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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

WILEY

Lutz Creek watershed, Barro Colorado Island, Republic of Panama

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Abstract

Lutz creek is a small (9.69 ha) catchment located on Barro Colorado Island (BCI), a 1500-ha island in Lake Gatún, the principal freshwater reservoir (425 ha, 26 m above sea level) of the Panama Canal watershed in central Panama. In 1972, a concrete V-notch weir was installed on the creek, located at 9°09′42.8358″N, 79°50′15.6699″W, and hydrological record keeping began. The island was first established as a research station in 1923 and precipitation data collection was initiated in 1925. A meteorological tower, installed in 1972 and located a few meters from the weir, is currently instrumented to collect air temperature, relative humidity, wind speed and direction, evapotranspiration and solar radiation. In addition, since 1972, gravimetric soil moisture has been measured at least biweekly at 10 sites located throughout the Lutz Catchment above the location of the weir. Data collection and the administration of BCI are the responsibility of the Smithsonian Tropical Research Institute (STRI; https://stri.si.edu) which funds the data collection and storage. Data are in the public domain, entitled 'Lutz Watershed And Meteorological Tower' and are available at the STRI Physical monitoring website https://biogeodb.stri.si.edu/physical_monitoring/.

1 | DATASET NAME

Lutz Watershed and Meteorological Tower.

2 | WATERSHED DESCRIPTION

Barro Colorado Island (BCI) ranges in elevation from 26 to 167 m asl (Figure 1). The island is fully forested, with what has been characterized as a lowland seasonal tropical forest, with a mix of deciduous and evergreen trees (Leigh Jr. et al., 1982). The highest part of the island is a gentle plateau. Annual rainfall averages 2645 mm, with strong seasonality. BCI is one of the most intensively studied areas of the global tropics because of the century-long presence of a research station and ongoing scientific investigation focused mainly on terrestrial forest ecology, entomology, animal behaviour and related fields. Forests on BCI are aging and growing taller, reflecting a multifaceted land-use history, in which local-scale agriculture ended in the early 20th century (Albrecht et al., 2017). Shortly after the 1923 establishment of the BCI research station, all agriculture ended. The geology and soils on BCI are complex (Baillie et al., 2007; Johnsson & Stallard, 1989); the island is a small piece of an island-arc terrain that has been repeatedly faulted and folded near sea level while being buried under a mix of both marine and terrestrial sediments. BCI is home to the first of what is now a global network of more than 70 forest research plots known as the Forest Global Earth Observatory (ForestGEO, see

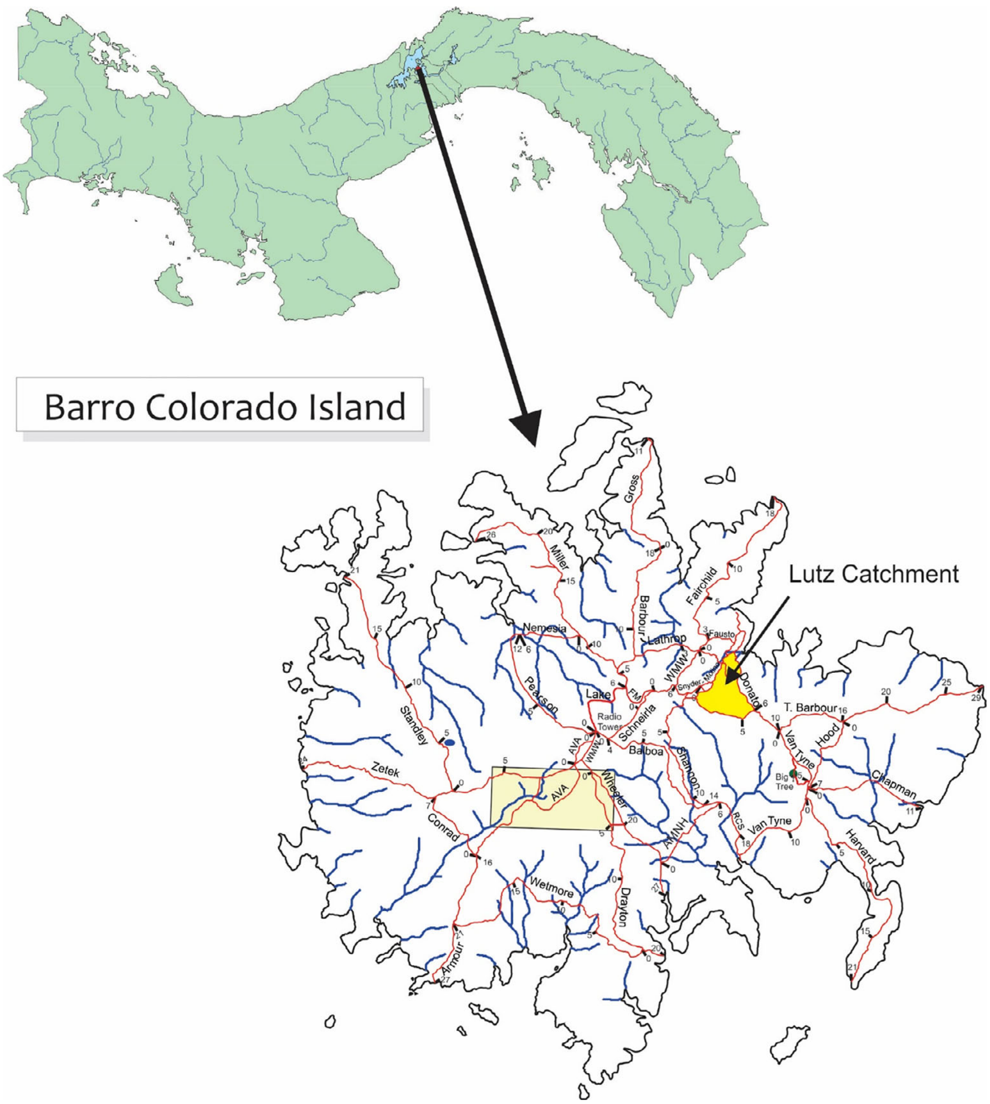

FIGURE 1 Map showing location of Lutz catchment on Barro Colorado Island and location of the 1500 ha island in the Republic of Panama. Shaded rectangle in island centre is ForestGEO research plot. Red lines show named trails

Anderson-Teixeira et al., 2015 and https://forestgeo.si.edu/). ForestGEO is dedicated to advancing long-term study of the world's forests to strengthen science capacity in an era of rapidly changing landscapes and climate to understand and predict forest dynamics.

The Lutz Catchment hydrological study site is located on the Northeastern slopes of BCI, located in the middle of Gatun Lake in the central part of the Republic of Panama (weir at 9°09′42.8358″N, 79°50′15.6699″W; Figure 2). The watershed is underlain by Oligocene tuffaceous and fossiliferous sandstone bedrock, rich in calcite, and clay-rich (smectitic) soils overlie a thick saprolite (Baillie et al., 2007; Johnsson & Stallard, 1989). The study was established in 1972 as part of a larger environmental monitoring program on the island (Windsor, 1990). The size of the Lutz catchment is 9.69 ha. The catchment is characterized by steep hillslopes that drain rapidly into the stream. Sensors on a nearby 48-m-high, walk-up tower record temperature, relative humidity, solar radiation, wind speed and direction, and evapotranspiration. In addition, gravimetric soil moisture has been measured at least biweekly at 10 sites located throughout the Lutz Catchment above the location of the weir. The climate is tropical maritime with pronounced wet (May–December) and dry (January–April) seasons and little variation in monthly average temperatures. Average yearly precipitation is 2645 mm (±490 *SD*) and ranges between 1699 and 4487 mm. Average dry season precipitation is 143 mm (±229 *SD*) while average wet season precipitation is 2522 mm (±424 *SD*). Yearly average temperature at canopy height is 25.9 C (±0.5 *SD*). Monthly average temperatures range from 25.2 C to 26.6 C. Evapotranspiration averages 3.6 mm/day (±0.3 *SD*)—5.2 mm/day during the dry season and 2.8 mm/day during the rainy season. On average, 34% of recorded precipitation drains through the weir—ranging between 16% and 53%. Modelling presented in Kinner and Stallard (2004) requires that a substantial portion of rainfall be lost to deep groundwater. This interpretation is supported by the presence of downstream springs and seeps. Lutz Creek data improve our understanding of basic hydrological processes and inform our ongoing research into the complex terrestrial ecosystems of the island and the region. A general description of hydrological conditions and issues faced in Panama is provided by Larsen (2019).

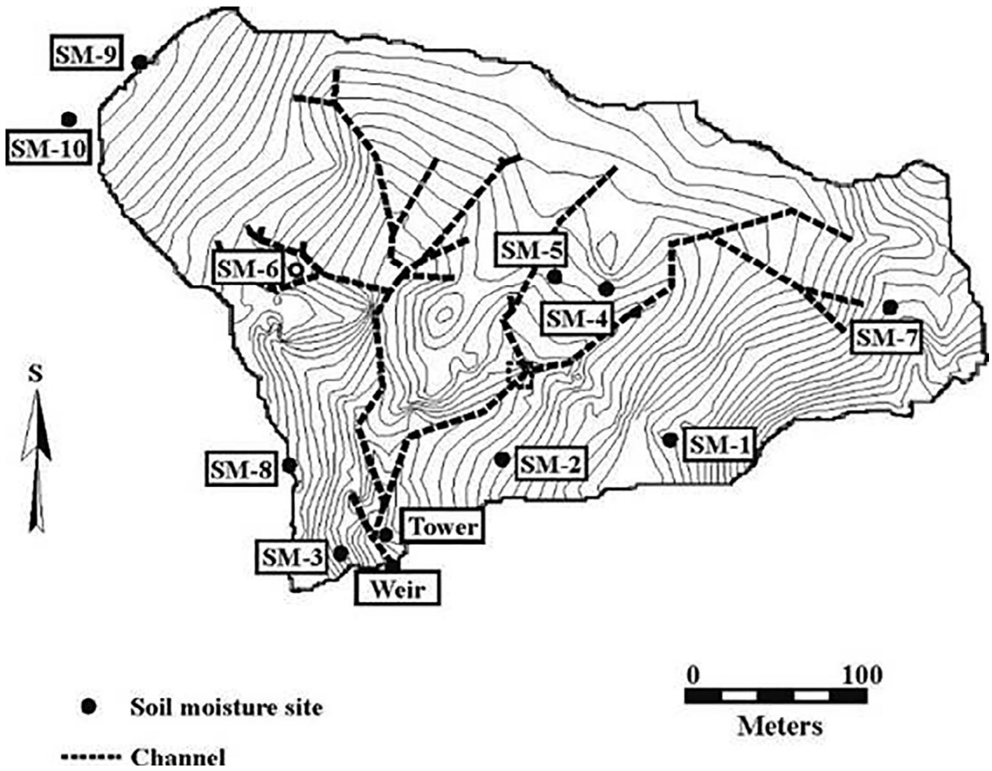

FIGURE 2 Relief map of Lutz Creek watershed, Barro Colorado, showing location of weir, meteorological tower, and soil moisture monitoring sites. Contour interval is 2 m

3 | DATA MEASUREMENTS AND METHODOLOGY

Data are collected using two different methods: electro-mechanical (electronic sensors, data loggers, chart recorders, etc.), and manual (rain gauges, max–min thermometers, sling psychrometers, soil samples, etc.) by a technician (Table 1). In general, manual measurements have shown themselves to be the most accurate over the long-term. Wherever possible, parameters are measured both manually and electronically. The exceptions to this rule are solar radiation (electronic only), estimated evapotranspiration (manual only), and gravimetric soil moisture (manual only).

Runoff is calculated by measuring water stage at the Lutz 120° V-notch weir with an ISCO 3230 Bubbler Flow Meter, using standard U.S. Geological Survey methods (Turnipseed & Sauer, 2010; Figure 3). Between 1972 and 1996, stage was recorded using a stilling well, a float, and a paper chart recorder (which records stage at a constant rate) with charts that were later digitized by hand. Since 1996, electronic sensors have been used to record weir stage at 5-min intervals. The runoff record for this weir is more than 99% complete (Figure 4). The authors believe it to be one of the longest, most complete micro-catchment run-off datasets in the neotropics. Precipitation is collected by both manual and electronic gauges, the latter recording every 5-min. Temperature, relative humidity, wind speed and direction and solar radiation are recorded every 15-min using electronic sensors. Gravimetric soil moisture (also described as soil humidity) is measured at 10 locations throughout the catchment by taking weekly (December–May) or biweekly (June–November) soil samples at two depths at each sample location. Evapotranspiration data are manually recorded using atmometers 4–5 days per week.

4 | QUALITY ASSURANCE

All data are reviewed using custom-built software. Data are visually reviewed for problems such as spikes, drift, range deviation, step changes, and gaps. When problems are fixable with high certainty (e.g., little to no variability in the data), they are altered. Data are flagged as having been altered and the type of anomaly detected is noted. When problems are determined to be unfixable, they are flagged as bad. Data that are potentially suspect are also flagged as such. In all cases, the original data are retained and provided with the distributed files. Small gaps (<4 time units) are automatically filled using simple linear regression. Larger gaps are filled manually when possible, or with data from another sensor with which a highly-significant correlation has been established. Daily and monthly averages are also calculated and plotted against long-term trends in order to search for sensor anomalies that are not apparent when looking at the original data. Because of the highly unpredictable nature of tropical convective precipitation, these data are rarely, if ever, altered or gap-filled.

5 | DATA AVAILABILITY AND ACCESS

A summary of data types is provided in Table 1, and each DOI in the table is a direct link to the data product. Sensor details are provided

TABLE 1 Summary of measurement information for sensors in the Lutz Creek watershed

Measurement type and reference URL	Sensor model	Manufacturer	Years in use	Resolution	Accuracy (error)	Reporting frequency
Manual Rain Gauge https://doi.org/10.25573/data.10042502.v3	260-2510 Standard Rain Gauge	Novalynx Corporation	1972–present	0.254 mm		Four to five times/week in the mornings
Electronic Rain Gauge https://doi.org/10.25573/data.10042463.v9	NA	NA	1929–1972	0.254 mm	NA	1/h, 1929–1972
	NA	NA	1972–1993	0.254 mm	NA	4/h, 1972–1983
	TB4	Hydrological Services	1993–Present	0.254 mm	±2%	60/min, 1983–1994
	Pluvio 2S	OttHydromet	2019–Present	0.001 mm	±2%	12/h, 1994–present
					±1%	1/h
Runoff https://doi.org/10.25573/data.10042460.v7	Model 71, Chart Recorder	Stevens	1972–2015	~1 mm	±1–5 mm	Analog recording, digitized every 3–90 min
	3230 Bubbler Flow Meter	ISCO	1993–2014	0.4 mm	±1.5–3 mm	12/h
	RLR-000101 Radar Level Recorder	Sutron Corp.	2014–present	0.001 ft	±.01 ft	12/h
Temperature	NA	NA	1990–1993	0.5C	NA	1/h, 1990–2000
https://doi.org/10.25573/data.10042394.v9	HMP35C	Campbell Scientific	1993–2000	0.1C	±0.2–3C	4/h, 2000–present
https://doi.org/10.25573/data.10042409.v9	HMP45C	Campbell Scientific	2000–2009	0.1C	±0.4–0.5C	
https://doi.org/10.25573/data.10042433.v9	CS215	Campbell Scientific	2009–present	0.1%	±0.3–0.4C	
https://doi.org/10.25573/data.10042442.v9	HMP60	Vaisala	2016–present	0.1%	±0.5C	
Relative Humidity	NA	NA	1990–1993	1.0%	NA	1/h, 1990–2000
https://doi.org/10.25573/data.10042400.v9	HMP35C	Campbell Scientific	1993–2000	0.1%	±2%–3%	4/h, 2000–present
https://doi.org/10.25573/data.10042424.v9	HMP45C	Campbell Scientific	2000–2009	0.1%	±2%–3%	
https://doi.org/10.25573/data.10042397.v10	CS215	Campbell Scientific	2009–present	0.1%	±2%–4%	
https://doi.org/10.25573/data.10042418.v9	HMP60	Vaisala	2016–present	0.1%	±3%–5%	
Evapotranspiration https://doi.org/10.25573/data.10042490.v1 https://doi.org/10.25573/data.10042481.v1	ET-Gage, Model 3710	Spectrum Technologies	1993–present	0.5 mm	NA	2–5/week in the mornings
Wind Speed	NA	NA	1971–1990	0.62 km/h	NA	1/h, 1971–2000
https://doi.org/10.25573/data.10042430.v8	05103 Young Wind Monitor	R.M. Young	1990–present	0.1 km/h	1.08–1.44 km/h	4/h, 2000–present
Wind Direction	NA	NA	1971–1990	1°	NA	1/day
https://doi.org/10.25573/data.10042427.v8	05105 Young Wind Monitor	R.M. Young	1990–present	1°	±3°	1/h, 1990–2000
						4/h, 2000–present
Solar Radiation	NA	NA	1983–1993	1 $J/m^2/s$	NA	1/h, 1990–2000
https://doi.org/10.25573/data.10042406.v7	LI200X Pyranometer	LiCor	1993–2019	0.01 $J/m^2/s$	±3%–5%	4/h, 2000–present
	SPLite2	Kipp&Zonen	2016–2019	<0.01 W/m^2	±3%–5%	
	CMP3 Pyranometer	Kipp&Zonen	2019–Present	<0.01 W/m^2	<5%	
	CMP10 Pyranometer	Kipp&Zonen	2019–Present	<0.01 W/m^2	±2%	
Gravimetric soil moisture https://doi.org/10.25573/data.10042517.v3	Manual collection	Not applicable	1972–present	Est.+/− 5%	Est.+/− 5%	Soil samples at two depths (0–10 cm and 30–40 cm), weekly (December–May) or biweekly (June–November)

Note: Each DOI provided in this table is a direct link to the data product. The abbreviation NA = not available, is listed for past data collection efforts when incomplete records were kept.

when known, but some instrument information is no longer known because of limited record collection in the 20th century. Lutz Creek watershed data are in the public domain, entitled 'Lutz Watershed And Meteorological Tower' and are freely available at the STRI Physical monitoring website: https://biogeodb.stri.si.edu/physical_monitoring/. The website also provides a detailed description of the research site, specific information about data collection methods, the installed equipment, and includes links to methods and manufacturers' equipment manuals for all current sensors. The data from each sensor are downloadable from a link beside the name of the data series. In addition, monthly and yearly summaries of all data are provided as Excel and PDF's respectively. A data use policy is available at: https://biogeodb.stri.si.edu/physical_monitoring/pages/datapolicy.

Data are updated monthly and are hosted on the Smithsonian Institution's FigShare data server which provides versioned DOI's for all data. Each download file contains a copy of the curated and original data, plus one or more metadata files that describe the contents of each file, sensor location and the methods used to collect the data.

An example of how to access the data for Lutz Creek runoff is as follows (other data types can be accessed by following the same path): Click on this link: https://biogeodb.stri.si.edu/physical_monitoring/. From that page, click on the BCI link, which takes you to: https://biogeodb.stri.si.edu/physical_monitoring/research/barrocolorado. Next, click on the link called Lutz Watershed And Meteorological Tower. After going to that link, scroll down to the section entitled 'Electronic Data Download' which connects to this link: https://smithsonian.figshare.com/articles/dataset/Barro_Colorado_Island_Lutz_Catchment_Runoff/10042460. Then scroll down the page to find the desired data-download link.

FIGURE 3 Photograph of Lutz Creek V-notch weir, Barro Colorado Island

6 | DATA FUNDING, CONTRIBUTORS AND OWNERSHIP

The STRI Physical Monitoring Program is funded by the Smithsonian Institution's U.S. Federal budget. The key contributors for this program are Steven Paton and his staff. All data are owned by the Smithsonian Institution, but are in the public domain and are freely available.

7 | HYDROLOGIC RESEARCH SUMMARY

The earliest synthesis of Lutz Creek hydrology is Dietrich et al. (1982), using watershed data to examine the hydrology and geology of the Lutz watershed and relate these to the functioning to the forest therein. Windsor (1990) summarized the hydrologic data up to that time. Johnsson and Stallard (1989) noted that the composition of clays in stream sediments on BCI were controlled by both their lithology and topography (transport-limited and weathering-limited) and that Lutz creek sediments are particularly smectitic. Godsey et al. (2004) used passive overland-flow detectors to examine the role of lithology in controlling runoff generation in Lutz watershed and the BCI plateau. Their conclusion was that overland-flow generation was common. The Godsey et al. study was designed to compare the Lutz Creek watershed, which has soils with abundant 2:1 clays, where overland flow was more frequent, with another watershed with 1:1 clays, where overland flow was less frequent, controlling for slope position and storm size. Further comparison was not made within Lutz Creek watershed.

The role of soil hydrologic properties and spatial distribution of sampling sites was expanded upon by Zimmermann and Elsenbeer (2008) and Zimmermann et al. (2013). The results of these two studies

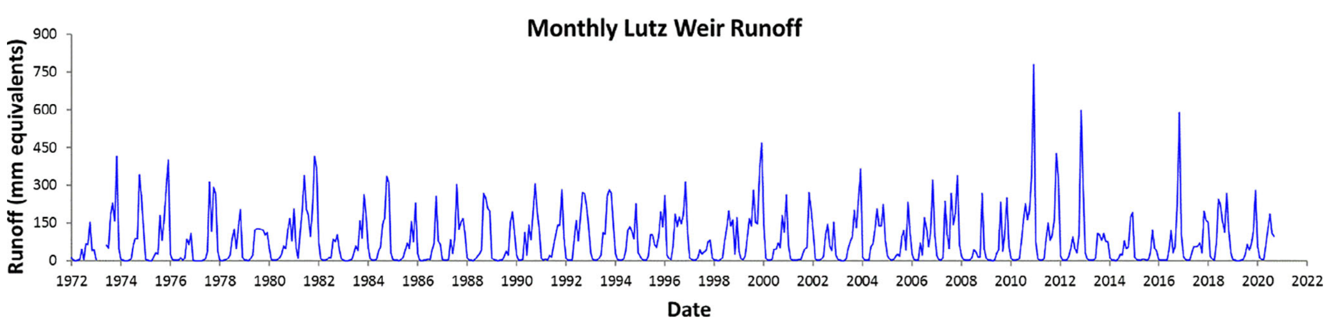

FIGURE 4 Monthly runoff at Lutz Creek, Barro Colorado Island, Republic of Panama, 1972–2020

were used to evaluate the role of erosion and transport on suspended-sediment dynamics in Lutz Creek by Zimmermann et al. (2012). The distribution of throughfall was examined in the Lutz watershed using more than 200 funnel collectors by Zimmermann et al. (2009) and Zimmermann et al. (2010). The role of outliers in throughfall amounts is significant, and Zimmermann et al. (2010) concluded that throughfall troughs would be a better approach for data collection. Stream chemistry and variation on end-member mixing analysis (EMMA) were used by Kinner and Stallard (2004) and Barthold et al. (2017) to examine sources of water during storm events. Barthold et al. (2017) focused exclusively on EMMA. Kinner and Stallard (2004) used a simple version of TOPMODEL (Beven, 1997) implemented through a Monte Carlo simulation to model stream chemistry and demonstrate that the resulting physical model was consistent with the historic soil-moisture data. Base-flow composition represents weathering in deeper parts of the soil profile, whereas during storm events stream water composition appears to be dominated by shallow and surficial flow paths. Numerous studies of tropical biology and ecosystem dynamics cite these studies and the meteorological and hydrological data available on the environmental monitoring program's web site.

ACKNOWLEDGEMENTS

Data collection and QA/QC were carried out mainly by Raúl Ríos during the 1990's and early 2000's, and then by Brian Harvey, from 2007 to present, under the supervision of Steve Paton. We are grateful to the many Panamanian staff of the Smithsonian Tropical Research Institute (boat drivers, facilities workers, trail maintenance staff, administrative staff, and others) who, during the past century, have assured that data collection continued under often difficult circumstances such as severe storms, U.S. military invasion, and most recently, a global pandemic. We thank the Smithsonian Institution for sustained funding in support of Lutz Creek watershed data collection.

DATA AVAILABILITY STATEMENT

All data are in the public domain and are freely available.

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