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Working Paper

Guideline: Community-based hydroclimate monitoring: planning, establishing and operating

David Walker, Alemseged Tamiru Haile, John Gowing, Yebegaeshet Legesse, Girma Gebrehawariat, Hailu Hundie, Daniel Berhanu, Geoff Parkin

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www.reachwater.org.uk

School of Geography and the Environment, South Parks Road, Oxford OX1 3QY, UK

reach@water.ox.ac.uk

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About the authors:

David Walker is a postdoctoral research associate working within the Water Group at the School of Engineering, Newcastle University, UK. He has a background in hydrogeology, specialising in water resource resilience to climate variability, land use change and increased abstraction for small-scale irrigation in sub-Saharan Africa and India. Alemseged Tamiru Haile is a researcher in hydrology at International Water Management Institute (IWMI), Addis Ababa, Ethiopia. He works on hydrological modelling with particular focus on surface water, floods, shallow groundwater resources and climate change. John Gowing is a reader in agricultural water management at Newcastle University, UK. He works on soil and water engineering in the context of sustainable rural development, with a particular focus on environmental and livelihood impacts of land and water development. Yebegaeshet Legesse is an environment expert in the Ministry of Agriculture (MoANR), Addis Ababa, Ethiopia. He works in the Sustainable Land Management (SLM) Programme as an environmental safeguard specialist ensuring the project interventions are environmentally sound and feasible. Girma Gebrehawariat currently serves the SLM Programme as a watershed management, monitoring and evaluation senior expert at the MoANR, Addis Ababa, Ethiopia. He has expertise in Geographic Information Systems and remote sensing applications for natural resources management practice. Hailu Hundie is an advisor for watershed development in the SLM Programme coordination unit at the MoANR, Addis Ababa, Ethiopia. Daniel Berhanu is a researcher in hydroclimatology in the Water and Land Resource Centre of Addis Ababa University, Ethiopia. He works on data analysis, interpretation and writing synthesised reports. Geoff Parkin is a senior lecturer in the Water Group, School of Engineering, Newcastle University. He has a background in water resources and hydrological modelling, with particular interests in integrated groundwater – surface water systems, and in community-based water management.

Key words:

Community-based monitoring; citizen science; participatory approach; hydroclimatology; hydrometeorology; water security; water resources; water management; shallow groundwater; land degradation; rural communities; RLLP; Ethiopia

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Project organisations:

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Purpose and scope:

This document has been developed following citizen science research in Ethiopia since March 2014, where multiple study sites have had community-based monitoring (CBM) implemented using an iterative process leading to continual improvement of the methodology. In addition, the manual considers successful CBM in India, the UK and South Africa which have informed and been informed by the Ethiopia research.

This document provides the first guideline to inform CBM implementation in Ethiopia. It is recognised under the World Bank funded Sustainable Land Management (SLM) programmes and Resilient Landscape and Livelihood Project (RLLP) that monitoring of water resources is required. However, the micro-watersheds involved in the projects are not covered by the formal hydroclimate monitoring network. This manual has been produced specifically to guide the planning, establishing and running of community-based hydroclimate monitoring at SLM/RLLP micro-watersheds in Ethiopia, but may be useful for other organisations, projects, and locations where CBM may be beneficial.

CBM is proposed as a solution to data scarcity in watersheds where a better understanding of water resources is required. CBM can provide continuous time series of hydroclimate data, which are invaluable in quantifying water fluxes and storage. River stage and flow, spring flow, groundwater level, and rainfall, can all be monitored by local communities following training and equipment installation. Implementing CBM to better understand the hydroclimatology could have a variety of purposes, which are outlined in Section 2. These include:

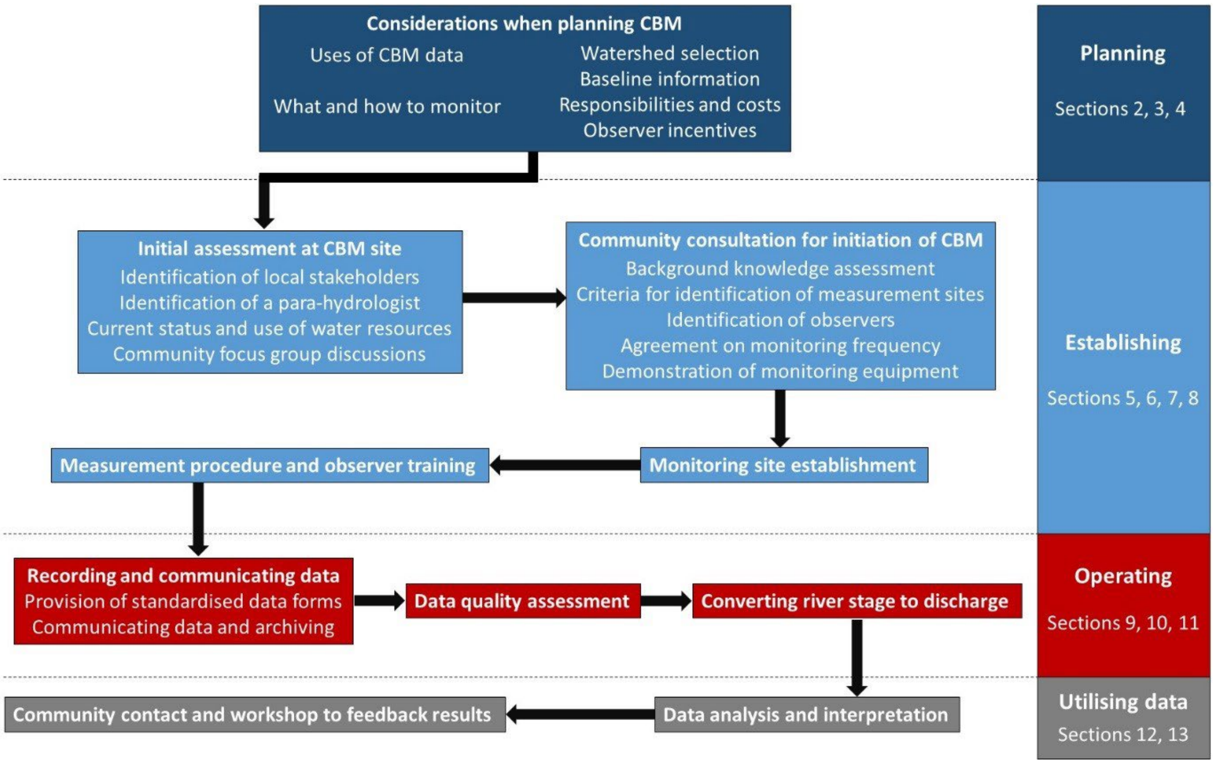
- Evaluation of the performance of sustainable land management interventions
- Identification of patterns, cycles and trends in rainfall to influence rainfed agriculture
- Assessment of the potential for using groundwater or river water for irrigation
- Monitoring impacts of groundwater pumping or river abstraction
- Provision of data to support anecdotal observations, e.g. concerning flood risks or climate change
- Assessment of potential climate change or land use change impacts on water resources

Data collected by local communities, a process known as "citizen science", provides benefits to both the experts and to the communities themselves. The experts, who could be scientists, researchers, or high-level stakeholders such as government ministries and non-governmental organisations (NGOs), benefit by obtaining data at low cost. The local community benefit by increasing their knowledge of their environment and water resources.

This guideline is aimed at technical staff involved in introducing CBM such as researchers, development agents and *woreda* (district) level experts. The purpose of the guideline is to present step by step procedures on how to plan, establish and operate CBM.

The guideline gives instruction for every required stage, such as:

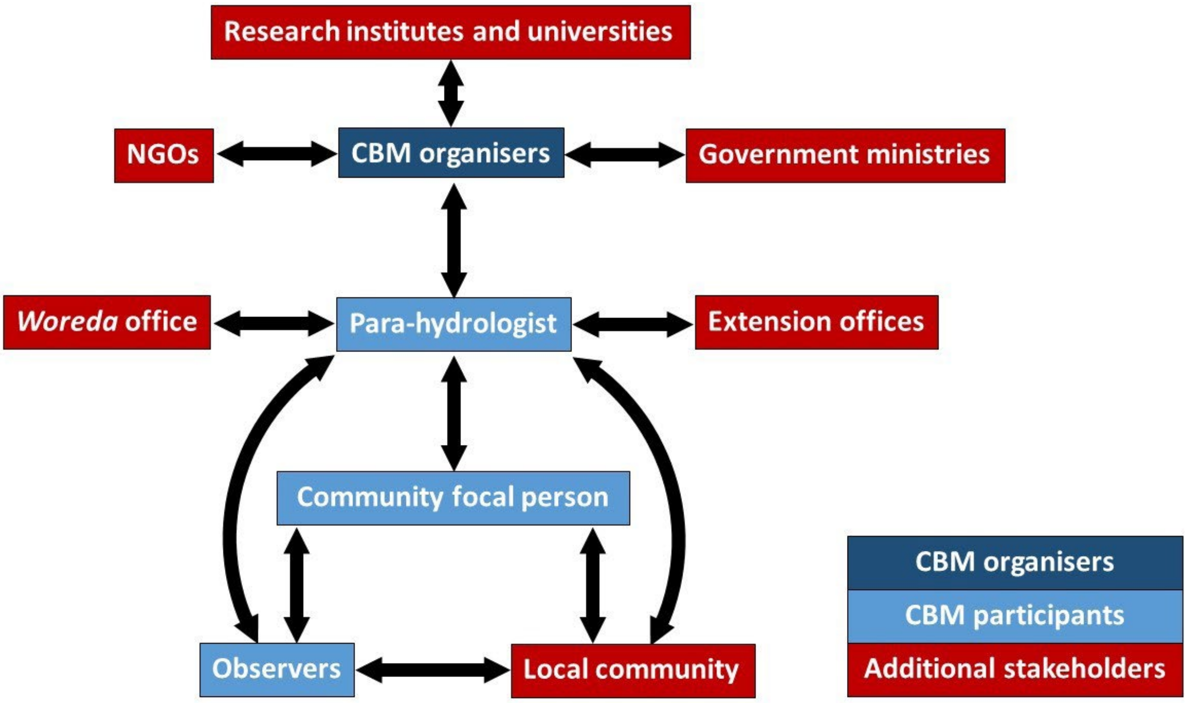
- How to decide what to monitor and how to go about monitoring it
- What must be carried out at the initial site visit and who needs to be involved
- What equipment is available, how to select appropriate equipment, and where to install it
- How to select and train the observers
- Data management and quality control
- How to analyse and interpret the data
- Providing feedback and findings to the community.



A methodology flow diagram is presented above. The steps shown in the diagram conform to sections of this guideline.

An organisational chart is presented on the following page showing the lines of communication for successful operation of CBM. The arrows also represent the flow of data and of knowledge. The various stakeholders and participants are discussed within this guideline. It is noted that the "CBM organisers" at whom this guideline is aimed may be from the adjacent stakeholders within the organisational chart, i.e. research institutes, universities, NGOs or government ministries. Similarly, the "para-hydrologist" is likely to be from the *woreda* office or an extension office. During community consultations and workshops at the planning stage and during later workshops to disseminate findings, additional arrows could be drawn representing a two-way flow of knowledge directly between the CBM organisers and the local community.

Despite its preparation specifically for the implementation of CBM at RLLP sites in Ethiopia, the methodology presented in this guideline should be largely applicable anywhere in the world. Different governance structures and cultural variations may mean that stakeholders must be approached and community consultations run in a country-specific manner. However, the technical detail here presented is widely applicable.



Document history:

The requirement for this guideline was first expressed by the Ministry of Agriculture and Natural Resources (MoANR) during a hydrogeology and citizen science capacity building workshop in Addis Ababa run by Newcastle University and International Water Management Institute (IWMI) in May 2018. The World Bank have stated that monitoring is required to confirm positive hydrological impacts of their funded watershed interventions in Ethiopia. The guideline was initially prepared by Newcastle University and IWMI based on experience of establishing and running multiple CBM programmes around Ethiopia, and elsewhere in the world. A two-day writing retreat was held in Bishoftu in October 2018 with participants from Newcastle University, IWMI, the MoANR SLM programme, and the Water and Land Resource Centre (WLRC). The aim of the writing retreat was to co-produce a guideline document drawing on our combined experiences, with significant input from the institutions who would be implementing the guideline. Further consultation with WLRC followed the writing retreat to ensure the usability of the guideline. The document then went through two stages of peer review, external (REACH, Oxford University) and internal (School of Engineering, Newcastle University), during finalisation. It is the intention of the MoANR to adopt this guideline for planning, establishing and operating CBM at the World Bank funded RLLP sites on commencement of the project in 2019..

Contents:

Glossary:

Catchment	See "watershed".
Citizen science	Scientific work undertaken by members of the public, often in collaboration with or under the direction of scientific institutions.
Community-based monitoring (CBM)	Regular monitoring of meteorology and hydrology, e.g. rainfall, river stage and groundwater level, by members of the public.
Current-meter	A device with an impellor or electromagnetic sensor that measures water velocity, which is used for flow gauging.
Datalogger	An electronic device that stores automatic measurements until the data can be downloaded.
Dip-meter	A measuring tape with an electronic tip that beeps when in contact with water, which is used for measuring depth to the water level.
Flow gauging	Measurement of water velocity and depth across a stream cross-section for calculation of flow (discharge).
Formal hydroclimate monitoring	Regular monitoring of meteorology and hydrology, e.g. rainfall, river stage and groundwater level, by trained professionals working for national institutions.
Kebele	The smallest administrative unit in Ethiopia; equivalent to a village or parish.
Manual rain gauge	A rain gauge that stores water; the stored water volume is measured every 24 hours to give the daily rainfall total.
Observer	A person who makes measurements; a data collector.
Para-hydrologist	A community member who, although not formally (university) trained in physical sciences or engineering, has acquired sufficient basic understanding of hydrological principles and techniques, and is recognised within the community as a competent person. Her/his role is to function as an intermediary between the community and external agencies.
Pressure transducer	An electronic device that automatically measures water pressure, which can be converted to water depth.
Recharge	Water that infiltrates into the ground and contributes to groundwater storage.

River stage	The water level of a river above a local reference elevation, i.e. the riverbed
Smartphone app	A computer program designed to run on a mobile phone.
Staff gauge	A graduated board placed into a river from which water level can be directly observed.
Tipping-bucket automatic rain gauge	An automatic rain gauge that accurately measures rainfall. Rainfall travels down a funnel and drips into a carefully calibrated pair of 'buckets' balanced on a pivot. The buckets rest on one side of the pivot until one of the buckets has filled to the calibrated amount (typically 0.2 mm of rain, although 0.5 mm buckets may be used in areas where intensive rainfall occurs). When the bucket has filled to this amount, the water causes the pivot to tip, which triggers an electronic switch, sending a message to the datalogger. The water empties down a drainage hole, and further rainfall then starts to fill the opposite bucket.
Watershed	The area drained by a river system. Also known as a catchment.
Woreda	The second smallest administrative unit in Ethiopia; equivalent to a district.

List of abbreviations and acronyms:

ATA	Agricultural Transformation Agency
CBM	Community-based monitoring
IWMI	International Water Management Institute
mbgl	Metres below ground level
MoANR	Ministry of Agriculture and Natural Resources
MoWIE	Ministry of Water, Irrigation and Electricity
NGO	Non-governmental organisation
NMA	National Meteorology Agency
PET	Potential evapotranspiration.
RLLP	Resilient Landscape and Livelihood Project
SLM	Sustainable Land Management

1. Introduction

This section provides background on the hydrological system, also known as the water cycle, describing which aspects of the system can be monitored. Background is then provided on the two classes of hydroclimate monitoring: formal and informal.

1.1. The hydrological system

The hydrological system is usually described as a cycle with water passing from one reservoir to another. The sun's energy causes surface water from land and sea to evaporate, which then condenses to form clouds. Precipitation follows, which is intercepted by vegetation or reaches the ground surface to then runoff or infiltrate into the soil. Evapotranspiration occurs from soil and vegetation, while some infiltrated water recharges underlying aquifers. Surface water and groundwater flows will generally return to the sea through rivers, and the cycle continues. The hydrological cycle can be simplified for an individual watershed to show the hydrological balance over a long period (Figure 1). The watershed hydrological balance can also be described as an equation:

$$P = Q + E \pm \Delta S$$

Where P is precipitation, Q is discharge (river flow), E is evapotranspiration, and ΔS is change in storage (surface or subsurface). Note that groundwater recharge is not included in Equation 1 as a loss from the system as it contributes to ΔS. Quantifying the variations over time and space of the components in Equation 1 provides understanding of how a watershed functions, and shows the impacts of any changes. Where these components are not formally monitored, citizen science can provide the time series data to fill this observational.

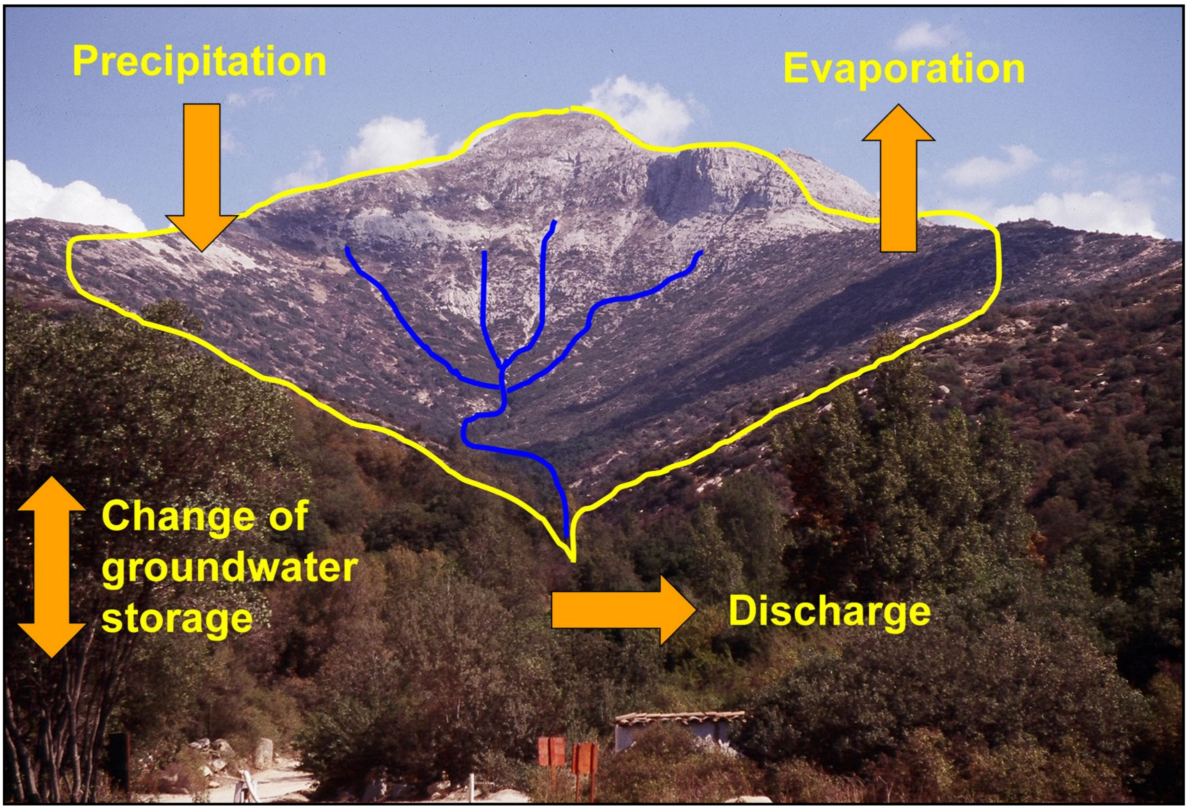


FIGURE 1: The hydrological balance (Photo from: James Bathurst).

1.2. Formal hydroclimate monitoring networks

Formal monitoring is conducted by formally trained observers (data collectors), typically employed by national hydroclimate institutions. Strengths of these formal monitoring networks are the long period datasets and data accuracy. Unfortunately, formal hydroclimate monitoring networks are sparse in many regions of the world. Groundwater level data in particular are largely non-existent in sub-Saharan Africa and other developing regions. Rainfall and river flow monitoring stations are declining in number as national institutions, particularly in the developing world, embark on cost-cutting practices . Where hydroclimate monitoring networks do exist, the density is often too low for anything smaller than regional water resource assessment. The importance of quantitative information on the rainfall which controls spatially and temporally variable water resources and of time series data of the surface/groundwater resources themselves is not in doubt.

Rainfall and other meteorological variables are collected in Ethiopia by the National Meteorology Agency (NMA) while river stage data is collected by the Ministry of Water, Irrigation and Electricity (MoWIE). The NMA and MoWIE monitoring network density is low, especially in rural areas. Shallow groundwater levels, i.e. hand dug wells and springs, are not monitored; however, some attention is given to shallow groundwater by the Agricultural Transformation Agency (ATA): The ATA launched shallow groundwater mapping in 2013 across selected areas in Ethiopia. The mapping is based on extensive field data of shallow aquifers, remote sensing, and modelling. In 2019 the ATA approved Phase 4 of the mapping; in each phase shallow groundwater in new geographic areas is mapped to promote smallholder irrigation.

1.3. Citizen science (informal hydroclimate monitoring)

"Citizen science" is defined by the Oxford English Dictionary as "scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (OED, 2018). An alternative commonly reported definition from Lewenstein (2004) gives: "The participation of non-scientists in the process of gathering data according to specific scientific protocols and in the process of using and interpreting that data".

Citizen science has existed for many years with successful applications including wildlife surveys, public health, and astronomy. Research has also shown that high quality hydroclimate data can be collected by non-specialists from local communities, to complement that from formal sources or provide time series where no formal alternatives are available (Walker et al., 2016). The authors have taken into account wider experience in the published literature on CBM, but this document aims to distil experience into practical guidance, so for simplicity of presentation, a full review of the literature is not included here.

Boxed text 1 - Established community-based monitoring (CBM)

Our citizen science research in Ethiopia extends to five study sites shown in Figure B1. CBM was established at each site sequentially with each programme learning from experience at the previous sites. Details of each study site is shown in Table B1.

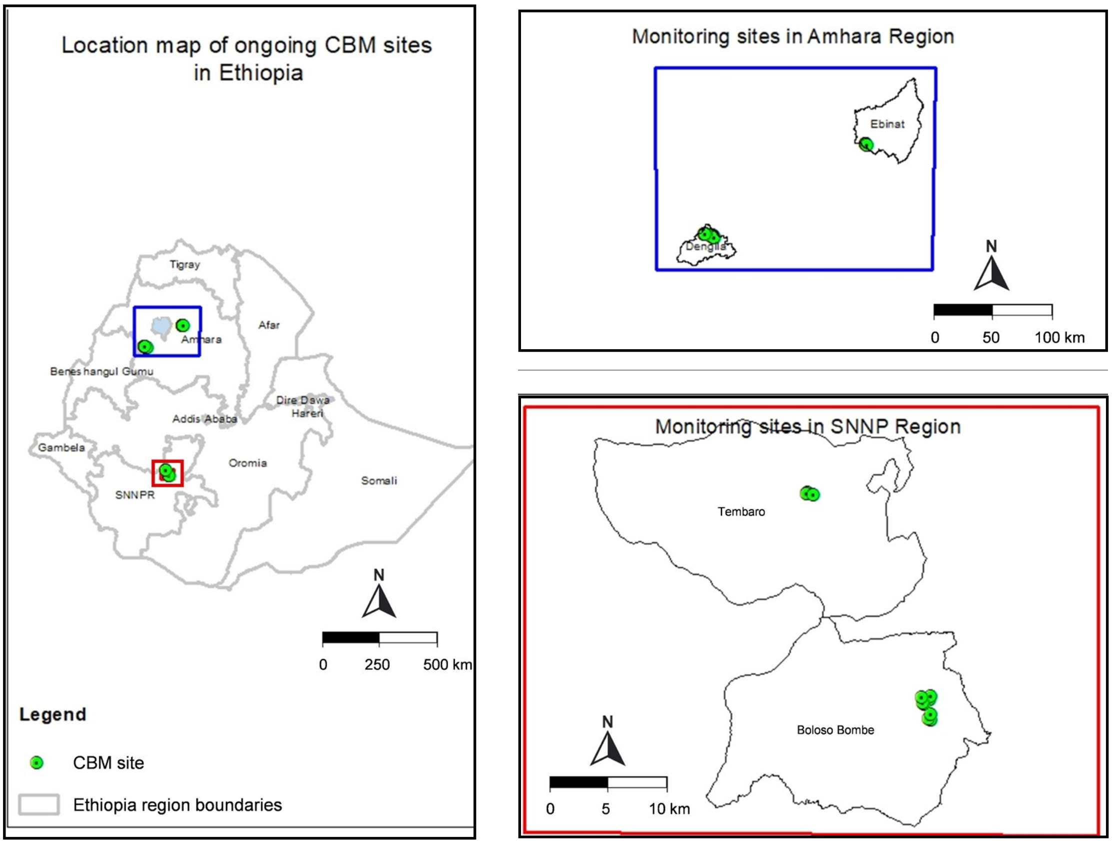


FIGURE B1: Location map of the five established citizen science study sites.

TABLE B1: Details of the five established citizen science study sites.

Woreda	Kebele	Monitored	Date established	Purpose of monitoring
Dangila	Dangesheta	Rainfall 2x rivers 5x wells	March 2014	Assess the potential to use shallow groundwater for small-scale irrigation
Boloso Bombe	Ferawocha	Rainfall 2x rivers 1x spring 4x wells	February 2017	Evaluate the hydrological impacts of land degradation interventions
Dangila	Ajuri	Rainfall 1x river 4x wells	April 2017	Aid with adaptive management of shallow groundwater
Tembaro	Sigesu	Rainfall 1x river 1x spring	March 2018	Evaluate the hydrological impacts of land degradation interventions

2. Uses of CBM data

This section provides examples of various uses for CBM hydroclimate data.

2.1. Monitoring impacts of sustainable land management intervention

The World Bank funded Sustainable Land Management (SLM) programme in Ethiopia aimed to reduce land degradation and improve land productivity in selected watersheds (World Bank, 2017). The subsequent Resilient Landscapes and Livelihoods Project (RLLP) will further promote effective landscape management activities to increase land productivity and help improve the livelihoods of 3.2 million Ethiopians, particularly those who are vulnerable to climate variability, recurrent drought and floods, and land degradation (World Bank, 2018). Hydroclimate monitoring is a requirement of these projects and enables the impacts of watershed interventions conducted under the SLM and RLLP projects to be evaluated.

Land degradation interventions aim to reduce soil erosion and increase groundwater recharge by slowing down and retaining surface water runoff. Interventions include gully rehabilitation, runoff collection trenches, regrading or terracing slopes, re-planting degraded land, and physical barriers (e.g. aloe) preventing grazing on recovering land. Monitoring the watershed's water fluxes will reveal the success of interventions in enhancing water availability within the watershed, and provide a basis to support evaluation of erosion protection (direct assessment of erosion and sediment yield is beyond the remit of this guidance document). Monitoring groundwater levels would show if recharge has increased. Monitoring river flow would show if dry season low flows have increased. Monitoring rainfall and comparing to river flow will show if the lag times between rainfall events and flood peaks have been slowed.

2.2. Informing rainfed agriculture

Rainfed agriculture is the main source of livelihood for 90% of the population of Ethiopia. Production is widely water-limited and many farmers have to cope with the twin problems of limited total rainfall amount combined with its unreliable occurrence and erratic distribution. In the absence of irrigation, increasing water productivity offers the only option to improve rainfed agriculture. There is abundant evidence that doubling yield is achievable by 'producing more crop per drop of rain' through adoption of available sustainable agriculture practices on farmers' fields.

The entry point for interventions to transfer knowledge from 'bright spots' is understanding the local field water balance and in particular the severity and frequency of dry spells. CBM derived rainfall data provides the basis for identifying best-bet interventions and for exploring options with farmers in participatory on-farm research.

2.3. Determining availability of groundwater or river water for irrigation and water supply

In areas with distinctly seasonal rainfall, following the main rainfed growing season, a second growing season could be achieved utilising irrigation to improve food security and alleviate poverty. This is possible if the water source remains available and accessible throughout the second growing season, and quantity exceeds what is needed for domestic supply. Monitoring of groundwater levels or river flow, depending on which is the source of irrigation, will show the recession of the water resources following the wet season. Quantification of water resources and recession rates at the time of planting can inform choices of crops and how large an area to cultivate.

This system of monitoring to inform agricultural management decisions is successfully ongoing in Burkina Faso (WaterAid, 2018): Groundwater levels are monitored and plotted by community members involved in market gardening to aid decision-making on what and when to plant, or whether to focus on livestock, or resort to alternative livelihoods during drought years.

2.4. Monitoring impacts of groundwater or river abstraction

Where abstraction takes place from multiple water sources, it is wise to monitor the water availability of the different sources. If the monitoring data indicates that a particular well, borehole, river or spring has low water availability, this may be related to upstream water usage. Investigation and management of all sources within an area is recommended; using monitoring information as a basis for shared decision-making on water allocation. I.e. usage of particular water sources can be restricted or halted.

Such a scheme is working successfully in Burkina Faso where restrictions may be placed on the amount of water each person can take meaning subsequent water users are not left short. Decisions are also made on whether to halt certain water-using activities, such as brick making, in order to maintain the water for domestic use (WaterAid, 2018).

2.5. Provision of data for community empowerment

Local communities are often acutely aware of their own environment and any trends in climatological or hydrological behaviour. This is especially true for communities dependent on regular weather patterns and those severely impacted by extremes. Unfortunately, institutions reliant on possibly distant formal hydroclimate data may not be sympathetic to local stakeholders' causes when this formal data does not match their claims. CBM data can support local stakeholders' arguments. Additionally, it can increase their quantitative awareness, establishing a basis for shared understanding in discussions with institutional stakeholders. This results in local empowerment and improved environmental governance through citizen science.

Identification of patterns in groundwater level and rainfall monitored since March 2014 in Dangila *woreda* has enabled the observer to identify groundwater drought (a sustained period of below average groundwater availability due to low recharge). The observer who records groundwater level informs well owners when he observes unusually low or high groundwater level. This has empowered the observer to advise well owners on groundwater utilisation and crop management, e.g. suggesting an increase or decrease in rate of water abstraction or suggesting earlier planting. Additionally, the observer advisers well owners to maintain the well cover when he notices that groundwater has become turbid due to flood water entering the well. When the groundwater stored in the well becomes extremely low, the observer advises the owners to clean or deepen the well. The observer also explains to other community members about the effects of well diameter on groundwater storage and the potential of groundwater for backyard irrigation.

2.6. Support decision making through modelling

This is a more advanced use of CBM data where it can be used for hydrological modelling. These models aim to accurately represent the natural processes occurring in watershed, in terms of precipitation and evapotranspiration, infiltration and recharge, groundwater and river flow, and groundwater and surface water storage. Future scenarios, such as land use and/or climate change, can then be applied and the impacts on water resources can be simulated. Water resource and agricultural management decisions can be informed by the results of this modelling. See Boxed text 2 for an example.

Boxed text 2 - Dangila *woreda*

CBM was initiated in Dangesheta *kebele*, Dangila *woreda*, in February 2014. The community were consulted and involved in siting the rain and river gauges and identifying the wells to be monitored. Hydrologically suitable areas were identified, i.e. narrow channels and valleys for the river gauges where river stage fluctuations would be most pronounced and open areas with no overhead obstructions for the rain gauge. Certain locations were excluded for being too open where the community expressed concern over the security of the equipment. Ultimately the rain gauge was situated within the smallholding of the community member who would monitor the gauge. The monitored wells were chosen to provide a transect from close to the river and floodplain up towards a watershed boundary that would include successful wells with perennial supply and also unreliable seasonal wells. Another influence on monitoring well selection was the route that could be taken by the community member who would measure well level which leads in a broad circle from their house to their place of work.

The five monitoring wells are manually dipped every two days with a dip-meter and the rain gauge is measured daily at 9am by reading the level of the internal graduated cylinder. The river gauges are monitored daily at 6am and 6pm by reading the river stage from the permanently installed gauge boards. Hard copy records of measurements are provided by community monitors on a monthly basis to the Dangila *woreda* office, where they are transferred to an Excel spreadsheet and forwarded to the research team.

The CBM hydroclimate data has been statistically compared to formal ground observation and remote sensing data and its quality has been confirmed (Walker et al., 2016). The CBM time series are presented in Figures B2 and B3.

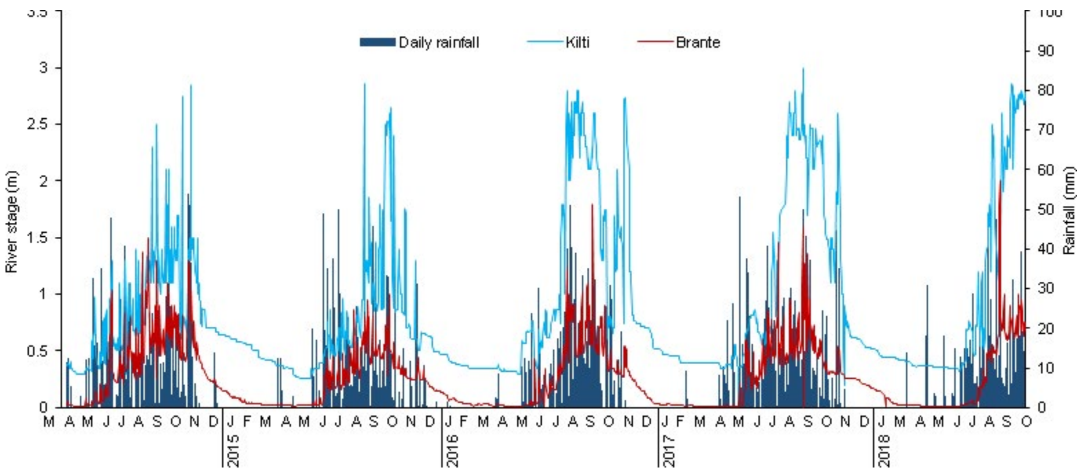


FIGURE B2: Plot showing daily rainfall and river stage in two rivers (Kilti and Brante) from the Dangila CBM.

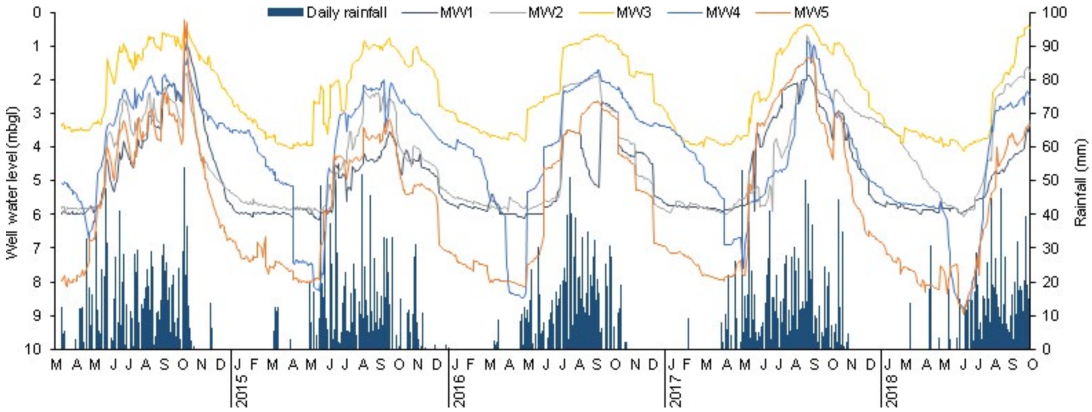


FIGURE B3: Plot showing daily rainfall and groundwater level in five monitoring wells (MW) from the Dangila CBM.

A hydrological model is a simplification of a real-world system that aids in understanding, predicting, and managing water resources. Such models simulate processes such as precipitation, evapotranspiration, infiltration, surface runoff, groundwater flow, river flow and water storage on the surface, in the soil, and in aquifers.

Field hydrogeological investigations (e.g. geological and water point surveys, pumping tests and hydrochemistry sampling) and the CBM data were used to construct and calibrate numerical hydrological models for Dangila *woreda*. These models defined areas of varying potential for irrigation based on shallow groundwater availability and accessibility (Figure B4).

Potential future scenarios were developed of climate variability, increased abstraction for small-scale irrigation, and land use change. Running these scenarios in the models suggested that the groundwater resource was resilient to climate variability, abstraction for small-scale irrigation would not significantly negatively impact surface and groundwater availability, nor would conversion of pasture or scrubland to arable land. However, increased planting of eucalyptus would significantly reduce dry season surface and groundwater availability (Walker, 2018).

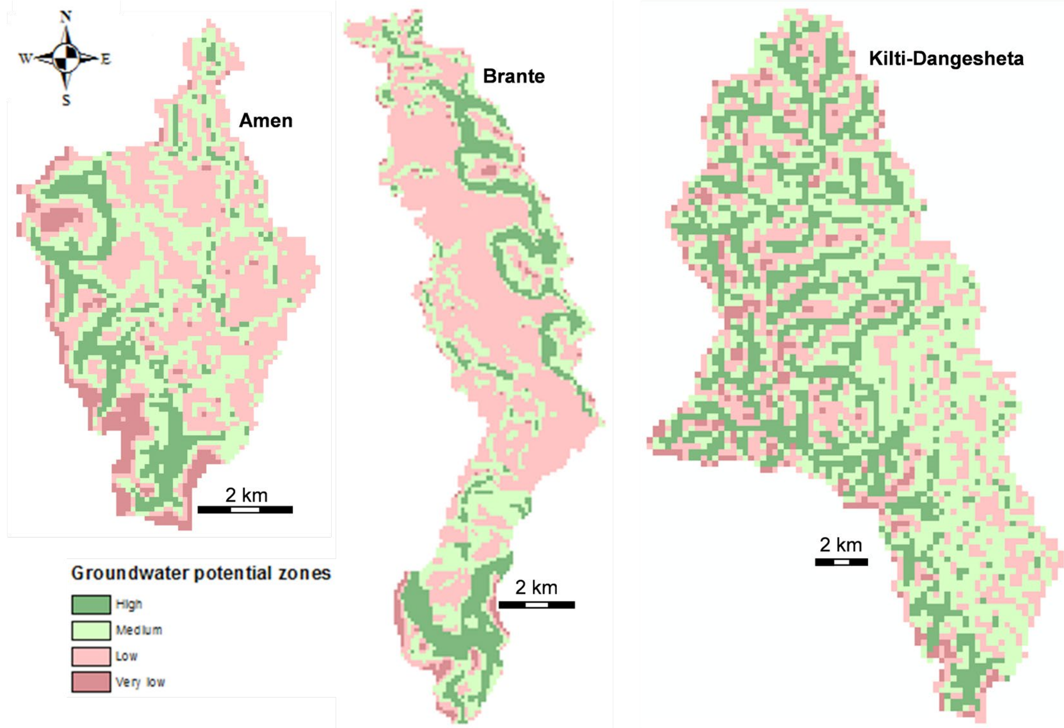


Figure B4: Maps showing the potential for use of shallow groundwater for small-scale irrigation.

3. What and how to monitor

Recalling Equation 1, all of the hydrological balance flux and storage components can be measured with CBM. This section describes the required equipment and monitoring protocols. Decisions on what to monitor depend on the purpose of the monitoring (consider Section 2) and the hydrological system of the particular watershed, e.g. groundwater monitoring wells and springs may be absent where the water table is deep. All the observations should be recorded on specially prepared data forms (see Section 9). The recommended measuring frequencies are presented in Table 1. As in most of Ethiopia, if the study site has a distinct wet season when most of the annual rainfall is received in several months, and a distinct dry season when little rainfall is received, the monitoring frequencies are permitted to vary.

Monitoring rainfall provides understanding of water resource availability. For example, increases in water resources determined from the spring/well/river monitoring may be due to climatic changes rather than intervention impacts. Decreases in water resources may be due to droughts rather than over-abstraction. These checks could be conducted with formal rainfall records but if none are available then incorporating rainfall monitoring into CBM is useful. Manual rain gauges that store rainfall which is measured and emptied daily (at 9am) are most appropriate for CBM (Figure 2a).

Monitoring river flow at the study watershed outlet shows the rate at which water resources are lost as runoff from the study site. Comparison with rainfall records indicates the “flashiness” of the hydrological system; rapid response of a river hydrograph to rainfall suggests high overland flow, whereas delayed and low response would suggest more rainfall infiltrates and gradually enters the river through groundwater flow. There are several methods for measuring river flow; the most appropriate for citizen science involve measuring river stage then converting it to flow (Figure 2b), constructing weirs, the float method, or with smartphone apps. The measurement frequency depends on how quickly the river flow responds to rainfall; at least once per day (at the same time) is recommended. However, in the dry season if river stage is constant, the frequency can be decreased to weekly. A flashy river (one that responds quickly to rainfall, such as in a small steep watershed) may see stage fluctuations occurring over short spaces of time, though it may be difficult to convince an observer to take a measurement more frequently than twice per day, e.g. 6am and 6pm.

Monitoring spring flow indicates groundwater availability. Comparison with rainfall data suggests groundwater residence time, i.e. rapid spring flow response following a rainfall event indicates short groundwater flow paths and short residence time whereas as little spring response would suggest that the spring water is likely to be from an older and deeper source. Typically, a stopwatch and water container are most appropriate for spring flow monitoring. Springs that have high flow (> 0.5 l/s) can be monitored using the same methods as for river flow; small weirs in particular are useful for monitoring undeveloped springs. As with river monitoring, the measurement frequency depends on how quickly the spring responds to rainfall. The response is generally slower than for rivers, therefore, daily is suggested as a maximum frequency and every two days or weekly may be more appropriate.

Monitoring groundwater level is a direct indication of groundwater storage. Groundwater is monitored by measuring the depth to the water table from a fixed point in wells or boreholes (Figure 2c). A dip-meter is required that emits a noise when the probe on the end of a measuring tape touches the water. For large-diameter wells with shallow water tables it may be possible to measure using a simple low-cost measuring tape if the contact with the water is visible. Groundwater response to rainfall is generally slower than for rivers, therefore, monitoring every two days or weekly would usually be appropriate.

Monitoring evapotranspiration shows the water lost to the atmosphere and is a difficult flux to quantify. If it is deemed necessary, and if possible, data should be obtained from formal sources. This data may be a time series of *potential* evapotranspiration (PET) or it may be a time series of meteorological datasets that are used to compute PET.

(a) (b) (c)

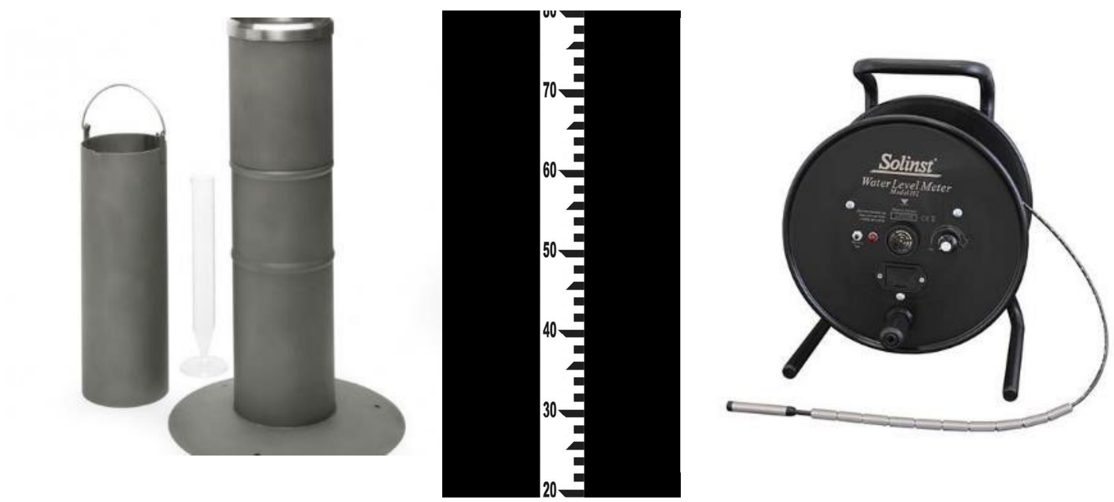


FIGURE 2. Typical CBM equipment: (a) manual rain gauge, (b) staff gauge, (c) dip-meter.

Table 1. Recommended measurement frequencies for CBM.

Parameter	Measurement frequency	Alternative measurement frequency	Comments
Rainfall	Daily at 9am	-	
River stage	Daily	Twice daily at 6am and 6pm	Measurement of flood peaks additional to the daily or twice daily monitoring should be encouraged
Spring flow	Every 2 days	Weekly during dry season and daily during wet season	The alternative measuring frequency assumes high fluctuation of flow in the wet season and little change in the dry season
Groundwater level	Every 2 days	Weekly during dry season and daily during wet season	The alternative measuring frequency assumes high fluctuation of groundwater level in the wet season and little change in the dry season

4. Planning CBM

This section presents the criteria for selecting a study watershed, useful baseline information that should be obtained at the watershed, and the responsibilities and costs that must be considered at the CBM planning stage.

4.1. Watershed selection

Important points for consideration are:

- Purpose of the monitoring: Is the aim only to improve local-scale monitoring of hydrological impact of SLM/RLLP interventions? If other scenarios described in Section 2 are applicable to the proposed watershed, for example a watershed showing potential for irrigation, such sites should be prioritised.
- Demographic, socioeconomic and agricultural factors: If the population is low in all or part of the watershed it may be difficult to find observers. The livelihoods of the local population will affect their interest in CBM. A local community directly impacted by hydroclimate variability will likely show more interest in monitoring that variability. Such examples include: watersheds where rainfed agriculture is prevalent; where irrigation and domestic water is collected from a single or few water sources, and; where flooding or drought impact livelihoods.
- Accessibility: Can the watershed be reached by road for site visits and equipment installation? The site should be accessible year-round, i.e. roads should not be impassable during seasonal flooding.
- Climate: In a semi-arid region where months go by with zero rainfall and zero river flow, the community may not sustain interest in monitoring rainfall and river flow though may have greater interest in groundwater monitoring. A monitoring frequency could be prescribed that reduces in the dry season, i.e. from daily to weekly or two-weekly.
- Hydrology: Rivers should not be too flashy, i.e. the river stage should not rise and

fall within very short (hours) spaces of time, such that flood peaks are missed by the monitoring as these short peaks may represent substantial proportions of monthly flow totals. More responsive monitoring could measure these short-lived flood peaks but it may be making excessive demands on the observer. Ensure the monitoring sites are accessible year round, for example, flood peaks should not be so high and so sustained (e.g. weeks or months) that monitoring sites are impossible to access.

- Hydrogeology: If groundwater monitoring is desired, the watershed must contain wells, boreholes or springs.

4.2. Baseline information

In order to determine if watershed interventions are having a positive hydrological impact, we need hydrological data prior to the intervention for comparison. This "baseline data" informs our understanding of the hydrological system under land degradation. An improvement in dry season baseflow availability or greater groundwater levels due to SLM/RLLP interventions will only be revealed with comparison to pre-intervention river flows and groundwater levels. Therefore, hydroclimate monitoring should commence as early as possible prior to interventions; for a minimum of one, preferably two or more, wet seasons. Alternatively, a paired watershed approach can be implemented, when two nearby and hydrologically similar watersheds are selected for monitoring. Only one watershed undergoes interventions, and monitoring data can be compared between watersheds to assess hydrological impacts. In reality, even neighbouring watersheds often have differences in soil, geology, vegetation, slope and climate, thus hydrologically similar paired watersheds are very difficult to achieve.

It may be most likely that CBM commences following interventions. In this case, monitoring should be established as soon as possible and the long-term (over several years) incremental change in hydrometeorology can be evaluated. What's more, the community can be consulted to share their observations of "baseline" conditions prior to interventions and prior to land degradation. Longer term rainfall and river flow records from nearby formal monitoring should be obtained in this case. In addition to supporting the communities' anecdotal information about the historic hydroclimate, analysis of nearby formal monitoring data could reveal if changes in the hydroclimatology of the study watershed are due to long term climatic changes rather than as a result of interventions.

4.3. Responsibilities and costs

It must be decided at the planning stage who is responsible for which aspects and which costs of the different CBM steps described in this guideline. This may be stated in contractual documents or it should be decided between the relevant stakeholders. Responsibilities include community consultation, equipment installation, observer training, observer payments, receiving data, data analysis and interpretation, data archiving, community feedback, and equipment maintenance. Costs to consider are equipment, observer payments/incentives, travel for site visits, and workshops (e.g. venue hire, refreshments, etc, if necessary).

4.4. Observer incentives

In addition to the capital costs of the monitoring equipment, there may be further costs in running the CBM. There are three options for compensating the time expended by the local observers (and para-hydrologists) in conducting hydroclimate monitoring:

1. The local observers are paid cash, typically a pre-agreed monthly total
2. The local observers are given non-monetary incentives
3. No payment or incentives are provided

For Options 1 and 2, the size of the payment or incentive would be based on the frequency of monitoring and effort expended. E.g. an observer who monitors groundwater levels in a well next to their house once per week could reasonably be expected to receive less than an observer who has to walk some distance twice per day to monitor river stage. Cash payment should be considered an incentive rather than a wage, i.e. payment should be less than received by NMA and MoWIE observers. Non-monetary incentives must consider local livelihoods. Successful examples of incentives from research in rural Ethiopia include rubber boots, umbrellas, mobile phone airtime, and beehives (where there is experience). Non-monetary incentives also include training that may be at the watershed or workshops elsewhere in the country.

There are numerous examples from around the world where Option 3 is successful: the incentives for citizen scientists are simply being involved in the project and knowing that the data could positively impact their lives. This approach is successful where the data has an obvious and immediate impact, for example in Burkina Faso for controlling water use and making agricultural management decisions (WaterAid, 2018) or in the UK where flood waters regularly threaten homes (Starkey and Parkin, 2015).

Clearly Option 3 is the most sustainable and should be the goal of CBM. However, where the monitoring is for long-term benefits to the community, some payment or incentives may have to be given to attract observers and maintain their interest. Option 2 is desirable over Option 1 for reasons of sustainability though in both cases the funder of the incentives or payments must be decided, and the available budget determined.

5. Initial assessment at CBM site

This section concerns the tasks to be undertaken during the initial visit to the study watershed.

5.1. Identification of local stakeholders

Initially, the *woreda* administrator must be contacted who will provide connection to the agricultural and water resource *woreda* office. Local (kebele) leaders should be sought in order to gain acceptance to work at the watershed, and acceptance by the local community. The local community are likely the most important stakeholders to consider for the whole project as they will be hosting and conducting the CBM. The various livelihoods of the local community and the water sources they depend on should be explored to increase understanding of this key stakeholder.

Further local stakeholders should be identified who have interests in water resources: water users' associations or committees, local NGOs, and especially stakeholders who abstract water, e.g. water companies or irrigating farms. These stakeholders may have baseline data and/or may be influencing the hydrology of the watershed.

5.2. Identification of a para-hydrologist

We recommend nominating a para-hydrologist to act as an intermediary between the community and those who initiated the CBM. The role of the para-hydrologist is to:

- Coordinate monitoring activities
- Provide guidance to the observers
- Collate, digitise and quality check the data
- Archive and forward the data
- Liaise with higher level stakeholders
- Disseminate findings to the local community

Careful selection of a para-hydrologist is an important matter to ensure the effectiveness of the CBM. The para-hydrologist should be a community-member with sufficient basic understanding of hydrological principles. They should be in a position that is respected by the community and known to be a competent and responsible person. Examples of the positions of para-hydrologists selected at study sites in rural Ethiopia include *woreda* (District level) irrigation officers and natural resource officers. The benefits of selecting a para-hydrologist at district rather than local (village, or *kebele*) level is their access to computers and internet, and often higher levels of education and language proficiency beyond the local language or dialect.

An accompanying guideline concerning selection and training of a para-hydrologist has been produced in tandem with this guideline on CBM. We urge consultation of this additional document if a para-hydrologist is to be employed at the study site.

5.3. Current status and use of water resources

A walkover survey of the watershed conducted with local stakeholders will reveal water sources (wells, springs, boreholes, rivers) and the degree of water use (any irrigation, only domestic use, any other uses?). Water dependent ecosystems, such as wetlands, should be identified at this stage. Many water resource issues will likely become apparent during this walkover survey through observation and discussion. In areas of water scarcity, the initial visit is recommended to take place at the time of greatest water scarcity, i.e. late in the dry season, in order to identify perennial wells, springs and rivers for monitoring. Knowledge of the local environment gained during the walkover survey will be invaluable when it comes to the focus group discussions and workshops.

5.4. Community focus group discussions

Community focus group discussions help to identify the community's perceived water resource/hydroclimatic issues. These may be declining water tables, flooding, water quality, food security, climate change, upstream abstractions, etc. The CBM can then target the hydroclimate issues experienced by the community. The para-hydrologist should be involved and may be able to act as translator (if required).

Gender separated focus groups should be considered where different genders generally have well-defined roles within the community because each group will have a different awareness of water resources. Similarly, separate focus group discussions could also be conducted with other marginalised groups, such as separating pastoralists from cultivators and separating rainfed from irrigating cultivators. Separation gives each group an equal opportunity to express their views.

Participatory mapping (Figure 3) can provide an inventory of community water resources, identification of locations vulnerable to natural hazards, identification of spatial patterns in exposure to hazards, both obstacles and

(a) (b)

FIGURE 3: (a) and (b) Participatory mapping in Dangila *woreda*. The map had the rivers and churches already drawn on (locations taken from topographic maps) to guide the participants. The community added wells and springs, noting whether they were seasonal or perennial, and irrigated plots. Photos from: Geoff Parkin and David Walker.

pathways to improving community resilience to hydroclimatic variability, and suggest locations for monitoring.

Focus group discussions and participatory mapping are also an opportunity for community members to learn from each other about their environment and water resources.

6. Community consultation for initiation of CBM

A community workshop must be held to explain the CBM and inform the community as to its purpose. The workshop should involve 20-30 interested community members from different social groups and from throughout the watershed. A suitable central location for the workshop must be located, with shade from sun or rain if it is held outside. Consider providing drinks and snacks in accordance with local customs. The para-hydrologist should assist with the workshop and may be able to act as translator (if required). The main agenda for the workshop should include:

- An assessment of the community's knowledge of the local hydroclimatology (Section 6.1).
- Identification of appropriate measurement sites (Section 6.2).
- Identification of observers who will conduct the monitoring (Section 6.3).
- Discussion on the monitoring frequency (Section 6.4).
- Demonstration of monitoring equipment (Section 6.5).

6.1. Background knowledge assessment

The community should be asked to describe the hydroclimatology of the watershed to demonstrate their current level of understanding. The following should be discussed: the rainfall amount, seasonal and interannual distribution and trends; timing and scale of effect of rainfall on rivers, springs and wells; the impact of climate variability on their livelihoods; and the importance of monitoring these variables in the watershed.

6.2. Identification of measurement sites

Sections 2 and 3 provided information on deciding what should be measured at the study watershed; all possible monitoring sites are considered below. There are physical constraints as to where the measurements can take place. After these physical constraints are explained to the community, elicit suggestions of where best to locate the equipment. The location will also depend on who will be the observer.

Rain gauge

- A rain gauge must be located on level ground
- There must be no overhead obstructions such as trees that may interfere with the rainfall
- Place a rain gauge nearby the observer's home for security and ease of monitoring (Figure 4a)
- The top of the rain gauge should be between 0.5 and 1.0 m above the ground. Research has shown that as the height of a rain gauge increases, the rainfall amount measured is less than the actual rainfall due to wind-induced "undercatch".
- A sheltered area is preferable, avoiding wide open spaces and tops of hills for the reasons of wind-induced undercatch. Guidance states that the distance between a rain gauge and other objects should not be less than twice the height of the object above the rim of the gauge. For example, a rain gauge 1 m above ground, any building or tree 5 m high should be at least 8 m distant (5 m less 1 m, x 2) (Met Office, 2018).
- Installing multiple rain gauges has the advantages of involving more community members in the CBM and showing the spatial variation of rainfall. However, equipment and observer costs obviously

increase and at a small watershed with spatially consistent rainfall multiple rain gauges may be unnecessary.

River staff gauge

- River staff gauges should be installed in reasonably straight reaches of the river, preferably within a well-defined channel that contains most of the flow
- Solid bedrock is preferable for staff gauge installation (Figure 4b). The solid bedrock ensures flow is not unaccounted for that passes through sediments beneath the gauge and any constructions will anchor better onto bedrock than sediment.

Weirs

- Weirs should be constructed in a reasonably straight reach of a river, preferably within a well-defined channel that contains most of the flow.
- The river should be narrow at the construction location to minimise construction materials.
- Weirs should be constructed above solid bedrock with stable banks. The solid bedrock and stable banks ensure flow is not unaccounted for that passes through sediments beneath the weir and any constructions will anchor better onto bedrock than sediment.

Wells

- Wells should be identified that are representative of groundwater behaviour of various parts of the watershed, e.g. high, middle and low locations in the watershed.
- The spatial distribution will depend on accessibility. If only one dip-meter is available, then location will be limited by what is appropriate for an observer to walk.
- Ideally the monitoring well should not be used for groundwater abstraction or be close to an abstraction well that would induce drawdown of the water table.

(a) (b)

FIGURE 4. (a) A tipping-bucket automatic rain gauge installed in Dangila *woreda* in an open, level area beside the observer's house; note the protective fence. (b) A river staff gauge secured to bedrock in Dangila *woreda* (this particular staff gauge includes a pressure transducer for automatically monitoring river stage; the box on the top of the gauge contains a datalogger). Photos from: David Walker.

Springs

- Developed springs with an outlet pipe are easier to monitor than undeveloped springs.
- If the watershed has many springs, select springs that are representative of various parts of the watershed, e.g. high, middle and low locations in the watershed.
- Individual identification of monitoring sites

It is important that each monitoring site is given a clear, unique and easily identifiable number or code, together with the site name and location. This is discussed further in Section 9.

6.3. Identification of observers

Observers should be identified based on the following criteria:

- Observers should be nominated by the community. The observers must be responsible and respected in the community.
- Observers must be literate and numerate in order to conduct the monitoring and fill in the data forms.
- The observer should spend most of their time based within the watershed, i.e. not have work or family commitments that lead to extended periods of absence. A secondary observer (typically a family member) should be nominated to provide monitoring cover during any absences.
- Each observer should live near to the monitoring locations they are responsible for.
- Owners of wells should be encouraged to become observers.
- There should be a balance between men and women observers. Young adults should be encouraged to become observers.

An additional optional observer is a community focal person; see Boxed text 3.

Boxed text 3 – Community focal person

Background

In Boloso Bombe *woreda* during the community consultation for initiation of CBM, the community were asked for suggestions on how to ensure observers remained motivated and diligent. It was suggested to have a “community focal person” who, in the hierarchy, lies between the community members and the para-hydrologist. This has proved extremely successful in maintaining data quality and having early warning of maintenance issues.

Criteria

Whereas the para-hydrologist may live and work outside of the watershed, the community focal person should live in the watershed. The criteria for selection of a community focal person should also be something in between an observer and the para-hydrologist, i.e. a well-respected numerate and literate person. The constraints of living close to a monitoring site and always being present at the watershed do not apply.

Role

The role of the focal person is to quality check the monitoring by performing weekly checks of measurements. Such checks involve visiting all of the monitoring locations and taking a measurement which is recorded on their own data sheet. This measurement can be taken independently or with the observer. When the two sets of measurements are compared by the para-hydrologist and by the ultimate receivers of the data, the measurements should closely match. Large discrepancies need to be investigated as there may be equipment problems, additional required training, or data falsification may be occurring.

Findings

At study sites without these periodic quality control observations we have occasionally received data with unexpected "jumps", i.e. large differences in consecutive measurements. Sometimes these jumps have a physical or typographical explanation (see Section 10), however, sometimes they cannot be explained. Introduction of a community focal person in Boloso Bombe *woreda* to perform this independent validation has prevented these data inconsistencies.

6.4. Agreement on monitoring frequency

Monitoring frequency is partly dependent on the hydrometeorology, as discussed earlier in this document, and partly dependent on the will of the observers. The ease of monitoring must be considered, i.e. the distance covered and time required, as well as the incentives that the observers will receive. This discussion will likely happen simultaneously with discussion on identification of measurement sites and observer identification: The community may know that certain potential observers would not have the time for daily monitoring or that potentially walking long distances to monitor multiple wells would not be feasible for anyone at a higher frequency than weekly.

6.5. Demonstration of monitoring equipment

All the monitoring equipment should be demonstrated to the local community prior to installation. This may be part of the process of selection of observers. Wider understanding of the purpose and use of the equipment also ensures community 'ownership', which can lead to reduced risk of damage as well as better potential use of the recorded data.

A bucket of water and small water container will be needed (Figure 5). The precise measurement of low rainfall quantities must be carefully demonstrated using the rain gauge with simulated rainfall amounts. Allow all community members to touch and use the rain gauge and test several of them with different rainfall amounts. Allow everybody to play with the dip-meter measuring the water level in the bucket. Water level on staff gauges can also be demonstrated in the bucket of water. Spring flow measurements and weir monitoring can be demonstrated by pouring water between containers, though it is best to demonstrate these monitoring techniques at the measurement locations if possible.

(a) (b) (c)

FIGURE 5. Equipment demonstration in Boloso Bombe and Dangila *woredas*. (a) River staff gauge. (b) Dip-meter. (c) Rain gauge. Photos from: David Walker and Geoff Parkin.

7. Establishment of monitoring sites

This section details the establishment of the monitoring sites. In all cases, as many community members as are interested should participate in the construction. This removes the mystery of the equipment and generates a sense of ownership to increase security and encourage maintenance.

7.1. Rain gauges

The two most common means of rainfall measurement are with manual gauges and tipping-bucket automatic gauges (Figure 6). Tipping-bucket rain gauges are not recommended for CBM and are included here for reference only.

- The advantages of manual gauges are their low-cost and simplicity. Rainfall lands on a funnel and is directed into a graduated cylinder where the rainfall total can be read. The standard for daily rainfall measurement is to take the reading at 9am with the total referring to the previous day. The collected rainfall is then discarded prior to reassembly. It is important that the observer keeps the rain gauge clean and free of debris.
- Tipping-bucket automatic rain gauges can provide hourly or even higher frequency rainfall intensity measurements. However, these rain gauges are expensive and require an observer with a laptop to download the data who has undergone more specialist training. This does not allow community involvement; therefore, these are not applied for CBM.

(a) (b) (c)

FIGURE 6. Different types of rain gauge: (a) a low-cost plastic manual gauge, (b) an expensive copper manual gauge (this is a design recognised by international standards for rainfall monitoring), and (c) a tipping-bucket automatic gauge. Photos from: Mintamer Ferede.

Materials and equipment required for rain gauge installation are:

- Rain gauge
- Strong metal or wooden post to mount the rain gauge
- Large adjustable metal bands with nuts and bolts (jubilee clips) plus a spanner and pliers to secure the rain gauge to the post
- Shovel and pick to excavate a hole for the base
- Cement, sand, gravel and water to make concrete for the base (may not be required)
- Spirit level to ensure verticality of the post
- Wood or strong branches and hammer and nails to construct a protective fence around the rain gauge (may not be required)

The steps in installing a rain gauge are:

1. Carefully design the rain gauge installation (fix the dimensions) at the installation location (Figure 7a); measure the post length considering whether it will be concreted or pushed into the ground while the rain gauge cylinder diameter and length must be considered for the attachments that will secure the rain gauge to the post.
2. Acquire equipment and materials. The rain gauge should be ordered ahead of time. Other materials can be locally obtained.
3. Fabricate the metal or wooden post with attachment for the rain gauge (Figure 7b). A height above ground of 1 m is recommended for stability and ease of monitoring. Therefore, the post should be around 1.4 m in length to allow a section to be placed into the ground. This step should be conducted by the metalworkers or woodworkers from whom the equipment was acquired.

(a) Identification of the precise rain gauge location avoiding overhead obstructions and careful design of the installation.

(b) Fabrication of the metalwork and attachment to the rain gauge.

(c) Excavating a hole for the concrete base.

(d) Installing the rain gauge and adding concrete.

(e) The finished concrete base.

(f) Simple fence constructed around the rain gauge.

(g) A rain gauge in Tembaro *woreda* that doesn't require a concrete base as the post is inserted deep into firm ground.

FIGURE 7. Rain gauge installation in Boloso Bombe *woreda* (except where stated). Photos from: David Walker and Alemseged Tamiru Haile.

4. Transport the equipment and materials to the installation location.

5. Mount the rain gauge to the post (Figure 7b). It is easier to secure the rain gauge to the post prior to erection.

6. If the ground is solid and a long section of post of around 0.4 m can be inserted securely into the ground, then concrete may not be necessary (Figure 7g) and you can skip to step 10.

7. Excavate a hole around 0.4 m deep (Figure 7c).

8. Mix concrete for the hole in which to secure the post (Figure 7d).

9. Insert the pole into the concrete using a spirit level to ensure it is vertical (Figure 7e).

10. A simple fence made from wood or branches at a distance of about 1 m around the rain gauge may be necessary to protect it from vehicles and animals, particularly cattle (Figure 7f). This should not obstruct rain from entering the raingauge.

7.2. Rivers

Staff gauges can be installed in rivers, and the water depth in the river (i.e. river stage) can be read from the measurement board. In strongly seasonal rivers, damage to staff gauges is likely during periods of high flow, especially if the river carries floating debris; see Boxed text 4. In this case, an alternative method of measurement is to construct a fixed reference point in the bank above the flow and measure down to the water surface (Figure 10).

The stage observations must then be converted from river stage to river flow. This conversion is not trivial and involves development of a rating curve requiring additional fieldwork; this is briefly described in Section 11 and presented in detail in the para-hydrologist guideline document.

For safety and ease, river monitoring equipment should be installed when the river is at its lowest level, i.e. towards the end of the dry season. The various methods of monitoring have their equipment and installation detailed below.

River staff gauge

Materials and equipment required are:

- Measuring staff gauge boards
- Wooden planks on which to attach the measuring staff gauge boards
- Screws and screwdriver to secure stage boards to wooden planks
- Angle iron to strengthen the wooden planks and for supports
- Drill to make holes in the wooden planks and in the angle iron to secure them together (can be done at the time of purchase)
- Nuts, bolts and washers plus a spanner and pliers to secure wooden planks to angle iron
- Shovel and pick to excavate a hole for the base and supports
- Stone hammer to break rocky river bed and prepare the bed to place concrete for the base and supports
- Cement, sand, gravel and water to make concrete for the base and supports
- Spirit level to ensure verticality of the staff gauge
- Long tape measure for surveying the channel profile

The steps in constructing a staff gauge are:

1. The staff gauge should be carefully designed at the installation location; lengths and positions of supports should be measured considering where they will be attached to the riverbed and banks (Figure 8a). The height of the staff gauge is dependent on the likely flood stage. Experience has shown that staff gauges higher than two metres are vulnerable to flood damage. Also consider step 7 when

(a) Identification of the precise staff gauge location with potential bedrock and tree stump anchors and careful design of the installation.

(b) Fabrication of the woodwork and attachment of the gauge boards to the wooden planks; conducted at the woodworkers' yard.

(c) Bolting the wooden planks to the angle iron on the riverbank.

(d) A temporary diversion of flow to allow a concrete base to be constructed.

(e) Preparing the bedrock by chipping away the weathered surface and cleaning.

(f) The staff gauge and a support concreted to cleaned bedrock; a further higher support was hammered into the river bank and concreted.

FIGURE 8. River staff gauge installations in Boloso Bombe *woreda*. Photos from: David Walker.

designing the height of the staff gauge.

2. Acquire equipment and materials. The measuring stage boards should be ordered ahead of time. Other materials can be obtained locally. Nuts, bolts and washers should be acquired before drilling of the angle iron and wood to decide the correct length and diameter of the drilled holes.
3. The angle iron should be cut, drilled and any welding conducted by the metal workers from whom it was obtained. This work should be supervised with the design in hand to ensure correct construction.
4. The wooden planks should be cut and drilled by the woodworkers from whom they were obtained, using the already prepared angle iron and the gauge boards as templates to ensure the size and holes match (Figure 8b).
5. Transport equipment and materials to the installation location.
6. The measuring staff gauge boards, wooden planks and angle iron should be assembled on the riverbank. This involves bolting the angle iron to the wooden planks and screwing the measuring stage boards to the wooden planks (Figure 8c).
7. If the riverbed is sediment, a short section ~0.2 m, of the wooden plank should protrude below the measuring staff gauge board to be secured into the riverbed. If the riverbed is bedrock, then the base of the measuring staff gauge board should be flush with the wooden plank.
8. The gauge should be placed in the lowest point in the riverbed to ensure that low flows are monitored; some channel bed adjustment may be required.
9. If necessary, temporary diversion of flow will enable a small hole to be excavated into sediments and filled with concrete into which the staff gauge is inserted (Figure 8d).
10. The staff gauge should be oriented with the narrowest edge towards the flow to reduce the force of the flow on the installation, but oriented to allow the observer to be able to see the gauge board from a safe location on the river bank (Figure 8e).
11. Additional holes can be excavated into the banks or concrete can be placed directly onto cleaned bedrock taking advantage of natural fractures into which the supports can be secured (Figure 8e and 8f).
12. Use a spirit level to ensure verticality is maintained when bolting the supports to the staff gauge.

FIGURE 9. Surveying the channel profile at a newly installed river staff gauge in Boloso Bombe *woreda*. Photo from: David Walker.

Following construction of the staff gauge, the channel must be surveyed at the gauge location to acquire an accurate channel cross-section profile (Figure 9). This is required for converting river stage to river flow (see Section 11). The steps involved in surveying the channel are:

1. A tape measure should be secured across the channel at bank top height and pulled tight, ensuring it is horizontal with a spirit level.
2. Another tape is used vertically at 0.2-0.5 m intervals across the river to measure the depth to the bed in order to obtain the channel cross-section profile. It can be helpful to use a long piece of wood to make the vertical measurements.

Boxed text 4 – Flood damage to traditional staff gauges

Background

Due to its seasonal climate with distinct wet and dry seasons, many small rivers in Ethiopia are dry or have very low flow for parts of the year and high flow during the wet season. Where watersheds are steep and runoff is high, these rivers can be "flashy" with rapid increase in flow during rainfall events.

Findings

Several staff gauges have been damaged by short duration high flows following intense rainfall events. Often it is floating debris, such as fallen trees, that causes the damage in addition to the water flow. Where the river stage reaches 2 m or above during floods, damage to traditional staff gauges seems likely.

Solutions

In certain cases the solution may be to simply build the staff gauge more strongly with additional angle iron supports or move the staff gauge to a section of river with less turbulent flow.

If the location is suitable, multiple shorter stage boards can be installed, stepped up the river bank so that each board progressively measures higher flows. These need to be carefully installed so that the gauge boards are at the correct elevation relative to each other.

For rivers with a flood stage of around 2 m and above, it is recommended that the alternative monitoring technique described below "Measuring the river

(a) (b) (c)

(d)

(e)

FIGURE B5. Flood damage to river staff gauges: (a) a 3-metre staff gauge in Dangila *woreda* under construction, (b) the same staff gauge following the first wet season, the wire and thick wooden branch are temporary support, note the broken angle-iron support and missing upper section, (c) the upper section of the same staff gauge was retrieved and stored by local children. (d) A different 3-metre staff gauge in Boloso Bombe *woreda* under construction, (e) the same staff gauge broken in half a few days later following a flood. Photos from: Geoff Parkin, David Walker, and Dawit Bundoro

Measuring river stage from bank top

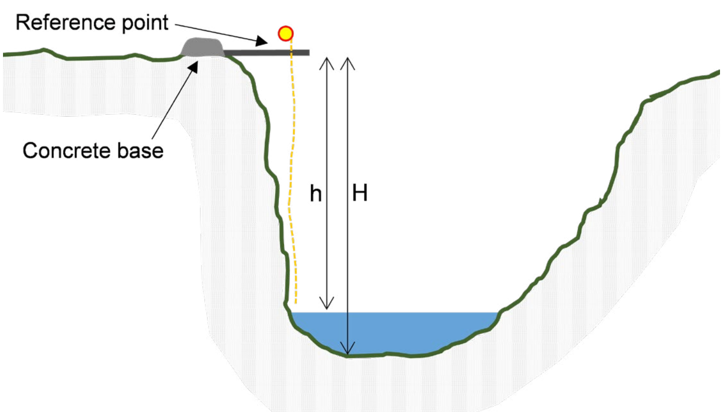
Materials and equipment required are:

- Wooden or metal (e.g. angle iron or rebar) bar to form reference point for measuring
- Further wood or angle iron for supporting the reference point; which would therefore also require screws and a screwdriver or nuts, bolts, spanner and pliers.
- Shovel and pick to excavate a hole for the base and supports
- Cement, sand, gravel and water to make concrete for the base and supports
- Dip-meter or tape measure for the monitoring
- Long tape measure for surveying the channel cross-section profile

The steps in constructing a bank top reference point are:

1. The installation should be carefully designed at the location (Figure 10a); lengths and positions of supports should be measured considering where they will be attached to the river bank top.
2. Acquire equipment and materials.
3. The wood or metal should be cut, drilled and any welding conducted by the wood/metal workers from whom it was obtained. This work should be supervised with the design in hand to ensure correct construction.
4. Transport equipment and materials to the installation location.
5. The wooden or metal bar that forms the fixed reference point at the bank top must be firmly secured to the bank. This could be achieved by inserting supports deep into solid ground, inserting the bar into a concrete base with or without supports, or nailing the bar to a tree trunk (Figure 10b).
6. The bar / reference point should be placed above the lowest point in the riverbed to ensure that low flows are monitored. However, the observer should not have to lean too far to take a measurement when high flows prevent access to the river channel. Some channel bed adjustment may be required in order that low flows pass below the reference point – this should be considered when locating the bank top reference point.
7. The channel profile must be surveyed as described previously.

(a)



(b)

FIGURE 10. Measuring river stage from the bank top. (a) The measuring principal: 1. The distance from the reference point to the riverbed, H, is measured at the time of construction and periodically; 2. Monitoring consists of measuring the distance from the reference point to the water surface, h, using a dip-meter, measuring staff or tape measure, and; 3. Subtracting h from H gives river stage. (b) A fixed reference point secured at the top of a riverbank in Boloso Bombe *woreda*. Photo from: Dawit Bundoro.

Weirs

Weirs initially involve more construction than staff gauges but are more robust and give river flow rather than only stage, though the data still requires some mathematics for this conversion. The aim of a weir is to channel all of the flow through a notch of known geometry (Figure 11). The height of the flow above the notch can be converted to flow using an equation based on the weir geometry. Therefore, monitoring is as for a staff gauge with a measurement being read, often from a small staff gauge within the weir or by using a measuring tape. For citizen science, weirs are more suited to small streams otherwise the engineering task would be significant. Seasonal rivers may need a combination weir with a v-notch for low flows and a rectangular section above for wet season flows.

Materials and equipment required are:

- Shovel and pick to excavate banks and bed
- Cement, sand, rocks, gravel and water to make concrete for the weir
- Metal weir plate
- Tape measure or measuring staff gauge board for the monitoring

It is recommended that expert assistance is sought for weir construction. The following steps are presented as an overview of weir construction:

1. The installation should be carefully designed at the location.
2. Acquire equipment and materials.
3. Transport equipment and materials to the installation location.
4. The riverbed and banks must be cleaned prior to installation and bedrock should be exposed in which to key the concrete.
5. Rocks should be built up into the approximate shape of the weir
6. Mix concrete and construct the weir.
7. The metal weir plate should be set into the concrete with the notch or base of the weir at the level of low flow.
8. If the weir is large, then a measuring staff gauge board could be permanently fixed to the weir with zero at the level of the notch (Figure 11).

7.3. Wells and boreholes

Dip-meters are preferred for measuring the depth to the water table though they can be expensive. Tape measures may be suitable for large diameter shallow wells in the absence

(a) (b)

FIGURE 11. (a) A rectangular weir in Kimakia watershed, Kenya. (b) A v-notch weir in Peru. Photos from: Alemseged Tamiru Haile and Buytaert et al. (2014).

of dip-meters. The number of dip-meters required depends on the number of well observers, which depends on the number of wells that will be monitored and the distance between them.

Materials and equipment required are:

- Dip-meter or tape measure
- Wood or metal saw or file

There are no installation steps as existing wells can be used for the monitoring. However, the wells/boreholes to be monitored should have a permanent mark made at the top of the well, e.g. a filed notch within the metal or concrete rim or a saw cut within a wooden rim, which will be the reference point for all measurements (Figure 12).

The following background information on the well/borehole is very useful when it comes to interpreting groundwater level response:

- Well depth.
- Well diameter.
- Well lining, e.g. concrete, wood, unlined.
- If available, a description of the type of material encountered when the well was dug.
- Well cover, e.g. clay pot, metal lid, no cover.
- It is very important to note whether rainfall or overland flow can directly enter the well (this should be prevented, if possible)
- Use of the well, e.g. domestic, irrigation, unused.
- Typical timing of abstractions, e.g. only first thing in the morning, throughout the day, never.
- Surrounding land use, e.g. house compound, orchard, crops, bare ground.
- Topography, e.g. floodplain, steep/shallow slope.

7.4. Springs

The piped outlets of developed springs lend themselves to a simple monitoring method involving a stopwatch (typically on a mobile phone) and a container (e.g. a bucket or jerry can) (Figure 13). This method involves measuring the time taken to fill a container of known volume. The observer or para-hydrologist can calculate flow in litres per

(a)

(b)

FIGURE 12. (a) and (b) Measuring groundwater levels in hand-dug wells in Boloso Bombe *woreda*. Photos from: David Walker.

FIGURE 13. Measuring spring flow in Boloso Bombe *woreda* utilising a jerry can and mobile phone stopwatch. Photo from: David Walker.

second if the container volume and time to fill are recorded.

Materials and equipment required are:

- Bucket, jerry can or other container of known volume
- Stopwatch or mobile phone

A developed spring with a single outlet pipe is most suitable for monitoring. No additional construction is required. Undeveloped springs can be problematic to measure unless the emergence is from a single free-falling "spout". Flow measurement may be impossible where water emerges from multiple "eyes", when the eye is within a pool, or when the spring is a large area of seepage.

8. Measurement procedure and observer training

Observers must be trained at their assigned measurement sites following any equipment installation. This is in addition to the monitoring equipment demonstration, where the observers should have been present. A potential substitute observer, such as a family member, should also be present to learn how to monitor if the primary observer is ever absent, e.g. due to illness or family and work commitments. The para-hydrologist and community focal person (if applicable) should also be present for this training as they must be experienced in the use of all monitoring equipment at all measurement sites.

The para-hydrologist will require greater training than observers who collect the data and should ultimately be able to train observers themselves. The additional training of the para-hydrologist includes quality checking data, plotting data, the use of a current-meter and development of a rating curve (see the para-hydrologist guideline document).

8.1. Rainfall

Accuracy of manual gauges depends on the thoroughness of the observer checking the gauge, recording the data, emptying it, and resetting it. Training should involve simulating different rainfall quantities, i.e. by pouring water into the rain gauge, and testing that the observer can correctly take a measurement. It is important to test their understanding of the graduated measurements where small quantities of rainfall can be measured to more decimal places than larger quantities. It is important that all water is removed following recording the rainfall before the rain gauge is reassembled.

Measurement procedure:

1. A measurement must be taken every day at 9am.
2. The observer must remove the funnel from the top and the container from within the rain gauge (this step is unnecessary for the low-cost plastic rain gauges and you should skip to point 8).
3. Any rain water in the container is poured into the graduated measuring cylinder supplied to the observer at the establishment of the CBM.
4. Ensure all the rain water is within the measuring cylinder (Figure 14a).
5. Ensure the measuring cylinder is vertical by placing the flat base on a horizontal surface.
6. Carefully read the rainfall measurement.
7. During periods of high rainfall, the cylinder may need to be filled multiple times, and the totals combined. The observer should also check whether the container has overflowed into the outer section of the rain gauge. If so, this overflowed rain water must be separately measured and the totals combined.
8. Concerning low-cost plastic rain gauges, the rainfall total should be carefully read directly from the rain gauge at the water level.
9. Write the measurement into the data form being careful with decimal point placement and ensuring the correct date.
10. It is important that zero rainfall is recorded as zero and not simply left blank on the data form.
11. Shake out all water and reassemble the rain gauge.
12. Return the graduated measuring cylinder to a secure storage location (if applicable).

Caution:

- Make sure no rain water is spilled and consequently unmeasured. For instance, rainfall measurement should be done far away from children, chicken or cattle since these may drink or spill the rain water before measurement.
- When the measurement time coincides with a rainfall event, the measurement must be taken quickly and the rain gauge reassembled promptly in order to not miss much of the rainfall.
- If a measurement is missed, it must be noted on the data form that the measurement taken the following day is a two-day rainfall total.

Maintenance instructions: The rain gauge must be kept clean and free of debris, any overhead obstructions such as branches and high grass must be removed.

8.2. River stage

Training should involve simulating different river stages, i.e. by using a stick to mimic the water level on the stage board, and testing that the observer can correctly take a measurement. It is important to test the observers’ understanding of the gauge board or dip-meter, ensuring they know which markings the numbering relates to and which direction from a numbered mark (up or down) to read centimetre-scale measurements.

Measurement procedure:

1. A measurement must be taken at the specified time and frequency.
2. The observer must ensure the river is safe to approach, i.e. flow is not too high.
3. The water level should be watched for a minute or so to ensure the stage is steady. If water level is not steady then the approximate average level should be recorded.
4. Carefully read the water level measurement from the staff gauge (Figure 14b) or by lowering the end of the dip-meter until a beep is heard as the end reaches the water.

5. Write the measurement into the data form being careful with decimal point placement and ensuring the correct date.

Caution:

- Measuring river stage from staff gauges, bank top reference points, and weirs must be conducted safely. If high river flow prevents safe access to the measurement location, no attempt should be made to take a measurement and an explanatory note should be added to the data form.

Maintenance instructions: the equipment must be kept free of debris (e.g. tree branches or sediment) and the observer must ensure low flows still pass at the measuring point. If sediment deposition, scour, and bank erosion significantly alter the channel profile, the channel must be resurveyed.

8.3. Groundwater level

The distance from a permanent reference point, e.g. a notch cut into the top of the well, to the water table should be read from the measuring tape and recorded as metres below ground level (mbgl). If the only potential monitoring wells are used for abstraction, groundwater level measurement should occur hours after the usual abstraction period when the water table has recovered to background level. This is often best done first thing in the morning.

Training should involve simulating different water levels, i.e. by dipping the dip-meter into a bucket of water, and testing that the observer can correctly take a measurement. It is important to test the observers' understanding of the dip-meter, ensuring they know which markings the numbering relates to and which direction from a numbered mark (up or down) to read centimetre-scale measurements. The observers should be trained in the switching on and off of the dip-meter, and encouraged to switch it off immediately after measurement in order to preserve battery life. The observers should also be trained how to change the batteries.

Measurement procedure:

1. A measurement must be taken at the specified time and frequency.
2. The observer must ensure the well is safe to approach, i.e. there has been no collapse of ground around the well.
3. Lower the end of the dip-meter tape into the well until a beep is heard on contact with water.
4. Slowly move the tape up and down to find the precise water level, at the same time placing the tape against the marking (the permanent reference point) at the top of the well.
5. Carefully read the water level measurement (Figure 14c).
6. Write the measurement into the data form being careful with decimal point placement and ensuring the correct date.
7. Replace any well covering that was present prior to measurement.

Maintenance instructions: keep the dip-meter clean and replace the batteries if necessary (the CBM organisers are responsible for supplying the batteries). Measure well depth monthly to check that the depth remains constant, i.e. no sidewall collapse has occurred. Note any changes to the well cover that may be permitting direct rainfall or overland flow to enter the well.

8.4. Spring flow

It is important to establish a protocol for recording the time taken to fill the container: minutes and seconds is recommended. The container should be large enough that it isn't filled too quickly, which would make accurate timing difficult, and not too large that filling takes a long time. A container that takes between one and three minutes to fill would be ideal, therefore, a 10 litre bucket or jerry can usually work. If seasonal flow fluctuation is high then a smaller container should be used in the dry season; ensure that the size of the container is written on the data form.

Training should involve simulating different water flow rates, i.e. by filling containers of different sizes at the spring, and testing that the observer can correctly take a measurement.

Measurement procedure:

1. A measurement must be taken at the specified time and frequency.
2. Place the empty container under the flow at the same time as starting the stopwatch.
3. Stop the watch at the moment when the water overflows the container.
4. Make a note of the time on the stopwatch.
5. Repeat the test twice (repeat steps 2-4) to obtain three measurements, ensuring that all the water is removed from the container between tests.
6. If mathematically proficient, the observer can average the results and write the measurement into the data form being careful with decimal point placement and ensuring the correct date. Alternatively, all three measurements should be recorded to be averaged by the para-hydrologist.

Maintenance instructions: the measuring container should be replaced if it becomes misshapen or damaged.

8.5. Filling in the data forms

The observers must be instructed and tested on filling in the standardised data forms that are discussed in detail in Section 9 and provided in Appendix A. Instruction should be given to prevent common errors. Experience shows that common errors in recording measurements include:

An additional column is provided on each data form for observers' remarks. The observers should be encouraged to provide comments on:

- Maintenance issues, e.g. non-functioning dip-meter, damaged river staff gauge, etc.
- Changes at the monitoring site, e.g. a growing tree that may begin to shade a rain gauge, bank erosion at a river monitoring location, a cover added to a previously open well, etc.
- Observations or measurements greater than the required frequency, e.g. the maximum river stage during a high flow event, etc.
- Suggestions for improvement of the CBM, e.g. halting of monitoring of a well that shows no seasonal response, reduced

(a) (b) (c)

FIGURE 14. Observer training in Boloso Bombe and Ebinat *woredas*. (a) Rain gauge. (b) River staff gauge. (c) Dip-meter. Photos from: David Walker.

frequency of monitoring a spring that responds slowly to rainfall, etc.

- Explanations for extremely high or low values, e.g. very intensive rainfall, overland flow into a well, excessive groundwater abstraction from a well, etc.

Such comments have proven very useful in the past for both the sustainability of the CBM and to provide hydroclimate information that is not available from formal monitoring datasets. For example, useful comments provided on data forms from research in rural Ethiopia include:

- River stage peaks occurring between the 6am and 6pm monitoring times.
- Spring flow decrease due to damage to the outlet pipe.
- Difficulties in groundwater level monitoring after a rope and washer pump was installed at the monitoring well.
- Problems with a dip-meter.
- River staff gauge destroyed by floating debris during a flood.

Further additional information can be provided on the electronic forms by the para-hydrologist, such as photographs showing maintenance at monitoring sites and of extreme events, and comments on the observers' comments.

9. Recording and communicating data

This section concerns the protocols for providing, managing and archiving the standardised data forms.

9.1. Identification and recording of monitoring locations

During the establishment stage of monitoring site identification and equipment installation, each monitoring site should be given a clear, unique and easily identifiable number or code and a short name. The site locations should be recorded in terms of a local description, together with an accurate location taken with a GPS measurement device. An overview document should be prepared by the CBM organiser, and a copy held by the para-hydrologist, summarising in a table and a map the list of monitoring sites, with their number/code, name, and GPS location, with any additional relevant information, e.g. name of observer(s). Any changes to the monitoring sites should be recorded in this document.

9.2. Provision of standardised data forms

Data forms should be provided in electronic format to the para-hydrologist. The para-hydrologist is responsible for printing and distributing the blank data forms to the observers. Standardised data forms are provided in Appendix A.

At the onset of CBM it may be necessary to spend time with the para-hydrologist in order to convert the data forms into local language. However, the language of the CBM organisers should remain on the data forms as well to aid quality checking and analysis.

The data forms have been designed to be simple and user-friendly. The name of the monitoring location and name of the observer should be pre-printed on the data form to prevent confusion as to which dataset refers to which particular measurement location. Data forms would typically be distributed and collected monthly, therefore, the dates should be pre-printed on the data forms, taking care when converting between calendars, e.g. from the Western to the Ethiopian calendar.

9.3. Communicating data and archiving

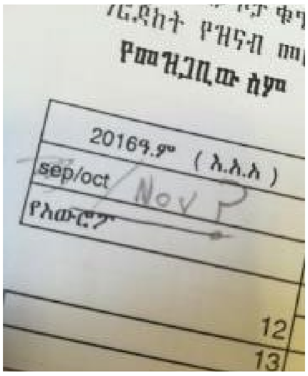
A protocol must be developed for obtaining the data from the observers. Typically, a para-hydrologist would distribute and collect the paper data forms, type up the data onto a specially prepared Excel spreadsheet, then email the data to the CBM organisers. The paper copies must be carefully archived for potential consultation should there be issues with the electronic datasheets. The CBM organisers are likely to be the people reading this document; possibly a representative of a government ministry, a university, a research institute, or an NGO. Data quality checking is the subject of Section 10, but it must be determined who will conduct this. We recommend a two-step data quality check: (i) initial check conducted by the para-hydrologist, and (ii) final check to be conducted by CBM organisers. Further important considerations are: who owns the data and what is the protocol for sharing the data more widely?

10. Data quality assessment

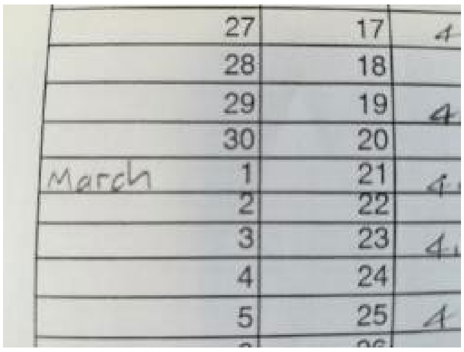
Data quality checking must be conducted prior to analysis. Data quality checking is typically conducted by the CBM organisers. However, some of the quality checking could and should be conducted by the para-hydrologist, so that any obvious issues can be resolved immediately, perhaps with some minor re-training of the observer. The quality control procedure involves checking:

1. Days and months: Is the month labelled correctly (Figure 15a) and does the month have the correct number of days (Figure 15b)? If two different calendars are in use (e.g. in Ethiopia), have the dates been converted correctly (Figure 15a and 15b)?
2. Locations: Have the particular monitoring locations been correctly identified? Often this issue becomes apparent when the data is plotted (Figure 15c), though if measurements are similar for the confused locations this issue may not be identified.
3. Completeness: Have the data been recorded for all the monitoring locations (Figure 15d) and is the data complete for each monitoring location (Figure 15e)?
4. Typing up errors: Incorrect typing up should become apparent via the other checks. Additional commonly observed errors are commas used in place of decimal points and extra spaces beside decimal points (Figure 15f). These errors make plotting and analysing the data more problematic.
5. Weekly quality control observations: If a community focal person is making weekly (or two-weekly or monthly) observations, are these quality control observations similar to the daily observations (Figure 16a)?
6. Consistency: Does the data have any large "jumps", i.e. large differences in consecutive measurements? These jumps may have a physical explanation, such as extreme rainfall events that cause spikes in groundwater level and river stage (Figure 16b). The jumps may be typographical errors (typos), such as when 1.08 m or 3.07 mbgl are incorrectly recorded as 1.8 m or 3.7 mbgl respectively (Figures 16c and 16d). If jumps in the data do not have a physical nor typographical explanation then further investigation is required.

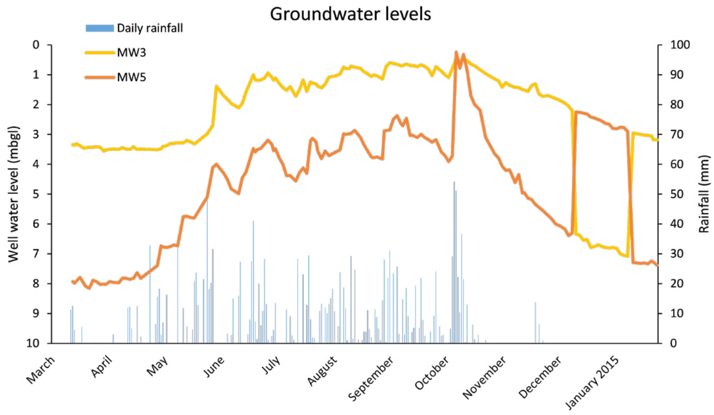
(a) Data forms being photocopied from the previous month and manually relabelled can cause confusion – it is better to use forms with the correct month pre-printed.



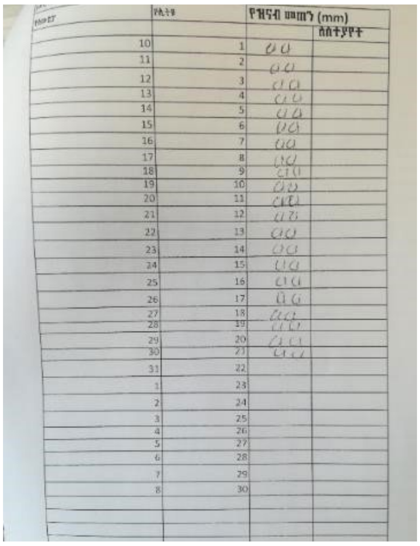
(b) Incorrect data form indicating 30 days in February – this could be due to the form being photocopied from an earlier month or due to incorrect conversion of the Ethiopian to Western calendar.



(c) Two groundwater monitoring wells being incorrectly labelled for the month of December 2014 which became apparent when the data was plotted.



(d) An incomplete rainfall dataset



(e) Certain months of monitoring data missing and another month incomplete.

	Rainfall	River	Spring	Well 1	Well 2	Well 3
January	✓	✓	✓	✓	✓	✓
February	✓	✓	✓	✓	✓	✓
March	✓	✓	✓	✓	✓	✓
April	✓	✓	✓	✓	✓	✓
May	✓	✓	X	✓	✓	✓
June	✓	X	✓	✓	✓	✓
July	✓	✓	✓	incomplete	✓	✓
August	✓	✓	✓	✓	✓	✓

(f) The red circles show where commas have been used instead of decimal points while the orange circles show where extra spaces have been inserted beside decimal points.

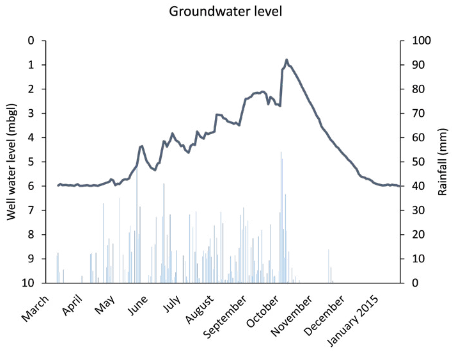
Month	Day	Rainfall	Well 1	Well 2	River 1	River 2
April	1	1.5	2.18	2.15	1.3	1.3
	2	2,1			1.3	1.3
	3	0	2.2	2,17	1.4	1.45
	4	0			1.3	1,6
	5	11. 7	2. 09	2.11	1.7	1,8
	6	6.6			1 .7	1.7
	7	0	2.16	2.12	1.6	0.74

FIGURE 15. Examples of data quality issues. Photos from: David Walker.

(a) Weekly quality control groundwater level observations that are consistent with the observers' measurements taken every two days.

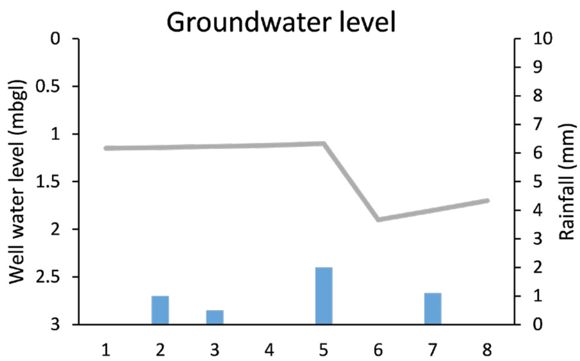
Groundwater level (mbgl)							
Mero Gota	weekly QC	Naba Chemso	weekly QC	Darcho Mandado	weekly QC	Darge Chafago	weekly QC
13.93		12.02		11.56		14.11	
	13.93		12.02		11.6		14.11
14		12.02		11.58		14.13	
13.97		12.02		11.6		14.02	
14		12.02		11.58		14.02	
	13.96		12.02		11.6		14.02
13.96		12.02		11.6		14.02	
13.97		12.02		11.6		14.02	
13.99		12.02		11.6		14.03	
13.96		12.02		11.6		14.03	
	13.96		12.02		11.6		14.02

(b) A jump in groundwater level in October 2015 of around 1.5 m that can be explained by an extreme rainfall event of 105 mm in 48 hours.



(c) A jump (decrease) in groundwater level of almost a metre that did not match rainfall data as it occurred simultaneously with a rainfall event. The jump was explained by typographical errors in the groundwater level measurements, which have been corrected in (d).

Month	Day	Rainfall	Well 1
April	1	0	1.15
	2	1	1.14
	3	0.5	1.13
	4	0	1.12
	5	2	1.1
	6	0	1.9
	7	1.1	1.8
	8	0	1.7



(e) Corrected typographical errors from (f) and consequent corrected groundwater level plot.

Month	Day	Rainfall	Well 1
April	1	0	1.15
	2	1	1.14
	3	0.5	1.13
	4	0	1.12
	5	2	1.1
	6	0	1.09
	7	1.1	1.08
	8	0	1.07

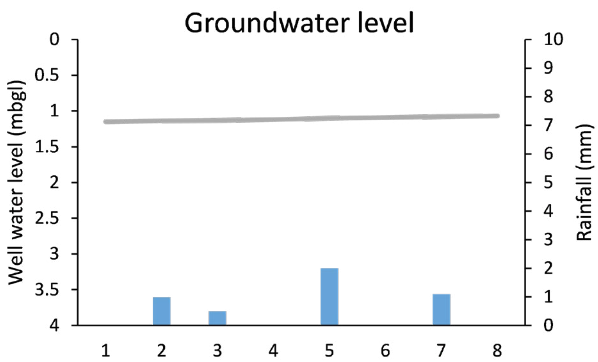


FIGURE 16. Examples of data quality issues with groundwater level data.

11. Converting river stage to flow

River stage must be converted to river flow in order to quantitatively understand a watershed's water resources. This step would generally be conducted by the para-hydrologist or by the CBM organisers, and is addressed in more detail in a para-hydrologist guideline document. An overview of the methods is presented below. If river monitoring consists of stage measurements from a staff gauge or measuring from a bank top reference point then the time series of stage measurements should be converted to flow by developing a rating curve (a graph of flow against stage). If a weir is present, the time series of river stage above the base of the weir can be converted using equations.

11.1. Flow gauging

The recommended method of generating a stage-discharge (flow) relationship, or rating curve, is to conduct velocity measurements at various times when the river stage is at various levels. Velocity measurements are conducted by "flow gauging" using a current-meter. River stage is plotted against flow and the line of best fit through the points is the stage-discharge relationship, or rating curve.

11.2. Smartphone apps

Smartphone apps are a recent development and are still unproven in natural river systems. The method analyses a video of the water surface, applying 3D particle tracking velocimetry (3D-PTV) to estimate the flow velocity, which it then converts to flow (see Lüthi et al. (2014)). The potential advantage of this method is that it is a very fast method of obtaining flow directly that does not require entering the river (other than obtaining the riverbed profile); it is therefore very safe and can be utilised in high flow conditions. However, research is ongoing and preliminary testing suggests the technique can give inconsistent results.

11.3. Float method

Where a current meter is not available the flow may be estimated using the float method. The velocity of flow is estimated by releasing a float at different locations across a river and timing the travel between two measured points. A velocity coefficient is applied (assumed to be 0.65) to allow for the typical velocity decrease with depth.

11.4. Weir equations

The time series of stage measurements above the base of the weir can be converted into flow by applying an equation that describe this relationship. Each type of weir has a unique equation to convert stage to flow. These equations can easily be applied to all stage measurements on an Excel spreadsheet to give a flow time series.

12. Data analysis and interpretation

Simple data plotting, analysis and interpretation should be conducted by the para-hydrologist for immediate community feedback. More in-depth analysis and interpretation should be conducted by the CBM organisers who it is expected will have greater hydrological expertise.

The received monthly datasets should be compiled into continuous time series; this facilitates application of quality control procedures and conversion (if necessary). After quality control procedures have been passed, the data is ready for analysis and interpretation.

Plotting the data reveals the water resource behaviour. The seasonality of the data indicates variations in resource availability. Relationships between different datasets, such as rainfall vs groundwater level and rainfall vs river or spring flow, can inform the conceptual model of the study site.

For example: a short time lag between a rainfall peak and a river flow peak indicates rapid runoff; a slow and gentle recession of groundwater levels following cessation of the wet season indicates a groundwater resource that could buffer droughts; spring flow that shows no relationship with rainfall may suggest that the spring is emerging from a deeper groundwater source perhaps via a fracture; high and rapid groundwater level fluctuations suggest a low-storage aquifer that may not support abstraction. There are many other such interpretations that can be formed from analysing the collected data and time should be spent on this process by a person familiar with the study watershed and who has hydrological/hydrogeological expertise.

13. Community contact and feedback workshop

13.1. Maintaining contact between CBM organisers and community

It is extremely important for the CBM organisers to maintain contact with the community who are conducting the monitoring. This should be via email or telephone with the para-hydrologist, especially to acknowledge receipt of data, and also to discuss any issues such as equipment failure or changes at the monitoring locations.

Repeat visits to the study site by the CBM organisers are crucial to show the community that their hard work is appreciated and has a purpose.

13.2. Workshops to feedback results

Annual workshops should be organised for the local community in order to provide feedback on the CBM and to share findings. Research in East Africa by Comte et al. (2016) indicated that local stakeholders are critical of researchers who commonly do not share project findings.

These workshops should be run by the para-hydrologist and as many community members as are interested, in addition to the observers, should be encouraged to attend. Data should be presented as clearly and simply as possible using large plots as well as any other creative visual aids that can be thought of (Figure 17). The workshops are an opportunity for the community to query aspects of the CBM, to provide further hydroclimatic observations, and, most importantly, to increase their own understanding of their water resources. Additionally, queries can be put to the community to help explain any unusual monitoring data, such as jumps in time series or unexpected patterns and relationships. From our own experience, such queries have proved invaluable in understanding

(a)


(b)


FIGURE 17. Community feedback workshops in Dangila and Boloso Bombe *woredas*. (a) Discussing differences in well responses (the blue cut outs represent water level in monitoring wells). (b) Presenting river flow time series plots. Photos from: David Walker.

groundwater level fluctuations prior to use of the data in modelling and recharge studies.

13.3. Review and evaluation

CBM should be continually reviewed and evaluated in order to ensure it remains fit for purpose and cost-effective. It is acceptable to make changes to the monitoring equipment, locations, frequency, incentives and personnel if deemed necessary though such changes should be discussed openly with the community during feedback workshops.

An example of when review and evaluation has been effective is highlighted in Boxed text 4 where staff gauges at Boloso Bombe woreda proved unsuitable for a high energy river and alternative monitoring equipment was developed in collaboration with the community.

External factors may necessitate relocation of monitoring equipment. For example, construction of a weir to divert water for an irrigation scheme at Ebinat woreda meant the staff gauge had to be moved upstream beyond the influence of water retained behind the weir.

After at least 12 months, the hydroclimate time series can be evaluated to assess if the monitoring frequency is appropriate. For example, if groundwater levels fluctuate slowly then monitoring frequency could be reduced. Similarly, river monitoring frequency may be reduced during dry season low flows but may need to be increased during the wet season in rivers that respond rapidly to rainfall. In these cases, it is important to be sensitive to the community's wishes because the potential loss of incentives for an observer if monitoring frequency decreases must be considered. Equally, a well owner may feel excluded if it is suggested that their well is no longer monitored, if, for example, the groundwater level never fluctuates.

14. Summary

The purpose of this manual is to give guidance on the planning, establishing, and operating of CBM. Various scenarios have been described where hydroclimate monitoring could provide improved understanding of water resources, such as the monitoring of land degradation intervention impacts and monitoring of groundwater levels to assess the impacts of abstraction and climate variability in order to better manage the resource. The manual has described what can be monitored: rainfall, river and spring flow, and groundwater level, and how and why they should be monitored. The planning stage was detailed including identifying important stakeholders, selecting a focus watershed, incentives for community observers, and data management. The monitoring site initial visit and subsequent workshop are discussed, with high importance being given to selecting a para-hydrologist, a community focal person, and the observers. The manual described how to select the monitoring locations, how to setup the equipment, and then how to train the observers. Standardised data forms (included in Appendix A) are explained along with data quality control procedures and methods to convert river stage to flow are presented. Analysis and interpretation of the data is discussed. Finally, we highlight the importance of future workshops to provide feedback and project findings to the community.

As stated in the "Purpose and scope" section: This document has been developed following research in Ethiopia since March 2014, where multiple study sites have had CBM implemented using an iterative process leading to continual improvement of the methodology. In addition, the manual incorporates experiences from successful CBM in India, the UK and South Africa which have informed and been informed by the Ethiopia research. Variations on the guidance presented here may well be suggested by researchers based on their own experience of setting up and running CBM, especially if that experience results from other parts of the world. However, we are confident in proposing that if the guidance in this document is carefully followed, a successful CBM programme will result.

References:

Bonsor, H.C. and MacDonald, A.M. (2011) An initial estimate of depth to groundwater across Africa. British Geological Survey Open Report OR/11/067, Wallingford, UK, 26pp.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Bastiaensen, J., De Bièvre, B., Bhusal, J., Chanie, T., Clark, J., Dewulf, A., Foggin, M., Hannah, D.M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandey, B., Paudel, D., Sharma, K., Steenhuis, T., Tilahun, S., Van Hecken, G. and Zhumanova, M. (2014) 'Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development', Frontiers in Earth Science, 2.

Comte, J.-C., Cassidy, R., Obando, J., Robins, N., Ibrahim, K., Melchioly, S., Mjemah, I., Shauri, H., Bourhane, A., Mohamed, I., Noe, C., Mwega, B., Makokha, M., Join, J.-L., Banton, O. and Davies, J. (2016) 'Challenges in groundwater resource management in coastal aquifers of East Africa: Investigations and lessons learnt in the Comoros Islands, Kenya and Tanzania', Journal of Hydrology: Regional Studies, 5, pp. 179-199.

Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Dieulin, C. and Mahé, G. (2009) 'Rainfall and water resources variability in sub-Saharan Africa during the twentieth century', Journal of Hydrometeorology, 10(1), pp. 41-59.

Lewenstein, B.V. (2004) 'What does citizen science accomplish', Working Paper, Cornell University. Available at: https://ecommons.cornell.edu/handle/1813/37362 [Accessed: 31 July 2018].

Lüthi, B., Philippe, T. and Peña-Haro, S. (2014) 'Mobile device app for small open-channel flow measurement', Proceedings of the 7th International Congress on Environmental Modelling and Software (iEMSs' 14). pp. 283-287.

Met Office (2018) Weather observations website (WOW). Available at: https://wow.metoffice.gov.uk/ (Accessed: 14 August 2018).

OED (2018) "citizen science" Oxford English Dictionary. Available at: http://www.oed.com/view/Entry/33513?redirectedFrom=citizen+science (Accessed: 1 November 2018).

Starkey, E. and Parkin, G. (2015) Community Involvement in UK Catchment Management. Available at: http://www.fwr.org/Catchment/frr0021.pdf (Accessed: 30 October 2015).

Walker, D. (2018) Resilience of shallow groundwater resources and their potential for use in small-scale irrigation: a study in Ethiopia. PhD thesis, School Engineering, Newcastle University, UK.

Walker, D., Forsythe, N., Parkin, G. and Gowing, J. (2016) 'Filling the observational void: Scientific value and quantitative validation of hydrometeorological data from a community-based monitoring programme', Journal of Hydrology, 538, pp. 713-725.

WaterAid (2018) Clean water today - and every day. Available at: https://medium.com/@WaterAidUK/clean-water-today-and-every-day-53808efbbc9b (Accessed: 31 July 2018).

World Bank (2017) Sustainable Land Management Project (SP133133). Available at: http://projects.worldbank.org/P133133?lang=en (Accessed: 10 December 2017).

World Bank (2018) Resilient Landscapes and Livelihoods Project (RLLP). Available at: https://www.worldbank.org/en/news/press-release/2018/07/30/ethiopia-world-bank-supports-ethiopias-efforts-to-build-a-green-economy (Accessed: 18 October 2018).

Appendix:

Standardised data forms

1. Daily river stage
2. Groundwater level
3. Spring flow
4. Daily temperature and relative humidity
5. Quality control - Groundwater level
6. Quality control - Rainfall, river, spring
7. Flow gauging

DAILY RIVER STAGE ዕለታዊ የወንዝ ከፍታ

Project name የፕሮጀክት ስም	Project location የፕሮጀክት ቦታ

Measurement location መለኪያ ቦታ

Observer's name የአንባቢዉ ስም

Month ወር	Year አመት	Time of observation የማንበቢያ ሰዓት

European calendar	በኢትዮጵያን ቀን መቁጠሪያ	River stage የወንዝ ከፍታ	Comments አስተያየቶች
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GROUNDWATER LEVEL የከርሰ ምድር ውሃ ጥልቀት

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Measurement location መለኪያ ቦታ
Observer's name የአንባቢዉ ስም

Month ወር	Year ኣመት

European calendar	በኢትዮጵያን ቀን መቁጠሪያ	Groundwater level የከርሰ ምድር ውሃ ጥልቀት	Time of observation የማንበቢያ ሰዓት	Comments ኣስተያየቶች
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* m bgl = metres below ground level ከመሬት ከፍታ በታች

SPRING FLOW — የምንጭ ፍሰት

Project name የፕሮጀክት ስም	Project location የፕሮጀክት ቦታ

Measurement location መለኪያ ቦታ

Observer's name የአንባቢዉ ስም

Month ወር	Year ኣመት	Container volume (litres) የመጫኛ መጠን (ሊትር)

European calendar	በኢትዮጵያን ቀን መቁጠሪያ	Time to fill ለመሞላት በሰከንድ	Time of observation የማንበቢያ ሰዓት	Comments ኣስተያየቶች
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DAILY TEMPERATURE (CURRENT, MAXIMUM, MINIMUM) AND RELATIVE HUMIDITY
ዕለታዊ ሙቀት (የአሁኑ, ከፍተኛ, ዝቅተኛ) እና አንጻራዊ እርጥበት

Project name የፕሮጀክት ስም	Project location የፕሮጀክት ቦታ

Measurement location
መለኪያ ቦታ

Observer's name
የአንባቢዉ ስም

Month ወር	Year አመት	Time of observation የእይታ ጊዜ

European calendar	በኢትዮጵያን ቀን መቁጠሪያ	Temperature የሙቀት መጠን	Max. temp. ከፍተኛ ሙቀት	Min. temp. ዝቅተኛ ሙቀት	Relative humidity አንፃራዊ እርጥበት	Comments አስተያየቶች
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QUALITY CONTROL - GROUNDWATER LEVEL **የጥራት ቁጥጥር - የከርሰ ምድር ውኃ ጥልቀት**

Project name የፕሮጀክት ስም	Project location የፕሮጀክት ቦታ

Observer's name የአንባቢዉ ስም

Month ወር	Year ኣመት

Measurement location መለኪያ ቦታ							
European calendar	በኢትዮጵያን ቀን መቁጠሪያ	GW level የዉሃ ጥልቀት	GW level የዉሃ ጥልቀት	GW level የዉሃ ጥልቀት	GW level የዉሃ ጥልቀት	GW level የዉሃ ጥልቀት	Comments አስተያየቶች
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* m bgl = metres below ground level ከመሬት ከፍታ በታች

QUALITY CONTROL - RAINFALL, RIVER, SPRING **የጥራት ቁጥጥር - ዝናብ, ወንዝ, ምንጭ**

Project name የፕሮጀክት ስም	Project location የፕሮጀክት ቦታ
Observer's name የአንባቢዉ ስም	

Month ወር	Year ኣመት	Container volume (litres) የመጫኛ መጠን (ሊትር)

Measurement location መለኪያ ቦታ							
European calendar	የኢትዮጵያን ቀን መቁጠሪያ	Rainfall ዝናብ	River stage የወንዝ ከፍታ	River stage የወንዝ ከፍታ	Time to fill ለመሞላት የሚጨርሰዉ(በሰከንድ)	Time to fill የሚጨርሰዉ(በሰከንድ)	Comments አስተያየቶች
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FLOW GAUGING	የፍሰት መለኪያ

Project name የፕሮጀክት ስም	Project location የፕሮጀክት አካባቢ

Flow gauging location ፍሰት የሚለካበት ቦታ

Flow conditions / river observations የፍሳሽ ሁኔታዎች / የወንዞች ጠርዞች

Observer's name የመዝጋቢዉ ስም	Staff gauge river stage (m) የወንዝ ከፍታ (m)

Time ሰዓት	Day ቀን	Month ወር	Year አመት

Distance from bank ከባንክ ርቀት	Measurement ልኬት	Water depth የውሃ ጥልቀት	Velocity at 60% depth በ 60% ጥልቀት ያለው ቮልፎ	Comments አስተያየቶች
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