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Lecture Notes 2002

IWRM Group Work

Integrated Water Resources Management

July 2002

Contents

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1 Scope of the work

The Mupfami Basin is a fictitious watershed situated somewhere in the Southern African region. There is a serious absolute shortage of water resources to be expected in the future. The absolute shortage is aggravated by the fact that also the quality of the available water resources is on the decrease. Due to discharges of domestic, agricultural and industrial waste into the river, large problems have arisen with regard to the water quality conditions.

A few characteristics of the prevailing problems in the Mupfami catchment:

(i) The presence of a large group of poor, rural people with limited access to domestic water and with historically no access to irrigation water and with a poor level of agricultural technology (rain-fed hazards, unbalanced use of fertiliser, poor soil conservation, erosion);

(ii) The presence of an economically powerful group of commercial estate farmers, employers of large numbers of workers, who are willing and capable to invest, provided that this will result in sustainable production (for themselves);

(iii) Rapidly growing towns with a lack of basic needs including domestic water supply and sewerage system and main producers of organic water pollution;

(iv) An increase in industrial production, with related environmental pollution;

(v) The interest of a mining industry to start activities in the catchment, which will bring considerable employment but also bring threads to the water quality (sulphuric acid, heavy metals, cyanide etc.)

(vi) Governmental institutions with limited capacity and no funds;

(vii) A legal framework based on stimulating private initiative and restricted Government intervention;

(viii) Water rights established on the "date priority" system, in which early settlers have the first access to water.

At present the country is in disarray and water legislation has not yet been approved although policy principles have been formulated. Policy principles, options for strategic approaches and institutional arrangements are reflected in Annex VII and can further be traced in your reader on “Water Law and Institutions”. The Government, however, has still limited ideas on how to translate these policy principles in to strategies and institutional arrangements.

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The National Government has decided to undertake a feasibility study for the identification of the most effective management strategy to improve the water quantity and water quality situation in the region, at minimum costs. The feasibility study should include the most appropriate organisational framework required for the monitoring, supervision and management of the water quantity and quality in the country and the sample catchment. For the execution of this feasibility study the National Government has hired a few teams of experts to produce independently and in competition several management instruments to overcome the chaos in the country in the Mupfami catchment.

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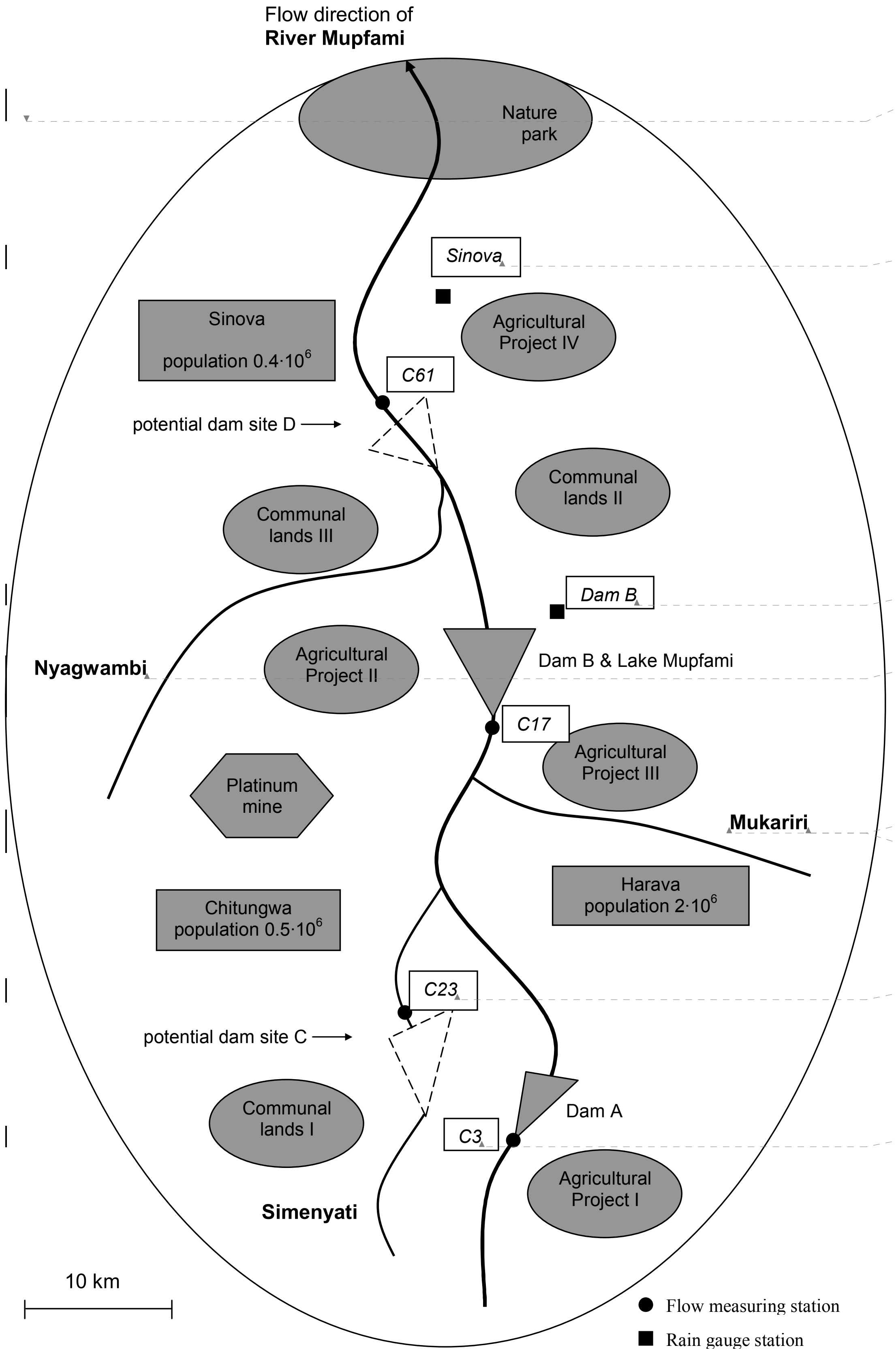
Figure 1.1 (next page) Schematic map of the Mupfami catchment



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2 General information

NOTE
The basin has been derived from physical features of especially the Manyame basin and to a lesser extent of the Mupfure basin in Zimbabwe. Some physical and social-economic data have been improvised. Please, be aware, that although some aspects of the following description may resemble the real situation in the respective basins, the case will in practice not offer any real solutions neither can any existing pattern in the real situation give the full lead to a solution of the case.

2.1 Physical and social economic conditions

The Mupfami catchment is situated in the country Mababwe. The total area of the catchment amounts to approximately 7000 $(km)^2$. The general elevation ranges from about 1,500 m upstream to about 750 m downstream. The river and most of its tributaries are ephemeral (sometimes dry) and flood flows are only registered between November and May.

Two distinct seasons are experienced; a hot wet summer period from October to March with average temperatures of 25ºC and a cold dry period for the remainder of the year with average temperatures of 15ºC. The mean annual rainfall for the relevant part of the catchment is about 800 mm/year with a total average runoff of approximately 80 to 100 mm/year and a coefficient of variation of approximately 100%.

The catchment's population is estimated to be about 4 million people spread over settlements ranging from urban centres to communal areas (Annex II). The major towns in the area are Harava, Chitungwa and Sinova. Agriculture and industry are the dominant economic activities with industry, mining and tourism playing less dominant, but substantial roles.

2.2 A quick overview

Starting from the upstream side the Mupfami river forms the border between Communal[1] Lands I on the left bank and Agricultural[2] project I on the right bank (Annex III, IV). Government dam A could supply these cores, although at present the dam is used for urban water supply. A potential dam site C is located on the main tributary to the upstream Mupfami River and could be utilised for any purpose or whatsoever, provided that construction would render sufficient return (Annex V).

Further downstream we find the rapidly growing cities Harava and Chitungwa. The towns are confronted with a deteriorating level of coverage of basic needs including domestic water supply and

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1 Communal Lands represent large groups of poor, rural people with limited access to domestic water and with historically no access to irrigation water and with a poor level of agricultural technology (rain-fed hazards, unbalanced use of fertilizer, poor soil conservation, erosion) applied on relatively marginal soils.

2 Agricultural Projects represent economically powerful groups of commercial estate farmers, employers of large numbers of workers, who are willing and capable to invest, provided that this will result in sustainable production (for themselves);

sewerage system and are main producers of organic waste water and other potential pollutants. The Dam B (governmental) is the main supply of drinking water to the towns. The dam also supplies Government water to agricultural projects II, III, IV.

A permit is requested for the establishment of a platinum mine near Chitungwa. The mine will be located upstream of the Dam B and may produce high levels of toxic pollutants. The platinum mine will employ 10,000 persons, will have a great economic spin-off and will use at full capacity a maximum of $10 * 10^6$ m^3/month from Dam B. A special concern, however, is that the mine has applied for a license to evacuate processed water on a tributary to the Mupfami River.

Downstream of Dam B one can find Communal Lands III on the left and Communal Lands II on the right bank. A potential dam, hereafter named Dam D, could supply these projects. The commercial farmers of Agricultural Project IV have requested for a permit for the establishment of the potential dam, referred to as Dam D, to be financed through private funding. The commercial farmers are prepared to donate 20% of the yield of the dam to the communal farmers free of charge, provided that the water is going to be used for irrigation. Dam D could also be used to meet the increasing domestic water demand of towns Harava, Chitungwa and Sinova. Sinova is located just downstream of the potential site of dam D. In the case of supplying the domestic water for Harava and Chitungwa the water has to be pumped back over a distance of approximately 125 km and 400 m uphill.

Finally, the Mupfami flows into the nature reserve. The nature reserve is heavily depending on the preservation of some base flow to protect the wildlife. Also, some natural variability would contribute to the performances of the aquatic ecosystem. Ecologists have recommended the government that a 12% of what would be the natural flow will not bring damage to the current situation, if only the flow is not get lower than 3 Mm^3/month. Furthermore, a stable groundwater table is required for the preservation of the dolomite caves present within the nature reserve. The nature reserve is very important for the tourism in the area. Tourism is the sector with the second highest revenue return (after agriculture).

The Mupfami catchment does not flow into the ocean, although it leaves the country of which the Mupfami catchment is a part. The government has a bilateral long term agreement that at it will provide at least 5 Mm^3/month, as long as the reservoir content of dam B has not reached the dead storage level. The downstream country is negotiating with the government to get more.

2.3 Domestic and industrial waste disposal

One of the big problems is the fact that a number of larger industries such as a fertiliser industry are located in or around Harava. The wastewater of these industries is at the moment discharged without any treatment into the River Makuriri, a tributary to the Mupfami.
The water quality in the rivers is, in many cases, not up to the standards (see Annex VI).

In all major cities there is a central sewage system, to which 90% of the households are connected. Treatment of domestic water for Harava and Chitungwa takes place in two sewage treatment plants, which are quite overloaded. Pump capacities of the wastewater pumps are gravely insufficient often resulting in untreated water being disposed of. (See article). The wastewater of Sinova is discharged without any treatment into the Mupfami river and thus poses a threat to the integrity of the water quality in the nature park.

The eutrophication of Lake Mupfami has created an explosive growth of water hyacinth, which at the end of the summer, when Lake Mupfami is spilling is resulting in massive movements of thousands of tons of water hyacinths over the spillway of Dam B, clogging up the return channel. This channel is not designed for taking up this type of stresses and besides, the excess water can not move freely through the return channel and is flowing back to the toe of the dam thus causing a serious threat of a complete dam failure (Annex VI).

The Department of National Parks, assisted by the Provincial Water Engineer, has taken up the annual duty of "cleaning" up the Lake chemically. Efforts of mechanically removing the water hyacinth are undertaken, but machinery and manpower are gravely insufficient. It is to be expected that the majority of the normally floating water hyacinth is sinking down to the bottom of the Lake after its exposure by round-up.

In the small villages, a minority of the population has been provided with sceptic tanks. Some families have installed Blair-toilets, but the majority of the population is still using open toilets. There is no treatment of domestic wastewater in these cases. The water supply for smaller towns and other rural communities is mainly organised through groundwater abstraction.

2.4 Administration and public services

Governmental water management institutions are traditionally organised on administrative boundaries. The Mupfami catchment is spread over two administrative provinces and five districts.

A province is headed by the provincial Governor and public administration is carried out through the provincial and district offices of Local Government in conjunction with decentralised offices of the national sector Ministries.

At present and in the past the Office of the Provincial Water Engineer carries out the water management function. Competencies are clear, but both human and financial resources are lacking to the extent that authorities are more and more turning to survival strategies. Planning is completely absent and conflicting interests are settled randomly.

Water rights are allocated through the Administrative Court on the sole criteria of economic viability. There is a link to hydrology but it is a weak one.

The Government is confronted with the difficult situation that an organisational structure is required within a very short time to address structural long-term problems in a politically acceptable, but also adequate and sustainable way.

Annex VII presents further details regarding the organisational aspects of the country with Mupfami catchment as a pilot area.

2.5 Monitoring and modelling

The hydrological data available for the Mupfami catchment are available for approximately 45 years:

- at four locations monthly runoff data are available;
- at three locations monthly rainfall data are available;
- at one location average monthly pan evaporation data are available.

The locations are shown in the schematic map of the catchment, on page 2. In Annex 1, the tables with the data are given, but the data are also digitally available, from the hydrological department of the government.

The water department of the government has made a water resources system simulation model of the Mupfami catchment. The model uses monthly time steps and is made available to the consultants. As it is programmed in EXCEL, the consultants are free to make adjustments to the programme.

3 Terms of reference

The Government of Mababwe invites the IHE-participants to carry out a feasibility study to identify the most effective IWRM plan in order to improve the situation in the Mupfami catchment, part of their country.

The IWRM-plan should be in accordance with the international principles, concepts and tools of Integrated Water Resources Management as offered in the module Water Law and Institutions. Furthermore, the produced IWRM-plan, as an advisory framework for the future organisation must consist of:
(i) water quantity aspects,
(ii) water quality aspects and
(iii) institutional, administrative and financial aspects.

3.1 Water quantity aspects

Reallocations and new developments should serve the political priorities: communal and small holder development, resettlement and rural and urban industrialisation. On the other hand it is not acceptable to undermine the financial resource base of both the government and the stakeholders. The government has decided that it will make its decisions for new investments in the water management of the Mupfami catchments, based on the current situation and the expected situation in 2020. The government expects that the changes in climate do have a negligible influence in comparison to the changes in economy and population growth.

1. Inventory of the current problems.
- How often are there shortages?
- Are these shortages acceptable: Who, what is the victim and to what extent?

2. Forecast of autonomous developments between now and 2020.

3. Definition of policy alternatives.
- Should new dams be built and/or should demands be managed?
- On what basis are these policy alternatives preselected?

4. Framework for choosing between different policy alternatives.
- Where do experts decide and where do policy makers decide?

5. Choice of preferred policy alternative.
- On what indicators is the decision making process based?
- What is the contribution of modelling in the decision making process?
- Are water quality aspects relevant in the decision making? If so, how?

6. Suggestions for an improved monitoring system and data management system.

3.2 Water quality aspects

The IWRM-plan should include an identification of the most effective management strategy to improve the water quality situation in the catchment at minimum costs, including the monitoring, operation and maintenance aspects. Specifically, the following items should be tackled:

1. Inventory of waste discharges from cities + industries and proposals for sanitation of these waste streams (see Annex.VI for details industries)
2. Inventory of non-point sources of pollution, specifically nutrients and pesticides from agriculture and proposed abatement measures (see Annex.VI)
3. Overview of the effects of the sanitation measures on the river and lake systems (e.g using models). Especially the eutrophication of lake Mupfami should be tackled; at the same time the integrity of the ecological quality of the nature park must be secured.

3.3 Institutional, administrative and financial aspects

The following outputs are required:

1. Advise on the formulation and the establishment of a water sector reform and on the production of a new legal and institutional framework. Describe the principles that should rule new legislation and take special aim at the mutual interaction between those principles.

2. Design a National Water Resources Management Strategy which gives due attention to:

- Commercialisation of the water sector;
- Water pricing and water services pricing;
- Cost recovery;
- Functional decentralisation and co-ordination;
- New and equitable water allocation criteria;
- Representation of stakeholders.

There should be a clear answer to the following questions:

a. What are the common problems in the country, based upon the situation in this sample river basin?
b. What are the possible development and management scenarios to tackle the identified problems?
c. What measures are selected in order of priority and which financial means are generated and allocated for the respective measures. (What is the time horizon of the respective measures?)
d. What trade-offs are going to be made. How are the winners going to compensate the losers (think about power, water and profit sharing).

3. Formulate a decentralisation approach with a focus on this sample river basin with special attention on:

- Stakeholder participation
- Water management within hydrological boundaries
- Cost recovery
- Integrated and co-ordinated river basin planning of water quality, water quantity and

environmental integrity.

It is advisable to think carefully about problems of transition.

4. Compose an integrated river basin management plan for this sample river basin. Give due attention to the integration of water quantity, water quality and environmental integrity. Design a water allocation scenario in which new principles of water allocation are introduced. Give special attention to equity and cost recovery.

NOTE

The government is fully aware of the limited time and lack of data. Therefore, the government is more interested in the approach and underlying principles rather then absolute figures and accuracy of estimations. The government expects inventiveness and justified assumptions. Missing pieces of information should be acquired from literature or the appointed resource persons. These resource persons are Dr.ir. De Groen for water quantitative aspects, Dr. Kelderman for water qualitative aspects and Drs.ing. Jaspers for institutional and administrative aspects.

4 Organisation

4.1 Programme of the group work

The group work is carried out during the period 2 July 2001 – 26 July 2001. During this period the participants are fulltime assigned to the group work. The group work reports (the IRWM-plans) are to be handed in by the **23th of July 2001**. A detailed schedule of activities is presented in table 4.1.

The group work itself will be introduced on Monday afternoon the **1th of July 2001**. The participants will be introduced to the case. The participants are. Each team is expected to produce an IWRM-plan. Make sure that the various disciplines are evenly distributed over the teams. The teams are expected to select a chairperson who will chair the meetings with the government, and will also supervise the integration of the report to the government.

Ms. De Groen, our special "consultant", will act as a resources person for all the teams on water quantity issues. She will instruct the operation of the WAFLEX-model, that has been made for this particular catchment (description in Annex VIII).

Presentations on the inception report will be held on Friday morning the **5th of July 2001**. The government expects per team a preliminary plan of approach, time schedule and a possible subdivision in subgroups (concentrating on e.g. water quantity aspects, water quality aspects, institutional and administrative aspects). The government suggests that each subgroup, if applicable, elects a co-ordinator for: a) contacts between the different subgroups; b) contacts with the government.

The following presentations on the progress will be held in principle each Friday morning. Each group gets 30 minutes to present, followed by a discussion. On Friday the **26th of July 2001** the final IWRM-products will be presented to a panel; each group gets 45 minutes to present. The final plans will be checked on its accordance with the Terms of Reference agreed upon. The technical reliability, economic feasibility and political implications will be taken into consideration. The final plans will be compared and the most appropriate one will be selected for 'implementation'.

NOTE

The participants are expected to organise as much as possible themselves. This is one of the key-elements of the educational objectives of the group work: organising and participating in a multidisciplinary team. The role of the IHE staff supervisors will focus on the introduction of the group work, the offering of facilities and advise and finally the assessment and evaluation of the group work.

Table 4.1: Detailed schedule IWRM Group work (maybe adapted to the course of events)

	Date	Component	Time	Room
	Mon 1/7	*Introduction to the case*	13.45-15.30	
	Fri 5/7	*Presentation inception report* Team A: 8.45-9.30 Team B: 9.45-10.30 general discussion	8.45-12.30	
	Fri 12/7	*Presentation on progress (30 min. presentation)* Team B: 8.45-9.30 Team A: 9.45-10.30 general discussion	8.45-12.30	
	Fri 19/7	*Presentation on progress* Team A: 8.45-9.30 Team B: 9.45-10.30 general discussion	8.45-12.30	
	Fri 26/7	*Presentation of the final IWRM-products (45 min. presentation)* Team B: 8.45-9.30 Team A: 9.45-10.30 general discussion	8.45-12.30	

4.2 Expected output

The government expects an **integrated** report; for this the chairperson and the subgroup co-ordinators have a special task. However, each individual consultant will be responsible for delivering a definite part of the final report, on a specific selected subject of the group work.

The report is to be submitted on or before the **23th of July 2001**, and should have a format of not more than **50 pages** (main document).

4.3 Appraisal of the groupwork

Group work objectives

The group work is meant as an instrument to integrate the different subjects and skills the participants have mastered during their courses. The participants are challenged to actually apply and demonstrate their acquired knowledge and skills.

The underlying educational principle of a group work method is that the participants learn by doing instead of reading/listening to how it should be done. The educational objective of the group work is to train the participants in:

- carrying out an integrated water resources study (under time pressure, with a limited availability of information)
- participating in a multidisciplinary team, which involves (among others) the set-up of a work plan, working according to a work plan, the distribution of tasks
- presenting and reporting on the study.

Tasks of participants

The task of the participants in the group work is to contribute to the formulation of a National Water Resources Management Strategy and to an Integrated Water Resources Management plan (IWRM-plan) for a sample river basin and to work out specific details of the plan and strategy.

The main tasks in the study are:
- to conduct an integrated problem analysis and to formulate study issues,
- to formulate a study approach,
- to work out in sufficient detail alternative solutions to the identified problems and issues,
- to integrate the proposed solutions into a Strategy and a IWRM-plan,
- to report on the study and
- to present progress and results of the study.

Marking of the groupwork

The teams will get a mark for their performance. The mark will be based on an evaluation of three aspects of their performance:

(i) *Content*
- approach
- inventiveness
- underlying principles
- quantitative justification

(ii) *Organisation*
- planning/execution of study
- team work

(iii) *Presentation*
- oral presentation
- report

5 Literature

Boxtel, A. van, Hoevenaars, J. and Koudstaal, R., 1993. Incomana Case Study. IHE lecture notes HH 369/98/1.

Department of Water Affairs and Forestry, 1997. White Paper on a National Water Policy for South Africa.

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Poko, B., 2000. 'Water allocation criteria under the new legislation in Zimbabwe' MSc thesis DEW 113

Savenije, H.H.G., 1996. Water Resources Management, Concepts and Tools. IHE lecture notes WERM 011/96.

Shoniwa, S., 1996. Review of water resources, water use and water rights in the Mupfure Basin. IHE M.Sc. Thesis HH 277

Available in the WERM groupwork library (see red table opposite of secretary's office)

Title	Author
Hazards and Opportunities	Ian Scoones et Al
Dambo Farming in Zimbabwe	Richard Owen, Katherine Verbeek, John Jackson and Tammo Steenhuis
Rural Water Supplies and Sanitation	Peter Morgan
Balancing Rocks	Carlos Lopes
Small-Scale Agriculture in Zimbabwe	E.E. Whingwiri, K. Mashingaidze, M. Rukuni
Lake Chivero A Polluted Lake	N.A.G. Moyo
Water for Agriculture in Zimbabwe	E. Manzungu, A. Senzanje, P. van der Zaag
The State of Zimbabwe's Environment	M. Chenje, L. Sola, D. Paleczny
Water in Southern Africa	M. Cheje, M. Z. Chivasa, A.S. King, E. Laisi
The Southern African Environment	S. Moyo, P. O'Keefe and M. Sill
Small-Scale Agriculture in Zimbabwe	E.E.Whingwiri, M. Rukuni, K. Mashingaidze, C.M. Matanyaire
The Practice of Smallholder Irrigation	E.Manzungu, P. van der Zaag
Virtual Water, as a water demand management tool: the Mupfure river Basin Case	N.L. Nyagwambo
Integrated Water Management: Harare Water Supply Study for Kunzwi and Manyame Dams	Hodson Makurira
Water Demand Management in Zimbabwe	M.C. Visser
Application of reservoir modelling to hydrotopes identified by remote sensing	Piotr Wolski
Urban Sanitation in Zimbabwe and the relation to environmental pollution	Dr. P. Taylor, Eng. N.R. Mudege
Preliminary Analysis for the Mupfure Experimental Catchments	Musariri Musariri
Integrated Water Management: Harere Water Supply study for Kunzwi and Manyame Dams	Hodson Makurira
Map of Zimbabwe: Chegutu	
Map of Zimbabwe: Chegutu	
Map of Zimbabwe: Harare	
Map of Zimbabwe: Harare	
Water for Agriculture	Mandel Training Centre
Hardrock Hydrogeology of the Nyatsime Catchment	Blessing Mudzingwa
Pesticides in Zimbabwe	Charles F.B. Nhachi, Ossy M.J. Kasilo

Annex I-A RAINFALL DATA

These data are also made available in digital format (data mupfami.xls).

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STATION NAME: Sinova ZONE: Long.

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YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APRIL	MAY	JUN	JULY	AUG	SEPT	TOTAL
50/51	8.1	76.5	125.7	170.7	52.3	32.8	9.1	27.7	0.8	0.0	7.4	3.6	514.7
51/52	85.3	30.2	90.7	251.0	250.4	42.4	14.2	7.4	0.3	0.0	0.0	11.4	783.3
52/53	31.2	144.3	117.3	226.3	214.1	217.4	16.8	0.5	0.0	0.0	0.0	0.0	967.9
53/54	9.7	197.1	172.0	314.5	198.1	76.5	10.9	0.3	0.0	0.0	0.0	5.1	984.2
54/55	10.4	96.3	255.0	184.2	132.6	137.9	26.7	3.6	5.6	3.0	0.0	0.0	855.3
55/56	11.7	83.6	195.6	240.8	175.5	296.7	40.6	13.2	24.6	2.0	15.5	4.8	1104.6
56/57	33.0	210.8	178.1	231.6	112.0	122.4	22.1	16.5	0.0	0.0	3.0	13.5	943.0
57/58	46.5	41.4	166.9	466.3	256.5	14.5	73.7	0.0	4.3	0.3	0.0	19.6	1090.0
58/59	32.3	72.4	149.4	143.5	205.7	73.4	3.8	5.3	14.2	0.5	0.0	8.6	709.1
59/60	2.3	112.5	160.5	119.6	119.9	13.7	77.2	45.5	9.1	0.0	0.0	0.0	660.3
60/61	14.0	49.8	220.0	169.9	170.2	131.1	55.6	0.0	7.6	4.8	0.3	26.7	850.0
61/62	1.5	186.4	159.8	396.7	205.5	78.0	73.2	0.3	0.0	0.0	0.0	0.0	1101.4
62/63	0.0	171.5	310.9	142.7	274.6	108.7	29.2	0.0	6.4	0.0	0.0	0.0	1044.0
63/64	49.5	73.4	114.6	218.4	92.5	50.3	2.8	0.0	0.0	0.0	2.5	0.0	604.0
64/65	4.6	46.5	200.2	199.1	136.7	6.6	3.8	2.8	0.0	0.0	0.0	7.6	607.9
65/66	27.9	93.5	55.9	92.2	360.4	80.0	58.9	7.4	0.8	0.0	3.3	3.6	783.9
66/67	13.5	79.0	113.8	195.3	240.3	194.6	9.9	7.4	24.9	0.5	23.4	2.0	904.6
67/68	23.4	71.1	93.5	50.7	81.3	8.6	21.3	4.1	0.0	0.0	0.0	0.0	354.0
68/69	10.7	81.5	240.8	229.1	141.7	137.7	8.6	3.0	0.0	0.0	4.6	3.0	860.7
69/70	44.5	252.0	116.8	67.6	23.1	99.8	0.0	0.0	0.0	0.0	0.0	19.8	623.6
70/71	5.6	225.6	78.7	280.4	200.2	7.6	2.5	9.7	0.0	0.0	0.0	11.4	821.7
71/72	32.0	63.2	89.1	273.3	122.0	122.8	73.7	10.5	0.2	0.3	0.0	5.3	792.4
72/73	33.2	45.3	25.8	148.0	80.3	83.7	6.4	8.3	0.0	0.2	0.0	0.0	431.2
73/74	36.7	112.5	261.0	167.7	263.1	176.0	40.5	9.3	3.2	8.6	0.1	0.1	1078.8
74/75	32.5	173.3	292.3	153.8	227.1	35.6	50.2	0.0	0.0	0.0	0.0	11.2	976.0
75/76	7.6	86.1	166.7	165.9	165.4	163.8	110.5	17.8	2.4	0.0	0.0	14.5	900.7
76/77	18.8	48.1	117.1	157.7	265.2	150.3	65.3	0.0	0.0	0.0	0.0	30.8	853.3
77/78	9.0	88.7	255.3	302.4	158.1	405.5	78.3	7.8	0.0	3.2	0.0	0.0	1308.3
78/79	40.3	119.1	151.9	176.6	66.5	96.8	19.6	0.0	0.0	0.0	0.0	0.0	670.8
79/80	50.0	60.0	270.0	137.9	100.0	199.7	76.3	0.1	0.0	1.5	1.3	11.4	908.2
80/81	30.1	116.0	172.9	99.5	309.3	115.3	26.3	0.1	0.0	0.0	0.0	10.5	880.0
81/82	61.7	95.6	50.4	169.9	119.9	44.3	3.9	26.0	0.0	3.0	0.0	0.0	574.7
82/83	80.0	48.7	137.2	157.9	61.5	44.1	14.9	14.7	0.0	2.5	0.5	0.0	562.0
83/84	19.2	56.6	123.3	101.1	129.3	106.3	28.0	22.8	0.0	2.0	0.0	13.0	601.6
84/85	10.0	91.6	224.2	231.0	116.5	192.2	2.3	7.5	0.0	4.0	0.0	13.0	892.3
85/86	49.3	42.9	199.2	204.9	162.4	146.9	58.4	0.0	0.0	0.0	0.0	0.0	864.0
86/87	40.3	75.2	174.2	94.1	46.9	79.9	0.0	0.3	0.0	0.0	0.2	3.6	514.7
87/88	6.4	29.4	96.5	188.7	197.3	204.1	56.4	18.8	15.4	7.5	0.0	0.0	820.5
88/89	36.8	49.1	166.5	360.3	370.9	95.6	10.7	0.0	0.0	0.0	33.0	0.0	1122.9
89/90	31.2	42.4	88.5	178.1	231.6	49.6	47.9	0.3	0.0	0.0	6.6	2.7	678.9
90/91	41.2	106.9	184.9	166.1	201.4	68.1	0.3	0.0	0.0	0.0	0.0	5.3	774.2
91/92	116.0	53.3	163.6	103.6	13.2	64.9	14.8	0.0	0.0	0.0	0.0	0.0	529.4
92/93	0.3	74.0	205.5	101.5	242.0	108.1	103.0	0.0					834.4
93/94	15.2	78.7	150.2	126.8	67.3	47.6	4.0	0.0	0.0	0.0	0.0	138.9	628.7
94/95	138.9	13.2	151.6	64.3	115.4	15.1	0.5	0.0	0.0	0.0	0.0	0.5	499.5
95/96	32.3	81.8	100.7	330.8	0.0	100.8	0.0	0.0	0.0	0.5	0.0	16.1	663.0
96/97	0.1	65.8	176.6	333.3									575.8
average	30.5	91.8	159.8	193.3	162.5	105.4	31.6	6.5	2.7	1.0	2.3	9.3	789.5

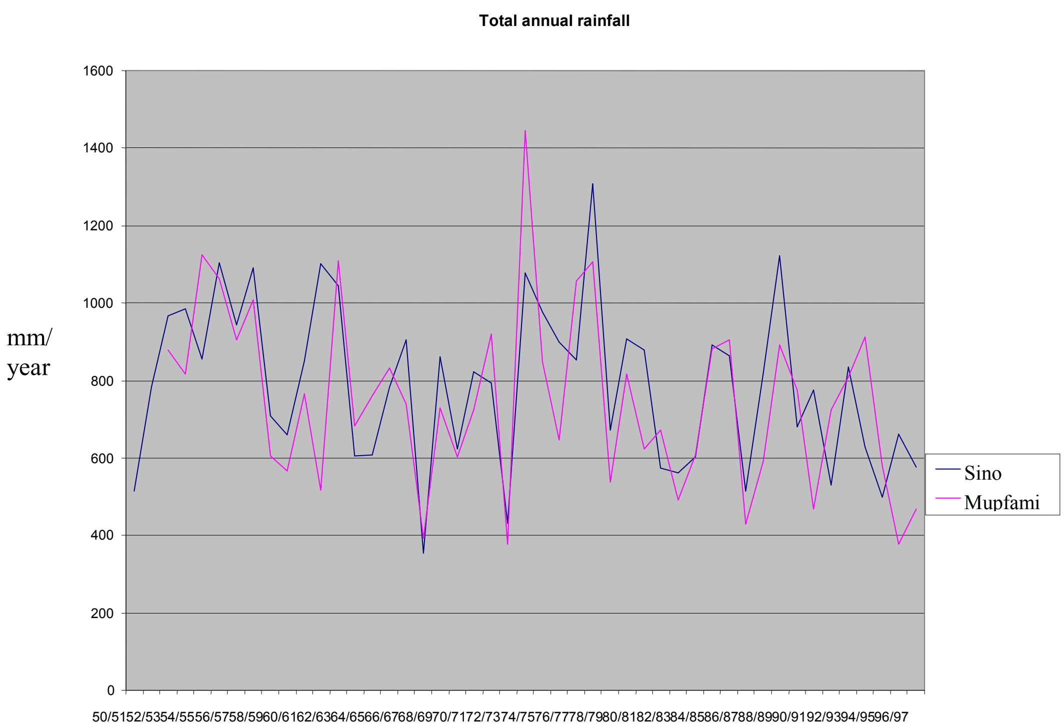
RAINFALL

STATION NAME: dam B

ZONE:
Long.

3.0

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APRIL	MAY	JUN	JULY	AUG	SEPT	TOTAL
52/53	36.1	135.7	107.5	265.7	180.0	129.4	17.7	0.0	0.0	0.0	6.5	0.0	878.6
53/54	0.0	146.9	164.6	150.8	250.9	57.9	21.0	0.0	0.0	0.0	0.0	23.8	815.9
54/55	24.3	167.2	346.1	329.0	123.8	76.3	48.8	10.1	0.0	0.0	0.0	0.0	1125.6
55/56	23.5	103.5	189.1	133.0	216.5	376.6	14.4	0.0	4.5	0.0	0.0	0.0	1061.1
56/57	2.5	153.1	343.0	110.2	158.8	91.9	32.2	8.6	0.0	0.0	5.0	0.0	905.3
57/58	31.1	33.6	148.7	289.9	355.5	46.1	86.8	0.0	0.0	0.0	0.0	15.7	1007.4
58/59	66.7	38.0	171.1	196.2	83.2	24.8	0.0	19.3	2.7	0.0	0.0	3.5	605.5
59/60	2.7	84.8	168.3	27.8	106.3	30.9	106.3	28.9	10.8	0.0	0.0	0.0	566.8
60/61	26.6	61.6	200.6	126.4	145.4	74.3	108.4	0.0	11.9	1.7	0.0	8.3	765.2
61/62	2.5	120.0	86.9	121.8	78.9	54.1	53.9	0.0	0.0	0.0	0.0	0.0	518.1
62/63	0.0	198.5	305.2	130.9	319.9	63.3	92.1	0.0	0.0	0.0	0.0	0.0	1109.9
63/64	144.9	95.1	121.0	189.0	117.5	14.1	0.0	0.0	0.0	0.0	0.0	0.0	681.6
64/65	19.7	124.9	279.4	239.6	67.7	22.2	0.0	0.0	0.0	0.0	0.0	6.3	759.8
65/66	23.3	158.6	48.2	77.8	398.9	84.3	40.6	0.0	0.0	0.0	0.0	0.0	831.7
66/67	0.0	75.8	109.1	188.9	164.4	87.0	38.0	41.4	13.9	0.0	20.7	0.0	739.2
67/68	23.1	63.3	126.9	69.2	62.4	1.2	45.3	0.0	0.0	0.0	0.0	2.5	393.9
68/69	0.0	154.0	197.7	155.1	25.6	120.4	62.1	2.5	0.0	0.0	3.8	8.6	729.8
69/70	59.3	25.3	238.7	72.0	28.6	48.0	109.5	0.0	6.3	0.0	0.0	13.9	601.6
70/71	15.9	282.5	81.6	123.3	97.7	44.7	31.4	36.0	0.0	0.0	0.0	10.2	723.3
71/72	6.9	75.2	179.7	285.4	163.0	99.8	65.2	22.5	0.0	0.0	0.0	22.1	919.8
72/73	14.8	108.6	49.0	76.5	69.7	39.0	20.5	0.0	0.0	0.0	0.0	0.0	378.1
73/74	25.1	248.6	294.5	364.2	288.1	175.4	19.3	14.6	0.0	9.0	5.0	0.0	1443.8
74/75	8.0	130.5	266.0	177.4	225.5	8.5	30.9	0.0	0.0	0.0	0.0	0.0	846.8
75/76	6.7	37.0	157.8	173.8	88.5	154.0	28.1	0.0	0.0	0.0	0.0	0.0	645.9
76/77	19.5	78.0	139.1	180.0	339.5	263.5	10.2	0.0	0.0	0.0	0.7	27.5	1058.0
77/78	20.5	33.0	310.9	212.5	252.5	229.5	47.3	0.5	0.0	0.0	0.0	0.0	1106.7
78/79	53.5	59.3	105.0	190.0	37.0	52.0	41.6	0.0	0.0	0.0	0.0	0.0	538.4
79/80	25.5	70.7	345.5	97.6	176.7	62.3	14.6	0.0	0.0	0.0	0.0	24.1	817.0
80/81	12.5	41.0	105.7	113.8	257.7	82.0	11.0	0.0	0.0	0.0	0.0	0.0	623.7
81/82	54.0	106.5	85.5	133.0	188.8	66.9	32.0	4.5	0.0	0.0	0.0	0.0	671.2
82/83	104.7	21.1	129.0	110.0	63.5	45.0	2.2	11.0	0.0	5.0	0.0	0.0	491.5
83/84	17.0	27.7	137.5	120.0	123.5	123.5	19.0	21.0	0.0	0.0	0.0	18.0	607.2
84/85	21.5	78.0	181.5	275.5	129.0	196.0	0.0	0.0	0.0	0.0	0.0	0.0	881.5
85/86	13.0	54.5	286.5	304.5	110.0	126.0	10.5	0.0	0.0	0.0	0.0	0.0	905.0
86/87	48.5	59.0	165.0	93.0	33.2	30.5	0.0	0.0	0.0	0.0	0.0	0.0	429.2
87/88	0.0	10.0	137.0	283.0	21.4	123.1	2.0	0.0	15.0	0.0	0.0	0.0	591.5
88/89	54.0	46.0	184.0	204.0	287.5	102.6	13.0	0.0	0.0	0.0	0.0	0.0	891.1
89/90	48.0	73.0	76.5	230.0	195.9	58.0	93.0	0.0	0.0	0.0	0.0	0.0	774.4
90/91	13.5	47.5	125.0	108.0	102.0	64.7	0.0	0.0	0.0	0.0	0.0	6.5	467.2
91/92	32.5	60.5	313.2	81.5	68.0	147.0	17.5	4.0	0.0	0.0	0.0	0.0	724.2
92/93	0.0	53.5	176.5	259.0	142.5	135.5	41.0	0.0	0.0				808.0
93/94	16.0	182.5	170.5	285.5	81.0	31.5	15.0	0.0	0.0	0.0	130.0	0.0	912.0
94/95	138.0	20.0	214.0	132.5	33.5	41.0	0.0	0.0	0.0	0.0	0.0	0.0	579.0
95/96	0.0	83.0	0.0	294.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	377.0
96/97	0.0	112.0	152.5	203.5									468.0
average	27.9	92.0	176.0	177.4	146.8	88.7	32.8	5.1	1.5	0.4	4.0	4.4	750.6



Total annual rainfall
mm/ year
1600
1400
1200
1000
800
600
400
200
0
50/5152/5354/5556/5758/5960/6162/6364/6566/6768/6970/7172/7374/7576/7778/7980/8182/8384/8586/8788/8990/9192/9394/9596/97
Sino
Mupfami

Annex I-B Flow data

These data are also made available in digital format (data mupfami.xls).

MONTHLY RUNOFF SUMMARY / Potential dam site C

River:	SIMENYATi	Station number:	c23
Location:	Potential dam site C	Zone:	CH5
Date opened:	10/0/53	Latitude:	1804 S
R/T Code No.:	3023 1 11	Longitude:	3104 E
Notch Capacity:	47.699 m3/s	Grid Reference:	
R/T Notes:		Area:	500 km2

Monthly runoff in thousands of cubic metres

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total	total unit R/off mm	max flood m3/s	days no flow
----	---	---	---	---	---	---	---	---	---	---	---	---	-----			
56/57	215	1000	21400	28500	15100	19400	6080	2740	1660	1170	1120	378	98800	198	57.9	0
57/58	1250	1000	16000	27100	47100	21100	8890	2620	1830	1370	937	857	130000	260	251	0
58/59	445	950	3560	28800	28100	8980	1780	1330	770	607	352	156	75800	152	153	0
59/60	48	919	6550	2800	6690	1600	876	1200	472	335	176	41	21700	43.4	51.9	1
60/61	981	536	7750	16800	27200	9600	20900	4490	1600	1440	761	370	92400	185	249	6
61/62	152	12400	2620	7870	8110	2760	2020	843	463	315	197	50	37800	75.7	64	0
62/63	8	1330	43300	15400	33700	13000	14900	3370	2170	1540	953	456	130000	260	170	36
63/64	302	581	1280	2440	1020	259	62	22	12	31	28	3	6040	12.1	5.15	38
64/65	0	0	2150	17400	2400	920	275	84	41	35	12	0	23317	48.2	23.4	111
65/66	154	1480	683	380	11800	9300	3220	1310	1070	514	253	88	30252	60.6	53.2	26
66/67	14	9	645	4000	8880	15000	1800	1830	652	418	284	329	33861	67.8	67.6	54
67/68	157	170	195	37	396	26	83	16	0	0	0	0	1080	2.2	0.93	177
68/69	0	374	6340	15000	4240	18900	24300	3080	1480	832	510	221	75277	150.6	143	46
69/70	335	646	10600	5320	1280	612	233	66	40	35	18	0	19185	38.4	23.4	30
70/71	0	36	1810	6380	1190	859	796	562	226	118	35	0	12012	24	24.9	88
71/72	145	805	292	15100	17400	10100	16600	4870	1750	1220	691	316	69289	138.6	102	20
72/73	1310	630	151	497	942	609	57	1	0	0	0	0	4190	8.4	4.6	150
73/74	1	4030	33400	*	*	*	*	*	*	*	*	*	*	*	*	*
74/75	*	*	*	*	*	*	*	*	*	839	630	256	*	*	*	*
75/76	112	8	1820	3960	5070	4730	7600	1780	1160	689	351	173	27400	54.9	23.6	23
76/77	92	37	2280	1670	24700	78800	8140	3750	2180	1600	988	435	124672	252.1	146	0
77/78	207	323	2470	30500	33300	31800	17300	5250	2930	1860	1030	437	127000	255	148	1
78/79	1960	829	6660	4740	1310	2320	485	118	74	81	25	2	18600	37.2	32.1	24
79/80	0	1510	11300	9010	7620	6120	1450	335	271	135	63	93	37900	75.7	69	47
80/81	245	478	11600	43300	94000	30300	11800	7160	3220	2160	1380	1280	207000	414	251	12
81/82	655	1950	873	8080	5760	1490	477	379	161	127	74	9	20000	40.1	61.3	7
82/83	43	75	134	1100	317	442	6	13	0	0	0	0	2130	4.3	10.1	168
83/84	0	0	507	440	516	231	62	0	0	0	0	36	1790	3.6	6.38	230
84/85	0	272	2520	22500	21400	10200	2170	894	408	354	130	59	60900	122	148	49
85/86	33	333	2720	20700	14200	11000	11600	4020	2060	1380	699	254	69000	138	56.9	16
86/87	477	152	5550	3760	1790	676	166	16	0	0	0	0	12600	25.2	25.8	138
87/88	12	0	3100	3490	14700	11100	2930	1330	544	458	130	9	37700	75.4	63.9	69
88/89	438	116	3810	2740	17600	7100	2050	1360	585	243	153	19	36200	72.4	67.7	34
89/90	123	93	24	2850	14000	29000	6350	2050	908	572	269	33	56300	113	181	40
Mean	300	1002	6487	11020	14744	11197	5483	1777	898	620	371	192	53131	106.5	85.5	51
Max.	1960	12400	43300	43300	94000	78800	24300	7160	3220	2160	1380	1280	207000	414	251	230
Min.	0	0	24	37	317	26	6	0	0	0	0	0	1080	2.2	0.93	0
Days	1023	990	1023	1003	902	992	960	985	960	1020	1014	999	11871	1641		
St.Dev.	455	2194	9669	11211	18728	15429	6859	1869	924	630	404	278	49201	75.6		
Skew	2.281	4.712	2.612	1.176	2.728	2.976	1.358	1.142	0.941	0.878	0.962	2.373	1.304	0.961		
C.V.	1.516	2.19	1.49	1.017	1.27	1.378	1.251	1.052	1.03	1.016	1.09	1.445	0.926	0.885		
mean flow m3/s	0.102	0.346	2.14	3.92	5.12	2.61	1.45	0.485	0.257	0.178	0.108	0.058	1.37			

Remarks:- none

Data collected and processed by the Hydrological Branch, Ministry of Lands, Agriculture & Water Development, Zimbabwe

Processed: 01/02/94 Printed: 11/11/94

MONTHLY RUNOFF SUMMARY / Inflow Dam A

River:	Mupfami	Station number:	C3
Location:	Inflow Dam A	Zone:	CH5
Date opened:	3/5/42	Latitude:	1759 S
R/T Code No.:	3003 1	Longitude:	3104 E
Notch Capacity:	111.969 m3/s	Grid Reference:	
R/T Notes:		Area:	793 km3

Monthly runoff in thousands of cubic metres

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total	total unit R/off mm	max flood m3/s	days no flow
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51/52	11	36	75	35600	61500	10600	3230	1460	704	203	166	153	114000	143	292	10
52/53	116	635	1770	25800	81000	81600	31600	10500	5940	4110	2690	1890	248000	312	369	0
53/54	136	512	4330	12100	35400	17900	5460	2840	1550	1030	637	500	82300	104	76.7	0
54/55	184	291	15300	67100	73100	36400	11700	7710	4760	2670	1670	922	222000	280	301	2
55/56	310	1630	5410	12900	23400	61100	24100	10300	5960	3650	1900	1980	153000	192	204	0
56/57	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
57/58	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58/59	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
59/60	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
60/61	377	189	2320	30100	57600	20800	30900	9210	5380	3550	1990	822	163238	205.7	192	0
61/62	402	21600	7760	16100	25000	9870	10900	3750	2240	3440	835	176	102073	128.7	67.4	0
62/63	99	201	67100	53700	108000	37300	27800	11100	7350	5320	3780	2060	324000	408	672	0
63/64	2050	2070	2620	4480	6250	1710	193	167	163	169	146	92	20100	25.3	9.48	0
64/65	35	19	3910	29700	15100	4920	1370	493	362	235	115	69	56400	71.1	64.5	1
65/66	87	559	1870	657	9260	13400	5630	2830	1530	773	393	230	37200	46.9	23.7	0
66/67	49	12	106	2550	26800	45300	5130	3230	1500	895	504	622	86700	109	157	0
67/68	252	117	125	127	275	121	74	5	5	5	5	5	1120	1.4	0.458	1
68/69	5	132	2570	30100	10900	25800	20800	4990	2160	1160	582	207	99400	125	116	2
69/70	127	436	21700	18200	5830	3090	668	269	126	114	70	26	50700	63.9	59.8	0
70/71	11	3860	7580	12100	3160	643	287	206	76	86	43	15	28000	35.3	15.4	5
71/72	5	157	364	38100	45000	21700	34200	11600	3880	2850	1270	499	160000	201	153	9
72/73	1570	1380	86	176	6	1550	264	53	40	27	20	3	5170	6.5	12.2	40
73/74	0	47	22700	141000	119000	71500	23100	17600	6490	8520	713	1080	411000	518	494	65
74/75	0	166	29900	31300	59200	34500	14300	4540	1460	803	478	312	177000	223	165	41
75/76	164	60	91	7580	14500	26800	18700	4680	1840	665	286	117	75500	95.2	142	0
76/77	122	117	121	1170	59500	105000	24900	7610	3970	1880	687	275	205000	259	357	0
77/78	*	*	*	87500	76800	87600	48500	18000	10700	7670	2990	976	341000	430	192	0
78/79	787	861	18100	16000	11400	16800	5380	1540	1210	1390	1230	1190	75900	95.7	57.6	0
79/80	1230	1270	9380	32000	20300	7590	3970	302	1	0	0	16	76100	95.9	55.3	111
80/81	0	29	7310	58900	200000	93900	29900	16500	5980	1760	262	0	414541	520	257	107
81/82	0	0	0	23000	27800	7240	1090	250	0	0	0	0	59380	75.5	117	232
82/83	25	213	271	300	66	373	294	160	0	0	0	0	1702	2.1	1.2	204
83/84	0	0	3	0	9	33	0	0	0	0	0	0	45	0.1	0.31	332
84/85	0	0	0	36100	66100	43300	8450	1200	195	144	0	10	155499	196	135	170
85/86	0	0	769	52900	54200	26800	25000	10800	2460	1210	92	16	174247	220	106	75
86/87	0	0	0	18400	11600	2160	707	37	22	50	105	0	33000	41.7	123	214
87/88	26	22	136	1130	20100	37900	8180	2070	138	8	0	0	69700	87.9	81.8	153
88/89	3	4	11	51	68000	24000	6280	1480	85	0	0	0	99900	126	109	182
89/90	0	160	79	34	23600	10900	11900	1850	29	23	2	1060	49700	62.7	55.3	104
Mean	240	1081	6878	25627	40564	28291	12713	4838	2237	1554	676	437	124931	157.4	150	58
Max.	2050	21600	67100	141000	200000	105000	48500	18000	10700	8520	3780	2060	414541	520	672	332
Min.	0	0	0	0	6	33	0	0	0	0	0	0	45	0.1	0.31	0
Days	1178	1140	1183	1209	1092	1197	1162	1209	1170	1209	1197	1182	14128	2060		
St.Dev.	474	3710	13124	29630	42154	29266	12780	5434	2737	2170	958	605	111829	148		
Skew	2.759	5.443	3.338	2.094	1.866	1.252	0.929	1.135	1.324	1.858	1.819	1.541	1.256	1.777		
C.V.	1.973	3.43	1.908	1.156	1.039	1.034	1.005	1.123	1.224	1.396	1.418	1.382	0.895	0.992		
Mean flow m3/s	0.072	0.15	2.14	6.5	10.5	7.62	3.37	1.22	0.614	0.424	0.198	0.14	2.71			

Remarks:- none

Data collected and processed by the Hydrological Branch, Ministry of Lands, Agriculture & Water Development, Zimbabwe

MONTHLY RUNOFF SUMMARY / Inflow point Lake Mupfami

River:	MUPFAMI	Station number:	C17
Location:	Inflow point Lake Mupfami	Zone:	CH4
Date opened:	23/09/52	Latitude:	1753 S
R/T Code No.:	3017 6	Longitude:	3046 E
Notch Capacity:	1580 m3/s	Grid Reference:	
R/T Notes:		Area:	2220. km2

Monthly runoff in thousands of cubic metres

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total	total unit R/off mm	max flood m3/s	days no flow
----	---	---	---	---	---	---	---	---	---	---	---	---	-----			
53/54	0	0	0	26200	91000	45000	8230	2490	1400	746	776	728	177000	79.6	149	92
54/55	794	735	60900	203000	235000	95500	20900	19100	8120	4090	1730	1250	652000	293	572	0
55/56	966	1050	1800	19900	47500	200000	59700	20500	11900	13300	2860	4210	384000	173	232	0
56/57	5530	13300	69000	119000	62800	83700	25400	11500	4670	3020	1310	1020	400000	180	264	0
57/58	974	939	12600	87100	67300	62500	16900	9760	5300	3130	1690	1110	269000	121	190	0
58/59	1070	1000	3770	20800	17800	21900	15900	15600	14900	9650	985	1000	124000	56	18.3	0
59/60	1060	1040	1100	1040	965	1030	1010	1070	1030	1110	1110	1040	12605	5.7	0.79	0
60/61	1030	1080	1200	27400	104000	41600	67800	12500	5170	2780	1660	1050	267000	120	157	0
61/62	1100	23600	12000	27700	49900	14000	14200	2610	1040	1200	1150	1080	149580	67.6	44.7	0
62/63	1160	1180	121000	113000	262000	79600	70000	17700	9400	6420	2670	1420	685550	309	332	0
63/64	1240	1040	1280	1580	10800	1860	1130	1220	1200	1250	1200	1210	25010	11.3	7.91	0
64/65	608	473	108	79500	32300	6170	1400	1170	1180	1210	1580	1270	126969	57.7	91.3	0
65/66	1340	1120	1130	1130	1360	29600	13400	2800	1650	894	967	847	56238	25.8	32.9	0
66/67	981	823	2460	833	14300	75300	10900	3420	1480	1330	2220	1190	115237	51.8	131	0
67/68	1030	2260	1010	1290	1180	1240	893	941	1160	932	838	3030	15804	7.1	5.71	0
68/69	3460	3010	1210	1340	1240	42200	16000	6100	1570	1240	967	2310	80647	36.3	40	0
69/70	3290	3190	24500	39500	7620	2800	992	1040	883	2060	2970	3150	91995	41.4	86.6	0
70/71	3860	3570	2670	1050	1120	1180	1140	1080	1070	2630	4350	2710	26400	11.9	3.18	14
71/72	5350	5060	1870	10100	149000	54100	88900	19400	4820	1330	2940	6140	349000	157	219	0
72/73	6540	6820	6700	2310	1190	1030	1340	1790	1490	1750	2580	4320	37900	17.1	3.65	0
73/74	5350	1780	1060	238000	287000	167000	40400	33700	8600	14200	2410	3660	803000	362	405	0
74/75	6040	5790	96800	82000	180000	78400	32200	7890	3140	1150	1260	2600	498000	224	244	0
75/76	4540	4730	1720	1240	11200	57000	35000	6280	1360	1150	1230	1060	126000	57	140	3
76/77	1510	1360	1470	762	140000	354000	92200	10500	1230	8	0	0	603000	272	420	90
77/78	0	0	1900	201000	232000	284000	96100	22300	7580	2040	52	0	847000	381	264	142
78/79	0	0	16200	25900	6670	16400	380	0	0	0	0	0	65600	29.5	49.4	250
79/80	0	0	0	28100	26800	29800	3570	0	0	0	0	0	88300	39.8	53.4	258
80/81	0	0	0	84500	457000	180000	58200	35000	6810	1650	0	0	823000	371	383	171
81/82	0	0	0	1450	3770	633	0	0	0	0	0	0	5850	2.6	10.7	289
82/83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
83/84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366
84/85	0	0	0	0	4760	8510	763	1	0	0	0	0	14000	6.3	9.35	283
85/86	0	0	0	7740	13700	5150	5300	957	235	17	0	0	33100	14.9	22.6	182
86/87	0	0	0	943	520	0	0	0	0	0	0	0	1460	0.7	3.53	329
87/88	0	0	0	0	11300	40500	13100	149	0	0	0	0	65100	29.3	34.4	285
88/89	0	0	0	0	10100	4500	1800	264	0	0	0	0	16700	7.5	18.9	261
89/90	0	0	0	48	12100	4870	8730	2470	80	0	0	0	28300	12.7	15.7	225
Mean	1633	2359	12373	40429	70980	58085	22885	7536	3013	2230	1152	1316	224009	100.9	129	90
Max.	6540	23600	121000	238000	457000	354000	96100	35000	14900	14200	4350	6140	847000	381	572	366
Min.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Days	1144	1110	1147	1147	1042	1139	1110	1147	1110	1147	1136	1121	13500	3240		
St.Dev.	2040	4516	28400	63324	106541	82677	29214	9583	3786	3439	1137	1518	265494	148		
Skew	1.251	3.564	2.826	1.929	1.993	2.187	1.392	1.479	1.554	2.545	0.816	1.411	1.266	1.28		
C.V.	1.249	1.914	2.295	1.566	1.501	1.423	1.277	1.272	1.257	1.542	0.987	1.153	1.185	1.148		
Mean flow m	0.441	0.493	2.82	12	24.1	18.7	7.24	2.35	0.916	0.632	0.263	0.319	5.75			

Remarks:- none

Data collected and processed by the Hydrological Branch, Ministry of Lands, Agriculture & Water Development, Zimbabwe
Processed: 01/02/94 Printed: 11/11/94

MONTHLY RUNOFF SUMMARY / Cit C/Potential Dam site D

River:	MUPFAMI	Station number:	C61
Location:	CitC/Potential dam site D	Zone:	CH3
Date opened:	18/12/64	Latitude:	1721 S
R/T Code No.:	3061 03	Longitude:	3013 E
Notch Capacity:	16.523 m3/s	Grid Reference:	
R/T Notes:		Area:	5340. km2

Monthly runoff in thousands of cubic metres

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total	total unit R/off mm	max flood m3/s	days no flow
----	---	---	---	---	---	---	---	---	---	---	---	---	-----			
64/65	0	49	12300	168000	61000	16200	4430	1760	1770	1570	1350	872	269301	50.4	2.9	0
65/66	810	8090	7360	2960	75800	113000	38800	11000	7530	3190	1830	875	272000	50.9	285	0
66/67	489	665	2240	15300	30600	158000	29900	13500	5600	3500	3970	1610	266000	49.7	520	0
67/68	761	1420	3430	3950	10200	3760	1530	836	622	1010	537	1350	29400	5.5	11.1	0
68/69	2020	3590	20600	166000	55700	99000	110000	14700	6140	3470	2200	1240	485000	90.9	172	0
69/70	2420	3840	75500	99300	36800	12200	8790	3210	1820	1760	2370	1990	250000	46.8	268	0
70/71	2050	18900	36800	89800	75900	14500	7520	5240	2670	2550	2300	3630	261860	49.1	187	0
71/72	4290	5710	7780	51300	195000	118000	189000	37500	11500	6160	3790	7160	637190	119	278	0
72/73	7530	6560	7040	4480	4200	5070	753	964	568	669	698	3140	41672	7.8	15.9	0
73/74	4470	9120	70500	407000	484000	243000	76800	52400	17300	20900	7320	4800	1397610	262.2	611	0
74/75	6030	13300	210000	187000	400000	180000	53800	19400	8710	4090	2040	1420	1085790	204	0	0
75/76	2130	3240	5550	30900	26000	43500	70700	38600	16100	5200	3170	4710	250000	46.8	60.8	0
76/77	4110	3220	9430	4960	49300	337000	97100	23300	9910	5470	9620	8450	561000	105	1100	0
77/78	3040	3180	16100	486000	499000	508000	173000	46400	14700	10800	5820	4510	1770000	332	1440	0
78/79	6350	1960	6340	4630	14300	11700	3930	4840	3170	3580	6850	5040	72700	13.6	28.3	0
79/80	6430	3250	7710	10400	8460	37900	12200	1860	2640	3540	6670	6590	107650	20.2	33.6	0
80/81	5720	5590	5760	5230	111000	189000	75000	57700	4730	2570	7130	9480	480000	89.9	514	0
81/82	6510	12500	15300	19600	11900	1260	2030	4970	8180	11900	11900	12300	118000	22.1	24.8	0
82/83	10400	9160	10900	18500	9220	7750	5080	7850	10600	10600	11800	11200	123000	23.1	44.8	0
83/84	4550	9550	10500	5740	12000	9070	5820	2250	1340	763	900	1320	63800	11.9	32.1	4
84/85	1400	2190	12800	31500	55600	47700	10700	3630	5440	4590	6450	7230	189000	35.4	107	0
85/86	4500	2230	12700	155000	114000	101000	109000	31800	7340	5420	8060	8550	559000	105	826	0
86/87	6340	4450	10800	8020	2630	4860	1840	7020	7900	7570	9650	7430	78500	14.7	24.8	0
87/88	3280	8280	6780	10900	20900	35800	6430	6910	7220	7860	9430	8990	133000	24.9	104	0
88/89	5520	5330	6520	6500	18800	158000	134000	36400	7170	11900	6730	1560	398000	74.6	475	0
89/90	1680	1590	2080	11300	118000	30100	42400	19000	6090	3460	3800	2930	242000	45.4	323	0
Mean	3955	5652	22800	77087	96165	95591	48867	17424	6798	5542	5245	4937	390056	73.1	288	0
Max.	10400	18900	210000	486000	499000	508000	189000	57700	17300	20900	11900	12300	1770000	332	1440	4
Min.	0	49	2080	2960	2630	1260	753	836	568	669	537	872	29400	5.5	0	0
Days	806	780	806	797	718	806	771	806	780	806	799	787	9462	4		
St.Dev.	2554	4448	42367	124288	142613	121095	56243	17477	4587	4578	3480	3466	426530	367		
Skew	0.444	1.29	3.843	2.313	2.172	1.995	1.169	1.016	0.701	1.754	0.372	0.519	2.08	1.807		
C.V.	0.646	0.787	1.858	1.612	1.483	1.267	1.151	1.003	0.675	0.826	0.664	0.702	1.094	1.275		
Mean flow m	1.03	1.34	3.46	15.8	20.5	26.9	13.9	4.8	1.95	1.5	1.63	1.48	7.76			

Remarks:- none

Data collected and processed by the Hydrological Branch, Ministry of Lands, Agriculture & Water Development, Zimbabwe
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Annex I-C OPEN-PAN EVAPORATION DATA

Table 1 Average monthly open-pan evaporation at Sinova.

Month	E_{pan} (mm)/month	month	E_{pan} (mm)/month
Jan	125	July	128
Feb	116	Aug	168
Mar	140	Sep	232
Apr	126	Oct	262
May	117	Nov	190
June	108	Dec	143

Annex II POPULATION AND EMPLOYMENT

Table 1 Population distribution x million inhabitants

	1985	1990	1995	2000
Harava	1	1.1	1.4	2
Chitungwa	0.1	0.15	0.25	0.5
Sinova	0.3	0.32	0.35	0.4
Rural area	0.5	0.65	0.9	1.1
Total	1.9	2.22	2.90	4

Average net population growth in the country is 3.5%.

Table 2 National employment figures (%)

	1985	1990	1995	2000
Agriculture	55	46	35	26
Industry	15	15	13	12
Tourism	2	3	4	6
Service sector	5	6	8	9
Government	12	15	20	18
Unemployed	11	15	20	29
Total	100	100	100	100

Annex III ECONOMIC ACTIVITIES

III.a Agricultural Activities

Table 1 Official agricultural activity per project during summer (ha dry land)

		Maize	Wheat	Tobacco	Cotton	Groundnut	Beans	Other	Total
Commercial Agriculture	Project I	3500		2700	600	2000			8800
	Project II	750		150	600		1000		2500
	Project III	400		750				150	1300
	Project IV	300		200	300		100	100	1000
Communal Agriculture	Project I	10000		100	1000	500	100	100	11800
	Project II	10000			500	300			10800
	Project III	18000		200	1000	500			19700

Table 2 Official agricultural activity per project during summer (ha irrigated)

		Maize	Wheat	Tobacco	Cotton	Groundnut	Beans	Other	Total
Commercial Agriculture	Project I	500		2000	150	200			2850
	Project II	100		100					200
	Project III	800		1000					1800
	Project IV	4000		200	300		300	500	5300
Communal Agriculture	Project I								
	Project II								
	Project III								

Table 3 Official agricultural activity per project during winter (ha irrigated)

		Maize	Wheat	Tobacco	Cotton	Groundnut	Beans	Other	Total
Commercial Agriculture	Project I	200	500						700
	Project II	200	300						500
	Project III	300	2000	1000					3300
	Project IV		5000						5000
Communal Agriculture	Project I								
	Project II								
	Project III								

Table 4 Estimated average transpiration of crop, potential yield and average economical parameters per irrigated crop in Zimbabwe in 1995/1996 for the sector commercial agriculture

	Unit	Maize (summer)	Wheat (winter)	Tobacco (summer)	Cotton (summer)	Groundnut (summer)	Beans (winter)
Average potential transpiration of crop (T_{pot}) over season of 4 months	mm/ crop/season	460	500	250	300	490	275
Daily interception threshold *D* (fictive amount)	mm/day	2	1.5	1.5	1	1	0.5
Crop yield response K_y (see Water for Agriculture, FAO 1979)	-	1.25	1	1	0.95	0.7	1.15
Average potential yield	ton/ha	7	5.5	3	3.5	5.5	6
Market price	$/ton	400	600	2000	600	500	500
Land price (lease)	$/ha/ year	200	300	400	200	200	200
Total equipment costs (lease)	$/ha/ year	400	600	1000	400	300	300
Inputs (fertiliser, seeds, pesticides)	$/ha/ crop	300	400	500	300	300	300
Labour costs	$/ha/ month	40	50	120	100	70	70
Miscellaneous operational (except energy, water)	$/ha/ month	50	80	120	60	50	50

- For the surroundings of Mupfami catchment, effective rainfall can be estimated on a monthly basis using the following equation (De Groen, 2002):

$$P_{eff,m} = P_m * \exp\left(\frac{-1.76 * D}{P_m^{\ 0.45}}\right) \qquad \text{(III.1)}$$

where

$P_{eff,m}$ monthly effective precipitation (mm/m)

P_m monthly precipitation

- For crop yield response on water stress, the FAO procedure of 1979 (see lecture note Water for Agriculture) gives the best estimate locally available:

$$1 - \frac{Y_a}{Y_{max}} = K_y * \left(1 - \frac{T_a}{T_{max}}\right) \qquad \text{(III.1)}$$

where

Y_a actual yield (ton/ha)

Y_a maximum yield (ton/ha)

T_a actual transpiration over the season (mm)

T_{max} maximum transpiration over the season (mm)

III.b General financial data

- The cost of electricity utilised for pumping is 15 USD per 100,000 m^3 in horizontal position. Every meter of head is 1% cost increment.

- Discount interest rates for 2000 were 15 %/year.

Annex IV WATER USE

Urban, Industrial, Mining

The water resources of Mupfami catchment are increasingly committed to the domestic water supply of the big expanding urban agglomeration of Harava and Chitungwa. Lake Mupfami is for 80% owned by the municipalities of Harava + Chitungwa. The bulk of the water for industry is also supplied by the municipalities. The amount of unaccounted for water is some 40%. A feasibility study for the rehabilitation of the water system in Harava would cost 24 10^6 US$, which could bring down the unaccounted for water to 25%.

Urban people almost all have private connections to the water supply system and use on average 70 l/cap/day. The use of drinking water for gardening is increasing the water use in high density areas to about 90 l/day in dry periods. In the luxurious low density areas, most residents have private boreholes, not righted, and the average consumption for watering is about 80 l/cap/day in dry months.

The treatment works for supply of drinking water of Harava and Chitungwa are combined and have a design capacity of 9 Mm^3/month, but efficiency has gone down to 8 Mm^3/month. For Sinova the treatment plant is just new and has a design capacity of 4 Mm^3/month.

Some rural towns and smaller business centres are depending on boreholes and motorised pumps for their domestic water supply. Parts of the towns and centres have reticulated water.

During periods of drought hundreds of boreholes were drilled to depths of about 60 to 80 m to overcome the fact that the regular town and rural boreholes were running dry. This did not solve the problem completely and from time to time water had to be supplied through water tankers and even by constructing emergency pipelines at enormous costs.

Commercial Agriculture

Commercial agriculture historically caters for the bulk of the water use. Countrywide, the share of the sector agriculture is about 80% of the total surface water abstraction. Early colonial settlers established huge commercial farms and the water right system of prior appropriation or “first come, first get” was a guarantee for successful extensive investment in the sector Agriculture. In the Mupfami catchment upstream of Lake Mupfami approximately 30% of the Mean Annual Run-off is believed to be absorbed by water rights for commercial agriculture prior to the water right of Dam B which dates from the fifties (first stage)’. These rights are also satisfied by approximately 30% of the catchment area. Downstream of Dam B, a lot of irrigated wheat cultivation takes place from private dams to the extent of 50% of the Mean Annual Runoff generated on also 50% of the downstream catchment area.

Communal Agriculture

In the communal lands the main source of income is predominantly rain fed, subsistence agriculture. The staple food is maize. Here and there some small scale irrigation is applied with small movable pumps, driven by petrol or Diesel engines. Water is abstracted from the rivers when they are flowing or from pools after the rivers have ceased to flow.

Rural Domestic Water Supply in Communal Lands

Drinking water is mainly supplied through bore holes with communal hand pumps or motorised pumps or through family wells. Cattle watering is done mainly from pools or small communal dams.

Annex V TECHNICAL DETAILS ON RESERVOIRS AND POTENTIAL DAM SITES

	Active storage capacity
Dam A	12 Mm^3
Dam B	734 Mm^3

The Urban, Industrial and Mining demand (unrationed UIM demand) of Harava+Chitungwa amounts to 175 Mm^3/year. If there is any storage in Dam A, this will be used to meet the demand of Harava+Chitungwa. Dam B supplies the remaining part of the water demand of Harava+Chitungwa, if possible. Dam B also supplies Sinova. There are no data available of consumption in Sinova.

The percentage of Unaccounted For Water for Harava and Chitungwa amounts to 40%.

Dam B is also used for agriculture. The amount of raw water that can be sold to farmers is determined each year, at 1 April. At that date the storage is sold, that is the surplus over the storage that is needed to satisfy 21 month's not rationed UIM demand, counting on only a 4% low inflow in the following rainy season. (This surplus water is called "agreement water".) The government makes agreements with the individual commercial farmers to deliver a certain amount of water each year for a number of years, provided the water is available. Not more than the 10% yield of the dam, after subtraction of the projected UIM demand, will be committed in such agreements.)

The water (storage) right of dam B is from 1950 for the first stage of 253 Mm^3 and from 1974 for the rest of the storage.

Table 1 Potential dam site C (on a major tributary)

Crest height (m)	Volume (Mm^3)	Costs M US$ (present)
31	52	7.8
36	81	9.7

Table 2 Potential dam site D

Crest height (m)	Volume (Mm^3)	Costs M US$ (present)
43	122	13.3
51	248	18.1
56	450	23.9

Annex VI WATER QUALITY ASPECTS

NOTE
Data of the Mupfami Lake are extracted from Lake Chivero, Zimbabwe (Moyo, 1997). The consultants are allowed to apply other 'real-life' data in their case.

Introduction

Lake Mupfami was created in 1952 as the principal water supply for the city of Harava. It is located downstream of the city, which discharges effluent into the tributary Makuriri. .The catchment of Lake Mupfami comprises 2200 $(km)^2$, consisting of approximately 10% urban development and 90% rural areas.
The population of Harava has doubled over the last 15 years to 2 million inhabitants, see Annex II table 1, and so has the volume of the sewage effluent from the sewage treatment plant of Harava, which drains on the Makuriri river. Chitungwa is smaller (0.5 million) but growing faster. As the newspaper article in Figure VI-1 shows, the capacity of the sewerage treatment plants is largely insufficient, with a capacity of 1.0 and 0.5 million population equivalents, respectively. A large problem is the constant overloading of the two treatment plants, resulting into bad effluent qualities.

For most industries, no hard data are available on the wastewater composition of their effluents, in view of secrecy considerations.

Water quality in the rivers

Especially downstream of Harava, the large domestic and industrial wastewater discharges have caused a serious deterioration of the river quality, with, in many stretches, anoxic conditions. The following Table is an illustration of that. However, the problem is quite local, since the river water flows into lake Mupfami after about 10 km's. More serious may be the problem downstream Sinova, where the river water flows into a nature park, and may thus cause local bad water quality, in violation of the required highest water quality standard (class I; see Table A VI-2) .

Figure VI-1 Newspaper article on the sewerage treatment in Chitungwa

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A town besieged by sewage

Tichaona Zinhumwe reports from Chitungwa, the fastest growing town in the Mupfami catchment, besieged by sewage that runs down the streets in rivers

The stench of sewage hangs over parts of this former black township that has become Mupfami's third largest and fastest growing town.

Raw sewage overflows from drains onto streets in Chitungwa and eventually ends up in rivers that flow into Reservoir B, the main source of water for the town and for the capital, Harava, 30km away.
Chitungwa's sewerage facilities are failing to cope with its rapid population growth, spurred by rural-urban migration over the years. In the 1970s, it was home to 30,000 people. At the last census in 1992, nearly 500,000 lived there.

Although the Chitungwa Town Council started a project to rehabilitate and expand its sewerage system in 1995, sewage remains a headache for the town planners and a health hazard for residents.

The town's engineer, Mohindar Khosla, said the upgrading of the Chitungwa sewerage system was being done in phases at a cost of 8.5 million US dollars with funding from the state. He said, however, that it was slow going since the government was releasing the money in "dribs and drabs".

The council has so far received the equivalent of 2.3 million US dollars, which it has used to build sewage ponds about two kilometres southwest of the town.

Khosla admitted that, for the past two decades, Chitungwa's sewerage treatment plant has been handling much more waste than the maximum 18 million litres a day it was designed for. In 1992, it was receiving 34 million litres daily.

As a result raw sewage was being pumped into the Zimenyati until August 1994, when the Tobacco Association (TA) successfully took the Town Council to court for polluting the river, which passes through a farm owned by the association.
The council was ordered to pay the TA the equivalent of 16,500 US dollars for polluting the river and thus rendering its water unsuitable for use on the farm.

But recently, the council dumped 24,000 litres of raw sewage into the Zimenyati -- a tributary of the Mupfami, which flows into Lake Mupfami -- after two of its sewerage pumps broke down. As a result, the water in the upper Zimenyati is slimy, greenish and smelly.

Chitungwa residents have complained of a diarrhoea outbreak and they blame it on flies attracted by sewage leaking from burst sewer pipes that sometimes overflows into homes.

An official in the Town's Health Department confirmed that there had been cases of diarrhoea but denied that they were sewage-related. "As soon as a report is made on burst sewer pipes we spray chloride of lime to stop flies from breeding," said the official, who asked not to be identified by name.
He attributed the cases of diarrhoea to the high consumption of sugarcane grown on the banks of Mupfami River, explaining that people in the area sometimes blocked manholes to divert the sewer water to their canefields. "Chances are the cane is contaminated by chemical residue from the raw sewage and this might explain the increase in diarrhoea cases," he said.

But during a recent visit to the St. Mary's suburb of Chitungwa, *IPS* saw sewage flowing on streets and clouds of flies. People there said burst pipes sometimes went unattended for months, even after reports were made to the council.

"When the manholes overflow we are subjected to such a foul smell that we cannot even eat our meals," said St. Mary's resident Olivia Paul.

Another resident, Maria Mutambara, was scooping out sewage which had formed a small pond in her yard when *IPS* visited the area. "My children have complained of severe headaches and running stomachs," she said. "I suspect it's caused by this dirty water."

At a recent workshop on the rehabilitation of the catchment area of Lake Mupfami and nearby Lake Mupfami, Dr. Ngoni Moyo, a University of Zimbabwe fish biologist, said that the discharge of poorly treated effluent had resulted in unacceptably high levels of harmful waste such as phosphates and nitrates in the area's waterways. He recalled that the high toxicity levels in the lake caused massive fish deaths in April this year and spoke of a "looming disaster" if Chitungwa continued discharging poorly treated effluent into the water bodies that feed into Lake Bi.

"Today it's fish dying and tomorrow it's human beings," he said.
(-- IPS/Misa, November 20 2001)

Table A VI –1. Water quality in Mupfami river (max./min. values)
(N.B. the water quality upstream is up to the highest water quality standard (class I).

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Parameter	Mupfami River, downstream Harava
O_2 (% sat.)	< 30%; often anoxic
BOD_5 (mg/L)	11
NH_4-N (mg/L)	3-5
NO_3-N (mg/L)	10-25
P_{tot} (mg/L)	0.2-0.7
T.S.S. (mg/L)	35
pH	6.5-7
MPN coliform	10^4/100 mL
Cr-tot (µg/L)	>100
Cd-tot (µg/L)	>10
Pb-tot (µg/L)	>50

Eutrophication

Lake Mupfami has an average water depth of 10 m (maximum: 25 m) and a residence time of around 1 year. The lake has become more and more eutrophic over the last decades, as is evident from the water quality data presented in Fig. A VI 2. (Moyo, 1997).

The rapid increase in the phosphorus and nitrogen concentrations especially set in after 1990; for the period 1985-1990, a massive water hyacinth infestation has partly masked this nutrient increase. Estimations have earlier been made on the P loadings onto the lake (Moyo, 1997), *viz.* increasing from 4 (in 1973) to >10 g/m^2yr^{-1} (in 1996). BOD levels have increased from 1 mg/L, in 1990, to *ca.* 6 mg/l, in 1996. The Consultants are however invited to make their own assessment, based on the point and non point sources of pollution, to further substantiate above figures. Lake Mupfami can now be classified as a hypereutrophic lake.

Occurrence of dense mats of toxic blue green algae is an evident pattern in the lake (Moyo, 1997). As a consequence, treatment cost for the drinking water production has drastically increased over the last few years.

Oxygen and ammonia levels

Due to the increasing pollution levels, oxygen contents in Lake Mupfami have consistently gone down (Moyo, 1997); this has resulted into periods of extensive fish kills in the lake, *e.g.* in March 1996.

Temperature stratification is another characteristic of Lake Mupfami. During stratification periods, enhanced nutrient release rates may be expected from the anoxic sediments (Kelderman, 1996). This will result into high levels of e.g. ammonia (see Fig. A VI-2.), which will, at the prevailing high pH values in the lake, dominantly be in the un-ionized, toxic NH_3 form (Moyo, 1997; Kelderman, 1996).
High NH_3 levels may be a major cause of fish deaths in Lake Mupfami.

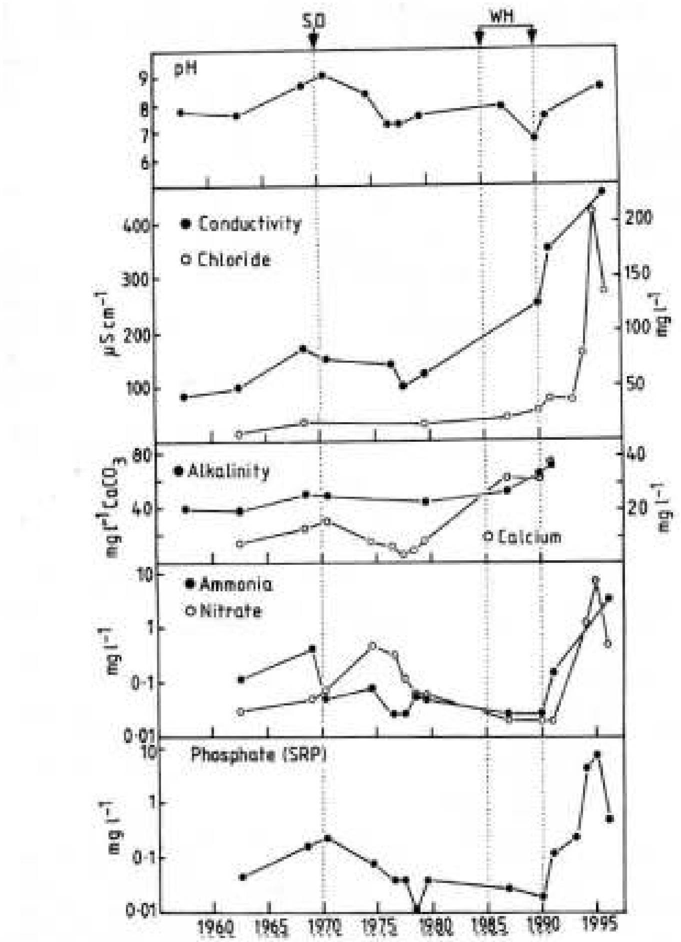

Fig. A VI-2 Developments of different water quality parameters for Lake Mupfami.

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6 Additional remarks

Non-point sources of pollution have not been quantified yet in the region. Try to make an estimate of nutrient and pesticide levels levels with the data given in the hand out on the crops used in the agricultural projects. For the communal lands, the vegetation may be used as “open land and grassland” with a ground cover of 0-20% (see Moyo 1997).

Finally, it is worthwhile to look at the potential harm of the heavy metal loads onto the lake, keeping in mind the above mentioned loads from industries. Special; attention should be given to possible accumulation of heavy metals in the sediment.

Literature

Moyo, N.A.G. (ed.). Lake Chivero, a polluted lake. University of Zimbabwe Publications, Harare, Zimbabwe, 134 pp.

Kelderman, P. , 1996. Water Chemistry and Biology. IHE lecture notes HH 277/96/1, 54 pp.

Table./..

Parameter		Water Quality Class I	II	III	IV	V
Basic Requirement		All water bodies should not cause the following by unnatural reasons: a. nuisance caused by settleable deposits; b. floatable materials, such as oil and grease, or materials that cause aesthetic nuisance; c. nuisance caused by colour, odour or turbidity; d. toxic or abnormal physiological effects or damages on humans, animals or plants; e. nuisance caused by production of waterborne living things.				
Temperature, °C within		Variation of water temperature caused by human activities should be controlled: -Average maximum temperature increase ≤1 °C in summer. -Average maximum temperature increase ≤ 2 °C in winter.				
pH (in units)		6.5 - 8.5				6 - 9
Sulphates[1] (as SO_4^{-})	≤	<250	250	250	250	250
Chlorides[1] (as Cl)	≤	<250	250	250	250	250
Soluble Iron[1]	≤	<0.3	0.3	0.5	0.5	1.0
Total Manganese	≤	<0.1	0.1	0.1	0.5	1.0
Total Copper[1]	≤	<0.01	1.0	1.0	1.0	1.0
			0.01*	0.01*		
Total Zinc[1]	≤	0.05	1.0	1.0	2.0	2.0
			0.1*	0.1*		
Nitrate (as N)	≤	<10	10	20	20	25
Nitrite (as N)	≤	0.06	0.1	0.15	1.0	1.0
Non-ionized Ammonia	≤	0.02	0.02	0.02	0.2	0.2
Kjeldahl Nitrogen	≤	0.5	0.5	1	2	2
Total Phosphorus (as P)	≤	0.02	0.1	0.1	0.2	0.2
			0.025**	0.05*		
Permanganate Value	≤	2	4	6	8	10
Dissolved Oxygen	≥	Saturation 90%	6	5	3	2
Chemical Oxygen Demand (COD_{Cr})	≤	<15	<15	15	20	25
Biochemical Oxygen Demand (BOD_5)	≤	<3	3	4	6	10
Fluoride (as F^-)	≤	<1.0	1.0	1.0	1.5	1.5
Selenium (IV)	≤	<0.01	0.01	0.01	0.02	0.02
Total Arsenic	≤	0.05	0.05	0.05	0.1	0.1
Total Mercury[2]	≤	0.00005	0.00005	0.0001	0.001	0.001
Total Cadmium[2]	≤	0.001	0.005	0.005	0.005	0.01
Chromium (VI)	≤	0.01	0.05	0.05	0.05	0.1
Total Lead[2]	≤	0.01	0.05	0.05	0.05	0.1
Total Cyanide	≤	0.005	0.05	0.2	0.2	0.2
			0.005*	0.005*		
Phenol[2]	≤	0.002	0.002	0.005	0.01	0.1
Oil (Petroleum)[2]	≤	0.05	0.05	0.05	0.5	1.0
Anionic Surfactant (LAS)	≤	<0.2	0.2	0.2	0.3	0.3
Total Enteric Bacteria[3] (no/L)	≤			10,000		
Benzo(a)pyrene (µg/L)	≤	0.0025	0.0025	0.0025		

[1] Standards that can be allowed to modify according to local water body characteristics.
[2] Lowest detection limits from analytical methods.
[3] Trial standards.
* For fisheries protection.
** For lakes or reservoirs.

Table A VI-2 Water quality classes

Annex VIl INSTITUTIONAL ASPECTS

Colonial inheritance

The country was recently de-colonised through a serious liberation battle. Power was taken over by the Liberation Army, consisting of various indigenous fractions. The former minority Government, representing (white) colonial settlers only, was overthrown. Thus, a “condemnable apartheid” regime ended, which was characterised by inequality, indignity and abuse of resources through a small, but very rich and powerful layer of people.

In the past both land and water use were monopolised by the minority rulers. The indigenous population was historically banned to the poorer marginal “communal lands”. These lands are consequently densely populated and are characterised by poor soils, sensitivity for erosion and absence of nutrients. Many rural people have migrated to the capital to join the army of the impoverished urban and peri-urban labour force.

The new Government now consists of a Government of national unity in which the main dominant interest groups are represented. The Government is mainly composed of former freedom fighters, that are relatively loyal to each other, but with limited capacity in matters of public administration.

Stakeholders

The prevailing social structure in the country is more or less representative for Southern Africa. A few typical groups of interest:

A large group of poor, rural people with limited access to domestic water and with historically no access to irrigation water and with a poor level of agricultural technology (rain-fed hazards, unbalanced use of fertiliser, poor soil conservation, erosion) applied on relatively marginal soils in the communal lands.

An economically powerful group of commercial estate farmers (mainly white), employers of large numbers of workers, who are willing and capable to invest, provided that this will result in sustainable production (for themselves) and under condition that investments are secured. Although recently isolated and stripped of political power, this group still forms the backbone of the economy.

Rapidly growing cities and towns with a deteriorating level of coverage of basic needs including domestic water supply and sewerage systems and main producers of organic waste water and other potential pollutants. The big cities, which were formerly generating considerable industrial activity, are now stagnant in productivity. Economic regulation of the new Government is haphazard and investment risks for entrepreneurs are high. The labour force in the big cities is rapidly growing and unemployment is huge (about 40%). The rural towns, who were historically focussing on supporting commercial agriculture and the limited development of agro-industries, are virtually stagnant.

A large force of civil servants has been created at all levels, also to ease the pain of the unemployment. Effectiveness of public administration, however, is low. The governmental system of public administration is under pressure with an increasing inefficiency and growing budget deficits.

Water allocation

The bulk of the water use is historically attributed to the sector commercial farming through private water rights, that were issued on a "first come, first get base" and on the assumption of perpetual use. Water is picked up from private storage or directly from flow, if available. Most of the private storage rights are from smaller dams on the tributaries. Some, however, are lumped in huge dams on the main streams, administered by private syndicates of commercial farmers. Of late, the call for private sector participation in the development of government infrastructure becomes louder and louder.

Government, subdued to the same system of prior appropriation, is having substantial storage in larger (government) dams from which growing urban and industrial demands are supplied. The water supply of bigger cities is predominantly covered by surface water abstraction from these government dams. Excess water from government dams is sold to the private sector. Rural towns are either supplied from government dams or through groundwater supply from series of bore holes. Smaller communities are covered for water supply by motorised tube wells or small hand pumps on bore holes.

Agricultural water use in the communal lands is mainly rain fed. Here and there surface water is abstracted from smaller (stock watering) dams and in an exceptional case groundwater is used for irrigation.

Policies and trends

The country is in disarray and water legislation has not yet been approved although policy principles have been formulated in a policy document. The following principles have been chosen as guidelines:

- Water resources management on hydrological boundaries
- Integrated planning of water quantity, water quality and environmental integrity
- Decision making at the lowest appropriate level
- Stakeholder participation in decision making
- Equitable representation of stakeholders in decision making notably of women
- Decision making through predefined publicly accessible plans
- Horizontal co-ordination of natural resources planning
- Functional decentralisation of water management to river basin organisations
- Equitable water allocation
- Vertical co-ordination of strategic and operational plans
- Priority for demand management
- Management of water as a social and economic good
- Application of the principles of water pricing and water valuation
- Cost recovery and "polluter pays" principle

These principles were formulated haphazard, after an extensive but poorly structured stakeholder participation.

Although the focus of the new Government is to create a bearable existence for the millions of rural poor, no resettlement or development policies have been formulated as yet.

Legal framework

The legal framework is in a process of being adapted. However, the authorities are expecting some valuable recommendations to emerge from the management strategy to be produced in this feasibility study. The traditional legal framework was based on stimulating private initiative and restricted Government intervention. Water rights were established on the "date priority" system, in which early settlers have the first access to water. The rights were issued on the assumption of perpetuity. About 60% of the national storage capacity is "owned" by individuals in private smaller to medium size dams and larger "syndicate" dams. This "first come, first get" system has led to grave discrepancies in raw water distribution, especially in situations of over-commitment, where the Government, who is subjected to the same system of water rights, is not even capable of guaranteeing drinking water. River basin outline plans were never produced. In order to stimulate the exploitation of "underutilized" land, water rights were issued by the Water Court on the sole criteria of economic viability. There were no title deeds to communal lands and subsequently water rights could not be attached to this category of land use. Although there was a legal provision for primary water rights (for domestic use and cattle), this right was not secured through further regulation. The law opened the possibility of establishing River Boards in parts of the river basins on hydrological boundaries. Groups of estate farmers have utilised this option.

In the mean time all water rights have been suspended. However, the Constitution stipulates that any improvements to land or infrastructure have to be compensated. Violation of this principle will certainly imply that the crucial international donor community will refrain from financing any new activities.

Institutional framework

The management (quantity and quality) of raw water is in principle under the provincial office of the Ministry of Water Resources. The management of smaller piped water supply systems for small towns or rural centres is basically under the same office. This office is subject to a command relation with both its national office and with the Provincial Governors. Co-ordination lines are supposed to be in existence with other sector agencies at provincial level as well as with the provincial offices of Local Government.

The water treatment and water supply of the cities and larger towns are under the authority of the respective City or Town Councils. The river basins are spread over various political provinces and districts. The care for rural drinking water supply through bore holes and hand pumps is managed by the district offices of Local Government, supervised by the provincial offices of Local Government.
The provincial and district offices of the (sector) Ministry of Agriculture carry out all agricultural functions. Hence, they are also in charge of most of the communal irrigation schemes. These schemes are heavily subsidised and peasant farmers are not paying for any operation and maintenance costs. There is a tendency to transfer the operation and maintenance of the schemes to the users.

At a decentralised level there is no provision yet for the management of environmental aspects. Environmental aspects are under the authority of the national Ministry of Environment through some de-concentrated regional offices of National Parks and Wildlife.

Effectiveness and efficiency of all Governmental services is low and in some cases even absent. The day-to-day water management is de facto carried out by the River Boards, who finance their activities of monitoring and policing by the application of a management fee to each water right holder. These boards are only available in the commercial areas. The Boards consist of commercial farmers only, although the Provincial Water Engineer is formally in charge. Specific problems are that only water right holders are members. All commercial water abstraction is metered.

Financial arrangements

The shortage of funds is gigantic. In the past decade Government was forced to borrow heavily. The country is heavily subjected to a regime of Economic Structural Adjustment imposed by IMF and World Bank. Debt ratio is over 60%. Recently, Government entered in to partnerships with the private sector under various scenarios (mainly build-operate-transfer) in order to be able to cover public services. There is a growing pressure from the private sector to be able to further invest in large-scale water infrastructure (mainly build-operate-own) for private use in commercial agriculture and even for drinking water supply.

Government institutions operate according to the traditional dual system of appropriation and working accounts. New developments are principally financed from appropriation through the national budget or increasingly through donors.
Operational costs are sometimes recovered by a general pricing mechanism per activity e.g. treating and supplying clean water and drilling bore holes. The idea is that working accounts are breaking even in costs and revenue. The bookkeeping, however, is complex and bureaucratic and accountability is low.

Revenue from raw water sales is collected by the Provincial Water Engineer, but is returned to Treasury. There is very little or no allocation for Operation and Maintenance for existing dams, which are consequently falling apart.

In fact, hardly any public investment is done in the water sector, and this is mainly affecting the rural communities in the communal lands, that have been deprived from both domestic and irrigation water for generations.

Human resources development

Although the educational level in the country is very satisfactory, it is extremely difficult for a Government agency to retain skilled staff, because the remuneration and prospects for career development in Government are very meagre and the private sector is offering greener pastures for people who want to work. Consequently, young promising staff members only remain in Government to learn the necessary skills in order to march off as soon as possible to greener pastures. Government bureaucracy does not offer any incentives to the remaining personnel to perform. The result is a general degrading of the Government machinery with a logical negative impact on efficiency and effectiveness.

ANNEX VIII ASPECTS FOR WATER RESOURCES SYSTEM MODELLING

VIII.a Background

To get an idea about the possibilities of the reallocation of water in the Mupfami catchment, a Water Resources System Simulation model will be helpful. In a Water Resources Simulation model, the influence of the operation on the water resources system is studied, given certain hydrological conditions.

These notes do not explain the fundamentals of hydrology, water management, statistics, computer programming, which are all necessary to make a good water resources system model. The notes rather offer 'check-lists' to remind the modeller of the possibilities and dangers of water resources system modelling and the steps to go through to make a good model. Most of these steps may seem very obvious, but to use modelling efficiently and effectively in a decision making process for longterm planning, which is necessary in the Mupfami catchment, it often goes wrong at these obvious steps. It is important that the modeller wonders how his work fits into the decision making process; the modelling should get the correct place in the Framework for Analysis.

To analyse the problems and possible solution in the Mupfami catchment, the expert teams will have available a Water Resources Simulation Model, which is premodelled in Excel. A subgroup in the team of experts will be using the model tools to assist the decision making.

Steps in development of a simulation model

1. Definition of the problem, boundary conditions, assumptions
2. Setup of a model for planning purposes (water balance)
3. Determination of the model input
4. Definition of the parameters of structures, abstractions (demands and allocation)
5. Debugging of the program, model tests.

After the development of the model, it will be used for analysis and the different development steps will be reconsidered.

1 Definition of problem, boundary conditions, assumptions

Start verbally then go to technical and quantitative specification

- Is there lack of water during some years or during some parts of the year?
- Is the idea to increase the overall benefits in the catchment, or is it important that regional differences or differences between different types of stakeholders are changed?

Comply with limits of:

- available input data;
- knowledge about processes.

2 Setup of a model for planning purposes (water balance)

The following questions need to get attention:

- Should part of the river basin be modelled or the whole river basin?
- In which units can we subdivide the area to model?
- Can various agricultural/urban activities be modelled as one node?
- Should a tributary be modelled as an 'inlet' or does it require a separate branch?
- Are we going to model unmeasured inflows and abstractions?

For the Mupfami there is already a model available at the start of the groupwork, thus most of the above questions have been answered. However, it is important to realise that these decisions have been made. If the model set up as it is does not satisfy your needs, you can change it. Anyway, you still have to decide how to input/model unmeasured inflows and abstractions.

3 Choice of input series

Which hydrological time series will be used?

The economical feasibility of certain investments depends on how the time series that are used in the modelling compare to a time series of a lot of years. This requires a comprehensive hydrological analysis. However, at the stage of the decision making process where the decision makers have to make a choice between different policy alternatives, it may be sufficient to make a comparison based on a limited length of the time series. For the Mupfami case study, in first instance a time series of 10-year is recommended. The choice of the input time series depends on both the data availability and on how representative the period is.

Combining hydrological time series and other input parameters

Apart from the hydrological time series, there are scenarios of water demand and there are strategies to manage water demand and supply, which the experts, together with the government, will decide upon. It is strongly recommended to make separate computations for the base year and for the year at the end of the time horizon (the government prefers 2020). Thus in a particular computation the demands are the same for each January, each February etc.. For each computation the hydrological time series of a representative 10 year period are used for computation. In this way it is tested how the catchment in the new situation (scenario + strategy) deals with hydrological uncertainty.

What can be expected as return flows from the towns?

Make a sensible estimate, based on storm flow and on drinking water use.

What are the demands that we can aspect?

The input series of the demands, for both the base year and the year at the end of the time horizon, are the outcome of both autonomous developments (f.e. growth of the cities) and of strategies (f.e. change of crops, change of irrigation system, investments in mining).

4 Definition of the parameters of structures, abstractions (demands and allocation)

Reservoirs

- Evaporation/rain losses; are they significant in the water balance?

If so, determine volume - surface area relationships, potential evaporation/time step. N.B. You need to have the reservoir storage as a level to verify, as a volume to know the amount and as a surface area to compute net evaporation.

- Define operation rule curves (See lectures on reservoir operation; dead storage level, flood leve, utility rule curve with level and percentage of rationing on demands).

Allocation

For a certain river flow or a certain water release from a reservoir (maybe steered by demand or right), water should be allocated to downstream users. It is most easy to model the allocation of water from upstream to downstream. However, priority allocation is far more realistic (or maybe not; illegal abstractions will if necessary take any water that passes). Is it necessary for the decision to be made to arrange allocation according to a water rights system?

5 Debugging of the program, model tests

To find possible mistakes in the programme, be critical on your model results. Do the results look sensible?

Realise that when you do a verification with historical time series, the operation of the reservoirs may have been different than the way it was prescribed by the rule curves.

VIII.b Water Resources System model for Mupfami

The Mupfami model is programmed in Excel, following the principles of WAFLEX, a programme set up by Prof. Savenije. Below a very short introduction is given. Each team will appoint a few modellers, whom will be explained verbally, by Marieke de Groen (marieke.de.groen@resource.nl).

Start at the worksheet <MENU>.
The buttons either bring you to input or to output, as shown by the heading.
Grey buttons bring you to tables or “maps”, yellow ones to graphs.
The major inputs are:

- time series for rainfall, evaporation and inflows. The input of inflows is further explained below.
- demands. You define the demands for every month in a year. The demands in January should be the same for each January in the 10 years that you calculate, unless this demand depends on the rainfall and evaporation.

- rule curves. For each dam the dead storage level and the flood rule curve have already been put in. As part of the strategy you can adjust the utility rule curves; in which month, at what storage level, can the reservoir only supply a certain percentage of the demand?

N.B. Reservoir C and D are already shown in the schematic maps, although they have not yet been built. They are shown, but are not yet used in the modelling. You can make them operational by indicating in the worksheet <menu> that they exist and by making a small change in the demand-sheet at the location of the reservoir.

Inflows and demands
To create the time series for inflows your group needs to use the data of the discharge gauges C3, C23, C17, C61, (making assumptions about historical abstractions upstream of these gauges). All available data are provided on a separate DATA MUPFAMI.XLS-spreadsheet. Also, with the crop water demands, rainfall and the reservoirs, you need to estimate how the reservoirs will operate.

N.B.1 If you cannot open the worksheet, you may have the Excel set up in a mode that protects against macros (because macros may contain viruses). This can be changed by using the menu item Tools-Options-General and then putting the macro protection in a average mode (or off, if you use the Office 1997). Another problem might be that there is no Excel-Visual basic installed at your computer. Go to the helpdesk to install this.

N.B.2 All cells that are meant for input use bright blue text.

Overview of worksheets
Menu Here the user can use buttons to navigate from input to output and can fill in if reservoir C and D exist. (n.b. including reservoir C and D also means a small change in the worksheet Demand; demand may than not travel further upstream). He/she also has to fill in the maximum capacity of the dam and the storage to start the computation with, but the figures that are default in are in principle ok.

Supply Overview model set-up, computation of flow

- Cells of the same colour have the same type of formula. Red users are using. Pink users are potential users.
- Be careful when you want to change the model set up (for example to have a certain agricultural project make use of another dam). Some cells need dragging and some cells need copying. If you understand the formulas this should not be a problem, if you don't then better keep the set up as it is.
- Light blue coloured cells are connecting users that depend on the reservoir; the location of the connected abstractions refers to priorities; more upstream, earlier priority. In principal the model gives the water to the user demanding it most upstream in the model. However, for Mupfami reservoir shortages can be shared between users, by giving weights to the different types of users (move to cell $weight to see).
- Harava prefers to abstract from reservoir A instead of from Mupfami reservoir. There are a few reasons for this (1) reservoir A is upstream , so Harave does not need to pump, (2) Harava is the

only user for reservoir A, while it shares Mupfami with other users. (3) Reservoir A is a very small reservoir in comparison to its inflow, so it refills quickly. Hint: If agricultural project area 1 starts relying on reservoir A, this strategy may need to be changed.

Demand Computation of demands from reservoirs. Have a look in the cells; the formulas compute from downstream to upstream.

Series Tables with time series for input and output
Everything on the left of the black vertical line is input, everything on the right is output.

There are four types of time series the programme requires as input:
1 Precipitation and evaporation
2 Inflows
3 Gauges
4 Demands

Fill time series of precipitation and evaporation for those dams for which it is necessary to compute net evaporation (maybe negative if more rainfall). If a back-of the envelope computation shows that inflows and outflows are very large in comparison to net evaporation, then do not bother to model evaporation losses.

For different users different demands need to be specified. Demands are either specified for the base year or for the year at the time horizon. In that way in a computation it is looked how sensible a certain set up is for the hydrological time seris. For urban users and industrial it is logical to keep the demand per year constant. For agriculture the cropping pattern is the same for all years, but irrigation demands depend on rainfall.

For agricultural users demands depend on cropping pattern. Also, some agricultural project areas have their own dams (see descr. INFLOW 4,5,67..) which will supply a large part of the water need. Obviously, if you not only having dry irrigation, but also supplementary irrigation in the wet season, demands depend on rainfall as well. Design a separate spreadsheet to compute your demands.

Only for advanced users:

- New input columns can be created by inserting a column. Copy the column on the left to the newly created column. N.B. In the coloured horizontal range there are lookup functions that look for the current time step ($count), in the table ($table) with the column offset number that is mentioned three lines above.
- The model will become faster but less flexible if you replace formulas in the input time series by values.
- In the output-part everything is computed in the range $control (or computed in a macro and put in the range $control). A macro copies the line control to the right location in the time series.

Dams Rule curves of dams, area elevation curves.
You can use the default rule curves as a start, but one of the management options is to increase the percentage of rationing or to put the rule curves for rationing at a different reservoir storage level. The

area elevation curves are taking account of the local topography at the dam sites. You cannot change them.

Only for Mupfami dam the flux of net evaporation is modelled. (In reservoir A in the rainy season there is far more water flowing in and spilling than can evaporate.)

Res.	Graph time series reservoir storage
Flows	Discharges at different points in the model
Releases	Releases and requests from dams.
Short	For each user a graph of the demand and the shortage.