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STUDY OF OPTIMIZING TECHNIQUES OF RESERVOIR OPERATION

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Abstract— Water being a prime natural resource, its essentiality and need is getting increased constantly. The management of water is crucial keeping in view the assessment and the availability and utilization. It needs proper planning and efficient management of water is foremost for development of a country. For efficient use of water resources, reservoirs are to be planned and operated under proper management of water resources system. For using this water efficiently for different purposes like water supply demand, municipal and irrigation water supply, hydroelectric power generation etc… there is need optimizing techniques of reservoir operation. Some of the optimizing techniques are Stochastic dynamic programming (SDP) model, System dynamic (SD) model, Intelligent decision support system (IDSS) approachetc.,

Keywords— Reservoir, Optimizing techniques, Stochastic Dynamic Programming, System Dynamic Model, Intelligent Decision Support System.

INTRODUCTION

In India, reservoirs are usually constructed to serve multiple purposes, such as irrigation, municipaland industrial water supply, hydropower generation and flood control. Because of the high temporal and geographical variability of rainfall in this country, reservoir operation occupies an important place in the utilization of water resources. Water being a prime natural resource, its essentiality and need is getting increased constantly. The management of water is crucial keeping in view the assessment and the availability and utilization. It needs proper planning and efficient management of water is foremost for development of a country. For efficient use of water resources, reservoirs are to be planned and operated under proper management of water resources system. After a dam has got constructed, detailed guide line in the form of Reservoir Operating Policy will have to be given to the operator for enabling him to take decision about storing or releasing of water.

Reservoir operation is one of the challenging problems for water resources planners and managers. To obtain optimal operating rules, a large number of optimization and simulation models have been developed and applied over the past several decades.

PURPOSE OF RESERVOIR

Direct water supply

Many dammed river reservoirs and most bank-side reservoirs are used to provide the raw water feed to a water treatment plant which delivers drinking water through water mains. The reservoir does not simply hold water until it is needed; it can also be the first part of the water treatment process. The time the water is held for before it is released is known as the retention time.

Hydroelectricity

A reservoir generating hydroelectricity includes turbines connected to the retained water body by large-diameter pipes. These generating sets may be at the base of the dam or some distance away. Some reservoirs generating hydroelectricity use pumped re-charge in which a high-level reservoir is filled with water using high-performance electric pumps at times when electricity demand is low and then uses this stored water to generate electricity by releasing the stored water into a low-level reservoir when electricity demand is high. Such systems are called pump-storage schemes.

Controlling watercourses

Reservoirs can be used in a number of ways to control how water flows through downstream waterways.

1 Downstream water supply: water may be released from an upland reservoir so that it can be abstracted for drinking water lower down the system, sometimes hundreds of miles further down downstream

2. Irrigation: water in an irrigation reservoir may be released into networks of canals for use in farmlands or secondary water systems. Irrigation may also be supported by reservoirs which maintain river flows allowing water to be abstracted for irrigation lower down the river.[18]

3. Flood control: It is also known as an "attenuation" or "balancing" reservoir, flood control reservoirs collect water at times of very high rainfall, then release it slowly over the course of the following weeks or months. Some of these reservoirs are constructed across the river line with the onward flow controlled by an orifice plate. When river flow exceeds the capacity of the orifice plate water builds behind the dam but as soon as the flow rate reduces the water behind the dam slowly releases until the reservoir is empty again. In some cases such reservoirs only function a few times in a decade and the land behind the reservoir may be developed as community or recreational land. A new generation of balancing dams are being developed to combat the climatic consequences of climate change. They are called "Flood Detention Reservoirs". Because these reservoirs will remain dry for long periods, there may be a risk of the clay core drying out reducing its structural stability. Recent developments include the use of composite core fill made from recycled materials as an alternative to clay.

4. Canals: Where a natural watercourse's water is not available to be diverted into a canal, a reservoir may be built to guarantee the water level in the canal; for example, where a canal climbs to cross a range of hills through locks.

5. Recreation: On salmonid rivers special releases are made to encourage natural migration behavior’s in fish and to provide a variety of fishing conditions for anglers.

1.1. Flow balancing

Reservoirs can be used to balance the flow in highly managed systems, taking in water during high flows and releasing it again during low flows. In order for this to work without pumping requires careful control of water levels using adjustable sluices.

1.2. Recreation

The water bodies provided by many reservoirs often allow some recreational uses such as fishing, boating, and other activities. Special rules may apply for the safety of the public and to protect the quality of the water and the ecology of the surrounding area. Many reservoirs now support and encourage less informal and less structured recreation such as natural history, watching, landscape, walking and hiking and often provide information boards and interpretation material to encourage responsible use.

ENVIRONMENTAL IMPACTS OF RESERVOIR

RESERVOIR SEDIMENTATION

Rivers carry sediment down their riverbeds, allowing for the formation of depositional features such as river deltas, alluvial fans, braided rivers, oxbow lakes, levees and coastal shores. The construction of a dam blocks the flow of sediment downstream, leading to downstream erosion of these Sedimentary depositional environments, and increased sediment build-up in the reservoir. While the rate of sedimentation varies for each dam and each river, eventually all reservoirs develop a reduced water-storage capacity due to the exchange of storage space for sediment. Diminished storage capacity results in decreased ability to produce hydroelectric power, reduced availability of water for irrigation, and if left unaddressed, may ultimately result in the expiration of the dam and river.

COASTAL EROSION

As all dams result in reduced sediment load downstream, a dammed river is said to be "hungry" for sediment. Because the rate of deposition of sediment is greatly reduced since there is less to deposit but the rate of erosion remains nearly constant, the water flow eats away at the river shores and riverbed, threatening shoreline ecosystems, deepening the riverbed, and narrowing the river over time. This leads to a compromised water table, reduced water levels, homogenization of the river flow and thus reduced ecosystem variability, reduced support for wildlife, and reduced amount of sediment reaching coastal plains and deltas. This prompts coastal erosion, as beaches are unable to replenish what waves erode without the sediment deposition of supporting river systems. Channel erosion of rivers has its own set of consequences. The eroded channel could create a lower water table level in the affected area, impacting bottomland crops such as alfalfa or corn, and resulting in a smaller supply.

EFFECTS ON HUMAN

While reservoirs are helpful to humans, they can also be harmful as well. One negative effect is that the reservoirs can become breeding grounds for disease vectors. This holds true especially in tropical areas where mosquitoes and snails can take advantage of this slow flowing water.

OPERATION

Water falling as rain upstream of the reservoir together with any groundwater emerging as springs is stored in the reservoir. Any excess water can be spilled via a specifically designed spillway. Stored water may be piped by gravity for use as drinking water, to generate hydro-electricity or to maintain river flows to support downstream uses. Occasionally reservoirs can be managed to retain high rain-fall events to prevent or reduce downstream flooding. Some reservoirs support several uses and the operating rules may be complex. Most modern reservoirs have a specially designed draw-off tower that can discharge water from the reservoir at different levels both to access water as the reservoir draws down but also to allow water of a specific quality to be discharged into the downstream river as compensation water.

The operators of many upland or in-river reservoirs have obligations to release water into the downstream river to maintain river quality, support fisheries and maintain downstream industrial and recreational uses or for a range of other requirements. Such releases are known as compensation water.

METHODOLOGY

OPTIMISING TECHNIQUES OF RESERVOIR OPERATION

Optimising techniques of reservoir operation are used for different operations like water supply, flood control, hydropower generation, irrigation supply etc..,

SDP (STOCHASTIC DYNAMIC PROGRAMMING):

The SDP involves two steps as follows:

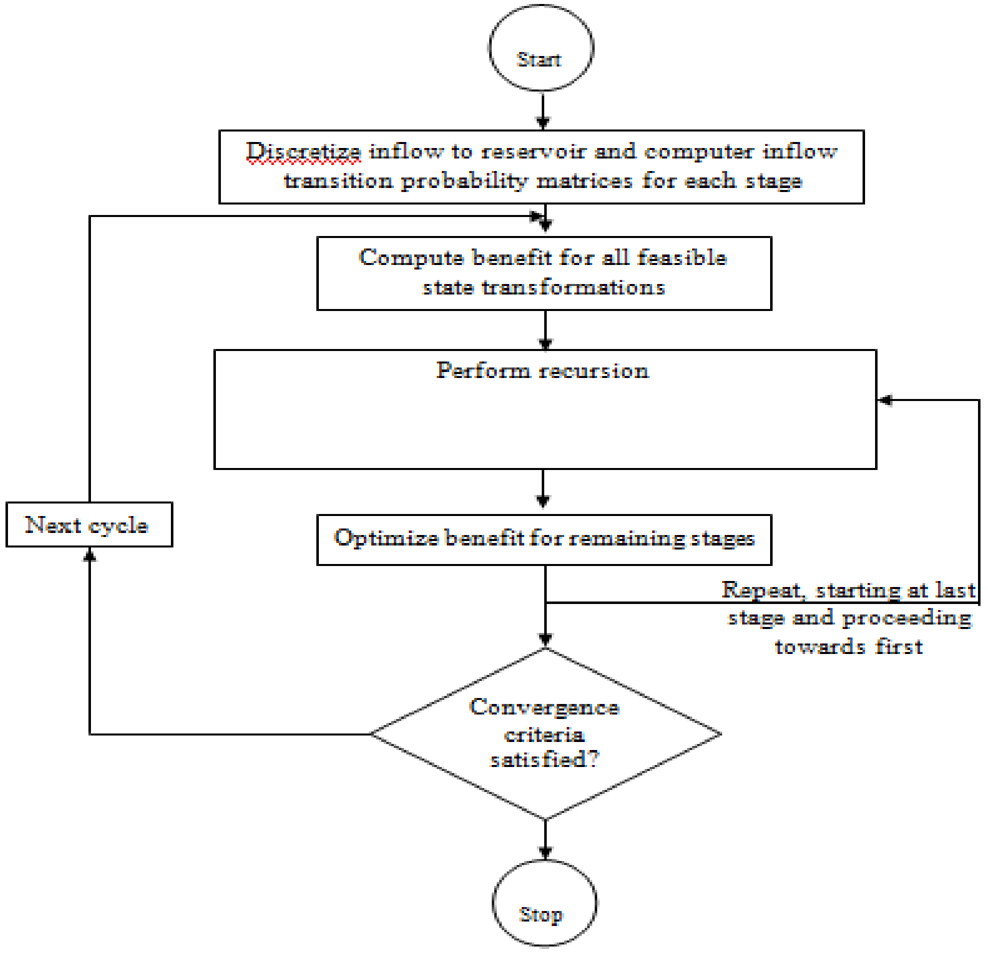
1. Discretized the Inflow and Reservoir Storage: The inflow during the same time period are discretized into N intervals from minimum to maximum. The probability of inflow interval i (during time period t) to inflow j (during time period t + 1) is also computed from the observed inflow series.
2. Finding the optimal solutions: By using Equation

$F(S_{i,}I_{i,}I_{i+1}\ldots\ldots I_{i+n}) = \max B_i(S_i,R_i)+E_{i+1}(f(S_{i+1},I_{i+1,}I_{i+2}\ldots\ldots\ldots I_{i+n}))$

The optimal solution is found and saved as optimal operating rules. The following operating rules are used in this paper. .

$V_{t+1} = D(V_t,I_t)$

Where$t_1$is the reservoir storage need to decide, and V_t and I_t are the current reservoir storage and inflow.[3]



Flowchart describing SDPModel

SYSTEM DYNAMIC (SD) APPROACH:

This study deals with modeling reservoir operation using the SD approach. The model is developed for a single multipurpose reservoir with a focus on flood management role of the reservoir. Then, the model is used to develop a reservoir operational policy for high-flow years to minimize flooding. The model also serves as a tool for studying impacts of changing reservoir storage allocation and temporal distribution of reservoir levels and outflows. The general architecture of the model is presented in this section, and model sectors and the complex dynamic relationships among these sectors are also discussed.

The SD model of a reservoir can be constructed graphically on the screen by employing basic building blocks, i.e., stocks,flows, connectors, and converters available in the model development tool. In the reservoir model the storage is represented as a stock. Varying inflows and outflows cause changes in storage volume over time. Inflows and outflows are represented by building block ‘‘flow.’’ Converters are provided to extend the range of calculations that can be performed on flows, and they house data and logical/mathematical functions to operate the system. Reservoir operating rules are also implemented through converters. Connectors (directed arrows) link various elements of the model, i.e., converters, flows, and stock, to indicate relationships and influence. The simulation model uses differential and difference equations to describe the complex dynamic systems.[5]

A general reservoir simulation model for flood management purpose can be divided into three main sectors: the reservoir,the upstream area, and the downstream area.

Reservoir

This is the core sector of the reservoir model. Inflows and outflows from the reservoir are the main components of this sector. Flow from all tributaries directly contributing to the reservoir is considered as inflow to the system. Inflow datafiles, one for each flood year, are provided to the model as input. Total reservoir outflow consists of reservoir releases,spill, evaporation, and seepage losses. Reservoir storage can be described in terms of mass balance equation:

Storage(t) = Storage(t - 1) + (Qin -Qout) . dt(1)

Storage at time step t is equal to the storage at a previous time step plus the difference of inflow and outflow. The solutioninterval (dt) is selected to ensure stability within the computation process.

Upstream Flooding

This sector calculates the area flooded upstream of the reservoir. Upstream flooding is triggered by a combination ofreservoir inflow, reservoir level, and reservoir outflow. The number of days when the upstream area is flooded is alsocounted in this sector.

Downstream Flooding

This sector calculates individual and total flooded area and duration of flooding due to the reservoir operation at selectedlocations between the dam and the final disposal point of the river. All sources and sinks affecting the flow in the river areintroduced in this sector. To set up a general reservoir simulation model for flood management purpose inflows, system constraints and operating rules are required. Additional data might be required depending on specific objectives of the study.

As output, the model provides information on variation of the reservoir levels, area flooded upstream and downstream of the reservoir, and duration of flooding. Once all sectors are developed and model relationships and operating rules are defined, the user can simply run the simulation and evaluate the impacts of alternate operating rules.

CHANCE-CONSTRAINED GOAL PROGRAMMING (CCGP) MODEL:

Chance-constrained goal programming (CCGP) may be considered as the extension of goal programming (GP) and chance constrained programming (CCP), two popular methodologies in reservoir operation studies. Each of these methodologies has an attractive feature in such a way that CCP allows the direct consideration of random variables in the model and GP allows the direct consideration of multiple goals which may be conflicting and non commensurate. In GP, the underlying philosophy is based on "satisfying" rather than "optimizing." Instead of attempting to minimize or maximize various objective functions, GP is concerned with the conditions of achieving pre-specified targets or goals. CCGP combines the advantages in both methods so that it is capable of solving systems with multiple objectives and stochastic inflows.[9]

APPLICATION

The CCGP model is applied to a three-reservoir system which is a portion of the Red River reservoir system in Oklahoma. These reservoirs are: Denison, Broken Bow and Pine Creek. Denison reservoir is operated for the purposes of flood control, water supply and hydroelectric power, regulating flows of Red River, improving navigation, and recreation. The purposes of Broken Bow reservoir are flood control, recreation, hydroelectric power, water supply, fish and wildlife protection, and water quality control. For Pine Creek reservoir, its purposes are flood control, water supply, water quality control, fish and wildlife protection, and recreation. The system is operated by the U.S. Army Corps of Engineers. The data required in the CCGP model may be classified into three categories: physical data, hydrological data, and demand date. Physical data are data which relate to the constraints of the model, e.g. reservoir and power plant capacities, maximum and minimum flows, storage-elevation-area relationship, and flood control storages. Hydrological data include natural inflows into and evaporations from the reservoirs. These data are provided in the U.S. Army Corps of Engineers (1970). Demand data involve various demands to be satisfied by the reservoirs such as demand for M&I water supply, contracted amount of hydroelectric power generation, and desired storage levels for recreational purpose. The data which involve hydroelectric power generation are supplied by Southeastern Power Administration in Tulsa, Okla.

The goals are ranked, with the more important one first, as: water supply for M&I, water supply downstream, hydroelectric power generation, recreation, and flood control.

The proposed CCGP methodology allows the reservoir manager to rank various goals according to their relative importance. The target levels for the goals are usually available in most systems. Trade-offs among conflicting goals can be evaluated so that a non dominated and satisfactory solution can be obtained. The use of conditional CDF's which consider the correlation between inflows can improve the accuracy of the results. A possible extension to this study is to use nonlinear goal programming to approximate the nonlinear functions (due to the hydropower generation) in the formulation. Another extension would be to use a combine approach of dynamic programming (DP) and goal programming (GP) to solve the problem. That is, each individual period may be solved by GP, and the most appropriate release decision and storage level for each period are identified by DP so that the problem is optimized over the whole planning horizon. The objective function of the GP in each period is to minimize the undesirable deviations from target values during that period. A possible objective function of the DP formulation would be to maximize the amount of hydropower generated during the whole planning horizon. Thus, nonlinearity due to the hydropower function can be handled by DP. However, the GP formulation in each period may have to be solved a number of times according to the possible levels of hydropower generation during that period.[9]

BAYESIAN STOCHASTIC DYNAMIC PROGRAMMING (BSDP):

BSDP is the proposed model using stochastic dynamic programming (SDP) and Bayesian decision
Theory (BDT)

Stochastic dynamic programming (SDP)

SDP model which employs the best forecast of the current period's inflow to define a reservoir release policy and to calculate the expected benefits from future operations. The best forecast includes information about the entire flow data like inflow, outflow, storage capacity but whether this technique
Provides better operating policies in real-time operation has not been proven**.**

Bayesian decision Theory (BDT)

The use of Bayesian decision theory (BDT) in reservoir operation because of its flexibility in being able to incorporate new information in the interpretation of probabilities. It is nothing but the revision of
State transition probabilities in classical SDP in order to capture the uncertainty of the forecast. It develops a forecasting system in which probabilistic data are continuously updated on the basis of current information. 1970].Bayesian decision procedures not only optimally account for forecast uncertainty, but in Contrastto other decision procedures,they ensurea nonnegative economic gain from a real-time forecast matterhow large the forecast uncertainty is.

Bayesian stochastic dynamic programming (BSDP)

The proposed model, called Bayesians stochastic dynamic programming(BDT and SDP), which includes in flow, storage and forecast state variables, describes stream flows with a discrete lag 1 Markov process and uses BDT to incorporate new information by Updating the prior probabilities to posterior probabilities is, used to generate optimal reservoir operating rules. T his continuous updating can significantly reduce the effects of natural and forecast uncertainties in the model. In order to test the value of the BSDP model for generating optimal operating rules, real-time reservoir operation simulation models are constructed using 95 years of Monthly historical inflow. Two versions of BSDP models are generated. Each generates optimal operating policies capturing the natural and forecast discrimination of system. [12]
Reservoir operators and planners need to have a strategy for how much water to release overa planning period for the best use of the stored water.
BSDP is used here to find an optimal set of policies.
In BSDP, the decision variables (release) depend on thestate of the system, which is defined by three variables inthis study.

1. The characteristic storage at the beginning of time period
2. The characteristic inflow into the reservoir
3. The characteristic forecast for the next time period

IMPLICIT STOCHASTIC MODEL

The implicit stochastic model is aimed at solving the specific problem of the optimal reservoir yield
When the demand is not known. The model is created to assist in the long-term comprehensive water
Management planning.

The approach used for optimizing the multipurpose reservoir yield belongs to the group of implicit stochastic techniques. In order to solve the problem of reservoir yield estimation, a three-level algorithm is proposed which uses the results of an external autoregressive moving average (ARMA) model for generating inflow sequences as the input data (Figure 2). At the first level, the simulation approach is used for computing the objective function. The reservoir rules are computed at the second level. Finally, the third level is used for estimating the single multipurpose reservoir yield based on the predefined relative level of supply.[16]

Simulation Model, First Level

The simulation model is based on the continuity equation. Here we calculate storage, release and water demand.

Simulation model, second level

In this we compare whether loss will occur or not. If release is more than demand loss will not occur. If release is less than demand loss will occur. If loss was happened then the process will repeated by assuming the suitable optimal values and loss is calculated by recursion

Simulation model, third level

In this level we calculate the yield by assuming the maximum storage and all reservoir purposes

CONCLUSION:

This paper gives brief description of different optimizing techniques of reservoir operation. These operations are used to operate reservoir in a proper way to utilize water in an efficient manner for the purposes like power generation, irrigation purposes, drinking water supply, flood control etc.,.

In this paper Stochastic Dynamic Programming model is used for Hydroelectric power generation, System Dynamic Approach model gives optimizing technique of flood control, Chance Constrained Goal Programming model gives optimizing techniques of multipurpose reservoir (flood protection, municipal and industrial (M&I) water supply, hydroelectric power generation, recreation etc.), Bayesian stochastic dynamic programming (BSDP) gives optimizing techniques of inflow and storage and finally Implicit Stochastic Model for reservoir yield operation.

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