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Optimum Fresh Water Price at TITAB Reservoir, Bali Province of Indonesia

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ABSTRACT

The watershed at Titab dam of Buelleng regency at Bali Proince was approximately 69.54 km^2 with river length of 25 km. The project of Titab Dam was functioned to supply water irrigation at Saba and Puluran with each number area of 1396.40 ha and 398.42 ha; drinking water and hydro electrical power of 3.15 MW. This paper studied the fresh water price at Titab Dam due to the rule and human need after building the reservoir. The research method was consisted of simulation and optimization due to Benefit-Cost Ratio. Result showed that population of Buleleng Regency in the year of 2025 was predicted as 2,343,380 persons and it was used as the basic of analysis. Net benefit of water need in the year of 2025 was Rp. 130,680,082.750. It was based on Benefit Cost Ratio (BCR) with Internal Rate of Return was 12%. The optimization result presented that existing drinking water price was Rp. 800.-/m^3 and the maximum price was Rp. 5,500.-/m^3, but simulation result showed that existing drinking water price was Rp. 982.-/m^3 and the maximum price was Rp. 5,695.-/m^3. The result was used as the consideartion for decision maker on determining water price at study location so that ratio of benefit and cost was more than one.

Keywords: optimization, simulation, net water price, Titab reservoir.

INTRODUCTION

Million of people in the world were directly on functionong watersheds which provided such as drinking water, energy, irrigation, and fishery. Mistakes in determining the priority and plan of watershed could had great and serious ramification [1]. The challenge of how to plan and manage water resources was one of the greatest on our time. To increase demand for multiple users of water, recognition of flow requirements, and an interval of other values were added to the challange [2]. Tools that combined analytical and deliberative capacities were used in the process of water planning and management in various parts. Some countries were moving towards water sector reforms. Hence, practical issues of how water management institutions could give better regulation and allocation of water rights had emerged [3]. The reliability of access or equivalent with the uncertainty which associated with water availability at their diversion point became a parameter that was similarly to influence the application by users for water licenses, as well as their willingness to pay for licensed used [4][5]. Water was also become as an international traded commodity[6], in which international tradeoffs were observed and maintained through country commitments as regards the global commitment to sustainable development [7].

Models of water distribution could developed using either an optimization or a simulation approach. Many systems which studied water resources management, was focussed on the global policy results of large-scale systems However, the tendency of current research was specifically modelling the systems, with more emphasis on quantitative results. Some researchers formulated an appropriate strategy that stroke a balance between mitigating of water shortages and limit total of financial costs.

The objective of this study was to determine fresh water price at Titab Dam due to the rule and human need after building the reservoir. Simulation and optimization due to Benefit-Cost Ratio was used to analyze this research. Result was hoped as the consideartion for decision maker on determining water price at study location.

MATERIALS AND METHODS

Titab reservoir was located at Sub unit of River Basins (Sub SWS) of Bali Penida, Buleleng Regency and it was adminitratively concluded 4 villages including Telaga, Ularan, Busungbiu, and Ringdikit. The number area of watershed at dam location was 69.54 km^2 with tiver length of 25 km. Titab Dam was functioned as 1) Water irrigation supply at Saba with number area of 1,396.40 ha and Puluran with number area of 398.42 ha; and 2) drinking water supply and hydro electrical power of 398.42 ha. Map of location was as in Figure 1 below.

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Figure 1 Map of Location

Based on the objective of water demand as described above, the dam was designed with the height of 59.8 m from river bed, effective storage of 10.37 millions m^3 that was between High Water Level (HWL) at elevation of 156.00 m and Low Water Level (LWL) at elevation of 131.20 m. The condition of water supply at North and East of Bali was not good compared with at West and Centre of Bali. It caused rice field at North of Bali was dependent on rain and traditional irrigation. On the other hand it was demanded to optimize the potency of water resources due to that some population had saved their income from agriculture and plantation.

Nowadays, fresh water demand at Buleleng was needed for fullfiling the needs of domectic and industry that was 15 m^3/s. This data was recorded by Regional Company of Drinking Water (PDAM) at Buleleng Regency. It was predicted continously increasing in the future as well as the development of Buleleng Regency. There was alternative effort to anticipate this cases that was to function groove of Tukad Saba as long storage for fresh water storage. This long storage was made by building Titab reservoir at the downstream of Tukad Saba river.

Some data were needed in this study those were 1) technical data of Titab reservoir and the facility of water management; 2) data of construction cost and life time of structure; 3) data of rainfall at Tukad Saba watershed; 4) data of irrigation number area at Tukad Saba watershed; 5) data of cropping pattern at Tukad Saba watershed; 6) data of river discharge at Tukad Saba from the year of 2005 until 2010; 7) population of Buleleng Regency from the year of 2005 to 2010; and 8) number of industry at Buleleng Regency from the year of 2005 to 2010. The procedure on obtaining fresh water price in this study were as follow:

1. To calculate construction cost based on technical data of Titab reservoir.
2. To analyze cost based on construction cost, operation and maintenance cost, and life time of structure.
3. To predict the projection of population in the year of 2025.
4. To analyze fresh water demand based on the projection of population.
5. To analyze fresh water demand due to existing water source for detecting what the source could be enough or not for supplying until the year of 2025.
6. To analyze water production from water usage leval of Binangun District so that was obtained benefit value.
7. To determine net water price according to the result of economical analysis.
8. Public Electrical Company (PLN) carried out analysis on system of electrical interconnection and electrical price of PLN at Buleleng Regency.

Water price of irrigation in this study was determined by following the procedure as follow: 1) To calculate total cost of Titab Reservoir Project based on the cost of construction, operation and maintenance; 2) To analyze net benefit during economical age of project; 3) To analyze ratio of benefit-cost (B/C ratio), Internal Rate of Return (IRR), and sensitivity analysis; and 4) To analyze water price of irrigation. Simulation and optimization of water price in this study could be carried out too after finishing these analysis as above.

Simulation of Reservoir Operation

Mass storage equation was used to simulate the reservoir operation. The formula was as follow [8]:

$$Z_{t+1} = Z_t + Q_t - D_t - E_t L_t \quad \text{.......} \quad (1)$$

(subject to $0 \leq Z_{t+1} \leq C$)

Note;

Z_{t+1} = storage volume at the end of t period (initial storage at (t-1) period
Z_t = initial storage at t period
Q_t = inflow during t period
D_t = release during t period
E_t = losses of net reservoir evaporation during t period
L_t = other losses
C = active storage capacity

Usage age of reservoir

Usage age of reservoir was determined by the formula as follow [8]:

$$T = \frac{V}{Lj} \quad \text{(2)}$$

Note:

T = usage age of reservoir (year)
V = reservoir capacity (m³)
Lj = sediment rate (m³/year)

Hydro electrical power

Generated power of hydro electrical power was analysis using the formula as follow [9]:

$P = 9.81 \text{ x } Q \text{ x } H_{eff} \text{ x } Eff$……………………………………..…......................…….(3)

Note

P = generated power (kW)
H = effective head (m)
H_{eff} = electrical generated discharge (m³/s)

Time value of money

a. Future value factor
$F = P_o (1+ i)^n$ ……………………………………………………………....… (4)
Note: $(1+ i)^n$ = compounding factor (F/P), so the formula was written as:
F = Po (F/P, i%, n)
b. Annual payment
F = A (F/A, i%, n) …………………………………………………………..…. (5)
c. Sinking Fund Factor
A = F (P/F, i%, n) ……………………………………….......…………… (6)
d. Present Value Factor
P = F (P/F, i%, n) …………………………………………….....………… (5)
e. Present value of annuity Factor
P = A (P/A, i%, n) ……………………………………………………....... (7)
f. Capital Recovery Factor
A = P (A/P, i%, n) ……………………………………………………….….. (8)

Indictor of feasibility economy

Indicator of feasibility economy was formulated as follow [10]

a. Net Preaent Value (NPV)

$$P = \frac{F}{(1+i)^n} \quad \text{(9)}$$

Note

P : present value
F :future value
I : rate of interest

b. Benefit Cost Ratio (BCR)

$$BCR = \frac{\text{PV benefit}}{\text{PV cos}} \quad \text{(10)}$$

Note

PV : present value
BCR : benefit cost ratio

c. Internal Rate of Return

$$IRR = I' + \frac{NPV}{NPV' - NPV''} \quad \text{...} \qquad (11)$$

Note

I' : rate of interest with NPV > 0
I" : rate of interest with NPV < 0
NPV : net present value
NPV' : NPV >0
NPV" : NPV <0

RESULTS AND DISCUSSION

Projection of population growth was predicted using exponential method that was $P_n = P_0 . e^{r.n}$, P_0 was as the number of population in the year of 2010, n was years projection, r was rate of population growth, and P_n was population in the projection of year. Projection of population growth was presented as in Table 1.

Table 1 Projection of population growth at Buleleng Regency

No	Year	Number of population
1	2011	917,400
2	2012	980,958
3	2013	1,048,920
4	2014	1,121,589
5	2015	1,199,294
6	2016	1,282,382
7	2017	1,371,226
8	2018	1,466,225
9	2019	1,567,807
10	2020	1,676.425
11	2021	1,792,569
12	2022	1,916,759
13	2023	2,049,554
14	2024	2,191,548
15	2025	2,343,380

The goodness of fit test on projection method used coefficient of correlation. The result showed that the coefficient of corelation for exponential method was approximate to +1. It indicated that this method was suitable for prediction population growth at location of study.

Economical analysis

Analysis of Benefit-Cost Ratio was carried out based on interest Bank of Indonesia of 12% in 2008 and life time of Titab Reservoir was 60 years. It was obtained total of cost at present was Rp 774,848,487,402.-; and benefit was Rp. 130,680,082,750.-; so that analysis of BCR was as follow:

$$BCR = \frac{Rp1,087,781,088,814}{Rp774,848,487,402} = 1.404 > 1$$

B/C of Titab reservoir was more than 1 (> 1), it could be said that this project was economically feasible or the project exeeded the break event point.

The second method used in economical analysis was based on Net Present Value (NPV) or the difference between Benefit and Cost (B-C). In this method, interest rate had to be more than zero (> 0). If NPV = 0, it meant that the benefit of project was the same as investation cost. If NPV < 0, it meant that the project economically was not feasible to be built [10]. The result of analysis for this method was as follow: benefit at present was Rp 1,087,781,008,814.-; total of cost was Rp 774,848,487,402.-, so that the difference between benefit and cost (B – C) was Rp 214,043,338,793.-.

Internal Rate of Return (IRR) was defined as level of interest rate which made benefit and cost had the same value or B – C = 0 or B/C = 1 [10]. Based on the 10^{th} equation as above, it was obtained the IRR as follow: NPV' = positive = 90,725,222,039; NPV" = negative = -7,083,128,664; so

$$IRR = 14\% + \frac{90,725,222,039}{(90,725,222,039 - (7,083,128,664)}(14\% - 15\%) = 14\% + 0.93\% = 14,93\% > 12\%$$ (the standard of interest that was used in this study)

The sensitivity analysis was intended to know what matter with the project result if there was the possibility of changes in determining on the value of benefit and cost, and it was just as an estimation. Therefore there were some asumptions which were not the same as real condition. In this study, it was carried out for the conditions as follow: [11]

- Cost was up to 10%, benefit was remain
- Cost was down to 10%, benefit was remain
- Cost was remain, benefit up to 10%
- Cost was remain, benefit was up to 10%
- Cost was up to 10%, benefit was down to10%,
- Cost was down to 10%, benefit was up to 10%

Analysis of fresh water price

The analysis of fresh water price was due to the most critical condition when benefit was down to 10% and the cost was up to 10%, so that minimum water sale price could be charged to consumers and project of Titab Reservoir was really feasible. At this condition: B/C = 1.126; B-C = Rp 256,754,029,530.-; IRR = 15.203%; rate of interest = 12%; the average of fresh water demand = 0.493 m^3/s; fresh water demand per-year = 0.493 x 365 days x 24 hours x 60 minutes x 60 seconds = 15,547,248 m^3/year. Then fresh water price was as follow

$$= \frac{Rp.256.754.029.530}{15.547.248 X (8.324) X (1.1761)} = \text{Rp. } 1{,}127/\text{ m}^3$$

The electrical services at Buleleng Regency was carried out by Public Electrical Company (PLN) of Singaraja. Source of electrical supply to Public Electrical Company of Buleleng was as interconnection from some hydro electrical power of Java-Bali. Cost on operation and maintenance of hydro electrical power at Titab Reservoir was estimated by River Basins Public of Bali Regional Government (BWS Bali Pemda) as follow: Rp. 1,752,065,073.-.

Depreciation value was influenced by interest and life time of project. Based on interest of 12% and life time of project of 60 years, it was obtained SFF value = 0.00013 and the depreciation was 0,00013 x Rp. 11,425,875,700 = Rp.1, 485,363.-

Yearly annual cost was included analysis of constant yearly cost during life time of project and not for inconstant annual cost. For this study:rate of interest was 12%, depreciation was Rp. 1,485,363.-; cost of operation and maintenance was Rp. 1,752,065,073.-; so that annual cost was Rp. 3,124,655,520.-. Therefore the average of price could be calculated. Rate of each customer of social was 466.60; household was 758.80; business was 758.80; industry was 589.00; government and lighting of public road was 792.00. Total of average value per-kWh for 1 month was 663.042. According to basic value as above, Public Electrical Company (PLN) estimated for the usage of Block I was Rp. 663,042.-. So that the income per-kWh for 1 year was 12 x Rp 663,042 = Rp 7,956.-.

Analysis of electrical price

The life time of hydro electrical power project was 60 years and interest rate of 12%. Project cost of Titab Reservoir for hydro electrical power was Rp. 11,425,875,700.00; annual cost of Titab Reservoir for hydro electrical power (A/P, 12, 60) was Rp. 1,372,642,444-; cost of electrical energy per-kWh was Rp. 2416,-; value of electrical sale at Block I was Rp. 663,042; benefit of electrical energy per-kWh was Rp. 1,752.-; Benefit of electrical energy per-year was Rp 995,036,136.00

Benefit of agriculture

Benefit of project was obtained from the increasing of agricultural product before and after project building of Titab Dam. This kind of benefit was as tangible one. Cropping pattern included rice-second crop-wine was planned at location of study. Effective rainfall used in this study was of 50% dependable probability and cropping start was on November 1. Project of Titab Reservoir would directly influence irrigation water supply on dry season, so that would increase the harvest and economy of society. This kind was as intangible benefit.

Analysis of Benefit Cost Ratio used present value method. Rate of interest used in this study was 12% as described above. Life time of Titab reservoir was 60 years. The analysis was as follow: Total of cost at present was Rp 744,848,487,402.-; Benefit total of irrigation at present was Rp. 154,150,729,909.-; Construction cost at present was Rp 1,283,150,675,758.-, so that BCR was as follow:

$$BCR = \frac{Rp1{,}283{,}150{,}675{,}758}{Rp774{,}848{,}487{,}402} = 1.656 > 1$$

B/C of Titab Reservoir was more than 1 (> 1). It meant that this project was economically feasible or this project exeeded the break event point.

The second method in economical analysis used Net Present Value that was to find the net Benefit (B – C). This method evaluated project that NPV of present interest would more than zero (> 0). If NPV = 0 it meant that the benefit of project was the same as investation cost. If NPV < 0 it meant that the project was economically not feasible to be built. Case of this study used interest of 12%, total of benefit at present (B) was

Rp. 1,283,150,675,758.-; total of cost at present (C) was Rp. 774,848,487,402.-; and the difference between benefit and cost (B-C) was Rp. 508,302,188,356.-

Internal Rate of Return (IRR) was defined as rate of interest which caused benefit and cost had the same value or B-C = 0 or rate of interest that caused B/C ratio = 1. In this case: positive NPV = 15%, negative NPV = 20%, so that IRR was as follow:

$$IRR = 15\% + \frac{149{,}348{,}734{,}645}{(149{,}348{,}734{,}645 - (307{,}834{,}002{,}072)}(20\% - 15\%)$$

= 15% + 0.6%

= 15.06 % > 12% (the interest tha was used)

Determination of irrigation water price

The analysis was carried out based on the most critical condition that was when benefit was down to 10% but cost was up to 10%, so that minimum water sale price could be charged to consumers and project of Titab Reservoir was really feasible. On the condition of benefit was down to 10% and cost was up to 10%, water sale price was analyzed as follow: B/C ratio was 1.55; B-C was Rp.449,776,631,758.-; IRR was 16.648%; interest of bank was 12%; total of irrigation water demand was 407,652,010.26 m^3/year; price of irrigation water was

$$= \frac{Rp.449.776.631.758}{407.652.010.X(8{,}324)X(1.761)} = \text{Rp.88,69m}^3\text{/year}$$

Simulation of reservoir operation and optimization of price on reservoir fresh water

This kind of analysis used solver. The storage capacity of Titab Reservoir was analyzed based on map of measuring result. The highest elevation was +162.00 m. Relation between elevation, reservoir capacity, and number area of storage was presented as in Figure 2.

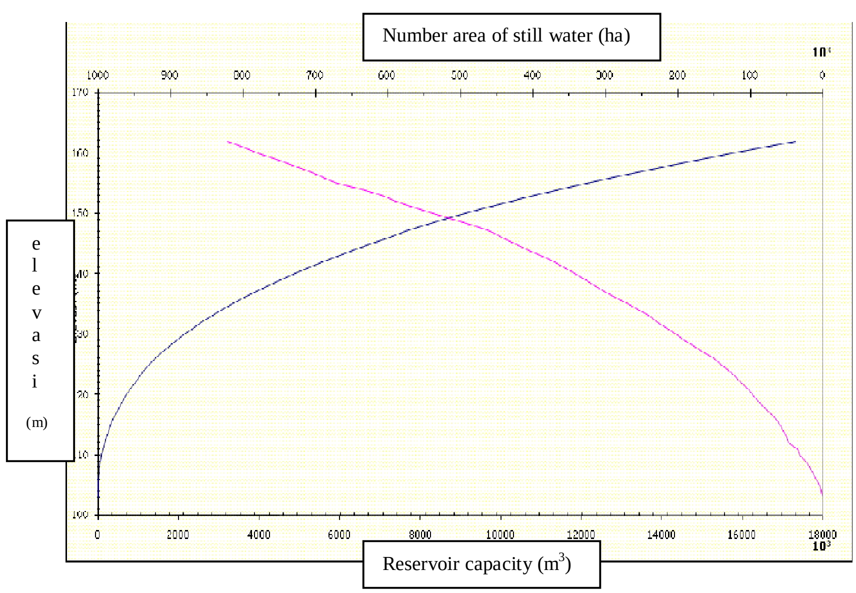

Figure 2 Storage capacity curve and number area of Titab Dam

Reservoir simulation was intended to know the successfull level of reservoir based on water supply and number of water demand as reservoir outflow for irrigation and fresh water. The capacity of effective storage was analyzed using the storage capacity curve and number area of Titab Reservoir as presented in Figure 1. The base principal in capacity analysis of effective storage was using dependable discharge that was Q80, but outflow discharge for irrigation was using selected alternative which was added by fresh water, maintenance flow, discharge for electrical energy power, and evaporation of dam. Dead stirage was designed at the elevation of 131.20 m with storage capacity of 2.19 juta m^3. Analysis of effective storage produced effective storage for Titab Reservoir was 10.37 x 10^6 m^3 and volume of total storage was 12.795 juta m^3.

The price optimization for reservoir in this study was carried out for one reservoir without connection with other reservoir. The objective function was to maximaze total of net benefit and the constraints were included $X_i \geq$ demand volume; $\sum^{n}_{i=1} X_i \leq$ certain volume; $Y_i \leq$ ratio of model; Bi = Benefit per-m^3; $Z = \sum^{n}_{i=1} X_i \; Y_i$; and Z = Total of reservoir cost. The result of optimization was included the changes of storage volume and elevation of reservoir along the year; reliability of reservoir; and the pattern of reservoir operation. This simulation used 15 daily discharge for each year, but outflow was based on irrigation water demand for 6 alternative cropping start with some variations those were January 1, January 16, February 1, February 16, March 1, and March 16, fresh water demand until the tear of 2025, maintenance flow, evaporation, and water demand for electrical energy power.

Failure of storage simulation was determined with percentage of failure number due to total of simulation period, the maximum result was 20% or percentage of significant number was 80%. Table 2 and Figure 3 presented optimization result of simulation water price with cropping start on January 1. Table 3 and Figure 4 presented optimization result of simulation water price with cropping start on January 16.

Table 2 Optimization result of simulation water price (Result of solver) [12] (Cropping start on January 1)

		Kendala			Hasil optimasi			
Vol.Tot.Outflow	?	335	$X10^6 m^3$	<	Total Alokasi	199.000		
Beaya Dam	?	4,287	X10^8Rp	=	Total Harga	4,287		
					Total Net Benefit	40,171		
Pengguna		Alokasi X10^4m^3	Benefit X10^Rp		Alokasi	Harga / m^3	F.power	F.Expon
PLTA	?	100.00	99.00		100.00	10.28	55	118
Irigasi	?	167.00	154		167.00	16.67	46	109
Air Baku	?	68.00	130		68.00	6.99	62	122
Jumlah		335	383		335	34	162	350
Nilai Rata-rata		112	13		112	11	54	117
	?	Vol.Inflow	Vol.Out	Vol Wdk	Alok X Harga	Alok X net ben	Ratio	F.Logarit
Pengguna		335.000		13				
PLTA			100		1,028	8,872	43	91
Irigasi			167		2,784	22,934	17	71
Air Baku			68		475	8,365	48.50	106
Jumlah		335.000	335		4,287	40,171	108	268
Nilai Rata-rata					2,515	23,823	13	87

Sumber : Perhitungan

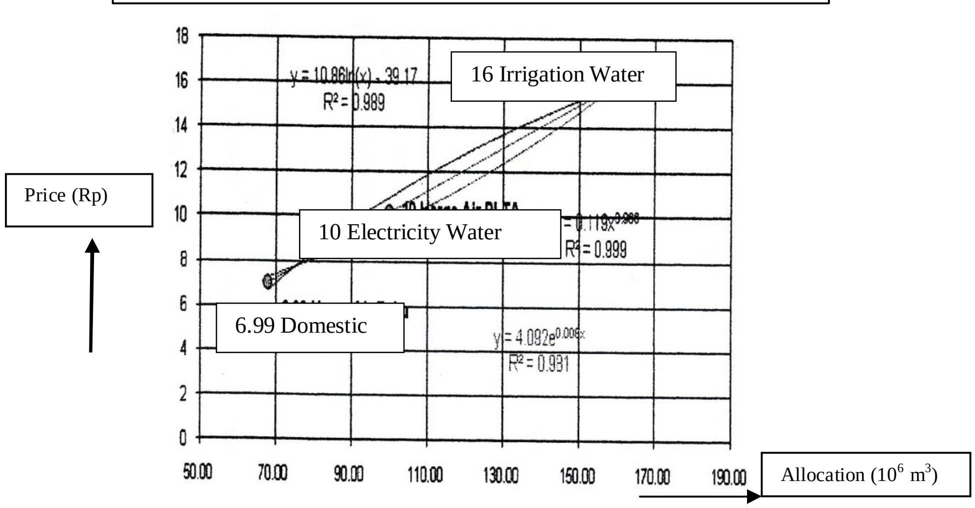

Figure 3 Allocation and Water Price (January 1)

The result of cropping start on January 1 presented that inflow of reservoir was 101,388,636 m^3, number area of Saba irrigation: cropping pattern-1 was 1,396.4 ha; cropping pattern-2 was 1,186.94 ha; and cropping pattern-3 was 1,256.76 ha, number area of Puluran irrigation: cropping pattern-1 was 398.42 ha; cropping pattern-2 was 338.657 ha; cropping pattern-3 was 358.578 ha, fresh water supply was 0.526 m^3/s; volume of total storage was 12.795 million m^3; maximum elevation of reservoir water level was 156 m; maintenance flow was 0.29 m^3/s; discharge of hydro electrical power for interconnection supply was 0.77 m^3/s; maximum hydro power was 3.15 MW and the minimum power was 1.36 MW.

The result of cropping start on January 16 presented that all kinds item were the same as cropping pattern start on January 1, the exeption was maximum hydro power was 3.18 MW and the minimum power was 1.32 MW.

Table 3 Optimization result of simulation water price (Result of silver) [12] (Cropping start on January 16)

		Kendala			Hasil optimasi			
Vol.Tot.Outflow	?	343	X10^{6}m^3		Total Alokasi	207		
Beaya Dam	?	4,287	X10^8Rp		Total Harga	4,287		
					Total Net Benefit	41,348		
Pengguna		Alokasi X10^{6}m^3	Benefit X10^Rp		Alokasi	Harga / m^3	F.power	F.Expon
PLTA	?	101	99		101	10.24	54	118
Irigasi	?	174	154		174	16.00	45	108
Air Baku	?	68.00	130		68.00	6.90	62	122
Jumlah		343	383		343	33	162	349
Nilai Rata-rata		114	12		114	11	54	116
	?	Vol.Inflow	Vol.Out	Vol Wdk	Alok X Harga	Alok X net ben	Ratio	F.Logarit
Pengguna		343		13				
PLTA			101		1,034	8,965	43	91
Irigasi			174		2,784	24,012	16	69
Air Baku			68		469	8,371	48	106
Jumlah		343	343		4,287	41,348	107	266
Nilai Rata-rata					2,513	24,577	12	86

Sumber : Perhitungan

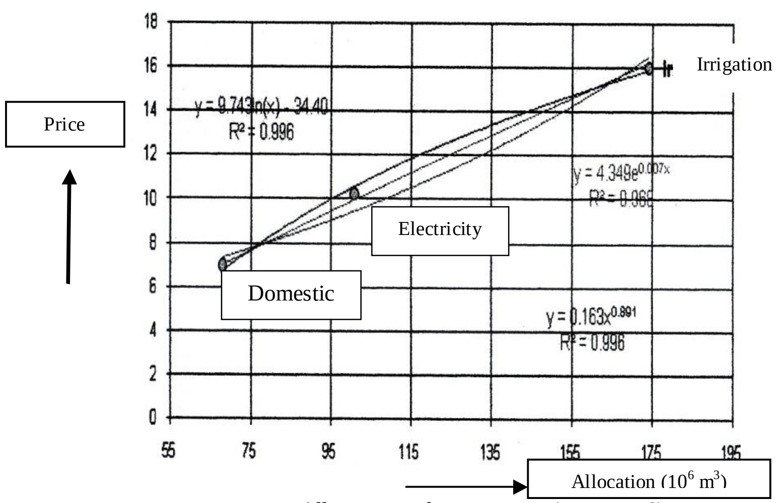

Figure 4 Allocation and Water Price (January 16)

CONCLUSION

Based on the analysis as above, it was concluded that there were price of fresh and irrigation water at Titab reservoir, and simulation about both of them as follow:

1. Fresh water price:
   - There were 2 kinds of benefit those were tangible benefit was R p 130,680,082,750.- and intangible benefit
   - The net benefit(B-C) was Rp 256,754,029,530.-; B/C ratio was 1.31; and IRR was 15.203%
   - Fresh water price was Rp. 1,127.- per-m^3 when cost was up to 10%, benefit was down at 10%, and the cost was Rp 256,754,029,530.-
2. Irrigation water price:
   - There were 2 kinds of benefit those were tangible benefit was Rp 154,150,729,909.- and intangible benefit included sense of safety and increasing harvest for the farmers and increasing income for regional government.

- The net benefit (B-C) was Rp 449,776,631,758 -; B/C ratio was 1.55; and IRR was 16.648%
- Fresh water price was Rp. 88.69.- per-m^3 when cost was up to 10%, benefit was down at 10%, and the cost was Rp 529,946,667,935.31.-

3. Water price based on the result of comparison analysis showed that minimum price of existing water was Rp. 800.-/m^3 and the maximum price was Rp. 2,700.-/m^3, but based on simulation result there was obtained no minimum water price and the maximum price was Rp. 2,951.-/m^3. Therefore, to obtain B/C ratio was more than one (> 1), decision maker could apply the water price which had been analyzed as above.
4. Electrical price at Buleleng regency was included the analysis as follow: average price of social was 466.60, household was 708.81, buisness was 758.80, industry was 589.00, government and lighting of public road was 792.00, and price of total average was 663.02. Therefore the income during 1 year was Rp 7,956.- per-kWh

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