

## Performance of Shallow Groundwater Irrigation Schemes in Nganjuk-East Java, Indonesia

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### ABSTRACT

The use of shallow groundwater for irrigation in Indonesia has not shown maximum benefit yet. Improvements are still required in order to increase performance. The performance of shallow groundwater irrigation schemes (SGWIS) has been evaluated by using the parameters of well efficiency, pump operation, irrigation efficiency, and irrigation cost. Research indicates that well efficiency is around 55-77% with optimum discharge of 4–17 l/s. Relatively, the performance of pump operation was not optimum, and the irrigation efficiency varied at 49-81%. Irrigation cost was about 257 USD per Ha per planting season for onions; equal to 0.02 USD per kg of onion production. Based on existing criteria, the performance of SGWIS in Nganjuk was relatively better than that in other regions of Indonesia; nevertheless the performance might be able to be increased, either by improvement of pump operation management, improvement of the conveyance system, or improvement in the technology of irrigation application.

**Keywords:** Irrigation cost, irrigation efficiency, pump operation, shallow groundwater.

### 1. INTRODUCTION

The development of groundwater irrigation schemes in the District of Nganjuk has been conducted intensively since 1975, through development of shallow wells and deep wells. Most of the shallow wells are located in the northern part of Nganjuk, in the sub-districts of Rejos, Gondang, Sukomoro, Bagor, Nganjuk, Lengkon, and Wilangan. While most of the deep wells are scattered throughout the southern part of Nganjuk, in the sub-districts of Pace, Loceret, Berbek, Sukomoro and Nganjuk.

Generally, groundwater is used for irrigation in the dry season, which occurs during the second planting season (PS<sub>2nd</sub>) and third planting season (PS<sub>3rd</sub>). Several crops that are usually cultivated

in that season are secondary crops (*palawija*), such as soybeans and corn, and horticultural crops, such as chilies, onions, watermelons, melons, and vegetables. The average annual rainfall in the District of Nganjuk (data from 1993 – 2003) was 2,285 mm/year with 90 rainfall event days per year. Average monthly rainfall was 190.4 mm/month, with relative fluctuation along the year. Under the Oldeman classification, the climate in the District of Nganjuk is classified as type C<sub>3</sub>, with 5 dry months (June – October) and 6 wet months (November – April). This indicates that this area can be planted only in paddy (during PS<sub>1st</sub>) and in secondary crops (during PS<sub>2nd</sub>) throughout a year, but this depends on the irrigation water supply.

Shallow wells, generally less than 15 m in depth, are constructed by digging, boring, driving, or jetting (Todd 1980). The results of a study by the Republic of Indonesia Department of Agriculture (RIDA) in 1998 showed that the use of shallow groundwater for irrigation had not given maximum benefit yet. The system needed to be improved in order to increase the performance of the shallow groundwater irrigation schemes (SGWIS), especially in relation to the management of wells and pumps, the increasing of irrigation efficiency, and the arrangement of cropping patterns.

The objective of the research was to review performance of SGWIS, including the parameters of well efficiency, pump operation, irrigation efficiency, and irrigation costs.

## 2. METHODS

The research area was located in the District of Nganjuk, East Java Province, Indonesia. The sampling location for collecting field data was the SGWIS which had been developed in relation to several of high economy-value crops, and which had cropping intensity of more than 200%, in the Sub-district of Sukomoro.

Data was collected by observation and field measurement, soil sampling, interviews, and collecting secondary data. The methods were as follow:

1. Step drawdown and continuous pumping test to measure aquifer and well characteristics
2. Measurement of H-Q (*head-discharge*) of pump operation
3. Measurement of soil water content, irrigation depth, and water losses to determine irrigation efficiency
4. Soil sampling and analysis of soil physical properties
5. Observation and interviews; to collect data on cropping patterns, cropping intensity, irrigation scheduling, crop budgets, pipeline layouts, and pump operation
6. Collecting secondary data; including data on climate and cropping factors.

Data analysis was conducted to determine aquifer and well characteristics, efficiency of pump operation, irrigated command areas, irrigation water requirements, irrigation efficiency and irrigation cost.

### 3. RESULTS AND DISCUSSION

#### 3.1. Aquifer and Well Characteristics

Aquifer and well characteristics were determined by pumping tests, both the step draw-down test, as well as the continuous test. The pumping test results were pumping discharge (Q), draw-down ( $S_w$ ), pumping duration and groundwater recovery time. Figure 1, Figure 2, and Figure 3 show the result of the pumping tests at 3 wells in the research area.

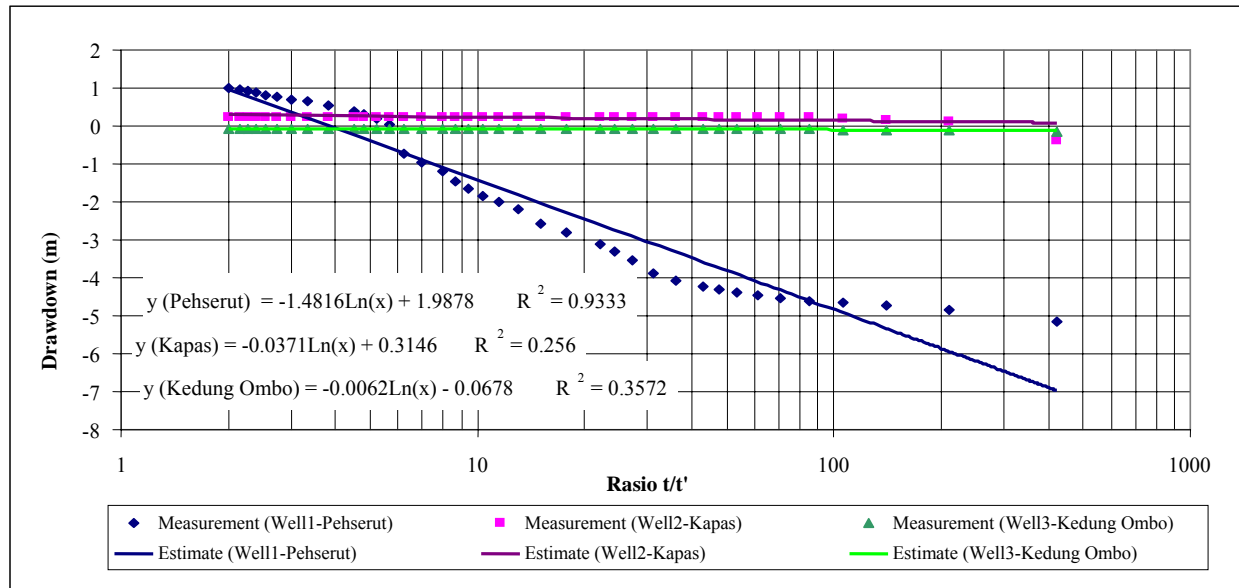


Figure 1. Continuous recovery test results

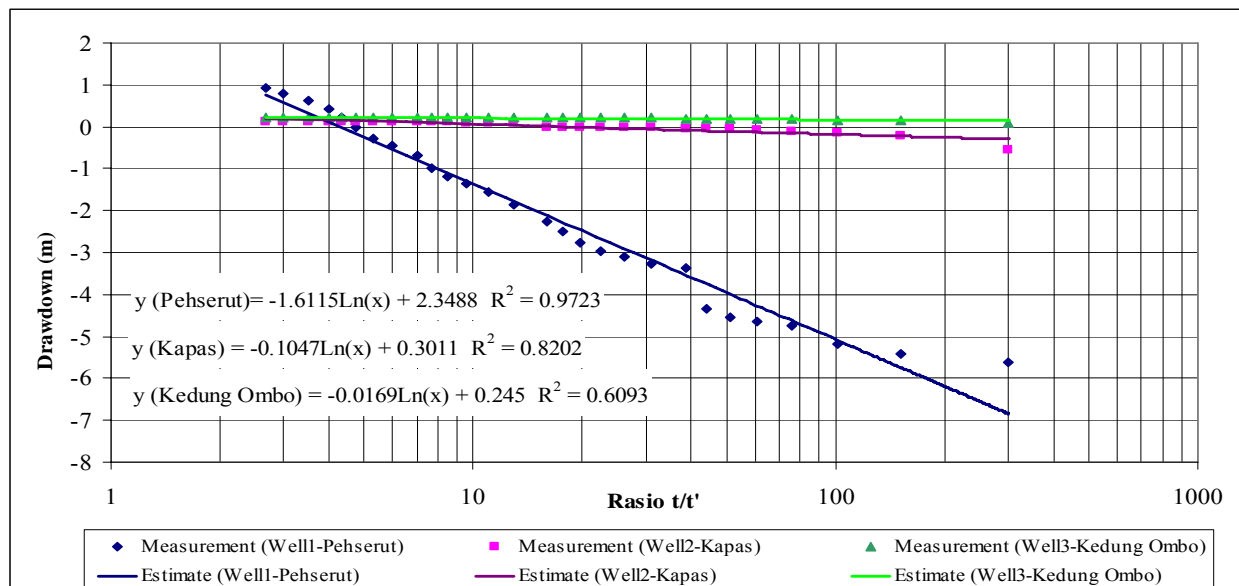


Figure 2. Step drawdown recovery test results

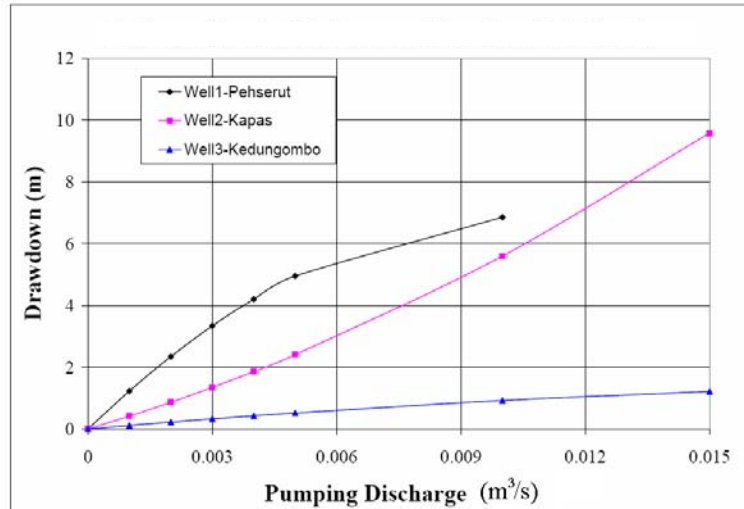


Figure 3. Pumping discharge and drawdown relationship

The transmissivity of the unconfined aquifers varied at 67 - 1272 m<sup>2</sup>/day. If compared with the boundary of aquifer classification for irrigation development (Suharyadi, 1989), the transmissivity could be classified as low class to high class for developing irrigation, because it was less than 300 m<sup>2</sup>/day and more than 1000 m<sup>2</sup>/day. The hydraulic conductivity was about 3.3 – 41.6 m/day. These values show that the aquifers in the area were composed of relatively the same materials. According to Linsley *et al.* (1989), the hydraulic conductivity of materials originating from sand is 41 m/day, whereas hydraulic conductivity for materials that are composed from sandstone is 4.1 m/day.

Specific capacity value will change as a function of pumping discharge and pumping time. If discharge is divided by drawdown in a pumping well, the specific capacity of the well is obtained. For a specified duration of pumping, the well efficiency is given as a percentage of the measured specific capacity in the field compared with one computed (Todd, 1980). The specific capacity of the unconfined aquifer in the research area varied at 95 - 161 m<sup>2</sup>/day, while well efficiency was around 55 - 77%. The efficiency of the wells was relatively high (>50%), which showed that well construction at those locations was good, with precise placement of filters on developed aquifers. Results of research by RIDA (1998) show that 75% of shallow wells in Indonesia have well efficiency of more than 50%.

Optimum pumping discharge is influenced by aquifer transmissivity, construction of wells, and placement of filters on sapped aquifers. The optimum discharge value indicates the discharge that can be utilized for irrigation through 24-hour pumping without resulting in a drawdown of the water table that would exceed the depth of the aquifer. The optimum pumping discharges in the research area were about 5-17 l/s in the wet season and 4-16 l/s in the dry season. The result of RIDA research (1998) stated that optimum pumping discharge in other areas in Indonesia varied at 3.0 – 13.0 l/s during the dry season and 3.0 – 13.2 l/s during the wet season. The optimum discharge is the reference discharge of the amount that could be pumped in exploiting groundwater for irrigation along the year. In fact, the pumping of shallow groundwater for

irrigation contributes to shallow groundwater recharge. That fact shows the cyclic use of irrigation water. Elhassan *et al.*, (2003) stated that generally, paddy field areas and non paddy field areas contribute equally to the total annual recharge of the shallow aquifers of a given area. The percentages for the different recharge sources in relation to the total gross recharge in Nasunogahara-Japan are 42% from paddy fields, of which 25% is from paddy fields irrigated by groundwater, 17% from paddy fields irrigated by canal water, 45% from non-paddy lands, and 13% from river underflow.

### 3.2. Pumps and Irrigated Command Area

The irrigated command area in the research location varied at 1.1 – 9.4 ha/well, with each well being served by one pump. In 2005, the population of pumps for shallow groundwater irrigation in Nganjuk was 5,033 units, with an average irrigated command area of 7.3 ha/pump. The shape of planted area blocks is generally rectangular, around 40 – 60 m in length and 20 – 40 m in width.

Of the many types of pumps available, the centrifugal, propeller, and reciprocating pumps are by far the most common (Wijdieks and Bos, 1985). The main type of pump usually used by farmers in the research area is the centrifugal pump that has a 3 inch suction pipe and actual discharge of 2.6 – 7.4 l/s. The power for these pumps is generated by 7.0 – 8.5 HP diesel engines. The results of RIDA research (1998) showed that the most commonly used type of pump was the centrifugal pump of various brands, with a suction pipe diameter of 1.5-4.0 inch. The pumping discharges were varied at 6-10 l/s for a 3-inch pump and 19 l/s for a 4- inch pump. Pumps were usually powered by 4 – 16 HP diesel engines and 3- 5 HP gasoline engines.

The radius of influence (R) can be estimated from the texture and other characteristics of the aquifer (Schwab *et al.*, 1981). According to pumping test results, the radius of influence in this research area varied at 118 - 348 m, which was used to measure the area of well influence (AWI). The AWI was assumed to be circular in shape with a drawdown shape as a consequence of pumping. The area of influence could be smaller or larger than either the potential irrigated command area ( $ICA_{pot}$ ) or the actual irrigated command area ( $ICA_{act}$ ). However, Qi Lu and Sato (2007) stated that the assumption of radially symmetric, horizontal, and steady flow is an ideal model. The correlation is weak between the ideal model and an actual aquifer system. This may account for some of uncertainties in the results.

The  $AWI/ICA_{act}$  ratio varied at 1.32 – 3.88 ( $>1$ ), indicating that the area was densely populated, because the distance between a given well and other surrounding wells was less than 2R (diameter of influence). The  $AWI/ICA_{pot}$  ratio of 1.87 – 5.52 ( $>1$ ) illustrates that if a well's discharge is not enough to irrigate the larger irrigated area, any development of new wells in this area must be based on a distance between wells equal to or more than 2R. The  $ICA_{act}/ICA_{pot}$  ratio was 1.42, indicating that the actual irrigated command area tended to exceed the optimum irrigated area. Figure 4 shows the schematic of calculated radius of influence in the research area. Irrigated areas with an  $AWI/ICA_{act}$  ratio of less than one were located mostly nearby the border of the research area, which was about 12% of the total area.

The value of  $ICA_{act}/ICA_{pot}$  ratio  $\geq 1$  means that the actual irrigated area in SGWIS has exceeded the potential irrigated command area, meaning that from the point of view of adequate irrigation water supply, it is no longer possible to expand the area covered. Should the ratio value of  $ICA_{act}/ICA_{pot}$  be  $\leq 1$ , the irrigated command area of SGWIS can still be expanded through maximum utilization of optimum well discharge.

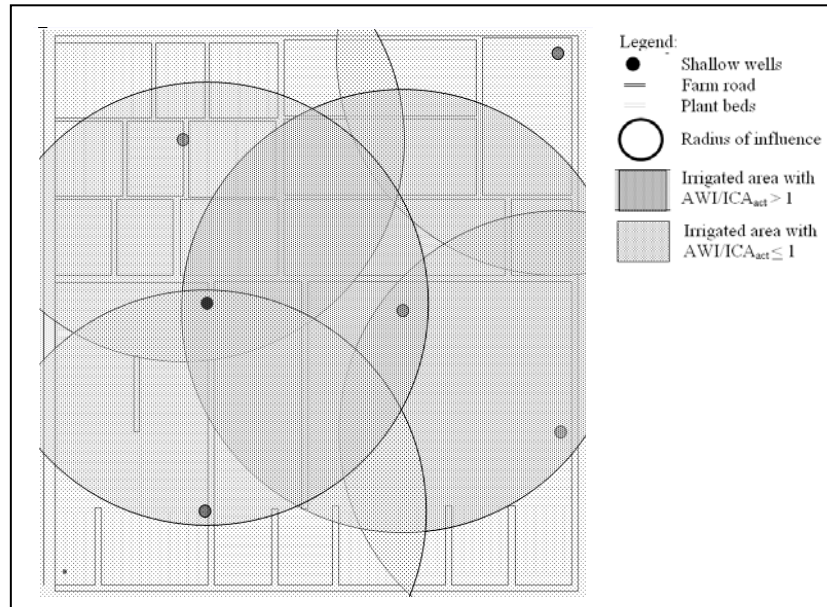


Figure 4. Schematic of calculated radius of influence in the research area

From the point of view of irrigation water adequacy, the  $ICA_{act}/ICA_{pot}$  ratio should be  $\leq 1$  so that the water requirement for growing crops can be met. From the point of view of conservation of shallow groundwater, the  $AWI/ICA_{pot}$  ratio should be  $\leq 1$  in order to prevent the overlapping of groundwater cone depressions. In order to achieve the desired conditions, the following technical efforts, among others, must be made:

1. Shallow groundwater should not be utilized for rice crops in PS<sup>2nd</sup> and PS<sup>3rd</sup>.
2. Reduce the population of shallow wells to a ratio of  $AWI/ICA_{act}$  or  $AWI/ICA_{pot} \leq 1$  through integrated management of wells and pumps. The  $ICA_{act}$  must not exceed  $ICA_{pot}$  nor be less than  $AWI$  ( $AWI \leq ICA_{act} \leq ICA_{pot}$ ).
3. Increase irrigation efficiency, especially if points (1) and (2) are difficult to implement. Figure 5 shows that irrigation efficiency must be increased in line with the cropping pattern applied as seen in the following:
  - a. In Kapas Village, irrigation efficiency has to be increased to a minimum of 73% for cropping pattern scenario (1) and 89% for cropping pattern scenario (2)
  - b. In Pehserut Village, irrigation efficiency must be increased to a minimum of 73% for cropping pattern scenario (1) and 93% for cropping pattern scenario (2).

The irrigation efficiency of the SGWIS in the research area might be able to be increased, either by improvement of pump operation management, improvement of the conveyance system, or

improvement in the technology of irrigation application. Clyma (2002) stated that improving water management in an irrigated area can save substantial water. With serious shortages in water supplies, water conservation is an urgent priority. Improved water management also increases productivity, and reduces or controls the waterlogging and salinity impacts of irrigation. According to Yuanlai Cui *et al* (2004), strategies for improving the water supply system include: rebuilding and rehabilitation of canal system, completion of hydraulic structure, establishing a reasonable irrigation water demand plan and improving irrigation water, management level, increasing water use efficiency in distribution and on farm system, and changing crop patterns

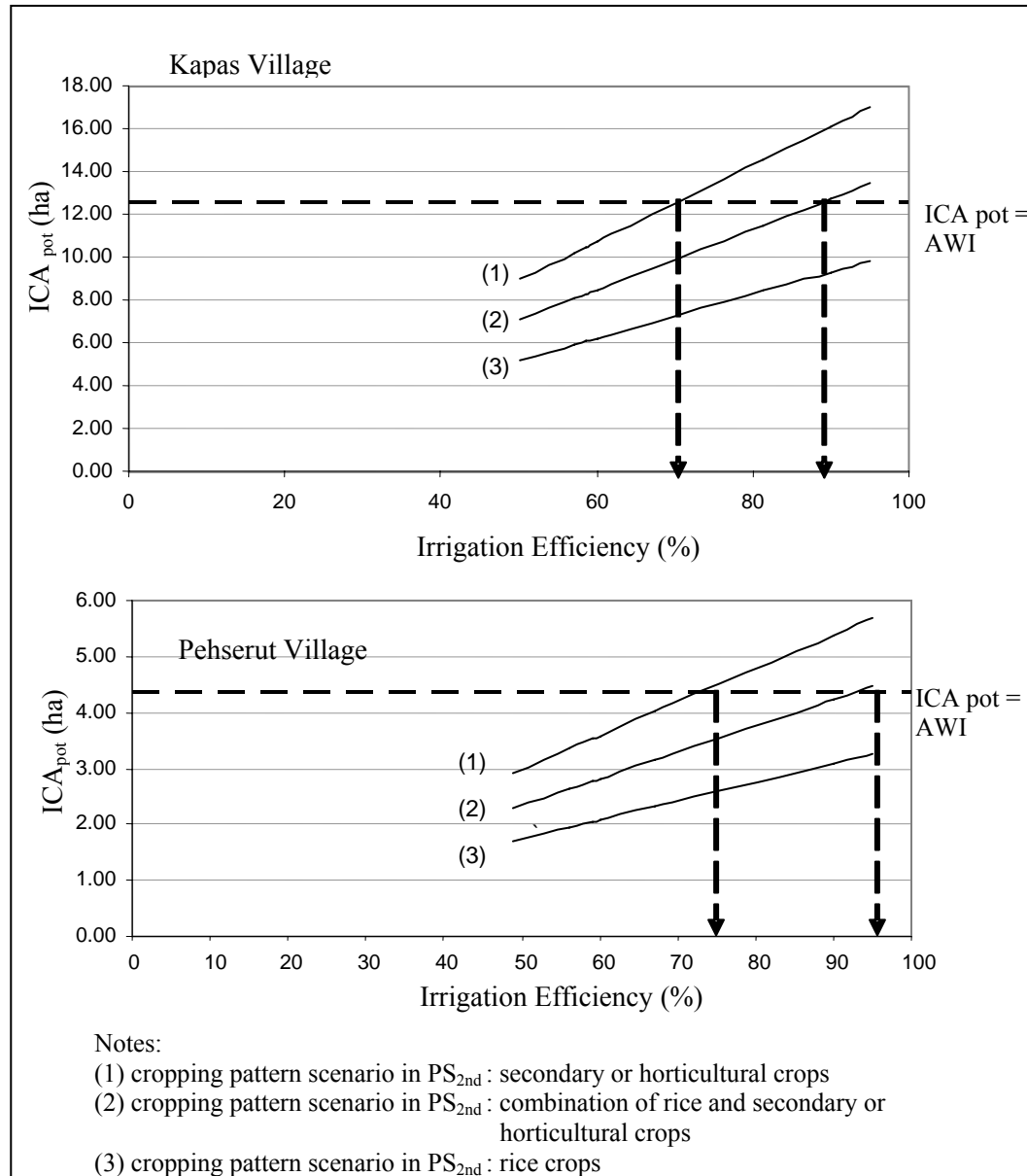


Figure 5. The ICA<sub>pot</sub> related to cropping patterns scenario and irrigation efficiency



The research on the technical performance of pump operation was focused on analysis of the ratio of actual discharge and pump capacity ( $Q_{act}/Q_{cap}$  ratio), also on the ratio of the actual head and the specification head of the pump ( $H_{act}/H_{spec}$  ratio). Those parameters were used to see how extensively the pumps were operated optimally. The  $Q_{act}/Q_{cap}$  ratio varied at 0.17 – 0.48, whereas the  $H_{act}/H_{spec}$  ratio varied at 0.32 - 0.41 . These values show that the operational performance of pumps remains less than optimal. In line with technical specifications, the maximum pump discharge is 13.3 – 21.7 l/s, while the pump's total dynamic head is 19 - 25 m. With the ratio value of  $Q_{act}/Q_{cap}$  and  $H_{act}/H_{spec}$ , this means that the unutilized pump capacity and pressure head are respectively 4.77 – 11.50 l/s and 5.27 – 11.05 m. The fact that the pressure head inherent in SGWIS has yet to be utilized optimally means that no additional expenditure will be required for pumps and power sources in the application of trickle irrigation systems.

Pumping discharge values vary widely depending on the size of the pumps utilized by the farmers. In general, there is an apparent tendency for pumping discharges in a segment of the reasearch area (Pehserut Village) to be larger than the optimum well discharge. This means that the size of the pumps used in this area is relatively larger than that required by the technical specifications. The pumping discharge in another segment of the research area (Kapas Village) is relatively smaller than the optimum well discharge. Due to the  $Q_{act}/Q_{cap}$  ratio  $\leq 1$ , the pumping efficiency at this location could be raised. Even so, any increase in pumping discharge must be done in tandem with the establishment of the distance between wells in order to prevent an excessive drawdown.

### 3.3. Cropping Patterns and Irrigation Application

Exploitation of shallow groundwater for irrigation has the potential to create a chance for farmers to improve their cropping patterns, their cropping intensity, to better their application of cultivation technology, thus increasing their production and income. The cropping patterns in the research area were *paddy-paddy-corn-mung bean*; *paddy-onion-chili-onion*; *paddy-melon-onion*; and *peanut-onion-corn-onion*. Cropping intensity varied at 300-400%. Results of research by RIDA (1998) showed that the exploitation of shallow groundwater for irrigation had increased cropping intensity to 200-280%.

There are three main surface irrigation methods, i.e. basin irrigation, border irrigation, and furrow irrigation (Kay, 1989). The irrigation method applied in shallow groundwater irrigation schemes in the research area was surface irrigation, with a basin system for paddy and a furrow system for secondary crops (*palawija*). The applications of irrigation depth and irrigation interval depend on the planting season, the crops and the irrigated area. In the wet season (PS<sub>1st</sub>), the pumps generally were not operated because the water requirement of paddy had been fulfilled by rainfall and existing surface irrigation schemes. In PS<sub>2nd</sub>, the pumps were operated in order to provide irrigation water for paddy, secondary crops (*palawija*), and/or horticultural crops to maintain an irrigation depth of 8-20 mm, with an irrigation interval of 3 -5 days. While in PS<sub>3rd</sub>, the pumps were operated to irrigate the areas planted in secondary crops (*palawija*) of corn and soybean and the horticultural crops of onions, melons, chilies, and watermelons, at an irrigation depth of 4-10 mm with an irrigation interval of 1-2 days. The actual total irrigation depth at the



research location ranged from 108 to 451 mm throughout PS<sup>2nd</sup> and 112 to 522 mm throughout PS<sup>3rd</sup>, as can be seen in Table 1.

Table 1. The actual irrigation depth in the research area

Crops	Actual irrigation depth (mm/season)	
	PS <sub>2nd</sub>	PS <sub>3rd</sub>
Corn	144	144
Soybean	108	112
Onions	451	497
Melons	225	311
Chilies	367	522
Watermelons	225	311

As a comparison, in Mkoji sub-catchment-Tanzania, increasing the interval of irrigation for the maize crop beyond the conventional 7 days will lead to a significant decrease in grain yield irrespective of the depth of water applied at irrigation. The optimal schedules, which minimized grain yield and crop consumptive use reductions and maximized deep percolation reductions, were the 9-day irrigation interval at 50 mm irrigation depth and the 10-day irrigation interval at 55 mm irrigation depth (Igbadun *et al.*, 2006). While in Tamilnadu-India, a rotational system is widely adopted, with the irrigation interval varying between 4 to 7 days depending upon the soil, rainfall, crop and crop stage. At equitable and dependable supply at the right times cannot therefore be ensured for individual holdings. Research findings have clearly indicated that it is enough to allow only a 3-5 cm depth of water in a rice crop, with the next irrigation coming after the water stored is completely depleted (Anbumozhi *et al.*, 2001).

The effect of crops characteristics on water requirements is represented by the crop coefficient ( $k_c$ ) which presents the relationship between reference ( $ET_o$ ) and crop evapotranspiration ( $ET_{crop}$ ) or  $ET_{crop} = k_c \times ET_o$ . The values of  $k_c$  vary with the crop, its stage of growth, the growing season and the prevailing weather conditions (Raes, 1989). The calculated water requirement unit (WRU) varied at 0.66 – 1.16 l/s per Ha during the period of May-June and August-September. The value was a half-monthly measure of the maximum water requirement unit with the above cropping patterns. Relatively large differentiations occur in the WRU in relation to the alternative cropping patterns. The largest WRU value of 0.97 – 1.16 l/s.ha occurs in PS<sup>2nd</sup> rice crops. If a combination of rice and secondary or horticultural crops is planted for PS<sup>2nd</sup>, the WRU is relatively smaller at 0.85 l/s.ha. The smallest WRU value, about 0.60-0.67 l/s.ha occurs with the planting of secondary or horticultural crops in PS<sup>2nd</sup>. When shifts in the planting schedule occurs, the WRU will be larger, approximately 0.90 – 1.37 l/s.ha, than the WRU during normal conditions. The seasonal water requirements for onions depended on the planting date; i.e. 451 mm/season for May-2, and 478 mm/season for June-1, and 497 mm/season for June-2 planting dates. By comparing the actual onion crop yields of 13 tons/ha, the approximate water requirement was about 347 – 382 liter per kg of onions produced.

Irrigation efficiency is a term used to describe all the water losses in surface irrigation. It describes the water required by the crop in relation to the amount of water applied (Kay, 1989).

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The research on irrigation efficiency of SGWIS includes water-conveyance efficiency and water-use efficiency. The irrigation efficiency ( $E_f$ ) was calculated by the formula of  $E_f = W_n / W_r$ , where,  $W_n$  is the water beneficially used for plant growth, and  $W_r$  is the water introduced into the distribution system. The measurement and calculation results of irrigation efficiency are presented in Table 2. The irrigation efficiency varied at 49.02 – 81.26%. The relatively low irrigation efficiency of some schemes in the research area was caused by water losses along conveyance and evaporation in bed channels. In Madiun, the region adjacent to the research area, irrigation efficiency was 59% (Harjoko, I.Y., 1998), while for Indonesia as a whole; surface irrigation efficiency was around 60 - 70% (Kalsim, 2002).

Table 2. Irrigation efficiency of SGWIS in the research area

Planted area blocks	Irrigation efficiency (%)	
	Location -1	Location -2
1	67.18	81.26
2	49.02	58.64
3	56.24	60.03
4	59.20	57.05
Average	57.91	64.24

### 3.4. Irrigation Cost

Calculation of irrigation cost involves the consideration of the general elements of cost, which are direct materials, direct labor, and overhead (DeGarmo et al., 1979). The investment cost of SGWIS includes cost of pumps, engines, pipe networks, well construction and pump houses. The irrigation cost in the research area was about Rp 2,350,000,- (257 USD) per Ha per planting season for onions; equal to Rp 180,- (0.02 USD) per kg of onions. The irrigation cost consists of 19 USD of fixed cost and 238 USD of variable cost, which is about 8% of the total production cost for onions. The cost of irrigation in PS<sup>3rd</sup> is relatively higher than the irrigation cost for PS<sup>2nd</sup> because the volume of water or length of pumping time per PS<sup>3rd</sup> is relatively larger than for PS<sup>2nd</sup>. When compared to the average selling price for crop products, the cost of groundwater irrigation per product unit ranges between 2.5 – 5.0 %. Research results by RIDA (1998) in some locations in Indonesia showed that the proportion of the groundwater irrigation cost varied at 3 – 20% of the total crop production cost.

## 4. CONCLUSION

The performance of SGWIS in the research area, in terms of well efficiency, pump operation, and irrigation efficiency, was relatively better than that for other locations in Indonesia; nevertheless this performance might be able to be increased either by improvement of pump operation management, improvement of conveyance system, or improvement in the technology of irrigation application. In order to expand irrigation area coverage to be larger than or equal to the area of well influence ( $ICA_{act} \geq AWI$ ), the irrigation efficiency of SGWIS would have to be increased to a minimum of 80%. The potential irrigated command area is approximately 4.37 – 12.56 ha/well.

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