OPTIMIZATION OF DJUANDA MULTIPURPOSE RESERVOIR OPERATION

THESIS

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JOINT MASTER DOUBLE DEGREE PROGRAM
PARAHYANGAN CATHOLIC UNIVERSITY INDONESIA
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BANDUNG
AUGUST 2017

HALAMAN PENGESAHAN

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OPTIMASI OPERASI WADUK SERBAGUNA DJUANDA

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ABSTRAK

Air telah memainkan peranan penting dalam perkembangan sosial ekonomi dan kehidupan manusia. Manajemen sumber daya air mutlak diperlukan untuk melestarikan sumber daya air terus menerus sejalan dengan pertumbuhan populasi dan peningkatan kebutuhan air. Waduk merupakan salah satu fasilitas sumber daya air dimana menajemen sumber daya air harus diterapkan secara efektif untuk memastikan penyediaan air berdasarkan rancangan fungsi waduk. Waduk serbaguna selalu memiliki masalah yang lebih kompleks dibandingkan dengan waduk fungsi tunggal berkaitan dengan optimasi waduk untuk mendapatkan operasi waduk yang optimal dan efektif. Waduk Djuanda adalah salah satu waduk serbaguna besar di Indonesia. Fungsi utama waduk adalah untuk menyediakan air irigasi, kebutuhan air domestik perkotaan dan industri (DMI), pencegahan banjir dan pembangkit listrik tenaga air (PLTA). Operasi waduk optimal harus memenuhi seluruh fungsi waduk terutama dalam hal penyediaan air dan pecegahan banjir. Optimasi Waduk Djuanda dilakukan dengan pendekatan multi obyektif dengan bantuan perangkat lunak *Microsoft Excel* dengan modul *solver* terintegrasi di dalamnya. Data runtut waktu operasi Waduk Djuanda sejak Tahun 2003-2005 digunakan untuk mengembangkan model operasi tahun jamak Waduk Djuanda. Optimasi dilakukan terhadap realisasi operasi tahun jamak Waduk Djuanda dan pola operasi yang ada. Fungsi obyektif ditentukan untuk meminimalkan kuadrat deviasi antara pasok air dan permintaan dan juga memaksimalkan ketersediaan tampungan banjir tahunan. Beberapa fungsi kendala juga didefinisikan secara bersamaan. Kurva *trade-off* didapatkan sebagai solusi alternatif terbaik berkaitan dengan fungsi obyektif. Kinerja operasi waduk optimal kemudian dinilai dengan membandingkan parameter optimal terhadap parameter yang ada. Parameter optimal menunjukan nilai lebih baik sehubungan dengan fungsi obyektif.

Kata Kunci: Optimasi operasi waduk, optimasi multi obyektif, waduk serbaguna, fungsi obyektif, *trade-off*

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ABSTRACT

Water has played a significant role in socio-economic development and human life. Water resources management absolutely needed to sustain water resources continuously in line with population growth and increasing of water needs. Reservoir is one of water resources facility where water resources management must be applied effectively to ensure provision of water based on designed function of reservoir. Multipurpose reservoirs always have more complex problems than single purpose reservoirs related to reservoir optimization in order to get optimal and effective operation. Djuanda Reservoir is one of large multipurpose reservoir in Indonesia. The main functions of reservoir are to supply irrigation water, water needs for domestic municipal and industrial (DMI), flood regulator and hydropower. Optimal reservoir operation must satisfy all functions of reservoir especially in terms of water supply and flood regulator. Optimization of Djuanda Reservoir is conducted by multi objectives approach using assistance of Microsoft Excel program with solver module embedded. Time series data of existing Djuanda Reservoir Operation since Year of 2003-2005 is utilized to develop multi-year Djuanda Reservor operation model. Optimization is conducted to realization of multi-year Djuanda Reservoir operation and existing rule curve. Objective functions are determined as minimizing squared deviation of water release and demand also maximizing annual flood storage availability. Some constraints are defined simultaneously. Trade-off curve is obtained as the best alternative solution regarding to objective functions. Optimized reservoir operation performance then have been assessed by comparing the optimized parameters against the existing ones. The optimized parameters demonstrate the better value corresponding to objective functions.

Keywords: Reservoir operation optimization, multi objective optimization, multipurpose reservoir, objective function, trade-off

PREFACE

Reservoir operation optimization has become concern in water resources management. In order to achieve water efficiency and sustainable conservation of water resources, reservoir operation optimization is necessitated to deliver the best solution among existing objectives. While certain objectives must be gained the other ones could not be neglected. The best compromise is offered by the optimization method to accommodate certain objective without sacrificing the other objectives. This research is conducted in Djuanda Multipurpose Reservoir where the author currently works. The author wishes this research would be one of alternative solutions for policy maker regarding to Djuanda Reservoir operation policy.

Eventually, the author is grateful to the Great Allah SWT and the beloved family that support the author finishing the research. In this chance, the author would also like to thank to these parties:

1. The author's supervisors Mr. Doddi Yudianto, Ph.D and Prof. Zhang Xiuju, Ph.D for their kind attention and patience to direct and advise the author during research.
2. The gratitude is also delivered to Prof. R.W. Triweko, Mr. Salahudin Gozali, Ph.D and Mr. Bambang A.R. M.Eng as reviewer lecturers that have given valuable comments and advise to improve this research output.
3. Head of Civil Engineering Study Program of Parahyangan Catholic University Graduate School.
4. Head of College of Hydrology and Water Resources Hohai University China.

5. Director and Assistances Director of Parahyangan Catholic University Graduate School.
6. Dean of International School of Hohai University China.
7. Secretariat members of Parahyangan Catholic University Graduate School for their kind services and cooperation.
8. International School members of Hohai University China.
9. The Board of Director of Jasa Tirta II Public Corporation and their staffs that have put their thrust and waited for the author finishing the study at Parahyangan Catholic University and Hohai University.
10. The author's colleagues that have supported the author anytime needed.
11. All people have contributed to this research.

The author would like to receive pleasantly of any valuable comments and constructive input to improve this research.

Bandung, August 2017

The Author

Rahmat Sudiana

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CHAPTER 1 INTRODUCTION

1.1 General Background

Water has played a significant role in socio-economic development due to the magnitude and widespread occurrence of its positive and negative effects. The quality of human life is directly dependent on how well these resources are managed. Water management activities are intended to enhance the positive contributions of water or control its negative effects (Nandalal, et al., 2007). Water becomes a prime natural resource, its essentiality and need is getting increased constantly. The management of water is decisive keeping in view the assessment and the availability and utilization. It needs proper planning and efficient management of water is foremost for development of a country (Mythili, et al., 2013).

Providing water to consumers is a concern of how much water needed to be delivered and where is it. Due to increasing demand and decreasing of water resource quality, the sustainable and efficient provision of water has become a complex work of considering numerous resources of traditional and alternative water resources and watershed management tools for affecting the quantity, quality, routing and use of water as it flows throughout the watershed (Titcomb, et al., 2006). Water allocation issues in the basin context are related to spatial heterogeneity of water availability, water storage and water conveyance facilities, water demand, and water management institutions along the main channel and the tributaries (Yang et al., 2012).

The history of man-made reservoirs can be traced back to antiquity. Perhaps at the beginning the ‘‘water reservoir’’ was no more than a huge tank to store water during the wet season for use during the dry season. Today, with the development of civilization, reservoirs can be found all over the world (Nandalal, et al., 2007). According to Takeuchi (2002), there are presently about 40,000 large reservoirs in the world impounding approximately 6000 km^3 of water and inundating an aggregate area of 400,000 km^2. Recent surveys show that this number increases at a rate of approximately 250 new reservoirs each year. These figures clearly reflect the fact that reservoirs, irrespective of their interference in the aquatic ecosystem of the respective watercourse, have a firmly established position in our striving to harness and manage the available water resources.

The reservoirs can serve single or multiple purposes including hydropower generation, water supply for irrigation, industrial and domestic use, flood control, improvement of water quality, recreation, wildlife conservation, and navigation. The effective use of reservoir systems has become increasingly important. Next to the exigency of the rational use of a limited resource, a better-managed reservoir may make the physical extension of the system – to add new reservoirs – unnecessary. The operation of a single reservoir for a single function does not present many analytical problems, but the same is not true when a reservoir fulfils a number of potentially conflicting objectives or where several reservoirs are operated conjunctively (Nandalal, et al., 2007).

Water resources systems are planned to attain a number of objectives or goals some of which may conflict with one another. The multi-objective approach offers procedures for the generation of non-inferior alternatives and for structured interactions between decision-makers and modellers. The resolution of conflicting objectives requires appropriate organizational and legal structures which ensure also the implementation of effective management policies (Buras, 1982). Multi-objective optimization problems represent an important class of real-world optimization problems. Typically such problems involve trade-offs. For example, in the case of a multi-purpose reservoir, which mainly serves hydropower and irrigation as key purpose, the reservoir operator may wish to maximize benefits from hydropower generation, while releasing sufficient water for irrigation to meet the demands. These objectives are typically conflicting with each other. A higher profit from hydropower generation would decrease the irrigation releases (Reddy and Kumar, 2006).

Water resources management is multi-objective optimization problem. It is difficult task to estimate reservoir operating policies that maximize all the benefits provided by these reservoirs and also minimize their contrary impacts. It is complex decision making process which will involve a number of variables, risks, uncertainties and also conflicting objectives. Reservoirs serve many purposes. They are used to drive turbines generating electricity; they also are used to supply water for irrigation, city and industrial uses and also for flood protection. Reservoirs may be built to satisfy a single purpose or multipurpose. Some of the purposes are conflicting in nature. For example for power generation, the reservoir should be as full as possible to increase the head, whereas for flood protection, it should be emptied to provide for maximum storage of flood water if flood occurs (Adeyemo, 2011).

Reservoirs optimizations have been developed from time to time. It indicates that reservoir optimization playing an important role in order to achieve water management efficiency and affectivity. A lot of algorithms have been developed to optimize reservoirs operations based on certain needs and condition of reservoirs. In 1977, The Monte Carlo Approach has been applied to optimize of the operation rules for a storage reservoirs system (Kindler, 1977). Hydroelectric power systems in multi-reservoir could be optimized by differential dynamic programming (Gjelsvik, 1982). Optimization of reservoir addressed for irrigation provision has been described by e.g. Schmidt, et al. (1983) and Raju, et al. (2012). Optimum multi-objective reservoir operation for flood control and ecology has been demonstrated by Ditmann, et al. (2007). An artificial fish swarm algorithm has been used by Peng (2011) to optimize cascade reservoirs operation. Accommodating more complex reservoir operation within multi-objective function, some of multi-objective algorithms have been developed in order to overcome such complex problems. Multi-objective differential evolution algorithm for engineering problems has been introduced by Adeyemo, et al. (2009). Evolutionary algorithms are stochastic search algorithms which have many applications in water resources management (Adeyemo, 2011). Zhao, et al. (2012) has improved dynamic programming for reservoir operation optimization with a concave objective function. Azmeri, et al. (2013) used genetic algorithms to determine cascade reservoir operation for optimal firm-energy whilst Andrea (2014) applied implicit stochastic optimization techniques for multi-reservoir water systems under drought conditions. Peng, et al. (2014) used multi-objective optimization model for coordinated regulation of flow and sediment in cascade reservoirs. Multi-objective optimizations of reservoir systems using public domain software as tools e.g. Hec-ResPRM have been conducted by Faber and Harou (2006) and also Faber and Harou (2007).

1.2 Problem Definition and Limitation

The Reservoirs of Saguling, Cirata, and Djuanda operated in series or cascade. They are known as Citarum Cascade Reservoirs System. Saguling Reservoir is located in the most upper course of the system while Cirata Reservoir is located in the middle course of it. Djuanda Reservoir is located in the lowest course of cascade reservoirs system. Saguling reservoir releases water as become inflow for Cirata Reservoir meanwhile Djuanda Reservoir gets inflow from Cirata Reservoir's water releases. There is "equilibrium pattern of Citarum Cascade Reservoirs" applies in the operation of Citarum Cascade Reservoirs. This is to maintain the percentage of effective storage distribution volume in every end months of the three reservoirs always in equal portion condition (Legowo, et al., 2009).

Citarum Cascade Reservoirs is a complex reservoir, besides structurally different, the three reservoirs also have a definitely contradicted management system. Saguling and Cirata are designed for hydropower plants as single purpose reservoirs but Djuanda is designed as a multipurpose reservoir. All reservoirs rely on same resources, consequently this condition has considered addressing management and operational problem. In order to obtain the optimal reservoir operation, it would require complex algorithms for Citarum Cascade Reservoir. Therefore, an approach toward new management and operation system are urgently required in order to achieve effective and efficient outputs (Azmeri, et al., 2013).

Figure 1.1 illustrates the situation of Djuanda Reservoir at Citarum Cascade Reservoirs where this research would be conducted. Loebis and Syariman (1993) stated that since all reservoirs have to be operated jointly, the problem of water regulation appears especially during the dry season. In this case, the Djuanda Reservoir suffers an inferior condition where there is no natural inflow entering the reservoir. Opposite condition takes place during wet season where Djuanda Reservoir has to retain abundant discharge water not only from Cirata outflow but also from local inflow originated from two rivers directly flow into reservoir. This is a consequence where Djuanda Reservoir located at the lowest course of Citarum cascade reservoirs system. Until now, the severest flood has ever occurred in Djuanda Reservoir operation history is in 2010 while reservoir water level elevation reached until +108.40 m.asl (spillway crest at +107.00 m.asl) with maximum spill discharge of 449.63 m^3/s and total outflow 676.09 m^3/s. Over spilled condition took place along 42 days while reservoir water level elevation higher than +107.00 m.asl. Figure 1.4 illustrates Djuanda Reservoir water level in 2010 during flood event.

Technically, electric energy production may put into optimum in the Saguling and Cirata Reservoir but not in the Djuanda Reservoir, since the Djuanda is also responsible for irrigation, drinking water, industrial water and flushing purposes. In this case, Djuanda Reservoir has to serve more objectives than the others (Loebis and Syariman, 1993).

Based on above conditions, it reflects how important reservoir operation optimization in Djuanda Multipurpose Reservoir itself that must function as water provider, power generator and flood regulator. Although Citarum Cascade Reservoirs System has a general rule curve that apply for all reservoirs, it is important to optimize Djuanda Multipurpose Reservoir operation as one of Citarum Cascade Reservoirs in order to deliver more alternative solutions related to operation problems especially for decision maker or policy maker. The optimum design of any system is dependent not only on the objectives and related specifications, but also on the probable operating policy applied by policymakers. The analysis of operating policies for optimal output of a given reservoir system can therefore deliver as the logical basis for developing the optimal design. Factually, operating policy is a requisite component of every reservoir simulation model (Nagy, et al., 2002). Based on this, the research would then be conducted on Djuanda Reservoir operation only without involving the upper course of cascade reservoirs (Saguling and Cirata reservoir). In this case, Cirata Reservoir outflow and two local rivers inflow are assumed as Djuanda Reservoir natural inflow.

1.3 Description of Study Area

Location of study located at Djuanda Reservoir in Citarum River West Java Indonesia. Citarum River decided by the government as one of national strategic river basin in Indonesia. Citarum River Basin consists of three major reservoirs i.e. Saguling Reservoir, Cirata Reservoir and Djuanda (Jatiluhur) Reservoir. These reservoirs operated by different parties with their own operation objectives respectively. Saguling and Cirata Reservoir known operated by subsidiary of State Electric Company (PT. Indonesia Power and PT. Pembangkitan Jawa Bali) under parenthood of Ministry of Energy and Mineral Resources. Djuanda Reservoir operated by State Owned Company (Jasa Tirta II Public Corporation) under parenthood of Ministry of Public Works. Saguling and Cirata Reservoir concern in power generation only (single purpose) meanwhile Djuanda Reservoir acting as multipurpose reservoir as many objectives must be achieved simultaneously. Its main roles are providing irrigation water supply, Domestic Municipal and Industrial (DMI) water supply, flood control, hydropower generation, and fishery. The location of Djuanda Reservoir can be illustrated in Figure 1.1.

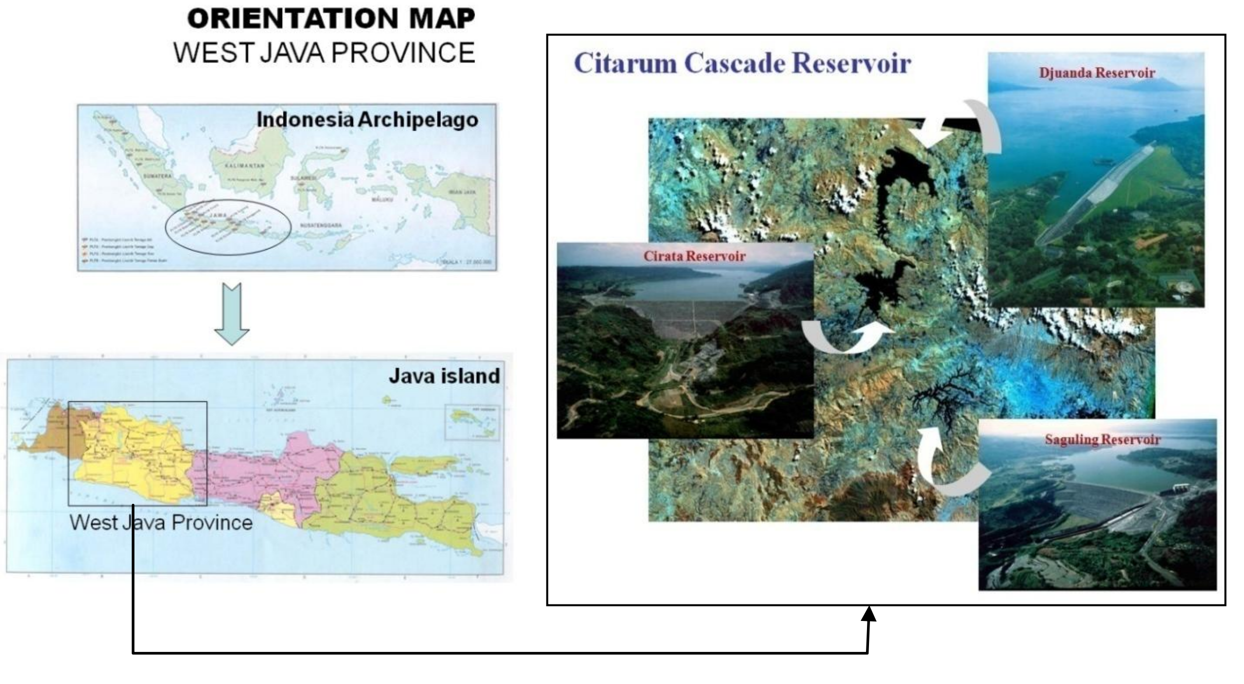

Figure 1.1 Location of Djuanda, Cirata and Saguling Reservoir at Citarum River (Jasa Tirta II Public Corp)

1.4 Research Objectives

This research aims to optimize Djuanda Reservoir operation in multi objective mode. Along one or more reservoir operated in multi objective, there will always be some contradictions among different objectives. Thus the research conducted to optimize operation of the reservoir as their objectives can be optimally achieved by giving optional best trade-off among several objectives. Specifically the objectives of this research described as follow:

1. Evaluating realization of Djuanda Reservoir multi-year operation.
2. Simulating Djuanda Reservoir multi-year operation based on realization of Djuanda Reservoir multi-year operation.
3. Optimizing Djuanda multipurpose reservoir operation with multi objective optimization approach in order to give the best trade-off options. The Objective functions are minimizing deviation between water releases and demand also minimizing flood risk by increasing flood storage capacity.
4. Analyzing the results of Djuanda Reservoir operation generated by the optimized model within several year operations. In this step, optimized model performance based on objective functions and constraints would be assessed according to the best trade-off criterions.
5. Simulating optimized Djuanda Reservoir operation by considering downstream water demand increment.

1.5 Urgency of the Research

Optimization in Djuanda Reservoirs needs to sustain water resources in Citarum River Basin as well. While the needs of firm energy must be available in majority supplied by Saguling and Cirata Reservoir, the other ones cannot be neglected. Water supply for irrigation, drinking water, industrial water etc should be provided appropriately. Figure 1.2 and Figure 1.3 describe water utilization in Citarum River Basin Year of 1990-2013 whence trend of industrial and domestic needs growth in positive number. Water utilization for irrigation purpose does not relatively increase but fluctuating in certain range (Idrus, et al., 2012). Along 1990-2013 irrigation water has been utilized annually at minimum 4.30 billion m3 and maximum 6.55 billion m3. It is reasonable that irrigation area would not possibly increase otherwise decreasing because of land use changes. Increasing of industrial and domestic water needs must be considered as challenges in the future water resources management and should be anticipated immediately. These great challenges actually become concern not only for the government but also whole stakeholders.

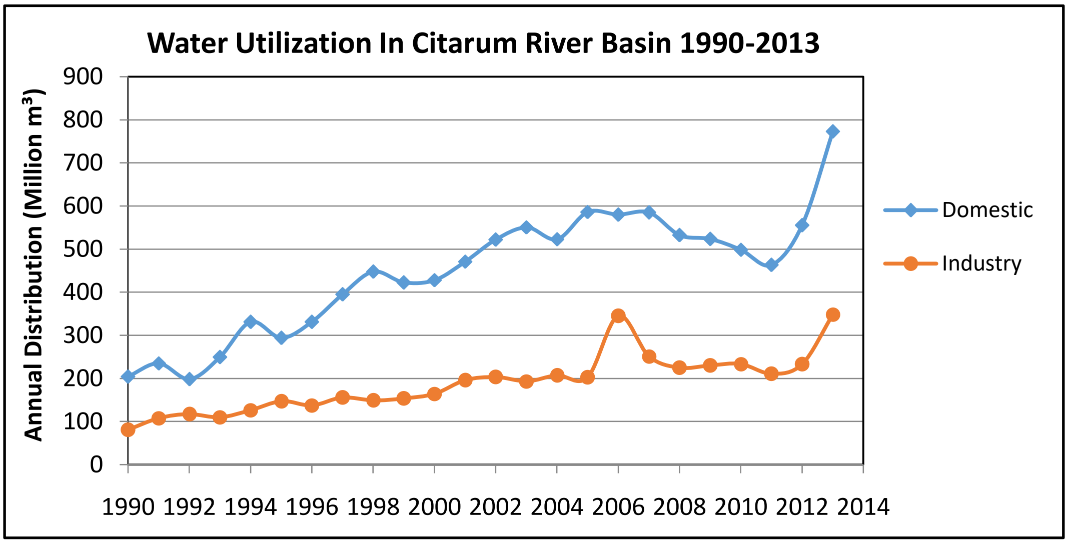

Figure 1.2 Water Utilization In Citarum River Basin 1990-2013 (Jasa Tirta II Public Corporation)

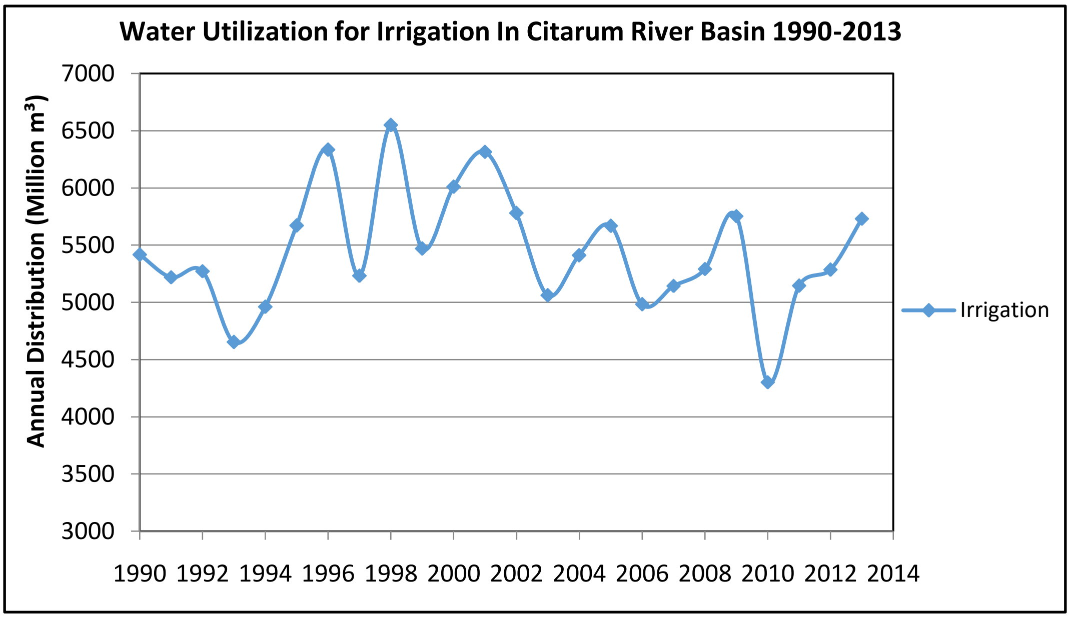

Figure 1.3 Water Utilization For Irrigation In Citarum River Basin 1990-2013 (Jasa Tirta II Public Corporation)

Lesson is learnt from 2010 flood phenomenon when Djuanda Reservoir over spilled and causing flood event in the downstream area particularly at Karawang Regency and surrounding region (https://nasional.tempo.co, accessed on 3/8/2016). Government reported the losses in the Karawang Regency itself reached until USD 200,000,000 (Surachmat, et al., 2012). In that time, flood event became worse because Cibeet River (local river at Karawang as Citarum tributary) also flowed in peak discharge condition. Djuanda Reservoir is completed with ungated spillway structure therefore when spilled water flow over spillway crest, it cannot be controlled properly. Because of this event, economic losses had been incurred including rice fields inundation then causing crop failure, infrastructure damage, health and sanitary problems, disconnected transportation et cetera. Water level in Djuanda Reservoir during 2010 flood event is depicted in Figure 1.4.

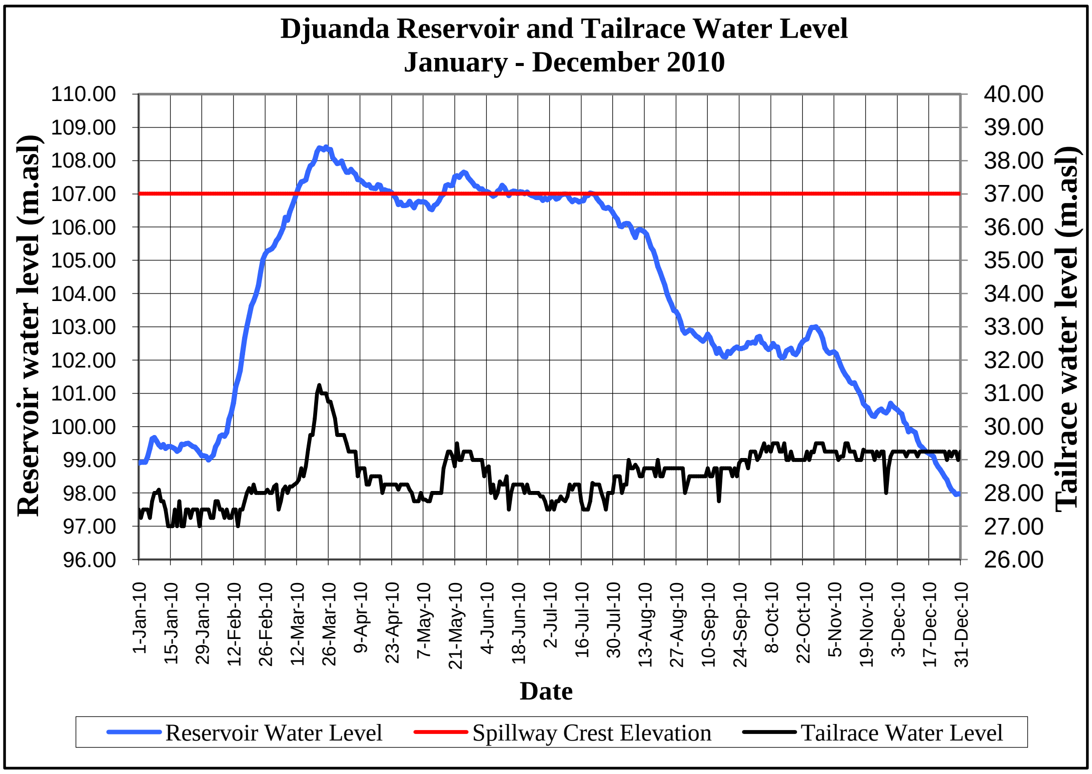

Figure 1.4 Djuanda Reservoir Water Level in Year of 2010 (Jasa Tirta II Public Corporation)

Optimizing Citarum Cascade Reservoirs using genetic algorithm has been conducted by Azmeri et al. (2013) concerning in firm energy production from 3 (three) cascade reservoirs (Saguling, Cirata and Djuanda) with objective function of maximizing total firm energy and applying several complementary constraints. This optimization cannot be implemented absolutely since Djuanda Reservoir is a multipurpose reservoir in terms energy generation is not its main objective. The main objective of Djuanda Reservoir is to fulfill downstream water needs i.e. irrigation, domestic, municipal and industrial. Therefore multi-objective optimization needed to achieve optimal solution among several objectives. In this research multi objective approach optimization would be applied whence multi-objective functions and several constraints also concurrently applied.

1.6 Research Methodology

A series of literature reviews has been conducted continuously in order to obtain sufficient information and recent knowledge for supporting the research. A lot of researches provide much knowledge about multi-objective optimization of reservoir operation. Previous researches about Citarum Cascade Reservoirs significantly contribute input to this research.

Data collection is activity to support this research and being conducted simultaneously with literature reviews. Data have to be collected such as characteristics of reservoir and hydropower plant, water allocation plan and realization, time series data of multi-year reservoir operation, precipitation, evaporation, inflow and outflow et cetera. Simulation and optimization with multi-objective functions is used in order to satisfy downstream water needs, minimizing deviation between releases and demand also minimizing flood risk by increasing flood storage capacity. The constraints are limitation of minimum reservoir water level due to safety issue, daily depletion of reservoir water level and limitation of maximum reservoir water level to prevent spilling. The optimized multi-year reservoir operation would be simulated and assessed whether it has satisfied certain criterions. The results of simulation would then be compared with the observed multi-year reservoir operation respectively. Performance of optimized model would be assessed by decided criterions related to the objective functions. After analyzing and assessing the model operation performance, if it meets decided criterions then would be the optimal reservoir operation model and able to be properly considered as one of solutions. If there is any unsatisfactory condition, the operation model must be optimized again until delivering desired results. This research would be conducted by using assistance of spread sheet program (Microsoft Excel) with Solver Module embedded. The flow chart of research could be scrutinized in Figure 1.5.

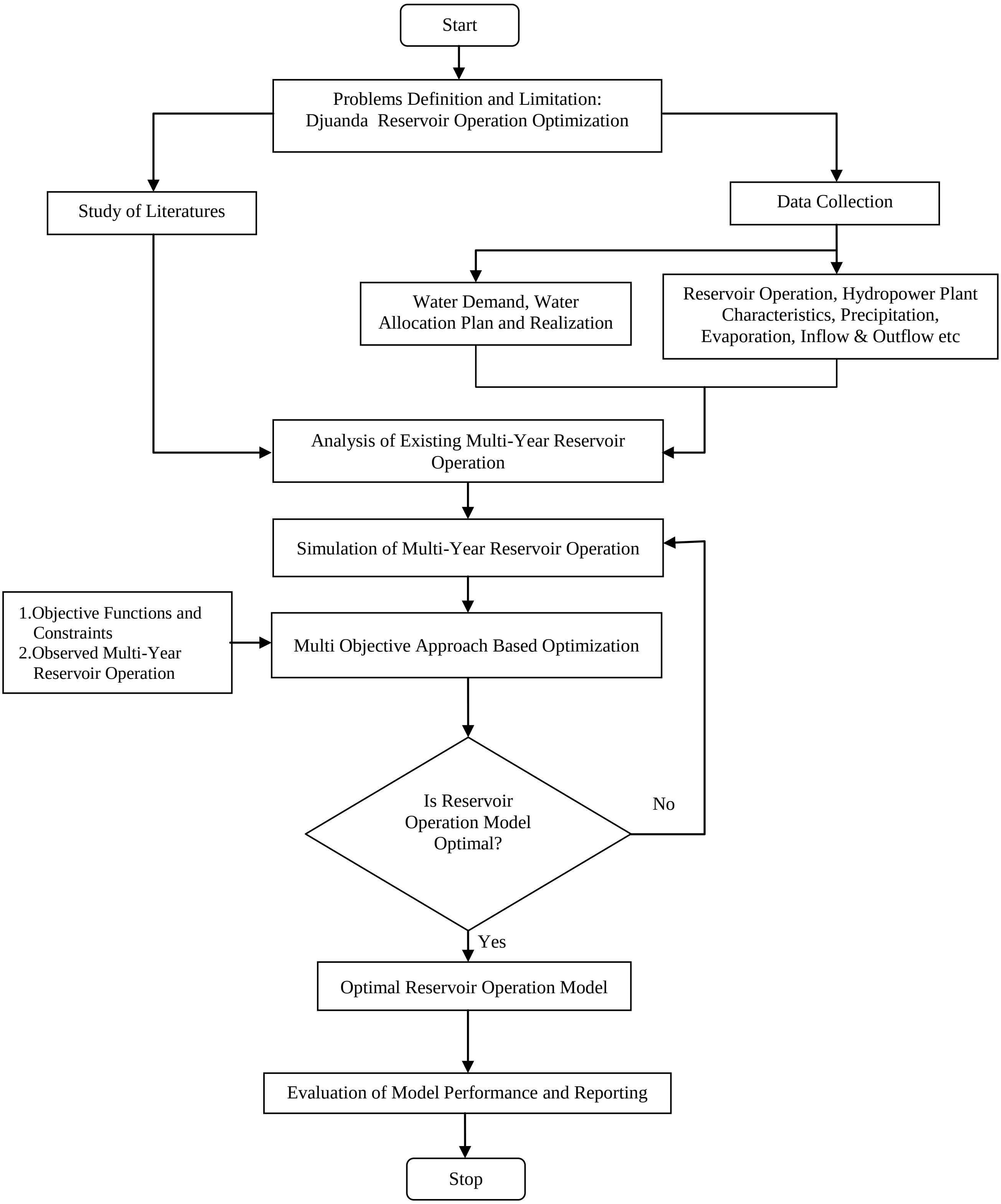

Figure 1.5 Methodology of Research Works