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Allocation and Water Price Model at Multi Reservoir River System

Rispiningtati

Brawijaya University, Water Resources Engineering Department, Engineering Faculty, 65145 Malang Indonesia
rispiningtati@ub.ac.id

ABSTRACT
Many water planning researches have been done but water pricing has not been considered as the prime factor. Cost allocation is required whenever a project deals with multi-purpose groups. An optimization model which is accommodatingthe water allocation and water price must be developed in Indonesia. The new linear optimization model is developed to present a method for the determination of equitable impact fees and optimal water allocation for large water systems. The proposed method is demonstrated on a river system with 13 major dams. Each reservoir system serves 5 uses (irrigation, hydro-electric and flood control, industrial and domestic need). Using optimization with cost of dam and its facilities as target and the objective function is maximization of total net benefit of user income, water allocation as X variable and water price as Y variable will produce the optimal result. The result is the optimal water allocation with minimal water price which is present on 3 simulation analysis. The result of model is in a graphic and table presentation, which can be use easily to determine the water allocation and water price per m^3 in all reservoir system.The equation optimization result of multiple reservoir on Model I, which is theallocation increases and water price decreases is $Y = 250.88\ X^{-0.3315}$. While on Model II which is the allocation increases andwater price increases is $Y = 0.09\ X^{0.91}$.ForModel III which is thewater price is equate to benefit the equation is $Y = 0.09\ X^{0.90}$

Keywords: Model,Optimization, Allocation, Water Price

INTRODUCTION
Water as an important resource is to be considered for human life to continue their life. The older of the world the higher the global temperature increase. It reflects to the rain water volume decrease [1].
Pigram[2] declare at *Water Policy Agreement* at Australia. The regulation of water payment must be appropriate to have distribution continuity.Mc. Neil [3] also says that water is an economy commodity which cost of water consisted of distribution, production and transmission. Beecher [4] comments that the water cost optimization is based on the demand and regulation of water need allocation. Research done by Labadie [5] and Leon [6], is about water allocation optimization without water cost.
Several opinions above would be the base of estimating the cost and allocation of water research. For the mean time the optimization study of water cost and allocation simultaneously is not be conducted yet. So the gap of the old research is the optimization is just for the allocation only without any consideration of water cost.
The research considered necessary, is the regulation of water allocation at river systems with water as an economic commodity.To get the allocation regulation and water cost appropriately, the new optimization model must be conducted.The new model be used in this research is applied to the Brantas River at East Java Indonesia. The new model will optimized the water allocation together with the water cost.To show the new and old model, it can be seen at the example bellow. The model is used to regulate the multifunction reservoir. The reservoir has 5 functions; the first is the Irrigation (Y1X1); second is the Hydropower (Y2X2); third is the Flood Control (Y3X3); forth is Domestic Water(Y4X4); and fifth is the Industrial (Y5X5)

MATERIAL AND METHODS
The old model objective functions are:
Max Z (Income) = Y1X1 + Y2X2 + Y3X3 + Y4X4 + Y5X5
The constrains are; X1, X2, X3, X5 ≥ User need (Constrain volume); X1+X2+X3+X4+X5 ≤ Reservoir Capacity; Y1,Y2, Y3,Y4,Y5 = Unit Cost of Water or X coefficient; X1,X2,X3,X4,X5→ variable

The new model objective functions are:
Maximize X and Minimize Y; Z= Y1X1 + Y2X2 + Y3X3 + Y4X4 + Y5X5
The constrains are; X1,X2,X3,X4,X5≥ User need(Constrain Volume); X1+X2+X3+X4+X5 ≤ Reservoir Capacity; Y1,Y2, Y3,Y4,Y5 = Water Variable Cost; X1,X2,X3,X4,X5→ Water allocation variable

Regression Analysis
The program required is to optimize the water allocation unit and the water price. The difference between the old and new model could be seen in Figure 1.

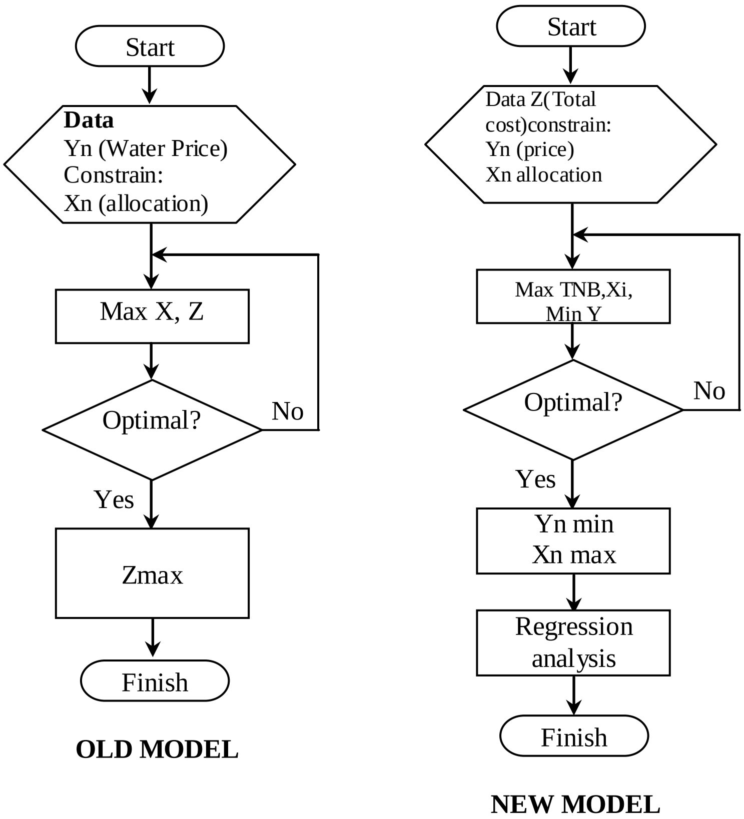

Figure 1: Old and New Model Comparison

TheResearch ModelTheory

The research or water allocation and price model

Require some explanation about phrases use in the model such as:

1. Water Allocation is a control of water volume to distribute water for water users [7].
2. Water price is the price of each unit of water that is distribute to water user [8].
3. Water usersare the Irrigation,Hydropower, Flood control, Industrial, Domestic water, Flashing need [9].
4. Irrigation user is a unit volume water that could be distributed to the irrigate farm area.
5. Hydropower user is the water unit volume to produce electric energy.
6. Flood control user is the water volume that must be retarded to cope flooding at the dam or reservoirdown-stream area.
7. Industrial water is specified as water volume use for lake recreation such as boating, surfing. Fishery and others [10].
8. Domestic Water is the unit volume of water use for public need.
9. Flushing Water is the water volume that should always be at the river or base flow.

The new model as the tool is used to find the optimal solution.The process start with the mathematical model to be answered(a) What variables or unknown factors that must be found; (b) What constrain that required to optimizethe process; (c) What are the objective functions to gain the best result.

The river manager will determine the water volume amount required or discharge to be drawn from each reservoir at the river system. To draw the water volume amount there is a calculation as an economic allocation to get a maximal income,on the otherhand the user-need abundant water with a minimal price. For example; the reservoir has 6 million m^3storage at the first semester and 8 million m^3 at the second semester [11]. The Irrigation required two times amount of water than the Hydro power does at the first semester. At the second semester Hydro power require 2 times more than the irrigation requirement.Hydropower required a one million m^3 more than the irrigation requirement. Hydropower requirement should always bellow two millions m^3 of water. The price of each unit for irrigation, in Indonesian Dollar thousand (Rp), is twoand three for the Hydropower.

To solve the problem, there are some variables to be considered, which is

(a) The variable: X1 = irrigation requirement;X2 = Hydropower requirement;

(b) Objective Function:Maximize Z = 3 X1 + 2 X2; Constrain:X1 +2 X2 $\leq$ 6 10^6; 2X1 + X2 $\leq$ 8 10^6; X1 – X2 $\leq$ 1 .10^6;X1$\leq$ 2 .10^6;X1 $\geq$ 0;X2 $\geq$ 0

The mathematical model can be solved using agraphical method as follows:

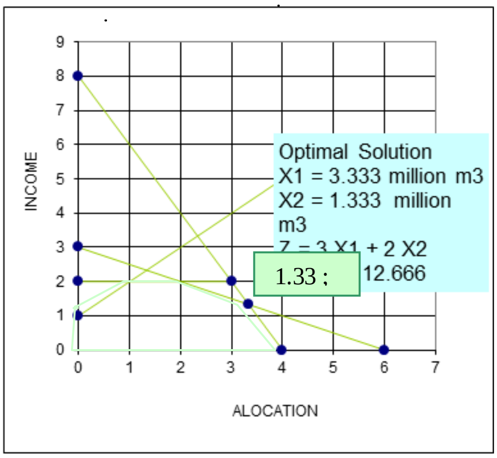

Figure 2: Graphical Optimization solution

The graphical method shows the optimal solution related with the extreme point.For example for two variables it should has more than two variables. It should be better to use the Simplex Method in Linear Programing [12].

Water Allocation and Water Price Model

The Objective Function is to maximize X and minimize Y

$$TNB = \sum_{i=1}^{n} (Bi - Yi)\, Xi \tag{1}$$

If n =5 then TNB = (B1-Y1)X1 + (B2-Y2)X2 + (B3-Y3)X3 + (B4-Y4)X4 + (B5-Y5)X5; Variables are; -Y1, Y2,Y3,Y4,Y5 (WaterPrice); - X1,X2,X3,X4,X5 (Water Allocation)

The constrains are; Z = Y1X1 + Y2X2 + Y3X3 + Y4X4 + Y5X5 (Target); X1,X2,X3,X4,X5… ≥ Requirement (Volume Constraints); X1+X2+X3 +X4+X5 ≤ Reservoir Capacity (Volume Constraints); Y1,Y2,Y3,Y4,Y5 ≤ Decision Ratio; B1, B2…..B5 = income per m^3; Z = Target (Cost of Reservoir and its facility); TNB = Total Net Benefit

The Decision Ratio

The boundary meet three constraints based on the of Water Price Optimization decision. The constraints are: 1. Price Increase for less utilize of water[13].

2. More water utilized more water price[1].
3. The water price increase when the benefit is higher [14].

Regression Analysis in power equation

Regression equation: $Y = \alpha\ X^{\beta}$ (2)

This equation can be expressed in a logarithmic equation $\text{Log}\hat{Y} = \log \alpha - \beta \log X$. This term is a linear function in log x with variable: $Y = \log \alpha$; $X = \log x$. The non-linear regression turn into linear regression: $Y = \text{arclog}\alpha\ X^{\beta}$

$\alpha = 1/n \sum yi - \beta/ n \sum xi = \tilde{y} - \beta x$; $\beta = (\sum xi\ yi - n\ x\ \tilde{y})/ (\sum xi^2 - n\ x^2)$; Where yi = Total price; xi = total allocation and n = sample amount. The regression effect Y toward X can be obtained $R^2 = 1 - S^2Y/SY^2$, where: $S^2Y=1/(n-2)\{ \sum^n (yi - \tilde{y})^2 - ß \sum^n(xi-x)^2 \}$; $Sy2 = 1/(n-1) \sum^n (yi - \tilde{y})^2$

If the R^2 value is approach to 1 then all data would comprise in the regression equation.

1. Exponential equation following: $Y = \alpha e^{\beta x}$ (3)

This equation is change to Lne equation to be Ln Y = Ln α -β x Ln e. This form as a linear function in Ln e, with variable Y =Ln y; X = x; The non-linear equation is turn into linear equation $Y = \text{arcln}\alpha\ e^{\beta x}$; α, β , R^2 be obtained equal to the power equation

2. The general term of Logarithm equation Y = αln X + β; This term be converted to linear equation Y = Y and X = ln X; α, β , R^2 be obtained equal the power equation

Research MethodModel Structure

Brantas River has 13 dams withevery reservoir has users such as Irrigation,Hydropower,Flood Control, DomesticWater and Industry (Figure 3 and Figure 4). The Two Steps optimizations are the Outflow optimization and the Price optimization.

Outflow optimization be conducted on all reservoir at Brantas River. Every reservoir has different function as yearly or daily reservoir. Yearly reservoir has a large reservoir it can store a year water inflow (discharge). Daily reservoir has a small reservoir it can just store a one of water inflow(discharge). At Brantas River there are four yearly reservoirswhich areSutami,Wonorejo,Selorejo,Bening and the rest are as daily reservoir.

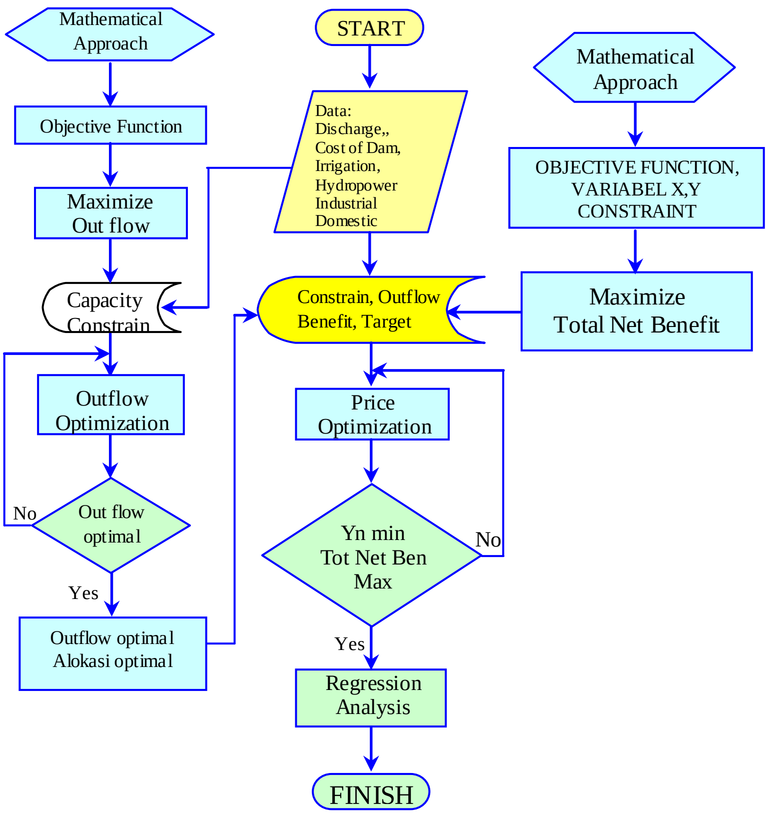

Figure 3: Model Flow Diagram

Constraints determination

1.Optimization of a single reservoir if it is not related with other reservoirs, the Maximize Total Net Benefit of each users

Max: $TNB = \sum^{n}_{i=1} (Bi\text{-}Yi)\ X\ i$, n = 5

Constrain: Xi ≥ Water Volume requirement; $\sum^{n}_{i=1} X_i \le$ Water volume regulation; Y i….≤ ratio model; Bi = Benefit per m^3; $Z = \sum^{n}_{i=1} X_i Y_i$; Z = Total cost of reservoir

2. Multi reservoir optimization, if it is more than one reservoir which it is interconected.

Max : $TNB = \sum^{n}_{i=1} (Bi\text{-}Yi)\ X\ i$, n = 57

Constrain:Allocation: Xi ≥ Water Volume requirement; $\sum^{n}_{i=1} X_i$. ≤ Reservoir water volume;Regulation Price: Yi ≤ Ratio model; Bi = Benefit per /m^3; Target: $Z = \sum^{n}_{i=1} Yi\ Xi$, n = 57

Constraints arrangement

Water volume constraints that is complicated because of the large amount of related user water volume. Thedischarge is always change depend on the climate conditions [11]. The amount of discharge is interconected betweenuser and reservoirwithdraw.As at the reservoir scheme where donstream reservoir depend on upstream reservoir, small change at the upstream reservoir will change all distribution system. Thecontinuitas formulaupstream discharge = down stream discharge if no additional or minus at any time. The notation =∑Qn inflow = ∑Qn outflow(n = 1,2………13).

The model determination with a single reservoir scenario as part of the multi reservoir. The operation model with a large reservoir at Brantas River must be a one packed plan it could not be seperated. The acceptable rule must be given to the user to cope water payment fairly.Cost componen that is

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related with time in this research is apply for 12 % rate annualy. The main constraints are include the reservoir capacity, price rule which is summerized in Table 1.

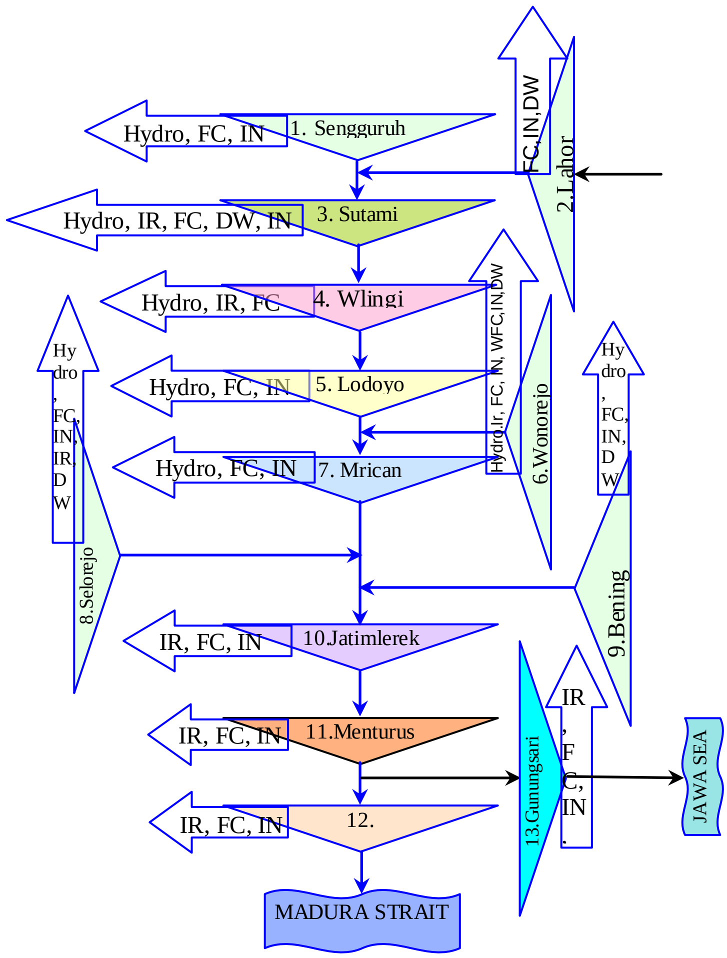

Figure4: BrantasRiver scheme

Table1: Constrain record

(Objective Function)Max :TNB= $\sum^{n}_{i=1}$ (Bi-Yi) X i , n = 57				
1	2	3	4	5
Reservoir Out flow	Requirem ent User	Model I Price Decrease Allocation Increase	Model II Price Increase Allocation Increase	Model III Price equate Benefit
Q1 ≥ ∑X11+.. X13	X11..X13 ≥ M11.M13	Y111..Y113 ≤ R111…R113	Y121…Y123≤ R121…R123	Y131…..Y133≤ R131….R133
Q2 ≥ ∑X21+..X25	X21...X25 ≥ M21..M25	Y211...Y215 ≤ R211…R215	“	“
Q4≥ ∑X41+ .X45	X41…..X45≥ M41….M45	Y411…..Y415 ≤ R411…R415	“	“
Q14≥ ∑X11+.. X134	X11…X115≥ M11….. M134	Y111…….Y1314 ≤ R111…R1314	Y121…….Y1324 ≤ R121…R1324	Y131…..Y1314≤ R131….R1334

(**Note:**Line 1: Objective function of Price optimization; Column 1: Outflow Total Volume; Column 2: Total user requirement<= Total Outflow; Column 3: model I Price Decrease, Allocation Increase: Price <1st Coefficient Ratio Model; Column 4: model II; Price Increase, Allocation Increase: Price <2nd Coefficient Ratio Model; Colom 5:model III Price equate to Benefit: Price<3rd Coefficient Ratio Model). [Note: (continuation) Single reservoir Optimization; Optimization 1: Colom 1,2,3 (3 processes); Optimization 2:Colom 1,2,4 (3 processes); Optimization 3: Colom 1,2,5 (3 processes); Each Reservoir has 10 constraint equation and 8 variables; **Total Amount of variables** X= 72; Y = 72; **Total constraints equations**; 90(allocation constrains) + 90(price constrains)+ 9(Volume reservoir constrains) + 9 (cost of reservoir)+ 9 (incoming flow constraint) = 207 equation)]

Multi reservoir Optimization (13 reservoirs)

Optimization 4: (3 processes). Variable X = 132 and variable Y = 132. The Total constraint equations are132allocation constrain + 132 price constrain + 33 Volume reservoir constrain + 33 cost of reservoir+ 33 incoming flow constraint = 363 equations.

Reservoir category

Single reservoirs consist of 4 reservoirs which are Sengguruh, Wonorejo, Selorejo,Bening.
Multi reservoirsconsist of 9 reservoirs: Lahor, Sutami, Wlingi, Lodoyo, Mrican, Jatimlerek, Menturus, Lengkong, Gunungsari.

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Model I: (Price Decrease, Allocation Increase):
The Ratio Numberis applied to control the water unit price on the "Price decreases, Allocation Increases". Ratio Number is determined as1: Z /(Xi * Bi) as a general expression.
For Model I, the coefficient ratio is thecost of the reservoir divided by the allocation timesthe constant.

Z /(Xi * Bi) *C (4)

The water price Y ≤ Ratio of each user; so Y1 ≤ Z / X1 * B1*C; Z = Reservoir Annual Cost; X1 = User 1; B1= User 1 benefit per m^3; C = conversion constant.

Model II:Price Increase, Allocation Increase
The ratio number for model IIisthe allocationtimes benefit divided bythe average cost times constant.
The ratio number formula for Model II =Xi* Bi / (Z / n) * C (5)

For user 1:
Y1 ≤ X1 * B1/ (Z/ n) *C; X1 = User 1 allocation (m^3); B1= Benefit (Rp/m^3); Z = Total cost of reservoir (Rp); n = user number; C = Conversion constant.

Model III: Price proportional to Benefit*;*
The Model III Ratio Number is the User allocation times benefit divided by the average allocation times total benefit times constant.
Ratio number formula for Model IIIisXi*Bi/((∑ $^{n}{}_{i=1}$X$_i$)/n)*∑$^{n}{}_{i=1}$B$_i$)) *C (6)
For user 1 on the Reservoir that has 4 users:
Y1≤X1xB1/((∑$X^4{}_1$)/4*(∑$B^4{}_1$))*C (7)

Where:Y1 is theWater Price per m^3; B1is the User 1 benefit (Rp/m^3); (∑$X^4{}_1$)/4is theAverage allocation (m^3); ∑B $^4{}_1$is the Total benefit (Rp/ m^3); C is the Conversion constant.

RESULT AND DISCUSSION

Table 2: Optimization of Model R II.3. Multi Reservoir

Model R II.3. Price proportional to Benefit			Constraints				Optimization Result						
Multi reservoir capacities			?	10363 x10^6m^3			Total Allocation			9983 x10^6m^3			
Cos of multi reservoir			?	607992 x10^6Rp			Total Water Price			607992 x10^6Rp			
Total Allocation & Benefit				10363	7197		TotalNet Benefit			621329 x10^6Rp			
Average of Allocation & Price				253	59	14.8	286	13.7	16724	18828.2	12	22	15
1	2	3		4	5	6	7	8	9	10	11	12	13
Reservoir name	607991	User		Allocation i	Benefit	Ratio	Allocation i	Price	AllxPrc	Alokxnb.	P	E	L
1.Sengguruh	50889	Hydro	?	1342	68	40.1	1342	37.9	50873	40316	55.9	38	44
Outflow optimal	1342	F.Control	?	1.42	352	0.2	1.42	0.1	0.18	500	0.1	1	-9
Cost	39976	Industry	?	19	105	0.9	19	0.8	15.8	1984	1.2	1	11
3.Sutami	269100	Hydro	?	1761	234	181.5	1761	152.7	268824	143976	71.2	129	46
Outflow optimal	1761	F.Control	?	28	253	3.1	28	2.4	66	6934	1.7	1	14
Cost	139048	Industry	?	109	46	2.2	109	1.9	210	4804	5.9	1	25
4.Wlingi	125807	Irrigation	?	352	203	31.4	352	29.7	10456	61000	16.9	2	34
Outflow optimal	2529	Hydro	?	2177	60	57.5	2177	53.0	115343	15501	86.0	434	48
Cost	94961	F.Control	?	2	526	0.4	2	0.2	0.3	999	0.2	1	-6
		Industry	?	19	53	0.4	19	0.4	7.8	992	1.2	1	11
5.Lodoyo	33785	Hydro	?	1674	29	21.3	1674	20.2	33783	14763	68.0	100	46
Outflow optimal	1674	F. Control	?	0.5	532	0.1	0.5	0.0	0.0	250	0.0	1	-17
Cost	87100	Industry	?	5.0	200	0.4	5.0	0.4	2.1	998	0.4	1	1
6.Wonorejo	1505	Irrigation	?	45	203	4.0	45	3.8	170.5	8944	2.7	1	18
Outflow optimal	110	Hydro	?	110	180	8.7	110	8.2	905.4	18895	6.0	1	25
Cost	27496	F.Control	?	1	217	0.1	1	0.1	0.1	249	0.1	1	-10
	0	Industry	?	76	26	0.9	76	0.8	62.4	1914	4.3	1	22
		Dom. Wtr.	?	65	500	14.3	65	5.6	367.0	32133	3.7	1	21
7. Mrican	57309	Irrigation	?	825	203	73.5	825	69.5	57309	109792	36.2	8	40
Outflow optimal	1092.8	F.Control	?	1	424	0.1	1	0.1	0.03	250	0.1	0.8	-15
Cost	40000	Industry	?	2	147	0.1	2	0.1	0.2	250	0.1	0.8	-7

8. Selorejo	12512	Irrigation	?	270	203	24.1	270	22.7	6138.2	48549	13.3	1.7	32
Outflow optimal	270	Hydro	?	270	264	31.3	270	23.4	6331.3	64949	13.3	1.7	32
Cost	40196	F.Control	?	2	417	0.4	2	0.2	0.50	1000	0.2	0.8	-5
		Industry	?	50	40	0.9	50	0.8	41.7	1958	3.0	0.9	19
9. Bening	75	Irrigation	?	27	203	2.4	27	2.3	61.4	5407	1.7	0.8	14
Outflow optimal	27 27	F.Control	?	5	450	1.0	5	0.4	2.3	2306	0.4	0.8	1
Cost	8283.6	Industry	?	27	37	0.4	27	0.4	11.2	989	1.7	0.8	14
12.Lengkong	54613	Irrigation	?	783	203	69.7	783	69.7	54611	103983	34.5	7.4	40
Outflow optimal	910.25	F.Control	?	3	385	0.4	3	0.4	1.14	1000	0.2	0.8	-4
Cost	43976	Industry	?	4	132	0.2	4	0.2	0.8	499	0.3	0.8	-1
13Gunung Sari	1500	Irrigation	?	80	203	7.1	80	7.1	569.2	15622	4.5	0.9	22
Outflow optimal	237.69	F.Control	?	3	385	0.5	3	0.5	1.52	1153	0.2	0.8	-3
Cost	61970	Industry	?	2	132	0.1	2	0.1	0.14	204	0.1	0.8	-8
E97*F97/(F54*E55)*800		Domestic wtr	?	65	500	14.3	65	14.3	929.0	31571	3.7	0.9	21

The optimization result showsthe water allocation and price of each reservoir with three categories. This result is useful to determine the minimal water price on the right allocation. The graph presentation is easily to obtain the water allocation and its price.If Y variable as price function and X variable as allocation function then the relation between X and Y has to be transformed in a regression function. Therefore the regression function show the price and allocation correlation on all conditions.

The result consist of three principal graphs, first is the relation between the water allocation and water price on multi reservoir user group (Figure 5), second is the relation between water allocation and water price on single reservoir user (Figure6). Lastly, is the relation between water allocation and water price on multi reservoir user (Figure 7).User group in Figure 5are 9 Irrigation user,6 Hydropower user,13 flood control user,13 Industries and 2 domestic water user. User group in Figure 6 are the Irrigation user,Hydropower,Flood control,Industrial,Domestic Water.

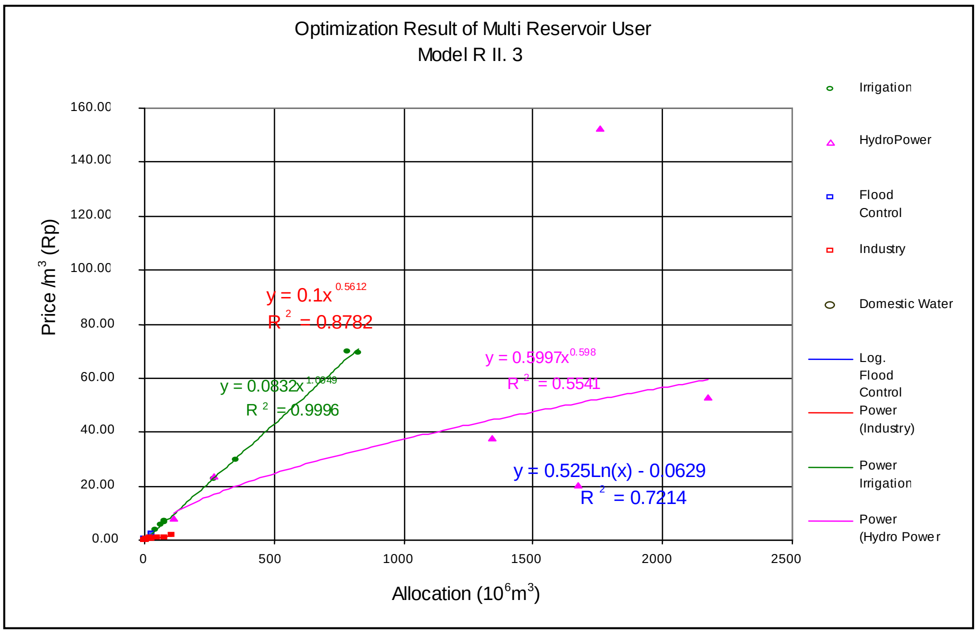

Figure 5: Graph of Multi Reservoir model R II.3(Price equate Benefit)

(Example: Water Allocation 500 ($10^6 m^3$) for Irrigation, Water Price = Rp.45 / m^3)

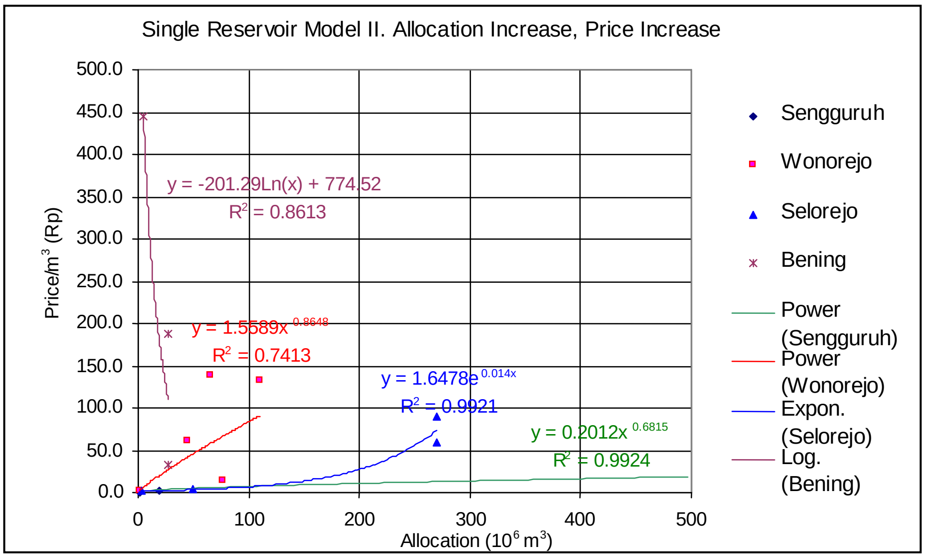

Figure 6: Graph of Water Allocation & Price Single Reservoir Model R1.2

Example: Water Allocation 200 ($10^6 m^3$) on Selorejo Reservoir, Water Price = Rp.25 / m^3

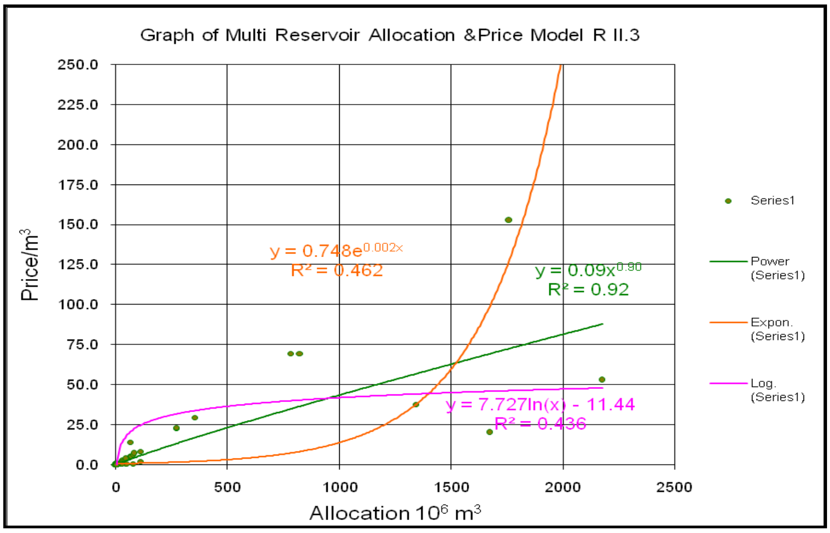

Figure 7: Graph of Water Allocation & Price Multi Reservoir Model R1.2

(Example: Water Allocation 1000 ($10^6 m^3$), Water Price = Rp.40/m^3)

CONCLUSIONS

The Research Model has been made to optimize the water allocation and water price.The result that is the regression function relation between water allocation and price show the equation on the chosen model. X ($10^6 m^3$) is the Water Allocation, Y (Rp) is the Water Price/m^3, Z (Rp 10^6) is the Cost of Reservoir and TNB (Rp 10^6) is The Total Net Benefit

1. Model with Allocation Increase and Price Decrease

Single Reservoir	Multi Reservoir
$Y = 250.88\ X^{-0.3315}$	$Y = 305.24X^{-0.26}$
Z = 39976;TNB = 53713	Z = 607992;TNB = 645914

2. Model with Allocation Increase and Price Increase

Single Reservoir	Multi Reservoir
$Y = 1.5589\ X^{0.8648}$	$Y = 0.09\ X^{0.91}$
Z = 27496; TNB	Z = 607992;TNB =

3. Model with Price equate Benefit

Single Reservoir	Multi Reservoir
$Y = 1.6964e^{0.0139X}$	$Y = 0.09\ X^{0.90}$
Z = 40196;TNB = 50144	Z = 607992; TNB = 621329

4. Model with Price equate Benefit for user group

User	Regression Equation
Irrigation	$Y = 0.0832\ X^{1.0049}$
Hydropower	$Y = 0.5997\ X^{0.598}$
Flood Control	Y = 0.525Ln(X) -0.0629
Industrial	Y= 0.1X 0.5612
Domestic Water	Y = 0.308 X

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