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WATER, SANITATION, ENVIRONMENT and DEVELOPMENT

Reappraisal of water systems on River Densu

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Definition and objectives

The development of multi-site water supply systems based on abstraction from major rivers in Ghana has often been piece-meal and studies are designed to justify individual projects being considered and this approach undoubtedly often results in the irrational and unfair allocation of water to potential and current users along the stretch of the river.

The River Densu which typifies this problem, feeds the Weija Reservoir in Accra, Ghana's capital. The Weija Reservoir serves the dual purpose of municipal water supply of 78 million cubic metre per annum to Accra and to irrigate 1,890 hectare of land with a water requirement of 30.8 million cubic metres per annum.

The river is also extensively used as a source of municipal water supply to Ghana's Eastern Region capital, Koforidua* (1984 population 166,000) and Nsawam* (population 66,400). Several communities along its stretch also depend on this river for their domestic water supply needs.

Whereas the Weija Reservoir in Accra spills water almost every year, shortages are experienced in Koforidua because the flows of the Densu fall below peak dry seasonal demand.

In this paper an attempt is made to develop a rational water supply planning and management model that would estimate and optimally evaluate total system costs and benefits associated with reservoir capacities, yields and operating policies that are required to augment and improve the water supplies to Koforidua and Nsawam and for operating the existing Weija Reservoir.

The paper also provides information on the impact of upstream water impoundments and increased abstraction and regulation projects on the inflows and hence the management and operation of the Weija Reservoir in Accra.

Methodology and analysis

Techniques of systems analysis instead of traditional methods have been employed in this paper. The two-step approach is used. The particular method employs a Linear Programming (L.P.) optimisation model to find a first good approximation in a preliminary screening process. This is followed by a detailed simulation model that further analysis, evaluates and improves on the parameters obtained in the L.P. process, (Loucks *et al* 1972).

Hydrological data

Up to date hydrological data from 1955 to 1983 exist at four sites on the river, although this data is beset with several gaps. The gaps in the data are filled using the transposition method (Loucks 1981).

The historical hydrological data is extended 300 years using the seasonal lag-one Markov model of the form:

$$Q_{i+1} = A_i + B_i Q_i + E_i$$

where A_i, B_i are constants in a Linear regression model.

Q_i, is the previous flow;

Q_{i+1}, is the current flow;

E_i, is the error term in the model.

Design alternatives

Three design alternatives were analysed as follows:

- Alternative one
  Construct an impounding reservoir at Koforidua to meet the long term water supply demand targets for both Koforidua and Nsawam. The reservoir is to provide regulated flow at Nsawam for run-of-river abstraction behind a small intake weir.
- Alternative two
  Construct one reservoir at Koforidua to meet its needs only. The raw water requirements for Nsawam is met by pumping water from the Weija water works.
- Alternative three
  Construct two reservoirs of suitable capacities, one at Koforidua and the other at Nsawam to meet the target demands of two towns separately.

All three investment plans are evaluated using the following Linear Programming optimisation model which is based on mass balance for routing stream flows through reservoirs and the river channel.

Minimise $Z = \Sigma^{n}_{i=1} K_i$

Subject to:

$$S^i_{t+1} = S^i_t + I^i_t + R^{i-1}_t - R^i_{tw} - R^i_t$$

$$S^i_t < K^i$$

$$S^i_t, I^i_t, R^i_t, R^i_{tw}, K^i > 0$$

where

S^i_t = Storage volume in reservoir at the beginning of period "t" at site "i"

S^i_{t+1} = Storage volume in reservoir at the end of period "t" at site "i"

I^i_t = Unregulated (or incremental) inflow into the reservoir during period "t".

R^i_{tw} = Release for water supply during period "t" from reservoir "i".

R^i_t = Excess release from reservoir "i" during period "t".

K_i = Reservoir capacity at site "i".

The minimum active storage capacity required for a given set of releases is found by minimising storage capacity of reservoir subject to the constraints for all time periods.

Simulation

The results of the L.P. optimisation is used in a simulation model. The essence of this model is to reproduce the behaviour of the basin system in every important respect using mathematical expressions. However non-mathematical logical processes are also considered. Control is exercised through a monthly operating procedure which has monthly inflows, releases and target outputs. The model is run using a personal computer. The flow chart shows the procedure involved (figure 1).

The simulation results are further analysed and interpreted for reliability of the system meeting demand at all times. The reliability R of the system for any reservoir is expressed as follows:

$R = 1 - f$

$R\% = (1-f)100$

where f is failure rate within the design life of the project.

The final choice of investment plan is selected through a comparative economic analysis and the least cost option selected.

Results, conclusions and recommendations

A statistical test of significance for any difference between the statistics of the historical streamflow and those of the synthetic flows generated show that at the 95% confidence interval, various sequences of flows can be assumed to come from the same population.

Linear programming optimisation

The results of the LP optimisation model show that a definite trend of bigger sized reservoirs are required with decreasing inflows.

The results also show that when investment scheme alternative three is run, no separate storage is required at Nsawam. This alternative was eliminated from further study.

Simulation

The simulation results yielded information on reliability of reservoirs for various sizes and various inflow configurations. The results show a definite increase in reliability with increase in size of reservoirs required at Koforidua for the two surviving alternatives.

The Weija reservoir yield analysis also indicates that with increased abstraction upstream for water supply to Koforidua and Nsawam there is sufficient water to meet the combined requirements for water supply to Accra and for irrigation.

Economic analysis

From the point of view of least cost investment alternative one has been found to be more attractive.

Conclusions

The Densu River basin system lends itself to analysis through the use of systems analysis techniques and was in particular shown to yield very consistent results through the use of Linear Programming optimisation models and detailed computer simulation techniques using a personal computer.

The water resources of the River Densu abound and are sufficient for the long term water supply requirements of all major potential users along its stretch with high reliability. Regulation is however required.

It was shown that of the three investment schemes investigated alternative three was eliminated by L.P. optimisation whereas simulation and a least cost analysis showed that alternative one is most attractive.

Finally it was established that the Weija Reservoir system would not be jeopadised by impoundment and increased abstraction upstream for water supply.

This paper has attempted to show that it is possible to use simple analytical tools to plan and manage river basin schemes and in particular narrow down the options in water resources development for multi-site systems.

References

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Table 1

Cost Comparison

Size of reservoir (Million M³)	*Reliability %*	*Cost US $*
Alternative one		
4.8	96	11,700,000
8.4	99	12,800,000
Alternative two		
4.8	96	17,300,000
8.4	99	19,000,000

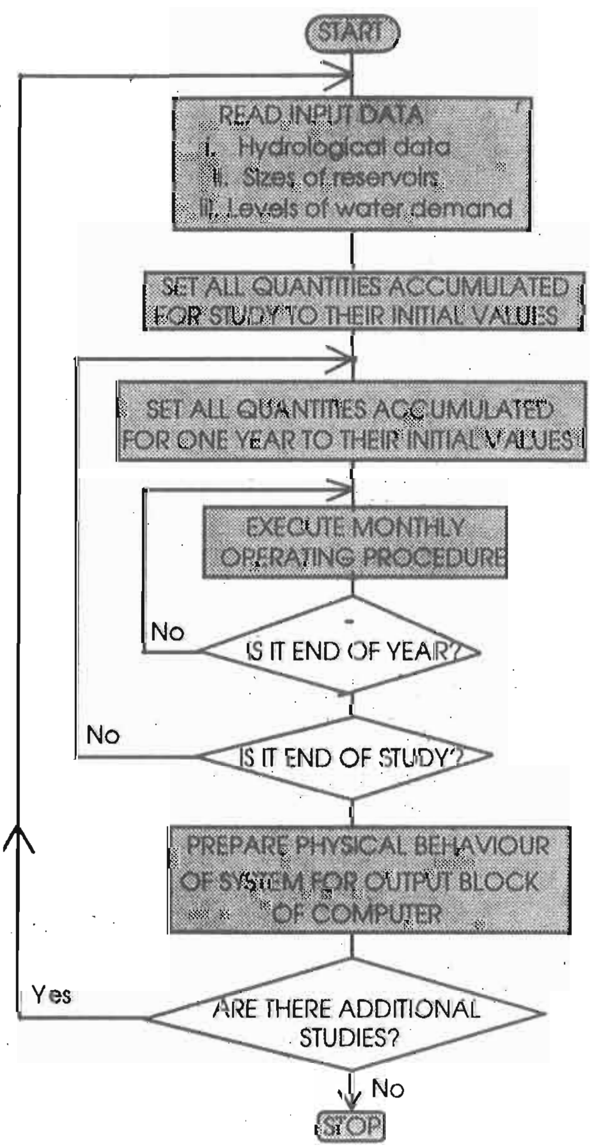

Figure 1

* The population includes all surrounding communities that benefit from a water supply scheme.

⁺ Inflows are made dimensionless by dividing by the mean monthly inflow.