專論

乾季時期多目標水庫動態運轉策略之研究

Dynamic Dry-period Operation Policy for Multipurpose Reservoir

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摘要

臺灣地區之降雨量在時間分佈上極不勻稱，以致枯水期間（每年11月至翌年4月）經常面臨缺水的威脅，尤以南部地區爲甚。爲有效掌握水庫在枯水期之供水能力，本文提出一套動態且實用的水庫運轉策略，該運轉策略之重點在於能預先合理調配水庫水量之供應，避免缺水集中發生在枯水期末，使得在枯水期內之每一旬皆能分擔部份之乾旱缺水衝擊。

本文以「曾文及烏山頭串聯水庫系統」爲理論驗證與實例應用研究對象。先對整個水庫系統進行模擬分析，根據模擬之結果，以迴歸分析求出全年各旬之水庫蓄水量與總缺水量之相關性並找出判定係數最高的一旬，視爲水庫營運管理之關鍵旬。再用 ARIMA模式預測曾文水庫之旬入流量，然後以 DDDP 模式演算兩座水庫在未來各旬之最佳放水量。

由於 DDDP 模式在以往之研究及應用上，尚存有若干瑕疵，本文於是改良該模式之「水庫末端狀態」及「水庫決策變數」。事實證明改良後之 DDDP 模式較具實用價值。最後，比較 DDDP 模式與水庫現行規線模擬模式之優劣，結果顯示由 DDDP 模式求出之放水決策，較能符合水庫營運之實質要求。

ABSTRACT

Rainfall in Taiwan varies dramatically with seasons. There is always a threat of drought during the dry season. In order to improve the utility of reservoir water yields, this paper proposes a practical process for release policy of multipurpose reservoirs. This policy can manipulate in advance the reasonable quantity of releases from the reservoir, consequently it can alleviate the deficit of water supply occuring concentrically in some intervals and reduce the impact of drought within the whole dry season.

The method is applied to the system of Tsengwen-Wushantou serial reservoirs in southern Taiwan as an example. First, A simulation analysis based upon the existing system policies is performed. According to the simulation outputs, the "Key Ten-day" is selected by using regression analysis. Secondly, the inflow series of Tsengwen reservoir in every ten-day interval is forecasted by using ARIMA model.

Finally, the optimum releases of forthcoming 36 ten-day periods for both reservoirs are obtained by the application of DDDP model.

To overcome the DDDP limitations in the application, an "Imaginary Reservoir" concept is created to modify and adjust the model's computation procedures for the final state and decision variables of the reservoirs. Results show that the modify DDDP model has more efficient than the original DDDP model. At last, the difference between DDDP model and existing operation rules is compared. The results indicate that the modified DDDP model synchronized with predicted inflow series offer an efficient operation policy which satisfy the demands of analysed reservoir system.

I. INTRODUCTION

As the time of rainfall in Taiwan is not well-distributed, the exploitation of water resources depends much upon the storage of reservoirs. In general, abundant rainfall as well as great storage in reservoirs during the wet season (May to October) can fully offer all kinds of water supply, Fig. 1. However, reservoir managers are usually troubled during the dry season (November to next April) when facing the great water demands in the downstream areas with little remaining water in the reservoirs and lack of rainfall supply in the upstream areas of the watersheds. Therefore, it is necessary to search for proper release policy to completely solve this annual problem of water deficit.

System analysis concept (especially optimization approaches) is a breakthrough in water resources technology in the past two decades. Recently, it has been applied in planning, design, operation and management. With aid of the high-speed computation of computers, the optimization theory works even more practically and has been applied in research of various water resources problems.

Bellman's dynamic programming (DP) is one of the often adopted optimization technique. But the increase of state dimension will result in highly exponent growth of the computation loading, and thus such a curse of dimensionality hinders DP to be widely applied. To overcome this obstacle some algorithms have been developed, such as IDP (State Incremental Dynamic Programming), DDDP (Discrete Differential Dynamic Programming) (Yeh, 1985). Among these algorithms, the analysis of the combined operation of multireservoir series with the DDDP model (Heidari et al., 1971) seems to be the most presentative.

The special hydrological and socio-economical conditions in southern Taiwan region result in the shortage of water supply very frequently despite many reservoirs have been built. Since there is little systematic research on this subject up to now, this paper proposes a process of making release policy during the dry season by using dynamic programming method in an attempt to promote more efficient operations. The system of Tsengwen–Wushantou serial reservoirs in Tsengwen drainage basin is applied to demonstrate the credibility and feasibility of the release policy.

II. RELEASE POLICY AND MODEL MODIFICATION

1. Release policy

This paper proposes a process of policy making for water releases from reservoirs during the dry seasons to make the release policy more scientific, avoid unnecessary human errors, and thus improve the efficiencies of reservoir operation. The flow chart of this process is shown in Fig. 2. The mathematical skills and models adopted in the process include:

(1) Simulation Analysis,
(2) Regression Analysis,
(3) Forecast of the inflow series of reservoirs in every ten-day interval by the ARIMA model (Autoregressive Integrated Moving Average Process), and
(4) Reservoirs operation with the DDDP model (Discrete Differential Dynamic Programming).

2. The Key Ten-day

In Taiwan region, the operating period of water works is used to be ten-day unit, therefore this paper proposes a concept of the key ten-day to assess the utilization of reservoir water yields during the dry season for the purposes of reducing the adverse impact of water deficit. It is assumed that in the operating period just before the coming dry season, there must be a ten-day interval (defined as the Key Ten-day), in which the storage of the reservoirs will critically determine the utilization of reservoir water yields during the coming year. The future utilization of reservoir water yields can thus be foreseen with the reservoir storage in the Key Ten-day. Then in case of potential water deficit, reservoir managers can arrange water supplies for all the damands in advance. It can undertake the bearing of the impacts of drought during the whole dry season, avoid their concentrating in the later stage of the season, and thus greatly decrease the inconvenience and impacts of water deficit. According to the simulation outputs, the Key Ten-day in this paper is picked up with the highest determination coefficient of regression analysis. The analytical procedures are simply depicted as follows:

Assumed that the total ten-day periods of the specific reservoir's hydrologic year is T, and S_{ij} is the initial storages of reservoir during the year i, ten-day j, DFT_{ij} is the total deficit of reservoir within one hydrologic year starting from the year i, ten-day j to the year (i+l), ten-day (j-l). Suppose that the total simulation period is N years, then we can form the data pairs for every ten-day j (S_{ij}, DFT_{ij},), i= 1, 2, 3, ... N, and their regression equations is

$$DFT_j = A_j \cdot S_j + B_j \qquad (1)$$

In which, DFT_j is the total deficit of reservoir from ten-day j to the coming year ten-day (j-l); S_j is the initial storage of reservoir during ten-day j corresponded to DFT_j; and A_j, B_j are regression coefficients. R_j^2 is determination coefficient. Running up the above computational procedures, we can obtain a set of R_j^2, j= 1, 2, ... T, and compare these R_j^2 each other, then the ten-day period in which the largest determination coefficient existed among R_j^2 set is defined as the Key Ten-day. The Key Ten-day is the significant point of the process of policy making for reservoir releases during the dry season.

3. Modifications of the DDDP model

The DDDP model is one of the discrete dynamic programming algorithms by using the recursive equation and trial trajectory. Because there are existed flaws in previous research and applications, some modifications are made in this paper focusing on the final state and the decision variables of reservoirs in that model.

(1) No advance fixing the final state of reservoirs:

In the computation of the original DDDP model, the vectors of the initial and the final states assume to be already known (Hsu and Lee, 1984). That is, at searching for the optimal trajectory in the corridor, the initial and final points should be already fixed, and the optimal trajectory can only move between these two fixed points. Thus the initial and final storages of the reservoir operation within a hydrologic year must be both fixed in advance and the optimal releases by the reservoirs can then be iteratively worked out. This method is not only unreasonable, but unpractical for actual reservoir operation (Hong, 1988).

In studying te optimal trajectory within a hydrological year, the initial storage of reservoirs is already known. Yet it is quite doubtful that resulting from this already known point, the ending point of the optimal trajectory solution should be the very fixed final point. If it is preassumed that the optimal trajectory must go back to the fixed ending point, the objective function derived from the system will be distorted and unable to represent the optimal solution.

Therefore the initial storage of reservoirs has to be fixed in advance in the dynamic programming of reservoirs. As for the final storage, it need not be fixed. Let the optimal storage of the reservoirs in each period, including the final storage, of course, be obtained by using the iteration method with the optimal operating

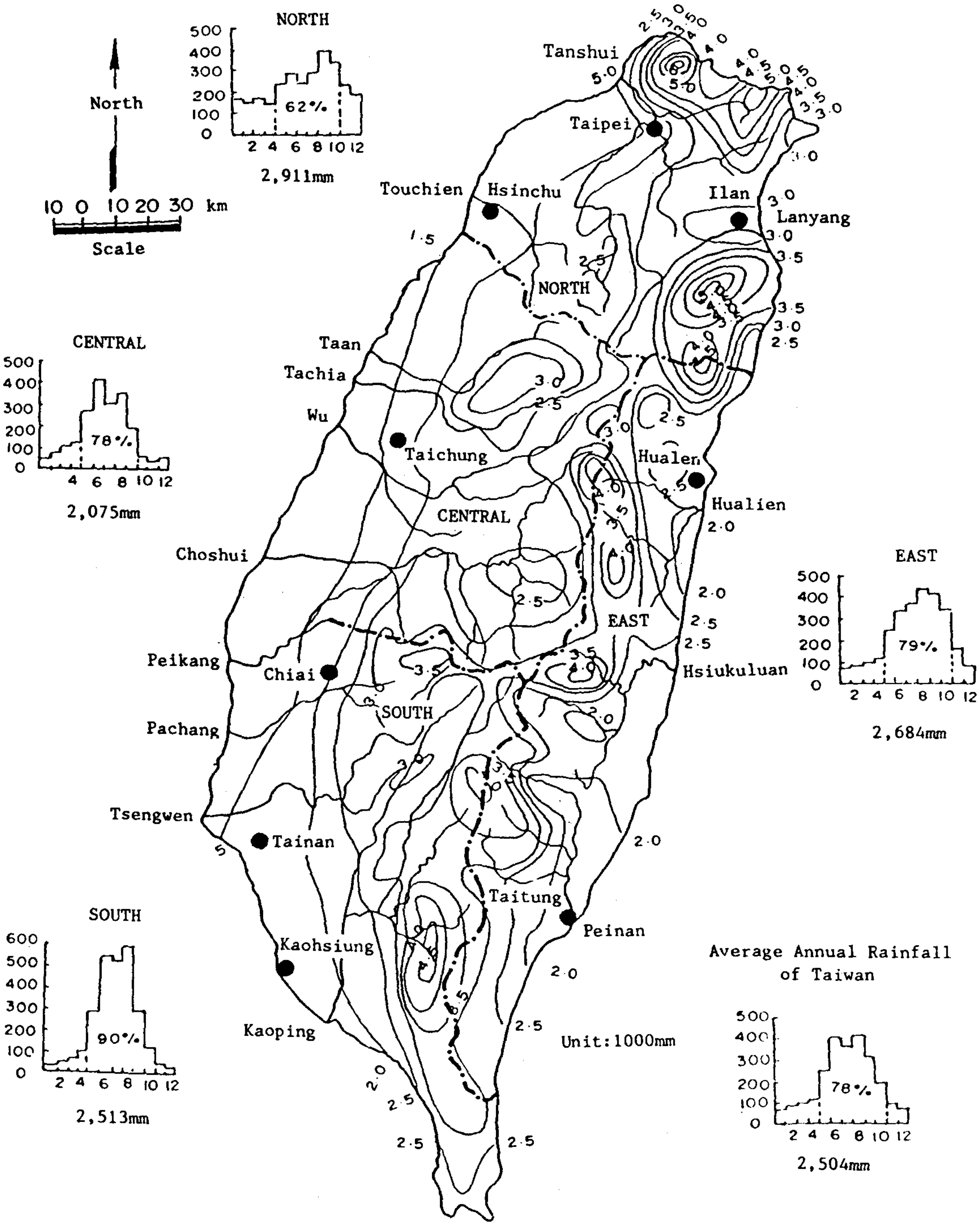


Figure 1. Annual Isohyetal Map of Taiwan (1949-1986)
Source: Water Resources Commission, MOEA, Taipei, ROC, 1989.

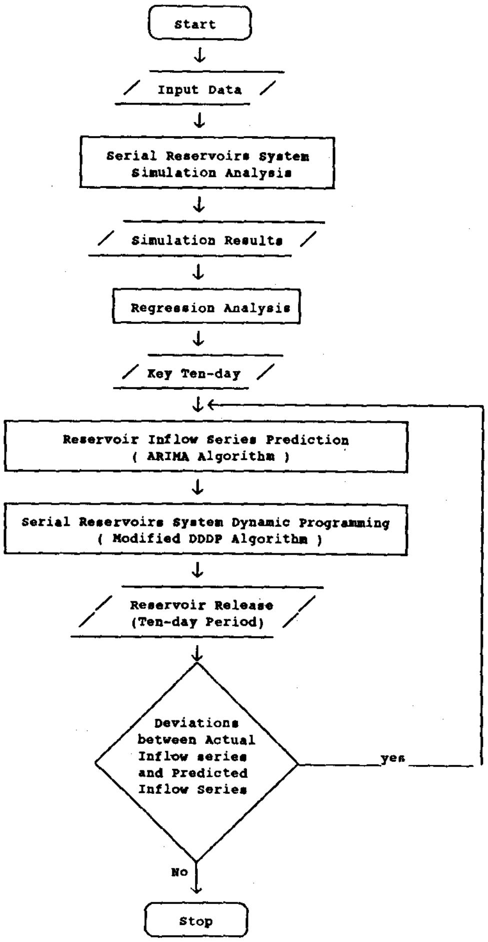


Figure 2. Flow Chart of Release Policy Determination.

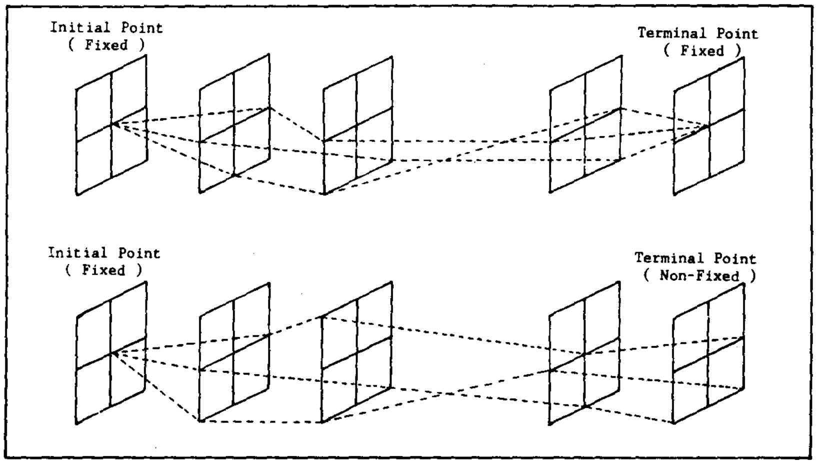


Figure 3. Comparative Graphs in Different Terminal Point Condition Using DDDP Model.

rules and starting from the initial point. The comparison of these two methods is shown in Fig. 3. The upper graph is one with a fixed ending, in which the optimal trajectory has to go back to the fixed center point, without certainty for the total deviation in the system to be minimum of the nine points in the last step. The lower graph, however, represents the non-fixed ending, in which the final state of the reservoirs is not determined yet, and will depend on which of the nine points in the last step is the minimum total deviation. Then it can represent the indeed optimal trajectory.

(2) The increase of decision variables of reservoirs:

In order to work with the computation of transferable systems, the state and decision dimensions of DDDP model have to be equal. In other words, one reservoir can only decide one release, two reservoirs can decide two releases, and so on. It hinders the model to be widely applied.

There are two reservoirs in the system of Tsengwen-Wushantou series, so only two releases can be decided (one for Tsengwen reservoir and the other for Wushantou reservoir). There are three purposes, however, for the release by Wushantou reservoir, which are irrigation, industrial, and public water supplies. In previous investigations, industrial and public water supplies were managed as the constraints in the system. In other words, only the optimal release for irrigation could be worked out for Wushantou reservoir. That is no way to have a further idea of the optimal releases for industrial or public water supplies.

In order to overcome these limitations, the concept of "imaginary reservoir" is adopted in this paper. One more Wushantou reservoir is imaginarily set up in the process of working out the optimal releases for Wushantou reservoir. It is thus accomplished for one Wushantou reservoir to release water for irrigation and the other for industrial and public water supplies. This method still meet the theory that three states produce three decisions. However, in the actual application it breaks the existed limits, for the reservoir operation able to control the interaction of irrigation and public (including industrial) water supplies. It increases the efficiency of reservoir operational management. The comparison of these two methods is shown in Fig. 4.

It is shown that there are 37 ten-day intervals and steps in one hydrological year in the computation process of the traditional DDDP model, working out the optimal release for irrigation for each ten-day interval, but without that for public water supply. With modifications in Fig. 4(b), there still existed 37 ten-day intervals for the computation, but the number of steps is increased to be 73. That is, there is one more step (an imaginary Wushantou reservoir) for each ten-day interval. Therefore in the computation for the first ten-day interval there is only one step (the first step) for Tsengwen reservoir to work out the optimal release. However, there are two steps (the first and second step) for Wushantou reservoir to respectively work out thsoe for irrigation and public (including industrial) water supplies. When it is thus applied to the latter ten-day intervals, only the 1st, 3rd, 5th, . . . , 73th steps are valid for Tsengwen reservoir, but all the steps (the 1st, 2nd, 3rd, . . . , 73th) are applied to Wushantou reservoir.

III. CASE STUDY

1. Introduction of the reservoir system

Tsengwen reservoir is located in the upstream of Tsengwen river in southwestern Taiwan shown as Fig. 5. It is a multipurposed reservoir with the functions of irrigation, water supplying, hydropower generation, and flood control etc. Wushantou reservoir is located in the vicinity of Tsengwen reservoir and synchronized with each other for multipurposed operation. The Tunkou diversion weir was erected along the mainstream of Tsengwen river 6 kilometers downward from Tsengwen damsite to block the tailwater of hydropower generation in Tsengwen reservoir, and flowing it to Wushantou reservoir with the diversion tunnel under Wushan Peak and the trumpet-shaped spillway at the western outlet of diversion tunnel (Seekou). The releases by reservoir are supposed to depend on the combined active storage of Tsengwen and Wushantou

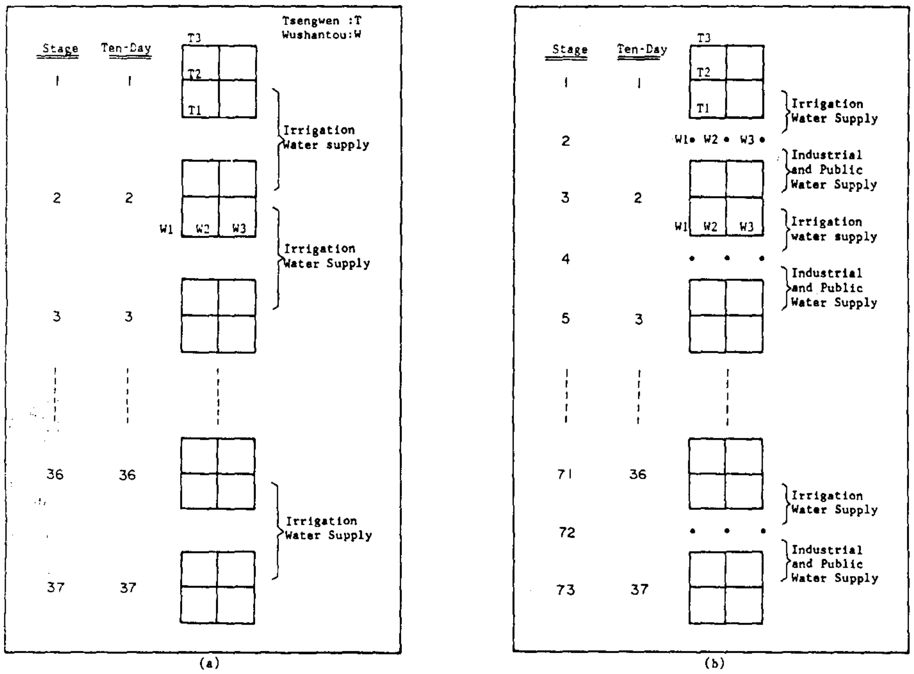


Figure 4. Comparative Graphs in Different Number of Decision Variables Using DDDP Model.

reservoir, and regulate by the operating rule curves of reservoirs (Fig. 6) to decide which one of the release policy should abide by under normal, reduced, and re-reduced conditions. (TRAB, 1973; Young et. al., 1986).

2. Simulation of the reservoir system

(1) System description

According to the system plan of Tsengwen-Wushantou serial reservoir, the reservoir system is represented by a network as shown in Fig. 7.

All of the nodes have to abide by the hydrological continuity. The simulation of the reservoir system is controlled by the hydrologic-budget equations and the constraints in the system, which are explained below.

(2) The hydrologic-budget equations and the constraints

A. hydrologic budget equations

(a) TSG(I+l)= TSG(I) + TIN(I) – TEV(I) – TPW(I) – TSP(I)

(b) TRLS(I) = TSP(I) + TPW(I)

(c) EIN(I) = 0.97*[TRLS(I) + ELAT(I)] – ERIGH(I)

(d) WIN(I) = 0.9*ETUN(I) + WLAT(I) (2)

(e) WSG(I+l) = WSG(I) + WIN(I) – WEV(I) – WSP(I) – WRLS(I)

(f) WRLS(I) = WIRR(I) + WIDU(I) + WPUB(I)

B. System constraints

(a) TPW(I) ≦ TPWMAX(I) = 56cms (3)

(b) ETUN(I) ≦ ETUNMX(I) = 56cms

I = 1, 2, ... 36

(The notations of above variables are given in Fig. 7.)

According to the present operating rules (Fig. 6) of the reservoirs, the results of the simulation analysis present that during 13 years period, there are 5 years with water deficit, and the deficit is even higher than billion cubic meters. It is apparent that the utilization of reservoir water yields of the system of Tsengwen-Wushantou serial reservoirs has been put to the

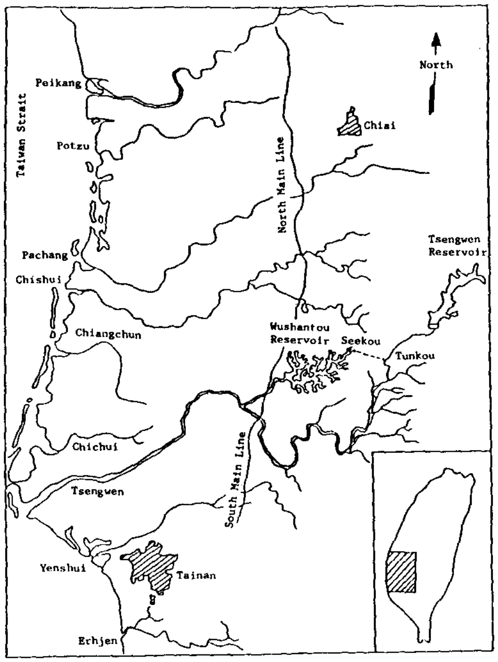


Figure 5. Tsengwen and Wushantou serial reservoir system.

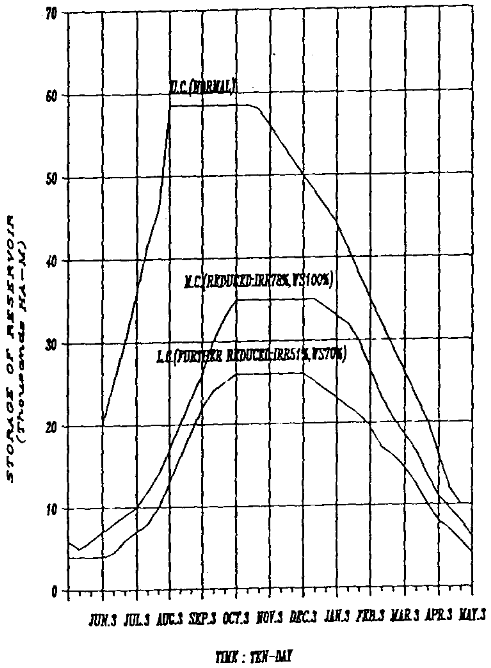
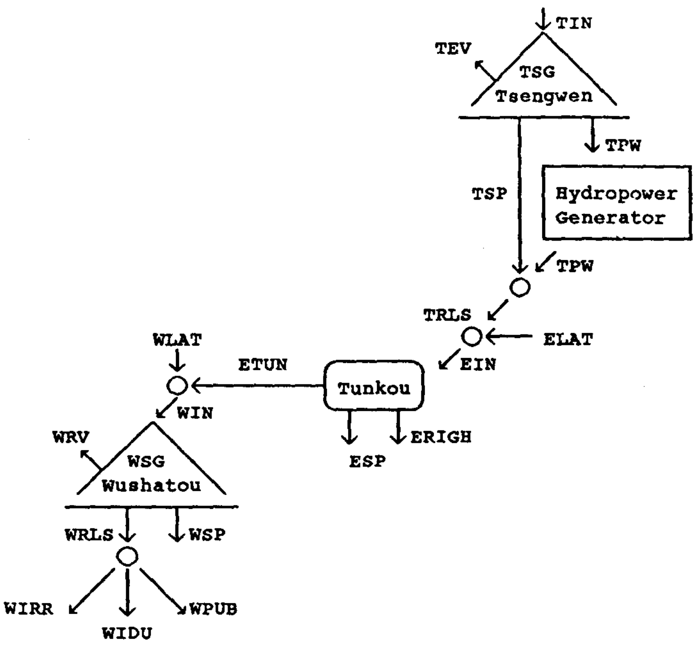


Figure 6. Existing Reservoirs Operation Rule Curves for Tsengwen-Wushantou System.



NOTATION:

TIN : Inflows to Stengwen Reservoir
TEV : Evaporation Volumes from Tsengwen Reservoir
TSG : Storages of Tsengwen Reservoir
TPW : Hydropower Water Requirements from Tsengwen Reservoir
TSP : Spillage Volumes from Tsengwen Reservoir
TRLS : Total Releases form Tsengwen Reservoir
ELAT : Lateral Inflow Volumes along the Reach between Tsengwen Damsite and Tunkou Diversion Weir
EIN : Inflow Volumes to Tunkou Diversion Weir
ESP : Spillage Volumes from Tunkou Diversion Weir
ERIGH : Water Right Reservation Volumes for Downstream Areas of Tunkou Diversion Weir
ETUN : Diverted Volumes Conveyed by Tunnel from Tunkou to Seekou
WLAT : Inflow Volumes from Wushantou Watershed
WIN : Total Inflow Volumes to Wushantou Watershed
WEV : Evaporaation Volumes from Wushantou Watershed
WSG : Storage Volumes of Wushantou Watershed
WSP : Spillage Volumes of Wushantou Watershed
WRLS : Total Releases from Wushantou Watershed
WIRR : Irrigation Water Supplies from Wushantou Watershed
WIDU : Industrial Water Supplies from Wushantou Waterhsed
WPUB : Public Water Supplies from Wushantou Watershed
TPWMAX : Maximum Capacity of Penstock for Hydropower in Tsengwen Reservoir
ETUNMX : Maximum Capacity of Diversion Tunnel from Tunkou to Seekou

Figure 7. Network of Tsengwen and Wushantou reservoirs System.

test, and how to enhance the reservoir operation and management is highly worth concerning.

3. Determination of the Key Ten-day

The steps of the determination of the Key Ten-day are explained as follows:

(1) According to the results of simulation analysis of the serial reservoir system (the hydrological year of the simulation is from the first ten-day interval of July to the last ten-day interval of next June), those data pairs, including the total storage volumes of each specific ten-day period and their correspondent total water deficit incurred in the coming year respectively, can be obtained consequently.

(2) Define the total storage (the combination of Tsengwen and Wushanton) of the reservoir system during the first ten-day interval of July as variable X.

(3) Accumulate the water deficit from the first ten-day interval of July to the last ten-day interval of next June to be the total water deficit of that hydrological year, and define it as variable Y.

(4) There are results of simulation to be analyzed for totally 12 years. Therefore there are 12 sets of (X,Y) for the first ten-day interval of July. The determination coefficient for that tend-ay interval can be obtained by regression analysis.

(5) With the same way, the determination coefficients of the mid ten-day interval, the last ten-day interval of July, . . . , to the last ten-day interval of next June, totally 36 ten-day intervals, can be computed respectively. The highest determination coefficient falls on the mid ten-day interval of September, so that ten-day interval is determined as the Key Ten-day for the system of Tsengwen-Wushantou serial reservoirs. The relationship between the reservoir storage within the Key Ten-day in the past years and the total water deficit in the coming years is shown in Fig. 8. The regression equation offers a reference for evaluating the utilization of reservoir water yields. The Key Ten-day can redefine the hydrological year of reservoir operation, and further ensure the effect of warning for the utilization of reservoir water yields during the dry season.

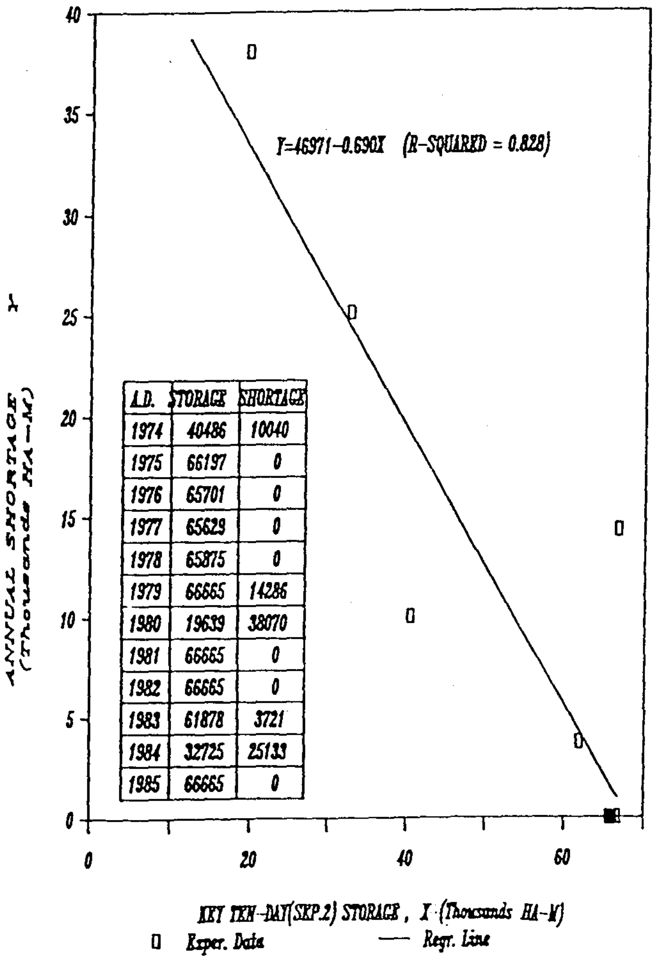
4. Forecast of the inflow series

Besides determining the Key Ten-day, data of the future inflow series of the reservoirs are necessary for making the dry season. The inflow series can only be forecasted with a mathematic model since it has not yet happened. In this paper, the inflow series of Tsengwen reservoir in each ten-day interval is forecasted with ARIMA model (Montgomery and Lynwood, 1976; Hsu, 1984). Based upon the conclusion of Hsu (1984), the multiplicative seasonal model ARIMA (p,d,q)*(P,D,Q) is adopted and its explicit form is

$$\phi(B)\Phi(B)\,\nabla^{d}\,\nabla_{s}^{D}\,x_{t}=\theta(B)\,\Gamma(B)a_{t} \qquad (4)$$

in which, B is the backward shift operator defined by $BX_t = X_{t-1}$, and $B^s X_t = X_{t-s}$; a_t is the normally independently distributed white noise residual with mean 0 and variance σ_a^2; $\phi(B) = 1-\phi_1, B-\phi_2 B^2 - \ldots\ldots - \phi_p B^p$ is the non-seasonal autoregressive (AR) operator and the ϕ_i, i = 1, 2, . . . p are the nonseasonal AR parameters; $\nabla = 1-B$ is differencing operator and ∇ is the nonseasonal differencing operator of order d to produce nonseasonal stationarity of the dth differences, usually d = 0, 1 or 2; $\Phi(B) = 1-\Phi_1 B^s - \Phi_2 B^{2s} - \ldots - \Phi_p B^{ps}$ is the seasonal AR operator of order P and the Φ_i, i = 1, 2, . . . P are the seasonal AR parameters; $\nabla_s^D = (1-B^s)^D$ is the seasonal differencing operator of order D to produce seasonal stationarity of the Dth differenced data, usually D = 0, 1, or 2; $\theta(B) = 1-\theta_1 B-\theta_2 B^2 - \ldots\ldots - \theta\, qB^q$ is the non-seasonal moving average (MA) operator and θ_i, i = 1, 2, . . . q are nonseasonal MA parameters; $\Gamma(B) = 1-\Gamma_1 B^s - \Gamma_2 B^{2s} - \ldots\ldots - \Gamma_Q B^{Qs}$ is the seasonal MA operator of order Q and the Γ_i, i = 1, 2, ... Q are the seasonal MA parameters; s is the seasonal length (i.e. s = 36 for average 10-day sequences).

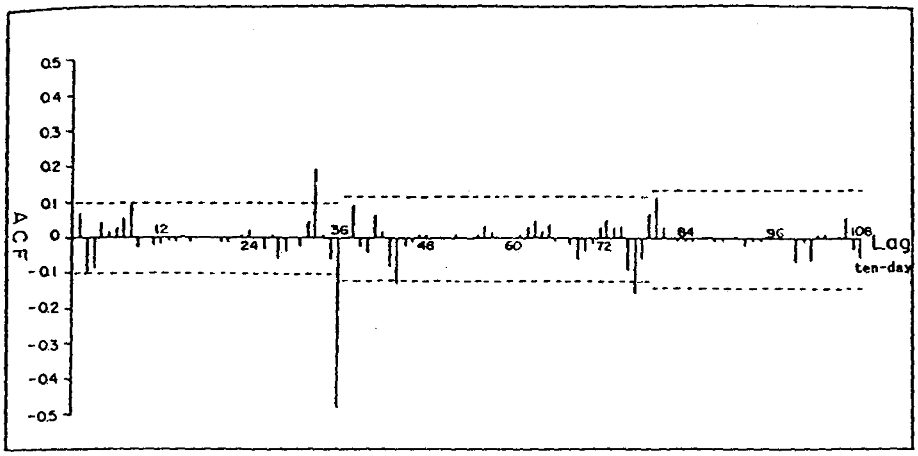
Since the building of reservoirs may change the statistical features of streamflows, only the inflow series after reservoir building is analyzed in this paper. And the time sequence of the inflow series are chosen, as the Key Ten-day is in mid September, from mid September, 1974 to the first ten-day interval of September, 1986, totally



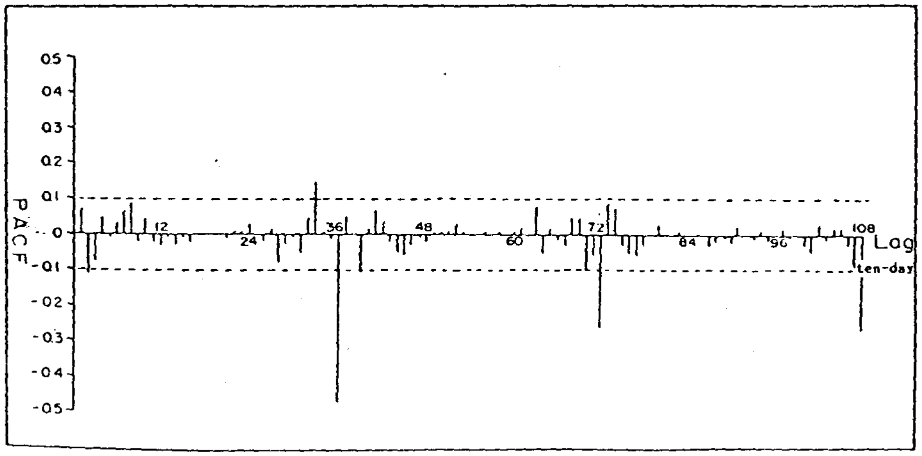
A.D.	STORAGE	SHORTAGE
1974	40486	10040
1975	66197	0
1976	65701	0
1977	65629	0
1978	65875	0
1979	66665	14286
1980	19639	38070
1981	66665	0
1982	66665	0
1983	61878	3721
1984	32725	25133
1985	66665	0

Figure 8. Schematic Relationship for Tsengwen-Wushantou serial Reservoirs System.

432 ten-day intervals in 12 years. The observed values of the inflow series from mid September, 1986 to the first ten-day interval of September, 1987 are kept separately for examining the forecasted ones from ARIMA model. By the way of model identification, parameter estimation, and diagnostic checking, the ARIMA model of the inflow series of Tsengwen reservoir in each ten-day interval is (2,0,0) x (3,1,1). Fig. 9 shows the acf and pacf graphs in the condition of D = 1, d = 0. This model can forecast the future inflow series of Tsengwen reservoir in each tend-day interval. Fig. 10 shows a comparison between the forecasted and observed values in the same periods of time. It is apparent that the forecasting errors are smaller during the dry season but larger during the wet season. The total error in a whole year is only 2448 ha-m, and is a very good forecasting result for the utilization of reservoir water yields. The large errors during the wet season are mainly due to the complicated precipitation factors, especially the storms by



(A) ACF



(B) PACF

Figure 9. (A) Autocorrelation function (acf) and (B) partial autocorrelation function (pacf) graphs in the condition of D=1, d=0, for the inflow series of Tsengwen reservoir (mid Sept. 1974~1st ten-day of Sept. 1986).

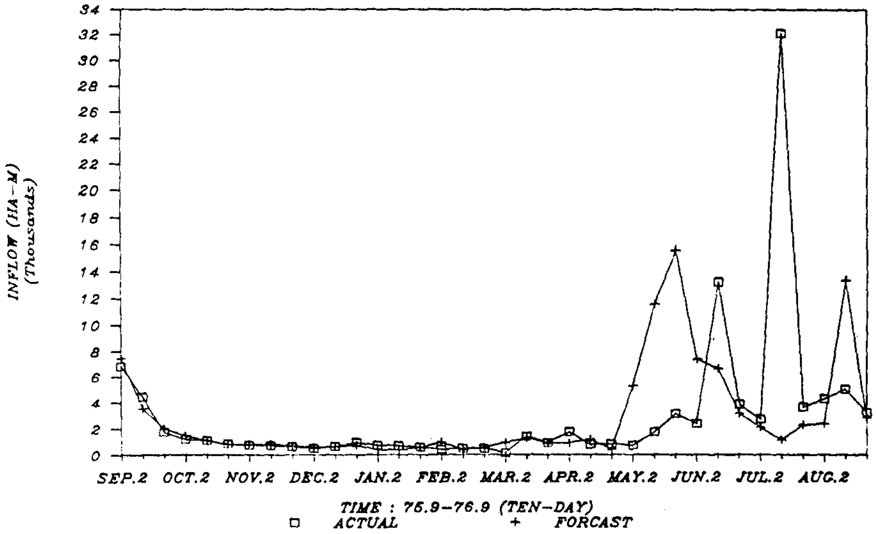


Figure 10. Comparison between the forecasted and observed values in the same forecasting period (Sep. 1986 to Sep. 1987) for Tsengwen reservoir inflow series.

typhoons, which may cause completely different runoff estimation and routing methods because of varied time and space.

5. Computation with DDDP model

The operating releases of Tsengwen and Wushantou reservoirs in each ten-day interval are computed in this paper using DDDP model.

(1) Objective Function:

Dynamic programming is largely dependent on the precise definition of the objective function. It defines the total effect obtained by the objective function to be maximum or minimum, making the decision variables iteratively work out the expected solution. Therefore the objective function in fact determines the results of the system analysis. The objective function in this paper is defined as follows:

$$\text{DEVIATION} = \sum_{i=1}^{8} W_i * \text{ADD}_i$$

Variables description:

① DEVIATION: total deviation of the system. The deviation is the difference between the actual releases and the planned water supplies of the reservoirs.

② W1, W2, W3, W4, W5, W6, W7, and W8 are calculating weights for each item. They can be assigned in advance, and lead the iterative computation of the testing trajectory toward the expected direction.

③ ADD1: overflow spillage releases by Tsengwen reservoir. The released water of Tsengwen reservoir must go through the pipes of the power plant, the upper limit of which is 56 cms. Water released above this limit is called overflow spillage.

④ ADD2: deficit of releases by Tsengwen reservoir. The planned release by reservoir for each ten-day interval in principle is supplied by Tsengwen reservoir for the water stage of Wushantou reservoir not to vary too much. If Tsengwen reservoir cannot meet this requirement, the lacked yield is considered as deficit.

⑤ ADD3: overflow spillage of Tunkou weir. The inflow of Tunkou must be led through the diversion tunnel to arrive Wushantou Reservoir. If the left volume space of Wushantou reservoir is unable to take in all that of Tunkou inflows, the water which does not flow into the diversion tunnel is considered as overflow spillage of

Tunkou weir.

⑥ ADD4: deficit of Tunkou inflow. When the inflow led from Tunkou is unable to meet the requirement of the active storage of Wushantou reservoir, about 5500 ha-m, which is 68% of the total active storage, the lacked yield is considered as deficit of Tunkou inflows.

⑦ ADD5: waste of irrigation supply, including:

(A) The surplus of releases for irrigation which is beyond the allowed maximum water supply. The allowed maximum water supply is added with 2% of the planned water supply for irrigation to make the iterative solution more reasonable.

(B)The relases by the spillway of Wushantou reservoir during the irrigation period. In principle, Wushantou reservoir must avoid spilling water. If it is necessary, water should be spilled from the Tunkou diversion weir.

⑧ ADD6: deficit of irrigation supply. If the actual release for irrigation is lower than the planned supply, the lacked yield is considered as deficit.

⑨ ADD7 and ADD8: defined the same as ADD5 and ADD6 except changing the supplying objective to the industrial and municipal water supplies, and the weight to be 5%.

In this paper, the minimum total deviation of the system is regarded as the optimal state, and the deviation in each item is given different penalty by being assigned different weight. It can thus lead the optimal trajectory as expected. The objective function is in general defined as the square deviation to balance the relative effects of the positive and negative deviations. However, the adverse impacts caused by the deficit and surplus of water supply will differ in degree. Storing the water in reservoirs can solve the problems of water surplus, but the drought caused by water deficit will certainly bring about great damage and inconvenience for human activities. Therefore the objective function in this paper is defined as one power of the deviation rather than square of it. As for the positive and negative deviations, they are treated with different weighted penalty in order to manifest the different physical meanings.

(2) Process of computation:

A. Set up the parameters:

(a) The initial states and the corridors:

the initial storage of Tsengwen Reservoir 27,000 ha-m

the initial corridor width 2,200 ha-m

the initial storage of Wushantou Reservoir 7,300 ha-m

the initial corridor width 650 ha-m

every time after the computation of one cycle, the corridor width is reduced to 0.7 of itself, and continue the computation of next iterative cycle.

(b) Testing Trajectory:

It is always set to be 27,000 ha-m for Tesengwen reservoir and 7,300 ha-m for Wushantou reservoir from the mid ten-day interval of September to the first ten-day interval of next September.

(c) Constraints:

(i) State Variables:

The upper and lower limits of active storage in Tsengwen reservoir are set to be 58,520 and 0 ha-m respectively. In the meanwhile, the upper and lower limits of active storage in Wushantou reservoir are 8,145 and 0 ha-m respecitvely.

(ii)Decision Variables:

The upper and lower limits of the penstock capacity for power generating in Tsengwen Reservoir are 56 cms and 0 cms respectively. The lower limits of releases for irrigation, industrial and public water supplies are 0 ha-m, and there are no upper limits for these supplies.

B. Results:

The comparison between the computation results from the DDDP model and the simulation model in the same conditions is shown in Fig. 11. It is explicit that the release policy from the DDDP model can meet the water demands better with less total yearly deficit than from the simulation model. The difference between them reaches 6,311 ha-m. It is due to that DDDP model can set up the optimal release by the reservoirs for each operating interval, and mini-

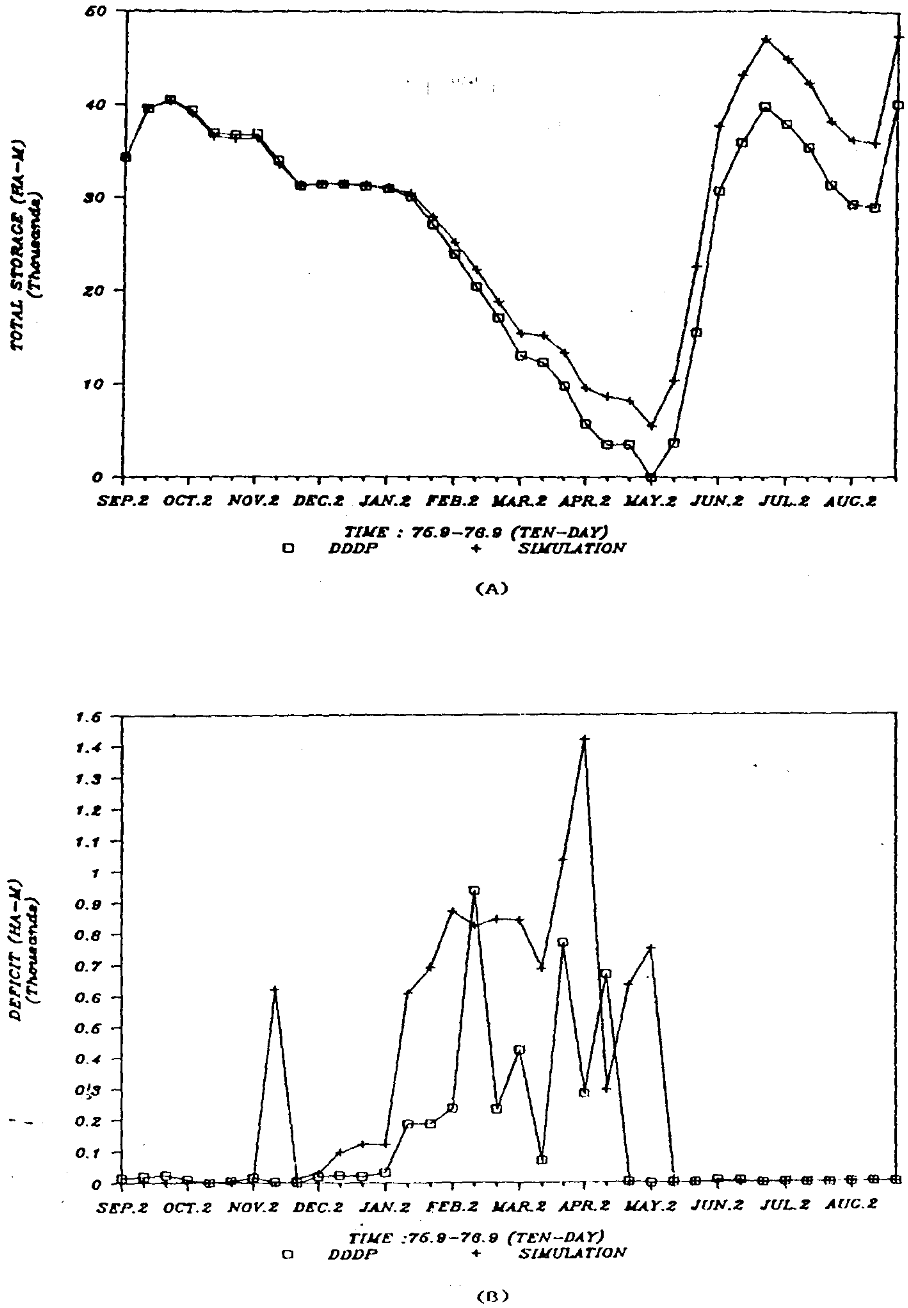


Figure 11. Comparisions between the computational results from the DDDP model and the simulation model in the same conditions for (A) storges, and (B) deficits, of Tsengwen-Wushantou serial reservoirs system.

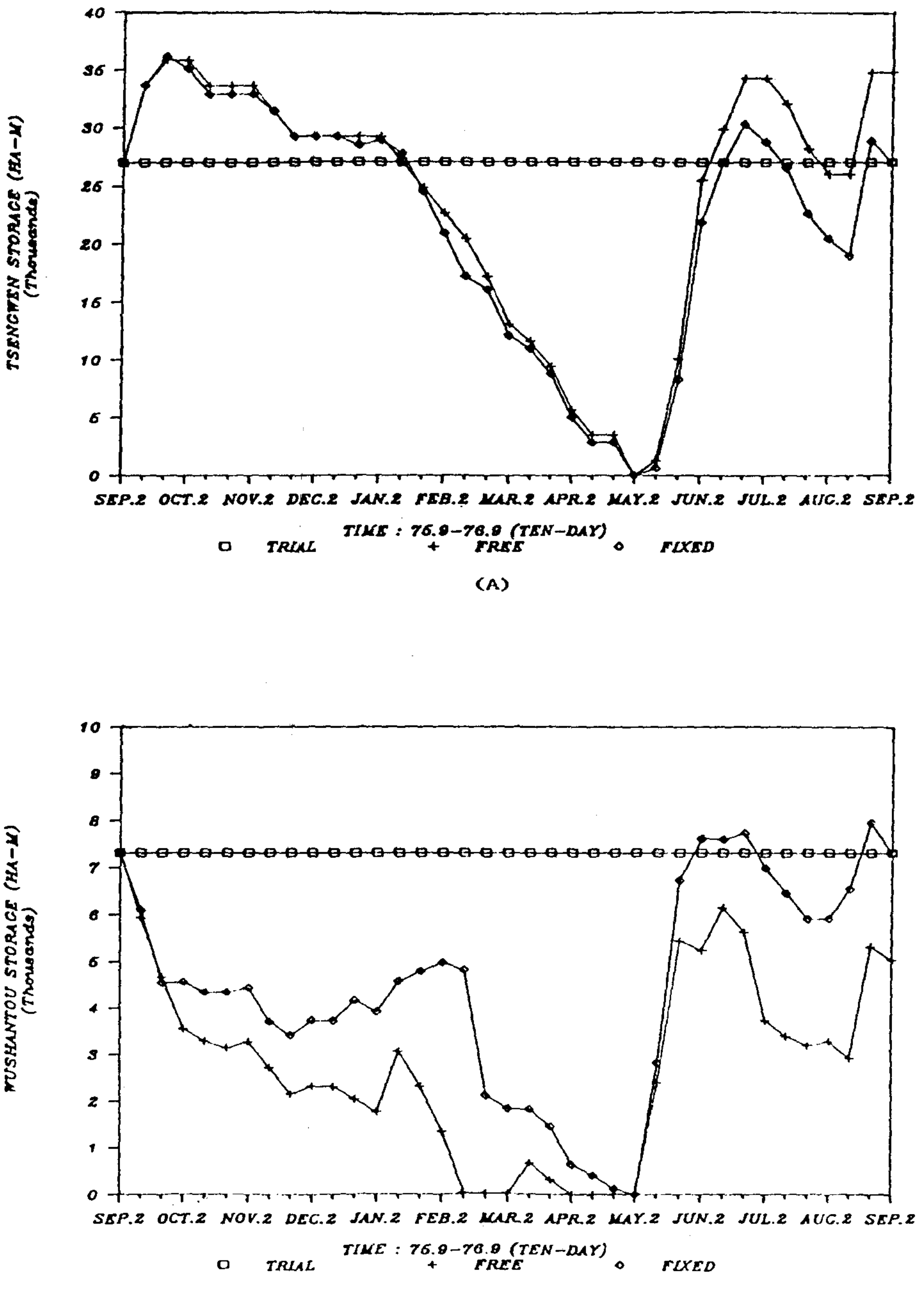


Figure 12. Comparisions between the computational results from the traditional and modified DDDP in the same conditions for (A) storges of Tsengwen reservoir, and (B) Wushantou reservoir.

mize the supply deviation in the whole hydrological year. The simulation model, however, can only determine present releases abiding by the already fixed operating rules, and it is unable to assess the future utilization of reservoir water yields or control the arrangement of future water supplies. That will be all right during the wet season, but it will cause the deficit of water to concentrate in the dry season. Consequently, it is the greatest flaw of the simulation model.

Finally, the effect of modifying the final state of DDDP model is examined in this paper and the comparison graph is shown in Fig. 12. With fixed final state of reservoirs, the release by Tsengwen reservoir in the last ten-day interval is 4,671 ha-m, with 4,606 ha-m of which flowing to the Tunkou diversion weir. But the left volume space in Wushantou reservoir is only 3,319 ha-m at that time. Thus there will be 1,287 ha-m of water spilled and wasted at Tunkou weirsite. Besides, the total release by Wushantou reservoir in that ten-day interval is 3,898 ha-m which is 845 ha-m more than the demanded 3,053 ha-m in the downstream areas and makes a waste, too. Therefore, the DDDP model will waste enormous release to meet the premise of the fixed final state of reservoirs. That makes it unqualified for the management of reservoir operation. Furthmore, the optimal trajectory determined by the fied final point is unable to ensure the total deviation of that point to be the minimum of the nine knots in the last step. This makes it inconsistent with the optimization theory of dynamic programming.

IV. CONCLUSIONS

1. The concept of the Key Ten-day proposed in this paper can refine the hydrological year of reservoir operation, and it can ensure the effect of warning for the utilization of reservoir water yields during the dry season. In the example of Tsengwen-Wushantou series reservoirs, the hydrological year is defined from the mid ten-day interval of September to the first ten-day interval of next September. It can reinforce reservoir management.

2. In spite of the accidental deviations of the inflow forecast by ARIMA model, the model can maintain the major statistic features of the historically observed values and efficiently offer a way to analyze the future trends. However, in application, more attention should be paid to the higher forecasting errors during the west season, which are mainly due to the excessive precipitation factors.

3. The objective function in an optimization model can determine the results of the model application. In general, the objective function are defined as minimum Sum square deviations to reduce the larger positive and negative deviations. But with the different meanings of the adverse impacts occurred by the deficit or surplus of water, the validity of square deviations is still doubtful. The deviations of the objective function in this paper are defined as only one power, and differently weighted penalties are given to the positive and negative deviations to manifest the different physical meanings. It is found that this method can further reflect the actual conditions of the reservoirs.

4. Since the DDDP model has existed some flaws in application, it is modified in this paper on two species. First, the final state of the reservoirs is not fixed in advance, but is got by free iteration of the optimal trajectory according to the optimization theory. It is proved that it can meet the requirements of actual reservoir operation better than with fixing the final state in advance. Second, the decision variables are increased by adding an imaginary reservoir. In this paper the imaginary reservoir is another Wushantou Reservoir. It makes one reservoir releases water only for irrigation and the other for public water supplies (including industrial uses). Consequently, the optimal releases for irrigation and public water supplies can be individually worked out to easily control the releases for different purposes.

5. In the case study, the DDDP model in system analysis offers the more satisfactory outcomings than the simulation model under the present operating rules. It is mainly because DDDP model can make the optimal release policies to minimize the deviation of water supplies within the whole year. However, the simulation model must follow the present operating rules to decide the releases, and it is unable to assess in advance for the utilization of

reservoir water yields in the forthcoming periods. Furthermost, the DDDP model can clarify the interrelationship of the supply purposes as they go in conflict and offer references to the decision-makers. But the simulation model can not do that.

6. The proposed release policy for multipurpose reservoirs during the dry season in this paper comprise the determination of the Key Ten-day, the inflow forecast, and the policy making of the optimal releases.

7. The uncertainty in hydrology increases the risk of the model application of water resource system. The risk makes it difficult for applying the system analysis models to actual reservoir operation. In fact, all policies for reservoir operation have their own risks, but they may differ in degree. The existence of a few risks ,hence, is acceptable when carefully managed. As for the interaction relationship between the policies for reservoir operation and the risks, futher research will be of significant value.

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