



THE EVALUATION OF THE PRESENT AND POTENTIAL WATER RESOURCES MANAGEMENT FOR THE LAKE CHILWA BASIN

by

**Geoffrey M. S. Chavula,
Department of Civil Engineering,
The Polytechnic, P / Bag 303,
Blantyre 3.**

ABSTRACT

The paper discusses the general principles of water resources management namely assessment, planning, development, allocation, protection, conservation and monitoring; and examines their implementation in the Lake Chilwa catchment area.

The water balance equation has been used as a basis for assessing the availability of water resources in the Basin. Mean values of rainfall, surface runoff and baseflow and evapotranspiration have been computed using the Thiessen and Isohyetal methods, the HYDATA software and CROPWAT package respectively. Results obtained from the evaluation of the water balance equation indicate that evapotranspiration values exceed the amount of annual rainfall, prompting the suggestion that water demand for evapotranspiration processes are met from water in storage.

General circulation models suggest that the continued emission of greenhouse gases into the atmosphere will lead to an increase in temperature by 2.6 - 4.7 °C by the year 2075, whereas rainfall will continue to show variability with floods and droughts wrecking havoc in the Basin.

For the sustainable management of water resources in the catchment area, the study has recommended the development of a water resources master plan. The responsible water authority in consultation with all stakeholders should develop such a plan, a task which can only be achieved where there is political commitment and availability of financial and human resources, among other things.

1. INTRODUCTION

The Lake Chilwa Basin is important for a number of reasons including fishing, agricultural production, research and a source of water supply for the Municipality of Zomba.

According to Petermann (1990), Lake Chilwa provides income for some 650 full time and 500 part time fishermen. Kululanga and Chavula (1993) state that Lake Chilwa contributes about 10 - 20% of the total fish landings for the whole country. Apart from being a source of revenue for the fishermen as well as a foreign exchange earner for the country, fish is one of the cheapest form of protein in Malawi. This assertion is supported by the relatively high per capita consumption estimated to exceed 12 kg annually (Kululanga and Chavula, 1993). But the productivity of Lake Chilwa in as far as fisheries resources are concerned is highly dependent on lake levels. For example, when the lake dries up fish production grinds to a halt. Therefore the sustenance of lake levels which are conducive to fish production is a prerequisite for maintaining the fisheries industry. Yet measures have not been put in place to prevent this basin lake from drying up during protracted drought spells.

The local population depend on the flood plain of Lake Chilwa for rice production and cattle grazing. The Ministry of agriculture has also established rice irrigation schemes in the Basin where people grow rice on a commercial basis. The sustainability of agricultural production is heavily reliant upon the availability of water in the flood plain such that during drought periods the yields are greatly reduced. This implies that agricultural production in the flood plain is very vulnerable to changes in weather conditions. It is therefore necessary that water conservation measures should be developed so as to cushion the agriculture sector from the adverse effects of droughts.

The Lake Chilwa has been a center of several biological studies. While some of the previous research activities have been carried out with a view to determining the impact of lake level changes on the biological productivity of Lake Chilwa, and to describe the geological history of the lake, etc. the current study is intended to provide data which can be used in the development of a water resources master plans for the Basin.

Previous studies on water resources assessment have either used very crude data to determine the availability of water resources in the catchment area (Petermann, 1990) or applied inaccurate methods in the evaluation of the water balance equation. However, in this study an attempt has been made to use updated data from the Meteorological Department and the Ministry of Water Development in order to evaluate the water balance equation. Computer software have been utilized to determine the mean annual rainfall, runoff, evapotranspiration, and the potential impact of climate change on water resources.

Semi-structured interviews have been extensively used in collecting the valuable information from stakeholders on the management of water resources within the catchment area.

2. WATER RESOURCES MANAGEMENT

Water resources management encompasses seven major water related activities namely assessment, planning, development, allocation, conservation, protection and monitoring. Grigg (1985) defines water resources management as people's control over water as it passes through

its natural cycle, with balanced attention to maximizing economic, social and environmental benefits.

2.1 Assessment of Water Resources

In brief, the assessment of water resources entails the quantification of water resources as well as the determination of the suitability of the water, in terms of its quality, for various uses. An assessment of water quality for the Basin was not carried out during the study because of financial constraints. It is envisaged that future studies will include the characterization of water resources in the Lake Chilwa catchment area in terms of quality.

The relationship between the various parameters in the water balance equation can be represented by the following expression and conceptual model (Yates, 1994), Figure 1

$$S_{max}(dz/dt) = (P_{eff}(t)(1 - \alpha) - R_s(z,t) - R_{ss}(z,t) - E_v(PET, z, t) - R_b) \quad (1)$$

where:

- P_{eff} = effective precipitation (length/time)
- R_s = surface runoff (length/time)
- R_{ss} = sub - surface runoff (length/time)
- E_v = evapotranspiration (length/time)
- R_b = baseflow (length/time)
- S_{max} = maximum storage capacity (length)
- z = relative storage ($0 \leq z \leq 1$)
- R_t = total runoff
- α = coefficient of direct runoff
- R_d = direct runoff

The terms used in equation (1) can be expressed in continuous function form as follows:

(a) Direct runoff (R_d) is given as

$$R_d = \alpha P_{eff} \quad (2)$$

(b) Sub -surface runoff (R_{ss}) is given as

$$R_{ss} = \beta z^{\gamma} \quad (3)$$

where β is the sub surface runoff coefficient and γ is the power term.

(c) Surface runoff coefficient R_s is described in terms of storage state z , the effective precipitation P_{eff} and the base flow as (α = surface runoff coefficient)

$$R_s(z, P, t) = \begin{cases} z - (P_{eff} - R_b) & \text{for } P_{eff} > R_b; \\ 0 & \text{for } P_{eff} \leq R_b \end{cases} \quad (4)$$

Total runoff R_t is the summation of the four runoff components namely R_s , R_{ss} , R_b and R_d as follows:

$$R_t = R_s + R_{ss} + R_b + R_d \text{ ----- (5)}$$

Baseflow (length/time) is the flow value determined as the flow that is exceeded 95% of the time.

Evapotranspiration E_v is a function of potential evapotranspiration (PET) and the relative storage of the catchment. A non-linear function has been developed to describe E_v (Kaczmarek, 1993):

$$E_v(z, PET, t) = PET \left(\frac{[5z - 2z^2]}{3} \right) \text{ ----- (6)}$$

The Priestly Taylor Method for potential evapotranspiration uses the simplification of the Penman equation:

$$E = \left(\frac{E_r + E_a}{\gamma + 1} \right) \text{ ----- (7)}$$

where:

E = combined evaporation estimate (mm/day)

E_a = evaporation estimate which assumes unlimited availability of energy.

E_r = evaporation estimate which assumes the ability of the system to remove moist air is not limiting.

γ = slope of the saturated vapour pressure curve.

γ = psychrometric constant

Priestly and Taylor (1972) found that the Penman equation when applied to very large areas, the second term of the equation is approximately 30% of the first term; thereby reducing the equation to the form, which is an estimate of the reference crop evapotranspiration (E_{rc}) as given below:

$$E_{rc} = \frac{\gamma}{\gamma + 1} [R_n - G] \text{ ----- (8)}$$

where γ is given a value of 1.26 in humid climates and 1.74 in arid climates. G is the soil heat flux which can be assumed to be equal to zero. R_n is the net radiation which can be computed by equation (9) given below:

$$R_n = [(1 - alb)[0.25 + 0.5(n/N)]R_a] - (f)(0.34 - 0.14 e_d) \sigma (T + 273.2)^4 \text{ ----- (9)}$$

where

n = bright sunshine hours per day (h)

N = total day length (h)

R_a = extraterrestrial radiation ($\text{MJ m}^{-2}\text{day}^{-1}$)

σ = Stefan-Boltzmann constant

T = mean air temperature ($^{\circ}\text{C}$)

e_d = vapour pressure (kPa)

alb = albedo (short-wave radiation reflection coefficient)

f = cloudiness factor

In its simplified version, the water balance equation for a catchment area may be written as:

$$P = R_s + R_g + E_t \text{ ----- (10)}$$

where P is the precipitation, R_s is the amount of surface runoff, R_g is the groundwater discharge term and E_t is evapotranspiration. The above stated equation assumes that there are no changes in surface and groundwater storage, and this is particularly true when sufficiently long period of analysis is used. It is this equation that has been used for the assessment of water resources in the Lake Chilwa Basin.

2.1.1 Rainfall regime

Rainfall in the Lake Chilwa Basin results from one major synoptic system namely the Inter Tropical Convergence Zone (ITCZ); and takes place from November to April. Occasionally, rainfall over the catchment area also results from Tropical Cyclones as they cross the Mozambique Channel into Malawi. This type of rainfall is characterized by heavy down pours usually causing flood disasters. The Zaire Air Boundary (ZAB) which has its source in the Southern Hemisphere subtropical high pressure belt just off the western coast of the Republic of South Africa and Namibia accounts for a very small amount of the total rainfall that occurs in the basin. The ZAB is mostly active in the Central and Northern regions of Malawi.

It has also been observed that when both the ITCZ and Tropical Cyclones are concurrently overhead in the Basin flood disasters are a common occurrence as heavy rainfall takes place. For example, the ITCZ and the Zomba Cyclone caused heavy loss of life in Zomba in 1946 when nearly 711 mm of rainfall fell in 36 hours (Chiotha et al, 1997). Figure 3 shows the distribution of rainfall in Malawi.

2.1.2 Analysis of rainfall data

The estimation of average rainfall for the Lake Chilwa Basin is one of the major sources of error in evaluating the water balance equation. Dolamore (1987) has used the arithmetic mean for the rainfall stations located in the catchment area in order to determine the average rainfall. The main shortfall with this approach is that it assumes that the gauging stations are uniformly distributed and that the basin has uniform topography, which is not true of the basin under study. In this case, the average rainfall obtained by Dolamore (1987) should be used with a lot of caution. It is even more confusing to use the rainfall data supplied by Dolamore (1987) in the water balance equation because of the various mean rainfall values that were obtained for different lake levels.

The National Water Resources Master Plan (1986) and Petermann (1990) also used average rainfall for the stations either located in the flood plain, the mountainous areas or near the shore of Lake Chilwa to determine the average rainfall for the Basin. This approach is not accurate in the determination of the average rainfall for the catchment area because of the inadequacy of rainfall stations located in each of the physiographic zones. Notwithstanding this shortfall, the authors have used these values in their evaluation of the water balance equation. The National Water Resources Master Plan (1986) gives the average rainfall value of 800 - 1000 mm per annum whereas Petermann (1990) gives a figure of 1023 mm / year.

Hill and Kid (1980) used both the Theissen Polygons and the isohyetal map to determine average rainfall for 47 catchment areas in the country including the Lake Chilwa Basin. The data they used for the Lake Chilwa Basin was said to be of generally good quality i.e. without a lot of gaps

and recorded over a period of 13 - 19 years. In their calculation, the average rainfall was found to be 1480 mm per annum . However, this figure is an average value for only three selected stations in the whole Basin.

Kalk et al (1979) used the Thiessen Polygons to determine the average rainfall over the catchment area. An average value of 998 mm / year was obtained over a 10 year period of analysis i.e. 1961 - 1971.

It is apparent from the data presented above that all the authors disagree on the figure for the average rainfall over the catchment area. Therefore there is need to analyze the rainfall data once more in order to get a figure for the average rainfall that can be used with confidence in the evaluation of the water balance equation. In this respect, computer packages for drawing the Thiessen polygons and the isohyets have been used with a higher density of gauging stations in order to get a better value of average rainfall for the Basin.

2.1.3 Analysis of Evapotranspiration data

Previous studies have extensively used pans to measure evapotranspiration values for the catchment area. But the accuracy of measuring evapotranspiration by using pans is questionable especially where correction coefficients have to be applied to adjust the recorded values. Data for pan evaporation is available for Khanda, Makoka, Zomba, Zomba Plateau, Chancellor College and Likangala Irrigation Scheme meteorological stations.

An attempt was made by the Institute of Hydrology (UK) to use the Penman Equation in order to determine evapotranspiration values for Khanda Station but the results obtained differ markedly from those computed by the Department of Meteorology (National Water Resources Master Plan, 1986)

As a result of the weakness pointed out above, the current study has applied the Penman Equation in order to determine a good estimate of annual evapotranspiration for the catchment area. The advantage of the Penman Equation is that it takes into account climatic factors that have a direct bearing on evapotranspiration such as temperature, wind speed, humidity, sunshine hours and solar radiation

2.1.4 Analysis of surface runoff data

As stated by Kalk et al (1979), seven perennial rivers, together with numerous small seasonal streams flow into Lake Chilwa and its marginal swamps and marshes namely Domasi, Likangala, Thondwe, Namadzi, Phalombe, Sombani and Mnembo. The first six of the above listed rivers are in the Malawi part of the catchment area whereas Mnembo originates from Mozambique (Figure 4). However, flow data for Mnembo river is not available; and this is the major source of error in computing the average value of surface runoff for use in the water balance equation. All the rivers arising from the Malawi side of the Basin exhibit annual variability, with maximum flows occurring in February and falling rapidly thereafter, Figure 5.

One notable feature about rivers draining the Lake Chilwa catchment area is that they are perennial in their upper reaches but they gradually lose their flow in the

Chilwa - Phalombe plains due to the porous nature of the area. This has led to the suggestion that flows recorded by some gauging stations located very far from the lake do not give a clear indication about the amount of surface runoff that actually ends up in the lake (Kalk et al, 1979).

Surface runoff data used in the water balance equation has mainly been calculated from the discharge data for Sombani, Phalombe, Namadzi, Thondwe, Likangala and Domasi. The mean runoff value so obtained is not a true representation of the total surface runoff for the catchment area as flows from the Mozambique side of the catchment area are not taken into account. This problem will remain unresolved as long as flow data from the Mozambique side of the Basin is not made available. In this regard, the mean value of surface runoff used in the water balance equation can best be described as an estimate.

2.1.5 Analysis of baseflow

Most of the previous studies have used inflow data in their evaluation of the water balance equation. In these computations, the inflow value has comprised both baseflow and surface runoff. But for a thorough assessment of water resources in the Lake Chilwa Basin there is need to determine the amount of groundwater flow and surface runoff that takes place within the catchment area separately. Although Petermann (1990) and the National Water Resources Master Plan (1986) have used the 95% river flow as baseflow, no attempt has been made to use hydrograph separation using the semi - log method and groundwater level fluctuations to compute the amount of baseflow. Information on groundwater recharge is valuable in the development of master plans for water resources. Studies done by Smith - Carington and Chilton (1983) on groundwater resources for the whole country have not given recharge values for the Lake Chilwa Basin. Hence it was felt necessary to calculate the annual groundwater recharge value.

2.2 Water Resources Planning

Water resources planning involves setting modalities for a systematic and sustainable development of water resources with a view to averting the depletion and degradation of the resource. The U. S. National Water Commission (1972) defines water resources planning as a creative and analytical process of hypothesizing sets of possible goals; assembling needed information and consequences of alternative courses of action for attainment of such goals; displaying the information and consequences of alternative actions in an authoritative manner; devising detailed procedures for carrying out the actions, and; recommending courses of action as an aid to decision makers in deciding a set of goals and courses of action to pursue. It is at the planning stage that the use to which water will be put after development is determined and optimized i.e. whether the water resources will be developed to cater for domestic needs, irrigation, hydropower generation, navigation or recreation, etc.

At present, a water resources master plan has not been developed for the whole of the Lake Chilwa Basin. However, fragmented plans for water supply and irrigation are being developed under the water supply scheme for the Municipality of Zomba and flood plain irrigation for Machinga ADD respectively. There was no stakeholder involvement in the development of these fragmented plans. Stakeholder involvement in all phases of the project cycle i.e. from inception to operation and maintenance, removes communication breakdown and its inherent problems between the beneficiary community on one hand and government officials on the other. Decisions made on the management of water resources without the participation of stakeholders is a recipe for disaster as the programme runs the risk of failure. This may arise from the fact that the project may be implemented on the basis of inadequate information or the project may be misunderstood by the community. Involvement of stakeholders in water resources management

increases the community's sense of "ownership", enhances decision making, increases efficiency and reduces the need for enforcement.

At present all water resources development is guided by the 1994 Water Resources Management Policy and Strategies, the Water Act 1969 and the Water Works Act 1995. The following statements give a summary of the policy:

- Water should be managed and used efficiently and effectively so as to promote its conservation and future availability in sufficient quantity and acceptable quality.
- All programmes related to water should be implemented in such a manner that mitigates environmental degradation and at the same time promotes enjoyment of the asset by all beneficiaries
- The approach to allocation of water should be designed in such a way that recognizes water not only as a social but also an economic good, and in a manner that achieves maximum benefit to the country
- Investment of public funds in water and related programmes should be guided by the expected net economic, social and environmental benefits of the programme to the country as a whole
- In planning and providing water supply services, consideration should be given to safe disposal of the resultant waste water
- The government shall facilitate the participation of stakeholders (including users and special target groups) both in the public and private sectors to ensure that the needs of their relevant interests are taken into account in the development of water systems
- The pricing of water should reflect demand and the cost of water services. Pricing should aim at reduction of government financial support to the sector over time.

However, as pointed out in the State of the Environment Report (1998), the policy is silent on several important issues including water resources conservation, protection of catchment areas, cooperation between Malawi and its neighbouring countries on shared water bodies, water resources evaluation and monitoring. These weaknesses have compelled the government to review the policy and the Water Act. It is expected that the revised Water Resources Policy and Strategies and the Water Act will be ready towards the end of the year 2000.

Harmonization of the relevant policies such as the Environmental Management Policy, the Fisheries Policy, the Forestry Policy, the Parks and Wildlife Policy, the Agricultural and Irrigation Policy, and the Water Policy has not yet been done although all the above listed policies have a direct bearing on water resources management. Harmonization of these policies will help in sorting out conflicts over water use by the various sectors. For example, the Agricultural and Irrigation Policy is promoting the use of dambos for crop production especially during the dry season because dambos retain a lot of moisture. But the Water Act does not recommend cultivation close to river banks because such practices exacerbate soil loss through erosion, consequences of which are prevalent sedimentation problems that the country is facing. The above scenario calls for a compromise between dambo cultivation and sedimentation control. This can only be achieved through the harmonization of the two policies.

The development of the Water Resources Master Plan for the Lake Chilwa Basin should take into account the potential impacts of global Climate Change resulting from the concentration of greenhouse gases in the atmosphere. Climate Change studies done in Malawi for the catchment areas drained by North Rukuru, Bua, Linthipe and Shire rivers show that with global warming temperatures in these basins will increase by 2.49°C - 4.72°C with carbon dioxide doubling by

the year 2075, whereas precipitation will either increase or decrease depending on the type of the general circulation model (GCM) used (Chavula and Chilwa, 1998). These findings imply that floods and droughts will continue to take place in Malawi even under Climate Change scenario. Results obtained from the WatBal model show that the river basins are very sensitive to changes in both temperature and precipitation patterns. This is supported by the prevalence of floods during heavy storms and the drying up of rivers during drought spells.

In view of the above, there was a felt need to conduct Climate Change studies for the Lake Chilwa Basin in order to determine the potential impacts of global warming on water resources in general and lake levels in particular. The results of these studies will be valuable in devising appropriate adaptive strategies for the Basin.

2.3 Development of Water Resources

The Development of water resources involves the actual implementation of the physical works such as the construction of storage dams for water supply purposes, installation of diversion structures on river courses, borehole drilling, construction of conveyance channels for irrigation schemes, etc. The National Water Resources Master Plan (1986) lists three major water development projects namely water abstraction for rice irrigation at Likangala, Khanda and Domasi rice schemes; abstraction for urban (Zomba, Domasi, Chiradzulu and Phalombe) and rural (Lifani, Zomba East, Phalombe, Migowi, Kawinga, Sombani, Chingale and Zomba South) water supply purposes; and fisheries production (fish farming and prawn hatchery at Domasi Station). The expansion of the Zomba Water Supply Scheme is one of the major development activity currently taking place in the catchment area.

The State of the Environment Report (1998) points out nine pressure indicators which pose a big challenge to the development of water resources in Malawi namely; increased demand for water resources due to rapid population growth, the expansion of the industrial sector, and the increase of hectarage under irrigation agriculture; increased sedimentation loads in water bodies; water pollution arising from indiscriminate disposal of domestic wastes and industrial effluents; encroachment of agricultural activities and human settlements on catchment areas and marginal lands; infestation of water bodies by invasive plants mainly water hyacinth; frequent occurrences of droughts and the potential impacts of Climate Change. The State of the Environment Report (1998) also spells out the physical and policy measures being implemented by the Malawi Government in a bid to solve problems of water resources development in the country, e.g. the expansion of some of the existing water supply schemes in order to meet the growing demand for water, the protection of degraded catchment areas, implementation of both chemical and biological measures to control the spread of water hyacinth and curbing the sedimentation of water bodies. As stated in Section 2.2, the Water Resources Policy and Strategies and the Water Act are being reviewed in order to address some of the water resources development problems highlighted above.

2.4 Allocation of Water Resources

Allocation of water resources deals with the distribution of the available water resources to the various sectors in accordance with set regulations. It has been a tradition in Malawi to view the allocation of water resources to the domestic consumption water supply sector as being of paramount importance without looking into water resources as an economic good. Although the master plan has not yet been drawn for the Lake Chilwa Catchment area, domestic water supply

and irrigation are the major users of the available water resources in the Basin. The National Water Resources Master Plan (1986) quotes a figure of 15,670 m³/day allocated to water supply, 120,067.85 m³/day allocated to irrigation and 9,088 m³/day allocated to the Department of Fisheries for fish farming and prawn hatchery, Table 1. The water abstractions figures stated above need updating as more water rights have been granted since 1986.

Table 1: Summary of licensed surface water abstractions in m³/day by water resources units (W.R.U) as on June, 1985 (Source: National Water Resources Master Plan, 1986)

| W.R.U | Main river & tributaries | Irrigation | Water supply | Industrial & other uses | Total |
|-------|-------------------------------------|------------|--------------|-------------------------|------------|
| 2.A | Sombani river | - | 1,114.50 | - | 1,114.50 |
| 2.B | Phalombe & Likangala river system | 15,477.40 | 7,951.13 | 1,853.00 | 25,281.53 |
| 2.C | Domasi & Naisi rivers | 104,590.45 | 4,968.00 | 9,096.20 | 118,654.65 |
| 2.D | Namianga, Zumulu & Chanyungu rivers | - | 1,637.00 | - | 1,637.00 |
| TOTAL | | 120,067.85 | 15,670.63 | 10,949.50 | 146,687.68 |

2.5 Conservation and Protection of Water Resources

Conservation and protection of water resources aim at safeguarding the resource from depletion and deterioration. The depletion and degradation of water resources may be caused by several factors including deforestation which results in reduced baseflows, encroachment upon catchment areas by human settlements and agricultural production activities which accelerate sedimentation problems in reservoirs and river channels, excessive use of agrochemicals and uncontrolled waste disposal which cause water pollution, etc. The construction of the Zomba Dam on the Mulunguzi river is a good example of a water conservation project being implemented in the catchment area at the moment. Under the National Water Development Project, the catchment area of the Mulunguzi Dam will be protected with funding from the World Bank, although at present it is not yet known what catchment protection measures will be implemented. In general, the protection of water resources is guaranteed by the legal framework as stated in the Water Act.

2.6 Water Resources Monitoring

Water resources monitoring is a process whereby the availability and quality of water resources is observed over a predetermined time interval. This may involve measuring discharges in rivers; recording lake levels; observing fluctuations in groundwater levels using autographic recorders installed on wells; measuring water quality parameters to determine the suitability of the water for the intended use; installation of sediment traps for use in measuring the rate of sedimentation in rivers and reservoirs; measuring climatic variables such as temperature, rainfall, wind speed, solar radiation, humidity; etc. This process is important in that it enables water resources managers to make informed decisions on what corrective measures to implement if the quantity and quality of water resources exceeds or falls short of the recommended limits. Several gauging stations have been in operation for a long time within the catchment area, measuring such variables as river discharge, rainfall, temperature, evaporation and water level of Lake Chilwa (Figure 6). Water quality measurements are mostly done on adhoc basis, although for the Zomba Water Supply Scheme carries out this task regularly before the water is distributed to consumers.

One major weakness of the water monitoring system in the catchment area is that the network of gauging stations is not dense hence it is extremely difficult to get a true representation of the measured variables e.g. average rainfall for the basin as pointed out in Section 2.1.

In addition to monitoring variables mentioned above, the Water Resources Board is supposed to monitor the amount of water abstracted against the licensed volumes in the case of water abstraction; and the quality of effluents discharged into receiving waters in respect of licenses for effluent discharge. But this is not being done. It is therefore highly likely that more water is being abstracted and that low quality effluent is being discharged into receiving water bodies. This is another area which needs immediate redress.

Two important variables are not being monitored namely leakage and rate of sedimentation. The Municipality of Zomba does not have in place a leakage monitoring system like that of the City of Blantyre where leakage in pipe distribution networks are monitored by step tests on a regular basis. These are usually done at night when it is assumed that water is not in use. The process involves isolating pipes for leakage monitoring and recording minimum inflows in the main pipes and comparing the readings with observed flows. If disparities occur, such that there is an increase in the night flows in an area, then appropriate measures are immediately taken to control leakage.

To reinforce leakage monitoring, bylaw inspection exercises are carried out by Blantyre Water Board officials at least once in a year. This involves sending out teams of water experts to industrial establishments to check leaks in taps, sinks, toilets, pipes, etc. which may not be reported to the Water Board. Such an efficient leakage monitoring system is required for the Municipality of Zomba as the water supply scheme is very old and has been in operation since its construction in 1958 without replacement of pipe networks.

Sedimentation is one of the major problems that beset water resources management in Malawi. Several water supply service providers are at the moment grappling with sedimentation control. For example, the Blantyre Water Board conducts regular dredging at its Walkers Ferry intake point because of the siltation problems of the Shire river. With the increase in population growth and extensive cultivation in the catchment area, it is obvious that sedimentation is a big threat to the existence of Lake Chilwa. Therefore there is need to monitor and control the rate at which sediments are accumulating in the lake.

3. GAPS IDENTIFIED BY THE LITERATURE REVIEW

It has been pointed out in the preceding discussion that water resources management encompasses seven processes namely assessment, planning, development, allocation, conservation, protection and monitoring. Hence as far the Lake Chilwa catchment area is concerned there is need to ensure that the available water resources are sustainably managed by putting in place a water resources master plan. The current study has provided the basic data that will be used in the development of the water resources master plan for the whole of the Lake Chilwa Basin.

One of the activities that hydrologists have been preoccupied with in their studies of the Lake Chilwa Basin has been the evaluation of the water balance equation as a preliminary step in assessing the availability of water resources in the catchment area. Several problems have been encountered in the evaluation of the water balance equation, especially the determination of rainfall, evaporation and runoff values for use in the equation. These problems have been compounded by inadequate data used for evaluating the equation. An attempt has therefore been made to revisit the evaluation of the water balance equation by using updated rainfall data for all the rain gauge stations located in the catchment area; and then applying the Thiessen and isohyetal methods to determine the value of average rainfall for the basin. The advantage of using the isohyetal method is that it takes into account topographical differences within the catchment area.

The Penman equation has been used in the determination of the mean value for evapotranspiration for the catchment area. Although the computations have been based on data from Makoka Research Station only, the approach gives a better estimate of water loss through evapotranspiration than the figures used in previous studies which were obtained from pan measurements.

In addition to making some improvements on the mean values of rainfall and evapotranspiration, the inflow variable has been separated into surface runoff and baseflow. This will enable planners to have a clear idea about the amount of surface and ground water resources replenished annually in the catchment area.

4. METHODOLOGY

Conventional procedures for assessing the quantity of water resources in a given catchment area were used in order to evaluate the parameters of the water balance equation; whereas semi-structured interviews were employed with a view to getting information from the various stakeholders regarding water resources management in general especially with respect to planning, development, allocation, conservation, protection and monitoring of water resources within the Lake Chilwa Basin.

In order to determine the average rainfall for the whole catchment area, both the isohyetal and Thiessen Polygon methods were used. Rainfall data analysis was carried out by personnel from the Department of Meteorology at Chileka who made use of SURFER computer software to draw the isohyets whereas Idris software was used for drawing the polygons over the catchment area. However, in the case of the isohyetal method the measurement of the areas enclosed by the isohyets was done by personnel from the Department of Surveys in Blantyre using a plannimeter and digitizing techniques.

The average value of evapotranspiration for the Lake Chilwa catchment was computed by using the CROPWAT package with climate data obtained from Makoka Research meteorological station. No attempt was made to estimate the mean evapotranspiration using pan measurements because of the inherent inaccuracies in the procedure especially in determining the pan coefficients.

The runoff value used in the evaluation of the water balance equation was calculated by personnel from the Hydrology Section of the Ministry of Water Development in Lilongwe using the HYDATA software.

4.1 Average rainfall

The Thiessen Polygon and isohyetal methods were employed in the evaluation of the average rainfall for the catchment area. In the former approach, polygons were constructed over the 11 meteorological stations as indicated in Table 2 and Appendix 1; whereas in the latter, isohyets were drawn over the catchment area at 40 mm interval, see Figure 7. However, it was not possible in the computation of the average rainfall using the isohyetal method to include areas that receive less than 840 mm of rainfall. As a result, 5,433 km² was taken to be the total area of the catchment rather than the recorded 8,350 km². Table 3 and Appendix 2 show total areas measured for the different isohyets.

4.2 Evapotranspiration

The climate data for Makoka Research meteorological station was used in the estimation of the average value of evapotranspiration with CROPWAT software. The software evaluates the Penman equation from the given climate data to produce an estimate of annual evapotranspiration.

4.3 Runoff

While most of the previous studies have used total runoff in their attempt to evaluate the water balance equation for the Lake Chilwa Basin, the current study has applied the separated values of total runoff i.e. baseflow and surface runoff. The separation of the hydrographs into baseflow and surface runoff was done by using the HYDATA package in order to determine the amount of annual groundwater flow and the volume of surface runoff. Hydrographs of seven rivers namely Likangala, Naisi, Thondwe, Phalombe, Namadzi, Mulunguzi and Domasi were analyzed. The availability of data on groundwater recharge and surface runoff on an annual basis is valuable in the planning process involving the development of water resources in a given catchment area.

4.4 Climate Change

In order to determine the potential impact of global warming on temperature and precipitation patterns in the Lake Chilwa catchment area, a report on the impacts of climate change on water resources of Malawi by Chavula and Chirwa (1998) was used to provide data on the general circulation models (GCMs). Four GCMs were used to generate data on both temperature and precipitation namely the Geophysical Fluid Dynamics Laboratory (GFDL), the Goddard Institute for Space Studies (GISS), the Canadian Climate Center (CCC) and the United Kingdom Meteorological Office (UK89). The baseline data for the catchment area, i.e. data for temperature and precipitation for conditions where global warming does not take place, was

obtained by averaging temperature and precipitation data for Makoka, Mangochi and Bvumbwe meteorological stations from 1961 - 1990. Differences between the baseline data (1*CO₂) and the doubled CO₂ (2*CO₂) for monthly temperatures, and the ratio between monthly precipitation were then calculated. The climate change scenarios were created by adding temperature differences to temperature baseline data, and multiplying the baseline precipitation values by precipitation ratio (2*CO₂ / 1*CO₂).

4.5 Stakeholder views on water resources management

Semi-structured interviews were conducted in order to get information from the various stakeholders in their involvement in the management of water resources within the catchment area. A questionnaire (Appendix 3) was administered to the rural community, residents of the Municipality of Zomba, the private sector and the public sector with a view to getting their views pertaining to planning, development, allocation, conservation, protection and monitoring of water resources.

5. RESULTS AND DISCUSSION (FINDINGS)

Presented in this section are the results of the various tasks carried out during the study in regard to the management of water resources management in the Lake Chilwa catchment area.

5.1 Water resources assessment

In order to evaluate the water balance equation, mean values were calculated for rainfall, runoff and evapotranspiration.

Table 2: Average rainfall using the Thiessen Polygon method

| Name of station | Polygon area (km ²) | Weight | Rainfall (mm) | Weighted rainfall (mm) |
|------------------------|---------------------------------|--------|---------------|------------------------|
| Chiradzulu Forest | 216.7 | 0.0310 | 1046 | 32.4 |
| Domasi Irr. Scheme | 1815.125 | 0.2597 | 1174 | 304.9 |
| Dzaone Agriculture St. | 306.15 | 0.0438 | 926 | 40.6 |
| Fort Lister Phalombe | 726.525 | 0.1039 | 1453 | 151.0 |
| Jali Market | 470.25 | 0.0673 | 1002 | 67.4 |
| Kamwendo Admarc | 485.825 | 0.0695 | 811 | 56.4 |
| Mpyupyu Farm | 175.27 | 0.0251 | 1033 | 25.9 |
| Ntaja Agriculture St. | 889.25 | 0.1272 | 987 | 114.1 |
| Phalombe Mission | 252.75 | 0.0362 | 998 | 36.1 |
| Tamani Agriculture St. | 1222.25 | 0.1749 | 895 | 156.6 |
| Ulongwe - Chiradzulu | 429.15 | 0.0614 | 939 | 57.6 |
| | 6989.225 | 1.0 | | 1042.9 |

Table 3: Average rainfall using the isohyetal method

| Value of isohyet (mm) | Area enclosed (km ²) | Amount of rainfall (mm) |
|-----------------------|----------------------------------|-------------------------|
| 1440 | 2.4 | 0.65 |
| 1400 | 17.1 | 4.53 |
| 1360 | 27.0 | 6.86 |
| 1320 | 27.9 | 6.88 |
| 1280 | 45.7 | 10.94 |
| 1240 | 66.6 | 15.45 |
| 1200 | 52.7 | 11.83 |
| 1160 | 126.9 | 27.6 |
| 1120 | 121.8 | 25.55 |
| 1080 | 218.3 | 44.20 |
| 1040 | 156.7 | 30.57 |
| 1000 | 1734.5 | 325.65 |
| 960 | 155.2 | 28.0 |
| 920 | 644.2 | 111.46 |
| 880 | 1930.5 | 319.81 |
| 840 | 105.1 | 16.64 |
| TOTAL RAINFALL | | 986.62 |

5.1.1 Average rainfall

An average rainfall value of 1042.9 mm per annum was obtained for the catchment area using the Thiessen Polygon method whereas an estimated value of 986.62 mm per annum was calculated using the isohyetal method, see Tables 2 and 3 respectively. The two average rainfall values can be rounded off to 1000 mm per annum. This average rainfall value is very close to 998 mm / annum computed by Kalk et al (1977) using the Thiessen Polygon method although the analysis used rainfall data for a ten year period only i.e. from 1961 to 1971. However, in the current study rainfall data averaged over a period of 30 years i.e. 1961 - 1990 was used for each of the stations in the computation of the mean rainfall value. The value of average rainfall obtained by the Ministry of the Water Development in their National Water Resources Master Plan (1986) gives a range from 800 - 1000 mm per annum, and Petermann's (1990) value of 1023 mm per annum are in close agreement with the average rainfall determined by this study. However, there is a big disparity between the average annual rainfall value obtained by the current study and the 1480 mm per annum value calculated by Hill and Kid (1980). It can therefore be stated that some of the studies done in the past to determine the average rainfall over the Lake Chilwa Basin were correct although they did not take into account rainfall directly falling on the surface of Lake Chilwa; and used data that was averaged over a comparatively short period.

Table 4: Evapotranspiration values computed using CROPWAT

Reference evapotranspiration - Penman
 Project: Lake Chilwa
 Latitude: 15.5 South

Climate Station: Makoka
 Altitude: 1029 m

| Month | Temp. °C | Humidity % | Windspeed (km/day) | Sunshine hours | Radiation (mm/day) | E _{to} mm |
|-------|----------|------------|--------------------|----------------|--------------------|--------------------|
| Jan | 22.6 | 84 | 130 | 5.8 | 5.0 | 4.43 |
| Feb | 22.4 | 84 | 138 | 5.6 | 4.9 | 4.32 |
| Mar | 22.2 | 83 | 138 | 6.1 | 4.7 | 4.20 |
| Aprl | 20.8 | 79 | 138 | 6.5 | 4.1 | 3.86 |
| May | 19.0 | 73 | 112 | 7.4 | 3.5 | 3.47 |
| Jun | 17.0 | 70 | 138 | 7.1 | 3.0 | 3.22 |
| Jul | 16.9 | 68 | 173 | 7.2 | 3.1 | 3.57 |
| Aug | 18.5 | 60 | 173 | 8.2 | 3.8 | 4.59 |
| Sept | 21.0 | 53 | 190 | 9.1 | 4.8 | 6.00 |
| Oct | 22.8 | 56 | 216 | 8.8 | 5.4 | 6.69 |
| Nov | 23.3 | 65 | 199 | 7.5 | 5.4 | 6.06 |
| Dec | 20.1 | 77 | 156 | 5.5 | 4.8 | 4.49 |
| TOTAL | 20.6 | 71 | 158 | 7.1 | 4.4 | 1670 |

Table 5: Volume of baseflow and surface runoff

| Station number | Name of river | Surface runoff (mm/y) | Baseflow (mm/y) |
|-------------------|---------------|-----------------------|-----------------|
| 20221 | Likangala | 578.08 | 265.50 |
| 20308 | Naisi | 168.34 | 123.83 |
| 20222 | Thondwe | 195.82 | 69.89 |
| 20210 | Phalombe | 828.72 | 493.45 |
| 20233 | Namadzi | 500.79 | 86.72 |
| 20208 | Mulunguzi | 623.79 | 485.11 |
| 20303 | Domasi | 667.39 | 492.29 |
| AVERAGE FOR BASIN | | 508.99 | 288.11 |

5.1.2 Evapotranspiration

A total evaporation value of 1670 mm per annum was obtained for Makoka meteorological station using CROPWAT software; and it is this value that has been taken as the mean evapotranspiration figure for the catchment area, see Table 4. However, this value may not be representative of the whole catchment area as the climate data used in the computation of evapotranspiration was based on data from one station only since the other stations did not have adequate data. Pan measurements for Khandu, Makoka, Zomba, Zomba Plateau, Chancellor College and Likangala Rice Scheme give an average value of 1591 mm per annum for evapotranspiration, a value which is not very different from the 1670 mm per annum figure calculated using CROPWAT.

5.1.3 Runoff

Table 5 shows the results obtained for hydrograph separation for Likangala, Naisi, Thondwe, Phalombe, Namadzi, Mulunguzi and Domasi rivers using the HYDATA software. An average total runoff value of 508.99 mm per annum was obtained for the Basin i.e. a mean value of

220.88 mm for surface runoff and a baseflow figure of 288.11 mm. These computed values of baseflow and surface runoff do not include discharge for Mnembo river which arises from Mozambique and has no records for discharge data. However, considering that the calculated values of baseflow and surface runoff were obtained from hydrometric data collected from seven rivers and then averaged, the exclusion of data from Mnembo from the computation of runoff may not seriously affect the total runoff value. It has therefore been assumed that the mean annual surface runoff and baseflow for the catchment area are 220.88 mm and 288.11 mm respectively.

5.1.4 The water balance equation

As stated in Section 2, the water balance equation in its simplified form may be presented as:

$$P = R_s + R_g + E_t$$

where P is precipitation, R_s is surface runoff, R_g is baseflow and E_t is evapotranspiration.

Therefore using the values obtained in the study, the water balance equation may be rewritten as:

$$1000 = (220.88 + 288.11 + 1670) \text{ mm}$$

which is obviously not a balanced equation as the right hand side of the equation is NOT equal to the left hand side, with the evapotranspiration value alone exceeding the average rainfall.

The following are some of the deductions that can be drawn from the water balance equation for the Lake Chilwa Basin:

- there is an excessive loss of water resources through evapotranspiration processes as evidenced by the large value of the E_t parameter. Hence it is not surprising that surface water bodies within the catchment area including Lake Chilwa itself are vulnerable to drying up during prolonged drought spells as the rate of water loss is very high.
- the amount of groundwater recharge is very large when compared with the national average which ranges from 15 - 80 mm as stated by Smith - Carington and Chilton (1983) and Chavula (1989). However, the whole of the catchment area has about 400 operational boreholes. Assuming that each water point supplies water to a design population of 250 people at a rate of 27 litres per person per day, then the amount of groundwater that is being abstracted is 0.118 mm per annum (i.e. the total amount of groundwater abstracted per annum divided by the total catchment area), a figure which is much less than 1 mm. This implies that large stocks of groundwater resources in the catchment area are not being utilized for water supply purposes.
- the evaluation of the water balance equation has revealed that nearly half of the annual precipitation received by the catchment area is converted into total runoff, with 220.88 mm translated into surface runoff alone. This is obviously a very high surface runoff figure hence it is not surprising to note that the Basin experiences floods during heavy storms. The National Disaster Management Plan for Malawi (Chiotha et al, 1997) lists Likangala and Thondwe rivers as being very vulnerable to flood hazards. Suggestions have been made in the disaster management plan that upstream storage dams should be constructed as mitigation measures for flood disasters.

since the evapotranspiration value exceeds the total precipitation, it is highly likely that most of the water being lost through evaporation in the catchment area is derived from storage, (Lake Chilwa?).

5.1.5 Climate change

Results obtained from the GCMs suggest that temperature will increase in the Lake Chilwa Basin by 2.6 - 4.72 °C with carbon dioxide doubling in the year 2075 whereas precipitation will either increase as indicated by the GFD3, GISS and UK89 models or decrease as shown by the CCC model, see Tables 6 and 7, and Figures 8 and 9. Although there is a lot of uncertainty about climate change, adaptive measures that can be applied over a wide range of climate change scenarios such as the construction of dams and exploitation of groundwater resources need to be considered for implementation in the catchment area. For example, on one hand dams can be used for flood mitigation during periods of heavy storms whereas on the other they can be used for water storage during prolonged droughts.

Table 6: Temperature data for Climate Change scenario in °C

| Month | Baseline | GFD3 | GISS | CCC | UK89 |
|-------|----------|-------|-------|-------|-------|
| Jan | 23 | 25.14 | 27.31 | 25.26 | 25.45 |
| Feb | 23.3 | 26.0 | 27.42 | 25.42 | 26.54 |
| Mar | 22.6 | 25.55 | 26.53 | 25.1 | 25.33 |
| Apr | 21.4 | 23.54 | 26.57 | 23.8 | 24.86 |
| May | 19.5 | 22.06 | 24.21 | 21.77 | 24.15 |
| Jun | 17.6 | 21.55 | 22.27 | 20.04 | 21.94 |
| Jul | 17.3 | 20.73 | 22.72 | 20.05 | 20.63 |
| Aug | 19.0 | 22.87 | 24.71 | 22.11 | 21.74 |
| Sept | 21.6 | 25.03 | 26.73 | 24.77 | 24.55 |
| | | | | | |

| | | | | | |
|------------------|------|--------|--------|-------|-------|
| Oct | 23.7 | 27.77 | 28.85 | 27.02 | 26.46 |
| Nov | 24.1 | 26.82 | 28.07 | 27.02 | 28.74 |
| Dec | 22.4 | 24.67 | 26.71 | 24.61 | 25.74 |
| Average increase | | + 3.02 | + 4.72 | + 2.6 | + 3.4 |

Table 7: Precipitation data for Climate Change scenario in mm

| Month | Baseline | GFD3 | GISS | CCC | UK89 |
|---------------------|----------|--------|--------|--------|--------|
| Jan | 222.5 | 258.1 | 200.25 | 166.88 | 255.88 |
| Feb | 210.9 | 221.44 | 229.88 | 158.18 | 310.02 |
| Mar | 168.8 | 160.36 | 185.68 | 165.42 | 65.83 |
| Apr | 54 | 81.0 | 85.32 | 66.42 | 57.78 |
| May | 13.5 | 9.86 | 31.32 | 13.10 | 16.74 |
| Jun | 9.2 | 6.62 | 11.04 | 8.92 | 5.89 |
| Jul | 9.5 | 8.55 | 12.83 | 10.17 | 4.75 |
| Aug | 4.7 | 4.61 | 4.42 | 4.51 | 4.7 |
| Sept | 4.0 | 3.36 | 3.52 | 3.68 | 4.0 |
| Oct | 24.2 | 21.78 | 20.57 | 17.91 | 24.2 |
| Nov | 81.7 | 69.44 | 82.52 | 75.16 | 62.91 |
| Dec | 200 | 224 | 210.00 | 242 | 274 |
| Percentage increase | | + 6.6 | + 7.4 | - 7.0 | + 8.3 |

5.2 Water resources planning

A water resources master plan has not yet been developed for the Lake Chilwa catchment area. However, plans are underway to develop one for the Municipality of Zomba by the Southern

Region Water Board. Since the rural area within the basin falls under the responsibility of the Ministry of Water Development, it will be very difficult to develop a master plan that will cover the whole catchment area as the two organizations will eventually be autonomous; and may therefore have different priorities. However, water resources plans for areas not covered by the Municipality of Zomba and other urban centres such as Thondwe, Domasi, Namadzi and Phalombe are likely to include the development of water resources for irrigation and domestic consumption. It may also be necessary to development plans for the utilization of Lake Chilwa itself especially for purposes of developing the fisheries industry, although such an option was abandoned in the past.

5.3 Water resources allocation

The Water Resources Board is mandated to allocate water resources to the various sectors in the country, including the allocation of water resources in catchment area of Lake Chilwa.

Irrigated agriculture and domestic water supply still remain the major users of water resources in the Lake Chilwa catchment area. Although it was recommended in Section 2 that the amount of water allocated to various sectors be updated, the additional allocations have had little impact on the 1986 figure quoted in the National Water Resources Master Plan (1986) document. However, the total volume of water allocated to the sectors may change with the completion of the construction work of the Zomba Dam and the other six urban water supply schemes of Thondwe, Namadzi, Phalombe, Namwera Turn Off, Zomba Plateau and Domasi. Therefore it can be assumed that at the moment the amount of water abstracted for use within the catchment area is slightly above that quoted in the National Water Resources Master Plan (1986) figure of 146,687 m³/day.

5.4 Water resources development

In addition to the existence of irrigation schemes, fish ponds and water supply systems within the catchment area, there are other activities that are being implemented in the catchment area especially in the field of water supply. A dam designed by Lahmeyer International is being constructed on Mulunguzi river on the Zomba Mountain to boost water supply for the Municipality. The construction work is being carried out by CMC and CCC Joint Venture. The scope of the work involves the dam structure itself, the spillway, treatment works, 13 reservoirs and main supply lines. The project is being funded by the World Bank under the National Water Development Project. However, funds for the extension and rehabilitation of the distribution networks have not yet been identified. It is envisaged that once the dam is completed, current shortages in water supply will be eased. For example, at the moment residents of upper Matawale usually get most of their water supply at night due to low pressures experienced in the area during the day because of the high demand for water supply by upstream users, which has far exceeded the design capacity.

The following water supply schemes have also been lined up for implementation: Thondwe, Domasi, Namadzi, Phalombe, Namwera Turn Off and Zomba Plateau.

Feasibility studies for Thondwe Water Supply are being done by SNC - Lavalin International Inc. in association with Water Resources and Engineering Consultants (Pty) Ltd. Groundwater resources have been identified to be the water supply source for the town as they are generally cheaper and quicker to develop than surface water resources which require treatment before

consumption and may take a long time to commission especially where they involve the construction of large dams. The project started in 1998 and is being funded by the World Bank.

Expansion and rehabilitation work on Domasi Water Supply Scheme is being done with funding from the African Development Bank (ADB). The design work was done by Wanjoyi Consulting Engineers and was finalized in January, 1999.

Namadzi Water Supply Scheme will involve pumping water from the protected spring upstream of the bridge on the Blantyre - Zomba road. JICA has been approached by the Malawi Government to provide funding for the extension and rehabilitation of the scheme.

The water supply scheme for the new Phalombe Boma has been designed, but the whole project of setting up the new district center will cost MK 43,000,000.00.

Feasibility studies for the Namwera Turn Off Water Supply Scheme are being done by Metaferia Consulting Engineers under the National Water Development Project.

The Zomba Plateau Water Supply Scheme will supply water to Kuchawe Inn, residents of the Zomba Plateau and surrounding villages. Designs for rehabilitation works were done by Wanjoyi Consulting Engineers. The African Development Bank has been approached to provide funding for the implementation of the project.

5.5 Conservation and protection of water resources

The construction of the Zomba Dam is the major water conservation project ever carried out in the catchment area. But some of the stakeholders living on the shores of Lake Chilwa have suggested that more upstream storage dams should be constructed with a view to retaining excess surface runoff during periods of heavy storms thereby mitigating flood disasters and the flooding of the flood plains which are used for rice production. They further suggested that the retained water would then be released in a regulated manner thereby avoiding flooding problems. In addition to this, more of the stored water would be released from the dams during prolonged drought spells in order to stabilize lake levels. Such measures would protect the lake from drying up during protracted drought periods, hence the fishing industry would not be interrupted by droughts. Although the suggestion appears to be plausible, it is not yet known whether or not such a project would be feasible in light of ecological and financial implications.

On the protection of the catchment area from degradation, the stakeholders suggested the intensification of agroforestry and afforestation programmes although there appears to be inadequate land in the catchment area for woodlots as most of the land that is available is being utilized for crop production. There is also lack of coordination in the implementation of catchment protection measures amongst various government agencies namely the Department of Forestry, the Ministry of Water Development, the Department of Fisheries, Ministry of Agriculture and Irrigation and the Department of Environmental Affairs. Therefore there is need to integrate all catchment measures, and fully involve the local communities in such a process. It has been suggested that decentralization may help to solve the problem of lack of coordination between line ministries.

The protection of the Mulunguzi catchment will be the largest project to be implemented in the Lake Chilwa Basin in regard to catchment management. The World Bank will provide funding for the project under the National Water Development Project.

5.6 Water resources monitoring

The study has revealed that stakeholders are not involved in the monitoring of water resources in the catchment area; and that the network of gauging stations used for collecting hydrological data is sparse and poorly maintained. From the interviews that were conducted, it was also established that the Municipality of Zomba does not have a systematic leakage monitoring programme for its network. It has also been noted that sedimentation is one of the major threats to the availability of water resources in the Basin and yet no measures have been put in place to monitor and curb sedimentation in the catchment area.

6. CONCLUSION

From the evaluation of the water balance equation, an average rainfall value of 1000 mm per annum has been estimated, although the actual figures computed for the Thiessen Polygon and the isohyetal methods are 1042 mm and 986.62 mm per annum respectively. The calculated values of total runoff, surface runoff, baseflow and evapotranspiration are 508.99 mm, 220.88 mm, 288.11 mm and 1670 mm per annum respectively.

One of the striking features of the water balance equation for the Lake Chilwa Basin is that the values for the four parameters of the equation do not balance: the value of evapotranspiration alone exceeds the amount of precipitation received annually. This has prompted the suggestion that the amount of water required to meet the demand for evapotranspiration processes are derived from storage.

Previous studies done by Smith - Carington and Chilton (1983) and Chavula (1989) put average values of annual groundwater recharge for the whole country at 15 - 80 mm. However, the groundwater recharge value of 288.11 mm per annum for the Lake Chilwa Basin, which comprises the alluvial aquifer, is much higher than the national average; and yet groundwater resources in the catchment area remain virtually unexploited as much less than 1 mm of the baseflow is abstracted for use. Therefore the catchment area has a great potential for groundwater development.

The results of the evaluation of the water balance equation also shows that 220 mm out of the 1000 mm of annual rainfall received in the catchment area is transformed into surface runoff. It is therefore not surprising to note that the basin experiences flood disasters during periods of heavy storms. The situation is exacerbated by the depletion of vegetation cover through unsustainable agricultural practices and unplanned human settlements. Although administrative measures for flood disaster mitigation are being applied for the Lower Shire Valley, some stakeholders in the Lake Chilwa Basin recommend the construction of upstream storage dams which would play the dual role of mitigating flood disasters and sustaining lake levels.

The study has shown that a water resources master plan for the catchment area has not yet been developed. It has been mentioned that the Southern Region Water Board is responsible for the development of water resources for the Municipality of Zomba and urban centres such as Domasi, Namadzi, Thondwe, Namwera Turn Off and Phalombe whereas as the Ministry of Water Development oversees the development of water resources in the rest of the catchment area. With such a fragmented water resources management system, it is not possible to sustainably manage water resources in the Lake Chilwa Basin. It is therefore strongly recommended that the Southern Region Water Board should liaise with the Ministry of Water

Development in order to develop a water resources master plan for the catchment area. The development of the master plan should be done with the active participation by the local community and other stakeholders.

Irrigated agriculture and domestic water supply remain major users of water resources in the catchment area. Although most of the water resources abstracted both for irrigation and domestic consumption are derived from surface water resources, there is great potential for developing groundwater resources. The National Water Resources Master Plan (1986) states that 146,687.68 m³/day of surface water resources are abstracted for either irrigation, domestic consumption or industrial production. This amount is equivalent to 6.7 mm of the total annual rainfall, yet the water balance equation shows that a total of 220.88 mm per annum of annual rainfall are lost as surface runoff. This implies that 214.18 mm of annual rainfall ends up in Lake Chilwa as only 6.7 mm per annum are abstracted for irrigation, domestic water supply, industrial production and other uses.

The depletion of vegetation cover in the catchment area through poor agricultural practices and the establishment of human settlements has accelerated surface runoff. It is therefore encouraging to note that the Ministry of Agriculture and Irrigation is promoting good land husbandry practices. But much more work needs to be done in order to achieve this objective.

The Ministry of Water Development through the National Water Development Project will soon commence work on the protection of the Mulunguzi catchment area with funding from the World Bank. This will be the major catchment protection project to be carried out in the Lake Chilwa Basin.

Findings from the study show that water resources monitoring in the catchment area is generally inadequate. The density of gauging stations is sparse. There are very few properly managed gauging stations for collecting hydrological data. It is therefore recommended that both the Ministry of Water Development and the Water Resources Board should expand the present network of gauging stations. This should include the installation of hydrometric stations on Lake Chilwa itself. It is further recommended that stakeholders should be involved in some of the activities related to the monitoring of water resources in the catchment area.

7. RECOMMENDATIONS

- A better value of mean evapotranspiration for the catchment area should be computed using climate data obtained from several stations
- Detailed studies should be done in order to determine the amount of water in storage
- A Water Resources Master Plan for the Basin should be developed with the involvement of all stakeholders
- More water points should be constructed in order to meet the current demand for water resources
- Groundwater resources should be developed as they largely remain untapped
- Measures to protect the catchment area from degradation should be intensified
- People should not be allowed to settle in marginal lands
- Sedimentation in reservoirs, rivers and Lake Chilwa should be monitored and controlled
- Measures to mitigate flood disasters should be put in place
- Levels of Lake Chilwa should be stabilized

- More gauging stations should be installed to monitor discharge, rainfall and evapotranspiration
- Stakeholders should be involved in water resources monitoring
- The Water Resources Board should monitor volumes of water being abstracted against the licensed volumes
- The Water Resources Board should monitor the quality of effluents being discharged into receiving water bodies
- Robust and resilient anticipatory adaptive measures to climate change should be implemented

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