

Improving Hydrometeorological Data Collection Network, Data Management, and Relevant Institutional Frameworks in the Commonwealth of Dominica

Hydrometeorological Consultant's Report to the
Project Coordination Unit
Pilot Programme for Climate Resilience (PPCR)
Disaster Vulnerability Reduction Programme (DVRP)

April 1, 2015

By: Fred L. Ogden, Ph.D., Civil Engineering Professor

E-mail: ogdenf@gmail.com

Executive Summary:

This report contains findings and recommendations to improve climate data acquisition, management, and data dissemination based on my visit to Dominica in January, 2015. During this trip I met with personnel from a number of agencies to gather facts regarding their needs. I obtained data regarding the existing hydrometeorological network. Based on data provided to me, I performed analyses of the suitability of the existing data and performed a network design aimed at increasing disaster preparedness.

Existing hydrometeorological data sets are sparse to nonexistent. I recommend acquisition of high quality instrumentation and implementation of practices to increase data collection, archival and dissemination using information technology.

The existing hydrometeorological network is insufficient to capture the spatial variability of rainfall in Dominica. The primary agencies with hydrometeorological interest in Dominica would benefit by coming to an agreement on the highest priority instrumentation sites and establish a historical monitoring network that will be maintained in perpetuity. These sites will include weather, rainfall, and stream flow.

Archiving and dissemination of data can be improved. At present there is no national agency charged with water resources assessment or enforcement of environmental regulations related to water quality. The quasi-private water provider DOWASCO is the closest thing that exists to an "agency" that could fill this need.

Natural hazards such as landslides are complex and difficult to predict. Flash flooding can be predicted to some extent through installed instrumentation and warning systems.

Groundwater resources in Dominica are poorly understood in general. These resources could be used to provide drought mitigation, particularly in northwestern Dominica.

Training opportunities are needed to create expertise within agencies to fully take advantage of available information technologies. Furthermore, there are opportunities wherein foreign experts could be retained on agency fellowships to help mentor agency staff in best practices.

As part of my charge, I make recommendations for water resources assessment and hydrometeorological data management and dissemination. Given limited resources, creating of new agencies is unlikely to succeed. Therefore recommendations focus on existing entities.

I recommend acquisition and installation of the following instrumentation by site type:

- 5 ea. complete telemetered meteorological/rainfall stations
- 22 ea. telemetered stream gauging stations
- 16 ea. telemetered rainfall gauging stations
- 5 ea. line-of-Sight radio repeaters.
- 6 ea. shallow groundwater monitoring sensors for investigative studies in piezometers.

The budget request also includes all items required for installation of the network, spares, training, maintenance, and functionality guarantees. See the budget for details.

Engineering Design Disclaimer

This report contains analyses and recommendations for improving the National Hydrometeorological Network in the Commonwealth of Dominica. The contents of this report shall not be construed as Engineering design. The actual installation of instrumentation, towers, and construction of instrument shelters, etc., depends upon local site conditions. The services of an Engineer licensed to practice in the Commonwealth of Dominica shall be employed to perform the actual design of needed structural elements in accordance with applicable local and Commonwealth building codes.

Table of Contents

1. Introduction.....	4
2. Methodology.....	4
3. Analysis of Meteorological Network.....	6
3.1 Rain Gauge Network.....	7
3.2 Annual Precipitation vs Elevation.....	9
3.3 Monthly Precipitation vs Elevation.....	10
3.4 Spatial Correlation of Rainfall.....	12
3.5 Rainfall Network Analysis Observations and Conclusions.....	17
4. Recommendations for Stream Gauging/Monitoring.....	19
4.1 Agency Recommended Sites.....	19
4.2 DOWASCO Recommended Sites.....	19
4.3 Environmental Health Department Recommended Sites.....	21
4.4 Dominican Meteorological Service Recommended Sites.....	23
4.5 Appropriateness of Stream Gauging Sites.....	24
4.6 Water Quality Measurements in Association with Stream Gauging.....	27
5. Data Archiving, Sharing and Dissemination using Information Technology.....	28
6. Hydrometeorological Equipment Purchase Specifications.....	28
6.1 Automated Climate Stations with Telemetry Options.....	29
6.2 Automated Rain Gauge Stations with Telemetry Options.....	30
6.3 Line-of-Sight Repeater Stations.....	30
6.4 Instrument Shelters.....	31
6.5 Telemetered Stream Gauging Stations.....	33
7. Equipment Vendor Requirements.....	34
8. Rehabilitation and Reuse of Existing Equipment.....	34
9. Identification of Long Term (Historical) Monitoring Sites.....	35
10. Training, Staffing, and Retention.....	36
11. Recommendations to Improve Private Sector Interactions.....	38
12. Recommendations to Improve Agency Analytical Capability.....	39
13. Recommendation to Establish a Hydrometeorological and Climatological Data Dissemination Centre.....	40
14. Quantity and Cost Estimates, Budget Summary.....	42
14.1 Quantity Estimation:.....	42
14.2 Cost Estimates:.....	43
14.3 Cost Basis for Instrumentation Support.....	45
14.4 Budget Summary:.....	46
15. References.....	47
16. Acknowledgments.....	48
Appendix A. Name, Elevation and Location of DOMEX Rain Gauges Used in P-E and Spatial Correlation Analyses.....	49
Appendix B. Existing, Past (Abandoned) or Planned Meteorological Instrumentation in Dominica.....	50
Appendix C. Commonwealth of Dominica Hydrometeorological Technical Working Group.....	52
Appendix D. Example Memorandum of Understanding Regarding Network Operation and Data Sharing.....	53

1. Introduction

The overall objective of this project was to analyze the existing hydrometeorological and hydrological data collection networks in the Commonwealth of Dominica. During January 19-23, 2015, I visited Dominica to learn about the existing hydrometeorological network, stakeholders, data users, and agencies. During this period my visit was facilitated by the Office of the Disaster Vulnerability Reduction Programme (DVRP). I met with personnel from DVRP, Dominica Meteorological Service (DMS), Dominica Water and Sewerage Company Ltd. (DOWASCO), and members of the Hydrometeorology Working Group that come from a variety of agencies and ministries.

Because of the sufficiency of water supplies and relatively small population, the water resources infrastructure of Dominica is underdeveloped compared to Island nations that have more complex water resources issues or larger populations. Figure 1 shows the scale of the island with key rivers and mountain peaks.

In the context of climate resilience, accurate long term hydrometeorological data are most valuable. The period of record varies between data types and collecting agency. Long term climate records from the two airports on the island (Canefield and Douglas-Charles) are archived in accordance with WMO standards by the Caribbean Institute for Meteorology and Hydrology (CIMH).

Understanding of potential impacts of climate change on water resources availability requires data sufficient to perform water balance calculations at watershed and aquifer scales. Accurate water balance computations require accurate measurements of as many components of the hydrological cycle as possible, aided with well informed estimation methodologies for those components that are difficult to measure directly such as actual evapotranspiration.

In all interviews with agency personnel, I asked a series of questions to attempt to ascertain the status of existing data and networks, efforts to rescue data in paper form, the use of information technology and computation, training needs, staffing levels, and equipment uses/needs. If there were gaps, I asked for suggestions on how these gaps might be filled. Most of the suggestions involved staffing levels, staff retention, and associated budgetary problems.

2. Methodology

During my visit to Dominica, I became familiar with the unique conditions that exist in Dominica owing to the extremely small population of the country. I focused on agencies that collect hydrometeorological and hydrological data, with less emphasis on data users. My background as a university researcher, as well as service on U.S. national review committees provides me with a good sense for the scope of needs by hydrometeorological and hydrological data users.

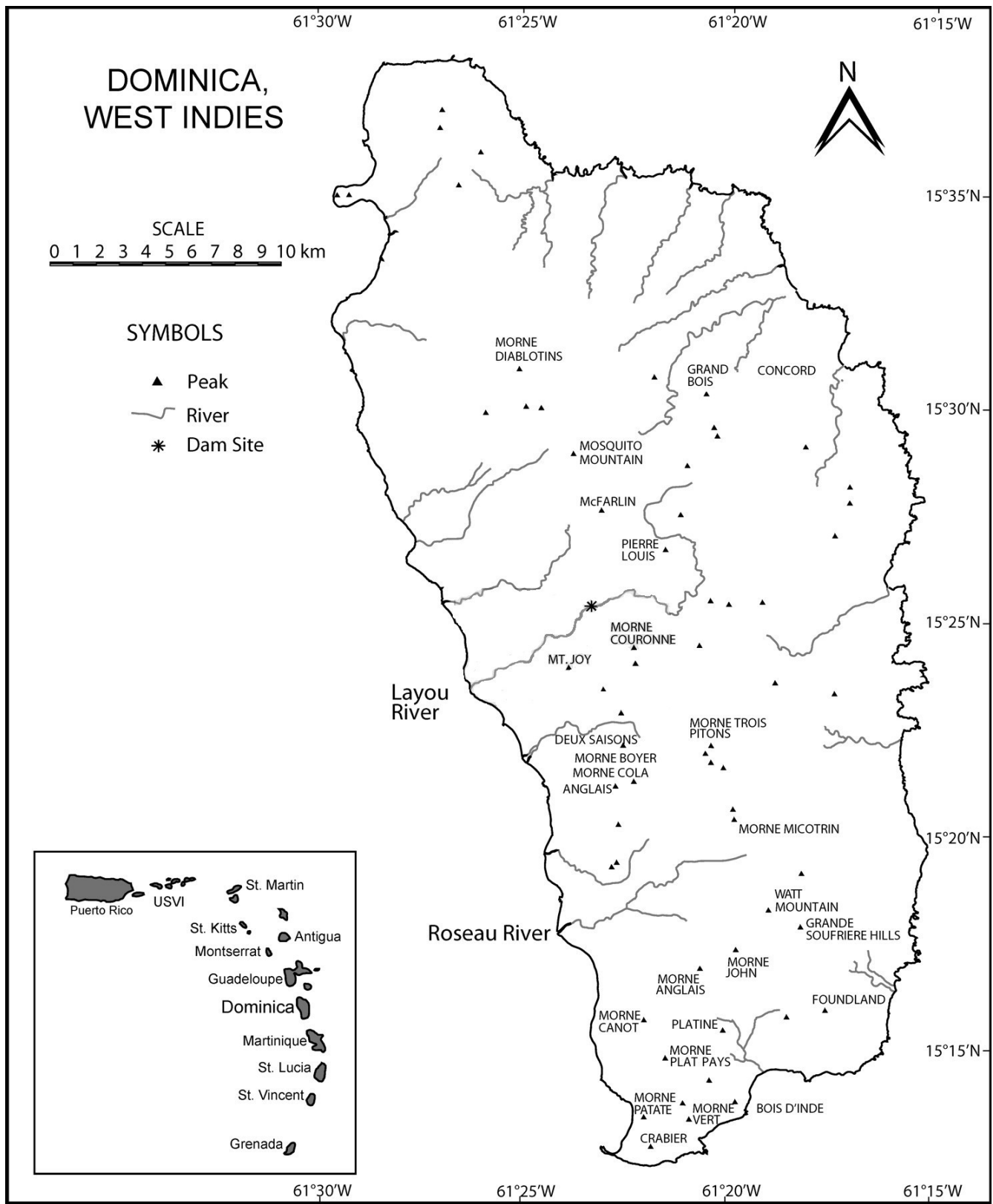


Figure 1: Scale map of the island of Dominica.

Data provisioning using information technology is nonexistent in Dominica. While some of the long-term climate records collected by DMS are archived by CIMH, there are no in-country data portals. Here I have focused on computer literacy for staff, information management skills, considered different software options, and the value of online data availability for optimal use of water resources, energy savings, education and outreach.

Analysis of the climatological monitoring network allows constructive recommendations regarding generation of products, archival records, and potential research areas to provide highly-relevant information to policy makers. The needs of the country are to evaluate risk and reducing impacts of disasters. However, before these analyses are possible, a sufficient quantity of high-quality hydrometeorological data must exist. For this reason, I performed a detailed analysis of data from an experimental rain gauge network (DOMEX), with emphasis on rainfall space-time variability.

Recommended equipment is cost estimated. Costs associated with labor and construction are also estimated, but these cost estimates are highly uncertain. Therefore, only after bids are received through the procurement process will the costs of labor and construction be known with more certainty.

3. Analysis of Meteorological Network

An important application of meteorological data is validation of downscaled climate simulations. These methodologies require simulation of past conditions and comparison with past observations in a statistical sense. One criteria that is used to evaluate the value of existing data sets is the question: “Do sufficient quantities and qualities of data exist to allow closure of the water balance in a watershed with uncertainty less than the sum of the measurement errors?” This is a worthwhile standard to keep in mind when thinking about long term hydrometeorological data collection. High quality measurements at enough points to describe spatial variability, at consistent intervals and locations, over a long time period are required. In the face of a changing climate, there is no such thing as a “long enough” period. Consistent, continual, data collection of indefinite duration is required.

A number of key gaps were identified in each monitoring network with the assistance of agency personnel, and through my analysis of existing monitoring sites. My analysis, which focused on rainfall measurements, is described below. Rainfall measurements were taken as the prime focus because rainfall tends to be more varied in space and time than other meteorological parameters such as temperature, dew point, and wind speed. Another highly variable quantity in time is net radiation, which is strongly affected by the occurrence of cloudiness, but more highly correlated in space.

Lang (1967) analyzed the spatial distribution of annual rainfall across Dominica. The result of that analysis is shown in Figure 2. Note that the units of rainfall shown in this figure are inches (1 in. = 25.4 mm). Dashed lines indicate estimated rainfall, not measured. The data used by Lang (1967) consisted of rainfall accumulations from a number of plantation sites dating from the 1930's. The location of those rainfall records is unknown.

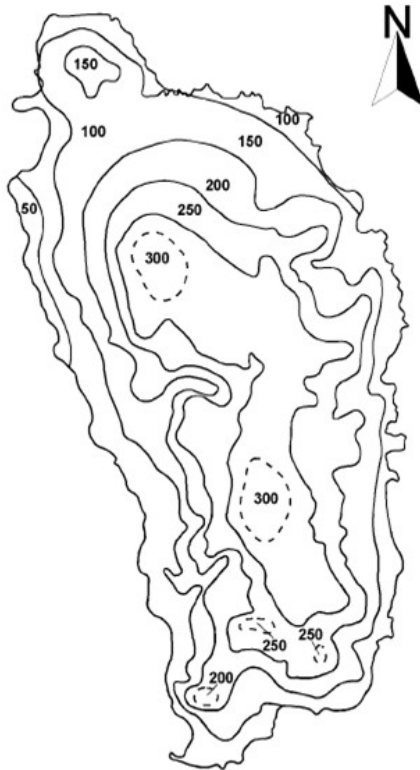


Figure 2: Estimated annual rainfall over Dominica (inches). After Rouse et al. (1986) from Lang (1967).

3.1 Rain Gauge Network

There are two long-term rain gauge sites in Dominica. These are the two airports on the island, Canefield and Douglas-Charles. Starting in 2007 an experiment run by a group from Yale university installed an ad-hoc rain gauge network across the southern portion of the island to examine topographical factors on tropical rainfall. This experiment was called “DOMEX”, and Figure 3 shows locations of the ground-based DOMEX instrumentation. Following the end of the experiment, the rain gauges and loggers were left in the care of the Dominica Meteorological Service, who continues to operate it. I performed an analysis of rainfall space-time variability and precipitation vs. elevation relations using the DOMEX tipping bucket data. The hypothesis that there is a significant increase in precipitation with elevation was tested, by analyzing monthly rainfall data vs station elevation.

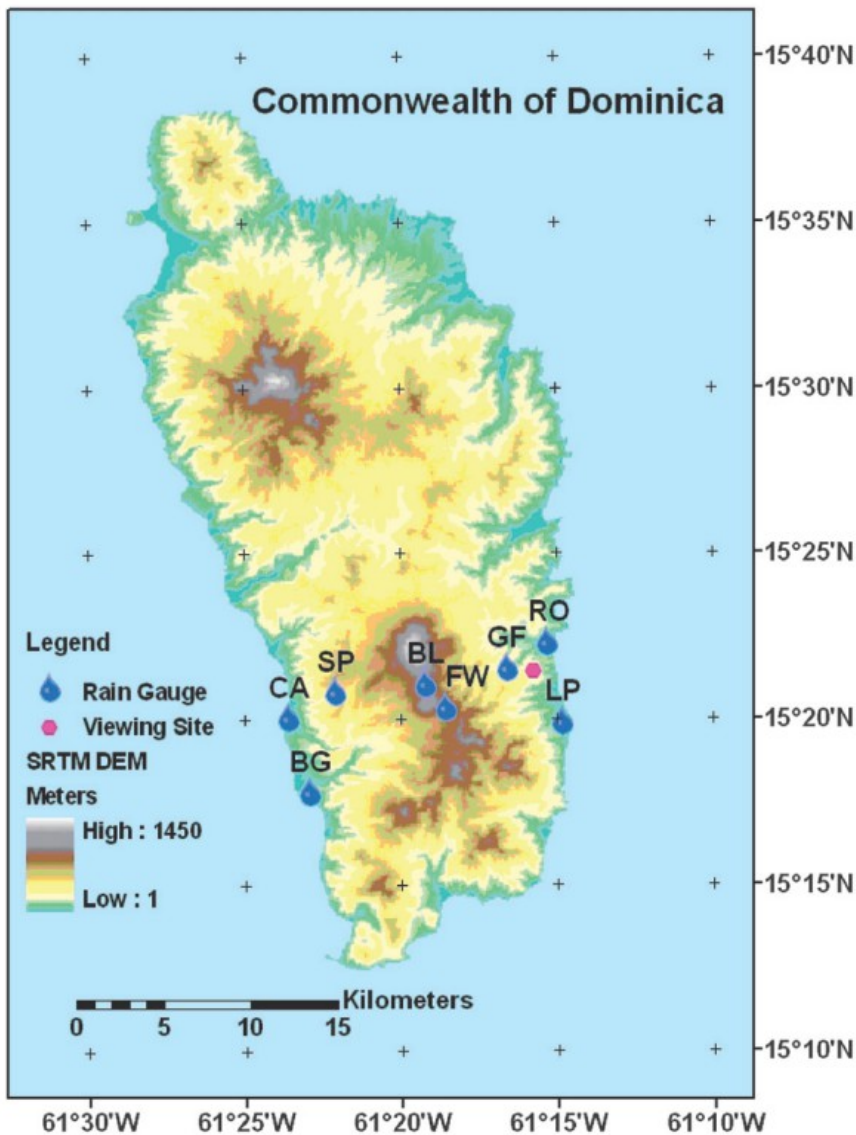


Figure 3: Location of DOME X tipping bucket rain gauges. BG=Botanical Garden, BL=Boeri Lake, CA=Canefield, FW=Freshwater Lake, GF=Grand Fond, LP=LaPlaine, RO=Rosalie, SP=Springfield. After Smith et al. (1989).

The DOME X tipping bucket data were recorded as date/time stamps for individual tips. The HOBO rain gauges (Onset Computer Corp.) used in DOME X had a 0.2 mm per tip resolution, and the HOBO data loggers recorded the date/time of individual tips to the nearest second. HOBO data loggers are known to suffer from clock drift in an amount up to several minutes per month. Because some of the sites were not visited more frequently than after several months, there might be time errors associate with the individual tips up to approximately 10 minutes or more.

The DOMEX tipping bucket data were binned into hourly, daily, and monthly values for each gauge in the period of record. There are gaps in the data set. Figure 4 shows the nature of the monthly rainfall database by plotting months with/without data for each of the 11 DOMEX stations over the period of record.

3.2 Annual Precipitation vs Elevation

It is widely held that precipitation amounts increase with elevation on tropical islands. Potential impacts of climate change, downscaled to smaller scales from climate model output should be able to reproduce this effect, if it is present. For this reason, I analyzed the DOMEX tipping bucket rainfall dataset with coverage of parts of 2007, 2008, 2009, 2011-2014, to determine if these data capture or suggest a precipitation vs elevation (P-E) relationship.

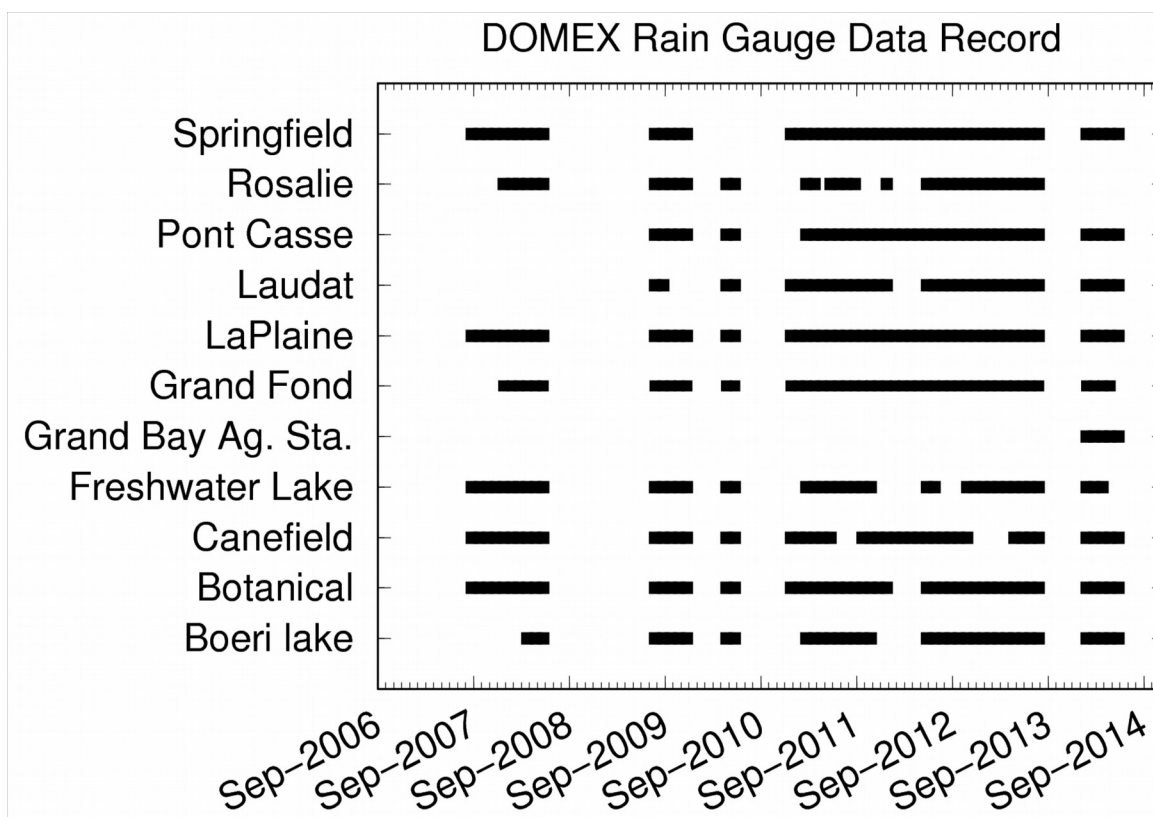


Figure 4: Tapestry plot showing the quantity of data in the DOMEX database after conversion to monthly values. Each small black square denotes one monthly value of rainfall at one station. Missing squares denote missing data. Note intermittent network-wide data gaps that indicate lost or misplaced data. Not all months are complete.

Annual rainfall amounts for stations with no missing values during a particular year using monthly rainfall data for the period of record (all data shown in Figure 4). Figure 5

shows daily rainfall vs station elevation the extremely wet rainfall period from May-June, 2010.

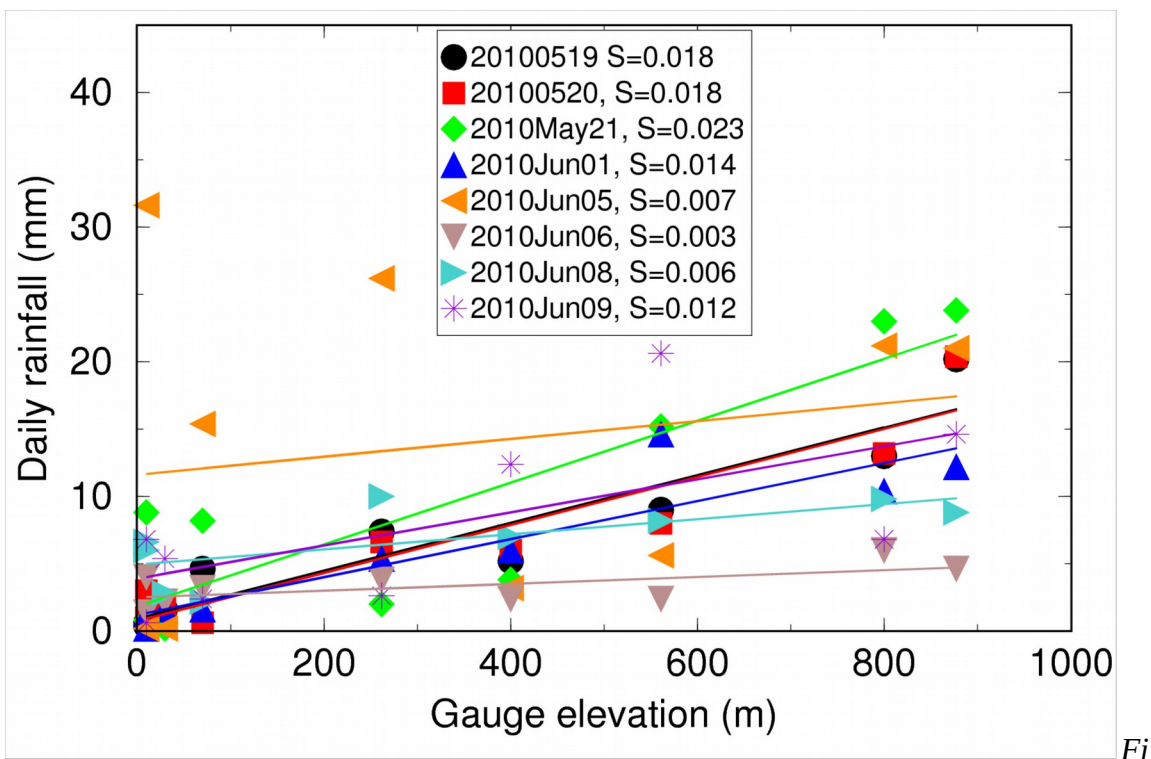


Figure 5: Daily rainfall vs station elevation for all stations with no missing data during the extremely rainy period in May-June, 2010. Lines show linear regressions. Legend shows slope of regression S in mm m^{-1} over the time period of one day.

Results shown in Figure 5 clearly indicate that at the daily level, there is a significant precipitation vs elevation relation. The t-statistics of the regression indicate confidence in the regression slope on 6 of 8 days. There are occasionally stations at lower elevations that receive more rainfall than the highest stations in the network, but this seldom occurs.

3.3 Monthly Precipitation vs Elevation

Only station-months with complete records (no missing data in any month during a particular season) were included in the analysis. Figure 6 shows precipitation vs elevation for the months of data shown in Figure 4.

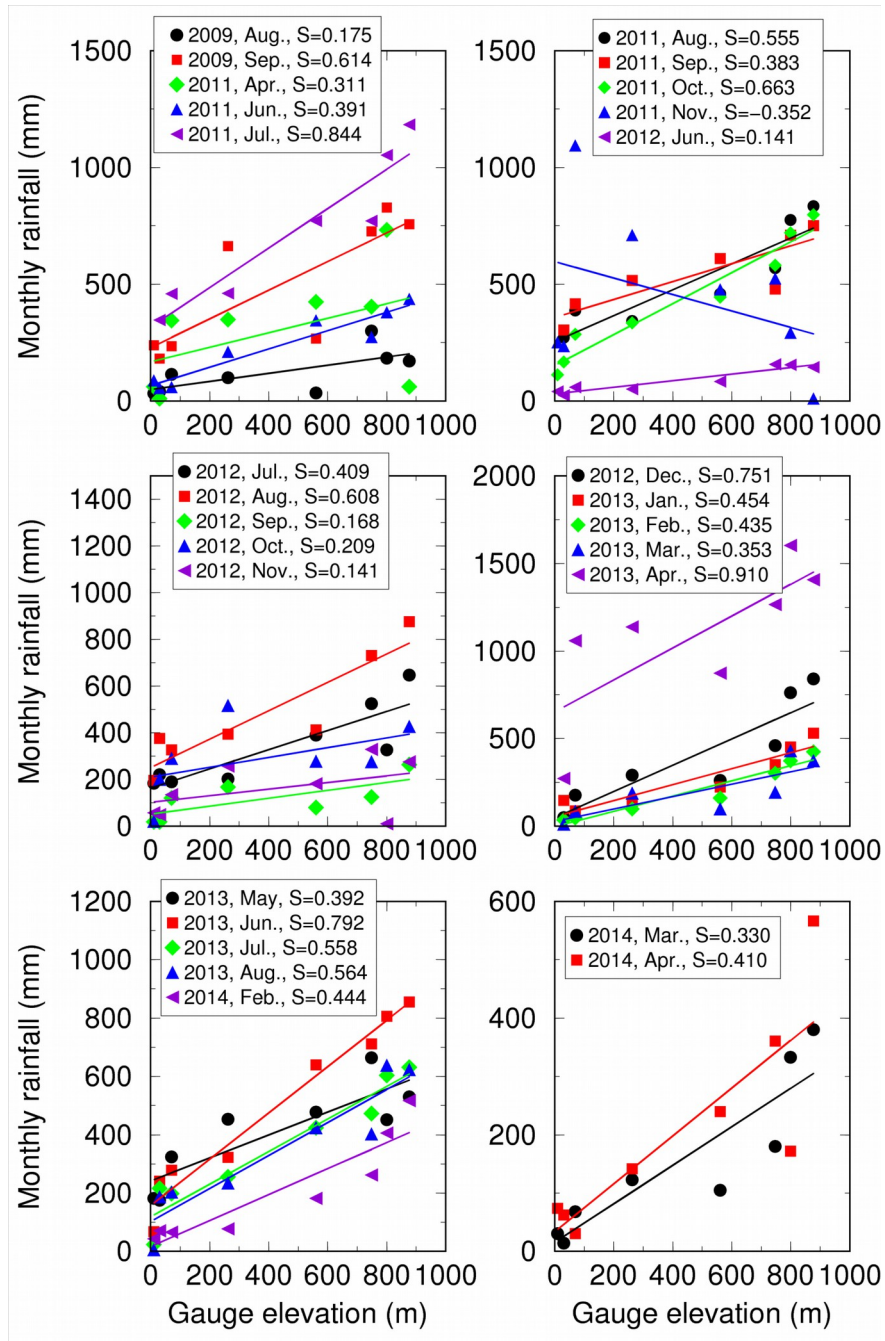


Figure 6: Monthly precipitation vs. elevation relations for 27 months with complete records shown in Figure 4 from DOMEX rainfall data. Note regression slope S has units of mm per m over the time period of one month.

Results shown in Figure 6 confirm the existence of a very strong precipitation vs. elevation relationship over the island of Dominica. This outcome has very important implications for rain gauge siting. Elevation is extremely important in siting rain gauges. The assumption that nearby rain gauges that lie at significantly different elevations, for example greater than 100 to 200 m, are correlated is likely not valid.

The distribution of the precipitation vs. elevation relation slope from month to month is shown in Figure 7.

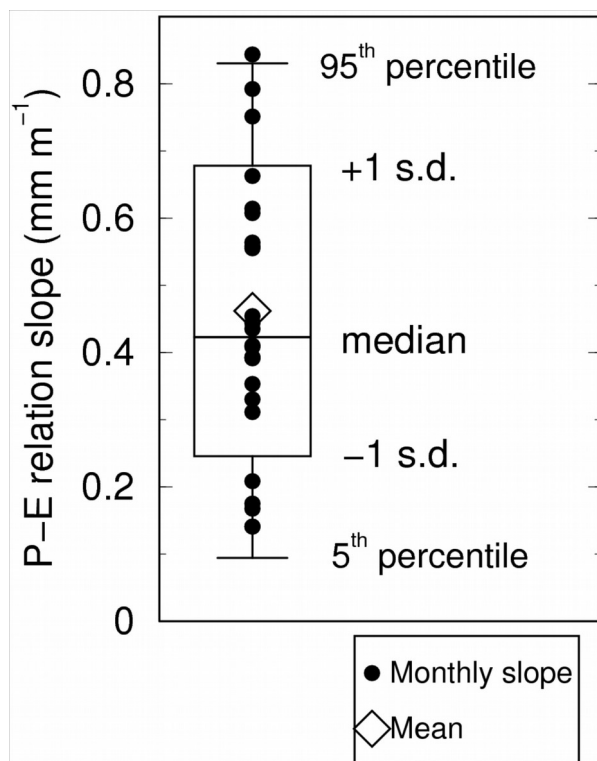


Figure 7: Distribution of monthly precipitation-elevation relation slope, from DOMEX data.

The results shown in Figure 7 indicate that there is considerable variation in the slope of the precipitation vs. elevation relationship at the monthly time scale. The median value is 0.423 mm m⁻¹, while the mean value is 0.462 mm m⁻¹.

3.4 Spatial Correlation of Rainfall

The adequacy of the spatial distribution of stations in a rain gauge network to capture the spatial variability of rainfall is an important question. Of course, this adequacy depends upon the time scale of interest. In general, the correlation of rain gauge measurements at two stations at fixed locations increases as the time-period increases. Similarly, as the distance between stations increases, the correlation between their rainfall measurements over a fixed time period will decrease. At some distance, the two stations are considered to be completely uncorrelated. This distance is called the “correlation length”. The correlation length is defined as the distance between two stations where for a given period of rainfall measurement, there will be some correlation between the two stations. The calculation of spatial correlation is best performed using data from a wide range of events. In this regard, extreme events are not considered separately from “ordinary” events, as they are all

members of the expected event population.

The sampling period (e.g. hourly, daily, monthly, annual) has a very large effect on the correlation length. Hourly correlation lengths for tropical rainfall in Panama are less than 6 km, while daily correlation lengths range from 20 to 30 km (Niedzialek and Ogden, 2000; Ogden et al. 2013). The rainfall regime of Panama is maritime and very similar to that of Dominica, because the narrow isthmus of Panama does not have a significant influence on convection. In this regard, convection in Panama is very similar to that occurring on large tropical islands such as Dominica.

In general, the correlation length increases with increasing integration time. Calculation of the correlation length requires mathematical operations on a complete set of data. Missing values can be estimated, but this data filling exercise is tedious and can confound the results; it is best to start with a complete, non-filled data set with no missing values. The DOMEX rain gauge network data set shown in Figure 3, was processed to identify the largest period of complete rainfall data in the record. This processing revealed that there were 11 months of complete data with rainfall at 10 gauges. This results in 110 gauge-months of data.

Monthly rainfall from these 11-months of data from 10 station were used to calculate the covariance and correlation coefficient for each pair of stations at the monthly time scale. Those results are shown in Figure 8. A one parameter exponential was fit to the data to model the correlation (ρ) vs distance (d) relation. The model used is:

$$\rho = e^{-bd} \quad (1)$$

where the parameter b is the inverse of the correlation length L_c ($b=1/L_c$). The use of a one parameter correlation model (Eqn. 1) assumes that rain gauges installed adjacent to each other will be perfectly correlated. In essence, this assumption neglects measurement errors due to systematic effects such as rain gauge miscalibration, wind effects, and random measurement errors.

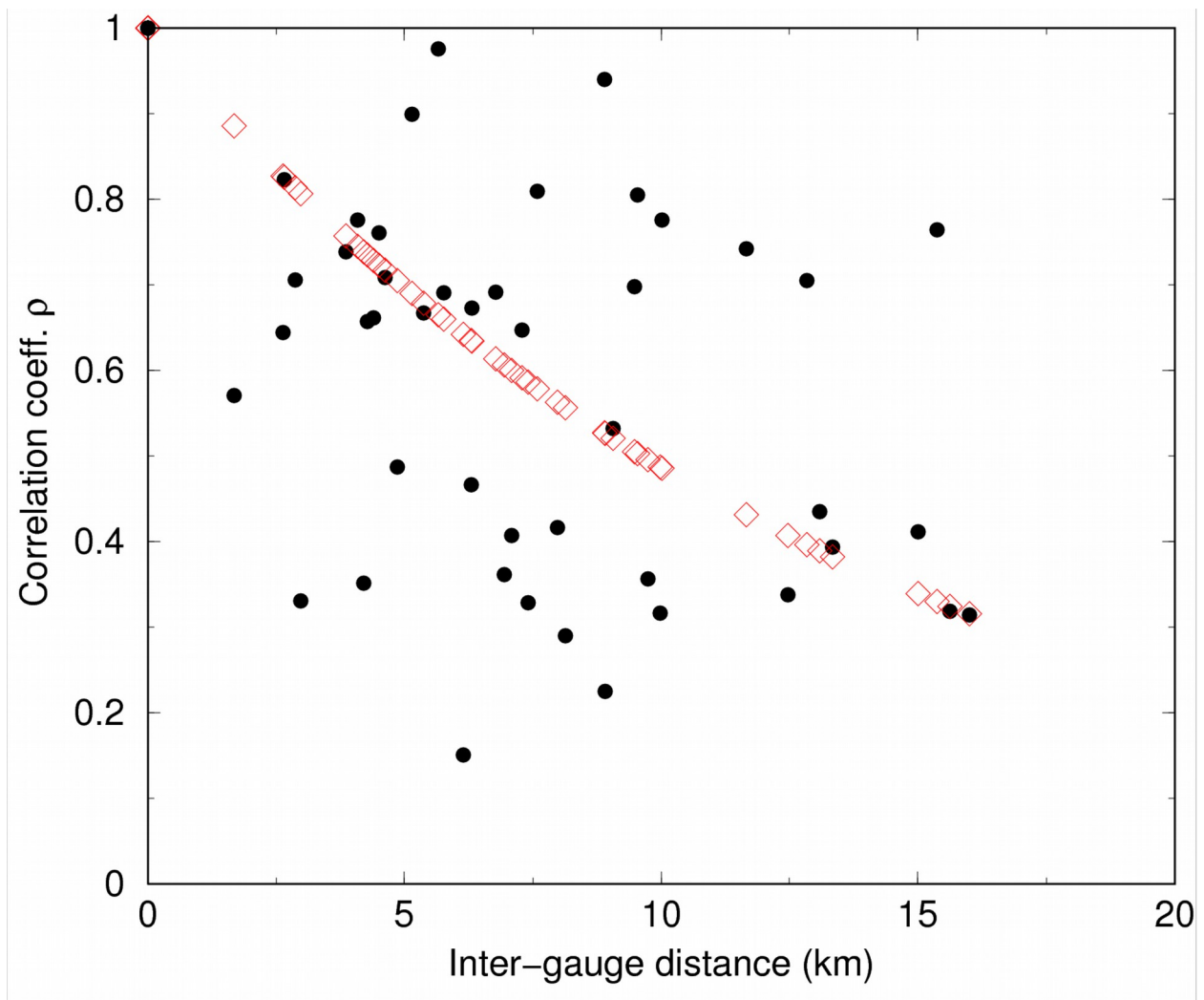


Figure 8: Correllelogram for monthly rainfall accumulations vs. inter-gauge distance.

The inter-gauge distances varied from a maximum of 16 km to a minimum of 1.6 km. The median and mean inter-gauge distances were 7.1 and 7.7 km, respectively. The elevation of these 24 gauges ranged from 10 m to 870 m above sea level.

The results shown in Figure 8 have two interesting features. There are two populations of correlations that deviate from the “typical” situation. These anomalous stations are those that are far from the modeled correlation (red squares). Given that the inter-gauge distances are quite close, the spread from the model indicates that something else is affecting the correlation.

Some station pairs at short separation distances (<15 km) have anomalously low correlations. These low correlations with space are due to factors other than rainfall variability that cause rain gauges to disagree such as malfunctioning or miscalibrated rain gauges, plugging of the rain gauge, poor gauge placement near structures or trees, or data entry errors. Including these malfunctioning gauges in the fitting of the exponential model is conservative and will lead to a shorter correlation length estimate.

There are some station pairs with large inter-gauge separation distances that have anomalously high correlations. Including these station pairs when fitting the exponential model will result in a bias that will lead to over-estimation of the correlation length because these stations are not typical. These highly-correlated but widely-separated stations were removed from subsequent analysis to avoid their effect in increasing the correlation length.

The correlation between gauge pairs separated by vertical distance was analyzed to ascertain if gauge elevation is a key determinant of correlation. These results are shown in Figure 9, which plots correlation between gauge pairs vs. the vertical separation distance (m).

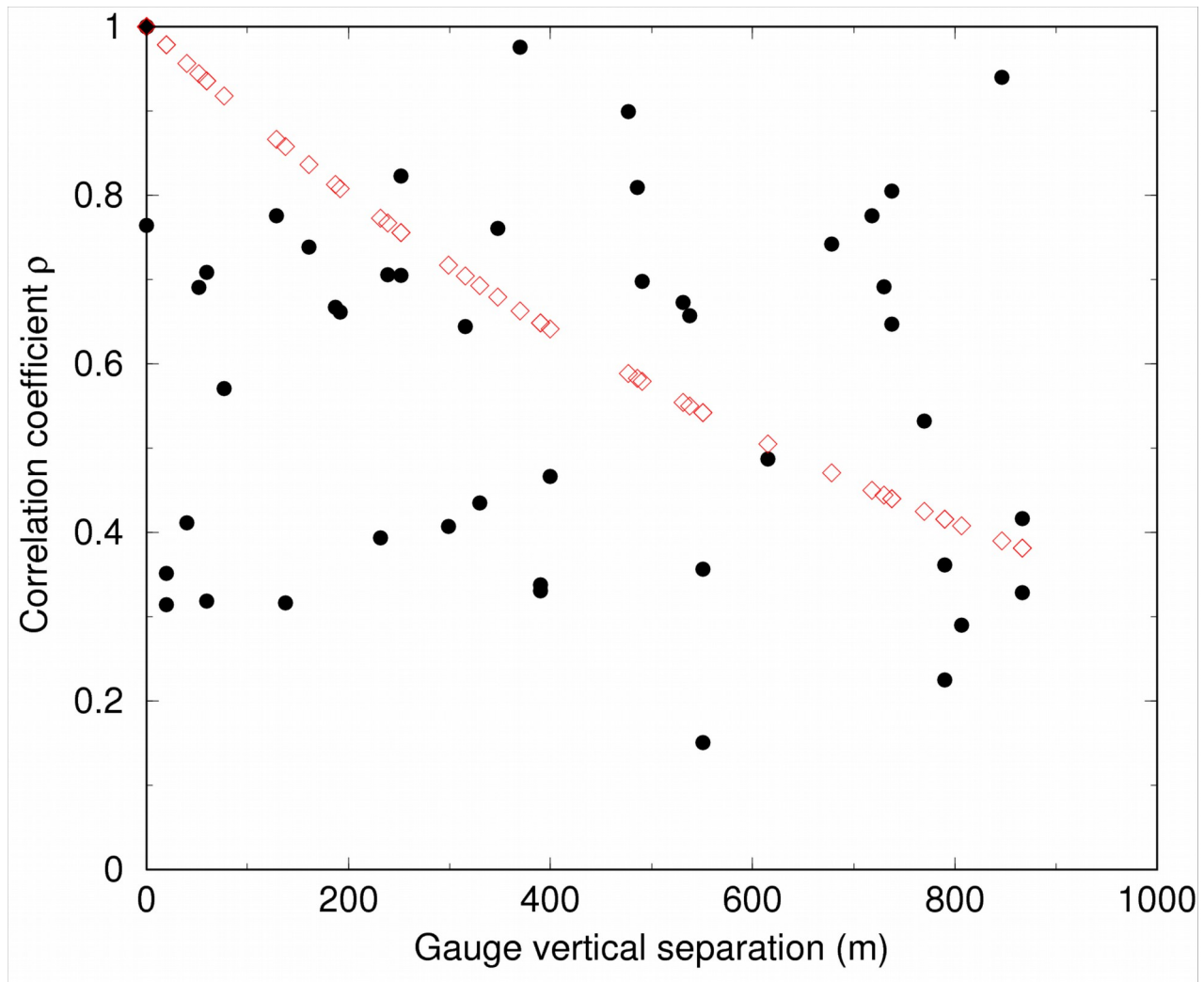


Figure 9: Plot showing correlation between monthly rainfall recorded at pairs of rain gauges as a function of their vertical separation.

The results shown in Figure 9 clearly indicate that vertical separation is not a reliable predictor of correlation between rainfall gauges. Compared with the spatial correlelogram shown in Figure 8, the agreement in Figure 9 is quite poor. Taken together the results shown in Figures 8 and 9 indicate that topography is the dominant control, and that spatial extrapolation of rainfall more than a few km horizontally or 100 m vertically is not

recommended. Conversely, this result indicates that rainfall measurements are required in each watershed where flash flood warnings are needed. The only exception would be in smaller watersheds (<5 km²) where there are rain gauges in adjacent watersheds.

3.5 Rainfall Topographic Concerns

Given that topography has such a dominant effect on rainfall spatial variability in Dominica, an analysis was performed to identify the distribution of elevation across the island. Data used were three arc-second (90 m) Shuttle Radar Topography Mission (SRTM) processed data, downloaded from the Consortium for Spatial Information (CGIAR, 2015). Those results are shown in Figure 10, which shows the hypsometric distribution of the island of Dominica. Note that about 80% of the island lies at or below 600 m elev.

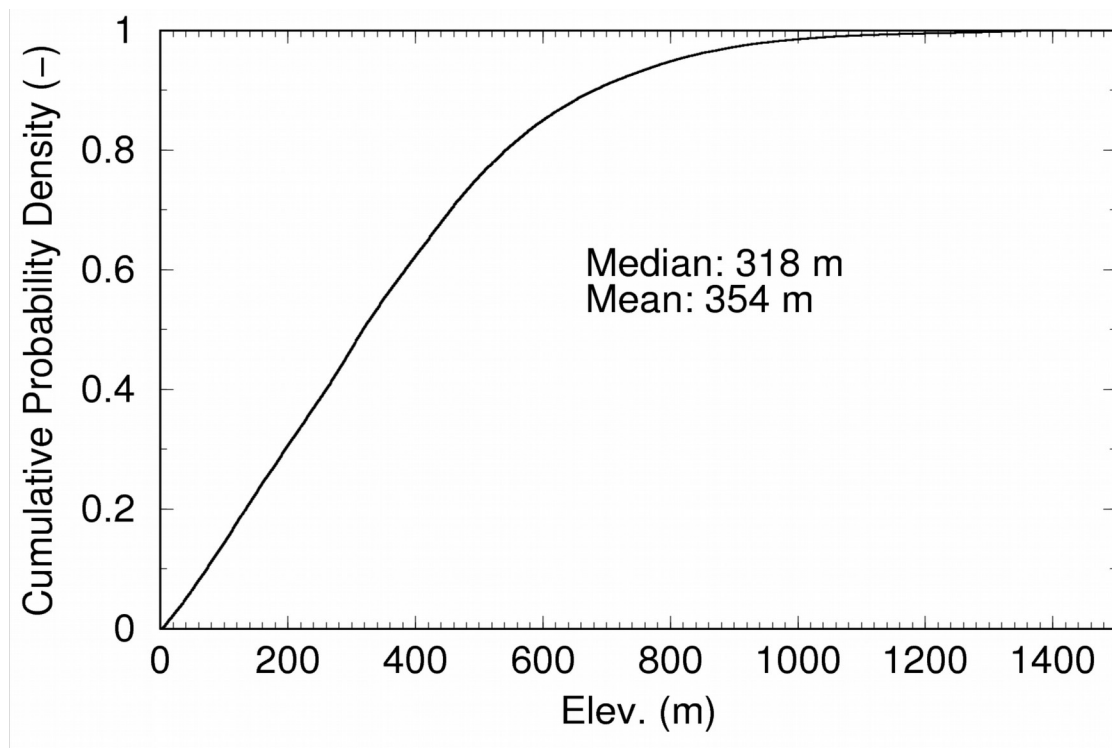


Figure 10: Hypsometric curve of the island of Dominica as calculated using 90m Shuttle Radar Topography Mission (SRTM) data.

Given the strongly linear precipitation vs. elevation relationship identified in Figure 6 the implications are that the mean precipitation occurs at the mean elevation. As shown in Figure 10, this occurs at a cumulative probability density of 0.5, or an elevation of 354 m. As such the hypsometric curve shown in Figure 10 can be used to guide placement of rain gauges at the catchment scale. In smaller catchments less than approximately 5 km², one rain gauge placed at approximately the mean elevation of the catchment would suffice.

For larger catchments, particularly those that span a significant range of elevation, two or more rain gauges might be necessary. In that case, road access and cleared area might

determine the placement of one rain gauge at an elevation that is different from the mean elevation. For example, consider that a gauge is placed at an elevation of 200 m. Notice that according to Figure 10 this corresponds to approximately the 28th quantile, which is 22 quantiles below the mean. A second gauge might be best placed at the elevation corresponding to 22 quantiles above the mean elevation, the 72nd quantile. According to Figure 10 this elevation would be approximately 460 m. Of course, separate hypsometric curves may be developed using topographic data from the catchment of interest for more accurate analysis.

3.5 Rainfall Network Analysis Observations and Conclusions

1. The existing DOMEX rainfall data set from 2008-2014 has some gaps, due to missing data. These gaps reduce the utility of these data in climate research and studies, where uninterrupted data are most valuable.
2. The DOMEX data set that I obtained from the Dominica Meteorological Service was difficult to use. Most of the data were stored as date/time tips. However, some of the data were binned into 5-minute intervals. During different deployments, the HOBO data loggers sometimes recorded different parameters such as temperature on an even interval, which made the file format change from one data period to the next for the same site. This required writing separate data processing/binning codes each different data format.
3. There is a very strong precipitation vs. elevation (P-E) relationship in Dominica. The slope of this relationship is approximately 0.42 mm per meter of elevation. In other words an increase of 1000 m in elevation results in a 420 mm increase in rainfall.
4. Because of the strong P-E relationship in Dominica, the correlation length of monthly rainfall is quite short (< 15 km). The vertical correlation length is less than 200 meters elevation, so interpolation of rainfall fields using rain gauges will require a significant number of rain gauges and a technique such as co-Kriging. Key watersheds for water supply or flash-flooding/landslid potential should be instrumented more densely with rain gauges, depending upon the response time of the watershed.
5. Data gaps must be minimized. Data infilling is one partial solution, depending upon the distance to nearby stations. However the short spatial correlation distance prevents this without a redundant network design. Data gap filling is difficult. Depending upon the integration interval (hourly, daily, monthly), gap filling is impossible without several nearby stations within the correlation length for that time interval.
6. Telemetry to identify problems with equipment in the field in near real-time will be a benefit to help minimize data gaps.
7. Installation of redundant rain gauges at each station will also help. Installing at least two rain gauges at each site helps to identify a malfunctioning rain gauge. Installing three rain gauges on each station allows determination of which rain gauge is bad. One of the

three rain gauges should be of a very high-quality, while the redundant gauge(s) can be of lower cost.

8. Annual calibration of tipping-bucket rain gauges and meteorological sensors is essential. Swapping calibrated and cleaned spares in the field for dirty rain gauges that are in need of calibration is good practice. Without calibration on an annual basis drift will increase measurement error.

9. Gaps in the instrumental record must be minimized. Procurement of high-quality instrumentation that can withstand the rigors of long-term deployment and harsh environmental conditions is important. Sometimes the most convenient equipment is not the most reliable or durable equipment.

10. Security of instrumentation is a concern. Private sector interests such as hotels/resorts, plantations, mines, and telecommunications companies can provide valuable data. Telecommunications companies often have secure facilities on hilltops. Perhaps siting regulations could be altered to allow government access for installation and maintenance of hydrometeorological equipment. Concrete instrument shelters should be constructed at long term historical monitoring sites that are not located in secure sites.

11. Hydrometeorological data management is an important gap. The current state of the hydrometeorological data base is minimal. While there exist a number of vendors that sell database software, this software is often proprietary and requires an expensive commercial database engine (e.g. Oracle). There are a host of open-source alternatives (mySQL, PostgreSQL). The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) in the United States has developed a hydrological database known as Hydrologic Information System (HIS). See <http://his.cuahsi.org> and <http://www.cuahsi.org/HydroShare.aspx> for more details on this set of tools, which is free and sustained by a significant user's community.

12. Training on database operations and web dissemination of data using open source tools will help move agencies along a sustainable path.

13. Basic data should be disseminated to the public free of charge on-line. Data products that involve analysis above and beyond quality assurance/quality control such as synthesis, statistical analysis, modeling, etc., should be reimbursable at all agencies. Cost recovery for these activities will allow sustainable staffing and help maintain technical capabilities.

14. Data backups using cloud computer services provided by reputable vendors is a cost-effective approach for insuring data permanence. Similarly, basic data should be regularly transferred to outside agencies such as WMO or the U.S. National Climatic Data Center for archival storage.

15. Training by equipment vendors on instrument setup and maintenance is required, and should be a component of any request for quotation.

16. Meteorological instruments shall be sited, to the extent possible by terrain, according to

WMO (2003) Class 1 or Class 2 standards wherever possible. The World Meteorological Organization (WMO) and U.S. Climate Reference Network (USCRN) have general guidelines that classify a site for precipitation gauge siting. This detailed information is available online in publications WMO-No. 8 CIMO Guide (2010) and U.S. Climate Reference Network Site Information Handbook (NOAA/NESDIS 2012). The following summarizes these guidelines:

Class 1 Precipitation Measurement Site:

- Flat horizontal ground with a slope less than 1/3 (an elevation change of 1 unit over a horizontal distance of 3 units) or 19 degrees with no impact from surrounding terrain features (such as mountains, etc.).
- Surrounding trees, shrubbery or other obstacles of a uniform height at a distance equal to or greater than 4 times the height of the precipitation gauge inlet.
- Uniformity for the above purpose means that there is less than a factor of 2 difference in lowest and highest obstacle and an obstacle is defined as material that subtends over at least a 10 degree arc as viewed from the gauge.

Class 2 Precipitation Measurement Site (Site induced measurement error up to 5%):

- Same as Class 1 site except the obstacle is located a distance of at least 2 times the height of the precipitation gauge inlet.

Class 3 Precipitation Measurement Site (Site induced measurement error of 10% to 20%):

- Open land surrounding gauge with a slope less than 1/2 (30 degrees).
- Obstacles are located at a distance of at least 1 times the height of the precipitation gauge inlet.

Class 4 Precipitation Measurement Site (Site induced measurement error over 20%):

- Land surrounding gauge with a slope greater than 1/2 (30 degrees).
- Obstacles are located at a distance of less than 1 times the height of the precipitation gauge inlet.

Class 5 Precipitation Measurement Site (Site induced measurement error over 50%):

- Obstacles overhanging the gauge, such as trees, roof edges, etc.

4. Recommendations for Stream Gauging/Monitoring

4.1 Agency Recommended Sites

In a meeting with the Hydrometeorology Technical Working Group (see Appendix C for list of attendees), I asked the agency representatives in attendance to provide a list of desired stream gauging locations. This list was to include the name of the river, approximate coordinates, and a justification.

4.2 DOWASCO Recommended Sites

The stream gauging sites proposed by DOWASCO and listed in Table 1, are shown in Figure.

11.

Table 1. PROPOSED RIVERS FOR STREAM GAUGING BY DOWASCO¹

RIVER NAME / COMMUNITY	POTENTIAL INSTALLATION LOCATION	JUSTIFICATION
Demetrie River, Peinville	N15:37'16" W61:25'47"	Water supply
Blenheim River	N15:35'30" W61:23'25"	Bulk Water Export Potential
Hodges River, Calibishie	N15:32'24" W61:21'35"	Water supply, Irrigation
Melville Hall River	N15:31'37" W61:20'11"	Bulk Water Export Potential
Pagua River, Concord	N15:28'10" W61:18'05"	Flood Risk
Fond Figes River, Fond Melle	N15:24'30" W61:17'46"	Irrigation
Ouayaneri River, La Plaine	N15:20'07" W61:16'18"	Water Supply
White River, Delices	N15:17'28" W61:16'21"	Only river originating from Boiling Lake
Pichelin River	N15:15'40" W61:18'42"	Water Supply
River Claire, Giraudel	N15:18'01" W61:20'02"	Water Supply Expansion potential (Water Area 1)
Roseau River	N15:18'33" W61:21'44"	Flood Risk
Layou River	N15:24'51" W61:23'38"	Flood Risk, Dominica's longest river
Coulibistrie River	N15:28'22" W61:25'39"	Water Supply to majority of West Coast
Indian River, Portsmouth	N15:34'15" W61:27'17"	Only river navigable by boat, tourism and ecological interests (mangroves, etc.)

¹Note: one of the reasons for choosing these rivers is to cover a wide geographical spread of the island and cover different types of watersheds.

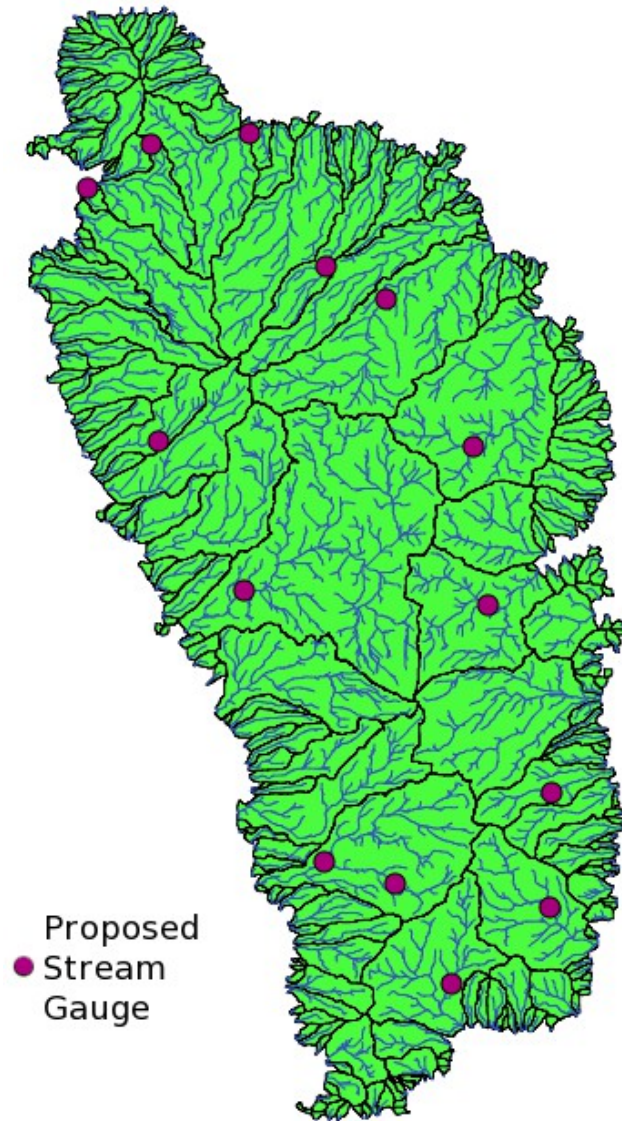


Figure 11: Stream gauging sites suggested by DOWASCO, corresponding to those in Table 1.

4.3 Environmental Health Department Recommended Sites

The Environmental Health Department identified the following rivers for stream flow monitoring which will assist in flood prediction and increase recreational safety and enjoyment.

- The Roseau River: transverse the city of Roseau and has a history of overflowing its banks and impacting households and businesses since parts of the city lie directly on the river banks.

- The Layou River: this river has a history of flash flooding which has resulted in the evacuation of almost the entire Layou community. This river accommodates a great amount of aquatic recreation and supports agricultural activities in the upper Layou Valley.
- The Indian River: The deepest river on the island flows through the town of Portsmouth. This river is supplied by a number of tributaries that meander throughout the neighbouring communities. The Indian River is also impacted by the town's waste and storm water. The river supports a number of ecosystems and provides sufficient biomass for migratory birds. Because of its ecological structure the river also provides habitat for reproduction of a large number of animal species and birds. The economic value of the Indian River supporting artisan fishermen and tourism cannot be understated. Because of the location of this river as well as its size it is of particular concern in times of heavy continuous rainfall.
- The Belfast River: (no comments provided)
- The Checkhall River: This river flows through the urban communities of Mahaut and Massacre and during heavy rains can be further filled by runoff from storm drains on the slopes in the communities. The river has a history of flash flooding and was the cause of significant economic loss in recent times.
- The Castle Bruce River: this is an extensive body of water that meanders from the base of Mount Trois Piton. Many agricultural holdings can be observed on its banks as farmers of that community depend on this water for farming. Fishing is also noticeable. Presently Waters from the Castle Bruce River is being used for agricultural irrigation project supplying water to farms miles from its banks. The eco-environmental benefits from this river can be observed in the estuary as it supports both aquatic and terrestrial ecosystems. If this River is to overflow its banks the losses which will be incurred would be considerable both in agricultural losses as well as damage to infrastructure.
- The Castle Comfort River: This body of water flows from the heights of the Roseau Valley it flows through a number a number of communities most of which are agricultural. This River can be classified as medium to large by Dominica's standards and sustains fishing and recreational activities by residents of the area. This River has a history of flooding and has the potential for serious economic losses if there is a major overflow of that river.
- The Loubiere River: This is a small free flowing river flowing through the urban community of Loubiere it is inhabited on both banks. It is impacted by the waste water and storm water of most of the community. The river is also impacted by the Dominica Brewery and Beverage factory which is on the banks of the river.

- The Canefield River: (no comments provided)

The Environmental Health Department also recommends measurements for rivers that serve as the source for drinking water. These were listed by DOWASCO in Table 1, with the exception of the Springfield River, which is the primary source of potable water for the capitol.

4.4 Dominican Meteorological Service Recommended Sites

The Dominican Meteorological Service could not provide coordinates, and some of the rivers that they recommended are quite small. The primary reasons for recommending monitoring of these streams is flash-flooding and landslides. Appropriate siting for stream gauging locations will depend upon personal inspection of each site as described in Section 4.4.

Table 2. PROPOSED RIVERS FOR STREAM GAUGING BY MET. SERVICES

RIVER NAME / COMMUNITY	POTENTIAL INSTALLATION LOCATION	JUSTIFICATION
Mahaut	Above Mahaut town	Flooding and landslides
Checkhall	Above Canefield town	Flooding and landslides
Picard	Above Picard town	Flooding and landslides
Colihaut	Above Colihaut town	Flooding and landslides
Massacre	Not provided (small stream)	Flooding and landslides
St. Joseph	Not provided (small stream)	Flooding and landslides
Campbell	Not provided	Flooding and landslides
Bellevue	Not provided	Flooding and landslides

The first four stations listed in Table 2 are shown in Figure 12. The last four stations listed in Table 2 are very small streams.

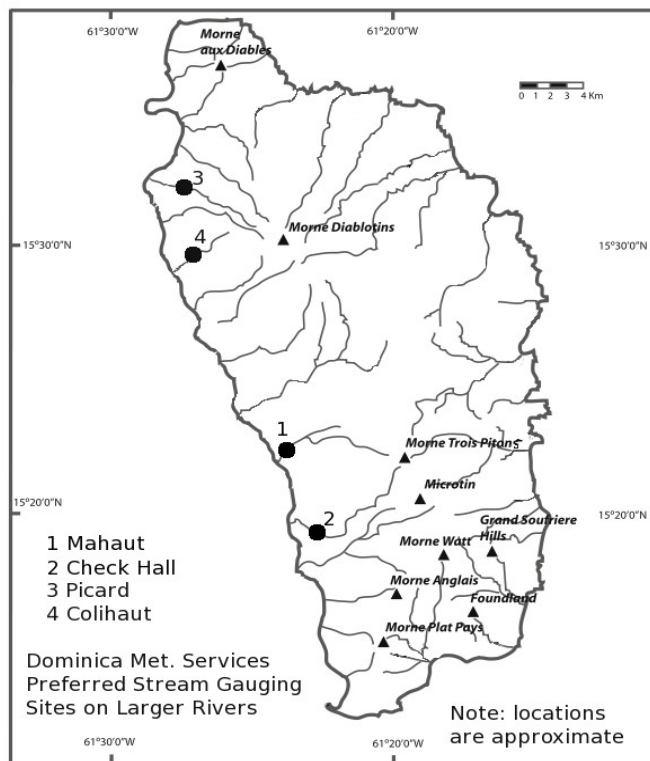
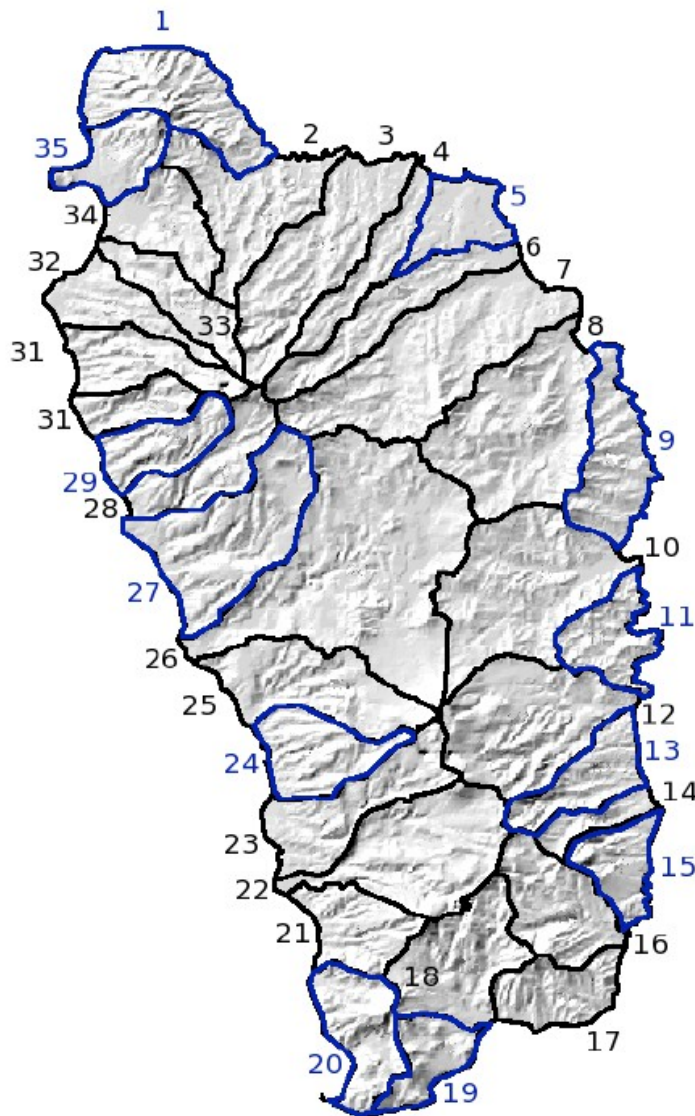


Figure 12: Suggested stream gauging sites by Dominican Meteorological Service for Flash-flood and Landslide protection. Not all sites listed in Table 2 are shown here.

4.5 Appropriateness of Stream Gauging Sites

Cox (2005) through funding by the Australian government, produced a report wherein a watershed management strategy was proposed. Cox (2005) identified the watershed management units shown in Figure 13. The watershed boundaries shown in black in Figure 13 are watersheds containing rivers that reach the sea at a single point. The watershed unit “complexes” shown with blue boundaries contain a number of small streams, each with its own point of discharge to the sea. The primary distinguishing feature of black watersheds is that they represent convergent topography and a major river or stream, while the blue watershed “complexes” represent divergent topography with numerous small streams.



WATERSHED MANAGEMENT UNIT

- 1 Morne Aux Daibles complex
- 2 Blenheim*
- 3 Hampstead*
- 4 Salee
- 5 Woodford Hill complex
- 6 Eden
- 7 Clyde*
- 8 Pagua*
- 9 Morne la Source complex
- 10 Belle Fille
- 11 Good Hope complex
- 12 Rosalie
- 13 Ouayaneri-Morne Jaune complex
- 14 Sari-Sari
- 15 Boetica complex
- 16 Pt. Mulâtre
- 17 Petite Savanne complex
- 18 Stewart
- 19 Grand Bay complex
- 20 Soufriere-Scotts Head complex
- 21 Sibouli*
- 22 Roseau
- 23 Boeri*
- 24 Massacre-Mahaut complex
- 25 Belfast*
- 26 Layou
- 27 Macoucheri complex
- 28 Batali
- 29 Coulibistri complex
- 30 Colihaut*
- 31 Dublanc*
- 32 Jargie*
- 33 Picard
- 34 Indian
- 35 Cabrits/Douglas Bay complex

NOTES:

Watershed management unit complexes are an amalgamation of more than one watershed basin. Watershed areas of less than 500 ha were amalgamated to form complexes

* Watershed management units dominated by a main drainage basin but amalgamated with a small adjacent basin

Figure 13: Watershed Management Units (after Cox, 2005)

Figure 13 was used as a basis for preliminary design of an island-wide flood warning network. The design is preliminary because the sites selected for rainfall stations and streamflow stations were selected based solely on geometrical considerations. Site access or physical appropriateness were not considered. This preliminary network design is shown in Figure 14, and consists of 42 stream gauge and 38 rain gauge locations.

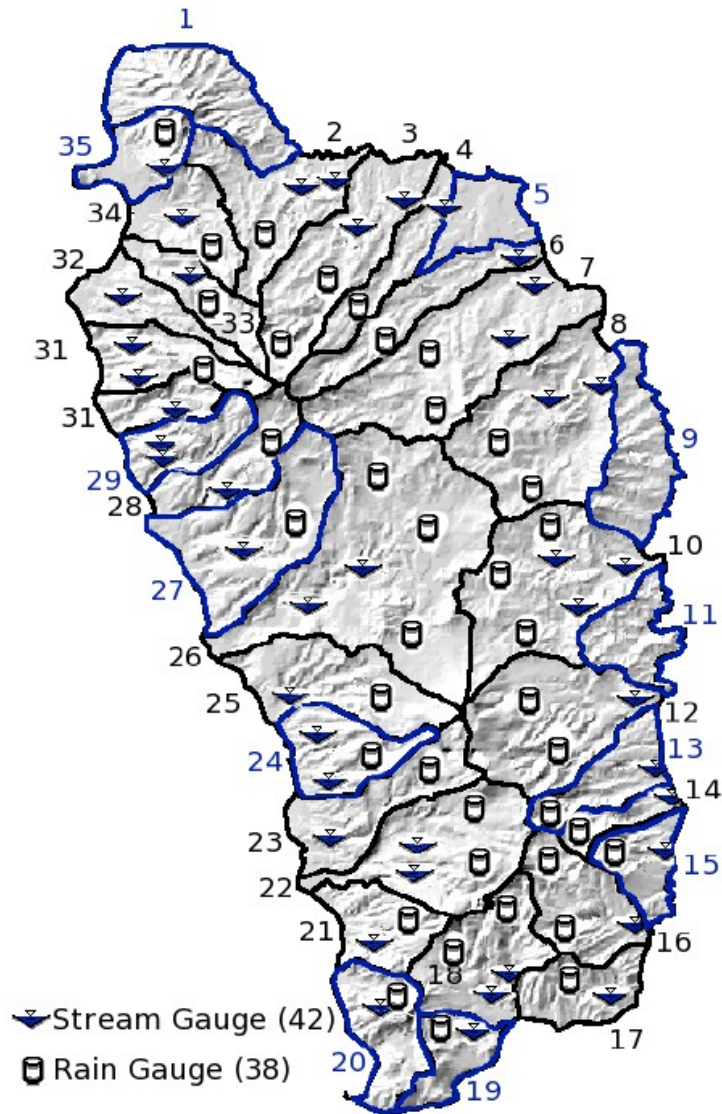


Figure 14: Large, island-wide flash flood warning network, shown as built-out example (preliminary).

Figure 14 provides an example of a thorough network that covers most of the Commonwealth, as if each drainage basin of appreciable size is worthy of installation of a flash-flood warning system. According to the prioritised lists provided in Tables 1 and 2, this is not the case. However, this preliminary design provides a realistic point of consideration, and supports the notion that the recommended number of stations is realistic.

Selection of desirable stream gauging stations depends on a number of factors. Included in these are (1) cost risk of adverse consequences due to low/high flow in terms of loss of life, damage to property, adverse environmental impacts on habitat or water quality; (2) ability to establish a stage-discharge relationship with certainty; (3) ability to transmit data from the site; (4) flood wave travel time from the gauging site to the location where a flash-flood warning is desired, and (5) site access for routine maintenance and flow measurements. These five considerations are essentially equally important.

The potential stream monitoring sites listed in Sections 4.2-4.4 provide a starting point for creation of a prioritized list of sites. The relative importance of each site must be established by thorough consideration of the benefits of gauging at a particular location compared to the risks of a catastrophic event occurring with little or no warning. Ranking these sites is beyond the scope of this study.

Selection of sites from a hydraulic standpoint will require that project technical staff receive training in site selection from a competent authority or hiring of a consultant with considerable experience in stream gauging. Each prospective stream gauging site will require individual assessment using the above five criteria.

4.6 Water Quality Measurements in Association with Stream Gauging

The run-of-the-river nature of public drinking water intakes operated by DOWASCO make the public water supplies in Dominica sensitive to hydrological events. The primary contaminant of concern is turbidity. Public drinking water intakes along rivers are frequently closed during runoff events to minimize the amount of turbid water that enters the potable water supply system.

The equipment budget includes turbidity and electrical conductivity probes. The turbidity probes are intended for connection to stream level stage recorders. These probes shall have integral wipers to automatically clean their optics, and other anti-fouling measures to help ensure long-term operation in the field with maintenance visits once per month. These turbidity probes would be best installed at public water supply intakes together with telemetered stage measurements. Telemetry will allow these turbidity measurements to serve as a real-time warning of increasing water turbidity that can instruct field workers to close intake valves in a timely fashion.

The conductivity probes are a less expensive way to measure water quality. In many instances there is a relationship between total dissolved solids (TDS) and turbidity. Co-installation of these sensors will allow identification of such relationships in Dominican rivers. Widespread installation of conductivity probes will allow creation of a baseline TDS data set for the country.

5. Data Archiving, Sharing and Dissemination using Information Technology

Data sharing is important and in the best interest of the people of Dominica. Data sharing avoids redundancy, enhances information flow, and promotes network reliability and consistency because an increase in the number of regular users results in increased inspection and data quality control. Redundancy is not always bad. However, different agencies collecting identical data at the same point is wasteful and inefficient. If a site is high priority for more than one agency, they should work together to ensure data quality, rather than set up redundant measurements at the same location in the absence of cooperation.

Different agencies have different objectives during routine operations. The quasi-private Dominica Water and Sewer Company Ltd. (DOWASCO), for instance, is focused on water supply, and is run using a business model, and they have the budgetary ability to plan for equipment operation independently from other agencies. However, DOWASCO does not at present have the hydrologic and hydraulic expertise to operate hydrological networks and prediction networks that fill the needs of the general public. The budget includes funds for stream gauging equipment, and hand-held water quality monitoring instrumentation for DOWASCO.

IT Cost Mitigation Strategy

Agencies should train their staff in the use of open source software tools. Linux is a powerful operating system with a nearly infinite supply of free open-source software. Databases, web servers, data processing tools, compilers, integrated software development environments, and a host of other tools come with a basic Linux installation. Properly educated IT staff can create tools with vast functionality in the Linux environment using these standard tools. There are many advantages. First, the software is free. Linux has been around since 1992, and most of the original software written in 1992 still works today in 2015. This consultant ran the analysis and produced this report on a Linux machine using the free LibreOffice software. There is an excellent free GIS program for Linux called “qgis” that has almost all the functionality of ESRI Arc/Info, and additional capabilities in some respects. Free open source software saves money at the expense of requiring trained personnel. Costs are saved in terms of licensing and required update fees. Training opportunities around Linux are predominantly at universities, and staff appropriately trained may be difficult to retain because those skills are in high demand. This can be offset somewhat through retention incentives, and is not unique to individuals that are trained in Linux, as Microsoft-certified individuals are also in high demand in the private sector. Universities provide the best educational opportunities in open-source software capabilities, use, and development. Arrangements should be sought for Linux short courses offered by University personnel.

6. Hydrometeorological Equipment Purchase Specifications

The following section provides a list of equipment specifications for consideration in the development of the Terms of Reference and Request for Bids for the equipment. These

specifications are written in a general form so as to not exclude particular equipment vendors from bidding on the project.

6.1 Automated Climate Stations with Telemetry Options

These stations shall consist of:

- 1 ea., 2-D ultrasonic anemometer
- 1 ea., shortwave radiation pyranometer
- 1 ea., leaf wetness indicator
- 2 ea., soil moisture sensors
- 1 ea., barometric pressure sensor
- 1 ea., temperature and relative humidity sensor with shield and mast-mount.
- 3 ea., tipping bucket rain gauges. One of these gauges shall be constructed of metal with machined metal parts and at least 20 cm (8") orifice diameter. The other rain gauges could be made of ABS plastic of the type produced by Davis Instruments (Rain Collector II). Rain gauges shall be installed at least 3 m from the instrument enclosure, tower, or data mast. The rain gauges shall be installed as near to the ground as possible on a leveling base. Vegetation shall not be allowed to grow above the rain gauges or above a 30-degree cone extending upward from the gauges.
- 1 ea., data logger with sufficient memory to store at least two months of 30-minute data for all sensors, with connections to telemetry peripherals. The data logger shall be ruggedized with no circuitry exposed to the environment within the weatherproof enclosure. The only exposed components shall be data and power connectors. The maximum allowable time drift shall be 1 minute per month.
- 1 ea., weatherproof enclosure with replaceable gaskets. Gaskets shall be fungus, mold, mildew, and insect resistant, and otherwise suitable for long-term deployment in tropical climates. Enclosure shall include a pass-through grounding lug.
- 1 ea., (optional) telemetry transmitter with antenna. Transmitters shall be GPRS, GSM -or-digital spread spectrum Ethernet-addressable radio depending on site conditions and signal availability
- 1 ea., solar panel, voltage regulator, and sealed lead-acid battery capacity sufficient to run the station for at least nine days without direct sunshine.
- 1 ea. Tripod and associated mounting hardware. All bolts and U-bolts, washers, and nuts shall be stainless steel. Tripod shall be constructed of galvanized steel, and shall include a grounding rod, lightning rod, and grounding cable.
- 1 ea. Fenced enclosure. The enclosure shall be constructed entirely of galvanized pipe and wire. The fence shall be at least 2.4 m tall, 6 m x 6 m in horizontal dimensions and topped with circular-wrap razor wire. The gate shall include non-removable hinges and a lock protector.
- 1 ea. (Optional) Instrument shelter constructed of cinder-block with concrete roof with recess for solar panel installation as described in Section 6.4.

6.2 Automated Rain Gauge Stations with Telemetry Options

These stations shall consist of:

- 1 ea., weatherproof enclosure with replaceable gaskets. Gaskets shall be fungus, mold, mildew, and insect resistant, and otherwise suitable for long-term deployment in tropical climates. Enclosure shall include a pass-through grounding lug.
- 1 ea., data logger with sufficient channels to record data from three tipping bucket rain gauges. The data logger shall be ruggedized with no circuitry exposed to the environment within the weatherproof enclosure. The only exposed components shall be data and power connectors. The maximum allowable time drift shall be 1 minute per month.
- 3 ea., tipping-bucket rain gauges with leveling mounts suitable for connection to threaded galvanized steel pipe. Rain gauges shall be installed at least 3 m from the instrument enclosure, tower, or data mast.
- 1 ea., (optional) GPRS or GSM radio modem with antenna -or- (optional) digital spread spectrum Ethernet-addressable radio with antenna
- 1 ea., solar panel, voltage regulator, and sealed lead-acid battery capacity sufficient to run the station for nine days without direct sunshine.
- 1 ea., Tripod and associated mounting hardware. All bolts and U-bolts, washers, and nuts shall be stainless steel. Tripod shall be constructed of galvanized steel, and shall include a grounding rod, lightning rod, and grounding cables.
- 1 ea., 6 m tower. Tower shall be constructed entirely of galvanized steel with welded cross-members in each section. Individual sections may be bolted. Bolts and clamps shall be made from stainless steel. Guy-wires shall be galvanized. Tower shall be painted alternatively red and white with epoxy paint. The tower shall be grounded by connection to a copper-clad metal rod driven into the soil at least 1.5 m.
- 1 ea. Fenced enclosure. The enclosure shall be constructed entirely of galvanized pipe and wire. The fence shall be at least 2.4 m tall, 6 m x 6 m in horizontal dimensions and topped with circular-wrap razor wire. The gate shall include non-removable hinges and a lock protector.
- 1 ea. (Optional) Instrument shelter constructed of cinder-block with concrete roof with recess for solar panel installation as described in Section 6.4.

6.3 Line-of-Sight Repeater Stations

There are probably locations in headwaters areas in the interior of Dominica where mobile GSM phone service is not an option for telemetry. In these locations a VHF/UHF radio repeater is required to pass data from sites with using line-of-sight (LOS) to a central data collection platform, the following shall be required:

- 1 ea., weatherproof enclosure with replaceable gaskets. Gaskets shall be fungus, mold, mildew, and insect resistant, and otherwise suitable for long-term deployment in tropical climates. Enclosure shall include a pass-through grounding lug.
- 1 ea., data logger with the ability to communicate with at least eight remote sites using Ethernet-addressable VHF or UHF radio connections.
- 1 ea., (Optional) Digital spread spectrum Ethernet-addressable radio with antenna.

- 1 ea., Solar power option including solar panels and sufficient sealed lead-acid battery storage capacity to run the system for nine days without direct sunshine
- 1 ea., Tripod and associated mounting hardware. All bolts and U-bolts, washers, and nuts shall be stainless steel. Tripod shall be constructed of galvanized steel, and shall include a grounding rod, lightning rod, and grounding cables.
- 1 ea. Fenced enclosure. The enclosure shall be constructed entirely of galvanized pipe and wire. The fence shall be at least 2.4 m tall, 6 m x 6 m in horizontal dimensions and topped with circular-wrap razor wire and topped with circular-wrap razor wire. The gate shall include non-removable hinges and a lock protector.
- 3 ea. (Optional) tipping-bucket rain gauges connected to data logger. Rain gauges shall be installed at least 3 m from the instrument enclosure, tower, or data mast.
- 1 ea. (Optional) Instrument shelter constructed of cinder-block with concrete roof with recess for solar panel installation as described in the section 6.4.

6.4 Instrument Shelters

Long term monitoring requires instrument security. The Panama Canal Authority struggled for decades with vandalism and difficult environmental conditions. To solve these problems, they devised an instrument shelter that is literally bullet proof. Agreements with cooperating land-owners through a lease/security arrangement would be beneficial to help prevent theft and vandalism. An example instrument shelter is shown in Figure 15.



Figure 15: Instrument shelter constructed in 2010 by Autoridad del Canal de Panama (ACP) with embedded solar panel and rain gauge funnel on the precast concrete roof. Photographed from heliconter.

General Specifications for an instrument shelter include:

1 ea., reinforced cinder-block structure, approximately 1.5m x 1.5m in inside dimensions, with a steel door with an integral padlock protector. The lowest eave of shelter should be at least 2.8 m above ground level to increase the difficulty of roof access. The instrument shelter should have a shallow sloping roof made of pre-cast concrete. The pre-cast concrete roof shall contain a formed depression for installing a recessed solar panel to hide the panel from observers. The roof of the shelter should also contain an approximately 4 cm diameter hole to allow an antenna mast to pass through the roof. Mounting the antenna internally to the structure will eliminate a climbing pathway for vandals to access the roof. The instrument shelter should have a substantial concrete foundation to promote stability and prevent local soil erosion from undermining the walls of the structure. Figure 16 shows a conceptual sketch of a completed instrument shelter installed at a stream gauging location.

Stream gauging instrument shelters shall be fenced using heavy gauged galvanized mesh wire mounted on galvanized steel poles. The fence shall be at least 2 m height and topped with coiled razor wire. Gates shall have non-removable hinges, and lock-protectors. Fencing shall be installed a minimum of 3 m from the walls of the instrument shelter. On steep slopes, fencing shall be installed to prevent vandals from bridging from the high slope to the roof of the instrument shelter.

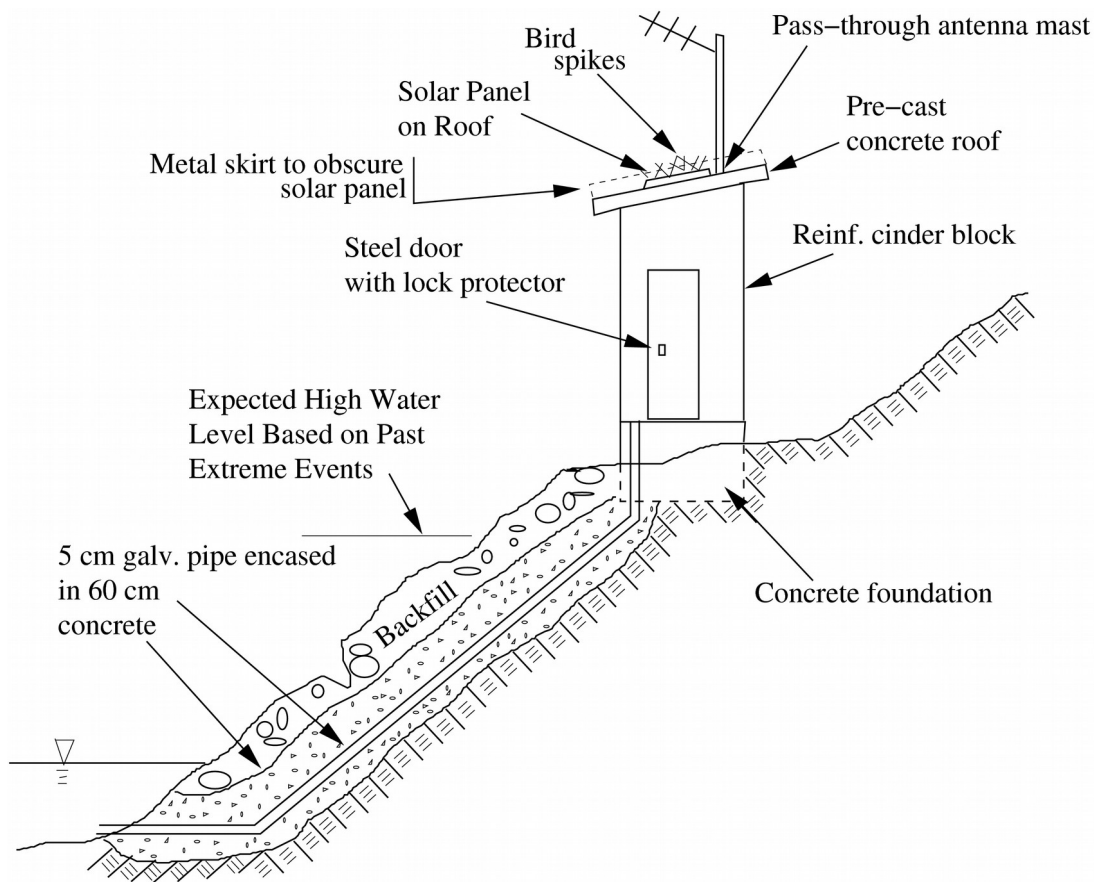


Figure 16: Conceptual sketch of a vandal-resistant instrument shelter.

6.5 Telemetered Stream Gauging Stations

Long term stream flow monitoring is difficult in the Caribbean because of occasional very high flows. The example stream stage monitoring station shown in Fig. 16 contains the following features:

1 ea. Data logger with GSM modem or VHF/UHF radio communications capability. Data logger shall have ability to interface with one each of pressure-transducer or stage bubbler, one barometric pressure sensor, and up to three rain gauges. In high-priority (historical) sites, three rain gauges shall be installed on the roof of the instrument shelter. In ordinary sites, two rain gauges shall be installed on the roof of the instrument shelter. If a fenced enclosure is constructed, these rain gauges can be installed near ground level at a distance at least three times the height from the nearest and tallest obstruction. Communications software may be able to use SMS capability to minimize bandwidth and data transmission costs. However, this option prevents remote trouble-shooting of instrumentation problems.

1 ea. Solar panel, voltage regulator, and sealed lead-acid batteries to provide power for a minimum of nine days without direct sunshine.

1 ea. Optional pressure transducer. The pressure transducer shall be non-vented to avoid requiring desiccant. The maximum range of the pressure transducer shall have a maximum absolute pressure greater than that resulting from the expected maximum high water level in addition to high atmospheric pressure.

1 ea. Optional stage bubbler. Stage bubblers can be operated using dry compressed gas, at the expense of regularly changing gas cylinders. Other models that use air compressors require regularly changing of desiccant canisters. As desiccant canisters are cheaper and much easier to transport and install than gas cylinders, the use of compressor-based bubblers requiring frequent desiccant changes is economically preferable. This economic preference comes with the requirement of regular site visits to change the desiccant (e.g. monthly).

1 ea. Optional turbidity sensor. Turbidity sensors shall include anti-fouling measures such as optical window wipers, integral biocides, etc. Turbidity sensors shall be installed so as to be exposed to the flow, but protected from floating debris or burial by sediment. Turbidity data shall be included in the telemetry data stream to allow warning of turbidity increases.

1 ea. Optional electrical conductivity sensor. Conductivity sensors shall be installed so as to be exposed to the flow, but protected from floating debris or burial by sediment.

Regarding the selection of pressure transducer or bubbler, the optimal choice would be a bubbler from an operations standpoint. Bubblers require little maintenance, have no moving parts in contact with water, and are entirely contained within the instrument shelter. Bubblers have the drawback of requiring more power, regular changes in desiccant, and are more expensive. Innovative bubbler designs incorporate a small air compressor and do not require gas cylinders. Desiccant is required because of the high humidity in the tropics.

Pressure transducers are 1/2 to 1/5 the cost of a bubbler system. They have very low power requirements, so they are better suited for remote sites with poor solar charging characteristics due to vegetation or prevalent cloudiness. Pressure transducers tend to drift over time, and therefore require frequent calibration. Manual measurements of stage using a staff gauge and inclusion of these measurements in the site metadata allow detection and removal of sensor drift by editing. The selection of which technology to use (bubbler or pressure transducer) at a particular site will depend upon the characteristics of the site and priority of the site.

7. Equipment Vendor Requirements

Supervision

The selected equipment vendor shall supervise the installation of their equipment. This supervision shall include representatives being in the field and inspecting the installation after initial training. Inspection shall include all sensors, data loggers, and telemetry equipment. Deficiencies in the facilities shall be noted and reported to agency personnel in charge of the installation so that they may correct these deficiencies.

Certificate of Completion

Upon satisfactory installation of the equipment, the vendor shall issue a certificate of completion. This certificate shall note the sensors, data loggers, and radio telemetry equipment installed in a report not to exceed one page per site. Upon receipt of this report, the receiving agency shall certify receipt based on data being received from the installation.

Guaranteed Period of Performance

The vendor shall guarantee performance of their sensors and equipment for a minimum period of two years. If the equipment warranty is longer than two years, then the longer period shall apply. In the event a problem is identified, the vendor shall be promptly contacted. The vendor shall promptly request a description of the problem. The vendor may then suggest possible solutions. If these proposed solutions do not solve the problem, the vendor shall send a representative to work with Dominican personnel to find a solution. This requirement does not apply in cases of vandalism or natural disasters.

8. Rehabilitation and Reuse of Existing Equipment

Climatological Stations

Dominican Meteorological Services has a number of meteorological stations inherited from past studies. As a result, there are instruments made by a variety of manufacturers in the network, with equipment manufactured by Davis Instruments, Campbell Scientific, NESAs,

and SUTRON. It is likely that there are enough useful components left over from these stations that could be used to repair other sites for some time, which is a desirable outcome. The data loggers should be sent to the manufacturer for calibration as required. It is likely that all or most of the wind speed/direction sensors will be inoperable and need new bearings or replacing. Calibration of shortwave pyranometers is quite straightforward and can be done by DMS staff by comparing the output of older sensors with new, factory-calibrated units under direct sunlight. Temperature probes are quite robust. However, when combined with a relative humidity sensor in the same sensor head, they will require replacement. The constantly high relative humidity associated with tropical locations shortens the life of relative humidity sensors. In my experience these require replacement every two to three years in tropical settings. Appendix B contains a list of relic, legacy, and abandoned equipment reported by the various agencies.

9. Identification of Long Term (Historical) Monitoring Sites

Climatic studies require consistent, long-term hydrometeorological and hydrological data. Many nations have identified long term monitoring networks that are given extra attention. Given the history of instrumentation placement, characteristics of different sites, and existing data record, steps should be taken to protect and maintain instruments at key monitoring sites.

Water resources planning and management in the complex hydrogeological setting of Dominica is difficult. As the population of the country grows, water resources will come under increasing demands. In the context of potential changes in climate and certain changes in land-use, the management problem is paramount. Decisions regarding land-use and climate-change impacts and their mitigation must be based on high quality observations.

Agencies should identify those sites and parameters in their network with the longest period and denote them as historical. I do not have access to the quantity of data to do so. However, these sites should include meteorology, rainfall, stream flow, ground water levels, surface and ground water quality.

One way to focus this activity is to identify important watersheds or aquifers where significant long-term data are desired, and focus on those areas. These “special study areas” should be in some way typical of the challenges faced due to climate, land-use, or population changes. Other special study areas might be those that are relatively untouched by human activities for collection of baseline pre-development data.

Measurement sites designated as historical should have concrete instrument shelters constructed. These will help to ensure continued occupation of the site, reduce the threat of vandalism, protect data loggers, and promote collection of continuous long-term data.

In the case of special study basins, the following instrumentation is proposed.

1. Stream gauging at a range of scales to understand the effect of landscape position on

runoff generation. For instance “do hillslopes produce more runoff than lowland areas?” is one question that this instrumentation can help answer. Scales of interest would vary from about 10 ha to 10 km².

2. Ground water wells that observe ground water over a range of scales. These wells, which should be far from water production wells, would be instrumented to allow observations of the response of the ground water table to input precipitation. Data from this network will be useful for answering questions such as “where does most ground water recharge exist?”.

3. Piezometers near rivers to measure underflow- the amount of water moving down-valley below the river bed. These would consist of two transects of wells perpendicular to the river, spaced about 200 m apart. Pumping, slug, or tracer tests could be used to infer the down-gradient hydraulic conductivity.

4. Increased density of rain gauges. In special study watersheds, the inter-gauge spacing should be smaller, for instance 2 km for daily rainfall, and less than 1 km for hourly rainfall.

10. Training, Staffing, and Retention

From the 2nd National Communication of the Commonwealth of Dominica under the UNFCCC, Section 5.3.6.4 Institutional Capacity:

“Dominica lacks a significant institutional capacity to carry out its responsibilities and obligations. At present, each of the stakeholders is “doing their own thing”. There is no central clearinghouse for the data and no central purchasing office for equipment. Several government departments are monitoring for rainfall-wind speed and direction in basically the same area, whilst a large section of Dominica has no records or history of rainfall data. If there was better sharing of information and coordination there would not be any duplication of effort and the existing human resources could possibly cover the entire country. Both time and money would be saved and the coverage could be extended to weekends and holidays.

Currently all the stakeholders in Dominica are facing the same problems, viz:

Lack of funds;

Lack of trained personnel; and

Broken equipment/no equipment.

The most pressing need in Dominica is for all the stakeholders to sit down and discuss their equipment and manpower needs, and decide on an institutional protocol for collection, storage, dissemination and submission of climate-related data to the appropriate users.

Consideration has to be given to the role of the Environmental Coordinating Unit in this process, as the principal institutional responsibilities for climate change related issues in Dominica rests with that Unit. It serves as the main national implementing agency for most of the major international environmental conventions working with partner ministries and organizations to promote the awareness and adoption of the various provisions and approaches embodied in international environmental agreements,

including the UNFCCC. However the ECU does NOT have the legal authority (legislative mandate) giving it jurisdiction for developing, maintaining and disseminating climate change data in the Commonwealth of Dominica.

Consideration also has to be given to the role and function of the meteorological services. There is an ongoing demand for meteorological information for a variety of uses – aviation, disaster management, agriculture, water supply, hydroelectric power, and climate change monitoring – that cannot be supplied by the current aviation-focused service.

There is also a need to develop and/or strengthen the working relationship with the private sector - especially DOMLEC and DOWASCO - in the gathering and sharing of climate change related information.”

Capacity building for participation in Systematic Observation networks;”

In the context of these recommendations, developing strong interactions with the private sector are essential. While DOWASCO is a wholly government-owned private entity at this point in time, there are not guarantees that it will remain so.

The network proposed in this report will require a significant staff of trained personnel to operate. Figure 17 shows an estimated staffing requirement that does not include consideration for position gaps due to vacations, sick- or annual-leave, maternity, etc. Where these positions are located within the various involved agencies is at the discretion of the involved ministries. Based on discussions held with the hydrometeorology working group, the recommendation is that if these new positions are to be created within existing agencies, then these positions will be split between Domica Meteorological Services and DOWASCO.

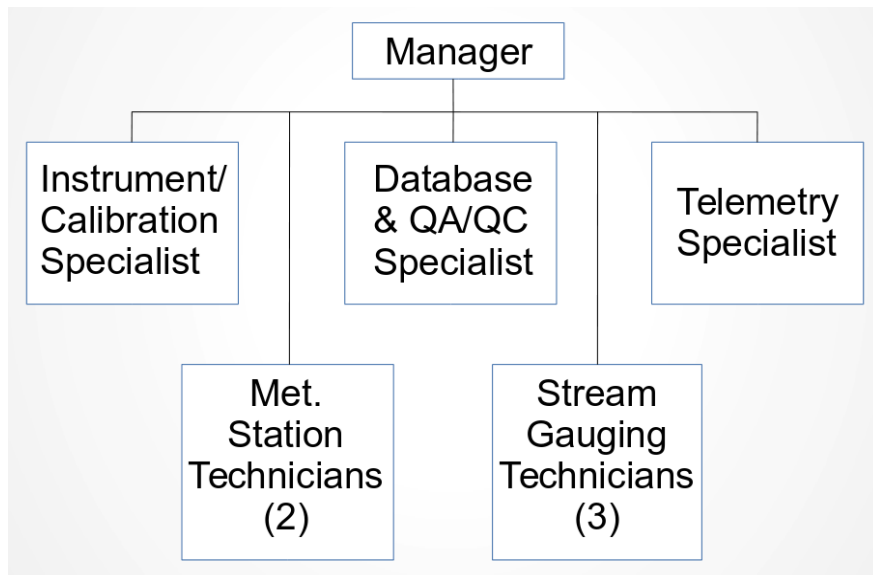


Figure 17: Recommended minimum staffing levels and specialties required for operation of proposed hydrometeorological network. This diagram includes 9 staff.

11. Recommendations to Improve Private Sector Interactions

There is an important role for the private sector to play in this projects. The private electrical company, DOMLEC, and mobile phone providers LIME and Digicell each have infrastructure that facilitates data collection and transfer. Figure 18 shows the locations of all proposed or potential instrumentation sites and the location of LIME and Digicel transmission towers.

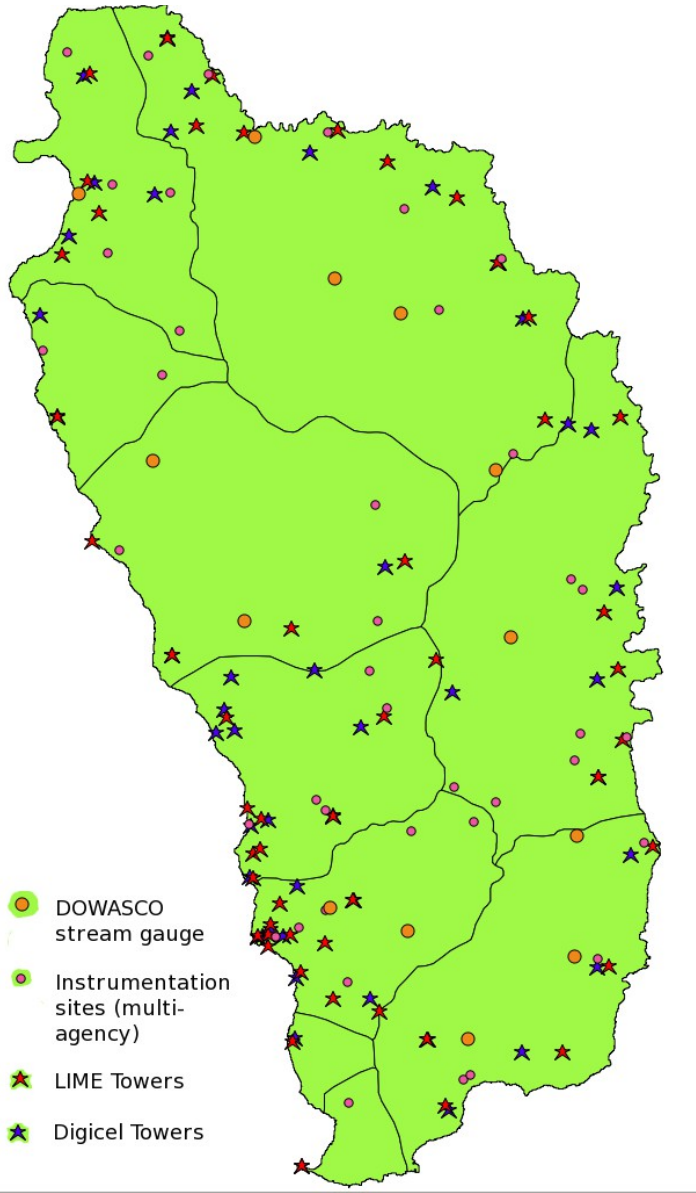


Figure 18: Location of stream and weather/rainfall gauging sites relative to mobile phone towers by Digicel and LIME.

In a meeting with the National Telecommunications Regulatory Agency (NTRC) in January, 2015, the issue of access to mobile phone telecommunications sites was raised. The NTRC license of mobile phone transmission sites includes two features that might enable access to secure facilities for siting of data transmission equipment or sensors. First, the license does include a national defense stipulation. Second, the license requires that occupation of real estate for the purposes of telecommunication does not prevent other licensed telecommunications providers access to that same real estate. This aspect of the law was written to prevent monopolization of good tower sites by one provider or another.

If the justification for the hydrometeorology data collection network can be explained in terms of national defense, then the existing NTRC licenses may provide a means by which the mobile phone providers will be required to collaborate on network siting and data transmission. Alternatively, if the national agency charged with hydrometeorological data transmission becomes registered as a telecommunications provider, this will provide access to existing sites. Finally, the regulatory framework might be altered to add a civil-defense function to the NTRC telecommunications license.

Similarly, DOMLEC may have data transmission capabilities that can be leveraged. This possibility should be explored as one possible way to improve data transmission redundancy and resiliency in Dominica.

12. Recommendations to Improve Agency Analytical Capability

Data Quality Assurance/Quality Control (QA/QC)

Data QA/QC is an institutional demand. That is to say, everyone who looks at data must be aware of what the data should look like, and make a note if something seems wrong and communicate this fact rapidly to people that repair equipment, and people that use data. Technicians working in the field are the first line of defense for checking the proper operation of instruments. They must be taught how to examine the performance of every sensor deployed in the field.

The second line of defense depends on whether or not the data are telemetered. Non-telemetered data must be examined by the office staff for consistency. Telemetered data can be passed through a checking program to identify potential problems with data or sensors. This program would consist of a value range test on data from different sensors. Values that are out of the expected range would generate an alert that could go into a log, or possibly trigger an e-mail to a technician or district office once per day.

Data processing should be a scheduled activity with at least two dedicated personnel trained to process data. Processing includes editing, flagging suspect or bad data, and applying calibration factors or shifts. It is important to have at least two persons trained in data processing so that this important activity does not cease when there is an illness or vacation. Backlogs of data processing are very hard to overcome given the constant flow of

incoming data. Making up for lost time in data processing is akin to swimming upstream.

Modeling

The budget request includes software and training for agency staff to acquire and learn to use hydrological modeling software. The Watershed Modeling System produced by Aquaveo is recommended, because it serves as middleware between GIS and hydrological models, and supports a variety of hydrological models of different capabilities. These models range from the simple rational method (runoff coefficient) suitable for small catchments, to the slightly more complex HEC-1 curve number and synthetic unit hydrograph method, to the sophisticated US Army Corps of Engineers, Gridded Surface/Subsurface Hydrological Analysis (GSSHA) model.

Interactions with Universities

UWI, CIMH, and CCCCC are regional entities with relevant areas of excellence. Identification of existing programs/centers that augment agency capabilities, provide training, or perform basic services is perhaps a cost effective way to take advantage of their capabilities.

There are few or no long-term training opportunities for agency personnel to attend university on leave, and return with new skills and capabilities. These programs can provide important training opportunities and return to the agency many-fold increases in capability. The acute problem that impedes such action is the question of personnel retention. Appropriate adjustment of staff salaries and classifications will be required.

Forging interactions with researchers at foreign universities is a beneficial way to infuse agencies with new ideas, tools, methodologies, and create productive collaborative relationships. The proposed improvements to the long-term stability of the hydrometeorological network, identification of special study areas, and a general increase in high quality data collection combined with free dissemination of basic data will make Dominica an attractive place for researchers from foreign universities to come and conduct hydrometeorological, hydrological, and climate-related science.

13. Recommendation to Establish a Hydrometeorological and Climatological Data Dissemination Centre

At present only CIMH provides basic data from Dominica online. Dominica Meteorological Services states that there is a need to increase staff in this area before they could begin serving data online. DOWASCO, as a quasi-private company that is wholly-owned by the government, does not have a mandate to provide data to the public. Given limited budgets, I recommend that one entity be identified and charged with this task. Staffing levels are the primary concern. The selected entity must be staffed appropriately to enable this function.

The reason for making one entity in charge of IT for data dissemination is that it avoids duplication of efforts and provides a focal point for this task within the Government of Dominica. Buy-in by different agencies is a concern. One way to promote this idea is to assign staff from the data dissemination centre to each relevant data producing agency or visa versa. This will help ensure that the needs of individual data producing agencies are communicated to the data dissemination centre. The centre concept will promote standardization, and help employ top-notch staff. The Centre may also contract with private sector entities for assistance. Care must be taken in contracting to ensure that Centre staff are trained to understand, edit, and maintain software tools. The hydrometeorology working group suggested that the GeoNode system be employed. However, the GeoNode system is customized for geospatial data, while hydrometeorological and hydrological data are fundamentally time-series data. Open source software such as the CUAHSI Hydroserver should be used to avoid recurring licensing fees and planned obsolescence that is common with private sector software. Data backup system may use contracted cloud storage.

14. Quantity and Cost Estimates, Budget Summary

In this section I provide a cost estimate for one (1) of each station type. There are probably some savings on shipping and insurance given the quantity of materials being purchased. However, these budget estimates include no contingency. Labor cost are estimated based on my experience elsewhere in the Caribbean, and might be inappropriate for Dominica.

14.1 Quantity Estimation:

<u>TOTAL STATION NUMBERS BY TYPE</u>	<u>Desired</u>
Number of meteorological stations:	5
Number of stream gauging stations:	22
Number of rain gauge only stations:	16
Number of UHF/VHF repeaters:	5
TOTAL SITES:	48
Number with GOES	0
Number sites with UHF/VHF	5
Number of sites with GSM Mobile Telem.	43

<u>TELEMETERED SITES</u>	<u>No. of sites</u>	<u>Number needed per site</u>	<u>Total number needed</u>	<u>Number in working order</u>	<u>Number of spares needed</u>	<u>Number to purchase</u>
<u>Rain Gauge sites:</u>	16	3	48	0	12	60
<u>Stream gauging huts</u>	22	1	22	0	0	22
<u>Water Level Sensors:</u>	22	1	22	0	5	27
<u>Barometric Pressure Sensors:</u>	5	1	5	0	4	9
<u>Temperature/Rel. Hum. Sensors:</u>	5	1	5	0	5	10
<u>Solar Radiation Sensors:</u>	5	1	5	0	7	12
<u>Wind Speed/Direction Sensors (2-D sonic):</u>	5	1	5	0	5	10
<u>GPS Antenna</u>	5	1	5	0	3	8
<u>Solar Panels (12W) Class:</u>	48	1	48	0	5	53
<u>Batteries</u>	48	1	48	0	48	96
<u>GOES Transmitters</u>	0	1	0	0	0	0
<u>VHF/UHF Radios (including antenna)</u>	5	1	5	0	2	7
<u>VHF/UHF Radio Repeater</u>	5	1	5	0	1	6
<u>YAGI Antenna</u>	10	1	10	0	2	12
<u>GSM Modem</u>	43	1	43	0	7	50
<u>Voltage Regulators</u>	48	1	48	0	8	56

<u>NON-TELEMETERED SITES</u>	No. of sites	Number needed per site	Total number needed	Number in working order	Number of spares needed	Number to purchase
Stream gauging sites with staff gauges	22	1	22	0	0	22

14.2 Cost Estimates:

Note: numbers in green blocks appear in summary budget.

<u>DATA LOGGERS</u>	<u>No. of sta.</u>	<u>Cost per sta.</u>	<u>Subtotal</u>	<u>Shipping</u>	<u>TOTAL</u>
Met stations	5	\$1,550.00	\$7,750.00	\$1,000.00	\$8,750.00
Streamflow stations	22	\$1,550.00	\$34,100.00	\$1,400.00	\$35,500.00
Rain only stations	16	\$1,250.00	\$20,000.00	\$1,000.00	\$21,000.00
Repeaters	5	\$1,250.00	\$6,250.00	\$250.00	\$6,500.00
TOTAL COST DATA LOGGERS:			\$68,100.00	\$3,650.00	\$71,750.00

<u>Misc. Hardware</u>	<u>No. needed</u>	<u>Cost per sta.</u>	<u>Total Cost</u>
Tripods	5	\$800.00	\$4,000.00
Weatherproof Enclosures 14x16"	26	\$350.00	\$9,100.00
Mounting hardware for enclosures (stainless st	26	\$100.00	\$2,600.00
Towers (three-leg, galvanized), 20 ft. Includes concrete base and guy wires	9	\$1,480.00	\$13,320.00

NEW INFRASTRUCTURE (Huts, fenced enclosures)

<u>ITEM</u>	<u>QTY.</u>	<u>UNIT COST</u>	<u>SUB-TOTAL</u>	<u>SHIPPING</u>	<u>TOTAL COST</u>
New instrumentation huts (concrete & reinf. Cinder block)	22	\$5,000.00	\$110,000.00	\$0.00	\$110,000.00
Fenced enclosures streamflow sites	22	\$2,000.00	\$44,000.00	\$0.00	\$44,000.00
Steel Doors	22	\$1,000.00	\$22,000.00	\$0.00	\$22,000.00
Foundations for instrumentation huts	22	\$1,000.00	\$22,000.00	\$0.00	\$22,000.00
					\$198,000.00

MOUNTING ENCLOSURES AND HARDWARE

Weatherproof enclosures (see calculations sheet)	26	\$350.00	\$9,100.00	\$1,430.00	\$10,530.00
Mounting hardware (see calculations sheet)	26	\$100.00	\$2,600.00	\$0.00	\$2,600.00
20 ft. towers (see calculation sheet)	9	\$1,480.00	\$13,320.00	\$1,485.00	\$14,805.00
Tripods for met stations (see calculation sheet)	5	\$800.00	\$4,000.00	\$1,000.00	\$5,000.00
					\$32,935.00

ACQUISITION OF SENSORS AND INSTRUMENTS TELEMETERED STATIONS

ITEM (sensors)	QTY.	UNIT COST	SUB-TOTAL	SHIPPING	TOTAL COST
Rain Gauges (tipping bucket, all metal, machined parts, 8")	20	\$550.00	\$11,000.00	\$700.00	\$11,700.00
Rain Gauges (tipping bucket ABS plastic)	40	\$120.00	\$4,800.00	\$1,400.00	\$6,200.00
Leveling base for rain gages	60	\$120.00	\$7,200.00	\$1,080.00	\$8,280.00
2-D Ultrasonic Wind Speed/Direction	10	\$1,400.00	\$14,000.00	\$200.00	\$14,200.00
Temperature/Rel. Hum w/shield	10	\$670.00	\$6,700.00	\$200.00	\$6,900.00
Barometric Pressure	5	\$800.00	\$4,000.00	\$100.00	\$4,100.00
Solar Radiation w/mount	12	\$570.00	\$6,840.00	\$240.00	\$7,080.00
Stream Water Level (transducers, non-vented)	6	\$1,100.00	\$6,600.00	\$330.00	\$6,930.00
Stream Water Level (bubblers), number estimated:	14	\$5,900.00	\$82,600.00	\$770.00	\$83,370.00
Water conductivity probes	20	\$355.00	\$7,100.00	\$300.00	\$7,400.00
Turbidity sensors, incl. spare wipers & calib. Stds.	5	\$5,400.00	\$27,000.00	\$300.00	\$27,300.00
Water quality sondes (DO,TDS,T,pH) 4m cable	4	\$2,950.00	\$11,800.00	\$220.00	\$12,020.00
Data loggers	see calculations page		\$68,100.00	\$3,650.00	\$71,750.00
					\$267,230.00

HAND OPERATED EQUIPMENT

ITEM (hand-held personal equipment)	QTY.	UNIT COST	SUB-TOTAL	SHIPPING	TOTAL COST
2-D ultrasonic flow meters w/ wading rods	2	\$8,500.00	\$17,000.00	\$500.00	\$17,500.00
2-D Acoustic Digital Current Profiler (ADCP) for boat	1	\$30,000.00	\$30,000.00	\$600.00	\$30,600.00
Propeller current meter (Ott or Price or similar) w/rod	2	\$1,100.00	\$2,200.00	\$0.00	\$2,200.00
Automatic programmable water quality samplers w/bubbler	2	\$2,700.00	\$5,400.00	\$400.00	\$5,800.00
Depth integrated suspended sediment samplers (wading)	2	\$650.00	\$1,300.00	\$0.00	\$1,300.00
Depth integrated suspended sediment sampler (DH59 or eq)	2	\$1,200.00	\$2,400.00	\$0.00	\$2,400.00
Groundwater monitoring transducers with data loggers	6	\$1,050.00	\$6,300.00	\$0.00	\$6,300.00
Field laptops (Panasonic toughbook, or equiv.)	4	\$2,400.00	\$9,600.00	\$300.00	\$9,900.00
Rain gage calibration sets	6	\$130.00	\$780.00	\$90.00	\$870.00
Memory cards (CF or SD 2 GB)	50	\$22.00	\$1,100.00	\$50.00	\$1,150.00
Real Time Kinematic GPS System (2 cm accuracy)	2	\$7,900.00	\$15,800.00	\$500.00	\$16,300.00
Handheld GPS Units (Garmin GPS 60CSx or equiv.)	8	\$380.00	\$3,040.00	\$60.00	\$3,100.00
Surface water quality test kits, Hach No. 2558900 or equiv.	2	\$329.00	\$658.00	\$120.00	\$778.00
					\$98,198.00

TELEMETRY EQUIPMENT

ITEM	QTY.	UNIT COST	SUB-TOTAL	SHIPPING	TOTAL COST
GSM modems	50	\$720.00	\$36,000.00	\$1,750.00	\$37,750.00
VHF/UHF radios	10	\$660.00	\$6,600.00	\$500.00	\$7,100.00
YAGI Antennae with cables and surge protectors	10	\$920.00	\$9,200.00	\$750.00	\$9,950.00
Ethernet interfaces for data loggers with VHF/UHF radio:	10	\$320.00	\$3,200.00	\$500.00	\$3,700.00
GPS antenna	8	\$150.00	\$1,200.00	\$100.00	\$1,300.00
Towers (see calculation sheet for number)	9	\$1,200.00	\$10,800.00	\$0.00	\$10,800.00
					\$70,600.00

POWER EQUIPMENT

ITEM	QTY.	UNIT COST	SUB-TOTAL	SHIPPING	TOTAL COST
Solar panels	53	\$180.00	\$9,540.00	\$1,325.00	\$10,865.00
Voltage regulators	56	\$105.00	\$5,880.00	\$300.00	\$6,180.00
Batteries, sealed, lead acid, (12V gel-cell, 32Ah)	96	\$120.00	\$11,520.00	\$2,880.00	\$14,400.00
					\$31,445.00

CENTRAL DATA CENTER

ITEM	QTY.	UNIT COST	SUB-TOTAL	SHIPPING	TOTAL COST
Office computers	6	\$1,200.00	\$7,200.00	\$240.00	\$7,440.00
Network accessible storage appliance (15 TB) with RAID di	2	\$1,800.00	\$3,600.00	\$120.00	\$3,720.00
					\$11,160.00

HYDROLOGIC ANALYSIS HARDWARE AND SOFTWARE

ITEM	QUANTITY	UNIT COST	SUBTOTAL	SHIPPING	TOTAL COST
	Licenses				
WMS (incl. GSSHA, HSPF,Stormdrain,Map,River,Drain,HEC)	1	\$4,301.75	\$4,301.75	\$0.00	\$4,301.75
					\$4,301.75

14.3 Cost Basis for Instrumentation Support**SUPPORT FOR INSTRUMENTATION**

ITEM	BASIS	UNIT COST	SUBTOTAL	SHIPPING	TOTAL COST
Estimated as 7.5% of instrumentation cost	\$369,275.00	7.50%	\$27,695.63	\$0.00	\$27,695.63

TRAINING on Hydrologic methods and models

ITEM	QTY.	UNIT COST	SUBTOTAL	SHIPPING	TOTAL COST
USGS Stream gaging training for two personnel	2	\$1,200.00	\$2,400.00	\$0.00	\$2,400.00
WMS GSSHA/HEC-HMS Training	2	\$800.00	\$1,600.00	\$0.00	\$1,600.00
Air fare for agency personnel for training (round-trip tickets)	6	\$1,200.00	\$7,200.00	\$0.00	\$7,200.00
					\$11,200.00

14.4 Budget Summary:

HYDROLOGIC EQUIPMENT, SOFTWARE, TRAINING, AND SUPPORT BUDGET SUMMARY

Commonwealth of Dominica, prepared by Fred L. Ogden, Hydromet. Consultant., March 2, 2015.

ITEM	COST
NEW INFRASTRUCTURE (Huts, fenced enclosures)	\$198,000
MOUNTING ENCLOSURES AND HARDWARE	\$32,935
ACQUISITION OF SENSORS AND INSTRUMENTS TELEMETERED STATIONS	\$267,230
HAND OPERATED EQUIPMENT	\$98,198
TELEMETRY EQUIPMENT	\$70,600
POWER EQUIPMENT	\$31,445
CENTRAL DATA CENTER	\$11,160
HYDROLOGIC ANALYSIS HARDWARE AND SOFTWARE	\$4,302
SUPPORT FOR INSTRUMENTATION	\$27,696
TRAINING on Hydrologic methods and models	\$11,200
TOTAL AMOUNT OF THIS BUDGET:	\$752,765

NOTES:

1. This budget does not include any vehicles
2. This budget includes no offices or permanent structures other than instrument huts.
3. This budget assumes all materials are shipped from Miami via a cargo freight forwarding company.
4. This budget assumes that 7.5 percent of instrument costs is sufficient to provide support/training/troubleshooting from manufacturers, in Dominica.
5. All amounts are U.S. Dollars

15. References

- CGIAR, 2015. ftp://srtm.csi.cgiar.org/SRTM_v41/SRTM_Data_ArcASCII/srtm_24_09.zip accessed 28 March, 2015.
- Cox, C. 2005. A guide for watershed management planning in Dominica. Financed by the Government of Australia. Copy provided by DOWASCO.
- Lang, D.M., 1967. Soil and land use surveys, No. 21: Dominica. *Soil and Land Use Surveys, Trinidad*: Imperial College of Tropical Agriculture, 1-58.
- Niedzialek, J., and F.L. Ogden, 2010. First-order catchment mass balance during the wet season in the Panama Canal watershed. *J. Hydrol.* 462-463:77-86.
- NOAA/NESDIS, Dec. 2012, Climate Reference Network, Site Information Handbook, U.S. Department of Commerce.
- Ogden F.L., T.D. Crouch, R.F. Stallard, and J.S. Hall, 2013. Effect of land cover and use on dry season river runoff, runoff efficiency, and peak storm runoff in the seasonal tropics of central Panama. *Water Resour. Res.*, .
- Rouse, W.C., A.J. Reading, and R.P.D. Walsh, 1986. Volcanic soil properties in Dominica, West Indies. *Engrg. Geol.* 23 (1986):1-28.
- Smith, R.B., P. Schafer, D.J. Kirshbaum, and E. Regina, 2009. Orographic precipitation in the tropics: Experiments in Dominica. *J. Atmos. Sci.*, DOI: 10.1175/2008JAS2920.1.
- Stormcarib.com http://stormcarib.com/climatology/MKJP_weekly.htm, accessed 4 November, 2013.
- WMO, 2003. WCDMP Guidelines for siting of meteorological instruments. WMO/TD No. 1185.

16. Acknowledgments

I thank Mr. Collin Guiste, Ms. Tamika Lafond, and Ms. Andrea Marie of PPCR/DVRP for their assistance in facilitating my mission to Dominica, and their help in arranging reviews of this report.

I gratefully acknowledge the assistance of Mr. Marshall Alexander of Dominica Meteorological Services in providing a field visit of existing meteorological and rain gauging sites and in reviewing this report. Mr. Magnus Williams of DOWASCO was instrumental in providing guidance regarding stream gauging locations, and in reviewing this report. I applaud the work by the hydrometeorology working group in advance of my mission. Their input, guidance and discussions were very helpful to me.

Appendix A. Name, Elevation and Location of DOMEX Rain Gauges Used in P-E and Spatial Correlation Analyses

Station Name	Elev (m)	Latitude (N)	Longitude (W)
		dec. degr.	dec. degr.
Boeri Lake	877	15.35165	61.32018
Botanical Garden	30	15.2987	61.38237
Canefield	10	15.33523	61.39267
Freshwater Lake	800	15.3403	61.3097
Grand Bay Agricultur Station	173	15.24469	61.32181
Grand Fond	262	15.36065	61.27583
LaPlaine	70	15.33262	61.24692
Laudat	561	15.33294	61.33536
Pont Casse	748	15.38067	61.34356
Rosalie	10	15.37348	61.25482
Springfield	400	15.34767	61.368

Appendix B. Existing, Past (Abandoned) or Planned Meteorological Instrumentation in Dominica

Owner	Type	Name	Details	Working?	Lat. (N)	Lon. (W)	Brand	Location Source	Data Collection	Collection Freq.
Agriculture	Weather Station	Syndicate	To be removed and placed in Pond Case	Yes	15.52064	61.4179	Vantage Pro2	Ministry of Agriculture Data-base	Manual	Semi-annually
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.51318	61.4679	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.52808	61.3225	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.5714	61.4213	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.62286	61.459	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.39593	61.3479	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.41407	61.345	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Proposed	Weather Station	Proposed	Proposed, details unknown	No	15.29031	61.264	Unkn.	Paper Map with Push-Pins	Unkn.	Unkn.
Met Office	Rain Gauge	Pont Casse	DOMEX Project, tipping bucket gauge, co-located with forestry gauge	Yes	15.38061	61.3435	HOBO RG3	Trimble Juno SC Hand-held Receiver	Manual, data-logger pendant	Unkn.
Agriculture	Weather Station	Grand Bay Agricultural Station	Damaged by insects, no longer exists	No	15.24604	61.3133	Vantage Pro2	Ministry of Agriculture Data-base	Manual	Semi-annually
Met Office	Rain Gauge	Grand Fond	DOMEX Project tipping bucket gauge,	Yes	15.36291	61.2727	HOBO RG3	CIMH Dominica Met Assessment Report	Manual, data-logger pendant	Unkn.
Met Office	Rain Gauge	Laudat	DOMEX Project tipping bucket gauge,	Yes	15.33726	61.3326	HOBO RG3	CIMH Dominica Met Assessment Report	Manual, data-logger pendant	Unkn.

Met Office	Rain Gauge	Springfield	DOMEX Project tipping bucket gauge,	Yes	15.34662	61.3689	HOBO RG3	CIMH Dominica Met Assessment Report	Manual, data-logger pendant	Unkn.
Met Office	Weather Station	Canefield	Canefield Airport Weather Station. The HOBO gauge is located on the southern end of the runway.	Yes	15.33962	61.392	HOBO RG3 & Met. Sta.	CIMH Dominica Met Assessment Report	Manual, data-logger pendant	Unkn.
DOWA SCO	Pressure Sensor	Springfield	Data Logger with pressure sensor, solar panel, modem and rain gauge	Yes	15.34488	61.3641	OTT	DOWASCO Database	Automatic, GSM	Unkn.
Met Office	Rain Gauge	La Plaine	DOMEX Project tipping bucket gauge .Agricultural Training Centre	Yes	15.33265	61.247	HOBO RG3	Trimble Juno SC Hand-held Receiver	Manual, data-logger pendant	Unkn.
Met Office	Rain Gauge	Rosalie	Rosalie Bay Resort, Solar Panel and GSM Modem	Yes	15.37143	61.2535	Sutron	Trimble Juno SC Hand-held Receiver	Automatic, GSM	Unkn.
DOWA SCO	Pressure Sensor	Portsmouth	Data Logger and Pressure Sensor. Station does not boot up	No	15.54913	61.444	OTT	DOWASCO Database	Unkn.	Unkn.
DOWA SCO	Pressure Sensor	Castle Bruce	Data Logger and Pressure Sensor Removed but will be re-installed in a different location	No	15.42572	61.2695	OTT	DOWASCO Database	Unkn.	Unkn.
DOWA SCO	RADAR	Hampstead	Data Logger and RADAR On site but non functional	No	15.59347	61.3632	OTT	DOWASCO Database	Unkn.	Unkn.
DOWA SCO	RADAR	Rosalie	Data Logger and RADAR Located on the Rosalie Bridge leading the the Three Rivers Ecolodge	No	15.3729	61.2703	OTT	DOWASCO Database	Unkn.	Unkn.

Appendix C. Commonwealth of Dominica Hydrometeorological Technical Working Group

Name	Designation	Organisation	Contact No.	E-Mail
Mr. Magnus Williams	Chief Engineer	DOWASCO	275-1155	m.williams@dowasco.dm
Miss Ferdinia Carbon	Senior Environmental Health Officer	Environmental Health Department	266-3466 265-6476	environmentalhealth@dominica.gov.dm cferdinia@hotmail.com
Mr. Mandela Christian	Programme Officer	Office of Disaster Management	448-7777	dcmandela@gmail.com odm@dominica.gov.dm
Mr. Adissa Trotter	Agricultural Officer	Division of Agriculture	266-3804	aictudoa@gmail.com divisionofagriculture@dominica.gov.dm
Mr. Marshall Alexander	Weather Forecaster	Dominica Meteorological Services	449-1990	marshallalexander@hotmail.com metoffice@cwdom.dm
Miss Kimisha Thomas	Environmental Officer	Environmental Coordinating Unit	266-5256	ecu@dominica.gov.dm
Miss Jacqueline Andre	Forest Officer	Forestry, Wildlife and Parks Division	266-5856	andrej@dominica.gov.dm
Mr. Andrew Magloire	Chief Fisheries Officer	Fisheries Development Division	266-5291	fisheriesdivision@dominica.gov.dm
Mr Justinn Kase	Utility Engineer	Independent Regulatory Commission	Local: 440-6634 Intl. 1.305.396.3527	jgkase@ircdominica.org
Mr. Jason Timothy	Generation Engineer	DOMLEC	448-2681	Jason.timothy@domlec.dm
Mr. Collin Guiste	Project Coordinator Chairperson/ Hydromet TWG	Disaster Vulnerability	266-3139 448-3873	ppcrdvrp@cominica.gov.dm

Appendix D. Example Memorandum of Understanding Regarding Network Operation and Data Sharing

DRAFT MEMORANDUM OF UNDERSTANDING
BETWEEN

Dominica Water and Sewerage Company Ltd.

AND

Dominica Meteorological Service

This MEMORANDUM OF UNDERSTANDING is hereby made and entered into by and between the Dominica Water and Sewerage Company, Ltd., hereinafter referred to as DOWASCO, and the Dominica Meteorological Service, hereinafter referred to as DMS. The activities described under this memorandum are an anticipated result of a successful effort by the PPCR/DVRP Project Coordination Unit to obtain funding for the improved hydrometeorological network for the Commonwealth of Dominica.

1. PURPOSE:

This memorandum of understanding establishes a collaborative agreement regarding the creation, operation, and maintenance of an improved hydrometeorological network on the island of Dominica, delineates the areas of responsibility for the involved parties, establishes areas of joint responsibility, and provides for the storage, quality-control, analysis and dissemination of collected data.

2. STATEMENT OF MUTUAL BENEFIT AND INTERESTS:

The parties to this agreement hereby acknowledge that the collection, quality control, archival, and dissemination of high-quality hydrometeorological data on the island of Dominica is of benefit to all Dominicans and within the purview of their respective responsibilities by statute and law within the Commonwealth of Dominica.

3. DMS SHALL:

1. Identify, in cooperation with DOWASCO and other Dominican agencies, appropriate locations for installation of a network of recording and telemetered meteorological and precipitation stations. Some of these sites might include those controlled by private entities such as the Dominica Electricity Services (DOMLEC) and/or the mobile phone providers in Dominica. Access concerns to be addressed in negotiation with land owners.
2. Install or supervise the installation of a network of recording and telemetered meteorological stations in accordance with WMO siting and exposure standards.
3. Install or supervise the installation of a network of recording and telemetered rain gauge stations in accordance with WMO siting standards.
4. Operate and maintain the stations installed in C.1 and C.2 to minimize data gaps.
5. Create and execute a program of scheduled maintenance and instrument/sensor calibration to ensure data quality through inspection and monitoring. Sensors shall be calibrated as per

manufacturer specifications. Calibrated spares shall be deployed to avoid creation of data gaps.

6. Perform quality control of meteorological variables and rainfall amounts.
7. Create a database containing metadata such as instrument types, serial numbers, date of last calibration, location, date/time of change/replacement of instruments/parts.
8. Populate the database with time series of meteorological variables at regular intervals such as hourly. All time values shall be stored in Universal Coordinated Time (UTC), which is Atlantic standard time (local time) plus 4 hours.
9. Accept data from DOWASCO-managed stream gauging stations. These data shall include metadata on sensor types, sensor manufacturer, calibration dates, and time-series of water stage and discharge.
10. Transfer quality data to the entity agreed upon by DMS and DOWASCO for dissemination of data.
11. Coordinate with other Dominican agencies were beneficial in the routine maintenance of the installed meteorological equipment. This coordination includes routine cleaning of tipping bucket rain gauges, removal or cutting of vegetation to maintain WMO instrument siting and exposure standards, identification of suitable sites for instrument location and placement, and training of personnel from collaborating agencies in cleaning and maintenance of meteorological sensors/stations.
12. Maintain a backup copy of the hydrometeorological database on Google Drive or equivalent cloud-based service.
13. Transmit meteorological variables to WMO or other regional standards organizations (CIMH or U.S. NCDC) within XX days of data collection. This activity shall not supersede maintenance of the local database on behalf of the Government of the Commonwealth of Dominica.

4. DOWASCO SHALL:

1. Identify, in cooperation with DMS and other Dominican agencies, appropriate sites for installation of stream gauging sensors. Site selection shall consider water real-time resources management and future assessment, flash flood potential risk and warning (EWS), and other considerations as necessary.
2. Obtain training, or employ the services of a hydraulics expert, to identify specific stream gauging sites with characteristics conducive to development of low uncertainty stage-discharge relations. This service might be provided at the option of DMS and DOWASCO by experts from other Caribbean entities such as CIMH, or staff from the Water Resources Authority of other nations.
3. Supervise construction of infrastructure suitable for deployment of stream gauging sensors. This infrastructure shall consist of instrument shelters constructed at a location of sufficient elevation above the stream to avoid anticipated flood damage during large hydrologic events. Installations shall include a staff gauge for manual reading of water levels.
4. Perform routine stream flow measurements using established procedures to establish rating curves.
5. Perform surveys of reach cross-sections and perform backwater analyses for high-flows to establish rating curve points for those flows that are unsafe to physically measure using current meter techniques.
6. Install stage measuring sensors.

7. Develop data logger program to record and transmit stage data time-series. Time units shall be Universal Coordinated Time (UTC), which is Atlantic standard time + 4 hours.
8. Equip stage measurement stations with GSM cellular modems or line-of-sight radio telemetry as needed.
9. Operate the stage measurement stations to minimize data gaps.
10. Create and execute a program of scheduled maintenance and instrument/sensor calibration to ensure data quality. Sensors shall be calibrated as per manufacturer specifications. Calibrated spares shall be deployed to avoid creation of data gaps.
11. Train field personnel to perform manual stage measurements by way of a staff gauge. Each field crew shall carry a notebook for recording manual stage measurements. These field observations shall be recorded in a log book at a central location, and shall include date, time (local), stage, and other notes/observations.
12. Perform quality control of stage measurements using manual observations of water stage provided during field visits to stage measurement stations.
13. Transmit quality-controlled water stage and discharge time-series data and sensor/equipment metadata to the entity agreed upon by DMS and DOWASCO for dissemination of data.

5. IT IS MUTUALLY UNDERSTOOD AND AGREED BY AND BETWEEN THE PARTIES THAT:

1. PARTICIPATION IN SIMILAR ACTIVITIES. This instrument in no way restricts the DMS or DOWASCO from participating in similar activities with other public or private agencies, organizations, and individuals.
2. COMMENCEMENT/EXPIRATION/TERMINATION. This MOU takes effect upon the signature of the DMS and DOWASCO and shall remain in effect for _____ from the date of execution. This MOU may be extended or amended upon written request of either the DMS or DOWASCO and the subsequent written concurrence of the other(s). Either the DMS or DOWASCO may terminate this MOU with a 60-day written notice to the other(s).
3. RESPONSIBILITIES OF PARTIES. The DMS and DOWASCO and their respective agencies and office will handle their own activities and utilize their own resources, including the expenditure of their own funds, in pursuing these objectives. Each party will carry out its separate activities in a coordinated and mutually beneficial manner.
4. PRINCIPAL CONTACTS. The principal contacts for this instrument are:

DMS Project Contact

DOWASCO Project Contact

Phone:

Phone:

FAX:
E-Mail:

FAX:
E-Mail:

DMS Administrative Contact

DOWASCO Administrative Contact

Phone:
FAX:
E-Mail:

Phone:
FAX:
E-Mail:

5. NON-FUND OBLIGATING DOCUMENT. Nothing in this MOU shall obligate either the DMS or DOWASCO to obligate or transfer any funds. Specific work projects or activities that involve the transfer of funds, services, or property among the various agencies and offices of the DMS and DOWASCO will require execution of separate agreements and be contingent upon the availability of appropriated funds. Such activities must be independently authorized by appropriate statutory authority. This MOU does not provide such authority. Negotiation, execution, and administration of each such agreement must comply with all applicable statutes and regulations.

6. AUTHORIZED REPRESENTATIVES. By signature below, DOWASCO and DMS certifies that the individuals listed in this document as representatives of the Parties are authorized to act in their respective areas for matters related to this agreement.

THE PARTIES HERETO have executed this instrument.

DOWASCO

DMS

DATE

DATE