Optimization of planting pattern plan in Logung irrigation area using linear program

Wasis Wardoyo, Setyono
Civil Engineering Department, Faculty of Civil Engineering and Planning, Institut Teknologi Sepuluh Nopember (ITS), Jl. Arief Rahman Hakim, Surabaya 60111
E-mail: w4515wardoyo@gmail.com

Abstract. Logung irrigation area is located in Kudus Regency, Central Java Province, Indonesia. Irrigation area with 2810 Ha of extent is getting water supply from Logung dam. Yet, the utilization of water at Logung dam is not optimal and the distribution of water is still not evenly distributed. Therefore, this study will discuss about the optimization of irrigation water utilization based on the beginning of plant season. This optimization begins with the analysis of hydrology, climatology and river discharge in order to determine the irrigation water needs. After determining irrigation water needs, six alternatives of planting patterns with the different early planting periods, i.e. 1st November, 2nd November, 3rd November, 1st December, 2nd December, and 3rd December with the planting pattern of rice-secondary crop-sugarcane is introduced. It is continued by the analysis of water distribution conducted using linear program assisted by POM-Quantity method for Windows 3 with the reliable discharge limit and the available land area. Output of this calculation are to determine the land area that can be planted based on the type of plant and growing season, and to obtain the profits of harvest yields. Based on the optimum area of each plant species with 6 alternatives, the most optimum area was obtained at the early planting periods on 3rd December with the production profit of Rp 113,397,338,854,- with the planting pattern of rice/ beans / sugarcane-rice / beans / sugarcane-beans / sugarcane.

1. Introduction
Indonesia is one of the country in the world that has a large agriculture field. Horticultural crops have important and strategic roles in national and regional development, such as improving food sustainability, gross domestic product (GDP), income sources, and regional and national economies. Agriculture has become an attractive factor for upstream and downstream industry growth that huge contribution to national economic growth. One of the irrigation area that should support this task is Logung Irrigation Area. This located in the Logung River, Kudus Regency, Central Java. Logung Irrigation Area, which has an area of 2810 Ha gets water supply from Logung River. Recently, the performance of this irrigation area tend to decrease because of uneven distribution of water. It becomes even worst by unpredictable rainy seasons that cause drought during the dry season and flooded during the rainy season. Therefore, such a method is introduced in order to solve this problem and to increase the crops productions, especially during dry season.

One of the method introduced to improve agricultural products in Logung irrigation area is by regulating a best way of water distribution. This method is done based on linier programming approach. By this methods, the water demand can be adjusted depend upon the water availability in Logung Dam. The appliability of linier programming in case of water resources optimization has already introduced by Frizzone et.al [1], Jakovskis [2] Wafa Dipalla [3], Anieting [4] Pearson and McRoberts [5] and Suhardono[6]. The water demand is determined by planting pattern. Optimal planting pattern arrangement simulated based on the type of plants and water
availability. The planting pattern will be optimum when the optimum agricultural product is achieved. Thus, this study will discuss the optimization of planting pattern in Logung irrigation area using linear programming.

1.1. Problem analysis
The Logung irrigation area is potential to increase its agriculture products. One of the capital of this area to be improved is the availability of water and the characteristic of catchment area [7, 8]. The water availability in Logung catchment area is slightly fluctuated between dry and rainy season. By introducing some scenario based on starting time of planting, area of planting, type of planting and net field rate of each crops, then the irrigation water needs of each alternative planting pattern in the Logung irrigation area can be determined. Furthermore, the maximum profit production of each the planting pattern is calculated. The better planting pattern is determined based on the value of production’s profit where the higher will be the better.

1.2. Aims
There are three main aims of this study i.e. adjusting the water availability, calculating the irrigation water needs and calculating the maximum profit production of each planting pattern. Six starting time of planting pattern is introduced: 1st November, 2nd November, 3rd November, 1st December, 2nd December, and 3rd December respect to planting period of padi. The water availability is adjusted based on hydrological data, topographical data and some supported data. The maximum profit production is found by multiplying the amount of each product and the unit price of each crops.

1.3. Limitation of analysis
On analysing this case, some limitation is done i.e. Scope of analysis in this study are: the data used are secondary data in the field, this study is only analyzing water for irrigation and not considering sedimentation, all irrigation channels are assumed in a good condition so that there is no water loss due to channel damage or wiretapping and selected planting pattern is rice, beans, and sugarcane.

2. Methods
This part explains the step on reaching the aim of research. Starting with collecting, reading and understanding some related references, follows by data collection, application of some formula and data analysis of water need. Finally it ended with optimization step, that consist of variation on the beginning of planting pattern and calculation of harvest yields benefit.

2.1. Literature review
On reaching the aim of study, some basic knowledge should be understood well. The basic knowledge has been learned on undergraduate lectures that consist of hydrology, hydraulics, irrigation and optimization stage aspects [9]. The basic design of channel and its operation sourced to design criterion of irrigation channel [10], while the operation of Logung Dam is stated on Design of Logung Dam [11]. The applicability of linear program on optimization of water resources case is already proved by many experts [1,2,3,4,5,6] as mentions above.

2.2. Data collection and analysis
The data used in this study consist of Catchment and Irrigation area data, Hydrology and Hydraulic Data. Firstly the data of the catchment area and Logung river. The most important thing is the data of discharge. The 10 days measurement data of discharge from 2006 up to 2015 are available. Based on this data then the discharge distribution can be determined. Total area of irrigation field as the study area is an important parameter to be known, besides the type of crops, crops limitation and crop’s water need. By knowing this, the scenario of optimization can be determined. The climatology data is also needed to calculate water balance not only in the field but also in irrigation intake and dam.

2.3. Optimization of planting patterns
Based on the result of water needs analysis from each alternative of planting pattern and reliable volume, it becomes the input of Linear Program to obtain the optimum planting pattern. The stage of finding optimum planting pattern is shown on Figure 1.
3. Results and discussion

After calculation, some result should be analysed in order to support the optimization model. The outcome analysis are reliable discharge, water balance, water need for irrigation and harvest yields.

3.1. Hydrological analysis

This part explains the process of hydrologic analysis. Based on discharge data of Logung River (Table 1) that collected from measurements, it can be analysis the characters of discharge. Refers to this characters, then distribution type and design discharge can be determined. By knowing design discharge then prediction of discharge can be estimated.

3.1.1. Calculation of the reliable discharge

The discharge data was collected from the discharge measurement in Logung River on 2006 up to 2015.

Figure 1. Optimum planting pattern
| Month | Year | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| January | 1 | 1,242 | 1,237 | 0.998 | 2.200 | 6.930 | 15.730 | 13.927 | 4.657 | 13.818 | 11.212 |
| | 2 | 0.995 | 0.664 | 0.585 | 6.100 | 7.480 | 17.866 | 10.236 | 1.530 | 16.404 | 9.296 |
| | 3 | 1.513 | 0.681 | 0.540 | 9.827 | 8.000 | 12.521 | 4.583 | 5.643 | 32.768 | 8.522 |
| | 4 | 3.278 | 0.380 | 0.605 | 9.400 | 8.780 | 14.837 | 2.477 | 0.000 | 13.489 | 8.774 |
| February | 2 | 2.860 | 0.445 | 0.591 | 8.456 | 6.060 | 19.147 | 1.820 | 0.676 | 11.118 | 5.837 |
| | 3 | 2.231 | 0.613 | 0.593 | 7.275 | 6.450 | 18.547 | 1.349 | 3.611 | 9.520 | 9.125 |
| | 4 | 2.322 | 0.809 | 0.611 | 6.380 | 2.350 | 27.767 | 1.068 | 0.105 | 10.161 | 8.567 |
| March | 2 | 1.176 | 0.519 | 0.556 | 4.900 | 0.680 | 22.619 | 0.676 | 0.014 | 11.118 | 5.837 |
| | 3 | 0.907 | 0.390 | 0.425 | 5.064 | 0.800 | 17.696 | 0.383 | 1.705 | 9.851 | 7.134 |
| | 4 | 0.862 | 0.366 | 0.574 | 6.380 | 0.740 | 16.180 | 0.234 | 3.973 | 13.030 | 5.770 |
| April | 2 | 0.838 | 0.422 | 0.469 | 5.350 | 0.770 | 15.223 | 0.091 | 4.177 | 6.560 | 10.126 |
| | 3 | 0.815 | 0.435 | 0.483 | 5.360 | 0.730 | 14.033 | 0.029 | 0.010 | 6.025 | 10.598 |
| | 4 | 0.714 | 0.433 | 0.518 | 5.510 | 0.608 | 12.892 | 0.000 | 10.913 | 7.949 | 8.256 |
| May | 2 | 0.652 | 0.430 | 0.628 | 5.770 | 0.820 | 15.444 | 0.000 | 8.167 | 9.012 | 8.509 |
| | 3 | 0.619 | 0.388 | 0.369 | 4.527 | 0.864 | 13.256 | 0.000 | 1.857 | 10.494 | 10.472 |
| | 4 | 0.556 | 0.361 | 0.389 | 5.280 | 0.380 | 11.504 | 0.419 | 1.809 | 7.400 | 11.098 |
| June | 2 | 0.521 | 0.378 | 0.483 | 5.290 | 0.070 | 10.236 | 0.401 | 1.140 | 7.400 | 11.165 |
| | 3 | 0.500 | 0.390 | 0.570 | 0.700 | 0.010 | 8.643 | 0.364 | 0.823 | 14.518 | 10.829 |
| | 4 | 0.480 | 0.377 | 0.516 | 0.350 | 0.000 | 5.561 | 0.348 | 0.585 | 8.656 | 12.181 |
| July | 2 | 0.472 | 0.359 | 0.433 | 0.000 | 0.000 | 2.552 | 0.345 | 0.471 | 9.226 | 12.181 |
| | 3 | 0.459 | 0.350 | 0.445 | 0.000 | 0.364 | 1.383 | 0.344 | 0.423 | 9.520 | 12.181 |
| | 4 | 0.430 | 0.368 | 0.482 | 0.000 | 0.500 | 0.295 | 0.366 | 8.256 | 9.701 | 12.181 |
| August | 2 | 0.416 | 0.382 | 0.518 | 0.000 | 0.680 | 0.166 | 0.425 | 8.649 | 10.301 | 12.181 |
| | 3 | 0.407 | 0.350 | 0.528 | 3.055 | 0.990 | 0.166 | 0.434 | 8.613 | 10.829 | 12.181 |
| | 4 | 0.409 | 0.376 | 0.573 | 0.170 | 0.870 | 0.166 | 0.463 | 10.306 | 8.233 | 10.829 |
| Sept | 2 | 0.444 | 0.380 | 0.648 | 0.100 | 0.580 | 0.166 | 0.403 | 10.829 | 8.958 | 10.829 |
| | 3 | 0.458 | 0.380 | 0.694 | 0.100 | 0.580 | 0.166 | 0.352 | 10.829 | 9.482 | 10.829 |
| | 4 | 0.443 | 0.380 | 0.711 | 0.100 | 0.490 | 0.000 | 0.357 | 8.256 | 9.520 | 10.144 |
| October | 2 | 0.496 | 0.380 | 0.828 | 0.100 | 1.230 | 0.150 | 0.307 | 7.405 | 10.104 | 9.858 |
| | 3 | 0.533 | 0.380 | 0.917 | 0.300 | 1.409 | 1.409 | 0.306 | 6.613 | 10.169 | 9.520 |
| | 4 | 0.586 | 0.376 | 0.901 | 0.180 | 1.740 | 5.641 | 2.353 | 5.935 | 10.367 | 9.520 |
| Nov | 2 | 0.559 | 0.343 | 1.057 | 0.200 | 3.340 | 10.589 | 2.476 | 5.878 | 10.829 | 9.520 |
| | 3 | 0.779 | 0.346 | 1.377 | 0.650 | 10.420 | 9.446 | 3.049 | 5.373 | 9.913 | 9.520 |
| | 4 | 0.860 | 0.368 | 1.017 | 2.200 | 0.800 | 14.366 | 8.221 | 7.151 | 10.828 | 12.898 |
| Dec | 2 | 1.839 | 0.530 | 1.075 | 2.200 | 1.970 | 11.722 | 7.137 | 11.420 | 7.596 | 12.268 |
| | 3 | 0.000 | 0.662 | 2.412 | 2.200 | 3.491 | 13.092 | 7.377 | 13.997 | 8.865 | 11.134 |

Source: Calculation Result

The discharge data was sorted from the largest to the smallest to determine the probability of being fulfilled by 80% or unfulfilled by 20%.
To know the amount of surface runoff, the area of rainfall influence can be determined using Thiessen Polygon method. If the land use and rainfall intensity are known, then free surface discharge can be calculated.

### Table 2. Calculation records of reliable discharge (m³/dt)

| Rank | January  | February  | March  | April  | May  | June  |
|------|----------|-----------|--------|--------|------|-------|
| 1    | 15,730   | 17,866    | 32,768 | 14,837 | 19,147 | 18,547 |
| 2    | 13,927   | 16,404    | 12,521 | 13,499 | 9,661 | 9,590 |
| 3    | 13,818   | 10,236    | 9,827  | 9,400  | 8,602 | 9,125 |
| 4    | 11,212   | 9,296     | 8,522  | 8,780  | 8,456 | 7,275 |
| 5    | 6,930    | 7,480     | 8,000  | 6,060  | 6,450 | 2,550 |
| 6    | 4,657    | 6,100     | 5,643  | 3,278  | 2,860 | 6,100 |
| 7    | 2,200    | 1,530     | 4,583  | 2,477  | 1,820 | 9,520 |
| 8    | 1,242    | 0,995     | 1,513  | 0,605  | 0,591 | 8,233 |
| 9    | 1,237    | 0,664     | 0,681  | 0,448  | 0,613 | 0,611 |
| 10   | 0,998    | 0,585     | 0,540  | 0,000  | 0,000 | 0,000 |

| Rank | July     | August    | September | October | November | December |
|------|----------|-----------|-----------|---------|----------|----------|
| 1    | 12,181   | 12,181    | 12,181    | 12,181  | 12,181   | 12,181   |
| 2    | 8,656    | 9,226     | 9,520     | 9,701   | 10,306   | 10,829   |
| 3    | 5,561    | 2,552     | 1,383     | 8,256   | 8,649    | 8,613    |
| 4    | 0,585    | 0,472     | 0,459     | 0,500   | 0,680    | 3,055    |
| 5    | 0,516    | 0,471     | 0,445     | 0,518   | 0,500    | 0,000    |
| 6    | 0,480    | 0,433     | 0,423     | 0,430   | 0,425    | 0,528    |
| 7    | 0,377    | 0,359     | 0,364     | 0,368   | 0,416    | 0,434    |
| 8    | 0,350    | 0,345     | 0,350     | 0,366   | 0,382    | 0,407    |
| 9    | 0,348    | 0,344     | 0,295     | 0,166   | 0,350    | 0,170    |
| 10   | 0,000    | 0,000     | 0,000     | 0,000   | 0,166    | 0,100    |

### Source: Calculation Result

#### 3.1.2. Water balance

Climatological calculation is calculated in order to determine the magnitude of plant evapotranspiration. The parameters should be consider on this calculation are air temperature, wind speed, relative humidity and duration of solar irradiance. The available data of climatology is from 1993 up to 2014. The result of calculation called as the potential evapotranspiration is shown at Table 3. Based on this table, the water balance can be estimated.

#### 3.2. Water needs for irrigation

##### 3.2.1. Effective Rainfall Calculations

Firstly, the rainfall station should be available on study area. There are three rainfall station: Rahwatu Station, Gembong Station, Tanjungrejo Station. To know the amount of surface runoff, the area of rainfall influence can be determined using Thiessen Polygon method. If the land use and rainfall intensity are known, then free surface discharge can be calculated.
### Table 3. Climatological data and potential evaporation calculation every month in 1993 - 2014

| No | Data                          | Unit | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|----|-------------------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | Average Temperature (T)       | °C   | 23,09 | 23,15 | 23,49 | 23,74 | 23,34 | 22,94 | 23,16 | 23,80 | 24,56 | 24,36 | 23,58 |
| 2  | Average Solar Irradiance      | %   | 19,05 | 21,14 | 33,91 | 35,55 | 49,27 | 47,14 | 55,14 | 60,23 | 61,27 | 59,14 | 42,59 | 24,41 |
| 3  | Average Relative Humidity (RH)| %   | 82,41 | 82,05 | 82,32 | 81,86 | 81,64 | 80,77 | 78,68 | 76,68 | 72,64 | 72,41 | 78,91 | 83,27 |
| 4  | Wind Velocity                 | km/hr | 2,62 | 3,11 | 2,01 | 1,04 | 0,68 | 0,72 | 0,86 | 0,83 | 0,99 | 1,04 | 0,81 | 1,79 |
|    |                               | km/day | 62,95 | 79,53 | 48,33 | 24,98 | 16,36 | 17,24 | 20,73 | 19,96 | 23,67 | 24,87 | 19,53 | 42,98 |
| 5  | Saturated Vapor Pressure (ea) | mbar | 28,25 | 28,36 | 28,93 | 29,42 | 29,35 | 28,68 | 27,99 | 28,37 | 29,63 | 30,86 | 29,09 |
| 6  | Real Vapor Pressure (ed)      | mbar | 23,28 | 23,26 | 23,81 | 24,08 | 23,96 | 23,16 | 22,02 | 21,76 | 21,52 | 22,35 | 24,05 | 24,22 |
| 7  | Vapor Pressure Difference (ea-ed) | mbar | 4,97 | 5,09 | 5,12 | 5,34 | 5,39 | 5,51 | 5,97 | 6,62 | 8,11 | 8,52 | 6,43 | 4,87 |
| 8  | Wind Function (f(u))         | km/day | 0,44 | 0,48 | 0,40 | 0,34 | 0,31 | 0,32 | 0,33 | 0,33 | 0,34 | 0,33 | 0,32 | 0,39 |
| 9  | W                             |       | 0,74 | 0,74 | 0,74 | 0,75 | 0,75 | 0,74 | 0,73 | 0,74 | 0,75 | 0,76 | 0,76 | 0,74 |
| 10 | Weighting Factor (1-W)       |       | 0,26 | 0,26 | 0,26 | 0,25 | 0,26 | 0,27 | 0,26 | 0,25 | 0,24 | 0,24 | 0,24 | 0,26 |
| 11 | Extraterrestrial Radiation (Ra) | mm/day | 15,80 | 16,00 | 15,60 | 14,70 | 13,40 | 12,80 | 13,10 | 14,00 | 15,00 | 15,70 | 15,80 | 15,70 |
| 12 | Shortwave Radiation (Rs)     | mm/day | 5,45 | 5,69 | 6,54 | 6,29 | 6,65 | 6,22 | 6,89 | 7,72 | 8,35 | 8,57 | 7,31 | 5,84 |
| 13 | Net Shortwave Radiation (Rns) | mm/day | 1,36 | 1,42 | 1,64 | 1,57 | 1,66 | 1,55 | 1,72 | 1,93 | 2,09 | 2,14 | 1,83 | 1,46 |
| 14 | Real Vapor Pressure Function (f(ed)) |       | 0,13 | 0,13 | 0,13 | 0,12 | 0,12 | 0,13 | 0,13 | 0,13 | 0,12 | 0,12 | 0,12 | 0,12 |
| 15 | Radiation Function (f(N/N)) |       | 0,27 | 0,29 | 0,41 | 0,42 | 0,54 | 0,52 | 0,60 | 0,64 | 0,63 | 0,63 | 0,48 | 0,52 |
| 16 | Temperature Function (f(T))  |       | 15,27 | 15,28 | 15,57 | 15,45 | 15,43 | 15,34 | 15,23 | 15,29 | 15,48 | 15,64 | 15,59 | 15,40 |
| 17 | Net Longwave Radiation (Rln) | mm/day | 0,53 | 0,57 | 0,78 | 0,80 | 1,05 | 1,03 | 1,21 | 1,32 | 1,37 | 1,31 | 0,94 | 0,61 |
| 18 | Net Radiation (Rn)           | mm/day | 0,83 | 0,86 | 0,86 | 0,77 | 0,62 | 0,52 | 0,51 | 0,61 | 0,72 | 0,84 | 0,89 | 0,85 |
| 19 | Correction Factor (c)        |       | 1,10 | 1,10 | 1,00 | 1,00 | 0,95 | 0,95 | 1,00 | 1,00 | 1,00 | 1,00 | 1,10 | 1,10 |
| 20 | Potential Evapotranspiration (Eto) | mm/day | 1,30 | 1,40 | 1,17 | 1,03 | 0,84 | 0,80 | 0,90 | 1,01 | 1,34 | 1,46 | 1,35 | 1,29 |

Source: Calculation Result

**Figure 2.** Map of Thiessen polygon
(Source: Brantas river basin organization or balai besar wilayah sungai brantas)
### Table 4. Weighting factor calculation

| Station Name | Area (Ha) | Percentage (%) |
|--------------|-----------|-----------------|
| Rahwatu      | 452,595   | 16              |
| Gembong      | 2176,498  | 78              |
| Tanjungrejo  | 180,908   | 6               |
| **Total**    | **2810**  | **100**         |

Source: Calculation Result

The average rainfall calculation using Thiessen polygon in 2014 was shown in the following table:

### Table 5. Average rainfall on 2014 (mm)

| Year | Station Name | Weighting Factor (Factor) | Jan-01 | Feb-01 | Mar-01 | Apr-01 | May | June | July | Aug-01 | Sep-01 | Oct-01 | Nov-01 | Dec-01 |
|------|--------------|---------------------------|--------|--------|--------|--------|-----|------|------|--------|--------|--------|--------|--------|
| 2014 | Rahwatu      | 16                        | 108,63 | 131,82 | 114,56 | 84,45  | 360,59 | 54,72 | 46,68 | 15,11  | 218,99 | 125,63 | 79,75  | 143,32 |
| 2014 | Gembong      | 78                        | 82,42  | 145,21 | 133,6  | 75,84  | 126,57 | 141,24 | 98,76  | 166,24 | 99,66  | 163,88 | 116,37 |
| 2014 | Tanjungrejo  | 6                         | 41     | 36     | 108    | 276    | 92    | 69    | 37    | 74     | 0      | 16     | 4      | 30     |
| 2014 | **Average**  | **100**                   | **108,9348** | **131,6439** | **146,2048** | **92,7282** | **92,0118** | **122,2465** | **140,1581** | **109,2703** | **160,0572** | **88,7437** | **152,0109** | **101,7842** |

Source: Calculation Result

### Table 6. Average rainfall data records (mm)

| Rank | January | February | March | April | May | June |
|------|---------|----------|-------|-------|-----|------|
| 1    | 164,78  | 360,59   | 215,32 | 300,65 | 161,86 | 160,06 |
| 2    | 156,75  | 131,64   | 155,79 | 246,83 | 104,09 | 150,39 |
| 3    | 156,22  | 126,16   | 146,79 | 82,49  | 97,16  | 122,25 |
| 4    | 153,28  | 124,89   | 146,24 | 180,19 | 92,46  | 119,00 |
| 5    | 124,56  | 124,69   | 138,99 | 179,54 | 92,01  | 109,04 |
| 6    | 108,93  | 123,49   | 109,61 | 110,06 | 61,82  | 88,85  |
| 7    | 106,63  | 101,43   | 107,18 | 92,73  | 61,78  | 88,58  |
| 8    | 84,45   | 54,72    | 81,26  | 79,86  | 41,78  | 87,65  |
| 9    | 83,19   | 46,68    | 77,07  | 36,93  | 26,60  | 82,28  |
| 10   | 57,75   | 15,11    | 17,76  | 36,02  | 16,38  | 47,73  |

Effective Rainfall (mm)
After obtaining the average rainfall, an effective rainfall calculation for rice, secondary crops, and sugarcane is calculated. The result of calculation can be seen at Table 7.

**Table 7. Effective rainfall calculations for rice crops (mm/day)**

| Rank | January | February | March | April | May | June |
|------|---------|----------|-------|-------|-----|------|
| 1    | 164.78  | 360.59   | 215.32| 300.65| 161.86| 170.63|
| 2    | 136.75  | 151.79   | 246.83| 104.09| 150.39| 87.26 |
| 3    | 136.22  | 166.16   | 223.49| 97.16 | 122.25| 152.74|
| 4    | 133.28  | 124.89   | 146.24| 180.19| 92.46 | 140.16|
| 5    | 114.56  | 128.49   | 138.99| 179.34| 92.01 | 101.04|
| 6    | 108.93  | 123.49   | 109.61| 110.06| 61.82 | 88.85 |
| 7    | 108.63  | 107.18   | 92.73 | 67.88 | 88.58 | 123.94|
| 8    | 84.45   | 54.72    | 71.06 | 87.65 | 104.95| 92.02 |
| 9    | 83.19   | 46.68    | 77.07 | 36.93 | 26.60 | 82.88 |
| 10   | 57.75   | 15.11    | 17.76| 36.02 | 16.38 | 47.73 |

| Rank | July | August | September | October | November | December |
|------|-----|--------|-----------|---------|----------|----------|
| 1    | 95.18| 58.10  | 46.51     | 68.45   | 52.58    | 18.68    |
| 2    | 63.10| 35.61  | 29.94     | 46.62   | 49.16    | 14.31    |
| 3    | 36.86| 34.22  | 25.51     | 37.00   | 32.38    | 11.80    |
| 4    | 25.80| 23.05  | 19.74     | 28.83   | 22.18    | 9.52     |
| 5    | 22.00| 12.48  | 15.50     | 15.15   | 11.66    | 8.23     |
| 6    | 8.59 | 4.44   | 15.16     | 10.73   | 11.22    | 7.44     |
| 7    | 7.77 | 3.14   | 7.83      | 9.83    | 7.89     | 1.39     |
| 8    | 6.99 | 0.00   | 1.79      | 2.68    | 0.00     | 0.00     |
| 9    | 0.00 | 0.00   | 0.00      | 0.00    | 0.00     | 0.00     |
| 10   | 0.00 | 0.00   | 0.00      | 0.00    | 0.00     | 0.00     |

Source: Calculation Result
Table 8. Effective rainfall calculations for secondary crops (mm/day)

| Month | Periods | 50% re 80 mm/10 days | Re mm/month | Eto mm/month | Re Pol mm/month | Re Pol mm/month |
|-------|---------|----------------------|-------------|--------------|-----------------|----------------|
| Jan-01 | 42.22 | 1.93 |
| Jan-02 | 27.36 | 100.21 | 39.14 | 58.04 | 1.93 | 1.93 |
| Jan-03 | 40.63 | 1.93 |
| Feb-01 | 39.93 | 1.86 |
| Feb-02 | 20.86 | 104.62 | 42.08 | 55.83 | 1.86 | 1.86 |
| Feb-03 | 43.82 | 1.86 |
| Mar-01 | 52.18 | 1.75 |
| Mar-02 | 26.01 | 99.11 | 34.98 | 52.45 | 1.75 | 1.75 |
| Mar-03 | 20.92 | 1.75 |
| Apr-01 | 15.29 | 1.53 |
| Apr-02 | 52.84 | 86.66 | 30.76 | 45.75 | 1.53 | 1.53 |
| Apr-03 | 17.54 | 1.53 |
| Mei-01 | 12.38 | 0.57 |
| Mei-02 | 13.76 | 29.71 | 25.27 | 17.21 | 0.57 | 0.57 |
| Mei-03 | 3.58 | 0.57 |
| Jun-01 | 15.90 | 0.44 |
| Jun-02 | 22.48 | 23.96 | 2.05 | 4.44 | 0.44 |
| Jun-03 | 6.30 | 0.44 |
| Jul-01 | 3.50 | 0.04 |
| Jul-02 | 0.00 | 4.39 | 28.91 | 1.28 | 0.04 | 0.04 |
| Jul-03 | 0.89 | 0.04 |
| Aug-01 | 1.34 | 0.04 |
| Aug-02 | 0.00 | 1.34 | 30.17 | 0.00 | 0.00 | 0.00 |
| Aug-03 | 0.00 | 0.00 |
| Sep-01 | 0.00 | 0.00 |
| Sep-02 | 0.00 | 0.00 | 40.04 | 0.00 | 0.00 | 0.00 |
| Sep-03 | 0.00 | 0.00 |
| Okt-01 | 0.00 | 0.00 |
| Okt-02 | 5.60 | 29.78 | 43.72 | 17.96 | 0.60 | 0.60 |
| Okt-03 | 24.08 | 0.60 |
| Nov-01 | 55.88 | 1.97 |
| Nov-02 | 27.33 | 112.37 | 40.59 | 59.21 | 1.97 | 1.97 |
| Nov-03 | 29.15 | 1.97 |
| Des-01 | 25.17 | 2.13 |
| Des-02 | 54.26 | 123.52 | 38.61 | 63.97 | 2.13 | 2.13 |
| Des-03 | 44.09 | 2.13 |

Source: Calculation Result
### Table 9. Effective rainfall calculations for sugarcane crops (mm/day)

| Month | Periods | 50% re 80 | Re | Eto | Re Pol | Re Pol |
|-------|---------|-----------|----|-----|--------|--------|
|       |         | mm/10 days| mm/month | mm/month | mm/month | mm/month |
| 1     | Jan-01  | 50.67     | 2.53 |
|       | Jan-02  | 32.89     | 132.25 | 39.14 | 75.96   | 2.53 |
|       | Jan-03  | 48.76     | 2.53 |
|       | Feb-01  | 25.05     | 125.54 | 42.08 | 73.10   | 2.44 |
|       | Feb-02  | 52.59     | 2.44 |
|       | Feb-03  | 62.61     | 2.29 |
|       | Mar-01  | 31.21     | 118.93 | 34.98 | 68.69   | 2.29 |
|       | Mar-02  | 25.11     | 2.29 |
|       | Apr-01  | 18.34     | 2.00 |
|       | Apr-02  | 31.21     | 118.93 | 34.98 | 68.69   | 2.29 |
|       | Apr-03  | 25.11     | 2.29 |
|       | Mei-01  | 14.85     | 0.76 |
|       | Mei-02  | 16.51     | 35.65 | 25.27 | 22.89   | 0.76 |
|       | Mei-03  | 6.29      | 0.76 |
|       | Jun-01  | 19.07     | 0.58 |
|       | Jun-02  | 30.98     | 20.96 | 17.48 | 0.58 |
|       | Jun-03  | 7.56      | 0.58 |
|       | Jul-01  | 4.20      | 0.07 |
|       | Jul-02  | 5.17      | 10.91 | 2.19  | 0.07 |
|       | Jul-03  | 1.07      | 0.07 |
|       | Aug-01  | 1.61      | 0.00 |
|       | Aug-02  | 1.61      | 30.17 | 0.00  | 0.00 |
|       | Aug-03  | 1.61      | 0.00 |
|       | Sep-01  | 0.00      | 0.00 |
|       | Sep-02  | 0.00      | 0.00 |
|       | Sep-03  | 0.00      | 0.00 |
|       | Okt-01  | 0.00      | 0.00 |
|       | Okt-02  | 8.83      | 35.71 | 43.72 | 23.99   | 0.80 |
|       | Okt-03  | 28.90     | 0.80 |
|       | Nov-01  | 6.76      | 2.58 |
|       | Nov-02  | 32.80     | 134.84 | 40.59 | 77.48   | 2.58 |
|       | Nov-03  | 34.98     | 2.58 |
|       | Des-01  | 30.20     | 2.79 |
|       | Des-02  | 65.11     | 146.22 | 38.61 | 83.67   | 2.79 |
|       | Des-03  | 52.90     | 2.79 |

Source: Calculation Result

#### 3.2.2. Land preparation

Water needs for land preparations determine the maximum demand of irrigation water in the new irrigated area. Affecting factors of the water demand for land preparation are evapotranspiration and location. It is calculated using methods developed by Van de Goor and Zijlstra (1968). The water need for land preparation is shown in Table 10.
### 3.2.3. Water needs for planting

#### Table 10. Calculation of water needs for land preparation (lt / ha)

| No | Parameter | Unit | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|----|-----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | Eto mm/day | 1.30 | 1.40 | 0.37 | 0.17 | 0.84 | 0.80 | 0.90 | 1.01 | 1.34 | 1.46 | 1.15 | 1.29 |
| 2  | Eo + 1.1 x Eto mm/day | 1.44 | 1.54 | 1.28 | 1.13 | 0.93 | 0.88 | 0.99 | 1.11 | 1.47 | 1.60 | 1.49 | 1.42 |
| 3  | Perlokasi mm/day | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| 4  | M = Eo + P mm/day | 3.44 | 3.54 | 3.28 | 3.13 | 2.93 | 2.88 | 2.99 | 3.11 | 3.47 | 3.60 | 3.49 | 3.42 |
| 5  | T day | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 |
| 6  | S mm/day | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 | 300.00 |
| 7  | K = M x T/S (X=1) mm/day | 11.50 | 12.22 | 11.41 | 11.65 | 11.21 | 11.25 | 11.31 | 11.83 | 11.59 | 11.59 | 11.85 | 11.19 |

#### Table 11. Water needs of rice crops at the beginning of planting on 1st November

| No | Parameter | Unit | Rice, 1st November | Etc | NFR | OF |
|----|-----------|------|--------------------|-----|-----|-----|
| 1  | Eto mm/day | 1.35 | 1.40 | 1.15 | 1.30 | 1.33 |
| 2  | Re x 1.1 | 0.00 | 0.46 | 1.11 | 2.05 | 1.10 |
| 3  | P mm/day | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4  | WLR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5  | Rice Coefficient | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Source: Calculation Result

---

International Conference on Mathematics: Pure, Applied and Computation
IOP Publishing
IOP Conf. Series: Journal of Physics: Conf. Series 974 (2018) 012048
doi:10.1088/1742-6596/974/1/012048
The alternative calculations for planting pattern in the optimization study are as follows:
- Alternative 1: the beginning of planting on 1<sup>st</sup> November
- Alternative 2: the beginning of planting on 2<sup>nd</sup> November
- Alternative 3: the beginning of planting on 3<sup>rd</sup> November
- Alternative 4: the beginning of planting on 1<sup>st</sup> December
- Alternative 5: the beginning of planting on 2<sup>nd</sup> December
- Alternative 6: the beginning of planting on 3<sup>rd</sup> December

Table 11, Table 12 and Table 13 show the water need in difference time of the beginning of planting time.

Table 12. Water needs of secondary crops at the beginning of planting on 1<sup>st</sup> November

| Planting Season | Month | Periods | Eto | Re | Secondary Corps, 1<sup>st</sup> November | Etc | NFR | DR |
|----------------|-------|---------|-----|----|-----------------------------|-----|-----|----|
| 1 2 3          | 1     | 4 5     | 6   | 7 8 | 9 10 11 12 13              |     |     |    |
| Nov           | 1     | 1,35 1,97 | 0,50 0,50 | 0,68 | -1,30 | -0,15 | 0,00 |
| Dec           | 1     | 1,29 2,13 | 1,00 0,75 | 0,63 | 0,79 | 1,02 | -1,13 | -0,13 | 0,00 |
| Rainy Season  | 1     | 1,30 1,93 | 0,64 0,82 | 1,00 | 0,82 | 1,07 | -0,81 | -0,10 | 0,00 |
| Jan           | 1     | 1,40 1,86 | 0,45 0,64 | 0,82 | 0,64 | 0,83 | -1,13 | -0,13 | 0,00 |
| Mar           | 1     | 1,35 1,97 | 0,50 0,63 | 0,50 | 0,63 | 0,76 | -1,21 | -0,14 | 0,00 |
| Apr           | 1     | 1,29 2,13 | 1,00 0,75 | 0,63 | 0,79 | 1,02 | -1,13 | -0,13 | 0,00 |
| Dry Season I  | 1     | 1,30 1,93 | 0,64 0,82 | 1,00 | 0,82 | 1,07 | -0,81 | -0,10 | 0,00 |
| May           | 1     | 1,40 1,86 | 0,45 0,64 | 0,82 | 0,64 | 0,83 | -1,13 | -0,13 | 0,00 |
| Jun           | 1     | 1,35 1,97 | 0,50 0,50 | 0,50 | 0,68 | 0,66 | -1,09 | -0,13 | 0,00 |
| Jul           | 1     | 1,29 2,13 | 1,00 0,75 | 0,63 | 0,79 | 1,02 | -1,02 | -0,12 | 0,00 |
| Aug           | 1     | 1,30 1,93 | 0,64 0,82 | 1,00 | 0,82 | 1,07 | -0,81 | -0,10 | 0,00 |
| Sep           | 1     | 1,40 1,86 | 0,45 0,64 | 0,82 | 0,64 | 0,83 | -1,13 | -0,13 | 0,00 |
| Oct           | 1     | 1,35 1,97 | 0,50 0,63 | 0,50 | 0,63 | 0,76 | -1,21 | -0,14 | 0,00 |
| Nov           | 2     | 1,35 1,97 | 0,50 0,50 | 0,68 | -1,30 | -0,15 | 0,00 |
| Dec           | 2     | 1,29 2,13 | 1,00 0,75 | 0,63 | 0,79 | 1,02 | -1,13 | -0,13 | 0,00 |
| Rainy Season  | 2     | 1,30 1,93 | 0,64 0,82 | 1,00 | 0,82 | 1,07 | -0,81 | -0,10 | 0,00 |
| Jan           | 2     | 1,40 1,86 | 0,45 0,64 | 0,82 | 0,64 | 0,83 | -1,13 | -0,13 | 0,00 |
| Mar           | 2     | 1,35 1,97 | 0,50 0,63 | 0,50 | 0,63 | 0,76 | -1,21 | -0,14 | 0,00 |
| Apr           | 2     | 1,29 2,13 | 1,00 0,75 | 0,63 | 0,79 | 1,02 | -1,13 | -0,13 | 0,00 |
| Dry Season I  | 2     | 1,30 1,93 | 0,64 0,82 | 1,00 | 0,82 | 1,07 | -0,81 | -0,10 | 0,00 |
| May           | 2     | 1,40 1,86 | 0,45 0,64 | 0,82 | 0,64 | 0,83 | -1,13 | -0,13 | 0,00 |
| Jun           | 2     | 1,35 1,97 | 0,50 0,50 | 0,50 | 0,68 | 0,66 | -1,09 | -0,13 | 0,00 |
| Jul           | 2     | 1,29 2,13 | 1,00 0,75 | 0,63 | 0,79 | 1,02 | -1,02 | -0,12 | 0,00 |
| Aug           | 2     | 1,30 1,93 | 0,64 0,82 | 1,00 | 0,82 | 1,07 | -0,81 | -0,10 | 0,00 |
| Sep           | 2     | 1,40 1,86 | 0,45 0,64 | 0,82 | 0,64 | 0,83 | -1,13 | -0,13 | 0,00 |
| Oct           | 2     | 1,35 1,97 | 0,50 0,63 | 0,50 | 0,63 | 0,76 | -1,21 | -0,14 | 0,00 |

Source: Calculation Result
modeling is to solve problems in Logung irrigation area, Kudus Regency based on steps as follows:

3.3.1. Optimization Model

The optimization modeling equation uses a linear equation or called as linear programming. The modeling is to solve problems in Logung irrigation area, Kudus Regency based on steps as follows:
1. Determining the optimization model
2. Determining the optimized variables, i.e. land area for each type of plant at each season
3. Determining the limits value on the modeling (based on calculations)
4. Optimization model Arrangement
5. Optimization process (in this study using POM-QM application program for Windows 3)
6. Analysis of optimization results (based on maximum profit and intensity of planting)

### Table 13. Water needs of sugarcane crops at the beginning of planting on 1st November

| Planting Season | Month | Periods | Eto | Re | Sugarcane, 1st November | Etc | NFR | DR |
|-----------------|-------|--------|-----|----|------------------------|-----|-----|----|
|                  |       |        | mm/day | c1 | c2 | c3 | c4 | mm/day | L/ha | L/ha |
| 1                | 2     | 3      | 4    | 5  | 6  | 7  | 8  | 9    | 10   | 11   |
| 2 Nov            | 1,35  | 2,58   | 0,55 | 0,55 | 0,60 | 0,58 | 0,79 | -1,80 | -0,21 |
| 3 Nov            | 1,35  | 2,58   | 0,55 | 0,55 | 0,60 | 0,58 | 0,82 | -1,84 | -0,21 |
| 4 Nov            | 1,29  | 2,79   | 0,80 | 0,55 | 0,55 | 0,63 | 0,82 | 0,00  | 0,00  |
| 5 Dec            | 1,29  | 2,79   | 0,80 | 0,80 | 0,55 | 0,81 | 0,92 | -1,86 | -0,22 |
| 6 Jan            | 1,30  | 2,53   | 0,90 | 0,80 | 0,80 | 0,83 | 1,08 | 0,00  | 0,00  |
| 7 Feb            | 1,30  | 2,53   | 0,90 | 0,90 | 0,88 | 0,88 | 1,55 | -1,38 | -0,16 |
| 8 Mar            | 1,30  | 2,53   | 1,00 | 0,90 | 0,95 | 1,24 | 1,10 | -0,15 |
| 9 Apr            | 1,40  | 2,44   | 1,00 | 1,00 | 0,95 | 1,38 | 1,06 | -0,12 |
| 10 May           | 1,40  | 2,44   | 1,00 | 1,00 | 1,00 | 1,40 | 1,04 | -0,12 |
| 11 Jun           | 1,17  | 2,29   | 1,05 | 1,05 | 1,00 | 1,19 | 1,10 | -0,13 |
| 12 Jul           | 1,12  | 2,29   | 1,05 | 1,05 | 1,05 | 1,23 | 1,06 | -0,12 |
| 13 Aug           | 1,03  | 2,00   | 1,05 | 1,05 | 1,05 | 1,08 | 0,92  | -0,11 |
| 14 Sep           | 0,84  | 0,76   | 1,05 | 1,05 | 1,05 | 1,05 | 0,88  | 0,12  | 0,01 |
| 15 Oct           | 0,80  | 0,58   | 1,05 | 1,05 | 1,05 | 1,05 | 0,84  | 0,03  | 0,03 |
| 16 Nov           | 0,80  | 0,58   | 1,05 | 1,05 | 1,05 | 1,05 | 0,84  | 0,26  | 0,03 |
| 17 Dec           | 0,80  | 0,58   | 1,05 | 1,05 | 1,05 | 1,05 | 0,84  | 0,26  | 0,03 |
| 18 Jan           | 0,90  | 0,70   | 1,05 | 1,05 | 1,05 | 1,05 | 0,95  | 0,87  | 0,10 |
| 19 Feb           | 0,90  | 0,70   | 1,05 | 1,05 | 1,05 | 1,05 | 0,95  | 0,87  | 0,10 |
| 20 Mar           | 0,90  | 0,70   | 1,05 | 1,05 | 1,05 | 1,05 | 0,95  | 0,87  | 0,10 |
| 21 Apr           | 1,01  | 0,00   | 1,05 | 1,05 | 1,05 | 1,05 | 1,06  | 0,12  | 0,19 |
| 22 May           | 1,01  | 0,00   | 1,05 | 1,05 | 1,05 | 1,05 | 1,06  | 0,12  | 0,19 |
| 23 Jun           | 1,34  | 0,80   | 1,05 | 1,05 | 0,97 | 1,30 | 1,30  | 0,15  | 0,23 |
| 24 Jul           | 1,34  | 0,80   | 1,05 | 1,05 | 0,97 | 1,30 | 1,30  | 0,15  | 0,23 |
| 25 Aug           | 1,34  | 0,80   | 1,05 | 1,05 | 0,97 | 1,30 | 1,30  | 0,15  | 0,23 |
| 26 Sep           | 1,34  | 0,80   | 1,05 | 1,05 | 0,97 | 1,30 | 1,30  | 0,15  | 0,23 |
| 27 Oct           | 1,34  | 0,80   | 1,05 | 1,05 | 0,97 | 1,30 | 1,30  | 0,15  | 0,23 |

Source: Calculation Result
3.3.2. Analysis of harvest yield
Harvest yields are the result of net income from crops harvesting by farmers. It is defined as net income, that can be found as the difference between the gross production and production cost. Table 14 shows the basic calculation of harvest yields for Kudus Area.

| No | Detail                      | Rice                        | Corn                        | Sugarcane                  |
|----|-----------------------------|-----------------------------|-----------------------------|---------------------------|
| 1  | Product Price (Rp/ton)      | Rp4.000.000                 | Rp4.000.000                 | Rp380.000                 |
| 2  | Productivity (ton)          | 7                           | 6.4                         | 110                       |
| 3  | Production (Rp/ha)          | Rp28.000.000                | Rp25.600.000                | Rp41.800.000              |
| 4  | Production Cost (Rp/ha)     | Rp13.580.000                | Rp12.100.000                | Rp30.000.000              |
| 5  | Profitability (Rp/ha)       | Rp14.420.000                | Rp13.500.000                | Rp11.800.000              |

Source: semarang.bisnis.com, tabloidinsartani.com, isknews.com

3.3.3. Mathematical Model for Optimization
The linear programme classified the parameter of optimization as functional purpose and function constraints. Two approaches are used as basic assumption: maximize based on land area and water need. The optimization model equations used in this study are as follows:

Functional purpose
Maximize based on land area

\[ Z = X_{p1} + X_{w1} + X_{p2} + X_{w2} + X_{p3} + X_{w3} + X_t \]  

where:

\[ X_{p1} = \text{Land area for rice crops in the rainy season (Ha)} \]
\[ X_{w1} = \text{Land area for secondary crops in the rainy season (Ha)} \]
\[ X_{p2} = \text{Land area for rice crops in the 1st dry season (Ha)} \]
\[ X_{w2} = \text{Land area for secondary crops in the 1st dry season (Ha)} \]
\[ X_{p3} = \text{Area of land for rice crops in the 2nd dry season (Ha)} \]
\[ X_{w3} = \text{Land area for secondary crops in the 2nd dry season (Ha)} \]
\[ X_t = \text{Land area for sugarcane crops in once growing season (Ha)} \]

Function constraints

* Reliable discharge:

\[ V_{p1}.X_{p1} + V_{w1}.X_{w1} + V_t.X_t \leq Q_1 \text{ (periods 1 – 12)} \]  
\[ V_{p2}.X_{p2} + V_{w2}.X_{w2} + V_t.X_t \leq Q_2 \text{ (periods 13 – 24)} \]  
\[ V_{p3}.X_{p3} + V_{w3}.X_{w3} + V_t.X_t \leq Q_3 \text{ (periods 25 – 36)} \]

where,

\[ V_{pi} = \text{water needs of rice crops in each season (lt/s/ha)} \]
\[ V_{wi} = \text{water needs of secondary crops in each season (lt/s/ha)} \]
\[ V_t = \text{water needs of sugarcane crops in each season (lt/s/ha)} \]

* Maximum area

\[ X_{p1} + X_{w1} + X_t \leq A_{total} \]  
\[ X_{p2} + X_{w2} + X_t \leq A_{total} \]  
\[ X_{p3} + X_{w3} + X_t \leq A_{total} \]

where, \( A_{total} = 2810 \text{ Ha} \)

* Sugarcane

\[ X_t \geq X_{te} \]

where, \( X_{te} = \text{Minimum required sugarcane area (141 Ha)} \)
• Non-negativity
\[ X_{p1}, X_{w1}, X_{p2}, X_{w2}, X_{p3}, X_{w3}, X_t \geq 0 \]  

3.3.4. Analysis of Optimization Results

The optimization analysis is based on two objectives, i.e. the maximum area and maximum profit. Iterative analysis is conducted using POM-QM for Windows 3.

The iteration data result using POM-QM program for Windows 3 obtained the optimum area data on each plant type with each alternative planting pattern. Then, it can be known the planting intensity in every planting season. Moreover, the extent area data will obtain the results of agricultural production annually.

Table 16 shows that the greatest profit of production is obtained in alternative 6 with the early planting periods on the 3rd December.

Figure 3. Optimization model of land area with alternative planting pattern 1
Source: Input POM-QM for Windows 3

Figure 4. Result of land area analysis by linear programming
Source: Input POM-QM for Windows 3
### Table 15. Planting intensity based on land area optimization results

| Alternatives | Planting Season | Area | Plant Intensity |
|--------------|-----------------|------|-----------------|
|              | Rice            | Secondary Crops | Sugarcane       | Rice | Secondary Crops | Sugarcane | Total |
|              | Ha              | Ha                | %               | Ha         | %               | Ha            |
| MH           | 236             | 2383               | 191             | 8.41        | 84.8            | 6.8          |
| 1            | MK1             | 288                | 524             | 2331        | 6223            | 191           | 191         | 10.24 | 18.64 | 82.96 | 221.48 | 6.8 | 20.39 | 260.51 |
| MK2          | 0               | 1509               | 0               | 0           | 53.72           | 0            | 0            |
| MK1          | 335             | 2284               | 191             | 11.91       | 83.29           | 6.8          |
| 2            | MK1             | 226                | 561             | 2393        | 6062            | 191           | 191         | 8.05  | 19.96 | 85.16 | 235.71 | 6.8 | 20.39 | 256.06 |
| MK2          | 0               | 1384               | 191             | 0           | 49.27           | 6.8          |
| MK1          | 722             | 1897               | 191             | 25.69       | 67.51           | 6.8          |
| 3            | MK1             | 290                | 1012            | 2330        | 5422            | 191           | 191         | 10.31 | 16   | 82.9 | 192.97 | 6.8 | 20.39 | 249.36 |
| MK2          | 0               | 1196               | 191             | 0           | 42.55           | 6.8          |
| MK1          | 577             | 2042               | 191             | 20.54       | 72.66           | 6.8          |
| 4            | MK1             | 202                | 779             | 2417        | 5637            | 191           | 191         | 7.18  | 27.72 | 86.02 | 200.62 | 6.8 | 20.39 | 248.73 |
| MK2          | 0               | 1178               | 191             | 0           | 41.94           | 6.8          |
| MK1          | 331             | 2388               | 191             | 11.77       | 83.44           | 6.8          |
| 5            | MK1             | 186                | 517             | 2433        | 6449            | 191           | 191         | 6.63  | 18.39 | 86.57 | 228.52 | 6.8 | 20.39 | 268.3 |
| MK2          | 0               | 1728               | 191             | 0           | 61.51           | 6.8          |
| MK1          | 350             | 2269               | 191             | 12.47       | 80.74           | 6.8          |
| 6            | MK1             | 190                | 540             | 2429        | 7254            | 191           | 191         | 6.76  | 19.22 | 86.45 | 258.13 | 6.8 | 20.39 | 297.75 |
| MK2          | 0               | 2556               | 191             | 0           | 90.95           | 6.8          |
| MH           | 1852            | 0                  | 26              | 65.9        | 0               | 0.93         |
| Existing     | MK1             | 1852               | 3704            | 0           | 1852            | 26            | 26          | 65.9 | 131.8 | 0   | 65.9 | 0.93 | 2.78 | 200.47 |
| MK2          | 0               | 1852               | 26              | 65.9        | 0               | 0.93         |

Source: Calculation Result

### Table 16. Profit results based on land area optimization results

| Alternatives | Planting Season | Area | Plant Intensity |
|--------------|-----------------|------|-----------------|
|              | Rice            | Secondary Crops | Sugarcane       | Rice | Secondary Crops | Sugarcane | Total |
|              | Ha              | Ha                | %               | Ha         | %               | Ha            |
| MH           | 236             | 2383               | 191             | 8.41        | 84.8            | 6.8          |
| 1            | MK1             | 288                | 524             | 2331        | 6223            | 191           | 191         | 10.24 | 18.64 | 82.96 | 221.48 | 6.8 | 20.39 | 260.51 |
| MK2          | 0               | 1509               | 0               | 0           | 53.72           | 0            | 0            |
| MK1          | 335             | 2284               | 191             | 11.91       | 83.29           | 6.8          |
| 2            | MK1             | 226                | 561             | 2393        | 6062            | 191           | 191         | 8.05  | 19.96 | 85.16 | 235.71 | 6.8 | 20.39 | 256.06 |
| MK2          | 0               | 1384               | 191             | 0           | 49.27           | 6.8          |
| MK1          | 722             | 1897               | 191             | 25.69       | 67.51           | 6.8          |
| 3            | MK1             | 290                | 1012            | 2330        | 5422            | 191           | 191         | 10.31 | 16   | 82.9 | 192.97 | 6.8 | 20.39 | 249.36 |
| MK2          | 0               | 1196               | 191             | 0           | 42.55           | 6.8          |
| MK1          | 577             | 2042               | 191             | 20.54       | 72.66           | 6.8          |
| 4            | MK1             | 202                | 779             | 2417        | 5637            | 191           | 191         | 7.18  | 27.72 | 86.02 | 200.62 | 6.8 | 20.39 | 248.73 |
| MK2          | 0               | 1178               | 191             | 0           | 41.94           | 6.8          |
| MK1          | 331             | 2388               | 191             | 11.77       | 83.44           | 6.8          |
| 5            | MK1             | 186                | 517             | 2433        | 6449            | 191           | 191         | 6.63  | 18.39 | 86.57 | 228.52 | 6.8 | 20.39 | 268.3 |
| MK2          | 0               | 1728               | 191             | 0           | 61.51           | 6.8          |
| MK1          | 350             | 2269               | 191             | 12.47       | 80.74           | 6.8          |
| 6            | MK1             | 190                | 540             | 2429        | 7254            | 191           | 191         | 6.76  | 19.22 | 86.45 | 258.13 | 6.8 | 20.39 | 297.75 |
| MK2          | 0               | 2556               | 191             | 0           | 90.95           | 6.8          |
| MH           | 1852            | 0                  | 26              | 65.9        | 0               | 0.93         |
| Existing     | MK1             | 1852               | 3704            | 0           | 1852            | 26            | 26          | 65.9 | 131.8 | 0   | 65.9 | 0.93 | 2.78 | 200.47 |
| MK2          | 0               | 1852               | 26              | 65.9        | 0               | 0.93         |

Source: Calculation Result
4. Conclusion and Suggestion

4.1. Conclusions
The conclusions in this study are as follows:

1. Based on the analysis of Logung river discharge data, it can be concluded that the reliable discharge was obtained with 80% probability of reliability. The highest discharge at 80% reliability is 1.8386 m³/s and 0.307 m³/s in the lowest discharge.
2. This study has been analyzed with six alternatives of planting pattern, i.e. 1st November, 2nd November, 3rd November, 1st December, 2nd December, and 3rd December, These alternatives are used as a basic of the water demand calculation for rice, secondary crops, and sugarcane.
3. The extent calculation of the iteration results by POM-QM program for Windows 3 has been obtained from six alternatives of planting patterns. The maximum value is obtained about 8366.77 Ha at the early planting periods in 3rd December with the planting pattern of rice/ sugarcane-beans / sugarcane-rice / sugarcane-beans / sugarcane. The obtained maximum profit value is Rp 113,397,338,854,00.

4.2. Suggestions
The suggestions for the further study are as follows:

1. The application of this optimization study results should be done by approaches and socialization about how to farm well, how to choose a superior seed, how to deal with pest attacks, and other things to farmers in the Logung Irrigation area, Kudus Regency.
2. Based on the data of each alternative existing planting pattern, in the dry season II can’t be planted rice. The amount of water at the beginning of the rainy season is very high. It can be used for the irrigation area expansion to obtain the maximum harvest.
3. There should be maintenance and management of irrigation buildings such as weirs and irrigation channels to minimize water loss due to irrigation buildings damage. In addition, it needs a controlling in order to no illegal tapping.

References
[1] Frizzone J.A.; Coelho R.D ; Dourado-Neto D and R. Soliani, Linear programming model to optimize the water resource use in irrigation projects: an application to the Senator Nilo Coelho Project, Scientific Agriculture Vol 54, June 1997.
[2] Jacovkis P.M., Gradowczyk H., Freisztav A.M. and E. G. Tabak, A Linear Programming Approach to Water-Resources Optimization, ZOR - Methods and Models of Operations Research, pp 33:341-362, 1989
[3] Difallah W., Belkacem Draoui K., and F. Bounaama, Linear Optimization Model for Efficient Use of Irrigation Water, International Journal of Agronomy, Vol. 2017, Article ID 5353648, 2017.
[4] Anieting A.E, Ezugwu I.O and S. Ologun, Application of Linear Programming Technique in the Determination of Optimum Production Capacity, IOSR Journal of Mathematics (IOSR-JM) e-ISSN: 2278-5728, Volume 5, Issue 6, pp 62-65, March April 2013
[5] Pearson L. and McRoberts N., Watershed Management Conference, ASCE, Madison Wisconsin, United Stated, August 2010
[6] Suhardono, Optimasi Penggunaan Lahan Pertanian dengan Program Linier, Thesis, Master Degree, Universitas Brawijaya, 2012.
[7] Balai PSDA Seluna, Rainfall data of Logung Catchment Area, Kudus, 2015.
[8] Setiono, Optimasi Rencana Pola Tanam pada daerah sungai logung, Kudus, dengan menggunakan program linier, Final Assignment,Undergraduated, Department of Civil Engineering, ITS, 2016.
[9] Anwar N., Analisa Sistem Untuk Teknik Sipil, Handout, Department of Civil Engineering ITS,
Surabaya, 2001

[10] Direktorat Jenderal Sumber Daya Air, Departemen Pekerjaan Umum, *Standard of Irrigation Design Criterium – Irrigation Networking*, 2010.

[11] Hidayat A.W and Indriyono Sukawi, *Perencanaan Embung Logung, Jekulo, Kudus*, Undergraduated Final Assignment, Universitas Diponegoro, 2007.