# Iwokrama Baseline Climate and Hydrology Monitoring Programme

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## Introduction

Hydrometeorological instrumentation is a critical component of climate and hydrology monitoring and supports all research related to the water cycle with climate as a key driver. Establishing a baseline understanding of the climate and water-cycle is vital for sustainable forest management, assessments of forest ecosystem services in support of payment mechanisms, biodiversity, carbon capture and storage, ecology and impacts on human populations amongst others.

A new hydroclimate instrumentation program has been established in Iwokrama which is designed to provide baseline datasets for a variety of applications. The set-up is also designed to anticipate varied possible uses for long-term research.

Specifically, the research strategy is based on the following concepts:

- **Quantifying rainfall and evapotranspiration budgets at different timescales**
  The primary aims of the meteorological instrumentation are to provide baseline datasets which can help to quantify the rainfall and evapotranspiration components of the water balance for the Iwokrama rainforest reserve, and to characterise the rainfall inputs at storm, seasonal, and inter-annual timescale.
- **A transect through the climate transition zone**
  Previous studies on regional climate patterns (specifically, a project recently completed by Newcastle University to collate and interpret climate data for the region[1]) indicate that Iwokrama is located at a key transition zone between the coastal-influenced climate with higher annual rainfall and two wet seasons, and the drier continental climate typically with a single wet season. The Rupununi savannah area to the south of Iwokrama also provides an interesting hydrometeorological contrast. The instrumentation is intended to characterise

[1] Bovolo C. I., Parkin G., Wagner T. (2009) *Initial Assessment of the Climate of Guyana and the Region with a Focus on Iwokrama.* School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK

these transitions in more detail, taking a north-south transect through the transition zone.

- **Characterising hydrological response of the landscape**
  The diverse landscape of the Iwokrama forest reserve is characterised by spatial variations in geology and soils, topography, and vegetation types. This diversity leads to different types of hydrological response, with consequences for other aspects such as nutrient cycling and erosion, so one aim of the hydrological instrumentation is to select locations that can support monitoring of these different responses.
- **Characterising forest management impacts**
  A key aspect of studies at Iwokrama is to understand the impacts of sustainable forest management. Based on the historical and planned forest harvesting programme, catchment monitoring locations have been selected to represent different stages in the harvesting cycle.

**Timeline:**

**May 2009:** a team from Newcastle University made an initial exploratory visit to Iwokrama

**Jan 2010:** purchasing and shipment of the instrumentation was completed

**Feb-Apr 2010:** installation of instrumentation was completed by a team from Newcastle University in collaboration with and aided by Iwokrama and HydroMet staff.

Funding for the instrumentation was provided by the Inter-american Development Bank (IDB).

## Monitoring Sites

The general selection criteria for specific instrumented sites include:

- Scientific requirements: spatial distribution, to represent the climate zone transect, different landscape types, different elevations for rainfall, and different stages of the forest harvesting cycle;
- compliance with established international standards, affecting in particular proximity of equipment to surrounding forest and buildings;
- accessibility for regular monitoring and maintenance;
- avoidance of potential for damage.

The instrumentation program comprises (see Table 1 and Figures 1-5):

- two fully automated weather stations (including raingauges and evaporation pans), operating at the Iwokrama Centre and Bina Hill Institute (Annai);
- four additional automated tipping bucket raingauges located at Turtle Mountain and along the forest road;
- two automated water quality monitoring probes;
- six locations on creeks where river levels are constantly recorded.
- Two separate portable field devices (an ADCP sonar system and a current meter) are also available to measure river flow rates, and a hand-held probe to measure water quality.

The rationale for choice of site locations is:

- The two AWS sites at Iwokrama field station and at Bina Hill Institute provide the end members of the climate transition from the forest to the savannah climate zones
- The set of raingauges (including tipping bucket raingauges and storage raingauges) from Iwokrama to Bina Hill provides further detail on the climate transition, as well as providing more detailed sampling of the spatial variability in convection-dominated rainfall, and providing localised rainfall associated with the catchment hydrological studies
- The raingauge at Turtle Mountain is located at a higher elevation, providing some local information on elevation-dependence of rainfall amounts
- The stream flow monitoring locations combined with the water quality continuous monitoring at Tiger Creek and at Blackwater Creek, provide information on an already harvested catchment area and a non-harvested catchment respectively. The stream flow monitoring location at 8-mile Bridge represents a catchment area which is not yet harvested, but is planned to be harvested within a year or two of installation.
- The stream flow monitoring locations at Tiger Creek, 8-mile Bridge, and Blackwater Creek are all located in catchments on similar landscape types with low nutrient status permeable sandy plains and terraces, low topographic variation, and similar forest types. The other two stream monitoring locations at Big Turu Bridge and Kuipari represent different landscape types, receiving water from steeper sloped shallow acidic soils, and thin nutrient-poor clay-loam soils, of steep catchments in the Iwokrama Granite Massif. They also represent the southern end of the climate transect across the Iwokrama reserve.

**Table 1 Hydro-meteorological instrumentation at Iwokrama with final installation dates**

| Location | Automatic weather station (incl. evap pan) | Tipping bucket raingauge | Manual storage raingauge | Stream flow gauging station | Stream water quality |
|---|---|---|---|---|---|
| Iwokrama field station | ✓ 10-04-10 | ✓ 26-03-10 | ✓ pre-existing | | |
| Below Iwokrama forest canopy cover | | ? to be confirmed | | | |
| Turtle Mountain | | ✓ 04-04-10 | | | |
| Tiger Creek (near 3-mile Bridge) | | | | ✓ 28-03-10 | ✓ 28-03-10 |
| Tiger Woods timber site (TGI) | | ✓ 29-03-10 | | | |
| 8-mile Bridge | | | | ✓ 18-03-10 | |
| Blackwater Creek | | | | ✓ 18-03-10 | ✓ 18-03-10 |
| Big Turu Creek | | | | ✓ 17-03-10 | |
| Kuipari Creek | | | | ✓ 17-03-10 | |
| Burro-Burro River | | | | ? to be confirmed | |
| Canopy walkway | | ✓ 30-03-10 | ✓ pre-existing | | |
| Unknown location | | | ? to be confirmed | | |
| Ranger Station 2 (RS2) | | | ✓ pre-existing (+ humidity, temperature) | | |
| Bina Hill | ✓ 08-04-10 | ✓ 08-04-10 | ✓ to be installed | | |

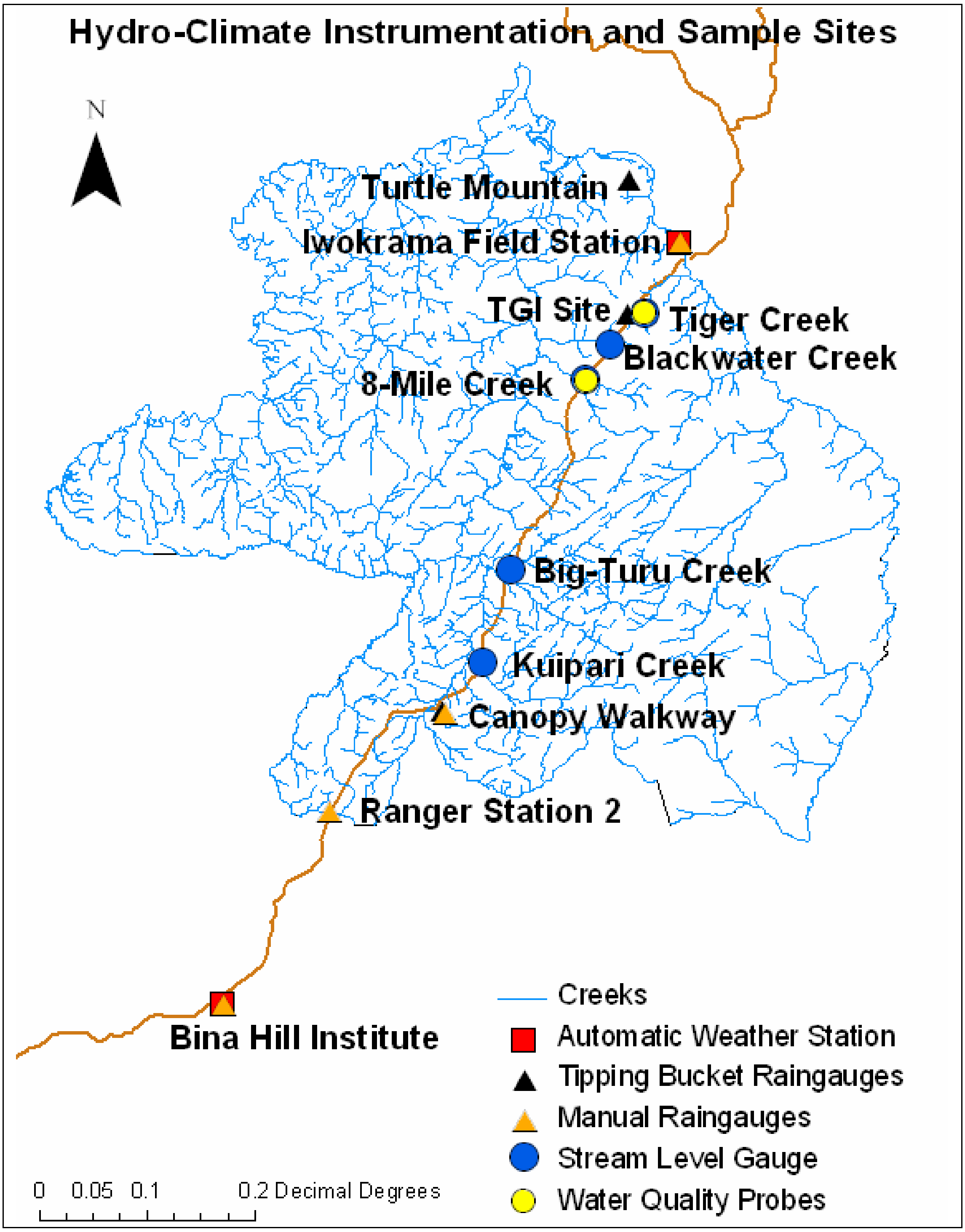



**Figure 1 Hydro-meteorological instrument locations. See also Figures 2-5.**

**Figure 2 Iwokrama Field Station Automatic Weather Station (centre back) with tipping bucket raingauge and evaporation pan (right), older manual raingauge (centre front) and older casing for manual humidity and temperature sensors.**

**Figure 3 Bina Hill Institute Automatic Weather Station (left) with tipping bucket raingauge and evaporation pan (right).**

**Figure 4 Tipping Bucket Raingauges at Tiger Woods Inc (left), Canopy Walkway (centre) and Turtle Mountain (right)**

**Figure 5 Stage (river level) gauges at Tiger Creek, 8-mile Creek, Big Turu Creek, Blackwater Creek, and Kuipari Creek (top left to bottom right). Water quality probes are also installed at Tiger Creek and Blackwater creeks.**

# Instrumentation

## *Instrument selection criteria*

The instrumentation has been selected to be consistent with international standards for installation of hydrometeorological equipment, national practices in Guyana, and robustness for long-term installation.

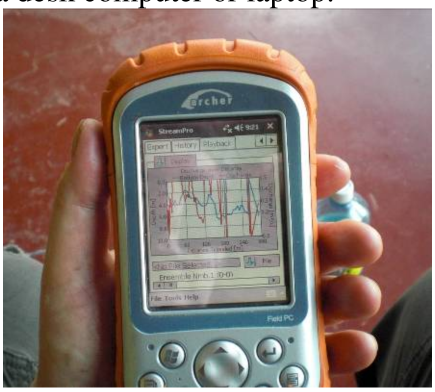
International standards have been followed as closely as possible, in particular those of the World Meteorological Organisation (WMO), for selection of types of instruments, their installation, and monitoring protocols.

Discussions were held with the national hydrometeorology organisation in Guyana, Hydromet, prior to purchasing and installing equipment, to ensure consistency as far as possible with national practices.

Equipment suppliers were chosen based on their reputation and previous track record in installation of equipment under similar tropical environments. Existing customers of suppliers (including national meteorological organisations) and other relevant organisations (including the LBA programme in Amazonia) were consulted prior to purchasing or installing equipment in the field. Particular attention was made to choose instruments that were most likely to perform well over long periods in a tropical forest environment.

## *Field computer*

A robust hand-held field computer, the Archerpad, is used to download data from all field equipment except the Automatic Weather Stations, which have a permanent landline connection to indoors computers. The Archerpad runs specialist software for each type of instrumentation on a Windows Mobile operating system, and data can easily be synchronised to a desk computer or laptop.



Archerpad field computer

## *Raingauges*

### Tipping bucket raingauge

A tipping bucket raingauge monitors rainfall intensity at a high resolution. The Casella raingauge comprises a metal cylinder with a funnel at the top, beneath which is a divided bucket assembly, pivoted at the centre. Rain from the funnel collects in one side of the bucket, which then tips when a predetermined volume of water has

been collected. The tipping action discharges the collected water and repositions the opposite side of the bucket under the discharge nozzle ready for filling. The bucket tips are monitored by means of a sealed reed switch.
The bucket size recommended and chosen for these installations is 0.5mm per tip, which is appropriate for tropical installations. Each tip of the bucket is recorded on a data logger, allowing rainfall intensities to be assessed. The data can then be aggregated to longer intervals (eg hourly, daily, monthly) as required.
The same model of raingauge is used with the Automatic Weather Stations (see below), where they are connected to the central logger through a protected cable, and for standalone installations, where a data logger and batteries are integrated within the gauge cylinder housing. The raingauges are all installed with the rim of the funnel at a height of 1m above ground, consistent with standard practice in Guyana.

Tipping bucket raingauge being tested in the field

Tipping mechanism inside tipping bucket raingauge

Existing storage raingauge at Iwokrama Field Station

### Storage raingauges

Storage (or manual) raingauges are the most commonly used type of raingauges in many places, as they are relatively cheap and easy to use. They comprise of a metal cylinder with a funnel, beneath which is a collecting jar. On a regular basis (usually daily), the jar is emptied into a measuring cylinder, and the total amount of rainfall collected during the measuring interval is recorded manually onto a data sheet. Additional Casella storage raingauges have been purchased for Iwokrama, to ensure that there is consistency between the new tipping bucket raingauge data and this more traditional method of recording rainfall.

## *Automatic weather station*

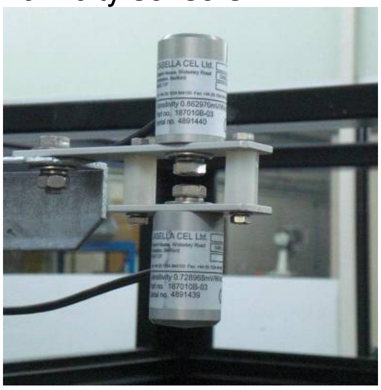
Casella Automatic Weather Stations (AWS) record all the variables needed to calculate rainfall and potential evapotranspiration at a site, allowing these two key variables of a catchment water balance to be estimated. Each AWS includes sensors for: temperature, humidity, wind speed, wind direction, solar radiation, back (ground) radiation, atmospheric pressure. In addition, each AWS includes a tipping bucket raingauge, and an evaporation pan.
Power is provided through solar panels, and a landline telemetry cable, which is connected directly to an indoors computer at each site. Data can be continually transmitted to the computer without operator intervention, allowing secure backups and internet access to datasets to be potentially set up.


Automatic Weather Station


Screen housing temperature and humidity sensors


Wind vane (wind direction)


Anemometer (wind speed)


Net (solar and back) radiation sensors


Logger, battery, and atmospheric pressure sensor

## *Evaporation pans*

Each weather station includes a Class A evaporation pan and water level sensor. Evaporation pans are used to measure rates of open water evaporation, which can be used to estimate total rates of evapotranspiration. The water level sensor is linked to the AWS data logger. Class A pans are an internationally-recognised standard design, allowing intercomparisons with other sites.


Class A evaporation pan


Evaporation pan water level sensor

## *Stream flow gauging*

### Stage (water level) monitoring

Stream stage (water level) is recorded continuously (at short time intervals eg 15 minutes) using a GEMS Level Sensor DCL9500 connected to a Frog data logger through a vented cable. The sensor measures water depth above the sensor tip, and is calibrated to record actual water level according to a gauge board. The sensor is housed within a stilling well, a narrow plastic pipe with holes which allow water level to equilibrate between the stream and the well. The gauge board and stilling well are securely installed to a permanent fixed point in the stream.

Water level pressure sensor

Frog data loggers and Archerpad field computer

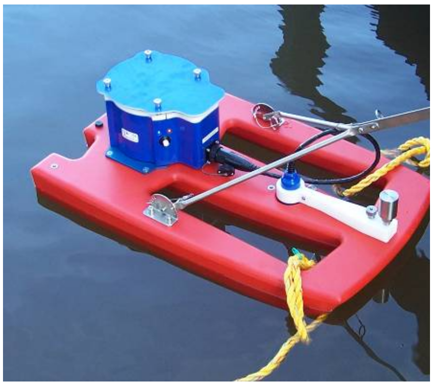
Gauge board and stilling well

### Stream flow measurements

As continuous stream flow rates are required as part of a catchment water balance, instantaneous measurements of stream flow must be made at different flow rates, to establish a relationship between water level and flow rate called a rating curve. Once such a relationship is established, the continuous water level data can be converted to continuous flow data.

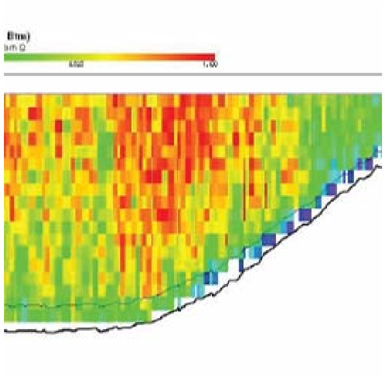
Two methods for measuring stream flow are used: current metering, and Acoustic Doppler Current Profiler (ADCP). A current meter is a device with a small rotating propeller that measures water velocity at each point across the stream. For this study, a Valeport current meter BFM002 wading set with 50mm diameter 1178 series impeller is used.

The ADCP is a floating instrument that is pulled slowly across a stream on a rope (or pulled across larger rivers with a boat), and measures water depth and velocity using sonic pulses. Both devices include software that automatically calculates total flow rate from the measurements.



Acoustic Doppler Current Profiler (ADCP)

ADCP sonic trans-mitter / receiver

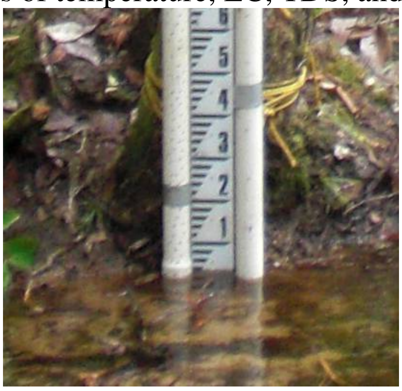


Output from ADCP: stream velocity cross-section

### *Handheld water quality multi-meter*

Continuous measurements of key water quality parameters are made using a YSI 600 XLM multi-parameter device, with sondes to measure: Temperature, Electrical Conductivity (EC), Oxygen Reducing Potential (ORP), Total Dissolved Solids (TDS), and pH. These devices are installed in stilling wells designed to protect the device while allowing a continuous throughflow of water, and record parameters at frequent intervals (eg 15 minutes). Calibration of each sonde is required using calibration standards, which can be carried out in the field.
In addition, a hand-held water quality meter (an Ultrameter) is available to take spot measurements at other locations of temperature, EC, TDS, and pH.

YSI 600 XLM multi-meter



Stream water level and quality monitoring station

# Initial Results

## *Automatic Weather Station*

Preliminary results are only available from the Automatic Weather station located at Iwokrama and some stream gauges. These are shown below.

Figure 6 shows solarimeter measurements (incoming and reflected radiation from the sun), atmospheric pressure, humidity and air temperature and hourly and daily precipitation totals. The results are shown for 13-3-10 to 13-4-10. Data gaps are due to the AWS unit being switched off during installation. All measurements have a large diurnal variation but also vary day to day.

Preliminary results for at the Iwokrama field station for the given time period show that direct solar radiation reached 1100 W/m$^2$ on 9$^{th}$ April 2010 whilst nett solar radiation reached over 750 W/m$^2$. Average peak values tend to be about 650 and 450 W/m$^2$ for direct and nett solar radiation respectively.

Daily measurements of atmosphierc pressure vary between 1009 and 1001 mb and are lowest during precipitation events. Humidity and Temperature are highly correlated. Temperature ranges between 22 and 34 degrees and temperature decreases during a precipitation event. Humidity is generally around 50% during the day but reaches 95 % at night. Precipitation events cause daily humidity levels to increase significantly. Over the short test period, daily (midnight to midnight) precipitation reached about 60mm/day whilst 5 minute intensities reached 25mm/hour.

The data can also be examined for daily cycles (Figure 7). Humidity over the period is generally very high at night but drops rapidly during the day from about 7am reaching is minimum at about 3pm before rising again at night. Where the humidity is particularly high during the middle of the day, this is caused by precipitation events. Temperature is generally quite steady during the night but rises rapidly from about 7am, again peaking at about 3pm.

Solar radiation is minimal at night but increases very rapidly at 6am when the sun rises and peaks at midday. In the evening, reflected radiation from the ground is higher than the direct radiation levels although reflected radiation levels very small of the order of 1 W/m$^2$.

River level data for a few sites is currently available (Figure 8). The rivers examined in the study appear to have different behaviours, peaking in response to precipitation at different times and in different ways, however water temperature between the river sites appears to be relatively well correlated and is very similar between all the streams.

Focussing on the Blackwater Creek river level, it can be seen that the creek begins to respond to precipitation events relatively quickly but that it takes about 3 days for the river to reach its peak level. Water levels then recede fairly slowly over several days.

The hydro-climate monitoring sytem is now mostly operational and further results will be available in due course.

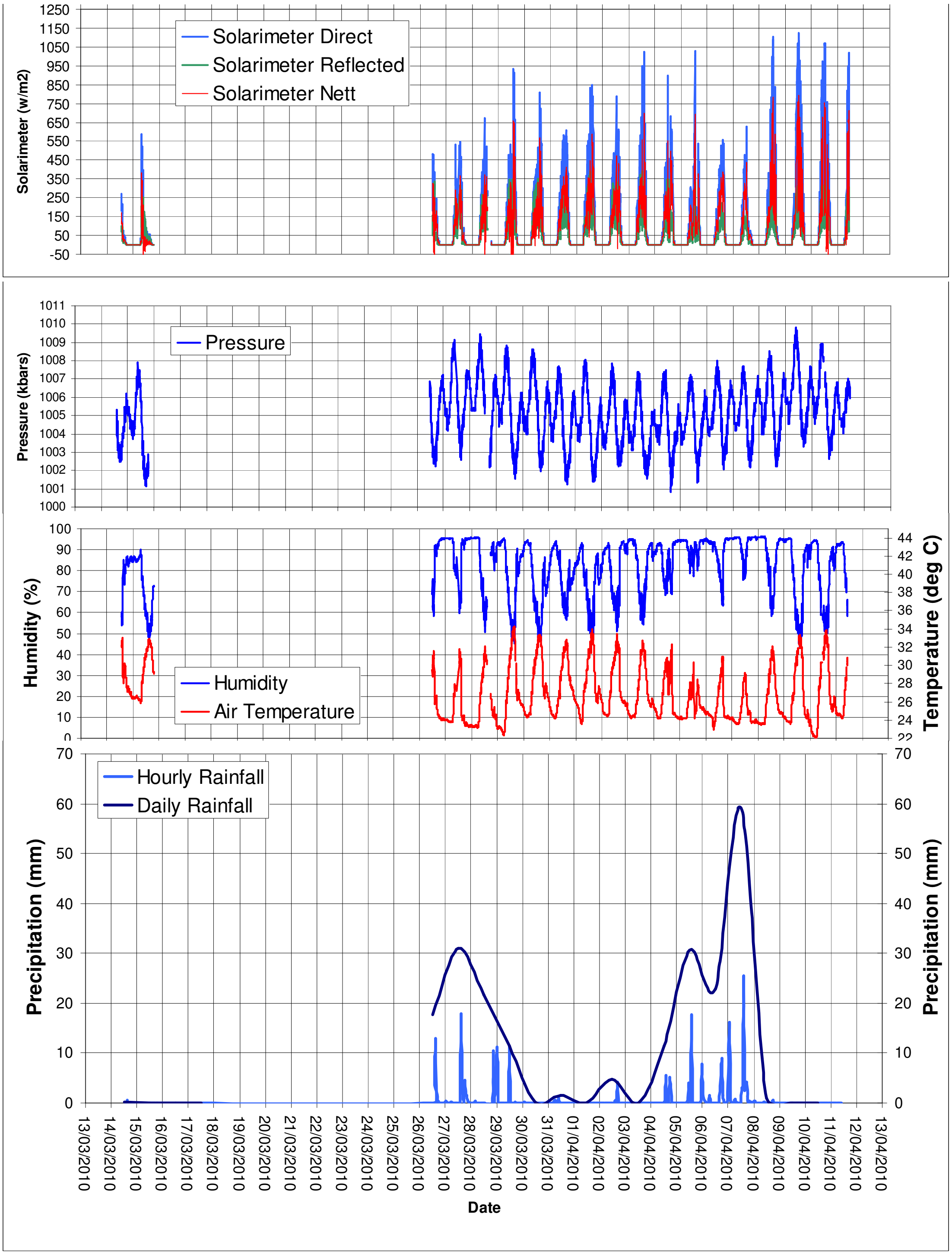



**Figure 6 Iwokrama Field Station Automatic Weather Station 1st results for continuous available data between 13/3/10 and 13/4/10.**

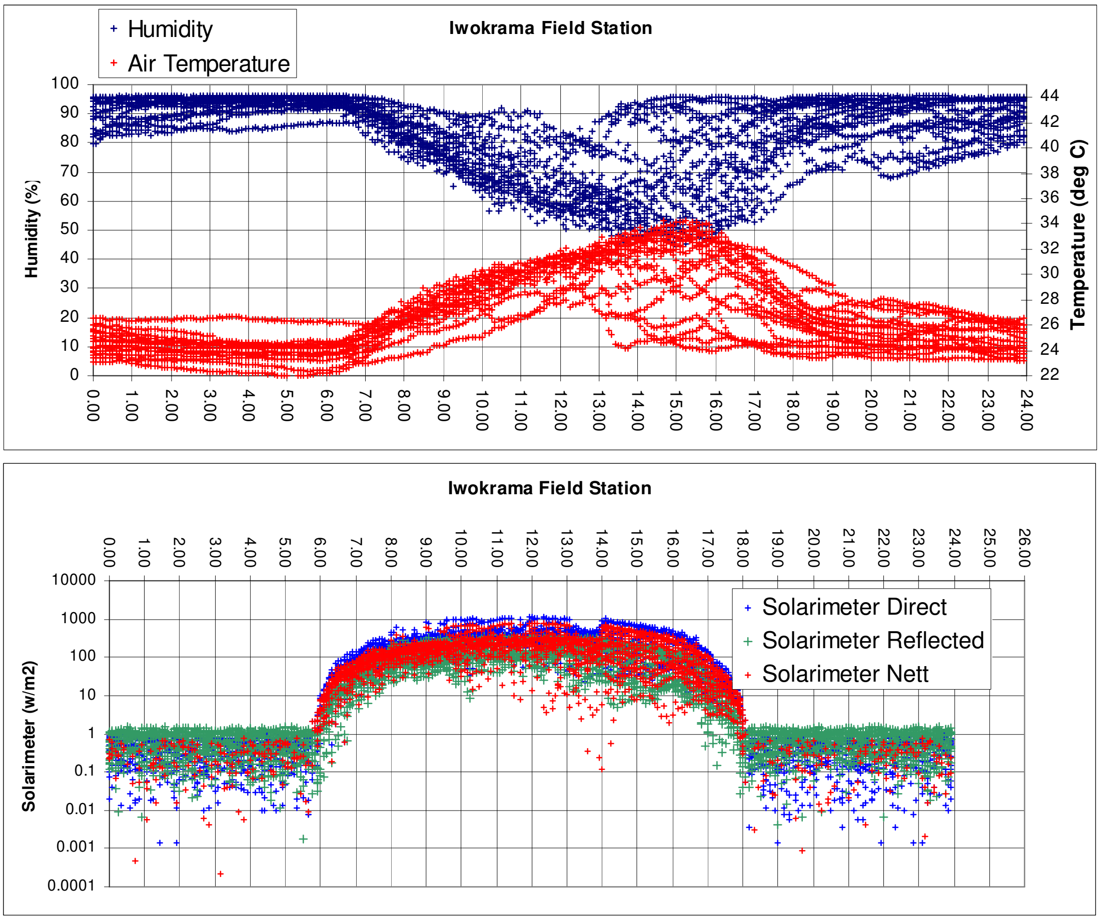



**Figure 7 Daily Iwokrama Field Station Automatic Weather Station 1st results for available data between 13/3/10 and 13/4/10 (note the log-scale for the Solarimeter graph).**

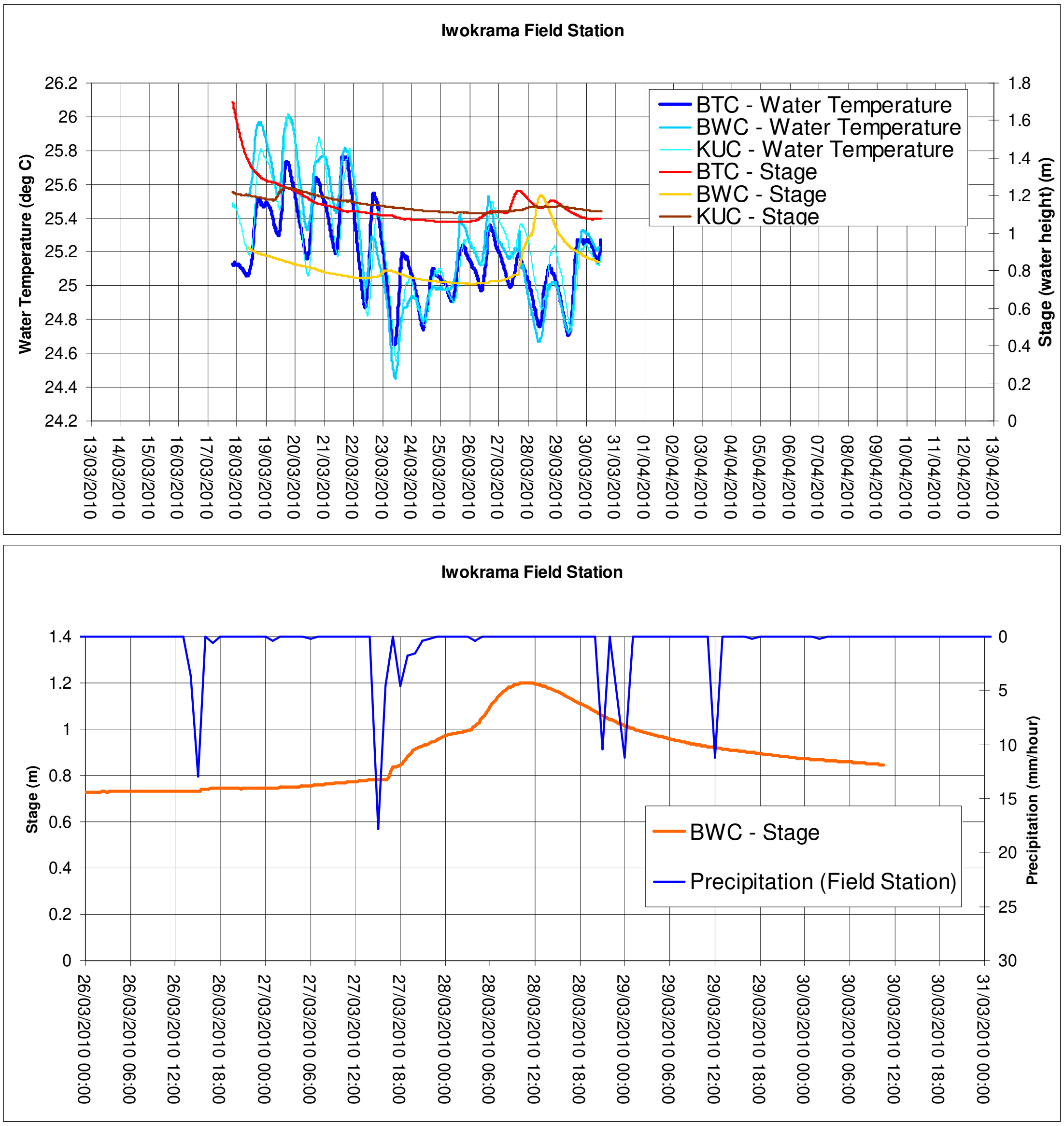



**Figure 8 Stream level and stream temperature for Blackwater Creek (BWC), Big Turu Creek (BTC) and Kuiparu (KUC) (top) and stream level and hourly precipitation for a select time-period for Blackwater Creek (bottom)**