Inflow calculation for on-farm ponds in northeast Thailand

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Abstract

In northeast Thailand, the on-farm pond is one of the most essential technologies for water resource management. To utilize an on-farm pond to its highest potential and in an environmentally sound way, its inflow calculation must be accurately performed. This study presents a suitable method for calculating the water harvesting of the on-farm ponds. Two methods, namely the watershed routing technique and the synthetic unit hydrograph method, were compared to the observed runoff data. The data were obtained from two on-farm ponds near Khon Kaen, in the northeast of Thailand. The rainfall data was obtained from automatic weather station, while the runoff data was interpreted from the water level recorders in the two ponds. Three sets of the rainfall-runoff data were selected from the complete series of the whole wet season of 2006. The comparison results show that the unit hydrograph method gives better agreement to the observed data than the watershed routing method in both the peak discharge and the runoff volume. The coefficient k values of the routing technique are in the ranges 0.6-1.2 and 0.56-2.8 for the north and the south pond respectively. The coefficient C_p values of the synthetic unit hydrograph are in the ranges 0.26-0.65 and 0.26-0.98 for the north and the south pond respectively. The present study should help those who are involved in on-farm pond management.

Keywords: Inflow calculation, On-farm ponds, Watershed routing, Synthetic unit hydrograph, Northeast Thailand

Introduction

An on-farm pond is one of the most appropriate technologies for water harvesting in northeast Thailand. The undulating landscapes, which dominate the northeast topography, enhance the efficiency and usability of on-farm ponds, by providing catchment areas and reasonable head for water conveyance. An on-farm pond is therefore an essential feature for every farm in northeast Thailand. It can be used for many purposes e.g. farm water supply, supplementary irrigation, live stock water consumption, fish raising, and even flood mitigation (Suresh, 2002; Ngigi et al.,2005; Yoo and Boyd, 1994; and Kumar, 1992).

The climate of the northeast is monsoonal which consists of wet season from mid May to mid October and dry season during the rest of the year. Since more than 80% of annual rainfall falls in the wet season, an on-farm pond harvests water during 6 months of the wet season and supplies water for the next 6 months. The ability to predict the on-farm pond inflow rate from the known rainfall is very important for the on-farm pond design, construction, and management.

Two methods of calculation were compared using the data from inflow into two nearby on-farm ponds near Khon Kaen. The analyses show that the synthetic unit hydrograph method is more appropriate than the watershed routing method.

Rainfall runoff modeling techniques

There are two types of runoff modeling from rainfall, i.e. hydraulic methods and lump methods. The hydraulic methods make use of the concepts of open channel flow theory which involves solving the Saint-Venant equations with appropriate boundary and initial conditions (Chow et al.,1988). The hydraulic methods are tedious and time consuming even using a computer model. By contrast, the lump methods are much simpler and work surprisingly well especially with irregular small watersheds (Beven, 2001). Two simple lump models have been used in this study, the watershed routing technique and the synthetic unit hydrograph method.

The watershed routing technique.

The watershed routing model is based on the assumption that the outflow from the watershed varies nonlinearly with the storage in the watershed. We may write an equation as van den Akker and Boomgaard (1996)

$$S = KQ^n \tag{1}$$

where S = the water stored in the watershed, Q = the outflow from the watershed, and K and n are parameters. By linearizing equation (1), the calculation is made much simpler while the accuracy is still acceptable (Beven, 2001), leading to

$$S = KQ \tag{2}$$

By converting volume onto depth of water spreading throughout the watershed, we obtain

$$S_l = kq_l \tag{3a}$$

$$S_2 = kq_2 \tag{3b}$$

where s_1, s_2 = depths of water storage at time steps 1 and 2, q_1, q_2 = discharges as depth per unit time at time steps 1 and 2 respectively. From continuity equation,

$$s_2 = s_1 + (i - 0.5(q_1 - q_2))\Delta t \tag{4}$$

where i = intensity of excess rainfall, and Δt = time interval. By substituting (3) into (4) and rearranging,

$$q_2 = \frac{k - 0.5\Delta t}{k + 0.5\Delta t} q_1 + \frac{\Delta t}{k + 0.5\Delta t} i \tag{5}$$

This is the watershed routing model. It can be used to predict the next step flow rate from knowing the present flow rate and intensity of rainfall. The depth flow rate, q, can be converted to volume flow rate, Q, by multiplying q with the watershed area, A.

The synthetic unit hydrograph

The unit hydrograph is a direct runoff hydrograph resulting from a unit rainfall (1 cm depth) of a specific rainfall duration (Shaw, 1994). The unit hydrograph is normally derived from records of rainfall and runoff data. When dealing with small watersheds, coupled rainfall and runoff data are hardly available, we therefore resort to the synthetic unit hydrograph. The unit hydrograph that is synthesized from topographic and climatic features is called a synthetic unit hydrograph. Essentially, the idea is that the lag time of each watershed is constant and can be evaluated from the watershed characteristics (Shaw, 1994) The lag time, t_l, is the time lapse between the middle of the rainfall duration and the hydrograph peak. For a small watershed, the lag time can be assumed to be about 0.6 of concentration time, t_c, as

$$t_l = 0.6 t_c \tag{6}$$

The concentration time is the time taken for the water surge to move from the hydraulically remote part of the watershed to the outlet. There are several formulas for the concentration time calculation. One of the most practical formulas is the Kirpich's formula (Brutsaert, 2005) written as,

$$t_c = 0.0195 C_k (L / S^{0.5})^{0.77} \tag{7}$$

where t_c is in minutes, L = the length of the main channel from the furthest divide to the outlet in km, S = the average slope, and C_k = the Kirpich coefficient depending on type of flow and surface, e.g. 0.2 for concrete channel to 2 for overland flow on grass surface.

Time to peak, t_p, is defined by the time since the excess rainfall starts until the peak discharge is reached. Therefore, the time to peak can be obtained from

$$t_p = t_l + \frac{D}{2} \tag{8}$$

where D = excess rainfall duration. For each unit hydrograph, it is reasonable that the peak discharge, u_p, varies directly with the watershed area, A, and inversely with the time to peak, t_p, hence

$$u_p = \frac{C_p A}{t_p} \tag{9}$$

where C_p is proportional constant, u_p is in $m^3s^{-1}cm^{-1}$, A is in km, and t_p is in hours.

The shape of a unit hydrograph may be assumed as the gamma function distribution (Aron and White, 1982). Akan and Houghtalen (2003) suggest an equation for coordinate of unit hydrograph as

$$u = u_p[(t/t_p)\exp(1-(t/t_p))]^{n-1} \tag{10}$$

where t = time, u = unit discharge at time t (in $m^3s^{-1}cm^{-1}$), and n is a constant which related to C_p as

$$n = 1.0685 + 0.1175C_p + 0.782C_p{}^2 \tag{11}$$

The formula (11) is modified from Akan and Houghtalen (2003).

Materials and methods

Two on-farm ponds in Wangwa, a village about 25 km south of Khon Kaen, were chosen as study sites (Fig.1a). The two ponds are closed together, and one is considered the north pond while the other is considered the south pond. The north pond has the dimensions of 20×30×4 m. Its elevation of the bottom is 194.40 m above mean sea level. The south pond has the size of 17×33×4 m and the elevation of the bottom is 195.0 m amsl. Fig. 1b shows the satellite image of the ponds and their environment which consists of upland crops, fallows, and eucalyptus woodlands.

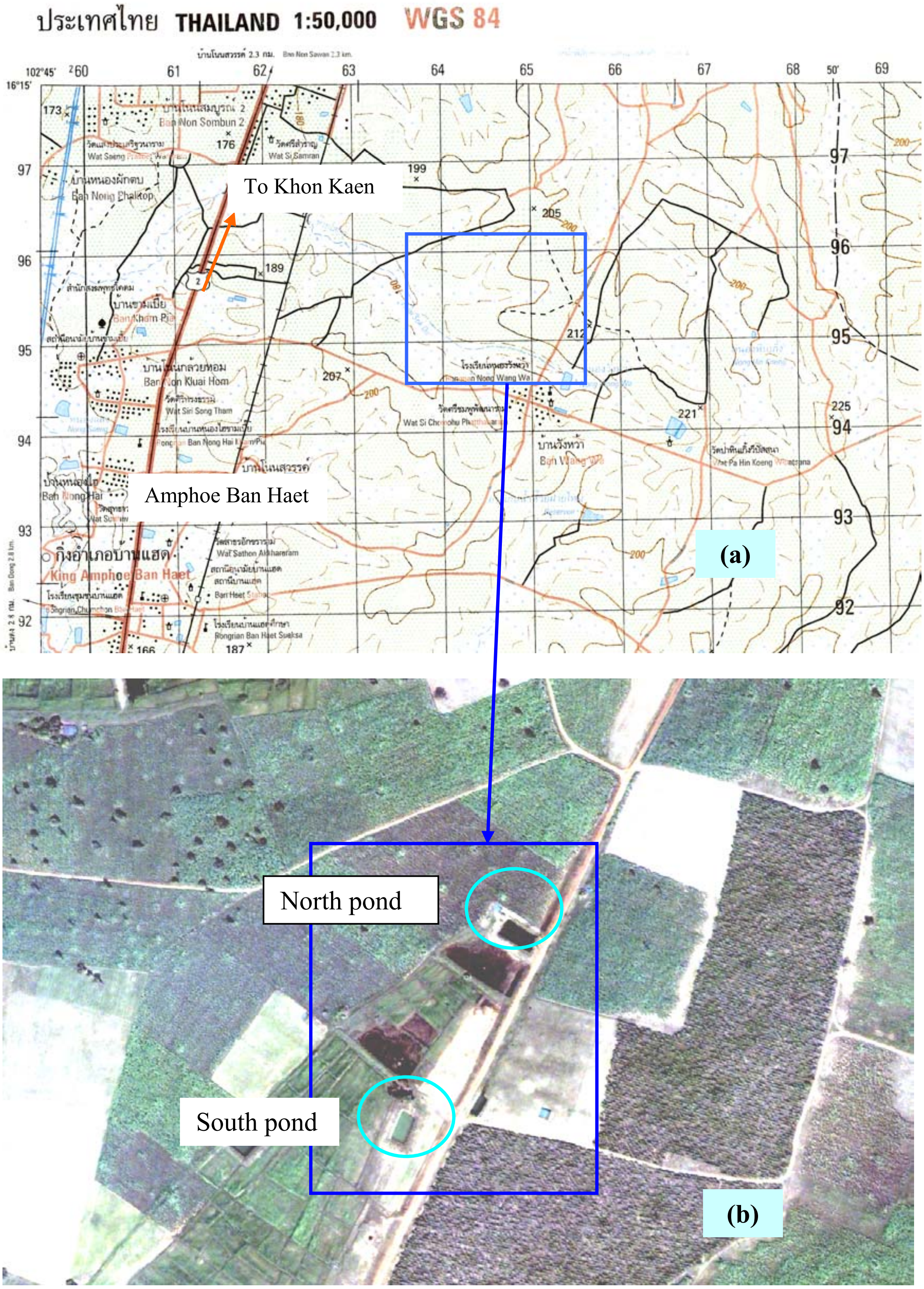


Figure 1: Location of the two experimental ponds, (a) topographic map, (b) satellite image

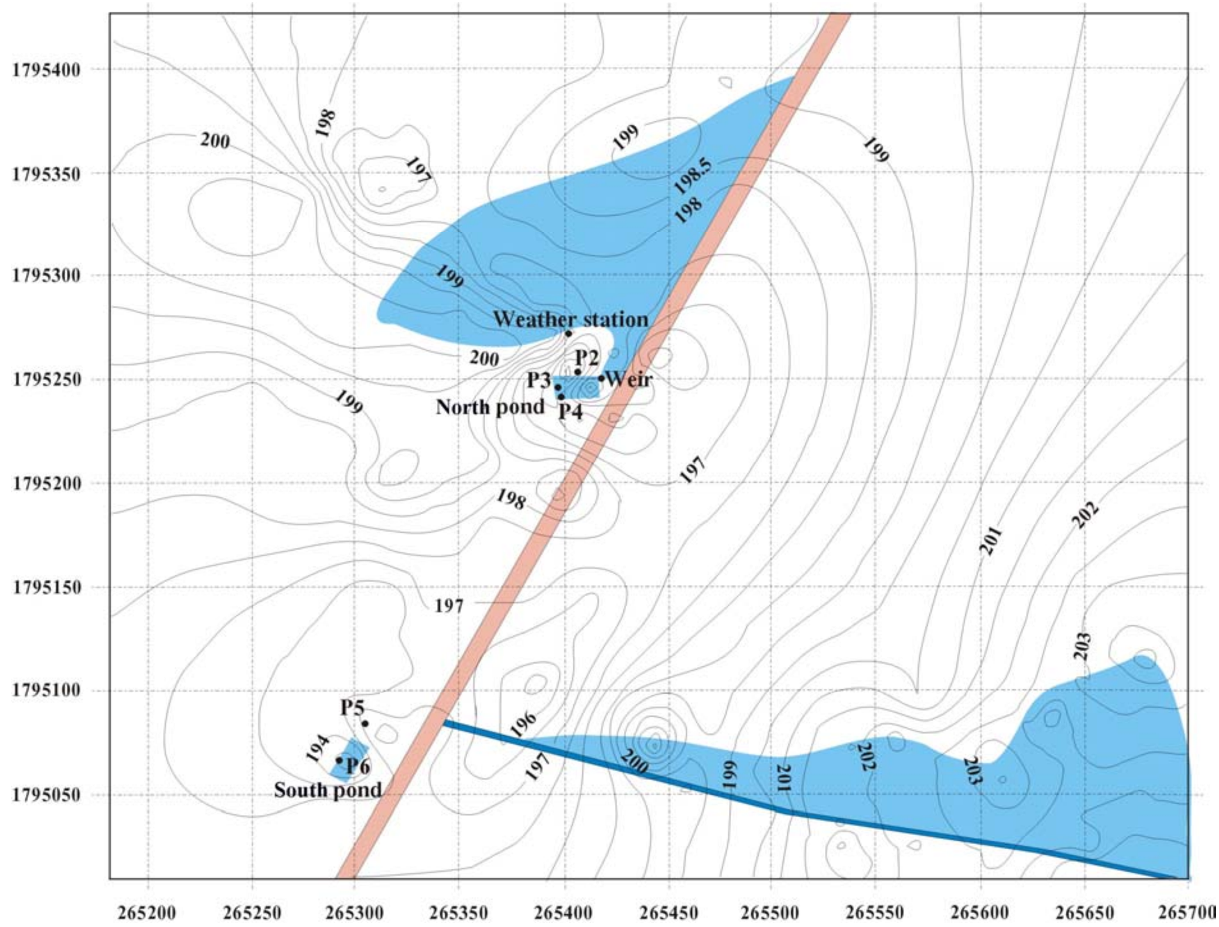


Figure 2: Location of ponds and envelopments

The surrounding topography of the two ponds was surveyed using a level and a hand-held GPS. The topographic contours and the watershed areas of the two ponds are shown in Fig. 2. The catchment of the north pond resembles a butterfly shape which should produce a sharp peak with a short time base. The catchment of the south pond is an elongated shape that should produce a mild peak with a long time base. The outlet from the watershed or the inlet into the pond for each of the cases is quite special. For the north pond, the inlet is at the northeast corner of the pond and close to the road, therefore we installed a rectangular weir for inflow measurement. For the south pond, the outflow from the watershed passes through a ditch which leads across a road to the pond, a complicated inflow arrangement. The length and slope of the main channel for the north pond are 167 m and 0.0096 respectively, and for the south pond are 480 m and 0.0165 respectively. The areas of the watershed of the north and the south pond are 10643 m^2 and 12618 m^2 respectively. Piezometers were installed to observe groundwater levels, two for the north pond at P_2 and P_4 in Fig. 2 and one for the south pond at P_5.

Automatic water level recorders were installed on each pond, each piezometer, and at the rectangular weir of the inlet of the north pond. An automatic weather station was set up near the north pond. It recorded rainfall, air and dew point temperatures, relative humidity, wind speed and direction, and net radiation.

All recorders were set to record every 10 minutes during the whole rainy season of the year 2006. We selected 3 prominent storm events on 30 Aug, 17 Sept., and 19 Sept. 2006 for this study. Tables 1 and 2 show the data of rainfall and runoff for the north and the south pond respectively. The runoff data were interpreted from the changing volume of the pond storage with time.

Table 1: The data of rainfall and runoff into the north pond.

Time (min)	30 August 2006		17 September 2006		19 September 2006	
	Rainfall (mm)	Runoff (m^3/s)	Rainfall (mm)	Runoff (m^3/s)	Rainfall (mm)	Runoff (m^3/s)
0	0	0	0	0	0	0
10	0.20	0.0050	1.00	0	0	0
20	3.80	0.0040	5.20	0.0120	2.60	0.0120
30	10.60	0.0560	12.00	0.0440	4.00	0.0440
40	4.60	0.0600	5.40	0.0340	7.20	0.0340
50	3.00	0.0490	4.20	0.0290	4.80	0.0290
60	0.60	0.0240	6.40	0.0230	4.40	0.0230
70	0.80	0.0020	4.60	0.0260	1.60	0.0260
80	0.60	0.0080	1.80	0.0250	2.00	0.0250
90	0.60	0	1.00	0.0060	0.60	0.0060
100	0.60	0.0040	0.60	0.0050	0.20	0.0050
110	1.20	0.0090	0.20	0.0010	0	0.0010
120	1.60	0.0130	0.20	0.0010	0.20	0.0010
130	0.60	0.0020	0	0	0	0
140	0	0.0080	0	0	0	0

Table 2: The data of rainfall and runoff into the south pond.

Time (min)	30 August 2006		17 September 2006		19 September 2006	
	Rainfall (mm)	Runoff (m^3/s)	Rainfall (mm)	Runoff (m^3/s)	Rainfall (mm)	Runoff (m^3/s)
0	0	0	0	0	0	0
10	0.20	0	1.00	0.00187	0	0.0309
20	3.80	0.0056	5.20	0.0150	2.60	0.0075
30	10.60	0.0234	12.00	0.0122	4.00	0.0168
40	4.60	0.0439	5.40	0.0196	7.20	0.0112
50	3.00	0.0608	4.20	0.0168	4.80	0.0187
60	0.60	0.0767	6.40	0.0281	4.40	0.0112
70	0.80	0.0215	4.60	0.0374	1.60	0.0355
80	0.60	0.0215	1.80	0.0215	2.00	0.0140
90	0.60	0.0131	1.00	0.0122	0.60	0.0140
100	0.60	0.0084	0.60	0.0019	0.20	0
110	1.20	0.0224	0.20	0.0047	0	0.0075
120	1.60	0.0037	0.20	0	0.20	0.0056
130	0.60	0	0	0	0	0
140	0	0.0075	0	0	0	0

A graph of a rainfall and runoff relationship is called a hydrograph. In this study, for each rainfall event and each pond, we compared the predicted hydrograph to the corresponding data set. Two methods were used to calculate the predicted hydrographs i.e. the watershed routing technique and the synthetic unit hydrograph.

The calculation method for the watershed routing technique started with the assumption of the k value. The initial value of depth runoff, q, may be set to zero. The equation (5) was used consequently to obtain q of all time steps. The depth runoff value q were converted to the volumatic runoff Q by multiplying q with the watershed area, A. We adjusted the k value until the most suitable hydrograph was approached.

A synthetic unit hydrograph for each watershed was obtained by first measuring the length, L, and the slope, S, of its main channel. From these topographic data, the lag time, t_l, of the watershed was calculated from equation (6) and (7) by choosing the Kirpich coefficient C_k equal to 2. The time to peak, t_p, was calculated from equation (8) using the rainfall duration D equal to 10 minutes. By trial the C_p value, the value of peak discharge, u_p, of the unit hydrograph and the value of n were obtained from equations (9) and (11) respectively. Then the value of u_p, C_p and n gave a synthetic unit hydrograph by the equation (10). From the unit hydrograph and the rainfall data, we computed the corresponding hydrograph using standard method explained in almost all hydrology texts e.g. Chow et al. (1988), Shaw (1994), and McCuen (2004). We adjusted the C_p value until arriving at the most suitable hydrograph.

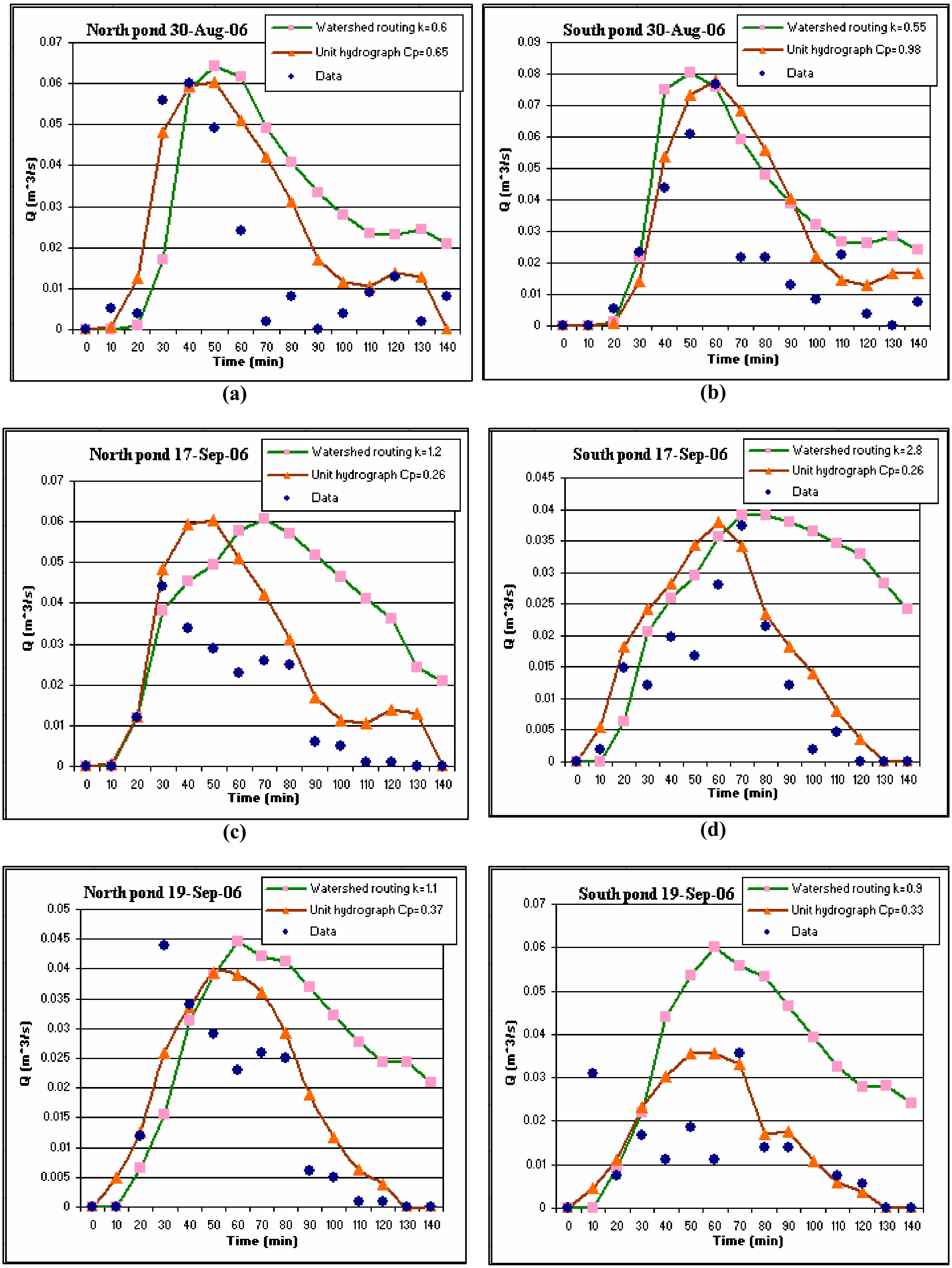
Result and discussion

Three sets of rainfall-runoff data for each pond are shown in table 1 and 2 for the north and the south ponds respectively. The observed hydrographs were plotted and compared with the two predicted methods in Fig. 3. It is clear from Fig. 3 that the synthetic unit hydrograph method has better agreement with the observed hydrograph than the watershed routing technique. For peak discharge, the unit hydrograph method gives lower values that are closer to the observed data than the routing technique, although not by much. However, for the volume of flow, the watershed routing technique predicted much larger volumes than the observed data or the unit hydrograph method.

Table 3 shows the variation of the value of k and C_p for the routing technique and the unit hydrograph method. The k values vary in the ranges 0.6-1.2 and 0.55-2.8 for the north and the south pond respectively. The C_p values vary in the ranges 0.26-0.65 and 0.26-0.98 for the north and the south ponds respectively. The variations in both k and C_p demonstrate the nonlinearlity of the flow system. The average values of k and C_p of both ponds are fairly close, especially the C_p values. It is suggested that the runoff calculation from rainfall for an on-farm pond water harvesting in northeast Thailand should be done by using the synthetic unit hydrograph. The suitable C_p value can be obtained by fitting the model to several observed data then averaging the values.

Table 3: The most suitable values of k and C_p

Rainfall event	North pond		South pond	
	k	C_p	k	C_p
30 August 2006	0.6	0.65	0.55	0.98
17 September 2006	1.2	0.26	2.8	0.26
19 September 2006	1.1	0.37	0.9	0.33



(a) (b)

(c) (d)

(e) (f)

Figure 3: Comparisons of the predicted runoffs to the observed data, (a), (c), and (e) for the north pond and (b), (d), and (f) for the south pond.

Conclusions

1. The synthetic unit hydrograph method gives better results than the watershed routing technique for both the peak discharge and the runoff volume.
2. The k-values of the routing technique vary in the ranges 0.6-1.2 (average value 0.97) and 0.55-2.8 (1.42) for the north and south pond respectively.3.
3. The C_p-values of the unit hydrograph method vary in the range 0.26-0.65 (0.43) and 0.26-0.98 (0.52) for the north and south pond respectively.
4. The variations in K and C_p demonstrate the nonlinearlity of the flow systems.

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