WATER AND SANITATION FOR HEALTH PROJECT

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# RUHENGERI WATER RESOURCES STUDY RWANDA

## WASH FIELD REPORT NO. 181

MAY 1986

Prepared for
the Ruhengeri
Resource Analysis and Management Project
under the auspices of USAID, Rwanda
WASH Activity No. 230

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# RUHENGERI WATER RESOURCES STUDY
# RWANDA

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by

Philip Roark
and
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May 1986

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| A.I.D.R. | Association Internationale pour le Développement Rurale |
| BCEOM | The French engineering firm doing the World Bank water projects |
| BCEOM-SAUR | The French engineering organization that did the institutional study for the World Bank water projects |
| CFNR | Centre de Formation en Nutrition de Ruhengeri |
| Coforwa | Compagnons de Fontainiers de Rwanda |
| DGE | Direction Générale d'Eau |
| FRW | Rwandan francs ($1 U.S. = 80 FRW) |
| FSIP | The USAID Farming Systems Improvement Project |
| MINITRAPE | Ministère de Travaux Publiques et de l'Energie |
| RRAM | Ruhengeri Resources Analysis and Management Project |
| UNICEF | United Nations Children's Fund |
| USAID/R | U.S. Agency for International Development/Rwanda |
| | |
| C | Degrees Celsius |
| cu. m | cubic meters |
| cu m/s | cubic meters/second |
| ET | Evapotranspiration |
| I | Infiltration |
| lps | liters per second |
| km | kilometer |
| ml | milliliters |
| mm | millimeter |
| P | Precipitation |
| ppm | parts per million |
| R | Runoff |
| sq. km | square kilometer |

## EXECUTIVE SUMMARY

As part of the Ruhengeri Resource Analysis and Management (RRAM) Project, a water resources analysis was undertaken by a two-person team from March 10 to April 4, 1986. The team, consisting of a hydrologist and a sanitary engineer, gathered data and prepared an analysis of specific issues concerning watershed management and water supply. Following are the principal findings and recommendations of the report.

### Watershed Management

The Ruhengeri Prefecture consists of several distinct environments, each of which is characterized by a unique set of hydrologic variables. Quantities of precipitation, runoff, evapotranspiration, and infiltration have been determined on a preliminary basis for each of four watersheds. The quantification of the hydrologic variables establishes an average baseline condition from which future changes may be monitored.

While average hydrologic conditions have been established, the annual variations have been found to be large. For this reason, a modest extension of the hydrologic and meteorological network is recommended. Data are also needed on sedimentation rates in conjunction with soil erosion studies, information which has been previously unavailable in Rwanda.

The Rugezi Marsh is a fragile environment which, from a hydrologic perspective, will require a complex water control system if it is to be developed for agricultural purposes. Any development should proceed only with a thorough analysis and with caution, because the potential for irreversible degradation of the marsh is large. In the past, falling water levels at Lake Bulera appear, from a preliminary analysis, to have been the result of overdepletion for hydropower purposes. At present, the lake is returning to normal levels as hydropower production has been brought into balance with water supply.

Arsenic, from tungsten mining, has been found in high concentrations in sediment samples, but not water samples. The arsenic, in its present state, is not considered a health hazard, but should be monitored for future changes.

Erosion and sedimentation are obvious problems. In addition to soil loss from crop lands, stream sedimentation from roads and mining operations is problematic. In consideration of the steep slopes and high rainfall, some erosion losses are inevitable. As a result, specific measures have been recommended to reduce erosion losses.

Montane forests within the national park lands have important hydrologic value in buffering torrential stream flow and in reducing erosion losses. Any degradation of these forests can be predicted to influence crop production negatively on the valuable lands in the Lava Zone.

### Water Supply

The most widespread and most suitable technology for domestic water supply is springs, with or without piped delivery systems, where they are available.

Rainwater catchment is a promising technology, but the storage cisterns that are required are too expensive for widespread adoption by the general public. Rainwater catchment is less expensive than piped water supply systems on a per capita basis and presumably would be adopted if it were subsidized at the same level. Rivers and lakes are undesirable water supply sources, because they are contaminated and because treatment and/or pumping systems are unlikely to be sustained with the resources that are locally available. Wells do not appear to be applicable.

Overall, the Ruhengeri Prefecture is reasonably well covered with water supply sources. The Lava Zone is not well covered, but the World Bank is proposing to finance a major distribution system from several major springs. The user charges necessary to sustain this system are high, and the system may, therefore, not be sustained. The probability of the system being sustained in operation would be improved if the pumping and treatment portions of the project were deferred and if an intense program of community development were undertaken to make the users aware of their responsibilities for constructing and maintaining the system and for paying tariffs.

Rainwater catchment systems for the people living in the Lava Zone would cost only one quarter as much as the proposed World Bank system, and even these costs could be reduced appreciably if less costly storage cisterns could be developed. Rainwater catchment systems would also have the advantages of greater probability of being sustained by the users; less walking for water, a greater volume of water during most parts of the year, and lower operation and maintenance costs.

The RRAM Project should not undertake a water supply program because: reasonably effective service exists in all of the Prefecture except in the Lava Zone, and the World Bank is proposing to serve the Lava Zone; implementation of a water supply project would require a field staff which the RRAM Project does not have; the resources that could be committed to a water supply project are unlikely to make a significant difference in the situation; and a water supply intervention is not central to the RRAM Project purposes of natural resource analysis, management, and policy development.

# Chapter 1

## INTRODUCTION

At the request of the Ruhengeri Resource Analysis and Management (RRAM) Project, the Water and Sanitation for Health (WASH) Project provided a hydrologist, and the Environmental Planning and Management (EPM) Project provided a sanitary engineer to assist the project. The RRAM Project is a part of the Environmental Training and Management for Africa (ETMA) program, which is managed by the South-East Consortium for International Development (SECID). The EPM Project is managed by the International Institute for the Environment and Development, Washington, D.C. The RRAM Project is financed under a regional grant by USAID.

The RRAM Project is designed to help sustain the regional resource base and to minimize environmental problems associated with development in the Ruhengeri Prefecture of Rwanda, which is depicted in Figure 1-1 on the following page. The first step of the process is to assist the Ruhengeri Prefecture in establishing an adequate environmental information base from which effective regional resource management strategies and interventions can be developed by the Government of Rwanda (GOR).

Within the domain of water resources, an initial consultancy was provided by Dr. Eric Schiller in August 1985. Dr. Schiller identified basic water resources information and specific issues of concern. He recommended a set of more specific activities to be undertaken by a subsequent mission. This report is a result of this recommendation.

The authors of this report, Philip Roark, hydrologist and team leader, and Bonneau H. Dickson Jr., sanitary engineer, arrived in Rwanda on March 10, 1986 and departed April 4. Most of their time in country was spent inspecting the project area and reviewing the documentation that was available at the project office in Ruhengeri. Several trips were made to Kigali to obtain additional information from government offices there and to hold discussions with government officials.

Objective of the hydrological consultancy were to:

- Collect and analyze the available hydrological and meteorological data.
- Conceptualize a preliminary hydrological balance for the study area.
- Analyze specific water resource issues which have been identified.
- Advise on further data gathering and analysis that should be performed.

The sanitary engineering consultancy was designed to:

- Inventory the existing domestic water supplies.
- Project the water demand.
- Identify water scarce areas and quantify the water deficits.
- Evaluate various water supply technologies.
- Recommend a plan for water supply development.

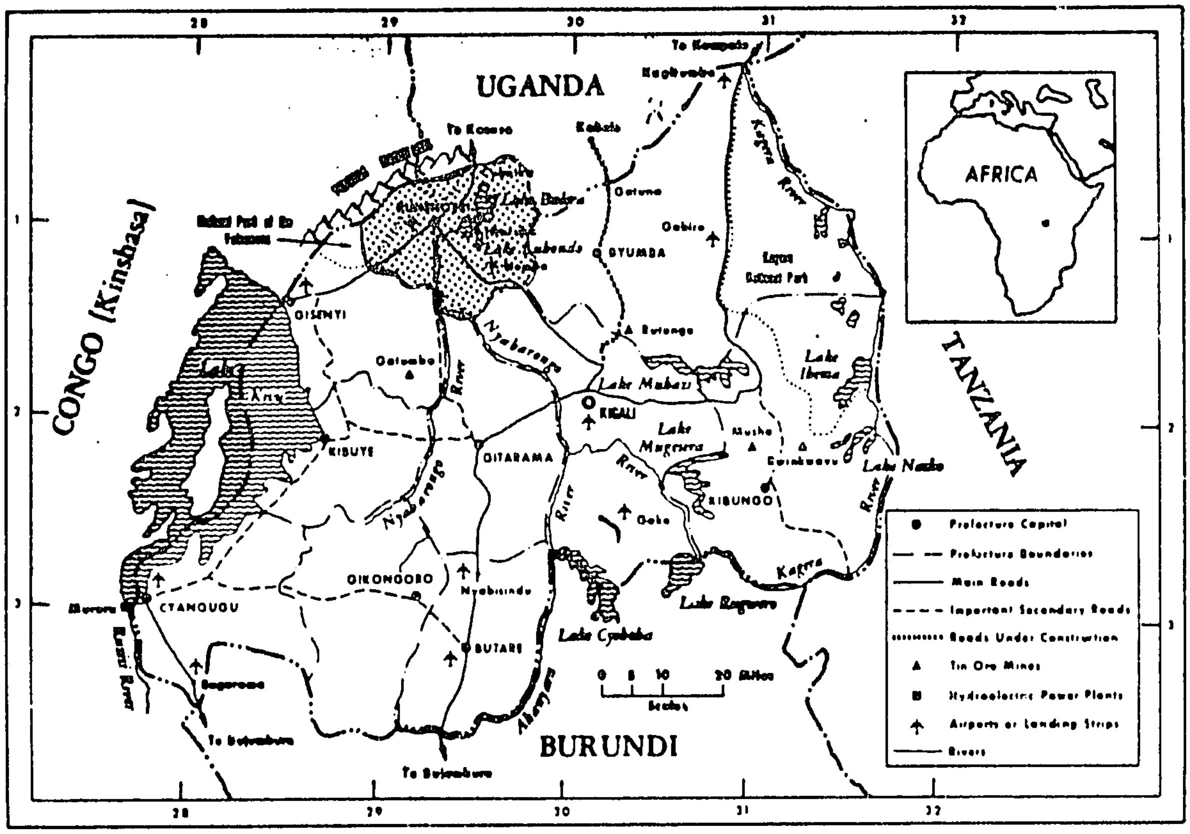



Figure 1-1. Ruhengeri Prefecture

This report consists of nine chapters, including this introductory chapter, and a final "Conclusions and Recommendations" section. The remainder of the report is arranged in eight chapters, as follows:

2. Provides the basic hydrologic data from which analysis was undertaken and reviews the sources of these data.

3. Analyzes four representative watersheds in the Ruhengeri Prefecture for their varying hydrologic character.

4. Reviews problematic areas regarding water resource issues and provides recommendations regarding further interventions.

5. Reviews such issues as quantity, quality, and institutional capabilities and details alternative water supply technologies.

6. Presents an inventory of the existing sources of domestic water in the Ruhengeri Prefecture.

7. Classifies domestic water needs into water demand by commune.

8. Recommends approaches and options to watershed management and domestic water supplies.

Appendices A through E are identified in the Table of Contents.

# Chapter 2

## EXISTING DATA COLLECTION SYSTEMS AND DATA

This second chapter of the report furnishes the basic hydrologic data from which the analysis was undertaken and reviews the sources of these data.

### 2.1 Meteorology

Meteorological data are collected by the Climatological Division within the Ministry of Telecommunications (Ministère des Postes et des Communications). The Province of Ruhengeri contains one synoptic meteorological station located at the Ruhengeri Airport. The Ruhengeri Station measures weather phenomena in accordance with international standards, including air temperature, soil temperature, humidity, wind, rainfall, sunshine duration, and evaporation. Instantaneous recording instruments are used for rainfall and humidity. Other readings are taken periodically during the day according to standard practices. The staff at the Ruhengeri Station are well trained in equipment operation and conscientious recording data.

In addition, weather information is collected at 15 other locations in the province by a variety of organizations and individuals. The organizations include Catholic parishes, schools, agricultural services and others. The data collected are primarily daily rainfall, but occasionally includes other data as well. Data collected from the various organizations outside the Climatological Division vary somewhat in quality, but nonetheless represent a valuable and needed addition to the total climatological network. A station established at Karisoke in 1979 has recently been upgraded to a full synoptic station which will provide data from high altitudes (3,000 meters). Data from high altitudes have previously been lacking.

Collected data are sent to the Climatological Division in Kigali for processing and analysis. A yearly bulletin is published, which includes monthly rainfall, 24-hour maximum rainfall, average and extreme temperatures, monthly insulation, atmospheric pressure, humidity, and vapor pressure. More detailed information, such as short duration rainfall intensities, is available in the archives of the climatological division and can be made available, if requested.

For the purposes of the present water resource investigation, rainfall data have been collected from six stations. The stations were selected to provide representative coverage of the province as well as for their length of record. The selected stations are indicated below and are located on the map in Figure 2-1. Total annual rainfall for each station is provided in Table 2-1.

The Ruhengeri Station provides quality rainfall data of an exceptionally long period, 58 years, with few interruptions. The annual average rainfall is 1,338 millimeters (mm). It is always tempting to discern weather cycles but few climatological data offer real evidence of cycles and the Ruhengeri data is no exception. The past 13 years have shown an increase of 11 percent in precipitation over the long-term average, in spite of below-average rainfall

| Selected Station | Altitude (meters) | Length of Complete Record Years |
|---|---|---|
| Ruhengeri | 1,878 | 58 |
| Rwankeri | 2,250 | 39 |
| Kinoni | 1,770 | 18 |
| Ruhunde | 2,235 | 31 |
| Nemba | 1,675 | 15 |
| Kerisoki | 3,000 | 6 |

for three of the past four years. The recent drought has been severe enough to cause sharp decreases in crop production, but is not unprecedented.

The yearly distribution of rainfall exhibits a bimodal pattern. The monthly average rainfall distribution is shown in Figure 2-2. The primary season is from February through May, with a secondary season from September to December.

A short dry season occurs in July and August. July is markedly drier than other months. July has an average number of days with rain of 3.7 days, totaling 25.8 mm, which is notable in reference to surface catchments for domestic water supply. Figure 2-3 provides the monthly average number of days with rainfall.

Maximum 24-hour rainfall is shown in Figure 2-4. Maximum 24-hour rainfall at Ruhengeri is not particularly high with a value of 68.3 mm, but comparable values may occur at any time of the year. High rainfalls during periods of minimum vegetative cover, before germination or after harvest for example, will lead to high soil erosion losses. It is noted that other rainfall stations in the province have recorded 24-hour maximums as high as 124 millimeters. Rainfall data for other stations included in this study are provided in the appendices.

## 2.2 Hydrology

Hydrologic data collection is the responsibility of Rural Engineering (Génie Rurale) within the Ministry of Agriculture, Stock Raising, and Forestry (Ministère de l'Agriculture, de l'Elevage et des Forêts). There are four gauging stations located within Ruhengeri Province that are currently in operation and provide a relatively long series of record. These stations are indicated below and are shown on the map in Figure 2-1. Table 2-2 provides information regarding average annual flow for each station.

| Station | River | Length of Complete Record Years |
|---|---|---|
| Ngaru | Mukungwa | 12 |
| Rwaza | Mukungwa | 14 |
| Rusomo | Rugezi | 23 |
| Sud Rwerere | Cyohoha-Base | 16 |

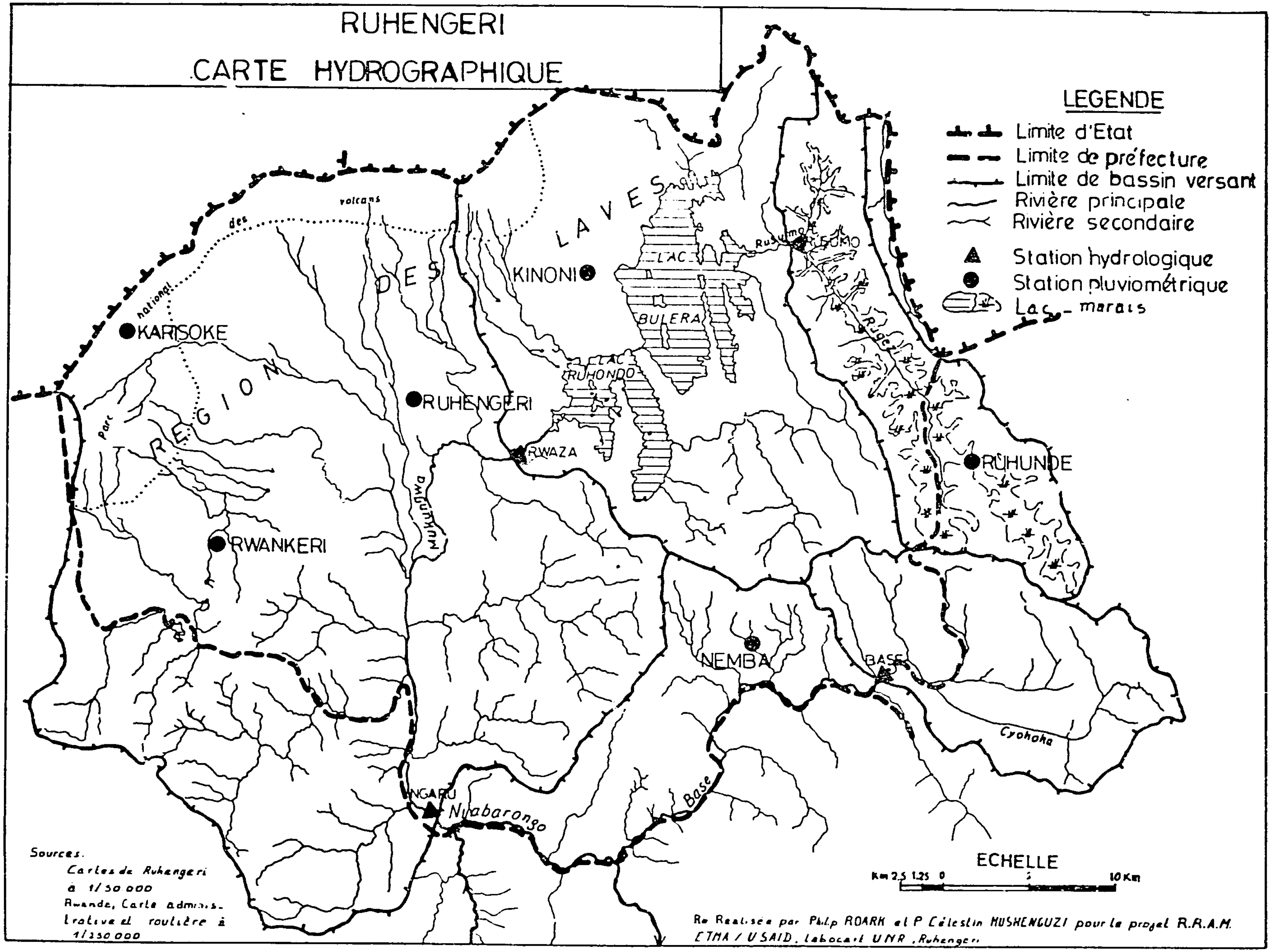



Figure 2-1. Hydrologic Map

Table 2-1

Annual Precipitation

mm

| Year | Stations | | | | | |
|---|---|---|---|---|---|---|
| | Ruhengeri | Rwankeri | Ruhunde | Nemba | Kinoni | Karisoke |
| 1985 | 1,174 | 1,270 | 1,169 | 1,385 | 1,234 | |
| 1984 | 1,072 | 1,005 | 1,021 * | 1,416 | 1,034 | 1,673 |
| 1983 | 1,244 | | 1,200 * | 1,570 | | 2,000 |
| 1982 | 1,448 * | 1,194 * | 1,397 | 1,697 | | 2,038 |
| 1981 | 1,201 | 1,251 | 1,277 | 1,569 | 1,075 | 2,220 |
| 1980 | 1,665 | 1,039 | 1,258 | 1,384 | 1,169 | 1,722 |
| 1979 | 1,619 | 1,373 | 1,287 | 1,643 | 1,152 | 2,096 |
| 1978 | 1,601 | 1,290 | 1,262 | 1,534 | 1,165 | |
| 1977 | 1,579 | | 1,401 | 1,724 | 1,183 | |
| 1976 | 1,568 | | 1,054 | 1,372 | 987 | |
| 1975 | 1,895 | 1,388 | | 1,545 | 1,201 | |
| 1974 | 1,679 | | 1,297 | 1,850 | | |
| 1973 | 1,495 | 1,104 | 1,424 | 1,734 | 1,110 | |
| 1972 | 1,558 | | 1,450 | 1,501 | 1,371 | |
| 1971 | 1,764 | 1,537 | 1,302 | 1,350 | 1,226 | |
| 1970 | 1,282 | | 1,255 | | 1,128 | |
| 1969 | 1,693 | 1,026 | 1,405 | | 1,235 | |
| 1968 | 1,453 | | 1,734 | | 1,144 | |
| 1967 | 1,278 | 1,102 | 1,833 | | 1,144 | |
| 1966 | 1,345 | 1,329 | 1,468 | | 1,148 | |
| 1965 | 1,309 | 1,293 | 1,445 | | 1,176 | |
| 1964 | 1,399 | 1,342 | 1,398 | | | |
| 1963 | 1,801 | 1,449 | 1,432 | | | |
| 1962 | 1,440 | 1,172 | 1,104 | | | |
| 1961 | 1,406 | | 960 | | | |
| 1960 | 1,120 | | 797 | | | |
| 1959 | 1,218 | 1,232 | 1,214 | | | |
| 1958 | 1,261 | 1,022 | 1,471 | | | |
| 1957 | 1,254 | 1,020 | 1,451 | | | |
| 1956 | 1,320 | 1,409 | 1,191 | | | |
| 1955 | 1,409 | 1,210 | 1,344 | | | |
| 1954 | 1,304 | 1,181 | 1,079 | | | |
| 1953 | 1,481 | 1,353 | | | | |
| 1952 | 1,015 | 1,353 | | | | |
| 1951 | 1,579 | | | | | |
| 1950 | 1,081 | 1,169 | | | | |
| 1949 | 1,110 | 1,135 | | | | |
| 1948 | 1,009 | 1,040 | | | | |
| 1947 | 1,615 | 1,314 | | | | |
| 1946 | 1,003 | 1,224 | | | | |
| 1945 | 1,141 | 1,257 | | | | |
| 1944 | 1,077 | 1,083 | | | | |

Table 2-1 (Continued)

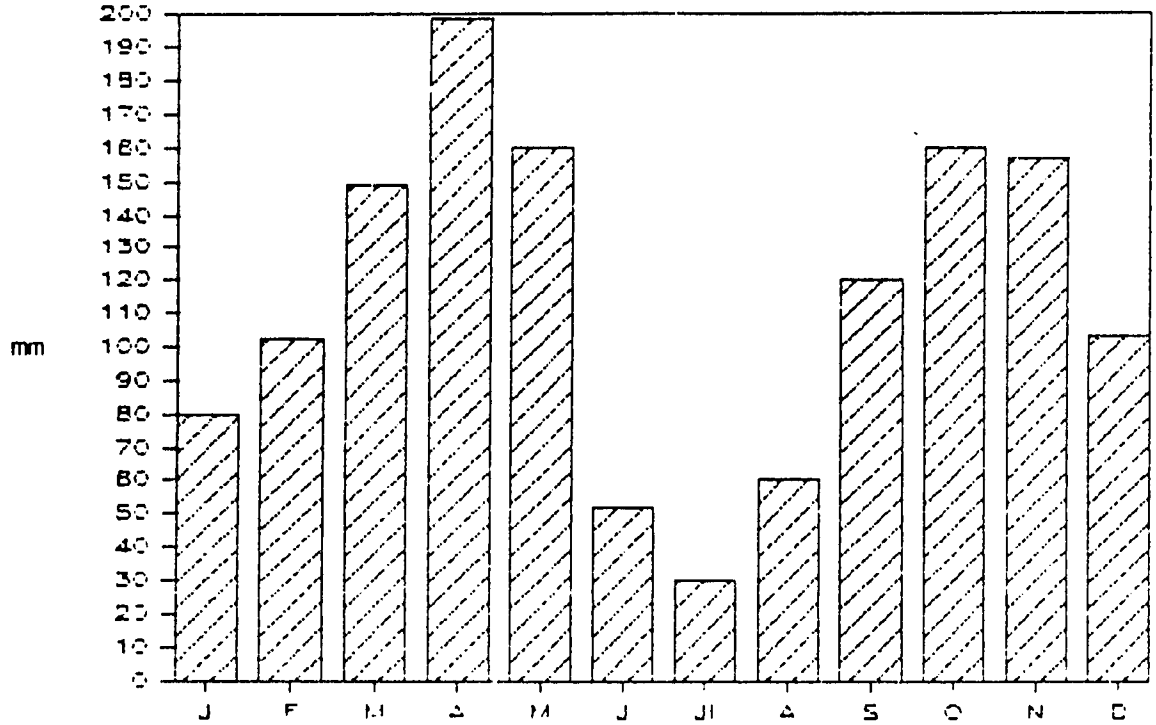
Annual Precipitation

mm

| Year | Stations | | | | | |
|---|---|---|---|---|---|---|
| | Ruhengeri | Rwankeri | Ruhunde | Nemba | Kinoni | Karisoke |
| 1943 | 1,161 | 1,155 | | | | |
| 1942 | 1,366 | 1,382 | | | | |
| 1941 | 1,292 | 1,590 | | | | |
| 1940 | 1,200 * | 1,240 | | | | |
| 1939 | 1,081 | 1,218 | | | | |
| 1938 | 1,207 | 1,232 | | | | |
| 1937 | 1,393 | 1,519 | | | | |
| 1936 | 1,234 | | | | | |
| 1935 | 1,127 | | | | | |
| 1934 | 1,152 | | | | | |
| 1933 | 1,136 | | | | | |
| 1932 | 1,279 | | | | | |
| 1931 | 1,126 | | | | | |
| 1930 | 1,428 | | | | | |
| 1929 | 1,222 | | | | | |
| 1928 | 1,259 | | | | | |
| Total | 77,628 | 48,502 | 40,380 | 23,274 | 20,882 | 11,749 |
| Count | 58 | 39 | 31 | 15 | 18 | 6 |
| Average | 1,338.41 | 1,243.64 | 1,302.58 | 1,551.60 | 1,160.11 | 1,958.17 |

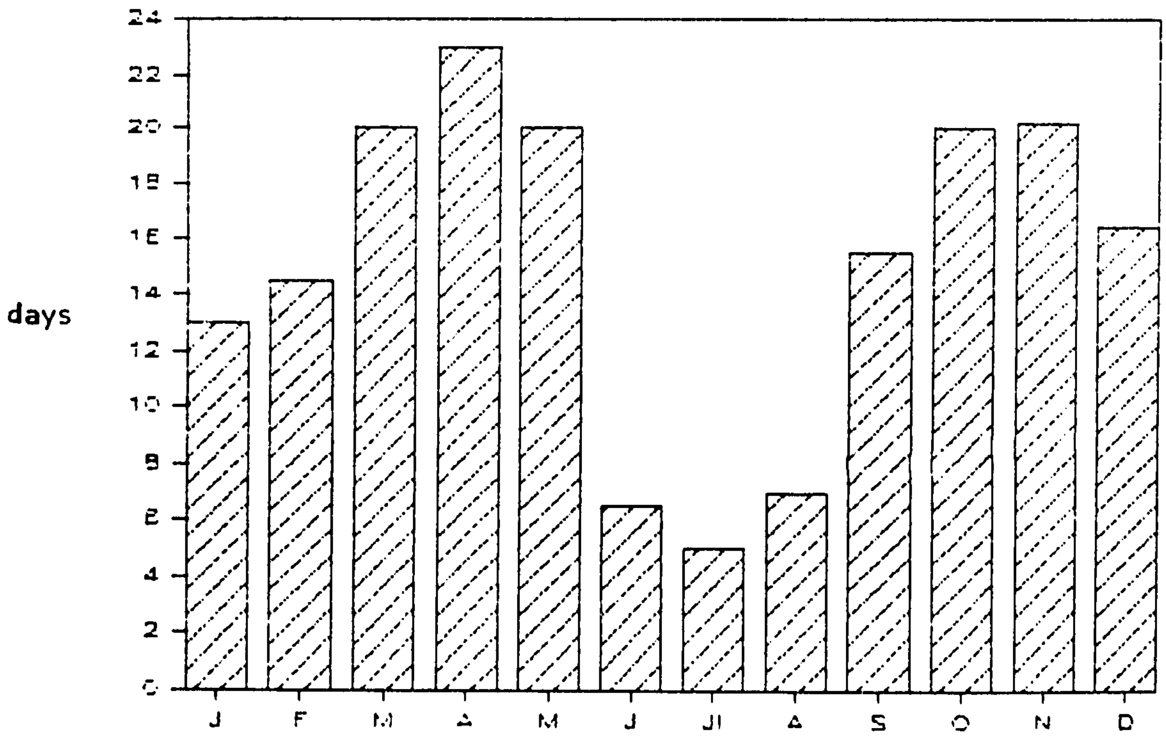
* Extrapolated or interpolated data.

## Figure 2-2



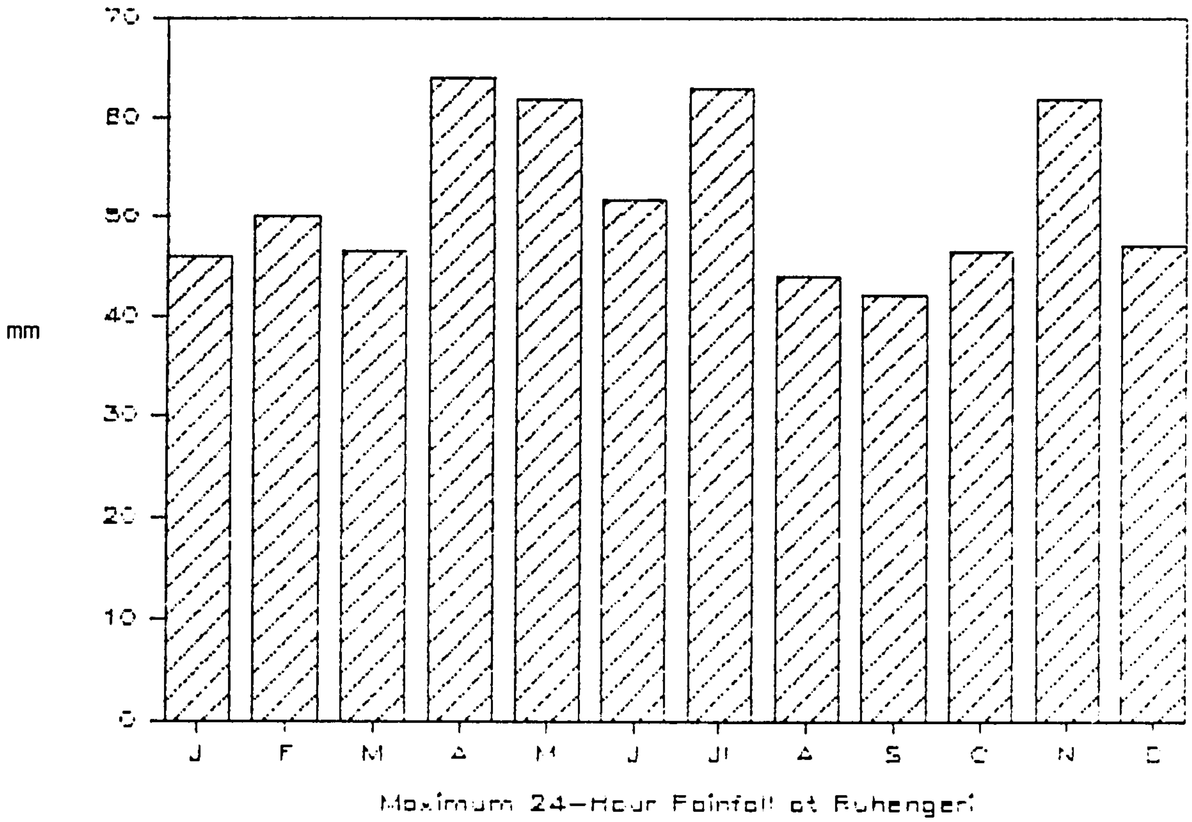

Average Monthly Flow at Ruhengeri

## Figure 2-3




Average Number of Days of Rainfall at Ruhengeri

Figure 2-4


mm
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O
N
D
Maximum 24-Hour Rainfall at Ruhengeri

Table 2-2

Annual Flow

(Cubic Meters per Second)

River Station

| Year Année | Mukungwa Ngaru | Mukungwa Rwaza | Rugesi Rusomo | Cyohoha Base Sud de Rwerere |
|---|---|---|---|---|
| 1985 | 50.98 * | 7.59 * | 1.08 * | 2.24 * |
| 1984 | 40.35 | 7.02 | 1.01 | |
| 1983 | 44.85 | | 1.24 | 1.62 |
| 1982 | 45.82 | | 1.14 | |
| 1981 | 38.39 | 10.36 | 1.23 | 2.46 |
| 1980 | 26.15 | | 1.16 | 1.68 |
| 1979 | | 9.21 | 1.27 | 2.78 |
| 1978 | 17.03 | 8.85 | 2.39 * | 2.41 |
| 1977 | 18.98 | 9.86 | 1.42 | 2.20 * |
| 1976 | 21.57 | 9.03 | 1.14 | 1.47 |
| 1975 | 23.10 | 9.07 | 1.54 | 1.96 |
| 1974 | 30.24 | | 1.52 | 1.96 |
| 1973 | 28.27 | 8.17 | 1.15 | 2.22 |
| 1972 | | 7.41 | 1.64 | 3.93 |
| 1971 | | 7.70 | 1.27 | 3.76 |
| 1970 | | 6.88 | 0.96 * | |
| 1969 | | 6.94 | | |
| 1968 | | 6.94 | | 5.49 |
| 1967 | | | | 4.40 |
| 1966 | | | 0.99 | 4.15 |
| 1965 | | | | |
| 1964 | | | 0.99 | |
| 1963 | | | 1.87 * | |
| 1962 | | | | |
| 1961 | | | | |
| 1960 | | | .72 | |
| 1959 | | | 1.22 | |
| 1958 | | | 1.62 | |
| 1957 | | | 1.31 | |
| Total | 385.73 | 115.03 | 29.88 | 44.73 |
| Years | 12 | 14 | 23 | 16 |
| Average | 32.14 | 8.22 | 1.30 | 2.80 |

* Extrapolated or interpolated data.

The Mukungwa River and its tributaries drain most of the Ruhengeri Province and parts of provinces located to the south and east, with a total area of 1,829 square kilometers. Most of its flow is received from the steep highlands along the Zaire Nile Divide and the more moderate slopes of the Lava Zone. (See Figure 2-5, "Ecological Zones".) The relative quantities of flow contributed by the two ecological zones are unknown, because most of the Lava Zone runoff infiltrates into the porous soils but presumably flows underground to occur as base flow in the Mukungwa River. On the basis of runoff coefficients of comparably sized watersheds in Rwanda, it appears that all of the flow received by the Lava Zone eventually is returned to the surface drainage system, in spite of the absence of permanent streams in the Lava Zone.

The gauging station located at Ngaru on the Mukungwa River essentially integrates the hydrologic character of a diverse set of watersheds, including the aforementioned Nile Zaire Crest and the Lava Zone but also the Bulera-Ruhondo lakes, the Rugezi Marshlands, and portions of the Central Plateau Highlands. Located on the prefecture border, the Ngaru Station measures flow which provides a significant contribution to the Nyabarongo River, which is the largest river in Rwanda. It is unfortunate that several years of data during the 1970s were rendered inaccurate when the Ngaru gauge was destroyed by a flood. This loss of data has made statistical treatments of flow less meaningful. It is recommended, therefore, that the restructuring of these data be attempted, even though it is recognized that some inaccuracies will occur.

The Ngaru Station has recorded an annual average flow of 32.14 cubic meters per second (cu. m/s) for 12 complete years of data. It is noteworthy that since 1981 there has been a marked increase in flow, an average of 44.06 cu. m/s, as compared with the average of 23.62 cu. m/s for the preceding seven years of record. This represents an 87 percent increase in flow. It would be prudent to verify that there have been no changes to the stream cross section which might effect the rating curve of the station. Rainfall figures as measured at Ruhengeri are 8 percent below average since 1981 and 23 percent above average for the seven years of record preceding 1981. Assuming that flow and rainfall data are correct, the only plausible explanation for the increased flow is that the rainfall as measured at Ruhengeri does not adequately reflect precipitation for the entire basin. This explanation is explored further in Chapter 3, "Water Balance Model."

Inflow from the Lake Bulera-Ruhondo system to the Mukungwa River is measured at the Rwaza Station. Flow from the lakes is regulated by the hydropower stations located at the outlets of both lakes. The watershed area of 497 square kilometers (sq. km), not including the Rugezi Marshlands, covers several ecological zones. The Lava Zone presumedly supplies significant subterranean flow from the north, while the drainage system from the Buberuka Highlands has a high percentage of runoff. The lakes themselves, with a surface area of almost 15 percent of the watershed, are replenished directly from rainfall. The Rwaza Station has measured an annual average flow of 8.22 cu. m/s over 14 years of complete records.

The Rusomo Station measures inflow from the Rugezi River, which then empties into Lake Bulera. The Rugezi watershed, of 189 sq. km, is dominated by

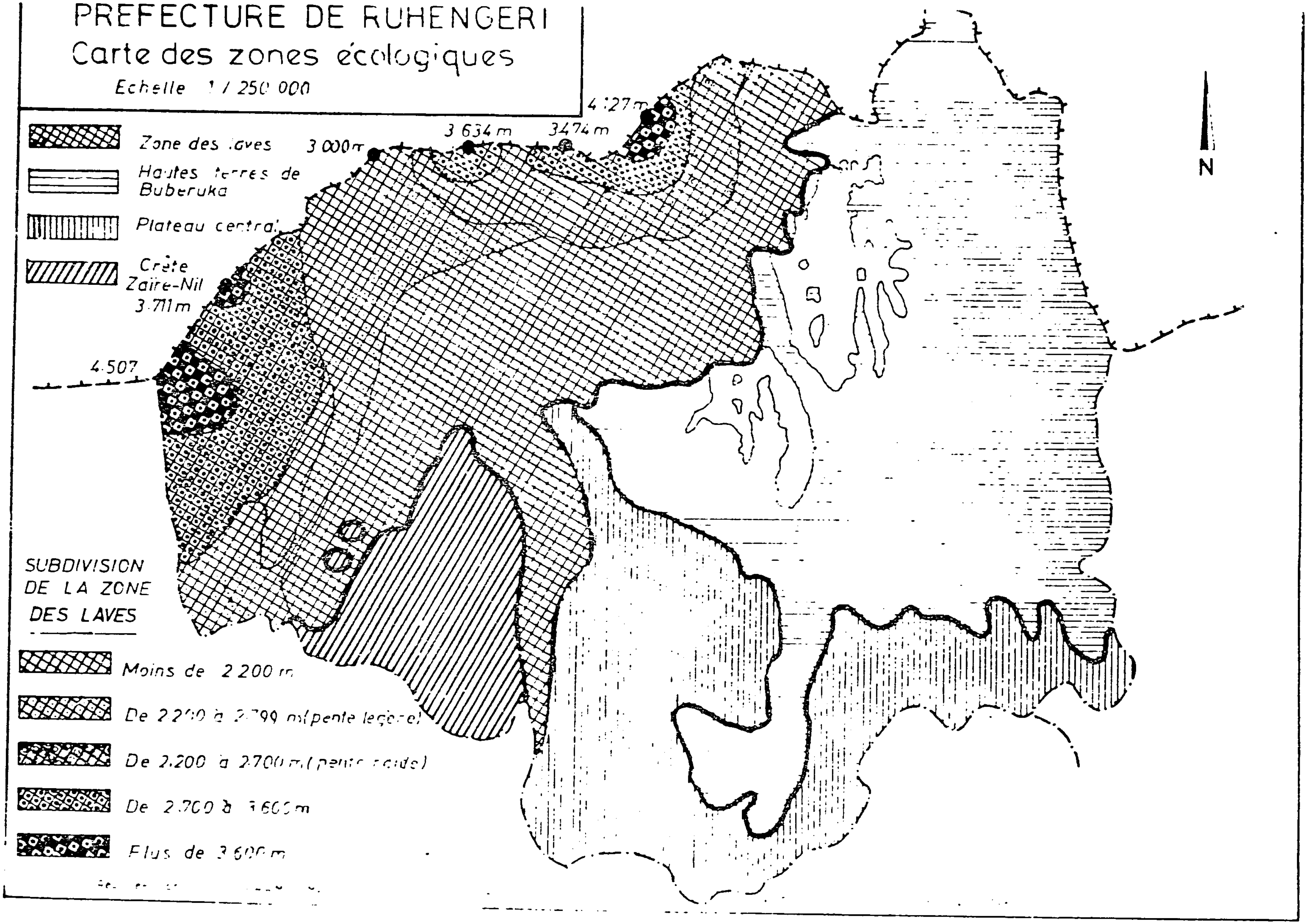


Figure 2-5. Map of Ecological Zones

marshlands underlain by peat formations which have a profound influence on flow. The marshlands tend to dampen flood flows from the slopes of surrounding hills, to allow considerable evapotranspiration losses from phyreatophyte vegetation, and to provide a generally constant flow, averaging 1.31 cu. m/s, at Rusomo.

The Cyohoha-Base river system is gauged at the Rwerere Station. This small watershed, extending over 174 sq. km, is only partially within the Ruhengeri Prefecture. The steep hillsides provide a relatively high runoff, averaging 2.83 cu. m/s.

The effect of elevation differences of the various hydrologic features is noteworthy. Figure 2.6, on the following page, provides a schematic profile across the Ruhengeri Prefecture running east and west. On the eastern side, the Rugezi Marshlands are perched above the surrounding basins and water flows in a step fashion from the Rugezi Marshlands to Lake Bulera, then to Lake Ruhondo, and finally to the Mukungwa River through a series of spectacular waterfalls (or penstocks as a result of the construction of hydropower plants). The relative scale of the volcanic mountain systems to the west provides an indication of the steepness of the slopes and their potential in producing runoff and influencing storm patterns. Storms generally move from east to west across the Prefecture. Rainfall can be expected to increase with altitude up to approximately 3,000 meters, according to studies undertaken elsewhere in East Africa.

Average monthly stream flow at Ngaru follows a pattern, as shown in Figure 2-7. Low flows occur during the month of August and high flows are usually in May, although April and November are also high. Maximum flood flows usually occur in April or May, but have also been recorded in March and June at Ngaru. An expected return period for flood flows is shown in Table 2-3. Minimum low flows are shown in Table 2-4 for various return periods at Ngaru. Additional hydrologic data for the four gauging stations in Ruhengeri Province are found in Appendix E.

Hydrologic data for all of Rwanda are published in yearbooks by the Agricultural Ministry. The yearbooks date from 1950 and include river heights, daily flow, maximum and minimum flow, and runoff coefficients. Unfortunately, there is a rather long delay between the completion of a hydrologic year and the publication of the data. The most recent publication was for 1981, which was dated June 1985, a delay of four and one half years. Data collected since 1981 are available in various forms at the offices of Rural Engineering.

It should be noted that the watershed areas indicated in this section are somewhat at variance with areas published in the hydrologic yearbooks. In particular, the yearbooks show the Mukungwa watershed to extend into Zaire and to have an area of 2,000 square kilometers. Information gathered by this study indicates that the Rwanda-Zaire border follows the ridge line and, therefore, Zaire does not contribute to runoff in the Mukungwa watershed. The area found by planimetering the 1:50,000 topographic sheets produced under the RRAM Project was 1,829 sq. km for the entire Mukungwa watershed and 1,143 sq. km if the Lake Bulera-Ruhondo and Rugezi systems are subtracted. The Rural Engineering Department is invited to verify the accuracy of these measurements.

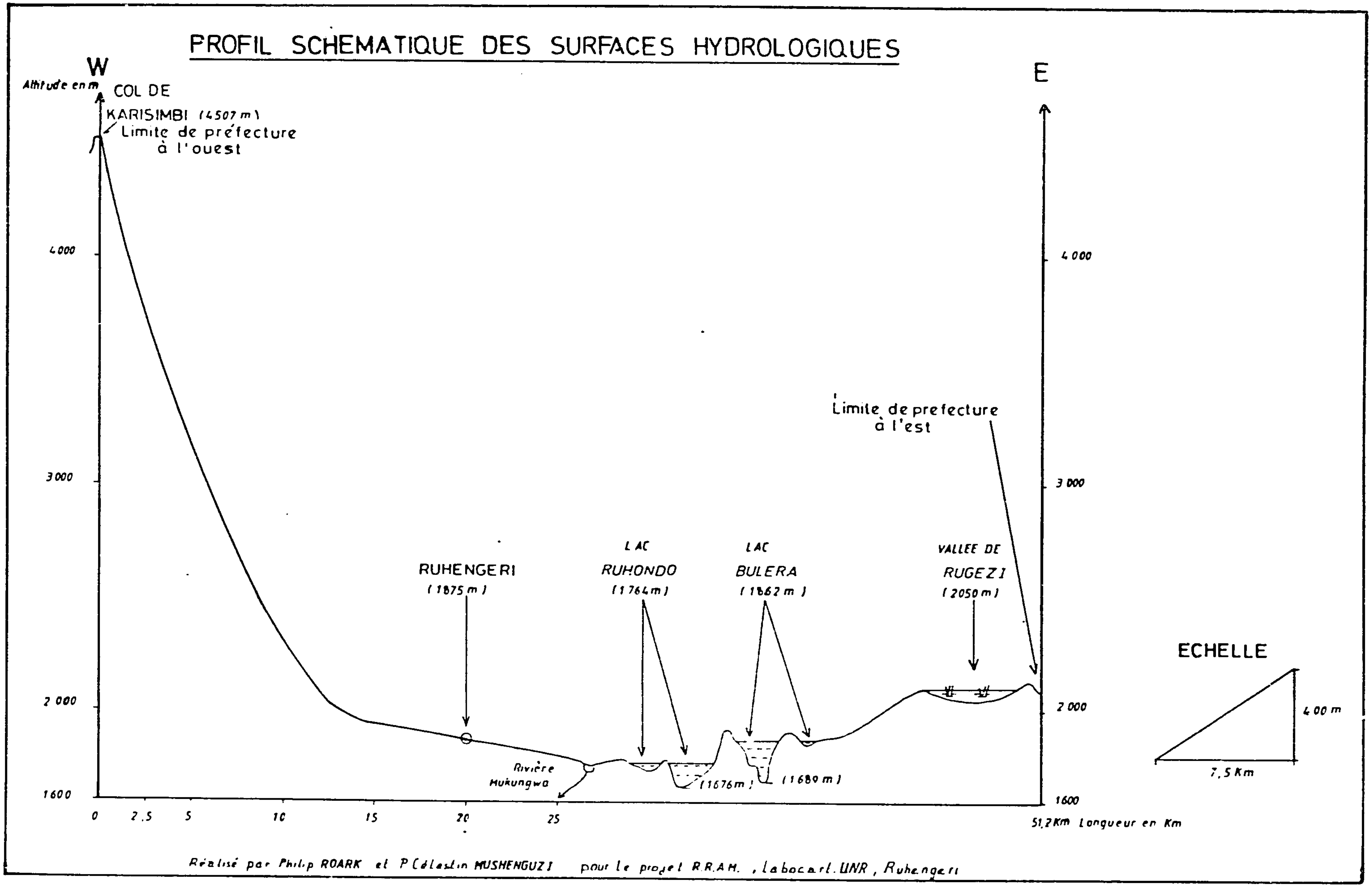


Figure 2-6. Schematic Profil

Figure 2-7

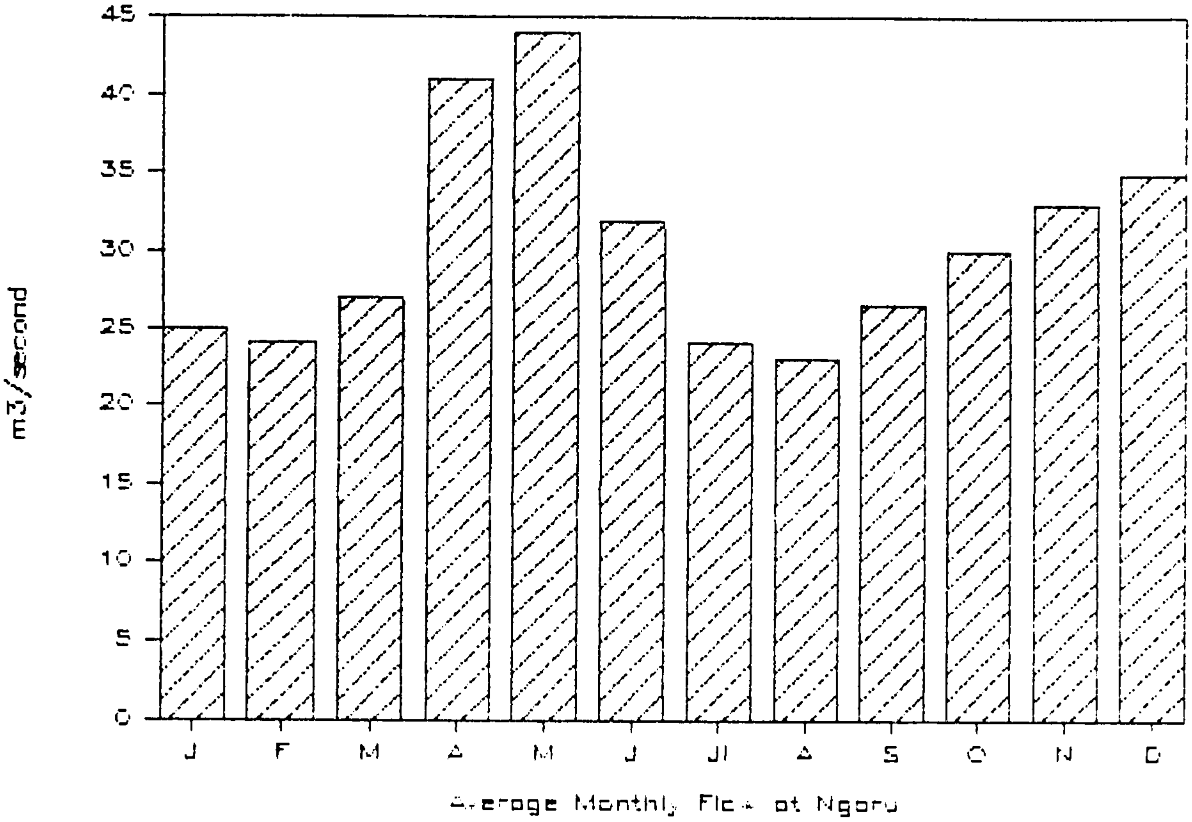
m3/second
0
5
10
15
20
25
30
35
40
45
J
F
M
A
M
J
Jl
A
S
O
N
D
Average Monthly Flow at Ngoru

Table 2-3

Maximum Flood Flow Frequency at Ngaru

| | | |
|---|---|---|
| 10% Chance of Exceedence | = | $141m^3/s$ |
| 50% Chance of Exceedence | = | $103m^3/s$ |
| 90% Chance of Exceedence | = | $65m^3/s$ |

Table 2-4

Minimum Low Flow Frequency at Ngara

| | | |
|---|---|---|
| 10% Chance of Exceedence | = | $26.8m^3/s$ |
| 50% Chance of Exceedence | = | $17.0m^3/s$ |
| 90% Chance of Exceedence | = | $7.1m^3/s$ |

Fluvial sediment transport has not been measured in Rwanda. It is apparent that considerable sediment is carried by rivers in the Ruhengeri Prefecture. Sediment transport is a function, in part, of cropland erosion. This issue will be addressed in Section 4.4, "Erosion and Sedimentation."

## 2.3 Evapotranspiration

Water losses through evapotranspiration (ET) are primarily determined by climatic factors. Many mathematical formulas have been developed for various climatic regions which generally require measurements of one or more variables, including temperature, humidity, wind, sunshine, and day length. Measurements of these climatic variables are available at the Ruhengeri synoptic station. The Ruhengeri Station also measures evaporation from a U.S. Class A pan.

For the purposes of the water balance study, the pan evaporation measurements have been chosen as the most reliable methodology for determining ET losses. Pan evaporation is, in comparison to prediction formulas, a direct measurement of evaporation and is particularly representative of free water bodies which include the Lake Bulera-Ruhondo system and the Rugezi Marshlands. Pan evaporation is primarily affected by temperature, humidity, and wind. The climate as measured at the Ruhengeri Station exhibits a remarkable consistency both between months as well as between years. Mean monthly temperatures rarely vary more than 1.5 degrees Celsius (C) from the average of 17.5 degrees C. Mean monthly relative humidity is always classified as high, above 70 percent. Wind speeds seldom exceed 50 km/day which is classified as light (light winds are less than 175 km/day) (Reference 15).

On the basis of six years (1980-85) of data gathering at Ruhengeri, average annual pan evaporation was 985 mm, with a small range of 925 mm to 1,024 mm. Measured pan values must be reduced by a pan coefficient (Kp) of 0.8. as specified in FAO publications (Reference 14). In addition, a crop coefficient (Kc) must be applied to account for the differences in transpiration between crops and other forms of vegetation. In consideration of the seasonal variation of crops, the amount of crop land, the existence of natural vegetation, and the dominance of lakes and marshes, the following Kc values are appropriate:

Kc = 1.0 for lakes and marshes
Kc = .90 for mature bananas, field crops and pasture (fallow).

As a result, two annual values of evapotranspiration will be applied for water balance calculations

For watersheds dominated by crop land, ET = 709 mm/year. For watersheds dominated by lakes or marshes, ET = 788 mm/year.

## 2.4 Infiltration and Groundwater

Except for development of springs, there has been almost no development of groundwater in the Ruhengeri Prefecture. In fact, very few wells have been drilled to date in Rwanda, and only in the eastern part of the country. According to personal communications from representatives of GTZ, the German technical aid organization, a drilling rig will be brought to Rwanda in May, 1986 to drill water wells in the southern part of Rwanda. Until such time that a network of wells are drilled and monitored, the occurrence of groundwater and the replenishment of groundwater through deep infiltration will remain a matter of conjecture. Estimates of infiltration have been developed in Chapter 3 as a part of the water balance model. Available information on spring development is presented in Chapter 6 as a part of the domestic water inventory.

## 2.5 Mapping

A hydrologic map at a scale of 1:50,000 has been prepared for the Prefecture of Ruhengeri. The map shows principal, secondary, and ephemeral stream channels. The map is accurate regarding the location of channels, because it was developed from aerial photos, however, indications of ephemeral and secondary streams are somewhat problematic. Stream channels in the Lava Zone are well established in most areas, but flow only for short periods and then often disappear completely. The hydrologic map has also been updated to include watershed boundaries and locations of climatic and river gauging stations.

Additional maps of interest for hydrologic analysis include slope maps, soils maps, and land use maps. A slope map is available at 1:50,000 scale, but the contour intervals of 75 meters do not allow as thorough a precision as desirable. Aerial photos taken in 1978-79 provide coverage at a 1:20,000 scale for the prefecture and were the source for a land use map. The land use map is the subject of further analysis from which data sheets are being produced. The data sheets tabulate information in units of four hectare plots for land use and other information collected under the RRAM Project. The data sheets should be valuable for the future if, for example, further hydrologic analysis is required for computer modeling. It is also understood that the Belgian Government is financing a soils and topographic survey which should improve the data base considerably. The soil survey portion of the Belgian study for Ruhengeri Prefecture has been completed, but the final publication date is uncertain.

# Chapter 3

## WATER BALANCE MODEL

This third chapter analyzes the four representative watersheds in Ruhengeri Prefecture according to their hydrologic character. The watershed model developed herein is meant to be a preliminary analysis of water balance within four distinct systems in the Ruhengeri Prefecture.

### 3.1 Watershed Systems

The model assumes that precipitation (P) follows one of three paths -- that it becomes stream flow (R), is lost through evapotranspiration (ET), or infiltrates (I) into the groundwater system. Precipitation and stream flow are measured, evapotranspiration is calculated, and infiltration is a residual. The equation is as follows: $P - R - ET = I$.

The location of the stream gauging stations in Ruhengeri Prefecture divides the area into systems representing diverse hydrologic units. The Mukungwa system is a watershed characterized by the steep slopes of the montane forest parklands, the extremely permeable soils of the Lava Zone, and the well-drained highlands along the Nile-Zaire Divide and the Central Plateau. Except for the Birunga Park, Rugezi Marsh, and scattered communal forests, most of the land is intensively farmed.

The Lake Bulera-Ruhondo system is characterized by the two lakes and their effect on evaporation and precipitation. It appears that the lakes receive somewhat lower rainfall and obviously have larger evaporation losses than surrounding areas. The operation of the hydropower plants clearly place man as a major influence on the hydrologic system.

The Rugezi Marshland, in contrast with most of Rwanda, has a hydrologic regime that is little affected by human influence. Evapotranspiration losses are significant, and the underlying peat formation acts as a continuously saturated sponge. Development of the Rugezi Marshland has been attempted (S.C.E.T. International, Inc.) but, except for small "estuaries" of the marsh, has not succeeded. Outside national parks, the marsh represents one of the largest undeveloped land areas in Rwanda. The question arises, however, if indeed it should be considered land or a shallow lake.

The fourth area, the Base-Cyohoha river system, is representative of a much larger part of Rwanda, the Central Plateau. Most of the watershed lies outside the Ruhengeri Prefecture. It is an area characterized by intensive cultivation on steep slopes with large altitudinal changes over short distances. It is probable that altitudinal differences cause significant changes in microclimates over distances less than a kilometer, but no references to specific studies have been found during the preparation of this report.

### 3.2 Mukungwa Watershed

To maintain a representative period of record for comparing the Mukungwa system with Lakes Bulera-Ruhondo and the Rugezi Marsh, the period from 1973 to 1985 was used. For the Ngaru Station, 12 complete years of record (Table 2-2) were employed in the water balance calculations. By subtracting average flow over the period from the lakes system, as measured at Rwaza, the average annual flow from the Mukungwa watershed was 23.92 cu. m/s. The water balance equation based on precipitation at Ruhengeri over the period is as follows:

| | | |
|---|---|---|
| Precipitation | 1,480 mm | 100% |
| Runoff | 660 mm | 45% |
| Evapotranspiration | 709 mm | 48% |
| Infiltration | 111 mm | 7% |

It must be emphasized that the foregoing figures are representative of long-term average conditions. When applied to individual years, and certainly when applied to shorter periods of duration, the equation may lead to unrealistic results. For example, if the high runoff year of 1985 were compared with rainfall at Ruhengeri, the water balance equation would indicate that runoff exceeds precipitation. This is apparently the result of assuming that rainfall at Ruhengeri is applicable for the entire basin. A review of the hydrologic yearbooks for Rwanda indicates many instances where high runoff values, sometimes exceeding 100 percent, are calculated. To minimize these errors, rainfall should be measured at several points in a basin and interpolation procedures used to provide a better estimate of total rainfall. For some basins, it may be necessary to increase the number of climatological stations.

The infiltration value of 7 percent is noteworthy, because observations indicate high infiltration rates within the Lava Zone. The relatively low value of 7 percent appears to substantiate the supposition that the Lava Zone infiltration eventually reappears as stream flow at lower elevations in the basin.

### 3.3 Lakes Bulera-Ruhondo

Stream flow, as measured at Rwaza for available data from 1973 to 1985 was 7.47 cu. m/s after subtracting inflow from the Rugezi River. Rainfall over the period was measured at Kinoni.

The water balance equation becomes as follows:

| | | |
|---|---|---|
| Precipitation | 1,131 mm | 100% |
| Runoff | 474 mm | 42% |
| Evapotranspiration | 788 mm | 70% |
| Infiltration | 131 mm | -12% |

An analysis of the water balance equation indicates that rainfall is negatively influenced by the lakes. Apparently, the lower altitudes and cooler day time air temperatures above the lakes tend to lower rainfall in the area, as compared with Ruhengeri. Evaporation losses are high, 70 percent, which again is a reflection of the lakes' influence.

The interesting part of the water balance equation is the negative value for infiltration. In this case, infiltration is represented by a change in storage of Lake Bulera. Runoff values have been augmented by drawing water out of storage from Lake Bulera. Since 1973, water levels in Lake Bulera have averaged 1.5 meters lower than in the previous years. Although no stage-volume relationships were available for this study, a drop of 1.5 meters over the 47 sq. km area of Lake Bulera closely approximates a volume corresponding to the 131 mm of infiltration calculated for the watershed. The problems associated with the drop in Lake Bulera levels are addressed in section 4.2 of this report.

### 3.4 Rugezi Marshland

Average stream flow at Rusomo was 1 33 cu. m/s for the 1973 to 1985 period. Rainfall was measured for the same period at Ruhunde. The water balance equation was calculated as follows:

| | | |
|---|---|---|
| Precipitation | 1,254 mm | 100% |
| Runoff | 233 mm | 18% |
| Evapotranspiration | 788 mm | 63% |
| Infiltration | 243 mm | 19% |

Runoff is low because of the low slopes within the marshland and the high evapotranspiration losses from phyreatophytes. Infiltration is relatively higher, which assumedly reflects the absorption into the peat formations. The Rugezi Marsh is, in effect, a perched lake with elevations above most of the surrounding valleys. Because the peat formations are permanently saturated it is logical to assume that losses occur outside of the basin, probably in the form of springs in surrounding basins and through known outlets such as the Fels diversion. The potential issues associated with development of the Rugezi marsh are addressed in section 4.1.

### 3.5 Cyohoha-Base Watershed

Because the Cyohoha-Base watershed is not a part of the Mukungwa Basin and since it represents a hydrologic regime of the Central Plateau, there has been no attempt to relate flow and rainfall measurements to the same time period as was used for the other systems. Rather, the entire period of stream flow record from 1966 to 1985 was used in the calculations. Stream flow was measured at Sud Rwerere and rainfall at the Nemba Station. The annual averages were 2.8 cu. m/s and 1552 mm, respectively. The water balance was calculated as follows:

| | | |
|---|---|---|
| Precipitation | 1,552 mm | 100% |
| Runoff | 507 mm | 33% |
| Evapotranspiration | 709 mm | 46% |
| Infiltration | 336 mm | 21% |

Rainfall is somewhat higher than in the other watersheds treated in this study. Runoff values of 33 percent appear typical of other Rwandan watersheds of comparable size. Evapotranspiration losses are similar to the Mukungwa watershed. Infiltration appears higher which allows replenishment of springs in the area.

It is noted that stream flow after 1972 has significantly decreased. It is unknown to the authors of this report if development of the tea plantations in the area or some other event has influenced stream flow. An explanation will require further investigation.

# Chapter 4

## PRELIMINARY ANALYSIS OF WATER RESOURCE ISSUES

Chapter four discusses water resource issues and presents recommendations regarding further interventions. It includes a discussion of the Rugenzi Marshland development, Lake Bulera Water levels, tungsten mining wastes, problems of erosion and sedimentation, and loss of montone forest infiltration.

### 4.1 Rugezi Marshland Development

The Rugezi Marsh represents one of the largest undeveloped areas in Rwanda outside the national park lands. The reason that it has been left largely unexploited is related to the nature and size of the marsh itself. The marsh, as described earlier in this report, is essentially a shallow lake covered with aquatic vegetation, which is rooted in a peat formation. The peat rests upon undulating rock formations which range from the surface of the marsh to a depth reaching 30 meters. Water flows from the surrounding hills bringing soil nutrients, which assists the productivity of the aquatic vegetation. There does not appear to be any one continuously defined channel through the marsh; rather water moves slowly as in a lake but restricted by the vegetation. Stream flow from the marsh bears the characteristic reddish color associated with iron concentrations.

The Rugezi Marsh appears to differ from smaller marshlands that have been successfully exploited in that smaller marshes tend to have one primary water course which can be structurally controlled. The Rugezi Marsh receives water rather equally in all directions from the surrounding hills. It has been reported (Reference 16) that control structures have been a problem in many marsh developments. This may be partially the result of placing heavy structures on soils which are incapable of supporting loads. For an area as large as the Rugezi, many control structures would be required to regulate water depths throughout the marsh, which would further require a rather sophisticated hydrologic operation plan.

A major attempt to develop the Rugezi Marsh was undertaken by a French firm (Reference 18) from 1971 to 1973 in an area known as Nyagafunzo. On the basis of available accounts, as no evaluation documents have been available for this study, it is understood that heavy equipment was introduced to construct channels and a small dam. The heavy equipment was found to be impractical, and manual labor was used to construct channels and a road across the marsh. Today, only faint outlines of the channels and the road exist. Small boats ferry passengers across the marsh. The dam was never built.

To lower water levels, a natural rock outlet of the marsh, known as the Fels outlet, was dynamited in 1972. Water levels fell too rapidly, however, thereby causing drying of the peat soils and consequently a small dam was constructed at the Fels outlet to control drainage. The project was ultimately abandoned, and no further attempts have been undertaken to develop the marsh except for small areas in some "estuaries."

In April 1985, Electrogaz (Rwandan utility responsible for hydropower operation) increased the height of the dam at the Fels outlet to reduce losses from the Rugezi system. This was reportedly done because of concern for falling water levels in Lake Bulera. A comparison of stream flows before the Fels outlet was opened in 1972, with stream flows occurring after 1972, however, shows no significant statistical change. In fact, based on available data, average annual stream flow has slightly increased from 1.26 cu. m/s (1957-1972) to 1.33 cu. m/s (1973 to 1985).

From a theoretical hydrological viewpoint, any large-scale development of the Rugezi Marsh would predictably cause -- increased total flow from the system, increased flood peaks, and increased sediment load at the Rugezi outlet. The actual magnitude of these increases can only be predicted based on actual development plans. It is clear that no development should take place without careful and detailed analysis.

It is recommended, should farming development be proposed, that it be initiated on one of the estuaries in a relatively limited scale. Only if that project proves successful over a significant period of time should it slowly be expanded. The Rugezi Marsh appears to be a fragile and complex environment which, in spite of the real need for increased food production, must be approached methodically and with caution.

## 4.2 Lake Bulera Water Levels

Since 1975, Lake Bulera has experienced lowering water levels through 1980. Since 1980, water levels have risen but have yet to reach previous levels. A hydropower installation at Ntaruka supplies a major portion of electricity for Rwanda and has necessarily reduced output in response to the lowered lake levels. Some electricity has been purchased from Zaire to make up the power deficit.

Figure 4-1, on the following page, provides a graphic representation of the various factors that affect water levels in Lake Bulera. Annual rainfall, as measured at Ruhengeri, was significantly above the long-term mean during the years of falling lake levels (1976 to 1980). Inflow to the lake from the Rugezi River has been fairly constant throughout the period, as was indicated in section 4.1.

Outflow, as measured at Rwaza from Lake Bulera-Ruhondo has increased. There are three gaps (1979, 1982 and 1983) in the record for which total flow is unknown. On the basis of the available record, however, stream flow increased significantly between 1975 through 1981. The last two years flows were below average, as was rainfall.

On the basis of information made available for this study, hydropower production, expressed in kwh, is also shown in Figure 4-1. According to the plotted figures, the highest power production corresponds to the years when the lake levels dropped. It appears that after 1981 power production was brought into phase with lake levels and both rose until 1985. Again, it would appear that power production of approximately 2,750,000 kwh/year corresponding to a flow of 7.8 cu. m/s at Rwaza are rough approximations of capacities required to maintain Lake Bulera at stable levels. This analysis neglects to

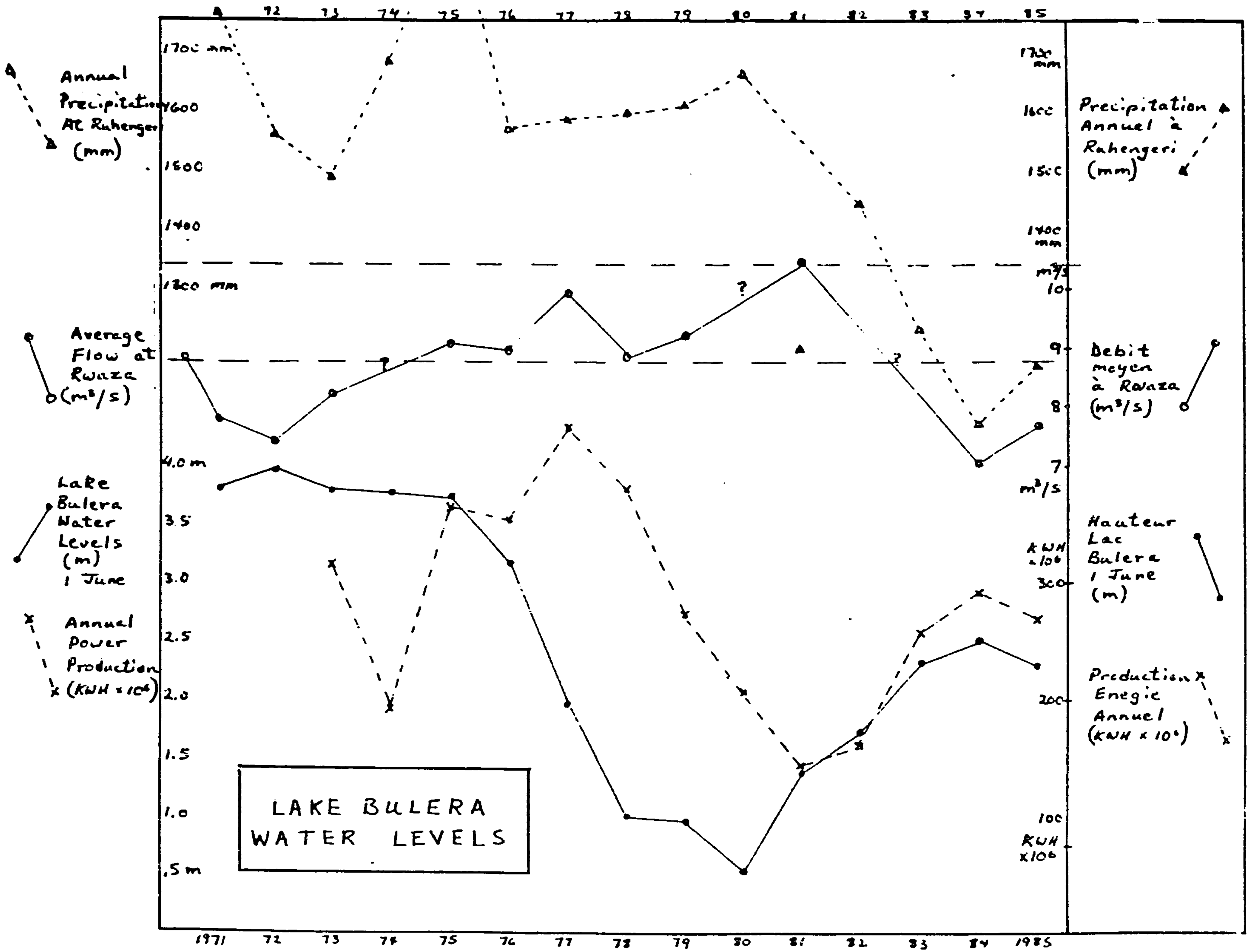


Figure 4-1. Lake Bulera Water Levels

evaluate the effect that Lake Ruhondo has on the flow at Rwaza. Since the completion of the hydropower station at Rwaza in 1982, stream flow has potentially been affected by operation of the dam. It is also possible that lake water is being lost through fissures in the lake bed but no real evidence exists to support this theory.

It must be emphasized that this study was based on incomplete data and that the results must be considered only preliminary. It is recommended that the operating utility, Electrogaz, review the analysis herein and provide a critique of the indicated conclusions.

### 4.3 Tungsten Mining Wastes

There is a major open pit tungsten mining operation at Gifurwe, located at the southern end of a valley, which drains into the southern arm of Lake Bulera. Since the mine was opened in 1947, large amounts of sediment from the mine have washed down the valley and into the lake. The sediment is dark gray, and the soil in the valley bottom has the same color, which is quite distinctive from the reddish soils of the hillsides. According to the Schiller report (Reference 13), the local farmers report that there is a decline in crop yields when the sediment bearing the mine tailings is deposited on the fields during floods. Because arsenic is often associated with ores of this type it was feared that the decline in crop yields might be caused by toxicity of the mine tailings. The decline in yields might also be due merely to the fact that the tailings are inert mineral matter without much nutrient value to plants.

To further investigate whether arsenic is present, five grab samples were taken. One of the samples was from the sediment at the mine, two were from the water in the stream where it is crossed by a bridge, and two were taken from the sediment in the stream at the bridge. The laboratory analyses of these samples (presented in Appendix D) revealed that there was an average of 131 parts per million (ppm) of arsenic in the stream sediment and 36 ppm in the sediment at the mine, but no arsenic in the stream water.

Arsenic is a heavy metal that can be toxic in acute doses. Unlike other heavy metals, however, the human body throws off arsenic and appears to be unaffected by chronic, low-level doses. Until penicillin was developed, arsenic was the drug most often used to treat syphilis, because it is toxic to the spirochete. It is probably still used in some medications. Medical studies in Taiwan in the early 1970s documented a relationship between skin cancer and arsenic in water, but the concentrations of arsenic in the water were probably quite high compared with the concentrations that appear to be occurring at Lake Bulera.

According to an expert on arsenic with the U.S. Department of Agriculture, background levels of 0.1 to 40 ppm of arsenic in soils are "normal," where there has been minimal usage of pesticides or other human activities. The levels are often higher if chemicals have been used. Concentrations of arsenic, as high as 100 ppm, usually have no effect on crops except for rice and some crops are tolerant of concentrations as high as 150 ppm. There is no documented case of a person having been acutely poisoned by arsenic which was bioaccumulated in a plant, probably because plants tend to die before they accumulate enough arsenic to be toxic to humans. Specific research has been conducted on the ability of maize and potatoes to accumulate arsenic, and both plants were found to die before significant levels of arsenic were found in their edible parts. Arsenic bound in the sediment from a mining operation does not necessarily pass into solution, and it is, therefore, not surprising that the laboratory analyses found no arsenic in the water. It is unclear why the concentration of arsenic is higher in the river sediment than in the mine tailings.

On the basis of available information, it seems unlikely that there is any danger to humans from eating crops grown in the soil that includes sediment from the tungsten mine. In addition, because there seems to be no arsenic in the water and since humans are unlikely to drink this water because of its black, muddy appearance, it seems equally unlikely that the water carries any health risk.

It is suggested that another set of similar samples be collected and analyzed to confirm that there is no arsenic in the water and that the concentration in the river sediment is higher than in the mine tailings.

## 4.4 Erosion and Sedimentation

The problems associated with farming steep slopes and the resulting soil erosion have been addressed by several authors. Studies undertaken by Patrick Wassmer, using a classic Wischmeier approach, have quantified soil loss under varying slopes and land treatments. As expected, the soil losses were high by world standards. Under the conditions of extremely intense land pressure, high rainfall, steep slopes, and falling food production, it is amazing that soil losses are not higher.

At the risk of being too optimistic, it can be stated that many farmers have instituted effective erosion control practices and these practices need to be extended to the majority of farmers who still have major erosion problems. Research is still needed, however, to determine which erosion control practices can maintain or increase crop productivity.

The key to erosion control research is to link the proposed practices to crop production and to farmer acceptability. Some erosion is inevitable and acceptable as long as crop production is unaffected. Quantification of this acceptable level should be the goal of future erosion research. Correspondingly, research should be continued as to the means and interest of farmers to undertake recommended control practices. The most effective erosion control practices will have little impact if they cost more than the farmer can afford or if the farmer does not believe in their utility. One practice that appears to be both effective and acceptable to farmers in many areas is the planting of Pennisetum sp. along field boundaries. This practice should be strongly encouraged as research continues on improving the plantings and on other alternatives.

Within Ruhengeri Prefecture, torrential stream flow in the Lava Zone has produced deep gullies in many areas. In consideration of the steep slopes and the easily erodable lava soils, elimination of erosion is infeasible. The only method to approach full control of the stream courses would be to construct drop structures from the base of the montane forest to the edge of the Lava

Zone. Such structures, made of concrete or rock and mortar, would be prohibitively expensive.

As an alternative, it is recommended that the stream courses be considered as factors which can be only partially controlled and necessarily allowed to exist. A significant part of the erosion loss can be reduced by prohibiting farmers from cultivating next to the channels, and by planting trees and grass along the banks as a buffer zone of at least 10 meters on each side. For locations where roads or buildings are threatened by the channel erosion, gabions can be installed to maintain the channel away from areas to be protected. Gabions are essentially wire baskets, which are filled with large stones. Their dimensions are normally 1 x 1 x 3 meters and they may be stacked or strung together to produce any size desired. It is a structure that is well suited for community work crews but requires someone with experience to site the gabions.

Outside of the easily erodable Lava Zone soils, stream bank erosion is nonetheless occurring in many areas. Again, it is often observed that cultivation takes place to the very edge of the stream bank with the result that during high flows the bank, left unprotected, slumps into the stream course. As described earlier, the solution is to encourage farmers to leave a buffer zone of trees and grass along stream courses. An excellent example of good conservation measures is found along the tea plantations of the Cyohoha-Base River along the southeast limits of Ruhengeri Prefecture. Stream banks are covered with grass and a road or path on each side of the stream provides a buffer zone between the stream and tea fields.

Apart from field erosion, which provides significant quantities of sediment found in streams, there are other practices which, in some areas, have been observed to contribute even larger quantities of sediment. Roads and mines provide sediment which is often dumped directly into stream courses. Streams in these areas often are lighter in color due to the dominance of minerals, as compared with the darker coloration of streams carrying soils with higher organic content. The sediments from areas dominated by roads or mines are coarser and heavier and tend to be deposited within a relatively short distance from their source areas. Locally this produces a change in gradient which may cause a realignment of the stream's course and result in flooding.

The recently completed national highway between Kigali and Ruhengeri offers both good and bad examples of erosion control measures. In many locations, road cuts have been revegetated with both trees and grass. In other areas particularly where mining of gravel or deep road cuts have occurred the surface is bare and erosion channels are developing. In still other areas lined conduits take rain water from the road surface and dump the water into gullies which erode into deep channels. Erosion and sedimentation from such areas is inevitable and vegetative controls are difficult to establish. It is recommended that, where possible, exposed areas continue to be returned to a vegetative cover to keep sedimentation to an acceptable minimum.

Secondary and tertiary roads throughout Ruhengeri Prefecture are also the source of erosion. The roads are usually locally maintained and occasionally major landslides can be observed because runoff water has been channeled from the roads on to fields below. The only solution that can be recommended, within the constraints imposed by land pressure and high costs of control structures, is to provide outlet channels that are evenly spaced so as not to concentrate large quantities of runoff and to allow a buffer zone of vegetation along these channels.

The problems associated with tungsten mining were addressed in Section 4.3, but gold mining is locally also a major source of erosion and sedimentation in the Buberuka Highlands (although there are few gold mines in Ruhengeri Province). The open surface placer mines are located directly in ravines draining the hills and in some locations run from the top of the hill to the valley below, a distance of several kilometers. The ravines are completely devoid of vegetation and soil cover and sediment transport is high. It appears that these mines produce a certain prosperity to the local community and, therefore, elimination of the mining is probably impractical. It can only be stated that these mines produce significant quantities of sediment and that the destructive effects of crop land losses from erosion and sedimentation must be weighed against the economic benefits of gold mining.

From the comments made in this section, it is clear that the recommendations are based on rather limited observations. No measurements of stream sediment transport are known to have been taken in Ruhengeri Prefecture. It is, therefore, recommended that a campaign be undertaken, through a complete hydrologic year, to measure sediment load at selected locations. The locations would be selected as representative of "normal" conditions as well as known problem areas. Such a study would provide a baseline condition from which future studies could compare the results of land use changes on sediment transport.

### 4.5 Loss of Montane Forest Infiltration

The Birunga National Park, along the northwest edge of Ruhengeri Prefecture, is a zone of natural montane forest. The forest contains several species of vegetation and wildlife, which are unique to East African montane systems and indeed to the world. In recent years, the park has received an increasing number of tourists which has become a significant source of revenue to Rwanda. At the same time, the park is under pressure from encroaching agricultural interests along its borders. Before 1958, the forest covered 339 square kilometers. Between 1958 and 1979, the forest was reduced 55 percent to an area of 151 square kilometers (Reference 16).

The reduction of forest land can be predicted to have several negative impacts on the hydrologic system. Because of the existence of five volcanoes within the park, slopes of 60 percent, and more, are common and the potential for runoff is enormous. Because of the extremely dense vegetative cover, however, runoff is largely reduced and subsurface flow increased. Following storms of intense duration, runoff from the park produces torrents of water which produce significant channeling in the Lava Zone agricultural lands. Further reduction of the forest will predictably lead to increased flooding, deepened channels, deposition of sediment on agricultural lands, and general loss of agricultural productivity. As stated earlier in this report, flows in the Mukungwa River have increased significantly during the past five years. The record is too short to state whether the reduction in forest cover is a possible cause of this occurrence, but the possibility exists and should be monitored in the future.

A gauging station placed at the foot of the montane forest several years ago on a tributary to the Susa River was later abandoned without any significant data. It is recommended that this gauging station be re-established in order to measure the actual contribution of the mountane forest to the hydrologic system.

# Chapter 5

## WATER SUPPLY ISSUES

This chapter presents an overview of what natural resource planners and managers need to know about several globally applicable domestic water supply issues and regarding locally feasible technologies. First, the quantity issues, quality issues, and institutional issues are discussed. Then there is a technical discussion of the potentially available sources of water and their applicability in Ruhengeri Prefecture.

The term "domestic water" will be used in this discussion to mean all of the water used for household purposes, including drinking, cooking, bathing, washing dishes, making beer, and watering livestock. The term "potable water" has been avoided, because it might be interpreted to imply a certain quality of water or water used only for internal consumption by humans.

### 5.1 Quantity Issues

A key question concerning water supply systems is "How much water is enough?" There is no definitive answer to this question, but there are some general guidelines. As a minimum, human beings require one to two liters of water per day to sustain life. It has often been observed that approximately 20 liters per capita per day (lpcd) are necessary to meet minimum requirements of hygiene; that is, beyond the amount of water that is drunk or eaten with food, additional water is needed for bathing and washing dishes and clothing if good health is to be maintained. It is recommended that, to the extent feasible, 20 lpcd be the minimum objective.

Some authorities believe that the health benefits increase with quantity up to the point that there is a tap in or at the house, which usually results in the usage of at least 50 lpcd. In highly developed countries with water piped to numerous fixtures within the house, usage usually is in the range of 300 to 400 lpcd. This level of usage includes water for washing machines, flush toilets, and other devices, many of which may be considered convenience uses rather than uses which directly contribute to health. Clearly, this level of usage is well above the minimum level needed to maintain a healthy existence.

If water is not piped to the house, but must instead be carried, the usage may be limited by how much the people are willing to carry rather than by how much water is available at the water point. The BCEOM socioeconomic study (Reference 2.a., pg. 13) reported that in a 1980 MINITRAPE study in Gisenyi Prefecture, it was found that people living next to a standpipe used 15 lpcd, but that the usage declined with the distance that the water was carried from the standpipe. Persons living 500 meters from a standpipe used only 8.5 lpcd, while persons living 1.5 kilometers from a standpipe used only 6.5 lpcd, which was considered to be an absolute minimum that people could get by with.

The RRAM socioecological study (Reference 3, pg. 106) found that in Rwanda the median daily water usage is 40 to 60 liters per family per day. This amounts to only about eight liters per person per day for an average family size of six persons. A recent institutional study by BCEOM (Reference 4, Annex C, pg.

5) estimated that the average usage in the Lava Zone is 8.0 lpcd during the wet season and 12.1 lpcd during the dry season. This consumption included the water used for washing clothes and for making beer. This level of usage is well below the minimum amount that is considered essential to meet minimum health requirements.

The basic design standard for persons carrying water from water points in the World Bank/BCEOM Lava Zone Project (Reference 2) is ten lpcd for 1985. Although as discussed above this number is at the low end of the acceptable scale, it seems to be widely used in projects in Rwanda. It may be a realistic number, because most people have to carry water significant distances and therefore may not use more than this amount even if it is available. The World Bank/BCEOM Lava Zone Project used a 1995 design allowance of 15 lpcd for people who carry water, which is closer to the recommended standard of 20 lpcd.

One further issue related to quantity in piped water systems is how to keep people from wasting water. It is often found that the taps are broken off or left open so that the water is discharged whether or not it is being used. This practice often results in there being no water available for users farther down the system. The hydraulic design of the system must be carefully considered to prevent some users from depriving others of water. To accomplish this objective, small pipe sizes or restrictor valves are furnished at the taps so that only a limited flow of water can be drawn even if the tap is left open. Reservoirs can also help ensure that water is available locally and can provide relatively large flows during short periods while being refilled by smaller, continuous flows.

The availability of an improved water supply, including the availability of larger quantities of water, may have far-reaching sociological effects. It is usually hoped that improving accessibility to water supplies will release time that had been spent carrying water for more productive activities. As discussed above, it is also expected that increasing the quantity of water used will result in improved health.

In addition to these positive effects, the availability of a better water supply may also have the negative effect of tending to increase population densities by causing people to settle near the supply. This phenomenon has been widely observed in the Sahel and was used as a tool in a German development project in the hills of northern Thailand. In the German project, a major objective was to improve the natural environment by convincing the farmers to practice stable agriculture and to stop cutting the forest. The provision of piped water supplies was specifically included in the program to make the villages more comfortable and thus more permanent so that the farmers would be less inclined to move the villages and practice slash-and-burn agriculture. Thus, in both the Sahel experience and the Thailand project design, there was a connection between the availability of a water supply and dwelling patterns.

## 5.2 Quality Issues

### 5.2.1 The Quality Objective

It is unrealistic to use the International Drinking Water Standards of the World Health organization, or similar national standards of highly developed countries, as an objective for drinking water quality in the rural areas of developing countries. The cost of providing water of such quality cannot be afforded, and the technology required to obtain such quality usually cannot be sustained with local skills. The objective in rural development situations should be to provide water of better quality than has been used in the past, even if the improved quality is less than ideal.

### 5.2.2 Quality Versus Quantity

Both the quality and quantity of the water supply can improve health. Infective diseases are often classified by the microbe causing them, but this does not help much in planning water supply systems. Feachem (Reference 5) provides the following breakdown of diseases, which is much more useful in evaluating the effects of a water supply system on the incidence of disease:

a. Waterborne

Waterborne diseases are passively carried by water. Fecal contamination of water is always involved. Examples include typhoid and cholera. To combat diseases of this type, the emphasis in a water supply program should be on improving water quality, especially where, as with typhoid, small doses are highly infective. On the basis of the information available, it does not appear that waterborne diseases are a major problem in Ruhengeri Prefecture. This situation may imply that the water sources used are relatively clean, or that feces are kept out of the general environment, but there may be other reasons as well.

b. Water-washed

These are diseases which often occur because people do not have adequate water to wash themselves properly, and perhaps ought to be more properly called water "not-washed" diseases. Examples include scabies, trachoma, and most diarrheal diseases. Although many diarrheal diseases are in this class, most of them can also be waterborne. The BCEOM socioeconomic study (Reference 2a, pg. 11) noted that in Rwanda diarrheal disease was the second leading cause of admissions to hospitals for children under the age of five (after measles). The breakdown of statistics by prefecture showed the rate in Ruhengeri Prefecture to be among the lowest in the country.

During a visit to the Mutobo Spring, it was noted that approximately 30 percent of the children who were standing around had a scalp disease. We were informed that the disease is called "ibihushi" in the Kinyarwanda language or "champignons des cheveux" in French, and that children commonly have it until they reach approximately 13 years of age. It is almost certainly ringworm of the scalp (Tinea Capitis). Skin diseases of this type are often greatly reduced if there is an adequate quantity of water available to permit frequent bathing. It is important to note that an improvement will be obtained in combating diseases of this type even if the water that is used for bathing is somewhat contaminated, that is, it is the quantity rather than the quality of the water that is important. It appears that water-washed diseases are relatively more important in Ruhengeri Prefecture than the other classes. This situation is understandable, considering the limited quantities of water used, and suggests that the water supply strategy should focus on increasing the availability of water and thus the quantity used rather than on quality.

c. Water-based Diseases

All of these diseases involve worms which become infective after passing through invertebrate water animals. Examples are guinea worm and schistosomiasis. A WASH Project evaluation of community water supply projects in Burundi noted that guinea worm (dracunculiasis) is unknown to occur in Burundi (Reference 6, pg. 35). No reports of guinea worm in Rwanda have been found in the literature reviewed. Schistosomiasis and its relationship to water supplies are discussed below.

d. Diseases of Water-related Insect Vectors

These diseases involve insect vectors which breed in or bite near water. Examples: biting near water -- Trypanosomiasis (sleeping sickness); breeding in water -- yellow fever, malaria, and dengue. Malaria is endemic in Rwanda and could be increased if water points develop into mudholes or cisterns which are uncovered serve as breeding grounds for mosquitoes.

e. Diseases of Defective Sanitation

These are infections primarily of defective sanitation. One such example is hookworm. All waterborne, some water-based, and a few water-washed diseases are affected by sanitation. It is probably impossible to get the full benefit of a water system without proper attention to sanitation as well.

### 5.2.3 Feasibility of Treatment

Water treatment in industrialized countries often consists of various combinations of chemical coagulation and flocculation, filtration, and disinfection. Such technologies are rarely sustainable in development situations. The use of chemicals or even of energy for pumping requires the recurrent input of cash to purchase the chemicals or power. The difficulty of obtaining cash in rural development settings is discussed below. Even if the cash to purchase outside items can be raised, there are rarely skilled technicians available to operate and maintain the water treatment systems.

The best that can usually be expected in development situations is to protect the source of water rather than to provide treatment. As discussed later in this chapter, the protection can take the form of capping and fencing springs or of providing shallow wells or infiltration galleries at surface water sources. These types of protective measures, once in place, continue to operate passively, with little need for operation or maintenance efforts.

### 5.2.4 Local Acceptance

It is important that the water supply which is developed by acceptable to the users. It has often been experienced that the local residents refused to use a new source that was provided, although it might be more convenient or more sanitary, because they found the water from their traditional source to be more palatable or otherwise acceptable. This situation often occurs where water from a new well contains iron or manganese and the users prefer the taste of water from their traditional sources, even though these sources may be highly polluted. A major difficulty often encountered in disinfecting water with various chlorine compounds is that most people who are unaccustomed to chlorinated water dislike the taste of it.

### 5.2.5 Bilharzia

Bilharzia, or schistosomiasis, was introduced into Lakes Bulera and Ruhondo in the late 1970s, apparently by infected Egyptian laborers who came to work on various projects in the area. This parasitic organism burrows into the urinary and intestinal tract of man, thereby resulting in debilitation and the loss of blood in the urine. A larval form of the organism is excreted and invades the bodies of freshwater snails. There the organism completes its development and releases cercariae, which, if they contact human beings, burrow through the skin and start the cycle again. The disease may be treated by chemotherapy. The drugs that were previously used often had unpleasant side effects, and it was sometimes difficult to persuade the patients to continue the course of treatment. Drugs that have recently become available have few side effects, but a protracted course of treatment is still required.

The schistosomiasis disease cycle may be broken in several ways. At one end of the spectrum, chemicals may be used to kill the freshwater snails so that the schistosomiasis organisms have no host in which to complete their life cycle. Application of chemicals to large bodies of water is obviously expensive, and it is difficult to reach all of the snails. Another means of breaking the disease cycle is to prevent urine and excreta from infected persons from reaching the water in which the snails live. Simple pit privies are effective in preventing the spread of schistosomiasis, because the organisms are filtered out by the soil. The use of latrines also has numerous other general benefits for environmental health.

Another approach to breaking the Bilharzia cycle is to keep people from coming in contact with the infected water. In areas where flood irrigation is practiced with infected water, farmers must go into the field and thus must contact the water. Lake water is used only to a limited extent for irrigation in Ruhengeri Prefecture; hence, this is not a major problem. Most of the exposure in Ruhengeri Prefecture is caused by people coming to the lakes to wash clothes or to obtain domestic water supplies. If adequate alternative supplies of water were provided so that the people did not have to use the lakes, the disease cycle would be broken.

Obviously, a danger exists that schistosomiasis will be spread if lake water is pumped through distribution systems. The danger could be reduced by locating the intake in deep water far from the edges of the lake where the snails tend to live. The cercariae that are discharged from the snails have a short life and must find and enter a human body within 12 to 24 hours after emerging or they die. Most of the cercariae therefore probably die off before they reach deep water.

The short life expectancy of the cercariae means that storage of the water for longer than approximately 24 hours will render it safe from spreading schistosomiasis. Storage will not, however, significantly reduce the levels of other pathogens. The lake waters are likely to be at least moderately contaminated with other pathogenic organisms and it is not recommended that lake water be pumped directly to distribution systems. As discussed below, it should usually be technically feasible to construct shallow wells in the alluvium at the edge of the lake so that schistosomiasis, as well as other pathogenic organisms, are filtered out.

#### 5.2.6 Latrines and Other Environmental Health Factors

As mentioned above, the use of simple pit latrines could break the schistosomiasis cycle. In addition, removing fecal material from the environment will greatly diminish the incidence of many other diseases as well. The construction and use of latrines should, therefore, be encouraged and in fact are actively encouraged by the Rwandan Government. Each family is required to have a latrine and is subject to a fine if it does not.

To further encourage latrines, it is suggested that domestic water supply programs be linked to the construction and use of latrines. This might be accomplished by allowing only those families who have latrines to use the water system or by charging a higher rate to those users who do not have latrines. Consideration could also be given to locating the standpipes only near those families, or groups of families, that have latrines.

It should be noted that water systems also may have negative environmental impacts. Unless standpipe installations are properly constructed, they can develop into mudholes which breed mosquitoes and bring humans into contact with animal excreta. It is desirable that all standpipes, or other water points, be well drained and that they have laundry and livestock watering facilities (see Section 5.4 below.)

### 5.3 The Institutional Capabilities Issue - Sustainability

#### 5.3.1 Types of Systems

Technologies do not exist in a vacuum. They are embedded in a matrix of social, economic, cultural, institutional, and other features. Creating a water supply system is futile unless the system will be sustained in operation over the years. To be sustained, there must be an institution that is willing and able to operate and maintain the water system. This can be as simple as a family caring for its own rainwater catchment system or as complex as a major public works department, mechanized equipment, and regular government budgets.

Water supply systems may be categorized by the type of institution that is needed to support them into "large/complex" systems and "small/simple" systems. The distinguishing characteristic of large/complex systems is not so much their size as the type and complexity of the inputs that are needed to keep them in operation. Any system that requires the input of materials or technical skills from outside the country is certainly in the large/complex category. Any system that requires the input of materials or technical skills from outside the user group is probably in the large/complex category.

### 5.3.2 The Effect of Cash Inputs

A major determinant of whether a system falls in the large, complex category is whether it requires the input of significant amounts of cash, especially if the inputs are required on a regular, recurrent basis. Most rural populations in developing countries operate only partially on a cash economy. Their total incomes may be substantial, taking into consideration all of the goods and services that they receive, but the portion of this income that is received in cash is almost always small. What little cash that is received is carefully hoarded for the purchase of special items, usually from outside the local community, that are unavailable in return for labor or by barter. The local population may be willing to donate significant amounts of labor and locally available materials, but they are unlikely to be forthcoming with significant amounts of cash, especially on a recurring basis.

Because cash is so highly prized, it is extremely difficult to convince the local population to pay cash money for a water supply if they have other alternatives for obtaining water without using cash. These alternatives may involve large amounts of labor and time (usually carrying water from a distant source) and may result in water of poorer quality. The farmer may nevertheless be willing to invest the labor and time and accept the poorer water quality to avoid spending cash. This situation may be especially true where it is the men who make the decisions about whether to spend cash, but it is the women and children who must carry the water. It has often been observed that requiring cash payment from the poorest users of a community water system results in those users resorting to traditional water sources and thus the loss of the health benefit that the system was intended to provide.

Any sort of pumped water supply system will require cash for the energy cost (electricity or fuel) and will, therefore, be in the large/complex category. It might be argued that the government should provide electricity free to such a system. If there were a surplus of hydroelectric power generation capacity available in Rwanda, the shadow price of producing extra electricity for such activities as pumping at public water supplies probably would be quite low. Rwanda does not, however, produce all of the power it needs, but buys power from Zaire. Power supplied by the government, therefore, has a real price, and the government has not expressed a willingness to make this contribution to rural water supply systems.

In summary, although the local population has some amount of cash, either a regular or significant cash input to the water supply system should be regarded as being virtually the same as an input from outside the user group. Any water system in rural Rwanda which requires the recurrent input of significant amounts of cash probably has a low probability of being sustained.

### 5.3.3 Tariffs

The Ministry of Public Works and Energy (MINITRAPE) has previously suggested that the tariff per family annually be 100 FRW for simple gravity piped water systems and 50 FRW for improved springs although consideration is now being given to a variable rate structure based on actual costs. These rates are widely used, but it is unclear whether they are in fact adequate to provide sufficient maintenance to sustain these systems over the long term. The experience of the Dutch volunteers (SNV) and Club 2/3 has been that it is extremely difficult to collect even these low tariffs. Typically, only approximately 60 percent of the families will pay their shares.

Another significant problem is accounting for the funds. The persons who collect the tariffs may not turn all of the money in to the water committee, and the water committee may not deposit all of the money in a bank account.

It is somewhat easier to collect a special one-time assessment when the water system has broken down and the use to which the money will be put and the benefits to the user are quite clear and immediate. The problem with as-needed collections is that the farmers usually have cash only at certain times of the year, and they may not have any cash at the time that the water system needs maintenance. In addition, they may be unable to raise a large amount of money if a major repair is required. These experiences suggest that the smaller and simpler the water system, the higher the probability that it will be kept in service.

### 5.3.4 Community Development

Large, complex water systems are almost always planned from the top down because the technologies that are employed are understood only by highly trained and technically skilled professionals and because the large amounts of money that are required can only be arranged by senior levels of the government. Such "top-down" planning usually occurs with only minimal inputs from the user populations and thus the users do not develop any sense of responsibility for the water system. In such cases, it is common to hear the users refer to the system as the government's system, and there is often an expectation that if the system needs maintenance that is is the responsibility of the government to provide it.

By contrast, small/simple systems are frequently planned from the bottom up, that is, the potential users are asked to make many of the decisions about the form that the system should take. It is also customary that the users provide most of the labor and local materials that are required to construct the system and to organize among themselves an institution for providing continuing operation and maintenance of the system. To organize a project in this fashion, a different type of planning and management input is required. Instead of senior government officials and highly trained professionals, local officials, community leaders, and community development personnel are required. The process tends to be slow. Usually, a requirement exists for much discussion with the user population before consensus and agreement are reached. The benefits of this approach are considerable, however. Usually the outside cost of such systems is much lower because most of the labor and locally available materials are provided "free" by the community. More importantly, the community develops both the technical skills and the sense of responsibility to allow the system to be maintained in the future without outside assistance.

### 5.3.5 Government Policy

In Rwanda, the central government has delegated the responsibility for rural water supplies to the communes. A law has been drafted encouraging the formation of local Water Users Associations. Although the law is still in draft form, it is in effect for all practical purposes and the rural populations are being urged to build and maintain their own water supply systems. It is expected that the law will be formally adopted at some point in the future if the self-help program which it encourages produces positive results.

The approach being taken by the central government is refreshingly candid and has many positive aspects. By frankly announcing that the central government will not have resources available in the near term future to help with rural water supplies, the local populations are set free to fend for themselves. In many developing countries, efforts to organize local self-help water supply projects are hampered, because some government agency has been given the responsibility for these supplies but not the resources to provide them. Under these circumstances, either the people refuse to organize their own water system in the expectation that the government agency will build one for them, or the agency forbids the community to do what it considers to be the agency's task.

### 5.3.6 Existing Government Institutions

The National Water Authority (Direction Générale d'Eau-DGE) was formed in February 1984 in MINITRAPE to be the organization with overall responsibility for water matters in Rwanda. According to information developed by the World Bank (Reference 10), the DGE has a staff of 40 in late 1985, of whom 21 were statute employees while 19 were under contract. The World Bank recommends that the DGE have broad responsibilities for: coordinating the water activities of other government agencies; inspecting and maintaining rural water supplies; overseeing project management of urban water supplies; assuming responsibility for urban sewerage systems; planning; and developing standard plans for water facilities. The World Bank plans to include assistance to the DGE in the Second Water Project, including the assignment of two German water experts for a two-year period, to help the DGE develop the recommended capabilities. Nevertheless, two requests by the DGE for expanded budgets and staffs have been refused by the Ministry of Finance, and it will probably take several years to develop the institutional capability of this relatively new organization. Although the responsibilities that the World Bank envisions for the DGE includes inspection and maintenance of rural supplies, this is not yet accepted policy of the Rwandan Government, and it is unlikely that support will be available in rural areas from DGE in the near to mid-term future.

Electrogaz is responsible for water supplies in major towns. It operates like a traditional utility. Supplies are metered to individual services, and users are billed. The system appears to work reasonably well in urban areas, in part because the user populations in the towns operate on a cash economy and are accustomed to making regular payments for such services.

For Electrogaz to be effective on rural water supplies where users are unaccustomed to paying cash for water service and where most water is dispensed to multiple users on unmetered standpipes, will require a considerably different operating mentality and probably alternative administrative and organizational arrangements. It is doubtful that Electrogas can incorporate such a drastically different role into its organization without severe difficulties. As an example, Electrogaz took over the operation of the Icyanya Global rural water delivery system when AIDR withdrew. Electrogaz is said to be having great difficulty collecting the 100 FRW annual fee from the users of the system and that the World Bank has been critical of Electrogaz for subsidizing this rural system with revenues from its urban systems although these systems are already operating at a deficit.

Electrogaz was the executing agency on the World Bank First Water Project and may become the operating agency for the Lava Zone system, although the BCEOM-SAUR institutional study (Reference 4) does not resolve this issue. It appears that the institutional arrangements for the operation of the Lava Zone system are still under discussion.

### 5.3.7 Institutional Summary

The official policy of the Government of Rwanda is that rural water supplies should be built and maintained at the communal level. Because the communes and local rural populations in Rwanda have limited financial and technical resources, the institutions that can be arranged to manage rural water supply systems will be capable of dealing only with small/simple systems. Large, complex systems cannot be supported and thus are inappropriate for rural populations, because of the lack of the necessary institutions to manage them, not to mention other restraints.

When selecting the type of water system to be implemented, consideration must be given to the institutional arrangements that will support the water system. The probability that the water system will be sustained over the long-term is usually dependent on the viability of the institutional arrangements more than any other single factor.

## 5.4 Springs

Sections 5.4 through 5.8 below provide a brief technical overview of the applicability of various water supply sources that might be used in Ruhengeri Prefecture. Terminology commonly used in Rwanda for describing various types of small water systems is presented in Table 5-1 on the following page. Springs are defined as places at which groundwater flows out of the ground and on to the surface. Springs may be used in their natural condition (source naturelle) or they may be improved (source aménagée) so that the water can be more easily captured and so that they remain cleaner and more sanitary.

When springs occur on hillsides, it is often possible to develop them so that the water discharges out of a pipe. The water from the pipe may be used to

Table 5-1

Terminology for Small Water Systems

| Local Term | Usual English Meaning |
|---|---|
| Source | Spring. |
| Source naturelle | A natural or unimproved spring. |
| Source aménagée | An improved spring, usually one that has been capped and provided with at least a spout and perhaps a faucet. For a spring that feeds a piping system, see "adduction." |
| Petite source | Spring. Might refer to natural and/or improved springs. |
| Adduction | A piped water system. These are usually supplied from springs and flow by gravity but could be pumped systems. |
| Tuyau refoulement | A pressure pipe on the discharge of a pump, as opposed to a gravity flow pipe. |
| Borne fontaine | A spigot supplied by a piped system. These are called "standpipes" in this report. The local construction practice in Rwanda is to build a more or less elaborate masonry structure around a borne fontaine. |
| Robinet | A spigot or tap. Usually synonymous with borne fontaine. |
| Point d'eau | Usually refers to a standpipe, but sometimes includes improved springs and, on rare occasions, natural springs. |

fill water containers at the site (source aménagée) or may be led away to distant points in a piping system (adduction). Springs may also bubble up in relatively flat ground. Marshy areas often are caused by such springs. If this type of spring occurs in a relatively small area, it may be possible to isolate it by placing a barrel around it. This approach may raise the water level sufficiently to allow the water to flow out of a spout, thereby allowing clean water to be captured.

In most cases, pathogens move only short distances through fine, granular soils, and springs will give water of a high sanitary quality, if they are not contaminated at the point where the water emerges. The opinion has been heard several times that spring water in Ruhengeri Prefecture is of poor sanitary quality, because the water flows through open passageways in the lava and thus is not filtered through fine grained soil. If, in fact, the spring water is flowing through open passages in the lava, it will not be filtered effectively and may, in fact, be bacteriologically contaminated. The belief that spring water is contaminated seems to extend to areas outside the Lava Zone where there are unlikely to be open subterranean passageways.

Few data on the bacteriological quality of spring water have been found. In the BCEOM design work, 24 samples of various waters from the Lava Zone were subjected to physical and chemical analyses. The results of these analyses are presented in Annex No. LAV-2 of Reference 2.b. All of the physical and chemical qualities of the waters tested were found to meet the World Health Organization Drinking Water Standards.

The BCEOM study (Reference 2.b., pp. 217-219) notes that bacteriological samples from five points were analyzed, but does not state the results. The text of the report notes that there is a serious risk of bacteriological contamination whether lava is permeable, but that in other geological areas the ground water is not vulnerable to contamination if the springs are well constructed. On page 247, the BCEOM report referenced above notes that neither the Mutobo nor the Rubindi spring is well protected. During a visit to the Mutobo Spring, it was noted that a length of the pipe from one of the three capped springs has been removed, and that the water that is being collected flows through an open ditch in an area that is heavily used by animals and humans. It is unknown whether whatever bacteriological contamination was found in the BCEOM work is an inherent characteristic of the groundwater or was introduced where the spring emerged from the ground or at some point like the ditch described above. Some water quality data on spring water collected by the Farming Systems Improvement Project are discussed in section 6.4.

To ensure the purity of the spring water, the area immediately above the spring should be kept clean and free of animals, preferably by fencing the area. A ditch should be provided to intercept surface runoff and carry it around the spring. A splash pad and drainage should be provided so that the area where the spring discharges does not become a mud hole. It is also desirable to provide a laundry pad so that clothes can be washed without having to carry water to the house. If cattle are watered at the spring, or are likely to be loose in the vicinity of the spring, it is desirable that a watering trough be provided somewhat downhill from the spring to keep the livestock out of the immediate vicinity where drinking water is drawn.

The per capita cost of piped systems supplied from springs varies widely but may average approximately 3,000 FRW per person (see section 6.11). Assuming a cost of 35,000 FRW for a capped spring without a piping system and usage by 300 people (50 families), the per capita cost of improved springs is approximately 120 FRW per person, or approximately $2 (U.S.). (An exchange rate of $1 U.S. = 80 FRW has been used in this report). Whenever available, springs are probably the first choice for rural water supplies in Ruhengeri Prefecture. They generally give relatively good quality water, are often the closest source to the users, are easy and relatively inexpensive to develop with local skills and resources, and often can feed piped water delivery systems. They are the most widely used existing water source, the best understood by the users, and the most sustainable.

## 5.5 Wells

Wells may be either drilled or dug. Drilled wells may reach great depths but require complex machinery and, because of a lack of drilling rigs in Rwanda, are expensive, costing perhaps $75,000 U.S. for a well 200 meters deep. Because the location of the groundwater table and the geological conditions in Ruhengeri Prefecture, especially in the Lava Zone, are not well known, drilling wells runs the risk that there will be many dry holes. Because drilled wells have relatively small diameters, pumps are required. Supplies of these pumps and service for them are unlikely to be readily available in rural areas of Rwanda at prices that rural populations find affordable. This technology does not appear to be applicable under the local circumstances.

Dug wells might be constructed near the lakes or the few perennial streams in the Prefecture. Water drawn from these wells would be filtered by passing through the natural soils and would thus be of better sanitary quality than water taken directly from the lakes or rivers. Dug wells will not, however, improve either the accessibility or quantity of water that is available.

Shallow wells near the edges of the lakes would allow people to draw water without having to contact the lake water and thus expose themselves to schistosomiasis. Even if shallow wells are available, however, people are likely to want to enter the lake to bathe, and thus the wells may not significantly reduce the exposure.

The yield that is available from a dug well may be increased by extending well screens (perforated pipes) out from the well. Such arrangements become similar to the infiltration galleries described in section 5.7 below. If a decision is reached to pump water from the lakes and distribute it to the nearby countryside, it is recommended that the intake for the system be a shallow well located as far back from the edge of the lake as is practicable. Filtration of the lake water through the natural alluvial soils should remove all schistosomiasis organisms and most other pathogens. The water surface in shallow wells located near a lake or a river will probably be sufficiently close to the surface that any type of locally available pump may be used.

The biggest threat to the quality of water available from wells is from flooding or from contaminated water leaking back down the well casing. Wells should, therefore, like springs, be protected from surface runoff, and the areas around them should be well drained.

While wells may be technically feasible in some parts of Ruhengeri Prefecture, the cost and uncertainty of deep wells, and the fact that dug wells do little to improve quantity or access to water, make this technology generally unattractive. The only application of wells which appears to have the possibility of being attractive is dug wells near the lakes. Such wells would allow people to obtain water without exposing themselves to the schistosomiasis-infected lake water. If lake water is to be distributed by pumping, it is strongly recommended that the intake be from a shallow well rather than from the lake itself.

## 5.6 Rainwater Catchment

### 5.6.1 Required System Size

Rainwater catchment from the roofs of individual houses appears to be a technically feasible water supply technology in Ruhengeri Prefecture. The socioecological study (Reference 3, pg. 10) found that 56.0 percent of the houses in the Lava Zone had corrugated metal or tile roofs, and that overall for all four areas studied 72.5 percent had tile or corrugated metal roofs.

Corrugated metal is sold in sheets approximately 0.67m x 1.4m, which cover approximately 0.65 square meters when lapped. Approximately 56 sheets are required for the typical house. The cost of the roofing varies with the gage (weight) but is typically about 500 FRW per piece. The cost of materials for a metal roof is, therefore, approximately 28,000 FRW.

From discussions with various Rwandans, it appears that the local residents find that thatch roofs harbor insects and small rodents and that thatch roofs are being replaced as rapidly as the population can afford other materials. It is, in fact, becoming difficult to find traditional houses in many parts of the prefecture. Rainwater also may be captured from thatch roofs, but because the drip line is irregular, larger gutters are required and some of the water will be lost.

An average house with a roof sloping in two directions has a total area of approximately 36 square meters, or 6 square meters per person for a family of six persons. To provide ten lpcd of water for one month (30 days), the required amount of rainfall can be calculated as follows:

(10 lpcd x 30 days)/(1000 liters/cubic meter) = 0.3 cu. meters.

0.3 cu. meters/6 sq. meters of roof = .05 meters = 50 mm.

Monthly rainfall data for Kinigi and Ruhengeri Town are presented in Table 5-2 on the following page. As indicated, there is at least 50 mm of rainfall in nearly all of the months except July. Thus, with only minimal storage a rainwater catchment system from the roof of an individual house would provide the usual Rwandan design standard of ten lpcd. During most months, the rainfall exceeds 100 mm and over 20 lpcd could be provided, which is more than the amount that is to be supplied by the World Bank system.

To provide ten lpcd during the dry month of July, storage would be needed. Assuming that there is 20 mm of rainfall in July, storage would have to

Table 5-2

Monthly Rainfall

(mm)

| Month | Kinigi | Ruhengeri |
|---|---|---|
| January | 107 | 77 |
| February | 139 | 104 |
| March | 186 | 148 |
| April | 250 | 244 |
| May | 194 | 150 |
| June | 62 | 52 |
| July | 26 | 20 |
| August | 60 | 47 |
| September | 111 | 111 |
| October | 142 | 151 |
| November | 166 | 141 |
| December | 134 | 107 |
| Total | 1,577 | 1,352 |

Source: Atlas du Rwanda (Reference 7). The monthly rainfall figures were scaled from the bar charts on Planche VIII.

provide the equivalent of the additional 30 mm to make up the total of 50 mm. This amounts to:

30mm x 6 sq. m. of roof = 0.18 cu. m/person
or approximately one cubic meter for a family of six

Because not all of the rainwater will be captured and because some years have less rain than average, it is desirable to provide somewhat more storage than the minimum amount. A desirable objective might be two cubic meters of storage, but the amount of storage provided must be tempered by the cost of providing this storage.

### 5.6.2 Past Experience and System Costs

Between 1978 and 1985, a program to introduce individual rainwater catchment systems was undertaken with UNICEF funding by the Nutritional Training Center of Ruhengeri (Centre de Formation en Nutrition de Ruhengeri (CFNR)). As shown in Table 5-3, several hundred cisterns were built, but these were heavily subsidized. The size of the cisterns ranged from 600 to 3,000 liters, but most held 1,200 liters. On the basis of experience, it appears that the rainwater catchment technology is well understood and accepted by the local population, but that the systems are too costly for the average family.

Only two major components to a rainwater catchment system exist: the collection system and the storage system. The collection system consists of simple gutters and a downspout of some sort to deliver the rainwater to storage. The cost of these components in Ruhengeri Prefecture is probably about 2,000 FRW. The cost of the cisterns is, however, quite high. The costs during the early part of the CFNR program using bamboo-reinforced concrete cisterns were approximately 30,000 FRW, but by the end of the program, the costs had come down to 17,000 FRW. On the basis of experience in Burundi, it appears that the costs could be reduced to the approximately 13,000 FRW. The total system cost for the collection system and the cisterns would thus be approximately 15,000 FRW, or approximately 2,500 FRW each for a family of six. This per-person cost is comparable to the costs that have been experienced with piped supplies from springs (see section 6.11.) This amount is a significant part of the estimated average annual income in Rwanda ($260 U.S. or 21,000 FRW according to World Bank, 1984) and is thus still unaffordable by all but the most affluent.

This technology might be widely adopted if the cost of the cisterns could be reduced to perhaps a quarter of the current costs, say a few thousand Rwandan francs. This reduction might be possible if the Mironko plastics factory in Kigali can make large (say 100 liter) containers at a reasonable price or if cisterns can be made by forming a basin with dry masonry or masonry using mud mortar and then making the basin waterproof by draping a sheet of plastic into it. It might also be possible to make cisterns of reasonable size by draping plastic inside of a suitable basket. Basket making is a highly developed art in Rwanda, but it has not been demonstrated whether the baskets are strong enough to hold significant quantities of water.

Nevertheless, even persons who have only minimal storage could significantly reduce the amount of time spent walking for water, because there are so many days with rainfall annually. The storage could take the simple form of some

TABLE 5-3

CISTERNS BUILT IN RUHENGERI PREFECTURE
UNDER THE CFNR/UNICEF PROGRAM

| Commune | Number of Cisterns |
|---|---|
| Butaro | 1 |
| Cyabingo | 7 |
| Cyeru | 0 |
| Gatonde | 1 |
| Kidaho | 108 |
| Kigombe | 72 |
| Kinigi | 38 |
| Mukingo | 14 |
| Ndusu | 1 |
| Nkuli | 4 |
| Nkumba | 19 |
| Nyakinama | 18 |
| Nyamugali | 0 |
| Nyamutera | 0 |
| Nyarutovu | 2 |
| Ruhondo | 9 |
| Total | 294 |

extra 20 liter jerry cans, although the price of these (300 FRW) is significant to poor families. An advantage of having numerous smaller storage containers is that they would be emptied more frequently and thus would be less likely to become stagnant or to breed insects. The cash operating and maintenance costs of such systems are probably low.

### 5.6.3 Quality Considerations

While rainwater is quite pure, it is likely to pick up some dust and leaf debris from the roof, especially if it has not rained for a long time. Bird droppings might on rare occasions contain organisms that are pathogenic to humans, and human and animal excreta that are left to dry in the fields might be carried by wind to the roof top. Nevertheless, contamination picked up by the rainwater on the roof is unlikely to be of much sanitary significance. The dust and debris are, however, objectionable from an aesthetic point of view. The cleanliness of the rainwater can be improved by letting the collected water run to waste for the first few minutes of a rainstorm to clean the roof and collection system.

A more serious threat is that the water will be contaminated or will become a breeding place for insects while stored. Contamination is especially likely if the cistern is underground so that if there are leaks groundwater can come from the outside in. Water must be dipped out of an underground cistern and the dipping bucket may carry much contamination into the cistern, especially if it is set on the ground while the cover is being removed. An above-ground cistern will not be subject to inward leakage and can have a gravity tap for drawing water.

The top of a cistern should be covered to prevent the entry of debris and of insects. A danger exists that mosquitoes will breed in the cisterns and that this may increase the incidence of malaria. The collected rainwater can discharge into the cistern through apiece of plastic insect screen which will catch any large debris from the roof and will prevent the entry (or escape) of any insects.

### 5.6.4 Summary of Rainwater Catchment

Rainwater catchment is a promising technology for those who can afford the storage cisterns, but with the present designs, this will be only the wealthiest portion of the population. In the Lava Zone, rainwater catchment appears to be the only technological alternative to the proposed World Bank piped distribution system from the Mutobo Spring.

Because roof-top rainwater catchment systems appear to be acceptable to and understandable by most of the population, and because they appear to offer the opportunity to greatly reduce the amount of time spent carrying water during most of the year, any contribution that the RRAM Project can make by an intervention that popularizes this technology may be worthwhile.

## 5.7 Rivers

Rivers and all surface waters are invariably contaminated, at least to a moderate extent. To the extent that the distribution of excreta in the environment is controlled by the use of latrines, surface water sources will be less contaminated, but they are unlikely ever to contain water of a high sanitary quality if there is significant human activity in the watershed.

Rivers are not a promising potential source of water in Ruhengeri Prefecture. In the Lava Zone, the riverbeds contain water only for brief periods following heavy rains. In other areas, the rivers may be perennial, but they are in the bottoms of the valleys while many of the people live high on the hills.

There have been some discussions of distributing river water by pumping. This action may be rather difficult to accomplish and is not recommended. In addition to the problems of contamination of surface water and providing power or fuel for the pump, and cash to pay for this energy, it is likely to be quite difficult to provide a suitable intake, except perhaps in the largest rivers. The small rivers and streams rise rapidly following rains and transport large volumes of silt and debris. These conditions tend to wash the intakes out during the peak flows and/or to clog them as the flow recedes. In addition, any system for pumping river water will definitely be in the large/complex category described in section 5.3 above, because it will require cash for the pumping energy.

If a decision is made to distribute water from a river, consideration should be given to taking the water from an infiltration gallery. The infiltration gallery would consist of one or more perforated pipes laid in the riverbed or in the soil alongside the river so that the water is filtered through the natural soil. This is in essence a shallow or dug well. Care will have to be taken to locate the infiltration gallery so that it is not washed out during high river flows. Wherever possible, springs should be used as sources of domestic water in preference to rivers.

## 5.8 Lakes

As with rivers, lakes are likely to be contaminated. Water of somewhat better quality may usually be obtained if water can be drawn from far offshore through an intake pipe, but even the offshore water is likely to contain significant quantities of pathogens. Offshore water does, however, pose less of a threat of spreading schistosomiasis, because the schistosomiasis organisms are associated with snails that live near the shore. If lake water is to be used, it is recommended that it be drawn through shallow wells or infiltration galleries as described above so that the water receives filtration through the natural soils.

# Chapter 6

## POTABLE WATER INVENTORY

This sixth chapter presents an inventory of all of the known sources of domestic water existing in Ruhengeri Prefecture. The information is discussed and tabulated according to the source from which the information was obtained. All of the known systems were marked on a 1:100,000 map as accurately as was possible from the information obtained. The map was left with the RRAM Project for drafting and inclusion in its natural resources inventory report.

### 6.1 Piped Water Systems Map

Piped water systems in Ruhengeri Province have been mapped by BCEOM and included in a 1985 report. The water systems shown include the existing Mutobo Spring and Mutera Spring systems and the four systems installed by the SNV. (See 6.2 below).

Data on the systems on the BCEOM map are tabulated in Table 6-1, which follows. In some cases, information on some of these systems was found in other lists and has been added to Table 6-1. The systems sponsored by the SNV are presented in Table 6-2.

### 6.2 The SNV (Dutch) System

The SNV is a Dutch volunteer organization, somewhat similar to the American Peace Corps. Until recently, it was called OVN (Organisation des Voluntaires Néerlandais).

The SNV has assisted local citizens in constructing four water systems in Ruhengeri Prefecture. These are tabulated in Table 6-2 and are included in the systems marked on the map. Three of the systems are in Nyarutovu and Nyamugali Communes on the southern edge of the prefecture and are rather small. The fourth system is a major system with 21 kilometers of pipe serving much of the Ruhondo Commune.

Although the SNV has a community development specialist, Ms. Wil van Dyk, living in Ruhengeri Town near the PNAP office, it does not have any additional water systems under planning or construction in Ruhengeri Prefecture at this time. The SNV is working actively in Gisenyi Prefecture to the west, including a program that involves the construction of rainwater catchments from roofs of houses.

### 6.3 The Club 2/3 (Coforwa) Systems

The Club 2/3 is a Canadian private volunteer organization which emphasizes education about the environment in high schools in Canada and sponsors aid programs abroad. Under the Hydraulique Rural de Ruhengeri Project, Club 2/3 in association with Coforwa has been assisting local residents in organizing and constructing piped gravity water supply systems in Nyamutera and Nyakinama

Table 6-1

Piped Water Systems on the Existing Map

| Commune | Secteur(s) | Name of System | Built by | Number of Standpipes | Yield lps |
|---|---|---|---|---|---|
| Butaro | Musama<br>Kayange | Runaba | | | |
| Butaro | Burkaragata | Rusasa | | | |
| Cyeru | Ruhanga<br>Gacundura<br>Butare<br>Ndago | Buberuka | | | |
| Ruhondo | Rwaza | Rwaza | | | 1.73 |
| Nyarutovu | Gitovu<br>Gakenke | Nemba | | 3 | |
| Ndusu | Janja | Janja-Paroisse | | 5 | |
| Ndusu | Muso<br>Janja | Janja-Kinoko | | 7 | |
| Ndusu | Rusoro | Rusoro | | 2 | |
| Ndusu | Kiringa<br>Mugunga | Ndusu | | 5 | |
| Gatonde | Busengo | Busengo | | 6 | |
| Gatonde | Kivune<br>Gakenke<br>Nyakagezi<br>Rusasa | Gatonde | Coforwa | 7 | |
| Gatonde | Gakenke | Gatonde (AIDR) | AIDR | 1 | |
| Nyamutera | Tubungo | Nyamutera | | 1 | |
| Kigombe | kabaya | Kigombe | | 4 | |
| Nyakinama | Kanza | | | | |
| Nyakinama | Kabere II<br>Rugarika<br>Muko | UNR Nyakinama | | 4 | 1.20 |
| Nkuli | Jenda<br>Mukamira | Jenda | | | 4.20 |
| Nkuli | Karera | Nkuli | Ctr. de Sante | 2 | .17 |
| Kinigi | Bisate<br>Nyaruguna | Bisate | | 2 | |
| Kinigi | Bisate | Susa-Bisate | AIDR, 1970 | 2 | .50 |
| Kigombe | Muzanze | Ext. Muzanze | | 4 | |
| Kinigi | Kabwende | Ryango | AIDR | | |
| Kinigi | Kabwende<br>Kanyamiheto<br>Muzanze | Cyarubindi | AIDR, 1967 | 9 | 1.50 |
| Kinigi | Gihora | Kibali | | 2 | |
| Kinigi | Kagano | Kangano | | 3 | |
| Nkumba | Ruhondo<br>Nyanga | Nkumba | | 6 | |
| Nkuli | Musumba | Mutera | AIDR, 1958 | 10 | 11.50 |

| Commune | Secteur(s) | Name of System | Built by | Number of Standpipes | Yield lps |
|---|---|---|---|---|---|
| Mukingo | Nyabirehe | | | | |
| | Rwinzovu | | | | |
| | Muhingo | | | | |
| | Shingiro | | | | |
| Mukingo | Busogo | Ext. Mutera | | 5 | |
| Mukingo | Gataraga | Butobo | AIDR, 1956 | | 200.00 |
| | Gikoro | | | | |
| | Kimonyi | | | | |
| Kigombe | Musanze | | | | |
| | Gahondogo | | | | |
| | Gashangiro | | | | |
| | Cyuve | | | | |
| | Rubange | | | | |
| Kinigi | Gihora | | | | |
| | Nyange | | | | |
| | Rwankuba | | | | |
| Nkumba | Gahunga | | | | |
| | Kabaya | | | | |
| | Giheta | | | | |
| | Maya | | | | |
| | Kinoni | | | | |
| | Mwiko | | | | |
| Kidaho | Rugarama | | | | |
| | Butete | | | | |
| | Kidaho | | | | |
| | Cyanika | | | | |
| Total | | | | | 221.00 |

Notes: The systems listed above were taken from a BCEOM map. In some cases, data that appeared on other lists were added to these data.

Table 6-2

Piped Water Systems Sponsored by the Dutch (SNV)

| Commune | Secteur(s) | Name of System | Cellule | Length meters | Number of Standpipes | Yield lps |
|---|---|---|---|---|---|---|
| Nyamugali | Kivumu<br>Muvumo | Kigeyo | | 2,922 | 9 | 0.49 |
| Nyamugali | Muvumo | Base | | 863 | 6 | 0.26 |
| Nyarutovu | Ruhinga II<br>Kiriba | Nyarutovu | | 2,082 | 7 | 0.47 |
| Ruhondo | Ntarama | Ruhondo | Nyagahondo<br>Burengo<br>Kirwa | 21,000 | 21 | |
| | Rusayo | | Kabusozo | | | |
| | Remera | | Karambo<br>Murandi<br>Bumoli<br>Muhororo<br>Sure | | | |
| | Gashaki | | Buhura<br>Gitonya<br>Burembo<br>Gitonya<br>Gitega | | | |
| | Ryandinzi | | Ruhangiro<br>Ruhehee<br>Ruma | | | |
| | Kiruli | | Karambi<br>Gasebeya<br>Kanyansyo | | | |
| | Mukono | | Kabera | | | |
| | Totals | | | 26,867 | | 1.22 |

| Commune | Total Cost FRW | Unit Cost FRW/m | Date Built |
|---|---|---|---|
| Nyamugali | 752,754.00 | 258 | December 1981 |
| Nyamugali | 719,460.00 | 834 | September 1982 |
| Nyarutovu | 1,098,025.00 | 527 | July 1982 |
| Ruhondo | 12,700,000.00 | 605 | September 1985 |
| Total | 15,270,239.00 | | |
| Average | | 556 | |

Communes in Ruhengeri Prefecture as well as in Gisenyi Prefecture. Coforwa (Compagnons de Fontainiers de Rwanda) is a Rwandan non-profit organization created by a Belgian priest about ten years ago and specializing in the construction of gravity fed piped systems.

Three systems have been completed, and an additional six are in varying stages of either planning or construction. Club 2/3 is now moving into the part of Kigombe Commune that is not in the Lava Zone (generally the area south of the Ruhengeri-Uganda highway) and Ruhondo Commune. Information on the piped water systems sponsored by Club 2/3 is presented in Table 6-3. In addition to these piped systems, the Club 2/3 has financed the construction of 106 springs at Nyamutura, 25 at Ruhondo and 29 at Nyakinama. All of this work is expected to be completed by September, 1986. An additional budget of $1,100,000 Can. has been requested or is in the process of being requested with $550,000 actually committed.

The method of operation that Club 2/3 uses involves the user populations in the planning and construction of the systems and maximizes the local input. An area desiring water service and a suitable spring are identified, usually in discussions with the bourgmestre and other commune officials. Meetings are then held with the local people, who are required to elect a water committee to represent the community. The layout of the system and the input that is expected from the community are discussed. These inputs include labor during construction, provision of locally available building materials, such as sand and rock, and the commitment to pay an annual maintenance fee by each family of users.

If the community agrees to participate in the water system, a formal contract is signed by the water committee for the community, by the commune officials, and by Club 2/3 and Coforwa. A bank account is set up to hold the annual fees until they are needed for maintenance. Typically, two local technicians are trained in the construction and maintenance of the system and are left with a kit of tools. One person is selected to be responsible for each standpipe along the system, usually from those who live closest to the standpipe. This person keeps the standpipe area clean, notifies the water committee when maintenance is required, collects the annual tariff from the users of that standpipe, and turns the money over to the water committee.

The ritual of having a formal contract is considered essential to ensure the commitment of the community. A similar process is conducted when a spring is capped, except that no formal contract is used. The annual charge per family is 100 FRW for piped water systems and 50 FRW for capped springs.

The experience with this procedure for building rural water systems has in general been satisfactory. All of the systems that have been started have been completed, and the systems seem to remain in operation. The main item that requires maintenance is the standpipes. These are often intentionally damaged when the system is new by people who wish to leave the water running or obtain a greater flow. Occasionally, a water point has been capped off when this happens and the local people informed that it will not be fixed until they agree not to damage it again. Intentional damage to the system seems to decline with time as the users become familiar with its limitations and the need to maintain it.

Table 6-3

Piped Water Systems Sponsored by Club 2/3

| Commune | Secteurs | Name of System | Length meters | Number of Standpipes | Yield (lps) | Total Cost FRW | Unit Cost FRW/m |
|---|---|---|---|---|---|---|---|
| Nyamutera | Tubungo | Nganzo | 4,813 | 5 | 0.25 | 3,030,988 | 630 |
| Nyamutera | Rugera<br>Tubungo | Rutarabana | 5,300 | 8 | 0.45 | 3,670,810 | 693 |
| Nyamutera | Kageri | Kagano | 2,816 | 4 | 0.35 | 2,553,125 | 907 |
| Nyamutera | Mukirangwe | Mukirangwe | 3,915 | 4 | 0.21 | 2,886,388 | 737 |
| Nyakinama | Gikoro<br>Nkotsi | Rugeshi | 5,338 | 7 | 0.70 | 4,830,118 | 905 |
| Nyakinama | Gikoro<br>Kabere III<br>Kabere II<br>Rugarika | Gakongoro | 7,699 | 10 | 1.10 | 7,084,877 | 920 |
| Nyakinama | Rutovi<br>Rusanze<br>Kabere II | Mugwata II | 2,703 | 6 | 0.50 | 2,748,328 | 1017 |
| Nyakinama | Rusanze<br>Kabere I<br>Muguri<br>Muko<br>Nkotsi | Rukore | 7,704 | 10 | 1.20 | 10,131,425 | 1315 |
| Nyakinama | Rusanze<br>Kitabura<br>Muguri<br>Gakoro<br>Muko | Muguli | 19,223 | 28 | 1.40 | 13,632,295 | 709 |
| Totals | | | 59,511 | | 6.16 | 50,568,354 | |
| Averages | | | 6,612 | | 0.68 | 5,618,706 | 870 |

Collection and handling of the annual maintenance fees also have been difficult. Only 50 percent to 60 percent of the families pay the agreed upon fees, and there is sometimes leakage of the funds between the time at which they are paid and the time that they are deposited in the bank account.

## 6.4 The Farming Systems Improvement Project (FSIP)

The Farming Systems Improvement Project (FSIP) is a long-term, USAID financed agricultural aid project covering all of Butaro, Cyeru, Nyamugali, and Nyarutovu Communes. This project thus covers all of the Buberuka Highlands and a part of the Central Plateau. In general, this is all of the area east of a north-south line through Lake Bulera and the eastern arm of Lake Ruhondo. The FSIP is envisioned as a ten-year project. A total of $13 million US in funding has been provided for the first five years of operations.

The current phase of the project includes an environmental sanitation component with a budget of $400,000 U.S. (32,000,000 FRW). With this money, the project intends to sponsor three piped water systems in each of the four communes that it covers. Mr. Vinh Van Pham, a general civil engineer, is assigned to the project; thus, the project has access to technical skills.

The bourgmestres of the four communes were asked to propose water projects for their communes and to submit data on these systems. The information that was received is presented in Table 6-4. As indicated, five systems have been completed, and an additional three are under construction.

Table 6-4, on the following pages, includes information on the unit costs of the systems in Rwandan francs per meter of pipe and per user. The FSIP project prefers to choose systems with low per-capita costs for implementation. Their target is systems with per capita costs in the range of 2,000 to 3,000 FRW per user, but the average of the systems undertaken to date has been 3,064 FRW per user, that is, slightly above their target range.

The priorities of the bourgmestres are not always the same as that of the FSIP project. In Butaro Commune, for example, the bourgmestre has assigned the highest priority to the first two systems listed, although they have the highest cost per user.

As shown in Table 6-4, the total cost of the proposed systems is almost 69 FRW million; thus, it will not be possible to fund all of the proposed water systems in the current phase of the FSIP project. Having more projects proposed than can be implemented is an excellent arrangement, because it allows the FSIP to choose among various projects based on its own criteria rather than have to face a proposed project on an "take-it-or-leave-it" basis.

During the work on these spring fed systems, Mr. Vinh has had bacteriological analyses conducted on three samples from each of seven springs for a total of 21 analyses. The data that were available from ten of these analyses showed coliform counts ranging from 13 to 918 per 100 ml, with a median value of 63. It is assumed that these were values for total coliforms, rather than fecal coliforms. These analyses indicate that the spring water is slightly contaminated, but even so, it is almost certainly of considerably higher quality than the water that is available from other sources. Continued efforts

Table 6-4

Projects Proposed to the Farming Systems Improvement Project (FSIP)

| System Name | Name of Spring | Length meters | Total Cost FRW | Unit Cost per Meter FRW/Meter |
|---|---|---|---|---|
| Butaro Commune | | | | |
| Kinyababa | Gatobororo | 4,242 | 4,383,188.00 | 1,033 |
| Kanyirabuhire | Kanyirabuhire | 1,678 | 1,200,155.00 | 715 |
| Rubayo | Rubayo (4 springs) | 3,071 | 2,598,722.00 | 846 |
| Kabere | Kabere | 2,058 | 1,621,547.00 | 788 |
| Musenyi | Musenyi | 4,609 | 2,955,579.00 | 641 |
| Cyeru Commune | | | | |
| Mahongora | Mahongora | 5,745 | 3,431,019.00 | 597 |
| Nyirantarengwa | Nyirantarengwa and Rutagara | 11,515 | 7,417,419.00 | 644 |
| Karegamazi | Karegamazi | 4,203 | 2,148,250.00 | 511 |
| Gakaranka | Gakaranka | 2,839 | 1,770,554.00 | 624 |
| Nyamirembe | Nyamirembe | 3,381 | 2,779,135.00 | 822 |
| Nyamugali Commune | | | | |
| Rutagara | Rutagara | 3,398 | 2,578,533.00 | 759 |
| Nyamakoma | Nyamakoma | 1,832 | 1,708,225.00 | 932 |
| Nyakagezi | Nyakagezi | 737 | 1,052,155.00 | 1,428 |
| Mugomero | Mugomero | 2,722 | 2,119,623.00 | 779 |
| Ruramba | Ruramba | 1,243 | 1,396,908.00 | 1,124 |
| Ndongoze | Ndongoze | 480 | 1,193,433.00 | 2,486 |
| Gatovu | Cyahafi and Nkombe | 2,515 | 1,915,045.00 | 761 |
| Nyartovu Commune | | | | |
| Nyamataha I | Nyamataha | 3,452 | 3,035,246.00 | 879 |
| Nyamataha II | Nyamataha | 6,624 | 3,808,517.00 | 575 |
| | | | 6,843,736.00 | |
| Nirabuyugi and Ryaruganzu Installation of standpipes | | | 1,014,822.00 | |
| Akagisayuru | Akagisayuru | 5,178 | 3,807,832.00 | 735 |
| Ruhondohondo | Ruhondohondo | 1,428 | 2,044,121.00 | 1,431 |
| Gashenyi | Gasuro | 6,467 | 5,811,474.00 | 899 |
| Totals | | 79,417 | 68,635,238.00 | 20,009 |
| Averages | | 3,453 | 2,745,409.52 | 870 |

Table 6-4 (cont'd.)

| Name of System | Yield (lps) | Number of Users | Cost per Capita FRW | Remarks |
|---|---|---|---|---|
| Butaro Commune | | | | |
| Kinyababa | | 600 | 7,305 | |
| Kanyirabuhire | | 150 | 8,001 | |
| Rubayo | | 600 | 4,331 | |
| Kabere | | 450 | 3,603 | |
| Musenyi | | 750 | 3,941 | |
| Cyeru Commune | | | | |
| Mahongora | 0.40 | 1,200 | 2,859 | Under construction |
| Nyirantarengwa | 0.90 | 1,650 | 4,495 | Under construction |
| Karegamazi | | 450 | 4,774 | |
| Gakaranka | | 450 | 3,935 | Under construction |
| Nyamirembe | | 600 | 4,632 | |
| Nyamugali Commune | | | | |
| Rutagara | 0.70 | 900 | 2,865 | Completed |
| Nyamakoma | | 300 | 5,694 | |
| Nyakagezi | 0.30 | 300 | 3,507 | Completed |
| Mugomero | 0.50 | 600 | 3,533 | |
| Ruramba | 0.40 | 450 | 3,104 | Completed |
| Ndongoze | | 150 | 7,956 | |
| Gatovu | | 300 | 6,383 | |
| Nyarutovu Commune | | | | |
| Nyamataha I | 1.60 | 750 | 4,047 | Completed |
| Nyamataha II | | 1,800 | 2,116 | Completed |
| | | 2,550 | 2,684 | Completed |
| Nyrabuyugi and Ryaruganzu Installation of standpipes | | 900 | 1,128 | Completed |
| Akagisayuru | | 600 | 6,346 | |
| Ruhondohondo | | 300 | 6,814 | |
| Gashenyi | | 1,500 | 3,874 | |
| Total | | 18,300 | 107,927 | |
| Averages | | 732 | 4,497 | |

are being made to protect the areas around the springs in an attempt to further reduce the level of contamination in the water.

The same set of laboratory analyses indicated that the water has a consistent pH of 5.5 in all of the springs. This measure is slightly acidic and might cause rapid corrosion of steel pipes, but all of the piping systems have been constructed from plastic pipe; hence, corrosion is not a problem. The users apparently do not object to this slightly acidic water.

## 6.5 The A.I.D.R. Springs

A.I.D.R. (Association Internationale de Développement Rural) is a Belgian-based, nonprofit engineering firm that specializes in rural development. It was formerly known as F.B.I. (Fonds de Bien-Etre Indigène). A.I.D.R. activities in Rwanda date back to prior to independence in 1962, but A.I.D.R. withdrew from Rwanda on October 15, 1985.

A.I.D.R. executed a countrywide UNICEF program, with the goal of capping 5,590 springs between 1976 and 1979. The program fell behind schedule, and the end date was extended. Reference 8 presents a listing of 527 springs that were capped in Ruhengeri Prefecture by A.I.D.R. as a part of this program and the condition of each during a follow-up inspection apparently made in 1982.

The springs were capped between 1976 and 1980, but the majority of the systems appear to have been installed in 1978. According to the tabulated results of the follow-up inspection, 40 (7.6 percent) of the springs needed rebuilding and 46 (8.7 percent) needed repairs. A total of 316 of the springs (60.0 percent) were found to be in excellent condition. Assuming that the springs that required rebuilding represented failures, the success rate for the project after an average of four years of operation was 91.3 percent. On the basis of experience elsewhere, this success rate is outstanding and indicates that maintenance of the springs is excellent. By contrast, an evaluation of a UNDP program of providing piped gravity water supplies to villages in the hills of Nepal found that 77 percent of the systems were inoperative only three years after they were first constructed. Many handpump projects have had similarly high failure rates.

The exact locations of the capped springs are not indicated in the A.I.D.R. report, but the springs have been identified by commune, secteur, and cellule. The springs capped by A.I.D.R. have been indicated on the RRAM water system map with hexagons. These hexagons have been placed just below the name of the secteur, because the exact locations of the springs are unknown. The total yield of all of the capped springs in liters per second has also been marked on the map. The density of the hexagons marked on the map gives an immediate visual impression of the density of water sources in each area. The number of springs and the total yield by commune is presented in Table 6-5, which follows.

## 6.6 The List in the Fourth Five-Year Plan

The fourth five-year plan (Reference 9) includes a list of 33 existing piped water systems in Ruhengeri Prefecture. This list is summarized in Table 6-6,

Table 6-5

Springs in Ruhengeri Prefecture Capped by AIDR

| Commune | Total Number of Springs | Total Yield of all Springs |
|---|---|---|
| Butaro | 45 | 7.54 |
| Cyabingo | 41 | 8.69 |
| Cyeru | 60 | 14.86 |
| Gatonde | 39 | 7.83 |
| Kidaho | 2 | 0.86 |
| Kigombe | 37 | 3.79 |
| Kinigi | 0 | 0 |
| Mukingo | 3 | 0.62 |
| Ndusu | 40 | 11.68 |
| Nkuli | 33 | 6.05 |
| Nkumba | 6 | 2.12 |
| Nyakinama | 42 | 8.84 |
| Nyamugali | 47 | 7.90 |
| Nyamutera | 42 | 4.77 |
| Nyarutovu | 47 | 14.10 |
| Ruhondo | 43 | 14.70 |
| Total | 527 | 114.35 |

Table 6-6

Water Systems Listed in the Five Year Plan

| Commune | Name of System | Built by | Length (meters) | Total Cost FRW | Unit Cost FRW/m | Year |
|---|---|---|---|---|---|---|
| Butaro | Rwabahima | Canada (Soeurs | 8,000 | 3,165,000 | 396 | 1984 |
| Butaro | Rusasa | Ste. Marie) | 12,000 | 4,000,000 | 333 | 1984 |
| Cyeru | Rugarama | USAID | 1,392 | 1,092,923 | 785 | 1984 |
| Gatonde | Bitorwa | MINITRAPE | 10,483 | 7,492,200 | 715 | 1984 |
| Gatonde | Bitanze-Rutare | MRND, Coforwa | 4,535 | 3,782,692 | 834 | 1984 |
| Kinigi | Cyabirumba | Coforwa, Commune | 2,750 | 1,194,500 | 434 | 1984 |
| Kinigi | Lyango | AIDR | 9,500 | | | 1984 |
| Kinigi | Nyagakangaga | Coforwa | 3,250 | 1,776,257 | 547 | 1984 |
| Kinigi | Rusumunu | Coforwa | 3,202 | 1,394,935 | 436 | 1984 |
| Kinigi | Bushokoro | AIDR | 2,500 | | | 1984 |
| Ndusu | Burera | Misereor | 1,876 | 3,120,098 | 1,663 | 1980 |
| Ndusu | Mbizi | | 3,642 | | | 1980 |
| Ndusu | Bisoko | MIRENA | 8,972 | 5,905,828 | 658 | 1983 |
| Ndusu | Rukaranka | MIRENA | 1,788 | 1,199,721 | 671 | 1983 |
| Nkumba | Bushoka | MIRENA | 4,000 | 5,000,000 | 1,250 | 1982 |
| Nyakinama | Kibombe | FDC | 6,200 | 4,500,000 | 726 | |
| Nyakinama | Rubindi | FDC | 1,500 | 4,606,665 | 3,071 | |
| Nyakinama | Munanira | German CARE | 2,400 | 1,970,970 | 821 | |
| Nyamutera | Nyakagezi | MINITRAPE | 3,000 | 3,000,000 | 1,000 | 1984 |
| Nyarutovu | Nyirabuyugi | USAID | 3,000 | | | |
| Nyarutovu | Ryaruganzu | USAID | 4,000 | | | |
| Nyarutovu | Ngiramazi | Suisse | 2,000 | 644,000 | 322 | |
| Ruhondo | Nyakagezi | FBI | 3,500 | | | 1956 |
| Ruhondo | Nkanku | Rixensart | 1,000 | 900,000 | 900 | |
| Total | | | 104,490 | 54,745,789 | | |
| Average | | | 4,354 | 2,281,075 | 648 | |

Note: This list contains only the projects that are not included in other lists.

but 11 systems that are included on other lists in this chapter have been deleted from this list.

The five-year plan also included a listing of the number of improved springs and standpipes by commune in 1980 and 1984. The list does not distinguish between springs and standpipes. This information is presented in Table 6-7, which follows. Many of the springs included in the list are probably those that were capped by A.I.D.R.

## 6.7 The Existing Lava Zone System

Despite the excellent soils of the Lava Zone, this area was largely unpopulated up through the 1950s, primarily because of the scarcity of surface water. Rainfall is adequate for two agricultural crops per year, but the soil is extremely porous and the rainwater rapidly disappears, thereby making it difficult to obtain water for drinking and domestic uses.

In 1956, an extensive piped gravity water distribution system was constructed in the Lava Zone. The major part of this system consisted of the development of the Mutobo Springs, ten kilometers west of Ruhengeri Town and a 63-kilometer long gravity pipeline which extended all the way to the Uganda border. Additional parts of the system included the development of the Mutera Springs and a gravity pipeline higher up on the slopes of the mountains reaching all the way to Shingiro Secteur in Mukingo Commune above Mukingo Town and the Mutobo Springs. The system also served major parts of Gesenyi Prefecture.

After independence in 1962, these extensive systems were maintained by A.I.D.R. with funds provided by the Rwandan Government. Most of the piping in the distribution system was made of galvanized steel, which was severely attacked over the years by the soft, acidic water from the springs. The severe corrosion problem led to increasing needs for maintenance and replacement and rapidly rising maintenance costs. At some point, government funds for operation and maintenance of the systems began to decline, and A.I.D.R. slowly curtailed its activities until finally all maintenance of the system ceased. The local populations were never involved in maintaining these systems and, therefore, were not organized to take over the maintenance of the system as the other organizations withdrew, even if they were financially capable of doing so. At present, much of the system is inoperative.

As discussed in the next section, the World Bank is proposing to finance a system in the Lava Zone which will replace most of the existing system. Some parts of the existing system will be rehabilitated and returned to service.

## 6.8 The Proposed World Bank/BCEOM Lava Zone System

The World Bank First Water Project financed the improvement of water supply systems in five secondary centers, including Ruhengeri Town, an extensive engineering study of a water supply system for the Lava Zone, and an institutional study of water projects in rural areas. All of the studies were conducted by a French organization, BCEOM. There is an extensive series of engineering reports (see Reference 2 and Documents Reviewed 2) dated 1982.

Table 6-7

Improved Springs and Standpipes by Commune
in 1980 and 1984

| Commune | 1980 | 1984 |
|---|---|---|
| Butaro | 45 | 175 |
| Cyabingo | 109 | 140 |
| Cyeru | 61 | 64 |
| Gatonde | 129 | 380 |
| Kdaho | 6 | 1 |
| Kigombe | 41 | 54 |
| Kinigi | 4 | 4 |
| Mukingo | 11 | 18 |
| Ndusu | 124 | 95 |
| Nkuli | 103 | 103 |
| Nkumba | 46 | 46 |
| Nyakinama | 43 | 42 |
| Nyamugali | 149 | 113 |
| Nyamutera | 40 | 107 |
| Nyarutovu | 47 | 47 |
| Ruhondo | 207 | 205 |
| Total | 1,165 | 1,594 |

Source: Projet régional pour le IVe plan quinquennal de développement 1987-1991. (Référence 9, pg. 132).

The institutional study (Reference 3) is dated 1985. It is planned that construction of the Lava Zone system will be financed in the World Bank Second Water Project.

The proposed World Bank project will replace the old gravity system that was built by A.I.D.R. with a new gravity system, will provide treatment and will pump water to a distribution line higher in the lava zone and parallel to the gravity line. Water will also be distributed to Gisenyi Prefecture from the pumped system.

Because there are virtually no other significant sources of water in the Lava Zone, it appears that a piped water system from the Mutobo and Mutera Springs is the only technological solution to providing domestic water in this area. The tariffs required by the proposed system are, however, high, and the arrangements for operating and maintaining the system have not yet been worked out. The proposed World Bank project is discussed in additional detail in section 8.6.2 of the report, and some suggestions are made for improving the cost-effectiveness of the project.

## 6.9 Prefectural and Communal Lists of Water Projects

From time to time, the prefectural government has been asked to prepare lists of all water systems in the prefecture. This was done, for example, during the planning for the A.I.D.R. spring capping program described above. No overall list is currently available at the prefecture, however.

A meeting was held with the bourgmestre of Cyeru Commune, Mr. Ezechiel Munyaneza, to discuss the water supply situation. The bourgmestre appeared to be well informed on matters of water supply, to consider it a major problem, and to be eager to obtain assistance in constructing additional water supply systems. His immediate improvement program consists of the five projects which he presented to the FSIP. As noted, three of these are under construction. Funding is being sought for the other two. According to the bourgmestre, the flows from the springs that will supply the two as yet unfunded systems have been measured and are adequate.

A dispute has arisen between Cyeru Commune and Cyabingo Commune over the use of a spring at the southwest corner of Cyeru Commune near the spring that supplies the SNV constructed Ruhondo system. Cyabingo would like to use this source to supply several secteurs in Cyabingo Commune but apparently needs permission to develop a source that is in another commune. The bourgmestre of Cyeru Commune wants to use the same spring to supply four secteurs to the north in Cyeru Commune (Mugamba, Karingorera, Rugendabare, and Ruhombo). He is particularly interested in providing a safe water supply along the lake, because of the problem of schistosomiasis, which he feels is serious. On the basis of conversations with this bourgmestre and many people involved in planning and constructing small water systems, it appears that in most communes the bourgmestre is likely to know of attractive projects and areas where the local people are interested in having a water system.

From an engineering point of view, it is desirable to plan water supply systems for entire areas, such as communes or groups of secteurs, to ensure that all areas are covered and that the available sources are optimally used.

For example, a situation could arise in which each of two areas could be supplied from Spring A, but one of the two areas also has other supply possibilities. If Spring A is developed to serve the area that has alternative sources, then the area for which Spring A was the only alternative would be left without a supply. Despite the desirability of having complete engineering knowledge before proceeding, it appears unlikely that adequate resources will be available to do this amount of study. The most practical approach, therefore, appears to be to take the projects that are proposed by the bourgmestres and the local people for implementation. During the detailed planning of these systems, consideration can be given to the extent possible to whether other alternatives would be superior and whether additional areas should be served.

## 6.10 The BCEOM List of Springs in the Lava Zone

Subsequent to the preparation of the engineering documents for the Lava Zone system in 1982, BCEOM continued to develop some additional and supplementary materials. BCEOM supplementary report (Reference 10, pp. 70-72) contains a list of water points in the Lava Zone and states that the reliable yield of the Mutobo Spring is 200 liters per second. The only copy of this report that is available in Rwanda is at the BCEOM office, but photocopies of the three pages listing the water points were obtained for the RRAM Project.

The list contains 14 water points in Ruhengeri Prefecture. (The Schiller report (Reference 13, pg. 11 ) includes a typographical error which said that 214 springs were listed). A total of seven of these points were already contained on lists previously presented in this chapter, including the Mutobo Spring, four standpipes supplied by the Mutera Spring, the Susa-Bizate system, and the Cyarubindi system. One of the systems listed is the municipal supply in Ruhengeri town.

The remaining six Ruhengeri Prefecture systems on the BCEOM list are presented in Table 6-8. Most of these systems appear to be small, and two of them apparently serve institutions. From the notes in the BCEOM table on the type of geology, it appears that four of the six may not be in the Lava Zone. (See the note at the bottom of Table 6-8). This list thus confirms reports from many other sources that there very few other sources of water in the Lava Zone than the large springs at Mutobo and Mutera.

One possible major source is at Rubindi. A waterfall can be seen from the big bend on the Ruhengeri-Gisenyi highway, about three kilometers west of the Mutobo Spring, to the north across a valley. The river plunges down the hillside and is said to disappear into the soil of the valley floor within about 10 meters. This may be the first water point listed in Table 6-8 and is probably the 500 lps river discussed in Reference 2.d., pg. 29. (See also Section 7.3.) The river probably emerges from a spring, which could potentially be capped, or it might be possible to install an infiltration gallery beside this river before it plunges down the hillside. A small system could serve approximately 30 houses in the valley beneath the waterfall. A larger system could supply a considerably larger area, because the available quantity of water is large and the river is located at a relatively high elevation.

Table 6-8

BCEOM List of Springs in the Lava Zone

| Commune | Name of Spring | Built by | Year | Yield lps | pH |
|---|---|---|---|---|---|
| Mukingo | Rubindi | | | | 7.0 |
| Nkuli | Muhama | | 1957 | 0.27 | 6.2 * |
| Nkuli | Kabere | | | | * |
| Kigombe | Kagobogobo | | | 0.70 | 6.7 |
| Nyakinama | Ruziku | AIDR** | 1978 | 1.20 | 6.8 * |
| Nyakinama | Kabilizi | AIDR*** | 1978 | | * |

Notes:

* These springs are noted as being in a "crystalline geography as compared to a "volcanic" geography. This probably means that they are not in fact in the Lava Zone.

** This spring serves the National Pedogogical Institute.

*** This spring serves the I.P.E.

Some of the yields given in the BCEOM list vary considerably from the yields listed in Table 6-1. It is also interesting to note the BCEOM list shows the pH to be 6.9 and 6.2 for the Mutobo and Mutera springs, respectively. The pH for the two springs listed in Table 6-8 that appear to be in the Lava Zone is 7.0 and 6.7. These values are close to neutral, and raise questions about the fears of the acidity of the spring water. These pH values for the Lava Zone are also considerably higher than the values measured by the FSIP at springs in the non-Lava Zone parts of the Prefecture.

## 6.11 Summary of Domestic Water Supply and Costs

In Table 6-9, the number of water points that serve each commune have been tabulated along with the total yields of these water points, where these are known. For those systems that serve more than one commune, the yield available to each commune was estimated. For example, it was assumed that one half of the 200 lps flow from the Mutobo Spring is available to Ruhengeri Prefecture and that it is equally divided among the five Lava Zone communes that it serves (Mukingo, Kinigi, Kigombe, Nkumba and Kidaho). Because the yield is unknown for many of the systems, the total yields presented in Table 6-9 are considerably smaller than the yields that are actually available.

The amount of domestic water that would be available per person per day based on the 1985 populations and the yields that are known is also tabulated in Table 6-9. As indicated, the per-capita quantity of water that is available is generally adequate, but it must be remembered that the numbers in Table 6-9 and the calculation assume that the five Lava Zone communes are being supplied with 100 lps from the Mutobo Spring. Although the quantity of water that is available in a given commune may be adequate, it may be distributed in such a way that large portions of the population do not have ready access to it. A feeling may be obtained for the accessibility of water by observing the distribution of the sources of water that were plotted on the map left with the RRAM Project. The map highlights that there is a problem with accessibility in the Lava Zone, with most of the people being dependent upon the Mutobo Spring system. Because this system scarcely works, the bulk of the Lava Zone population is left with few possibilities other than the long walk to the lakes.

Tables 6-2, 6-3, 6-4, and 6-6 include cost data on some of the systems. The unit costs of piped water systems are presented in these tables and include the costs of standpipes, reservoirs, and all other parts of the systems, that is, they are the total system cost divided by the number of meters of pipe that were installed. It can be observed that the unit cost of a simple gravity water system varies widely, but is usually in the range of 500 to 1,000 FRW per meter. For the systems on which data were available, the a total of 189 FRW million was spent to install 270 kilometers of pipe for an average cost of 700 FRW per meter. A typical cost for capping a spring was reported to be approximately 35,000 FRW.

The only set of data which included per capita costs was from the FSIP (Table 6-4). Again, there was considerable variation in the unit costs, but for all of the systems undertaken to date the average per capita cost has been 3,064 FRW per user for piped gravity supply systems from springs.

Table 6-9

Summary of All Water Systems by Commune

| Commune | Population 1985 | Piped System No. | Piped System Total Yield lps | Improved Spring No. | Improved Spring Total Yield lps | Total Sources No. | Total Sources Total Yield lps | Average lpcd in 1985 |
|---|---|---|---|---|---|---|---|---|
| Butaro | 47,807 | 4 | .00 | 45 | 7.54 | 49 | 7.54 | 14 |
| Cyabingo | 51,144 | 0 | .00 | 41 | 8.69 | 41 | 8.69 | 15 |
| Cyeru | 52,501 | 5 | 1.30 | 60 | 14.86 | 65 | 16.16 | 27 |
| Gatonde | 32,827 | 5 | .00 | 39 | 7.83 | 44 | 7.83 | 21 |
| Kidaho | 30,203 | 1 | 20.00 | 2 | 0.86 | 3 | 20.86 | 60 |
| Kigombe | 43,343 | 4 | 20.70 | 37 | 3.79 | 41 | 24.49 | 49 |
| Kinigi | 35,956 | 12 | 22.00 | 0 | .00 | 12 | 22.00 | 53 |
| Mukingo | 28,273 | 4 | 26.75 | 3 | 0.62 | 7 | 27.37 | 84 |
| Ndusu | 37,437 | 8 | .00 | 40 | 11.68 | 48 | 11.68 | 27 |
| Nkuli | 32,730 | 5 | 11.39 | 33 | 6.05 | 38 | 17.44 | 46 |
| Nkumba | 34,192 | 3 | 20.00 | 6 | 2.12 | 9 | 22.12 | 56 |
| Nyakinama | 46,206 | 12 | 7.30 | 42 | 8.84 | 54 | 16.14 | 30 |
| Nyamugali | 39,735 | 5 | 2.15 | 47 | 7.90 | 52 | 10.05 | 22 |
| Nyamutera | 29,327 | 6 | 1.26 | 42 | 4.77 | 48 | 6.03 | 18 |
| Nyarutovu | 47,226 | 7 | 2.07 | 47 | 14.10 | 54 | 16.17 | 30 |
| Ruhondo | 44,596 | 4 | 1.73 | 43 | 14.70 | 47 | 16.43 | 32 |
| Total | 633,503 | 85 | 136.65 | 527 | 114.35 | 612 | 251.00 | 34 |

The per-capita costs of the various types of water supplies discussed in this report are summarized below:

| Type of System | Cost per Capita (FRW) |
|---|---|
| Spring, without a Piped System | 120 |
| Spring, with a Piped System | 3,000 |
| Rainwater Catchment | 2,500 |
| The World Bank Mutobo Spring System (See Section 8.2.2.) | 11,400 |

# Chapter 7

## DOMESTIC WATER NEEDS

This chapter projects the quantity of water needed to meet the domestic water demands in Ruhengeri Prefecture, notes that this amount is small compared with the amount of water available, and then discusses in general terms the water needs of various areas within the Prefecture.

### 7.1 Domestic Water Demand

In Table 7-1, the December 31, 1985 population is presented for each of the communes in Ruhengeri Prefecture. This information was provided by the Prefecture by commune and secteur. An assumed population growth rate of 2.9 percent annually was used to estimate the 1995 populations. This is the rate of growth that was projected in the World Bank/BCEOM water demand study (Reference 2.c.). These populations were then multiplied by 23.3 and 36.0 lpcd to arrive at the estimated total domestic water demand in each commune in 1985 and 1995.

The per-capita water consumptions were derived from the information presented in the figures on pages 42 and 52 of the World Bank/BCEOM summary of the proposed Lava Zone water system (Reference 2.d.). The populations and water uses for the parts of the Lava Zone within Ruhengeri Prefecture were totaled, and the total water usage was divided by the population. It was assumed that one-third of the population and water usage in the Nile-Zaire Divide area was in Ruhengeri Prefecture and that the rest was in Gisenyi Prefecture.

The water demand estimates in the BCEOM study start with an assumed consumption by persons who carry water of 10 lpcd in 1985 and 15 lpcd in 1995, but then include higher allowances for the portion of the population living in built-up areas near the standpipes, for individual connections to private houses, and for institutional uses. An allowance of 20 percent for losses from the system is also included in the demand. While these unit demands were used for the design of the World Bank system, it is questionable whether the actual usage in rural areas will be this high, because most users will still have to carry water from springs or standpipes. The domestic water demand projected in Table 7-1 may, therefore, be taken as a maximum probable amount.

As shown in the table, the total domestic water demand in 1995 for the entire prefecture is conservatively projected to be 30,353 cubic meters per day, or:

$$(30,353)/(24 \text{ hours/day} * 60 \text{ min/hour} * 60 \text{ sec/min}) = 0.35 \text{ cubic meters per second or } 350 \text{ lps.}$$

This amount of water is small compared with the average flows in the major streams in the prefecture, amounting to approximately 1 percent of the average flow in the Mkungwa River at Ngaru. Because the flows, rainfall, and other hydrologic data which are discussed elsewhere in this report usually cannot be estimated with an accuracy even close to 1 percent, the amount of water needed for domestic water supply has little impact on the overall water resource situation.

Table 7-1

Estimated Water Demand by Commune

| Commune | Population | | Domestic Water Demand | | | |
|---|---|---|---|---|---|---|
| | 1985 | 1995 | 1985 | | 1995 | |
| | | | lps | cu. m/da | lps | cu. m/day |
| Butaro | 47,807 | 63,628 | 13 | 1,114 | 27 | 2,291 |
| Cyabingo | 51,144 | 68,069 | 14 | 1,192 | 28 | 2,450 |
| Cyeru | 52,501 | 69,875 | 14 | 1,223 | 29 | 2,515 |
| Gatonde | 32,827 | 43,690 | 9 | 765 | 18 | 1,573 |
| Kidaho | 30,203 | 40,198 | 8 | 704 | 17 | 1,447 |
| Kigombe | 43,343 | 57,686 | 12 | 1,010 | 24 | 2,077 |
| Kinigi | 35,956 | 47,855 | 10 | 838 | 20 | 1,723 |
| Mukingo | 28,273 | 37,629 | 8 | 659 | 16 | 1,355 |
| Ndusu | 37,437 | 49,826 | 10 | 872 | 21 | 1,794 |
| Nkuli | 32,730 | 43,561 | 9 | 763 | 18 | 1,568 |
| Nkumba | 34,192 | 45,507 | 9 | 797 | 19 | 1,638 |
| Nyakinama | 46,206 | 61,497 | 12 | 1,077 | 26 | 2,214 |
| Nyamugali | 39,735 | 52,884 | 11 | 926 | 22 | 1,904 |
| Nyamutera | 29,327 | 39,032 | 8 | 683 | 16 | 1,405 |
| Nyarutovu | 47,226 | 62,854 | 13 | 1,100 | 26 | 2,263 |
| Ruhondo | 44,596 | 59,354 | 12 | 1,039 | 25 | 2,137 |
| Total | 633,503 | 843,145 | 172 | 14,762 | 352 | 30,354 |

Note: An average per-capita water demand assumed to be as estimated in the World Bank/ BCEOM Lava Zone Project (Reference 2.d.), that is:

1985 = 23.3 lpcd
1995 = 36.0 lpcd.

These amounts allow for higher usages in developed sares, institutional uses, and 20 percent losses from the water system. See text.

The total domestic water needs for the year 1995 are estimated as:

30,353 cu. m/day * 365 days/year = 11,078,845 cu. m/year.

Over the 1,762 square kilometers of the prefecture, this amounts to the equivalent of:

(11,078,845 cu. m)/(1,762 sq. km x 1,000,000 sq. m/sq. km)) = 0.006 m or 6 mm of rainfall.

The average rainfall at Ruhengeri Town is approximately 1,338 mm annually. Approximately 7 percent of this rainfall, or the equivalent of 94 mm annually, is estimated to soak into the ground. The domestic water needs can, therefore, be met by taking less than 10 percent of the average annual flow that infiltrates into the groundwater.

Most of the domestic water will be taken from springs rather than from the lakes or rivers. The total yield of all sources that have been identified was shown in Table 6-9 to be 251 lps. Because the flows from many of the sources are unknown and thus not included in the total, and since the 1995 water demand is probably over estimated, it appears that the capacity of the existing sources of water probably will meet the 1995 domestic water demands. The 500 lps flow in the Rubindi River and rainwater catchment from roofs could also be developed.

## 7.2 The Perceived Need

It is difficult to determine the extent to which the farmers perceive the domestic water supply as a problem. In general, the shortage of domestic water and the long distances that it must be carried are frequently mentioned as a problem by residents of the Lava Zone, where, according to the socioenvironmental survey (Reference 3, pg. 104), 42.0 percent of the population has to go more than one km for water and 16.5 percent have to go more than two km. This problem is mentioned less often in other parts of the prefecture, possibly because there are relatively more water sources in these areas. In these three areas, the socioenvironmental survey found that on average only 28.6 percent have to go more than one km for water and only 6.2 percent have to go more than two km. In the survey of Bourgmestres and Agronomes carried out by Leslie Linn (Reference 12), domestic water was mentioned as a priority problem in only one of eight communes outside the Lava Zone, and then it was mentioned only third. On the basis of the limited information available, it appears that the rural population does consider the supply of domestic water to be a problem, but that this problem is considered to have a lower priority than the problems of agriculture and the shortage of firewood.

The following sections present an overview of the water problem by area within the prefecture.

## 7.3 Lava Zone

The Lava Zone is clearly the area with the most serious problem regarding domestic water supply. The socioenvironmental survey found that 16.5 percent of the population in this area had to walk more than two kilometers for water. The area has a high population density and rich agricultural potential, but there are few available sources of water. The only major sources currently being used or considered for water supplies are the Mutera and the Mutobo Springs, although there are a few small springs high on the mountainside in or near the national park, some of which have been developed. The BCEOM summary (Reference 2.d., pg. 29) notes that there appears to be a flow of 500 lps or more in the Rubindi River, just west of the Mutobo Spring. This river will be more difficult to capture than the springs, unless perhaps it issues from a spring. It is higher in elevation than the Mutobo Spring and has several times the flow; therefore, it has the potential for providing a much greater supply.

The World Bank, using the French consulting firm BCEOM, is proceeding with a major water distribution system from the Mutera and Mutobo Springs that will cover all communes in the Lava Zone. The distribution system will include two parallel distribution lines located relatively near the main Gisenyi-Ruhengeri-Uganda highway, which will mean that persons living high in the Lava Zone will still have to walk a considerable distance.

There are some lakes and bogs, and there may be additional small springs, in the national park that could be tapped to provide domestic water supplies in the upper elevations of the Lava Zone, or it might be possible to improve and extend the supplies from the springs that have already been tapped. From a policy point of view, however, it may be undesirable to make any further improvements in the water systems in the upper parts of the Lava Zone. Improvement of the water supplies near the boundary of the park may result in greater population densities and is likely to put additional pressure on the park lands. Pressure on the park will be even greater if some of the water systems have their intakes within the park since at least a minimal amount of human activity will be necessary to maintain these systems.

As discussed in section 8.6.2, it is considered questionable whether sufficient money can be collected to pay for the cost of pumping and thus whether the pumped portions of the proposed World Bank Lava Zone Project will be kept in service. It is recommended in section 8.6.2 that consideration be given to omitting the line that is served by pumping and instead use the resources to strengthen the gravity part of the Mutobo Spring system. This action will result in people in the upper part of the Lava Zone having to walk farther for water, but should result in greater reliability of the piped water supply. As noted above, it will also avoid creating an incentive for people to live near the national park.

Because there are so few sources of water in the Lava Zone, rainwater catchment systems could be especially helpful in reducing the amount of time that is spent carrying water in this area, especially for those persons who live near the park. As discussed in section 8.6.2, rainwater catchment technology appears to have a per-capita cost several times smaller than the proposed piped water system, significantly lower operation and maintenance costs, and a much higher probability of being sustained.

## 7.4 Buberuka Highlands

In general, springs are relatively plentiful throughout the Buberuka Highlands because the soil tends to retain water and release it slowly between rains and because the hilly terrain results in the emergence of groundwater at many places. The socioenvironmental survey (Reference 3, pg. 104) found only 4.2 percent who had to walk more than two km for water and no one who had to walk more than five km. As indicated in the various tables compiled in Chapter 6, numerous piped water systems and improved springs already exist in this area. The development of additional water supplies is a component of the FSIP Project which is operating throughout this area; therefore, the availability of domestic water supply points should increase in the future.

## 7.5 Central Plateau

The Central Plateau, like the Buberuka Highlands, is also relatively well endowed with springs. In addition, a considerable number of piped water systems have been developed in the past. The map that was marked to show the locations of these piped water systems shows that they cover the area fairly well except in Cyabingo Commune. There may in fact be piped water systems in Cyabingo Commune that were not identified during this study. The socio-environmental survey found however that 10.6 percent of the population walked more than two km for water and one family (0.6 percent) walked more than five km.

## 7.6 Nile-Zaire Divide

The soils in the Nile-Zaire Divide area are shallow and do not hold much moisture; therefore, there are relatively fewer springs. Nevertheless, the socioenvironmental survey found no one who had to walk more than five km for water and only 3.3 percent who had to walk more than two km. On the basis of this survey, the Nile-Zaire Divide area had the best accessibility to water of any of the four areas surveyed. Club 2/3 is sponsoring nine piped water systems in Nyakinama and Nyamutera Communes. As indicated on the RRAM Water Systems map that was marked, these systems provide effective coverage, except in the southeastern part of Nkuli Commune.

## 7.7 Ruhengeri Town

Ruhengeri Town is served by a conventional piped water system operated by Electrogaz. At present, the system is supplied by two shallow wells located near the stream that flows through the middle of town. As a part of the World Bank First Water Project, the town water system will be improved and additional supplies will be made available by gravity from the Mutobo Spring. Many of the users in Ruhengeri Town are served by individual metered supplies, although there are also some public standpipes.

The water system in Ruhengeri Town differs from the systems in the rural areas, because the town operates mostly on a cash economy and the water utility receives cash income from the metered customers. The problems and opportunities in this system are, therefore, not particularly relevant to those in the rural systems, and this system has not been covered in detail in this study.

## 7.8 Marshlands

Marshlands in Ruhengeri Prefecture represent some of the last remaining land that can be pressed into agricultural production, and a major interest of the RRAM Project is the investigation of the environmental impact of putting the marshlands into use. The marshlands present special problems of water supply, because the only feasible source of water within the marshlands themselves would be wells. Water from these wells might be of adequate bacteriological quality if the wells are constructed properly and protected from surface sources of contamination, but the water is likely to have the same tea-like color as the surface water in the marshes and it may have appreciable tastes and odors. This situation may make the water unpalatable to the users, even if it is potable.

Fortunately, the marshes tend to stretch out along valley bottoms and thus to be fairly narrow, with hills on both sides. It will probably prove to be technically feasible to supply water by gravity through pipes to the marshlands from springs on the nearby hillsides, if necessary. At present, the farmers live on the hillsides and go into the edges of the marshes only to work the fields. If this pattern continues as the marshes are developed, it may be unnecessary to provide water supplies out in the marshlands.

## Chapter 8

## ALTERNATIVE PROGRAMS FOR WATER RESOURCES MANAGEMENT

This chapter of the report provides recommendations for alternative programs in watershed management and domestic water supplies.

### 8.1 Watershed Management

Several opportunities for watershed management and research are indicated in a variety of subjects. In some cases, Rwanda Government divisions are the logical implementing organizations, while in others, it is expected that the universities would carry out field research. This section of the report is concerned with meteorology, hydrology, erosion control, tungsten mining, hydropower, groundwater, and watershed modeling.

#### 8.1.1 Meteorology

From the water balance study completed herein and from data presented in the hydrologic yearbooks, it is clear that single-point measurements of rainfall do not give a clear indication of total watershed precipitation. This fact is not surprising in consideration of the extreme differences in elevation found throughout Ruhengeri Prefecture and the likelihood of varying within relatively short distances.

As a starting point, an analysis of all weather stations, both official and nonofficial, should be undertaken. Rainfall, and other data, if available, should be collected for as many years as possible. The average rainfall over the area could then be determined by a combination of several methods -- arithmetic mean, Theissen polygon, or isohyets. This analysis would determine which stations are most representative of a particular area and would then provide a more reliable indication of watershed precipitation on an annual basis. The analysis would also show whether the weather stations should be extended over the area. It is suggested that this analysis could be undertaken by geography students at the National University of Rwanda.

#### 8.1.2 Hydrology

The present network of four stations in Ruhengeri Prefecture provides a representative measure of stream flow from diverse watersheds. It is, however, recommended that the station on the Susa stream be reestablished or a second location on the Mudakama be established to measure flow from the montane forest zone. Both locations have bridges which are excellent gauging sites. The future data collected would be useful for understanding not only the montane forest contribution in stream flow but also the losses that may occur from infiltration into the Lava Zone. It is understood that the Genie Rural has the necessary equipment, personnel, and interest to undertake this work.

A second hydrological recommendations is for the Rural Engineering (Génie Rural) to conduct a campaign of stream-suspended sediment measurements for selected locations. The sampling would be conducted periodically over the course of a year and would consist of two samples per station per month. This should be sufficient to determine the seasonal variation without placing too large a strain on the resources of Genie Rural. The sampling should be done at each of the gauging stations to relate sediment load to stream flow. It is probable that sampling equipment would have to be purchased and possibly some training provided.

Sediment sampling could also be undertaken in streams draining erosion control pilot projects. Analysis of the respective proportions of organic and mineral matter contained in sediments is often informative regarding the contributing source of the sediments.

### 8.1.3 Erosion

Recommendations on the need for research and extension of erosion control measures have been made by other consultants on the RRAM Project and will not be discussed in detail here except to reiterate several key points. Erosion control is certainly one of the more important development issues facing Rwanda and yet, while the needs are obvious, the solutions are difficult to implement. Erosion control techniques are sufficiently well known to government services, but the criteria for mass acceptance by farmers are not sufficiently established. Obviously, for acceptance of erosion control measures, the farmer must first believe that his production will be enhanced and, second, be within his economic (money and time) means. All future research into erosion should be undertaken with crop production and cost as primary variables.

Specific recommendations for erosion management would include the continued extension of Pennisetum sp. for planting along field boundaries and the use of gabions for protecting roads or structures from stream bank erosion. Areas of erosion due to the concentrated runoff from roads should be treated primarily by creating a buffer zone of vegetation and recognizing that erosion can seldom be completely eliminated. It is expected that the Soil Conservation Service (Direction du Genie Rural et de la Conservation des Sols) should carry out these recommendations.

### 8.1.4 Marsh (Marais) Development

The agricultural development of the Rugezi marsh falls within a separate category of marsh development because of its shear size. Hydrologic control of such a large feature will be complex and, considering the fragile nature of the underlying peat, should only be undertaken with extreme caution and careful analysis. The RRAM Project could assist this analysis by studying the existing developments on the Rugezi estuaries. These developments should be assessed as to their methods of crop production and as to their productivity. Such a study could be profitably carried out as dissertation research by an agricultural or geography student.

### 8.1.5 Tungsten Mining

On the basis of samples taken to date and discussed in Section 4.3 of this report, it appears that there is no specific threat from the arsenic. It is recommended, however, that occasional sampling be continued to monitor any changes in the existing concentrations of arsenic in the water and sediment.

### 8.1.6 Lake Bulera Water Levels

The preliminary analysis of the lowered water levels in Lake Bulera, presented in Section 4.2, points to increased flow for hydropower production as the cause. This analysis, however, contained some pertinent gaps in information and therefore must be considered as preliminary. It is recommended that Electrogaz be consulted to ascertain their views on the subject. Unless the technicians of Electrogaz request further assistance, it would appear that no further interventions by the RRAM Project are needed.

### 8.1.7 Groundwater

Information on the occurrence and quantity of groundwater is based largely on supposition. No direct measurements have been undertaken. While drilling exploratory holes would provide interesting data, particularly in the Lava Zone, this is an expensive undertaking and is, therefore, not recommended. If, in the future, drilling should happen to take place in Ruhengeri Prefecture through some other project, it is recommended that the RRAM Project monitor the results.

### 8.1.8 Watershed Modeling

The value of a watershed computer program is debatable. Obstensibly, a watershed model would be useful in predicting the effect of large-scale land use changes on the hydrologic regime. In theory, such effects as the widespread use of field crop erosion measures, the widespread increase or decrease in forested lands, or the development of the Rugezi marsh could be predicted by the model. The question, however, is whether there is adequate information to describe the existing watersheds such that a computer program can be written with sufficient accuracy. With data being collected under the RRAM Project, which is being tabulated in units of four square hectares, and with the results of a Belgian soils study and topographic survey, the available data show promise for adequacy in modeling. The Belgian topographic survey in particular is of large importance if greater accuracy can be obtained on slope maps. The completion date of this study is not yet known. It is recommended that any decisions on watershed computer modeling be postponed until all available data from the RRAM and Belgian projects are completed.

## 8.2 Domestic Water Supplies

In Chapter 9, it is recommended that the RRAM Project not become involved in implementing domestic water supply programs. Nevertheless, this section discusses the recommended attributes of a water supply program, in case a decision is made to undertake one. This section also analyzes the proposed World Bank/BCEOM Lava Zone project and suggests some modifications to it, discusses some organizations that are actively pursuing projects with the recommended attributes, and discusses contributions that might be made to the promising technology of individual rainwater catchment systems from the roofs of houses.

### 8.2.1 Project Principles

The following policy guidelines, or project principles, were adopted by the Thai-German Highland Development Programme. They appear to be working well in that project and to have universal applicability. It is recommended that any program of domestic water supply development that is undertaken incorporate these principles to the maximum extent possible:

- People's participation and bottom-up planning
- Self reliance (use only locally available inputs)
- Integration (use the existing government structures)
- Replicability (use programs that can be copied elsewhere)
- Rolling planning and continuous evaluation (learn as you go)
- Training

The issue of institutional capability was discussed in Section 5.3 above, and it was emphasized that for a project to be sustained, it must have institutional support. The most reliable support will be from the people who actually use the facilities, because they are the people with the most to gain. Systems that depend on outside inputs are likely to fall into disuse when these outside inputs are no longer available. Government budgets from levels outside those that can be influenced by the system users should also be considered as outside inputs, because the system that depends on these budgets will fail if the government does not furnish the promised funding in a timely fashion.

Bottom-up planning means involving the people in all phases of planning and constructing a project so that they accept the responsibility for the facilities and learn the skills necessary to maintain the facilities. People participation helps develop a sense of ownership of the system and usually greatly reduces the costs. Self-reliance emphasizes selecting systems that can be maintained with the resources available to the user group. Integration means using the existing social and governmental structures to the maximum extent possible. Projects which set up temporary, separate organizations which parallel existing, permanent government organizations are likely to fail when the project support is withdrawn, because they are not adopted and continued by the permanent organizations.

Domestic water supply programs in Rwanda should use the system of spring developers and caretakers (spring developers and responsables) that exists. This system consists of an official spring developer in each commune. The developer is paid with commune funds and reports to the bourgmestre. The objective of this system is to have the developer trained in constructing and maintaining simple gravity piped water systems and improved springs and to have them equipped with a minimum set of tools. The system is in place and appears to work relatively well.

Each water point has a caretaker (a "responsable"). These people usually serve without pay and are selected by the users of the water point. The caretaker has an important role in preventing damage to the water system and minimizing maintenance costs, especially because the standpipe is usually the part of the system requiring the most maintenance. The person-in-charge is also the agent who must collect the tariffs to provide continuing operation and maintenance of the system and thus is critically important to sustaining the system.

### 8.2.2 The Proposed World Bank/BCEOM Lava Zone Project

Because there are virtually no sources of water available in the Lava Zone, other than the large springs at Mutobo and Mutera, a large-scale piped water delivery system is the only alternative other than rainwater catchment that is technologically feasible for supplying domestic water to this area. The proposed World Bank/BCEOM Project, therefore, will fill a pressing need.

There appear, however, to be a number of components in the World Bank project that have a low probability of being sustained. In addition to replacing the existing but now badly deteriorated A.I.D.R. gravity systems, the World Bank proposes to provide additional treatment and to include several pumped supplies.

Part of the treatment is to remove carbon dioxide gas from the water. This can be done with simple spray aerators, through which the water flows by gravity; thus, there will be no moving parts and no chemicals or power to be purchased. In addition, however, there is treatment to raise the pH of the water to decrease its acidity. This appears to be unnecessary from the point of view of the consumers, who do not seem to complain about the water. The major disadvantage of the low pH was that it corroded the steel pipes and the concrete of the original system. Plastic pipes will be used in the new system and will not be affected. The limited amount of concrete that is exposed to the water can be lined at modest cost to provide protection. The proposed treatment will have high operation and maintenance costs. Pumping and chemicals for treatment will require the regular input of large amounts of cash money.

The "high pressure" (really upper elevation) system adds relatively little to the service provided because the pipes from this system parallel the gravity system and are only a few kilometers from it. The pumped system may, however, be the only means of supplying areas to the west in Gisenyi Prefecture and, therefore, may be necessary.

To summarize, the proposed World Bank project appears to be the only technological water supply solution in the Lava Zone other than rainwater catchment, but in addition to the basic gravity system, the World Bank proposes to include several high cost, high technology components.

The affordability of the proposed project is questionable. The institutional study (Reference 4, pg. F.9) notes that an annual charge of 624 FRW per family is necessary to pay for Level 3 costs of a simple gravity system. Level 3 includes replacement costs, as well as operation and maintenance costs and thus is the lowest level that will truly sustain a system. The Level 3 costs for systems involving pumping or treatment are somewhat over 2,000 FRW per family annually. These are significant amounts of cash money to the rural population. Table B.2 on page B.6 of the institutional study (Reference 4) states that the disposable cash income in Ruhengeri Prefecture after purchasing food is only 1,500 FRW per family annually; thus, the cost of a pumped and treated water supply would exceed the average disposable income. The estimated disposable income appears to be too low but the costs for the water supply nevertheless are significant to the users.

In Section 5.3, it was noted that several organizations have found it extremely difficult to collect 100 FRW per family annually, even following intensive programs of community development ("sensibilisation"). It was reported that Electrogaz has had difficulty collecting an annual tariff of 900 FRW in the town of Gitarama and 100 FRW from the rural users of the Ichanya Global system. The proposed Lava Zone Project has been planned from the top down until now, and little community development work has been done to date. It is understood, however, that the crucial necessity of the community input is recognized and that a BCEOM specialist will arrive in country in early April to address this issue specifically. Nevertheless, even with the best of community development programs it appears unlikely that the proposed tariffs can be collected.

Appendix G of the institutional study attempts to demonstrate that the necessary tariffs can be reduced to acceptable levels in several hypothetical communes based on the following assumptions:

a. Users of improved springs will pay tariffs equal to one-half or one-third of the tariffs for users of piped systems, in other words that users of improved springs will subsidize the users of the piped water system.

b. There are 40, 110, or 200 improved springs in the hypothetical communes.

c. Self-help labor (umuganda) will also reduce the operating and maintenance costs significantly.

d. Individual connections will be installed for paying customers.

Experience to date has been that users of improved springs can hardly be persuaded to pay 50 FRW per family annually to maintain their local springs and it seems very doubtful that they would be willing to pay a much higher tariff to support a piped system that serves other people. The BCEOM list of water sources in the Lava Zone (see Section 6.10 of this report) included few springs and certainly nowhere near 40, 110 or 200 per commune.

Table G.2 on page G.7 of the institutional study, shows that the financial projection assumes that the cost of the spring developers (and some other workers) will be provided by self-help labor (umuganda). The umuganda program involves one half day per week of free labor on public works projects, but does not include the contribution of labor during the rest of the week. The spring developers require a salary in order to live and thus cannot contribute all of their labor free. Because most of the spring developers are paid by the communes, it can be considered that this charge will not be included in the tariffs, but the official policy of the Rwandan government is that rural water supplies are the responsibility of the users. It is, therefore, questionable whether a government subsidy will be available, especially if a significant number of additional spring developers must be hired to maintain the system.

Finally, Table G.2 projects that approximately one-third of the revenues will come from the 25 customers with metered, individual connections. It seems questionable that there are in fact this many persons in a commune who are willing to pay for a private connection. In addition, it is unclear that the cost of reading and maintaining the meters is included in the recurrent costs. The private connections will have to be metered to prevent those who have them from becoming merchants of water.

The proposed Lava Zone system was probably laid out to meet certain minimum engineering criteria that were established during the conception of the project. The engineering work that has been done appears to be sound and probably met the criteria that were established. It nevertheless appears that even the lean system that has been proposed is unaffordable at present.

The proposed project will be much more cost effective and thus have a much higher probability of being sustained, if the treatment and the high pressure components are deferred until some later date when incomes are higher and higher tariffs can, therefore, be afforded. Some of the money that is saved could be used to increase the size of the gravity system. Standpipes could then be located at more frequent intervals along this system, and some additional piped branches could be installed to provide greater coverage. The probability of the system being sustained would also be improved by intensifying the community development program so that the users understand why tariffs must be paid.

Consideration should be given to rainwater catchment systems, the only other water supply technology that appears feasible in the Lava Zone. The cost of the proposed World Bank Mutobo Spring system as given on page 172 of Reference 2.d. is 1,457 million FRW. The number of users is given on page 155 as 127,500 in 1985. The unit cost of the proposed high pressure system is thus:

1,457,000,000 FRW/127,500 people = 11,400 FRW per person.

For a family of six, this amounts to 68,400 FRW.

In Section 5.6 of this report, it was noted that a rainwater catchment system for a family in a typical house using a bamboo reinforced concrete cistern for storage costs approximately 15,000 FRW and might be reduced significantly by further experimentation on storage containers. Thus, it appears that the proposed piped water system is four and one-half times as expensive as rainwater catchment systems. It certainly will have a much higher operating and maintenance cost and a much lower probability of being sustained. Rainwater catchment systems will provide more water on an annual basis than the proposed piped system, and with much less time spent carrying water. For the cost of the proposed system, corrugated metal roofs could even be included for those families who do not already have them.

Unfortunately, the World Bank probably cannot lend money for rainwater catchment systems because there is no organization to pay the loan back. Money lent for the piped water system will be repaid by the Government of Rwanda.

### 8.2.3 Small Water Systems

The most successful water systems appear to have been those which were small, which include no pumping or treatment, and which were planned and built with the help of the users. Such systems are currently being sponsored in Ruhengeri Prefecture by Club 2/3 and by the Farming Systems Improvement Project and in other parts of Rwanda by SNV (the Dutch) and by CARE. Projects sponsored by these organizations follow the principles outlined in Section 8.2.1 above.

If the RRAM Project is to undertake water supply projects, it is recommended that these be subcontracted to one of the organizations that is already engaged in this type of work, because these organizations are familiar with the requirements and already have trained field staffs.

### 8.2.4 Rainwater Catchment

Rainwater catchment systems from the roofs of individual houses were discussed in detail in Section 5.6. This technology appears to be suitable in Ruhengeri Prefecture, except for the cost of the storage cisterns. Even with the high cost of the cisterns of the current design, the per-capita cost of rainwater catchment systems is estimated at only 2,500 FRW. This amount compares favorably with the per-capita costs of 3,000 FRW for piped systems from springs (see Section 6.11) and 11,400 FRW for the proposed World Bank system (see Section 8.2.2).

If rainwater catchment systems were to be as heavily subsidized as the other systems, they would probably be widely employed. If a breakthrough can be made which lowers the cost of the storage cisterns, then this technology might be widely adopted by the local population, even without a subsidy.

# Chapter 9

## CONCLUSIONS AND RECOMMENDATIONS

### 9.1 Water Balance

Water balance calculations demonstrate a varied set of environmental systems within Ruhengeri Prefecture. Relative values of rainfall, runoff, evapotranspiration, and infiltration have been determined for each of four watersheds in order to establish a baseline condition of water resource inventory.

### 9.2 Gauging Stations

The extremely variable relief, soils, and land use within the Prefecture produce equally variable climatic and water flow conditions within short distance. It is recommended that a modest extension of rain gauging, stream gauging, and sediment sampling be undertaken to improve the understanding of available water resources.

### 9.3 Rugezi Marsh

The Rugezi Marsh has several competing interests which have proposed development of this area. The interests include retaining its natural condition as water supply for Lake Bulera hydropower, marais development of peat soils for agriculture purposes, and mining of peat for fuel in energy production.

From a hydrologic view point, any development of the marsh will tend to increase total flow, flood peaks, and sediment transport. The fragile and irreversible nature of the marsh requires careful planning if it is to be developed beyond its present state.

### 9.4 Water Levels in Lake Bulera

A preliminary conclusion has been drawn regarding the cause of the lowered water levels in Lake Bulera. Releases for hydropower production have simply overreached the recharge capacity of the lake during past years. During the most recent four years, hydropower releases have reached a balance with inflow, and the lake has moved toward normal levels.

### 9.5 Arsenic in the Mining Wastes

Arsenic in the mining wastes of a tungsten mine are present in high quantities in sediment samples but not in water samples. The arsenic is not considered a health hazard in its present form. Periodic sampling is recommended, however, to monitor any future changes.

## 9.6 Erosion

Erosion and sedimentation and the attendant loss of crop productivity are clearly major problems. Emphasis should be placed on extending known erosion control techniques and on research which relates control measures to crop productivity and farmer acceptance.

## 9.7 Loss of Montane Forest

The montane forests within the Birunga Park have important hydrologic value as a buffer zone for the high rainfall and extremely steep slopes which characterize the volcanic mountains of the park. Degradation of the forests would cause increased flood peaks and erosion, which is already a problem, of the lava soils below the park.

## 9.8 Domestic Water Supply Programs

The RRAM Project probably should not get involved in domestic water supply programs because:

a. Despite the frequent comments about the unavailability of domestic water, there is generally reasonably effective coverage except in the Lava Zone. The Five-Year Plan reported that there were 1,594 water points in the entire prefecture in 1984. The socioenvironmental study found that 67.9 percent of the families interviewed were within one kilometer of a water point and that 90.3 percent were within two kilometers.

b. In the Lava Zone, the World Bank/BCEOM is proceeding with a piped water supply project that will serve the entire area. Any attempt to do a domestic water supply project in the Lava Zone may undercut the World Bank work, or at least be viewed as an attempt to do so.

c. Implementation of domestic water supply projects requires an operations oriented field staff to help motivate and organize the system users. The RRAM Project does not have a field staff of the type needed.

d. A water supply program would be an applied, operational program. Such a program would not fit well with the main focus of the RRAM Project, which is natural resource analysis, management, and policy development.

e. It seems somewhat questionable whether domestic water supplies is at the top of the farmers' priority list, except perhaps in the Lava Zone. In discussions of priorities with Bourgmestres and Agronomes in eight communes outside the Lava Zone, water was mentioned as a problem only once and there it was mentioned third. Agriculture and firewood were rather consistently mentioned as top priority issues. An intervention in these areas appears to be more likely to generate enthusiasm from the farmers.

f. The budget that the RRAM Project might be able to devote to a domestic water program is likely to be small compared with the budgets of the other organizations working in this field. Thus, any contribution that could be made will certainly be modest and perhaps even unnoticeable.

## 9.9 Suggested Type of Water Program

If a domestic water supply project is to be undertaken, emphasis should be placed on the sustainability of the system and especially on the institution that is developed to manage the water system, because the capability of this institution is likely to be the single most important determinant of whether the system will be sustained. Small simple systems should be used instead of large, complex systems. Any system requiring pumping or chemicals probably has a low probability of being sustained, and should be avoided. It would be more practical for the RRAM Project to contract such work out to an organization experienced in this type of work and with an existing field staff, rather than to try to develop the field staff itself.

## 9.10 Domestic Water Supply Technologies

The domestic water supply technologies that are feasible in Ruhengeri Prefecture are evaluated as follows:

a. Springs, with or without piped delivery systems, are probably the best choice of technology, where they exist within reasonable distances of the users. They have low costs, are well understood by the local people, and have a high probability of being sustained. Improved springs without piped distribution systems usually cost approximately 120 FRW ($2 U.S.) per person served. The local people rarely seem to improve them without a subsidy.

   Piped gravity water systems from springs have an average cost of 3,000 FRW ($38 U.S.) per user. To date, all of them have been subsized.

b. Wells are not applicable, except that a shallow well alongside a lake or river would be preferable to using the lake or river water directly.

c. Lakes and rivers contain water of poor sanitary quality and are not recommended as sources of domestic water supplies. To improve the quality of the water, treatment would be required. To provide greater quantities or access, water would have to be pumped. Treatment and pumping systems have a low probability of being sustained.

d. Rainwater catchment from the roofs of individual houses appears to be a promising technology, especially in the Lava Zone where the distances to water points are the greatest. Rainwater catchment appears to be understood by and acceptable to the users, but the cost of the storage cisterns is unaffordable. Even with the current cistern design, the cost of rainwater catchment systems is only approximately 2,500 FRW ($31 U.S.) per person and is thus less than the per-capita cost of a piped water system from a spring. Presumably, rainwater catchment systems would be widely used if they were subsidized at the same rate as piped water systems. The cost of storage cisterns might be reduced by alternative designs. Further investigation and development of this technology would be a worthwhile contribution.

## 9.11 The World Bank Project

The proposed World Bank Lava Zone Project will, in fact, improve the water supply situation in the Lava Zone, if it can be sustained. The per-capita cost of the proposed system is 11,400 FRW ($143 U.S.), which is relatively high. The operation, maintenance, and replacement costs, and the tariffs necessary to meet them, are so high that it seems unlikely that the users will pay them. Without the regular payments of the tariffs, the system is likely to be out of operation soon. This is especially true of the treatment and pumping, both of which require large cash inputs. The gravity system might be sustained somewhat longer.

The cost-effectiveness and probability of the proposed Lava Zone project being sustained would be improved by deferring the treatment and pumping parts of the project. The probability of the system being sustained will also be increased by a major community development effort to involve the user population in the planning and construction of the system.

It appears that the proposed piped water system is four times more expensive than providing each family with a rainwater catchment system. For the per-capita cost of the World Bank system, corrugated metal roofs could even be provided as well. The recurrent costs of the rainwater catchment systems and the probability of them being sustained also appear to be much more favorable than for the proposed piped water system. In addition, rainwater catchment systems appear to reduce the time and effort spent carrying water much more than the piped water system and can provide greater quantities of water during most of the year. Rainwater catchment therefore appears to be a much superior technology to the proposed piped water system. One factor favoring the World Bank project is that it can be funded because the government of Rwanda will repay the loan. There is no organization in place to repay a loan for rainwater catchment systems.

## 9.12 RRAM Exposure

It is recommended that a brief (two or three pages) resume of the RRAM Project be created for distribution to various government agencies and other organizations concerned, directly or indirectly, with environmental and development issues. Several pertinent organizations and individuals visited during this consultancy were unaware of the project's goals and accomplishments to date. A written resume of the project should help to stimulate interest and foster increased cooperation among government agencies and other international development groups.

# APPENDIX A

## Officials Contacted

## Officials Contacted

1. Dr. Rufus L. Chaney, Research Agronomist, Agricultural Research Service, United States Department of Agriculture, Building 318, Barc-East, Beltsville, MD 20705, U.S.A. (Tel. 301 344 3163),

2. Christof Scheiffele, Director, CARE International in Rwanda, B.P. 550, Kigali, Rwanda. Tel 2402.

3. Alphonse Klomberg, Chef du Projet Hydraulique Rurale, and Egbert Hamel, Coordinateur Technique du Projet Hydraulique Rurale, Association Neerlandaise d'Assistance au Development (SNV), Rue Depute Kajangwe 5, B.P. 1049, Kigali, Rwanda. Tel 5619.

4. Ed Rawson, Farming Systems Improvement Project (FSIP)

5. Vinh Van Pham, Civil Engineer, Farming Systems Improvement Project.

6. Gaetan Thibaut, Club 2/3, Hydraulique Rurale a Ruhengeri,

7. Telephore Bizimungu, Directeur, Direction Generale d'Eau, Ministere de Travaux Publiques et de l'Energie.

8. ____________________, Directeur, Direction General de l'Energie, Ministere de Travaux Publiques et de l'Energie.

9. Roland Perrier, BCEOM, B.P. 438, Kigali, Rwanda. Tel. 5461.

10. Jean Lemay, Canadian Volunteer, UNICEF/Centre de Formation en Nutrition de Ruhengeri, Appropriate Technology Project.

11. Ezechiel Munyaneza, Bourgmestre of Cyeru Commune, B.P. 4, Kirambo, Ruhengeri Prefecture.

12. David DuPras, USAID, Kigali, Rwanda. Tel.

13. Ed Toth, USAID, Kigali.

14. Michael Fuchs-Karsch, USAID, Kigali.

15. A. William Weber, Project Manager, Resources Analysis and Management (RRAM) Project, B.P. 9, Ruhengeri, Rwanda. Tel. 424 (in Ruhengeri).

16. Vincent Nyamulinda, Assistant Manager, Resources Analysis and Management (RRAM) Project, B.P. 9, Ruhengeri, Rwanda. Tel. 424 (in Ruhengeri).

17. Fred R. Weber, Forester, 5797 Bogart, Boise, Idaho, USA, Tel. (208) 344-1150.

18. Emile Karega, Geologist, MINITRAPE, Direction General d'Energie, Kigali. Tel. 3720 or 3706.

19. Nicolas Bavugirije, Chef du Bureau, Hydrologie et Climatologie, Kigali.

20. Reverien Rushemeza, Directeur de Genie Rural, Kigali.

21. Emmamiel Ngilira, Chef de Station, Climatologie, Aeroport, Ruhengeri.

22. Gabriel Ntawuruhunga, Chef de le Centrale Hydroelectrique Ntaruka.

# APPENDIX B

## References

1. Parr, James (Editor) et al., Land Treatment of Hazardous Waste, Noyes Data Corp., Parkridge, N. J., U.S.A., p. 52, 1983.

Contains a discussion of arsenic in the environment.

2. BCEOM. "Rénovation et extension des reseaux d'eau potable dans cinq centres secondaires et dans la region des laves," Ministère des Travaux Publiques et de l'Energie. Octobre, 1982.

These are the engineering studies conducted by the French firm BCEOM as a part of the World Bank First Water Project. The First Water Project included construction in five secondary towns, including Ruhengeri. The studies done of the Lava Zone system form the basis of funding the construction of this system as part of the Second Water Project.

a. Etudes socio-economiques.

b. Systemes existants et ressources en eau

c. Demande en eau.

d. Avant-projet sommaire et factibilite technique lere phase.

3. Steinkamp-Ferrier, Lucie. "Les Paysans et Leur Environnement en Prefecture de Ruhengeri," Projet RRAM de Ruhengeri, Juillet 1985-Fevrier 1986.

4. BCEOM-SAUR. "Etudes institutionelle de la gestion des adductions d'eau en milieu rural, Rapport Final," Ministere des Travaux Publiques et de l'Energie, Electrogaz, December, 1985.

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8. Association Internationale de Developpement Rural (A.I.D.R.). "Amenagement de Petites Sources dans le Milieu Rural au Rwanda, Fiches Signalitiques." Volume III, UNICEF-Government of Rwanda, 1982 (?).

9. Anonymous, "Projet Regional pour le IVe Plan Quinwuennal de Developpement 1987-1991," Republique Rwandaise, Juin 1985.

10. BCEOM. "Etude Complementaire sur les Ressources en Eau," Rapport 1-H1, Ministere des Travaux Publiques et de l"Energie, Juin, 1984.

11. Bureau National d'Etudes de Projects (BUNEP). "Project 'Petites Sources en Milieu Rural' Evaluation Reactualisation, Rapport Definitif," Republique Rwandaise, Ministere du Plan, Mars 1980.

12. Linn, Leslie. "A Summary of Agroecological Concerns for the Ruhengeri Prefecture, Rwanda," and Ruhengeri Resource Analysis and Management Project, Ruhengeri, Rwanda, Nov., 1985.

13. Schiller, Eric J. "Water Resources Survey," Ruhengeri Resource Analysis and Management Project, August 1985.

This study provided an overview of the major natural resource questions in Ruhengeri Prefecture and developed scopes of work for the current consultancy.

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15. Doorenbos, J. "Agro-meteorological Field Stations." Irrigation and Drainage Paper 27, Food and Agriculture Organization of the United Nations, Rome, Italy, 1975.

16. Willardson, L. S. "Exploratory Study of Rwanda's Wetlands (Small Marais Development)," Agricultural and Irrigation Engineering Department, Utah State University, Logan Utah, February 15-March 7, 1986, Kigali, Rwanda.

17. van den Branden, J.L. "Evolution entre 1958 et 1979 du Couvert Forestier et du Debit des Sources dans Certaines Regions du Rwanda," Geomines-Somirwa, Bruxelles, Octobre, 1981.

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a. "Marais Rugezi: Périmètre Pilote." 1972
b. "Rapport sur l'execution des travaux d'aménagement du marais pilote Rugezi." 1972/73
c. "Marais Rugezi: Perimetre Pilote: Etude des structures de production et de gestion."

# APPENDIX C

## Documents Reviewed

1. Roark, Paula Donnelly and Michael Godfrey. "Murambi/Muhura Water Systems Project Multi Year Plan 1986-1989," CARE International in Rwanda, Sept. 1985 (?).

This project has now been renamed "Byumba Southeast" and may include as many as five communes.

2. BCEOM. "Renovation et extension des reseaux d'eau potable dans cinq centres secondaires et dans la region des laves," Ministere des Travaux Publiques et de l"Energie. Octobre, 1982.

These are the engineering studies conducted by the French firm BCEOM as a part of the World Bank First Water Project. The First Water Project included construction in five secondary towns, including Ruhengeri. The studies done of the Lava Zone system form the basis of funding the construction of this system as part of the Second Water Project.

a. Etudes preliminaires

(1) Criteres techniques et economiques.

(2) Plans.

b. Plan directeur

(1) Etudes financieres, tarifaires et institutionelles.

(2) Plans.

3. Freeman, Peter H. "RRAM at Mid-Point, Report on a Technical Management Consultation," February 1986.

5. Wassmer, Patrick. "Recherches Gecmorphologiques au Rwanda, Etude de l'erosion des sols et de ses consequences dans la Prefecture de Kibuye," These de Doctorat de 3eme Cycle, Geographie, Strasbourg (France), Octobre 1981.

7. Wash Field Report No. 73. Training in Spring Capping for Field Agents in Zaire. Arlington, VA. WASH Project, 1983.

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9. Tenaille, Gerard and M. Denis. "Alimentation en Eau Potable en Milieu Rural. Renforcement des Institutions et Formation du Personnel," World Bank, Kigali, Rwanda, November, 1985. (But now dated January 21, 1986 and perhaps revised).

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C.F.N.R. a Ruhengeri," Centre de Formation en Nutrition de Ruhengeri, Mai, 1985.

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Explains what the World Bank intends to include in the Second Water Project.

13. Poinsignon, Georges. "Estimation des Pluviometries et des Ecoulements de Frequence Rare sur le Bassin de la Riviere Rugezi," Ministere de l"Agriculture et de l"Elevage, Direction du Genie Rural et de l'Hydrologie, Division Hydrologie, Republique Rwandaise, Fevrier, 1975.

14. Pourrut, P. "Bassin versant du Rugezi, Campagne de Mesures 1974," Rapport Provisoire, Ministere de l"Agriculture et de l"Elevage, Direction du Genie Rural et de l'Hydrologie, Division Hydrologie, Republique Rwandaise, Fevrier, 1975.

15. Habimana, Sebastien. "Les Tourbieres du Bassin versant des Lacs Bulera et Ruhondo (Kiguhu et Rugezi-Kamiranzovu)," Institut Pedagogique National, Section Maths-Geographie, Mai, 1978.

16. Dosseur, H. "Etude Hydrologique des Bassins Representatifs de Byumba et de Gitarama," Rapport Provisoire, Campagne 1969-1970, Office de la Recherche Scientifique et Technique Outre-Mer (ORTSOM), Bureau Central Hydrologique, Paris, 1971.

# APPENDIX D

## Memorandum

## Laboratory Analyses of Stream Water and Sediments Downstream of the Tungsten Mine at Gifurwe

CDM

environmental engineers, scientists
planners, & management consultants

CAMP DRESSER & McKEE INC

One Center Plaza
Boston Massachusetts 02108
617 742 5151

3 March 1986

SECID
Mr. Earle N. Buckley
400 Eastowne Dr.
Suite 207
Chapel Hill, NC 27514

Dear Mr. Buckley:

This report documents the study of three sediments and two water samples from the Nyamusanze River in Rwanda which were received in the CDM/Boston Laboratory.

| CDM LAB # | SAMPLE DESCRIPTION | DATE COLLECTED | DATE RECEIVED |
|---|---|---|---|
| 17715 | Midstream Nyamusanze River | 8/28/85 | 1/21/86 |
| 17716 | Sediment from River's Edge | 8/28/85 | 1/21/86 |
| 17717 | Sediment from Point 2m from River's Edge | 8/28/85 | 1/21/86 |
| 17718 | Dried Mine Tailings | 8/28/85 | 1/21/86 |
| 17719 | Midstream | 8/28/85 | 1/21/86 |

Data from analytical tests performed on these samples is reported on the following page. Chemical analysis of the river water showed no abnormalities. Analysis of the river sediments however showed high levels of arsenic present. The arsenic present in the river sediments was three to four times that found in the tailings sample. Since the exact situation of the mine tailings is not known (age, exposure to elements, etc.) it can only be surmised that the lower arsenic value of the tailings is due to natural leaching towards the river as the bank sediment and the river bottom accumulate the heavy metal.

The solid samples were examined by Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray (EDX) spectroscopy to determine composition and mineralogy. Photographs of SEM images and EDX spectra are enclosed for your examination.

The sample from the river's edge is a mixture of chiefly angular, irregular quartz ($SiO_2$) grains and flakes of muscovite mica (potassium aluminum silicate). Also present are small columnar grains of tourmaline (iron aluminum silicate).

The sediment 2m from the river's edge shows a very limited mineralogy, consisting almost entirely of muscovite plus traces of quartz and tourmaline. The mine tailings likewise consist chiefly of muscovite with traces of quartz, tourmaline, and a titanium or iron-titanium mineral, probably rutile or ilmenite.

Examination of the river's edge sediment under an optical microscope shows an abundance of opaque matter which doesn't contribute to the EDX spectrogram. This is believed to be organic matter.

In our opinion, this study indicates the deposition of potentially hazardous mining waste in the area of this operation. The river water does not appear to contain appreciably levels of contaminants, but this may be due to a large dilution effect, and the river current. The arsenic levels found in the sediments are problematic. The angular nature of the grains and the limited mineralogy are strongly indicative of tailings from a mining operation. Also, tungsten ores are often found in pegmatitic rocks. This type of deposit would therefore contain large amounts of feldspar, which is very conspicuously absent from these samples. The missing feldspar suggests to us that these are tailings from an ore-dressing operation. The angular shape and uniform small particle size likewise indicate crushing and screening which would also be part of such an operation.

Should you have any further questions concerning this report, please do not hesitate to contact me directly.

Sincerely,

James F. Occhialini

James F. Occhialini
Laboratory Supervisor

JFO/ek

# ANALYTICAL RESULTS

| SAMPLE DESCRIPTION:<br>CDM LAB NO: | #1 MID-STREAM<br>17715 | #2 SEDIMENT<br>17716 | #3 SEDIMENT<br>17717 | #4 TAILINGS<br>17718 | #5 MID-STREAM<br>17719 |
|---|---|---|---|---|---|
| PH, STND.UNITS | 5.9 | X | X | X | 6.1 |
| TOTAL ORGANIC CARBON, MG/L | 7. | X | X | X | 12. |
| TOTAL ARSENIC | <0.010 MG/L | 146 MG/KG DRY WT.BASIS | 116. MG/KG DRY WT.BASIS | 36. MG/KG DRY WT.BASIS | <0.010 MG/L |
| TOTAL VOLATILE SOLIDS, % BY WT. | X | 5.0 | 1.3 | 0.9 | X |
| * TOTAL SOLIDS, % BY WT. | X | 99.6 | 99.9 | 72.7 | X |

X - ANALYSIS NOT REQUESTED

*THESE NUMBERS REFLECT SAMPLE STATUS "AS RECEIVED"

# EPA METHOD 300

- ALL CONCENTRATIONS IN MG/L -

| SAMPLE DESCRIPTION:<br>CDM LAB NO: | #1 MID-STREAM<br>17715 | #5 MID-STREAM<br>17719 |
|---|---|---|
| **ANION:** | | |
| FLUORIDE | 0.20 | 0.17 |
| CHLORIDE | 7.3 | 5.8 |
| NITRITE-N | <0.10 | <0.10 |
| ORTHO-P | <0.10 | <0.10 |
| BROMIDE | <0.10 | <0.10 |
| NITRATE-N | 1.6 | 1.0 |
| SULPHATE | 8.7 | 6.6 |

ANALYTICAL NOTES:

CHROMATOGRAPHIC CONDITIONS:

| | |
|---|---|
| UNIT: | DIONEX 2000i |
| ANION COLUMN: | P/N 035311 (AS-4A) |
| GUARD COLUMN: | P/N 035310 (AG-4A) |
| DETECTOR: | CONDUCTIVITY |
| ELUENT: | 0.75 MM $NaHCO_3$/2.2 MM $Na_2CO_3$ |
| RANGE: | 30. US |
| PUMP VOLUME: | 1.8 ML/MIN. |
| SAMPLE LOOP: | 100 µL (APPROX.) |

# APPENDIX E

## Hydrologic Data

Table F-1

Average Monthly Rainfall
Precipitation Moyen Mensuel

millimeters

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ruhunde | 90.5 | 110.9 | 145.0 | 232.6 | 143.7 | 36.8 | 18.6 | 48.1 | 114.2 | 118.9 | 146.8 | 99.9 | 1306.0 |
| Rwankeri | 75.9 | 95.1 | 135.5 | 194.2 | 149.7 | 42.9 | 20.1 | 52.9 | 116.1 | 132.2 | 143.5 | 93.3 | 1251.4 |
| Kinoni | 76.6 | 98.3 | 128.7 | 152.1 | 127.7 | 41.6 | 15.5 | 72.7 | 114.7 | 134.0 | 132.7 | 84.0 | 1178.6 |
| Nemba (Nord) | 110.3 | 135.8 | 160.7 | 221.7 | 166.6 | 56.7 | 20.9 | 51.5 | 125.0 | 152.3 | 218.3 | 132.8 | 1552.6 |
| Ruhengeri | 79.3 | 102.1 | 145.5 | 199.0 | 160.3 | 50.1 | 25.8 | 55.9 | 115.3 | 153.1 | 150.7 | 98.4 | 1335.5 |
| Karisoke | 100.9 | 123.3 | 205.7 | 308.9 | 193.7 | 91.7 | 71.7 | 137.4 | 154.2 | 203.0 | 188.4 | 143.2 | 1922.1 |

Table F-2

Average Days of Rainfall
Nombre de Jours de Pluie Moyen

millimeters

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ruhunde | 10.5 | 11.9 | 13.7 | 19.5 | 14.5 | 4.2 | 2.1 | 5.7 | 11.7 | 14.0 | 16.2 | 11.4 | 135.4 |
| Rwankeri | 11.3 | 12.2 | 16.1 | 18.5 | 16.6 | 5.8 | 2.5 | 7.0 | 13.4 | 16.6 | 17.9 | 13.5 | 151.4 |
| Kinoni | 11.9 | 14.1 | 17.7 | 19.8 | 17.3 | 6.5 | 3.4 | 8.7 | 15.1 | 18.4 | 19.4 | 14.0 | 166.3 |
| Nemba (Nord) | 13.1 | 14.6 | 17.4 | 23.3 | 17.0 | 5.4 | 3.4 | 6.1 | 13.4 | 18.7 | 22.0 | 15.7 | 170.1 |
| Ruhengeri | 12.0 | 14.0 | 19.5 | 23.0 | 19.1 | 6.7 | 3.7 | 7.4 | 15.8 | 20.1 | 20.8 | 16.5 | 178.6 |
| Karisoke | 18.7 | 18.1 | 26.5 | 28.1 | 24.4 | 14.7 | 12.0 | 15.8 | 21.5 | 25.2 | 26.5 | 22.6 | 254.1 |

Table F-3

Maximum 24 Hour Rainfall
Maximum en 24 Heures de Pluie

millimeters

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ruhunde | 48.6 | 52.0 | 65.5 | 58.0 | 90.0 | 54.5 | 41.1 | 63.6 | 53.0 | 48.8 | 53.7 | 57.0 | 90.0 |
| Rwankeri | 95.0 | 61.4 | 85.0 | 104.0 | 83.5 | 42.0 | 40.0 | 52.0 | 56.0 | 70.2 | 47.7 | 70.0 | 104.0 |
| Kinoni | 52.7 | 45.5 | 38.6 | 50.1 | 50.0 | 45.0 | 28.7 | 45.0 | 40.6 | 43.6 | 38.2 | 58.5 | 58.5 |
| Nemba (Nord) | 62.6 | 98.0 | 54.8 | 69.3 | 61.6 | 124.2 | 49.4 | 99.0 | 65.3 | 46.8 | 50.3 | 52.0 | 124.2 |
| Ruhengeri | 48.0 | 55.0 | 50.0 | 68.3 | 63.0 | 56.2 | 64.4 | 46.2 | 42.8 | 48.3 | 63.5 | 52.0 | 68.3 |
| Karisoke | 49.1 | 50.0 | 47.7 | 64.2 | 41.7 | 43.2 | 53.4 | 64.8 | 36.3 | 44.7 | 59.1 | 38.8 | 64.8 |

Table F-4

Average Monthly Stream Flow
Debit Moyen Mensuel
Mukungwa (Ngaru)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 35.84 | 35.01 | 36.60 | 61.68 | 60.43 | 46.54 | 39.38 | 38.17 | 43.76 | 54.10 | 67.65 | 92.60 | 50.98 |
| 1984 | 40.90 | 41.45 | 45.60 | 49.80 | 43.80 | 37.05 | 34.30 | 33.20 | 35.40 | 39.80 | 43.20 | 40.90 | 40.45 |
| 1983 | 44.13 | 41.93 | 42.02 | 54.42 | 57.03 | 46.18 | 34.77 | 35.52 | 37.00 | 45.62 | 47.48 | 52.21 | 44.86 |
| 1982 | 37.44 | 40.21 | 38.95 | 63.51 | 60.29 | 52.85 | 43.59 | 36.74 | 35 36 | 40.62 | 47.51 | 52.26 | 45.82 |
| 1981 | 24.04 | 28.38 | 33.80 | 56.75 | 49.63 | 40.34 | 38.71 | 31.59 | 40.76 | 33.88 | 40.59 | 42.28 | 38.40 |
| 1980 | 17.63 | 22.61 | 23.85 | 23.74 | 36.46 | 37.49 | 16.67 | 18.99 | 21.68 | 25.64 | 38.13 | 30.95 | 26.15 |
| 1979 | 14.30 | 20.33 | 14.35 | 19.22 | 48.38 | 23.68 | 17.04 | | 18.27 | | 22.79 | | 22.04 |
| 1978 | 13.36 | 14.65 | 26.25 | 27.60 | 30.38 | 17.56 | 12.99 | 10.83 | 10.54 | 8.14 | 17.32 | 15.32 | 17.08 |
| 1977 | 17.80 | 18.38 | 19.35 | 31.30 | 26.60 | 18.79 | 13.36 | 11.65 | 12.71 | 12.24 | 28.44 | 17.18 | 18.98 |
| 1976 | 20.03 | 24.18 | 21.35 | 27.20 | 32.57 | 22.01 | 17.52 | 16.86 | 17.93 | 21.05 | 20.62 | 17.42 | 21.56 |
| 1975 | 20.70 | 21.00 | 22.00 | 37.41 | 32.98 | 20.20 | 16.00 | 14.60 | 18.00 | 27.00 | 23.00 | 26.00 | 23.24 |
| 1974 | 25.95 | 23.32 | 24.88 | 48.58 | 42.83 | 35.91 | 36.02 | 23.51 | 25.68 | 23.24 | 28.20 | 24.81 | 30.24 |
| 1973 | 21.55 | 18.65 | 21.43 | 39.05 | 51.66 | 26.39 | 21.00 | 20.18 | 28.24 | 27.29 | 36.13 | 27.84 | 28.28 |
| 1972 | | | | | | 28.29 | 19.90 | 18.50 | 18.83 | 19.76 | 28.58 | 24.42 | 22.61 |
| Monthly Average Moyen Mensuel | 25.67 | 26.93 | 28.49 | 41.56 | 44.08 | 32.38 | 25.80 | 23.87 | 26.05 | 29.11 | 34.97 | 35.71 | 30.76 |

## Table F-5

Average Monthly Stream Flow
Debit Moyen Mensuel
Mukungwa (Rwaza)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 5.88 | 5.63 | 5.68 | 8.28 | 10.50 | 7.63 | 6.17 | 5.08 | 6.04 | 10.13 | 10.79 | 9.30 | 7.59 |
| 1984 | 5.62 | 6.60 | 8.84 | 9.82 | 9.26 | 6.46 | 5.20 | 6.46 | 8.14 | 5.62 | 5.76 | 6.60 | 7.03 |
| 1983 | 6.11 | | 7.98 | 5.38 | | 5.48 | | | | | 5.48 | 7.48 | 6.32 |
| 1982 | | | | | | | | | | | | | |
| 1981 | 7.58 | 13.89 | 12.45 | 8.25 | 6.62 | 6.49 | 13.97 | 10.85 | 13.01 | 7.12 | 15.11 | 9.89 | 10.44 |
| 1980 | 6.12 | 6.74 | 6.11 | 6.10 | 5.83 | 8.90 | 8.34 | 6.56 | 7.01 | | | | 6.86 |
| 1979 | 7.28 | 7.52 | 8.15 | 8.22 | 11.05 | 11.57 | 11.16 | 9.99 | 10.47 | 8.65 | 8.79 | 7.70 | 9.21 |
| 1978 | 9.64 | 9.45 | 11.63 | 11.26 | 11.13 | 9.92 | 9.64 | 8.67 | 5.87 | 5.38 | 6.27 | 7.23 | 8.84 |
| 1977 | 9.24 | 9.46 | 9.78 | 10.67 | 10.77 | 9.20 | 8.59 | 8.57 | 9.27 | 9.35 | 12.07 | 11.35 | 9.86 |
| 1976 | 8.08 | 9.16 | 9.14 | 9.27 | 9.30 | 9.70 | 8.35 | 8.38 | 8.94 | 9.79 | 9.69 | 9.61 | 9.12 |
| 1975 | 8.51 | 8.61 | 8.52 | 9.81 | 9.99 | 9.01 | 8.20 | 8.13 | 8.93 | 10.10 | 9.68 | 9.40 | 9.07 |
| 1974 | | | | | | | | | | | | | |
| 1973 | 7.33 | 7.42 | 8.06 | 9.20 | 9.68 | 8.60 | 6.99 | 6.98 | 8.34 | 8.28 | 9.00 | 8.20 | 8.17 |
| 1972 | 7.57 | 7.44 | 8.32 | 8.41 | 8.56 | 8.07 | 7.13 | 5.69 | 5.89 | 6.33 | 7.62 | 7.84 | 7.41 |
| 1971 | 7.49 | 9.91 | 7.55 | 6.46 | 7.36 | 9.03 | 7.26 | 6.36 | 6.90 | 7.87 | 8.56 | 7.63 | 7.70 |
| 1970 | 6.60 | 6.18 | 6.04 | 8.28 | 8.70 | 7.44 | 6.60 | 6.04 | 6.46 | 6.04 | 7.02 | 7.16 | 6.88 |
| 1969 | 5.76 | 6.74 | 8.56 | 8.98 | 9.40 | 8.14 | 5.76 | 4.92 | 5.34 | 5.90 | 6.88 | 6.88 | 6.94 |
| 1969 | 5.76 | 6.74 | 8.56 | 8.98 | 9.40 | 8.14 | 5.76 | 4.92 | 5.34 | 5.90 | 6.88 | 6.88 | 6,94 |
| 1968 | 5.34 | 5.76 | 8.14 | 8.56 | 11.12 | 9.88 | 7.16 | 5.34 | 4.92 | 4.92 | 6.04 | 6.04 | 6.94 |
| 1967 | 4.50 | 4.22 | 4.50 | 5.06 | | 10.52 | 5.20 | 3.80 | 4.92 | 4.62 | 7.30 | 8.00 | 5.69 |
| 1966 | | | | | | | | | 5.76 | | 6.04 | 4.92 | 5.57 |
| Monthly Average Moyen Mensuel | 6.91 | 7.73 | 8.22 | 8.39 | 9.29 | 8.57 | 7.73 | 6.87 | 7.31 | 7.25 | 8.28 | 7.90 | 7.71 |

Table F-6

Average Monthly Stream Flow
Debit Moyen Mensuel
Rusomo (Rugezi)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | .71 | .70 | .69 | 2.25 | 2.35 | 1.24 | .75 | .58 | .63 | .85 | 1.05 | 1.12 | 1.08 |
| 1984 | 1.30 | 1.01 | 1.35 | 1.97 | 1.30 | .85 | .65 | .61 | .61 | .97 | 1.10 | .97 | 1.06 |
| 1983 | .93 | .74 | .77 | 1.33 | 1.72 | .96 | .70 | .66 | .78 | 2.00 | 2.22 | 2.06 | 1.24 |
| 1982 | .75 | .66 | .65 | 1.71 | 3.33 | 2.26 | .96 | .67 | .91 | 1.17 | 1.91 | 1.81 | 1.40 |
| 1981 | 1.04 | .81 | .78 | 1.63 | 3.19 | 1.44 | .85 | 1.07 | .97 | 1.03 | 1.15 | .82 | 1.23 |
| 1980 | .67 | .69 | .77 | 1.49 | 2.63 | 1.99 | .94 | .66 | .73 | .64 | 1.48 | 1.31 | 1.17 |
| 1979 | 1.20 | 1.57 | 1.61 | 1.83 | 2.40 | 1.78 | 1.14 | 1.11 | .67 | .59 | .64 | .66 | 1.27 |
| 1978 | 1.17 | 1.29 | 2.80 | 2.90 | 3.33 | 1.48 | .95 | .77 | .82 | 1.01 | 1.11 | 1.19 | 1.57 |
| 1977 | 1.74 | 1.61 | 1.40 | 1.92 | 2.12 | 1.38 | .93 | .86 | .86 | .71 | 2.15 | 2.10 | 1.48 |
| 1976 | .83 | .81 | .80 | 1.11 | 2.33 | 1.58 | .92 | 1.08 | 1.05 | .98 | 1.10 | 1.08 | 1.14 |
| 1975 | .80 | .75 | 1.07 | 2.85 | 2.17 | 1.46 | 1.01 | .85 | 1.65 | 2.91 | 1.68 | 1.28 | 1.54 |
| 1974 | .89 | .69 | 1.48 | 3.44 | 2.08 | 2.07 | 2.48 | 1.22 | 1.27 | .85 | .87 | .84 | 1.52 |
| 1973 | .67 | .78 | .66 | 1.47 | 2.50 | 1.54 | .68 | .55 | .86 | .91 | 1.95 | 1.20 | 1.15 |
| 1972 | .88 | 1.23 | 1.89 | 2.54 | 3.67 | 2.71 | 1.61 | .76 | .76 | .87 | 1.56 | 1.19 | 1.64 |
| 1971 | .67 | .60 | .58 | 2.40 | 3.48 | 1.78 | 1.12 | .73 | .68 | 1.08 | 1.07 | 1.00 | 1.27 |
| 1970 | .65 | .69 | .89 | 1.30 | 2.25 | 1.10 | .69 | .61 | .59 | 1.05 | .99 | .73 | .96 |
| 1969 | .59 | 1.20 | 1.97 | 1.45 | | .63 | | | | .57 | .57 | .63 | .95 |
| 1968 | .81 | 1.15 | 1.55 | 2.57 | | 1.69 | | | | | | 1.40 | 1.53 |
| 1967 | .51 | .42 | .39 | .77 | 2.81 | 1.50 | .77 | | | .93 | .93 | 1.76 | 1.08 |
| 1966 | .89 | .81 | 2.11 | 1.55 | 1.76 | .81 | .53 | .49 | .77 | .61 | .77 | .73 | .99 |
| 1965 | | | .85 | 2.33 | 1.76 | .89 | .55 | .44 | .57 | .89 | 1.01 | 1.15 | 1.04 |
| 1964 | 1.20 | .73 | .93 | 2.04 | 2.25 | .81 | .51 | .45 | .51 | .85 | .65 | .89 | .99 |
| 1963 | 2.73 | 1.30 | 1.15 | 2.81 | 2.72 | 3.59 | .89 | .42 | .73 | .53 | 1.04 | 1.55 | 1.62 |
| 1962 | | | .93 | 1.35 | | | | | | 2.18 | 3.77 | 1.97 | 2.04 |
| 1961 | .39 | .45 | .51 | | | | | | | | | | .45 |
| 1960 | 1.15 | .77 | .65 | 1.69 | 1.25 | .61 | .47 | .40 | .53 | .55 | .53 | .45 | .75 |
| 1959 | 1.05 | .93 | .85 | 1.69 | 2.73 | 1.30 | .63 | .53 | .85 | 1.45 | 1.62 | 1.05 | 1.22 |
| 1958 | .93 | .89 | 1.50 | 3.41 | 5.24 | 2.41 | 1.20 | .65 | .65 | .73 | .59 | 1.25 | 1.62 |
| 1957 | .69 | .97 | 1.76 | 1.55 | 3.50 | 2.41 | .97 | .97 | .61 | .63 | .81 | .89 | 1.31 |
| Monthly Average Moyen Mensuel | .91 | .84 | 1.13 | 2.02 | 2.66 | 1.61 | .94 | .68 | .81 | 1.03 | 1.20 | 1.11 | 1.24 |

Table F-7

Average Monthly Stream Flow
Debit Moyen Mensuel
Base-Cyohoha (Sud Rwerere)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 1.08 | 1.96 | 1.74 | 5.62 | 2.06 | .99 | .88 | 1.10 | 1.35 | 1.69 | 4.80 | 3.56 | 2.24 |
| 1984 | | | | | | | | | | | | | |
| 1983 | .94 | .98 | 1.55 | 3.37 | 1.61 | .97 | .90 | 1.03 | 1.18 | 2.02 | 2.85 | 2.00 | 1.62 |
| 1982 | 1.27 | 1.10 | 1.06 | 2.94 | 3.38 | 1.39 | .86 | | | 1.71 | 2.36 | 2.17 | 1.82 |
| 1981 | 1.02 | 1.11 | 3.17 | 7.16 | 5.88 | 1.36 | 1.06 | 2.09 | 1.56 | 1.63 | 1.73 | 1.84 | 2.47 |
| 1980 | 1.21 | 1.18 | 1.13 | 2.29 | 2.76 | 1.34 | .85 | .88 | 1.44 | 1.12 | 3.78 | 2.35 | 1.69 |
| 1979 | 2.55 | 4.12 | 3.82 | 6.03 | 6.50 | 2.15 | 1.73 | 1.30 | 1.11 | 1.04 | 1.68 | 1.31 | 2.78 |
| 1978 | 2.74 | 1.67 | 5.39 | 3.16 | 4.84 | 1.39 | 1.06 | 1.10 | 1.19 | 1.82 | 2.39 | 2.22 | 2.41 |
| 1977 | 2.55 | 1.68 | 1.68 | 3.83 | 3.12 | 1.20 | .97 | .82 | 1.14 | 1.30 | | | 1.83 |
| 1976 | 1.13 | | 1.59 | 2.90 | 2.38 | 1.35 | 1.15 | 1.14 | .98 | .92 | 1.56 | 1.12 | 1.47 |
| 1975 | 3.22 | 1.36 | 1.92 | 3.42 | 2.03 | 1.78 | 1.26 | 1.84 | 1.32 | 2.39 | 1.20 | 1.77 | 1.96 |
| 1974 | 1.15 | 1.13 | 1.90 | 3.26 | 2.16 | 3.02 | 2.76 | 1.39 | 1.63 | 1.26 | 1.79 | 2.07 | 1.96 |
| 1973 | 1.81 | 1.76 | 2.01 | 4.50 | 5.19 | 1.52 | .97 | .97 | 2.89 | 1.33 | 2.48 | 1.17 | 2.22 |
| 1972 | 2.70 | 5.43 | 5.74 | 6.08 | 5.44 | 4.32 | 2.28 | 2.65 | 2.14 | 2.77 | 5.00 | 2.60 | 3.93 |
| 1971 | 2.14 | 2.06 | 1.45 | 5.04 | 15.65 | 2.05 | 3.73 | 1.86 | 2.06 | 2.75 | 3.80 | 2.50 | 3.76 |
| 1970 | | | | | | | | | | | | | |
| 1969 | 4.20 | 8.85 | 6.32 | 4.60 | 6.04 | 3.80 | 2.30 | | | | 2.23 | 2.30 | 4.52 |
| 1968 | 2.99 | 5.13 | 8.56 | 12.30 | 7.72 | 6.04 | 4.00 | 4.10 | 3.35 | 3.90 | 4.30 | 3.44 | 5.49 |
| 1967 | 2.99 | 3.44 | 4.10 | 4.60 | 9.60 | 4.00 | 3.17 | 2.38 | 3.90 | 2.75 | 6.04 | 5.79 | 4.40 |
| 1966 | 3.17 | 5.02 | 4.40 | 8.70 | 4.91 | 3.44 | 2.83 | 2.99 | 4.10 | 3.35 | 3.71 | 3.17 | 4.15 |
| 1965 | | | | | | | | | | | | | |
| Monthly Average Moyen Mensuel | 2.16 | 2.82 | 3.20 | 4.99 | 5.07 | 2.34 | 1.82 | 1.73 | 1.96 | 1.99 | 3.04 | 2.43 | 2.82 |

Table F-8

Maximum Flood Flows
Debit Maximal Mensuel
Mukungwa (Ngaru)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 40.90 | 42.00 | 49.80 | 14.00 | 76.00 | 50.40 | 43.20 | 40.35 | 57.00 | 68.00 | 68.00 | 103.00 | 103.00 |
| 1984 | 46.80 | 51.00 | 82.70 | 75.00 | 64.50 | 40.90 | 40.35 | 48.00 | 39.80 | 49.20 | 67.30 | 55.40 | 82.70 |
| 1983 | 49.20 | 46.20 | 61.00 | 101.60 | 68.00 | 61.70 | 38.70 | 42.00 | 42.60 | 61.00 | 56.80 | 67.30 | 101.60 |
| 1982 | 40.90 | 47.20 | 58.90 | 110.10 | 68.00 | 68.00 | 51.00 | 49.20 | 54.00 | 49.80 | 63.80 | 63.80 | 110.10 |
| 1981 | 34.85 | 30.60 | 57.50 | 108.60 | 72.20 | 48.60 | 51.60 | 79.90 | 68.00 | 45.60 | 49.20 | 51.00 | 108.60 |
| 1980 | 21.60 | 29.20 | 40.90 | 27.40 | 70.10 | 116.00 | 27.00 | 28.80 | 25.66 | 45.00 | 61.00 | 35.40 | 116.00 |
| 1979 | 19.20 | 30.60 | 40.90 | 42.00 | 155.00 | 69.40 | 34.30 | | 20.30 | | 27.90 | | 155.00 |
| 1978 | 21.20 | 31.00 | 59.60 | 58.00 | 58.38 | 25.00 | 15.20 | 13.68 | 20.00 | 11.40 | 29.13 | 22.00 | 59.60 |
| 1977 | 24.70 | 22.50 | 23.40 | 63.80 | 58.90 | 54.70 | 18.00 | 15.20 | 17.20 | 18.40 | 71.50 | 24.30 | 71.50 |
| 1976 | 25.60 | 40.40 | 28.30 | 38.70 | 83.40 | 27.00 | 18.80 | 20.40 | 21.60 | 51.00 | 29.20 | 21.60 | 83.40 |
| 1975 | 22.50 | 25.60 | 28.30 | 69.40 | 128.59 | 33.75 | 22.50 | 19.60 | 22.90 | 56.80 | 38.10 | 51.60 | 128.59 |
| 1974 | 27.90 | 26.50 | 42.00 | 137.80 | 74.30 | 52.20 | 79.90 | 26.50 | 33.75 | 25.20 | 43.80 | 31.00 | 137.80 |
| 1973 | 35.40 | 32.65 | 26.50 | 84.10 | 111.50 | 33.75 | 24.70 | 22.00 | 45.00 | 32.65 | 56.80 | 33.20 | 111.50 |
| 1972 | | | | | 40.35 | 63.80 | 23.80 | 26.10 | 63.10 | 22.50 | 39.25 | 31.00 | 63.80 |
| 1971 | | | | | | | | | | | | | |
| Monthly Average Moyen Mensuel | 31.60 | 35.03 | 46.14 | 71.58 | 80.66 | 53.23 | 34.93 | 33.21 | 37.96 | 41.27 | 50.13 | 45.43 | |

Table F-9

Maximum Flood Flows
Debit Maximal Mensuel
Mukungwa (Rwaza)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Maximum Month |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 6.60 | 6.04 | 6.60 | 9.40 | 11.80 | 8.70 | 7.02 | 5.76 | 8.70 | 10.94 | 11.65 | 10.66 | 11.80 |
| 1984 | 6.88 | 7.72 | 9.54 | 11.22 | 10.38 | 8.42 | 5.76 | 7.58 | 9.26 | 6.60 | 6.18 | 7.02 | 11.22 |
| 1983 | 6.74 | 7.58 | 7.02 | 5.90 | 7.02 | 6.74 | 6.88 | 6.46 | 7.86 | 8.84 | 5.90 | 8.70 | 8.84 |
| 1982 | 9.40 | 9.70 | 9.70 | 8.40 | 9.40 | 9.10 | 8.85 | 8.55 | 11.30 | 8.85 | 8.85 | 7.44 | 11.30 |
| 1981 | 15.20 | 15.55 | 13.70 | 9.70 | 7.30 | 7.30 | 18.00 | 11.80 | 11.15 | 8.85 | 13.70 | 10.70 | 18.00 |
| 1980 | 6.70 | 7.40 | 6.60 | 6.70 | 8.00 | 10.20 | 9.40 | 8.60 | 7.60 | | | | 10.20 |
| 1979 | 8.00 | 8.70 | 9.40 | 10.04 | 13.24 | 12.60 | 12.92 | 10.84 | 11.84 | 10.04 | 9.12 | 8.97 | 13.24 |
| 1978 | 10.36 | 10.52 | 12.28 | 11.96 | 11.96 | 10.36 | 10.04 | 9.40 | 6.88 | 5.90 | 7.30 | 7.58 | 12.28 |
| 1977 | 9.56 | 9.88 | 10.36 | 11.48 | 11.64 | 9.56 | 9.26 | 9.12 | 9.56 | 10.04 | 14.04 | 13.08 | 14.04 |
| 1976 | 8.42 | 11.00 | 9.88 | 9.72 | 9.72 | 9.26 | 8.56 | 8.84 | 9.40 | 11.00 | 10.52 | 10.52 | 11.00 |
| 1975 | 8.70 | 8.98 | 8.84 | 11.48 | 11.00 | 10.20 | 8.70 | 8.86 | 9.40 | 11.64 | 10.52 | 10.36 | 11.64 |
| 1974 | | | | | | | | | | | | | |
| 1973 | 8.00 | 8.00 | 8.56 | 10.04 | 10.20 | 10.20 | 7.44 | 7.44 | 9.26 | 8.56 | | | 10.20 |
| 1972 | 8.00 | 7.72 | 9.40 | 9.40 | 9.72 | 8.84 | 8.00 | 6.18 | 6.46 | 7.16 | 8.70 | 8.84 | 9.72 |
| 1971 | 8.00 | 10.84 | 8.84 | 8.00 | 7.86 | 10.68 | 7.86 | 7.44 | 7.72 | 8.56 | 9.12 | 8.70 | 10.84 |
| Monthly Average Moyen Mensuel | 8.61 | 9.26 | 9.34 | 9.53 | 9.95 | 9.44 | 9.19 | 8.35 | 9.03 | 9.00 | 9.63 | 9.38 | |

Table F-10

Maximum Flood Flows
Debit Maximal Mensuel
Rusomo (Rugezi)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | .89 | .81 | 1.05 | 5.04 | 3.32 | 1.55 | .93 | .63 | .85 | 1.55 | 1.55 | 1.76 | 5.04 |
| 1984 | 1.45 | 1.30 | 2.97 | 3.41 | 1.62 | 1.01 | .89 | .73 | .69 | 1.55 | 2.18 | 2.18 | 3.41 |
| 1983 | 1.25 | 1.25 | 1.35 | 2.65 | 2.11 | 1.20 | .81 | .89 | 1.35 | 3.95 | 3.59 | 2.89 | 3.95 |
| 1982 | 1.50 | 1.20 | .90 | 3.70 | 4.79 | 3.30 | 1.25 | .85 | 2.25 | 1.50 | 3.95 | 3.40 | 4.79 |
| 1981 | 1.35 | .90 | 1.05 | 2.75 | 4.80 | 2.40 | 1.00 | 2.00 | 1.35 | 2.00 | 1.55 | .90 | 4.80 |
| 1980 | .97 | 1.10 | 1.40 | 2.18 | 4.16 | 6.32 | 1.20 | 1.01 | 1.25 | 1.15 | 4.58 | 1.83 | 6.32 |
| 1979 | 1.83 | 2.81 | 1.83 | 2.49 | 3.86 | 2.49 | 1.62 | 1.15 | .77 | .61 | .97 | .97 | 3.86 |
| 1978 | 1.69 | 2.65 | 4.90 | 3.86 | 5.00 | 1.76 | 1.15 | | 1.45 | 2.10 | 1.45 | 1.90 | 5.00 |
| 1977 | 3.77 | 4.69 | 2.18 | 3.14 | 3.05 | 3.59 | 1.05 | 2.57 | 1.50 | 1.20 | 4.16 | 2.89 | 4.69 |
| 1976 | 1.01 | .97 | 1.35 | 1.83 | 6.44 | 2.41 | 1.15 | 3.14 | 1.45 | 1.50 | 1.69 | 2.49 | 6.44 |
| 1975 | .97 | .94 | 1.65 | 6.38 | 3.23 | 2.11 | 2.68 | 1.10 | 3.39 | 6.12 | 2.33 | 1.62 | 6.38 |
| 1974 | 1.30 | 1.10 | 5.60 | 4.48 | 2.57 | 3.95 | 4.27 | 1.62 | 2.65 | 1.35 | 1.20 | 1.76 | 5.60 |
| 1973 | .81 | 1.35 | .85 | 2.81 | 3.86 | 2.73 | .85 | .63 | 1.90 | 1.50 | 3.95 | 2.41 | 3.95 |
| 1972 | 1.05 | 1.97 | 3.05 | 4.69 | 4.79 | 3.59 | 3.05 | 1.25 | 1.20 | 1.15 | 2.83 | 1.95 | 4.79 |
| 1971 | .97 | .97 | 1.10 | 3.86 | 3.95 | 4.16 | 1.35 | .97 | 1.30 | 3.50 | 1.40 | 2.18 | 4.16 |
| 1970 | | | | | | | | | | | | | |
| 1969 | | | | | | | | | | | | | |
| 1968 | | | | 6.80 | | | | | | | | | 6.80 |
| 1967 | | | | | 5.60 | | | | | | | | 5.60 |
| 1966 | | | 4.37 | | | | | | | | | | 4.37 |
| 1965 | | | | | 3.50 | | | | | | | | 3.50 |
| 1964 | | | | 5.12 | | 7.88 | | | | | | | 7.88 |
| 1963 | | | | | | | | | | | | | |
| 1962 | | | | | | | | | | | | | |
| 1961 | | | | | | | | | | | | | |
| 1960 | | | | 4.58 | | | | | | | | | 4.58 |
| 1959 | | | | 4.58 | | | | | | | | | 4.58 |
| 1958 | | | | | 10.16 | | | | | | | | 10.16 |
| 1957 | | | | | 4.90 | | | | | | | | 4.90 |
| Monthly Average Moyen Mensuel | 1.39 | 1.60 | 2.23 | 3.91 | 4.30 | 3.15 | 1.55 | 1.32 | 1.56 | 2.05 | 2.49 | 2.08 | |

Table F-11

Maximum Flood Flows
Debit Maximal Mensuel
Base-Cyohoha (Sud Rwerere)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 1.42 | 8.40 | 4.00 | 8.40 | 3.18 | 1.15 | .95 | | 2.03 | 2.90 | 8.40 | 6.07 | 8.40 |
| 1984 | 2.10 | 2.10 | 5.58 | 5.40 | 1.90 | | 1.95 | 1.95 | | 3.10 | | | 5.58 |
| 1983 | 1.15 | 1.25 | 4.85 | 8.40 | 3.62 | 1.10 | 1.00 | 1.96 | 2.03 | 3.77 | 8.40 | 2.97 | 8.40 |
| 1982 | 1.85 | 1.85 | 1.55 | 8.30 | 6.70 | 4.10 | 1.00 | 1.10 | 5.65 | 5.55 | 8.40 | 3.55 | 8.40 |
| 1981 | 1.30 | 2.90 | 8.40 | 8.40 | 8.40 | 1.90 | 1.35 | 4.70 | 2.05 | 1.95 | 1.95 | 2.15 | 8.40 |
| 1980 | 1.90 | 1.54 | 1.54 | 2.97 | 7.31 | 4.85 | .95 | 1.90 | 2.16 | 1.36 | 8.30 | 4.60 | 8.30 |
| 1979 | 8.40 | 8.40 | 8.40 | 8.40 | 9.35 | 3.70 | 2.55 | 1.90 | 1.25 | 1.15 | 2.48 | 1.72 | 9.35 |
| 1978 | 8.40 | 3.40 | 8.40 | 8.40 | 8.40 | 1.60 | 1.20 | 1.42 | 1.48 | 3.32 | 4.00 | 4.85 | 8.40 |
| 1977 | 7.60 | 3.70 | 2.42 | 8.40 | 8.40 | 1.54 | 1.10 | 1.48 | 1.60 | 3.70 | 8.40 | | 8.40 |
| 1976 | 1.36 | | 3.92 | 8.10 | 8.40 | 1.78 | 3.04 | 1.48 | 1.10 | 1.36 | 7.13 | 2.55 | 8.40 |
| 1975 | 6.07 | 1.60 | 2.76 | 8.68 | 8.40 | 2.03 | 2.29 | 2.55 | 2.55 | 8.30 | 1.54 | 5.99 | 8.68 |
| 1974 | 1.78 | 1.30 | 7.90 | 6.50 | 2.83 | 7.50 | 6.33 | 1.60 | 2.55 | 1.78 | 2.49 | 3.25 | 7.90 |
| 1973 | 3.25 | 3.33 | 3.25 | 8.20 | 17.00 | 2.55 | 1.05 | 1.42 | 8.30 | 2.23 | 4.00 | 1.90 | 17.00 |
| 1972 | 4.00 | 9.30 | 9.30 | 11.97 | 7.86 | 7.56 | 4.80 | 7.86 | 3.90 | 5.35 | 7.02 | 3.80 | 11.97 |
| 1971 | 3.53 | 4.60 | 4.80 | 10.20 | 4.00 | 3.80 | 9.30 | 2.38 | 3.17 | 9.15 | 7.86 | 3.44 | 10.20 |
| Monthly Average Moyen Mensuel | 3.61 | 3.83 | 5.14 | 8.05 | 7.05 | 3.23 | 2.59 | 2.41 | 2.84 | 3.66 | 5.74 | 3.60 | |

Table F-12

Minimum Low Flows
Debit Minimal Mensuel
Mukungwa (Ngaru)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 31.00 | 29.00 | 28.80 | 38.70 | 50.40 | 42.00 | 34.30 | 32.65 | 34.85 | 39.80 | 66.60 | 68.00 | 28.80 |
| 1984 | 37.05 | 36.50 | 39.25 | 38.15 | 37.05 | 31.00 | 26.50 | 25.20 | 32.65 | 33.75 | 37.05 | 33.75 | 25.20 |
| 1983 | 38.70 | 38.15 | 37.05 | 43.50 | 48.60 | 35.95 | 33.75 | 32.65 | 30.60 | 34.85 | 38.70 | 45.20 | 30.60 |
| 1982 | 30.10 | 33.20 | 33.20 | 38.15 | 49.80 | 18.00 | 39.25 | 30.10 | 29.20 | 31.00 | 33.75 | 47.40 | 18.00 |
| 1981 | 18.80 | 26.50 | 24.70 | 29.70 | 34.30 | 36.50 | 22.90 | 22.50 | 31.00 | 29.20 | 35.40 | 30.15 | 18.80 |
| 1980 | 12.10 | 13.40 | 19.20 | 18.80 | 18.80 | 26.50 | 12.70 | 12.70 | 18.80 | 18.40 | 25.60 | 26.50 | 12.10 |
| 1979 | 9.78 | 16.00 | 5.40 | 7.50 | 15.60 | 13.68 | 9.78 | | 16.20 | | 18.40 | | 5.40 |
| 1978 | 11.40 | 9.78 | 17.20 | 18.80 | 19.20 | 15.20 | 11.73 | 8.15 | 7.83 | 6.90 | 11.08 | 12.05 | 6.90 |
| 1977 | 15.20 | 16.40 | 16.40 | 19.20 | 18.80 | 14.80 | 11.08 | 10.10 | 11.40 | 10.10 | 15.20 | 13.35 | 10.10 |
| 1976 | 18.00 | 20.40 | 18.80 | 22.50 | 21.20 | 18.80 | 16.00 | 15.20 | 16.40 | 16.80 | 16.00 | 15.20 | 15.20 |
| 1975 | 19.20 | 18.00 | 18.80 | 18.80 | 20.40 | 15.20 | 14.80 | 13.03 | 14.40 | 16.80 | 16.80 | 18.00 | 13.03 |
| 1974 | 23.40 | 21.20 | 20.40 | 34.85 | 31.00 | 29.20 | 26.10 | 21.20 | 22.00 | 21.60 | 21.60 | 20.40 | 20.40 |
| 1973 | 18.40 | 16.80 | 18.80 | 22.00 | 31.00 | 20.40 | 19.60 | 18.40 | 21.60 | 24.30 | 25.20 | 24.30 | 16.80 |
| 1972 | | | | | 26.10 | 22.90 | 17.20 | 16.40 | 16.00 | 16.80 | 19.60 | 20.40 | 16.00 |
| 1971 | | | | | | | | | | | | | |
| Monthly Average Moyen Mensuel | 21.78 | 22.72 | 22.92 | 26.97 | 30.16 | 24.30 | 21.12 | 19.87 | 21.64 | 23.10 | 27.21 | 28.82 | |

Table F-13

Minimum Low Flows
Debit Minimal Mensuel
Mukungwa (Rwaza)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 5.20 | 5.20 | 5.00 | 6.60 | 8.84 | 6.88 | 5.62 | 4.50 | 4.30 | 8.70 | 10.38 | 8.70 | 4.30 |
| 1984 | 5.10 | 5.20 | 8.00 | 8.40 | 8.28 | 5.20 | 4.90 | 5.00 | 6.74 | 5.20 | 5.62 | 5.90 | 4.90 |
| 1983 | 5.76 | 6.18 | 5.62 | 4.70 | 5.62 | 4.20 | 4.20 | 4.40 | 5.20 | 5.10 | 5.00 | 6.46 | 4.20 |
| 1982 | 8.00 | 8.15 | 7.45 | 7.15 | 8.40 | 7.85 | 6.60 | 5.00 | 9.40 | 6.04 | 5.34 | 6.60 | 5.00 |
| 1981 | 6.30 | 12.75 | 9.90 | 7.15 | 5.75 | 5.75 | 6.30 | 8.85 | 9.00 | 5.90 | 10.05 | 8.30 | 5.75 |
| 1980 | 5.50 | 5.20 | 5.80 | 5.50 | 4.60 | 7.70 | 7.00 | 5.30 | 5.90 | | | | 4.60 |
| 1979 | 6.18 | 6.46 | 6.32 | 6.18 | 6.60 | 8.02 | 10.04 | 8.98 | 9.88 | 7.58 | 8.42 | 6.74 | 6.18 |
| 1978 | 9.25 | 8.70 | 10.36 | 10.84 | 10.36 | 9.56 | 9.25 | 7.16 | 5.34 | 4.92 | 5.48 | 7.02 | 4.92 |
| 1977 | 8.98 | 9.26 | 9.12 | 10.20 | 9.72 | 8.98 | 8.00 | 8.28 | 8.98 | 8.98 | 10.04 | 10.36 | 8.00 |
| 1976 | 7.86 | 8.28 | 8.56 | 8.98 | 8.98 | 8.42 | 8.00 | 8.00 | 8.00 | 8.84 | 8.98 | 9.12 | 7.86 |
| 1975 | 8.00 | 8.28 | 8.28 | 8.70 | 8.26 | 8.28 | 7.86 | 8.42 | 9.12 | 9.12 | 8.84 | 8.56 | 7.86 |
| 1974 | | | | | | | | | | 7.86 | 9.72 | 8.70 | 7.86 |
| 1973 | 6.74 | 6.88 | 7.58 | 8.14 | 8.84 | 7.44 | 6.60 | 6.32 | 6.88 | 7.58 | | | 6.32 |
| 1972 | 7.16 | 7.16 | 7.77 | 7.58 | 6.60 | 7.02 | 5.90 | 5.20 | 5.20 | 5.90 | 6.82 | 6.60 | 5.20 |
| 1971 | 6.74 | 8.14 | 6.46 | 5.62 | 6.88 | 7.72 | 6.74 | 5.90 | 6.18 | 7.44 | 8.00 | 7.02 | 5.62 |
| 1970 | | | | | | | | 4.64 | | | | | 4.64 |
| 1969 | | | | | | | | 4.50 | | | | | 4.50 |
| 1968 | | | | | | | | | | 4.36 | | | 4.36 |
| 1967 | | | | | | | | 3.50 | | | | | 3.50 |
| Monthly Average Moyen Mensuel | 6.91 | 7.56 | 7.59 | 7.55 | 7.70 | 7.36 | 6.93 | 6.11 | 7.15 | 6.90 | 7.90 | 7.70 | |

Table F-14

Minimum Low Flows
Debit Minimal Mensuel
Rusomo (Rugezi)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | .61 | .63 | .61 | .77 | 1.62 | .93 | .63 | .55 | .55 | .61 | .77 | .85 | .55 |
| 1984 | 1.01 | .80 | .93 | 1.45 | 1.01 | .69 | .61 | .55 | .57 | .69 | .81 | .81 | .55 |
| 1983 | .73 | .61 | .57 | .97 | 1.20 | .81 | .61 | .61 | .61 | .65 | 1.62 | 1.45 | .57 |
| 1982 | .65 | .60 | .60 | .65 | 2.65 | 1.30 | .80 | .60 | .55 | 1.00 | 1.20 | 1.30 | .55 |
| 1981 | .95 | .70 | .65 | .80 | .90 | 1.00 | .75 | .70 | .80 | .80 | .85 | .75 | .65 |
| 1980 | .61 | .61 | .65 | .81 | 1.50 | 1.25 | .73 | .57 | .59 | .57 | .61 | 1.01 | .57 |
| 1979 | .81 | 1.00 | 1.05 | 1.55 | 1.69 | 1.25 | .97 | .77 | .61 | .57 | .57 | .61 | .57 |
| 1978 | 1.05 | .89 | 1.50 | 2.49 | 1.83 | 1.15 | .77 | | .65 | .81 | .89 | 1.01 | .65 |
| 1977 | .81 | 1.20 | 1.20 | 1.35 | 1.45 | 1.10 | .77 | .63 | .69 | .61 | 1.10 | 1.40 | .61 |
| 1976 | .65 | .73 | .69 | .73 | 1.25 | 1.01 | .77 | .65 | .93 | .81 | .73 | .85 | .65 |
| 1975 | .69 | .69 | .73 | 1.10 | 1.55 | 1.01 | .77 | .73 | .73 | 1.97 | 1.25 | .97 | .69 |
| 1974 | .73 | .61 | .77 | 2.11 | 1.83 | 1.40 | 1.62 | .89 | .89 | .73 | .73 | .73 | .61 |
| 1973 | .59 | .55 | .61 | .65 | 1.69 | .89 | .57 | .49 | .51 | .63 | .81 | .93 | .49 |
| 1972 | .77 | .85 | 1.20 | 1.45 | 2.81 | 2.11 | .89 | .63 | .61 | .69 | .93 | .85 | .61 |
| 1971 | .55 | .36 | .42 | 1.25 | 2.97 | 1.01 | .69 | .57 | .55 | .77 | .85 | .77 | .36 |
| 1970 | | | | | | | | | .53 | | | | .53 |
| 1969 | | | | | | | | | | | .51 | | .51 |
| 1968 | | | | | | | | | | | | | |
| 1967 | | | .36 | | | | | | | | | | .36 |
| 1966 | | | | | | | | .44 | | | | | .44 |
| 1965 | | | | | | | | .42 | | | | | .42 |
| 1964 | | | | | | | | .44 | | | | | .44 |
| 1963 | | | | | | | | .39 | | | | | .39 |
| 1962 | | | | | | | | | | | | | |
| 1961 | | | | | | | | | | | | | |
| 1960 | | | | | | | | .39 | | | | | .39 |
| 1959 | | | | | | | | .47 | | | | | .47 |
| 1958 | | | | | | | | | | .55 | | | .55 |
| 1957 | | | | | | | | | | .55 | | | .55 |
| Monthly Average Moyen Mensuel | .75 | .72 | .78 | 1.21 | 1.73 | 1.13 | .80 | .57 | .65 | .77 | .89 | .95 | |

Table F-15

Minimum Low Flows
Debit Minimal Mensuel
Base-Cyohoha (Sud Rwerere)

cubic meters/second

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | .95 | .95 | .85 | 1.60 | 1.15 | .90 | .80 | | .85 | 1.25 | 2.22 | 2.38 | .80 |
| 1984 | 1.20 | .95 | 1.25 | 1.30 | .90 | | .85 | 1.15 | | 1.25 | | | .85 |
| 1983 | .80 | .85 | .85 | 1.30 | 1.05 | .90 | .85 | .85 | .85 | 1.01 | 1.15 | 1.20 | .80 |
| 1982 | 1.00 | .90 | .90 | 1.00 | 1.35 | 1.00 | .80 | .80 | .85 | 1.00 | 1.05 | 1.05 | .80 |
| 1981 | .85 | .85 | 1.00 | 2.75 | 4.50 | 1.05 | .95 | 1.35 | 1.35 | 1.50 | 1.55 | 1.55 | .85 |
| 1980 | 1.05 | 1.05 | .95 | 1.00 | 1.42 | .95 | .80 | .80 | .90 | .90 | 1.05 | 1.30 | .80 |
| 1979 | 1.30 | 1.60 | 1.30 | 4.34 | 3.85 | 1.48 | 1.36 | 1.00 | 1.05 | 1.00 | 1.10 | 1.05 | 1.00 |
| 1978 | 1.54 | 1.05 | 2.09 | 1.78 | 1.54 | 1.20 | .95 | 1.00 | .95 | 1.05 | 1.15 | 1.30 | .95 |
| 1977 | .90 | 1.05 | 1.00 | 1.60 | 1.10 | 1.05 | .90 | .00 | .85 | .00 | 2.62 | | .00 |
| 1976 | 1.00 | | 1.05 | 1.54 | 1.60 | 1.15 | .90 | .90 | .90 | .85 | .85 | .90 | .85 |
| 1975 | 1.42 | 1.20 | 1.20 | 1.09 | 1.36 | 1.78 | 1.05 | 1.78 | .90 | 1.10 | 1.00 | .90 | .90 |
| 1974 | 1.00 | 1.00 | 1.00 | 1.72 | 1.48 | 1.20 | 1.36 | 1.25 | 1.20 | 1.15 | 1.48 | 1.34 | 1.00 |
| 1973 | 1.50 | 1.54 | 1.42 | 1.90 | 2.49 | 1.00 | .90 | .85 | .95 | 1.05 | 1.25 | .95 | .85 |
| 1972 | 1.87 | 2.30 | 2.68 | 2.68 | 3.44 | 3.26 | 1.80 | 1.52 | 1.52 | 1.73 | 2.75 | 1.66 | 1.52 |
| 1971 | 1.52 | 1.32 | .82 | 1.66 | 4.00 | 1.14 | 1.14 | 1.59 | 1.52 | 1.66 | 1.87 | 1.45 | .82 |
| 1970 | | | | | | | | | | | | | |
| 1969 | | | | | | | | | | | | 1.26 | 1.26 |
| 1968 | | | | | | | | | | | | 2.30 | 2.30 |
| 1967 | | | | | | | | 2.15 | | | | | 2.15 |
| 1966 | | | | | | | | 2.23 | | | | | 2.23 |
| 1965 | | | | | | | | 2.68 | | | | | 2.68 |
| Monthly Average Moyen Mensuel | 1.19 | 1.19 | 1.22 | 1.82 | 2.08 | 1.29 | 1.03 | 1.29 | 1.05 | 1.10 | 1.51 | 1.37 | |

Table F-16

Runoff Coefficients *
Coefficient d'Ecoulement

Percent

| Year<br>An | Base | Ngaru | Rwaza | Rugezi |
|---|---|---|---|---|
| 1985 | | | | |
| 1984 | | 54.0 | 30.0 | 13.0 |
| 1983 | 22.8 | 48.0 | | 13.6 |
| 1982 | | 52.0 | | 18.0 |
| 1981 | 34.0 | 50.0 | 40.0 | 16.0 |
| 1980 | 22.8 | 29.5 | | 15.0 |
| 1979 | 40.0 | | 37.0 | 16.6 |
| 1978 | 31.6 | 21.8 | 30.4 | |
| 1977 | | 20.0 | 31.0 | 18.2 |
| 1976 | 24.6 | 26.0 | | 21.3 |
| 1975 | 29.6 | 27.0 | 31.0 | 18.0 |
| 1974 | 26.0 | 32.7 | | 17.7 |
| 1973 | 26.3 | 30.4 | 26.0 | 13.5 |
| 1972 | 48.7 | | 26.6 | 20.3 |
| 1971 | 49.2 | | 24.8 | 15.6 |
| Average<br>Moyen | 32.3 | 35.6 | 30.8 | 16.7 |

* Based on Hydrological yearbooks.
Donnees du Annuaires Hydrologiques

## POWER PRODUCTION AT THE NTARUKA HYDROELECTRIC PLANT

### THOUSAND KILOWATT HOURS EACH MONTH

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total | Average | Maximum | Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | 28247 | 24022 | 26765 | 27560 | 28405 | 23931 | 26615 | 24818 | 25647 | 25535 | 26400 | 27185 | 315130 | 26261 | 28405 | 23931 |
| 1974 | | | | | 27770 | | 26931 | 26424 | 27423 | 29743 | 27169 | 32134 | 197594 | 28228 | 32134 | 26424 |
| 1975 | 29461 | 28238 | 30171 | 28418 | 31248 | 30737 | 32618 | 30983 | 31092 | 31537 | 31909 | 32951 | 369363 | 30780 | 32951 | 28238 |
| 1976 | | | 34152 | 32850 | 34391 | 34402 | 35394 | 36357 | 35946 | 35955 | 36430 | 36118 | 351995 | 35200 | 36430 | 32850 |
| 1977 | 36319 | 36196 | 40076 | 39330 | 41116 | 40790 | 38619 | 37584 | 37796 | 39419 | 39323 | 40179 | 466747 | 38896 | 41116 | 36196 |
| 1978 | 41985 | 37357 | 42902 | 44172 | 40337 | 42714 | 47014 | 26906 | 8134 | 6205 | 18267 | 24043 | 380036 | 31670 | 47014 | 6205 |
| 1979 | | 23712 | 25230 | 25156 | 23769 | 24749 | 28948 | 27884 | 25212 | 27198 | 26120 | 16227 | 274205 | 24928 | 28948 | 16227 |
| 1980 | 16471 | 15504 | 16611 | 15516 | 17558 | 17282 | 17514 | 16024 | 18007 | 17221 | 17480 | 19477 | 204665 | 17055 | 19477 | 15504 |
| 1981 | 17479 | 9488 | 2281 | 5312 | 11002 | 13096 | 25094 | 6899 | 9395 | 14292 | 19032 | 9183 | 142553 | 11879 | 25094 | 2281 |
| 1982 | 16530 | 22373 | 10472 | 23940 | 4682 | 4530 | 15855 | 9695 | 17690 | 21609 | 9183 | 9545 | 166104 | 13842 | 23940 | 4530 |
| 1983 | 15577 | 30293 | 22823 | 29445 | 17231 | 20027 | 26912 | 14976 | 21392 | 17217 | 16692 | 21655 | 254240 | 21187 | 30293 | 14976 |
| 1984 | 26774 | 42724 | 20784 | 28977 | 12548 | 13620 | 28715 | 32880 | 22609 | 21124 | 19525 | 21248 | 291528 | 24294 | 42724 | 12548 |
| 1985 | 22228 | 18764 | 21440 | 19500 | 18985 | 20407 | 27220 | 26009 | 25412 | 24853 | 22418 | 25401 | 272637 | 22720 | 27220 | 18764 |
| Average (Note 2) | 25107 | 26243 | 24476 | 26681 | 23772 | 23857 | 29035 | 24418 | 23520 | 23993 | 23842 | 24257 | 283600 | 25149 | | |
| Maximum (Note 2) | 41985 | 42724 | 42902 | 44172 | 41116 | 42714 | 47014 | 37584 | 37796 | 39419 | 39323 | 40179 | 466747 | 38896 | | |
| Minimum (Note 2) | 15577 | 9488 | 2281 | 5312 | 4682 | 4530 | 15855 | 6899 | 8134 | 6205 | 9183 | 9183 | 142553 | 11879 | | |

Notes:

1. Averages are based on the available data, i.e. the sum of the available data divided by the number of entries.
2. The annual average, maximum and minimum are calculated columnwise.