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Impact of the Gurara River (Nigeria) interbasin water transfer scheme on the Kaduna River at the Shiroro Dam

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Abstract The Kaduna River is impounded at Shiroro for the sole purpose of generating electricity. There is, however, a persistently low reservoir level between November and June due to seasonal fluctuations in the river inflows to the Shiroro Reservoir. A proposed scheme to increase Shiroro Reservoir storage is to transfer 1500 Mm^3 of water (which is about 10% of the mean annual inflow to Shiroro Reservoir) from the Gurara River to the Shiroro Reservoir between December and May. The interbasin water transfer is intended to stabilize the Shiroro Reservoir level. This paper examines the effect of the water transfer on the storage level of this reservoir. Fourteen years of daily inflow record were used to study the real-time operation of the reservoir. The results indicate that with the water transfer, the reservoir attains its maximum operating level in July and maintains it until September or October, whereas the maximum operating level would have been attained in August without the transfer. Although the interbasin water transfer into the Shiroro Reservoir would enhance power generation, there would be an increase in the frequency and severity of annual flooding downstream of the dam. Appropriate flood damage mitigation measures are recommended for the Kaduna River basin to optimize the benefit of the proposed interbasin water transfer scheme.

Key words impact assessment; interbasin transfer; reservoir operation

INTRODUCTION

Interbasin transfers involve the transfer of water from a basin (the donor) to another basin (the recipient) and can be used to balance uneven temporal and spatial distributions of water in the basins. The temporal variation of rainfall in Nigeria is well documented (Nicholson, 1981; Adefolalu, 1986; Jimoh & Webster, 1996). These studies have highlighted that there is a high inter-annual variation in rainfall. In particular, low annual rainfall occurred between 1961 and 1983. Low rainfalls have caused low inflows into the reservoirs, resulting in disastrous effects on hydroelectric power (HEP) generation and municipal water use. The Gurara interbasin water transfer scheme involves impounding water at Jere Dam (Fig. 1), then transferring the water to Abuja, the Federal Capital Territory (FCT) for municipal water supply, and to Shiroro Lake to augment flow for the generation of electricity (FMAWRD, 1986). Other benefits of the scheme include a reduction in the flooding of the lower Gurara basin, as well as improving the navigation activities at the lower Niger. Construction activities of the Jere Dam and the hydraulic system for transferring water to FCT started in 2001. The construction activity for the diversion to Shiroro for HEP generation will start in the next phase of development. The water transferred to FCT will be consumed

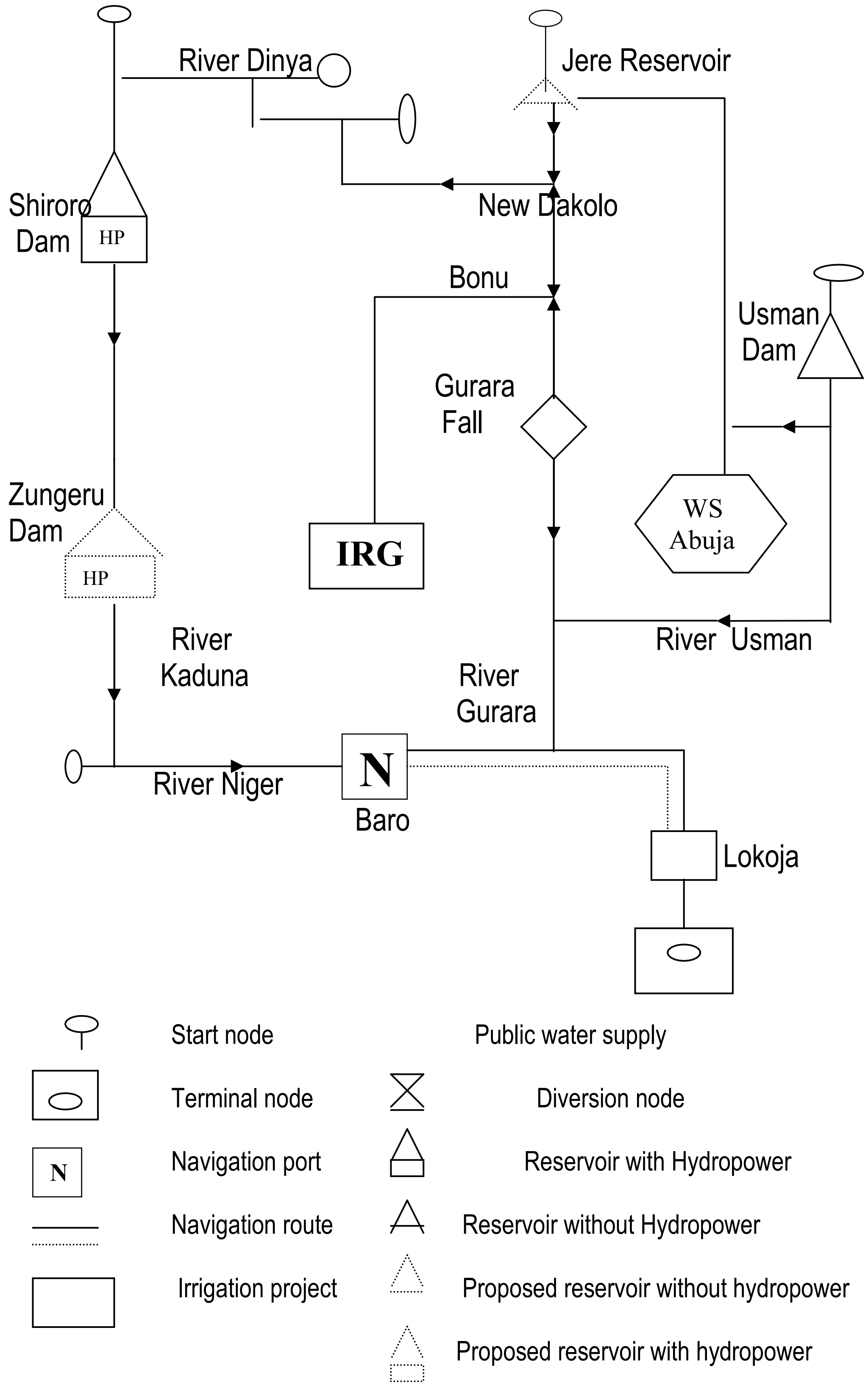

Fig. 1 Schematic representation of the Gurara River Interbasin Transfer Model (FMAWRRD, 1986).

by domestic activities in the territory, whereas about 90% of the water transferred to the Shiroro Reservoir will be released as tail-water after power generation.

The hydrological regime of a river is altered when its water is impounded for consumptive or non-consumptive purposes. Impounding water for consumptive purposes will reduce flooding downstream of a reservoir. This is not the case when the reservoir is used for non-consumptive purposes like HEP generation. For example, agricultural land and urban areas downstream of the Jebba Dam on the Niger River and the Shiroro Dam on the Kaduna River were flooded in 1998 and 1999 (Nigerian Tribune, 1999). This flooding was attributed to the occurrence of high rainfalls over a period of days in the catchments of the HEP dams (Kainji, Jebba and Shiroro dams) which filled the reservoirs and the floodgates of the dams were opened to prevent the dams from collapsing.

The aim of this study is to identify the change in the hydrological regime of the Kaduna River when water is transferred to Shiroro Reservoir (that is the hydrological regime during the post-transfer period). In particular, the study addresses the effect of the transfer of water on the probability of flooding.

THE STUDY AREA

The Gurara interbasin water transfer scheme is situated between latitudes 8°–11°N and longitudes 7°30′–8°30′E. It covers the Federal Capital Territory of Nigeria, the south eastern part of Niger State and the western part of Kaduna State (Fig. 2). The major rivers within the scheme are the Gurara, Kaduna, Tapa, Dinya, Usman and Jatau. The Gurara River basin is the donor, while the basins of rivers Dinya, Kaduna, Usman and Jatau are the recipients.

Jere Dam is located on the Gurara River at 9°05′N, 7°30′E (Fig. 2). The Gurara River extends over a distance of about 570 km from the plateau at an elevation of over 700 m, through Jere at 530 m and into the Niger confluence at an elevation of 40 m. The Gurara River flows in a general direction of northeast to southwest in its upper reaches, then turns southwards as it flows through FCT to its confluence with the Niger. The vegetation is basically savannah (southern Guinea Savannah zone) grassland interspersed with remnants of tropical forest. The watercourses are particularly forested with large trees from the fringing forests, with a few patches of typical natural forest reserves.

Shiroro Reservoir is situated on the Kaduna River at the confluence of the Kaduna River and the Dinya River. The reservoir is located on latitude 9°58′N and longitude 6°51′E (Fig. 2). The Kaduna River takes its origin northwest of Jos. The river flows in westerly and southwesterly directions from the Plateau, at an elevation of 1500 m through Kaduna town at an elevation of 633 m, then through Shiroro George and into the Niger. The major left-hand tributaries of the Kaduna River are the Sarkin River and the Dinya River, while the major right-hand tributary is the Tubo River. The entire catchment has a vegetative cover classified as Guinea Savannah.

The Gurara and Kaduna River basins lie in the intermediate zone between semi-arid climate in the north and sub-humid climate in the south, and the climate is influenced by the seasonal movement of the Intertropical Convergence Zone, which results in wet and dry seasons. Rain starts in May (or April) and lasts till October, with

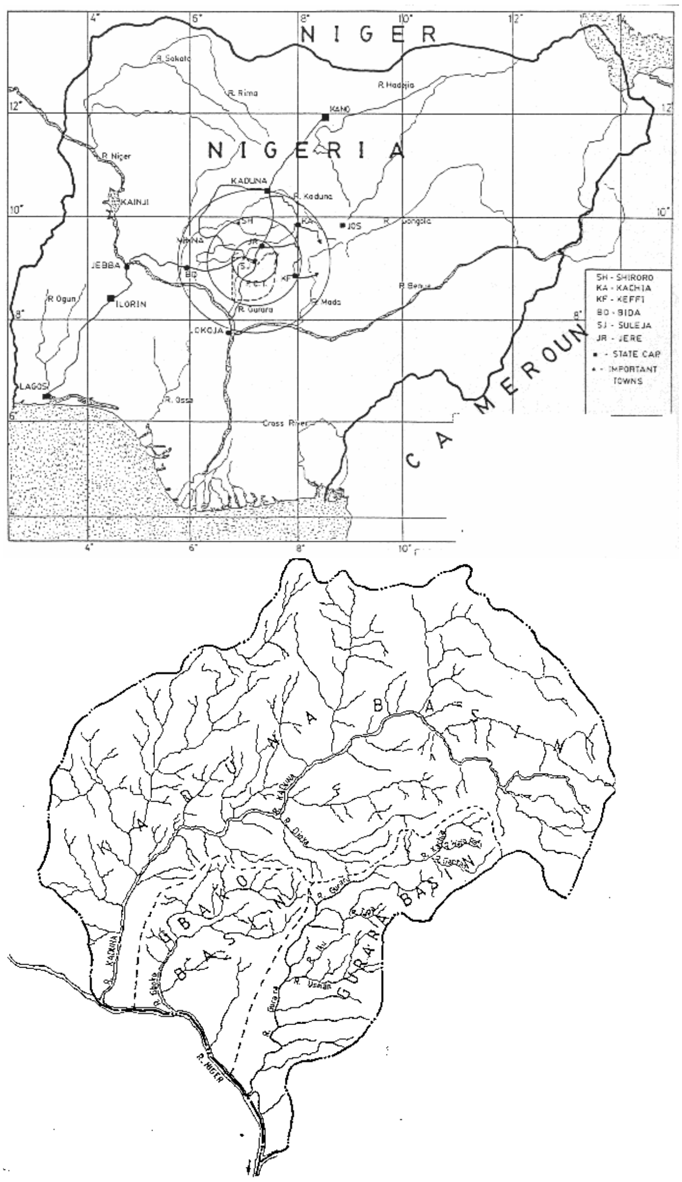

Fig. 2 Map of Nigeria showing the Gurara and Kaduna River basins.

the peak rainfall occurring in September. The dry season lasts between November and March. The mean annual rainfall of some locations in the scheme are as follows: 1300 mm at Minna, 1500 mm at Abuja, 1600 mm at Kafancha, 1250 mm at Kaduna and 1400 mm at Jos. The mean monthly maximum and minimum temperatures in the basins are 37.3°C and 19.7°C, respectively, and the hottest months are February, March and April.

METHOD OF INVESTIGATION

Fourteen years of data of daily inflows to Shiroro Reservoir were collected from the National Electric Power Authority, Shiroro. Other data collected include the reservoir level, evaporation, and the parameters of the hydropower plant such as operating storage levels, plant factor, and maximum and minimum allowable discharges. The data were then used to carry out a reservoir balance study based on defined operating rules. The following steps were adopted:

(1) Find the water in storage at the beginning of the day. Add the true inflow and the transferred flow (if any), and subtract the evaporation loss to obtain the initial volume of water stored (*Q*1).
(2) Assuming a plant factor of 0.45 (FMAWRD, 1986), obtain the minimum discharge through the turbines. Subtract the minimum discharge from *Q*1 to obtain *Q*2.
(3) If *Q*2 is less than the minimum operating storage (500 Mm^3), there is no excess flow to be released. Proceed to step 6.
(4) If *Q*2 is greater than 500 Mm^3 but less than 6500 Mm^3 (maximum operating level), proceed to step 6.
(5) Otherwise, if *Q*2 is greater than 6500 Mm^3, then release all excess flow above the maximum operating level.
(6) The storage at the end of the day becomes the storage at the beginning of the next day. Proceed to step 1.

This procedure was used for both the periods when water is transferred to the reservoir as well as for periods when there is no transfer of water. The transfer of water to Shiroro Reservoir depends on the allocation of water in Jere Reservoir to other competitive demands. FMAWRD (1986) reported that an annual flow ranging from 1500 to 2000 Mm^3 could be transferred to the reservoir. It is assumed in this study that 1500 Mm^3 of water would be available for transfer to Shiroro Reservoir, and the period of transfer is restricted to the period of low inflow to Shiroro Reservoir (which is between December and May, i.e. the dry months). The monthly distribution of water transferred to Shiroro Reservoir (Table 1) is based on the inverse ratio of the observed mean monthly flows during the dry months and the total monthly flows during the dry season.

The daily storage level obtained for the periods with and without transfer are compared using the following criteria: (a) the period when the maximum operating reservoir level is attained, (b) the duration over which this level is maintained within a year, (c) the volume of water spilled each year, and (d) the probability of flooding downstream of the dam.

RESULTS AND DISCUSSION

Figure 3 shows the amount of water spilled from Shiroro Reservoir with and without the water transfer. Without the water transfer, spillage started as early as on Julian date 230, and not later than on Julian date 240 (that is in the month of August), except in the years 1991, 1993 and 1999 when spillage started on Julian date 210 (in July).

Table 1 Monthly transfer to Shiroro Reservoir.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Fraction of *Q*	0.123	0.176	0.393	0.123	0.069	0.0	0.0	0.0	0.0	0.0	0.0	0.091	1.000

Q is the annual transfer (= 1500 Mm^3) to Shiroro Reservoir.

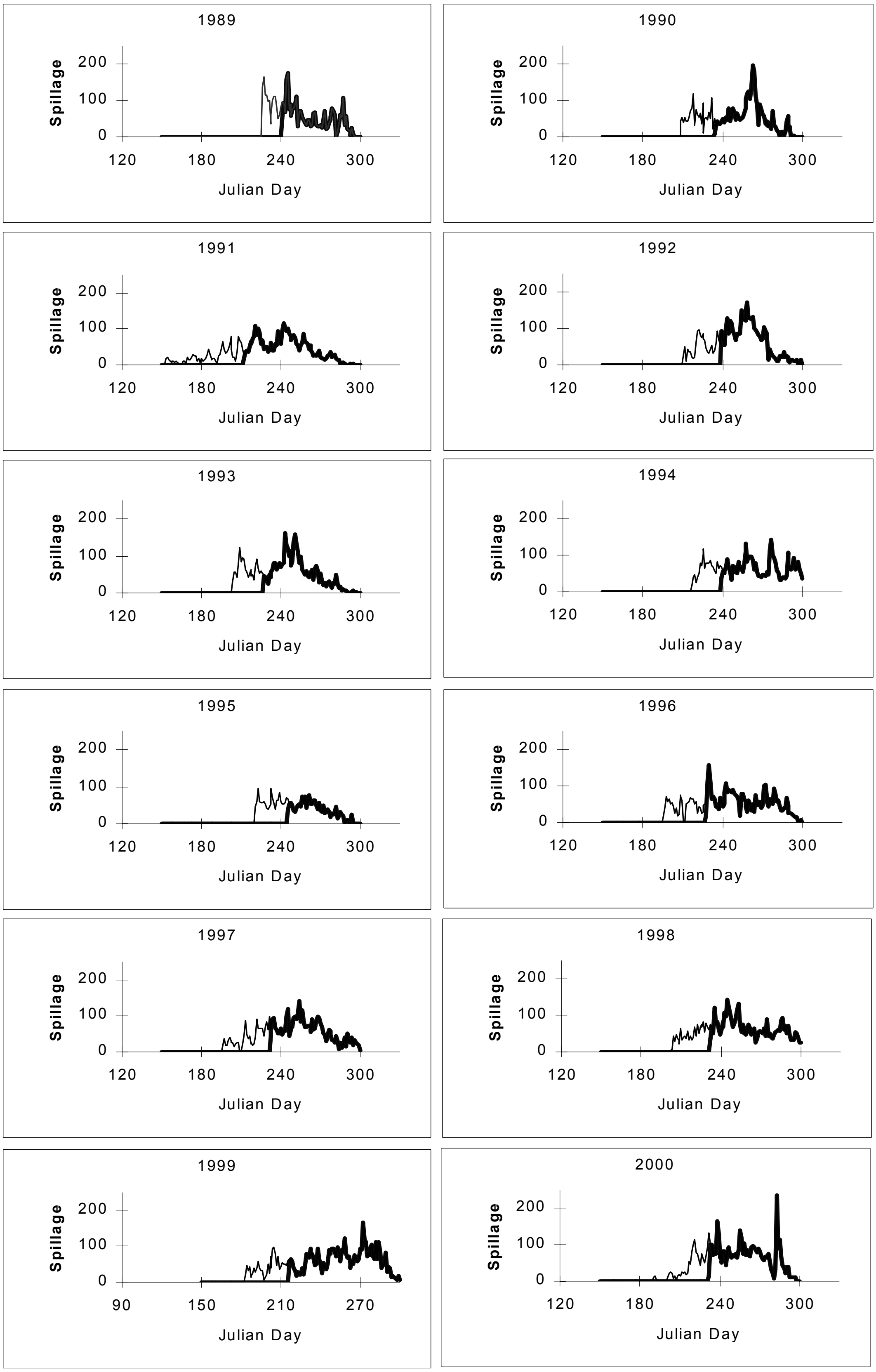

Fig. 3 Daily spillage from the Shiroro Reservoir. ▬ without water transfer, —— with water transfer .

The daily spillage then increased gradually from zero in July or August to a maximum value in September and decreased to zero on about Julian date 300 (October). The maximum value of the spillage was as high as 200 Mm^3 day^{-1} in 1990, 1992, 1999 and 2000, whereas in 1995, the maximum value was 100 Mm^3 day^{-1}. On the other hand, spillage would have started in July if water was transferred to Shiroro Reservoir between December and May.

Figure 4 shows the reservoir storage levels between 1989 and 2000. Without the water transfer, the reservoir attained its maximum operating level between Julian date 230 and 240 (that is in August) in 1991, 1993 and 1999. However, the reservoir would have attained its maximum operating level earlier than August if water was transferred to the reservoir. The operating level of the reservoir is then maintained at its maximum level until September or October with or without the water transfer. In addition, the volume of water that is spilled between September and October is independent of whether there is transfer of water or not. Without the transfer of water, severe flooding of the Kaduna plains downstream of Shiroro Reservoir is often reported in August and September, which coincides with the peak of the rainy season. The implication of the transfer of water is that there would be flooding of the plains as early as July. This is an environmental implication of the transfer of water from the Gurara basin to the Kaduna basin that needs to be addressed.

Figure 5 shows the flow duration curve for the spilled water. The figure shows the percentage of time that a certain flow, q is exceeded (${}_nP_q$ when there is no transfer of water, and ${}_tP_q$ with the water transfer). When q equals 50 Mm^3 day^{-1}, ${}_tP_q$ is usually greater than ${}_nP_q$. This means that the probability of flow in the river channel exceeding 50 Mm^3 day^{-1} with the water transfer is greater than that without the water transfer. For flows greater than 50 Mm^3 day^{-1}, the percentage of exceedence was the same with or without the water transfer, except in 1989, 1992, 1993, 1994 and 1995. The highest value of ${}_nP_{50}$ occurred in 1999 with or without the water transfer. This finding agrees with the reported (Nigerian Tribune, 1999) cases of flooding of the lower Kaduna basin. The hydraulic characteristics of the Kaduna River downstream of Shiroro Dam were surveyed, and it was found that the maximum bank full discharge the river channel can accommodate is 82 Mm^3 day^{-1}. Without the water transfer, the percentage of time that 82 Mm^3 day^{-1} is exceeded in 1991, 1992, 1999 and 2000 is greater than 15%. The percentage of exceedence is 10% in 1994, 1996, 1997 and 1998, while in 1989, 1990, 1993 and 1995, the percentage of exceedence is less than 10%. This also confirms the flooding of the Kaduna Plain that was reported in 1998 and 1999, as the number of days the river could exceed its bank full capacity is greater than 10%. The study showed that the percentage of days the river would flood the flood plains would increase by 5% if water were transferred to the reservoir.

The transfer of water between December and May to the reservoir is meant to increase the reservoir level so as to increase hydroelectric energy production. This objective would be achieved as indicated by the investigation. However, there will an increased probability of flooding of the river plain downstream from the dam and an increase in the time period that flooding may occur. These changes constitute negative impacts.

One possibility of reducing the negative impacts is by channel improvement. Jimoh (1999a,b) showed that the maintenance of natural and artificial watercourses in

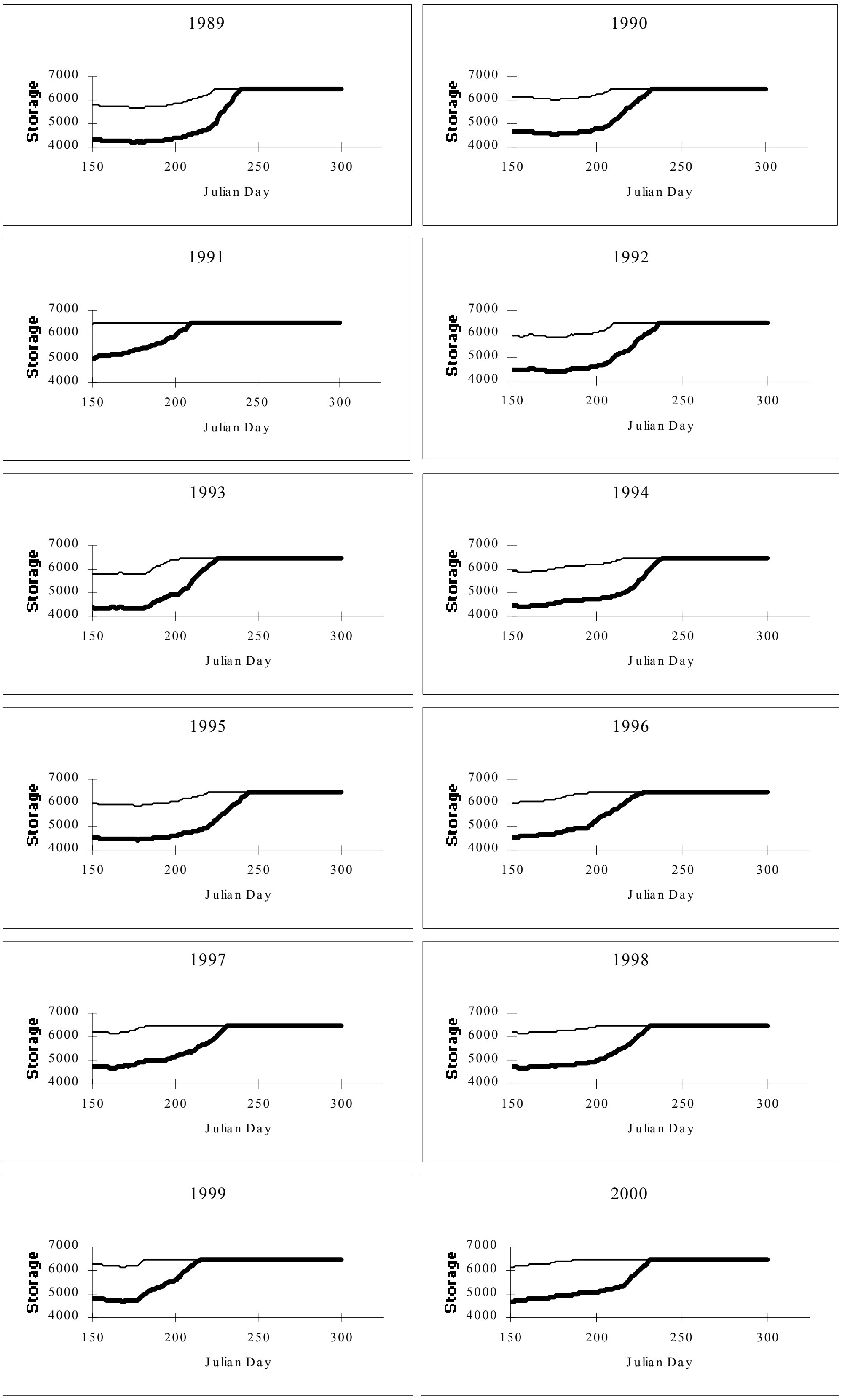

Fig. 4 Storage in million cubic metres at Shiroro Reservoir. ▬▬ without water transfer, —— with water transfer .

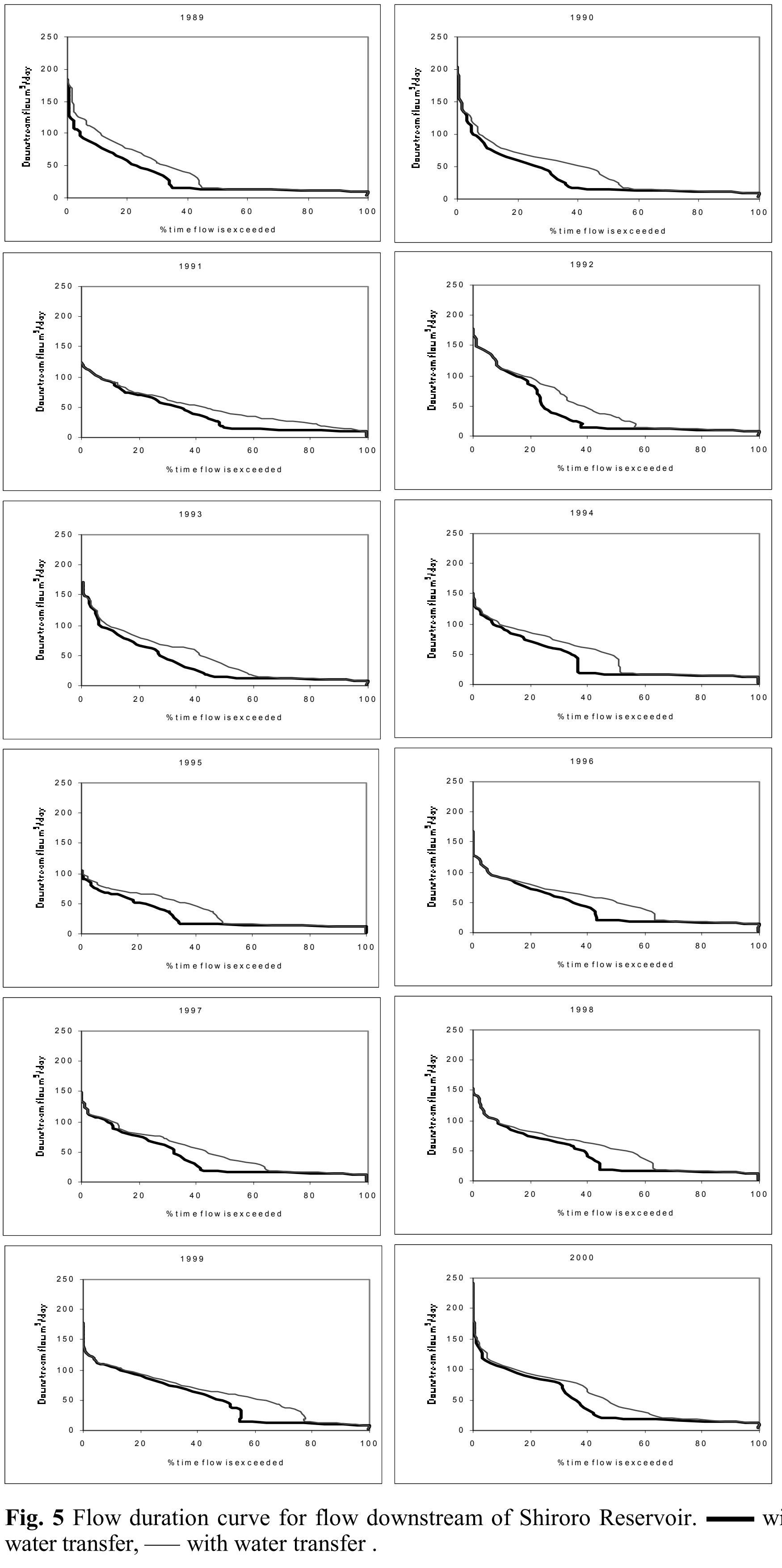

Fig. 5 Flow duration curve for flow downstream of Shiroro Reservoir. ▬▬ without water transfer, —— with water transfer .

Nigeria is often inadequate. The watercourses are often infested by weed. The channels are also sometimes used for dumping waste. The effect of these practices is a reduction in the hydraulic capacity of the channels. In order to enhance the hydraulic capacity of the Kaduna River, it is recommended that weed growth must be cleared regularly, and the channels must not be used for dumping refuse. Another possibility of mitigating the effect of flood damage in the basin is to build floodwalls along the channel to confine the flow as well as use of a proper flood warning system.

CONCLUSIONS

This study examined the flow regime of the Kaduna River downstream of Shiroro Reservoir when water is transferred from the Gurara River. The following conclusions can be drawn from the study:

(a) The Shiroro Reservoir remained full almost throughout the year with the water transfer in place.
(b) The water transfer scenario led to an early spillage of water from the reservoir.
(c) On average, with the water transfer, there is a 5% increase in the number of days the riverbank is overflowed.
(d) With the water transfer, there is an increase in the volume of water spilled every year.

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