International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 07, July-2019

Derivation of Optimum Operation Policies using Genetic Algorithm

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***Abstract*— Water is vital for all known forms of life, even though it provides no calories or organic nutrients. The quantity of water available for our needs is limited by the nature. Reservoir is an open-air storage area where water is collected and kept in quantity. So that it may be drawn off for our uses, like irrigation, power production, drinking purpose, flood control, recreation purpose etc. Since future inflows or storage volumes are uncertain, the challenge is to determine the best reservoir release or discharge for a variety of possible inflows and storage conditions. Hence proper management of reservoir becomes necessary and derivation of optimum release policy become relevant. This paper focuses on derivation of optimum operational policies for a single purpose reservoir using Genetic Algorithm (GA) in MATLAB. GA is one of the efficient operation techniques for optimization of reservoir based on the mechanism of natural selection and natural genetics.**

Key words*— Peringalkuth Reservoir, Genetic Algorithm (GA), Optimisation, Reservoir Operations, Optimum Operation Policy, Optimum Release, Optimum Power

I. INTRODUCTION

Water is very useful, it generates electricity and waters the grains, fruits and vegetables that people and animals eat. Indeed, the versatility of water as a solvent is essential to living organisms. It can also be very dangerous, causing much destruction from flooding and landslides. Without water, life as we know it could not exist. Although our planet is covered by seemingly vast oceans, only a small fraction of the water on earth is fresh and even less is readily accessible. As the population grow, it becomes more important to understand how to manage and protect our fresh water supply.

A reservoir is, most commonly, an enlarged natural or artificial lake or impoundment created using a dam to store water. It is also used for power production, drinking purpose, flood control, irrigation etc. Lack of fresh water and increasing water demand on the reservoir due to population growth, optimization of the existing reservoir is essential for maximum operational strategy and to cope with the present and future water demands. Optimisation is the science of choosing the best solution from a number of possible alternatives. Hence it is important to optimise the release for each month within the constraints.

A reservoir operation policy specifies the amount of water to be released from the storage at any time depending upon the state of the reservoir, level of demands and any information about the likely inflow in the reservoir. Reservoir operators need to know how much water to release and when. Reservoirs designed to meet the demands for water supplies, recreation, hydropower, the environment and flood control need to be operated in ways that meet those demands in the most reliable and effective manner. Since future inflows or storage volumes are uncertain, it is the challenge to determine the best reservoir release or discharge for a variety of possible inflows and storage conditions. Reservoir release policies are specifying the desired storage level for the time of year. The operator is to release water as necessary to achieve these targeted storage levels.

The Genetic Algorithm (GA) is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. GA repeatedly modifies a population of individual solutions. At each steps the GA selects individual at random from the current population to be parents and uses them to children for the next generation. We can apply the GA to solve a variety of optimization problems that are not well suited for standard optimization algorithm, including problems in which the objective function is discontinuous, non-differentiable, stochastic or highly nonlinear. The GA can address problems of mixed inter programming, where some components are restricted to be integer-valued.

II. LITERATURE REVIEW

Reservoir optimization is an important part of planning and management of water resource system. Management of reservoir systems from planning to operation is very challenging since the problem deals with many complicated variables according to the various demands [1]. It generates optimum operation policy in reservoir. It specifies the optimum release maintained at any time. So optimum benefit is obtained within system constraints. Various constraints include, the release for power and turbine capacity, irrigation demand, evaporation loss, storage continuity equation and reservoir storage capacity [2]. Hence, optimisation of reservoir operations has been a major area of study in water resources systems.

Reservoir optimization techniques are mainly classified into two, mathematical method and heuristic method. Mathematical method includes linear programming, non-linear programming and dynamic programming. Linear

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programming (LP) is applied in modeling reservoir systems optimization problems. But LP has the restriction to using linear and convex objective functions and linear constraints. Nonlinearity exists in most reservoir systems operation problems due to complex relationships among different physical and hydrological variables. Normally, hydropower generation problems are nonlinear and pose difficulties in obtaining their solutions. Such problems are generally solved by approximating a nonlinear problem to a linear problem or by successive application of LP. However, global optimality remains an obstacle in practical applications of nonlinear programming. Dynamic programming is used to solve multistage design processes. But it conflicts in memory arises. Hence these three methods are inefficient for reservoir optimization problem solving and it is quite difficult to use in real world problems of reservoir.

So highly sophisticated heuristic techniques are developed as an alternative to these simple differential techniques, as they can easily handle both nonlinearity and uncertainty [3]. Heuristic method includes Artificial Neural Network (ANN), Fuzzy logic and Evolutionary algorithm. ANN can be successfully applied for river flow or inflow forecasting, not for the derivation of operating policies for reservoir. Combination of rule based expert system and ANN models is called Decision Support Model (DSM) can be used for deriving operational policies. Hence ANN model cannot be used directly in derivation of optimum operational policies. Fuzzy logic is a simple approach which operates on the If-Then principle. Datta [4] discussed the complexities associated with real time reservoir operation models and contending that improvement in optimization algorithms, large scale simulations, geological information processing and use of artificial intelligence techniques combined with the tremendous advancement in computer technology, will certainly play an important role to overcome these complexities. Evolutionary algorithm method can overcome the complexities such as uncertainty, discontinuity, nonlinearity, multiobjective etc. It Includes Genetic Algorithms, Simulated Annealing, Ant Colony Optimization, Particle Swarm Optimization. From this Genetic Algorithm (GA) is mostly used for the reservoir optimization operations. GA can be used in multi-purpose reservoir effectively, hence it can be applied in single-purpose reservoir. GA model releases the required amount and it gives near global optimal values [5].

A study by Devisree M V and Nowshaja P T [2] conducted on the topic 'Optimisation of Reservoir Operations Using Genetic Algorithms' try to explore the potential of alternative GA formulations in application to a reservoir system, and to develop a self-created GA model in MATLAB. Their objective is to maximize the annual power production generated in Peechi Dam with the constraints such as release for power and turbine capacity, irrigation demand, storage continuity equation and reservoir storage restrictions. Certain comparison studies between GA and other optimisation techniques are carried out by various researchers and found that GA model can be used as an effective optimisation tool for reservoir operations. Jatin Anand et.al [6] deals with the application of Soil and Water Assessment Tool (SWAT) models and GA model employed at two reservoirs in Ganga River basin. On the basis of their results, conventional optimisation models offer merely single optimal solutions, while GA derived optimal reservoir operation rules are competitive and promising, and can be efficiently used for the derivation of operation of the reservoir. Subramani R and Vijayalakshmi [7] deals with the various advanced optimisation techniques such as evolutionary techniques, Particle Swarm Optimisation (PSO) and Genetic Algorithm. Based on their results, GA is much suitable with small number of parameters for solving combinational optimisation problems. Sumitra Sonaliya et.al [8] applied Genetic Algorithm model to the Ukai Reservoir project in Gujarat to develop policy for optimising the release of water for the purpose of irrigation. They concluded that the release developed by GA satisfy completely the irrigation demands and which leads to considerable amount in saving of water. Tilahun Derib Asfaw et.al [9] develop a GA model to optimize a weekly average power generation in Temengor Hydropower Dam. Reservoir operations was reviewed and they conclude that GA model gave a better release and reservoir level as compared to historical operation.

Based on the literatures it can be concluded that Genetic Algorithm can be used for water resources optimisation problems.

III. STUDY AREA

Peringalkuth Reservoir is selected as study area. It is formed by constructing a dam across Chalakkudy River in Thrissur district of Kerala state of India. The project is situated at about 10º18'45" N latitude and 76º38'40" E longitude. It is a non-overflow solid gravity type rubble masonry structure with total length of 366m. The dam is designed with maximum flood discharge of 2265.32cumecs. The catchment area of the dam is 512Sq.km. Fig. 1 shows the catchment area of Peringalkuth Reservoir.

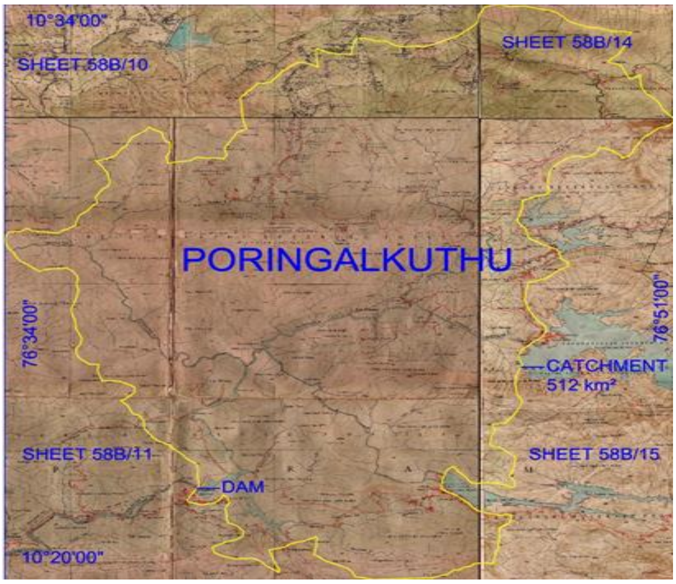

Fig. 1. Catchment Area of Peringalkuth Reservoir

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The water from the reservoir is directed through a tunnel and penstock to generate power. The tail water of the schemes is discharged into the Chalakkudy River. Maximum daily rainfall is 274mm observed. Full reservoir level is 423.98. Hydroelectric power production is the main function of this reservoir. The installed capacity of the power house is (4x9 MW) + (1x16 MW) = 52MW. Here 4 numbers of vertical reaction type Francis turbines of 8MW and each 1 number vertical reaction type Francis Turbine of 16MW are used.

IV. METHODOLOGY

A. *Objective of the Study*

To maximize the release of water for the power production of a single purpose reservoir, within the constraints. If R is expressed in meter cube per second (m3/s) and head causing flow, H in meters, then power produced P in watt is given by:

$$P=\eta\gamma RH \tag{1}$$

For the demonstration of applicability of GAs for optimisation problem a courser time interval of one month is chosen which can be further reduced to weekly or daily.

B. *Data Collection*

The input data like head causing flow in each month, turbine capacity and firm power are collected for 2010 to 2017. From these data, release corresponding to each firm power is calculated and tabulated as lower bound for release constraint; similarly flow corresponding to turbine capacity is tabulated as upper bound for release constraint. The required data for maximizing the power production within the constraints are collected. The installed capacity of the reservoir is 52MW and the firm power is 19.7MW. The live storage and the dead storage of the reservoir are $32Mm^3$ and $1.7Mm^3$ respectively. Table 1 shows the input data.

C. *Identification of Objectives and Constraints*

The objective function of the optimization problem and the governing constraints to be identified based on similar literatures. The identified objective function is to maximize the hydropower by optimising the release from the reservoir. The constraints to be considered are release constraints, reservoir storage-continuity constraints and reservoir storage-capacity constraints.

D. *Objective Function*

The identified objective function for optimising the release is,

$$P=\sum_{t=1}^{12} Rt \tag{2}$$

For all t = 1 to 12

Where, R is the release from the reservoir in each month and t is the time period. The objective function is subjected to the following constraints.

TABLE 1. INPUT DATA

Month	Head (m)	Firm Power (kWh)	Installed capacity (kWh)	Lower Bound (Mm^3)	Upper Bound (Mm^3)	Inflow (Mm^3)
Jan	163.65	14656800	38688000	32.87	86.75	36.36
Feb	162.09	13238400	34944000	29.97	79.11	41.50
Mar	162.79	14656800	38688000	33.04	87.21	36.06
Apr	162.09	14184000	37440000	32.11	84.77	34.60
May	163.51	14656800	38688000	32.89	86.83	35.75
June	165.69	14184000	37440000	31.41	82.92	110.76
July	167.97	14656800	38688000	32.02	84.52	137.30
Aug	168.58	14656800	38688000	31.90	84.22	175.24
Sep	168.27	14184000	37440000	30.93	81.65	157.62
Oct	165.4	14656800	38688000	32.52	85.84	82.48
Nov	166.56	14184000	37440000	31.25	82.49	97.84
Dec	165.4	14656800	38688000	32.52	85.84	66.91

E. *Release Constraints*

The releases into turbines for hydropower production should not be exceed the release corresponding to installed capacity and should be greater than release corresponding to firm power.

$$R_{FP} \leq R_t \leq R_{IC} \tag{3}$$

For all t = 1 to 12

Where, R_{FP} is the release corresponding to the firm power, R_{IC} is the release corresponding to installed capacity of turbine and R_t is the release at any time t.

F. *Reservoir Storage Continuity Constraints*

The storage of a month is equal to the sum of storage and inflow of the preceding month minus release of that month.

$$S_{t+1} = S_t + Q_t - R_t \tag{4}$$

For all t = 1 to 12

Where, S_{t+1} is the storage at the period t+1, S_t is the storage at the beginning of the period t, Q_t is the inflow during the period t and R_t is the release at the period t.

G. *Reservoir Storage-Capacity Constraints*

The storage of the reservoir at any time t should not be less than dead storage of the reservoir and should not be greater than the maximum storage of the reservoir.

$$S_{min} \leq S_t \leq S_{max} \tag{5}$$

For all t = 1 to 12

Where S_{min} is the minimum storage in the reservoir, S_{max} is the maximum storage in the reservoir and S_t is the storage in time t.

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H. Genetic Programming

GA is a search procedure based on the mechanism of natural selection and natural genetics, which combines the artificial survival of the fittest with genetic operators abstracted from nature. GA modelling has robostic random search capability hence it is gaining importance in reservoir optimization. The objective function is chosen in such a way that highly fitted strings (solutions) have high fitness values. The evolution starts from a set of coded solutions and proceeds from generation to generation through genetic operations, i.e., reproduction, crossover and mutation. Through the GA, an optimal solution can be found and represented by the final winner of the process. GA can handle any type of objective function. The various steps involved in genetic algorithm are:

1. The algorithm begins by creating a random initial population
2. Evaluation of the population - Based on the fitness of the population, corresponding weight can be assigned.
3. Generate offspring - Generate new individuals by applying crossover with parents.
4. Apply mutation to offspring - Evaluating the population. Repeat Steps (3 - 5) until the convergence criterion is reached.
5. The size of the populated is constant.

I. Genetic Algorithm in MATLAB

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces and interfacing with programs written in other languages.

Self-developed MATLAB code for implementing Genetic Algorithm provides full control on the genetic operations such as population, cross over and mutation, and also gives more freedom in developing constraints and penalty methods. In the program coded, the user can specify the size of the population.

The MATLAB also provides a Genetic Algorithm inbuilt tool box which gives a convenient method for doing GA very easily. The GA toolbox is provided with a certain filling ground, where we have to input the objective function, constraints, and upper bound etc. The tool itself provided the GA operation methods such as population, encoding, selection, crossover, mutation etc.

V. RESEULTS AND DISCUSSIONS

Self-created code for Genetic algorithm in MATLAB provides full control on genetic algorithm operations and it also provide freedom in developing constraints. The number of iterations given in the program coding is depend upon the user. The fitness function, selection process and mutation probability are evaluated by the program itself in accordance with its default values. The inputs are given in the optimum tool box, suitable solutions are displayed in the command box. Since GA is a heuristic search algorithm, in each GA operations, we are getting slightly different answers in each trial. 5 trials are carried out, from a set of 5 optimum solutions, the best solution is taken as the optimum value for this problem by checking as it manually while considering the constraints.

The optimum value of release and the storage of the reservoir for each month is obtained. Excess amount of water is set to be spilled if the storage exceeds the maximum storage. Table 2 shows the monthly optimum release, storage and spill.

TABLE 2. MONTHLY OPTIMUM RELEASE, STORAGE & SPILL

Month	Optimum Release (Mm^3)	Storage (Mm^3)	Spill (Mm^3)
January	35.22	16.14	0
February	44.67	12.98	0
March	33.19	15.85	0
April	34.44	16.00	0
May	44.15	7.60	0
June	82.92	32	3.44
July	84.52	32	52.78
August	84.22	32	91.02
September	81.65	32	75.98
October	82.48	31.99	0
November	82.48	32	15.34
December	80.11	18.79	0

A graph was plotted between release in y-axis and months in x-axis. Then the optimum release is compared with the maximum release and minimum release and found that it satisfies the constraints. Fig. 2 shows the graph between the release and time.

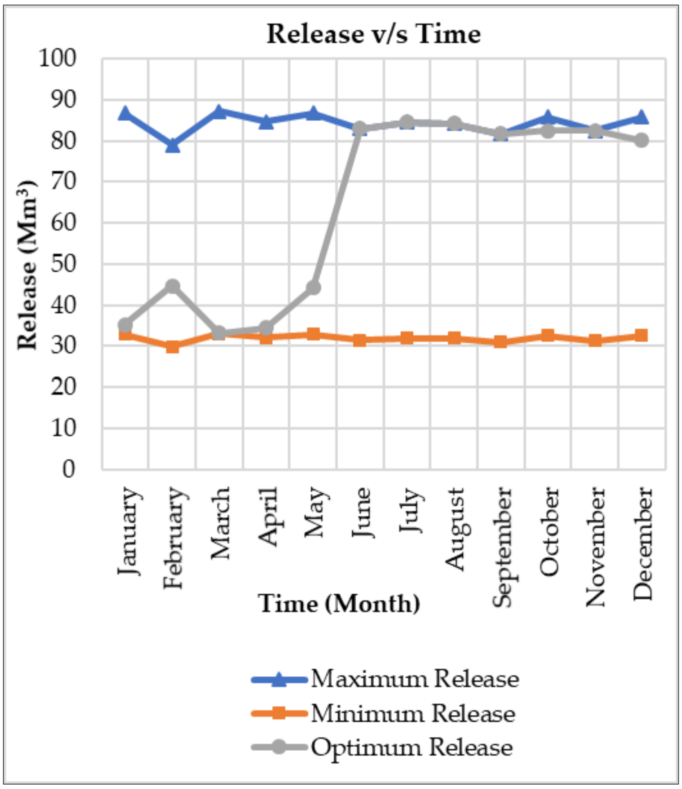

Fig. 2. Graph between Release and Time

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It is clear from the above graph that the optimum release given by the program is less from January to March compared with the maximum release. And it is slightly above the minimum release in April and May. It is so because of less availability of water. But there is a sudden increase in the optimum release from June to December, which is equal to the maximum release because there is high inflow during these months from monsoon, which is directly spilled. Hence the spill water observed in these months indicates the surplus amount of water available to produce more power.

The optimum power that can be produced corresponding to the optimum release was calculated. And we found that the calculated power is maximum compared to the actual power produced there. Table 3 shows the monthly optimum power obtained with optimum release.

A graph was plotted for the power produced with optimum release, firm power and installed capacity. Power is taken in y-axis and months in x-axis. By comparing three powers, it is clear that the obtained power is between firm power and installed capacity. So that it satisfies the constraints. Fig. 3 shows the graph between power and time.

TABLE 3. MONTHLY OPTIMUM POWER

Month	Optimum Power (kWh)	Optimum Power (MU)
January	15707729.48	15.71
February	19728470.79	19.73
March	14722086.11	14.72
April	15210562.53	15.21
May	19674703.54	19.67
June	37439683.64	37.44
July	38687960.77	38.69
August	38687246.12	38.69
September	37439437.32	37.44
October	37175374.14	37.17
November	37435373.37	37.43
December	36107204.12	36.11

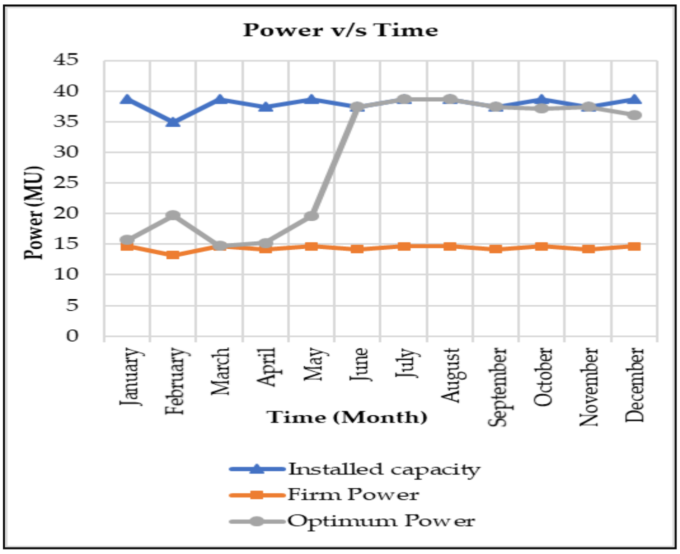

Fig. 3. Graph between Power and Time

It is clear from the above graph that optimum power calculated from the optimum release is less from January to May compared with the installed capacity due to less availability of water. But there is sudden increase in the power which is equal to the installed capacity from May to December due to the availability of surplus water.

The annual power obtained from MATLAB GA Optimtool box was 348.01 MU. Comparing the actual scenario of Peringalkuth dam for 2010 to 2017, the average annual power produced was 248.80 MU. A graph was plotted between power in y-axis and months in x-axis. Then the actual power produced is compared with the optimum power and the results are compared. Fig. 4 shows the graph between power and time.

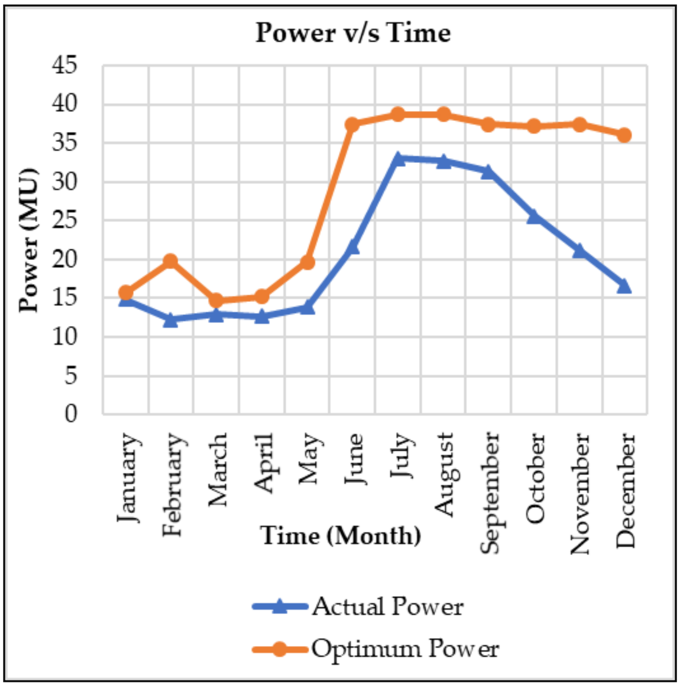

Fig. 4. Graph between Power and Time

From the graph it is clear that, optimum power is more than the actual power produced there. So, we can produce more power according to the downstream demand. From the optimisation, it is clearly identified that, the production of power can be maximized when the system follows this trend of reservoir release.

VI. CONCLUSION

In this study, self-developed GA code is used for deriving optimum operation policy for Peringalkuth reservoir, Kerala, India. The objective is to maximize the annual power by optimizing the release within the constraints. Among the various optimisation techniques, Genetic Algorithm was found to be an effective optimisation tool for the derivation of optimum operational policy. GA model can perform better, if applied in real world operation of the reservoir and it gave a better release and reservoir level as compared to historical operation.

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Using MATLAB, GA code was developed to found optimum release corresponding to each month within the constraints specified. Using this optimum release, the power is maximized. In Peringalkuth Reservoir, the actual power produced is 248.80 MU. But the optimum power calculated is 348.01 MU, which is higher than the actual production. From this, it is clearly identified that, the production of power can be maximised when the system follows this trend of reservoir release and surplus amount of water can be utilized.

It is evident from the study that the optimum power produced is more than the actual power production as there is surplus amount of water. Hence more power production can be achieved from existing power plant. The spill water observed in many months indicates the surplus amount of water even after maximum production limit of existing plant. Hence an additional plant for better utilization of water is recommended for more power production.

ACKNOWLEDGEMENT

The authors would like to thank Mrs. Aswathy J S, Assistant Professor of Civil Engineering Department, Thejus Engineering College, for providing support for conducting this study. We appreciate the data support from Peringalkuth Reservoir, Chalakkudy, Kerala.

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