DEVELOPMENT OF A PROGRAM FOR IMPROVED FLOOD PREPAREDNESS, WARNING, AND RESPONSE IN THE LIMPOPO RIVER BASIN OF BOTSWANA

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INTRODUCTION

During 1999-2000, many parts of the Southern African Region experienced devastating floods, most of which occurred from December 1999 through March 2000. Rainfall accumulations during February 2000 in Botswana have been estimated in some areas to have been greater than 1,000 millimeters (39.4 inches) in one storm event, which is more than twice the average annual rainfall. Many lives were lost; tens of thousands of people were displaced from homes, and more than $285 million of damage was reported.

The local water-related agencies in the Republic of Botswana were not well equipped to respond to these rapidly occurring major flood events. At the time of these floods, there was limited coverage of hydrological and meteorological monitoring stations in the Limpopo River Basin in Botswana, and only three stations provided near real-time reporting capability. In addition, the local data-collection agencies had no capacity to convert the raw data collected by Botswanan hydrologic and meteorologic agencies into the type of information needed by the Republic of Botswana National Disaster Management Office (NDMO) to prepare, warn, or effectively respond to these disasters. The information available to the NDMO decision makers during this flooding could have been significantly improved with the installation of additional, strategically placed, near real-time river and rainfall monitoring stations, along with training and the infrastructure to support rainfall/runoff modeling.

In response to these floods the U.S. Geological Survey (USGS) in cooperation with the U.S. Agency for International Development, Regional Center for Southern Africa (USAID/RCSA) developed a plan to improve flood preparedness, warning, and response in the Limpopo River basin in Botswana. The project, which was entitled "Village Flood Watch: A Program for the Improved Preparedness, Warning and Response in the Limpopo River Basin in Botswana," was made possible by a grant from the USAID/RCSA located in Gaborone, Botswana. In addition, the USGS worked closely with many national and international agencies to complete this project:

- European Organization for the Exploitation of Meteorological Satellites
- Republic of Botswana Department of Meteorological Services
- Republic of Botswana Department of Roads
- Republic of Botswana Department of Water Affairs
- Republic of Botswana National Disaster Management Office
- Southern African Development Community
- World Meteorological Organization

This program provided hydrological and meteorological parameters and a pilot hydrological runoff model that will assist the Botswanan governmental agencies in the propagation of hydrological runoff models in all the subbasins of the Limpopo River Basin for use in future flooding disasters. This report presents an overview of all phases of the project, along with selected data about gages within the Limpopo River Basin.

BACKGROUND

Botswana is located in southern Africa (fig. 1). Three river basins that have experienced recent devastating floods in the southern African region are the Zambezi, the Limpopo and the Olifants (fig. 1). Climate in Botswana is primarily continental to semi-arid to arid, with wettest conditions in the eastern and northeastern part of the country. Drought is common, and effective coping mechanisms have evolved to deal with its consequences. Flooding, however, characteristically has been much less frequent, and existing transportation infrastructure was not designed with large flooding in mind. Flooding in Botswana generally has been associated with periods of rainfall of high intensity and short duration; but in recent years, more extended periods of sustained, heavy rainfall have been experienced. The 1999/2000 rainy season was unusually wet in Botswana, with the worst floods occurring during February when tropical cyclone Eline came inland and dumped torrents of rain on the country. It has been reported that this single event resulted in greater than 1,000 mm of rain in some places. Many rivers in Botswana, and especially the Limpopo River Basin in the southeastern part of the country, rose over their banks, covered roads and bridges, and flooded many villages. Extensive damage occurred in 23 of 24 districts in the country. Thousands of homes collapsed or were heavily damaged, and subsequently tens of thousands of people were made homeless. Crops were lost, and transportation infrastructure was damaged or destroyed and made completely impassable at many locations for many days. Economic losses were estimated to be more than P1 billion (about $285,000,000).

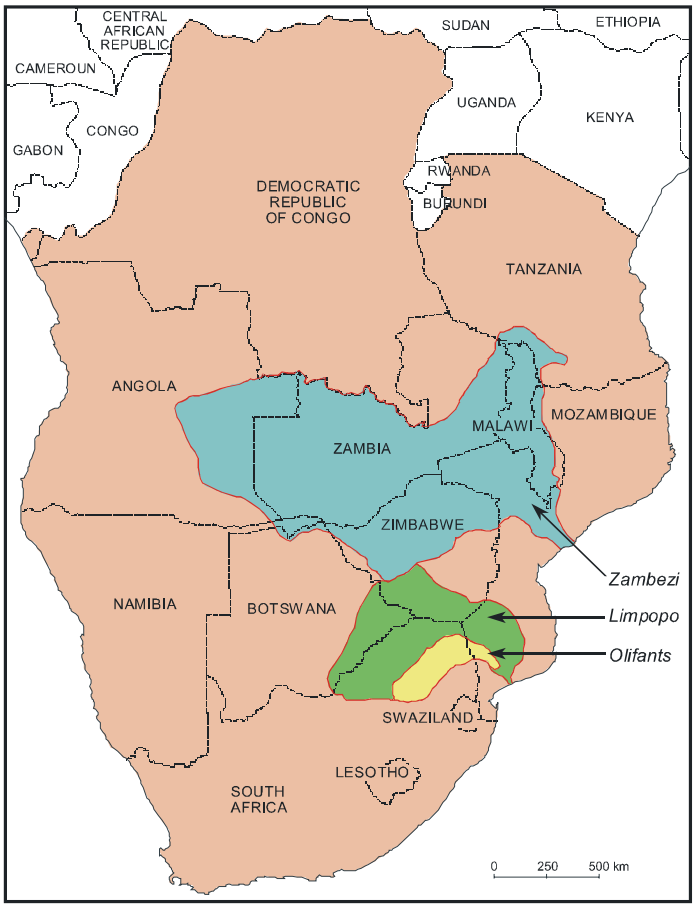

Figure 1.—Map of Southern Africa showing drainage basins of the Zambezi, Limpopo, and Olifants Rivers.

The floods of 1999/2000 in Southern Africa revealed significant gaps in all phases of flood disaster preparedness across the region. As a result, several plans were developed in an effort to improve data collection and dissemination in future events. These include the development of a Multi-Sectoral Disaster Strategy by the Southern African Development Community (SADC) Secretariat, a Floods and Droughts Management Plan prepared by the SADC Water Sector Coordinating Unit (WSCU), and a National Disaster Management Plan prepared in Botswana by the NDMO. The USAID also has initiated multiple activities designed to help with disaster relief in the region. Recognizing that timely hydrological and meteorological information crucial to decision makers at the national level was both limited and inadequate, one of the activities USAID initiated was the Village Flood Watch project described in this document. The USGS was asked by USAID to develop a work plan and to implement the project.

EXISTING INSTITUTIONS AND INFORMATION INFRASTRUCTURE

Mitigation of losses due to extreme precipitation and flooding events requires a sequence of actions: observation, communication, and response. During this project, the USGS worked with institutions presently contributing to this process to help ensure this project did not duplicate other efforts and to foster local involvement and participation.

In Botswana, hydrometeorological observations are made by regional (SADC) and national organizations - Department of Water Affairs (DWA), and Department of Meteorological Services (DMS). Through SADC, the World Meteorological Organization (WMO) has included Botswana in their Hydrologic Cycle Observing System (HYCOS) network of stream-gaging stations that report in a near real-time format. Before the Village Flood Watch Project, four near real-time stations were located in Botswana, and three of those were in the Limpopo River Basin. One of these three stations was destroyed during the severe flooding in 2000, and there currently are plans to replace it. A more extensive stream-gaging network is operated by DWA without real-time reporting capability. Offices at the district level carry out the stream-gaging program.

Precipitation stations are operated by the DMS, which has two offices in Gaborone (one at the airport and one at the city center) and field offices in 14 of the country's 24 districts. Telephone and fax are used regularly to communicate precipitation observations to the DMS headquarters staff in Gaborone. As a national meteorological service, DMS participates in the Global Telecommunications System (GTS) of the WMO. Readings from select stations are forwarded to WMO through the GTS to contribute to the joint data holdings of the world meteorological community. As a GTS participant, DMS also has access to precipitation observations made in neighboring countries. Beginning in 2001, the SADC Regional Remote Sensing Unit in Harare, Zimbabwe, gained access to daily satellite rainfall estimates from the United States National Oceanographic and Atmospheric Agency (NOAA) and precipitation forecast maps produced by the United States Air Force Weather Agency, through its participation in a Famine Early Warning System Network operated by the USGS. These products, in turn, are shared with DMS via the Internet. The DWA operates a separate and somewhat independent network of precipitation stations in many areas of Botswana, which is used by DWA in various catchment basins to support the development of future water resources in the country.

Seasonal forecasting has become a regular practice of SADC in recent years. With the advent of each rainy season in Botswana, DMS meets with NDMO and the media to discuss the forecast provided by a forum of regional and international experts. A press release regarding the expected onset of rains and expected characteristics of the upcoming rainy season is prepared and published in newspapers throughout Botswana. The regional approach of SADC offers a good opportunity and vehicle to implement real-time stream-gaging in Botswana because weather patterns are broad in scope and are not impacted by political boundaries.

Flood response actions are coordinated and directed by NDMO, and are implemented by the District Disaster Management Coordinators (DDMCs). Under the leadership of the District Commissioners, the DDMCs bring together the appropriate disaster relief agencies needed to help resolve the current disaster problem. These agencies may include: Botswana Defense Forces, Botswana Red Cross Society, Botswana Police Service, fire departments, and other District government departments. Services provided include search and rescue; evacuation to higher ground; provision of temporary shelter, sanitation, food and water; and rehabilitation of community services, neighborhoods, and homes. At present, there is no decentralization of institutional disaster management below the district level.

The hydrometeorological information from DMS and DWA are critical inputs to the NDMO, and cooperation with DMS is especially close because of its operational forecasting role. Under ordinary circumstances, DMS forecasts are broadcast twice daily on radio and television. During emergencies, there are additional radio programming slots available for more frequent forecast updates. In extreme situations, the media can be called upon to deliver live news coverage of a flood event.

The DWA is less directly involved with communication of flood watches and warnings. Stream flow data routinely are provided to the DDMCs and the NDMO who incorporate the data into their messages to the public.

GENERAL STRATEGY AND APPROACH

This report describes the general strategy and approach used in the Village Flood Watch Project to help establish the initial network of an effective pilot flood-warning system in Botswana, which is built on public involvement and awareness at the government and community level. The goals of the project were to improve the telemetry of extreme rainfall and stream levels and to provide needed information during times of flood disasters that will help trigger watches, warnings, and response at the government and village level.

The project also focused on the transfer of expert knowledge of hydrometeorological runoff modeling tools to national government agencies which can be used with near real-time rainfall, stream levels, stream flow and other basin characteristics to enhance flood-warning capabilities in the Limpopo River Basin. This knowledge can be transferred throughout the country to improve flood preparedness, warning, and response by national and local government agencies.

An initial USGS fact-finding mission to Gaborone in May 2001 provided sufficient information to outline an approach for the development of a village flood watch program. This initial mission provided sufficient information to propose a general strategy that ultimately was approved by USAID/RCSA. A second mission to Botswana in May 2002 gathered the information necessary to develop a detailed work plan as outlined in this document.

USGS experts worked closely with appropriate agencies at the international, regional, national, district, and community levels in developing and implementing this work. One of the initial tasks of the May 2002 mission was to identify the scope and scale of present precipitation and stream-flow data-collection systems. An effective flood-warning system requires timely precipitation and stream flow data over a wide area. During the May 2002 mission, personnel of the USGS worked with DMS and DWA scientists in mapping and evaluating the current hydrometeorological network and worked closely with them to identify additional sites that would be important for an early warning system. USGS recommended using the SADC-HYCOS network satellite system as a means to transmit the new real-time data being collected and agreed to work with SADC personnel to implement the program. Local authorities were integrally involved in the selection and placement of all-weather stations at additional secondary schools. Augmentation of the national hydrological and meteorological networks by additional and upgraded near real-time monitoring stations will not only serve community preparedness goals, but also will give the

NDMO, DWA and DMS a more complete picture of flood preparedness and needs during the crucial management of future flooding disasters in Botswana. These stations also will provide needed data to begin the development of a flood-warning network built on timely and appropriate hydrometeorological data-modeling techniques.

SPECIFIC OBJECTIVES

The specific objectives of the project were accomplished with close coordination among the USGS, DWA, DMS, USAID/RCSA, SADC, and select District managers and local village authorities. The major objectives implemented in the Limpopo River Basin were to:

- Upgrade and enhance selected key hydrological monitoring stations to provide data in a near real-time capacity to key government agencies and the public through the Internet.
- Provide two all-weather meteorological stations to selected local secondary schools, which will serve the dual purpose of additional automatic meteorological rainfall stations at the national level and provide an additional educational tool to the schools' curricula.
- Document critical floods that occurred from 1995-2000 by surveying channel geometry, selecting roughness coefficients in channel and valley reaches of selected newly constructed and upgraded near real-time stream-gages, indirectly computing peak discharges using open-channel hydraulic methods for these recent floods, and further developing stage/discharge relations at these gages.
- Provide hydrologists and meteorologists within the DWA and DMS with training and computer equipment needed to develop hydrological runoff modeling capabilities necessary to construct an effective flood-warning network for the river systems within Botswana.
- Provide hydrologists and meteorologists within the DWA and DMS with training and equipment for the successful operation, maintenance, and troubleshooting of electronic hydrological and meteorological equipment used in their networks.

This project was constrained by a 7-month time period in which the work had to be completed.

PROCEDURE

In May and July 2002, USGS personnel traveled to Botswana to meet with the department heads of Botswanan water-related government agencies; USAID contracting agents; and U.S. Embassy officials in a data-gathering mission. These trips provided the foundation for the existing project. Site visits were made to many existing and proposed river-gaging sites to provide the project with its initial reconnaissance of proposed hydrological and meteorological monitoring stations to be built and those to be upgraded in the Limpopo River Basin. From this reconnaissance, a total of eight sites were chosen for equipment installations. Of these eight, three were upgrades at existing stream-gaging sites, three were new stream-gaging stations, and two were new meteorologic stations at secondary schools. During June through August, personnel of the Mississippi District designed, and pre-built the river and weather gages that would be installed in the Limpopo River Basin (fig. 2). Personnel of the USGS Hydrologic Instrumentation Facility (HIF) at Stennis Space Center, MS were instrumental in working with personnel of the Mississippi District in the operation and programming of new micro-pulse radar stage sensors.

Instrumentation used in the project was mostly manufactured by Sutron Corp (the use of firm, trade and (or) brand names in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey). The data collection platform (DCP) acquired for the project is a Sutron 8210 (Model 821-0014), which is equipped with a Meteorological Satellite (METEOSAT) transmitter (Model 8200-2000). The European

Organization for the Exploitation of Meteorological Satellites (EUMETSAT) based in Darmstadt, Germany, allowed the use of their METEOSAT satellite for transmission purposes.

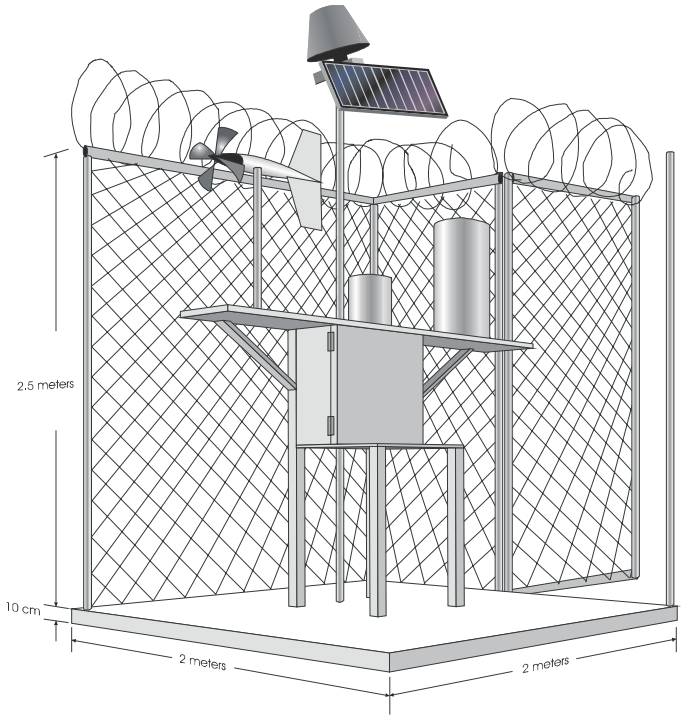

Figure 2.—Schematic of USGS designed meteorological gaging station for secondary schools in the villages of Moeng and Bobanong, Botswana.

A working relationship was also developed with the WMO in Geneva, Switzerland. Through the WMO, all hydrologic and meteorologic stations were assigned a unique WMO number, which allowed free transmission of the data through the METEOSAT. The WMO number also allows the data to be retransmitted from the EUMETSAT downlink in Germany through the WMO GTS. The GTS gives the project more global access to the data.

Sutron 5600-0530-1A incremental shaft encoders were used to measure river stage at the upgraded stilling-well sites. New HIF-tested, micro-pulse radar, stage sensors were used at the three newly constructed sites. The new radar sensors have shown promise in HIF testing at Stennis Space Center and at a USGS gage operated by the Mississippi District. The HIF-designed model, which for the purposes of the African work, was patterned for installation on a bridge handrail, and also for use on the downstream side of a railroad bridge. The HIF-designed model is unique in that it is interfaced with a Campbell Scientific CR-10 data logger that programs the unit and also serves as a redundant backup data logger for the gage.

Sutron Corp. also manufactured the following meteorological instrumentation used in the Village Flood Watch Project.

a. Accubar (Model 5600-0120) Barometric Pressure Sensor
b. Air Temperature (Model 5600-0311) High Accuracy Sensor
c. Relative Humidity (Model 5600-0313) High Accuracy Sensor
d. Wind Speed (Model 5600-0200) Sensor
e. Prop Vane (Model 5600-0201) Wind Direction Sensor
f. Stainless Steel Tipping Bucket (Model 5600-0425) Rain Gage

Highway and railroad bridge plans for proposed new river gages were obtained. Permits to build on Botswana highway and railroad bridges were applied for and granted from the Republic of Botswana Department of Roads and Botswana Railways Commission. Select secondary schools in the Limpopo River basin were contacted for participation in the meteorological station construction. The gages were pre-built, then disassembled, packed on crates, and shipped to Botswana in time for the arrival of the construction team in August through October.

In August and September 2002 three teams of USGS personnel traveled to Botswana for the construction and indirect measurement phases of the project. During this period, three new river gages were constructed, three existing river gages were upgraded to include near real-time transmitting capabilities and two new meteorological stations were constructed in the Limpopo River basin of Botswana (fig. 3).

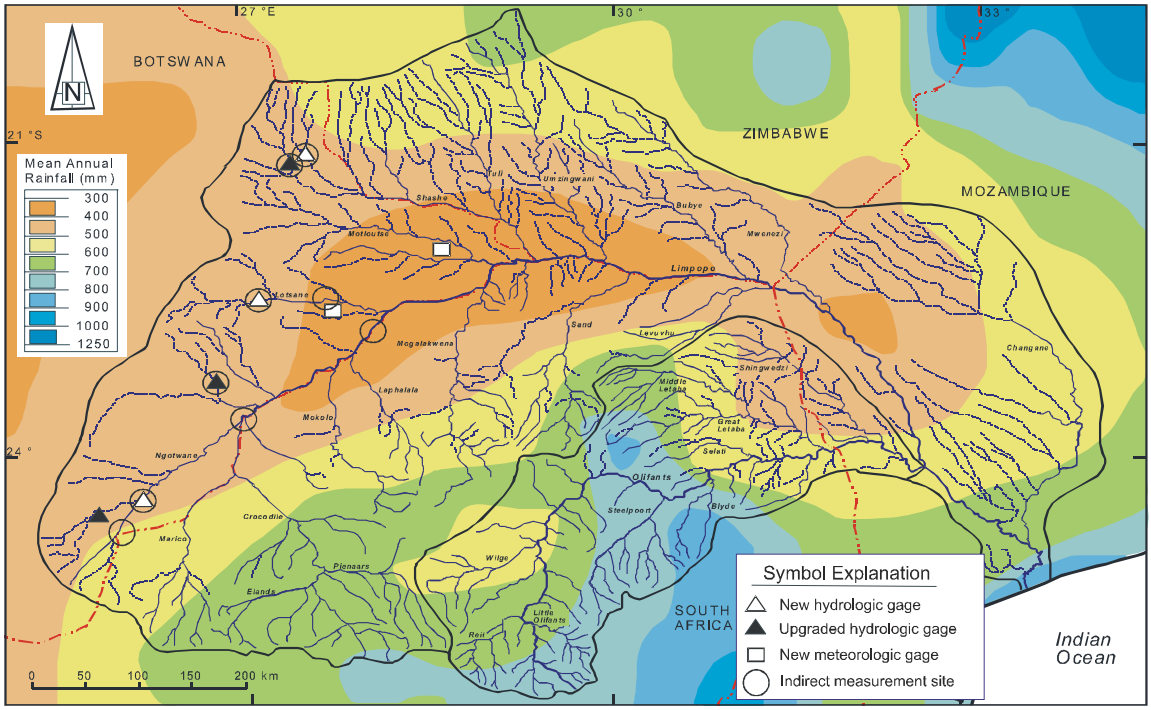

Figure 3.—Map of Limpopo River basin indicating new and upgraded hydrologic and meteorologic stations constructed in association with the Village Flood Watch Project and locations of indirect measurement studies for the documentation of 1995-2000 peak discharges.

From October through December 2002, training workshops on runoff modeling and DCP maintenance and operation were presented to engineers, hydrologists, and meteorologists of the Botswanan water agencies. USGS personnel worked closely with hydrologists and technical staff of the DWA to coordinate the implementation of anti-vandalism measures at all constructed and upgraded gages in the project, the formatting of data and the interface of the transmitted data to a Web-based access page in Pretoria, South Africa, and the completion of the construction phase of the project. The Web-based access page displays all transmitted data from the gages built in concert with the project. The Web page that will be used for the project and also be accessible by host-nation disaster managers and the public, is within the mission of the SADC-HYCOS:

http://www-sadchyco.pwv.gov.za/sadc/

IMPLEMENTATION AND RESULTS

The USGS worked in close cooperation with the USAID/RCSA, the U.S. Embassy, SADC-HYCOS, the DWA, DMS, NDMO, and local District managers to install, or upgrade, six hydrological gaging stations, and install two meteorological gaging stations to provide near real-time stage, precipitation and other meteorological parameters for use during flooding emergencies via the Internet and other appropriate communications methods. In addition the USGS provided training to the DWA and DMS in the operation, maintenance, and troubleshooting of the gages and provided training in the development and operation of a hydrological runoff model for use in developing flood-warning capabilities in the Limpopo River basin. The following paragraphs discuss the implementation and results of each objective.

Upgrade and enhance selected key hydrological monitoring stations to provide data in a near real-time capacity to key government agencies and the public through the Internet. Two USGS teams traveled to Botswana to work with the Republic of Botswana DWA, the DMS, and the NDMO to install three new river monitoring stations and upgrade three selected existing river monitoring stations with satellite transmitters and appropriate instrumentation to provide near real-time river levels and other information for use in the Botswanan and SADC-HYCOS hydrological networks. These data also will be served via the Internet through the SADC-HYCOS web portal. The following three stations were constructed as new river gages in the Limpopo River basin in Botswana. These stations will also serve as forecast points for future hydrologic runoff modeling efforts:

1. Notwane River at Mochudi
2. Lotsane River at Railroad Bridge at Palapye
3. Tati River at Francistown

The following sites were upgraded to near real-time transmitting capabilities by the addition of satellite transmitting equipment. These sites are existing river gages within the DWA network and are all stilling wells:

1. Metsemotlhaba River at weir WNW of Gaborone
2. Bonwapitse River at Ntshwaneng
3. Shashe River at Shashe Mooke

The USGS worked with the NDMO, DWA, and DMS to identify the appropriate organizations to work through for the construction, and lasting security of these new and upgraded hydrological stations. The two USGS teams associated with the construction project traveled to Botswana to install and upgrade the hydrological and meteorological gages, and assist personnel of the DWA and DMS in learning how to operate and maintain the network as well as interpret the data gathered.

Provide two all-weather meteorological stations to selected local secondary schools, which will serve the dual purpose of additional automatic meteorological rainfall stations at the national level and provide an additional educational tool to the schools' curricula. The two USGS teams also installed two all-weather meteorological stations at two secondary schools within the Limpopo River basin. Priority sub-basins and watersheds were identified by DMS for start up of the program during the May 2002 mission. Selected secondary schools in the Bobanong and Moeng areas were contacted for interest and assistance in installing all-weather stations used for the dual purpose of providing near-real time precipitation data to the DMS and for additional needed hydrological and meteorological education curricula. The meteorological stations record: air temperature, rainfall, wind speed, wind direction, barometric pressure, and relative humidity.

Most schools in the country lack Internet connectivity. However, their curriculum recently has been updated to include the effects of global climate change in Botswana. Having all-weather stations equipped for use in classroom instruction will provide "hands-on" activities throughout the school year. There are regular in-service training sessions available for geography teachers that would permit introduction of material on flood watch activities. A system of daily precipitation readings will be instituted on the school grounds with close coordination between selected secondary schools and meteorologists of the DMS, with student participation and integration of the work into the standard curriculum.

Document critical floods that occurred from 1995-2000 by surveying channel geometry, selecting roughness coefficients in channel and valley reaches of selected newly constructed and upgraded near real-time stream-gages, indirectly computing peak discharges using open-channel hydraulic methods for these recent floods, and further developing stage/discharge relations at these gages. A USGS team traveled to Botswana in August to September 2002 to survey selected historically critical flooding areas for channel and valley geometry and select roughness coefficients needed to indirectly compute peak discharge for the 1995-2000 floods. An appropriate one-dimensional open-channel hydraulic model was used to compute stage/discharge relations (fig. 4) to provide information for hydrological runoff modeling. Near real-time stream-level and -flow information will be used in concert with hydrological runoff modeling techniques to help improve pre-evacuation procedures of villages during flood disasters.

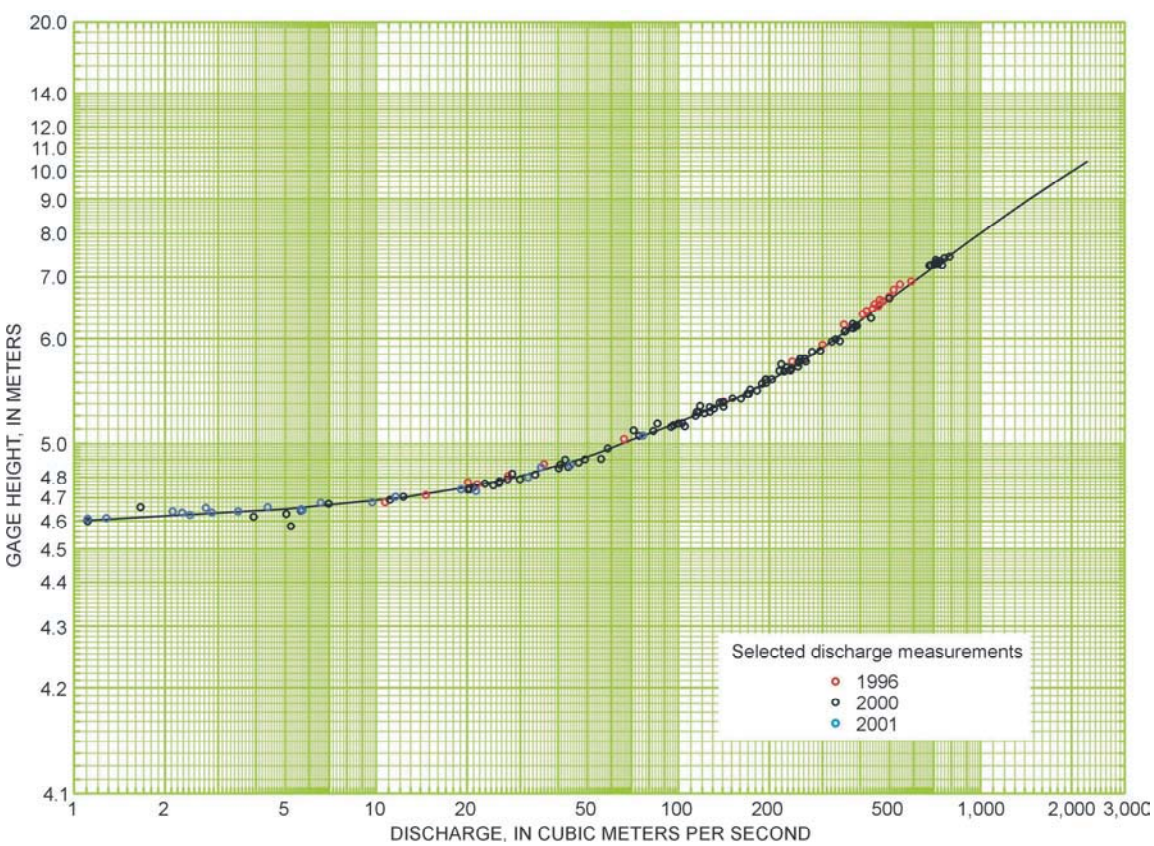

Figure 4.—Stage/Discharge relation, Limpopo River at Martin's Drift, Botswana.

The following sites were selected and surveyed for the computation of a stage/discharge relation and documentation of peak discharge during extreme floods from 1995-2000:

1. Notwane River at Mochudi
2. Lotsane River at Railroad Bridge at Palapye
3. Lotsane River at Maunatlala
4. Tati River at Francistown
5. Notwane River at Gaborone Dam at Gaborone
6. Limpopo River at Buffel's Drift
7. Limpopo River at Martin's Drift
8. Bonwapitse River at Ntshwaneng
9. Shashe River at Shashe Mooke

Channel and floodplain surveys at the Limpopo River sites required prior permission by the South African Government to survey channel and floodplain geometry on the right (south) bank and right (south) floodplain of the Limpopo River valley which is entirely in the Republic of South Africa. Permissions to survey in South Africa were obtained by the DWA prior to arrival of USGS personnel in Botswana. Surveyed cross-sections (fig. 5) along with selected roughness coefficients were used in selected one-dimensional hydraulic models (Hulsing, 1967, Sherman, 1989 and Brunner, 2002) to develop and extend stage/discharge relations at the 9 stream gages.

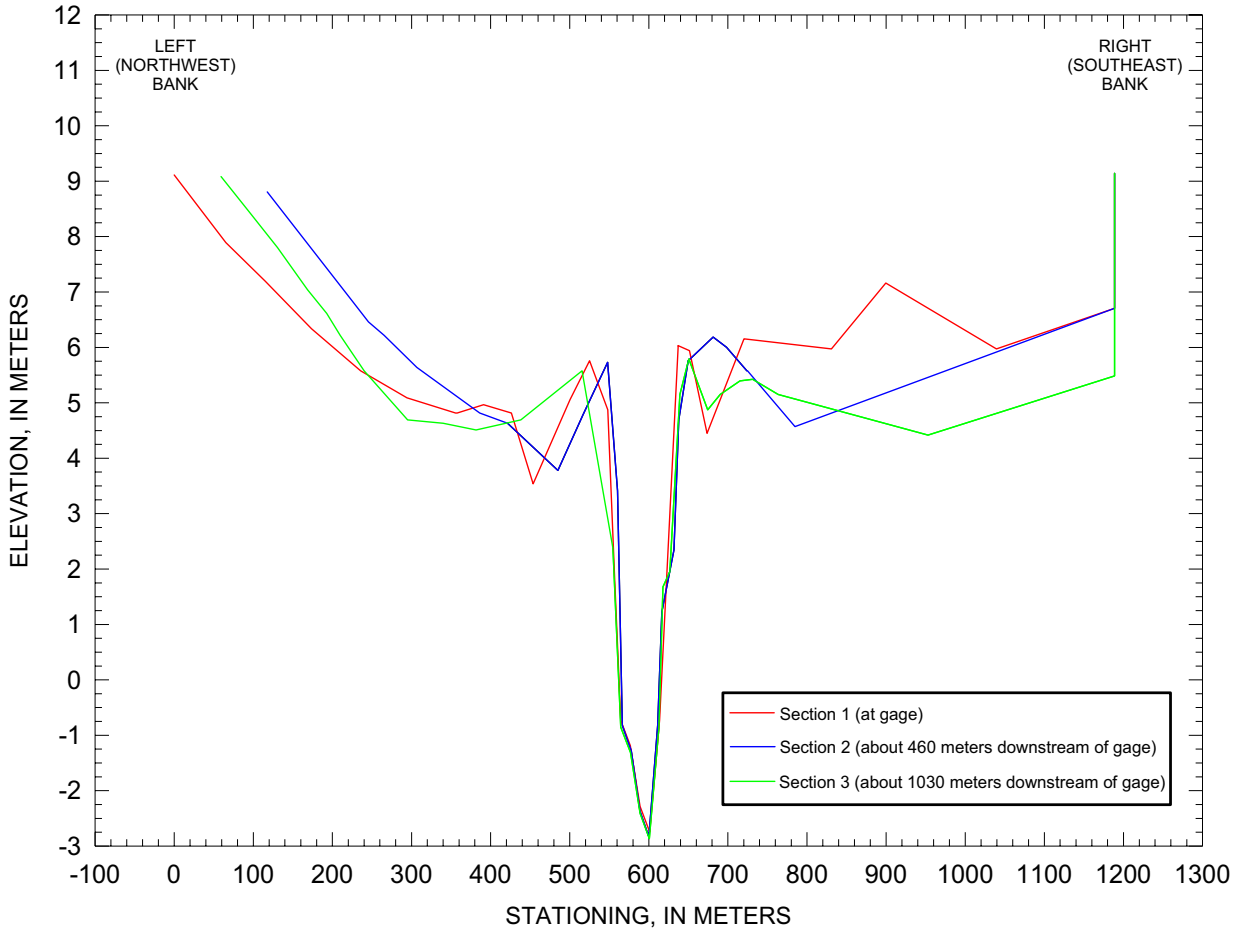

Figure 5.--Surveyed sections, Limpopo River at Buffel's Drift, Botswana.

The documentation of recent flood-peak discharges by indirect methods will be useful in the future development of flood-frequency analyses in Botswana (fig. 4). Figure 4 represents the extension of the stage/discharge relation at the Limpopo River at Martin's Drift, Botswana to allow for the calculation of discharges at this river gage during large floods. The stage/discharge relation extensions will also be used to calibrate hydrologic runoff models for tributaries in the Limpopo River basin. DWA personnel cannot effectively measure flood discharge at many of their gages due to inaccessibility during large floods. Also discharge measuring equipment used on cableways spans only the river channel and is ineffective when significant flow exists in the floodplain. Therefore stage/discharge relation extension to include flood flows was needed at all installed and upgraded gages.

The DWA was well positioned to help investigate this question, since they recorded high water marks at selected bridges throughout the country following the floods of 1995 and 2000. Such information is needed to provide a reference for warning messages emitted as a consequence of rainfall and stream flow exceeding threshold values.

In February 2003, a report of findings was published on the documentation of floods at these 9 stream gages as a provisional administrative report entitled "Stage-discharge ratings for 9 hydrological monitoring stations in the Limpopo River basin of Botswana." The provisional administrative report was published as a CD-ROM and distributed to the USAID/RCSA, DWA, DMS, and NDMO.

Provide hydrologists and meteorologists within the DWA and DMS with training and computer equipment necessary to develop hydrological runoff modeling capabilities needed to construct an effective flood-warning network for the river systems within Botswana. The development of flood warning capabilities in Botswana will help government agencies to alert downstream communities when water levels are rising at a threatening rate. A USGS team traveled to Gaborone, Botswana in October 2002 and provided training to hydrologists and meteorologists of the DWA, DMS, and Road Department of the Ministry of Works, Transport, & Communication on the techniques to develop and utilize rainfall-runoff relationship models. USGS staff from the HIF in Stennis Space Center, MS, the Office of the Regional Hydrologist for the Western Region in Menlo Park, CA and the National Mapping Discipline office in Maputo, Mozambique, implemented the U.S. Army Corps of Engineers Hydrologic Engineering Centers Hydrologic Monitoring System (HEC-HMS) for a pilot rainfall runoff model of a sub-basin in the Limpopo River drainage area. The training focused on a few critical basins. The method requires definition of basin characteristics such as watershed boundaries, shape, slope, and land use. These basin data can be estimated initially, but will have to be further developed and defined by DWA and DMS in order to get increased accuracy in hydrological runoff modeling in the Limpopo River Basin.

Provide hydrologists and meteorologists within the DWA and DMS with training and equipment for the successful operation, maintenance, and troubleshooting of electronic hydrological and meteorological equipment used in their networks. A USGS team from the HIF traveled to Gaborone, Botswana in November 2002, to train selected hydrologists and meteorologists of the DWA and DMS in the operation, maintenance, and troubleshooting of the electronic equipment being provided by the USGS (fig. 6). The team presented hands-on training using Sutron equipment. Laptop PC's were purchased and left with these agencies for the purpose of programming, maintenance and upkeep of DCP's installed in selected sub-basins.

Figure 6. Newly constructed micro-pulse radar, stage-sensor stream-gage at the Notwane River at Mochudi, Botswana.

SUMMARY

From May through December 2002, personnel of the USGS Mississippi District constructed eight hydrological and meteorological monitoring stations, and surveyed and computed peak flows for 1995-2000 flood events at nine river stations. USGS staff from the Hydrologic Instrumentation Facility (HIF) in Stennis Space Center, MS, the Office of the Regional Hydrologist for the Western Region in Menlo Park, CA, and the National Mapping Discipline office in Maputo, Mozambique, implemented the HEC-HMS as a pilot rainfall runoff model of a sub-basin in the Limpopo River drainage area. Six of the eight gages constructed record continuous river stage, and two other gages record continuous rainfall, wind speed/direction, barometric pressure, relative humidity and air temperature. The meteorological stations were constructed at selected secondary schools within the Limpopo River Basin for the dual purpose of providing additional meteorological data and adding to the school curriculum in the study of Earth sciences. In addition to the construction of monitoring stations and hydrological runoff model training, personnel of the USGS HIF provided a training workshop on basic electronics and troubleshooting hydrological instruments to Botswanan hydrologists and meteorologists.

All the hydrological and meteorological stations were designed to transmit data via the METEOSAT operated and maintained by EUMETSAT in Darmstadt, Germany. The data were formatted for output to the SADC-HYCOS real-time web portal at: http://www-sadchyco.pwv.gov.za/sadc/. This effort provides hydrological and meteorological parameters and a pilot hydrological runoff model that will assist the Botswanan government agencies in the propagation of hydrological runoff models in all the sub-basins of the Limpopo River Basin for use in future flooding disasters.

This project can neither stop nor reduce the extent of flooding in Botswana. It should, however, provide significant benefits to the NDMO, by providing them with timely information, rather than just raw data on rainfall. The project has provided the DWA and DMS with expanded data

networks into critically sensitive and representative areas, which gives them better spatial coverage. The project also provided these agencies with the ability to collect near real-time data, which gives them better temporal coverage and enables them to provide information to the NDMO much quicker than in the past. Finally, the project provides a transfer of technology that allows scientists from the DWA and DMS to translate some of the raw data they collect into the type of flood forecasting information that is critically important to the NDMO.

Forecast information also will be better understood because of the experience and the insights gained by the DWA through the quantification and documentation of past benchmark extreme events that have occurred from 1995-2000. Warnings issued to the community will therefore have a higher probability of eliciting compliance and of reducing vulnerability and impact in the event of a flood.

The techniques learned by the scientists at DWA and DMS for the Limpopo River Basin then can be applied throughout Botswana, which should provide long-term benefits to the people of Botswana on a national scale. Further, since the Limpopo River forms the boundary between several countries, the enhanced information developed by Botswana should aid the other bordering and downstream countries relative to potential flood hazards.

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