Map Atlas

Rainwater Harvesting Phase II

A Geographic Information System-based method for Estimation of Rainwater Capture Potential in St. John's, Antigua

An initiative financed by the United Nations Environment Programme (UNEP)
Division of Environmental Policy Implementation (DEPI)
P.O. Box 30552, Nairobi, Kenya
Implemented by the
Caribbean Environmental Health Institute (CEHI)
P.O. Box 1111
The Morne, Castries
St. Lucia
In partnership with the
Antigua Public Utilities Authority (APUA)
Cassada Gardens
St. John's, Antigua
October, 2009

Contents

Background

The information presented in this Atlas is intended to assist water resources managers, municipal officials, town and country planners in applying simple Geographical Information System (GIS)-based mapping methods and approaches to evaluate rainwater harvesting (RWH) potential in enhancing water security at the community level.

This effort is a Phase 2 United Nations Environment Programme (UNEP)-financed / Caribbean Environmental Health Institute (CEHI) collaboration to promote rainwater harvesting in the Caribbean. One of the components of this second phase was the generation of GIS map outputs that reflect the potential impact of climate change on rainwater harvesting potential and water availability in a select community in Antigua and Barbuda, the pilot country for this initiative.

Overview:

The community of Ottos, in the southern suburbs of St. John's Antigua was chosen as the study area for the spatial analysis of RWH harvesting potential. The selection of this particular community was due to the fact that a RWH demonstration model (one of four) was built under this project to serve as a teaching tool for best practices in rainwater harvesting, with emphasis on improving the quality of harvested rainwater.

Estimation of RWH capture potential was conducted for (1) building roof catchments, (2) non-built areas and (3) roads on the basis of rainfall data for one of the closest rainfall stations (data was provided by the Antigua and Barbuda Meteorological Services).

Rainwater capture potential was estimated for three rainfall scenarios; (1) mean rainfall, (2) actual rainfall for a meteorological drought year (year 2000) and (3) a 30% rainfall reduction from the mean, which corresponds to the projected decline in average rainfall based on the down-scaled Japanese global climatic models (Cashman et al., 2007).

Household water supply deficits were also estimated based on average water consumption and potable supply reliability scenarios. The deficit maps could assist in guiding targeting support within communities to identify households that are most vulnerable and require investment in RWH supply solutions.

Data sources and guidance resources:

- ***Antigua and Barbuda Drought Hazard Mapping (2001).*** USAID/OAS Post-Georges Disaster Mitigation: http://www.oas.org/pgdm
- ***Exploring the Water Management Implications of Potential Climate Change (2007)***, Dr Adrian Cashman, Dr John Charlery, Dr Leonard Nurse, University of the West Indies
- ***Potential for Rain Water Harvesting in Ten African Cities: A GIS Overview (2005)*** RELMA in ICRAF & UNEP
- ***Water Resources Assessment of Dominica, Antigua, Barbuda, St. Kitts And Nevis (2004).*** US Army Corps of Engineers Mobile District & Topographic Engineering Center. Available on-line at http://www.sam.usace.army.mil/en/wra/N_Caribbean/N%20CARIBBEAN%20WRA%201%20DEC%202004.pdf

Acknowledgements:

Hastin Barnes, Planning Engineer at the Antigua Public Utilities Authority and Mr. Keithley Meade, Chief Meteorological Services Officer, with the Antigua and Barbuda Meteorological Services for GIS input data and rainfall data provision respectively.

The atlas is available on the Caribbean Environmental Health Institute's website at www.cehi.org.lc and UNEP's website at www.xxxxx.com . For more information contact CEHI in St. Lucia at Tel: (758) 452-2501, Fax: (758) 453-2721; e-mail: cehi@candw.lc

Overview: Water resources - Antigua

Antigua and Barbuda is a water scarce country. Antigua's water demand ranges between 22,500 and 27,000 m^3/day (5 to 6 MGD) during non-drought periods and as much as 40,000 m^3/day (9 MGD) in drought periods (CEHI, 2006). Presently, the water supply on Antigua comes from three sources:

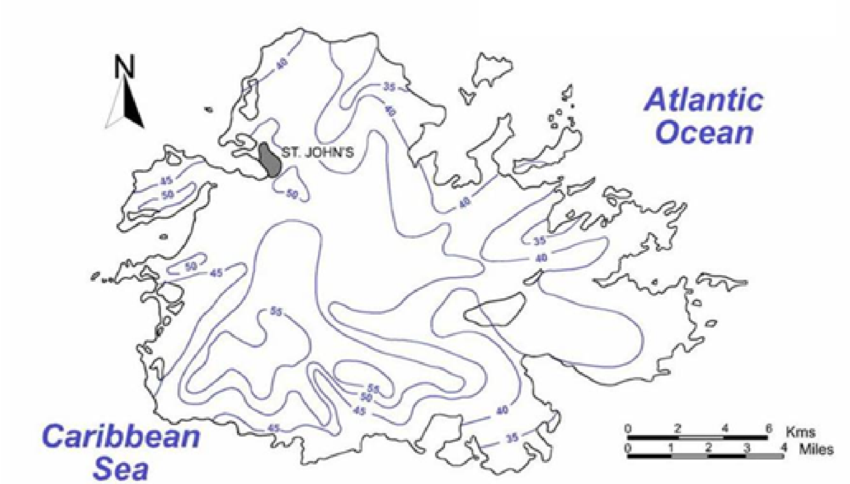
1. Ground water (wells): 10% of total supply;
2. Surface water (reservoirs): 20% of total supply;
3. Ocean (reverse-osmosis desalination plants): 70% of total supply

During droughts conditions, the water supply on the island is threatened as the surface sources (reservoirs) dry up; under these conditions ground water exploitation is increased to make up as much as 18% of the supply. Desalinated water is costly; a unit of desalinated water costs 3 times, and 1½ times the cost of a unit of water from ground and surface water sources respectively (APUA).

In light of the above, rainwater harvesting remains an attractive water supply augmentation method. The building code for the country stipulates that all dwellings must be built with facilities to store at least 3 to 4 days water requirements based on the house size; this approximates 18 m^3 (4,000 gallons) storage for every bedroom.

Antigua's annual rainfall ranges between 900 to 1,400 mm. The average annual rainfall is just over 1,000 mm. The dry season generally runs between December and April, while the wet season is between May and November. Monthly evapotranspiration rates can range between 87 mm for November to as much as 143 mm in March. On average, evapotranspiration exceeds precipitation 11 months of the year (US Army Corps of Engineers, 2004).

Antigua mean annual rainfall (inches)

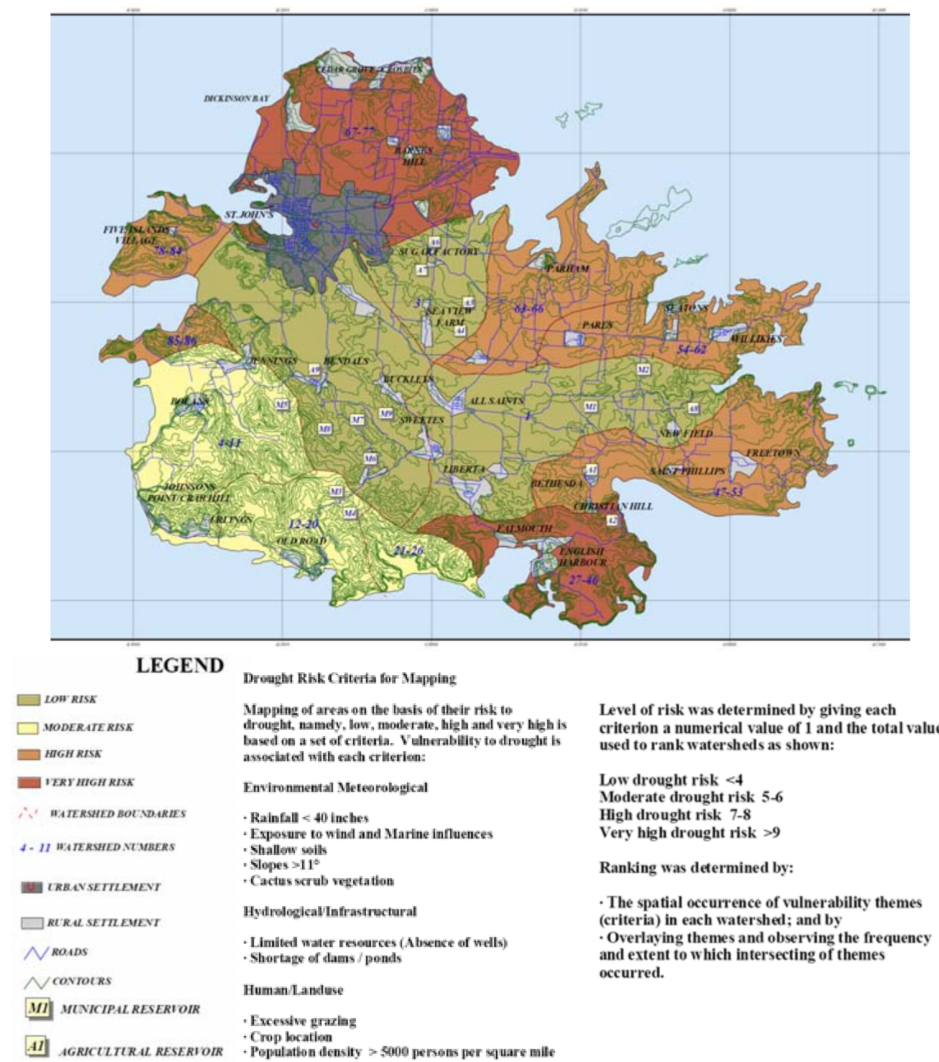


Precipitation Map of Annual Rainfall, Antigua (inches)

Source: Cooper, B. and V. Brown, *Integrating Management of Watersheds and Coastal Areas in Small Island Developing States of the Caribbean*, St. John's, Antigua: Ministry of Tourism and Environment, 2001, p. 6.

Drought risk map – Antigua

Source: USAID/OAS Post-Georges Disaster Mitigation Project
http://www.oas.org/pgdm



Source: www.oas.org/PGDM/hazmap/drought/antdrtsm.gif

A collaborative effort between the Caribbean Environmental Health Institute (CEHI), the Antigua Public Utilities Authority (APUA), and the United Nations Environment Programme (UNEP)

The study area

Ottos, St. John's, Antigua

This community is the location of a household rainwater harvesting demonstration project. The house is situated on Tindall Road. It is a typical 3-bedroom, 2-bathroom single-storey structure occupying 96 m^2 of floor space, with 4 residents. The house has a connection to the potable municipal supply (Antigua Public Utilities Authority) but the residents have traditionally relied on rainwater for potable needs. The estimated daily household water consumption is 0.5 m^3/day (500 litres/day). This household has 1,000 gallons (4.5 m^3) storage capacity dedicated to RWH.

This household represents the typical home found in the suburbs around St. John's, and in this mapping application the households in the study area were assumed to have similar profiles.

NOTE: *for purposes of demonstration all building structures were treated as households; in reality several of these were actually commercial properties (particularly in the northern area). This level of characterization to discern households from non-households was not carried out in this study.*

Study area – red outline

Aerial photo of study area (2000 image)

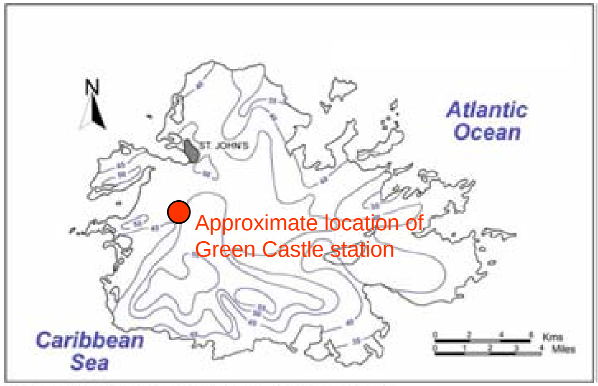
A collaborative effort between the Caribbean Environmental Health Institute (CEHI), the Antigua Public Utilities Authority (APUA), and the United Nations Environment Programme (UNEP)

Rainfall data used in rainwater capture analysis

Rainfall data from the Green Castle station was used in this rainwater capture analysis given its relatively close proximity to the study area. Green Castle is situated approximately 4 km from the Ottos area.

Three rainfall scenarios modelled:

1. **SCENARIO 1:** Mean annual rainfall
2. **SCENARIO 2:** Meteorological drought (<80% of mean annual rainfall) ; data from year 2000 used
3. **SCENARIO 3:** Climate change scenario; assuming reduction in mean annual rainfall by 30% (see box to right)



Precipitation Map of Annual Rainfall, Antigua (inches)

Source: Cooper, B. and V. Brown, Integrating Management of Watersheds and Coastal Areas in Small Island Developing States of the Caribbean. St. John's, Antigua: Ministry of Tourism and Environment, 2001, p. 8.

Green Castle station: Mean annual rainfall

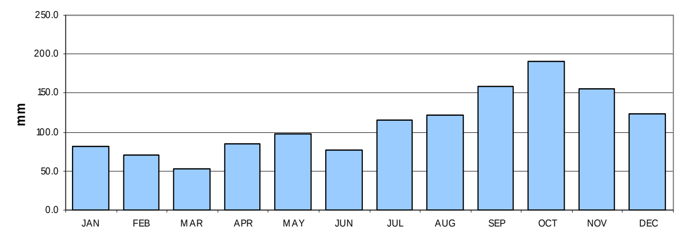
(source: Antigua and Barbuda Meteorological Services)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	% of mean
1989	94.2	57.7	58.7	65.0	26.7	38.6	68.3	85.6	325.6	88.1	83.6	33.0	1025.1	76.7%
1990	51.1	22.4	41.9	114.3	74.9	88.4	46.5	103.9	96.8	269.5	82.3	127.8	1119.6	83.8%
1991	101.6	70.6	38.1	30.5	67.8	65.3	152.4	83.8	184.2	89.7	164.3	67.8	1116.1	83.6%
1992	85.3	97.3	260.9	223.3	180.8	126.2	126.0	174.5	218.4	233.7	232.7	243.8	2202.9	164.9%
1993	77.2	49.3	29.7	50.5	355.6	138.4	173.0	52.1	93.0	96.5	101.9	80.0	1297.2	97.1%
1994	98.0	65.5	49.5	136.7	88.4	67.3	57.7	97.8	284.0	101.6	140.0	68.6	1255.0	94.0%
1995	36.8	91.2	100.1	23.9	45.2	25.4	77.5	308.6	335.8	179.6	76.2	100.3	1400.6	104.8%
1996	66.8	67.6	20.1	89.7	72.4	113.3	189.2	108.0	80.0	147.3	128.0	313.7	1396.0	104.5%
1997	52.1	162.6	10.2	78.7	76.2	66.0	149.9	228.6	211.1	168.4	52.6	41.1	1297.4	97.1%
1998	27.4	67.8	43.7	115.6	44.5	79.8	75.4	148.8	191.0	150.1	309.9	208.3	1462.3	109.5%
1999	58.9	34.8	93.5	119.6	72.9	55.9	190.8	54.9	91.9	151.4	474.0	78.0	1476.5	110.5%
2000	42.4	152.1	51.3	47.5	65.0	54.1	62.0	130.8	152.4	61.5	102.4	76.5	998.0	**74.7%**
2001	41.7	18.0	16.5	46.5	5.1	9.1	168.7	59.7	88.1	181.1	98.6	292.1	1025.1	76.7%
2002	34.3	20.3	42.4	252.2	31.8	52.8	120.9	73.4	93.7	170.2	81.0	71.4	1044.4	78.2%
2003	51.6	47.2	21.3	34.0	46.5	96.5	66.3	96.8	43.9	205.7	237.2	116.3	1063.5	79.6%
2004	64.5	158.8	74.9	74.4	365.8	113.0	146.6	63.2	66.3	254.5	223.3	195.8	1801.1	134.8%
2005	117.6	82.8	7.4	34.8	97.5	148.3	142.7	186.7	64.8	378.7	163.8	47.8	1472.9	110.3%
2006	303.8	47.5	15.2	27.9	135.4	90.4	98.3	158.5	224.5	226.3	61.5	90.9	1480.3	110.8%
2007	117.9	61.0	34.8	65.0	27.2	49.3	97.3	95.8	124.7	247.4	162.8	116.1	1199.1	89.8%
2008	180.1	60.5	56.9	53.8	85.1	66.5	83.1	109.7	202.7	423.9	147.1	113.5	1582.9	118.5%
2009	17.0	40.6												
AVG	81.9	70.3	53.4	84.2	98.2	77.2	114.6	121.1	158.6	191.3	156.1	124.1	1335.8	

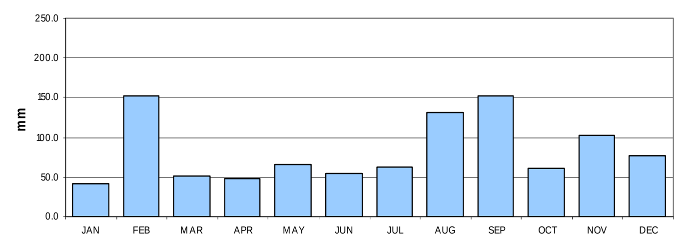
Quote: *"Although little detailed work has been carried out on the effects of the most recent climate change scenarios on the water resources of individual islands and Caribbean states, a few general inferences may be made on the basis of on-going climate modelling of the Caribbean Basin. The modelling, …… indicates that irrespective of scenario a likely significant decrease in overall rainfall especially during the important rainy season of up to 30% over the period 1990s to 2070s, region wide.*"

Source: **Exploring the Water Management Implications of Potential Climate Change (2007)**, Dr. Adrian Cashman, Dr. John Charlery, Dr. Leonard Nurse, University of the West Indies

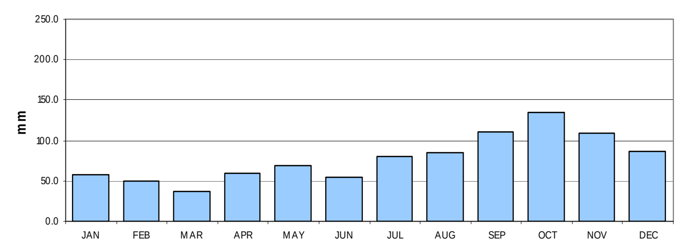
SCENARIO 1: Mean annual rainfall



SCENARIO 2: Year 2000 rainfall (meteorological drought)



SCENARIO 3: 30% reduction in mean rainfall



A collaborative effort between the Caribbean Environmental Health Institute (CEHI), the Antigua Public Utilities Authority (APUA), and the United Nations Environment Programme (UNEP)

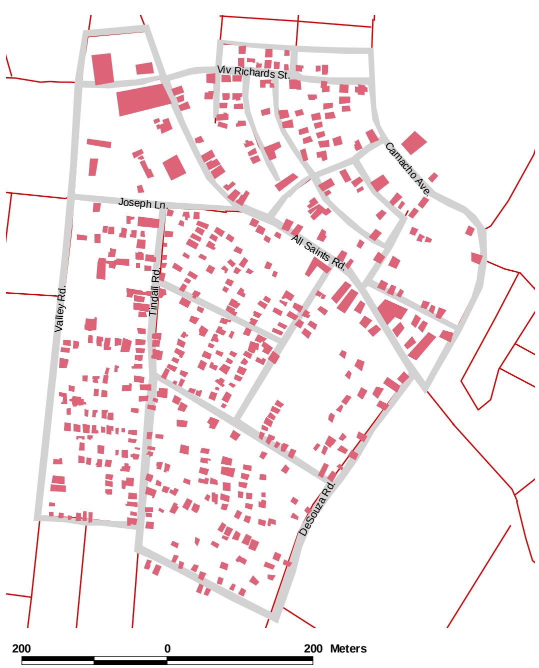
Rainfall capture potential - Data inputs

The input data layers were obtained from the APUA. These were the road network for Antigua and the building footprints (or roof areas)

Rooftops: A recent aerial photograph was used as backdrop for on-screen digitizing of the roof tops. A total of 446 building footprints were digitized from the aerial photograph. **NOTE:** Several building structures in the northern part of the study area are commercial buildings.

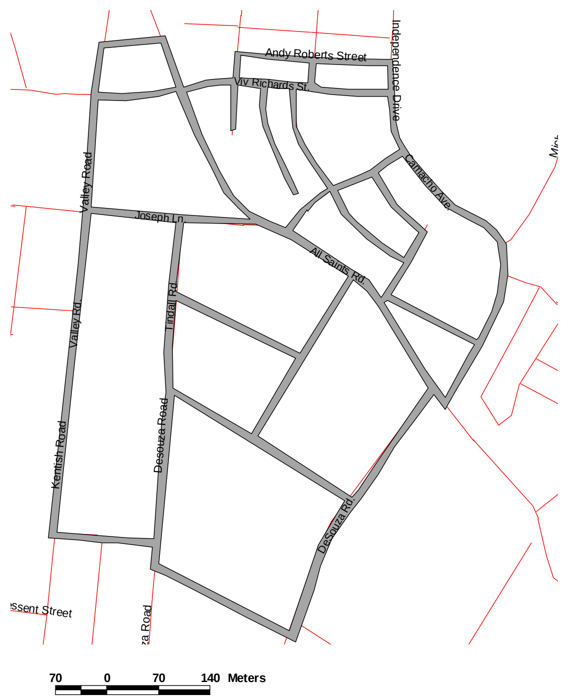
Roads: the source for this layer was a GIS line-type vector file. To estimate the rainfall capture the road surface area had to be generated as a new overlay. This was created by on-screen digitizing an approximate 10-metre corridor (following the road vector layer) that represented the roadway surface, drains, hardened sidewalk areas and verges. The total area of the road surface was computed in the GIS. **NOTE:** not all roads were captured (comparison to the Google Earth image); the total road area was therefore considered an underestimation.

Non-building areas: The overlay was generated by extracting out the building areas and road areas from the study area footprint.



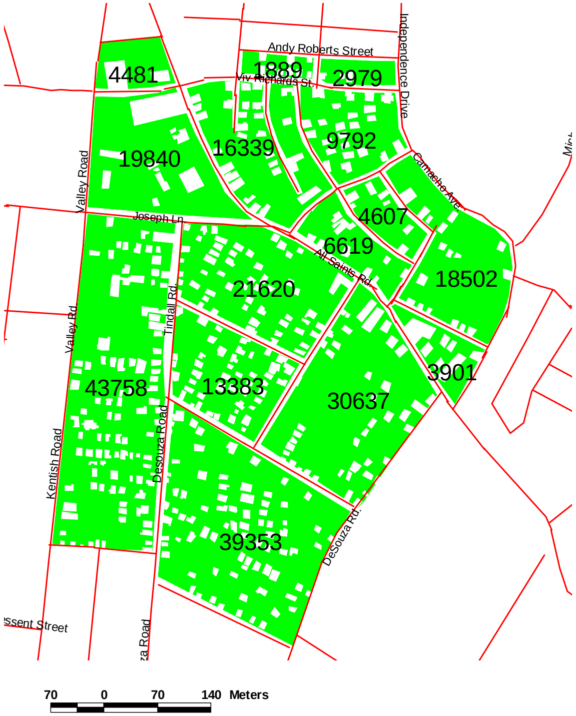
Building roof surfaces

Combined area: 50,837 m²



Road surfaces

Combined area: 55,196 m²



Non-building surfaces (sub-unit areas in m²) Combined area: 237,700 m²

A collaborative effort between the
Caribbean Environmental Health Institute (CEHI),
the Antigua Public Utilities Authority (APUA), and the
United Nations Environment Programme (UNEP)

UNEP CEHI CARICOM

Estimating annual rainwater capture

Rainfall capture potentials within the study area were estimated based on the following relationship:

Harvestable rainfall (litres) = Surface area (m^2) x rainfall (mm) x runoff coefficient (dimensionless)

About the runoff coefficient: The runoff coefficient is a factor that accounts for water losses that do not enter useful storage. In general the more impervious a surface the higher the runoff coefficient; in other words the greater the possibility of being able to divert and capture the rainfall that runs over the surface. The highest runoff coefficients are assigned to smooth metal sheet roofs, while the lowest coefficients are assigned to natural ground surfaces.

The following were the runoff coefficients assigned for the three surfaces:

Roof catchment surfaces: 0.80

Rationale: The majority of roofs in the area and across Antigua and Barbuda are constructed from sheet metal and can be expected to have a high runoff coefficient. Assignment of a 0.80 as opposed to a higher value was based on the assumption that rainwater harvesting may not be as efficient due to incomplete guttering, and leaky systems.

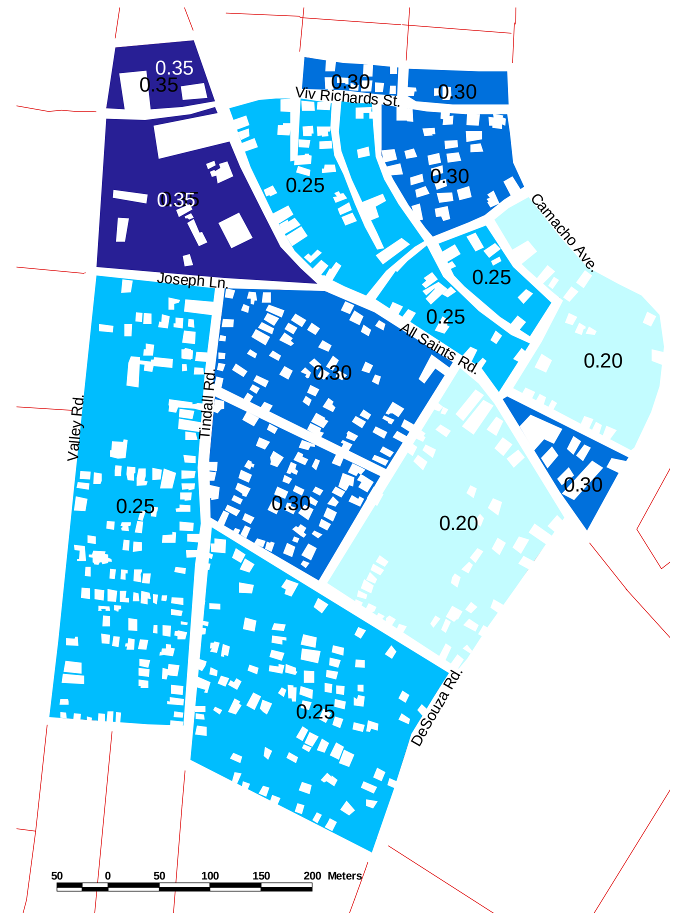
Road surfaces: 0.50

Rationale: The roads within the study area are dominated by secondary streets with hard asphalt surfaces, although in some places runoff may be impounded (on account of poor maintenance) and may permit localized infiltration. The runoff coefficient was assumed to be lower than what might be assigned to paved highways or major urban streets.

Non-building areas: variable between 0.20 and 0.35

Rationale: There are varied landscapes across the study area that includes undeveloped lots with scattered to moderately dense vegetation, to semi-surfaced unimproved lots, and in some instances, hard surfaced areas, mainly in the extreme northern area. The assigned coefficients varied between 0.20 and 0.35 on the basis of inspection of the aerial photo.

Runoff coefficients assigned to non-built areas

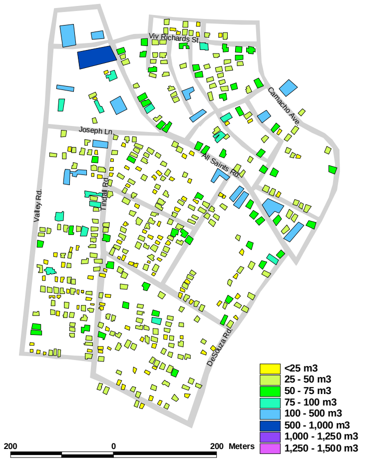


A collaborative effort between the Caribbean Environmental Health Institute (CEHI), the Antigua Public Utilities Authority (APUA), and the United Nations Environment Programme (UNEP)

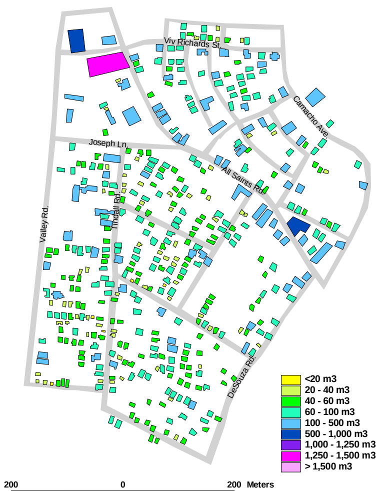
Rainfall capture potential: Buildings

The following rainfall maps illustrate the rainfall capture potential off the roof catchment surfaces within the study area. It was assumed that all roof surfaces were of similar material, in this case, metal sheeting as is almost universal across Antigua. The assigned runoff coefficient was therefore the same for all structures; a value of 0.8 used in all three rainfall scenarios. The capture potential across the entire area is the summation of rainwater capture from all structures.

SCENARIO 1: Mean rainfall conditions

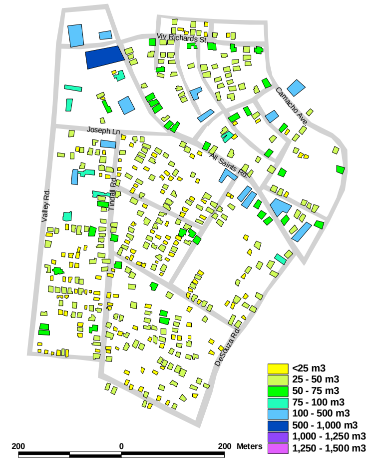


Dry season (Jan-Jun)
Capture potential: 18,920.2 m^3

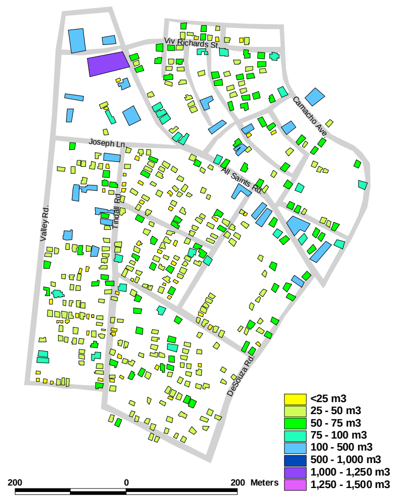


Wet season (Jul-Dec)
Capture potential: 35,215.4 m^3

SCENARIO 2: Meteorological drought Year 2000 rainfall

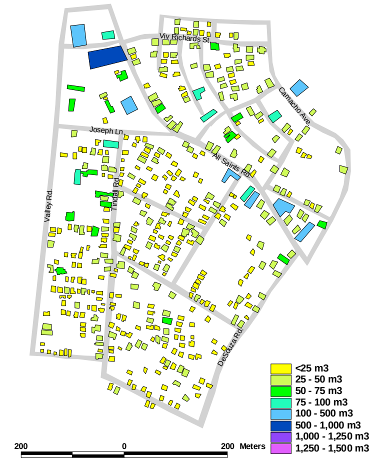


Dry season (Jan-Jun)
Capture potential: 16,777.2 m^3

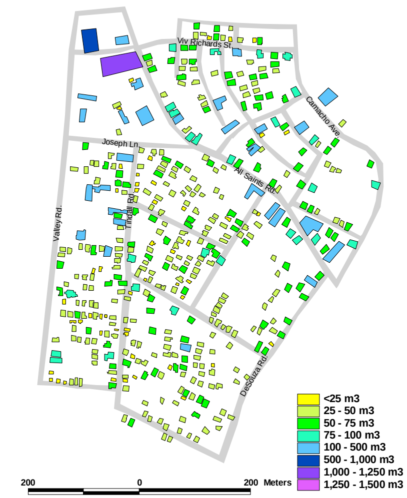


Wet season (Jul-Dec)
Capture potential: 23,810.5m^3

SCENARIO 3: 30% below mean rainfall



Dry season (Jan-Jun)
Capture potential: 13,241.4 m^3



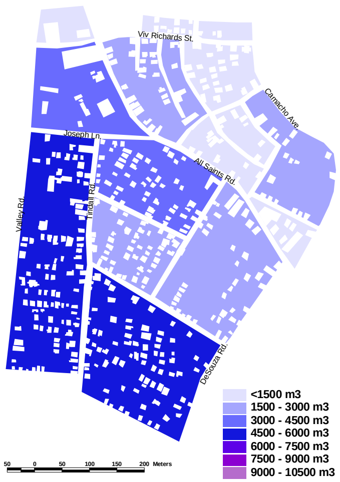
Wet season (Jul-Dec)
Capture potential: 24,648.9 m^3

A collaborative effort between the
Caribbean Environmental Health Institute (CEHI),
the Antigua Public Utilities Authority (APUA), and the
United Nations Environment Programme (UNEP)

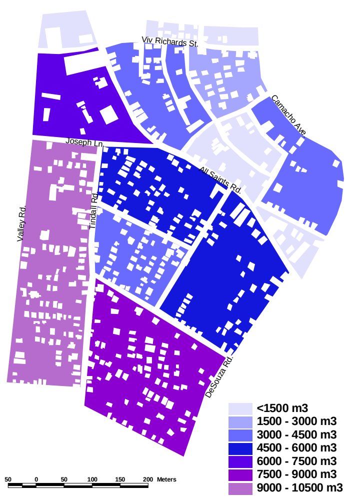
Rainfall capture potential: Non-built areas

The following maps illustrate the rainfall capture potential within each non-built sub-unit within the study area. The variability in capture volume is based on the runoff coefficient assigned to each sub-unit. Those areas that were more built-up with hard surfaces and structures were assigned higher runoff coefficients as compared to areas that were dominated by open fields and vegetation.   The capture potential across the entire area is the summation of the sub-units.

SCENARIO 1: Mean rainfall conditions

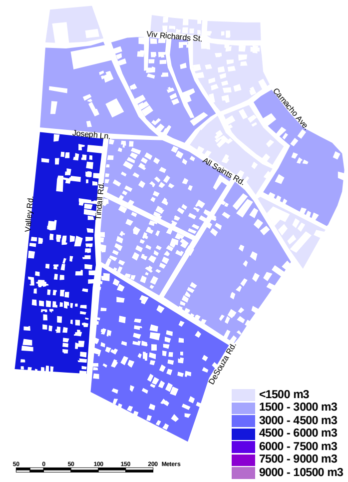


Dry season (Jan-Jun)
Capture potential: 28,879.6 m^3

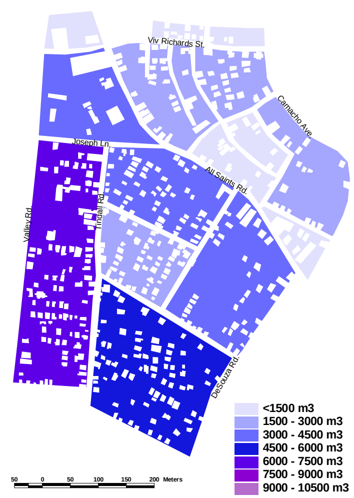


Wet season (Jul-Dec)
Capture potential: 53,751.9 m^3

SCENARIO 2: Meteorological drought Year 2000 rainfall

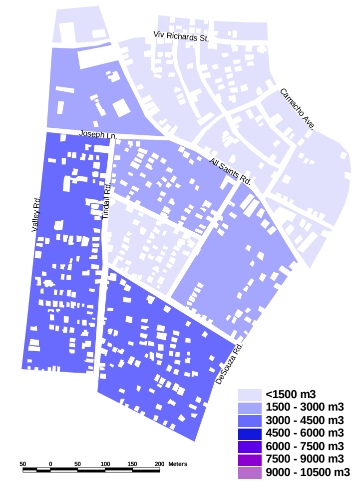


Dry season (Jan-Jun)
Capture potential: 25,607.2 m^3

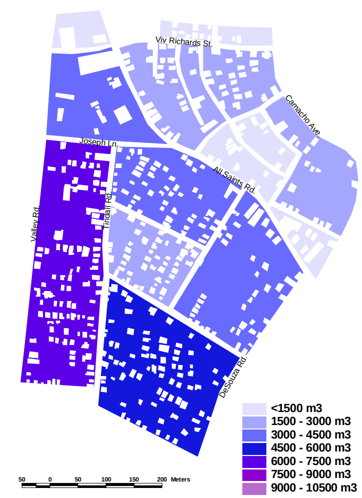


Wet season (Jul-Dec)
Capture potential: 36,345.1 m^3

SCENARIO 3: 30% below mean rainfall



Dry season (Jan-Jun)
Capture potential: 20,215.7m^3



Wet season (Jul-Dec)
Capture potential: 37,626.3 m^3

A collaborative effort between the
Caribbean Environmental Health Institute (CEHI),
the Antigua Public Utilities Authority (APUA), and the
United Nations Environment Programme (UNEP)

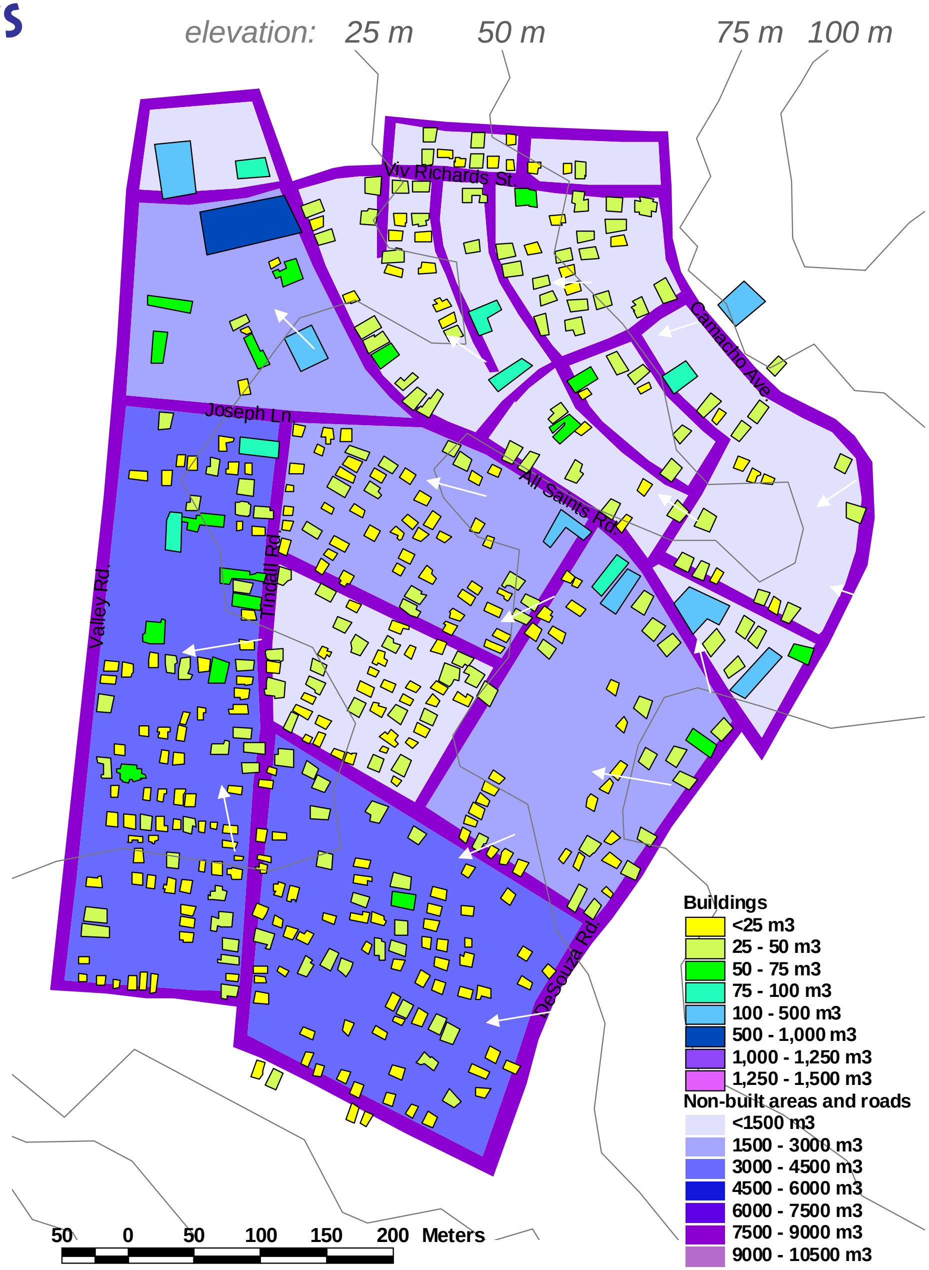
Capture potential: All areas

In this application the rainwater harvest potential under the influence of climate change is of interest. A 30% decline in mean rainfall will translate to a reduction in the capture potential that can be diverted to domestic RWH systems, and that which can be diverted to recharge aquifers (ground water) and reservoirs. This is an extremely important consideration in water supply maintenance.

The map illustrates the rainwater capture potential for each surface under a scenario with rainfall at 30% below the mean during the dry season (Jan to Jun).

Estimated rainwater capture volume (by area):

- **Buildings:** 13,241.4 m^3
- **Non-built areas:** 20,215.7 m^3
- **Roads:** 8,997.2 m^3
- **Combined:** **42,454.3 m^3**



White arrows are approximate flow direction

A collaborative effort between the
Caribbean Environmental Health Institute (CEHI),
the Antigua Public Utilities Authority (APUA), and the
United Nations Environment Programme (UNEP)

Estimating water supply deficits

An example of a simple analysis to estimate household water supply deficits based on variability in municipal water supply reliability under the 30% reduction in mean rainfall (climate change) scenario is presented. The example considers the dry season rainfall regime. Two daily household demand rates (per person) are evaluated with two potable water reliability scenarios. This analysis is intended to simulate conditions/challenges that may be faced in water service provision during extreme drought conditions with a view to identifying individual households that may be most vulnerable. With actual household data such an evaluation can provide useful emergency response guidance in water service delivery.

Water Supply Deficit

Of interest is supply deficit during the dry season where it is assumed that the municipal supply will be most challenged in terms of reliability. The supply deficit for each household is the difference between the harvestable rainfall and the augmentation target (the water that is required to meet household needs). This implies that the roof catchment surface is not of sufficient area to harvest the rainfall to meet the supply shortfall.

Assumptions:

(A) Household demand

Daily

- **SCENARIO 1:** 100 litres/person (22 gallons/person)
- **SCENARIO 2:** 200 litres/person (44 gallons/person)

6-month

- **SCENARIO 1:** 91.5 m^3
- **SCENARIO 2:** 183.0 m^3

(B) Municipal supply reliability ***(in this application defined as the % of demand met by the municipal water supply)***

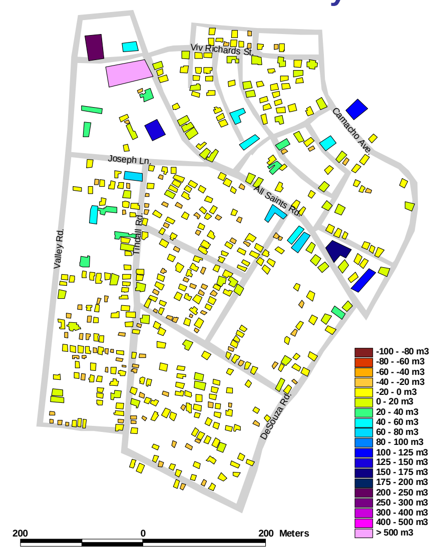
- **SCENARIO 1 at 60% supply reliability:** 54.9 m^3 supplied; household augmentation target: 36.6 m^3
- **SCENARIO 1 at 80% supply reliability**: 73.3 m^3 supplied; household augmentation target: 18.3 m^3
- **SCENARIO 2 at 60% supply reliability:** 109.8 m^3 supplied; household augmentation target: 73.2 m^3
- **SCENARIO 2 at 80% supply reliability:** 146.4 m^3 supplied; household augmentation target: 36.6 m^3

(C) Persons per household: 5

NOTE: Rainfall will be harvested during the wet season and be retained as storage during the first part of the dry season hence the estimated deficits will be lower in reality. Nonetheless those households that have deficits or come close to deficit situation are those that should targeted for investment in additional storage capacity.

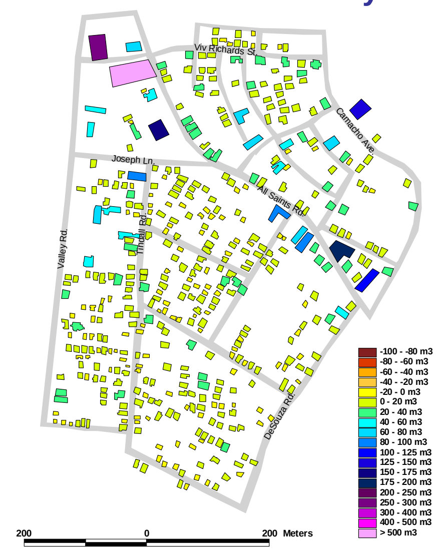
SCENARIO 1: Demand at 100 litres/person/day

60% reliability



Cumulative deficit: 5535.3 m^3

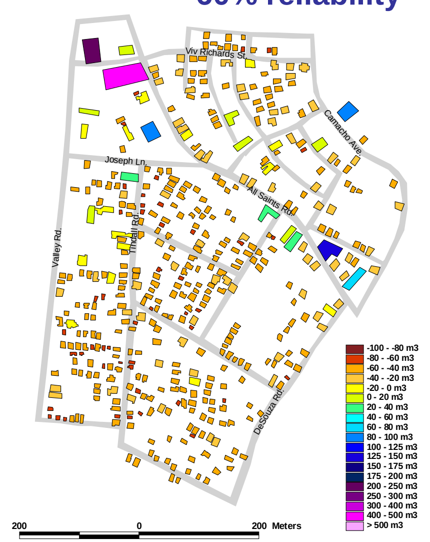
80% reliability



Cumulative deficit: 542.6 m^3

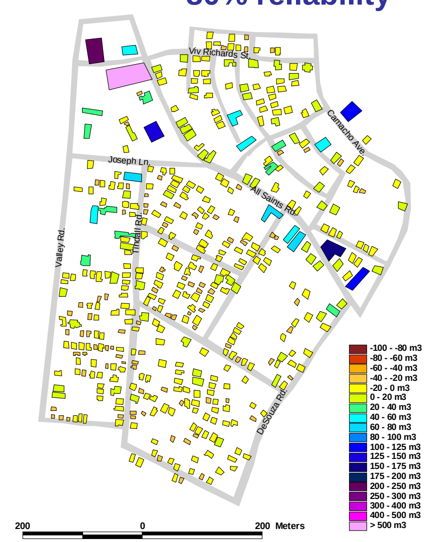
SCENARIO 2: Demand at 200 litres/person/day

60% reliability



Cumulative deficit: 20,653.9 m^3

80% reliability



Cumulative deficit: 5535.3 m^3

A collaborative effort between the
Caribbean Environmental Health Institute (CEHI),
the Antigua Public Utilities Authority (APUA), and the
United Nations Environment Programme (UNEP)

UNEP

CEHI CARICOM

ANTIGUA PUBLIC UTILITIES AUTHORITY