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RUNOFF ESTIMATES INTO THE WEIJA RESERVOIR AND ITS IMPLICATIONS FOR WATER SUPPLY TO ACCRA, GHANA

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Abstract: Accra has a population of about 2.3 million and is supplied with water from both the Kpong and Weija Water Works. Water from the Weija treatment plant is taken from the Weija Reservoir which is fed by Rivers in the Densu River Basin (DRB) that flow into the Reservoir at Weija. With increasing annual population growth of Accra at 4.4% and inadequate water supply to it, this study has examined the hydrological data available on the Weija Reservoir from 1980 to 2007 in an attempt to estimate runoff into the Reservoir with the view of determining whether water is available to meet its present and future demands. Results show that even though water abstraction from the Reservoir has increased almost four times since 1980, to more than 67 million m^3/year in 2007, and a maximum runoff of $7.97 \pm 0.21 \times 10^{-2}$ km^3/year was estimated in 2005, this value is less than the true runoff into the Reservoir. It was also observed that potential evapotranspiration has increased by 0.14% while precipitation has decreased by 0.93% in the DRB, indicating that runoff from the Basin into the Reservoir is probably decreasing, albeit slowly. Additionally, fishing and waste disposal methods are poor; land use practices and other anthropogenic activities in the DRB pose a threat to the sustainability of the Reservoir. Serious educational programmes and enforcement measures need to be urgently adopted to safeguard continuous water flow into the Reservoir. Proper hydrological data collection and data management practices are recommended for the Reservoir and Densu River Basin if detailed planning of the water resources of the Reservoir are to be achieved.

Keywords: Runoff; water supply; Accra; Ghana

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INTRODUCTION

The rapid growth of cities in developing countries is attributed mainly to rural-urban migration which is the result of perceived bias in the provision of development projects and social amenities in favour of the cities. The population increase in these cities has become a source of concern to city planners and water resource managers in their quest to manage housing, waste and supply of water to meet the needs of domestic and industrial users.

Accra is the capital city of Ghana and has an estimated population of 2.3 million. During the 1984 population census Accra had a population of about 970 000 and in 2000, the population was 1 660 000 (Anon, 1989; 2002).

With a population growth rate of 4.4%, it is much higher than the national average of 2.7%. Water supply to Accra is inadequate and regular water shortage in the city is a subject under constant discussion lately. Supply of water to Accra comes from the Kpong Water Works (KWW) and Weija Water Works (WWW) which are about 80 km north and 13 km west of Accra, respectively. Commercial water supply in Ghana is managed by the Ghana Water Company Limited (GWCL). The WWW draws its water from the Weija Reservoir which was constructed in 1952 by damming the Densu River at Weija (hereafter called the Reservoir and River, respectively). The water is treated and supplied to west Accra and some other areas of the city. The Densu River Basin (DRB) covers an area of about 2564 km^2 and forms part of the coastal river basins of Ghana lying between latitudes 5^o 30’ N and 6^o 20’ N and longitudes 0 ^{o} 10’ W and 0^o 35’ N (**Fig. 1**). From a population of 450 000 in 1984, the Ghana 2000 population census revealed that the DRB is home to 947 000 indicating an average yearly growth rate of 3.26% (Anon, 2000).

Effects of rapid urbanisation and increased agricultural and industrial activities in the DRB and around the Reservoir have impacted the quality of water in the River and Reservoir. Water from the Reservoir is noted to have characteristic odour arising from eutrophication (Ocansey-Colerangle, 1979). Immediate sources of pollution include leached agro-chemicals used by farmers immediately around the Reservoir and in the DRB. Unorthodox methods of fishing including the use of Dichloro-Diphenyl-Trichloroethane (DDT) and dynamite also add to the pollution problem of the River. Over-fishing of algae-feeding fish deprives the water of a vital part of its natural purification process. Inappropriate and or non-existent human waste management conditions prevailing in rapidly growing urban townships in the DRB such as Nsawam, located along the River contribute to the stress on the River. Cottage industries like local gin distilleries and others are sited along the banks of the River and thus discharge their waste into it. Poor land use practices in the DRB facilitate erosion leading to siltation of the River and the Reservoir, thus aiding flooding (Ocansey-Colerangle, 1979).

Together, the impacts enumerated above would determine the quantity and quality of water in the hydrological cycle in any environment including the DRB. In the light of the above, a twenty-seven year hydrological appraisal has been undertaken in the DRB to determine how these anthropogenic factors are affecting runoff and the availability of water in the Reservoir. Suggestions regarding a sustainable management scheme for the water resources of the reservoir have been made.

THE RESERVOIR

The dam of the Reservoir was breached and destroyed by floods in 1968 and work on a new dam at the same site commenced in 1974 and was completed in 1978 (Anon, 1997). At a normal water level of 14.33 m the Reservoir covers an area of 20.5 km^2 with a storage capacity of 113.5 × 10^6 m^3 (25 000 MG). The maximum designed water level is 15.25 m with a capacity of 143.115 × 10^6 m^3 (31 803 MG). It was projected that inflows into the Reservoir will be 315 000 m^3/day (70 MGD), while expected upstream consumption would be about 40 500 m^3/day (10 MGD) (Anon, 1997).

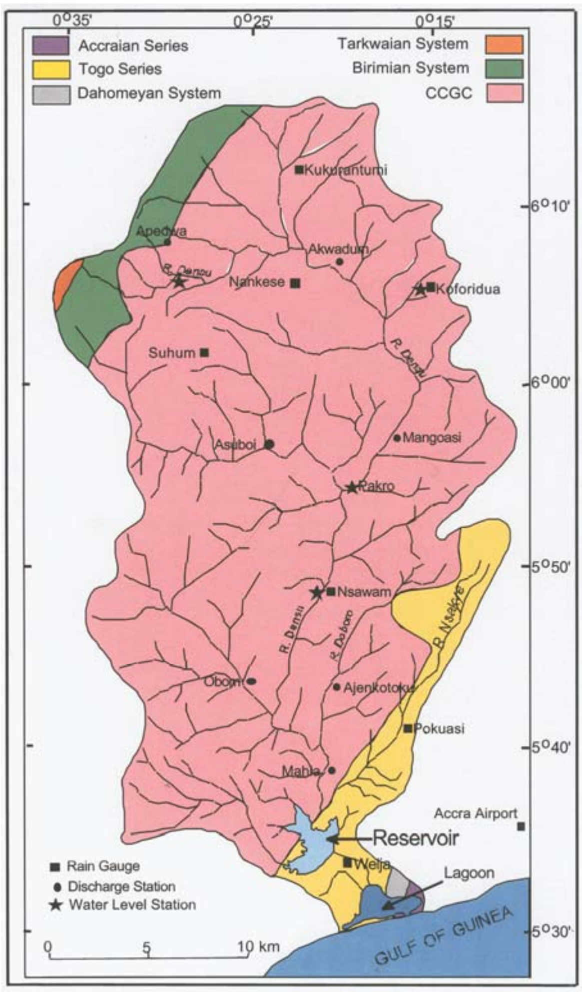

Fig. 1 Geological map of the Densu River Basin showing the Weija Reservoir and positions of meteorological stations.

PHYSIOGRAPHY

Climate, Vegetation and Soil

Climate and vegetation in the DRB is varied with the northern part belonging to the moist semi-deciduous rainforest zone. This zone exhibits a double maxima rainfall regime with an annual rainfall of between 1145 and 1650 mm. The central part consists of dry marginal forest-savannah transition zone with an average annual rainfall of 1370 to 1620 mm. In the south of the basin, the climate is a sub humid coastal savannah type that posts an annual average rainfall ranging from 750 to 1150 mm. The major and minor rainy seasons are respectively from April to July and September to November while December to February is dry with little rain and high temperatures (Anon, 1997). Average annual rainfall for the entire DRB ranges from 875 mm in the south to 1125 mm in the north.

Vegetation in the DRB is consistent with a hot and humid tropical climate and average temperatures are between 27 to 32°C. Potential evapotranspiration is from 860 mm to 1230 mm and average relative humidity varies between 65% in the dry season to about 95% in the wet season. During the dry season, water flow in the River falls to a minimum. About 96% of soils in the Densu basin comprises forest ochrosols and the remaining southern portion is covered with savannah ochrosols and savannah lithorols (Anon, 1997).

Topography and Drainage

The relief of an area has an important influence on ground water movement (Domenico & Schwartz, 1998). Topography is closely related to geology in the DRB and consists of three broad divisions namely: Western Lowland, Akwapim Range and Eastern Plains.

Low and rolling topography characterises the Western Lowland so that its base level is about 67 metres above sea level (m asl) and this is broken by steep low ridges in several places ranging from 300 to 567 m asl. These ridges comprise mainly gneiss and granite in the west and sandstone, siltstone and shale in the east. The ridges are generally parallel to the northeast trending regional structures, and commonly have steep western slopes and gentler eastern slopes (Ahmed *et al*., 1997). The Akwapim Range separates the Western Lowland and the Eastern Plains and also trends northeast southwest with its boundaries between 6.5 to 9.5 km wide and parallel to the regional folds and faults. It consists of quartzite and rises from 30 to 567 m asl with the western slopes much steeper than the eastern slopes. The Eastern Plain has isolated northwest trending range of low hills mostly capped by flaggy, micaceous quartzite (Ahmed *et al*., 1997).

A dendritic drainage pattern is exhibited by the DRB and generally consists of a dissected landscape which is a few metres high along the coast to about 700 m within the Akwapim Hills in the northeast (**Fig. 1**). Tributaries of the River are the Made, Kuia, Adeiso, Nsakye, Dobro, Suhyien and Jei (Anon, 1997).

GEOLOGY AND HYDROGEOLOGY

About 86.6% of the DRB is underlain by granite and granodiorite of the middle Precambrain Cape Coast Granite Complex (CCGC) while 8.8% consists of the Togo Series (**Fig. 1**). These two rock formations control the ground water conditions in the basin. The remaining 4.6% of the basin comprises the Birimian Volcanics, Tarkwaian, Dahomeyan and the Accraian rocks. At the source of the River, the rocks are metamorphosed lava, phyllite, schist, tuff and greywacke of the Birimian and towards its mouth it is underlain by quartzite, shale and phyllite of the Togo Series.

The bulk of the CCGC is a granitic to quartz-diorite gneiss which changes gradationally from a fine to medium-grained foliated biotite-quartz-diorite gneiss in the west to an exclusively hornblende-quartz-diorite gneiss in the east. Granitic rocks associated with the Birimian have no regular pattern of jointing and depth to bedrock hardly exceeds 6 m. The Birimian rocks are strongly foliated with widespread faulting and jointing with deep weathering in valleys. The phyllites of the Birimian are especially known to form aquifers due to intensive fracturing (Ahmed *et al*., 1997).

Foliation defined by the alignment of hornblende and biotite in the CCGC vary considerably, but most foliation planes dip at 40^o–50^o towards the southeast or northeast. Foliation plane poles dip at 42° along 078° and at 36° along 048° suggesting isoclinal folding. The regional folding trend deviates through an angle of at least 30° from a northeasterly direction in the north to almost east-west in the south (Ahmed *et al*., 1997). Several faults directions have been inferred based on the abrupt change in topography, displacement of dykes and mineralogical alteration of rocks in the fault zones. The most prominent faults strike at 045°, 065°, 335° and 300°. Well-developed vertical to sub-vertical joints are present in the CCGC with the trend of the dominant joints showing four joint sets namely, 0°, 055°, 285° and 325°. The relationship between some of the joints and the trend of the regional folding suggest that the northeast and northwest trending joints are basically first order tension joints while the others are shear joints (Ahmed *et al*., 1997).

Rocks of the CCGC are not inherently permeable because they are crystalline or strongly cemented and virtually have no primary porosity and permeability. Exploitable ground water in these strata occurs mainly in near-surface secondary features such as zones of weathering, joints and fissures. Generally, only low yields are obtained from wells installed in regolith aquifers suitable for potable supplies to small and medium size communities. Higher yields of water are expected along dykes acting as impoundment to ground water flow. Recharge to the regolith aquifers is by direct infiltration of precipitation over large areas and localised inflow through fractures. **Table 1** shows a summary of the expected groundwater potential of all formations in the DRB.

RUNOFF ESTIMATION OF THE RESERVOIR

Any scheme to manage the water resources in an area requires the assessment of water input and output. The main components influencing recharge to the Reservoir are direct precipitation on the reservoir, surface runoff of all streams and rivers and ground water inflow. Evaporation from the Reservoir and ground water outflow are output components. Surface runoff is affected by precipitation and evapotranspiration in the rest of the DRB.

Water abstraction for treatment is an artificial stress that affects the quantity of water present at any time in the reservoir. When the Reservoir level rises close to the maximum allowed, the spill way is opened to reduce stress on the dam. The difference between input and output is the change in storage. **Figure 1** shows the position of all meteorological stations in the DRB.

Data for runoff estimation of the reservoir

Systematic and regular hydrological data collection in Ghana has been a problem for some time mainly because of logistical constraints. Data archiving has also suffered resulting in data loss. Suffice to say that meteorological data collection and archiving has been undertaken relatively quite well. Data gaps therefore exist within the twenty seven years of information required to generate a trend for some hydrological parameters of the Reservoir and estimate runoff into it. Precipitation and potential evapotranspiration data are collected by the Meteorological Services Agency (MSA) on a daily basis. All quantities for this study are converted into yearly volumes of water and the units in cubic kilometer per year, (km^3/year) because of the large volumes of water involved. Abstraction, Reservoir water level and spillway data collection are the obligation of the WWW.

Status of gauging stations in DRB

Surface runoff or total river discharge is also referred to as stream flow. In the DRB, runoff data gathering is the responsibility of the Hydrological Services Department (HSD). Several rivers and their tributaries flow into the Reservoir and the principal tributaries of the River are the Made, Kuia, Adeiso, Nsaki, Dobro, Suhyien and Jei. Flow monitoring stations are located at Manhia, Nsawam, Pakro, Asuboi and Weija (**Fig. 1**).

Flow data at Manhia span from 1968 to 1975 only. Backwater effects from the Weija dam affected this gauging station and the site was abandoned. Data available for the Nsawam flow gauging station is from 1968 to 1980 with a gap between 1974 and 1975. For Pakro, the data is available from 1971 to 1977 and 1994 to 1996. The gauge has since been removed. The Asuboi gauge has been sited on the Kuia river and has data available from 1971 to 1993 with a six-year gap from 1982 to 1987. The gauge at the Weija site has data only from 1970 to 1971.

Table 1. Stratigraphic succession (younging upward) and summary of the expected water bearing properties of rocks of the Densu River Basin

System	Rock Type	Expected Water Bearing Properties	Area (%)
Accraian (Mid-Devonian)	Sandstone, grit and shale.	Finely layered, soft rock with horizontal or near-horizontal beds. Fine grain sandstone and silt; low permeability.	0.15
Togo Series (Upper Precambrian)	Quartzite, sandstone, shale, phyllite, schist and silicified limestone, phyllite, schist.	Highly folded, jointed and fractured layers of quartzite. Moderate to high secondary porosity and permeability in some localities which produce low to medium yielding aquifers.	8.8
Dahomeyan (Upper Precambrian)	Acidic, ortho- and paragneiss and schist and migmatite, many of which are rich in garnet, hornblende and biotite.	Primary porosity as well as fracturing of the massive paragneiss is very low. The lower weathered zone builds low yielding aquifers. Recharge is low and ground water potential is poor.	0.15
Tarkwaian Supergroup (Mid Precambrian)	Quartzite, phyllite, grit, conglomerate and schist, including basic intrusive.	Generally low primary porosity and permeability. Secondary features result in production of low to medium yielding aquifers.	0.14
Cape Coast Granite Complex (CCGC) (Mid Precambrian)	Granitoid undifferentiated.	Some few areas have highly foliated, jointed and weathered granodiorite resulting in secondary permeability. Moderate water bearing properties expected in these areas with regolith aquifers. On the whole, the CCGC has poor ground water potential.	86.6
Birimian Volcanics (Mid Precambrian)	Metamorphosed lava and pyroclastic rock and hypabyssal basic intrusive, phyllite and greywacke.	Secondary porosity and permeability through weathering and fractures in some places lead to moderate yield of groundwater.	4.1

Water balance equation for the reservoir

Due to the fact that flow data at all the gauging stations in the DRB is not continuous over the period of study but at best, is significantly disjointed coupled with the fact that these gauging sites are no longer operational, runoff into the Reservoir cannot be directly estimated. Runoff is therefore estimated as a difference of all the known parameters in **Eq. (1)**. The water balance equation for the Reservoir is written as:

$$\Delta S = P + RO - PE - ABS \pm GR \qquad (1)$$

where ΔS is the change in its storage, P is the precipitation or rainfall on it, RO is the surface runoff into it, PE is the evaporation from it and ABS is the abstraction from it. GR is the ground water inflow into or outflow from the Reservoir.

Runoff into the Reservoir comes from the DRB with precipitation, evapotranspiration, infiltration and anthropogenic stresses being the main components. There are eight meteorological stations located in the DRB namely, Koforidua, Nankese, Nsawam, Suhum, Kukurantumi, Accra, Pokuase and Weija (**Fig. 1**). Precipitation data is available at all stations but not for all the years at the Nankese and Kukurantumi stations. Between 1980 and 1985, data was available for 90% of the time for Nankese while from 1986 to 1988 no data was collected. At the Kukurantumi station no data was collected between 1980 and 1987 and only 30% data was available from 1988 to 1989.

Potential evapotranspiration data is present in only five of these stations. **Figures 2** and **3** show plots of yearly variation in precipitation and potential evapotranspiration respectively recorded at the meteorological stations in the DRB with their mean depicted in black. From **Fig. 2**, it is observed that precipitation in the DRB can be grouped into three zones. Weija and Accra are in the lower precipitation zone while Koforidua, Nankese, Suhum and Kukurantumi are in the higher precipitation zone. Nsawam and Pokuase are between the two zones with the former higher than the latter. The mean precipitation (without the Weija data) and its trend are depicted in black. It is observed from the trend that the mean precipitation in the DRB is slowly decreasing. The mean potential evapotranspiration is however slowly increasing (**Fig. 3**).

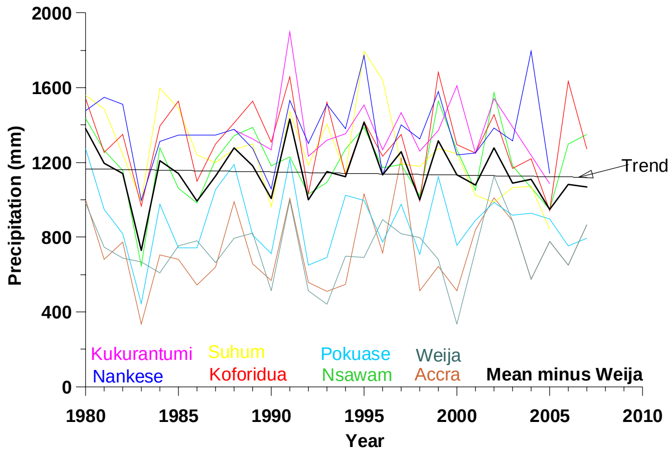

Fig. 2 Plot of annual precipitation recorded at the eight meteorological stations in the DRB including their mean annual plot (minus Weija data) in black and its trend (Data from Anon, 2008).

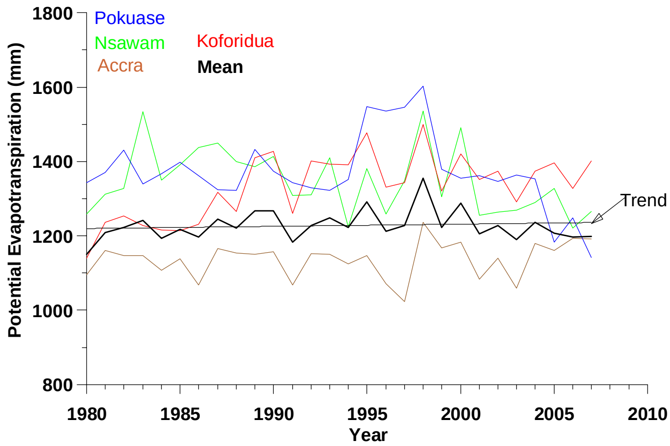

Fig. 3 Plot of annual potential evaporation recorded at five meteorological stations in the DRB including their mean annual plot and trend in black (Data from Anon, 2008).

Precipitation on reservoir (*P*)

Precipitation on the Reservoir is obtained from the Weija station which has been abandoned since 2003. Therefore, precipitation values for Accra which is about 10 km to the east and in the same zone with very similar values have been used from 2003 to 2007 to estimate the annual amount of precipitation on the Reservoir (**Figs 2** and **4**). The minimum and maximum precipitation on the Reservoir is 335 mm in 2000 and 1127 mm in 2002, respectively, with an annual mean precipitation of 732 ± 37 mm ($1.50 \pm 0.08 \times 10^{-2}$ km^3).

It should be noted that precipitation on the DRB minus that from Weija is the main input for runoff into the Reservoir and the minimum and maximum precipitation values are 730 mm and 1,430 mm respectively in 1983 and 1991 with a mean of 1,143 ± 158 mm.

Evaporation (*PE*)

Evaporation from the Reservoir was assumed to be equal to the mean annual potential evapotranspiration values. This is justified because in a particular region, potential evapotranspiration and open water evaporation are approximately the same over a one year period (Walker, 1962; Hayward & Oguntoyinbo, 1987). Potential evapotranspiration data for Weija was not consistently collected; therefore, the data for Accra was employed to represent the Reservoir. Minimum and maximum potential evapotranspiration values determined for Accra are 1023 mm in 1997 and 1235 mm in 1998 while the annual mean evaporation on the Reservoir over the twenty seven-year period is 1137 ± 57 mm (2.33 ± 0.12 × 10^{-2} km³). In **Figs 3** and **4**, the plot of estimated annual evaporation from the Reservoir on a yearly basis from 1980–2007 is shown.

Minimum and maximum potential evapotranspiration from the DRB are respectively 1150 mm and 1356 mm obtained in 1980 and 1998 with a mean of 1228 ± 126 mm.

Abstraction from the reservoir (*ABS*)

Abstraction of water from the Reservoir for treatment and supply to consumers is one way by which water leaves it. A plot of yearly abstraction is depicted in **Fig. 4** and reveals that there has been a steady increase in the quantity of raw water pumped annually for treatment from 1.84 ± 0.03 × 10^{-2} km³/year in 1980 to 6.86 ± 0.05 × 10^{-2} km³/year in 2006. This almost four-fold increase in abstraction over 26 years is an indication that demand for water by consumers has been increasing.

Storage changes (Δ*S*)

Water level measurements on the Reservoir were available from 1985 when a value of 13.48 ± 0.19 m was recorded (1986 and 1987 records were incomplete). A general increase in the water level is observed in **Fig. 4** with the highest level of 14.13 ± 0.19 m obtained in 2002. These measurements enabled changes in Reservoir storage to be determined. Since the Reservoir water surface area increases with increase in water level, an increase in water level will result in more volume of water per unit length. In **Fig. 4**, both annual water level and Reservoir storage changes are depicted.

Ground water inflow and outflow terms

From **Eq. (1)**, both ground water inflow and outflow require estimation. These two components are analysed

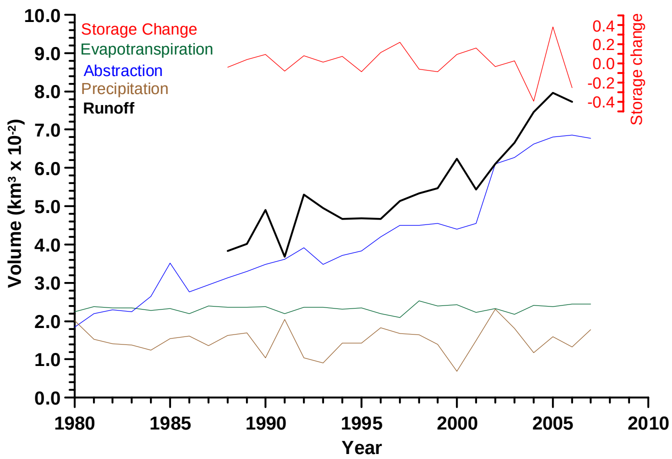

Fig. 4 Plot of the hydrological parameters used in the estimation of runoff in the Reservoir.

as follows: The area around the reservoir has been heavily developed since the late 1980's and large tracts of that area are without vegetation. Silt is washed into the Reservoir during times of precipitation and it is expected to settle at the Reservoir bottom and within fractures thereby acting as a seal which may eventually prevent ground water from flowing in and out of the reservoir. Ground water inflow or outflow may as a result be marginal or insignificant or possibly cancel each other out in **Eq. (1)**. Therefore, the net effect of these terms is estimated to be zero so that **Eq. (1)** can be written as:

$$RO = PE + ABS - P \pm \Delta S \qquad (2)$$

Spillgate

There are some periods that the Reservoir level rises close to maximum and therefore requires that the spillgate is opened to relieve pressure on the dam. Unfortunately, data on the times the spillgate is opened has only been documented from 1998 and are presented in **Table 2**. Even so, the volume of water discharged has never been determined. Since the Reservoir has filled to the required operating water level after its construction in 1978 and the maximum level of abstraction has not been reached, it can be assumed that the spillgate has been used periodically. Since the abstraction rate has increased four-fold and yet the spillgate has been employed frequently up to about 30% of the time in 2007, it can be assumed that runoff into the Reservoir is currently more than the abstraction rate.

DISCUSSION

Determining all the variables on an annual basis in **Eq. (1),** the yearly runoff can be estimated. **Figure 4** shows the graphical relationship between the main water balance components.

It is observed from **Fig. 4** that runoff into the Reservoir has increased consistently over the estimation period. From **Eq. (1)**, this is attributed to the fact that *P*, *PE* and Δ*S* have not changed appreciably over the study period but *ABS* has. Indeed *ABS* has increased almost four-fold and because it is positive, larger than the other terms, and has been increasing, runoff is also positive and appears to increase each year with a current maximum value estimated to be 7.97 ± 0.21 × 10^{-2} km^3/year in 2005. This value is 69% of the daily input into the Reservoir estimated by Anon (1997) and is expected to be greater than this value because the amount of water spilled is not accounted for in **Eq. (2)**.

The trend of runoff in **Fig. 4** suggests that the Reservoir is yet to reach its maximum potential for providing water for abstraction because runoff is more

Table 2. Periods in days when the Reservoir spillgate was opened to relieve pressure on the Dam between 1998 and 2007

Year	Period 1 (days)	Period 2 (days)	Period 3 (days)	Period 4 (days)	Period 5 (days)	Period 6 (days)	Period 7 (days)	Total (days)
1998	12	14						26
1999	13	32	9	20	16			90
2000	21	11	17	10				59
2001	38	23						61
2002	65	5	41					111
2003	29	2	15	6				52
2004	21	59						80
2005	5							5
2006	59	3	10	3	4	23	3	105
2007	20	24	27	14	9	33		127

than the current rate of abstraction. The maximum amount of runoff into the Reservoir cannot be determined until the plot peaks and/or levels off. This will be achieved in the future as *ABS* is increased to meet increased demand by consumers and the volume spilled is diverted into *ABS* or is accurately measured. The trend plotted on the data in **Fig. 5** suggests that the amount of water spilled is increasing each year.

The total amount of water leaving the DRB and flowing into the Reservoir is the "hydrologic circulation" or runoff which is the same as streamflow into the Reservoir assuming groundwater outflow from the DRB is insignificant (Dingman, 1994). The water balance equation for the DRB before all water regarded as runoff flow into the Reservoir can be written as:

$$RO(\text{runoff}) = P - ET - R \qquad (3)$$

where P is precipitation, ET is the actual evapotranspiration and R is groundwater recharge in the DRB, assuming groundwater outflow and groundwater inflow into the basin is insignificant.

Equation (3) shows that P and ET are externally imposed climatic "boundary conditions" and runoff is basically the difference between the two climatically determined quantities because R is expected to be small since DRB is made up of 86% CCGC with poor

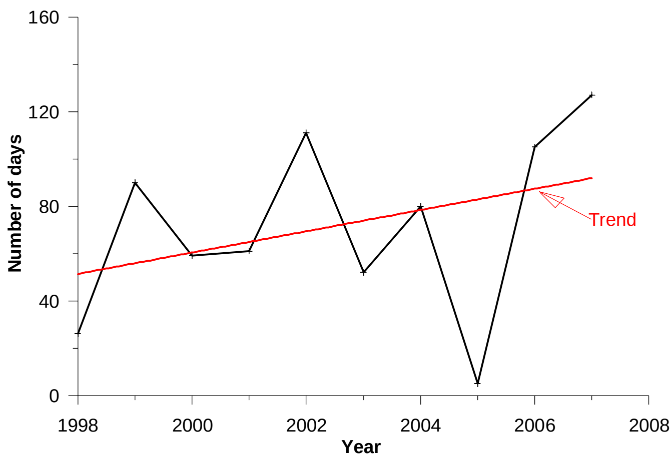

Fig. 5 Plot of number of days spillgate has been opened from 1998 to 2007 and a trend on the data.

groundwater potential in general. From **Fig. 2**, the trend on mean P is decreasing and has a negative gradient determined to be 1.68 while in **Fig. 3**, the trend for mean *PE* is increasing with a positive gradient of 0.60. The increase and decrease respectively in *PE* and P are 0.14% and 0.93% over the 27 years. The combined effect of P and *PE* is that "natural" runoff is possibly decreasing. The *residual* runoff is the *natural* runoff less all anthropogenic effects such as human use of water in the DRB before input into the Reservoir. Then, while residual runoff is in excess of water abstracted at the current time, water resource planners need to be aware that runoff is finite, possibly on the decrease albeit very slowly and a time is coming when it will equal abstraction without any spilling.

A very important factor which needs to be acknowledged is the effect of the poor land use practices in some parts of the DRB on runoff into the Reservoir (especially areas close to the Reservoir). These practices enumerated earlier have resulted in vegetation loss with the potential of increasing runoff and sediments into the Reservoir. The increased runoff may create an erroneous impression because while on the one hand there appears to be excess water which will be spilled, on the other hand, siltation is occurring and raising the Reservoir bottom thereby leading to a reduction in the total volume of water available for use. A survey of the Barekese dam in Kumasi revealed that between 1970 and 2005 the reservoir volume has reduced by about 30% of the original storage capacity (Oduro, 2008). So while water is currently available and is in excess of the amount required to supply consumers, the rate at which abstraction is increasing coupled with the fact that there is water shortage in many parts of Accra means that more water will be expected to come from the Reservoir to supply urgent needs.

Acknowledging that runoff into the reservoir is finite means that a time would come when abstraction would balance runoff and when this happens, water planners and water resources managers would have to find water for the populace. It should be mentioned that Kasoa is about 4 km east of the Reservoir and is becoming a large population centre with an estimated population of more than 100 000. Obviously, it would also put a stress on the water from the Reservoir. It is therefore imperative that a water balance for the DRB is required so that the amount of water entering the Reservoir as runoff is estimated for the planning and management purposes. An effort has to be made to estimate the amount of silt that has collected in the Reservoir. This can be accomplished by making use of the original topographic survey of the Reservoir area compared to the present profile of the Reservoir bottom. Regular hydrological data collection should be enforced and the Water Resources Commission (WRC) and Water Resources Research Institute (WRRI) should be mandated to serve as hydrological data banks to prevent the difficulties encountered in locating such data and also the possibility of data loss. Some of the data which need to be collected in addition to those already collected in the DRB are how much water is spilled from the Reservoir, flow gauging of all major rivers and streams discharging into the Reservoir, and a dedicated meteorological station at Weija. A serious campaign needs to be undertaken to educate people in the DRB in areas identified as high "hazard zones" in relation to their threat to runoff into the Reservoir. Additionally, both mitigation and enforcement measures need to be urgently adopted to safeguard continuous water flow into the Reservoir.

The work has shown how difficult it is to undertake a detailed assessment of water resources in some parts of the developing world because of either lack of financial resources or lack of a conscious effort in gathering the required data and its storage for future analyses. This study should therefore be seen as a first approximation of the state and trend of water inflow into the Reservoir. The results are however a fair assessment and water planners and managers at GWCL, WRRI and WRC should begin to identify and meticulously draw up plans for consistent data gathering, the type of data that can be used in detailed assessment of the Reservoir and other important water resources in the country.

REFERENCES

Ahmed, S.M; Blay, P.K.; Castor, S.B.; Coakley, G.J. (1997) The Geology of 1/4 ^{0} Field Sheets Nos. 33 Winneba N.E., 59, 61 and 62, Accra S.W., N.W. and N.E.

Anon. (1989) Population census of Ghana, Greater Accra Region, Statistical Service, Accra, Ghana. June 1989.

Anon (1997) Consultancy for the study of the ATMA development and Investment programme and of the Rehabilitation/Replacement of Kpong-Tema-Accra water pipeline, 4–21.

Anon (2002) Population and Housing Census, Ghana Statistical Service, March 2002. Accra, 44–46.

Anon (2008) Meteorological data from 1985 – 2007 for the Densu River Basin. Meterorological Services Authority, Accra.

Dingman, S.L. (1994) *Physical Hydrology, Prentice Hall, Upper Saddle River*, N. J. USA, 16–23, 331–334, 438–441.

Domenico, P.A. & Schwartz, F.W. (1998) *Physical and Chemical Hydrogeology*, John Wiley and Sons, New York, USA.

Hayward, D. F. & Oguntoyindo, J. S. (1987) *The Climatology of West Africa*. Hutchinson London, UK.

Ocansey-Colerangle, P. (1979) *The state of the Densu River/Reservoir*, 1–3.

Oduro, R. (2008) Personal communications.

Walker, H.O. (1962) *Weather and Climate in Agriculture and land use in Ghana*. Wills, J.B. (ed.) Oxford University Press.