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Cascade Reservoirs Construction

-- A Cost-Benefit Analysis of "New Kariba Dams"

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Abstract

This paper established the Cost-Benefit Optimization Model of cascade reservoirs to provide the most economic address selection planning. We applied the Simplified Triangle Method for Flood Routing to estimate the Maximum and minimum discharge of each dam, provided the management strategies in different months and locations for ZRA.

Keywords

0-1 Integral Programming, Cost-Benefit Optimization, Simulation.

1. Introduction

1.1. Background

June 2015, a report by the Institute of Risk Management of South Africa included a warning that the Kariba dam is in jeopardy of collapsing. Kariba Dam, one of the largest reservoirs in the world, straddling the border between Zambia and Zimbabwe, nourishes and protects more than 31 billion people along the Zambezi River and supplies nearly half the nations' electricity with its number of 6,400 GWh. 2015, water levels at Kariba Dam dropped to 12% of the capacity. Its base eroded by water streams, which not jeopardize more than 3 billion people's lives, but reduce 40% energy generation in the area of South Africa [1]. To be more specific, levels fell to 477.25 meters above sea level from 482.83 meters a year earlier, causing a 49% hike in electricity prices [2]. In order to prevent the worsening of levels drop, protect people from dangerous, and recover or enhance its capacity of power generation, three options had been proposed: 1)Repairing the existing Kariba Dam, 2) Rebuilding the existing Kariba Dam, 3) Removing the Kariba Dam and replacing it with a series of ten to twenty smaller dams along the Zambezi River. The aim of first two options is to recover the capacity of dam, and the third one is raised by the purpose of larger energy generation and additional buffers even there is an extreme condition. IRMSA and the World Bank had given a budget of first two options, and the third one is estimated by cost-benefit optimization model of cascade reservoirs. According to the costs and benefits analysis as well as risks and opportunities analysis, the ability to fund-raising should be given the priority.

Our task is to provide a detailed analysis of Option 3). This new system of dams should have the same overall water management capabilities as the existing Kariba Dam. Our analysis supports a recommendation as to the number and placement of the new dams along the Zambezi River. What's more, we developed a strategy for modulating the water flow through our new multiple dam system that provides a reasonable balance between safety and costs. In addition to addressing known or predicted normal water cycles, we provided guidance for extreme water that explains and justifies the actions that should be taken to properly handle emergency water flow situations. Our recommended strategy includes information the locations and lengths of time that different areas of the Zambezi River should be exposed to the most detrimental effects of the extreme conditions.

1.2. General Assumptions

The water storage capacity of the reservoir is equal to the maximum amount of water it can provide.

The benefits of building a reservoir are only included five parts: power generation, irrigation benefits, water supply, flood control benefits and income in recreation.

The cost of building a reservoir is only included five parts: construction of dams, construction of power stations, costs of maintenance, cost of population migration, and loss during the construction.

Regardless of the usage time of the dam, costs and benefits are current.

Without considering the number of the spillway gates and switch state in these small reservoirs.

1.3. Notations Table

The following table provides meanings of important notations used in our models.

Table 1: Notations Table

Symbols		Meanings	Unit
a_i		If build a dam at No.i point, $a_i = 1$; if not, $a_i = 0$	
Vi		Water storage capacity of No.i reservoir	m^3
Po_i		Population around No.i area	
Qi		Water-carrying capacity at the outlet of No.i dam	m^3/s
Benefits	Ei	Electric energy production by No.i power station	$
	H_i	Different height between No.i point and No.i+1 point	m
	κ	Coefficient of electricity conversion from water	
	Gi	Irrigation capacity by No.i reservoir	$
	ω_{ij}	Probability of type i flooding at No.i area	
	Ui	Income of urban water supply	$
Cost	Bi	Cost of construction of No.i dam	$
	Si	Cost of construction of No.i power station	$
	Mi	Cost of maintenance of No.i dam	$
	Hi	Cost of population migration	$
	Li	Loss during the construction of No.i dam	$
	λ	Coefficient of total costs	
	γ	Coefficient of annuity	

2. Dam Site Selection Project

In order to select the best economic plan for dam construction, we choose out as many dams as we can, then use 0-1 Integer Programming to determine the specific points to construct. It is worth to pay attention that not every dam would be built finally, and the economic factor is the most important to consider.

2.1. Selection of Start Point and End Point

The 2,574-kilometre-long River of Zambezi River flows through eastern Angola, along the border between Zambia and Zimbabwe to Mozambique. There are two main sources of hydroelectric power on the river, the Kariba Dam for Zambia and Zimbabwe and the Cahora

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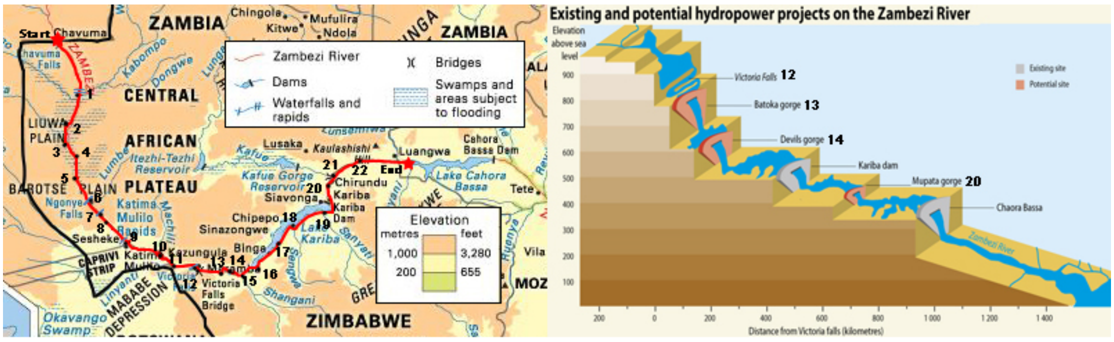
Bassa Dam for Mozambique and South Africa. In order to protect the sovereignty and integrity of Kariba Dam and substitute the role of it, the location of these smaller dams must not cross the border between Zambia and Angola (The black line in Figure 1), and it is no means to beyond the entry of the latter Reservoir. Thus, we select the Start Point at the national border at the point of Chavuma, and the End Point at the entry of Cahora Bassa Lake (Two red starts on the map).



•num means a place where is qualified to build a dam

Figure 1: Potential Dam Location

2.2. Principles of Dam Site

For decades, potential hydropower projects and dams had taken a great deal of research for scientists and academics. They think, locations of those rivers of big dropping variance is benefit for power generation (As marked on the right of Picture one) [4], and flooding areas must be protected by dams or other means. Finally, we selected the potential sites for dams as many as possible, which met at least one condition of follows:

1. High dropping variance of river;
2. Located at flooding and rainy areas;
3. Rapid or hurry water flows through the point;
4. Located at the branch of the river, which is narrow at its entry.

2.3. Mark Points on the Map

Along the chosen-distance-river, about 1200 kilometers, we marked 22 points on the map which meets at least one condition, especially at the location of Victoria Fall (No.12), Batoka Gorge (No.13), Devils Gorge (No.14) and Mupta Gorge (No. 20). And a description of these points as following:

Table 2: Description of potential Dam Site

Point number	Description
No.1 to No.5	Situated near geologic faults, in areas potentially vulnerable to flooding.
No.1, No.6, No.7, No.8, No.9, No.12	Marked as waterfalls or rapids, which would generate great potential energy.
No.10, No.15, No18, No.19, No.21	Located at the branch of Zambezi River
No.13, No.14, No.20	Formed as fast-flowing gorges naturally, which would be used as power stations.
No.11, No.16, No 17, No.22	Situated at the middle of two kinds of landscapes, creating a big difference in height.

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3. Cost-Benefit Optimization Model of Smaller Dams

3.1. Cost-benefit Optimization Model of Cascade Reservoirs

Since there are several factors deciding whether to build a dam at the 22 candidate locations, factors are

divided into two aspects, namely cost and benefit factors for preliminary analysis.

Our task is to build an optimal cost-benefit system of smaller dams on the basis of dynamic factors, then choose certain dams (between 10 to 20) to come into operation.

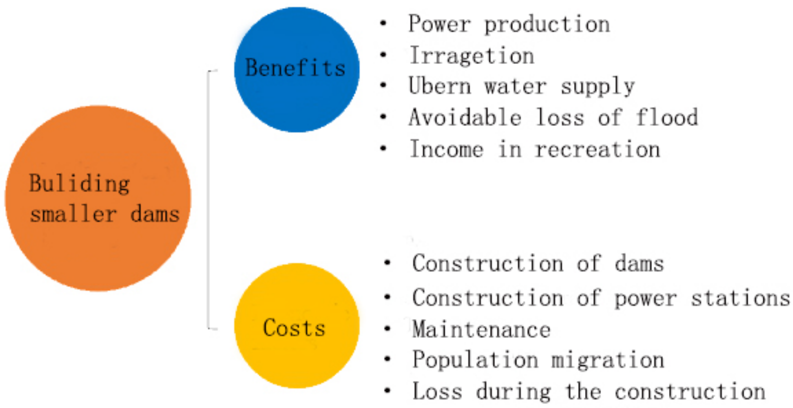

Figure 2: Benefits and Costs of Building Smaller Dams

3.1.1. Benefit Model of Smaller Dams

The benefit model is to measure the earning of each smaller dam in the selected region and calculate total earnings. We decide to select four parts: power generation capacity of cascade reservoirs, irrigation benefits, urban water supply benefits and the flood control benefit as the basis of the calculation of benefits of smaller dams.

(1) The revenue estimate model of generating electric of gradient reservoirs

Within the scope of the electricity supply, the electric energy demanded by each electricity sector needs to be integrated to describe the changes of electricity used for days and hours.

Annual load diagram: the graph representing the change of electricity used for each month in a year. Load figure commonly uses daily max (N'') min (N') load change curve and daily (or monthly) average load change curve.[5]

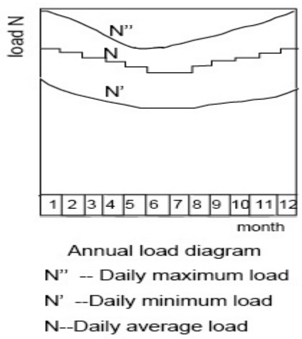

Figure 3: The annual load diagram

The electricity load chart is prepared, then based on the part that hydro power station should be as, the electricity that hydroelectric plants should generate can be determined, through the formula for output:

$$N_i = \gamma Q_i H_i \tag{1}$$

γ —— water density (= 1000 kg/ m^3)

Q_i —— power flow,unit m^3 /s

H_i —— drop, unit m

N —— output, unit kgf m/s

In engineering, the commonly used unit for N is kilowatt (kw), 1kw=102 kgf m / s, then

$$N = \frac{1000}{102} QH = 9.80QH \tag{2}$$

$$Q_i = \frac{102 N_i}{1000 H_i} = \frac{1N_i}{9.80H_i} \tag{3}$$

The electricity Hydro power station generate is also related to the efficiency of the turbine and generator, as a result, the actual formula for processing is

$$N_i = 9.8\eta_W \eta_E QH = \kappa QH \tag{4}$$

N ——output, unit kw

κ ——the combination of efficiency coefficient and unit conversion constant, 7.5-8.8 as often.[6] E_i——Electric energy production by No.i power station MW,unit $

Pw ——Price of each megawatt of power, unit kw/$

So the direct economic benefits brought by generating electricity is

$$E_i = \kappa QH \cdot Pw \tag{5}$$

(2) Estimation Model of Agricultural Irrigation Water

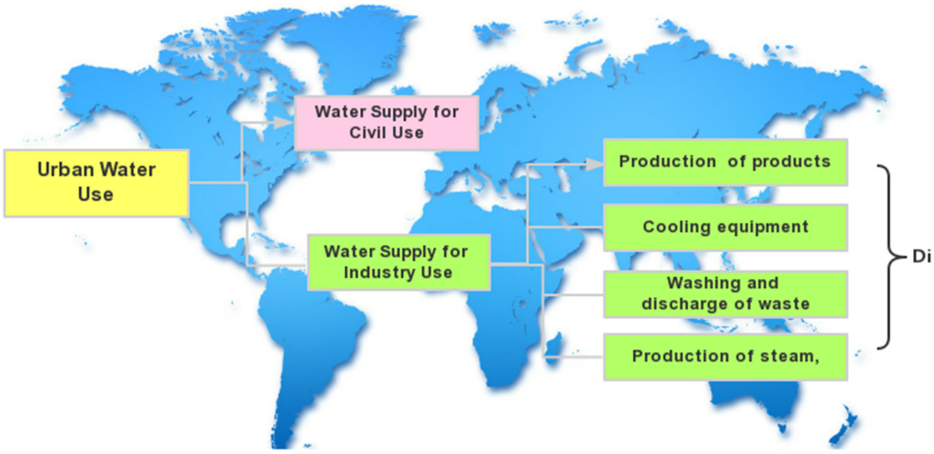

Figure 4: Distribution of Urban Water Supply

The appropriate moisture retention of crops not only rely on the effective supply of precipitation in the atmosphere but also need to be provided from the farmland conservancy measures to add water, which is called agricultural irrigation water.

Make sure the system of all kinds of agriculture [7], if given irrigated area and the percent of planted area of all kinds of agriculture, the amount of irrigation water and irrigation time can be gotten.

Above all, irrigation income for No. i is

$$G_i = V_{2i} \cdot P_g \tag{6}$$

G_i ——Irrigation capacity by No. i reservoir unit $

V_{2i} ——Water supplies of No. i point in irrigation, unit m^3

P_g ——Production of farmland, unit $/ m^3

(3) Estimate Model of Urban Water Supply

Assumption

The water supply of the No.i to the town is equal to the sum of the civil water supply and the industrial water supply within the responsible urban area.

$$V_{1i} = D_i + Po_i \cdot u \tag{7}$$

V_{1i} ——Water supplies of No.i reservoir in town, unit m^3

D_i —— Industrial water consumption of No.i, unit m^3

Po_i ——Population of No.i point, unit person

u ——Average water consumption in Zambian watershed, unit m^3 /year

U_i ——Income of urban water supply, unit $

Pr ——Price of urban water, unit $/ m^3

The next step is to calculate the total revenue of town water supply:

$$U_i = V_{1i} \cdot \mathrm{Pr} \tag{8}$$

(4) Estimation model of flood control benefit

The frequency and grade of the flood occurred in the representative year of each potential dam point are found, and the mathematical model is used to simulate the frequency of the flood in other years during the operation period of the system, and then calculate the expected value.[8]

$$F_i = D_{ti} \cdot \omega_{ii} \tag{9}$$

F_i ——Avoidable damage benefits from No.i dam, unit $

ω_{ii} ——Probability of type i flooding at No.i dam

D_{ti} ——Loss of type i flooding, unit $

(5) Calculate the total benefits of smaller dams

$$\mathrm{Tb} = \sum_{i=1}^{22} a_i \cdot (E_i + G_i + U_i + F_i) \tag{10}$$

Tb ——Total earnings of dams, unit $

3.1.2. Cost Model of Smaller Dams

In this model, costs are measured in terms of money and currency per year, and a coefficient of annuity, γ, is introduced into equations. More specifically, the total costs are divided into five parts: Construction fees of dams, Construction fees of power stations, Costs of maintenance, Cost of population migration, and Loss during the construction.

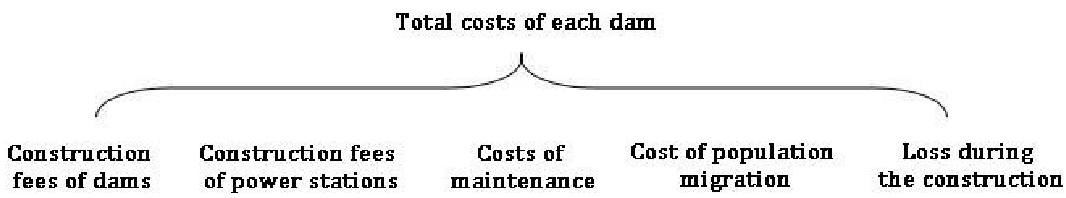

Figure 5: Components of Total Cost

The sum of values of five factors stands for the total costs of each dam. According the report by the Institute of Risk Management of South Africa, the dams must be used for more than 100 years, thus the total costs should be set aside for 100 years and we suppose γ as a average rate.

$$C(i)=[B_i(V_i)+S_i(V_i)+M_i+H_i(\mathrm{Po}_i)+L_i(V_i)]\cdot\gamma \tag{11}$$

$\mathrm{C(i)}$——Total costs of No.i dam

$\mathrm{B_i}(V_i)$——Cost of construction of No.i dam

$\mathrm{S_i}(V_i)$——Cost of construction of No.i power station

$\mathrm{M_i}$——Cost of maintenance of No.i dam

$\mathrm{H_i}(Po_i)$—— Cost of population migration

$\mathrm{L_i}(V_i)$ ——Loss during the construction of No.i dam

γ—— Coefficient of annuity

And the cost of whole construction can be measured as:

$$TC=\sum_{i=1}^{n=22}a_i\cdot C(i) \tag{12}$$

In order to estimate the costs accurately and actually, a coefficient of total costs, λ, is introduced as a coefficient to measure the cost of water storage of reservoir per m3. we consider the coefficient λ is related to water storage of reservoir, and use the following datas to construct a regression equation about Total Cost and Water Storage.

We find ten sets of data of Total Cost and Water Storage about the dams in 10 years.

Table 3: Datas of Total Cost and Water Storage about the dams in 10 years

Name of Dam	Three Gorges	Shuibuya	Goupitan	Longtan	Pubugou
Total Cost	\$ 2.7×1010	\$ 1.3×109	\$ 8.7×108	\$ 5.1×109	\$ 1.05×107
Water Storage	3.93×1010 m3	4.58×109 m3	6.45×109 m3	2.73×1010 m3	5.17×106 m3
Name of Dam	Hongjiadu	Tankeng	Wawushan	Dongping	Baishuikeng
Total Cost	\$ 1.85×108	\$ 9.58×108	\$ 3.1×108	\$ 1.34×108	\$ 5.09×107
Water Storage	4.92×109 m3	3.53×109 m3	5.84×108 m3	3.36×108 m3	2.46×108 m3

Applying the method of mathematical regression analysis with SPSS, one regression equation was given out.

$$Y=54.92+0.31X-3.69\times10^{-5}X^2+1.18\times10^{-9}X^3 \tag{13}$$

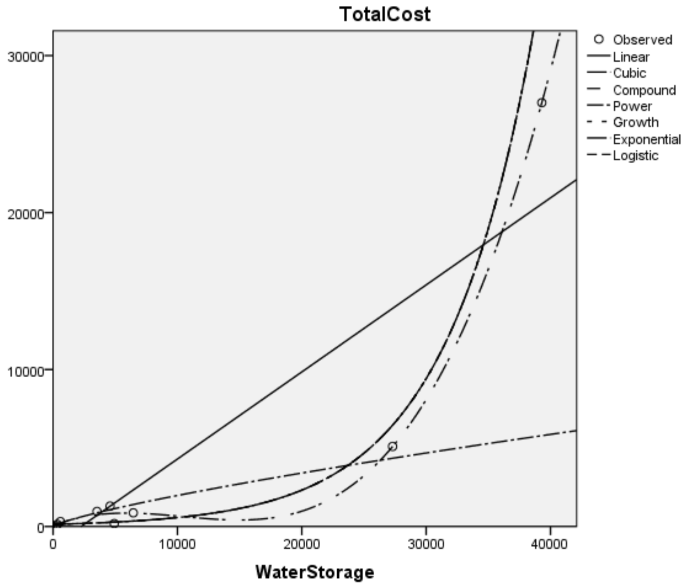

Figure 6: Fitting-figures of relation between Total Cost and Water Storage

test for equality performed by SPSS, and the results of it as follows:

Table 4: Model Summary and Parameter Estimates

Dependent Variable: TotalCost									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.796	31.133	1	8	.001	-1247.102	.555		
Quadratic	.958	78.946	2	7	.000	1405.901	-.590	3.069E-5	
Cubic	.999	1763.314	3	6	.000	54.920	.312	-3.693E-5	1.182E-9
Power	.845	43.461	1	8	.000	1.432	.785		
Growth	.695	18.267	1	8	.003	4.945	.000		
Exponential	.695	18.267	1	8	.003	140.434	.000		
Logistic	.695	18.267	1	8	.003	.007	1.000		
The independent variable is WaterStorage.									

R Square of Cubic is the largest, indicating that the fit is the best. And the Sig value is 0.000(The normal level is 0.05), less than the significance level, so we can reject the null hypothesis, that the curve fitting is better.

Considering the detrimental affect of extreme condition to dams, such as floodings and storms, a 2% increase should be added to its original costs[2]. And correct the Cost Function like this:

$$C(i)' = \lambda(V_i)\cdot(1+2\%)\cdot\gamma \tag{14}$$

$\lambda(V_i)$——Coefficient of total costs

$C(i)'$ ——Correct the cost of No.i dam

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3.2. Related Datas Simulation

Since the river's related datas are unkown or unstatistical, we use a random simulation model to simulate 22 sets of datas of these dams, according to the konwn datas of Vaictoria Falls and Kariba Dam in years.

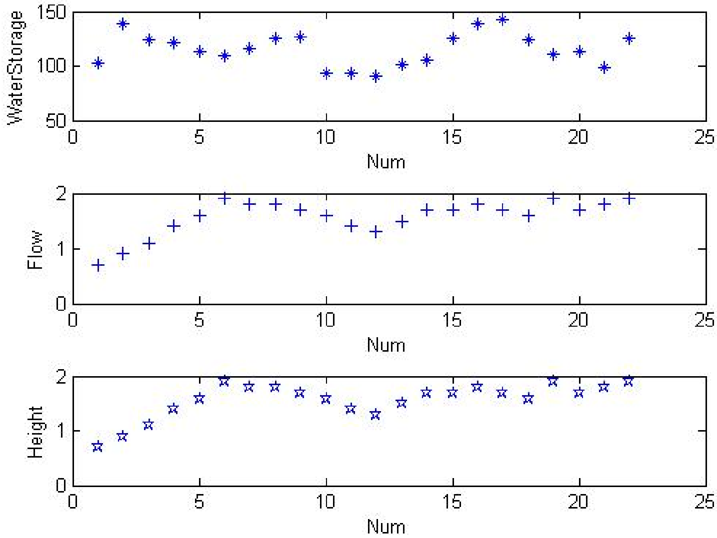

Figure 7: Simulation data's with MATLAB

And give out these datas in table:

Table 5: Simulation datas of Storage, Folws and Height

Num	Water Storage (m3)	Flows (m3/s)	Height (m)	Num	Water Storage (m3)	Flows (m3/s)	Height (m)
1	103.2	263.9	30.4	12	100	490.1	32.6
2	138.4	339.3	38.9	13	90.4	565.5	37.6
3	76	414.7	36.8	14	105.6	640.9	40.1
4	51.2	527.8	32.5	15	125.6	640.9	35.3
5	65.6	603.2	28.9	16	139.2	678.6	32.4
6	109.6	716.3	39.6	17	142.4	640.9	31.7
7	116	678.6	35.7	18	124	603.2	35.9
8	124.8	678.6	43.2	19	110.4	716.3	34.9
9	126.4	640.9	38.9	20	113.6	640.9	40.9
10	114.4	603.2	42.3	21	99.2	678.6	45.7
11	132	527.8	39.6	22	125.6	527.8	47.9

3.3. 0-1 Integer Programming in Determining Dam Sites

In this model, whether the dam can be built has not been decided. And we assume that there is a coefficient to show if the dam be constructed. The costs of the dam would be included if it would be built, which would be multiplied by a number of 1, while the other situation would be multiplied by the number of 0. Then the plan that lead to maximum benefit would be selected.

At first, introduce 0-1 variables:

$$a_i = \begin{cases} 1, \text{No.i dam is built} \\ 0, \text{No.i dam is not bulit} \end{cases}, \tag{15}$$

In order to maintain the power generation and irrigation capacity at original levels, objective function and constraints are listed:

$$\max \quad Tb - Tc = \sum_{i=1}^{n=22} a_i \cdot (B_i - C_i) \tag{16}$$

$$s.t. \begin{cases} \sum_{i=1}^{n=22} a_i \cdot V_i \geq V_{original} \\ \sum_{i=1}^{n=22} a_i \cdot E_i \geq E_{original} \\ a_i = 0 \text{ or } 1 \end{cases}$$

Considering benefit and cost factors mentioned above, write programs with Matlab, according to the objective function and constraints, to identify the most economic construction plan, then select the specific sites.

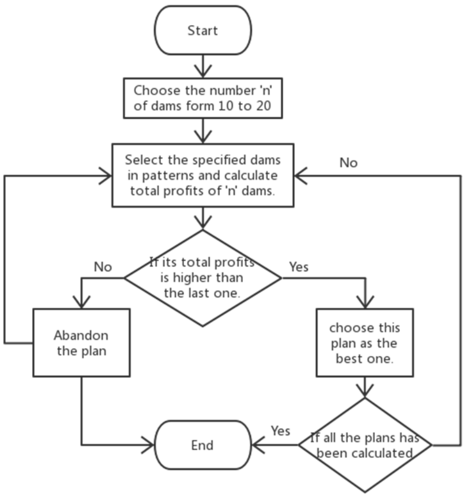

Figure 8: Sites Selection Program flow

Run the Program, and list selection results as follows:

```
>> cost
LP:                Optimal objective value is -2.334949.
Optimal solution found.
Intlinprog stopped at the root node because the objective value is within a gap tolerance of the optimal value; options.TolGapAbs = 0 (the default
value). The intcon variables are integer within tolerance, options.TolInteger = 1e-05 (the default value).

x_22 =

0    1    0    0    0    1    1    1    1    1    0    1    1    1    1    1    1    1    1    1    1    1

fval_22 =

-2.3349

flag_22 =

1
```

Figure 9: Sites Selection Results

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Finally, we select to build 17 dams along Zambezi River, they are:No.2, No.6, No.7, No.8, No.9, No.10, No.11, No 13, No.14, No.15, No.16, No.17, No.18, No.19, No.20, No.21, No.22.

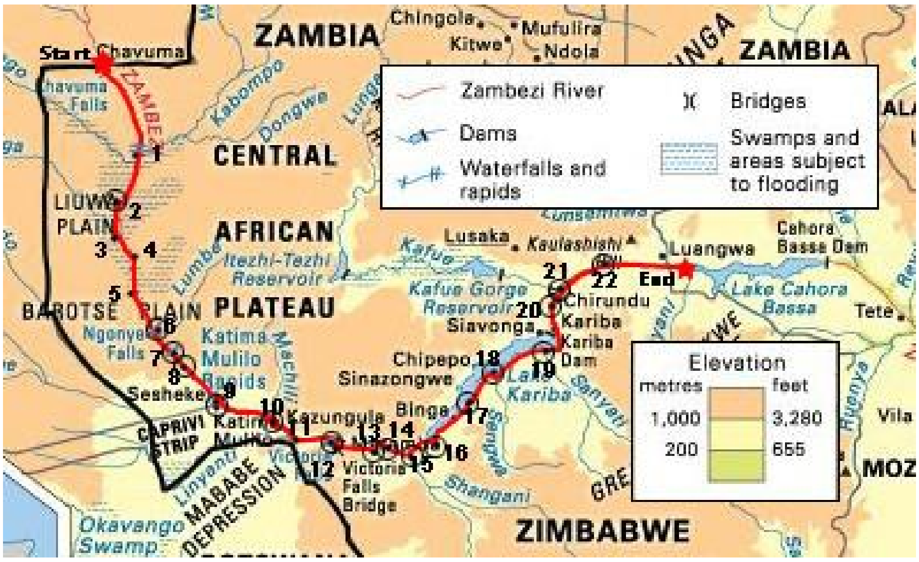

Figure 10: Sites Selection Map

4. Maximum and Minimum Discharge of Dams under Extreme Conditions

4.1. The Method of Calculating the Maximum Emission of Flood

Hypothesis: In the state of small watershed and small reservoir without considering the number of the spillway gates and switch state

Conception:

Flood detention capacity: The maximum amount of flood that can be accommodated

Flood storage capacity: The maximum amount of flood that can store

Supposing that the flow of storage and outbound flow are simplified as triangular, so the total flood storage is:

$$W = \frac{1}{2} Q_m T \tag{17}$$

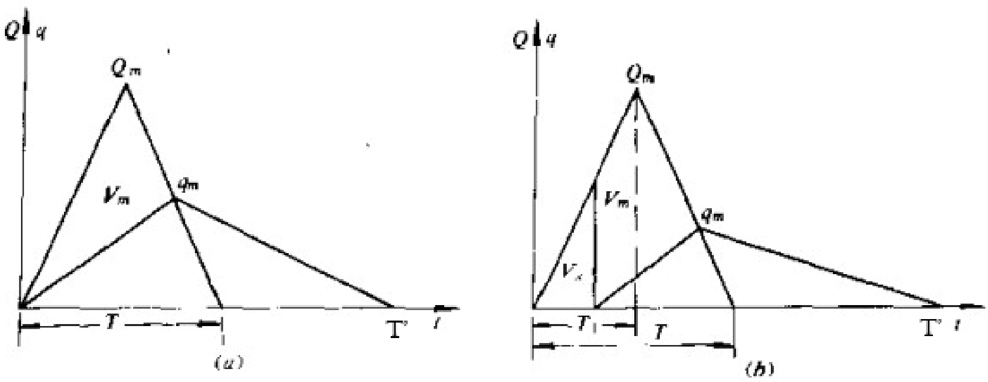

Figure 11: Simplified Triangle Method for Flood Routing

As for picture a, the maximum discharge flow of the reservoir from the dam height is:

$$q_m = Q_m\left(1 - \frac{V_m}{W}\right) \tag{18}$$

Q_m ——peak discharge

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V_m ——flood detention capacity

T——flood duration

As for picture b, the starting level of the reservoir is below the weir crest elevation, but the time of filling to the crest elevation is less than that of the flood peak, so the total flood storage is:

$$q_m = \frac{Q_m(1-\frac{V_m}{W})}{1-\sqrt{\frac{V_s T_1}{WT}}} \tag{19}$$

V_s——— flood storage capacity

The two equations are established from the point view of water balance [4].

4.2. Estimation of the Minimum Expectation Emission under the Constraint Benefit

In the season of water shortage, there are two main sources of water consumption in reservoirs, one is to meet power generation needs through the drainage, the other is to meet the area of irrigation and urban water supply minimum requirements through the remaining water storage reservoir.

Restrictions:

$$V_i' \geq q + (V_{2i}' + V_{1i}'); V_{2i}' \geq V_{2i}; V_{1i}' \geq V_{1i}; q \geq Q \cdot t \tag{20}$$

When the equal sign is established, minimum emissions q_{min} can be gotten

V_i' ——water storage capacity of reservoir during dry season, unit m^3

V_{2i}' ——the supply of irrigation water during dry season ,unit m^3

V_{1i} ——the water supply of the town, unit m^3

t —— the total time of power generation under normal conditions ,unit s

q_{min} ——the minimum expected discharge

5. Demonstration Analysis of Dam Discharge in Extreme Condition

Select No.12 dam to analyze which located near Victoria Falls of 17 dams, and estimate the maximum expected discharges and the minimum expected discharges under the extreme conditions. Then the suggestions were given. The analysis of other dam points of thinking process is similar, so do not repeat here.

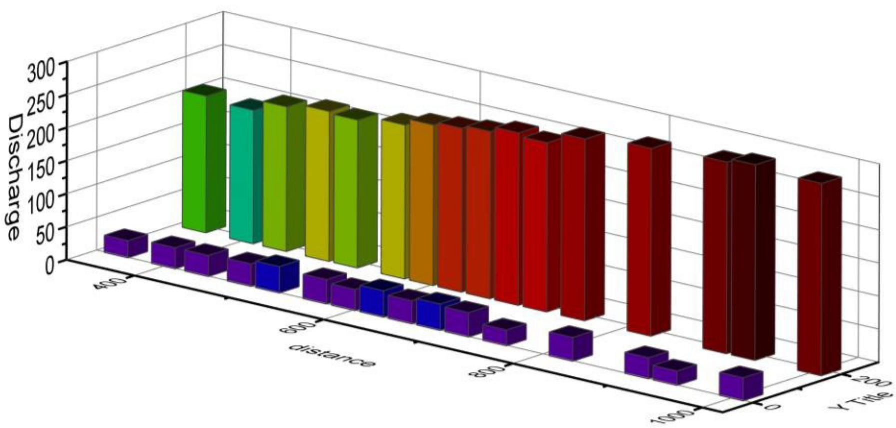

Figure 12: The Maximum Expected Discharge and the Minimum Expected Discharge of Different Dams

5.1. The Maximum Expected Discharges of No.12

According to the average monthly water flow data in the year which is representative, the month with mean flow exceeding 1000 m^3/s is the flood season. For the No.12 dam, February to June is usually the flood season. According to the historical data, March has the largest flow, and the flow is 8720 m^3/s.

Table 6: Zambezi River Monthly Average Flows at Victoria Falls(1907-2008)

Flow(m^3/s)	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	261	264	395	642	1055	1919	2716	2345	1473	768	467	337
Max	479	541	776	1296	5484	8720	7610	5297	3628	1770	914	610
Min	116	118	199	319	443	602	784	569	341	281	220	161

As can be seen from the above table,

$$Q_m = 8720\, m^3/s.$$

$$W = \frac{1}{2} \times 8720 \times 60 \times 60 \times 24 \times 30 = 11301120000\ m^3,$$

Suppose

$$V_{m12} = 3 \times 10^9 m^3,$$

From the flood control calculation of the maximum discharge's method can be seen, the maximum discharge flow of Reservoir i is

$$q_{m12} = 8720 \times (1 - \frac{5 \times 10^9}{11301120000}) \approx 4862\ m^3/s.$$

As for the maximum discharges, depending on the duration of its flood discharge.

$$W_{\max} = 4862T'$$

$W_{\max}$ ——The maximum discharges

T' ——The duration of flood discharge

When the maximum discharges are equal to the total amount of flood storage, the time required is

$$T' = \frac{2W}{q_{m12}} \approx 54 \text{ days.}$$

5.2. The Minimum Expected Discharges of No.12

We will estimate the minimum expected discharge of the No.12 dam under the condition of benefit constraint.

Step 1 Determine the monthly energy demand for the No.12 jurisdiction.

As can be seen from the above figure, the demand for electricity in the Kaliba area is not affected by the seasons. As a total of 17 small dams are built, the average monthly demand for power in the small dam jurisdiction is 10765kW.

Suppose,

$$N_{12} = 10765\text{kW}.$$

Step 2 calculate the minimum discharges required to meet the energy requirements

As knows,

$$H_{12} = 20.6m,$$

Set

$$\kappa = 8.0,$$

Then

$$Q_{12} = \frac{N_{12}}{\kappa H_{12}} \approx 65m^3/s,$$

So

$$q_{min} = Q_{12} \cdot t = 65t$$

The minimum discharges are related to the time of power generation,
in one month,

$$t = 60 \times 60 \times 24 \times 30 = 259200s,$$

Then

$$q_{min} = 168480000\,m^3$$

6. Recommendation

6.1. Proposal on the Number and Placement of the New Dams

For the construction of smaller dams in the Zambezi River Basin, not only to meet the construction of the feasibility of the conditions, but also should consider the benefits and the costs so that the difference reach an optimal value.

Table 7: Constraints on Dam Construction

Conditions		Description
Construction feasibility		①not cross the border ②high dropping variance of river ③Rapid or hurry water flows ④Located at flooding and rainy areas ⑤Located at the branch of narrow river
Cost - Effectiveness	Benefits	①Power generation ②Construction of power stations ③Irrigation ④Water supply ⑤Avoidable loss in flood ⑥Income in recreation
	Costs	①Construction of dams ②Costs of maintenance ③Cost of population migration ④Loss during the construction

Finally, we select to build 17 dams along Zambezi River, they are:No.2, No.6, No.7, No.8, No.9, No.10, No.12, No 13, No.14, No.15, No.16, No.17, No.18, No.19, No.20, No.21, No.22

6.2. Recommendations on Dam Management during the Flood Season

Reservoirs play a major role in flood control and water supply by controlling their discharges. The size of the discharge is affected by the objective factors such as dam site, dam height, flow, season and other subjective factors such as urban water supply demand, irrigation demand and power generation demand. Reasonable arrangements for discharges and the time of discharge is important to the reservoir management.

6.2.1. Management of the Dam in the Flooding

In the flood season, the reservoirs with small capacity, low altitude, large flow, suffers the largest adverse influences. The lengths of affected time are the entire flood season. Flood season at different dam sites is different, so the affected time is also different.

According to the historical data, when the average flow is more than 1000 m3 / s , flood season is arriving. Then measures should be taken in flood discharge.

For the No. 12 dam, the flood season is from February to June, and the maximum expected discharges are most likely to occur in March. Therefore, during this period, the reservoir management personnel should increase discharges according to the actual situation in order to avoid the risk of burst. From 2.3.2 we can see that the maximum expected discharges is affected by the time of flood discharge. When the flood season lasts, the maximum expected discharges in this month can be larger than that in the storage flood. For the next month, the time of flood discharge should be longer than 54 days. When the flood season is about to pass, the maximum expected discharges for the month should be less than the storage flood, in order to store water for the dry season, the time should be less than 54 days.

6.2.2. Dam Management of Dry Season

Under long-term low-water conditions, those reservoirs with small storage capacity and small water flow but high hydropower demand are most adversely affected. Its impact time should be the duration of the entire dry season.

According to the historical data, that the average flow is less than 300 m3 / s in one month is the dry season. When in the dry season, reservoir storage is low, this time the water is likely to be difficult to meet the requirements of water supply (urban water and irrigation water) and drainage power generation.

When generating electricity as the first function of the reservoir, the minimum expected discharges must meet the demand for power generation (which can be calculated from Equation 1), but at this time facing the shortage of water supply, the proposed treatment method has two: Plan A increase the water storage capacity ahead of time; Plan B apply upstream reservoir to increase discharges.

When the storage of water supply as the first function of the reservoir, to meet the urban water and irrigation water, the amount of water discharge is not enough to meet the demand for electricity generation, at this time, the proposed treatment methods are: Plan A increase the amount of water ahead of schedule; Plan B transfer power from other places.

Obviously, the cost of Plan B is expensive and the possibility of realization is unknown. Therefore, in order to prevent the shortage of supply in the dry season, water should be stored in the flood season.

7. Strengths vs Weakness

7.1. Strengths

1)Solve the problem from the actual situation. In full consideration of contours, topography, precipitation and other factors under the conditions of choice for dam sites.

2)Abstract the practical problems, with the use of 0-1 planning method to simulate the number and location of dams.

3)Determine the number and location of dams from the cost-benefit optimization point of view

4)Classification discussion. Reasonable recommendations are given for the maximum expected and minimum expected discharges for different regions under extreme conditions.

5)When in sensitivity analysis and modification of the model, we discuss each parameter, the results show that our model parameters have a wide range of applications.

7.2. Weaknesses

1)This model takes into account too many factors, leading to the settlement process is cumbersome, the solution is difficult.

2)One of the model parameters (flooding time) still needs to be determined experimentally and cannot be deduced from the existing physical constants.

3)For our emergency guidance proposal, only some key dams are considered, and there is no specific consideration for each type of dam.

8. Sensitivity Analysis

In order to better guide the establishment of multi-dam systems, the most benefits, we conducted a sensitivity analysis. Sensitivity analysis is particularly important if you are investing in a project that must be considered for feasibility.

The main purpose of investment sensitivity analysis is to reveal the influence of relevant factors on investment decision-making evaluation index, to determine the sensitive factors and seize the main contradictions.

Step 1 Select the sensitivity analysis indicator. Here, we use the cost-benefit principle. Therefore, we select net income as the sensitivity analysis indicator.

Step 2 Calculate the target value of the technical scheme. Normally, the value of the economic benefit evaluation index in the normal state is taken as the target value.

Step 3 Select Uncertainty. We choose the factor which largely effect the target value. Here, we mainly select the storage capacity as the uncertainty factor.

Step 4 Calculate the degree of influence of uncertain factors on analysis indicators. The principle of univariate sensitivity analysis is that only one uncertainty can be changed at a time.

Step 5 Identify sensitive factors, analyze and take measures to improve the anti-risk ability of technical solutions.

We take the storage capacity as the uncertainty factor, carries on the sensitivity analysis in MATLAB, obtains the result, like figure as follows:

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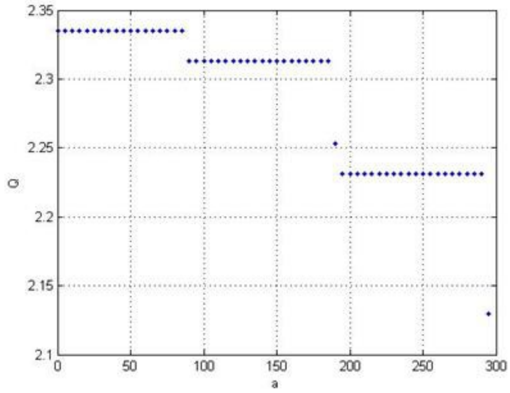

Figure 13: Sensitivity analysis curve

Through the above analysis, we can see that when the total storage capacity increases by 70-80, the total benefit is increasing. The reason is that some dams may be economically inefficient, so when increasing the storage capacity to a limit, then the economic benefits diminish. Therefore, the total storage capacity of these small dams should be increased by 70-80 is the economy.

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