LAND USE SUITABILITY FOR AGRICULTURE IN THE SESAN CATCHMENT: POTENTIAL FOR IRRIGATION DEVELOPMENT

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MK3
Optimising cascades of hydropower

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1 INTRODUCTION

The project “Optimizing the management of a cascade of reservoir at the catchment level” investigates the multiple uses for reservoirs within a catchment. The project was undertaken as part of the Challenge Program: Water and Food in the Mekong Basin.

The objective is to improve the management of a cascade of hydropower dams in order to provide benefits across sectors such as hydropower, agriculture, fisheries, and tourism. An additional goal is to ensure water storage infrastructure contributes to local economic development. The project aims to develop new operating rules for reservoirs to allow multiple uses for the water.

The study sites include the Sesan River catchment located in Viet Nam (Upper Sesan catchment) and Cambodia (Lower Sesan catchment) as well as the Nam Theum/ Nam Kadim catchment located in Lao PDR.

This report focuses on the Sesan catchment, where six hydropower dams are in operation, two dams (Upper Kontum and Sesan 4A) are under construction and five more are planned (Figure 1).

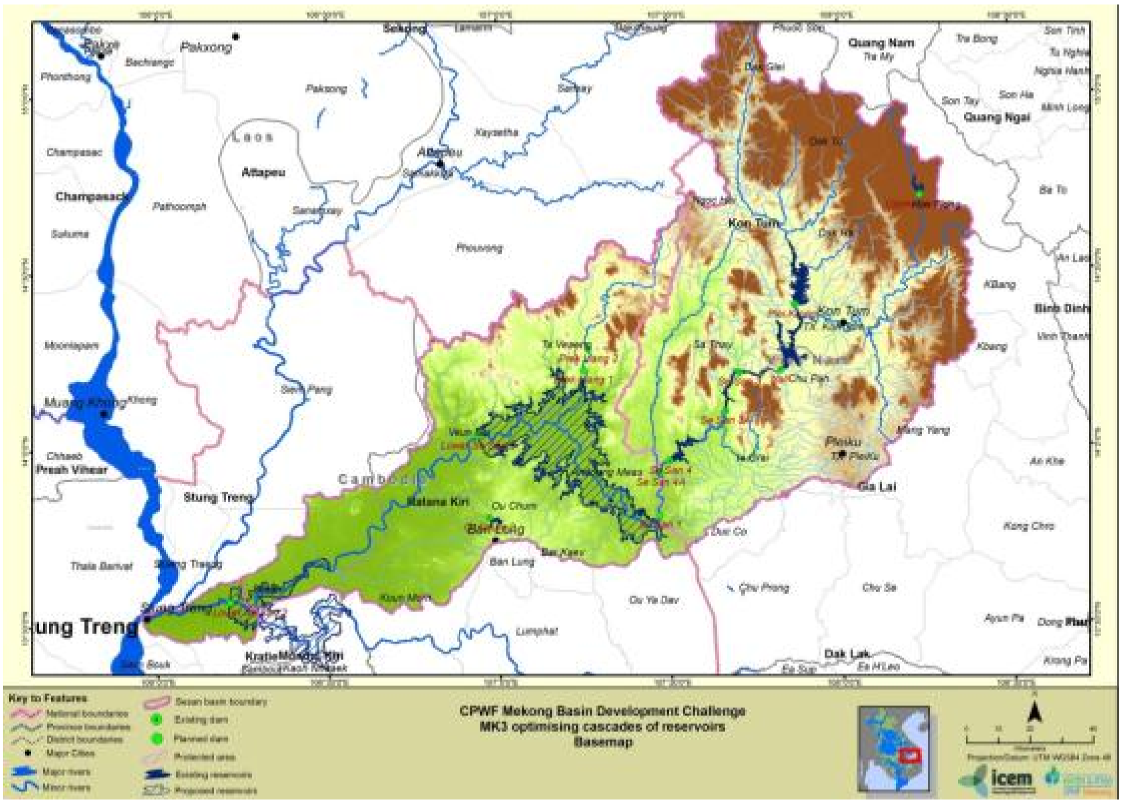

Figure 1: Sesan River catchment and its existing and planned hydropower dams

In this report, we:

- develop agro-ecological zoning to understand the diversity of climate, soil and land uses within the Sesan catchment
- identify recent agriculture trends and investigate the potential for agricultural development in the catchment
- assess the potential for developing irrigation in the context of dam cascades
- highlight suitable areas for developing irrigation and estimate the water needed for these projects

2 APPROACH AND METHOD

Agro-ecological zoning (AEZ) is widely used in agriculture planning. The FAO developed the methodology in the 1970s and it has since been used in various contexts and in countries around the world (FAO, 1976; FAO, 1978; FAO, 1996). Agro-ecological zoning is an integrated approach to planning and managing land resources that ensures land is allocated to uses that provide the largest sustainable benefits. It can be used to assess the potential of areas to support specific types of agriculture and other economic activities. GIS tools have enhanced the usefulness and power of AEZ.

We were interested in developing zoning to help scope out the multiple possible uses of a reservoir. Given the limited availability of data for the Sesan catchment, we slightly modified the generic AEZ approach. Details of the method and data source used in this study are found in Annex A. We used two approaches that included GIS tools (Figure 2) for:

- Agro-ecological zoning or broad scoping, where we aggregated land units by overlaying different GIS layers (climate, terrain, soil, and so on). This approach gave us a general sense of the distribution of agro-ecological zones within the catchment.
- Land use suitability analysis, where we evaluate the suitability of each land unit (or grid cell) for a single type of crop. The analysis is based on crop requirements as well as climate, terrain and soil characteristics. We used the linear model LUSET developed by IRRI (Kam, et al., 2000; Yen, et al., 2006).

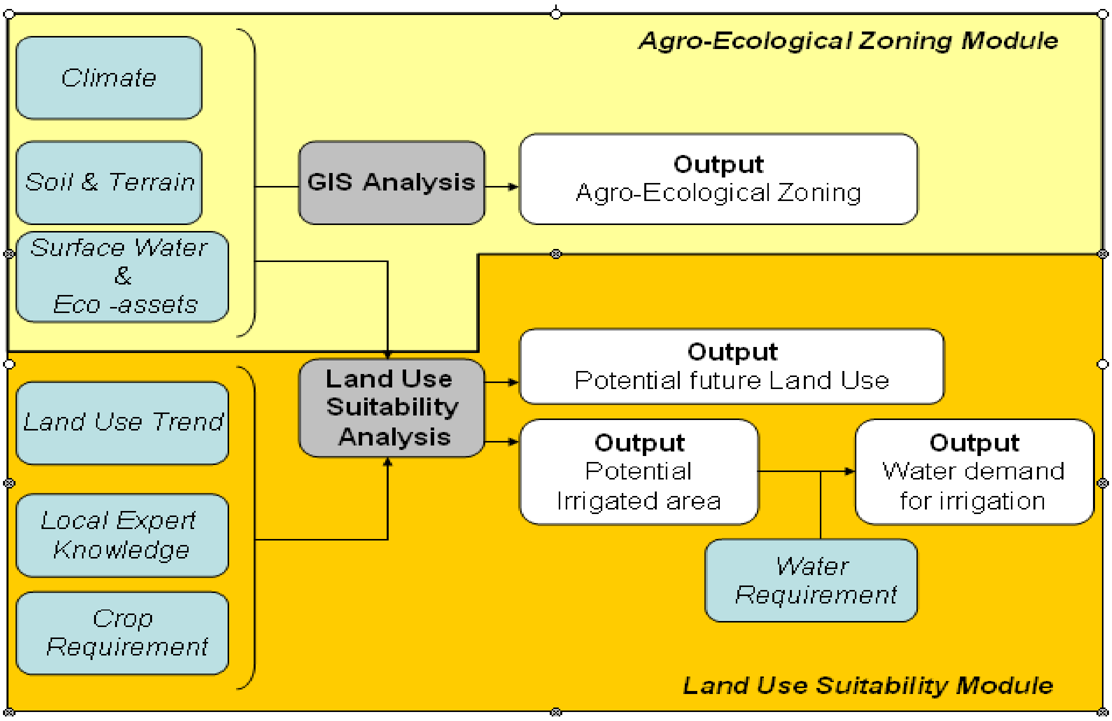

Figure 2: Research framework for agro-ecological zoning and irrigation potential in the Sesan catchment

Land use suitability was tested for irrigated rice in the catchments using this approach. We took into account the potential for irrigable land along the main river, where water is available in the dry season.

Similarly, suitability for supplementary irrigation for rainy season rice was tested along the tributaries since most of the tributaries in the Sesan catchment have water available only in the rainy season. The potential area for irrigation was calculated and the water requirements and demands were estimated based on available literature and local expert knowledge about water requirements of the rice varieties.

3 AGRO-ECOLOGICAL ZONING IN THE SESAN CATCHMENT

The Sesan River Basin surface covers an estimated 18,890 square kilometers. Almost 60 percent (11,260 km2) of the area occurs in Viet Nam and the remaining 40 percent (7,630 km2) occurs in Cambodia (3S ADB RETA project (http://reta.3sbasin.org; cited by Baran, et al., 2011). The basin contributes enough water to the Mekong River to make up between 10 percent and 16.7 percent of the river's flow rate (KCC, 2009; MRC, 1992 cited by Baran, et al., 2011).

The Sesan River's flow has already been altered in the Upper Sesan catchment of Viet Nam by several hydropower dams including Pleikrong, Yali, Sesan 3, Sesan 3A, Sesan 4A (Figure 1).

3.1 ECOLOGICAL CHARACTERISTICS

Terrain

The Lower Sesan catchment in Cambodia is dominated by a plain, which starts at the border with Viet Nam (downstream of the planned Sesan 1 dam). The catchment stretches across the Ratanakiri and the Stung Treng provinces. A flat plain covers most of the Stung Treng province (Figure 3), where 97 percent of the catchment has a gentle slope between 0 and 5 percent. Only 48 percent of the Ratanakiri province has a similar slope class. The landscape changes to steep slopes in the northern part of the catchment in Cambodia where the Virachey National Park is located.

In Viet Nam, the plains are limited to a small area along the Sesan River, around Pleiku city. Steep slopes with mountain ranges occur northeast of the Kon Tum province and between Kon Tum city and the border of Cambodia. About 23 percent of the catchment in the Kon Tum province slopes between 0 and 5 percent, while 43 percent of the province slopes by more than 15 percent. The catchment in Gia Lai province has a relatively flat terrain, with 42 percent of the area sloping by between 0 and 5 percent.

Soil

- Most of the catchment (81 percent or 1,461,000 ha) is composed of Acrisol, which includes eight different subtypes. The soils are found on steep mountainous and plain areas (Figure 4). They are old land surfaces and can be acidic. As such, they are not very productive soils and are used for shifting cultivation and for undemanding or acid tolerant crops such as cashew, rubber, or pineapple (FAO 2001).

- In the southern part of the catchment (14 percent of the total area) around Ban Long and Pleiku city, Ferralsol (red soil) is found in hilly areas that slope 5 percent to 15 percent. These soils are usually chemically poor but they have good physical properties. They are deep and are well adapted to rubber, cashew and coffee cultivation.

- Nitisol and Vertisol soils are found mainly in the southern parts of the catchment (3 percent of the total area). They have high clay content, are fertile and can support cash crops. Vertisols are especially hard to prepare for tillage due to their high clay content and Nitisols are considered to be well adapted for irrigated rice cultivation.

- Cambisol, Fluvisol and Andosol soil types occur sparsely in the catchment (0.39 percent or 7,106 ha, 0.43 percent or 7,916 ha and 0.24 percent or 4,302 ha respectively) and are considered relatively fertile soils.
- Leptosol also occurs rarely (less than 1% of the total catchment area), and are very poor, shallow and degraded soils that need to be kept under forest cover. They are found mostly in the Lower Sesan catchment in Cambodia.

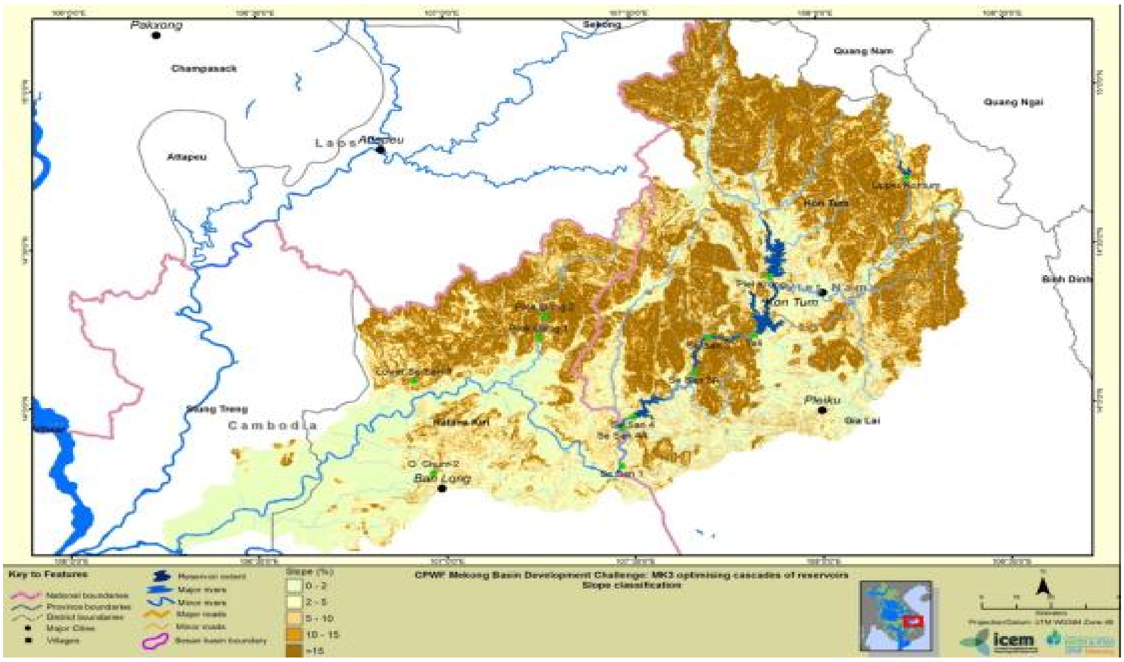

Figure 3: Slopes in the Sesan River basin (based on MRC database)

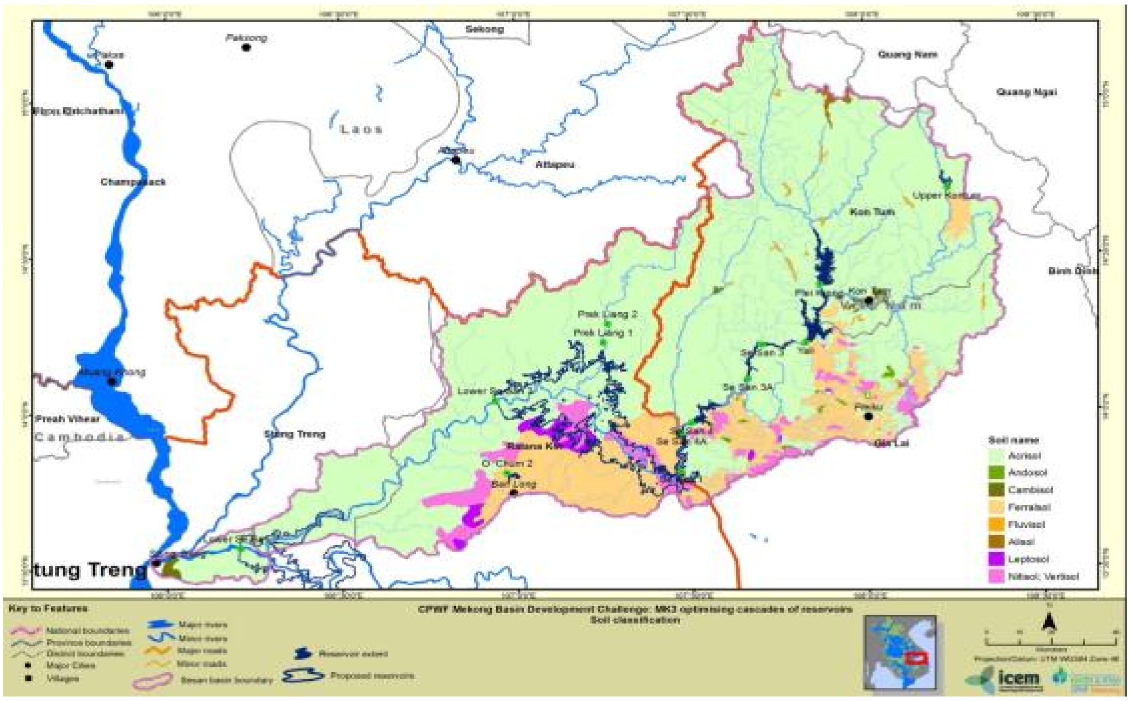

Figure 4: Soil type in the Sesan River basin

Climate

- The minimum temperatures of the coldest months are recorded at the highest elevations (Figure 5). The coldest temperatures (below 16.5 degrees Celsius) occur in the Ratanaikri province of Cambodia and in the Kon Tum and Gia Lai provinces of Viet Nam.
- Plains in the Lower Sesan catchment of Cambodia and areas downstream of the Yali dam have minimum temperatures above 18oC. The plains upstream of the Yali dam are coolest, with minimum temperatures between 16.5oC and 18.5oC.

- Annual rainfall also correlates with elevation. Plains in the the Lower Sesan catchment in the Stung Treng province and in the valley of the Sesan River in Viet Nam have the lowest average rainfall, below 2,000 millimeters per year. Mountain ranges in the northern and eastern parts of the Upper Sesan catchment experience the highest amounts of rainfall, more than 2,300 mm per year.

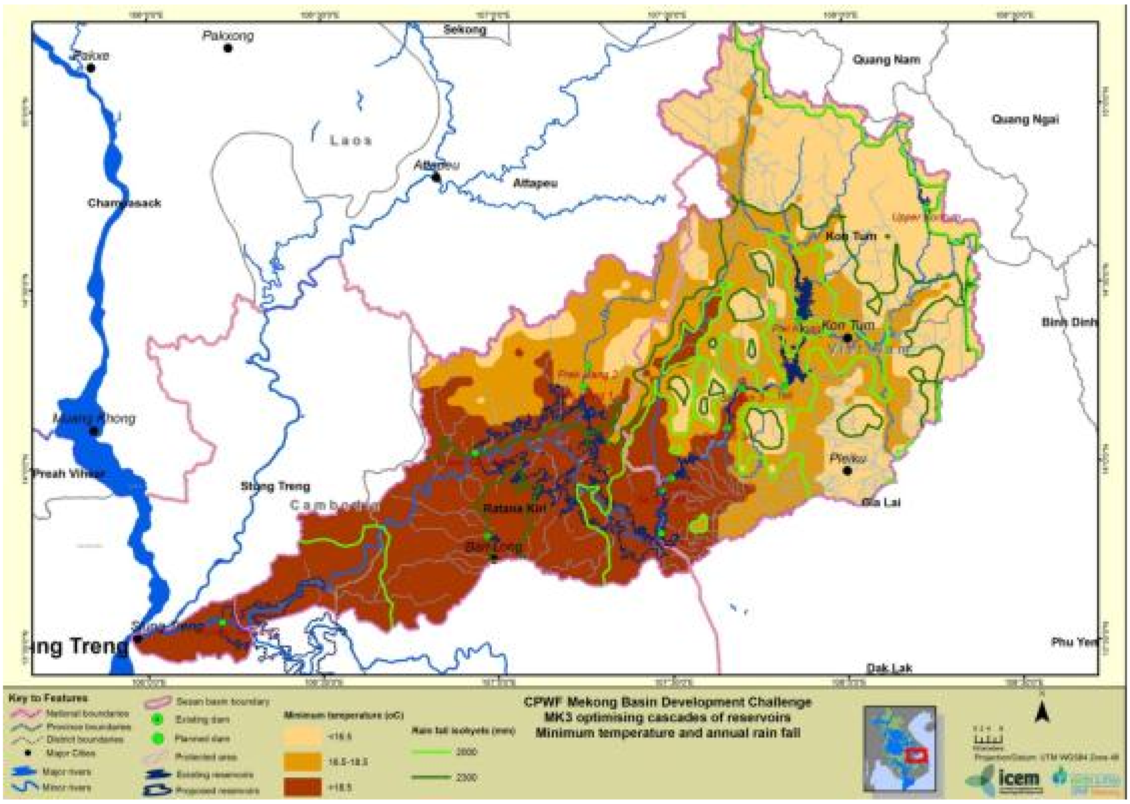

Figure 5: Average annual rainfall (mm/year) and minimum temperature of the coldest month in the Sesan River basin

3.2 AGGREGATION AND BROAD AGRO-ECOLOGICAL ZONING

In an attempt to combine and aggregate the different soil, terrain and climate characteristics, we reduced the number of classes.

The combination of four slope ranges1 X four soil types2 X two temperature ranges3 X two rainfall4 ranges is presented in Figure 6. The map is difficult to analyze since it contains 50 different land units. For each land unit, the areas and ratios are provided in the Annex C.

We present four main agro-ecological zones in Figure 6:

Fertile terrace and plateau (Light Green) – 5 percent of catchment

- These areas are found in various climatic regions, but are far less represented in cooler regions. They occur mainly on the plateau in Ratanakiri province along the Sesan River, and in

[1] Slopes classes: *Flat* (0-2percent); *Undulating* (2-5 percent); *Hilly* (5-15 percent); *Mountainous* (>15 percent)
[2] Four soils type: *Very Low fertility (Leptosol); Not fertile (Acrysol & Alisol); Less fertile (Ferralsol & Andosol); Fertile (Vertisol; Nitisol, Fluvisol and Cambisol)*
[3] Two classes for minimum temperature of the coldest month: Below 16.5°C; above 16.5 °C
[4] Two classes for annual rainfall: below 2,000mm/year; above 2,000 mm/year

small patches in the Upper Sesan region of Viet Nam. They represent less than five percent of the catchment area.

Red soil plateau (Red to Orange) – 13 percent of catchment

- The southern parts of the catchment in Ratanakiri (near Banlung city) and parts of the Gia Lai province are characterised by the occurrence of Ferralsol. The land has a gentle to moderate slope and warmer minimum temperatures. Such zones cannot be found in Stung Treng province.
- Similar agro-ecological zones with cooler minimum temperatures are found in the Kon Tum and parts of the Gia Lai province. The zones represent more than 13 percent of the catchment area.

Low fertility terrace and plain (Yellow to Brown) – 28 percent of catchment

- Flat areas with low fertility Acrisoil occur in all provinces of the catchment, covering 28 percent of the catchment area. Lower rainfall and higher minimum temperatures are found in Stung Treng and parts of the Kon Tum province. Areas with higher rainfall and higher minimum temperatures are found in Ratanakiri and parts of the Kon Tum province. These areas occur along the Sesan River, and represent large, flat areas in the lower Sesan catchment.

Low Fertility hill and mountain (Blue and Purple) – 51 percent of catchment

- This is the main agro-ecological zone and represents 51 percent of the catchment. The eastern and northern parts of the catchment in the Ratanakiri and Kon Tum provinces slope steeply and have low fertility Acrisol. In these zones, the minimum temperature decreases with the elevation, and rainfall is above 2,000 mm per year. Similar conditions are found on the mountain ranges that occur between the Yali dam and the Viet Nam - Cambodia border.

Other zones

- Other agro-ecological zones of minor importance like red soil mountain, fertile hills and mountains and leptosol represent 0.26 percent, 1.80 percent and 0.81 percent of the catchment respectively.

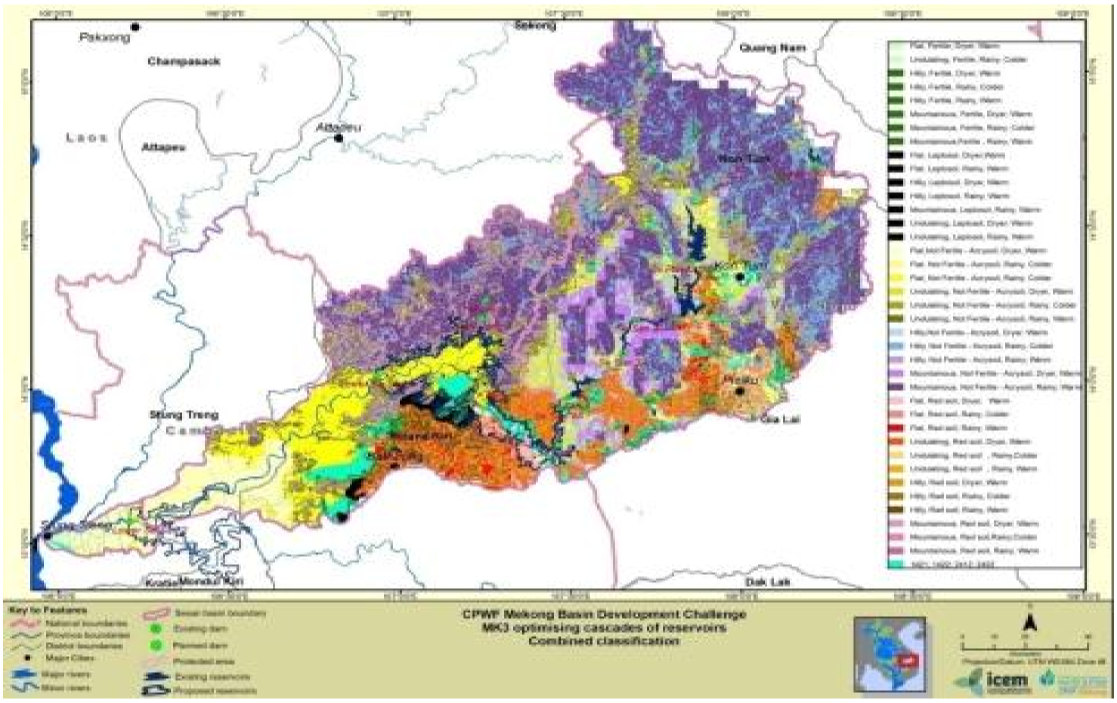

Figure 6: Agro-ecological zones in the Sesan River basin

4 AGRICULTURE TRENDS IN THE SESAN CATCHMENT

Although forests dominate both the Lower and Upper Sesan catchments, some land is rapidly being converted to agriculture in Viet Nam and, more recently, in Cambodia.

4.1 UPPER SESAN CATCHMENT [5]

In the Gia Lai and Kon Tum provinces of Viet Nam, forested areas are being progressively transformed to agricultural land planted with industrial crops such as cassava, rubber and coffee. Comparing the annual growth rate of various crops in the Upper Sesan catchment (including districts in Gia Lai and Kon Tum) between 2005 and 2009 revealed that cashew, rubber, cassava and black pepper were the most popular (Table 1).

Table 1: Annualised growth (2005-2009) and total area (ha) of the main crops in the Upper Sesan catchment (Viet Nam). (Source WASI 2011)

	Annualised Growth rate (2005-2009) Upper Sesan	Annualised Growth rate (2005-2009) Gia Lai Province	Annualised Growth rate (2005-2009) Kon Tum Province	Total Area (ha) – Upper Sesan 2009
Irrigated Rice	3.9	4.8	3.0	28,584
Rainfed Rice (upland and lowland)	-5.8	-10.4	-2.5	15,433
Cassava	8.9	12.0	7.6	53,404
Maize	-7.3	-14.5	-4.0	11,016
Coffee (Robusta)	0.1	0	0.8	57,133
Rubber	8.7	3.6	17.0	81,307
Black Pepper	9.6	10.9	-3.1	1,110
Cashew	11.4	15.6	-27.4*	8,568

* the area of cashew culture in Kon Tum was less than 900 ha in 2005 and less than 250 ha in 2009

The main crops in terms of area planted were rubber, coffee (C. canephora) and cassava. The area planted to rubber and cassava expanded rapidly in Kon Tum and Gia Lai, with an 8.7 percent annual growth rate. Coffee was stable over this period, with little change in the large areas planted with the crop. Most of the coffee, black pepper and cashew crops in the Upper Sesan catchment were planted in the Gia Lai province, mainly due to soil quality and the presence of Ferralsol. Despite the large annual increases in the cultivation of cashew and black pepper, they remained minor crops planted to less than 10,000 ha.

The rapid growth of industrial crops has shifted the cultivation away from rainfed rice (in the uplands and lowlands) and maize towards cassava and rubber. Forested areas on slopes and hills have also been converted to farms planted with these industrial crops. Cassava expansion has also happened on flat terrains such as plains and river terraces that were traditionally used for lowland rainfed rice and irrigated rice, and on the drawdown areas of the Yali reservoir that were traditionally planted with maize.

Cassava was less common in the Gia Lai Province and represented only 11 percent of the agricultural land there. In comparison, 30 percent of the cultivated area in Kon Tum province was planted with the crop.

[5] (see Annex B for Land Use Map 2003)

On the slopes of the Kon Tum province, experts have observed that rubber is progressively replacing[6] cassava. That is because cassava yields have declined due to soil erosion after just two to three years of culture, making the slopes more adapted to rubber (Provincial DARD Kon Tum, pers. com). Recently, a new perennial crop, Litsea glutinosea, has become popular in Kon Tum and has been replacing cassava on steep slopes.

The Upper Sesan is not very favorable for agriculture since the soils are mainly Acrisol and the terrain is not very flat. Even so, irrigated surface agriculture is well developed, with more than 28,000 ha planted to irrigated rice in both provinces. A multitude of small irrigation schemes ranging from 10 ha to 100 ha and associated with small-scale reservoirs (run-of-water reservoirs) are spread out along the region[7]. Irrigation allows for a double rice crop, with a first crop planted in the dry season (January to April) and a second crop planted in the rainy season from (July to October). The rice yield ranges from 5 tons per ha to 7 tons per ha (source: WASI).

4.2 LOWER SESAN CATCHMENT

Information on the agriculture sector of the Lower Sesan catchment in Cambodia is scarce and statistics about cultivated areas shows wide inter-annual variations. Trends in agricultural production and land use cover are difficult to discern.

Between 1980 and 2007, the average annual expansion of cash crops (maize, cassava, soya, peanut) happened at a rate of 9 percent, while the average growth rate for rice was 6.4 percent, according to Ministry of Agriculture, Forestry and Fisheries statistics. The additional arable land available for rice cultivation was greater than 50,000 ha (MRC 2009).

Table 2: Cultivated area of the main crops in Ratanakiri and Stung Treng provinces in 2008. (source: Provincial Data Book, 2009; Provincial Department of Agriculture 2010)

	Stung Treng (ha)	Ratanakiri (ha)
Irrigated Rice – Dry season	0	35
Irrigated Area – Rainy season	0	4,350
Rainfed Rice (upland and lowland)	4,819 (Sesan District)	26,392 (Lowland) 22,116 (Upland)
Cassava	6,000	3,084
Soya	1,932	24,533
Peanuts	0	19,321
Rubber	910	21,276 (2010)
Cashew	1,760	20,170 (2010)
Coffee	0	100

In the Stung Treng province of the Sesan district, 80 percent (25,773 ha) of the cultivated area was planted with lowland rainfed rice. Cassava (6,000 ha) and soya (1,932 ha) were the main cash crops, with a 600 percent increase in cassava cultivation and a 300 percent increase in soya cultivation

[6] Conversion of cassava crops to rubber plantation takes 3 to 4 years of intercropping
[7] The number of small scale irrigation is important and difficult to update. It was impossible to integrate it to the GIS analysis.
(see Annex B for Land Use Map 2003)

observed between 2006 and 2008 (Table 2). Maize cultivated area decreased by 50 percent over the same period. Cashew (1,750 ha) and rubber (910 ha) cultivation are more recent and of minor importance. Market-oriented agriculture production was driven by private concessions, which are now investing primarily in cassava.

In the Ratanakiri province, forested area decreased by 40 percent between 1997 and 2005. Up to 2005, farmers preferentially planted rainfed rice. After 2005, they preferred cashew and rubber and planted more than 20,000 ha to these crops. Overall, the Ratanakiri province is more oriented towards agriculture than Stung Treng, with larger areas planted to cash crops such as soya, peanuts, cashew and rubber.

Lowland rainfed rice and some irrigated rice varieties are planted in Ratanakiri on the alluvial terraces along the Sesan River, downstream of the proposed Lower Sesan 3 hydropower dam. Cassava production in Ratanakiri is less important than in the Stung Treng province and only 4,558 ha is planted to the crop. The cultivation of annual cash crops such as peanuts and soya expanded by 250 percent and 140 percent, respectively, between 2007 and 2008.

In contrast to the Upper Sesan catchment where irrigation is well developed, the Lower Sesan catchment is mostly rainfed. Only four irrigation schemes function in the Ratanakiri province, mostly as supplements in the rainy season. There are no irrigation schemes in Stung Treng province. Fewer than 50 ha are irrigated in the Lower Sesan catchment in the dry season .

The few irrigation schemes that exist supply water in the rainy season and are located on the Sesan River's tributaries. They are small scale, able to irrigate less than 200 ha on average (PDOWRAM of Stung Treng and Ratanakiri cited in MRC 2011). Cambodian authorities are planning to rehabilitate some of these irrigation projects to supply the flat, fertile areas along the Sesan River and its tributaries. The schemes could cover an estimated 1,188 ha in the dry season and 4,011 ha in the rainy season.

Seven potential irrigation projects have been identified within the Sesan catchment fed by the Sesan River, and in the O Kansieng and Prek Lamang sub-catchments, according to documents from MRC (2009). The projects have the potential to irrigate 7,500 ha, 5,000 ha and 27,000 ha, [THIS IS UNCLEAR. YOU MENTION 7 PROJECTS BUT ONLY 3 IRRIGATION POTENTIALS] respectively. Only two of them can supply water in the dry season.

4.3 SEASONAL CALENDAR, YIELD AND WATER REQUIREMENTS

The various annual and perennial crops planted in Viet Nam and Cambodia, together with their growing seasons and yields are presented in Table 3.

Table 3: Crops, cultural calendar and average yield in the Sesan catchment (source: field visit; WASI; Nesbitt 2005; Mainuddin & Kirby 2009; Provincial Data Book 2009 Ratanakiri & Stung Treng)

Crops	Country	Growing Season	Growing Period (days)	Yield (t/ha)
Annual Crops				
Lowland Rainfed Rice	Vn; Cbd	June/July to Oct/Nov	130	1.1 – 2.3 3-4
Upland Rice	Vn; Cbd	May/June to Sept/Oct	130	0.8 – 3.0
Dry Season Rice	Vn	Dec – March	<115	5 – 7
Cassava	Vn; Cbd	March/April – Dec/Jan	270-330	5 – 15
Maize	Vn; Cbd	Apr/May – Aug/Sept	100-120	1 – 4.5

Soya	Vn;Cbd	July/Aug – Dec	120	1.5 – 3.0
Peanuts	Cbd	July/Aug – Dec	120	1 – 1.6
Perennial				
Rubber	Vn; Cbd			1.5 – 2.5 (dry latex)
Coffee (*C. canephora*)	Vn; (Cbd)			2 – 6 (clean beans)
Cashew	Cbd (Vn)			0.3 – 1.5
Black Pepper	Vn			2 – 7
Litsea Glutinosa	Vn			15m^3 (6 – 7 years)

Agriculture is dominated by rainfed culture, which limits the cultural calendar to the rainy season; only rice and coffee are irrigated. Crop yields are usually lower in Cambodia than in Viet Nam, primarily because Cambodian farmers use fewer inputs and have less technical knowledge than their counterparts in Viet Nam.

Table 4 summarises the water requirements for the main irrigated crops in the Lower Mekong basin, as well as for coffee in Viet Nam, according to the Western Highlands Agro-Forestry Scientific and Technical Institute in Viet Nam. We report only the water requirements in the dry season since this is the critical period for crops, as mentioned by Nesbitt (2005).

Table 4: Water Requirement (Nesbitt 2005; WASI)

Crop	Water Requirement (m^3/ha)	Critical Period for irrigation (month)	Critical Period for irrigation (m^3/ha)
Dry Season Rice	2,074/ month	3.5	7,258 m^3/ha
Supplementary irrigation – Lowland Rice	4,000/ha (recession rice)	Variable	4,000 – 6,000 m^3/ha (for the entire period) Clay soil -105 days*
Coffee (*C. robusta*)	2,000 to 7,000 m^3/ha	4	1,500 to 2,000 m^3/ha (WASI)

** Paradis Someth Pers. Com.*

These data will be used in Section 6 to estimate the water requirements for different scenarios of irrigation development in the Sesan catchment.

5 LAND USE SUITABILITY FOR THE DIFFERENT CROPS WITHIN THE CATCHMENT – WHAT ARE THE SUITABLE OPTIONS?

5.1 LAND USE SUITABILITY IN THE SESAN CATCHMENT

Based on agricultural trends, we selected the main crops cultivated in the catchments and tested their potential for expansion using the LUSET model. The results are shown in Annex D. We tested cashew, black pepper, cassava, rubber, coffee, groundnuts, lowland and upland rice and maize. We assumed that the area of only one crop can expand at a time, and multiple crops do not all expand simultaneously. In addition, the potential areas for expansion presented in the figures and table do not take into account other land uses, such as urban land use and roads. They also do not include the official planned uses for the land in the provinces.

All the crops we tested showed great potential for expansion in the catchment. If we included only the land we assessed as moderately or highly suitable for agriculture, there was room to expand both perennial and annual crops, as presented in Table 5 and Figure 7.

Although cassava was already a prominent crop in the Upper Sesan basin, it had the highest potential for additional growth in both countries. In the Ratanakiri province of Cambodia, more than 100,000 hectares (Annex D – Figure 13) could be converted to cassava plantation. It was also possible to expand cassava cultivation temporarily, using it as an interim crop before planting perennials such as rubber, cashew or coffee. As has been observed in Kon Tum Province, cassava farms may be replaced by rubber within three years of intercropping.

In Cambodia, lowland rice cultivation could be expanded on heavy clay soils (Nitisol and Vertisol) and along the Gleyic Acrisol soils of the Sesan River (Figure 6; Annex D- Figure 18). Upland rice did not have much potential for expansion in Cambodia (Annex D- Figure 19). We could not do a similar comparison in Viet Nam between upland and lowland rainfed rice because we lacked detailed statistics.

Maize culture was well adapted to Upper Sesan catchment, according to our data (Annex D – Figure 17).

The results could be further optimised by using different cropping calendars in Upper and Lower catchments.

Table 5: Potential for expansion of difference crops within the Sesan catchment, in hectares, between existing land use (2010) and the results of LUSET model.

	Cambodia Lower Sesan	Viet Nam Upper Sesan	Sesan Catchment
Annual Crops			
Cassava	167,894	262,159	430,053
Upland rice	4,277	n.a	n.a
Lowland rice	57,560	n.a	n.a
Peanuts	104,664	124,574	229,239
Maize	6,259	70,752	77,011
Perennial Crops			
Black Pepper	170,469	183,352	353,821
Cashew	119,868	780,740	900,608
Coffee (Robusta)	150,345	284,523	434,868
Rubber	23,206	72,049	95,256

Of the perennial crops, rubber was most restricted in its range due to temperature and rainfall limitations. Moderately suitable areas for rubber were available in both Cambodia and Viet Nam (Annex D – Figure 19), with a slightly better potential for expansion in Viet Nam.

Robusta coffee fared better than rubber since it faced fewer restrictions due to temperature. The Kon Tum, Gia Lai and Ratanakiri provinces, which are rich in Ferralsol soils, had regions that were moderately or highly suitable for coffee culture.

Cashew and black pepper are robust, undemanding crops that had high potential for growth in the catchment (Annex D – Figures 12, 13). Cashew cultures were more adapted to mountainous and steep areas while black pepper was better in areas with higher temperature and low rainfall. However, there was relatively little commercial demand for cashew and black pepper, which made it unlikely the crops will expand much.

Our estimates of land suitable for coffee, black pepper and cashew cultivation in Viet Nam was much higher than the estimates used by provincial land use planners.

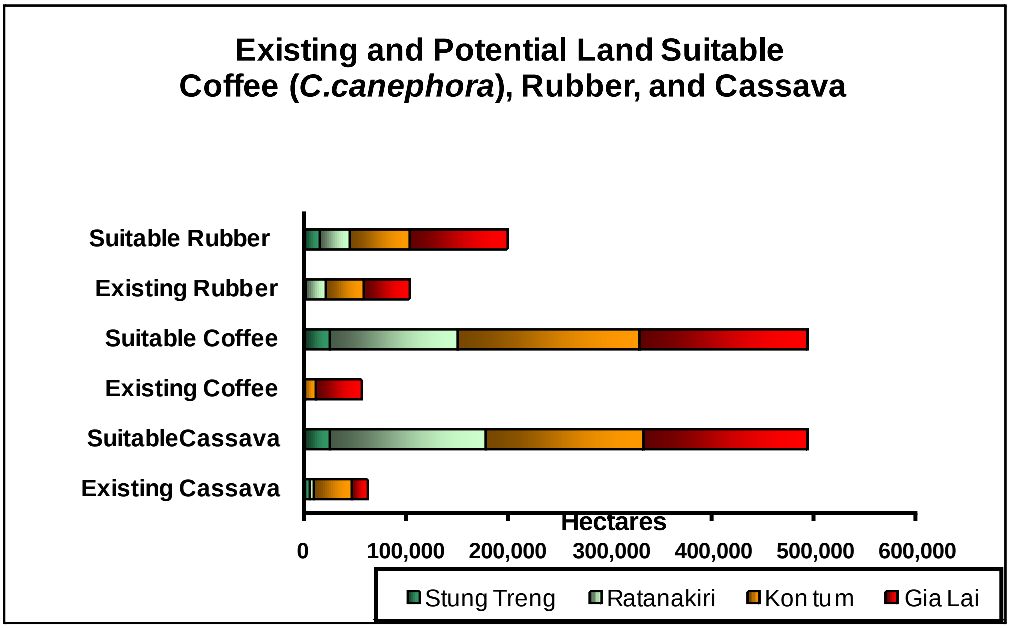

Figure 7: Existing and potential land suitable for coffee, rubber and cassava in the Sesan catchment, according to administrative boundaries (WASI 2011; Provincial Data Book 2009 Ratanakiri & Stung Treng)

The results presented are a coarse analysis of the suitability of the land for various crops, and do not represent the actual land use planning in each country. They also do not reflect the market demand for agricultural production. In addition, we did not model the land suitability for a perennial tree, Litsea Glutinosa, which has become popular in Kon Tum province.

5.2 PLANNED RESERVOIR – WHAT TYPE OF AGRICULTURAL LAND WILL BE SUBMERGED

In this section, we investigate the impact of reservoir development on potential agricultural land. We studied the Lower Sesan catchment where two hydropower reservoirs are planned: the Lower Sesan 2 in the Stung Treng province and the Lower Sesan 3 in the Ratanakiri province.

Both reservoirs are large, with estimated area at full supply of 414 km2 (41,400 ha) for the Lower Sesan 3 and 394 km2 (39,400 ha) for the Lower Sesan 2[8]. The reservoirs are located on flat or undulating areas of limited steepness. The agro-ecological zones that would be submerged by the dams are terraces covered partly in fertile alluvial soil (Nitisol and Vertisol) and partly in less-fertile Acrisol.

[8] for Lower Sesan2 reservoir, only a part of the reservoir is located in the Sesan catchment and more than 50 percent of the reservoir is located on the Srepok catchment.

Table 6: Area (ha) of highly and moderately suitable land for different crops that will be submerged by planned Lower Sesan 2 hydropower reservoir and Lower Sesan 3 in the Sesan catchment

	Lower Sesan 2*	Lower Sesan 3
Lowland Rice	>700 ha	>19,000 ha
Cassava	>800 ha	>21,000 ha
Maize	>500 ha	>5,500 ha
Rubber	>800 ha	>6,121 ha
Coffee	>800 ha	>7,000 ha
Peanuts	>200 ha	7,000 ha

**Sesan catchment only*

The land to be submerged by Lower Sesan 3 reservoir is more suitable for agriculture development compared to land to be submerged by Lower Sesan 2. Lower Sesan 3 will submerge more than 19,000 ha of land suitable for rainfed lowland rice (Table 6). Of this area, about 13,000 ha is highly suitable for lowland rice production, which is more than 80 percent of the 16,000 ha area cultivated with lowland rainfed rice in the Ratanakiri province. Yet, as of 2003, almost none of the area was planted with rice. The submerged area could also be planted, to a lesser extent, with cassava, rubber, maize and coffee (Table 6).

The land to be submerged by Lower Sesan 2 reservoir is less suitable for cultivating the crops we tested (the potential is less than 1,000 ha), but the area is still key to agriculture production in the Stung Treng province. Rubber could be planted on more than 800 ha of the catchment, adding to the current rubber plantation area in the province of about 1,000 ha.

Comparing Lower Sesan 3 with Lower Sesan 2, the former reservoir will have more impact on agriculture development since it will submerge land that has the greatest potential for both cash and grain crops.

6 POTENTIAL FOR IRRIGATION AND WATER REQUIREMENT

6.1 LAND USE SUITABILITY FOR DRY SEASON RICE AND SUPPLEMENTARY IRRIGATION RICE

We estimated the potential for irrigation in the catchment using a GIS approach, which included a land use suitability model for irrigated rice, the steepness of the terrain, and the distance to the river.

We selected a buffer area along the main river[9] within two modalities: 1 km and 5 km[10] on each bank of the river, with the slope of the terrain between 0 and 2 percent. These are regions where irrigation could theoretically be developed. Using the LUSET model, we analysed flat terrains that are between 1 km and 5 km from the river for their suitability for growing irrigated rice. We overlaid the two layers to identify land suitable for double rice cropping, where both dry season and rainy season rice can be planted.

[9] The major rivers are: Sesan and Prek Liang (Cambodia); Dak Hodrai; La Gra; Dak Pokong; Dak Ha; Dak Nghc; Dak Uy; Dak Ta Kam; Dak Poko in Viet Nam.

[10] The second modality (5 km) was decided based on local expert knowledge, representing the higher case scenario for irrigation scheme development, while 1km represent an average distance from the water source to design an irrigation scheme.

We included in our model rainy season or supplementary irrigation, which is the main type of irrigation currently available in the Lower Sesan catchment. We performed the analysis only on the Sesan River's tributaries, which can be used for irrigation in the rainy season.

When we considered a buffer of 1 km, the land suitability for irrigated rice was limited in the Lower Sesan catchment (Figure 8 and Table 7). About 10,900 ha of land were marginally suitable for irrigated rice, and 1,400 ha were moderately or highly suitable. In contrast, the Upper Sesan had more than 23,000 ha of land moderately or highly suitable for irrigated rice[11].

Table 7: Moderately and highly suitable area for irrigation within the Sesan catchment

	Lower Sesan Catchment (ha)	Upper Sesan Catchment (ha)	Total Catchment (ha)	Submerged by planned hydropower* (ha)
1 km Buffer				
Highly suitable	46	2,108	2,153	2,690
Moderately suitable	1,428	23,159	24,587	1,411
5 km Buffer				
Highly suitable	4,520	9,697	14,217	10,710
Moderately suitable	22,625	242,868	265,493	6,471

*we take into account only the planned reservoir Lower Sesan 2 and 3.

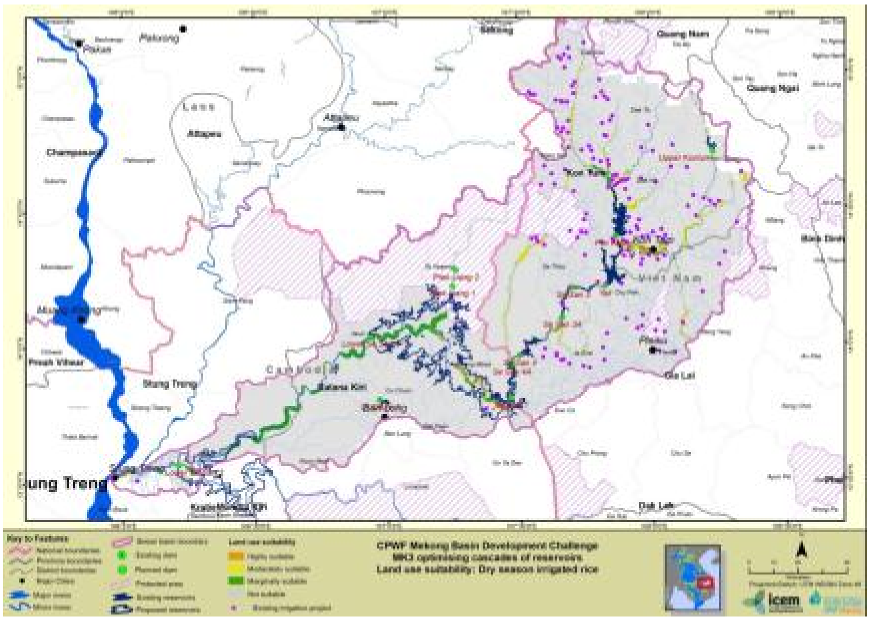

Figure 8: Potential dry season irrigated area in the Sesan catchment, within 1 km distance from the main rivers in the catchment

[11] Those area does not include the area submerged by future hydropower reservoir.

When we applied a buffer of 5 km, the area moderately or highly suitable for irrigated rice in the Lower Sesan catchment increased to more than 27,000 ha (Table 7 and Figure 9). Similarly, the area in the Upper catchment increased to more than 250,000 ha.

The Lower Sesan 3 reservoir would submerge most of the suitable area for irrigated rice in the Lower Sesan catchment. In the absence of the reservoir, the area highly suitable for dry season rice in Cambodia would be larger than the area in Viet Nam.

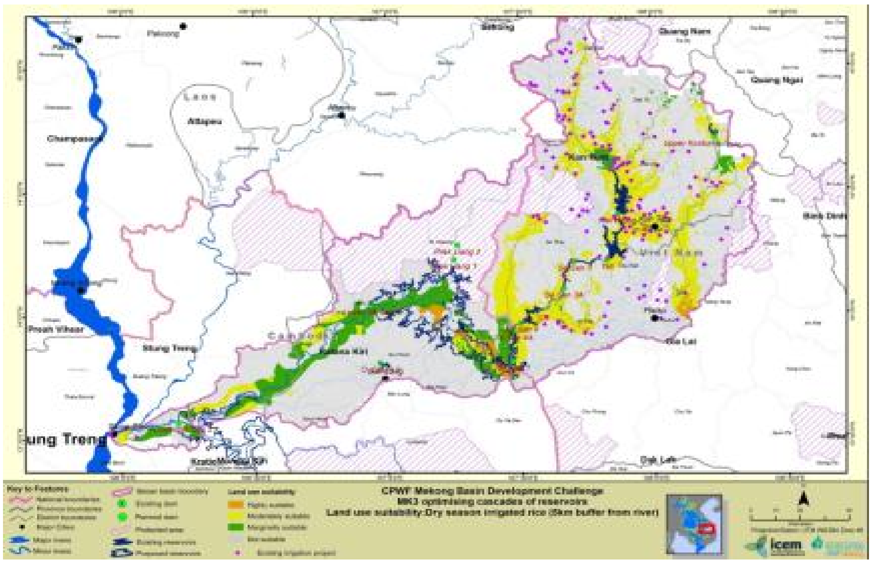

Figure 9: Potential dry season irrigated area in the Sesan catchment within 5 km from the main rivers

These values for potential irrigated area are very high and are only estimates due to the differences in the micro-topography, but they give an idea of the potential for irrigated rice development.

The locations of exiting irrigation schemes are presented in Figures 8 and 9. A buffer of 1 km does not include most of these schemes, which are located along tributaries and probably represent small-scale irrigation reservoirs used for dry season rice.

A 5 km buffer includes more of the existing schemes. We could not subtract these functioning irrigation schemes from our GIS analysis because of the large numbers of these projects in the Upper Sesan catchment.

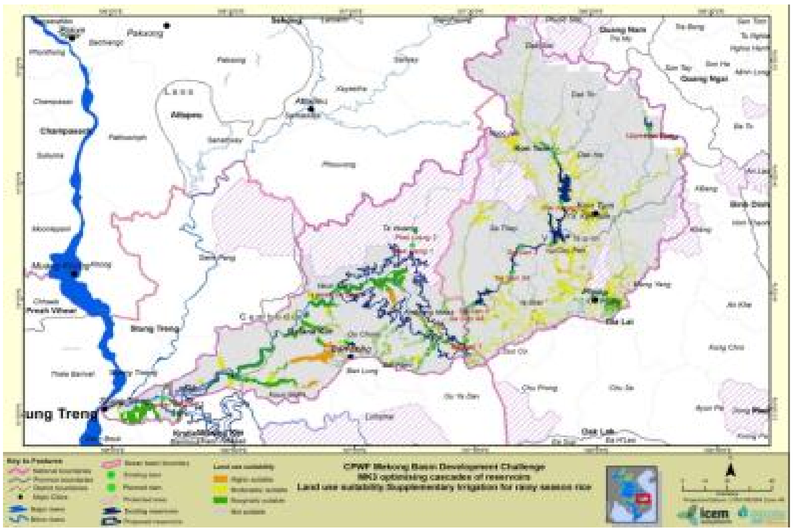

Figure 10: Potential rainy season irrigated area in the Sesan Catchment within 1 km from the Sesan river tributaries

The potential area for supplementary irrigation in the rainy season (1 km buffer from tributaries) is presented in Figure 10. More than 100,000 ha in Viet Nam are moderately suitable for supplementary irrigation derived from the Sesan River tributaries, and 10,000 ha are highly suitable. Some of these areas are already irrigated.

The potential is much less in the Lower Sesan catchment of Cambodia. Some highly suitable areas for supplementary irrigation occur in the Ratanakiri province (more than 9,000 ha). And moderately suitable areas (more than 12,000 ha) occur in the Ratanakiri and Stung Treng provinces. These areas are located in sub-catchments (tributaries) and can be counted as additions to dry season irrigation. As such, they increase the potential for irrigated agriculture by operating only in the rainy season.

6.2 DOWNSTREAM IRRIGATION

We studied the impact of a cascade of reservoirs along the Sesan River and estimated the potential dry season cultivation areas for existing and planned reservoirs. We considered only the downstream irrigated areas for each reservoir and did not include the irrigation potential of the reservoirs' drawdown area in our analysis. We selected only those areas that are moderately and highly suitable for agriculture that occur within the 1 km or 5 km buffer from the river.

Table 8: Potential irrigated area (ha) downstream each reservoir in Viet Nam. The estimated areas are the sum of the moderately and highly suitable land for dry season rice.

	Upper Kontum	Pleikrong	Yali	Sesan 3	Sesan 3 A	Sesan 4	Sesan 4A
Buffer 1 km	8,343	78	0	2	1,681	203	636
Buffer 5 km	>50,000	2,817	1,209	559	10,340	3,474	6,212

The Upper Kontum reservoir showed great potential for irrigating the plains downstream, around Kon Tum city (Table 8). However, much of this area is already developed with several irrigation schemes, and a similar observation can be made about the areas downstream of the Pleikrong reservoir. We also did not take into account urban development, which might overlap some of the suitable irrigated areas.

When the buffer was set at 5 km, the potential for irrigation was large for the Upper Kontum, Pleikrong, Sesan 3A, Sesan 4 and Sesan 4A reservoirs. But these figures have to be interpreted with caution since micro-topography variations will probably reduce the area available for irrigation. In addition, the population density in these areas is low, especially around Sesan 3A, Sesan 4 and Sesan 4A (less than five inhabitants per ha) and irrigation development is probably not a priority for local authorities. In areas where agriculture is not well developed, the land is covered in forest and grassland.

It would be most realistic to expect irrigation to develop downstream of the Upper Kom Tum and Pleikrong reservoirs, where density of population is higher, irrigation already existing and agriculture well developed.

Table 9: Potential irrigated area (ha) downstream of each reservoir in Cambodia. The estimated area takes into account moderately and highly suitable land for dry season rice.

	Sesan 1	Lower Sesan 3	Lower Sesan 2
Buffer 1 km	2,000	542	594
Buffer 5 km	15,000	9,329	2,033

At a 1 km buffer from the river, the potential for downstream irrigation was low in the Lower Sesan catchment (Table 9). The most suitable areas were located downstream of the planned Sesan 1 reservoir, but this land would be submerged by the Lower Sesan 3 reservoir.

Downstream of the Lower Sesan 2 and Lower Sesan 3 reservoirs, the terrain presented less than 1,000 ha of moderately suitable areas. When a 5 km buffer was considered, there was greater potential for agriculture, with the Lower Sesan 2 presenting 2,000 ha of suitable land and the Lower Sesan 3 presenting 9,000 ha. It is important to note that most of the suitable areas for irrigation downstream of the Lower Sesan 3 would not be submerged by Lower Sesan 2 reservoir.

These areas are not densely populated in Viet Nam, with less than two inhabitants per ha. Rainy season irrigation infrastructure is already present downstream of the Lower Sesan 3 and it could be modified to incorporate dry season irrigation as well.

6.3 WATER DEMAND

If we considered a realistic scenario for irrigation development within a 1 km buffer from the river, we could broadly estimate the water demand for dry season irrigation as well as for supplementary irrigation in the rainy season based on previous studies of water requirements for rice culture (see section 4.3, Table 4).

We considered a dry season rice crop that lasts for 105 to 120 days, with an average irrigation period of 3.5 months. The supplementary irrigation in the rainy season would be variable. We used the average water requirement given by a local expert of 5,000 m3 per ha per season

A simple calculation based on the crop water requirements and potential irrigated area gave us an estimate of the water needed from various reservoirs in the dry season (Figure 11).

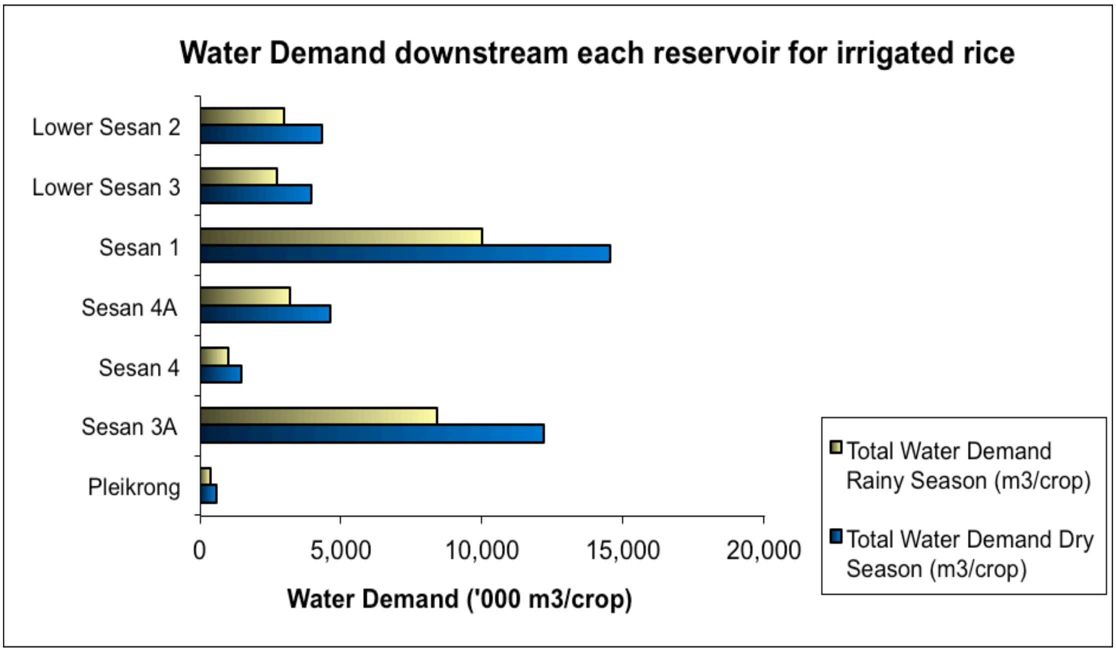

Figure 11: Water demand downstream of existing and planned reservoirs in the Sesan catchment for dry and rainy season rice irrigation, based on a 1 km buffer from the river.

We do not show in Figure 12 the water demand downstream of the Upper Kontum reservoir. In the dry season, the demand was greater than 60 million cubic metres, and in the rainy season, the demand was greater than 41 mcm. Similarly, in the irrigated areas downstream of Sesan 3, the demand was 0.014 mcm and 0.01 mcm in the dry and rainy season, respectively.

For the Sesan 3A and Sesan 1, their active water storage capacities were less than the water demand for irrigation.

For Sesan 3A reservoir, the water demand for downstream irrigation was two times larger than the active storage (4 mcm) in the rainy season and three times higher in the dry season. Taking into account the active storage of the reservoir and the estimated water demand in dry season, the maximum irrigated area downstream was only 551 ha instead of the 1,681 ha previously estimated. In this scenario, the reservoir was used for both irrigation and hydropower generation.

Similarly, active storage of the Sesan 1 reservoir was a limiting factor for irrigation development downstream. Irrigation fell by almost five times to 413 ha instead of the 2,000 ha estimated in our land use suitability analysis.

In the case of the Upper Kontum and Sesan 4A, the water demand for dry season irrigation was 50 percent and 61 percent of the active storage, respectively.

In the case of a cascade of reservoirs, water demand in the dry season was less than 2% of the active storage.

When we considered irrigation development within 5 km of the river, the water allocated for irrigating dry season rice represented 1 percent of the active storage of the Yali reservoir, 10 percent of the Sesan 4, and 21 percent of the Lower Sesan 3 (Table 10).

Table 10: Water demand downstream of existing and planned reservoirs in the Sesan catchment for dry and rainy season rice irrigation, based on 5 km buffer from the river.

	Upper Kontum	Pleikrong	Yali	Sesan 4	Lower Sesan 3	Lower Sesan 2
Irrigated area (ha)	16,800	2,817	1,209	3,474	9,329	2,033
Water demand in the dry season(mcm)	122	20.5	9	25	68	15
Active storage (mcm)	122	948	779	264	323	379
Ratio Water demand/Active storage	100	2.2	1.1	9.5	21	4

In the case of the Upper Kontum reservoir, the active storage limited the irrigable area and only 16,800 ha could be irrigated if the entire active storage was used for irrigation.

The Sesan 1, Sesan 3, Sesan 3A and Sesan 4A reservoirs were not designed as storage reservoirs and therefore, it is unlikely they can be used to irrigate large areas. But these reservoirs can provide water to downstream reservoirs, for electricity production and irrigation.

For Sesan 1, Sesan 3, Sesan 3A and Sesan 4A, the potential irrigated areas were limited by the active storage capacity of the reservoirs. The maximum downstream irrigated areas for these reservoirs was 413 ha (Sesan 1), 524 ha (Sesan 3), 551 ha (Sesan 3A) and 1,033 ha (Sesan 4A), respectively, assuming the reservoirs are operated for irrigation as well as hydropower generation. Sesan 3, Sesan 3A and Sesan 4A are used to regulate the releases of reservoirs that are further upstream. For example, Sesan 4A regulates the releases of Sesan 4.

Given these results, it appears that reservoirs should not be treated as independent units, even for irrigation purposes. The management of the water for hydropower and irrigation has to take into account the entire cascade of reservoirs to optimize water supply and the multiple uses of the water.

6.4 SCENARIOS FOR THE MANAGEMENT OF THE CASCADES OF RESERVOIR

It is interesting to study reservoirs with limited active storage to understand their implications for reservoir cascades. Such reservoirs are not designed for storage and are unlikely to provide water to irrigate large areas. Their storage capacity is used only as a buffer for short-term peak energy demands. Using the reservoir for irrigation would limit this buffer and compromise the reservoir's ability to generate hydropower. Such dams can, however, provide water to reservoirs downstream for irrigation and electricity generation.

The operation of these smaller reservoirs depends largely on the dams upstream, which are located higher in the catchment. The Sesan 3A is dependent on the releases from Yali, and the Sesan 1 is dependent on the releases of Sesan 4. The irrigation capacity of Sesan 3A will depend on the releases from Yali and Sesan 3, and Sesan 1 will depend on releases from Sesan 4 and Sesan 4A. This illustrates the importance of managing dams as cascades rather than individually.

We assumed in this study that the storage of water in one reservoir is of limited importance; it is more crucial to study the water in the entire system and learn to manage it. Therefore, we investigated whether there is enough water in the entire Sesan catchment to irrigate all the suitable areas at the right times of the year.

In the dry season from December to March or April, the entire catchment would face water demand for irrigation simultaneously, which raises the following questions:

- Is there sufficient water available in the system to irrigate all the potential agricultural areas? If not, what are the alternatives for optimal management?

- What will be the best management options to optimise hydropower production and water allocations for irrigation?

- Would we need to coordinate the cropping calendar across the catchment in order to optimise water use and stretch out the demand for water over a longer period?

- In the rainy season from May to October, could hydropower reservoirs be used for irrigation? Or will irrigation jeopardise hydropower generation and reservoir impoundment?

These questions were answered using a hydrological model that integrates the use of the reservoir for irrigation. We formulated four scenarios based on the different levels of irrigation development to be tested. For each scenario, we considered rice culture in the dry and rainy season and estimated the potential irrigated areas within a 1 km or 5 km buffer from the river. These scenarios and their corresponding potentials for downstream irrigation are presented in Table 11.

Scenario 1: Limited development within a 1 km zone from the river. Irrigation schemes are developed downstream of the Upper Kontum, Lower Sesan 2 and Lower Sesan 3 reservoirs.

Scenario 2: Moderate development (25% of the potential irrigated area) within a 5 km zone from the river. Irrigation schemes are developed downstream of the Upper Kontum, Pleikrong, Yali, Sesan 3, Sesan 4, Sesan 4A, Lower Sesan 2 and Lower Sesan 3.

Scenario 3: High development (50% of the potential irrigated area) within a 5 km zone from the river. Irrigation schemes are developed downstream of the reservoirs mentioned in Scenario 2.

Scenario 4: Full specific development with 50% of the potential irrigated area estimated within a 5 km buffer from the river downstream of the Yali, Sesan 3, Sesan 4, and Sesan 4A. And full development of the potential irrigated areas downstream of the Upper Kontum, Pleikrong, Lower Sesan 3 and Lower Sesan 2.

The modeling could highlight key periods when water shortages for irrigation and hydropower production may occur. It could also provide a better idea of the need for coordinating cropping calendars, which could help better distribute the water along the catchment.

Table 11: Scenarios for irrigation development in the Sesan catchmnent and potential irrigated area downstream of each hydropower reservoir (hectares)

	Upper Kontum	Pleikrong	Yali	Sesan 3	Sesan 4	Sesan 4A	Lower Sesan 3	Lower Sesan 2
Scenario 1: Limited	8,343						542	594
Scenario 2: Moderate	12,500	700	300	150	900	1,500	2,300	500
Scenario 3 High	25,000	1,400	600	300	1,700	3,100	4,600	1,000
Scenario 4 Full Specific	50,000	2,800	600	300	1,700	3,100	9,300	2,000

Changes to the cropping calendars in the dry and rainy seasons could be tested at a later stage to evaluate their effect on water demand.

The results from these scenarios help evaluate the role of reservoirs such as Sesan 1 or Sesan 3A whose active storage capacities are too limited to provide water for irrigation. The scenarios could also provide information about the dams' dependence on reservoirs upstream.

7 CONCLUSION

The purpose of this study was to scope the Sesan catchment for agriculture potential and evaluate whether hydropower reservoirs can be used for irrigation. The approach simplified the terrain and the local contexts since we used models of land use suitability and rather simple hypotheses for irrigation scheme development. We did not take into account micro-topography and population density. The study was also limited by the availability of data such as climate and soil characteristics in Cambodia. We also purposely limited our study to irrigation development for rice culture, and did not account for other crops.

The agro-ecological zoning approach summarised the diversity of the catchment and highlighted areas with similar characteristics. Zoning gave a rapid assessment of the diversity of agro-ecological zones within the catchment, from the mountain ranges of the Kon Tum Province to the lowland plains of the Stung Treng province. The diversity was reflected in agricultural trends. Viet Nam and Cambodia differed in the types of crops they could support, and in the levels of development of cash crops and irrigation. Both the Upper and Lower catchments showed highly dynamic agricultural expansion driven by market forces.

The use of a land suitability model gave us a better understanding of the potential for different crops in this catchment. But we could not do detailed geo-localised comparisons between the current levels of planting and future potential since detailed land use maps (or agriculture maps) were not available.

The land use suitability analysis showed that hydropower development would submerge some highly valuable land for agriculture, though the dams could be used for irrigation. We showed through a simple calculation that the water required for irrigation would be less than 10 percent of the active water storage in most cases if the schemes are located within 1 km from the river.

This study was limited by data availability and its large scope. The results are broad, but give us an idea of the potential of the reservoirs to be used for multiple purposes. Detailed case studies could further help model the operational rules of the reservoirs to optimise energy production and irrigation.

Further studies could investigate the management of a cascade of reservoirs via modeling in order to optimise the use of the water for irrigation and hydropower generation.

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