WORKING PAPER 120

SSI Working Paper 2

Establishing a Catchment Monitoring Network through a Participatory Approach

A Case Study from the Potshini Catchment in the Thukela River Basin, South Africa

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International Water Management Institute

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UNIVERSITY OF KWAZULU-NATAL

School of Bioresources Engineering and Environmental Hydrology

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Acronyms

ARC	Agricultural Research Council
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BEEH	Bioresources Engineering and Environmental Hydrology
DWAF	Department of Water Affairs and Forestry
ERT	Electrical Resistivity Tomography
LAS	Large Aperture Scintillometer
MCS	Mike Cotton System
MODIS	Moderate Resolution Imaging Spectroradiometer
PAR	Participatory Action Research
SCS	Soil Conservation Services
SSI	Smallholder Systems Innovations

Summary

Sound decision making for water resources and environmental management has to be based on factual information regarding the dominant hydrological processes, together with physical characteristics of a catchment. Such information can only be obtained through establishing a catchment monitoring network with a capacity to monitor such processes at different spatial and temporal scales. It is imperative that the local community and other stakeholders in the catchment participate in such an activity. This requires a constant effort to initiate a learning process, through which the local community is able to appreciate and recognize the importance of such a network (notwithstanding the willingness of the community to participate in the monitoring exercise). It is always useful to incorporate or consider any existing locally inspired knowledge and experience regarding the catchment monitoring network. This paper outlines the experience and challenges in establishing such a network at the Potshini catchment in the Thukela river basin of South Africa, and the opportunities in spatially upscaling such a network to capture as much information as possible in the future.

The catchment monitoring network in the Potshini catchment comprises gauging structures and instruments, most of them automated, for measuring and monitoring various hydrological and meteorological processes in the catchment at various temporal and spatial scales.

This paper highlights the initial phase of involving the community through a participatory learning process. This was achieved through the then Agricultural Research Council (ARC) Landcare Project Farmers’ Forum Meetings, individual discussions with leader farmers in the community and discussions/consultations with local leaders of the Potshini community. Reconnaissance surveys to gain a general understanding of the catchment were undertaken before detailed and specific site surveys were done as per requirements of each structure or instrument. A detailed design of structures was accomplished before construction and installation of the various monitoring instruments. Local artisans and masons were purposely involved in the construction of various structures and installation of some of the instruments, as part of a wider learning platform and technological transfer, to enable them to learn and appreciate operational mechanisms of the network.

INTRODUCTION

Catchment monitoring has always been important to water resources managers and scientists in pursuit of knowledge to understand the various hydrological processes taking place in a catchment and this ultimately leads to the development and implementation of effective water resources management strategies. The establishment of a catchment monitoring network involves a process, from the inception of the idea to the actual construction of the various structures and installation of the necessary equipment and instruments while engaging relevant stakeholders. In many cases, such a process is not documented, even though it is crucial to do so in order to share such experiences for the benefit of other stakeholders, including researchers, who may wish to undertake a similar exercise. In most cases, hydrologists in sub-Saharan Africa have concentrated on monitoring and studying the hydrological processes in protected pristine research catchments or in research catchments that lie in areas under single ownership in an effort to avoid the apparent socio-dynamics in catchments inhabited by larger communities, which could have negative impacts with regard to the safety of the installed instruments and structures. This paper strives to document a successful process of establishing a catchment monitoring network in the midst of a rural community inhabited by over 200 smallholder farmers, the Potshini community, in the KwaZulu-Natal province of South Africa.

The process of establishing the Potshini catchment monitoring network was initiated in early 2004 under the Smallholder Systems Innovations (SSI) in integrated watershed management research programme (Rockström et al. 2004) at the School of Bioresources Engineering and Environmental Hydrology of the University of KwaZulu-Natal. This paper forms an output from one of the PhD research projects within the SSI programme, Project 4b (Kongo 2004), with the general objective of developing strategies of water for sustainable food and environmental security in drought-prone tropical and subtropical agro-ecosystems.

Background Information

The Smallholder Systems Innovations (SSI) Programme

The SSI programme is an applied and development-oriented research programme, which aims to contribute to improved livelihoods of the rural poor and sustainable natural resources management in semiarid agro-ecosystems. The programme aims at assessing the extent to which water management in rain-fed smallholder farming can reach in securing human livelihoods in semiarid tropical savannahs while trying to analyze the upstream-downstream implications of upgrading rain-fed agriculture through the adoption of water use innovations (e.g., rainwater harvesting). This forms the main scientific challenge in the SSI programme, i.e., the advance of knowledge on how to balance water for food and nature, with particular focus on upgrading smallholder rain-fed agriculture in water-stressed catchments and river basins at large.

The objectives of the SSI programme, as adapted from the first SSI progress report (2003) are:

- Advance the knowledge for improved eco-hydrological landscape management at watershed and basin scales with particular focus on system interactions between water for food requirements in upgraded smallholder rain-fed farming systems and water for sustaining eco-hydrological functions and other societal needs.

- Analyze the hydrological, environmental and socioeconomic consequences of upscaling water system innovations in smallholder, predominantly rain-fed, agriculture at the watershed scale.

- Develop methodologies and decision support tools for improved rainwater management and equitable sharing of water between upstream and downstream users and uses in nature and society.

The SSI programme is also a multidisciplinary research programme encompassing biophysical and social research themes divided into six interrelated research projects (components) with the researchers working closely, in a participatory way, with other stakeholders including local communities at two pilot catchments (Potshini and Makanya) in two river basins (Thukela and Pangani) in South Africa and Tanzania, respectively. Figure 1 shows the layout of the six SSI research projects and their interactions. A brief description, focus and scope of coverage for each SSI research project, as highlighted in the proceedings of the first SSI progress report (2003), are as indicated below:

- Adaptive and participatory identification, development and assessment of water system innovations in rain-fed farming systems (Projects 1 and 2).

- Spatial analysis of potential and criteria for upscaling of water system innovations at the watershed scale (Projects 2 and 5).

- Research on the vulnerability and resilience of ecological functions to water dynamics in managed tropical agro-ecosystems (Projects 2 and 3).

- Research on hydrological processes at various scales and impacts of upscaling water use innovations on the hydrological regimes and ecosystems (Projects 4 and 5).

- Research on institutional and policy requirements to balance water for food and environmental security at the watershed and basin scales (Projects 4 and 6).

The Potshini Catchment

The Potshini catchment is predominantly a smallholder farming area and a sub-catchment of the Quaternary Catchment number V13D in the Thukela river basin in the foothills of the Drakensberg mountains in South Africa. The Thukela river basin has an area of 29,036 km^2, while the area of Quaternary Catchment V13D (Emmaus catchment) is 280 km^2. The Potshini sub-catchment comprises two nested catchments, one with an area of 1.2 km^2 and the other of 10 km^2. The mean annual precipitation at Potshini is estimated to be 675 mm and the estimated mean annual potential evaporation is between 1,600 and 2,000 mm (Smith et al. 2004). Due to the hilly terrain, a good drainage network has developed in the Potshini catchment with most of the streams being perennial and providing water for domestic use to the upper part of the catchment, while replenishing reservoirs for commercial farmers downstream. Figures 2a and 2b show the location of the Thukela river basin together with the main instrumentation sites at the Potshini catchment (cf. annex 2). Extremely low streamflows occur in winter (June to August). One of the main rivers, which drains the Quaternary Catchment V13D is the Lindequespruit, a tributary of the Little Thukela which later joins the Thukela river. The soils at the Potshini catchment are generally acidic with varying depths from 1.4 m to over 3 m on the lower parts of the catchment. Liming is advised for crop production.

Figure 1. Layout of the SSI projects (adopted from the 1st SSI progress report, 2003).

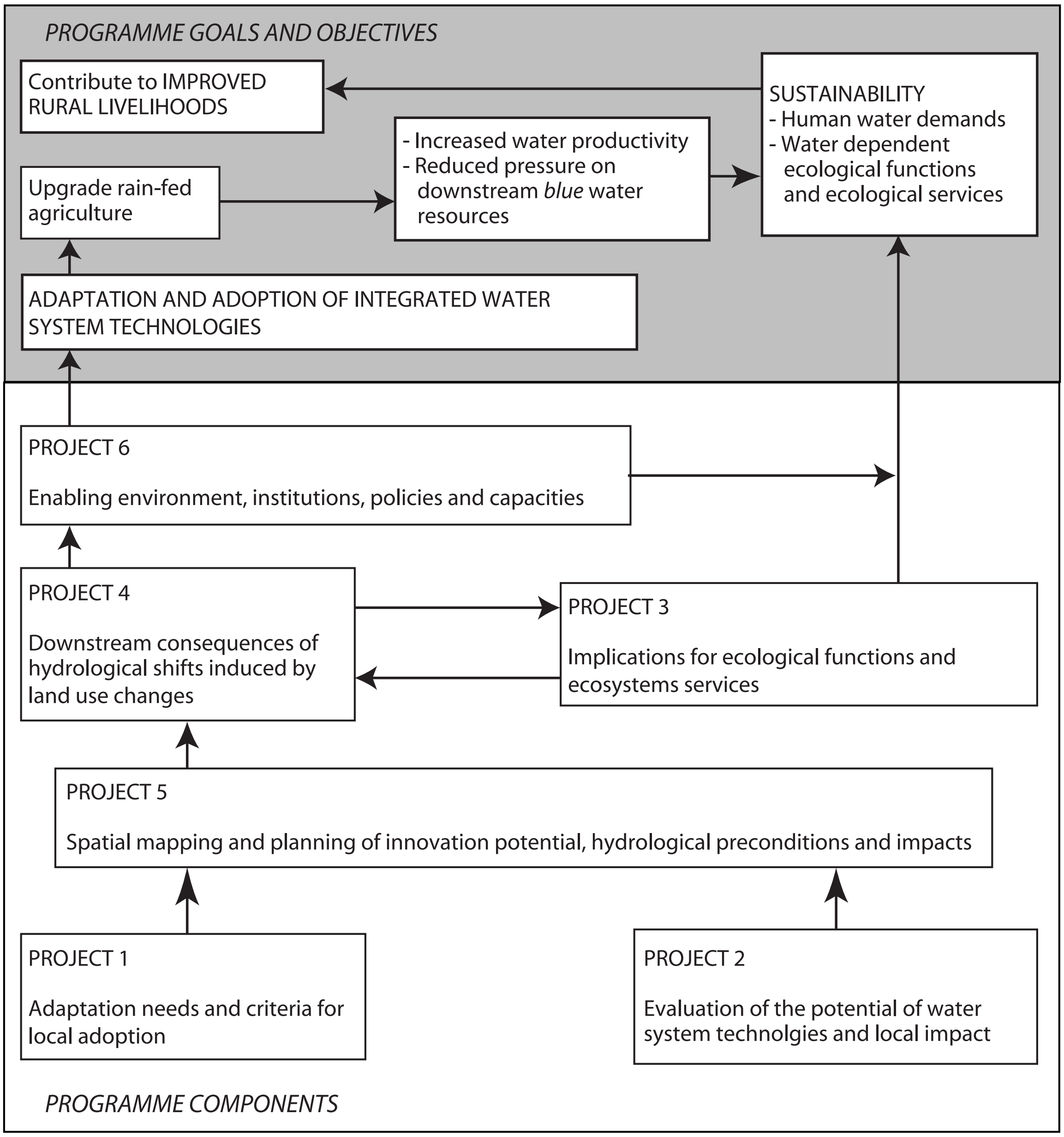


Figure 2a. An overview of the Thukela river basin and the Potshini catchment.

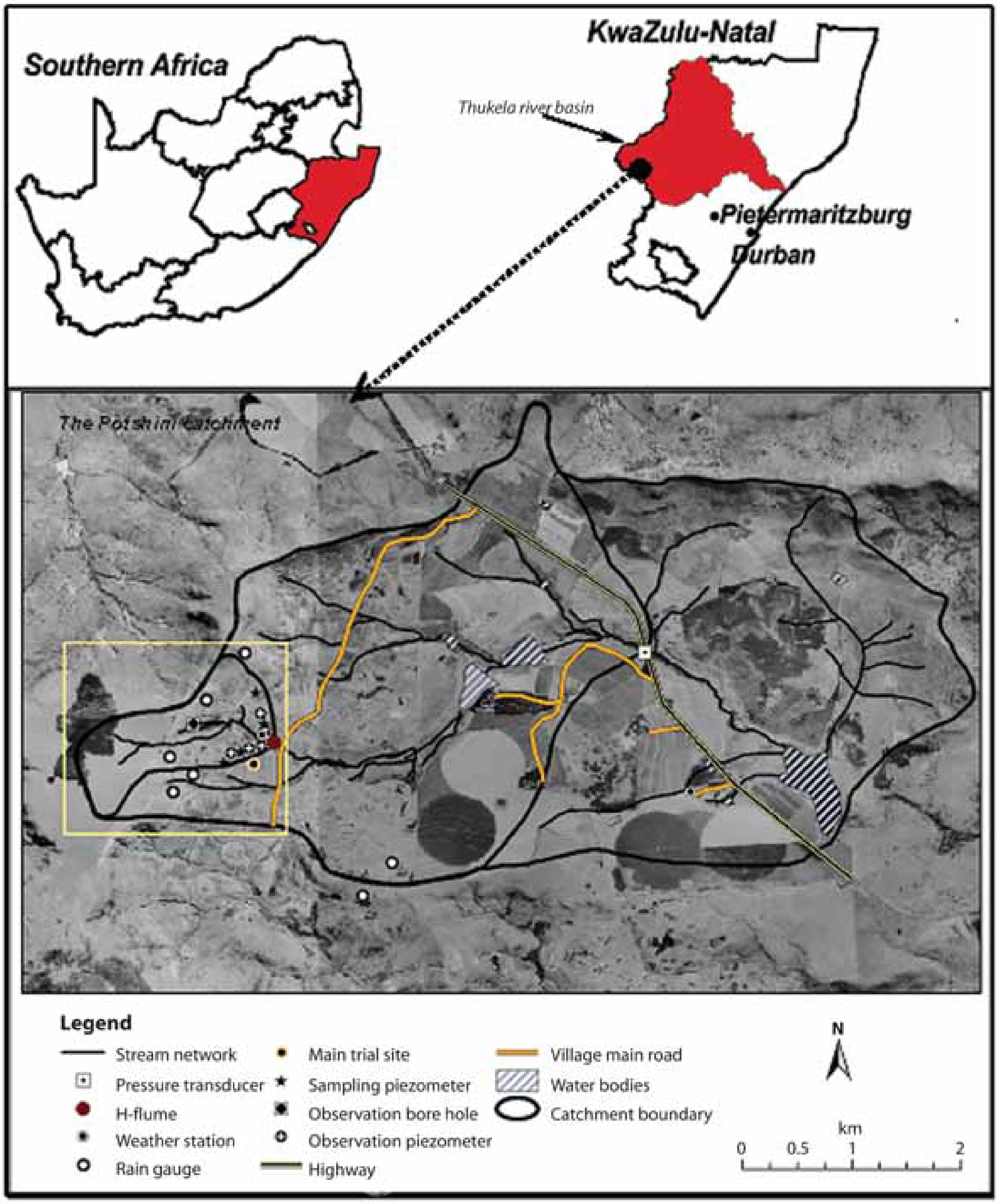
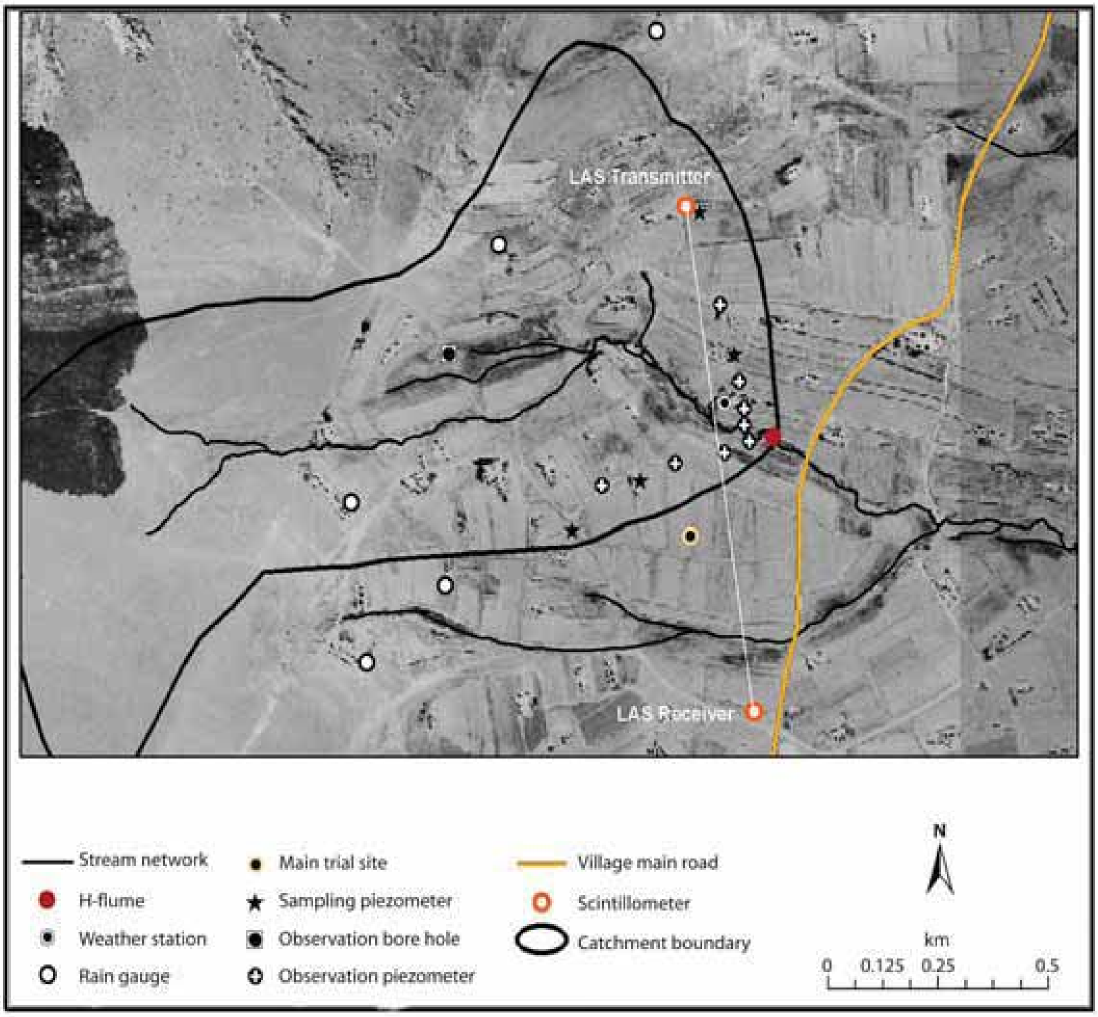


Figure 2b. The Potshini catchment.



Objectives of Establishing the Potshini Catchment Monitoring Network

To attain some objectives of the SSI programme it was imperative to establish a catchment monitoring network in the SSI pilot research catchment, the Potshini catchment in the Thukela river basin, to conduct a detailed hydrological monitoring exercise. The Potshini catchment monitoring network consists of gauging structures and instruments, most of them automated, for measuring and monitoring streamflows and sediment load, overland flow generated from runoff plots, shallow groundwater table, volumetric soil-moisture content, soil-moisture wetting fronts, soil hydraulics properties and meteorological parameters. The Potshini catchment monitoring network was established to accomplish a threefold mission aimed at:

- Monitoring the hydro-climatological regime of the Potshini catchment in an effort to have an in-depth understanding of the hydrological regime of the catchment and investigate the hydrological impacts of adoption and adaptation of water use innovations in the Potshini catchment and the Thukela river basin at large, through catchment monitoring, hydrological modeling and remote sensing techniques, at different spatial and temporal scales. This information is useful for decision making on policy development and reforms in the agriculture and water sectors as far as adaptation of rainwater harvesting techniques is concerned.

- Establish a capacity to assess, monitor and manage water and environmental resources in the Potshini catchment, especially relevant to the local community, in collaboration with various government departments (extension officers) through training on the basic methodologies of catchment monitoring.

- Provide an opportunity for future and further research through the establishment of a catchment monitoring network with a potential for upscaling and integrating into other networks. This is notwithstanding the fact that the network comprises several permanent structures which other researchers may use in their studies in the future. Such researchers will benefit from the already established cordial relationship with the local leaders and the community at large, which has been developed through the involvement of the community in various monitoring activities.

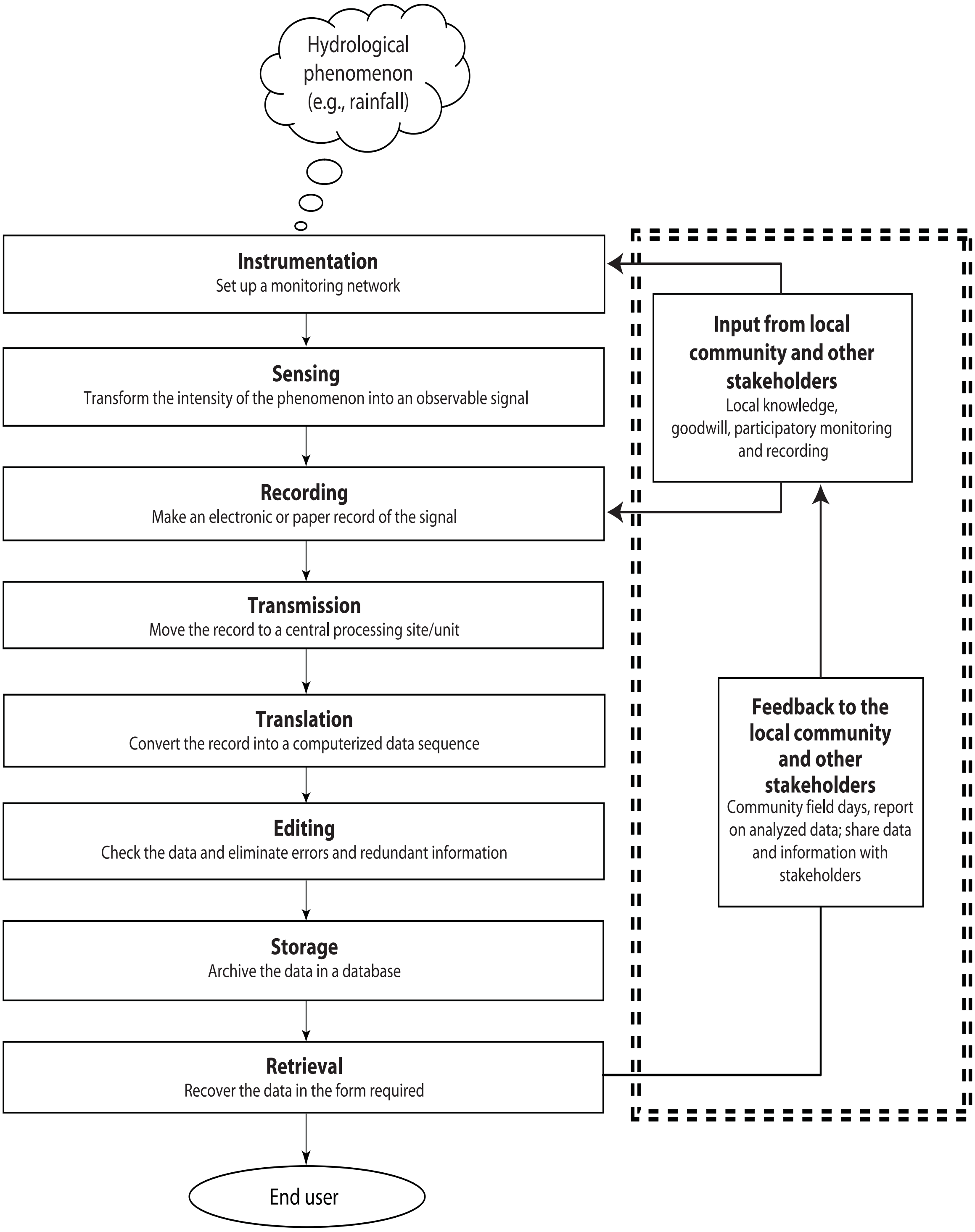
Although the catchment monitoring network at Potshini is newly established (2004), it has the potential to become an integral part of the decision-making process, from field (farm) to national level, on water and agricultural policy development. Such a process can be enhanced through a combination of well-planned data-collection strategies, training activities, scientific collaborations and publications. Training activities in the form of training workshops, seminars, field visits, field days, etc., are useful to both researchers and the communities where such a network has been established, and these should include the sharing of such a practical experience and information with other relevant stakeholders. In the SSI programme, this is achieved through its learning and outreach component (SSI 2005).

In this paper the basic procedures, such as engaging the local community, identification of suitable gauging sites and basic preliminary analyses of some of the hydrological data collected in the network are highlighted. Some of the basic scientific and conceptual principles governing the operational aspects of individual instruments and structures are discussed.

Overview of the Logical Hydrological Measurement Sequence

Although hydrological processes vary continuously in time and space they are usually measured as point measurements, i.e., measurements made through time at a fixed location. The resulting data form a time series, which may be subjected to further processing including statistical analysis and/or hydrological modeling. Chow et al. (1988) highlighted a sequence of logical steps commonly followed for hydrological measurements, beginning with the instrumentation of a physical device that senses or reacts to the physical phenomenon and ends with the delivery of data to the user. Such a sequence was adapted during the establishment of the Potshini catchment monitoring network with an additional participatory component where the input from the local community and other stakeholders was sought and incorporated as indicated in figure 3. In the absence of the participatory component, the sequence describes a scenario which is biased towards the understanding of the hydrological processes in a catchment by a researcher but void of the social dimension of how the local community perceives, understands and interprets the same hydrological processes. The social dimension comprises several elements including the understanding of the knowledge base of the rural community with regard to rainfall patterns, streamflows, temperatures, etc., the willingness of the community to learn more, and in quantifiable terms, of the various hydrological processes taking place in their midst and the importance of understanding such processes. Such an approach perpetuates a sense of ownership and imparts management skills of natural resources to the local community and hence ensures the security of the various installations constituting the catchment monitoring network.

Figure 3. Hydrological measurement sequence.



Note: Adapted from Chow et al. 1988. This is the sequence with an additional participatory component indicating the role of the local community and other stakeholders in establishing the Potshini catchment monitoring network. The feedback loop indicates sharing the analyzed data with the respective stakeholders.

The social dimension can be complicated if several stakeholders with diverse interests are involved in the establishment of a catchment monitoring network. Nevertheless, such diversity can be a source of inspiration and strength if a common understanding is sought at the initial stages. However, this must be based on good working relationships and trust as was experienced during the establishment of the Potshini catchment monitoring network. Although the steps indicated in figure 1 may appear to be obvious, even simple, they need to be followed and documented for the purpose of sharing the experience and knowledge which is the intention of this paper. Research catchments are typically established in areas where people do not live. In fact, people are usually excluded from such catchments as they add uncontrollable variables to the experiment and because of the risk of theft or vandalism. In this paper, we report the successful establishment and installation of various instruments and structures for a detailed catchment monitoring network that took place in the midst of a rural community in the KwaZulu-Natal province in South Africa. With reference to figure 3, the last two steps, i.e., storage and retrieval may not be of great concern to document in this paper though they are equally important. It is useful to note that, by the time of writing this paper, a database was concurrently being developed to store all the hydrological data being collected from the Potshini catchment monitoring network, with a user friendly interface and appropriate utilities for analyzing and retrieving data in an appropriate and desired format. Annex 2 indicates a summary of the main structures and instruments constituting the Potshini catchment monitoring network.

METHODOLOGY

The Participatory Process

The establishment of the Potshini catchment monitoring network involved the initial stage of the reconnaissance surveys to gain a general understanding of the catchment before detailed and specific site surveys were performed as per requirements of each structure or instrument. Local input was sought regarding the siting of structures and instruments and permission to develop a monitoring network was sought from the local farmers' forum and individual farmers as well as from the traditional leaders of the area. Local artisans and masons were purposely involved in the construction of various structures and installation of some of the instruments as part of a wider learning platform and technology transfer to enable them to appreciate the operational mechanisms of the network. This section of the paper strives to highlight the processes involved in selecting the various gauging and instrumentation/ experimental sites and community participation in the Potshini catchment, thus forming the Potshini catchment monitoring network. *Collaboration with other stakeholders and engaging the local community are described below.*

Since its initiation in 2004, the SSI programme collaborated with the Bergville Department of Agriculture and the former Bergville Landcare project under the Agricultural Research Council (ARC) at Potshini in the Emmaus ward where farmer-to-farmer extension proved to be successful in the adaptation of conservation tillage and other land management practices (Smith et al. 2004). The ARC-Landcare project provided a suitable launching pad and an entry point for the SSI programme in the Potshini community through its network and support in the Emmaus ward. The ARC-Landcare project initiated the monthly farmer forum meetings in 2002 which the SSI researchers have attended and participated since February 2004. Such meetings were useful platforms to the SSI researchers in updating the farmers in ongoing activities within the SSI programme, sharing information and making appointments with other stakeholders. The meetings were held at the Emmaus Community Hall. Figure 4 shows a farmers' forum meeting in session.

Figure 4. A farmers' forum meeting in session at the Emmaus Community Hall.

In order to meaningfully engage farmers and other stakeholders from the initial preparatory stages to the actual construction of various structures and instrumentation, a Participatory Action Research (PAR) approach was applied in establishing the Potshini catchment monitoring network. Permission was sought from the local and traditional leaders, individual farmers and the community at large to introduce the SSI programme to the community and construct or install various structures and instruments in the area. The culture and practices (e.g., abstaining from any field activities that involve digging or excavation of the soil during burials) of the Potshini community were respected at all times by the SSI research team. Respecting local culture, traditions and practices is always useful in perpetuating an environment conducive to interact with the local community thus getting its goodwill to safeguard any installations in the area. Several farmers in the Potshini community are voluntarily participating in the following activities:

- Recording of daily rainfall
- Monitoring of soil moisture under different land management practices
- Monitoring of discharge from runoff plots on their farms
- Enabling a conducive environment for interacting with other members of the community

The voluntary monitoring of daily rainfall in the catchment by some of the smallholder farmers in the Potshini catchment has been beneficial to both the SSI researchers and the smallholder farmers, especially in determining the appropriate time for them to plant the maize crop. The Potshini farmers have also appreciated the fact that conservation tillage preserves soil moisture in their farms and reduces surface runoff and hence causes less soil erosion. This is per preliminary results obtained from the SSI experimental runoff plots located in various experimental sites including farm fields belonging to some smallholder farmers in the community. These preliminary results have already been shared with the Potshini community through farmers' meetings.

Site Selection

The initial reconnaissance survey by the SSI researchers in the Emmaus ward of the Bergville district was made in February 2004. It served as an introduction for the researchers to the ongoing research-related activities in the ward and the district in general, in an effort to identify the existing challenges and opportunities for the successful implementation of the SSI programme in the ward and as a way of mapping strategies for implementation of individual SSI projects. The Bergville district is located in the Thukela river basin, one of the research basins in the SSI programme. This district and, in particular, the Emmaus ward were targeted in the reconnaissance survey due to the apparent opportunities for the SSI programme through the then ARC-Bergville Landcare project. The Landcare project provided an entry point for the SSI programme to the local community and, most importantly, its pivotal role in the adaptation of conservation agricultural practices (water use innovations) to the smallholder farmers in the ward.

The SSI projects which had taken off in the Thukela river basin by early 2004 were Projects 2 and 4 (cf. figure 1) and the challenge was to find a suitable catchment with most of the desired attributes for implementing Projects 2 and 4. It is useful to note that the initial setup and focus of Project 2 in the Thukela river basin were biased towards social-economic aspects of water use innovations and hence the task of monitoring the hydrological processes from field to catchment scale was implemented under Project 4 until mid-2005 when a full-time researcher was recruited under Project 2, with the scope to focus on the field water balance studies and hydrological processes. One of the common criteria during the 2004 reconnaissance survey was to find a catchment with smallholder farmers practicing rain-fed agriculture with notable water use innovations. Nevertheless, such a criterion was only sufficient for the successful implementation of Project 2 but not of Project 4 as far as hydrological monitoring is concerned. The existence of nested catchments and drainage connectivity with the Thukela river was of major concern for Project 4 and the SSI programme as a whole. The physical factors that have to be taken into account when constructing streamflow-gauging structures were considered in the reconnaissance survey. Figure 5 shows an inspection exercise of a culvert bridge as a possible gauging site in the Potshini catchment.

The catchment that was found to meet most of the requirements was the Potshini catchment, with minor challenges as compared to the many research opportunities for the SSI programme as a whole. In this regard, the research interests of all other SSI projects, i.e., Projects 3, 5 and 6 were indirectly secured and assured in the Potshini catchment as well.

Even though the inception of the SSI programme in Potshini was in early 2004, the instrumentation process could only be implemented during winter (dry season, June to October) after the farmers had harvested their crops and during low flows in the streams. This was partly for ensuring that a complete hydrological year was covered in the monitoring exercise and also for the convenience of constructing gauging structures and instrumentation during the dry season. *Involvement of the community and other stakeholders is described below.*

Figure 5. Inspection of a culvert bridge near the Potshini community as a possible gauging site.

Note: In picture: Victor Kongo and Johan Rockström - July 2004.

One of the challenges which emerged after the initial biophysical reconnaissance survey in the process of establishing a catchment monitoring network in the Potshini catchment was getting other stakeholders (e.g., the local community) to accept, and to participate in realizing, the objectives of the SSI programme and understand its dynamics within the community, including its international nature and perspective, given that several international researchers were expected to work in the community as well as the programme's comparative standing with the Pangani river basin in Tanzania.

One of the approaches used to address such challenges was through the facilitation of a communication process and dialogue between the SSI team and the relevant stakeholders in the catchment. It involved having meetings with the local leaders (e.g., traditional leaders, local government officials, relevant government department officials, etc.,) and the local community. The local community has continued to be a key stakeholder in the SSI programme and an effort has been made towards creating and maintaining a cordial relationship with the community, based on respect, trust and friendship. In 2004, after several meetings with the local traditional leader (*Induna*) of the Potshini community, he advised the SSI team to write to the local community through him, a summary detailing the kind of activities the team intended to do in the community so that he could read such a brief and pass the information during community meetings. This was done as indicated in annex 1, parts a and b, as an appreciation of the community's support to the SSI team, and also to highlight the main SSI research activities in the area.

The monthly Emmaus Farmers' Forum, a communication and management platform for farmers in the Emmaus ward under the ARC Landcare project, proved to be useful and an entry point for the SSI researchers, for dialogue with farmers and other stakeholders in the area. Through the forum, the SSI researchers managed to outline the objectives of the SSI programme in the area, its implementation and most importantly, the usefulness of voluntary participation of farmers in the SSI programme. The SSI researchers managed to effectively use the farmer-to-farmer learning structures previously put in place by the ARC Landcare project for contacting individual smallholder farmers on their willingness to voluntarily participate in the SSI programme, especially in the catchment monitoring exercise. It is through such forums that the ongoing good working relationship between the District Department of Agriculture office in Bergville and the SSI team was devised. Since then, the SSI programme has benefited and enjoyed the support of the Bergville Agricultural office and has been represented in the Bergville District Task Team (DTT), a bimonthly forum meeting organized by the Bergville Department of Agriculture office for all stakeholders and projects working in the Bergville district for food security, home economics, community resources and the agriculture sector. The SSI team has been participating in all field days organized by the Department of Agriculture in Potshini and other nearby wards in the Bergville district and, likewise, the Department of Agriculture has actively participated in, and to some extent, facilitated, some of the field days organized by the SSI team in Potshini. In 2004, the Bergville Department of Agriculture office actively participated in one of the reconnaissance surveys in the Potshini catchment during the process of locating potential streamflow-gauging sites in the Potshini catchment and also facilitated the first meeting between the SSI team and the traditional leaders of the Potshini community.

The SSI programme as a whole was warmly accepted by the local people in the Emmaus ward and Potshini in particular where participatory catchment monitoring and initial installation of various instruments and construction of streamflow-gauging structures began in August 2004. The voluntary participation of the local community in establishing and maintaining the Potshini catchment monitoring network has continued to be a source of inspiration to the SSI team in the Thukela river basin. One such motivating example is when one of the smallholder farmers participating in the monitoring exercise took the initiative to buy a new rain gauge after the one previously supplied and installed by the SSI team had been blown and ripped off by strong winds. The same farmer had previously been quoted saying that, "Nowadays I can walk confidently and tell the Potshini people the exact amount of rainfall they have received and not just argue without any measurable values."

Locating the streamflow-gauging sites and design of the gauging structures in the Potshini catchment involved the application of both the local knowledge and the conventional scientific approach. For example, the location and design of the instrumentation house of the H-flume (cf. Section on Construction and Instrumentation) were determined after consultation with the local leaders and farmers who advised that, once in a while (i.e., 4 to 5 years), the chosen site was prone to inundation and there was a need to build the house on higher grounds of the river bank. This advice was taken into account in the design and subsequent construction of the H-flume. The observations and advice from the local community were relatively in agreement with the results obtained in the modeling exercise done to determine the peak discharge from the Potshini catchment using the Soil Conservation Services (SCS) methodology.

Detailed Survey

The actual implementation of any structural engineering design has to be based on specific site surveys to determine aspects of the surface terrain, especially the slope and relative elevation. It is from such surveys that one can fairly estimate volumes of material to be excavated from a site and hence facilitate the orientation of such structures. As far as the construction of hydraulic structures is concerned, e.g., an H-flume, it is important to determine the stream channel characteristics including the bed slope, channel and flood plain elevation and the channel geometry, at least 150 m from both upstream and downstream of the gauging site, as was done when constructing the Potshini H-flume. A Theodolite or a Total-station is recommended for this kind of surveying exercise. It is important to note that the selection of a gauging site is influenced by several factors including the following:

- The streambed needs to be stable enough to accommodate a sound foundation and the weight of the hydraulic structure. A rocky bed is highly recommended.
- The channel banks have to be relatively narrow to avoid extra cost of closing the remaining section of the stream width. This happens when the hydraulic structure does not occupy the full width of the stream channel.
- The stream channel has to have a sufficient bed slope to allow free streamflow to avoid a backwater curve which could lead to inundation of the hydraulic structure.

The survey exercise along the Potshini stream was performed using a Theodolite, and its basic alignment and operational mechanism in the field are illustrated in figures 6 to 8.

Table 1 indicates sample data obtained from a survey exercise using a Theodolite when determining the bed slope, geometry and the layout of the Potshini stream. These data were analyzed using a spreadsheet to determine relative elevations of each surveyed point (station) before plotting the respective layouts of the Potshini stream (figures 9 to 11).

Table 1. A survey field data sheet.

Date:……18 June 2004...
Instrument reading by:…Victor Kongo
Staff gauge held by:…Mabomu Ndlovu

Height of instrument (mm):…1,435
Setup elevation (m): ……..…1,000

Station no.	Staff reading (mm)			Angles						Description
	Top	Middle	Bottom	Vertical (º ‘ “)			Horizontal (º ‘ “)			
1	2,241	2,050	1,857	91	58	0	0	0	0	Reference peg
2	1,161	999	838	91	9	0	67	33	10	
3	2,178	1,770	1,365	88	32	20	111	5	50	
4	2,263	1,900	1,540	88	33	20	111	7	30	

Figure 6. An illustration of a Theodolite and a staff gauge setup.

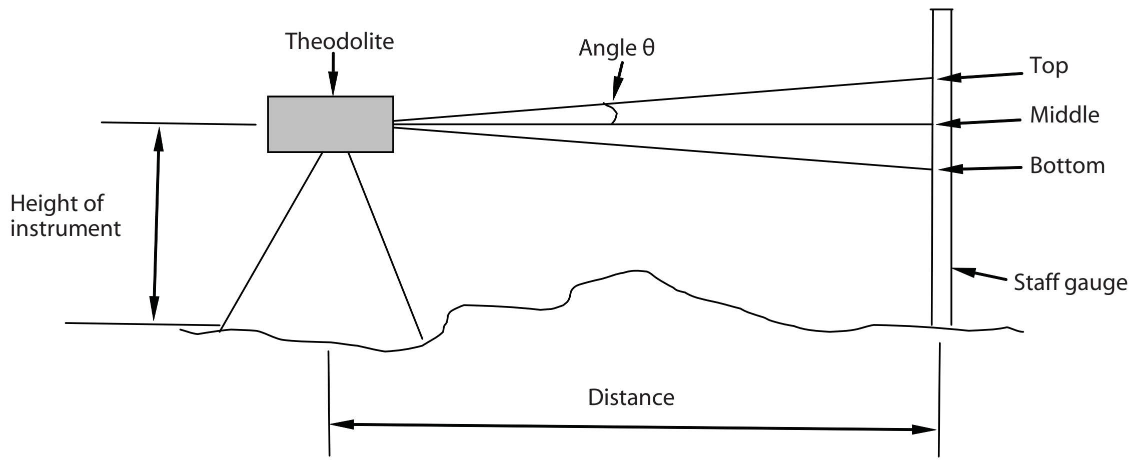


Figure 7. A Theodolite in use.

Figure 8. A staff gauge in use.

The distance in meters between the instrument (Theodolite) and the survey station was determined using equation 1:

$$L = 100(T - B)Sin^2\theta \tag{1}$$

where,
L = distance between the instrument and the survey station
T = the top staff reading
B = the bottom staff reading
θ = the vertical angle of sight (angle between top and middle staff readings)

The vertical elevation of any given survey station (point) was determined using equation 2:

$$V_e = S_e + H - M + \frac{100}{2\,sin(2\theta)} \tag{2}$$

where,

V_e = vertical elevation (m)
S_e = setup elevation (m)
H = height of instrument (m)
M = the middle staff reading
θ = the vertical angle of sight

The setup elevation could be referenced to a survey benchmark or an arbitrary peg. The latter is used to determine relative elevation in the absence of a benchmark as was applied during the survey exercise in the Potshini catchment. The relative distance from one survey station to another was determined through basic trigonometric rules thus enabling the creation of elevation-distance graphs and stream layouts as indicated in figures 9 to 11. Such an approach was also used in creating contour maps by importing the elevation-distance data into a GIS software package, i.e., ArcView, in an effort to determine the general slope of some of the smallholder farms in the Potshini catchment before installing the runoff plots.

Figure 9. Channel bed slope at the selected gauging site.

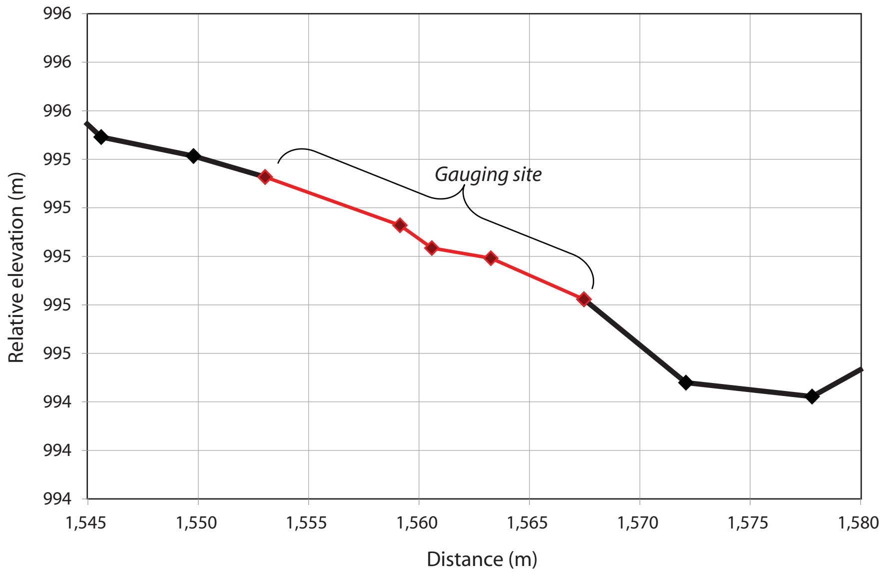


Figure 10. Cross-sectional area of the Potshini stream at the selected gauging site.

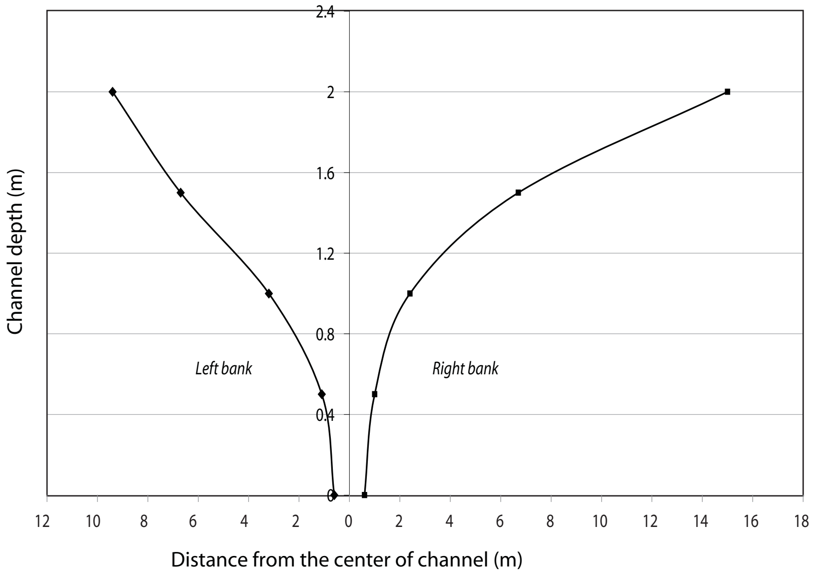
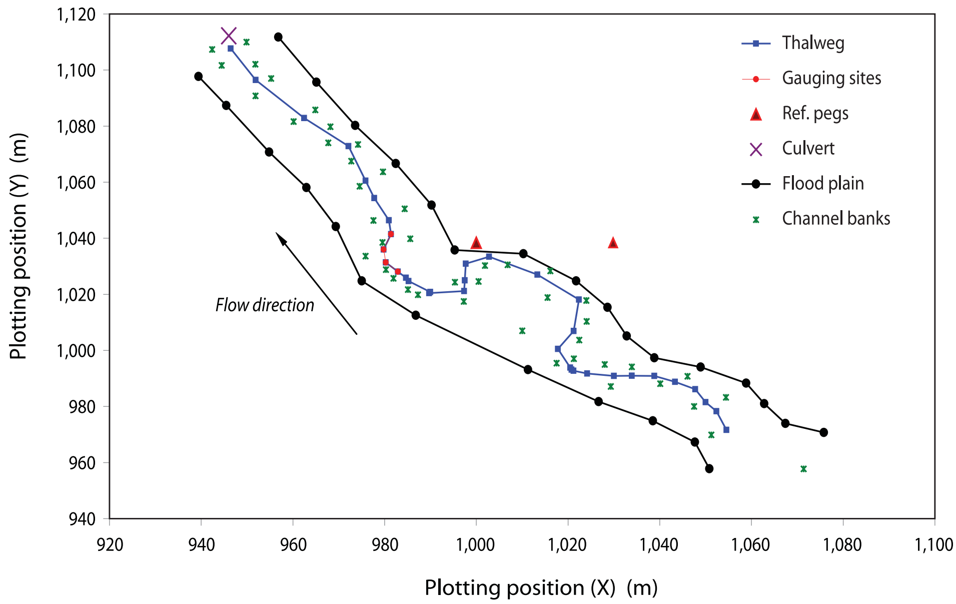


Figure 11. Survey layout of the Potshini stream near the gauging site.



Determination of Peak Discharge from the Potshini Catchment Using the SCS-SA Model

A sound design of any hydraulic structure in a river or a stream requires prior information of the flow regime, especially the peak discharge. Such information can be derived from empirical relationships between the catchment's physical and hydrological characteristics as in the Soil Conservation Service (SCS) method of estimating peak discharge from small catchments. In designing the Potshini H-flume, the catchment peak discharge was estimated using a modified version of the SCS method, which is designed to suit South African conditions. The modified version has been thus named SCS-SA (Schulze et al. 1992). In estimating the peak discharge from the Potshini catchment, the physical and hydrological characteristics of the catchment were taken into account, as required in the SCS-SA method.

The SCS Method

The SCS equation is given as:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{for } P > I_a \tag{3}$$

$$S = \frac{25400}{CN} - 254 \tag{4}$$

where,

Q = stormflow depth (mm)

P = daily rainfall depth (mm)

S = potential maximum soil water retention (mm)

≡ index of the wetness of the catchment's soil prior to a rainfall event

I_a = initial losses (abstractions) prior to the commencement of stormflow (depression storage, interception and initial infiltration [mm])

CN = curve number

≡ index expressing catchment's response to a rainfall event

Chow et al. (1988) highlighted an empirical relationship developed from small experimental catchments showing that

$I_a = 0.2S$

Schulze et al. (1992) recommended that, for South African conditions, this empirical relationship could be described as (the SCS-SA method):

$I_a = 0.1S$

On substituting, equation 3 can be rewritten as:

$$Q = \frac{(P - 0.9)^2}{P + 0.9S} \tag{5}$$

Stormflow depth represents a uniform depth over the catchment and may be converted to volume by introducing the catchment area.

Determination of Peak Discharge

In the SCS method, the peak discharge for an increment of time (ΔD) is defined as:

$$\Delta q_p = \frac{0.2083 * A * \Delta Q}{\Delta D / 2 + L} \tag{6}$$

where,

Δq_p = peak discharge of incremental unit hydrograph (m^3/s)
A = catchment area (km^2)
ΔQ = incremental stormflow depth (mm)
ΔD = unit duration time (hours), used with distribution of daily rainfall to account for rainfall intensity variations
L = catchment lag (hours)

Catchment response time *(L)* is an index of the rate at which the generated stormflow moves through the catchment. The general hydrological and physical conditions in the Potshini catchment favored the use of SCS lag equation in the SCS-SA model (Schulze 1992) for estimating catchment response time. Dry spells occur during winter (May to September) and most parts of the catchment end up having limited vegetation and mulch cover due to overgrazing and hence the area could be categorized as semiarid. The SCS lag equation is given as:

$$L = \frac{l^{0.8}(S^{'} + 25.4)^{0.7}}{7069 * y^{0.5}} \tag{7}$$

$$y = \frac{M * N * 10^{-4}}{A} \tag{8}$$

where,

L = catchment lag time (h)
l = hydraulic length of catchment along the main channel (m)
S' $= \frac{25400}{CN - II} - 254$
y = average catchment slope (%)
M = total length of all contour lines (m) within the catchment, according to the scale of the map
N = contour intervals (m)
A = catchment area (km^2)

Table 2 indicates the physical and hydrological parameters for the Potshini catchment used as inputs to the SCS-SA model. The catchment area, number of contours, total length of contours and the hydraulic length of the catchment were determined from a 1:50,000 topographical map covering the catchment while the long-term mean annual precipitation (MAP) was obtained from the nearby Bergville weather station.

Table 2. Physical and hydrological characteristics of the Potshini catchment.

Area (km^2)	No. of contours	Total length of contours (km)	Contour interval	Hydraulic length (m)	Slope (%)	MAP (mm)
1.1	7	5.75	20	1,400	10.46	675

The location of the catchment coincided with storm intensity distribution type 4 (Schulze et al. 1992). With the coefficient of initial abstraction being 0.1, the catchment lag time was found to be 0.35 hours. A summary of SCS-SA model results is indicated in table 3.

Table 3. Summary of the SCS-SA model results.

Return period (years)	2	5	10	20
Design daily rainfall depth (mm)	59	81	98	117
Computed curve number	74.5	74.5	74.5	74.5
Runoff depth (mm)	18.4	32.8	45.2	60.0
Runoff volume (1,000 m^3)	20.27	36.09	49.75	66.05
Peak discharge (m^3/s)	6.4	11.6	16.2	21.6

In designing the Potshini flume, a 2-year return peak discharge was considered, i.e., 6.4 m^3/s, though the actual design flow was taken to be 3.34 m^3/s. The reasons for adopting a lesser design flow are discussed in the next section of this paper.

Construction and Instrumentation Process

H-flume

As described by Ackers et al. (1978), a flume is a flow-measuring device formed by a constriction in an open channel; the constriction can be either a narrowing of the channel or narrowing in combination with a hump in the invert. By making the constriction sufficiently severe it is possible to produce critical flow conditions in the open channel. When this occurs there is a unique stage-discharge relationship that is independent of the conditions downstream, and it is on this principle that the critical-depth flume, such as the H-flume, is based.

The H-flume was developed by the SCS and consists solely of a uniformly converging section. The throat is formed by sloping the tops of the side walls downwards and inwards in the direction of flow. The advantage of such a sloping throat section is that as discharge and, hence, the depth of flow increase, the point at which the flow overtops the side walls moves further upstream so that the effective crest width also increases. The stage-discharge characteristics of an H-flume can be determined through theoretical equations derived from fitting the stage-discharge relationship from observed data so that discharge can be computed directly rather than by means of rating graphs or tables.

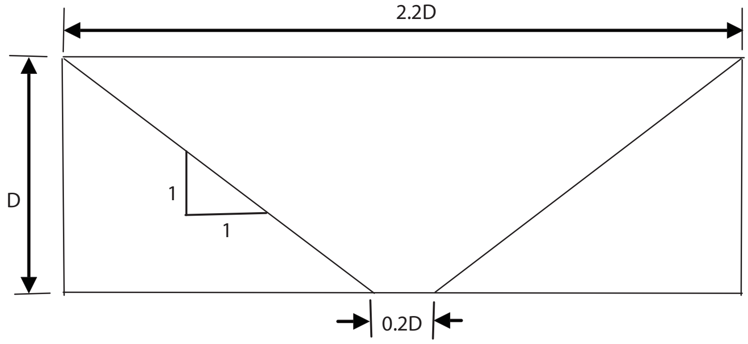
The Potshini H-flume

Any design flow has a cost implication in terms of the size of the hydraulic structure and the safety factors that are considered. As for the Potshini H-flume, it was found necessary to reduce the design discharge from 6.4 m^3/s to 3.34 m^3/s because the main concern in this study was the medium to low flows. It was also noted that the current H-flume's stage-discharge relationship developed by SCS could not hold for such high flows of the magnitude of 6.4 m^3/s, and it was necessary to use an H-flume rather than a weir in the catchment to facilitate accurate monitoring of sediment load from the catchment, which is rather difficult to implement using a weir (V-notch or crumped weir). If not well designed, weirs may end up being sediment traps leading to changes in the channel geometry (width and depth), and this is the main reason that weirs need to be recalibrated with time. This is not the case with H-flumes. The geometry and design of H-flumes allow free flow of the stream discharge, save for the constriction at the front end, thus enabling the implementation of a sediment-load-monitoring scheme as is the case with the Potshini H-flume. The fundamental concern and priority during the design and construction of the Potshini H-flume constituted maintaining structural stability of the structure during and after excessive loading events, i.e., peak floods. This concern was translated into safety and precautionary measures which were incorporated in the design and construction of the H-flume as follows:

- The instrumentation house was constructed on a higher ground (i.e., on the stream bank) to avoid damage to the flow-recording instruments in the house by unpredictable seasonal floods.
- The walls of the approach channel had to be reinforced with Y12 (12 mm high tensile) steel bars for every other brick and filled with concrete mortar.
- The section before the approach channel had to be lined with reinforced riprap, 3.0 m upstream, to avoid scouring of the bed and side walls. The area around the mixing pan (front end of the H-flume) was also lined with concrete to avoid scouring due to the erosive effect of the anticipated fast-falling and -flowing water during peak flows.
- The foundation of the approach channel wall was established at a 0.3 m depth into the bedrock, where the holes for the reinforcing Y12 starter bars were drilled into.
- The floor of the approach channel was cast upon a solid mass of a mixture of rock boulders and concrete mortar. This was necessary as an effort to raise the approach channel floor level to above 0.64 m which was required to avoid a backwater curve into the flume. At the moment, the floor level is raised to 0.72 m. Such a mass, i.e., a mixture of rock boulders and concrete, was also important to safeguard the structure (approach channel) from failing due to sliding by providing an extra mass, for the most probable mode of the structure's failure was by sliding and/or seepage and not by overturning since hydrostatic pressure differences (difference in water levels) between upstream and downstream of the H-flume were expected to have an insignificant influence on the overall stability of the structure due to the free-flowing nature of the flow.
- To avoid failure of the structure through seepage, three cutoffs were created along the streambed by digging three trenches (0.2 m wide, 0.4 m deep with spacing of 3.0 m) across the width of the streambed and filled with concrete mortar before casting of the approach channel floor. Such cutoffs are also useful in safeguarding the structure from sliding.

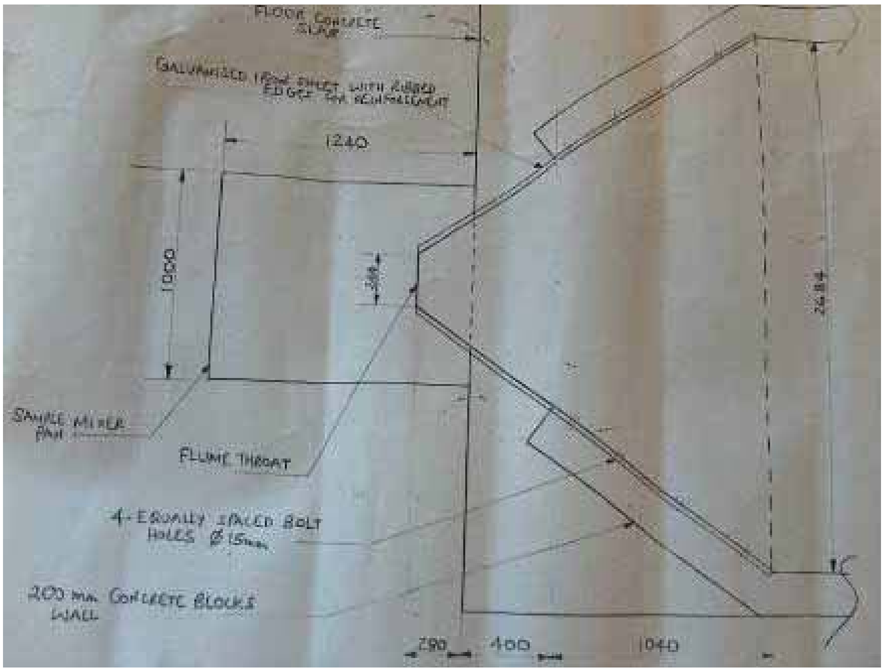
Figures 12 and 13 show the design and sizing criteria applied for the Potshini H-flume (Ackers et al. 1978) and design plan, respectively.

Figure 12. Front elevation of the H-flume.



Flume size (D)	Capacity m^3/s
1.22	3.34

Figure 13. Plan view of the Potshini H-flume.



The template below shows pictures taken during some of the construction stages of the Potshini H-flume.

Template 1. Construction stages of the H-flume.

A coffer dam

Drilling of starter bar holes into the bedrock

A mass of concrete and rock boulders

Reinforced walls of the approach channel

Setting of the H-flume

Instrumentation house on higher ground

Table 4 indicates the bill of quantities while figure 14 shows the Potshini H-flume in operation.

Table 4. Bill of quantities for the Potshini H-flume, 2004.

No.	Quantity	Description	Amount (ZAR)
1	810	Building blocks	3,240.00
2	3 m^3	Building sand	360.00
3	7 m^3	Concrete sand	1,400.00
4	6 m^3	Concrete stones	1,950.00
5	1 m^3	Plaster sand	320.00
6	80 bags	Cement	3,200.00
7	26 tons	Rock boulders (*bullets*)	Ferried using project vehicle
8	84 m	Reinforced bars (Y12, Y20)-HT steel	784.00
9	1	H-flume and stilling well (tank)	3,433.68
10	1	Instrumentation house door	473.00
11	1	6 m x 50 mm galvanized steel pipe	500.00
12		Labor	8,640.00
		Total cost	24,300.68
			US$4,000.00

Figure 14. The Potshini H-flume in operation.

Flow Rating under Different Upstream Heads for the Potshini H-flume

The monitoring of the flow rates at the Potshini H-flume is governed by a set of three rating equations, each describing a unique stage-discharge relationship for a given range of flow depths. Table 5 indicates the numerical values of the constants and variables used in the three rating equations which are:

i) For high flows (upstream heads greater than 0.061 m), the rating equation is given as:

$$Q = \sqrt{2g} * h^{3/2}(0.5 * b * K_0 + m * K_1 * h) \qquad (9)$$

where,

Q = streamflow (m^3/s)
g = acceleration due to gravity (m^2/s)
h = upstream head (m)
b = base width of flume throat (m)
m = side slope of flume throat (1 vertical: *m* horizontal)
K_o and K_1 = constants

ii) For low flows (upstream heads less than 0.031 m), the rating equation is given as:

$$Q = C_o(b + m * h) * h(h - a)^n \qquad (10)$$

where,

Q = streamflow (m^3/s)
C_o = constant
a = constant
b = base width of flume throat (m)
m = side slope of flume throat (1 vertical: *m* horizontal)
n = constant
C_o = constant with dimensions of $m^{(1-n)}.s^{-1}$

iii) For upstream head greater than 0.031 m and less than 0.061 m (transition flows), the rating equation is given as:

$$Q = \sqrt{2 * g} * h^{3/2}(0.5 * b * K'_o + m * K'_1 * h) \qquad (11)$$

where,

Q = streamflow (m^3/s)
g = acceleration due to gravity (m^2/s)
h = upstream head (m)
m = side slope of flume throat (1 vertical: *m* horizontal)
K'_o *and* K'_1 = constants

Table 5. Rating constants and variables for the Potshini H-flume.

Variable/constant	Value
a	0.003
b	0.244
C_o	2.023
m	1
n	0.522
K_o	0.7804
K'_o	0.8334
K_1	0.3788
K'_1	0.2728

For the transitional flows (>0.031 m and <0.061 m), the constants K'_o and K'_1 were determined so as to force the transition equation to tie in with the high-flow equation and with the low-flow equation at either end of the transition range. This was done by using equation 9 to determine the discharge for h=0.061 m and equation 10 for h=0.0305 m. Substituting these two pairs of Q, h values into equation 11 produced a pair of simultaneous equations, from which K'_o and K'_1 were calculated. The large H-flume is insensitive to measuring low flows below 0.003 m, as implied in equation 10 which will give zero or negative flow rates for upstream heads less than, or equal to, 0.003 m.

Operational Mechanism

Monitoring of the water levels and subsequent discharge in the Potshini H-flume are based on the principle of a piezometer, where the water level in interconnected columns will always be the same. In the Potshini H-flume, the approach channel is connected to a stilling well, 4.6 m away, by a 50 mm pipe at the floor level of the approach channel and slightly sloping in the direction of the stilling well. With this setup, the water level in the approach channel and the stilling well will always be the same thus making it possible to monitor the water levels in the approach channel by recording the water levels in the stilling well through the use of a floater and a data logger mechanism as illustrated in figures 15 and 16. The water level in the stilling well is stable and tranquil as it is not directly exposed to the turbulent flow conditions as in the approach channel thus making the stilling well the ideal setup for monitoring water levels in a stream. The floater in the stilling well oscillates with the rise and fall of the water level in the approach channel and such movements are translated into rotational movements through a pulley system in a shaft encoder, which is linked to an MCS data logger as shown in figures 15 and 16. The length and width of the approach channel are 11.64 m and 2.864 m, respectively.

Figure 15. Monitoring of the streamflow depth using a stilling well and floater mechanism at the Potshini H-flume.

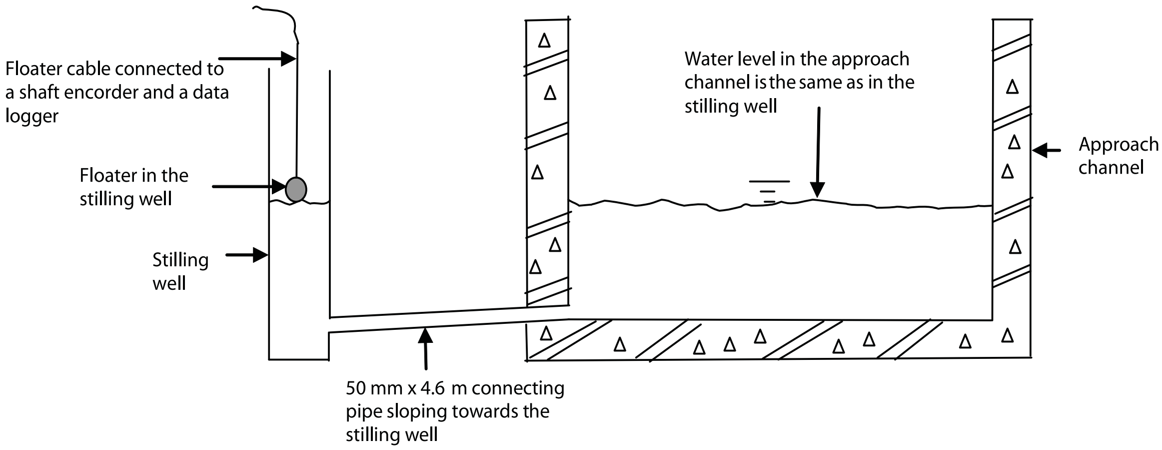


Figure 16. Stilling well, MCS data logger and ISCO sampler at the Potshini H-flume.

The MCS data logger then translates the rotational movements of the pulley system to water levels and subsequently into stream discharge through a set of polynomial equations. The MCS data logger cannot read the original calibration equations 9–11 and hence they have to be translated to a polynomial so that the logger can integrate flow volumes used to trigger an ISCO sampler. Equation 12 shows the polynomial equation in the Potshini H-flume's data logger; the values of the polynomial constants are indicated in table 6.

$$Q = A1(0) + A1(1)H + A1(2)H^2 + A1(3)H^3 + \ldots + A1(n)H^n + A2(0) + A2(1)H + \ldots + A2(n)H^n \qquad (12)$$

where.

Q = flow rate (m^3/s)

H = flow depth (m)

A1(0) = constant for first polynomial

A1(1) = 1st term of the 1st polynomial (x)

A1(2) = 2nd term of the 1st polynomial (x^2)

A1(3) = 3rd term of the 1st polynomial (x^3)

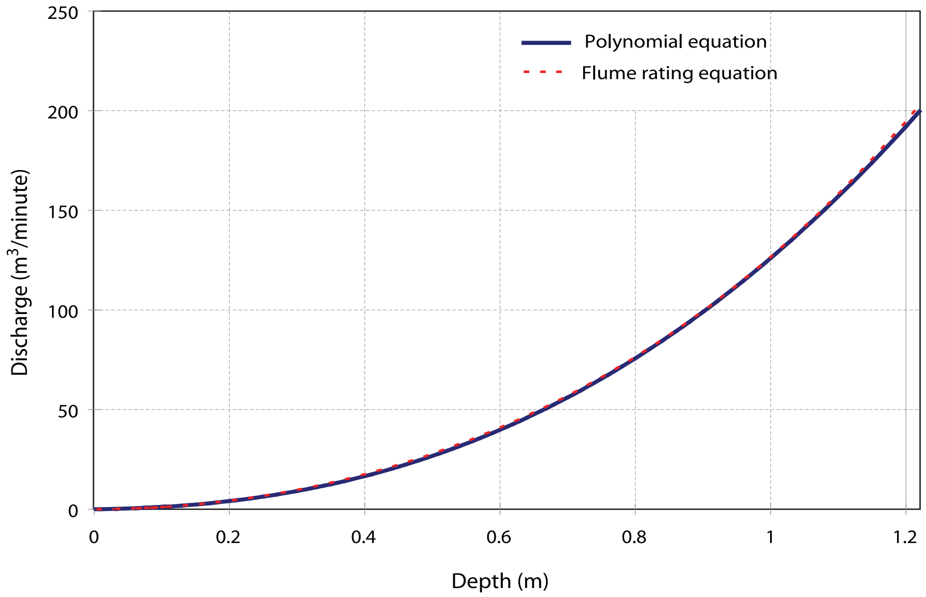
A1(n) = nth term of the 1st polynomial (x^n)

A2(0) = constant for the 2nd polynomial

A2(1) to *A2(n)* = 1st term to nth term of the 2nd polynomial (x to x^n)

The polynomial equation operates between "breakpoints" to simulate the calibrated flow rate equations of the H-flume. Such breakpoints are useful when such a data logger is used in a weir with a combination of notches, where the relationship between the flow rate and depth of flow is different for each notch. Breakpoint values are the heights at which the notch size and shape change, and hence the stage-discharge relationship. The constants of the polynomial equations are determined through a calibration exercise, which can be done on a spreadsheet, by trying to superimpose the estimates of discharge from the polynomial curve on to the stage-discharge curve of the H-flume. It is possible to fairly superimpose the two curves by changing one or more constants of the polynomial equations as was achieved when calibrating the MCS data logger for the Potshini H-flume. Table 6 indicates the various conditional parameters in the MCS data logger and ISCO sampler at the Potshini H-flume and figure 17 shows the polynomial and the rating curves for the Potshini H-flume.

Figure 17. Calibration curve of the MCS data logger at the Potshini H-flume.



When a predetermined volume of flow has been exceeded, then a relay mechanism in the MCS data logger switches on for a short time and transmits an impulse signal to the ISCO sampler to take a sample. The 500 ml water samples are stored in a set of 24 bottles which are replaced during subsequent data collection sessions.

The ISCO Sampler

It is always a challenge to take a representative and accurate water sample in streams for analytical work on water quality. This is compounded by the fact that streamflows originating from relatively small catchments are highly variable, especially where the catchment response is fast. A good sampling scheme should take into consideration such variations of flow by taking frequent samples during changing flows. Water quality (e.g., sediment load) will show less variation at constant flow and hence less frequent sampling is required. Such a sampling scheme can be achieved through the use of an automatic sampling system by the use of an ISCO sampler.

The Potshini H-flume was equipped with an ISCO sampler, with a capacity of 24 sampling bottles of 500 ml each, and controlled by an MCS data logger. The samples are then analyzed for suspended sediment load and isotopic composition of Oxygen-18 (^{18}O) and Deuterium. The number of samples and the sampling rate of the ISCO can be varied by the conditional parameters in the MCS data logger as shown in table 6. The sampling strategy in the Potshini catchment is to take infrequent samples during steady flows (low flows) and frequent samples during rapidly changing flows (events).

Table 6. Conditional parameters for the MCS data logger at the Potshini H-flume.

Parameter	Value	Description
Delta *Q*	5	Flow volume for changing flow (m^3)
Delta *q*	15	Flow volume for constant flow (m^3)
Delta *G*	0.01	Delta gradient (m)
Minimum sample	5	Minimum sample time (minutes)
Maximum samples	24	Maximum number of samples to be taken
Sampling head	3	Suction head (m)
Suction line	7	Total length of the suction line (m)
A1(0)	0	Polynomial variable
A1(1)	0.0013	Polynomial variable
A1(2)	1.747	Polynomial variable
A1(3)	0.062	Polynomial variable
A1(4)	0.2996	Polynomial variable

With reference to table 6, Delta *G* is used to establish if the flow is constant or changing. If the change in flow rate is less than Delta *G*, then a sample will be taken after Delta *q* m^3 of flow has passed the H-flume. Alternatively, if the change in flow is greater than Delta *G*, as in runoff events, then the samples will be taken after Delta *Q* m^3 of flow. The parameters Delta *Q*, Delta *q* and Delta *G* were derived through a calibration process, by simulating observed flow data while checking the sampling scheme of the data logger before adjusting the appropriate variables (Delta *G*, Delta *Q* and Delta *q*).

Monitoring of Streamflow Using Pressure Transducer

As far as streamflow monitoring is concerned, the choice of using any of the streamflow gauging structures primarily depends on a number of factors, one being the geometry of the stream channel at the site. For example, in wide channel sections of a stream where the construction of a flume or a weir may not be feasible (e.g., due to cost constraints), then a cheaper option is to use a pressure transducer to monitor the water levels in the stream with a fairly good level of accuracy and subsequently develop a rating curve for that section after carrying out a detailed survey of the cross section at the site. The cross section has to be stable (not changing with time) for the integrity of the developed rating curve to hold. In the Potshini catchment monitoring network, a pressure transducer together with a data logger was installed under a culvert bridge (cf. figure 5), approximately 5 km downstream of the Potshini community. This was done after a calibration exercise which entailed subjecting the transducer to pressure from a gradually increasing column of water, from 0 to 100 cm while recording the output voltage signal from the transducer in a data logger. A similar exercise was done for a decreasing water column. Figure 18 illustrates the calibration process while figure 19 indicates the calibration curve for a pressure transducer.
The calibration equation for the pressure transducer is indicated in equation 13 as:

Figure 18. Calibration of a pressure transducer.

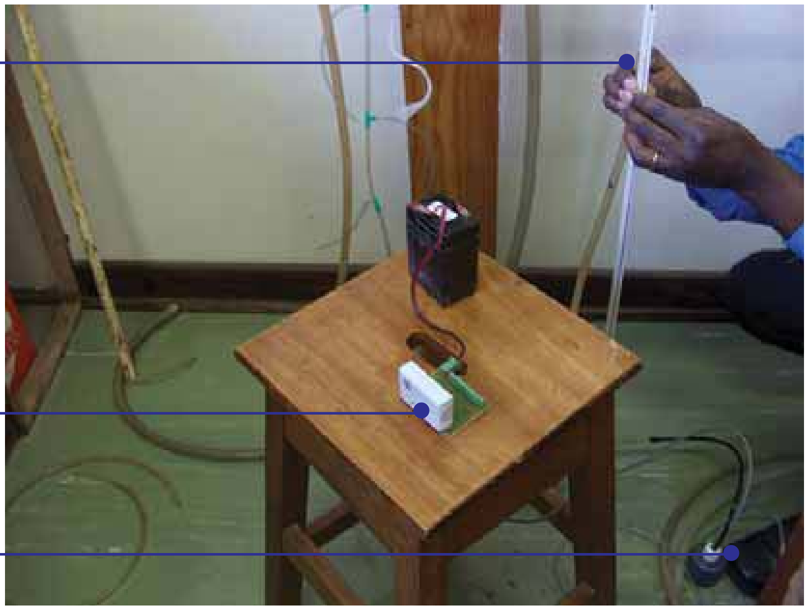
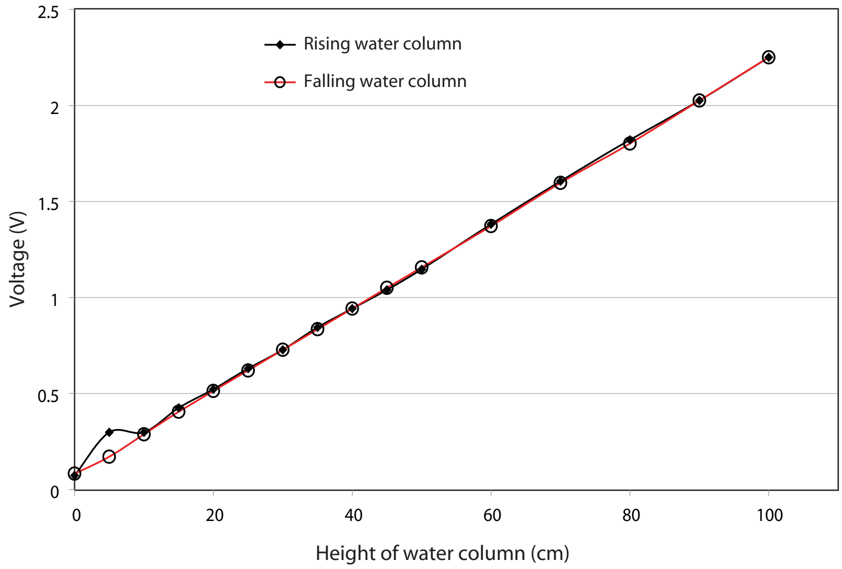


Figure 19. Calibration curve of a pressure transducer.



$$H = 13.5307564+0.45355129*V \quad (13)$$

where,
H = the depth of flow (cm)
V = voltage output from the pressure transducer (mV)

The basic idea is to be able to translate the output voltage signal of the pressure transducer into streamflow depths using the established rating curve at any given time. During installation, the pressure transducer was installed below the no-flow water level (zero flow) and the depth of water above it was recorded as the threshold value. The transducer needs to be submerged in water at all times to avoid "air-locks" in the pressure-sensing conduits. It is useful to protect the data logger and its power supply, i.e., the battery, against any anticipated vandalism or theft as was done in the Potshini catchment. This was achieved through locking the vulnerable parts in a small metallic safe box, which was permanently bolted onto a concrete wall. Nevertheless, the goodwill of the community living close to the pressure transducer was sought with regard to its safety.

Runoff Plots

The length of a standard runoff plot, as described by the SCS, is 22.13 m with an appropriate width greater than 2 m on a slope of 9 percent. Such a runoff plot is used in estimating the soil erodibilty factor in the Universal Soil Loss Equation-USLE (Wischmeier and Smith 1978). The approach and focus in this study were aimed at investigating hydrological processes within a runoff plot (a controlled micro catchment) and comparing such results from other runoff plots under different treatments but on similar slopes of less than 9 percent. This approach was adopted in designing and installing 11 runoff plots in the Potshini catchment, in an effort to investigate the influence and impact of conservation agricultural practices, i.e., water use innovations on surface runoff-generating characteristics in the predominantly agricultural catchment. The 11 runoff plots were designed while taking into account the rainfall intensities in the area. The length and width of the runoff plots were 10 m and 2.45 m, respectively, and strips of 0.245 m wide galvanized sheet metal were used to demarcate the area under each runoff plot. The knowledge of the rainfall intensity was useful in estimating the size of the tipping buckets and subsequent calibration of the tipping volumes.

The fundamental parameter which had to be determined before the installation of the runoff plots was the general slope of the respective sites, which was done through a leveling survey exercise. A local contour map for each site where the runoff plots were to be installed was created after a leveling survey exercise from which the general slope was estimated, which was found to range from 2 to 4 percent. Four sites were identified for the installation of the 11 runoff plots, i.e., five runoff plots at the former ARC-Landcare project main trial site and two runoff plots on each of three smallholder farms. Figure 20 shows runoff plots in one of the smallholder farms while figure 21 shows five runoff plots at the former ARC main trial site in the Potshini catchment.

Figure 20. A runoff plot in a farmer's field.

Tipping bucket at the end of a runoff plot

245 mm strips of galvanized sheet metal

Figure 21. Five runoff plots in the former ARC main trial site at Potshini.

The Tipping Buckets

The flow rate of overland flow from each runoff plot was measured using a tipping bucket, which was calibrated to accommodate two liters in each bucket. The number of tips was recorded using an HOBO event data logger linked to a proxy switch. A manual counter was used as a backup data recording system. The basic operational mechanism of the proxy switch and data logger entails attaching a small *button* magnet to one side of a tipping bucket, while a stationary proxy switch is fixed on the frame supporting the tipping buckets. As the buckets swing (tip) on their smooth fulcrum (oiled bearings), the proxy switch detects the changing magnetic field due to the movement of the magnet on the side of the swinging bucket. The proxy switch is set to send a logging signal to the data logger when it detects a maximum magnetic field, i.e., when the proxy switch and the magnet are aligned on the same axis and hence the chances of the "double counting" phenomenon, due to the rebounding action of the buckets as a result of the residual inertial forces, are more or less eliminated. Figure 22 shows a tipping bucket in one of the runoff plots in Potshini.

The manual counters are basically meant to be a backup data recoding system in case of failure in the data logger/proxy switch mechanism through vandalism or other means. The manual counters are bolted onto the main frame of the tipping bucket making it difficult to remove, unlike the data logger which is housed in a rather accessible and fragile housing and hence prone to abuse. Unlike the data logger, the manual counters indicate the cumulative number of bucket tips (cumulative volume of surface runoff) over a given time period (between successive downloads of data) which therefore do not have a corresponding time element associated with a storm to give an indication of runoff intensities from different land uses. The main disadvantage so far observed in the manual counters is the "double counting" phenomenon as observed in a number of cases during calibration of the tipping buckets, in both the laboratory and the field.

Figure 22. A tipping bucket and a data logger.

Sediment Samplers in Runoff Plots

The five runoff plots at one of the experimental sites in the Potshini catchment, the ARC-Main trial site, (cf. figure 21*)* were fitted with semiautomated sediment samplers with the objective of determining the sediment-load-generating characteristics of the respective tillage treatments (cf. table 10) under investigation and the isotopic composition of Oxygen-18 (^{18}O) and Deuterium. The sediment samplers were equipped with "splitters," which capture half of the discharge (runoff) from one side of one of the tipping buckets during each rainfall event. Each splitter (figure 23) is fitted with five outlet pipes of which one pipe drains into special designed tanks from which 500 ml runoff samples are manually taken after each rainfall event for analysis of sediment load and isotopic composition (Oxygen-18 and Deuterium). The tanks are always emptied after the sampling exercise to allow fresh samples to be taken in the subsequent rainfall event. The other four pipes freely drain into a drainage channel to facilitate a distributed flow of discharge from the splitter and the sampling of one-tenth of the total overland flow generated from each runoff plot. Figure 23 shows a split sampler attached to a tipping bucket.

The design of the special collecting tanks involved surveying the terrain of the area near the drainage channel (cf. figure 21) so as to determine the excavation depths and computing their capacities. A simple approach was used to determine the tank volumes, by assuming a realistic runoff coefficient of 0.2 and using the maximum daily rainfall event so far observed over the area in the last 3 years, which was 75 mm. A 20 percent "freeboard" volume was added in each tank as a safety factor to safeguard any incidences of overflows from the tank.

Conservation Tillage in the Potshini Catchment

Conservation tillage may be defined as any tillage sequence having the objective to minimize the loss of soil and water, and having an operational threshold of leaving at least 30 percent mulch or crop residue cover on the surface throughout the year (Rockström et al. 1999; Rockström 2000).

Figure 23. A sediment split sampler at the main trial site.

Conservation tillage aims at reversing a persistent trend in farming systems of reduced infiltration due to compaction and crust formation and reduced water-holding capacity due to oxidation of organic materials (due to excessive turning of the soil). From this perspective, conservation tillage qualifies as a form of water harvesting (and hence a water use innovation), where runoff is impeded and soil water is stored in the crop root zone. The Agricultural Research Council (ARC)-Landcare project in the Potshini catchment managed to spearhead the adaptation of conservation tillage practices by the smallholder farmers and covered a range of non-inversion practices from zero-tillage to reduced tillage. The conservation agricultural practices aim to maximize soil infiltration and productivity by minimizing water losses, i.e., total evaporation and surface runoff, while conserving energy and labor. The SSI programme has been investigating five tillage practices in the Potshini catchment since 2004 with regard to the runoff-generation characteristics and sediment load of each practice. Some results obtained from the experimental plots are discussed in the Results and Discussion section of this paper.

Monitoring of Shallow Groundwater Using Piezometers

The water balance of a catchment strives to account for the various components of a hydrological cycle including the interflows which form the shallow groundwater in a catchment. The occurrence of shallow groundwater in any catchment is generally influenced by two main factors, anthropogenic activities and biophysical characteristics of the catchment. Shallow groundwater contributes significantly to the total streamflow volumes and hence the necessity to establish its occurrence and flow rates. The direction of flow of shallow groundwater can be established from the water table or piezometric gradients, and with the knowledge of transmissivities of the soil, the subsurface flows can be computed using Darcy's law.

Through the collaboration and participation of the Potshini community, 12 piezometers were installed in the Potshini catchment. Since the catchment is predominantly an agricultural area for smallholder farmers, permission was sought from the local leaders and individual farmers (cf. annex 1b) to allow the boring of the 100 mm holes in some of the farms, on 2 transects, after a reconnaissance survey. The piezometers were strategically installed on sites where they could not interfere with the farming activities (at the edges or boundaries of farms), considering that most of the farming operations in the area make use of animal- and or tractor-drawn implements. Two transects, one on each side of the catchment, were identified and running more or less perpendicular to the general slope of the catchment. The relatively shallow soils on one of the transects hindered the boring of the holes to greater depths as indicated in table 7.

Table 7. Details of the piezometers in the Potshini catchment during installation.

Well ID	Position from the stream	Depth of water column in the well during installation (m)	Total depth of the well (m)	Elevation (masl)
PRB1_RC9	1st, Right bank	2.12	3.22	1,308
PRB2_RC7	2nd, Right bank	1.98	3.32	1,312
PRB3_RC8	3rd, Right bank	1.24	2.84	1,316
PRB5*	4th, Right bank	0.52	2.98	1,320
PRB4_RC6	5th, Right bank	0.63	3.38	1,324
PRB6*	6th, Right bank	0.1	3.2	1,334
PLB1_RC2	1st, Left bank	2.06	3.32	1,307
PLB2_RC4	2nd, Left bank	1.86	3.46	1,313
PLB3_RC3	3rd, Left bank	2.1	3.41	1,315
PLB5*	4th, Left bank	1.35	3.21	1,323
PLB4_RC5	5th, Left bank	2.08	3.38	1,328
PLB6*	6th, Left bank	0.64	3.32	1,335

* Wells are not automated and are mainly used for sampling of shallow groundwater for isotopic composition of Oxygen-18 and Deuterium analysis.

The basic approach was to bore the holes as deep as possible to depths reaching the bedrock. Special 63 mm diameter plastic pipes of appropriate lengths were inserted into the bored holes such that at least a 0.4 m length of the pipe was above the ground surface. Figure 24 shows one of the pipes being inserted into the bored holes. These special pipes had thin slots cut through the pipe over a length of 0.6 m from the bottom. It is through such slots that the shallow groundwater seeps into the pipe upon which the monitoring of fluctuation of the shallow groundwater table can be effected, i.e., a piezometer.

To prevent clogging of the minute perforation by the fine clay soil at the bottom of the wells, a clean (washed) sand screen was packed around the plastic pipes covering the perforations to a height of 0.8 m from the bottom of the wells. For each well, the depth of the rest of the well was filled with the previously bored soil material save for the top 0.3 m, where a cement mortar was cast around the 63 mm plastic pipe before a 0.4 m x 0.4 m concrete slab was cast on the top to a level slightly above the ground surface as shown in figure 25. Such cement and concrete works prevent any preferential flows from either side around the pipe when the soils are saturated during wet seasons. The top of each pipe was covered by a specially designed plug to prevent any foreign

Figure 24. Inserting the special plastic pipes into the bored wells.

Figure 25. A concrete slab being cast around a plastic pipe.

materials entering the pipes, especially material thrown by children and also to eliminate the chances of drops of rain falling into the pipes. Monitoring of the fluctuation of shallow groundwater in the piezometers is by both manual and automatic recording, with manual recording being applied in wells that indicate relatively less fluctuation of shallow groundwater while pressure transducers and HOBO data loggers were installed in piezometers that reflected relatively high fluctuations of groundwater. The data loggers and the batteries were secured in metallic safe boxes embedded in concrete, as shown in figure 26, to safeguard them from unfavorable weather conditions and vandalism. An insecticide was applied in all safe boxes to prevent ants and other insects from hibernating in them, which could damage the electronic system in the data loggers.

Figure 26. An HOBO data logger and battery secured in a safe box in one of the shallow groundwater wells in the Potshini catchment.

Monitoring of Deep Groundwater

As highlighted in the introductory section, since the inception of the SSI programme the SSI team sought a good working relationship and collaboration with other stakeholders including government agencies. This approach paid dividends when the SSI team approached the Department of Water Affairs and Forestry (DWAF) to get assistance in sinking deep observation groundwater wells in the Potshini catchment for monitoring the deep groundwater table in an effort to close the gap with regard to monitoring all the components of the hydrological cycle in the catchment. The DWAF has since then drilled two deep observation groundwater wells in the Potshini catchment (figure 27), and the SSI team will be responsible for data collection, and the collected data will be available to any interested party. At the end of the SSI programme, DWAF will take over the management of the wells as part of its monitoring campaign for groundwater in the Thukela river basin.

Figure 27. Monitoring of groundwater in a 120 m deep observation groundwater well in Potshini.

Electrical Resistivity Imaging Survey

The initial 2-D Electrical Resistivity Tomography (ERT) survey was carried out in the Potshini catchment in August 2005 using an ABEM Terrameter system along the 2-transects of piezometers (see figure 28 and table 7). More and detailed resistivity surveys are scheduled to be carried out on several transects in the Potshini catchment in the next 2 years. During a resistivity survey exercise, the depth of penetration of the electric current is proportional to the separation between the electrodes. In homogeneous grounds, varying the electrode spacing provides resistivity information with regard to the existing geological formations including groundwater. An electrode spacing of 5 m was used in the initial survey to facilitate the mapping of deeper grounds though shorter electrode spacing (1 and 2.5 m) will also be used in the scheduled surveys in the Potshini catchment. Figure 28 shows the layout of an ERT survey.

Figure 28. Layout of the ERT survey: An electrode near a shallow groundwater well in the Potshini catchment.

Soil Moisture Profiling Using Time Domain Reflectometry (TDR)

The basic principles for measuring volumetric soil-moisture content (%) using the TDR method is documented in some of the user manuals, e.g., TRIME-FM user manual (2003). It is a relatively easy, routine, safe and fast method compared to similar approaches, e.g., the neutron probe method, and makes it possible to profile the volumetric soil-moisture content. The soil-moisture measurement is facilitated by the use of access tubes which are inserted into the soil profile to convenient depths. Several methods have been suggested on how to insert these access tubes into the soil, one of them being by pre-boring holes with standard soil augers of relatively small diameter and inserting the access tubes into the bored holes as was done in the Potshini catchment. More than 16 access tubes of different lengths ranging from 1.2 m to 1.5 m were inserted in some of the smallholder farms in the Potshini catchment, with 10 access tubes being inserted at the former ARC-main trial site. The three smallholder farms, where runoff plots were installed, were also used for monitoring volumetric soil-moisture content under different tillage practices, with each runoff plot having a 1 TDR access tube. A weekly regime for monitoring volumetric soil moisture in the Potshini catchment was then launched, where readings were continued to be taken at varying depths at 30 cm intervals in each access tube.

Monitoring of Climatic Parameters

The SSI programme has been collaborating with the Agricultural Research Council (ARC) in the Bergville district in research and sharing of information where data gathering and sharing have been the main collaborative fronts. The SSI researchers have continued to benefit from, and get access to, the meteorological data from the ARC telemetric weather station located approximately 4 km downstream of the Potshini community, close to one of the stream-gauging structures, the pressure transducer under a culvert bridge. Uploading of data from the ARC weather station is on a daily basis, for both hourly and daily time steps. Another weather station was installed in the midst of the Potshini community by the SSI researchers to augment the ARC weather station in depicting the spatial variation of weather parameters in the area.

Sampling Rainfall for Isotopic Analysis

A sampling scheme of rainwater for isotopic composition of Oxygen-18 (^{18}O) and Deuterium was initiated late in 2005. A rainfall collector was installed in one of the weather stations of the Potshini catchment. The rainfall collector consisted of six bottles, connected to one another with a flexible pipe, with all the bottles tightly closed to create an airtight system. The operational mechanism of the system is such that rainwater from an automatic rain gauge fills the collecting bottles sequentially starting from the first. Each bottle has a capacity of 400 ml though one can adjust the holding capacity of each bottle to facilitate a distributed sampling of rainwater over a rainfall event. The biggest challenge is to make sure that the system remains airtight as the samples are not supposed to be exposed to air because the isotopic composition of Oxygen-18 (^{18}O) and Deuterium in a water sample changes if part of the sample evaporates. Figure 29 shows the rainfall collector in the Potshini catchment.

Figure 29. Rainfall collector in the Potshini catchment.

Manual Rain Gauges

Rainfall is one of the main parameters that drive the hydrological cycle in a catchment and hence the need to accurately estimate its occurrence, both spatially and temporally. Manual rain gauges, if well managed, can provide relatively accurate daily rainfall data in a catchment, and their affordability, availability and the ease of installing and taking readings make them attractive, especially to smallholder farmers. The fact that an individual has to take readings from a manual rain gauge on a daily basis promotes the philosophy of participatory catchment monitoring at the Potshini community where some of the smallholder farmers are voluntarily recording daily rainfall from manual rain gauges installed in their farms. Figure 30 shows a voluntary smallholder farmer, *Mama Secilia Vilakhazi*, in Potshini taking a reading from a manual rain gauge.

Figure 30. A smallholder farmer taking a reading from a manual rain gauge.

A rainfall data recording booklet, translated into the local language *(IsiZulu)*, was given to each household that volunteered to record rainfall. The smallholder farmers have been recording rainfall twice a day, i.e., at 09:00 and 17:00, from which the daily average rainfall could be computed as the total of the morning and evening readings. Table 8 indicates part of the rainfall recording booklet developed for the Potshini catchment.

Table 8. An extract from the daily rainfall data recording booklet.

Daily rainfall monitoring at: Mr./Mrs./Ms.………………………………………….................. GPS: S………….……..E………………….Elevation (masl):…………………................ All readings in mm					
Usuku (day)	Inyanga (month)	Unyaka (year)	Ekuseni (at 09:00)	Ntambama (at 17:00)	Isamba sosuku (daily total)
1	October	2004			
2	October	2004			
3	October	2004			
4	October	2004			

After a reconnaissance survey in the catchment, eight potential sites were identified in the 1.2 km^2 Potshini catchment for installing manual rain gauges; these sites were homesteads in the Potshini community. Persons in these homesteads were then approached, especially the head of the homestead, to seek permission and goodwill from the members of the homestead to install the manual rain gauges and, most importantly, take daily rainfall readings. There was cordial cooperation and participation from all homesteads approached and in each homestead, a person was identified to be responsible for taking readings from the manual rain gauge.

Monitoring of Total Evaporation Over Large Spatial Extents
The Large Aperture Scintillometer (LAS)

The measurement of total evaporation from the Potshini catchment using scintillation techniques (Kite et al. 2000; Meijninger and Bruin 2000) started in October 2005, though the exercise has been abandoned a couple of times, especially during the summer season, after the LAS (figures 31 and 32) was struck by lightning. Nevertheless, good data have been obtained from the LAS, which is scheduled to run until the end of 2007.

The LAS is an instrument that measures sensible heat flux as a function of the turbulent intensity of the refractive fluctuations of air (caused by heat, moisture and air pressure fluctuations) from the intensity fluctuations of a received electromagnetic signal (LAS 2000). This signal is transmitted by a light source, a transmitter, placed at a given distance away from a receiver (typically less than 10 km). At the receiver the turbulent intensity is measured as a refractive parameter from which the sensible heat flux along the transect is determined. The latent heat flux (and subsequently total evaporation) can be computed as a residual in the surface energy balance equation after measuring the soil heat flux using soil thermometers. Equation 14 describes the surface energy balance.

$$LE = R_n - H - G \tag{14}$$

where,

LE = latent heat flux (W.m^{-2}), which is readily converted to total evaporation (mm)
R_n = net radiation (W.m^{-2})
H = sensible heat flux (W.m^{-2})
G = soil heat flux (W.m^{-2})

Figure 31. The transmitter of the LAS in the Potshini catchment.

The transmitter of the LAS transmitting a dual beam of electromagnetic light signal at 125 Hz pulse rate. Such a pulse rate provides maximum accuracy and accounts for cross winds.

Figure 32. The receiver of the LAS in the Potshini catchment.

Air temperature and pressure sensors

Metallic safe box housing batteries and the Signal Processing Unit (SPU)

The LAS has been installed over a 1.03 km transect in the Potshini catchment and will be moved to other surveyed transects within the catchment with time. One limiting factor so far observed when using the LAS is the volatile data storage memory in the Signal Processing Unit (SPU) at the receiver, which is powered by two heavy-duty batteries. The volatile memory loses all the data in case of a power failure in the SPU and one needs to change the batteries every week to avoid loss of data. Due to its complex electronics systems, and especially when competent electronics technicians are not available, the scintillometer could be a challenge to use in a sustainable way in the event of breakdowns as was experienced in the Potshini catchment. Fortunately, there are electronics technicians at the University of KwaZulu-Natal who have been able to diagnose the causes of malfunctioning and handle all the repair work of the scintillometer.

The Surface Energy Balance Algorithm for Land (SEBAL)

The scintillation technique and the Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al. 1998a, b; Bastiaanssen et al. 2000) share a common background of exploring and trying to solve the energy balance equation on the earth's surface and linking the energy balance with the hydrological water balance through the evapotranspiration (total evaporation) process. The scintillation technique forms an intermediate scale of measurement and calibration of total evaporation between the field (point measurement, e.g., weather station) and the large-area remote sensing SEBAL estimates with no requirement for calibration from an instrument. The SEBAL computes the net solar radiation using equation 15 before applying the surface energy balance equation (equation 14) in computing the evaporative indices on each pixel over a satellite image. Equation 15 is given as:

$$R_n = (1-\alpha)R_s + (\varepsilon L_{in} - L_{out}) \tag{15}$$

where,

R_n = net solar radiation ($W.m^{-2}$)

α = surface albedo

R_s = solar radiation ($W.m^{-2}$)

ε = land surface emissivity

L_{in} and L_{out} = incoming and outgoing long wave solar radiation ($W.m^{-2}$), respectively

Most of the satellite images can be used in the SEBAL analysis so long as the thermal and shortwave bands are available. The main limitation in applying SEBAL includes the requirement that the satellite image needs to be cloud-free, which is a constraint in many parts of southern Africa, especially during summer. The constraint is further compounded by the overpass time and frequency of data capturing by some of the satellite imagers[1] as indicated in table 9.

Table 9. Satellite data compatibility with SEBAL and availability.

Imager	Frequency of capturing data	Spatial resolution (m)	Archive data	Availability
NASA-Landsat	8 or 16 days	30	Since 1982	Classified
NASA-MODIS	Daily	250; 500; 1,000	Since 1999	Free
NASA-ASTER	15 days	15	Since 1999	Classified
NOAA-AVHRR	Daily	1,000	Since 1980	Free

SEBAL has been tried and applied in the Potshini catchment and beyond in the Thukela river basin (Kongo and Jewitt 2006) and more detailed analyses will be carried out in the next 2 years of this study as an upscaling strategy for determining the spatial variation of total evaporation in this river basin, which is one of the main hydrological determinants in the Potshini catchment and this river basin at large.

[1]MODIS-Moderate Resolution Imaging Spectroradiometer.
ASTER-Advanced Spaceborn Thermal Emission and Reflection Radiometer.
AVHRR-Advanced Very High Resolution Radiometer.

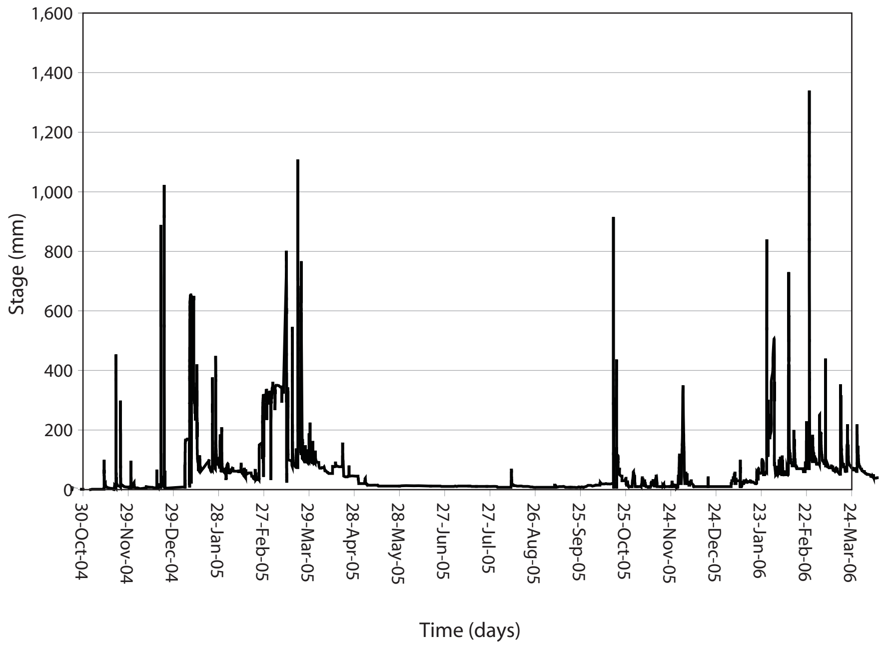
RESULTS AND DISCUSSION

Since the establishment of the Potshini catchment monitoring network in 2004, large volumes of different data sets have been generated and archived in a database at the School of Bioresources Engineering and Environmental Hydrology. This section highlights some of the results and data obtained from the catchment monitoring network including some of the challenges encountered so far.

H-Flume Data

One of the main problems identified with the Potshini H-flume is the deposition of sediment material on the floor of the approach channel which therefore requires changing the operational/design characteristics of the H-flume. This has a great influence on the accuracy especially in measuring low flows since the floor of the approach channel cannot be level in such a clogged state, which therefore prompts the flow path to meander and be on one side of the approach channel. At one time, after a heavy storm (50 mm of rainfall), it was observed that the right-hand side of the approach channel, where the 50 mm connecting pipe to the stilling well is connected (cf. figure 15), was silted and hence the flow path shifted towards the left-hand side of the channel. With this anomaly, the MCS data logger recorded zero flows, while in reality there was streamflow discharge passing through the H-flume. It is from this field experience that the approach channel of the H-flume has always been cleaned after every heavy storm event in the catchment. Nevertheless, good streamflow data have been recorded from the H-flume as indicated in figure 33.

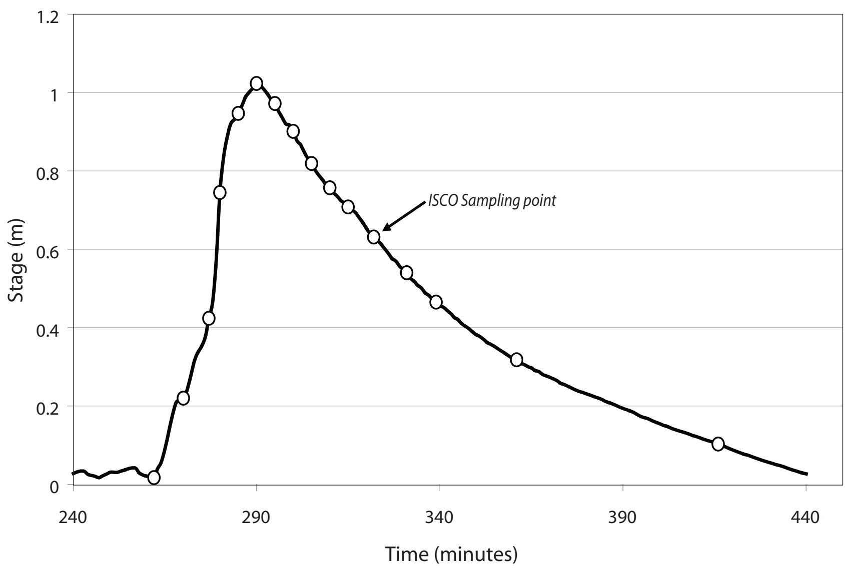
Figure 33. Streamflow data obtained from the Potshini H-flume.



The Sampling Scheme of the ISCO Sampler

A typical sampling scheme for the ISCO sampler at the Potshini H-flume is as shown in figure 34, where frequent samples are taken during a varying flow.

Figure 34. Sampling scheme for the Potshini H-flume.



Overland Flow from Runoff Plots

Table 10 indicates five tillage practices being investigated at one of the experimental sites in the Potshini catchment for their influence on runoff-generation characteristics, soil-moisture retention and subsequent crop yields. The cumulative overland flow from each treatment was measured by a tipping bucket. More details of the experimental results on the influence of conservation tillage practices on runoff-generating characteristics and soil-moisture retention in the Potshini catchment are presented in Kongo and Jewitt 2006.

Table 10. Conservation agricultural practices under investigation.

Plot no.	Treatment	Tillage practice	Cumulative overland flow-2004/05 (m^3)
1	Maize + conventional till + grazing	Conventional	1.238
2	Maize + winter intercrop + mulching*	Conservation	1.254
3	Pure maize + grazing	Conservation	0.45
4	Maize + summer intercrop + grazing	Conservation	0.308
5	Maize + summer intercrop + mulching*	Conservation	0.854

*Mulching facilitated by covering the runoff plots with fine mesh wire to keep off freely grazing livestock during winter.

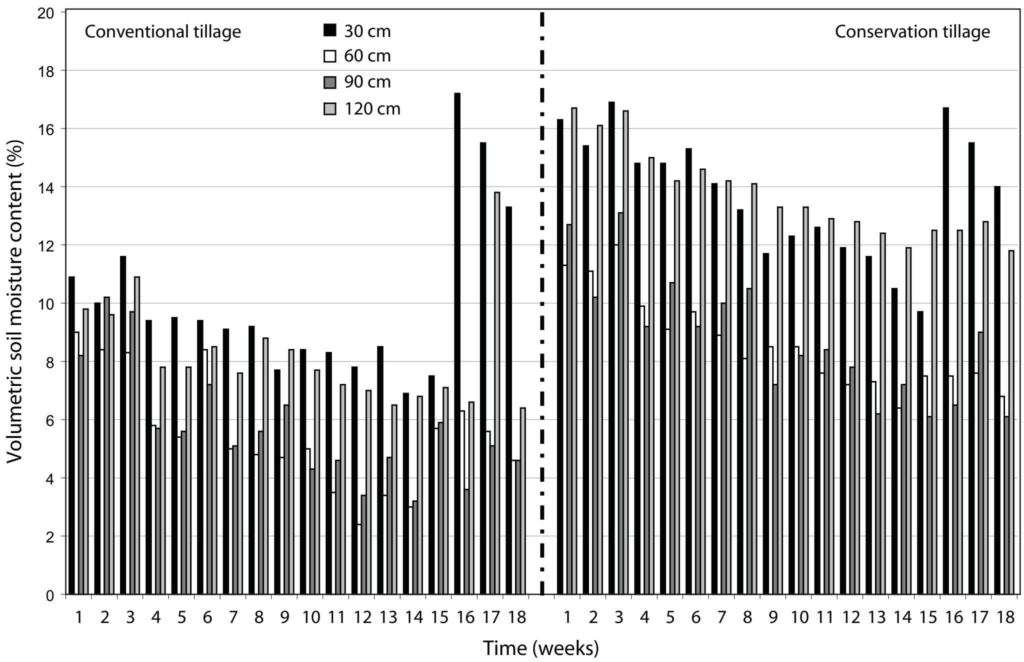
In this experimental setup, plot no. 1 (conventional tillage) is used as a control plot, while investigating the influence of four other tillage practices (treatments) on runoff generation and soil moisture in a controlled experimental environment. A similar uncontrolled experimental design has been set up on some of the smallholder farms belonging to leader farmers who participated in the former ARC-Landcare project in Potshini, though with only two treatments under investigation, i.e., conventional tillage (maize + conventional tillage + grazing) and conservation tillage (maize + conservation tillage + summer and winter intercrop + grazing). The experiments in the smallholder farms are meant to investigate the influence of such tillage practices on runoff-generation characteristics and soil moisture under a typical smallholder farm environment, where livestock is allowed to freely graze on farms in the community.

Soil Moisture Profiling

Figure 35 shows a graphical representation of the variation of volumetric soil-moisture content under different tillage practices, conservation and conventional tillage, in one of the experimental sites in the Potshini catchment.

One of the main observations made from figure 35 is that conservation tillage conserves more soil moisture, especially at greater depths, compared to conventional tillage. Such a tillage practice as conservation tillage could have a significant influence on the recharge of shallow groundwater in the catchment.

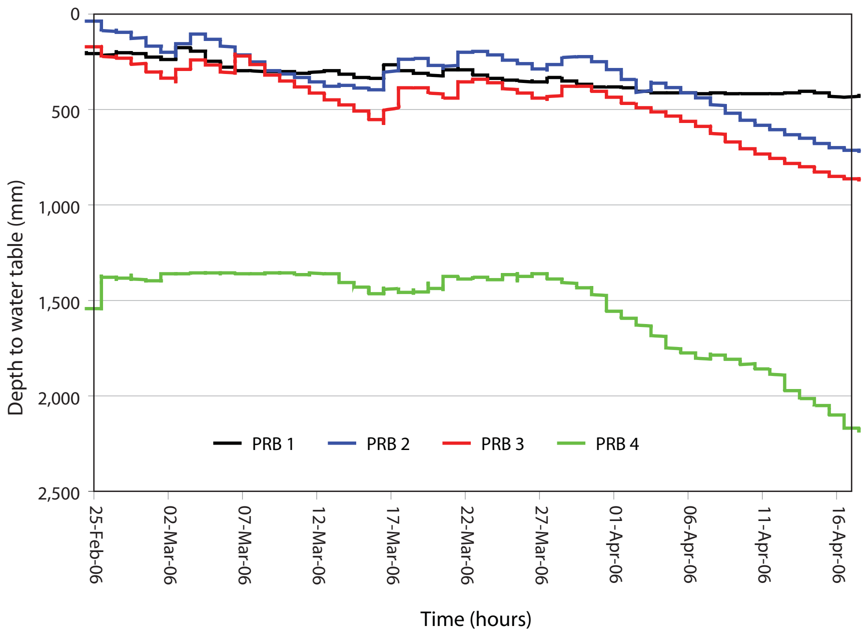
Figure 35. Comparison of volumetric soil-moisture content under conventional and conservation tillage practices in the Potshini catchment.



Fluctuation of Shallow Groundwater Table

Figure 36 shows the fluctuation of shallow groundwater along the transect on the right bank in the Potshini catchment between late February and April 2006 when heavy rainfall was recorded in the catchment. It can be noted from figure 36 that the piezometer close to the stream (PRB1) recorded relatively less fluctuation of groundwater table than the other three piezometers on the upper slopes of the transect, e.g., PRB4. This could be attributed to the influence of slope (piezometric gradient) and hence influencing interflows from the upper parts of the catchment, where the other three piezometer wells are located, towards the stream and hence maintaining the water table at a relatively stable state.

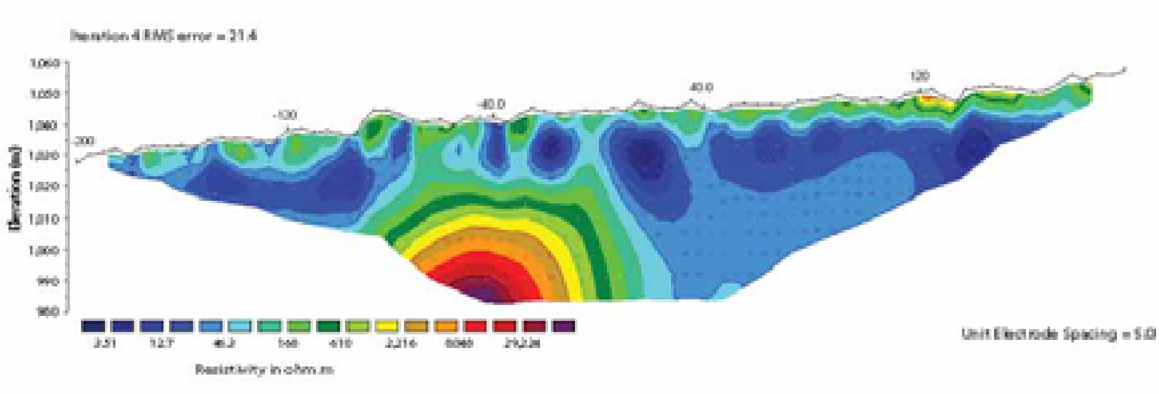
Figure 36. Fluctuation of shallow groundwater table in the Potshini catchment.



Electrical Resistivity Tomography (ERT) Survey

Figure 37 shows some initial results obtained from one of the resistivity survey exercises in the Potshini catchment. From this figure, one can deduce that the main underlaying subsurface materials (formations) in the surveyed transect have low resistivity values and hence the possibility of occurrence of groundwater or existence of soil material that has low resistivity, e.g., clay soils. The ERT survey is aimed at augmenting the piezometric monitoring of the groundwater in the Potshini catchment in an effort to characterize the sub-surface hydrological processes on hill-slopes in the catchment. It is recognized that the ERT measurements are best interpreted against other biophysical measurements and hence the complementary role.

Figure 37. ERT survey results from one of the transects in the Potshini catchment.

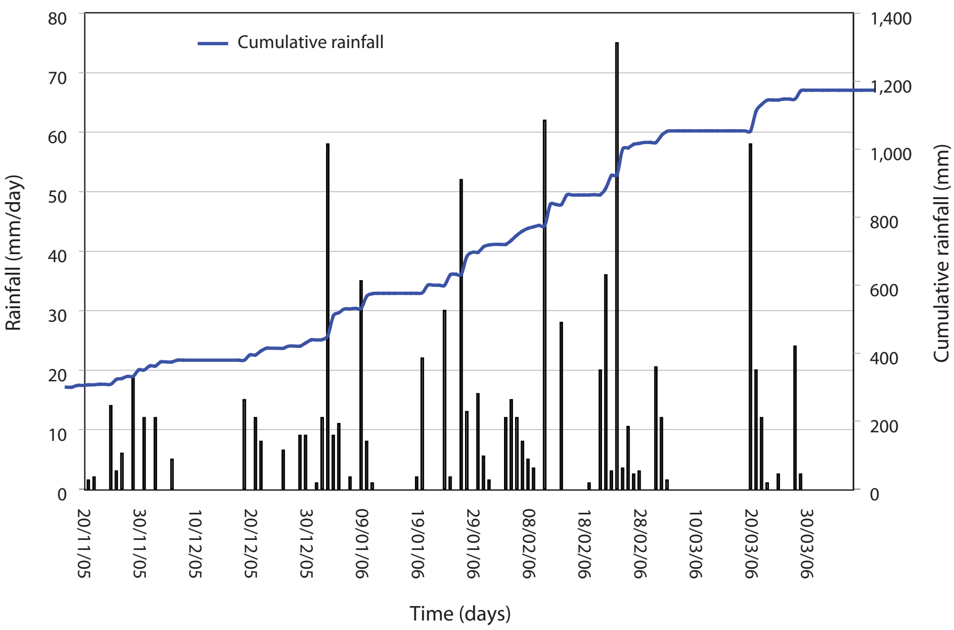


Detailed information and practical guidelines for carrying out the 2D electrical resistivity survey with the ABEM Terrameter system can be obtained from http://www.abem.com/files/res/2Dnotes.pdf and from the field user manual accompanying the instrument.

Manual Rain Gauges

Manual recording of daily rainfall by smallholder farmers has been going on in the Potshini catchment since 2004. Good and reliable daily rainfall data have been obtained from eight rain gauges. Figure 38 shows the variation of daily rainfall in the Potshini catchment as recorded by one of the Potshini smallholder farmers between November 2005 and April 2006.

Figure 38. Variation of daily rainfall in the Potshini catchment as recorded by one of the small-holder farmers.



Weather Stations

Figure 39 shows the variation of monthly rainfall and temperature as recorded in one of the weather stations in the Potshini catchment, while table 11 shows the various climatic parameters being recorded in the catchment. All the climatic parameters are recorded at a time step of 15 minutes from which the respective daily statistics can be computed.

Figure 39. Variation of rainfall and temperature in the Potshini catchment.

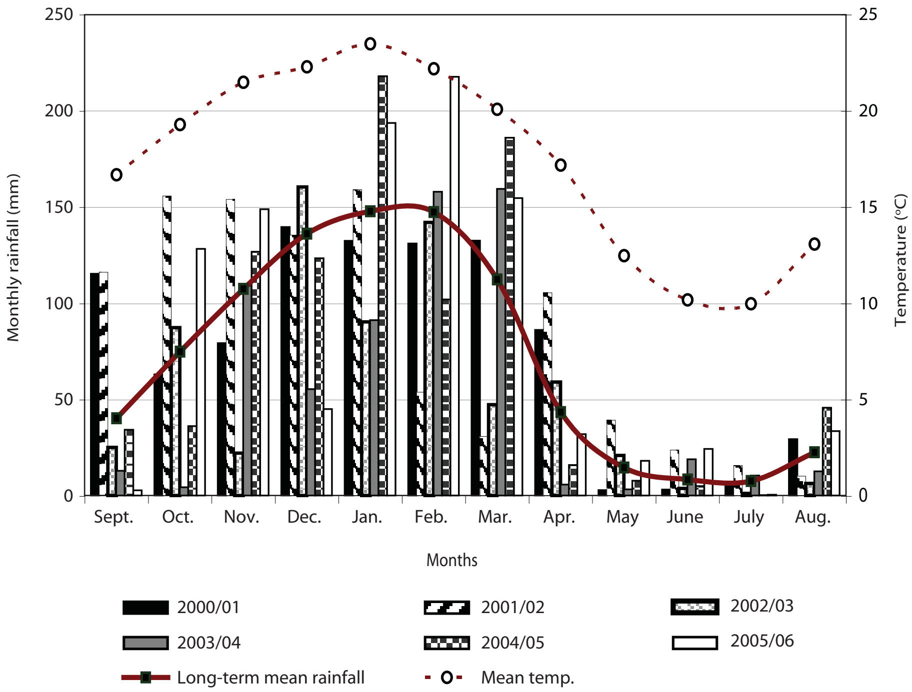


Table 11. Climatic parameters being recorded at one of the weather stations in the Potshini catchment.

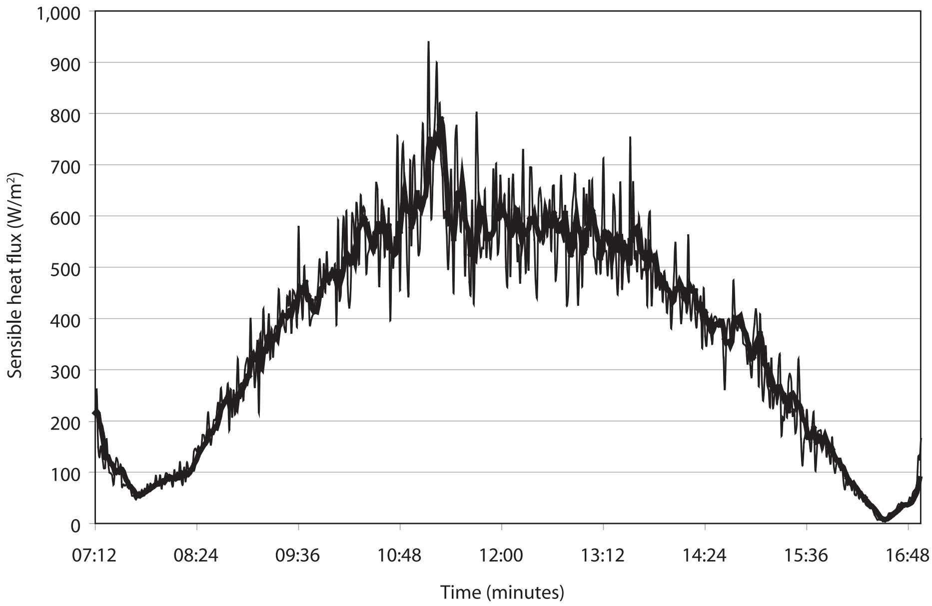
Year	DOY	Rn	T	RH	WS	Rain	Tx	Tn	RHx	RHn	Evap	CU	HU
2005	53.0	12.4	19.5	87.3	0.6	1.8	23.8	17.0	96.2	64.3	2.4	0.0	10.4
2005	54.0	20.0	22.3	80.0	1.0	63.9	28.6	16.7	94.6	49.2	4.0	0.0	12.7
2005	55.0	9.8	19.3	80.3	1.3	2.9	22.6	16.6	92.0	66.6	2.1	0.0	9.6
2005	56.0	18.8	20.3	81.7	1.2	3.4	26.2	17.2	94.7	58.7	3.6	0.0	11.7
2005	57.0	4.5	18.1	91.7	0.2	7.0	19.1	17.0	94.8	86.3	1.0	0.0	8.1
2005	58.0	17.4	19.7	85.3	0.7	13.2	25.4	16.8	94.7	58.9	3.3	0.0	11.1

Note: DOY = Julian Day of Year, RN = Radiation in MJ/m^2, T = Average Daily Temperature, RH = Average Daily Relative Humidity, WS = Average Daily Windspeed, Rain = Total Daily Rainfall, Tx = Maximum Daily Temperature, Tn = Minimum Daily Temperature, RHx = Maximum Daily Relative Humidity, RHn = Minimum Daily Relative Humidity, Evap = Daily Evapotranspiration, CU = Cold Units, HU = Heat Units.

Large Aperture Scintillometer (LAS)

Figure 40 shows sensible heat flux data recorded by the LAS in the Potshini catchment on 11 May 2006. The sensible heat flux values are relatively high because the measurement was done during a dry spell (start of winter) and hence most of the net radiation was being used to heat the air (sensible heat flux). The values of the sensible heat flux could have been low if the measurement had been done during a wet month of the year.

Figure 40. Sensible heat flux in the Potshini catchment on 11 May 2006.



Note: The thick line indicates a 6-minute moving average over the daytime.

CONCLUSION

Catchment monitoring is the fundamental approach to understanding the various hydrological processes in a catchment, on which researchers can base their analysis in an effort to generate information regarding water resources management. This paper highlights and underscores the importance of applying participatory research techniques in hydrological research studies where other stakeholders are involved. The experience drawn from establishing the catchment monitoring network in Potshini, a rural community in Bergville district in South Africa, has proved that there are more opportunities and benefits (both material and ideas) to be gained from other stakeholders. The level and stage of participation of each stakeholder differ but add up to the success of such a process. As is the case with similar projects, which are centered on the livelihood of rural communities, a proactive approach in reaching out to other stakeholders is recommended. This is useful especially at the inception of such projects in an effort to create a communication platform and common understanding, based on trust, respect and friendship.

The Potshini catchment monitoring network has several permanent structures and instruments which will benefit other researchers for a long period of time. The structures and instruments have been installed in individual farms belonging to willing smallholder farmers in the Potshini community. Some of the farmers have willingly agreed to monitor some of the hydrological processes and take readings accordingly. The traditional leadership in Potshini agreed to host and support the SSI programme, and the local leaders (elected) facilitated, to a great extent, the linking of the SSI researchers to the local municipality officials while the extension personnel from the Department of Agriculture in Bergville district and the ARC-Landcare project in Bergville played a key role in linking the SSI programme with other similar projects and stakeholders in the Bergville district and beyond. It is through one of the farmers' forums organized by the former ARC-Landcare project that the SSI programme was linked to the Department of Water Affairs and Forestry (Thukela catchment management) who, in turn, offered to support the catchment monitoring network in Potshini by sinking two deep observation groundwater wells.

The participatory process of establishing the Potshini catchment monitoring network has emerged with a positive impact on the local community and other stakeholders with regard to appreciating the research findings and, above all, the ability to sustain the goodwill of the local community in safeguarding the instruments and structures constituting the network.

ANNEX 1

Letter to the Traditional Leader in Potshini, the *Induna*

Part A -2004
(*IsiZulu*)

UNIVERSITY OF
KWAZULU-NATAL

School of Bioresources Engineering and
Environmental Hydrology

Private Bag X01, Scottsville, 3209, South Africa
Telephone (033) 260-5490 Fax (033) 260-5818

4 August 2004

Mnumzane

Ucwaningo olumayelana namanzi endaweni yasePotshini

Umnyango wabafunda ngokuba onjiniyela kwezemvelo kanye namanzi eNyuvesi i-KwaZulu-Natali inokuthokoza ukuqala uhlelo lokuthuthukisa izindlela zabalimi bezindawo ezincane, phecelezi Smallholder System Innovations (SSI), endaweni yasePotshini esifundeni sase-Bergville. Loluhlelo lusebenzisana nohlelo i-Landcare olukuyo lendawo yasePotshini.

Loluhlelo lubheka ukuthi zikhona yini izaba ezingenziwa ukwenza ngcono izindlela zokuziphilisa zomphakathi othembele emvuleni ngamanzi ezitshalo emasimini, okuyilokho okwenza iPotshini ibe yindawo lapho loluhlelo lungenziwa khona. Uhlelo lokucwaninga olufana nalolu luqhutshwa eTanzania futhi izinhloso zalo ziyafana nezalolu hlelo. Kuyisifiso sethu ukuthi sibe nesikufundayo emphakathini wasePotshini ngesikhathi nawo kukhona okufundayo kithina, ekuthuthukiseni izindlela zokusebenziswa kwamanzi nomhlaba (ukulima okungenabungozi kumhlaba, ukukhongozela kugcinwe amanzi emvula, njalonjalo). Lokhu kwenzelwa ukuthi kusimame isivuno emasimini njengoba kulinywa kwethenjelwe emanzini emvula. Sizophinde sihlole izinto eziphathelene namanzi endaweni yasePotshini, sibheke nokuthi lentuthuko ayizoba yini nomthelela engemuhle endaweni kanye nasemifuleni.
Ukukwazi ukufeza izinhloso zalolu hlelo kuzodingeka sifake amathuluzi kanye nemishini yokuthola isilinganiso samanzi agelezayo emifuleni, ukuthola umswakama osemhlabathini endaweni, ukubheka isimo sezulu nokunye. Lamathuluzi kanye nemishini ngeke kulimaze noma kuphazamise izitshalo kanye nezilwane. Ngeke futhi kuphazamise izindlela zokuphila zabantu bendawo. Isicelo sethu ukuba nisivumele ukuba sifake lamathuluzi kanye nemishini bese kuthi umphakathi ngobubele bawo usisize ekuyivikeleni. Uma lemishini namathuluzi kungaphatheka kahle kungaze kusize nabantwana belapha ePotshini ezifundweni zabo esikhathini esizayo.

Idlanzana labafundi (abavela emazweni ahlukahlukene nabalapha eMzansi Afrika) bazodamane befika kuthi ngezinye izikhathi bahlale ePotshini bezoqhuba ucwaningo ngaphansi kwalo loluhlelo. Sibonga kakhulu usizo kanye nokubambisana nathi kulolu hlelo lwethu kuze kube yilesi sikhathi.

Siyabonga futhi siyalangazelela ukuthi luqhubeke ubambiswano.

Abazithobayo

Prof. G.P.W. Jewitt
Umphathi luhlelo

Victor Kongo
Umfundi weziqu eziphakeme

Continued

ANNEX 1 - ***Continued***

Part B-2004
(English)

UNIVERSITY OF
KWAZULU-NATAL

School of Bioresources Engineering and Environmental Hydrology

Private Bag X01, Scottsville, 3209, South Africa
Telephone (033) 260-5490 Fax (033) 260-5818

4 August 2004

Dear Sir

Hydrological Monitoring in the Potshini Community

The School of Bioresources Engineering and Environmental Hydrology of the University of KwaZulu Natal is happy to initiate the Smallholder System Innovations (SSI) research project at Potshini in the Bergville district. The project will operate in collaboration with the Landcare project at Potshini.

The project has the objective of assessing the possibilities of improving the livelihoods of local communities practicing rain-fed agriculture and hence the reason for choosing Potshini as our research area. A similar project is being carried out in Tanzania with the same objective. We would wish to learn from the Potshini community, as they also learn from us, on possible water and land use innovations (conservation tillage, rain-water harvesting etc) for improved food production through rain-fed agriculture. We shall investigate water related issues in to Potshini Community, and whether these innovations have an impact on the environment and ecosystems on the downstream rivers.

To achieve our research objectives, we will have to construct flow measuring structures on some of the streams and install some instruments in the area for measuring soil moisture, monitoring the weather among others. These instruments will not have any effect on crops or animals and will not interfere with people's daily life in the Potshini community. We request your approval for the construction of these structures and the installation of these instruments and we humbly request for the goodwill of Potshini community in maintaining them. If well maintained, such structures could even be used by children from Potshini community for their studies in future.

Several students (both international and from S.Africa) will be visiting and occasionally staying at Potshini as they carry out their research studies under the SSI project. We are very grateful for the assistance and co-operation that our project has received to date.

Thanking you and looking forward for your continued co-operation.

Yours sincerely

GPW Jewitt
Associate Professor

Violet Kongo
PhD Student

ANNEX 2

Instruments and Structures Comprising the Potshini Catchment Monitoring Network

Site name	No. of instruments	Type/Name of instruments or structures	Mode of data recording
Bridge	1	Pressure transducer	Automatic
Broadcares	1	ARC weather station	Automatic
	1	Rain gauge	Manual
Hadebe	5	2 Runoff plots	Automatic
		2 TDR access tubes	Manual
Dladla	1	Rain gauge	Manual
		1 Rain gauge	Manual
Vilakazi	2	1 Scintillometer (transmitter)	Automatic
		1 Rain gauge	Manual
Madondo		2 Runoff plots	Automatic
	7	2 TDR access tubes	Manual
		1 Soil thermometer	Automatic
		Scintillometer (receiver)	Automatic
HMduba	1	Rain gauge	Manual
H-flume	2	1 H-flume	Automatic
		1 ISCO sampler	Automatic
PSch	1	Rain gauge	Manual
		10 TDR access tubes	Manual
MTSite	21	5 Runoff plots	Automatic
		5 Sediment samplers	Semiautomatic
		1 Soil thermometer	Automatic
Shongwane	1	Rain gauge	Manual
Hlongwane	1	Rain gauge	Manual
Cebhekulu		SSI weather station	Automatic
	2	Rainfall collector	Automatic
EMduba	1	Rain gauge	Manual
DMduba	1	Rain gauge	Manual
POTsh1	12	Piezometers	Four manual and eight automated
POTsh2	1	Observation bore hole	Manual

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