Discharge analysis for a system approach to river basin development with *Subak* irrigation schemes as a culture heritage in Bali

Mawiti Infantri Yekti[1,2*], Bart Schultz[1], I Nyoman Norken[2], Laszlo Hayde[1]

(1. *Chair Group Land and Water Development, UNESCO-IHE, Delft, the Netherlands*;
2. *Department of Civil Engineering, Udayana University, Bali, Indonesia*)

Abstract: Paddy terraces in Bali are important cultural landscapes. Traditionally, the flow within a river basin has been managed using a traditional technology called *Subak* irrigation. These schemes are based on the cropping patterns and indigenous water management, which are organized by the respective *Subak* associations. Unfortunately, this traditional technology is facing challenges: water shortage and competition with other water users. In order to sustain agriculture production of *Subak* irrigation schemes in the Yeh Ho River Basin, the available discharge in Yeh Ho River was analyzed in this study in light of the supply to the *Subak* irrigation schemes within the river basin. By using the Weibull formula, the historic supply data of several diversion weirs were analyzed independently. Based on this analysis it was possible to determine the water balance of the *Subak* irrigation schemes behind each diversion weir. Therefore a system approach was developed based on the managed flows within the river basin and the characteristics of the *Subak* irrigation schemes. The conclusion is that the discharge in the river will remain the most important factor to sustain the characteristic paddy terraces of these *Subak* irrigation schemes.

Keywords: river basin, *Subak* irrigation, *Subak* association, paddy terrace, weir, water distribution unit, continuous flow

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1 Introduction

According to Von Droste et al. (1995), paddy terrace landscapes are cultural landscapes and a unique characteristic of Asian countries. A special type of these landscapes concerns the *Subak* irrigation schemes in Bali, Indonesia. As a system, *Subak* irrigation is a widely known traditional irrigation of management institutions for rice cultivation in Bali (Roth, 2011). These schemes are based on agreed principles of technology, management of agriculture, and a religious community (Yekti et al., 2012). These landscapes were nominated for the World Heritage List of UNESCO (Fowler, 2003) and were officially added in 2012.

The most obvious characteristic of Bali is the abundance of agricultural fields. The large areas of fertile land and abundant water resources have permitted paddy cultivation for a long time, and rice cultivation has become one of the main economic activities. This has developed over the centuries in the specific socio-cultural, agro-ecological and political administrative environment of this mountainous island. As a consequence, the *Subak* irrigated rice agriculture became well adapted to, and embedded in the characteristic Balinese landscape of rugged mountains and steep valleys deeply incised by fast-flowing rivers.

Since the 9th Century, *Subak* associations have been in charge of the management of the *Subak* irrigation schemes by using diversion weirs (*empelan*) at several

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* **Corresponding author: Mawiti Infantri Yekti**, PhD candidate, UNESCO-IHE, Delft, the Netherlands. Mailing address: Jl. Tukad Pakerisan Gg. XVIB/9, Denpasar, Indonesia, 80225. Email: wiwiet91@yahoo.com, m.yekti@unesco-ihe.org.

points along the rivers. Through these weirs, irrigation water was supplied to the respective schemes and within the schemes distributed to each *Subak* association member by using water distribution units (*tektek/kecoran)*.

Depending on the location of the *Subak* irrigation scheme, an area of about 0.3-0.4 ha can generally be supplied by each water distribution unit. These units were supplied from the main/secondary/tertiary/quaternary canals within the system by using either the continuous flow system or an agreed scheduling system.

According to Geertz (1984), the details related to the technological aspects of *Subak* irrigation schemes were very complex and have not really been disclosed to researchers. In 1998 the Department of Public Works of the Government of Indonesia started to document the *Subak* irrigation systems by addressing the traditional, technological and religious aspects.

Recently *Subak* irrigation faced some challenges. There has been water shortage and competition has arisen between different users. Accordingly, the traditional way of water distribution has been influenced.

This study proposes that the sustainability of indigenous paddy terraces depends on the availability of the discharge in the river at all stages in the river basin. Therefore the main objective of this study was to analyze the available discharge on the weirs from historical data. This analysis can support the system of water supply to paddy terraces in *Subak* irrigation schemes, in order to sustain agricultural productivity at all stages in the river basin.

2 Background

2.1 Indigenous knowledge of *Subak* irrigation

Indigenous knowledge has been used to maintain *Subak* irrigation schemes, especially in paddy terraces. The technological aspects have been agreed and used by *Subak* associations since one thousand years ago. The indigenous knowledge of *Subak* irrigation in socio-religious-technical-agricultural aspects can be described as follows.

The farmers in a *Subak* irrigation system were gathered in an association called *Subak Gede* that managed the irrigation water diverted by a diversion weir (*empelan*) and formed a social-religious community. Within a scheme there were several *Subak* associations called *Tempek.*

A section of rice fields with an area of about 0.3-0.4 ha was supplied by a water distribution unit (*tektek/kecoran*) (Figure 1). The distribution unit had the following dimensions: 5-8 cm wide and 1-2 cm high, and was supplied from the main/secondary/tertiary/quaternary canal by using a continuous flow system or an agreed scheduling system. The agreed scheduling system may consist of:

* scheduling based on rotation of the cropping pattern;

* scheduling based on the starting time of land preparation in the paddy planting season, which was called *nyorog/nugel bumbung*;

* scheduling based on the season: wet season (*masa*) and dry season (*gadon*);

* scheduling based on the period of water use rights throughout the year.

The association in charge of the management at river basin level was called *Subak Agung*. Then the physical system, or irrigation network itself, consisted of an old, or new diversion weir (*empelan*), main canal (*telabah gede*), secondary canals (*telabah pemaron*), tertiary canals (*telabah cenik*), quaternary canals (*telabah pengalapan*), small canals that distributed the water evenly over the fields (*talikunda*), water distribution units (*tek-tek/kecoran)*, primary box (*tembuku aya*), secondary box (*tembuku pemaron*), tertiary box (*tembuku cenik*), box to distribute water among several landowners (*tembuku penyahcah*), which may be 5 land owners (*tembuku panca*) or 10 land owners (*tembuku penasan*). Finally there were boxes to supply water to one owner (*tembuku pengalapan*). To break through hills, some tunnels (*awungan*) may have been built, the structure at the end of a tunnel was called the outlet (*kibul*), drain (*pengutangan*), or receiving water body (*pangkung*).

In relation to the ritual aspects, one diversion weir had two Balinese temples (Hindu Religion), namely *Ulun*

Suwi, which were located near the diversion weir (*empelan*). In addition, namely *Ulun empelan* and *Ulun bedugul*, which were located near the primary and secondary boxes.

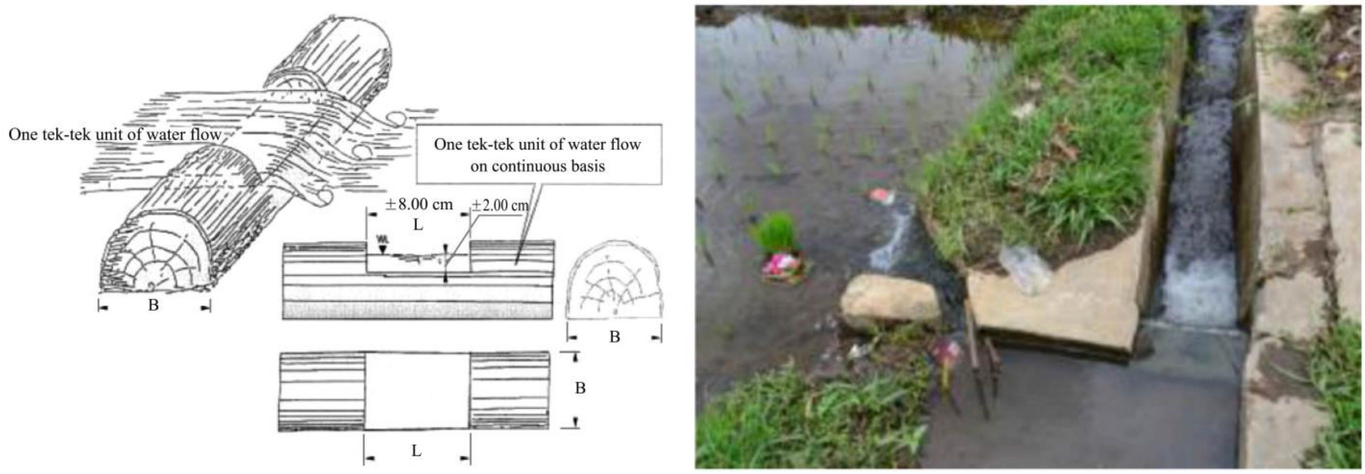


Figure 1 Typical water distribution unit (*tektek or kecoran*) in water flow on a continuous basis

The water distribution units within the system also showed religious aspects, with a Balinese temple called *Ulun carik* near the box of 5 or 10 landowners (*tembuku panca, or tembuku penasan*). The last in the hierarchy of *Subak* temples was called *Ulun carik* (Yekti et al., 2014).

The format of *Subak* water management was remarkably homogenous throughout Bali. The variations found were the result of unit size or region (Birkelbach, 1971). *Subak* associations applied the *Tri Hita Karana* concept (harmony between human beings and God, harmony between people and nature, and harmony between people and people). The *Tri Hita Karana* concept was analysed by Pusposutardjo (1997) and Arif (1999), who stated that the technological system of *Subak* irrigation was based on a socio-cultural community and had three subsystems: (i) cultural subsystem (way of thinking, the norms and principles); (ii) social subsystem (including economy); (iii) material subsystem (including technology). All these subsystems had a balance with the environment. In addition, the characteristics of the paddy terraces as a cultural landscape in Bali were bound to this philosophy (Luchman et al., 2009).

2.2 Study of the Yeh Ho river basin

The study location is Yeh Ho River Basin (160 km^2) in the South of Bali. Yeh Ho River is a perennial river with a length of 45 km. The basin characteristic of Yeh Ho River is an elongated shape with the main river on the right side (Figure 2). Yeh Ho River has three sections, including upstream, midstream and downstream. There are 5,270 hectares of irrigated fields along the river. Since the 1990s the organisation *Subak Agung* Yeh Ho has been in charge of the management of this river basin. The water diversion system in the upstream is called first time [*ngulu*], in the midstream second time [*maongin*] and in the downstream last time [*ngasep*].

The source of Yeh Ho River is a spring called *Gembrong*. Since late 1990, the observed discharge of some diversion weirs showed a reduction of discharge in the river, as a result, the distribution of water to the irrigation systems has been disturbed (Region River Office of Bali-Penida, 2006). This may be caused by the fact that the Bali Province Government, under the management of the regency's water company (*Perusahaan Daerah Air Minum*), has utilized this spring for domestic purposes since 1987 beyond its share of 65%. In 2001, in response to the claim of the farmers in the upstream scheme, *Tabanan* Regency Government decided to restore the 35% allocation of *Gembrong* Spring for them under *Subak Agung* Yeh Ho. However, this is not really followed in practise (Yekti et al., 2012).

Following source capturing of *Gembrong*, the sequence of twelve diversion weirs is (Department of Public Works, 2004): Aya, Penebel (new weirs), Benana, Riang and Sigaran (old weirs), then Jegu and Caguh (new weirs) in the upstream, Meliling I in the midstream, and Gadungan, Sungsang I, and Sungsang II in the downstream (Figure 2). In the period 2003-2006, Meliling II diversion weir was changed into Telaga Tunjung Dam in the midstream, built by the Department of Public Works. Due to the construction of the dam, the traditional way of water distribution has been influenced and therefore a new optimum distribution had to be determined. Because the topography of the river basin is relatively steep and the section of the river comparatively V-shaped, the storage volume is quite small compared to the storage height. The effective capacity of Telaga Tunjung Reservoir is one million m^3 and the height of the main dam is 33 m.

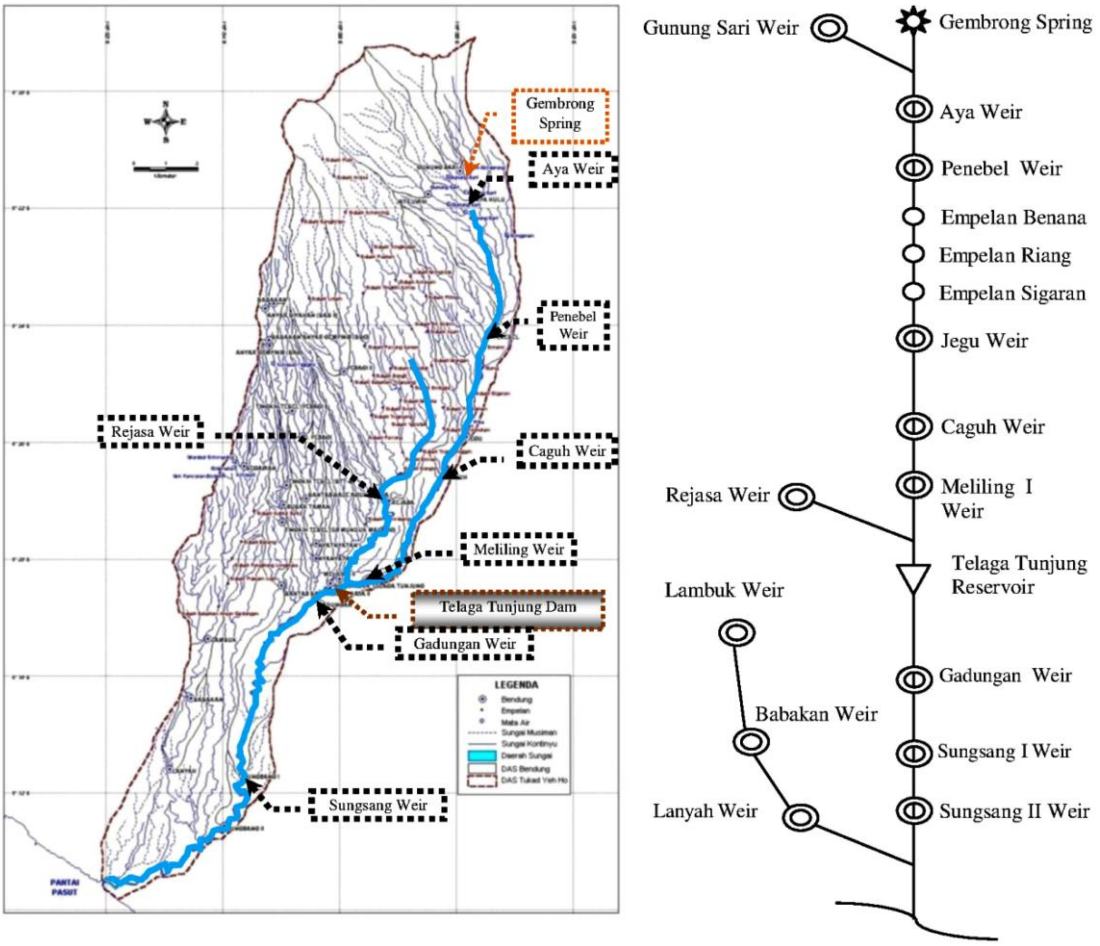


Figure 2 Yeh Ho River Basin and *Subak* irrigation schemes

2.3 Managed flow approach in the Yeh Ho River Basin

Subak irrigation is especially taking place in Tabanan Regency. Due to the good soil fertility, Tabanan Regency successfully produced a paddy harvest at 22,455 hectares of rice fields in 2010. The production was approximately 5 tons/ha of unhusked rice or 2.85 tons/ha of husked rice. Although there were changes in land use from paddy fields to housing, farmlands and dry fields have increased by 0.3% over the last two years, the paddy production was relatively stable (Statistical Central Agency, 2010).

In the Yeh Ho River, the purpose of the weirs was to elevate the water level in order to enable gravity flow to the *Subak* irrigation schemes. The purpose of the dam was to elevate the water level and to store water as well. This analysis can support the development of the arrangements of water supply to the paddy terraces of the *Subak* irrigation schemes in Yeh Ho River Basin in order to sustain agricultural productivity at the upstream, midstream and downstream level.

Based on the managed flow approach by Acreman (2010), this study was conducted to determine the managed flow related to defined links between flow regime and function of the river, to define the managed flow options, and to assess impacts of the managed flow options. The results of the study may support the analysis of the river basin with the Subak irrigation schemes as specified in Figure 3.

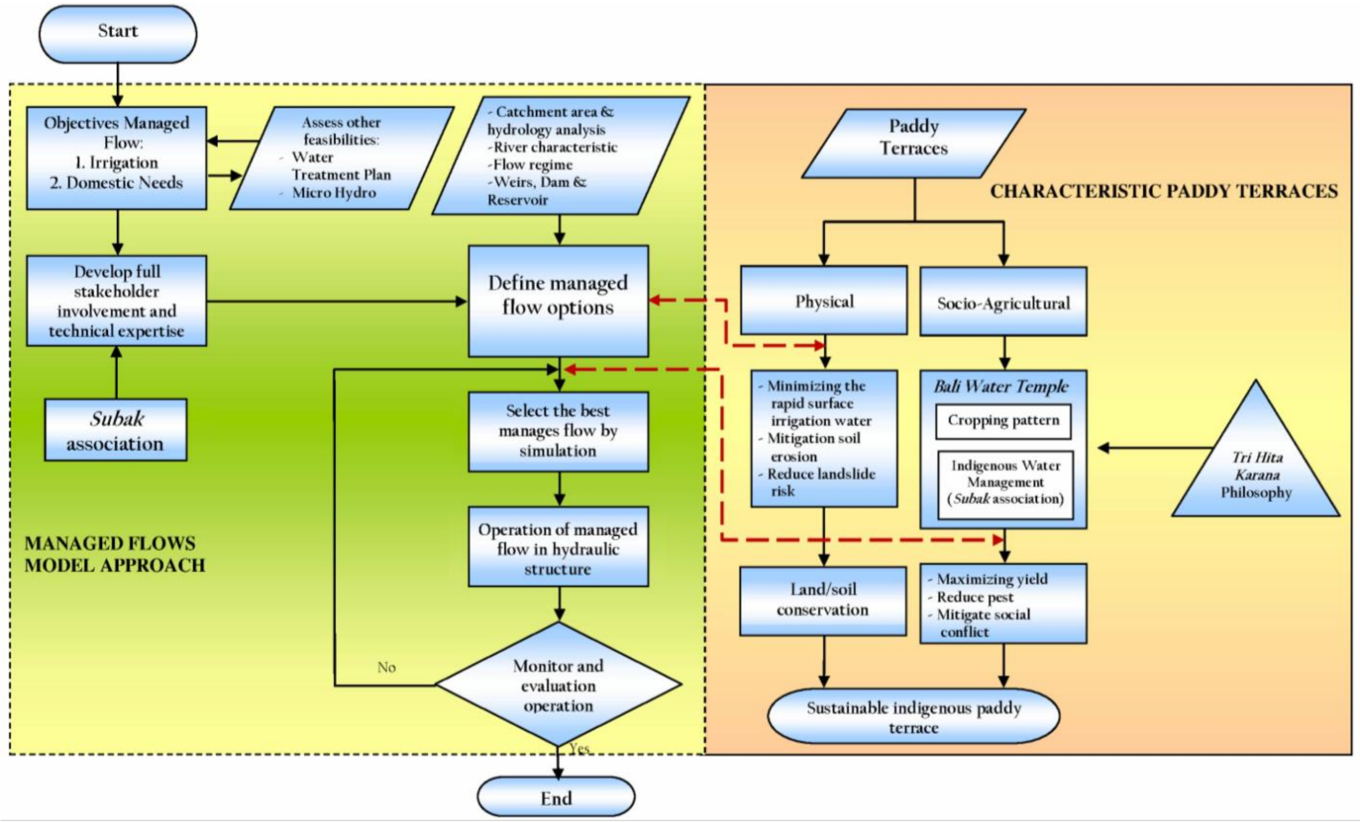


Figure 3 Development of managed flows model approach for sustainable water supplies to Subak irrigation schemes

3 Materials and methods

Gupta (2012) suggested that we needed a paradigm shift towards an information-based framework for model identification, one which drawed both on modern *system* and *information* theories, but also on the considerable conceptual (hydrological) knowledge that was historically developed and exploited before cheap computing made it so easy to play digital games.

Daily data inflows have been obtained from seven of the diversion weirs along the Yeh Ho River for which complete data of the period 2002-2010 were available. These data have been used for empirical flow frequency analysis. A popular method of studying the variability of streamflow is through flow duration curves that can be regarded as standard reporting output from hydrological data processing. The data can for example be used for (World Bank, 1999): evaluation of dependable flows in the planning of water resources engineering projects, evaluation of the characteristics of the hydropower potential of a river, assessment of the effects of river regulation and abstractions on river ecology, the design of drainage systems, flood control studies, computation of the sediment load and dissolved solids load of a river and comparison of adjacent river basins.

The traditional way of water distribution of *Subak* irrigation takes advantage of mutual agreements on using water through the continuous flow system. Based on this system, the return flow to the river also plays an important role as a source of water to the diversion weirs in the downstream. As a result, it is important to analyze the overflow weir data at the same time. The analysis has been done on a daily basis.

Meanwhile, in evaluating dependable flows, frequency analysis has been used on the daily mean discharges. The analysis has been used in assisting the execution of the regulation and water distribution which supplies the paddy terraces in the *Subak* irrigation schemes. Moreover, it has been used as inflow to the reservoir for further use downstream within the river basin.

By using the Weibull formula, the historic supply data of several diversion weirs were analyzed independently. The advantages of the Weibull formula are in the ability to provide reasonably accurate analyses and forecasts with small samples, as well as to provide a simple and useful graphical plot, which is important to engineers and managers (Abernethy, 2002). In the Weibull formula the *n* values (number of years) are distributed uniformly between 0% and 100% probability, so there must be $n+1$ intervals, $n-1$ between the data points and two at the ends (Chow et al., 1988):

$$P(X \geq x_m) = \frac{m}{n+1} \quad (1)$$

The analysis procedure was as follows:

- the frequency or number of maximum to minimum occurrences *m* in *n* years of 365 daily discharge data has been selected. The daily inflow, diversion and overflow data have been selected as well;
- the 80% of failure probability of the data has been analyzed to determine the minimum discharge. The percentage of probability of 50% can be considered as the mean discharge;
- the mean daily inflow, diversion and overflow have been plotted against the 365 days;
- the water balance of each diversion weir has been represented by a graph.

4 Results and discussion

Subak Agung Yeh Ho has managed 5,130 hectares of paddy fields before Telaga Tunjung Reservoir was built. Since the Telaga Tunjung Reservoir was in operation, the cropping patterns have changed as described in Table 1.

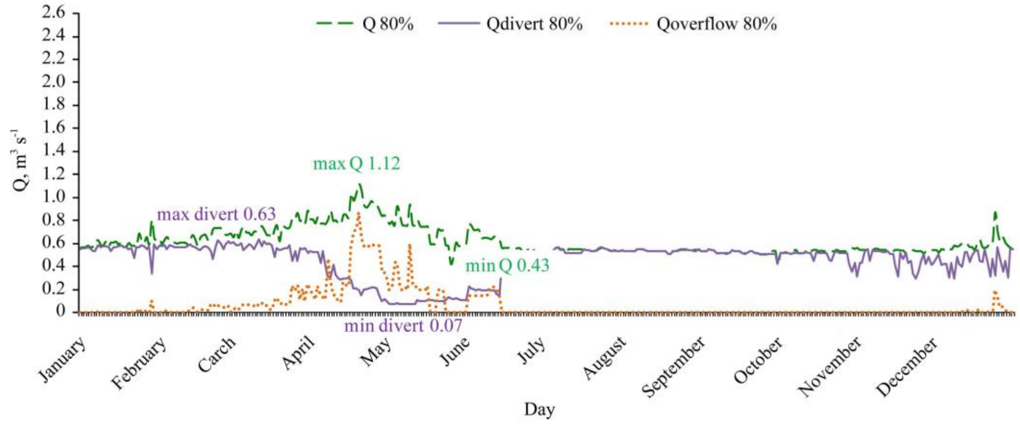
The cropping patterns in specific months have been determined and agreed by the *Subak* farmers. For many centuries, the cropping patterns as shown in Table 1 have been used and believed to be a fair system of water distribution. It is observed that the discharge in the river will remain the most important factor to sustain the cropping patterns. In addition to this, the water balance of each weir (*empelan*) has been used to determine the availability of water in relation with supplying paddy terraces in the concerned *Subak* irrigation schemes.

The diversion graphs in Figures 4a, 4b, 5a and 5b describe the probability of 80% and 50% of daily discharge patterns within a year for the two upstream weirs; Aya and Penebel Weir. Similar trends can be noticed for the Q_{inflow} and the Q_{divert}. These trends occurred during the dry season from June to October, when the wet season started.

Table 1 Cropping patterns of *Subak Agung Yeh Ho* before and after Telaga Tunjung Reservoir came into operation

Subak irrigation schemes	Functional paddy fields, ha	Blocks			When to start land preparation
		Upstream (*Ngulu*). ha	Midstream (*Maongin*), ha	Downstream (*Ngasep*), ha	
			Before		
1. Aya	644	644			Block I (*Ngulu*)
2. Penebel	731	731			Paddy I: Dec, Jan
3. Riang	25	25			Paddy II: July, Aug
4. Jegu	111	111			Block II (*Maongin*)
5. Caguh	1093		1093		Paddy I: Jan, Feb
6. Meliling	562		562		Paddy II: Aug, Sep
7. Sungsang	430			430	Block III (*Ngasep*)
8. Gadungan-Lambuk	1534		594	940	Paddy I: Feb, Mar Paddy II: Oct, Nov
Total field	5130	1511	2249	1370	
			After		
1. Aya	644	644			Block I (*Ngulu*)
2. Penebel	731	731			Paddy I: Dec, Jan
3. Riang	25	25			Paddy II: July, Aug
4. Jegu	111	111			Block II (*Maongin*)
5. Caguh	1093		1093		Paddy I: Jan, Feb
6. Meliling	142		142		Paddy II: Aug, Sep
7. Telaga Tunjung Reservoir					
- Meliling	420		420		Block III (*Ngasep*)
- Sungsang	430			430	Paddy I: Feb, Mar
- Gadungan	485		485		Paddy II: Oct, Nov
8. Lambuk	1187			1190	
Total field	5268	1510	2140	1620	

Source: Region River Office of Bali-Penida, 2006.



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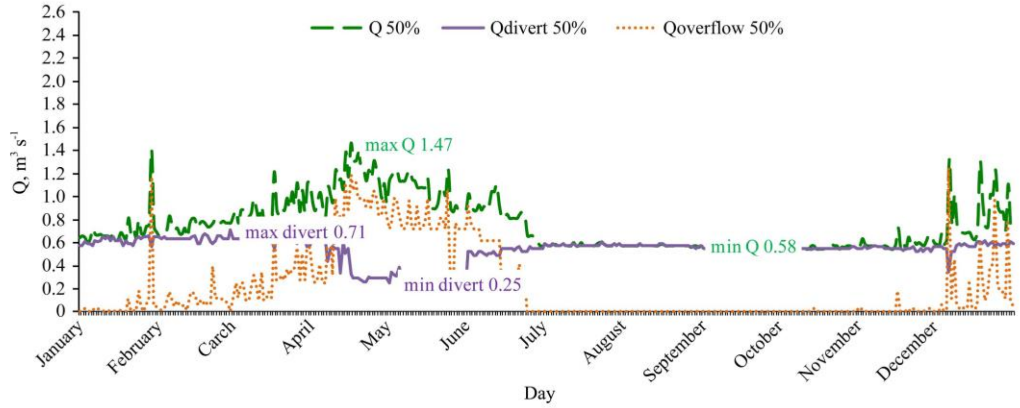

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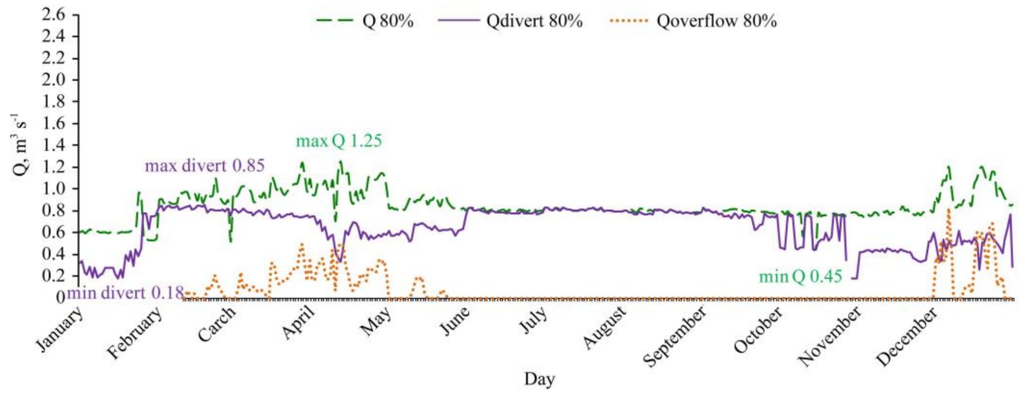
Figure 4 Daily flows through the Aya Weir



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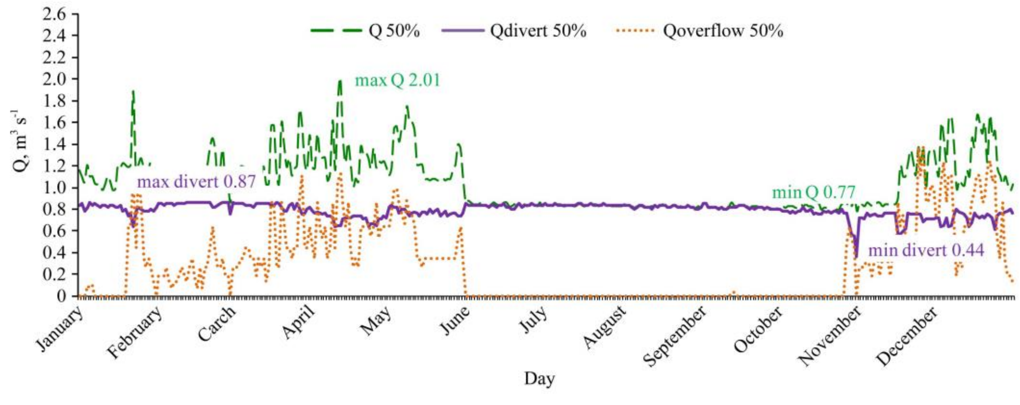

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Figure 5 Daily flows through the Penebel Weir

In the Aya Weir, the maximum diversions of 80% and 50% were respectively 0.63 and 0.71 $m^3 s^{-1}$ to supply the 644 hectares of paddy fields. The minimum diversions were respectively 0.07 and 0.25 $m^3 s^{-1}$. In the Penebel Weir, the diversions of 80% and 50% were respectively 0.85 and 0.87 $m^3 s^{-1}$ and the minimum diversions were respectively 0.18 and 0.36 $m^3 s^{-1}$. These should supply water to the 731 hectares of paddy fields. The land preparation started in December for Paddy I and July for Paddy II. The fluctuating trends show that $Q_{overflow}$ of 80% and 50% occurred from December to June. The peaks of Q_{inflow} 80% and 50% in the Aya Weir were 1.12 and 1.47 $m^3 s^{-1}$, while, the peaks of Q_{inflow} 80% and 50% in the Penebel Weir were 1.25 and 2.01 $m^3 s^{-1}$ respectively.

In the midstream, there are the Caguh and Meliling weirs in *Yeh Ho* River. In addition there is the Rejasa Weir in the tributary *Yeh Mawa* River as shown in Figure 2. The daily diversion graphs for the Caguh Weir and Meliling Weir in the midstream of *Yeh Ho* River with 80% and 50% probability are shown in the Figures 6a, 6b, 7a, and 7b. The months in which Q_{inflow} was fairly equal to Q_{divert} were from May, during the dry season, until November, when the wet season started.

In the Caguh Weir, the diversions of 80% and 50% probability were 0.95 and 1.08 $m^3 s^{-1}$. The minimum diversions were 0.23 and 0.33 $m^3 s^{-1}$ respectively. These provided water supply to the 1,093 hectares of paddy fields. In the Meliling Weir, the diversions of 80% and 50% probability were 0.61 and 0.76 $m^3 s^{-1}$, while the minimum diversions were 0.18 and 0.29 $m^3 s^{-1}$. These can supply 562 hectares of paddy fields. The land preparations commenced in January for Paddy I and in August for Paddy II. The fluctuating trends show that $Q_{overflow}$ of 80% and 50% occurred from December to May. In addition, the peaks of Q_{inflow} of 80% and 50% of Caguh Weir were 2.62 and 7.56 $m^3 s^{-1}$, while the peaks of Q_{inflow} of 80% and 50% of Meliling Weir were respectively 2.23 and 4.31 $m^3 s^{-1}$.

The diversions of the Rejasa Weir are shown in the Figures 8a and 8b. It had Q_{inflow} of respectively 2.28 $m^3 s^{-1}$ at 80% and 8.4 $m^3 s^{-1}$ at 50% probability. The minimum diversions at 80% and 50% probability were respectively 0.08 and 0.10 $m^3 s^{-1}$.

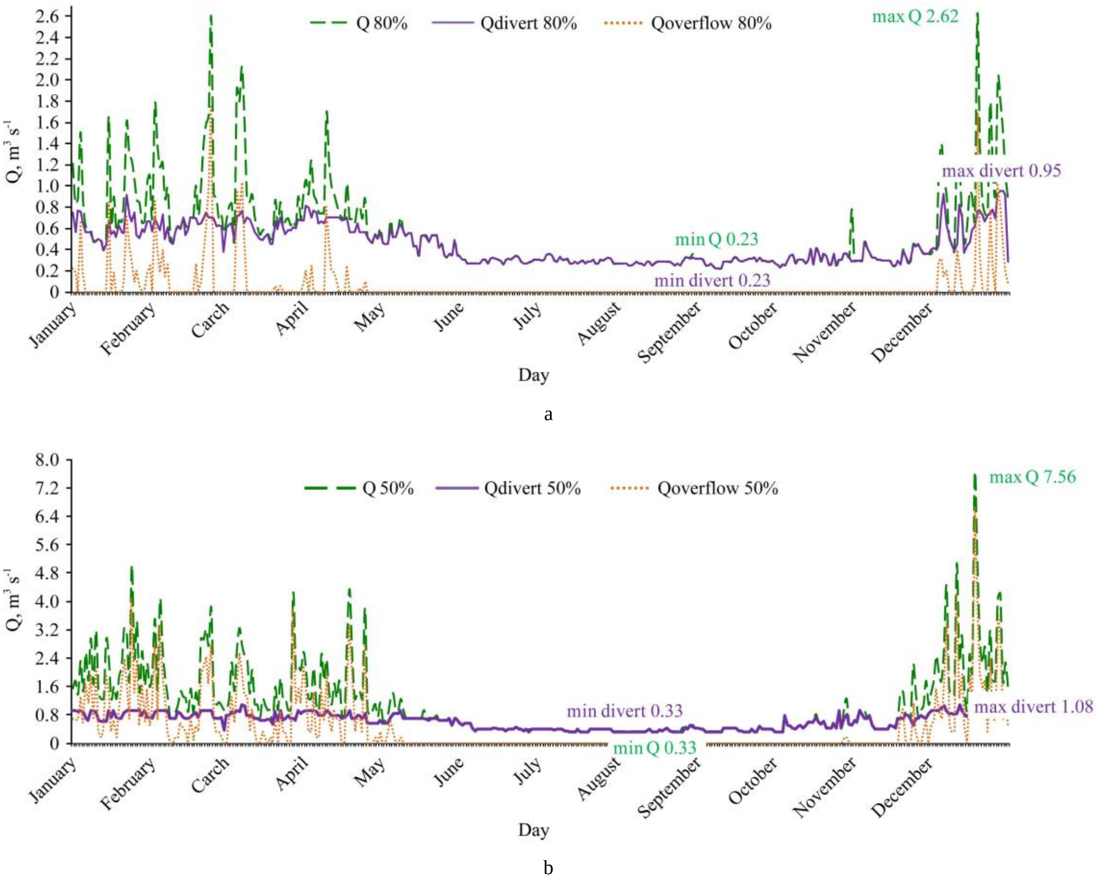
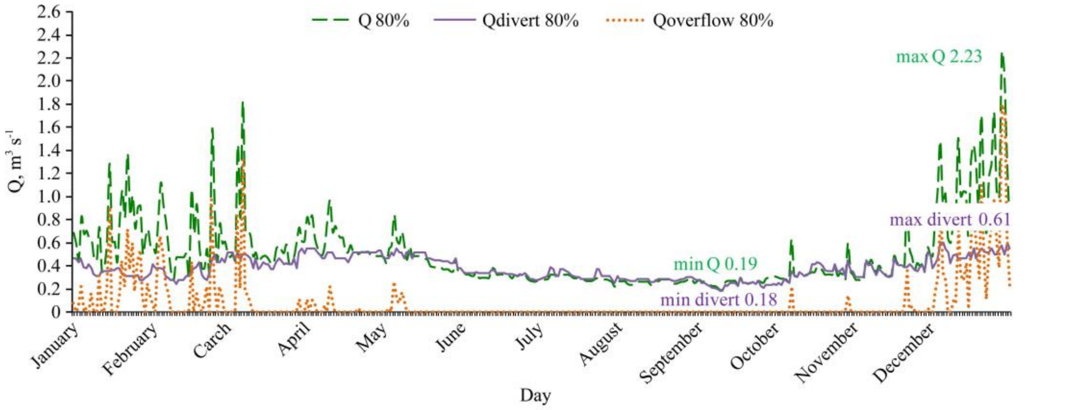


Figure 6 Daily flows through the Caguh Weir



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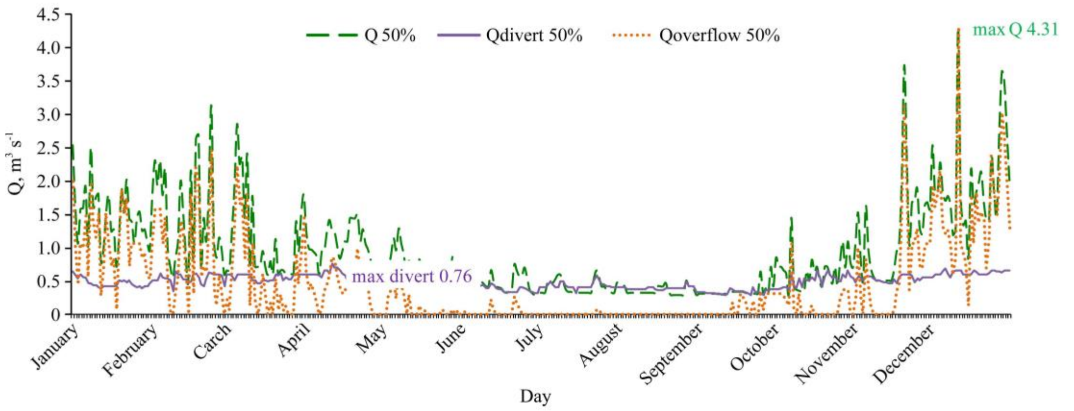

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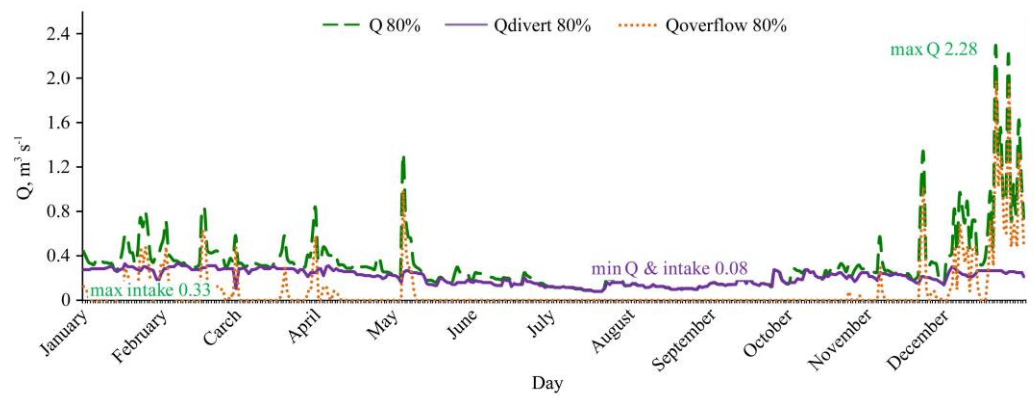
Figure 7 Daily flows through the Meliling Weir



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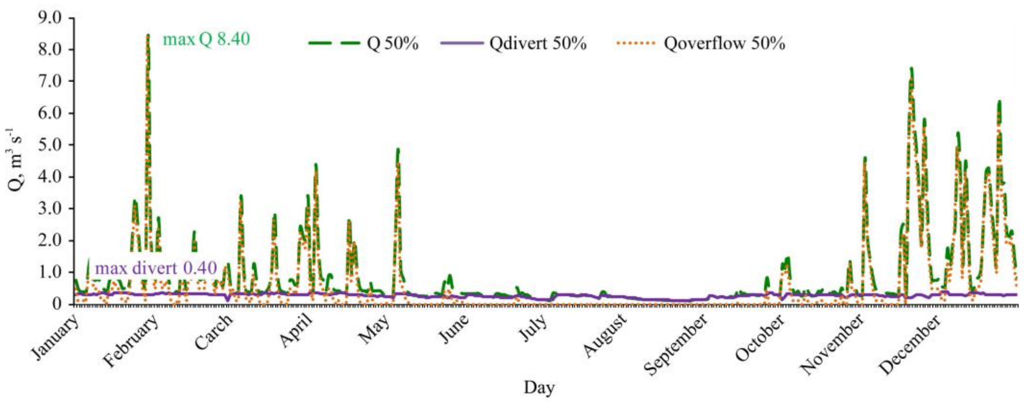

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Figure 8 Daily flows through the Rejasa Weir

The diversions in the downstream weirs Gadungan at 80% and 50% probability are shown in the Figures 9a and 9b. Similar trends of Q_{inflow} and Q_{divert} started in May during the dry season until December when the wet season started.

In the Gadungan Weir, the diversion at 80% was 0.28 $m^3 s^{-1}$, the same as that at 50% probability, while the minimum diversion was 0.05 $m^3 s^{-1}$. Before the Telaga Tunjung Reservoir started operation, the Gadungan Weir supplied two *Subak* irrigation schemes. The total area was 1,534 hectares. Since 2006, this area has been divided in 485 hectares, which is supplied by the Telaga Tunjung Reservoir and 1,187 hectares, which is at present still supplied by the Lambuk Weir, which will be replaced by the Lambuk Dam and a reservoir in the coming years.

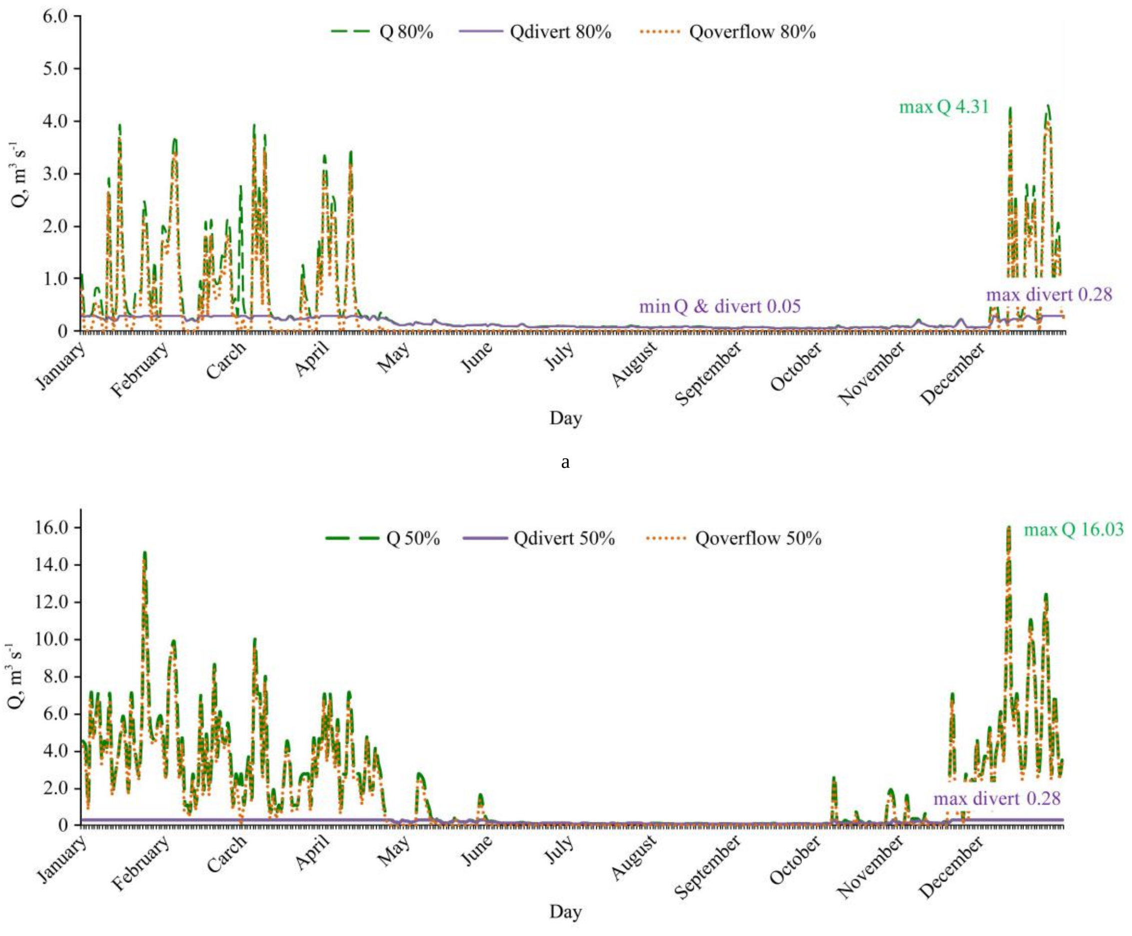

Figure 9 Daily flows through the Gadungan Weir

In the last, the Sungsang Weir, there was a diversion of 0.61 $m^3 s^{-1}$ at both 80% and 50% probability and the minimum diversion was 0.06 $m^3 s^{-1}$. This supplied 430 hectares of paddy fields. Downstream, the starting months of land preparation were February for Paddy I and October for Paddy II. The fluctuating trends show that $Q_{overflow}$ of 80% and 50% probability occurred from December to April. In addition to this, Q_{inflow} of 80% and 50% of the Gadungan Weir were 4.31 and 16.03 $m^3 s^{-1}$, and Q_{inflow} of 80% and 50% of the Sungsang Weir were 5.84 and 17.9 $m^3 s^{-1}$.

As an example the 50% monthly inflow, diversion and overflow for the Meliling section of Yeh Ho River are shown in Table 2. In this Table the inflow has been determined based on the difference between the observed diversion and overflow.

It is difficult to get the data for the diversions and overflows along the river consistent, because there is also a return flow from higher located schemes to lower located schemes. In order to obtain information on the water balance within a scheme, a clearly defined block has been monitored. As an example the average monthly water balance for one block of 4.7 ha in the Meliling Scheme is shown in Table 3.

Table 2 Average monthly inflow diversion and overflow of the weirs in the Meliling section of Yeh Ho River

	Diversion		Overflow		Inflow
	$m^3\ s^{-1}$	MCM	$m^3\ s^{-1}$	MCM	MCM
Jan	0.48	1.29	1.07	2.87	4.15
Feb	0.54	1.31	0.89	2.15	3.46
Mar	0.56	1.50	0.58	1.55	3.05
Apr	0.61	1.58	0.46	1.19	2.77
May	0.6	1.61	0.12	0.32	1.93
Jun	0.4	1.04	0.03	0.08	1.11
Jul	0.44	1.18	0.01	0.03	1.21
Aug	0.4	1.07	0.00	0.00	1.07
Sep	0.34	0.88	0.10	0.26	1.14
Oct	0.52	1.39	0.15	0.40	1.79
Nov	0.54	1.40	0.59	1.53	2.93
Dec	0.63	1.69	1.57	4.21	5.89
Annual		15.93		14.59	30.51

Note: MCM = million cubic metres.

The cropping patterns and indigenous water management, which were organized by the respective *Subak* associations, shown in the midstream second time [*maongin*], especially on the Caguh Scheme, limited irrigation water when land preparation was started in the period August - September. Also in the downstream last time [*ngasep*], especially on the Gadungan Scheme, there was limited irrigation water at the start of land preparation on period October - November. However, the Gadungan Scheme has been supplied by water released from Telaga Tunjung Reservoir already. On the contrary, for supplying the Caguh Scheme, it was dependable on the availability runoff in the river.

Table 3 Average monthly water balances for a clearly defined paddy terraces block of 4.7 ha in the Meliling Scheme

Average	WDUs/*Tektek*		Rainfall, mm day^{-1}	Evapotranspiration, mm day^{-1}	Return flow		Storage/additional supply, mm day^{-1}
	$m^3\ s^{-1}$	mm day^{-1}			$m^3\ s^{-1}$	mm day^{-1}	
Jan	0.033	60.0	19	4.4	0.065	119	–44.1
Feb	0.025	46.2	19	4.3	0.078	144	–82.8
Mar	0.017	31.9	18	4.2	0.075	137	–91.2
Apr	0.044	81.2	12	3.3	0.034	63	26.8
May	0.032	59.5	13	3.2	0.069	127	–58.4
Jun	0.036	66.7	12	2.7	0.116	213	–137.9
Jul	0.024	44.8	15	2.7	0.088	163	–105.5
Aug	0.022	39.9	2	3.5	0.075	139	–100.1
Sep	0.028	51.2	5	4.0	0.030	56	–3.3
Oct	0.027	48.8	4	4.3	0.026	48	0.7
Nov	0.026	48.5	13	4.3	0.042	77	–20.0
Dec	0.025	45.7	15	3.8	0.068	125	–68.6
Annual in mm		18732	4402	1338		42329	–20532

5 Conclusions

In conclusion, the same trends of daily flows of all the weirs in the upstream, midstream and downstream show that the available water of Q_{inflow} can be diverted, because there is limited flow in the river during the period of June until October in the upstream, May until November in the midstream, and May to December in the downstream. Therefore, the concerned off-takes are kept open during those periods. This is indeed based on the agreement among the Subak farmers under the supervision of an irrigation observer who represents the Government, which proves the possibility of continuous flow throughout the water distribution unit (*tektek*) at the lowest level of the paddy terraces system.

Therefore, it should be noticed that the sustainable indigenous paddy terraces depend on the availability of the discharge in the main river that needs to be sufficient for the diversions from the upstream, midstream to downstream. This system would have to be ensured during the dry season, although in the wet season, the recoverable flow increases sharply to the downstream. The results of the study provide a perspective to Subak farmers on how to use the water more accountable.

As a result, the source of water in the upstream is extremely important to sustain the river system. This has become the main reason why 35% of the Gembrong Spring in the upstream is claimed by the Subak Agung Association. In contrast, most of the Gembrong Spring has been managed by the regency's water company to supply domestic needs. Then, it was a big challenge for the Subak Agung Association to supply sufficient irrigation water to the Subak irrigation schemes in Yeh Ho River Basin.

The hydrologic aspects of the dependable flows, while using trends in water balance discharge behind each weir in the river are very important to sustain the Subak irrigation schemes. The dependable flows of the upstream schemes, Aya and Penebel have to be considered (Figures 4 and 5), because of the sequence of irrigation water supplies based on upstream [*ngulu*], midstream [*maongin*], and downstream [*ngasep*].

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