has these same tendencies within a smaller range, and summer peaks that are much lower, as seen in Figure A-3. Precipitation is a key factor in this difference. As required for ASCE standards, monitoring ET uses a well-watered crop or grass surface. Wildland conditions do not include irrigation to maintain a well-watered surface. Without this additional water, surface evaporation, as well as transpiration, slows down without the advent of rainfall. Consequently, much of the rainfall received occurs during winter months and could explain why winter rates are higher than expected and summer peaks are considerable lower. Many sites, especially Rainmaster, report little to no ET during winter months. This is most likely because, in much of the country (especially northern states), winter correlates with an expectation for continuous snow cover. In that case there would be virtually no ET, there would only be an expectation for evaporation and sublimation.

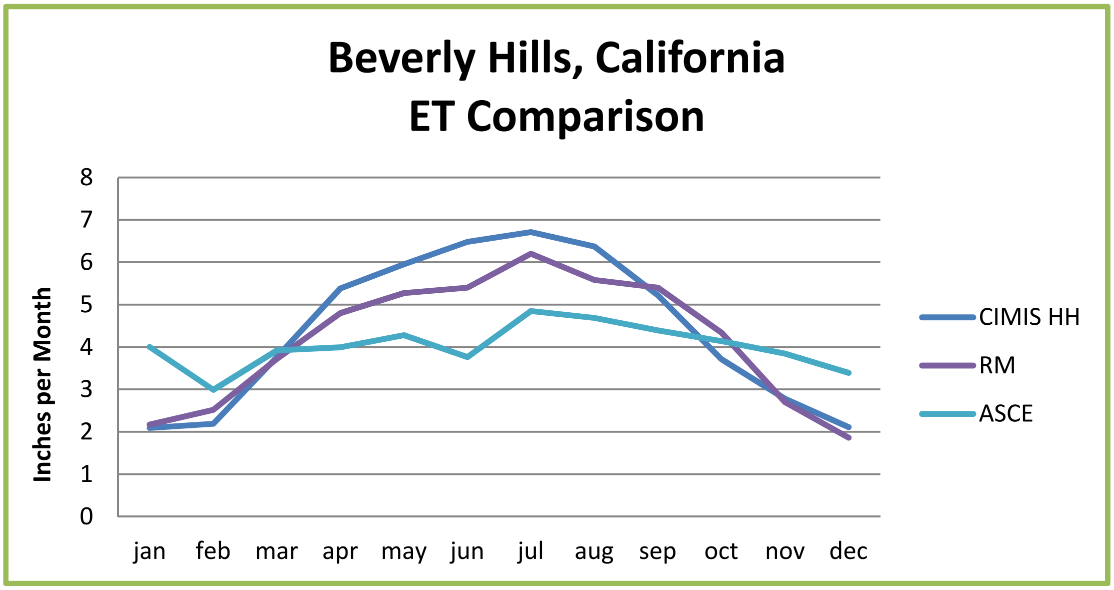


Figure A-3. CIMIS, Rainmaster, and RAWS ASCE Average Monthly Data Comparison.

- 1 in = 25.4 mm = 2.54 cm

A.3 ET Data Comparisons

A comparison of WRCC data against accepted values is required to validate the ET rates for use with bioretention devices. The comparisons were focused in locations where approved rates were available. Other areas where approved rates were not available were compared against Rainmaster data to ensure that each region of the U.S. was included. The goal for the comparison is to determine the differences associated with WRCC values when compared to approve rates. It is expected that the trends would vary by region with climate, elevation, distance from the equator, and land use. All these factors affect the growing season of plants and trees. For example, most areas of the southeastern U.S. have near year round growing seasons, where portions of the northern U.S. are severely limited due to surface freezing.

Additionally, factors such as vegetative density and plant species will also affect ET for a site. A study of the effects of site conditions on ET estimates was conducted in California to estimate ET for landscape plants. The study outlined three factors that distinctly alter the estimated ET for a site. In the next section, we will consider these factors to further refine the method of converting the WRCC wildland data into well watered ET estimates.

A.3.1 Landscape Coefficient Methods

A good lead to determining the relationship between the WRCC data and more practical agriculturally based values comes from a landscape plants study in California. The guide is a free publication from the California Department of Water Resources, and is a combination of two significant publications: *A Guide to Estimating Irrigation Needs of Landscape Plantings in California*: The Landscape Coefficient Method and *WUCOLS II*. The research was intended to reevaluate ET rates intended for crops for use in urban settings such as a landscaped park, home, or business. In theory, this research can be used in reverse to modify the natural conditions monitored in a wildland environment into useful rates for urban environments. There are three factors that are evaluated for a site that determine a site coefficient: Species factors, Density Factors, and Microclimate factors. These factors, once evaluated, are multiplied together to form a landscape plant coefficient (K_L). The coefficient is then multiplied by the local ET value (as seen in equation 5.2) to produce a water use estimate for the site. Because RAWS sites use a known water estimate, the guidelines can be used to estimate wildland conditions, and convert the values into more typical ET estimates that exceed annual rainfall. This, in turn, will help determine the potential water deficit in a given area.

A.3.2 Converting WRCC Data by the Landscape Coefficient Method

This proposed method was tested at the RAWS located in the Talladega National Forest, Oakmulgee Division in Brent, Al (Figure A-4). As previously stated, the site is erected in a small field surrounded by tall mixed timber. The ground cover surrounding the site is a low density cool season grass species. To develop a correction factor, you must first assign the three site condition coefficients as seen in Tables A-1 and A-2. The new coefficients are then applied to the growing season data (April to October) by dividing the original RAWS data by the new correction factor (K_L). The results, though initially rough, are raised to expected levels for a well water reference surface. Still, using this method requires the ability to visit a site. Without a site visit, it would be difficult to make the required assumptions to convert the data. Thus, this method could not be used for converting the RAWS data used in this report. The number of sites covered in the research and expansiveness of the travel area eliminate this method for the purposes of this project.

Figure A-4. Landscape Oakmulgee, Alabama RAWS Site Conditions.

Table A-1. Landscape Coefficient Methods Assessment Standards. (Costello et al., 2000)

Estimated Values of Landscape Coefficient Factors				
	Very Low	Low	Moderate	High
Species Factor	<0.1	0.1 to 0.3	0.4 to 0.6	0.7 to 0.9
Density Factor	-	0.5 to 0.9	1	1.1 to 1.3
Microclimate Factor	-	0.5 to 0.9	1	1.1 to 1.4

Equation 5-3 Landscape Coefficients Method

$K_L = \mathrm{k_S} * \mathrm{k}_d * \mathrm{k}_{mc}$
k_s = Landscape Coefficient
k_d = Plant Species Factor
k_{mc} = Microcimate Factor

Table A-2. Landscape Coefficient Estimate for Oakmulgee RAWS Data.

k values	**Observed Site Conditions**	**Assessed Category**	**Estimated Coefficient**
Species Factor	cool season grasses	High	.9*/.95
Density Factor	Low density groundcover	Low	0.75
Microclimate	Shaded with wind protection	Low	0.65
	$K_L = \mathrm{k_S} * \mathrm{k}_d * \mathrm{k}_{mc}$		.43*/.46
***Slight reduction in species factor to account for early spring growing season**			

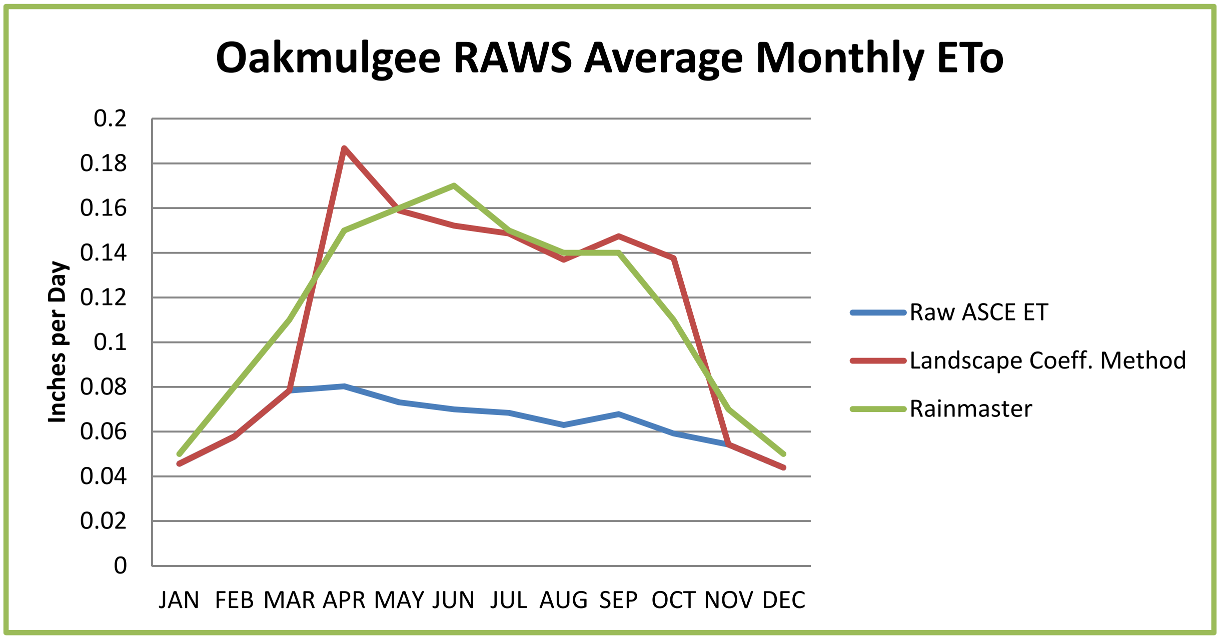


Figure A-5. Landscape Coefficient Method Estimate for Oakmulgee, Alabama RAWS.

- 1 in = 25.4 mm = 2.54 cm

A.3.3 Converting RAWS Data

A more practical approach is required for relating RAWS data to that of a well-watered crop. Similarly to the Landscape Method, by dividing RAWS data by approved rates, a coefficient is recovered that can be used to convert RAWS data into well watered ET estimates. To simplify the coefficients, they are rounded to the nearest 5/1000th place. For example, the 0.224451243 would be converted to 0.225. In the case that RAWS data exceeded approved values (almost always occurring in winter months), the coefficient is set to one in order show an increased potential for ET at the site. In areas where multiple ET sources are available, the highest estimates are utilized. In areas where no publicly available data can be used, the rates were compared to Rainmaster data with the nearest zip code. This method produces the best expected conditions for all data in the U.S. and could be useful in developing long-term coefficients for the sites covered in the report. Table A-3 shows how this method was developed. A full list of values for urban areas in the U.S. can be viewed in Appendix B.

Table A-3. Method for Converting RAWS Data.

	Correction Factor	=RAWS/Rainmaster	RAWS ASCE(in/day)	Rainmaster (in/day)	ASCE(in/day) Converted
JAN	1	#DIV/0!	0.02	0	0.019354839
FEB	1	#DIV/0!	0.03	0	0.026357143
MAR	0.4	0.389964158	0.04	0.09	0.087741935
APR	0.35	0.344761905	0.05	0.14	0.137904762
MAY	0.275	0.287347561	0.05	0.16	0.167184035
JUN	0.25	0.252042484	0.04	0.17	0.171388889
JUL	0.225	0.243330119	0.04	0.17	0.183849423
AUG	0.225	0.233873874	0.04	0.15	0.155915916
SEP	0.225	0.243162393	0.03	0.13	0.140493827
OCT	0.225	0.217350158	0.02	0.1	0.09660007
NOV	0.225	0.319910515	0.02	0.06	0.085309471
DEC	0.5	0.491721854	0.02	0.04	0.039337748

- 1 in = 25.4 mm = 2.54 cm

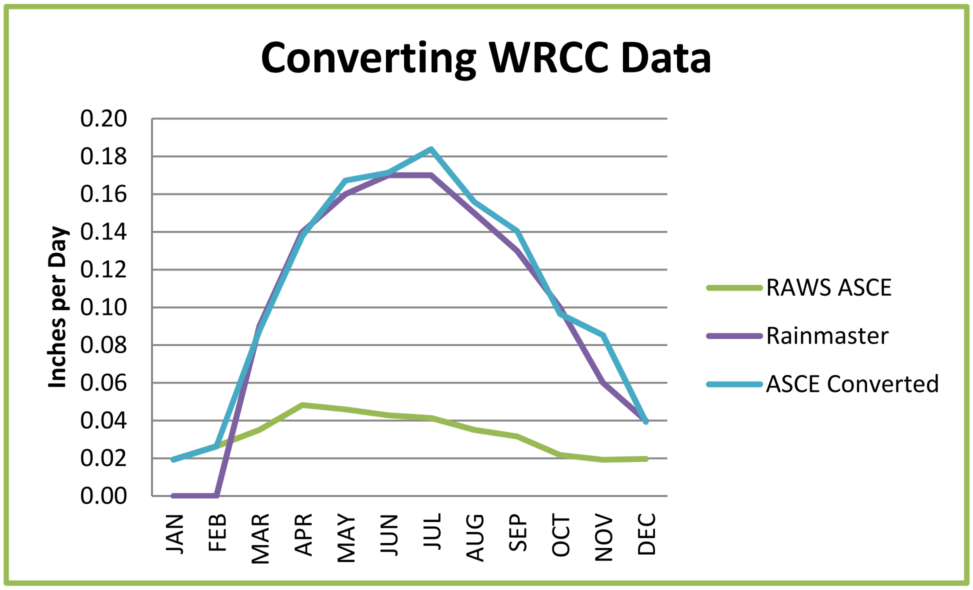


Figure A-6. Comparison of RAWS data to Rainmaster Averages before and after Conversion Method.

- 1 in = 25.4 mm = 2.54 cm

A.4 ET Discussion

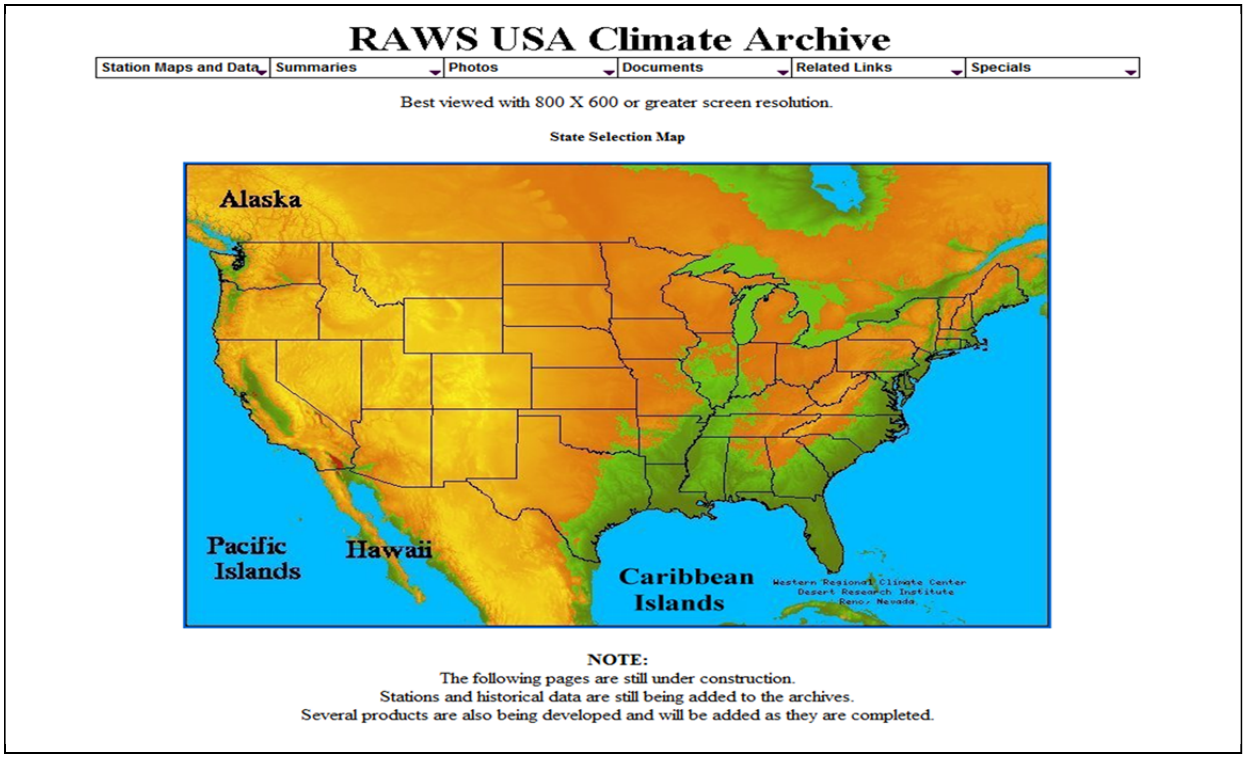
ET is defined as the rate at which readily available water is removed from the soil and plant surfaces expressed as the rate of latent heat transfer per unit area λET_{ref} or expressed as a depth of water evaporated and transpired from a reference crop (Jensen et al., 1990). Meaning that unless soil moisture is kept near field capacity, there will be times when ET estimates outweigh actual ET removed from the soil. Therefore, any comparison of ET methods or sources would instead follow a pragmatic approach. Calculating ET for the short reference crop does not mean that the values produced are only relevant for a small group of well watered cool season grasses. As is the same with K-P, the alfalfa reference crop is not the only crop serviced using this method. Instead, the short grass or alfalfa is merely a baseline for numerous other plant or crop surfaces that require ET estimates during a growing season. A plants actual ET is calculated from the product of these original equations by multiplying ET_o by approved coefficients for each plant type providing a daily estimate for the crop under well watered conditions. There are lists of approved coefficients (such as WUCOLS III) for both grass reference and alfalfa values, however these values are not interchangeable.

As previously stated, the primary difference between these two equations offered by the WRCC is their reference crop. In most cases, a short grass reference crop would be preferred in an urban setting because most landscapes are based on a well maintained grassy surface. Grasses are resilient plants and often recover in difficult drought conditions. However, grasses have limitations such as root depth that affect their applicability in stormwater reuse (e.g. rain gardens). Therefore, some users may believe that some plants and shrubs may be modeled better using an alfalfa reference ET. Alfalfa has a much deeper root system than turf grass. Hence some plants and shrubs with deeper root systems could have the ability to remove water held deeper in the soil than grass increasing the storage potential for a site as well as reducing losses from runoff. This approach could be supported in a study of prairie shrubs planted in rain gardens conducted in Wisconsin. The plants develop a root system capable of penetrating deep into the soil and may increase infiltrative capacity by creating macropores and other fissures allowing more rapid movement of water (Selbig, 2010). In reality, either of the methods could be useful for this kind of research because they offer the same information in a slightly different format. Coefficients have been developed for both grass and alfalfa references and since both rates are modeled from the same set of meteorological data there is not any significant difference between these values and the use of one over the other then becomes a matter of preference or necessity.

The eastern U.S. lacks good coverage of ET data. With increasing interest in researching stormwater water management issues, the collection of climate data in the eastern U.S. and more specifically urban areas is a necessity. Inversely, most RAWS units capable of monitoring the ambient conditions required to estimate ET using the Penman equation is most often located in the western U.S. Since the number of available RAWS locations is lower in the east; it is important to map the locations closest to urban areas. Conversely, there is limited documentation of the applicability of rural ET for use in urban areas.

It is estimated that there are noticeable differences in ET with land use (industrial areas, residential zones, downtown cityscapes). One of the issues that could exclude these stations as an ET source is the development of boundary layers from urban micro-climates (Grimmond and Oke, 1999). The formation of boundary layers may affect performance consistency between ET measured in a city versus ET collected along the edge of the city where a RAWS stations is most likely located. It is then important to continue documentation comparing the differences between urban experiments and rural based data and methods. Such experimentation will aid in the development of methods for utilizing this type of data in an urban setting.

Adding to the issue, since RAWS are located in natural environments, no supplemental irrigation is added to monitored zones creating an extremely reduced ET estimate for each site. The development of coefficients that modify the existing data to compare against approved rates could serve as a preliminary relation between the ambient differences for each site. As more data is recovered, a follow-up should be conducted to see if the coefficients are once again able to relate the natural conditions to those of a well-watered grass reference. Additionally, research should be conducted to determine if the elevated rates during winter months are a true perception for these sites. Otherwise additional time should be invested at determining the reason for the overestimation and developing a second relation to adjust the higher rates for winter months.



RAWS USA Climate Archive

Best viewed with 800 X 600 or greater screen resolution.

State Selection Map

NOTE:
The following pages are still under construction.
Stations and historical data are still being added to the archives.
Several products are also being developed and will be added as they are completed.

Figure A-7. RAWS Climate Archive Homepage. http://www.raws.dri.edu/

A.5 RAWS Climate Archive

The Western Regional Climate Center (WRCC) is conducting a project known as the Remote Automated Weather Stations (RAWS) Climate Archive. The WRCC is partnered with the Desert Research Institute (DRI) and the National Oceanic and Atmospheric Administration (NOAA). The WRCC provides climate information collected from RAWS units across the U.S. and stores the information on a server called the RAWS Climate Archive. The RAWS Climate Archive houses historical data for more than 2,200 RAWS base stations in nearly all 50 states and U.S. provinces. These units are remotely operated and solar-powered. The stations monitor wind, temperature, precipitation, humidity, solar radiation, and soil moisture and temperature. The data is collected via satellite at the National Interagency Fire Center in Boise, Idaho and forwarded to various organizations such as the WRCC. The discusses the methods by which data was retrieved from the site and converted for use in mapping.

A.6 Collecting Data for ET Calculations

From the RAWS homepage a base map of all U.S. states and provinces is shaded by a digital elevation map (DEM) as seen in Figure A-7. To find weather stations for an area select the state of interest. A new page with the selected state will appear on a magnified area of the map. Some states are of course small as seen in Figure A-8. The screen will include multiple states that border the state selected. In contrast, larger states such as Idaho will only provide the section of the state closest to the point of selection as seen in Figure A-9. On the left side of the screen a list of all stations in the magnified viewing area is provided to select a desired location by name. On the magnified map section there will also be points in the area denoting all locations on the map for which the archive has data. There are two types of points on this map. The first is the large point size and it denotes all active sites currently monitoring times series climatic conditions. The other points are smaller; they mark historic locations where data was once collected or sites that are currently inactive. Users may select locations from the list or by clicking on a point location. However, in some western states it is difficult to distinguish points that are close to each other, and selecting from the list may be preferred. Upon selecting a location, the archive will generate a list of all available data by month and year for the location as seen in Figure A-10. This is useful in determining if the sight has recorded enough data for use. All months highlighted in red contain at least partial data, and months colored in black are null. On the left hand side of this page is a list of query functions offered by the archive. For this project, we selected Daily Times Series Data. Upon selecting this option, a search engine appears where you can choose the timeframe of the desired data (Figure A-11). In addition, there are several optional monitoring conditions that can be selected to include Penman ET and ASCE reference ET (Figure A-12). Once the desired parameters are submitted, the archive will generate a tabular report that includes daily totals within the data range (Figure A-13).

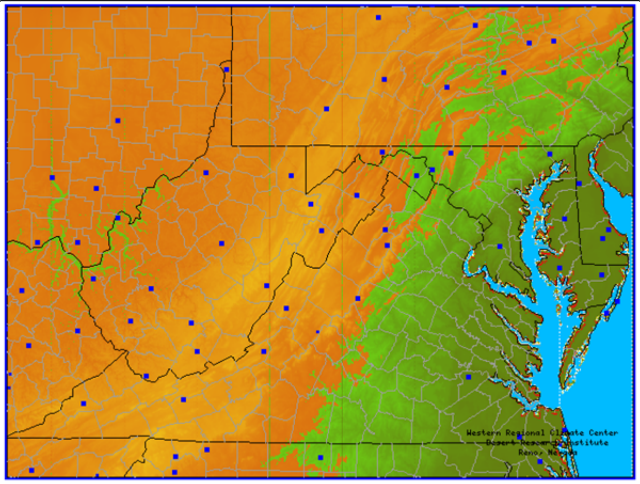


Figure A-8. State Selection: West Virginia.

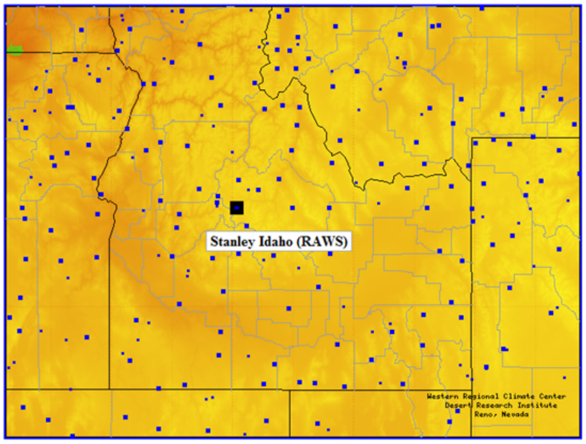
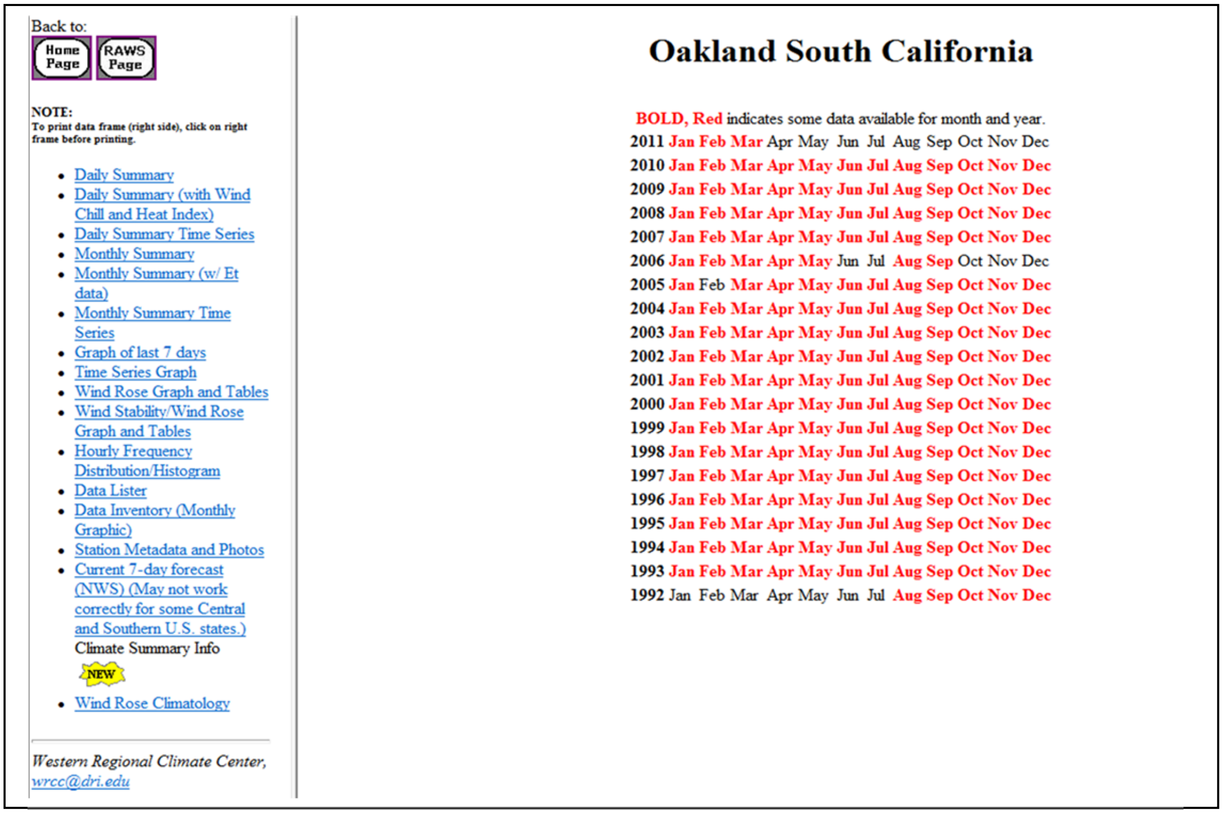


Figure A-9. State Selection: Southern Idaho.



Back to:

NOTE:
To print data frame (right side), click on right frame before printing.

- Daily Summary
- Daily Summary (with Wind Chill and Heat Index)
- Daily Summary Time Series
- Monthly Summary
- Monthly Summary (w/ Et data)
- Monthly Summary Time Series
- Graph of last 7 days
- Time Series Graph
- Wind Rose Graph and Tables
- Wind Stability/Wind Rose Graph and Tables
- Hourly Frequency Distribution/Histogram
- Data Lister
- Data Inventory (Monthly Graphic)
- Station Metadata and Photos
- Current 7-day forecast (NWS) (May not work correctly for some Central and Southern U.S. states.)

  Climate Summary Info
  NEW
- Wind Rose Climatology

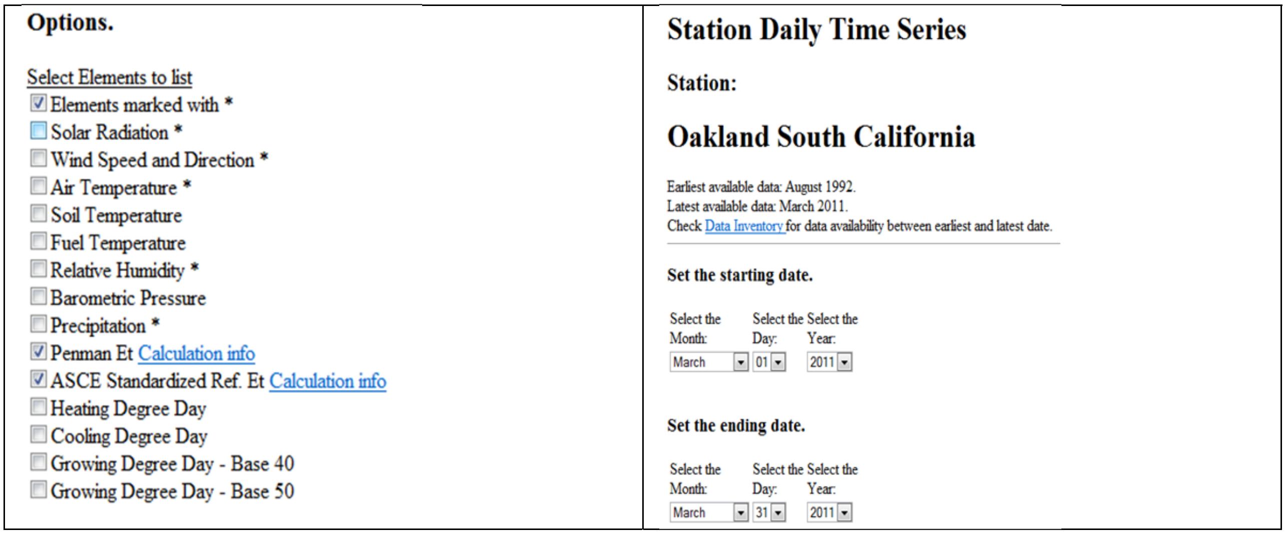
Western Regional Climate Center,
wrcc@dri.edu

Oakland South California

BOLD, Red indicates some data available for month and year.

2011	**Jan**	**Feb**	**Mar**	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2009	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2008	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2007	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	**Jan**	**Feb**	**Mar**	**Apr**	**May**	Jun	Jul	**Aug**	**Sep**	Oct	Nov	Dec
2005	**Jan**	Feb	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2004	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2003	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2002	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2001	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2000	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1999	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1998	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1997	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1996	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1995	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1994	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1993	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1992	Jan	Feb	Mar	Apr	May	Jun	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

Figure A-10. Available Data for South Oakland, CA.



Options.

Select Elements to list
☑ Elements marked with *
☐ Solar Radiation *
☐ Wind Speed and Direction *
☐ Air Temperature *
☐ Soil Temperature
☐ Fuel Temperature
☐ Relative Humidity *
☐ Barometric Pressure
☐ Precipitation *
☑ Penman Et Calculation info
☑ ASCE Standardized Ref. Et Calculation info
☐ Heating Degree Day
☐ Cooling Degree Day
☐ Growing Degree Day - Base 40
☐ Growing Degree Day - Base 50

Station Daily Time Series

Station:

Oakland South California

Earliest available data: August 1992.
Latest available data: March 2011.
Check Data Inventory for data availability between earliest and latest date.

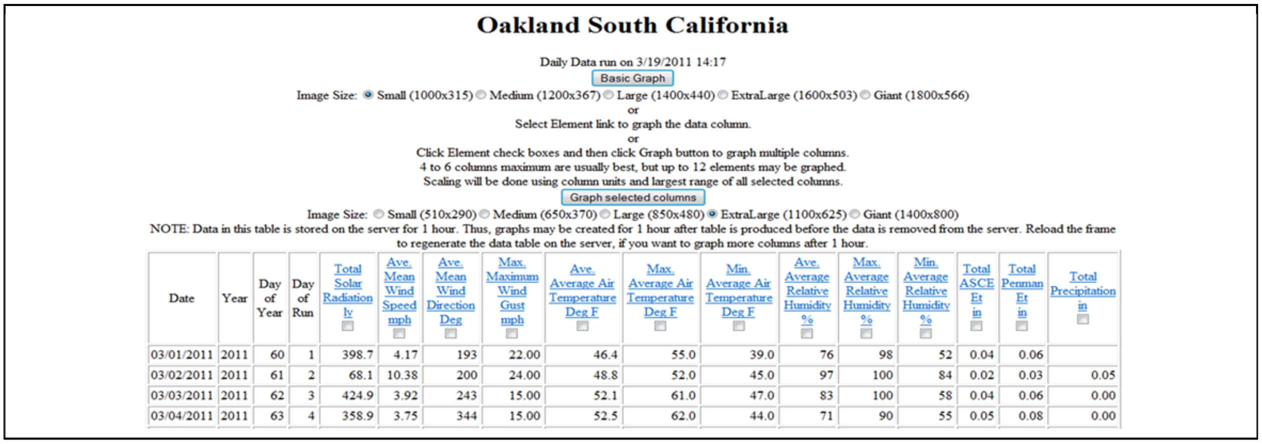
Set the starting date.

Select the Month: March
Select the Day: 01
Select the Year: 2011

Set the ending date.

Select the Month: March
Select the Day: 31
Select the Year: 2011

Figures A-11 and A-12. Historic Data Range Query Options and Optional Criteria for Daily Time Series Data.



Oakland South California

Daily Data run on 3/19/2011 14:17

Image Size: ● Small (1000x315) ○ Medium (1200x367) ○ Large (1400x440) ○ ExtraLarge (1600x503) ○ Giant (1800x566)

or

Select Element link to graph the data column.

or

Click Element check boxes and then click Graph button to graph multiple columns.
4 to 6 columns maximum are usually best, but up to 12 elements may be graphed.
Scaling will be done using column units and largest range of all selected columns.

Image Size: ○ Small (510x290) ○ Medium (650x370) ○ Large (850x480) ● ExtraLarge (1100x625) ○ Giant (1400x800)

NOTE: Data in this table is stored on the server for 1 hour. Thus, graphs may be created for 1 hour after table is produced before the data is removed from the server. Reload the frame to regenerate the data table on the server, if you want to graph more columns after 1 hour.

Date	Year	Day of Year	Day of Run	Total Solar Radiation ly ☐	Ave. Mean Wind Speed mph ☐	Ave. Mean Wind Direction Deg ☐	Max. Maximum Wind Gust mph ☐	Ave. Average Air Temperature Deg F ☐	Max. Average Air Temperature Deg F ☐	Min. Average Air Temperature Deg F ☐	Ave. Average Relative Humidity % ☐	Max. Average Relative Humidity % ☐	Min. Average Relative Humidity % ☐	Total ASCE Et in ☐	Total Penman Et in ☐	Total Precipitation in ☐
03/01/2011	2011	60	1	398.7	4.17	193	22.00	46.4	55.0	39.0	76	98	52	0.04	0.06	
03/02/2011	2011	61	2	68.1	10.38	200	24.00	48.8	52.0	45.0	97	100	84	0.02	0.03	0.05
03/03/2011	2011	62	3	424.9	3.92	243	15.00	52.1	61.0	47.0	83	100	58	0.04	0.06	0.00
03/04/2011	2011	63	4	358.9	3.75	344	15.00	52.5	62.0	44.0	71	90	55	0.05	0.08	0.00

Figure A-13. Summary Table for Daily Time Series Data with ET Added.

From these reports, the data can be imported into Excel where it can be sorted for use. For this report, the data is sorted by day of year and then separated by month. Then for each month, the average daily ET and standard deviation are determined using basic functions in Microsoft Excel. A full list of tables for each of the selected sites can be viewed in the List of Tables. To determine a site or group of sites that relate to an urban area, use the regionally based site maps. On each of these maps, the selected sites are placed geographically using ArcGIS 10. The locations are labeled according to their station ID from the List of Tables.

A.7 ET Mapping

ArcGIS 10 is geographic information system (GIS) program is capable of creating, editing, and analyzing geospatial data. The program was created by the Environmental Systems Research Institute (ESRI) which is the leading producer of GIS based software products worldwide. One of the goals of the project is to map locations ET for urban locations across the U.S. and ArcGIS 10 is well fitted to produce such products.

In addition to collecting and tabulating reference ET, a major goal for the project is mapping data spatially to aid in selecting the appropriate station for a site. The first step in producing these maps is attaining geographic locations for all sites in the RAWS archive. With the assistance of Jim Ashby, a senior climatologist with the WRCC, all locations and stations ID’s were received in a generic text file. The first step is to organize the data for later use with ArcGIS 10. This task is accomplished by importing the files (comma-delimited) into Excel. The files are then imported into to a GIS map as point data and form the basic information required to spatially relate map features for collected ET. A similar sequence is conducted for the stage and regional ET stations covered in this report.

Each time a new map is started in ArcGIS, a user must select a base map and coordinate system. This gives ArcMap a reference to place any additional data (such as the RAWS point data) added to the system. Since most of the data is located in the continental U.S., a GCS North American 1983 coordinate system is chosen over a state plane system. It is important to select the appropriate coordinate system based on your preferred projection area. Otherwise, points farthest from the center of projection will have significantly higher error and objects may appear nearer or farther from their actual location. This is important to the project because data collected from these RAWS locations will be selected for suitability based on distance from urban areas.

Next, a base map of U.S. Census Bureau state boundaries and territories is added into ArcMap. Once all layers are compiled an ESRI terrain map is added to help users interpret additional elements such as elevation for potential RAWS stations. Once all layers and attributes are added, map products can be produced for each region.

A.7.1 Reading Maps and Tables

Included with this report are two appendices-Appendix A: ET Map Key and Appendix B: Average Monthly ET Rates. The map key is used to determine the appropriate station to use for a site. Once the nearest station or stations is chosen from the map, the number can be cross referenced with the Map ID from the table in Appendix B. There are several tables from a number of resources to include two sets of data for RAWS (grass and alfalfa reference).

A.8 Considerations for Selecting Biofilter Vegetation

Implementing stormwater management practices demand certain plant life with specific characteristics. Ideal plants for these practices include turf grasses, plant, shrubs, and trees that withstand extended drought periods as well extremes like inundation from peak flow runoff events and excessive wastewater infiltration. Generally speaking, it is likely that most land cover options are fitted for one of these categories, but not recommended for the added moisture condition. The ability to cross reference plants that are suitable for droughts and high moisture produces fewer options to choose from. This report highlights preferred vegetative categories as part of a WERF-sponsored project aimed at exploring the beneficial uses of stormwater as well as examines some plants characteristics required for choosing specific species. This report also examines drought tolerance and recovery timelines, how to determine hardiness zone limitations for selecting species, and wastewater disposal through infiltration.

A.8.1 Methods for Selecting Groundcover

Selecting groundcover that will endure all seasons and accommodate healthy water consumption can be a difficult task. Quite often, plantings will accommodate extreme circumstances (such as 60 inches of annual precipitation), and succumb to other seasonal conditions such as a summer drought. Additionally, landscape plans are subject to their geographic region. Because of these limiting characteristics, selecting groundcover for stormwater management is an essential aspect of effectively implementing its practice. The best proven methods for selecting groundcover are hardiness zone mapping, heat zone mapping, the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) PLANTS Database, and by consulting the local agricultural extension office.

Hardiness zone mapping is a method of comparing local climates to a climate where a plant is known to grow well. This is the most common method and proves to work best because researchers can easily interpret the maps to eliminate plants that do not meet the hardiness criteria. Further, many recommended plant lists include a hardiness zone category designation.

Currently, two organizations have unique versions of the hardiness zone maps; United States Department of Agriculture (USDA) and National Arbor Day Foundation is featured in Figure A-14 with its 2006 version. The USDA map uses more categories and has more regional detail. The Arbor Day map, which was not USDA-approved, covers a more recent historic data range, but reduced the number of zones. Despite both maps being publicly accessible, most available resources reference the USDA Hardiness Zone map.

The second category that may be seen in plant lists is the heat index zone, this method is not as common on plant list. It is similar to a hardiness map, but represents the number days in a year above 86°F. Figure A-15 correlates to a map produced by the American Horticulture Society, and represents the severity of heat by location in the U.S.

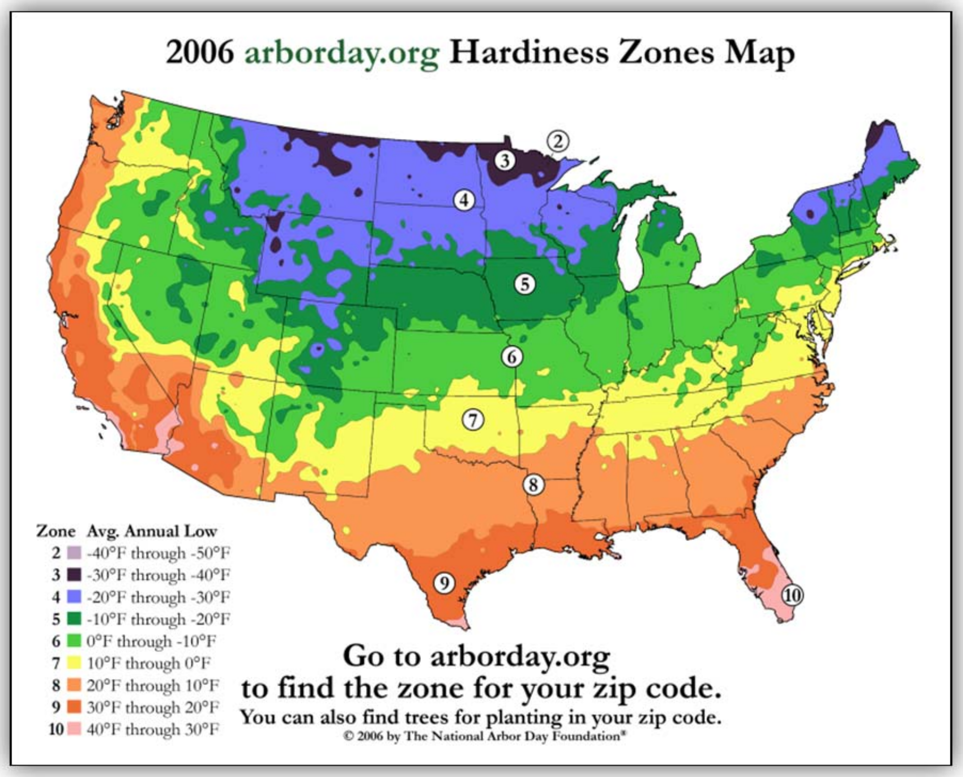


Figure A-14. Arbor Day Foundation Hardiness Zone Map, 2006. http://www.arborday.org/media/zones.cfm

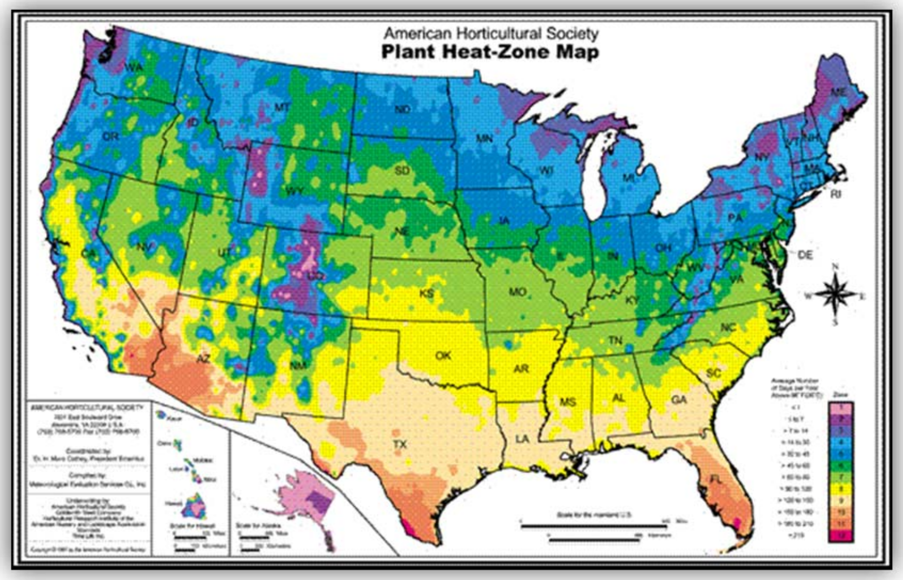
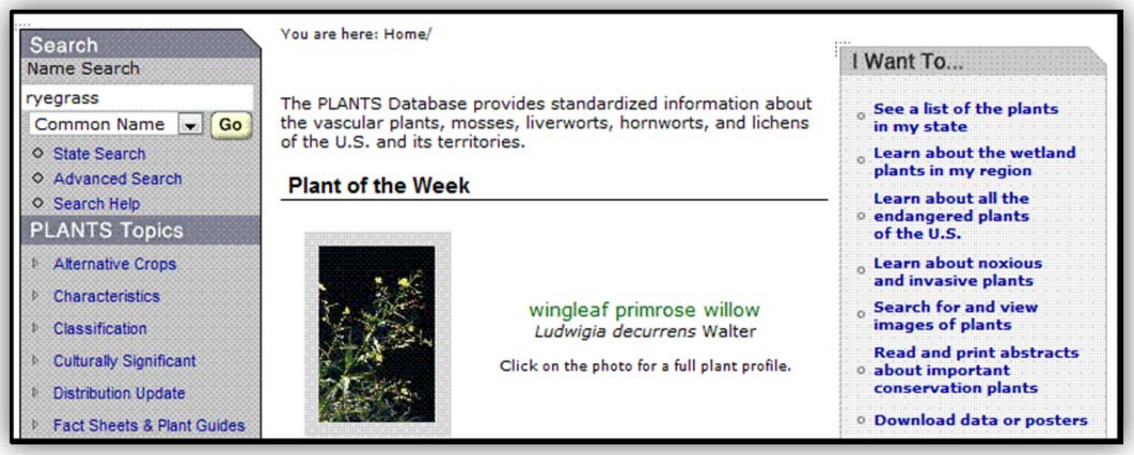


Figure A-15. American Horticulture Society Heat Zone Map, 1997. http://www.ahs.org/publications/heat_zone_map.htm
(Used by permission)

A third method, and an excellent online resource useful in determining appropriate land cover, is the USDA-NRCS PLANTS Database shown in Figure A-16. This simple database provides a great deal of useful information on most plants, shrubs, and trees that would be considered for water reuse techniques. It also includes several methods to search for plants. By far, the Advanced Search option is the most useful tool when developing an initial baseline for site conditions. This search option breaks down the plant classifications into two parts, each with several sub-categories, as seen in Table A-4. To use this option, simply visit each category and enter each applicable section in both parts of the search, as seen in Figure A-17. Once complete, the database produces a full report of all suitable species. Researchers may select special interest categories for viewing and comparison in the full report by selecting the display box to the right of each category.

For the purposes of this report, an example search was conducted to determine minimum and maximum precipitation rates for trees indigenous to the lower 48 states in the U.S. High water use and moderate drought tolerance were selected to reduce the number of positive results in the report. Growth rate, root depth, and maximum and minimum precipitation were all selected for comparison as well. The results are listed below in Table A-5. For this particular search, Red Maple, Eastern Cottonwood, and American Elm trees had exceeding standards for the regional criteria. If specific plants have been pre-selected for a site without verification for suitability for water reuse practices, the “Name Search” engine should be used because this option yields more detailed searches for particular plants using a common name, scientific name, or plant symbol.

The PLANTS database has the advantage of being a centralized resource. However, it is a relatively new resource, and not entirely inclusive. Despite being an excellent method for determining biofilter vegetation, its incomplete data cannot provide an entirely accurate suitability report. It is however a supplemental resource when coupled with outside data such as plant lists from outside sources such as an extension office or local arboretum.



You are here: Home/

ryegrass

The PLANTS Database provides standardized information about the vascular plants, mosses, liverworts, hornworts, and lichens of the U.S. and its territories.

Plant of the Week

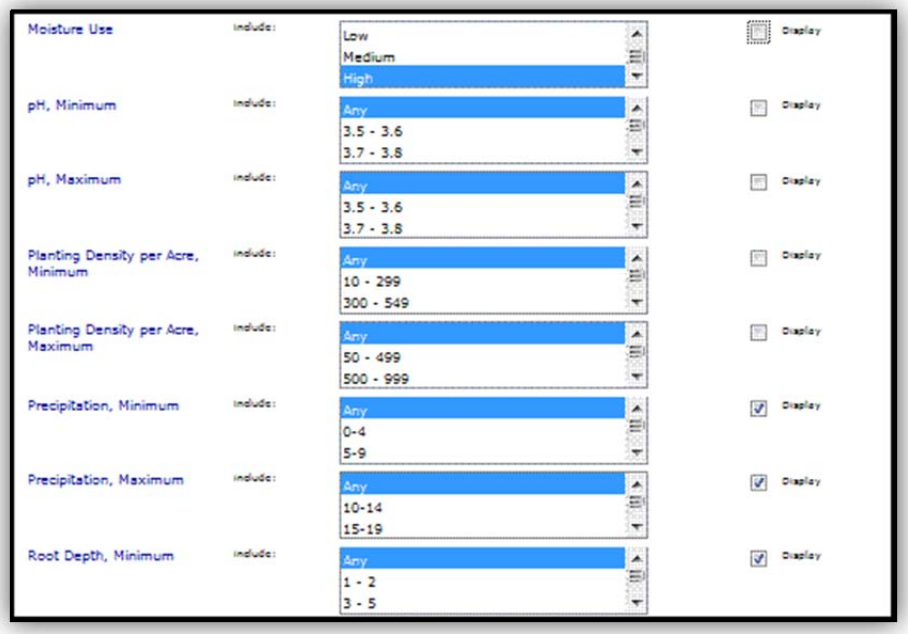
wingleaf primrose willow
Ludwigia decurrens Walter

Click on the photo for a full plant profile.

Figure A-16. USDA-NRCS PLANTS Database Homepage. http://plants.usda.gov/java/

Table A-4. PLANTS Database Advanced Search Selection Criteria.

1. Part A: PLANTS Core Data
    a. Distribution
    b. Taxonomy
    c. Ecology
    d. Legal Status
    e. Additional Information in PLANTS
2. Part B: Characteristics Data
    a. Morphology/Physiology
    b. Growth Requirements
    c. Reproduction
    d. Suitability/Use



Moisture Use	Include:	Low Medium High	☐ Display
pH, Minimum	Include:	Any 3.5 - 3.6 3.7 - 3.8	☐ Display
pH, Maximum	Include:	Any 3.5 - 3.6 3.7 - 3.8	☐ Display
Planting Density per Acre, Minimum	Include:	Any 10 - 299 300 - 549	☐ Display
Planting Density per Acre, Maximum	Include:	Any 50 - 499 500 - 999	☐ Display
Precipitation, Minimum	Include:	Any 0-4 5-9	☑ Display
Precipitation, Maximum	Include:	Any 10-14 15-19	☑ Display
Root Depth, Minimum	Include:	Any 1 - 2 3 - 5	☑ Display

Figure A-17. Selecting Plant Criteria and Options. http://plants.usda.gov/java/

Table A-5. PLANTS Database Selected Criteria Report. http://plants.usda.gov/java/

Scientific Name	Growth Rate	Precipitation (Minimum)	Precipitation (Maximum)	Root Depth, Minimum (inches)
Acer rubrum	Rapid	25	80	30
Alnus rubra	Rapid	24	220	25
Cephalanthus occidentalis	Moderate	20	80	14
Chionanthus virginicus	Slow	35	60	20
Morella cerifera	Moderate	34	60	20
Populus deltoides	Rapid	18	55	24
Populus fremontii	Rapid	20	26	32
Salix caroliniana	Rapid	30	60	20
Salix exigua	Rapid	20	30	20
Salix gooddingii	Rapid	12	55	28
Salix scouleriana	Rapid	11	40	12
Salix sitchensis	Rapid	35	60	24
Ulmus americana	Rapid	15	70	42
Ulmus rubra	Rapid	21	83	40

A.8.2 Optimum Groundcover Options

Concepts such as xeriscaping are aimed at reducing the amount of supplemental irrigation required on site. While these concepts reduce supplemental irrigation, they do not solve all issues involving stormwater management. An ideal landscape solution would include plants, shrubs, turfs, and trees capable of recovering, infiltrating and using high levels of water normally destined for storm drains, as well as being able to survive extended periods of drought when rainfall events are more sporadic. As one would expect, most landscapes cannot meet these criteria. In this section some species and plant characteristics that can improve water recovery if implemented into landscaping plans are discussed.

A.8.2.1Trees

One of the most common trees known for high water usage is the Hybrid Poplar (*Populus deltoides x Populus nigra).* Extensive research conducted for the tree has proved its usefulness in transpiring high levels of water when compared to other trees. The Hybrid Poplar also proves to be a resilient tree, as it is recommended for hardiness zones 3-9 by the Arbor Day Foundation. In fact, several varieties of poplar trees are commercially available, and most contain the suitable characteristics of fast growth, hardiness, high transpiration rates, and moderate to good drought tolerance.

Several other species easily transpire water at comparable rates to Poplars, however. The species listed in the previous section serve as excellent competitors to Poplar trees. Another significant competitor not listed by the PLANTS report is the Willow tree. Willow trees have the ability transpire more water than the Hybrid Poplars, but do not tolerate drought as well as Poplar varieties. An experiment comparing the coppice growth evapotranspiration (ET_o) rates for the two species concluded that Willow trees out-performed hybrid Poplars under fertilized and non-fertilized conditions (Guidi, et al. 2007). The results from the report can be viewed in Table A-6.

Table A-6. ET Rates and Crop Coefficients for Hybrid Poplars and Willow Trees. (Guidi et al., 2007) (Used by permission of Elsevier)

ET Rates for Two Coppice Fields

	Hybrid Poplar		Willow	
	2004	2005*	2004	2005*
ET (mm)	620-1190	890-1790	590-725	710-1100
crop coeff. (k_c)	1.25-2.84	1.97-5.30	1.06-1.90	1.71-4.28

***In the second growing season, fertilizer was added to both species increasing the growth rates and thus increasing potential evapotranspiration rates.**

A.8.2.2 Turf grasses

Some of the most resilient groundcover options are cool season grasses. These grasses cover many lawns from coast to coast in the U.S. They often become the pride of the neighborhood receiving unrivaled care through irrigation, fertilizer, and weed control. This care increases evapotranspiration (ET_o), creating a much higher water demand. Maintaining these green lawns while conserving water use encourages new concepts and goals for water conservation and reuse. The planning and development of stormwater management systems used for irrigation and infiltration now require consideration of grasses that have the ability to use water when it’s available as well as maintaining foliage density and a healthy appearance during extended drought periods.

Of the three categories covered by the report, grasses hold the most significant role as biofilter vegetation. Because converting traditional lawns from supplemental irrigation to on site water reuse options will in most cases take place only if it remains aesthetically pleasing. Considerable research conducted on cool season grasses has shown that varieties of Fescue are the best choice for use in stormwater reuse irrigation practices. In most experiments, Tall Fescue cultivars ranked highest among numerous turf grass varieties in drought tolerance thresholds. Tall Fescue’s ability to withstand water deficits may be related to deep root profiles typically associated with Tall Fescue. This characteristic allows the species to recover water from lower levels in the soil profile (Bremer et al., 2006). Though most Fescue varieties represent drought resistant turf options, there are numerous cool season grass options that can tolerate non-irrigated periods in excess of 30 days, as listed in Table A-7.

Table A-7. Ranking of Drought Tolerant Fescue and Bluegrass Varieties. (Karcher, et al., 2008)

Drought Tolerance in some Cool Season Grasses

Rank	Selection	Species	Day* (50%)	Rank	Selection	Species	Day* (50%)
1	2nd Millennium	TF	52.2	22	P-707	KBG	40.4
2	TB 390	HBG	49.2	23	ATF1252	TF	39.6
3	ATF1200	TF	47.8	24	Tulsa	TF	39.6
4	ATF1321	TF	47.4	25	Greystone	TF	39.5
5	KY-31	TF	46.6	26	Wyatt III (ATF 1253)	TF	39.4
6	Axiom III (ATF 1250)	TF	45.7	27	Signia	TF	39.1
7	ATF1254	TF	45.6	28	Diva	KBG	38.6
8	ATF1320	TF	45.3	29	ATF1251	TF	38.5
9	Greystone III (ATF1249)	TF	44.6	30	RK1	TF	38.1
10	Falcon IV	TF	44.3	31	Mallard	KBG	37.9
11	ATF1199	TF	43.9	32	Axiom	TF	37.5
12	Thermal Blue	HBG	43.8	33	Greystone Rhizoc (ATF1359)	TF	37.2
13	Wyatt	TF	43.7	34	Wyatt II	TF	37.2
14	ATF1255	TF	42.7	35	Rebel Exeda	TF	37.1
15	Axiom II	TF	42.3	36	ATF1167	TF	36.9
16	ATF1257	TF	42.2	37	Midnight	KBG	35.9
17	ATF1360	TF	41.6	38	Plantation	TF	34.3
18	ATF1256	TF	41.4	39	TB 676	HBG	32.7
19	ATF1258	TF	41	40	A00-1400	KBG	32.3
20	ATF1259	TF	41	41	Champlain	KBG	32.2
21	ATF805	TF	40.7	42	Solar Green	HBG	29.1
	HBG= Hybrid Bluegrass	KBG= Kentucky Bluegrass			TF= Tall Fescue	*50% Green Cover	

A.8.2.3Plants and Shrubs

Plants and shrubs find their place in all aspects of biofiltration management practices. Prime examples of their use are rain gardens and green roof cover sites. Some of the most successful and common green roof landscape plants are Sedums and Delosperma. In fact, most of the research and practices for green roofing includes a considerable percentage of sedums plantings.

Several institutions including Pennsylvania State University, North Carolina State University and Michigan State University are currently conducting research to improve non-irrigated green roof runoff techniques. The advantage sedums have lies in their ability store water, which enables them to withstand prolonged periods of drought. In fact, cacti, like sedums, are considered a succulent; this helps explain the reasoning behind choosing sedums for green roofing. These plants are subjected to large amounts of radiation from the sun, shallow and warm soil media, and at times drought. Leaf or stem succulence allows plants adapted to dry habitats to survive much longer during a drought before a critical relative water content is reached. When the water storage tissue ('hydrenchyma') and the assimilatory tissue ('chlorenchyma') can be anatomically distinguished, the former often suffers more loss of water during drought than the latter. This inherent ability helps to maintain the photosynthetic capacity of succulents during droughts, and thus making them suitable for green roofing. Furthermore, chlorophyll florescence can return to normal within 48 hours after 28 days without supplemental water (VanWoert, et al., 2005).

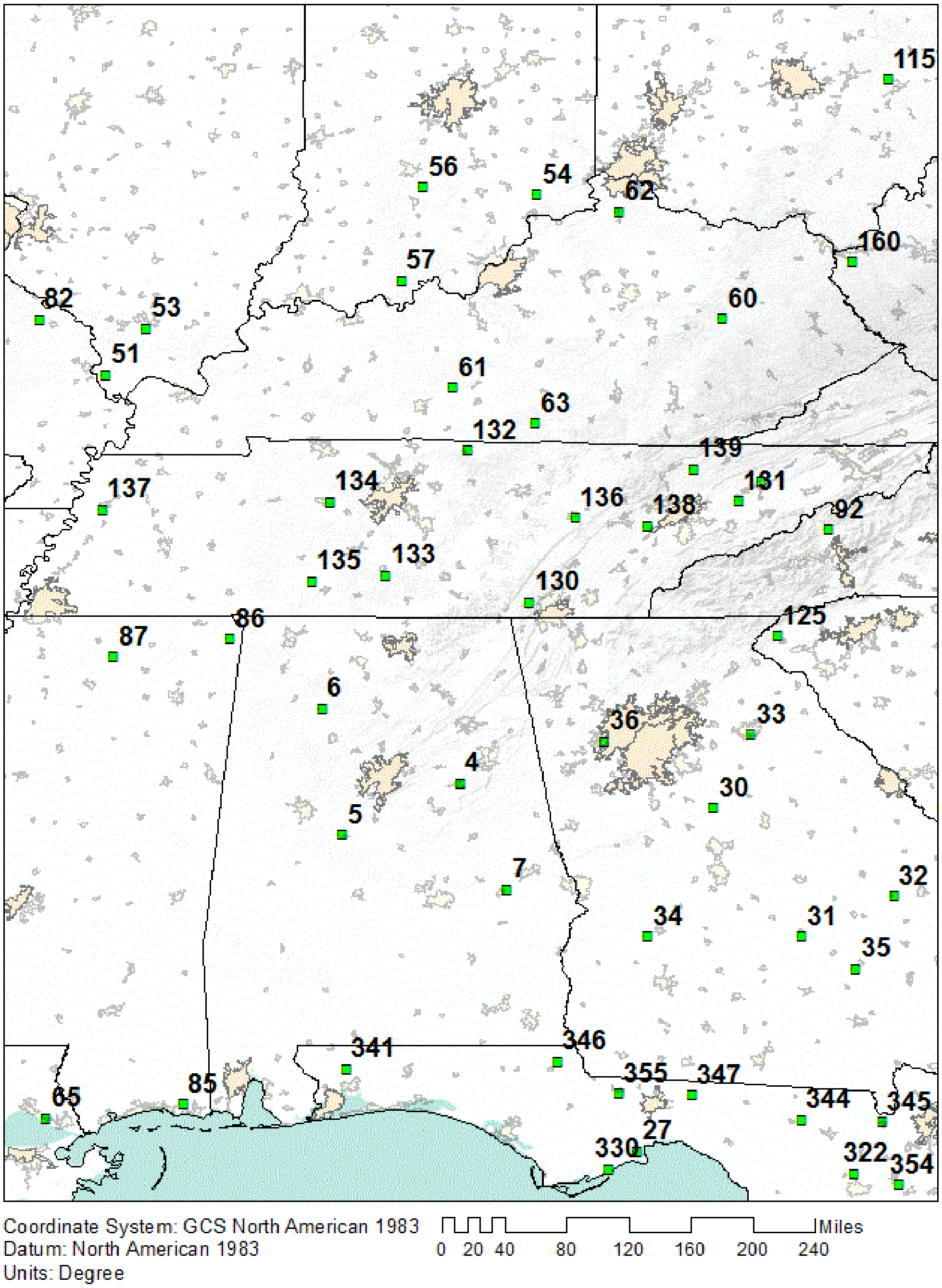
Of course, sedums are not the only species suited for green roofs. An additional factor to consider when choosing like plants is root depth. The media for green roofs is very shallow and lined to retain water normally lost to deep percolation. Therefore plants that rely on a taproot or characteristically have deeper root profiles would most likely not survive on a green roof project. These types of plants would be better suited for a rain garden.

Plants and shrubs that meet both drought tolerance and high infiltration rates are best suited for a surface based biofiltration system. The plants develop a root system capable of penetrating deep into the soil and may increase infiltrative capacity by creating macropores and other fissures allowing more rapid movement of water (Selbig, 2010). A possible resource for plants that meet these criteria and can withstand temporary inundation is the National Wetland Indicator List. The list covers vascular plants and designates them by category for their probable location in or near a wetland. The list separates the categories ranging from Obligate Wetland (OBL) to Obligate Upland (UPL), as seen in Table A-8. Plants listed in the intermediate range and upland range would most likely serve well under high levels of stormwater infiltration practices. Numerous extension services, universities, and state departments provide national and regional plant lists for biofilter vegetation. As previously mentioned, an additional resource is the PLANTS database which includes all the criteria necessary for selecting the types of plants currently registered with the database. A list of useful web-based resources for selecting biofilter vegetation is included in this report.

Table A-8. National Wetland Indicator Status Defined. http://plants.usda.gov/wetinfo.html#categories

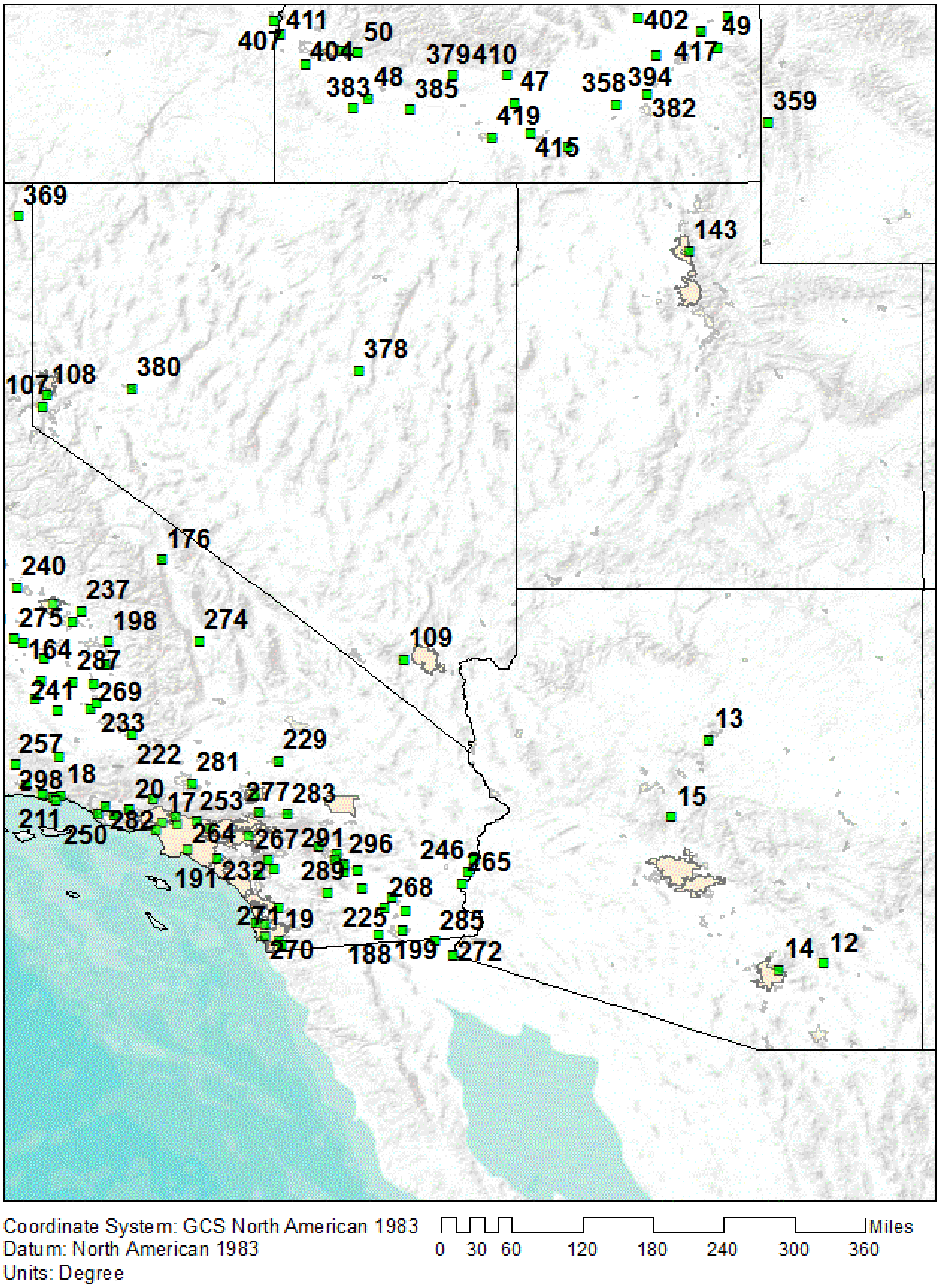
Indicator categories

Indicator Code	Wetland Type	Comment
OBL	Obligate Wetland	Occurs almost always (estimated probability 99%) under natural conditions in wetlands.
FACW	Facultative Wetland	Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
FAC	Facultative	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU	Facultative Upland	Usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
UPL	Obligate Upland	Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the regions specified. If a species does not occur in wetlands in any region, it is not on the National List.
NA	No agreement	The regional panel was not able to reach a unanimous decision on this species.
NI	No indicator	Insufficient information was available to determine an indicator status.
NO	No occurrence	The species does not occur in that region.

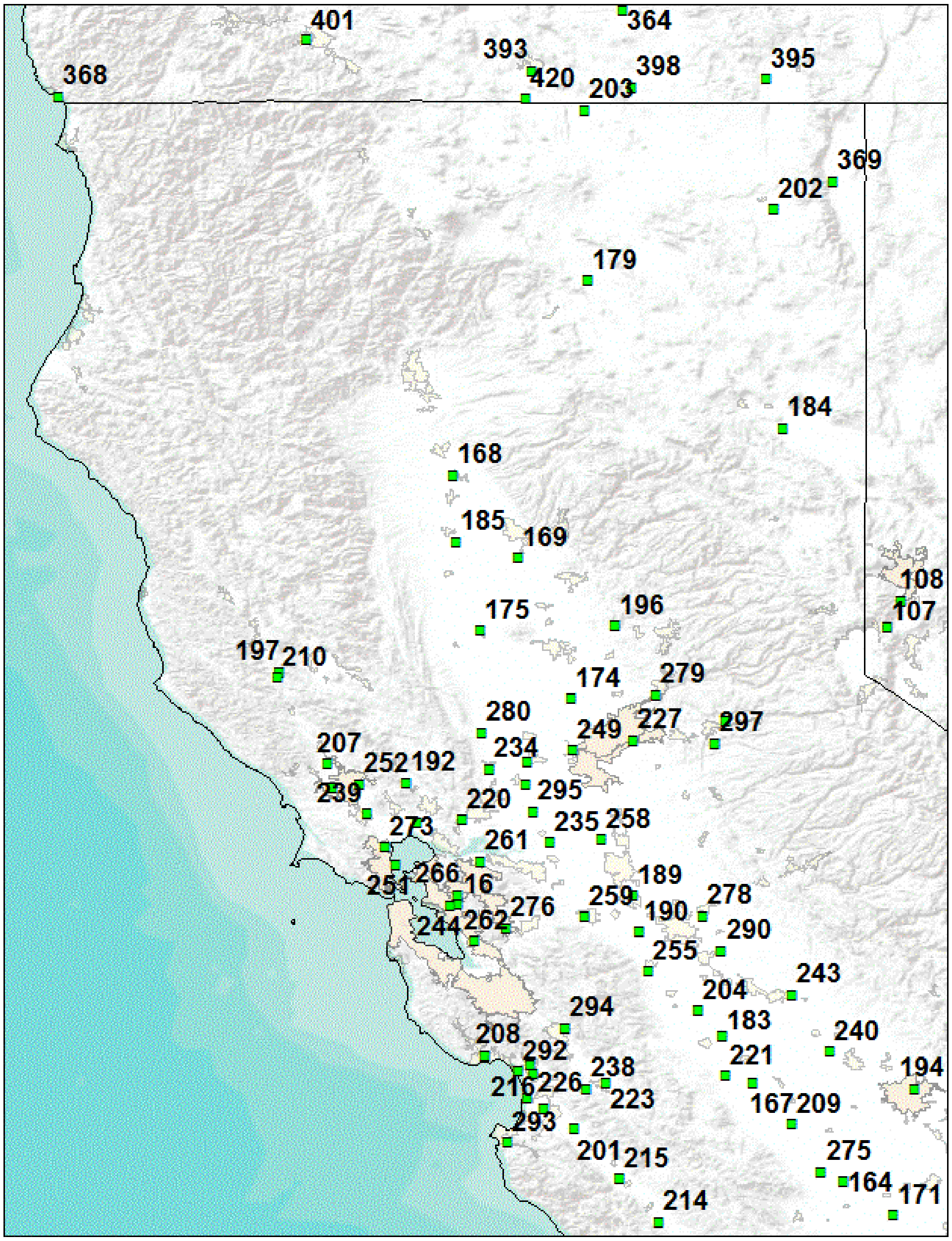


Coordinate System: GCS North American 1983
Datum: North American 1983
Units: Degree

Alabama, Kentucky, and Tennessee



Arizona, Utah, and Nevada



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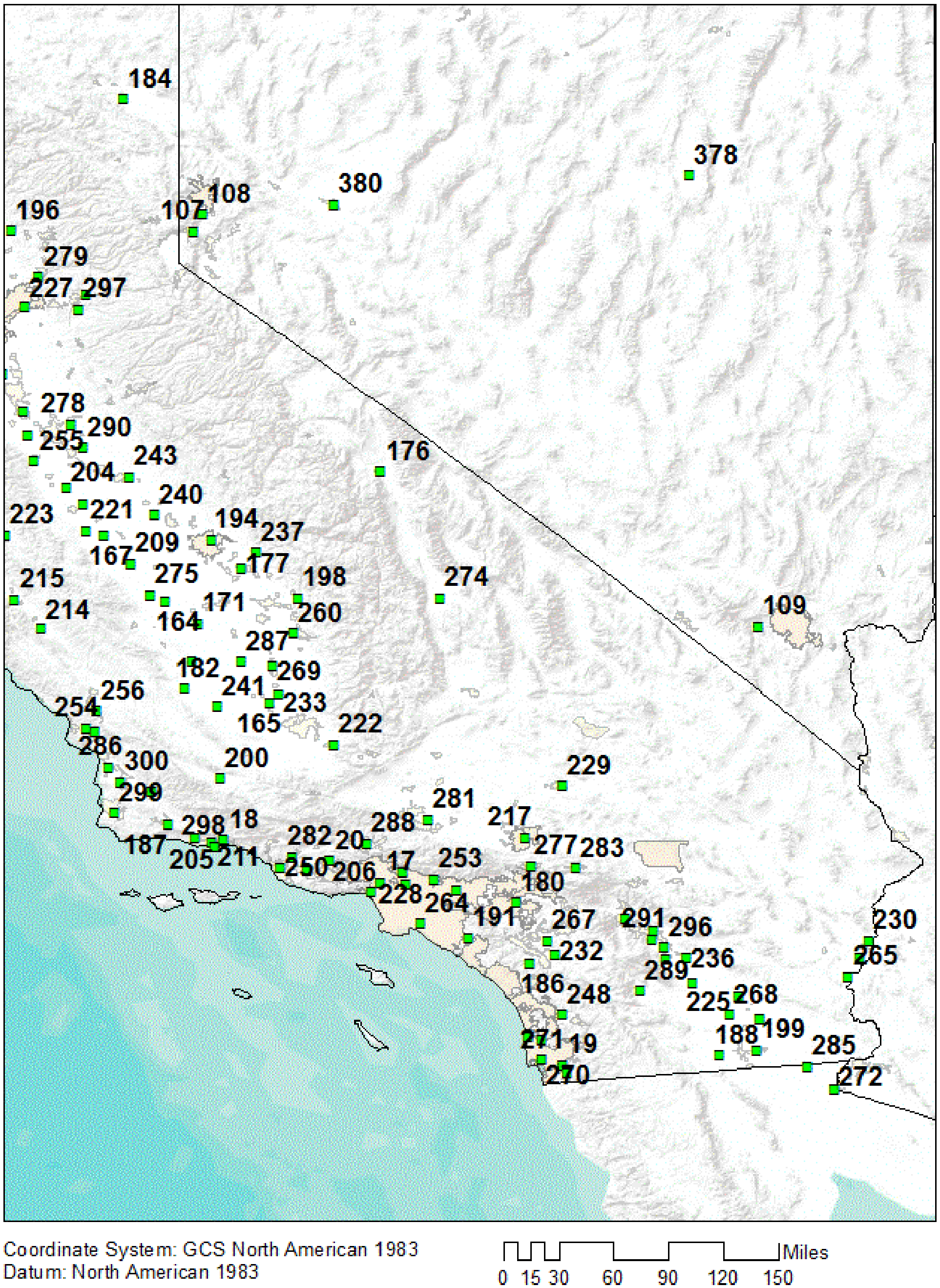
0 12.5 25 50 75 100 125 Miles

Northern California



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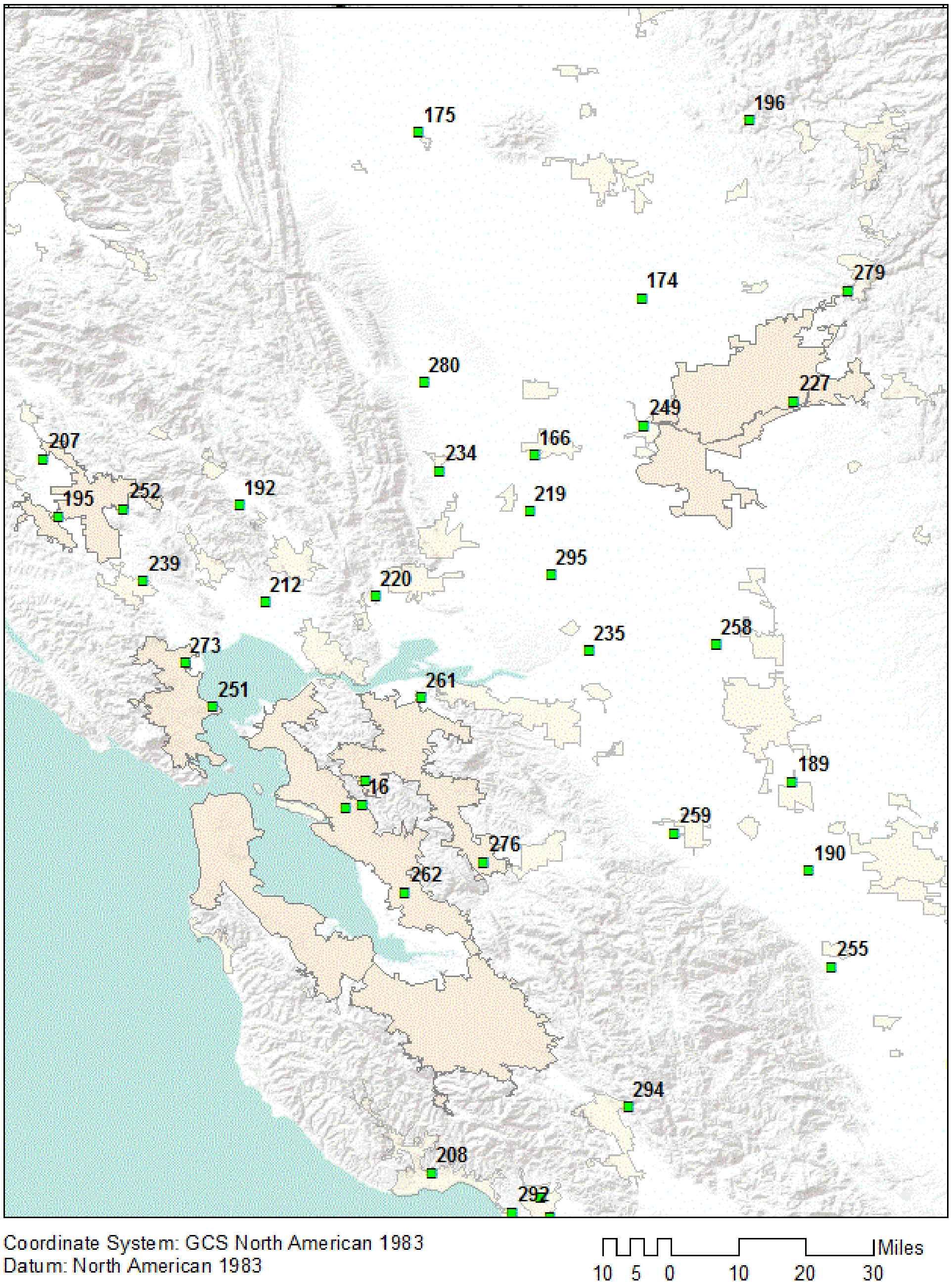
Southern California



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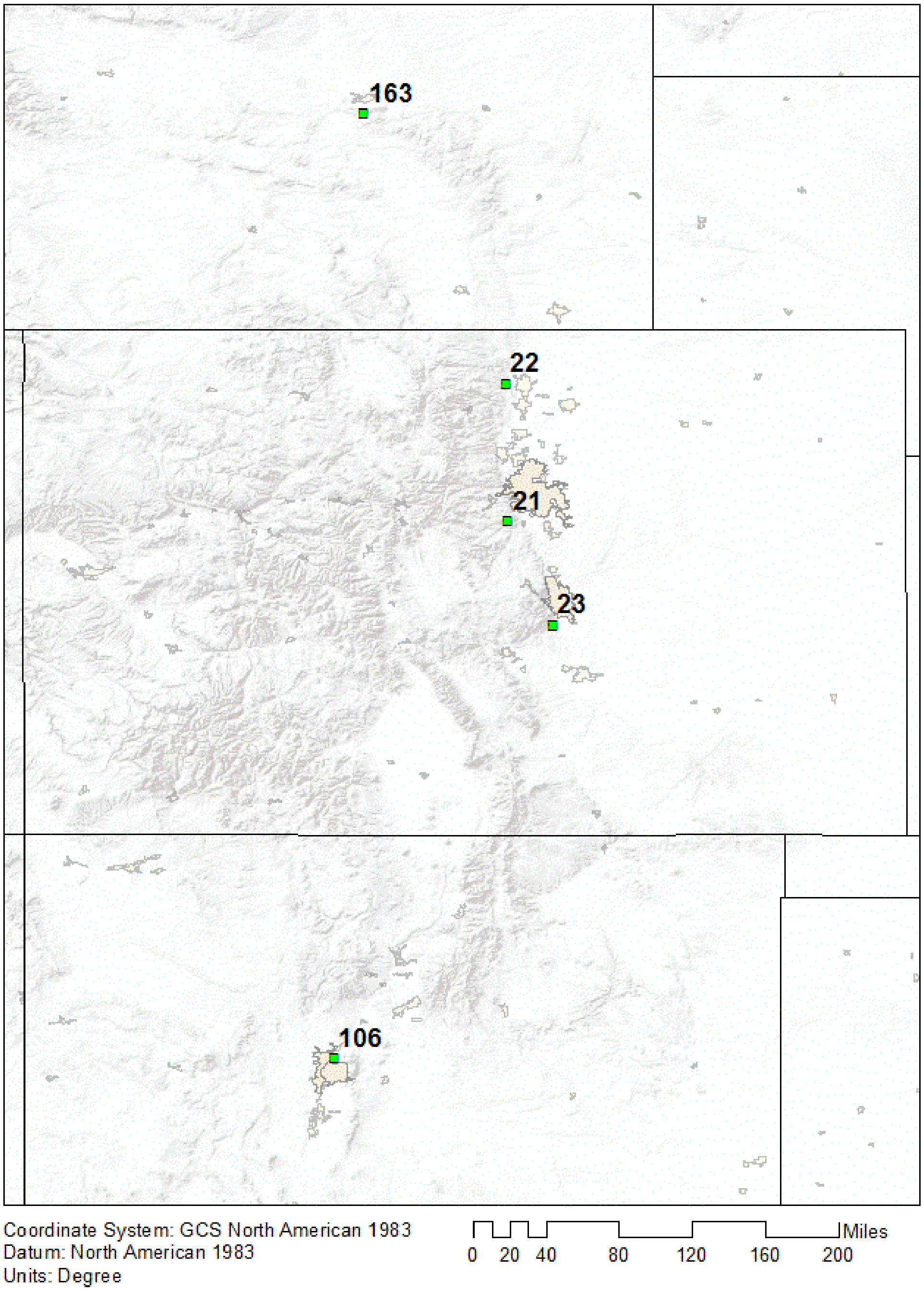
San Francisco Bay Area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80
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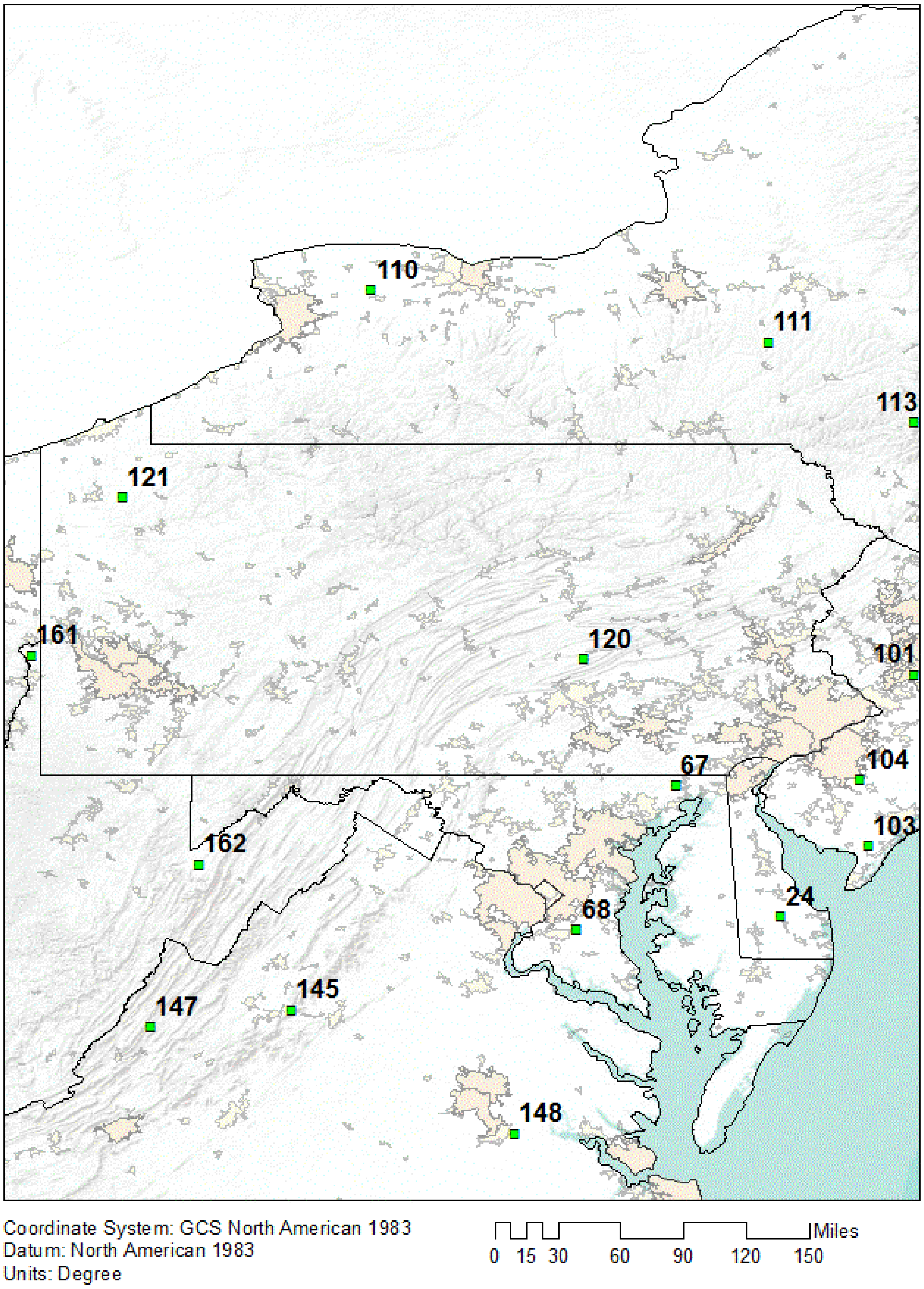
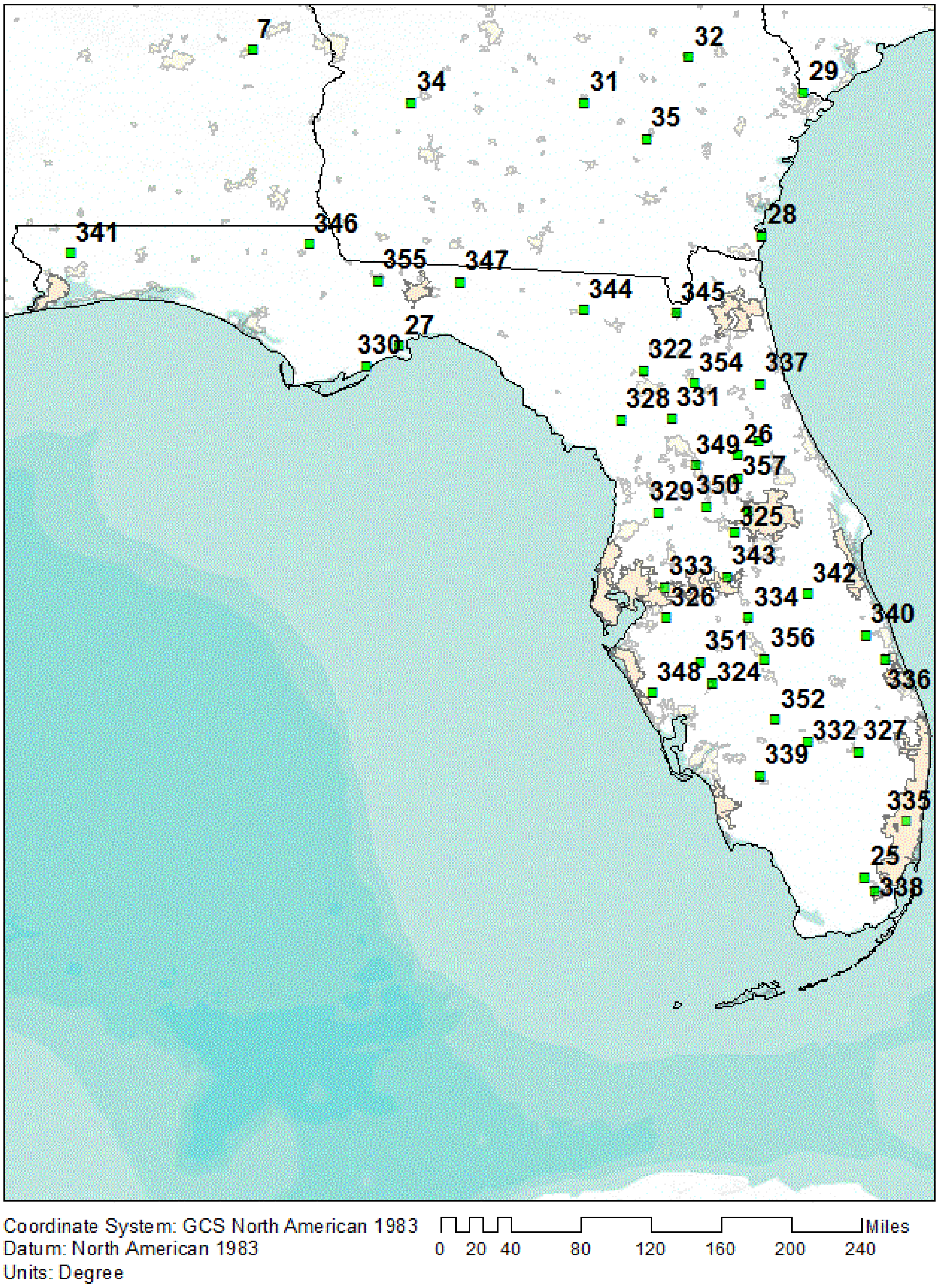
200
Miles

Colorado



Delaware, Pennsylvania, and Maryland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Datum: North American 1983
Units: Degree
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40
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200
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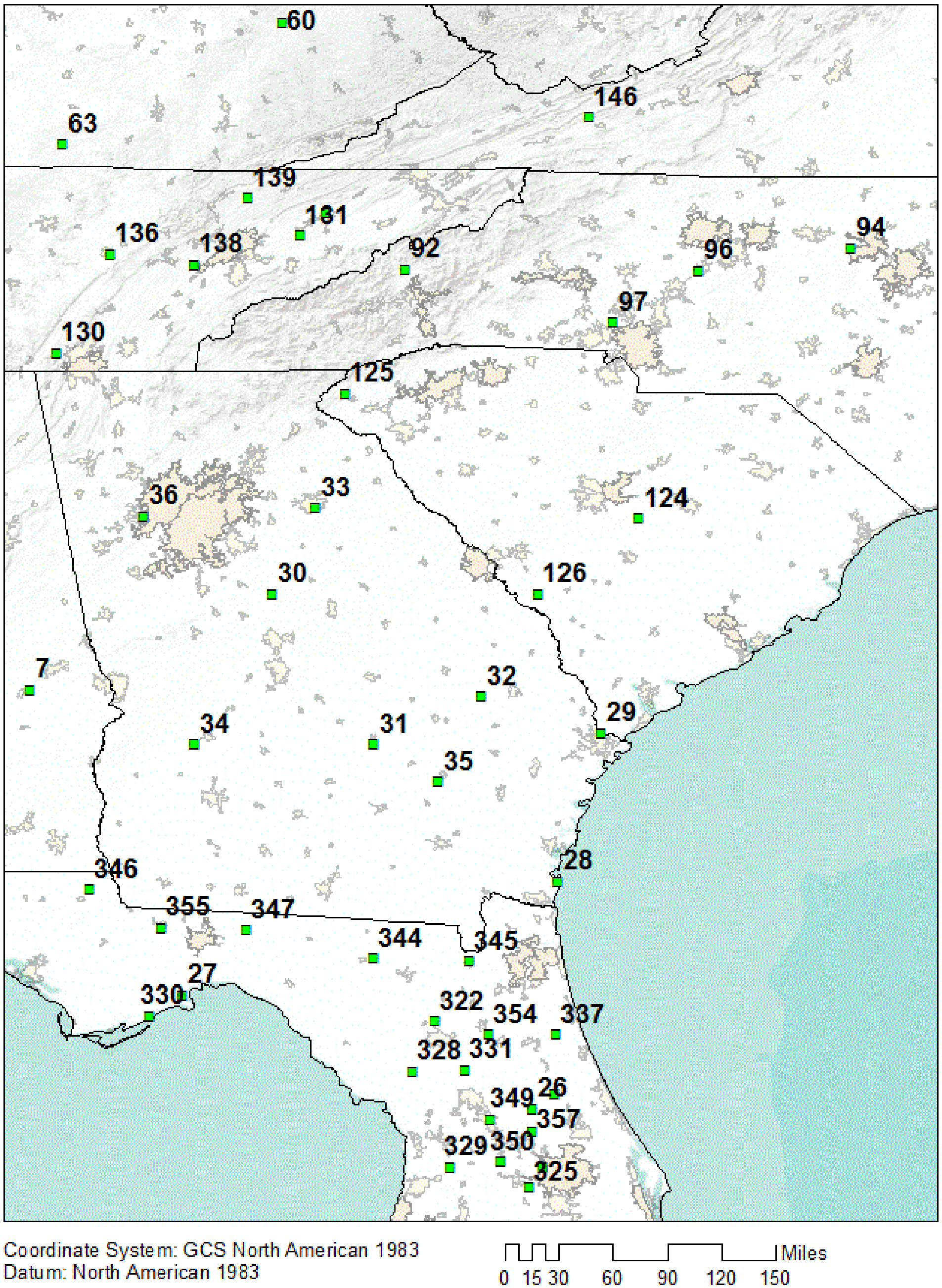
Miles

Florida



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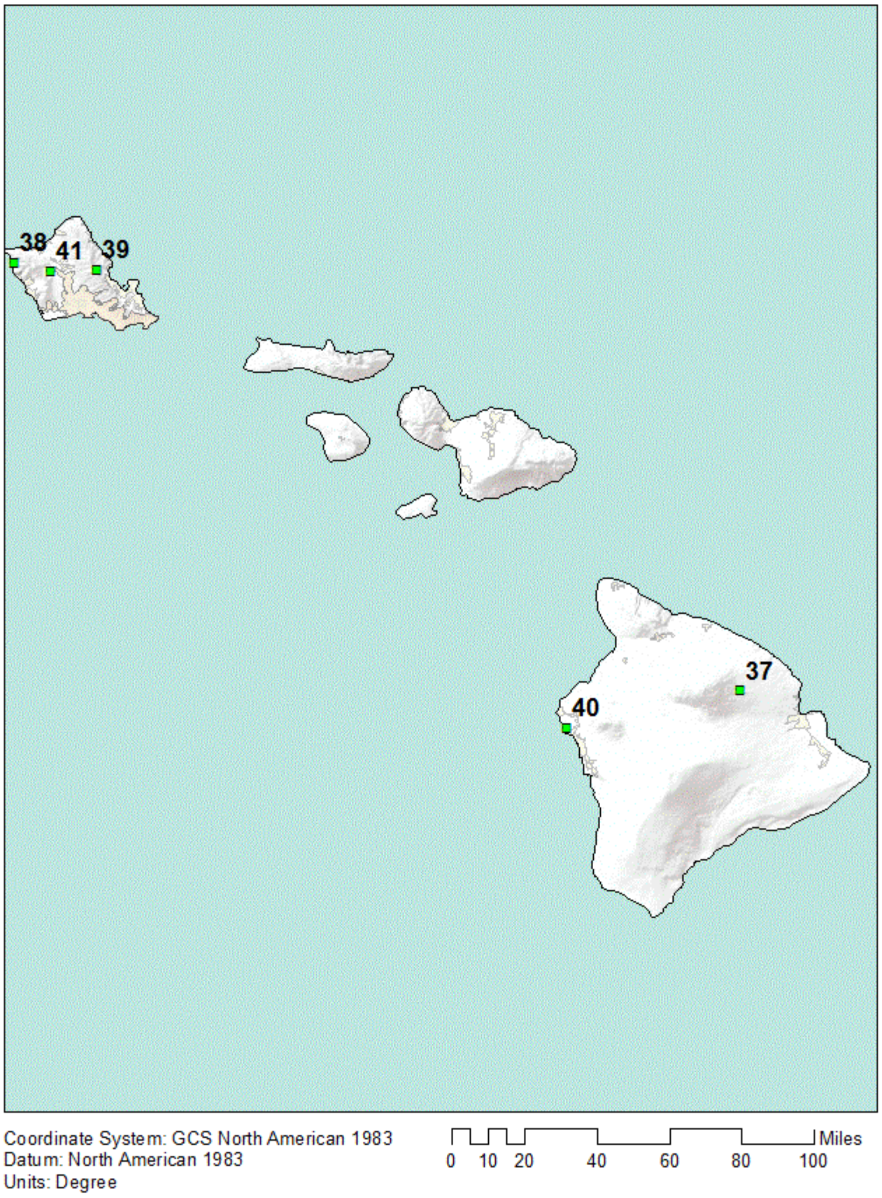
Units: Degree

Georgia and South Carolina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Datum: North American 1983
Units: Degree
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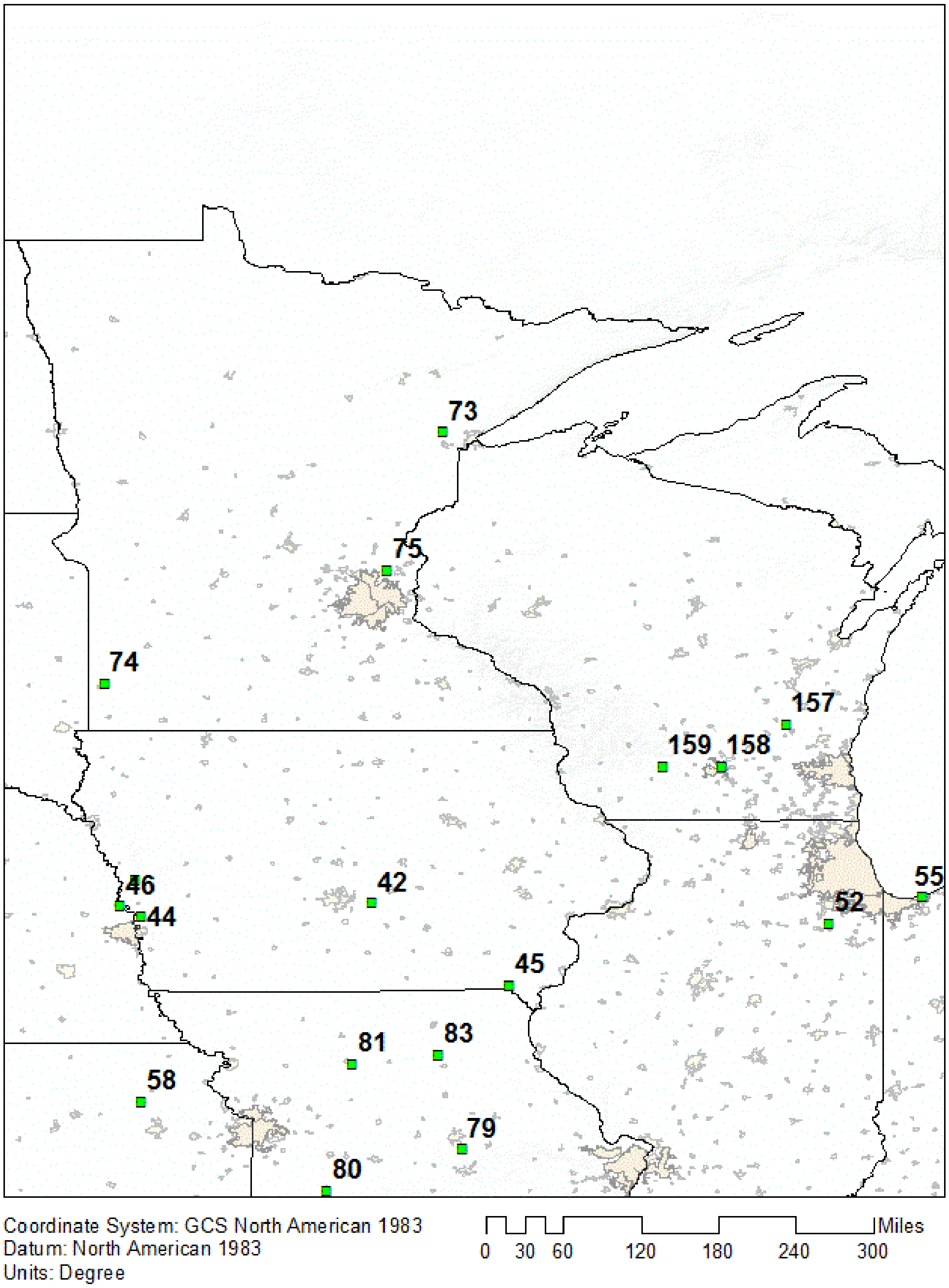
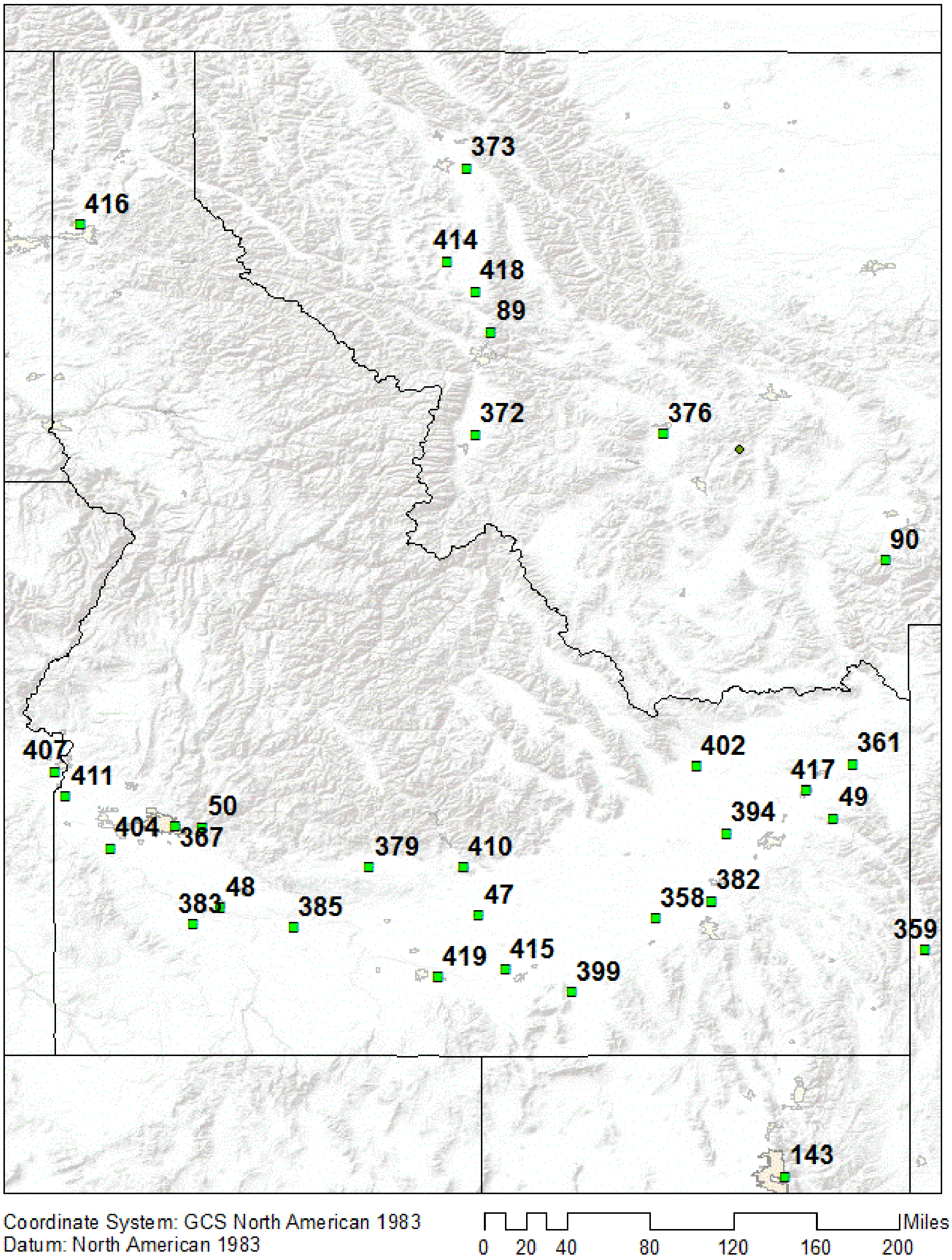
20
40
60
80
100
Miles

Hawaii



Iowa, Minnesota, and Wisconsin



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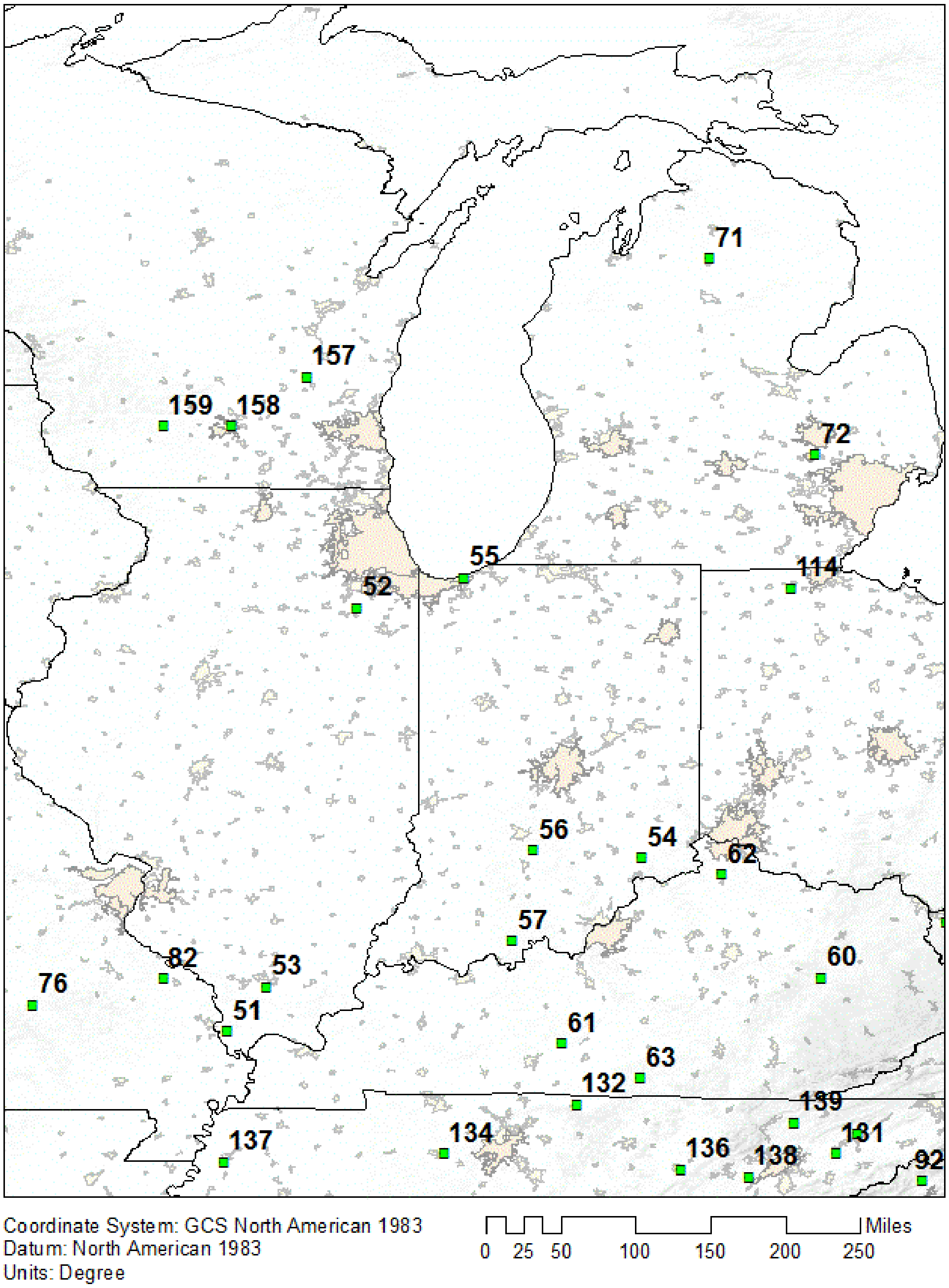
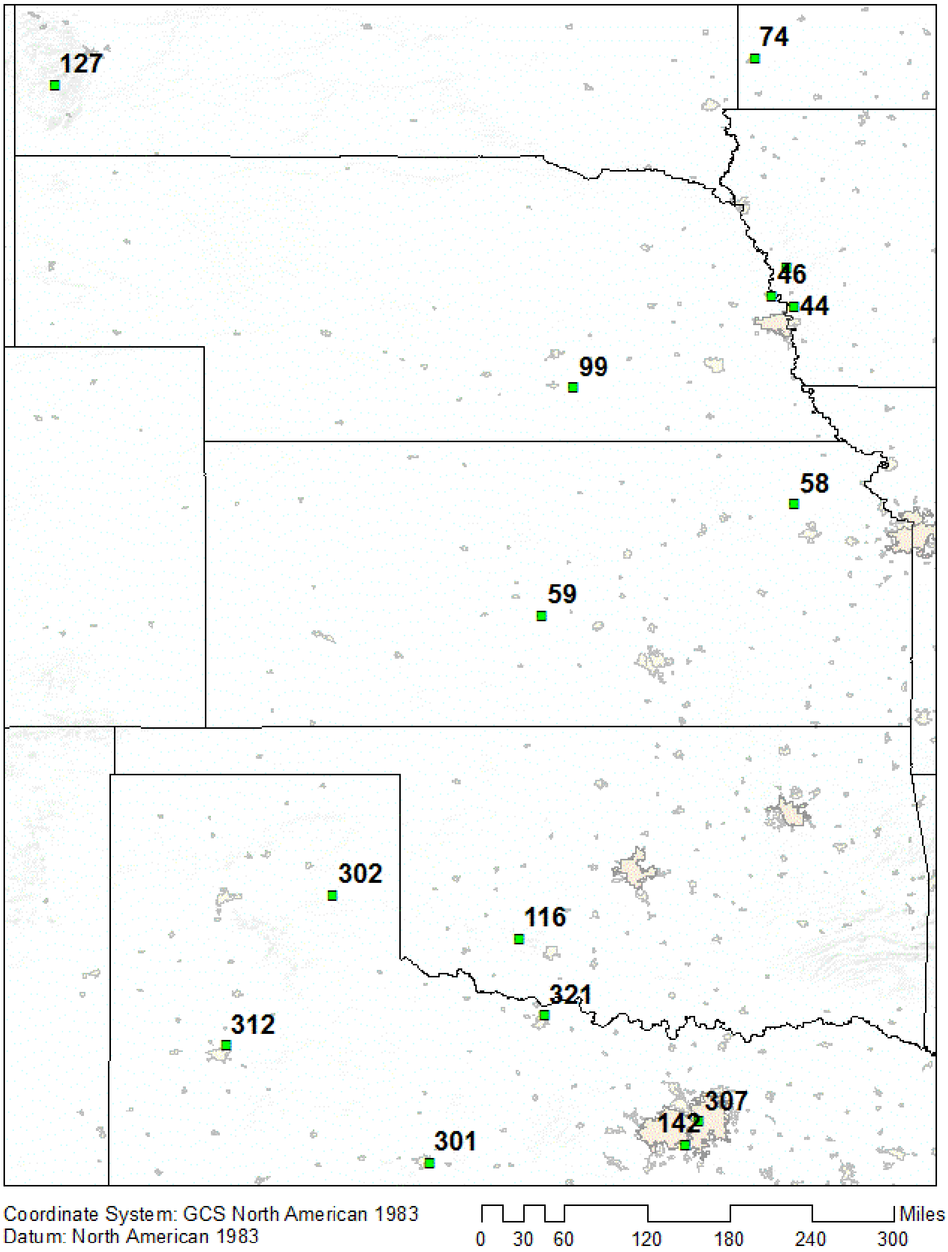
Idaho



Illinois, Indiana, and Michigan



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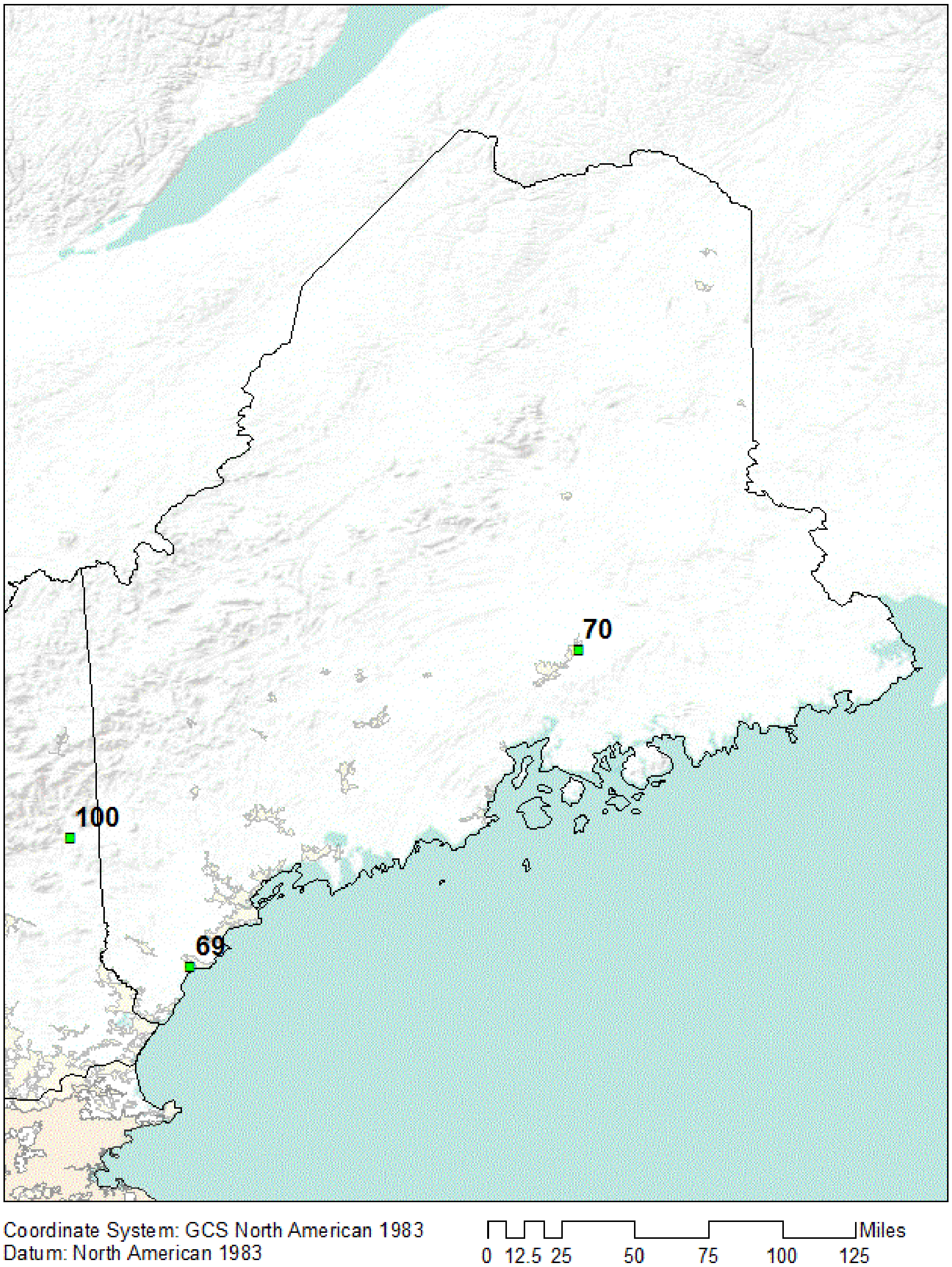
Units: Degree

Kansas, Nebraska, and Oklahoma



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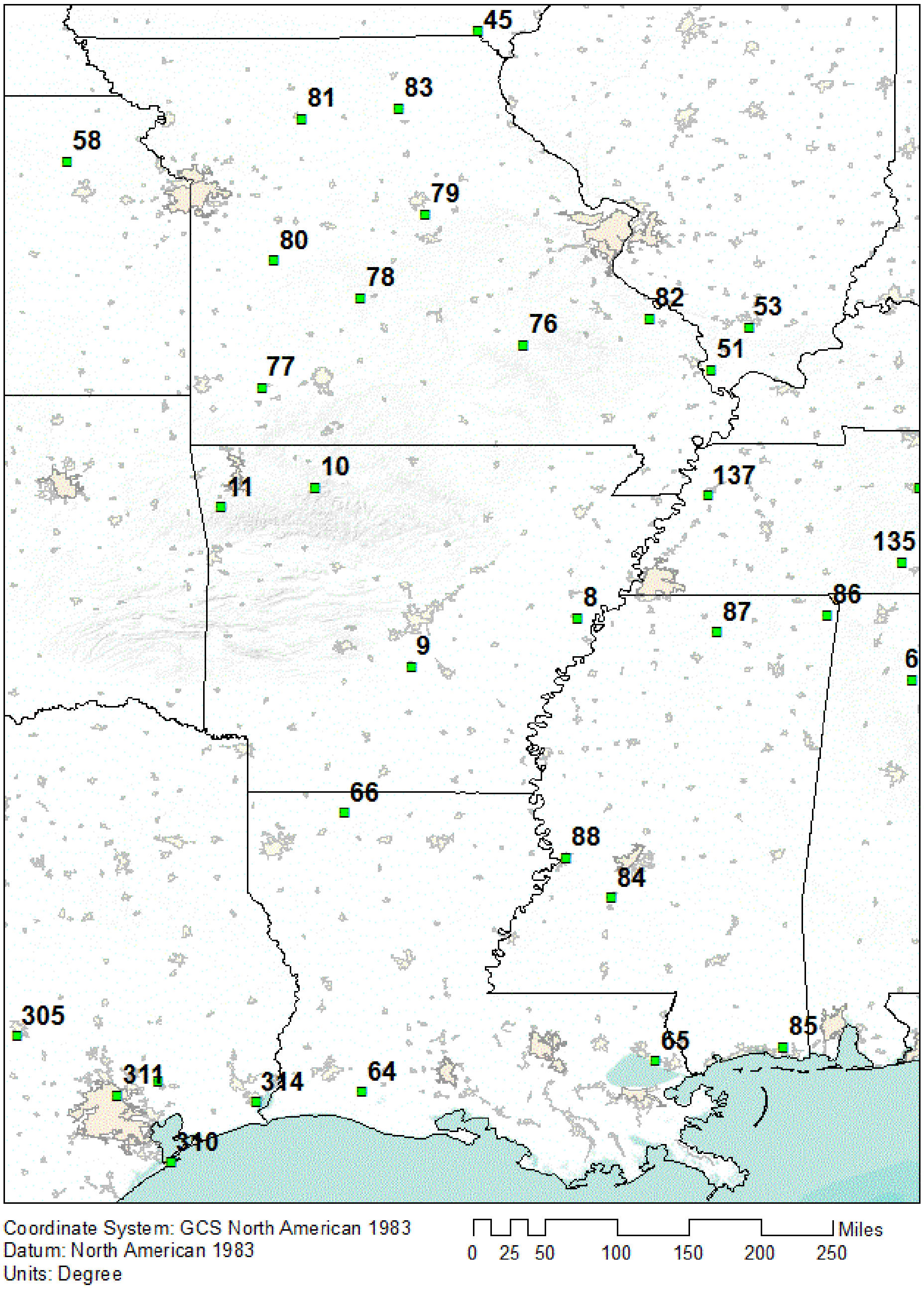
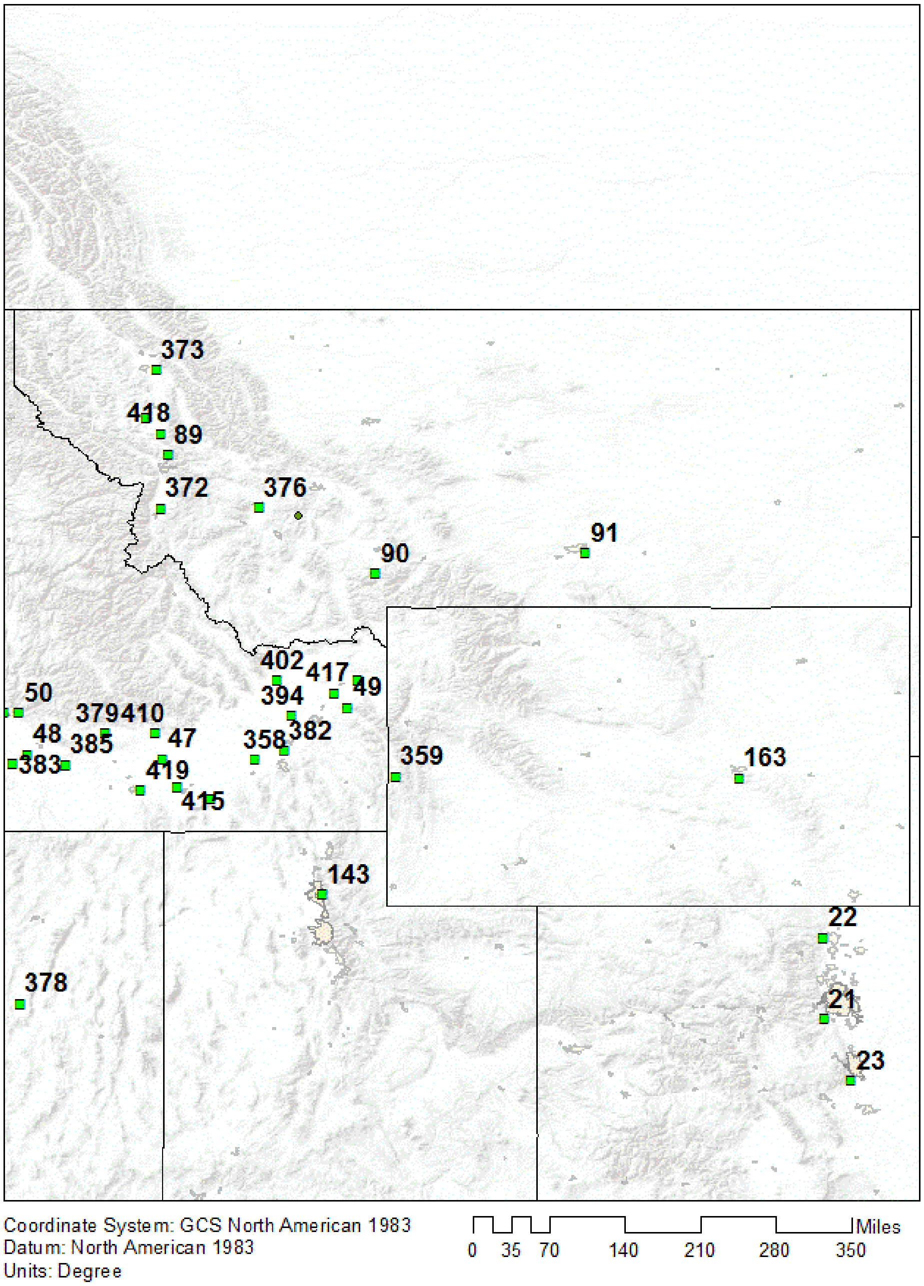
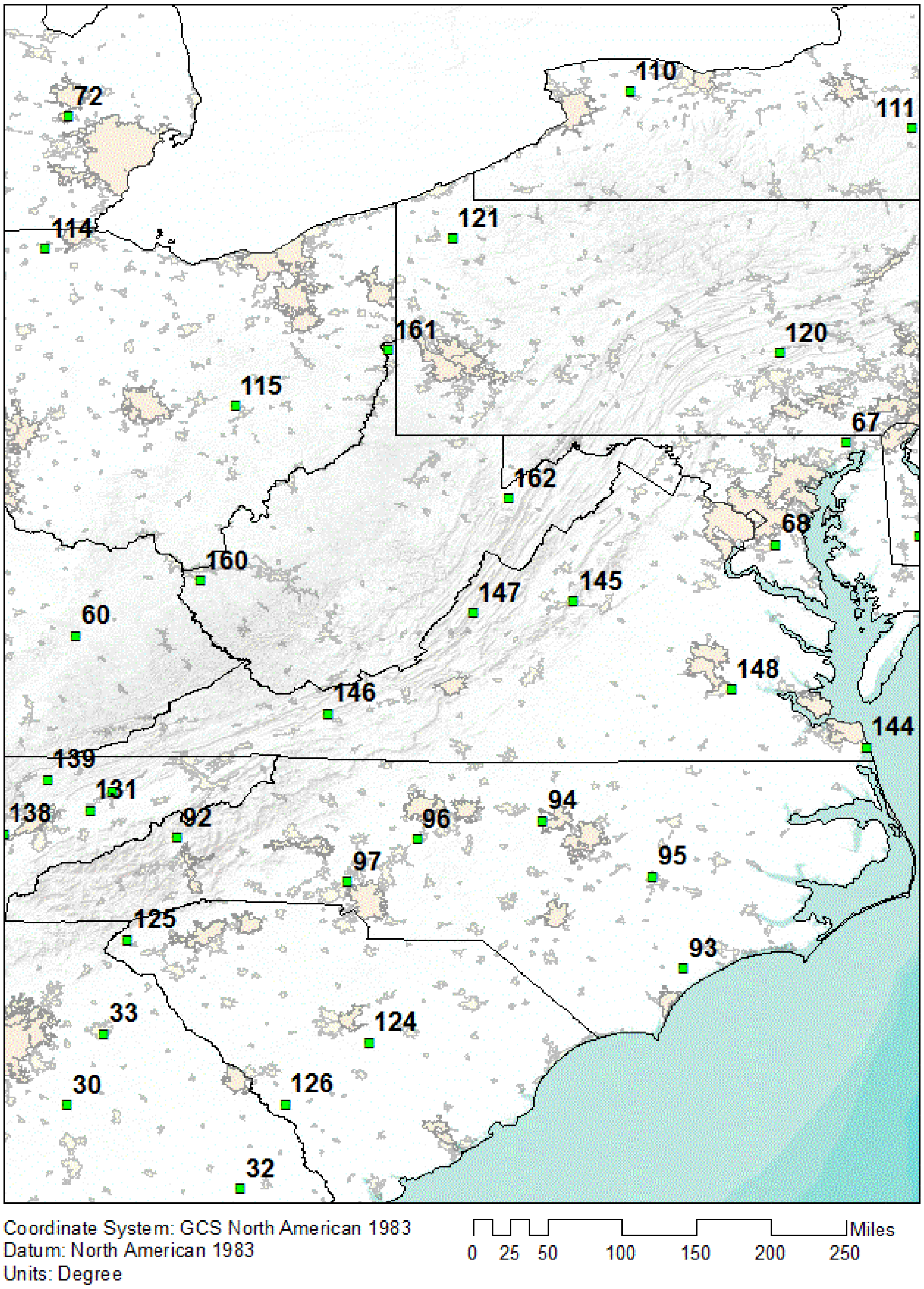
Maine



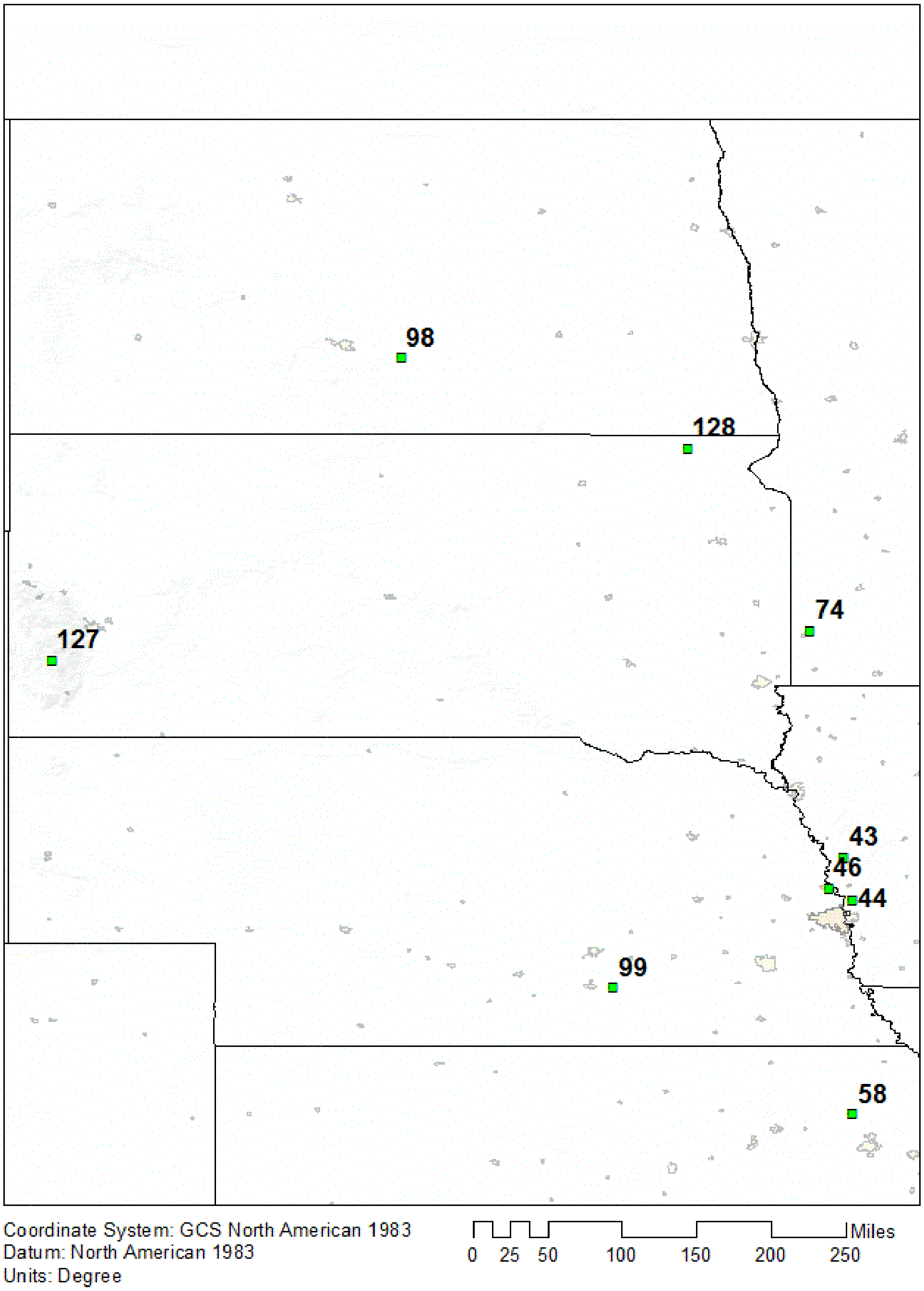
Missouri, Arkansas, Louisiana, and Mississippi



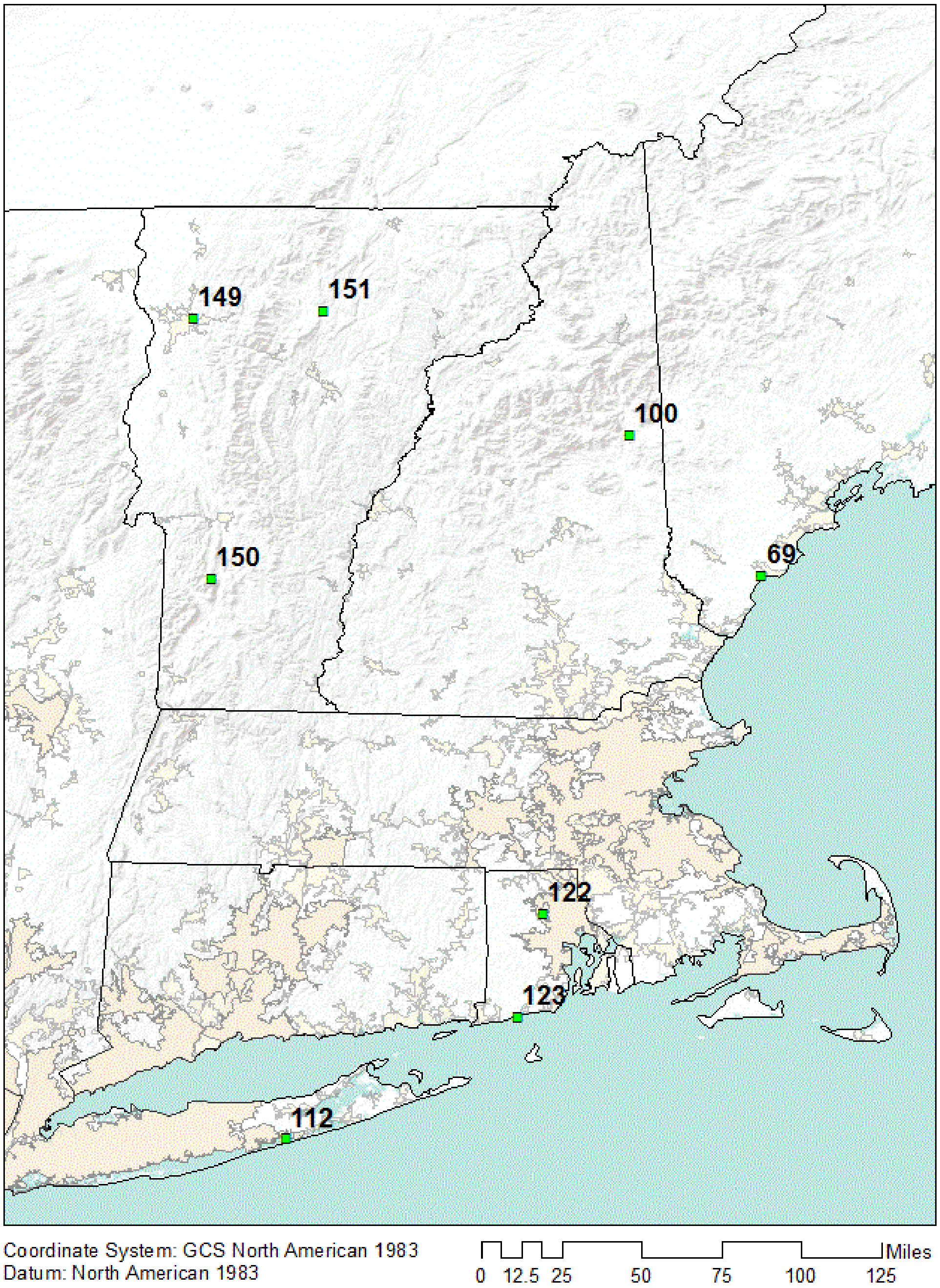
Montana and Wyoming



North Carolina, West Virginia, and Virginia



Nebraska, North Dakota, and South Dakota



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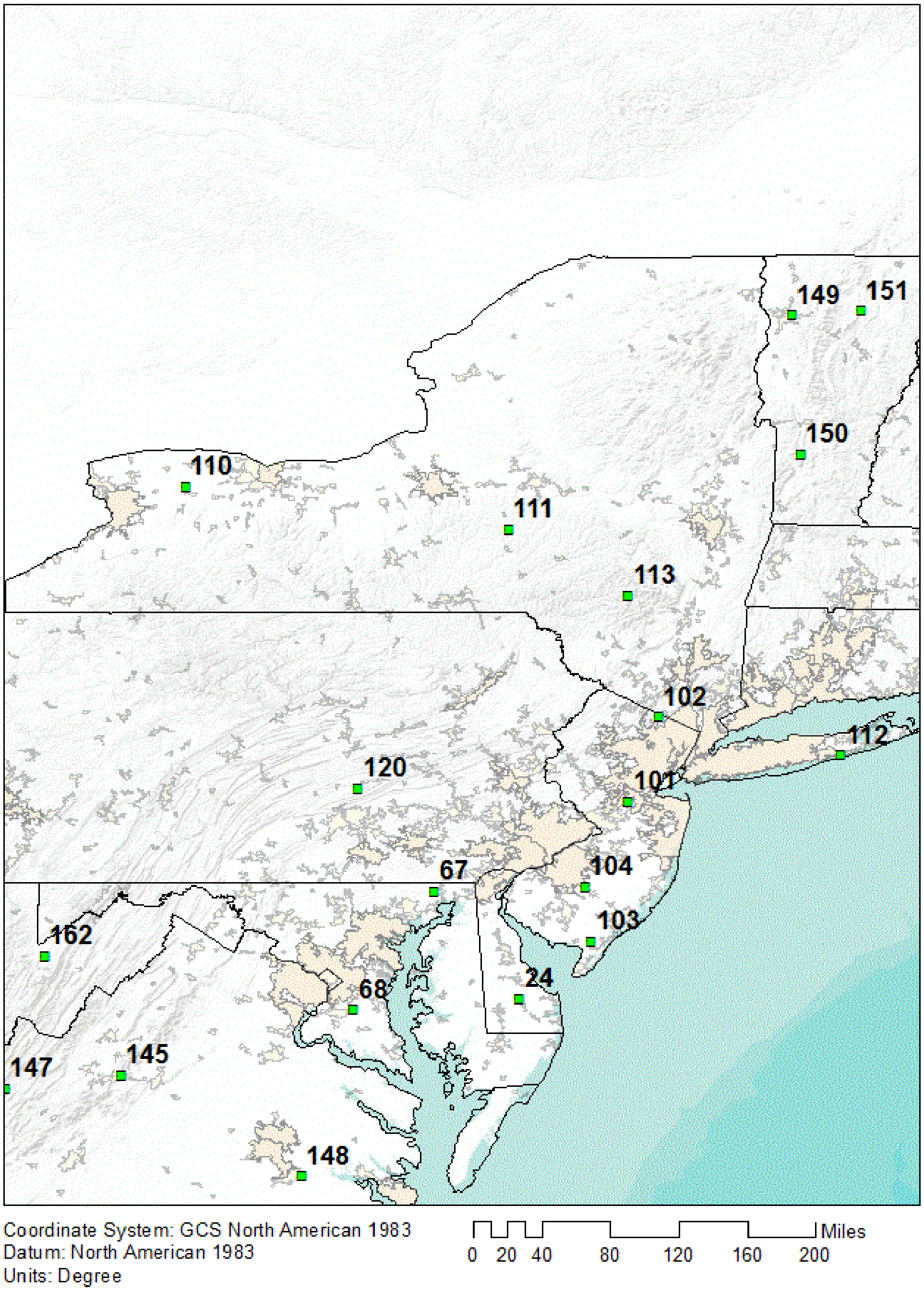
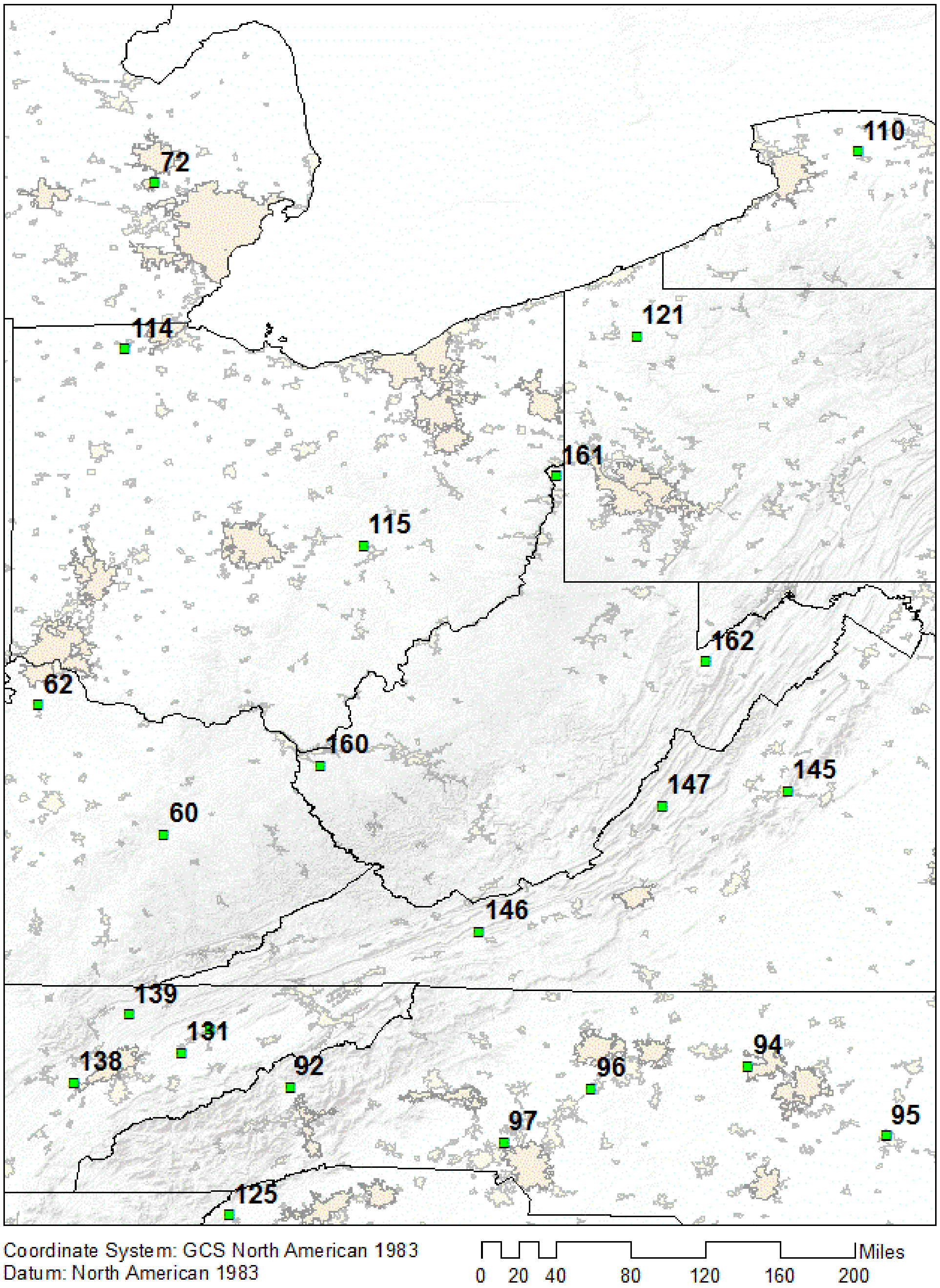
Units: Degree

New Hampshire, Massachusetts, Vermont, Connecticut, and Rhode Island



New York and New Jersey



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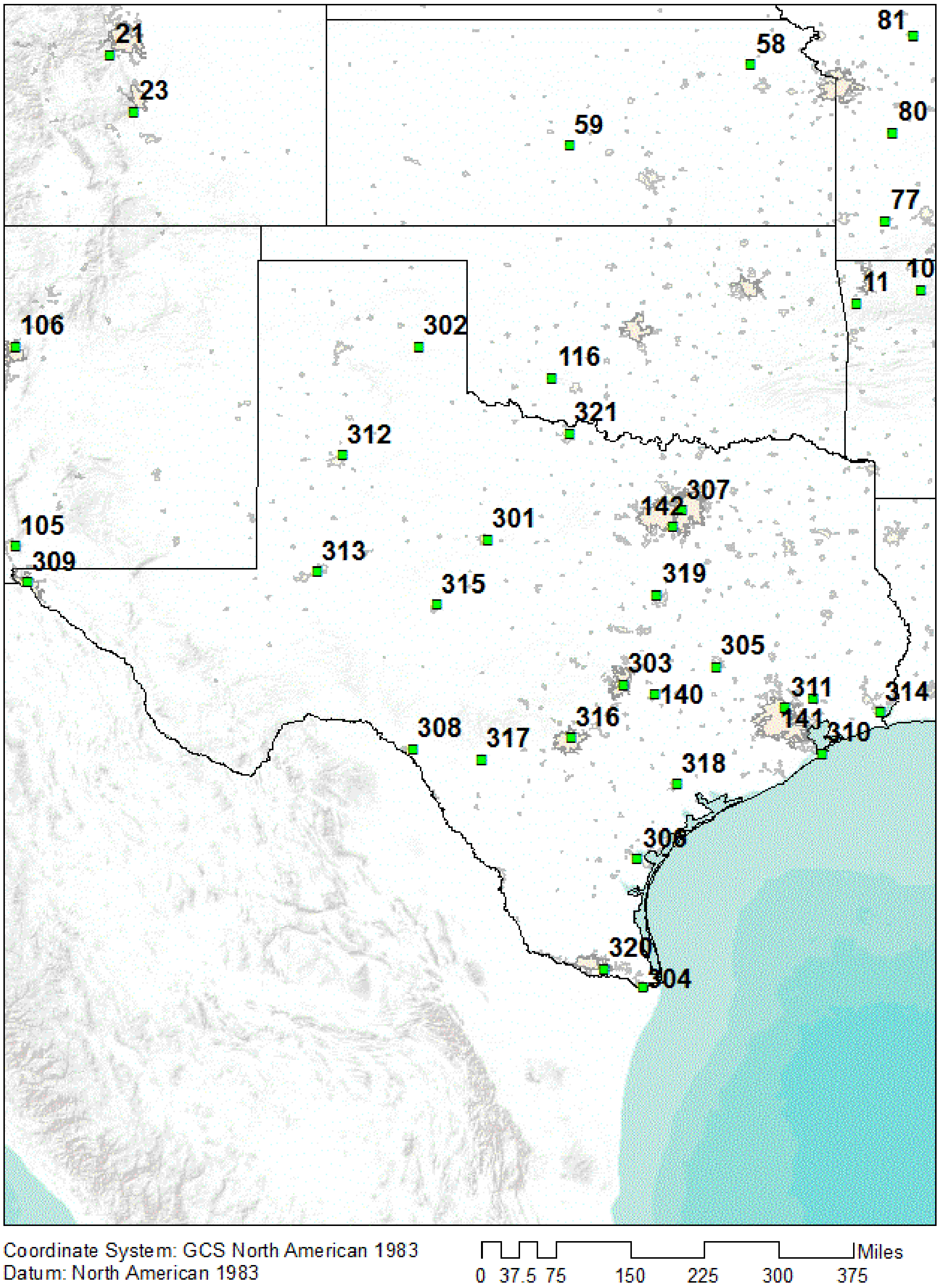
Ohio and West Virginia



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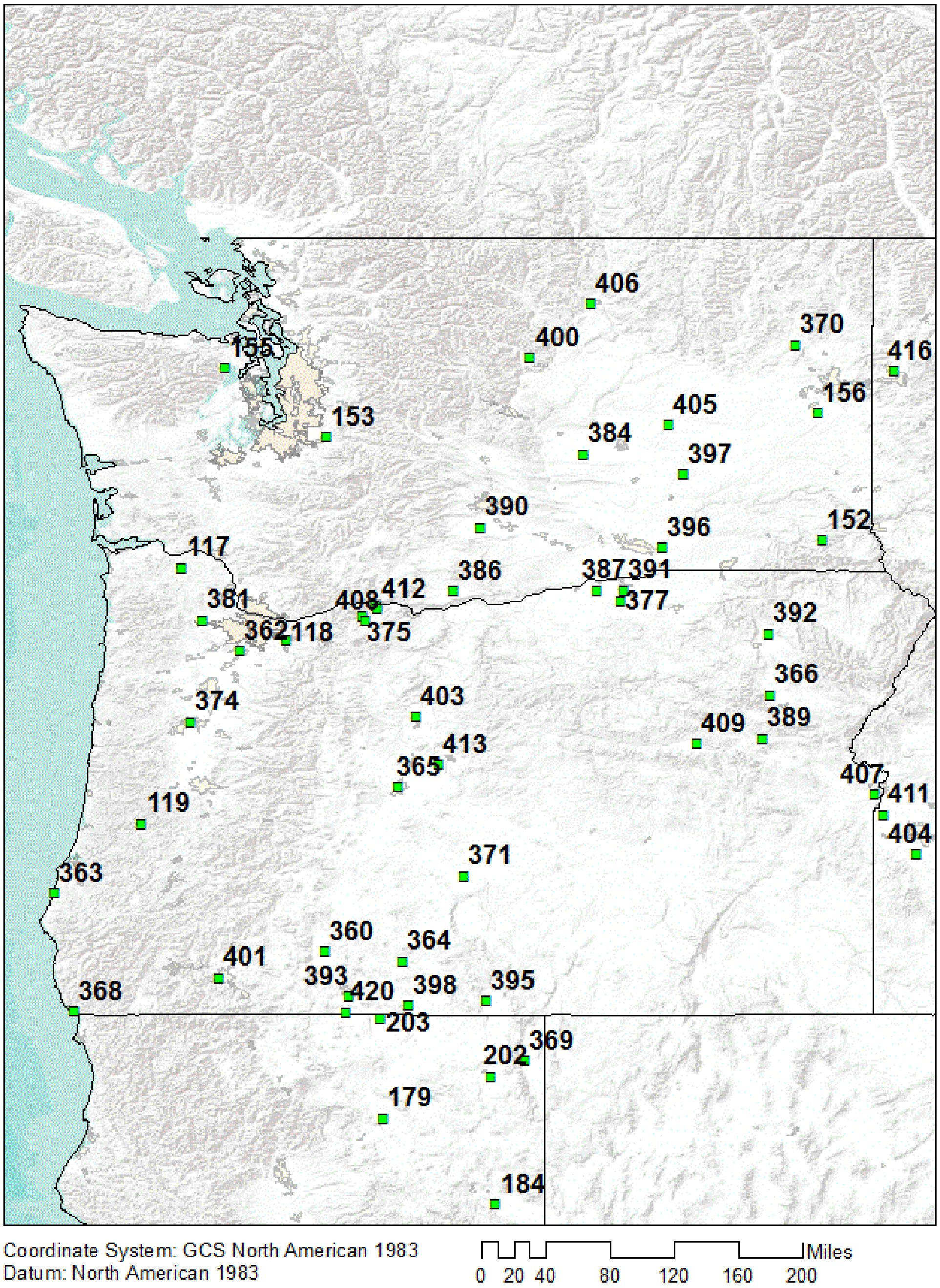
Units: Degree

Texas and Oklahoma



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Datum: North American 1983
Units: Degree

Washington and Oregon

APPENDIX B

AVERAGE MONTHLY ET RATES

ETo Kimberly Penman 1982

Map ID	State	Lat	Long	Elev	Station Name	Years of Data	Kimberly Penman Equation (1982) (ET_r) $(\frac{in}{day})$											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AK	64.84	-147.62	454	Fairbanks Alaska		Unavailable at this time											
2	AK	61.08	-149.73	1480	Rabbit Creek Alaska		Unavailable at this time											
3	AK	57.8	-135.13	450	Hoonah Alaska		Unavailable at this time											
4	AL	33.44	-86.081	600	Talladega Alabama	5	0.07	0.13	0.18	0.24	0.26	0.26	0.25	0.24	0.23	0.21	0.13	0.09
5	AL	32.96	-87.171	363	Oakmulgee Alabama	7	0.08	0.09	0.13	0.20	0.22	0.25	0.24	0.22	0.21	0.17	0.13	0.08
6	AL	34.14	-87.362	804	Bankhead Alabama	7	0.06	0.12	0.17	0.24	0.25	0.26	0.25	0.25	0.23	0.20	0.13	0.09
7	AL	32.45	-85.641	283	Tuskegee Alabama	5	0.08	0.13	0.17	0.24	0.26	0.27	0.27	0.25	0.23	0.19	0.13	0.07
8	AR	34.76	-90.722	253	Marianna Arkansas	3	0.06	0.07	0.13	0.18	0.21	0.27	0.26	0.25	0.20	0.16	0.11	0.06
9	AR	34.27	-92.393	270	Sheridan Arkansas	6	0.07	0.12	0.19	0.08	0.32	0.31	0.20	0.30	0.28	0.21	0.15	0.08
10	AR	36.07	-93.357	2365	Compton Arkansas	2	0.06	0.10	0.15	0.21	0.32	0.38	0.35	0.30	0.24	0.22	0.11	0.08
11	AR	35.87	-94.297	1633	Strickler Arkansas	6	0.06	0.07	0.12	0.16	0.19	0.23	0.24	0.24	0.20	0.15	0.11	0.07
12	AZ	32.4	-110.27	4175	Muleshoe Ranch AZ	13	0.09	0.15	0.22	0.29	0.35	0.37	0.29	0.29	0.31	0.25	0.16	0.11
13	AZ	35.15	-111.68	7000	Flagstaff Arizona	10	0.06	0.10	0.14	0.18	0.24	0.28	0.28	0.24	0.23	0.18	0.10	0.06
14	AZ	32.32	-110.81	3100	Saguaro Arizona	8	0.12	0.18	0.21	0.29	0.35	0.36	0.30	0.29	0.31	0.26	0.17	0.11
15	AZ	34.2	-112.14	2960	Sunset Point Arizona	13	0.13	0.18	0.31	0.29	0.36	0.41	0.44	0.47	0.45	0.31	0.20	0.15
16	CA	37.79	-122.14	1095	Oakland South CA	5	0.06	0.09	0.14	0.22	0.23	0.27	0.31	0.27	0.23	0.15	0.09	0.06
17	CA	34.13	-118.41	1260	Beverly Hills California	6	0.13	0.12	0.14	0.19	0.22	0.28	0.27	0.26	0.22	0.15	0.14	0.12
18	CA	34.46	-119.65	1500	Montecito California	6	0.09	0.09	0.11	0.16	0.17	0.22	0.26	0.29	0.20	0.13	0.12	0.08
19	CA	32.69	-116.97	425	San Miguel California	5	0.11	0.12	0.15	0.22	0.25	0.28	0.29	0.29	0.22	0.19	0.13	0.10
20	CA	34.29	-118.81	914	Simi Valley California	9	0.10	0.10	0.14	0.20	0.22	0.25	0.28	0.26	0.24	0.17	0.11	0.09
21	CO	39.48	-105.21	8725	Waterton North CO	9	0.05	0.10	0.13	0.19	0.23	0.26	0.26	0.25	0.23	0.18	0.10	0.05
22	CO	40.57	-105.23	6082	Redstone Colorado	11	0.06	0.06	0.08	0.09	0.18	0.21	0.22	0.20	0.20	0.08	0.07	0.05
23	CO	38.66	-104.85	6700	Ft. Carson Colorado	10	0.07	0.10	0.13	0.18	0.21	0.26	0.26	0.24	0.23	0.16	0.11	0.07
24	DE	38.74	-75.415	50	Redden Delaware	6	0.06	0.08	0.15	0.20	0.26	0.26	0.25	0.23	0.23	0.17	0.12	0.09
25	FL	25.63	-80.58	5	Chekika Florida	8	0.15	0.19	0.20	0.25	0.23	0.22	0.20	0.20	0.19	0.18	0.16	0.15
26	FL	29.11	-81.63	61	Central Florida	6	0.13	0.16	0.19	0.21	0.21	0.23	0.23	0.22	0.21	0.20	0.15	0.13
27	FL	30.01	-84.424	50	St. Marks (West) Florida	7	0.15	0.16	0.16	0.17	0.18	0.20	0.21	0.19	0.17	0.18	0.16	0.15
28	GA	30.92	-81.429	25	Stafford-CUIS Georgia	5	0.15	0.18	0.22	0.27	0.26	0.25	0.24	0.22	0.22	0.22	0.17	0.15
29	GA	32.1	-81.083	10	Savannah NWR SC	6	0.09	0.11	0.16	0.21	0.24	0.24	0.25	0.22	0.20	0.18	0.13	0.09
30	GA	33.21	-83.714	476	Oconee #1 Georgia	9	0.07	0.14	0.17	0.23	0.27	0.27	0.26	0.24	0.21	0.20	0.14	0.10
31	GA	32.01	-82.9	250	McRae Georgia	6	0.11	0.16	0.20	0.26	0.28	0.28	0.24	0.24	0.24	0.22	0.15	0.12
32	GA	32.39	-82.037	99	Metter Georgia	7	0.08	0.12	0.15	0.21	0.22	0.24	0.25	0.22	0.23	0.18	0.12	0.08
33	GA	33.9	-83.366	675	Watkinsville Georgia	6	0.08	0.09	0.14	0.16	0.18	0.23	0.25	0.23	0.21	0.17	0.11	0.08
34	GA	32.01	-84.33	526	Plains/Sumter Georgia	6	0.09	0.12	0.16	0.20	0.21	0.21	0.22	0.20	0.19	0.17	0.14	0.09
35	GA	31.71	-82.388	109	Baxley Georgia	7	0.08	0.12	0.15	0.18	0.21	0.24	0.22	0.19	0.18	0.17	0.12	0.09
36	GA	33.83	-84.74	907	Dallas Georgia	7	0.07	0.08	0.14	0.15	0.18	0.23	0.24	0.23	0.21	0.17	0.11	0.07

ETo Kimberly Penman 1982

Map ID	State	Lat	Long	Elev	Station Name	Years of Data	Kimberly Penman Equation (1982)(ET_r) $(\frac{in}{day})$											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
37	HI	19.82	-155.33	6400	Hakalau Hawaii	7	0.12	0.16	0.20	0.22	0.20	0.21	0.21	0.22	0.26	0.19	0.16	0.12
38	HI	21.53	-158.23	20	Makua Range Hawaii	10	0.13	0.17	0.17	0.18	0.20	0.19	0.18	0.17	0.20	0.17	0.14	0.12
39	HI	21.5	-157.9	2293	Oahu Forest NWR HI	4	0.16	0.12	0.14	0.13	0.15	0.13	0.12	0.11	0.14	0.15	0.24	0.19
40	HI	19.67	-156.02	25	Kaloko-Honokohau HI	6	0.12	0.14	0.15	0.17	0.20	0.20	0.21	0.19	0.20	0.18	0.14	0.13
41	HI	21.5	-158.08	980	Schofield Barracks HI	10	0.16	0.19	0.21	0.23	0.23	0.21	0.21	0.21	0.23	0.21	0.18	0.16
42	IA	41.57	-93.258	898	Neal Smith Iowa	8	0.04	0.05	0.10	0.17	0.17	0.22	0.26	0.23	0.18	0.12	0.09	0.05
43	IA	41.83	-95.928	1070	Loess Hills State Forest IA	8	0.06	0.06	0.11	0.18	0.21	0.25	0.25	0.25	0.20	0.14	0.08	0.05
44	IA	41.42	-95.854	1260	Loess Hills Hitchcock IA	3	0.05	0.06	0.11	0.16	0.21	0.28	0.34	0.25	0.22	0.12	0.07	0.04
45	IA	40.65	-91.724	651	Shimek State Forest IA	3	0.04	0.03	0.14	0.32	0.27	0.31	0.32	0.26	0.25	0.19	0.12	0.03
46	IA	41.53	-96.083	732	Desoto Iowa	7	0.03	0.05	0.10	0.19	0.30	0.38	0.53	0.53	0.34	0.21	0.07	0.03
47	ID	42.97	-114.06	4260	Rock Lake Idaho	10	0.03	0.09	0.11	0.15	0.18	0.20	0.25	0.24	0.20	0.13	0.07	0.03
48	ID	43.03	-115.87	3000	Mountain Home Idaho	7	0.04	0.08	0.12	0.14	0.18	0.19	0.26	0.24	0.21	0.14	0.07	0.04
49	ID	43.65	-111.58	7040	Moody Idaho	10	0.02	0.03	0.10	0.17	0.21	0.27	0.31	0.28	0.25	0.16	0.09	0.02
50	ID	43.59	-115.99	3170	Lucky Peak Idaho	12	0.04	0.07	0.12	0.16	0.20	0.23	0.26	0.22	0.19	0.12	0.08	0.06
51	IL	37.25	-89.378	700	Bean Ridge Illinois	8	0.04	0.10	0.15	0.21	0.28	0.31	0.32	0.26	0.26	0.19	0.10	0.07
52	IL	41.34	-88.131	489	Midewin Tall Grass IL	5	0.04	0.04	0.10	0.17	0.23	0.27	0.27	0.25	0.22	0.14	0.09	0.04
53	IL	37.68	-89.003	450	Crab Orchard Illinois	7	0.06	0.06	0.12	0.18	0.21	0.28	0.26	0.25	0.18	0.15	0.11	0.06
54	IN	38.93	-85.363	900	Big Oaks Indiana	6	0.04	0.04	0.11	0.16	0.21	0.26	0.26	0.23	0.21	0.14	0.10	0.06
55	IN	41.63	-87.088	647	Bailly Indiana	5	0.05	0.05	0.09	0.16	0.21	0.23	0.23	0.20	0.18	0.12	0.08	0.04
56	IN	39	-86.423	750	Hardin Ridge Indiana	8	0.05	0.05	0.13	0.21	0.28	0.32	0.30	0.24	0.22	0.18	0.12	0.08
57	IN	38.13	-86.625	718	Tipsaw Lake Indiana	7	0.04	0.12	0.15	0.22	0.27	0.30	0.28	0.24	0.23	0.18	0.12	0.08
58	KS	39.34	-95.854	1100	Potawatomi Kansas	3	0.05	0.07	0.10	0.15	0.18	0.22	0.28	0.19	0.20	0.11	0.08	0.05
59	KS	38.17	-98.5	1773	Stafford Kansas	7	0.07	0.09	0.12	0.15	0.18	0.22	0.25	0.22	0.19	0.14	0.09	0.06
60	KY	37.77	-83.633	1300	Koomer Kentucky	8	0.05	0.06	0.12	0.19	0.21	0.24	0.22	0.22	0.20	0.16	0.10	0.05
61	KY	37.13	-86.148	774	Houchin Meadow KY	4	0.05	0.10	0.16	0.22	0.23	0.29	0.28	0.24	0.22	0.15	0.10	0.05
62	KY	38.77	-84.602	935	Crittenden Kentucky	6	0.04	0.06	0.11	0.19	0.23	0.25	0.24	0.21	0.21	0.17	0.11	0.05
63	KY	36.8	-85.38	853	Alpine Kentucky	6	0.08	0.10	0.18	0.22	0.25	0.30	0.28	0.29	0.24	0.17	0.09	0.06
64	LA	30	-92.893	5	Lacassine Louisiana	6	0.08	0.10	0.14	0.17	0.21	0.25	0.22	0.22	0.20	0.19	0.15	0.09
65	LA	30.32	-89.933	11	Big Branch NWR LA	8	0.10	0.11	0.16	0.19	0.20	0.20	0.18	0.17	0.19	0.17	0.15	0.10
66	LA	32.8	-93.067	230	Caney - FTS Louisiana	7	0.10	0.13	0.17	0.22	0.27	0.31	0.26	0.27	0.26	0.25	0.18	0.11
67	MD	39.65	-76.139	300	Susquehanna Maryland	5	0.05	0.06	0.15	0.22	0.24	0.29	0.29	0.27	0.22	0.16	0.10	0.06
68	MD	38.65	-76.821	200	Cedarville Maryland	5	0.05	0.11	0.15	0.23	0.26	0.30	0.29	0.26	0.23	0.19	0.13	0.10
69	ME	43.35	-70.548	20	Rachel Carson Maine	5	0.04	0.05	0.10	0.14	0.19	0.23	0.24	0.21	0.18	0.13	0.06	0.04
70	ME	44.9	-68.64	114	Sunkhaze Meadows ME	9	0.03	0.04	0.06	0.15	0.18	0.22	0.23	0.22	0.19	0.12	0.05	0.03
71	MI	44.72	-84.709	1120	Grayling Michigan	6	0.03	0.04	0.09	0.16	0.22	0.24	0.24	0.22	0.17	0.10	0.06	0.03
72	MI	42.82	-83.696	906	Holly Michigan	4	0.03	0.04	0.09	0.14	0.23	0.29	0.30	0.27	0.21	0.13	0.08	0.04

ETo Kimberly Penman 1982

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							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
73	MN	46.84	-92.462	1330	Saginaw Minnesota	4	0.03	0.03	0.05	0.12	0.17	0.18	0.20	0.19	0.17	0.11	0.04	0.02
74	MN	44.03	-96.267	1660	Redstn Minnesota	3	0.03	0.04	0.06	0.14	0.18	0.24	0.25	0.23	0.20	0.13	0.07	0.03
75	MN	45.3	-93.101	900	Carlos Avery Minnesota	4	0.02	0.03	0.07	0.17	0.25	0.25	0.29	0.26	0.23	0.16	0.06	0.02
76	MO	37.5	-91.259	1333	Sinkin Missouri	9	0.06	0.09	0.14	0.19	0.25	0.27	0.28	0.25	0.23	0.18	0.09	0.05
77	MO	37.07	-93.897	1235	Mt. Vernon Missouri	6	0.06	0.10	0.13	0.16	0.27	0.20	0.25	0.21	0.20	0.14	0.09	0.07
78	MO	37.97	-92.901	1090	Macks Creek Missouri	5	0.06	0.09	0.14	0.19	0.23	0.25	0.28	0.25	0.23	0.16	0.09	0.07
79	MO	38.81	-92.257	798	Ashland Missouri	5	0.06	0.07	0.14	0.20	0.24	0.28	0.29	0.27	0.24	0.18	0.10	0.07
80	MO	38.35	-93.775	750	MDC Clinton Hqtrs MO	5	0.10	0.07	0.15	0.14	0.21	0.21	0.23	0.21	0.17	0.19	0.09	0.12
81	MO	39.77	-93.485	780	Chillicothe Missouri	6	0.05	0.05	0.10	0.16	0.18	0.22	0.25	0.23	0.21	0.15	0.09	0.05
82	MO	37.76	-90	946	Farmington Missouri	6	0.05	0.09	0.12	0.17	0.23	0.23	0.26	0.23	0.23	0.14	0.09	0.06
83	MO	39.87	-92.521	840	Atlanta Missouri	7	0.04	0.05	0.11	0.16	0.18	0.21	0.22	0.22	0.20	0.14	0.08	0.05
84	MS	31.95	-90.381	150	Copiah Mississippi	7	0.08	0.12	0.15	0.20	0.24	0.26	0.25	0.25	0.23	0.20	0.14	0.09
85	MS	30.45	-88.662	25	Sandhill Crane MS	7	0.10	0.17	0.20	0.25	0.27	0.26	0.25	0.23	0.23	0.22	0.16	0.12
87	MS	34.62	-89.314	500	Winborn Mississippi	7	0.07	0.11	0.15	0.20	0.24	0.26	0.26	0.25	0.22	0.19	0.11	0.08
88	MS	32.36	-90.844	248	Warren Mississippi	6	0.06	0.12	0.16	0.19	0.25	0.27	0.26	0.24	0.22	0.17	0.12	0.08
89	MT	47.04	-113.98	7920	Point 6 Montana	10	0.12	0.17	0.21	0.28	0.34	0.34	0.34	0.30	0.28	0.25	0.18	0.14
90	MT	45.45	-111.22	5370	Shenago Montana	3	0.02	0.02	0.03	0.05	0.10	0.17	0.30	0.25	0.15	0.06	0.03	0.02
91	MT	45.73	-108.4	4020	Soda Springs Montana	7	0.04	0.05	0.05	0.07	0.17	0.23	0.37	0.35	0.26	0.12	0.05	0.03
92	NC	35.8	-82.65	2171	7 Mile Ridge NC	6	0.05	0.06	0.09	0.14	0.26	0.36	0.55	0.50	0.37	0.17	0.07	0.05
93	NC	34.53	-77.722	20	Back Island NC	8	0.09	0.11	0.15	0.21	0.22	0.23	0.23	0.22	0.20	0.17	0.11	0.08
94	NC	35.97	-79.092	565	Duke Forest NC	10	0.09	0.13	0.17	0.24	0.27	0.29	0.29	0.28	0.27	0.23	0.15	0.10
95	NC	35.43	-78.023	87	Finch's Station NC	4	0.07	0.11	0.14	0.19	0.23	0.24	0.23	0.22	0.20	0.17	0.12	0.08
96	NC	35.79	-80.312	750	Lexington NC	7	0.08	0.12	0.16	0.22	0.22	0.23	0.23	0.21	0.22	0.17	0.12	0.08
97	NC	35.38	-80.993	500	Mt. Island Lake NC	6	0.07	0.12	0.15	0.20	0.21	0.23	0.22	0.20	0.19	0.16	0.10	0.08
98	ND	46.68	-100.24	1835	Long Lake NWR ND	3	0.07	0.11	0.15	0.21	0.26	0.26	0.26	0.24	0.23	0.19	0.13	0.08
99	NE	40.57	-98.17	1790	Rainwater Basin NE	2	0.03	0.04	0.08	0.10	0.13	0.14	0.16	0.13	0.11	0.07	0.06	0.03
100	NH	43.98	-71.141	460	White Mountain NF NH	6	0.05	0.06	0.10	0.14	0.17	0.23	0.22	0.20	0.18	0.13	0.08	0.05
101	NJ	40.41	-74.494	116	New Middlesex County NJ	5	0.04	0.04	0.06	0.16	0.18	0.23	0.25	0.22	0.17	0.13	0.06	0.04
102	NJ	41.12	-74.24	567	Ringwood New Jersey	3	0.04	0.05	0.14	0.22	0.28	0.30	0.33	0.30	0.29	0.20	0.18	0.07

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							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
103	NJ	39.23	-74.804	87	Woodbine New Jersey	4	0.05	0.07	0.15	0.18	0.26	0.25	0.27	0.24	0.22	0.19	0.14	0.13
104	NJ	39.68	-74.865	116	Ancora Hospital NJ	6	0.05	0.06	0.15	0.23	0.27	0.28	0.29	0.26	0.23	0.17	0.12	0.12
105	NM	32.32	-106.59	6172	Dripping Springs NM	11	0.09	0.13	0.18	0.23	0.27	0.26	0.24	0.20	0.19	0.16	0.12	0.09
106	NM	35.23	-106.59	5000	Sandia Lakes New Mexico	6	0.08	0.12	0.18	0.26	0.32	0.37	0.31	0.28	0.28	0.22	0.14	0.09
107	NV	39.24	-119.88	6310	Little Valley Nevada	8	0.04	0.09	0.12	0.16	0.21	0.25	0.28	0.25	0.24	0.15	0.08	0.04
108	NV	46.22	-112.23	6860	Galena Montana	8	0.06	0.07	0.11	0.14	0.19	0.22	0.27	0.23	0.21	0.14	0.08	0.05
109	NV	36.14	-115.43	3760	Red Rock Nevada	12	0.10	0.14	0.17	0.22	0.27	0.31	0.31	0.29	0.31	0.23	0.15	0.09
110	NY	43.06	-78.24	2700	Iroquois New York	8	0.03	1.14	0.06	0.15	0.17	0.19	0.20	0.18	0.15	0.10	0.06	0.04
111	NY	42.7	-75.5	1100	Sherburne New York	7	0.04	0.05	0.07	0.16	0.19	0.21	0.22	0.21	0.16	0.11	0.07	0.04
112	NY	40.8	-72.7	100	Eastport New York	6	0.04	0.06	0.13	0.21	0.25	0.26	0.27	0.25	0.23	0.17	0.13	0.11
113	NY	42.14	-74.494	1950	Belleayre Mt. New York	5	0.05	0.04	0.07	0.14	0.18	0.21	0.22	0.18	0.16	0.12	0.07	0.04
114	OH	41.53	-83.929	612	Maumee Ohio	5	0.03	0.03	0.14	0.21	0.29	0.38	0.41	0.38	0.30	0.19	0.12	0.03
115	OH	40	-82.081	641	Blue Rock Ohio	3	0.03	0.04	0.14	0.23	0.26	0.35	0.32	0.25	0.23	0.20	0.11	0.03
116	OK	34.77	-98.746	1800	Wichita Oklahoma	9	0.16	0.20	0.25	0.29	0.41	0.47	0.63	0.55	0.45	0.34	0.18	0.17
117	OR	46.02	-123.27	1090	Miller Oregon	5	0.06	0.09	0.16	0.18	0.23	0.26	0.30	0.26	0.24	0.16	0.11	0.09
118	OR	45.37	-122.33	744	Eagle Creek Oregon	6	0.04	0.05	0.10	0.13	0.18	0.21	0.26	0.24	0.20	0.10	0.06	0.04
119	OR	43.72	-123.63	1550	Devils Graveyard Oregon	6	0.04	0.07	0.11	0.14	0.18	0.20	0.22	0.22	0.18	0.12	0.07	0.06
120	PA	40.52	-76.778	1720	Wolf Pond Pennsylvania	4	0.04	0.04	0.11	0.16	0.19	0.24	0.24	0.22	0.17	0.13	0.07	0.03
121	PA	41.63	-79.957	1800	Erie Pennsylvania	3	0.03	0.04	0.11	0.16	0.21	0.27	0.26	0.23	0.20	0.14	0.08	0.03
122	RI	41.82	-71.533	278	Snake Den Rhode Island	3	0.04	0.05	0.12	0.20	0.23	0.24	0.26	0.24	0.23	0.16	0.08	0.05
123	RI	41.35	-71.65	40	Ninigret Rhode Island	7	0.05	0.06	0.14	0.20	0.24	0.25	0.27	0.25	0.24	0.18	0.14	0.12
124	SC	33.82	-80.781	122	Congaree South Carolina	5	0.09	0.11	0.15	0.23	0.26	0.29	0.29	0.26	0.23	0.20	0.13	0.09
125	SC	34.81	-83.125	1600	Andrew Pickens SC	8	0.07	0.12	0.16	0.22	0.23	0.24	0.25	0.23	0.21	0.19	0.13	0.08
126	SC	33.21	-81.591	390	Savriv South Carolina	7	0.10	0.12	0.18	0.24	0.24	0.25	0.24	0.22	0.23	0.18	0.13	0.11
127	SD	43.75	-103.63	5200	Custer South Dakota	3	0.06	0.05	0.10	0.18	0.20	0.26	0.30	0.23	0.22	0.14	0.08	0.05
128	SD	45.8	-97.451	2010	Marshall Co. SD	2	0.02	0.02	0.04	0.10	0.05	0.17	0.18	0.15	0.13	0.09	0.04	0.02
129	TN	36.26	-83.277	1163	Hamblen Co HQ TN	7	0.07	0.11	0.15	0.21	0.23	0.23	0.24	0.20	0.19	0.15	0.11	0.08
130	TN	35.13	-85.428	1920	Prentice Cooper SF TN	7	0.07	0.09	0.14	0.19	0.22	0.25	0.24	0.20	0.19	0.14	0.10	0.06
131	TN	36.07	-83.489	1750	Jefferson Co Tower TN	6	0.06	0.08	0.12	0.16	0.19	0.20	0.20	0.20	0.20	0.12	0.08	0.06
132	TN	36.54	-86.003	970	Lafayette Work Center Tn	7	0.07	0.09	0.16	0.20	0.24	0.27	0.25	0.23	0.21	0.18	0.10	0.08
133	TN	35.38	-86.766	1150	Lewisburg Tower Tn	6	0.06	0.09	0.14	0.21	0.24	0.26	0.26	0.22	0.21	0.15	0.11	0.07
134	TN	36.07	-87.283	706	Burns Tennessee	7	0.07	0.10	0.17	0.22	0.27	0.29	0.25	0.20	0.17	0.14	0.11	0.08

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135	TN	35.32	-87.458	860	Meriwether Lewis TN	7	0.08	0.12	0.20	0.26	0.29	0.29	0.29	0.29	0.27	0.21	0.13	0.08
136	TN	35.92	-84.997	1770	Crossville Area Office Tn	6	0.08	0.10	0.18	0.22	0.25	0.26	0.28	0.25	0.23	0.16	0.12	0.09
137	TN	35.99	-89.406	208	Dyersburg Tennessee	7	0.06	0.08	0.15	0.18	0.23	0.24	0.25	0.23	0.23	0.20	0.12	0.06
138	TN	35.84	-84.331	1240	Lenoir City Tennessee	7	0.06	0.10	0.14	0.18	0.24	0.26	0.24	0.23	0.22	0.17	0.10	0.08
139	TN	36.37	-83.899	1657	Chuck Swan SF TN	7	0.09	0.13	0.18	0.24	0.28	0.29	0.26	0.17	0.10	0.10	0.10	0.08
140	TX	30.17	-97.256	383	Bastrop Texas	7	0.12	0.15	0.21	0.25	0.30	0.33	0.33	0.31	0.28	0.22	0.15	0.11
141	TX	30.11	-94.931	100	Dayton Texas	7	0.08	0.10	0.14	0.17	0.20	0.22	0.21	0.19	0.19	0.14	0.10	0.08
142	TX	32.61	-96.993	520	Cedar Hill SP Texas	7	0.08	0.10	0.13	0.18	0.23	0.26	0.28	0.28	0.23	0.17	0.10	0.09
143	UT	41.15	-111.92	5100	Bues Canyon Utah	12	0.03	0.09	0.14	0.21	0.28	0.31	0.37	0.35	0.32	0.21	0.12	0.03
144	VA	36.68	-75.933	1200	Back Bay Virginia	8	0.06	0.09	0.12	0.15	0.16	0.19	0.20	0.17	0.15	0.11	0.09	0.07
145	VA	38.1	-78.785	2080	Sawmill Ridge Virginia	4	0.05	0.08	0.12	0.19	0.18	0.21	0.19	0.19	0.18	0.12	0.09	0.06
146	VA	37.01	-81.179	2540	Stony Fork Virginia	5	0.04	0.09	0.14	0.19	0.22	0.26	0.24	0.25	0.23	0.17	0.12	0.08
147	VA	37.99	-79.759	2580	Lime Kiln Virginia	4	0.06	0.10	0.15	0.20	0.24	0.26	0.26	0.24	0.21	0.17	0.10	0.07
148	VA	37.25	-77.25	50	James River Virginia	6	0.11	0.14	0.19	0.26	0.29	0.29	0.28	0.26	0.28	0.22	0.17	0.13
149	VT	44.51	-73.116	340	Essex Junction Vermont	6	0.04	0.04	0.06	0.15	0.20	0.24	0.25	0.22	0.18	0.12	0.07	0.04
150	VT	43.33	-73.033	668	Sweezy Vermont	9	0.04	0.05	0.07	0.15	0.20	0.23	0.23	0.22	0.19	0.14	0.07	0.04
151	VT	44.54	-72.529	1200	Elmore Vermont	6	0.03	0.04	0.06	0.13	0.18	0.20	0.22	0.20	0.17	0.12	0.05	0.03
152	WA	46.27	-117.5	4500	Alder Ridge Washington	8	0.04	0.06	0.08	0.15	0.18	0.23	0.32	0.25	0.20	0.11	0.07	0.04
153	WA	47.2	-121.96	771	Enumclaw Washington	6	0.07	0.09	0.12	0.16	0.18	0.27	0.31	0.30	0.22	0.14	0.10	0.09
154	WA	34.1	-118.22	920	Mt. Washington CA	7	0.05	0.07	0.12	0.14	0.17	0.22	0.26	0.26	0.24	0.13	0.07	0.06
155	WA	47.82	-122.88	62	Quilcene Washington	5	0.07	0.09	0.12	0.18	0.21	0.23	0.29	0.31	0.25	0.18	0.13	0.10
156	WA	47.42	-117.53	2230	Turnbull NWR WA	8	0.03	0.05	0.08	0.14	0.19	0.22	0.27	0.25	0.20	0.12	0.06	0.03
157	WI	43.57	-88.609	800	Horicon Wisconsin	8	0.03	0.03	0.11	0.19	0.19	0.24	0.15	0.15	0.15	0.16	0.14	0.03
158	WI	43.1	-89.333	857	Wautoma Wisconsin	5	0.03	0.04	0.08	0.15	0.22	0.24	0.26	0.22	0.18	0.12	0.07	0.03
159	WI	43.1	-90	1260	Dodgeville Wisconsin	5	0.03	0.03	0.06	0.13	0.19	0.24	0.25	0.21	0.17	0.12	0.07	0.03
160	WV	38.3	-82.417	735	Beech Fork West Virginia	3	0.04	0.10	0.15	0.19	0.21	0.23	0.23	0.20	0.19	0.15	0.11	0.08
161	WV	40.54	-80.584	1013	Tomlinson Run WV	6	0.03	0.04	0.16	0.20	0.27	0.26	0.26	0.26	0.26	0.19	0.13	0.09
162	WV	39.11	-79.426	3853	Davis (Bearden) WV	3	0.04	0.04	0.12	0.17	0.18	0.20	0.21	0.18	0.15	0.12	0.08	0.06
163	WY	42.71	-106.35	7740	Casper Mountain WY	11	0.04	0.09	0.12	0.16	0.19	0.21	0.25	0.23	0.19	0.14	0.09	0.03

ET_o ASCE Standardized Reference Equation

Map ID	**State**	**Lat**	**Long**	**Elev**	**Station Name**	**Years of Data**	**ASCE Standardized Reference Evaporation Equation (ET_o) $(\frac{in}{day})$**											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AK	64.84	-147.62	454	Fairbanks Alaska													
2	AK	61.08	-149.73	1480	Rabbit Creek Alaska													
3	AK	57.8	-135.13	450	Hoonah Alaska													
4	AL	33.44	-86.081	600	Talladega Alabama	5	0.04	0.08	0.11	0.15	0.16	0.16	0.16	0.15	0.14	0.12	0.07	0.05
5	AL	32.96	-87.171	363	Oakmulgee Alabama	7	0.05	0.06	0.10	0.13	0.15	0.16	0.15	0.14	0.14	0.10	0.07	0.05
6	AL	34.14	-87.362	804	Bankhead Alabama	7	0.04	0.08	0.11	0.17	0.16	0.17	0.16	0.16	0.14	0.12	0.07	0.05
7	AL	32.45	-85.641	283	Tuskegee Alabama	5	0.05	0.08	0.12	0.16	0.17	0.18	0.17	0.15	0.15	0.12	0.08	0.04
8	AR	34.76	-90.722	253	Marianna Arkansas	3	0.04	0.06	0.11	0.15	0.16	0.20	0.18	0.17	0.14	0.10	0.07	0.04
9	AR	34.27	-92.393	270	Sheridan Arkansas	6	0.04	0.07	0.12	0.08	0.19	0.20	0.21	0.19	0.17	0.11	0.08	0.04
10	AR	36.07	-93.357	2365	Compton Arkansas	2	0.04	0.06	0.11	0.16	0.17	0.22	0.18	0.19	0.15	0.15	0.09	0.05
11	AR	35.87	-94.297	1633	Strickler Arkansas	6	0.06	0.06	0.13	0.17	0.16	0.19	0.21	0.22	0.17	0.13	0.11	0.06
12	AZ	32.4	-110.27	4175	Muleshoe Ranch AZ	13	0.07	0.13	0.17	0.24	0.28	0.30	0.24	0.22	0.23	0.20	0.12	0.08
13	AZ	35.15	-111.68	7000	Flagstaff Arizona	10	0.04	0.07	0.11	0.16	0.20	0.24	0.22	0.18	0.17	0.13	0.07	0.04
14	AZ	32.32	-110.81	3100	Saguaro Arizona	8	0.09	0.14	0.17	0.24	0.28	0.29	0.25	0.22	0.24	0.19	0.13	0.08
15	AZ	34.2	-112.14	2960	Sunset Point Arizona	13	0.13	0.17	0.29	0.29	0.36	0.40	0.42	0.44	0.42	0.30	0.19	0.14
16	CA	37.79	-122.14	1095	Oakland South CA	5	0.05	0.07	0.11	0.15	0.18	0.21	0.22	0.19	0.16	0.12	0.07	0.05
17	CA	34.13	-118.41	1260	Beverly Hills California	6	0.07	0.08	0.10	0.14	0.14	0.15	0.12	0.12	0.10	0.08	0.08	0.07
18	CA	34.46	-119.65	1500	Montecito California	6	0.08	0.08	0.11	0.15	0.17	0.19	0.18	0.18	0.15	0.12	0.11	0.07
19	CA	32.69	-116.97	425	San Miguel California	5	0.07	0.09	0.11	0.15	0.16	0.17	0.18	0.18	0.14	0.12	0.08	0.06
20	CA	34.29	-118.81	914	Simi Valley California	9	0.10	0.09	0.11	0.15	0.15	0.17	0.20	0.17	0.16	0.13	0.10	0.08
21	CO	39.48	-105.21	8725	Waterton North CO	9	0.04	0.07	0.10	0.15	0.17	0.20	0.19	0.18	0.16	0.13	0.07	0.04
22	CO	40.57	-105.23	6082	Redstone Colorado	11	0.04	0.04	0.06	0.07	0.13	0.15	0.16	0.13	0.13	0.05	0.05	0.03
23	CO	38.66	-104.85	6700	Ft. Carson Colorado	10	0.05	0.08	0.11	0.16	0.18	0.22	0.21	0.18	0.17	0.13	0.08	0.05
24	DE	38.74	-75.415	50	Redden Delaware	6	0.04	0.05	0.11	0.14	0.18	0.18	0.18	0.15	0.13	0.10	0.08	0.06
25	FL	25.63	-80.58	5	Chekika Florida	8	0.11	0.14	0.17	0.21	0.20	0.18	0.16	0.16	0.16	0.16	0.13	0.11
26	FL	29.11	-81.63	61	Central Florida	6	0.08	0.12	0.15	0.19	0.18	0.18	0.16	0.16	0.15	0.14	0.10	0.08
27	FL	30.01	-84.424	50	St. Marks (West) Florida	7	0.10	0.11	0.13	0.14	0.14	0.15	0.15	0.13	0.13	0.12	0.10	0.10
28	GA	30.92	-81.429	25	Stafford-CUIS Georgia	5	0.07	0.09	0.13	0.19	0.17	0.17	0.16	0.14	0.14	0.13	0.09	0.07
29	GA	32.1	-81.083	10	Savannah NWR SC	6	0.06	0.09	0.13	0.17	0.19	0.18	0.17	0.14	0.14	0.12	0.08	0.06
30	GA	33.21	-83.714	476	Oconee #1 Georgia	9	0.04	0.09	0.10	0.14	0.17	0.17	0.17	0.14	0.11	0.11	0.08	0.06
31	GA	32.01	-82.9	250	McRae Georgia	6	0.06	0.09	0.12	0.17	0.18	0.18	0.16	0.15	0.15	0.13	0.08	0.06
32	GA	32.39	-82.037	99	Metter Georgia	7	0.06	0.09	0.12	0.16	0.17	0.18	0.18	0.15	0.16	0.12	0.08	0.06
33	GA	33.9	-83.366	675	Watkinsville Georgia	6	0.06	0.07	0.11	0.12	0.14	0.18	0.18	0.16	0.15	0.12	0.08	0.05
34	GA	32.01	-84.33	526	Plains/Sumter Georgia	6	0.07	0.09	0.13	0.16	0.17	0.17	0.17	0.15	0.14	0.12	0.10	0.07
35	GA	31.71	-82.388	109	Baxley Georgia	7	0.06	0.09	0.12	0.14	0.17	0.18	0.16	0.14	0.14	0.12	0.08	0.06

36	GA	33.83	-84.74	907	Dallas Georgia	7	0.05	0.06	0.10	0.12	0.13	0.16	0.17	0.16	0.14	0.12	0.07	0.05

Station Map ID	State	Lat	Long	Elev	Station Name	ASCE Standardized Reference Evaporation Equation (ET$_o$) $(\frac{in}{day})$												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
37	HI	19.82	-155.33	6400	Hakalau Hawaii	7	0.10	0.13	0.15	0.15	0.15	0.16	0.16	0.15	0.17	0.14	0.12	0.10
38	HI	21.53	-158.23	20	Makua Range Hawaii	10	0.11	0.14	0.15	0.16	0.17	0.17	0.17	0.16	0.18	0.15	0.13	0.11
39	HI	21.5	-157.9	2293	Oahu Forest NWR HI	4	0.12	0.15	0.16	0.16	0.17	0.17	0.17	0.16	0.18	0.15	0.13	0.11
40	HI	19.67	-156.02	25	Kaloko-Honokohau HI	6	0.09	0.11	0.12	0.13	0.14	0.15	0.16	0.14	0.15	0.13	0.10	0.10
41	HI	21.5	-158.08	980	Schofield Barracks HI	10	0.11	0.13	0.15	0.17	0.16	0.16	0.16	0.16	0.17	0.15	0.12	0.11
42	IA	41.57	-93.258	898	Neal Smith Iowa	8	0.03	0.04	0.09	0.17	0.18	0.19	0.19	0.15	0.15	0.11	0.07	0.03
43	IA	41.83	-95.928	1070	Loess Hills State Forest IA	8	0.02	0.03	0.09	0.19	0.21	0.19	0.17	0.17	0.17	0.11	0.06	0.03
44	IA	41.42	-95.854	1260	Loess Hills Hitchcock IA	3	0.03	0.08	0.08	0.14	0.17	0.19	0.19	0.16	0.14	0.10	0.06	0.05
45	IA	40.65	-91.724	651	Shimek State Forest IA	3	0.02	0.01	0.08	0.15	0.17	0.18	0.19	0.15	0.13	0.10	0.07	0.01
46	IA	41.53	-96.083	732	Desoto Iowa	7	0.02	0.03	0.08	0.14	0.17	0.18	0.20	0.16	0.14	0.12	0.06	0.02
47	ID	42.97	-114.06	4260	Rock Lake Idaho	10	0.02	0.06	0.09	0.14	0.17	0.20	0.24	0.21	0.17	0.11	0.05	0.02
48	ID	43.03	-115.87	3000	Mountain Home Idaho	7	0.03	0.07	0.12	0.15	0.18	0.19	0.25	0.21	0.18	0.13	0.06	0.03
49	ID	43.65	-111.58	7040	Moody Idaho	10	0.01	0.02	0.07	0.12	0.15	0.18	0.21	0.18	0.15	0.11	0.06	0.01
50	ID	43.59	-115.99	3170	Lucky Peak Idaho	12	0.02	0.05	0.09	0.13	0.17	0.21	0.25	0.21	0.17	0.11	0.05	0.05
51	IL	37.25	-89.378	700	Bean Ridge Illinois	8	0.02	0.06	0.10	0.15	0.17	0.19	0.19	0.15	0.15	0.12	0.06	0.04
52	IL	41.34	-88.131	489	Midewin Tall Grass IL	5	0.02	0.03	0.08	0.16	0.19	0.21	0.19	0.16	0.15	0.11	0.07	0.02
53	IL	37.68	-89.003	450	Crab Orchard Illinois	7	0.04	0.05	0.10	0.15	0.15	0.19	0.17	0.16	0.13	0.11	0.08	0.04
54	IN	38.93	-85.363	900	Big Oaks Indiana	6	0.02	0.03	0.08	0.13	0.15	0.17	0.16	0.14	0.13	0.10	0.07	0.04
55	IN	41.63	-87.088	647	Bailly Indiana	5	0.02	0.03	0.07	0.13	0.16	0.17	0.16	0.13	0.12	0.09	0.06	0.02
56	IN	39	-86.423	750	Hardin Ridge Indiana	8	0.03	0.03	0.09	0.15	0.17	0.20	0.18	0.15	0.13	0.10	0.07	0.04
57	IN	38.13	-86.625	718	Tipsaw Lake Indiana	7	0.02	0.06	0.09	0.14	0.16	0.17	0.16	0.14	0.13	0.10	0.06	0.04
58	KS	39.34	-95.854	1100	Potawatomi Kansas	3	0.04	0.06	0.10	0.16	0.17	0.18	0.20	0.17	0.16	0.11	0.08	0.04
59	KS	38.17	-98.5	1773	Stafford Kansas	7	0.05	0.08	0.13	0.17	0.19	0.22	0.24	0.21	0.18	0.14	0.08	0.05
60	KY	37.77	-83.633	1300	Koomer Kentucky	8	0.04	0.05	0.10	0.17	0.16	0.17	0.15	0.15	0.13	0.11	0.08	0.04
61	KY	37.13	-86.148	774	Houchin Meadow KY	4	0.03	0.06	0.11	0.15	0.15	0.18	0.18	0.15	0.13	0.09	0.06	0.03
62	KY	38.77	-84.602	935	Crittenden Kentucky	6	0.02	0.04	0.08	0.14	0.15	0.17	0.16	0.14	0.14	0.12	0.09	0.03
63	KY	36.8	-85.38	853	Alpine Kentucky	6	0.04	0.05	0.10	0.14	0.15	0.18	0.17	0.16	0.13	0.10	0.06	0.04
64	LA	30	-92.893	5	Lacassine Louisiana	6	0.06	0.09	0.12	0.16	0.17	0.18	0.16	0.15	0.15	0.13	0.09	0.06
65	LA	30.32	-89.933	11	Big Branch NWR LA	8	0.05	0.06	0.10	0.12	0.13	0.13	0.11	0.11	0.13	0.10	0.08	0.05
66	LA	32.8	-93.067	230	Caney - FTS Louisiana	7	0.06	0.09	0.12	0.16	0.17	0.18	0.16	0.16	0.15	0.13	0.09	0.06
67	MD	39.65	-76.139	300	Susquehanna Maryland	5	0.03	0.04	0.10	0.15	0.15	0.16	0.16	0.15	0.12	0.09	0.06	0.04
68	MD	38.65	-76.821	200	Cedarville Maryland	5	0.03	0.07	0.10	0.15	0.16	0.18	0.17	0.15	0.13	0.10	0.07	0.05
69	ME	43.35	-70.548	20	Rachel Carson Maine	5	0.02	0.03	0.07	0.10	0.13	0.14	0.14	0.12	0.10	0.07	0.04	0.02

Station Map ID	**State**	**Lat**	**Long**	**Elev**	**Station Name**	**ASCE Standardized Reference Evaporation Equation (ET₀) $(\frac{in}{day})$**												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
70	ME	44.9	-68.64	114	Sunkhaze Meadows ME	9	0.01	0.02	0.04	0.10	0.12	0.14	0.14	0.13	0.10	0.06	0.03	0.01
71	MI	44.72	-84.709	1120	Grayling Michigan	6	0.01	0.02	0.06	0.11	0.16	0.16	0.15	0.12	0.08	0.05	0.03	0.01
72	MI	42.82	-83.696	906	Holly Michigan	4	0.02	0.02	0.06	0.11	0.16	0.17	0.17	0.15	0.12	0.09	0.05	0.02
73	MN	46.84	-92.462	1330	Saginaw Minnesota	4	0.01	0.02	0.04	0.10	0.13	0.13	0.14	0.12	0.10	0.07	0.03	0.01
74	MN	44.03	-96.267	1660	Redstn Minnesota	3	0.01	0.02	0.04	0.12	0.17	0.19	0.18	0.15	0.13	0.09	0.04	0.01
75	MN	45.3	-93.101	900	Carlos Avery Minnesota	4	0.01	0.02	0.04	0.11	0.17	0.17	0.18	0.15	0.11	0.09	0.03	0.01
76	MO	37.5	-91.259	1333	Sinkin Missouri	9	0.04	0.06	0.10	0.15	0.17	0.18	0.18	0.16	0.14	0.11	0.06	0.03
77	MO	37.07	-93.897	1235	Mt. Vernon Missouri	6	0.05	0.08	0.11	0.15	0.22	0.17	0.20	0.17	0.15	0.11	0.07	0.05
78	MO	37.97	-92.901	1090	Macks Creek Missouri	5	0.04	0.07	0.12	0.16	0.17	0.17	0.20	0.17	0.15	0.12	0.07	0.05
79	MO	38.81	-92.257	798	Ashland Missouri	5	0.04	0.04	0.10	0.15	0.16	0.18	0.19	0.17	0.15	0.12	0.06	0.04
80	MO	38.35	-93.775	750	MDC Clinton Hqtrs MO	5	0.04	0.05	0.09	0.14	0.16	0.19	0.18	0.18	0.14	0.12	0.07	0.04
81	MO	39.77	-93.485	780	Chillicothe Missouri	6	0.03	0.04	0.09	0.15	0.17	0.10	0.20	0.17	0.15	0.12	0.07	0.03
82	MO	37.76	-90	946	Farmington Missouri	6	0.04	0.07	0.11	0.15	0.17	0.18	0.19	0.17	0.15	0.11	0.06	0.04
83	MO	39.87	-92.521	840	Atlanta Missouri	7	0.03	0.04	0.09	0.15	0.17	0.18	0.18	0.16	0.14	0.12	0.06	0.03
84	MS	31.95	-90.381	150	Copiah Mississippi	7	0.05	0.08	0.12	0.15	0.17	0.18	0.16	0.17	0.16	0.13	0.09	0.06
85	MS	30.45	-88.662	25	Sandhill Crane MS	7	0.06	0.10	0.13	0.17	0.18	0.17	0.17	0.15	0.16	0.14	0.09	0.07
86	MS	34.79	-88.218	300	Tishomingo Mississippi	5	0.04	0.07	0.11	0.15	0.16	0.18	0.17	0.16	0.14	0.12	0.07	0.05
87	MS	34.62	-89.314	500	Winborn Mississippi	7	0.04	0.07	0.12	0.14	0.16	0.18	0.17	0.16	0.15	0.11	0.07	0.05
88	MS	32.36	-90.844	248	Warren Mississippi	6	0.06	0.09	0.13	0.16	0.18	0.19	0.18	0.16	0.14	0.12	0.08	0.07
89	MT	47.04	-113.98	7920	Point 6 Montana	10	0.01	0.01	0.02	0.03	0.08	0.13	0.24	0.19	0.11	0.04	0.02	0.01
90	MT	45.45	-111.22	5370	Shenago Montana	3	0.02	0.03	0.03	0.05	0.11	0.15	0.25	0.23	0.16	0.07	0.03	0.02
91	MT	45.73	-108.4	4020	Soda Springs Montana	7	0.05	0.06	0.10	0.15	0.27	0.37	0.59	0.52	0.38	0.18	0.08	0.05
92	NC	35.8	-82.65	2171	7 Mile Ridge NC	6	0.06	0.07	0.10	0.15	0.15	0.15	0.14	0.13	0.11	0.10	0.07	0.05
93	NC	34.53	-77.722	20	Back Island NC	8	0.06	0.09	0.12	0.17	0.17	0.17	0.17	0.15	0.15	0.12	0.08	0.06
94	NC	35.97	-79.092	565	Duke Forest NC	10	0.05	0.08	0.10	0.15	0.17	0.16	0.16	0.14	0.13	0.10	0.08	0.05
95	NC	35.43	-78.023	87	Finch's Station NC	4	0.05	0.08	0.12	0.16	0.16	0.17	0.16	0.14	0.14	0.10	0.07	0.05
96	NC	35.79	-80.312	750	Lexington NC	7	0.06	0.10	0.13	0.16	0.16	0.17	0.16	0.14	0.13	0.11	0.07	0.06
97	NC	35.38	-80.993	500	Mt. Island Lake NC	6	0.05	0.09	0.12	0.16	0.18	0.17	0.17	0.15	0.14	0.12	0.08	0.05
98	ND	46.68	-100.24	1835	Long Lake NWR ND	3	0.02	0.03	0.08	0.13	0.15	0.16	0.18	0.16	0.12	0.08	0.05	0.01
99	NE	40.57	-98.17	1790	Rainwater Basin NE	2	0.03	0.05	0.10	0.15	0.18	0.21	0.20	0.17	0.15	0.12	0.07	0.03
100	NH	43.98	-71.141	460	White Mountain NF NH	6	0.02	0.02	0.04	0.10	0.12	0.14	0.15	0.13	0.09	0.07	0.03	0.02
101	NJ	40.41	-74.494	116	New Middlesex County NJ	5	0.02	0.03	0.09	0.14	0.17	0.17	0.18	0.16	0.14	0.10	0.09	0.04
102	NJ	41.12	-74.24	567	Ringwood New Jersey	3	0.01	0.03	0.12	0.12	0.14	0.14	0.13	0.11	0.10	0.13	0.11	0.05
103	NJ	39.23	-74.804	87	Woodbine New Jersey	4	0.04	0.05	0.11	0.14	0.17	0.17	0.18	0.16	0.13	0.12	0.09	0.09
104	NJ	39.68	-74.865	116	Ancora Hospital NJ	6	0.03	0.04	0.10	0.16	0.17	0.16	0.20	0.15	0.12	0.09	0.07	0.08

ET_o ASCE Standardized Reference Equation

Station Map ID	State	Lat	Long	Elev	Station Name	ASCE Standardized Reference Evaporation Equation (ET_o) ($\frac{in}{day}$)												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
105	NM	32.32	-106.59	6172	Dripping Springs NM	11	0.07	0.11	0.16	0.23	0.26	0.25	0.22	0.18	0.18	0.14	0.10	0.07
106	NM	35.23	-106.59	5000	Sandia Lakes New Mexico	6	0.05	0.08	0.13	0.19	0.22	0.24	0.20	0.17	0.17	0.13	0.08	0.05
107	NV	39.24	-119.88	6310	Little Valley Nevada	8	0.03	0.06	0.09	0.13	0.18	0.21	0.23	0.19	0.17	0.11	0.06	0.03
108	NV	46.22	-112.23	6860	Galena Montana	8	0.04	0.06	0.10	0.13	0.17	0.20	0.23	0.20	0.17	0.11	0.07	0.05
109	NV	36.14	-115.43	3760	Red Rock Nevada	12	0.07	0.11	0.15	0.22	0.26	0.31	0.30	0.27	0.26	0.19	0.11	0.07
110	NY	43.06	-78.24	2700	Iroquois New York	8	0.02	0.03	0.04	0.11	0.13	0.14	0.14	0.12	0.09	0.07	0.04	0.02
111	NY	42.7	-75.5	1100	Sherburne New York	7	0.02	0.03	0.05	0.12	0.13	0.14	0.14	0.12	0.09	0.07	0.04	0.02
112	NY	40.8	-72.7	100	Eastport New York	6	0.02	0.04	0.10	0.14	0.17	0.16	0.18	0.16	0.13	0.10	0.07	0.06
113	NY	42.14	-74.494	1950	Belleayre Mt. New York	5	0.03	0.04	0.06	0.11	0.13	0.14	0.14	0.11	0.09	0.08	0.04	0.02
114	OH	41.53	-83.929	612	Maumee Ohio	5	0.01	0.01	0.07	0.12	0.16	0.18	0.17	0.15	0.12	0.08	0.05	0.01
115	OH	40	-82.081	641	Blue Rock Ohio	3	0.01	0.02	0.08	0.13	0.14	0.16	0.16	0.13	0.12	0.08	0.05	0.01
116	OK	34.77	-98.746	1800	Wichita Oklahoma	9	0.14	0.20	0.26	0.34	0.41	0.48	0.60	0.53	0.40	0.30	0.17	0.15
117	OR	46.02	-123.27	1090	Miller Oregon	5	0.02	0.04	0.07	0.10	0.14	0.15	0.18	0.14	0.12	0.07	0.04	0.02
118	OR	45.37	-122.33	744	Eagle Creek Oregon	6	0.02	0.03	0.07	0.09	0.13	0.14	0.18	0.16	0.13	0.06	0.03	0.02
119	OR	43.72	-123.63	1550	Devils Graveyard Oregon	6	0.02	0.04	0.07	0.10	0.13	0.15	0.18	0.16	0.13	0.08	0.03	0.02
120	PA	40.52	-76.778	1720	Wolf Pond Pennsylvania	4	0.02	0.03	0.09	0.13	0.14	0.16	0.16	0.14	0.11	0.09	0.05	0.02
121	PA	41.63	-79.957	1800	Erie Pennsylvania	3	0.02	0.03	0.10	0.15	0.15	0.17	0.17	0.14	0.14	0.10	0.05	0.02
122	RI	41.82	-71.533	278	Snake Den Rhode Island	3	0.02	0.03	0.08	0.14	0.15	0.14	0.17	0.15	0.12	0.09	0.04	0.02
123	RI	41.35	-71.65	40	Ninigret Rhode Island	7	0.03	0.04	0.09	0.13	0.15	0.15	0.15	0.14	0.12	0.10	0.08	0.07
124	SC	33.82	-80.781	122	Congaree South Carolina	5	0.06	0.07	0.10	0.17	0.18	0.19	0.18	0.15	0.16	0.11	0.07	0.05
125	SC	34.81	-83.125	1600	Andrew Pickens SC	8	0.05	0.08	0.11	0.15	0.15	0.16	0.16	0.14	0.13	0.10	0.08	0.05
126	SC	33.21	-81.591	390	Savriv South Carolina	7	0.06	0.08	0.12	0.16	0.16	0.17	0.16	0.14	0.14	0.11	0.07	0.06
127	SD	43.75	-103.63	5200	Custer South Dakota	3	0.04	0.03	0.08	0.14	0.16	0.19	0.22	0.18	0.17	0.11	0.06	0.03
128	SD	45.8	-97.451	2010	Marshall Co. SD	2	0.01	0.02	0.03	0.12	0.03	0.18	0.19	0.16	0.13	0.09	0.04	0.01
129	TN	36.26	-83.277	1163	Hamblen Co HQ TN	7	0.04	0.06	0.10	0.14	0.15	0.15	0.15	0.13	0.12	0.09	0.06	0.04
130	TN	35.13	-85.428	1920	Prentice Cooper SF TN	7	0.05	0.07	0.11	0.15	0.16	0.17	0.16	0.14	0.13	0.10	0.07	0.05
131	TN	36.07	-83.489	1750	Jefferson Co Tower TN	6	0.04	0.06	0.11	0.14	0.15	0.15	0.15	0.14	0.14	0.09	0.06	0.04
132	TN	36.54	-86.003	970	Lafayette Work Center Tn	7	0.04	0.06	0.12	0.14	0.15	0.17	0.16	0.14	0.13	0.10	0.06	0.04
133	TN	35.38	-86.766	1150	Lewisburg Tower Tn	6	0.04	0.06	0.10	0.15	0.16	0.17	0.17	0.15	0.13	0.10	0.07	0.05
134	TN	36.07	-87.283	706	Burns Tennessee	7	0.04	0.06	0.11	0.15	0.16	0.17	0.16	0.15	0.13	0.10	0.07	0.06
135	TN	35.32	-87.458	860	Meriwether Lewis TN	7	0.04	0.06	0.10	0.14	0.15	0.16	0.16	0.15	0.13	0.10	0.06	0.04
136	TN	35.92	-84.997	1770	Crossville Area Office Tn	6	0.04	0.06	0.11	0.14	0.14	0.15	0.16	0.14	0.12	0.09	0.06	0.04

ET$_o$ ASCE Standardized Reference Equation

Station Map ID	State	Lat	Long	Elev	Station Name	ASCE Standardized Reference Evaporation Equation (ET$_o$) $(\frac{in}{day})$												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
137	TN	35.99	-89.406	208	Dyersburg Tennessee	7	0.04	0.07	0.12	0.16	0.19	0.19	0.18	0.17	0.16	0.14	0.08	0.04
138	TN	35.84	-84.331	1240	Lenoir City Tennessee	7	0.04	0.07	0.11	0.14	0.15	0.16	0.15	0.14	0.13	0.09	0.06	0.05
139	TN	36.37	-83.899	1657	Chuck Swan SF TN	7	0.04	0.07	0.10	0.14	0.15	0.16	0.15	0.14	0.13	0.09	0.06	0.04
140	TX	30.17	-97.256	383	Bastrop Texas	7	0.07	0.10	0.14	0.18	0.21	0.24	0.24	0.23	0.19	0.14	0.09	0.07
141	TX	30.11	-94.931	100	Dayton Texas	7	0.06	0.08	0.12	0.15	0.17	0.19	0.17	0.15	0.15	0.11	0.07	0.06
142	TX	32.61	-96.993	520	Cedar Hill SP Texas	7	0.07	0.09	0.13	0.17	0.20	0.23	0.24	0.23	0.18	0.14	0.08	0.08
143	UT	41.15	-111.92	5100	Bues Canyon Utah	12	0.02	0.05	0.09	0.14	0.18	0.21	0.24	0.21	0.18	0.12	0.07	0.02
144	VA	36.68	-75.933	1200	Back Bay Virginia	8	0.05	0.08	0.11	0.15	0.16	0.17	0.17	0.15	0.14	0.11	0.08	0.06
145	VA	38.1	-78.785	2080	Sawmill Ridge Virginia	4	0.04	0.06	0.09	0.13	0.13	0.14	0.13	0.12	0.12	0.08	0.06	0.04
146	VA	37.01	-81.179	2540	Stony Fork Virginia	5	0.02	0.06	0.09	0.13	0.13	0.14	0.13	0.12	0.11	0.08	0.06	0.04
147	VA	37.99	-79.759	2580	Lime Kiln Virginia	4	0.04	0.07	0.11	0.15	0.15	0.15	0.15	0.13	0.12	0.09	0.06	0.04
148	VA	37.25	-77.25	50	James River Virginia	6	0.05	0.08	0.11	0.16	0.16	0.17	0.16	0.13	0.14	0.10	0.08	0.06
149	VT	44.51	-73.116	340	Essex Junction Vermont	6	0.02	0.02	0.04	0.11	0.14	0.16	0.17	0.14	0.11	0.07	0.04	0.02
150	VT	43.33	-73.033	668	Sweezy Vermont	9	0.02	0.03	0.04	0.11	0.13	0.14	0.14	0.12	0.10	0.08	0.04	0.02
151	VT	44.54	-72.529	1200	Elmore Vermont	6	0.02	0.02	0.04	0.09	0.13	0.13	0.14	0.12	0.09	0.07	0.03	0.01
152	WA	46.27	-117.5	4500	Alder Ridge Washington	8	0.04	0.05	0.07	0.12	0.15	0.18	0.25	0.19	0.14	0.09	0.07	0.03
153	WA	47.2	-121.96	771	Enumclaw Washington	6	0.03	0.04	0.07	0.10	0.10	0.15	0.16	0.13	0.08	0.06	0.05	0.04
154	WA	34.1	-118.22	920	Mt. Washington CA	7	0.02	0.04	0.07	0.09	0.12	0.14	0.17	0.15	0.12	0.06	0.03	0.02
155	WA	47.82	-122.88	62	Quilcene Washington	5	0.02	0.03	0.05	0.09	0.11	0.12	0.15	0.12	0.07	0.05	0.03	0.01
156	WA	47.42	-117.53	2230	Turnbull NWR WA	8	0.01	0.03	0.06	0.10	0.14	0.17	0.20	0.17	0.12	0.08	0.03	0.01
157	WI	43.57	-88.609	800	Horicon Wisconsin	8	0.02	0.02	0.09	0.18	0.18	0.19	0.12	0.10	0.11	0.12	0.11	0.02
158	WI	43.1	-89.333	857	Wautoma Wisconsin	5	0.01	0.02	0.05	0.12	0.16	0.17	0.18	0.14	0.10	0.07	0.04	0.01
159	WI	43.1	-90	1260	Dodgeville Wisconsin	5	0.02	0.02	0.05	0.12	0.16	0.18	0.18	0.14	0.12	0.09	0.06	0.02
160	WV	38.3	-82.417	735	Beech Fork West Virginia	3	0.02	0.06	0.10	0.13	0.14	0.15	0.15	0.13	0.13	0.09	0.06	0.04
161	WV	40.54	-80.584	1013	Tomlinson Run WV	6	0.01	0.01	0.08	0.12	0.15	0.15	0.15	0.14	0.12	0.09	0.07	0.04
162	WV	39.11	-79.426	3853	Davis (Bearden) WV	3	0.03	0.02	0.09	0.13	0.13	0.13	0.13	0.11	0.10	0.08	0.06	0.04
163	WY	42.71	-106.35	7740	Casper Mountain WY	11	0.03	0.07	0.11	0.14	0.17	0.20	0.23	0.21	0.17	0.12	0.07	0.03

ET_o California Irrigation Management Information System (CIMIS)

Map ID	State	Lat	Long	Elev	Station Name	Years of Data	CIMIS Average Monthly Rates (ET_o) ($\frac{in}{day}$)											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
164	CA	36.336222	-120.112906	285	Five Points	N/A	0.04	0.07	0.13	0.20	0.25	0.28	0.28	0.26	0.21	0.15	0.08	0.04
165	CA	35.532556	-119.281794	360	Shafter/USDA	N/A	0.04	0.07	0.12	0.19	0.24	0.27	0.27	0.24	0.19	0.13	0.07	0.04
166	CA	38.535694	-121.776361	60	Davis	N/A	0.03	0.06	0.11	0.18	0.22	0.27	0.27	0.24	0.19	0.14	0.07	0.04
167	CA	36.851222	-120.590922	185	Firebaugh	N/A	0.03	0.06	0.12	0.19	0.24	0.27	0.27	0.23	0.18	0.13	0.07	0.03
168	CA	40.044053	-122.165514	250	Gerber	N/A	0.03	0.06	0.11	0.17	0.21	0.26	0.28	0.24	0.19	0.13	0.06	0.04
169	CA	39.608639	-121.824431	130	Durham	N/A	0.03	0.06	0.10	0.17	0.21	0.25	0.25	0.22	0.18	0.11	0.06	0.03
170	CA	38.753136	-120.733603	2780	Camino	N/A	0.05	0.07	0.10	0.15	0.19	0.25	0.29	0.26	0.21	0.14	0.06	0.04
171	CA	36.157972	-119.851425	193	Stratford	N/A	0.03	0.07	0.13	0.20	0.25	0.29	0.28	0.25	0.20	0.13	0.07	0.03
172	CA	36.768167	-121.773636	9	Castroville	N/A	0.05	0.06	0.10	0.14	0.15	0.16	0.13	0.12	0.10	0.08	0.05	0.04
173	CA	35.867750	-119.894900	340	Kettleman	N/A	0.03	0.07	0.13	0.20	0.24	0.28	0.29	0.26	0.20	0.14	0.07	0.04
174	CA	38.870600	-121.546075	32	Nicolaus	N/A	0.03	0.06	0.10	0.16	0.20	0.25	0.26	0.22	0.17	0.11	0.05	0.03
175	CA	39.226861	-122.024800	55	Colusa	N/A	0.03	0.06	0.11	0.17	0.21	0.25	0.27	0.23	0.18	0.12	0.06	0.03
176	CA	37.358514	-118.405528	4170	Bishop	N/A	0.06	0.09	0.15	0.20	0.23	0.25	0.26	0.24	0.18	0.13	0.08	0.06
177	CA	36.597444	-119.504036	337	Parlier	N/A	0.03	0.07	0.12	0.17	0.22	0.25	0.26	0.22	0.17	0.11	0.06	0.03
178	CA	33.042986	-115.415847	-110	Calipatria	N/A	0.08	0.11	0.17	0.23	0.28	0.31	0.30	0.28	0.23	0.17	0.10	0.07
179	CA	41.063767	-121.456019	3310	McArthur	N/A	0.02	0.05	0.09	0.14	0.18	0.23	0.27	0.23	0.17	0.10	0.04	0.02
180	CA	33.964942	-117.336983	1020	Riverside	N/A	0.08	0.10	0.13	0.18	0.19	0.22	0.23	0.22	0.18	0.13	0.10	0.08
181	CA	35.305442	-120.661783	330	San Luis Obispo	N/A	0.07	0.09	0.12	0.17	0.18	0.21	0.21	0.20	0.16	0.13	0.10	0.07
182	CA	35.649861	-119.959300	705	Blackwell's Corner	N/A	0.04	0.07	0.12	0.18	0.23	0.26	0.27	0.25	0.19	0.13	0.06	0.04
183	CA	37.096694	-120.753897	95	Los Banos	N/A	0.03	0.06	0.11	0.18	0.24	0.27	0.28	0.24	0.18	0.12	0.06	0.03
184	CA	40.289953	-120.434900	4005	Buntingville	N/A	0.03	0.06	0.11	0.16	0.20	0.24	0.27	0.24	0.18	0.11	0.05	0.03
185	CA	39.691822	-122.153506	198	Orland	N/A	0.03	0.06	0.11	0.17	0.21	0.25	0.26	0.22	0.18	0.12	0.06	0.04
186	CA	33.486650	-117.228269	1420	Temecula	N/A	0.09	0.10	0.12	0.16	0.18	0.21	0.22	0.22	0.18	0.13	0.11	0.09
187	CA	34.583144	-120.079239	490	Santa Ynez	N/A	0.05	0.08	0.11	0.17	0.19	0.21	0.21	0.19	0.15	0.12	0.07	0.05
188	CA	32.759575	-115.732067	40	Seeley	N/A	0.09	0.13	0.19	0.26	0.31	0.34	0.30	0.27	0.23	0.18	0.11	0.07
189	CA	37.834822	-121.223194	33	Manteca	N/A	0.03	0.06	0.11	0.17	0.21	0.25	0.26	0.23	0.17	0.11	0.05	0.03
190	CA	37.645222	-121.187764	35	Modesto	N/A	0.03	0.06	0.11	0.17	0.22	0.25	0.25	0.22	0.16	0.11	0.06	0.03
191	CA	33.688450	-117.721178	410	Irvine	N/A	0.07	0.09	0.12	0.16	0.17	0.20	0.20	0.20	0.15	0.12	0.09	0.07
192	CA	38.428475	-122.410206	190	Oakville	N/A	0.03	0.05	0.09	0.16	0.19	0.23	0.23	0.21	0.16	0.11	0.05	0.04
193	CA	34.056589	-117.813069	730	Pomona	N/A	0.06	0.07	0.11	0.15	0.16	0.19	0.21	0.21	0.16	0.11	0.08	0.06
194	CA	36.820833	-119.742308	339	Fresno State	N/A	0.03	0.06	0.10	0.17	0.22	0.27	0.28	0.25	0.18	0.12	0.06	0.03
195	CA	38.403550	-122.799931	80	Santa Rosa	N/A	0.03	0.05	0.09	0.14	0.17	0.20	0.20	0.19	0.14	0.10	0.05	0.03
196	CA	39.252561	-121.315669	940	Browns Valley	N/A	0.03	0.06	0.10	0.16	0.20	0.25	0.27	0.25	0.19	0.13	0.07	0.03
197	CA	39.006747	-123.080122	1160	Hopland	N/A	0.03	0.06	0.10	0.15	0.19	0.23	0.26	0.23	0.17	0.11	0.05	0.03
198	CA	36.360500	-119.059353	480	Lindcove	N/A	0.03	0.06	0.10	0.16	0.21	0.25	0.26	0.23	0.17	0.11	0.05	0.03
199	CA	32.806183	-115.446258	-50	Meloland	N/A	0.08	0.12	0.18	0.25	0.29	0.31	0.29	0.27	0.23	0.17	0.10	0.07

ET_o California Irrigation Management Information System (CIMIS)

Station Map ID	State	Lat	Long	Elev	Station Name	CIMIS Average Monthly Rates (ET_o) ($\frac{in}{day}$)												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
200	CA	34.942525	-119.673800	2290	Cuyama	N/A	0.07	0.09	0.12	0.18	0.22	0.26	0.27	0.25	0.20	0.15	0.09	0.06
201	CA	36.609444	-121.529300	120	Salinas South	N/A	0.04	0.06	0.11	0.16	0.18	0.21	0.20	0.19	0.14	0.11	0.06	0.04
202	CA	41.438214	-120.480308	4405	Alturas	N/A	0.03	0.05	0.09	0.12	0.16	0.21	0.24	0.21	0.15	0.09	0.04	0.02
203	CA	41.958869	-121.472372	4035	Tule Lake	N/A	0.02	0.05	0.09	0.13	0.17	0.21	0.23	0.21	0.16	0.09	0.03	0.02
204	CA	37.231861	-120.880819	75	Kesterson	N/A	0.03	0.06	0.11	0.18	0.24	0.27	0.28	0.24	0.18	0.12	0.06	0.03
205	CA	34.471333	-119.869294	640	Goleta Foothills	N/A	0.07	0.09	0.12	0.18	0.17	0.19	0.18	0.19	0.15	0.13	0.09	0.08
206	CA	34.044311	-118.476886	340	Santa Monica	N/A	0.06	0.08	0.11	0.15	0.15	0.17	0.17	0.17	0.13	0.11	0.08	0.07
207	CA	38.526336	-122.829297	85	Windsor	N/A	0.03	0.06	0.10	0.15	0.18	0.22	0.21	0.19	0.15	0.10	0.05	0.03
208	CA	36.997444	-121.996758	300	De Laveaga	N/A	0.04	0.07	0.11	0.16	0.16	0.18	0.16	0.16	0.12	0.10	0.05	0.04
209	CA	36.634028	-120.381811	191	Westlands	N/A	0.03	0.06	0.12	0.21	0.26	0.29	0.28	0.25	0.20	0.14	0.07	0.03
210	CA	38.982581	-123.089275	525	Sanel Valley	N/A	0.03	0.06	0.10	0.15	0.19	0.23	0.26	0.23	0.17	0.11	0.05	0.03
211	CA	34.437353	-119.737419	250	Santa Barbara	N/A	0.05	0.08	0.11	0.16	0.16	0.17	0.17	0.17	0.13	0.11	0.07	0.06
212	CA	38.219503	-122.354964	5	Carneros	N/A	0.03	0.05	0.10	0.15	0.18	0.22	0.22	0.20	0.16	0.11	0.05	0.03
213	CA	36.943964	-121.763942	110	Green Valley Rd	N/A	0.04	0.06	0.10	0.15	0.15	0.18	0.17	0.16	0.12	0.10	0.05	0.04
214	CA	36.121083	-121.084572	540	King City - Oasis Rd	N/A	0.05	0.07	0.12	0.18	0.21	0.24	0.24	0.22	0.17	0.13	0.07	0.05
215	CA	36.347306	-121.291350	235	Arroyo Seco	N/A	0.05	0.07	0.12	0.18	0.20	0.24	0.23	0.22	0.17	0.13	0.07	0.05
216	CA	36.716806	-121.691889	61	Salinas North	N/A	0.04	0.06	0.09	0.14	0.15	0.17	0.14	0.14	0.11	0.09	0.05	0.04
217	CA	34.475914	-117.263514	2890	Victorville	N/A	0.07	0.09	0.15	0.21	0.24	0.30	0.32	0.29	0.22	0.15	0.09	0.07
218	CA	33.841292	-116.478731	392	Cathedral City	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
219	CA	38.415564	-121.786911	37	Dixon	N/A	0.02	0.05	0.10	0.17	0.20	0.25	0.27	0.23	0.18	0.14	0.05	0.03
220	CA	38.233972	-122.116994	35	Suisun Valley	N/A	0.02	0.05	0.10	0.16	0.19	0.23	0.25	0.22	0.18	0.12	0.05	0.03
221	CA	36.890056	-120.731408	183	Panoche	N/A	0.04	0.07	0.12	0.20	0.24	0.28	0.27	0.23	0.18	0.13	0.07	0.03
222	CA	35.205583	-118.778414	500	Arvin/Edison	N/A	0.04	0.08	0.12	0.19	0.24	0.27	0.28	0.25	0.19	0.13	0.07	0.04
223	CA	36.854833	-121.362753	340	San Benito	N/A	0.04	0.06	0.10	0.15	0.18	0.21	0.22	0.21	0.16	0.12	0.06	0.04
224	CA	33.327703	-115.944842	-225	Salton Sea West	N/A	0.08	0.11	0.17	0.23	0.28	0.31	0.30	0.28	0.23	0.17	0.10	0.07
225	CA	33.220186	-115.580117	-226	Salton East	N/A	0.08	0.11	0.17	0.23	0.28	0.31	0.30	0.28	0.23	0.17	0.10	0.07
226	CA	36.902778	-121.741931	65	Pajaro	N/A	0.06	0.08	0.12	0.16	0.17	0.19	0.18	0.17	0.14	0.11	0.08	0.06
227	CA	38.649964	-121.218872	265	Fair Oaks	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
228	CA	34.196531	-118.230203	1111	Glendale	N/A	0.07	0.09	0.12	0.16	0.17	0.20	0.22	0.21	0.17	0.13	0.09	0.07
229	CA	34.884267	-116.979861	2040	Barstow	N/A	0.07	0.11	0.17	0.22	0.26	0.31	0.30	0.26	0.21	0.15	0.09	0.07
230	CA	33.662869	-114.558108	275	Blythe NE	N/A	0.07	0.11	0.16	0.22	0.28	0.32	0.33	0.29	0.23	0.15	0.10	0.07
231	CA	33.523694	-116.155750	12	Oasis	N/A	0.08	0.12	0.17	0.23	0.28	0.32	0.31	0.28	0.23	0.16	0.10	0.07
232	CA	33.558017	-117.031661	1536	Temecula East II	N/A	0.06	0.08	0.11	0.16	0.18	0.21	0.21	0.20	0.16	0.12	0.08	0.06

ET_o California Irrigation Management Information System (CIMIS)

Station Map ID	State	Lat	Long	Elev	Station Name	CIMIS Average Monthly Rates (ET_o) ($\frac{in}{day}$)												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
233	CA	35.603111	-119.212586	415	Famoso	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
234	CA	38.501258	-121.978528	136	Winters	N/A	0.03	0.06	0.11	0.17	0.21	0.25	0.26	0.22	0.17	0.11	0.05	0.03
235	CA	38.116125	-121.659214	-1	Twitchell Islan	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
236	CA	33.536894	-115.992803	-180	Mecca	N/A	0.05	0.09	0.13	0.19	0.25	0.29	0.30	0.27	0.21	0.14	0.08	0.05
237	CA	36.721083	-119.389028	450	Orange Cove	N/A	0.03	0.06	0.11	0.16	0.22	0.26	0.28	0.25	0.19	0.11	0.06	0.02
238	CA	36.822861	-121.467869	245	San Juan Valley	N/A	0.06	0.08	0.12	0.16	0.17	0.19	0.18	0.17	0.14	0.11	0.08	0.06
239	CA	38.266428	-122.616464	97	Petaluma	N/A	0.03	0.06	0.09	0.14	0.18	0.21	0.21	0.19	0.15	0.10	0.05	0.03
240	CA	37.016528	-120.186394	230	Madera	N/A	0.05	0.09	0.13	0.19	0.25	0.29	0.31	0.28	0.21	0.13	0.07	0.04
241	CA	35.505833	-119.691144	410	Belridge	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
242	CA	32.628208	-116.939281	580	Otay Lake	N/A	0.04	0.07	0.11	0.16	0.19	0.23	0.25	0.22	0.17	0.11	0.07	0.04
243	CA	37.314139	-120.386700	200	Merced	N/A	0.04	0.07	0.11	0.17	0.22	0.26	0.26	0.23	0.18	0.12	0.06	0.03
244	CA	37.780653	-122.180150	145	Oakland Foothil	N/A	0.04	0.06	0.10	0.15	0.18	0.21	0.22	0.20	0.15	0.11	0.05	0.04
245	CA	32.885847	-117.143142	445	Miramar	N/A	0.06	0.08	0.11	0.15	0.17	0.19	0.19	0.18	0.15	0.11	0.08	0.06
246	CA	33.532222	-114.633889	251	Ripley	N/A	0.08	0.12	0.17	0.23	0.28	0.32	0.31	0.28	0.23	0.16	0.10	0.07
247	CA	34.219386	-118.992439	130	Camarillo	N/A	0.06	0.08	0.11	0.15	0.17	0.19	0.19	0.18	0.15	0.11	0.08	0.06
248	CA	33.081050	-116.975697	390	Escondido SPV	N/A	0.09	0.10	0.12	0.18	0.20	0.23	0.23	0.22	0.19	0.13	0.11	0.08
249	CA	38.599158	-121.540406	40	Bryte	N/A	0.03	0.06	0.11	0.17	0.21	0.25	0.26	0.22	0.17	0.11	0.05	0.03
250	CA	34.233639	-119.196922	48	Oxnard	N/A	0.06	0.08	0.11	0.15	0.17	0.19	0.19	0.18	0.15	0.11	0.08	0.06
251	CA	37.995947	-122.466308	5	Point San Pedro	N/A	0.04	0.06	0.10	0.14	0.17	0.21	0.21	0.19	0.14	0.09	0.04	0.03
252	CA	38.419439	-122.658719	270	Bennett Valley	N/A	0.03	0.05	0.09	0.14	0.17	0.20	0.20	0.19	0.14	0.10	0.05	0.03
253	CA	34.146372	-117.985797	595	Monrovia	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
254	CA	35.335261	-120.735881	285	San Luis Obispo West	N/A	0.07	0.09	0.12	0.17	0.18	0.21	0.21	0.20	0.16	0.13	0.10	0.07
255	CA	37.438944	-121.138511	183	Patterson	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
256	CA	35.472556	-120.648142	885	Atascadero	N/A	0.07	0.09	0.12	0.17	0.18	0.21	0.21	0.20	0.16	0.13	0.10	0.07
257	CA	34.841878	-120.212736	536	Sisquoc	N/A	0.06	0.09	0.12	0.17	0.19	0.20	0.19	0.18	0.15	0.11	0.08	0.06
258	CA	38.129933	-121.386594	25	Lodi West	N/A	0.03	0.06	0.11	0.17	0.21	0.25	0.25	0.22	0.17	0.11	0.05	0.02
259	CA	37.725881	-121.475517	82	Tracy	N/A	0.03	0.06	0.11	0.18	0.22	0.26	0.27	0.23	0.18	0.12	0.06	0.03
260	CA	36.082056	-119.093422	400	Porterville	N/A	0.03	0.07	0.12	0.18	0.23	0.27	0.27	0.24	0.19	0.13	0.06	0.03
261	CA	38.015372	-122.020278	35	Concord	N/A	0.03	0.06	0.11	0.18	0.22	0.26	0.27	0.23	0.18	0.12	0.06	0.03
262	CA	37.598758	-122.053233	16	Union City	N/A	0.05	0.07	0.11	0.16	0.17	0.21	0.22	0.19	0.15	0.11	0.06	0.05
263	CA	32.901867	-117.250458	335	Torrey Pines	N/A	0.06	0.08	0.11	0.15	0.17	0.19	0.19	0.18	0.15	0.11	0.08	0.06
264	CA	33.798697	-118.094792	17	Long Beach	N/A	0.05	0.08	0.12	0.16	0.17	0.19	0.19	0.19	0.15	0.10	0.07	0.05
265	CA	33.383697	-114.719211	230	Palo Verde II	N/A	0.08	0.12	0.18	0.24	0.28	0.31	0.31	0.28	0.22	0.15	0.10	0.07
266	CA	37.837614	-122.140739	510	Moraga	N/A	0.03	0.05	0.09	0.15	0.18	0.22	0.24	0.20	0.16	0.11	0.05	0.03
267	CA	33.663325	-117.093383	1626	Winchester	N/A	0.09	0.10	0.12	0.18	0.20	0.23	0.23	0.22	0.19	0.13	0.11	0.08

ET_o California Irrigation Management Information System (CIMIS)

Station Map ID	State	Lat	Long	Elev	Station Name	CIMIS Average Monthly Rates (ET_o) $(\frac{in}{day})$												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
268	CA	33.078611	-115.660556	-200	Westmorland North	N/A	0.08	0.12	0.17	0.23	0.28	0.32	0.31	0.28	0.23	0.16	0.10	0.07
269	CA	35.833000	-119.255956	300	Delano	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
270	CA	32.729481	-117.139481	3684	Owens Lake North	N/A	0.07	0.09	0.15	0.21	0.24	0.30	0.32	0.29	0.22	0.15	0.09	0.07
271	CA	32.729578	-117.139342	377	San Diego II	N/A	0.07	0.09	0.11	0.15	0.16	0.18	0.18	0.18	0.14	0.11	0.08	0.07
272	CA	32.492658	-114.826164	48	UC-San Luis	N/A	0.08	0.12	0.18	0.25	0.29	0.31	0.29	0.27	0.23	0.17	0.10	0.07
273	CA	38.090933	-122.526703	1	Black Point	N/A	0.04	0.06	0.10	0.14	0.17	0.21	0.21	0.19	0.14	0.09	0.04	0.03
274	CA	36.358628	-117.943869	3682	Owens Lake South	N/A	0.07	0.09	0.15	0.21	0.24	0.30	0.32	0.29	0.22	0.15	0.09	0.07
275	CA	36.382028	-120.229850	270	Five Points South We	N/A	0.04	0.07	0.13	0.20	0.25	0.28	0.28	0.26	0.21	0.15	0.08	0.04
276	CA	37.663969	-121.885033	335	Pleasanton	N/A	0.03	0.05	0.09	0.15	0.18	0.22	0.24	0.20	0.16	0.11	0.05	0.03
277	CA	34.255142	-117.218139	5148	Lake Arrowhead	N/A	0.06	0.09	0.15	0.20	0.23	0.25	0.26	0.24	0.18	0.13	0.08	0.06
278	CA	37.727194	-120.850861	165	Oakdale	N/A	0.03	0.06	0.11	0.17	0.22	0.25	0.25	0.22	0.16	0.11	0.06	0.03
279	CA	38.887603	-121.102908	935	Auburn	N/A	0.05	0.07	0.10	0.15	0.19	0.25	0.29	0.26	0.21	0.14	0.06	0.04
280	CA	38.691786	-122.013808	174	Esparto	N/A	0.03	0.06	0.11	0.18	0.22	0.27	0.27	0.24	0.19	0.14	0.07	0.04
281	CA	34.614981	-118.032492	2550	Palmdale	N/A	0.07	0.09	0.15	0.21	0.24	0.30	0.32	0.29	0.22	0.15	0.09	0.07
282	CA	34.324639	-119.104875	218	Santa Paula	N/A	0.06	0.08	0.11	0.15	0.17	0.19	0.19	0.18	0.15	0.11	0.08	0.06
283	CA	34.237419	-116.865706	6910	Big Bear Lake	N/A	0.06	0.09	0.15	0.20	0.23	0.25	0.26	0.24	0.18	0.13	0.08	0.06
284	CA	33.748586	-116.252903	40	Indio II	N/A	0.08	0.12	0.17	0.23	0.28	0.32	0.31	0.28	0.23	0.16	0.10	0.07
285	CA	32.674353	-115.044381	120	UC-Andrade	N/A	0.08	0.12	0.18	0.25	0.29	0.31	0.29	0.27	0.23	0.17	0.10	0.07
286	CA	35.028281	-120.560033	255	Nipomo	N/A	0.07	0.09	0.12	0.17	0.18	0.21	0.21	0.20	0.16	0.13	0.10	0.07
287	CA	35.862583	-119.503569	210	Alpaugh	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
288	CA	34.426361	-118.517583	1410	Santa Clarita	N/A	0.09	0.10	0.13	0.19	0.19	0.23	0.25	0.25	0.19	0.17	0.12	0.10
289	CA	33.268447	-116.365050	578	Borrego Springs	N/A	0.09	0.13	0.19	0.26	0.31	0.34	0.30	0.27	0.23	0.18	0.11	0.07
290	CA	37.545869	-120.754531	150	Denair II	N/A	0.03	0.06	0.11	0.17	0.22	0.25	0.25	0.22	0.16	0.11	0.06	0.03
291	CA	33.678186	-116.272989	36	La Quinta II	N/A	0.08	0.12	0.17	0.23	0.28	0.32	0.31	0.28	0.23	0.16	0.10	0.07
292	CA	36.913083	-121.823653	240	Watsonville West II	N/A	0.06	0.08	0.12	0.16	0.17	0.19	0.18	0.17	0.14	0.11	0.08	0.06
293	CA	36.540889	-121.881958	75	Carmel	N/A	0.04	0.06	0.09	0.14	0.15	0.17	0.14	0.14	0.11	0.09	0.05	0.04
294	CA	37.138889	-121.575000	185	Gilroy	N/A	0.04	0.06	0.11	0.16	0.20	0.23	0.24	0.21	0.17	0.11	0.06	0.03
295	CA	38.278056	-121.741111	7	Hastings Tract East	N/A	0.05	0.08	0.12	0.17	0.22	0.26	0.28	0.25	0.19	0.13	0.07	0.05
296	CA	33.608611	-116.171667	-32	Thermal South	N/A	0.08	0.12	0.17	0.23	0.28	0.32	0.31	0.28	0.23	0.16	0.10	0.07
297	CA	38.636111	-120.793056	2050	Diamond Springs	N/A	0.05	0.07	0.10	0.15	0.19	0.25	0.29	0.26	0.21	0.14	0.06	0.04
298	CA	34.405556	-119.715000	440	Santa Barbara II	N/A	0.05	0.08	0.11	0.16	0.16	0.17	0.17	0.17	0.13	0.11	0.07	0.06

299	CA	34.672222	-120.513056	55	Lompoc	N/A	0.06	0.09	0.12	0.17	0.19	0.20	0.19	0.18	0.15	0.11	0.08	0.06

Station Map ID	**State**	**Lat**	**Long**	**Elev**	**Station Name**	**CIMIS Average Monthly Rates (ET$_o$) $\left(\frac{in}{day}\right)$**												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
300	CA	34.913472	-120.464778	215	Santa Maria II	N/A	0.06	0.09	0.12	0.17	0.19	0.20	0.19	0.18	0.15	0.11	0.08	0.06

ET$_o$ AgriMET

Map ID	State	Lat	Long	Elev	Station Name	Years of Data	AgriMet Average Monthly Rates (ET$_o$) $(\frac{in}{day})$											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
358	ID	42.95495	-112.82457	4400	ABEI	N/A	0.02	0.04	0.09	0.15	0.22	0.27	0.31	0.28	0.19	0.10	0.04	0.02
359	WY	42.732717	-110.94133	6210	AFTY	N/A	0.01	0.03	0.07	0.12	0.17	0.22	0.27	0.22	0.15	0.08	0.03	0.01
360	OR	42.565483	-121.97978	4150	AGKO	N/A	0.02	0.04	0.09	0.14	0.21	0.26	0.29	0.24	0.17	0.09	0.04	0.02
361	ID	44.02725	-111.45025	5300	AHTI	N/A	0.02	0.04	0.08	0.13	0.21	0.26	0.29	0.26	0.19	0.10	0.04	0.02
362	OR	45.28205	-122.75147	140	ARAO	N/A	0.02	0.04	0.07	0.11	0.16	0.20	0.25	0.20	0.13	0.06	0.03	0.02
363	OR	43.090817	-124.41663	80	BANO	N/A	0.03	0.04	0.07	0.10	0.14	0.16	0.17	0.14	0.11	0.07	0.03	0.02
364	OR	42.47805	-121.27397	4320	BATO	N/A	0.02	0.05	0.09	0.14	0.19	0.25	0.30	0.25	0.17	0.08	0.04	0.02
365	OR	44.0475	-121.32033	3620	BEWO	N/A	0.02	0.04	0.09	0.12	0.18	0.23	0.27	0.21	0.14	0.07	0.03	0.02
366	OR	44.875833	-117.96268	3420	BKVO	N/A	0.01	0.04	0.08	0.13	0.19	0.23	0.29	0.24	0.17	0.08	0.03	0.01
367	ID	43.600367	-116.17688	2720	BOII	N/A	0.02	0.04	0.08	0.13	0.19	0.25	0.28	0.23	0.14	0.07	0.03	0.02
368	OR	42.030083	-124.24033	80	BRKO	N/A	0.04	0.06	0.08	0.11	0.15	0.17	0.15	0.13	0.12	0.09	0.05	0.03
369	CA	41.5854	-120.17187	4600	CEDC	N/A	0.03	0.05	0.10	0.15	0.21	0.28	0.32	0.28	0.20	0.11	0.05	0.03
370	WA	48.031317	-117.73922	1950	CHAW	N/A	0.01	0.02	0.06	0.11	0.17	0.21	0.27	0.22	0.14	0.05	0.01	0.01
371	OR	43.2452	-120.72797	4305	CHVO	N/A	0.03	0.05	0.09	0.14	0.20	0.26	0.30	0.26	0.17	0.10	0.04	0.02
372	MT	46.328483	-114.0838	3597	COVM	N/A	0.02	0.04	0.08	0.13	0.18	0.22	0.26	0.21	0.14	0.08	0.04	0.03
373	MT	48.1869	-114.14802	2950	CRSM	N/A	0.01	0.03	0.06	0.11	0.17	0.20	0.25	0.21	0.13	0.06	0.02	0.01
374	OR	44.6341	-123.19	230	CRVO	N/A	0.02	0.04	0.07	0.12	0.17	0.22	0.28	0.24	0.17	0.08	0.03	0.02
375	OR	45.586417	-121.64065	1156	DEFO	N/A	0.01	0.03	0.07	0.11	0.17	0.23	0.28	0.22	0.13	0.06	0.02	0.01
376	MT	46.3355	-112.76685	4680	DRLM	N/A	0.02	0.04	0.08	0.13	0.19	0.22	0.29	0.24	0.16	0.08	0.04	0.02
377	OR	45.71875	-119.31105	760	ECHO	N/A	0.02	0.04	0.09	0.16	0.23	0.30	0.37	0.31	0.20	0.10	0.04	0.02
378	NV	39.686683	-115.97615	5897	EURN	N/A	0.03	0.05	0.11	0.16	0.23	0.30	0.33	0.29	0.20	0.12	0.06	0.03
379	ID	43.3093	-114.82172	5038	FAFI	N/A	0.02	0.04	0.08	0.14	0.20	0.25	0.30	0.26	0.19	0.11	0.04	0.02
380	NV	39.45845	-118.77677	3965	FALN	N/A	0.04	0.07	0.13	0.18	0.26	0.33	0.35	0.28	0.20	0.11	0.06	0.03
381	OR	45.553217	-123.08353	180	FOGO	N/A	0.02	0.04	0.07	0.11	0.17	0.21	0.26	0.22	0.15	0.07	0.02	0.01
382	ID	43.072733	-112.43238	4445	FTHI	N/A	0.02	0.04	0.09	0.15	0.21	0.26	0.30	0.29	0.20	0.11	0.05	0.02
383	ID	42.909667	-116.05492	2580	GDVI	N/A	0.03	0.05	0.11	0.16	0.23	0.30	0.35	0.29	0.19	0.10	0.05	0.02
384	WA	47.0442	-119.64233	1150	GERW	N/A	0.01	0.04	0.09	0.15	0.22	0.27	0.31	0.25	0.17	0.08	0.03	0.01
385	ID	42.88875	-115.35695	3025	GFRI	N/A	0.03	0.05	0.11	0.16	0.23	0.31	0.38	0.33	0.23	0.13	0.05	0.02
386	WA	45.812	-120.82423	1680	GOLW	N/A	0.01	0.04	0.08	0.14	0.21	0.28	0.33	0.28	0.19	0.09	0.03	0.01
387	OR	45.821183	-119.5214	528	HERO	N/A	0.02	0.05	0.10	0.16	0.24	0.31	0.36	0.31	0.20	0.10	0.04	0.02
388	OR	45.684767	-121.51803	530	HOXO	N/A	0.01	0.03	0.07	0.12	0.19	0.24	0.28	0.23	0.15	0.07	0.02	0.01
389	OR	44.487967	-118.02867	3600	HRFO	N/A	0.01	0.03	0.08	0.13	0.18	0.24	0.29	0.24	0.15	0.07	0.03	0.01
390	WA	46.383617	-120.57278	850	HRHW	N/A	0.02	0.04	0.10	0.16	0.23	0.29	0.32	0.26	0.18	0.09	0.04	0.01
391	OR	45.818467	-119.28465	598	HRMO	N/A	0.02	0.04	0.09	0.16	0.23	0.30	0.36	0.30	0.19	0.10	0.03	0.02
392	OR	45.431817	-117.97218	2750	IMBO	N/A	0.02	0.04	0.08	0.13	0.18	0.23	0.30	0.26	0.17	0.08	0.04	0.02
393	OR	42.16435	-121.75472	4100	KFLO	N/A	0.02	0.05	0.09	0.14	0.21	0.27	0.30	0.25	0.18	0.09	0.04	0.02

Station Map ID	State	Lat	Long	Elev	Station Name	AgriMet Average Monthly Rates (ET_o) $(\frac{in}{day})$												
						Years of Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
394	ID	43.5476	-112.32623	5190	KTBI	N/A	0.01	0.03	0.08	0.15	0.23	0.28	0.34	0.31	0.22	0.12	0.04	0.01
395	OR	42.1225	-120.52293	4770	LAKO	N/A	0.03	0.05	0.09	0.14	0.20	0.26	0.31	0.27	0.20	0.11	0.05	0.02
396	WA	46.205017	-118.93407	478	LEGW	N/A	0.02	0.05	0.10	0.16	0.23	0.29	0.32	0.27	0.18	0.09	0.04	0.02
397	WA	46.867367	-118.73962	1483	LIDW	N/A	0.02	0.04	0.09	0.15	0.21	0.27	0.32	0.27	0.18	0.10	0.03	0.01
398	OR	42.078517	-121.2254	4160	LORO	N/A	0.03	0.05	0.09	0.13	0.20	0.26	0.30	0.26	0.18	0.10	0.05	0.03
399	ID	42.437217	-113.41433	4410	MALI	N/A	0.03	0.05	0.10	0.16	0.21	0.28	0.32	0.28	0.20	0.12	0.06	0.03
400	WA	47.916667	-120.12445	1972	MASW	N/A	0.01	0.03	0.07	0.13	0.20	0.25	0.30	0.24	0.14	0.06	0.01	0.01
401	OR	42.3316	-122.9374	1340	MDFO	N/A	0.02	0.05	0.08	0.13	0.19	0.26	0.30	0.25	0.17	0.08	0.03	0.02
402	ID	44.01535	-112.536	4800	MNTI	N/A	0.01	0.03	0.08	0.15	0.21	0.26	0.30	0.26	0.17	0.09	0.03	0.01
403	OR	44.6801	-121.15	2440	MRSO	N/A	0.03	0.05	0.09	0.14	0.20	0.27	0.32	0.28	0.20	0.10	0.04	0.02
404	ID	43.441917	-116.63732	2634	NMPI	N/A	0.03	0.05	0.11	0.17	0.24	0.30	0.33	0.29	0.20	0.12	0.05	0.03
405	WA	47.309117	-118.87852	1650	ODSW	N/A	0.01	0.04	0.09	0.15	0.21	0.28	0.34	0.30	0.20	0.10	0.03	0.01
406	WA	48.401817	-119.5775	1235	OMAW	N/A	0.01	0.03	0.07	0.14	0.20	0.25	0.29	0.24	0.16	0.07	0.02	0.01
407	OR	43.979233	-117.025	2260	ONTO	N/A	0.02	0.04	0.10	0.17	0.24	0.30	0.35	0.30	0.20	0.11	0.04	0.02
408	OR	45.543567	-121.6134	1480	PARO	N/A	0.01	0.03	0.07	0.12	0.17	0.23	0.27	0.22	0.14	0.06	0.02	0.01
409	OR	44.441233	-118.62807	3752	PCYO	N/A	0.02	0.04	0.07	0.11	0.17	0.22	0.28	0.23	0.15	0.07	0.03	0.01
410	ID	43.3117	-114.16602	4900	PICI	N/A	0.02	0.04	0.08	0.14	0.21	0.26	0.31	0.27	0.18	0.10	0.04	0.01
411	ID	43.802233	-116.9442	2305	PMAI	N/A	0.02	0.05	0.10	0.16	0.23	0.29	0.32	0.27	0.18	0.10	0.04	0.02
412	OR	45.652167	-121.50917	616	PNGO	N/A	0.01	0.03	0.07	0.12	0.18	0.23	0.28	0.22	0.14	0.06	0.02	0.01
413	OR	44.248217	-120.94987	3200	POBO	N/A	0.04	0.05	0.09	0.13	0.19	0.26	0.31	0.26	0.18	0.11	0.06	0.04
414	MT	47.537433	-114.27595	3040	RDBM	N/A	0.01	0.03	0.06	0.12	0.17	0.20	0.24	0.19	0.12	0.06	0.02	0.01
415	ID	42.595467	-113.87392	4155	RPTI	N/A	0.03	0.05	0.10	0.16	0.23	0.28	0.32	0.28	0.20	0.12	0.05	0.02
416	ID	47.795433	-116.84132	2290	RTHI	N/A	0.02	0.03	0.06	0.12	0.18	0.20	0.26	0.23	0.16	0.07	0.03	0.01
417	ID	43.8477	-111.76813	4875	RXGI	N/A	0.01	0.03	0.08	0.14	0.21	0.25	0.27	0.26	0.18	0.10	0.04	0.01
418	MT	47.325933	-114.08037	2990	SIGM	N/A	0.02	0.03	0.07	0.11	0.17	0.21	0.28	0.24	0.14	0.07	0.03	0.02
419	ID	42.545683	-114.346	3920	TWFI	N/A	0.03	0.05	0.10	0.16	0.23	0.29	0.33	0.28	0.20	0.12	0.05	0.03
420	OR	42.01705	-121.78745	4080	WRDO	N/A	0.02	0.05	0.10	0.14	0.20	0.25	0.27	0.24	0.17	0.09	0.04	0.02

ET_o Florida Automated Weather Network

Map ID	State	Lat	Long	Elev	Station Name	Years of Data	FAWN Average Monthly Rates (ET_o) $(\frac{in}{day})$											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
322	FL	29.80	-82.41	160	Alachua	N/A	0.05	0.08	0.11	0.12	0.16	0.17	0.17	0.15	0.13	0.10	0.07	0.05
323	FL	28.64	-81.55	107	Apopka	N/A	0.06	0.09	0.12	0.16	0.18	0.17	0.18	0.17	0.15	0.11	0.07	0.05
324	FL	27.23	-81.84	64	Arcadia	N/A	0.06	0.09	0.12	0.16	0.18	0.18	0.18	0.16	0.15	0.11	0.07	0.05
325	FL	28.47	-81.65	196	Avalon	N/A	0.07	0.09	0.12	0.16	0.18	0.16	0.17	0.16	0.14	0.11	0.08	0.06
326	FL	27.76	-82.22	129	Balm	N/A	0.06	0.09	0.12	0.15	0.17	0.17	0.17	0.16	0.14	0.11	0.08	0.05
327	FL	26.66	-80.63	11	Belle Glade	N/A	0.08	0.10	0.12	0.13	0.14	0.14	0.13	0.11	0.10	0.06	0.06	0.07
328	FL	29.40	-82.59	116	Bronson	N/A	0.06	0.09	0.12	0.15	0.17	0.18	0.18	0.15	0.15	0.10	0.08	0.06
329	FL	28.63	-82.29	107	Brooksville	N/A	0.08	0.10	0.12	0.14	0.16	0.16	0.15	0.15	0.14	0.11	0.09	0.08
330	FL	29.84	-84.70	19	Carrabelle	N/A	0.06	0.08	0.11	0.14	0.17	0.16	0.15	0.14	0.11	0.08	0.05	0.05
331	FL	29.41	-82.17	60	Citra	N/A	0.06	0.08	0.11	0.14	0.17	0.17	0.16	0.15	0.13	0.10	0.07	0.05
332	FL	26.74	-81.05	19	Clewiston	N/A	0.07	0.10	0.12	0.16	0.19	0.18	0.18	0.16	0.14	0.11	0.08	0.06
333	FL	28.02	-82.23	69	Dover	N/A	0.12	0.13	0.14	0.15	0.16	0.15	0.15	0.15	0.14	0.13	0.13	0.12
334	FL	27.77	-81.54	164	Frost Proof	N/A	0.06	0.09	0.12	0.16	0.18	0.18	0.18	0.17	0.15	0.11	0.08	0.06
335	FL	26.09	-80.24	5	Ft. Lauderdale	N/A	0.07	0.10	0.13	0.16	0.18	0.17	0.18	0.17	0.14	0.12	0.08	0.06
336	FL	27.43	-80.40	19	Ft. Pierce	N/A	0.10	0.11	0.12	0.14	0.15	0.14	0.14	0.14	0.13	0.12	0.11	0.10
337	FL	29.69	-81.44	25	Hastings	N/A	0.06	0.09	0.11	0.15	0.17	0.18	0.17	0.16	0.14	0.10	0.07	0.05
338	FL	25.51	-80.50	8	Homestead	N/A	0.08	0.11	0.13	0.17	0.18	0.16	0.17	0.15	0.13	0.12	0.09	0.07
339	FL	26.46	-81.44	35	Immokalee	N/A	0.07	0.11	0.13	0.17	0.19	0.18	0.18	0.17	0.15	0.12	0.09	0.07
340	FL	27.62	-80.57	23	Indian River	N/A	Data not available at the time of collection											
341	FL	30.78	-87.14	210	Jay	N/A	0.06	0.07	0.10	0.14	0.16	0.17	0.17	0.15	0.13	0.10	0.07	0.05
342	FL	27.96	-81.05	69	Kenansville	N/A	0.07	0.09	0.11	0.14	0.16	0.17	0.17	0.16	0.14	0.10	0.07	0.05
343	FL	28.10	-81.71	154	Lake Alfred	N/A	0.07	0.09	0.12	0.16	0.18	0.18	0.17	0.16	0.14	0.11	0.08	0.06
344	FL	30.31	-82.90	165	Live Oak	N/A	0.06	0.08	0.10	0.14	0.16	0.17	0.17	0.15	0.13	0.09	0.07	0.05
345	FL	30.28	-82.14	126	Macclenny	N/A	0.05	0.08	0.10	0.13	0.15	0.17	0.16	0.15	0.12	0.09	0.06	0.05
346	FL	30.85	-85.17	115	Marianna	N/A	0.05	0.07	0.10	0.13	0.16	0.18	0.18	0.16	0.13	0.09	0.06	0.05
347	FL	30.53	-83.92	163	Monticello	N/A	0.05	0.07	0.10	0.13	0.16	0.17	0.17	0.15	0.13	0.09	0.06	0.04
348	FL	27.14	-82.34	16	North Port	N/A	0.06	0.09	0.11	0.15	0.18	0.18	0.17	0.17	0.15	0.12	0.07	0.06
349	FL	29.02	-81.97	79	Ocklawaha	N/A	0.06	0.09	0.12	0.16	0.19	0.18	0.18	0.17	0.15	0.11	0.07	0.05
350	FL	28.68	-81.89	90	Okahumpka	N/A	0.06	0.09	0.12	0.16	0.18	0.17	0.18	0.17	0.14	0.11	0.08	0.06
351	FL	27.40	-81.94	75	Ona	N/A	0.12	0.12	0.12	0.11	0.13	0.14	0.14	0.13	0.13	0.12	0.13	0.12
352	FL	26.92	-81.31	38	Palmdale	N/A	0.06	0.09	0.11	0.15	0.17	0.17	0.17	0.16	0.14	0.11	0.07	0.05
353	FL	29.22	-81.46	54	Pierson (moved 3/02/04)	N/A	0.06	0.08	0.11	0.15	0.17	0.16	0.16	0.15	0.13	0.10	0.07	0.05
354	FL	29.70	-81.99	148	Putnam Hall	N/A	0.08	0.10	0.14	0.16	0.17	0.16	0.15	0.14	0.10	0.07	0.05	0.05
355	FL	30.55	-84.60	240	Quincy	N/A	0.05	0.07	0.10	0.14	0.16	0.18	0.17	0.15	0.13	0.09	0.07	0.05
356	FL	27.42	-81.40	118	Sebring	N/A	0.06	0.09	0.12	0.15	0.17	0.17	0.17	0.15	0.14	0.11	0.07	0.05
357	FL	28.92	-81.63	120	Umatilla	N/A	0.07	0.10	0.13	0.17	0.18	0.17	0.17	0.16	0.13	0.10	0.07	0.06

ET_o Florida Automated Weather Network

Map ID	State	Lat	Long	Station Name	Years of Data	Average Monthly Rates for Texas ET Network (ET_o) $(\frac{in}{day})$											
						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
301	TX	32.417	-99.683	Abilene	52	0.07	0.09	0.13	0.18	0.21	0.26	0.27	0.24	0.18	0.14	0.09	0.07
302	TX	35.233	-100.700	Amarillo	52	0.06	0.08	0.12	0.17	0.19	0.25	0.26	0.24	0.19	0.13	0.08	0.06
303	TX	30.300	-97.700	Austin	70	0.07	0.10	0.14	0.18	0.21	0.24	0.23	0.23	0.19	0.14	0.09	0.07
304	TX	25.900	-97.433	Brownsville	79	0.09	0.11	0.14	0.17	0.19	0.21	0.22	0.21	0.17	0.14	0.10	0.08
305	TX	30.567	-96.350	College Station	47	0.07	0.10	0.14	0.17	0.20	0.23	0.23	0.22	0.19	0.14	0.09	0.07
306	TX	27.767	-97.500	Corpus Christi	52	0.08	0.11	0.14	0.17	0.19	0.21	0.22	0.21	0.17	0.14	0.10	0.08
307	TX	32.850	-96.850	Dallas/Ft. Worth	26	0.06	0.09	0.13	0.17	0.20	0.24	0.24	0.23	0.18	0.14	0.09	0.07
308	TX	29.367	-100.783	Del Rio	44	0.08	0.11	0.15	0.20	0.23	0.25	0.24	0.24	0.19	0.14	0.10	0.08
309	TX	31.800	-106.400	El Paso	52	0.09	0.13	0.20	0.27	0.32	0.37	0.30	0.29	0.26	0.19	0.12	0.08
310	TX	29.300	-94.800	Galveston	59	0.07	0.09	0.13	0.17	0.20	0.22	0.20	0.19	0.18	0.14	0.09	0.07
311	TX	29.967	-95.350	Houston	31	0.08	0.10	0.14	0.17	0.20	0.22	0.21	0.20	0.19	0.14	0.10	0.08
312	TX	33.650	-101.817	Lubbock	89	0.08	0.09	0.14	0.18	0.22	0.26	0.25	0.23	0.18	0.14	0.09	0.08
313	TX	31.950	-102.183	Midland	52	0.07	0.10	0.14	0.20	0.23	0.27	0.30	0.28	0.23	0.14	0.09	0.07
314	TX	29.900	-93.950	Port Arthur	53	0.07	0.09	0.13	0.17	0.20	0.22	0.19	0.18	0.18	0.13	0.09	0.07
315	TX	31.467	-100.433	San Angelo	54	0.09	0.11	0.17	0.23	0.27	0.31	0.30	0.27	0.22	0.16	0.11	0.08
316	TX	29.533	-98.467	San Antonio	54	0.08	0.10	0.14	0.18	0.21	0.23	0.24	0.23	0.19	0.14	0.10	0.08
317	TX	29.210	-99.786	Uvalde	N/A	0.08	0.11	0.15	0.20	0.22	0.24	0.24	0.24	0.19	0.14	0.10	0.08
318	TX	28.850	-96.917	Victoria	39	0.08	0.10	0.14	0.19	0.21	0.22	0.22	0.22	0.18	0.14	0.10	0.08
319	TX	31.617	-97.217	Waco	68	0.07	0.09	0.13	0.18	0.21	0.24	0.24	0.24	0.19	0.14	0.09	0.07
320	TX	26.159	-97.987	Weslaco	N/A	0.08	0.09	0.13	0.16	0.20	0.22	0.23	0.21	0.16	0.13	0.10	0.07
321	TX	33.967	-98.483	Wichita Falls	99	0.06	0.09	0.13	0.18	0.22	0.25	0.26	0.25	0.19	0.14	0.09	0.06

ET_o Florida Automated Weather Network