# Water Demand Analysis within the Pursat River Catchment

## Fostering Evidence-based IWRM in Stung Pursat Catchment (Tonle Sap Great Lake)

**December 2013**

*Prepared for:*

**Mekong Basin Leader CGIAR Challenge Program on Water and Food**






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# WATER DEMAND ANALYSIS WITHIN THE PURSAT RIVER CATCHMENT

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# ACKNOWLEDGEMENTS

The "*Fostering evidence-based IWRM in the Stung Pursat Catchment (Tonle Sap Great Lake), Cambodia project*" (also known as MK16) was successfully implemented as a result of collaboration between several partners.

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# 1.0 INTRODUCTION

The project, "*Fostering evidence-based IWRM in the Stung Pursat Catchment (Tonle Sap Great Lake), Cambodia*" (also known as MK16) was collaboratively implemented by the Ministry of Water Resources and Meteorology (MOWRAM), Tonle Sap Authority (TSA), Supreme National Economic Council (SNEC), Hatfield Consultants Partnership (HCP), and the Culture and Environment Preservation Association (CEPA) between December 2012 to December 2013. MK 16 is an initiative of the Challenge Program for Water and Food (CPWF), supported by funding from the Australian Aid program.

The project recognized the relationship between research and effective water management, and that conflicts and competition can occur amongst irrigated agriculture, hydropower, domestic water supply and sanitation, fisheries and other stakeholders. In addition, the project understands that strategies are available to translate integrated water resources management (IWRM) into governance practices through improved planning and management of water resources. Integrated planning can lead to multi-purpose storage reservoirs and other infrastructure projects, water allocation systems, and river operations which provide specifically for other uses.

In order to address water resources issues and develop capacities for implementing IWRM, there is a need for better collaboration between sectors and use of scientific data in decision making. Collaborative and informed decision-making rely on better understanding of, and access to quantitative and qualitative research results. Multi-stakeholder Platforms (MSPs) are forums to share and discuss such research outputs with various government sectors and water users.

This report contributes to the Stung Pursat MSP process by providing information about changes in water balance in Pursat. The objectives of the *Water Demand Analysis within the Pursat River Catchment* report are to:

- Present and compare the water balance in the Pursat catchment under two scenarios; a) natural scenario (absence of Dam No. 1, No. 3, and No. 5) and b) dam scenario (presence of Dam 1, 3, and 5); and
- Apply and critique the usefulness of the ISIS model for flood simulation in the Pursat catchment.

The methodology consisted of the following steps:

- Rainfall-runoff modeling of 19 nodes in the Stung Pursat basin for the period (1992-2011) using the semi-distributed model Unified River Basin Simulator (URBS);
- Computation of basin water balance, using results generated by URBS as inputs into a simplified excel spreadsheet calculator developed by JICA (2013);
- Application of the model IQQM to verify basin water balance computations; and
- Use of the ISIS model to determine areas in the catchment prone to flooding.

Water balance for Stung Pursat basin was assessed based on updated information related to:

- Water demands for irrigation and other purposes;
- River runoff taking into account the three dam development projects (Dams No. 1, 3, and 5); and
- Available water used by existing and planned water resources facilities and irrigation systems in the basin.

# 2.0 ENVIRONMENTAL SETTING

## 2.1 PHYSIOGRAPHY

The Stung Pursat river catchment is located in the Pursat province, south of the Tonle Sap Great Lake, and drains an area of 5,955 $km^2$ (Figure 2-1) (Ashwell et.al, 2011). The Stung Pursat river catchment is shared by six districts: Veal Veng, Kravanh, Sampov Meas, Krakor, Bakan, and Kandieng (CNMC, 2012).The river originates in the drier eastern slopes of the Cardamom mountains and flows for approximately 150 km, ultimately draining into the Tonle Sap Great Lake. Two main tributaries, the Stung Peam and Stung Santre (Prey Khong) rivers, flow in a northerly direction and meet the Pursat River just above Bac Trakuon. The drainage areas of Stung Pursat at Bac Trakuon (just below the confluence of the Pursat and the two tributaries) is 4,245 $km^2$ and at the Khum Veal gauging station (farther downstream near the town of Pursat) is 4,596 $km^2$ (CNMC, 2012).

Elevations in the Pursat catchment range between six and 1,717 m above sea level (masl)[1]. More than 75% of the catchment encompasses a hilly terrain, with an elevation greater than 30 masl, and is covered by forested land of varying densities (JICA, 2011). The remaining low-lying land is occupied by agriculture (Figure 2-2).

Major soil types in the Pursat catchment are: Dystric Leptosol and Cambisol in the upper reaches; Gleyic and Plintic Acrisols in the mid-elevation reaches and; Dystric Fluvisol and Dystric Gleysol in the lower elevation reaches (CNMC, 2012) (Figure 2-3).

[1] Elevations referenced to mean sea level based on the Ha Tien datum, Viet Nam

**Figure 2-1 Digital elevation model of the Stung Pursat catchment showing the elevation and network of hydrometeorological monitoring stations (JICA, 2011).**

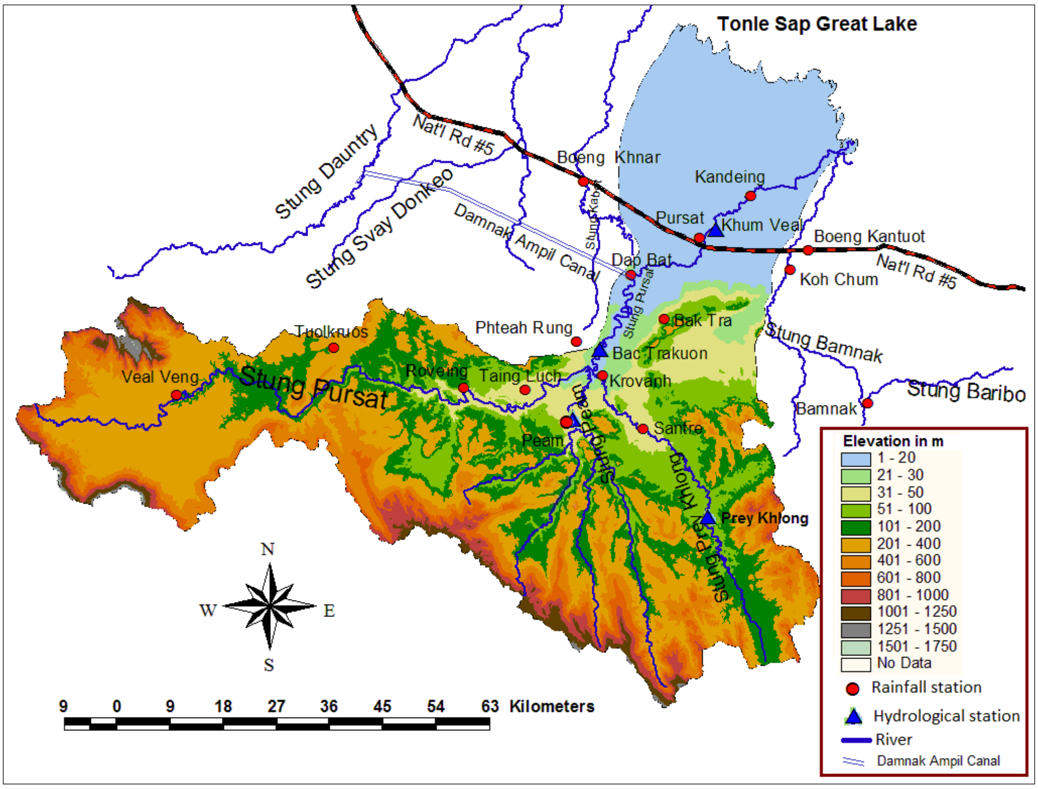
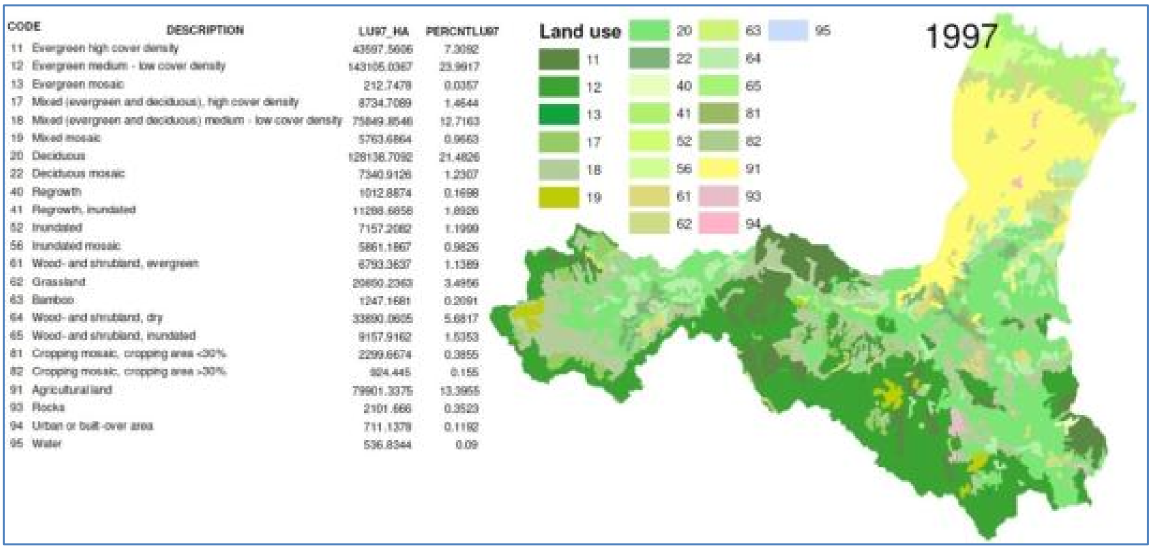
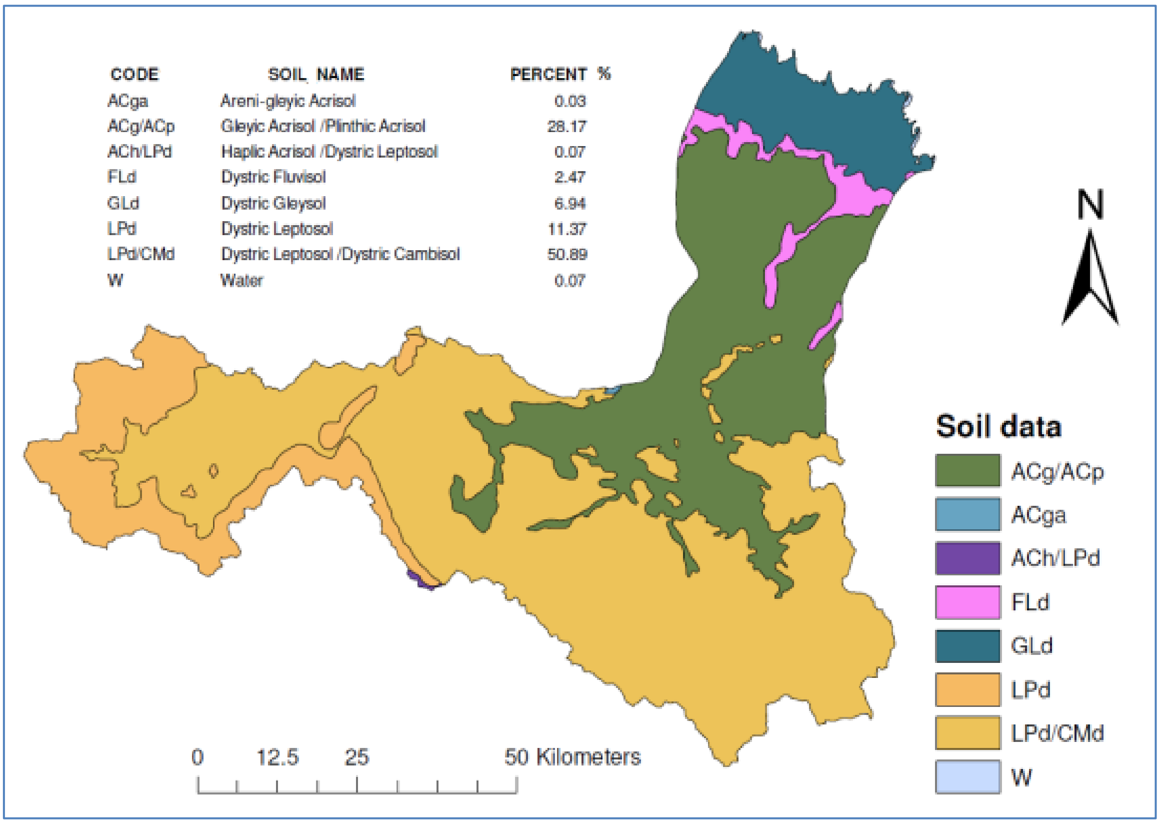



**Figure 2-2 Map of Forest Cover of the Stung Pursat catchment (CNMC, 2012 based on 1993-97 forest covers in MRCS, n.d.).**



| CODE | DESCRIPTION | LU97_HA | PERCNTLU97 |
|---|---|---|---|
| 11 | Evergreen high cover density | 43597.5606 | 7.3092 |
| 12 | Evergreen medium - low cover density | 143105.0367 | 23.9917 |
| 13 | Evergreen mosaic | 212.7478 | 0.0357 |
| 17 | Mixed (evergreen and deciduous), high cover density | 8734.7089 | 1.4644 |
| 18 | Mixed (evergreen and deciduous) medium - low cover density | 75849.8546 | 12.7163 |
| 19 | Mixed mosaic | 5763.6864 | 0.9663 |
| 20 | Deciduous | 128138.7092 | 21.4826 |
| 22 | Deciduous mosaic | 7340.9126 | 1.2307 |
| 40 | Regrowth | 1012.8874 | 0.1698 |
| 41 | Regrowth, inundated | 11288.6856 | 1.8926 |
| 52 | Inundated | 7157.2082 | 1.1999 |
| 56 | Inundated mosaic | 5861.1867 | 0.9826 |
| 61 | Wood- and shrubland, evergreen | 6793.3637 | 1.1389 |
| 62 | Grassland | 20850.2363 | 3.4956 |
| 63 | Bamboo | 1247.1681 | 0.2091 |
| 64 | Wood- and shrubland, dry | 33890.0605 | 5.6817 |
| 65 | Wood- and shrubland, inundated | 9157.9162 | 1.5353 |
| 81 | Cropping mosaic, cropping area <30% | 2299.6674 | 0.3855 |
| 82 | Cropping mosaic, cropping area >30% | 924.445 | 0.155 |
| 91 | Agricultural land | 79901.3375 | 13.3955 |
| 93 | Rocks | 2101.666 | 0.3523 |
| 94 | Urban or built-over area | 711.1378 | 0.1192 |
| 95 | Water | 536.8344 | 0.09 |

**Figure 2-3 Soil map of the Pursat catchment (JICA, 2013b).**




## 2.2 CLIMATE

Climate in the study area is influenced by tropical monsoon systems with distinct wet and dry seasons. The wet season, extending from May to November, is dictated by the southwest monsoon system, and receives approximately 90% of the total annual rainfall (CNMC, 2012). The dry season, extending from December to April, is influenced by the northeast monsoon system, and is characterized by the prevalence of hot and dry air with high potential transpiration demands during the months of March and April (CNMC, 2012).

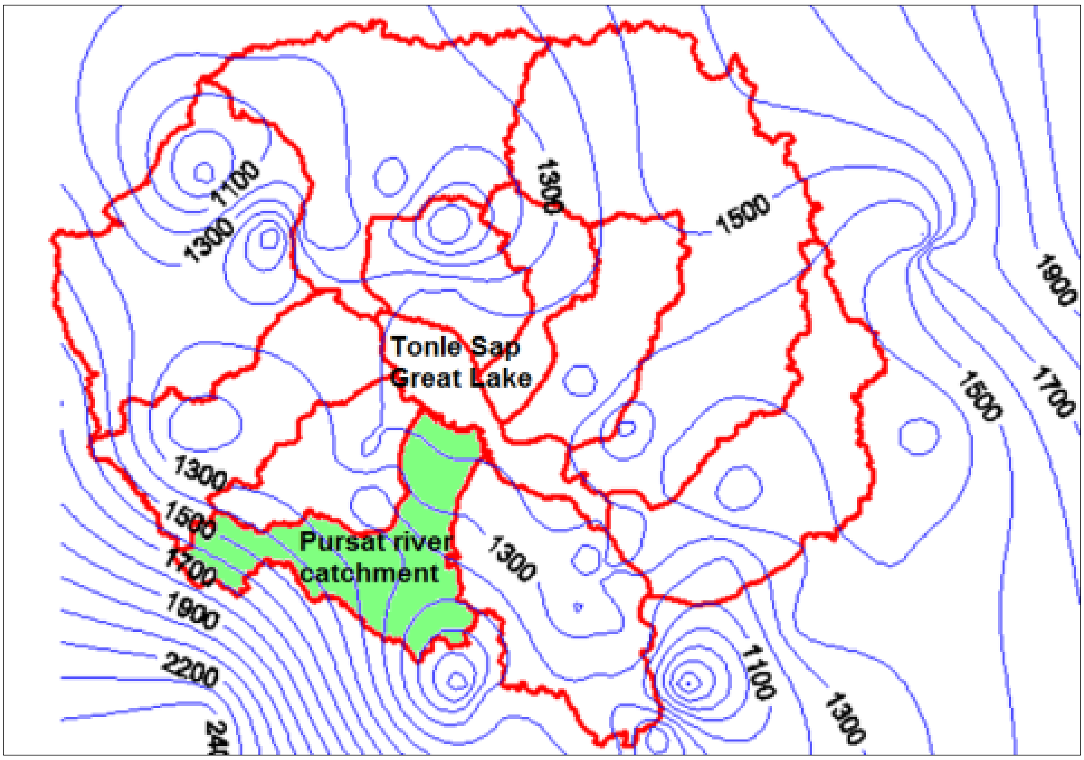
The Elephant and Cardamom ranges act as a barrier to the warm, moisture-laden westerly air masses from the Gulf of Thailand, creating a rain-shadow effect that extends from the eastern slopes of the mountain ranges to the adjacent low-lying lands. This translates into lower precipitation totals ranging between 900 and 1,800 mm of rainfall during normal years, and between 800 and 1,500 mm during dry years. The rain shadow effect is more pronounced during dry years and expands the extant of dry land from small dry sections located around the Tonle Sap Great Lake to a region that encompasses the entire lake area and peripheral low lands (CNMC, 2012).

Rainfall within the Pursat river catchment increases with elevation, but annual totals vary considerably from year to year (JICA, 2013b). The annual average rainfall ranges from 1,200 mm to 1,700 mm (Figure 2-6) (JICA, 2013a).

Maximum 24-hr rainfall throughout the region amounts to approximately 150 mm, and is generated by convective storms (CNMC, 2012). On occasions, a typhoon originating from the South China Sea or the Gulf of Thailand crests the Elephant and Cardamom ranges, bringing to the eastern low lands strong winds and torrential rains CNMC, 2012).

The monthly rainfall distribution for areas around the Tonle Sap Lake is characterized by having two distinct peaks (Figure 3-1 and Figure 3-2). The first peak occurs at the beginning of the wet season, between May and June, as the monsoon rain travels north. This peak is followed by a period of lower rainfall between June and August. The second peak occurs during the months of August and October, and is caused by a southerly shift in the monsoon circulation pattern. This period is characterized by heavy rainfall and widespread flooding conditions CNMC, 2012).

**Figure 2-4 Annual rainfall distribution for the Pursat and Tonle Sap catchments (MOWRAM, 2013).**




There is also substantial variability within the typical bimodal rainfall distribution. This translates into increased difficulties for rice farmers during the first months of the wet season when rainfall is most erratic and early season droughts are common. In addition to the main dry season (January to March or April), and prior to the wettest period of the year (end of August to end of November), there is a small dry season (July and/or early August). This dry period is marked by light showers or even dry spells. Short droughts during this period can last approximately 15 days or more, but on occasion extend to up 60 days after the first monsoon rains end. The cessation of heavy rain at the end of the wet season can also be abrupt and unpredictable (CNMC, 2012).

The temperature regime is consistently high with little daily or seasonal variation. Daily maximum temperatures vary between 36 °C during the hottest months (April-May) and 32 °C during the coolest months (December-January). Daily minimum temperatures vary between 25 °C and 17 °C. The annual average temperature is approximately 28 °C (CNMC, 2012).

Monthly mean relative humidity ranges from 66% in the dry season to 71% in the wet season, with a mean annual of 70% (CNMC, 2012). Table 2-1 summarizes long-term (1992-2011) average climate variables observed at the Pursat weather station.

**Table 2-1 Climate variables at Pursat meteorological station (1992-2011) (JICA, 2012).**

| Climate Components | Unit | Months of the year | | | | | | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| Tmax | °C | 33.3 | 34.5 | 35.7 | 36.3 | 36.1 | 35.3 | 34.7 | 34.4 | 33.2 | 32.4 | 32.1 | 31.6 | 34.1 |
| Tmin | °C | 19.5 | 20.5 | 21.8 | 24.4 | 24.5 | 24.7 | 23.7 | 24.1 | 23.4 | 23.1 | 21.4 | 16.9 | 22.3 |
| Rhmean | % | 65.8 | 63.0 | 64.6 | 65.5 | 67.1 | 68.0 | 67.9 | 71.0 | 73.9 | 75.8 | 74.2 | 71.0 | 69.0 |
| U(x) | m/s | 0.80 | 0.78 | 0.68 | 0.60 | 0.48 | 0.37 | 0.40 | 0.37 | 0.32 | 0.48 | 0.50 | 0.58 | 0.5 |
| n | hour/day | 9.5 | 9.0 | 8.8 | 7.7 | 7.3 | 5.6 | 6.4 | 5.0 | 5.5 | 6.6 | 7.4 | 8.5 | 7.3 |
| Rs | Mj/m².day | 12.2 | 13.7 | 16.2 | 15.6 | 15.6 | 14.6 | 15.4 | 13.7 | 12.9 | 12.7 | 12.8 | 13.8 | 14.1 |
| Pan Evaporation | mm/day | 3.7 | 4.4 | 4.5 | 4.6 | 4.0 | 4.0 | 3.4 | 3.4 | 3.0 | 3.1 | 3.1 | 3.4 | 3.7 |
| ETO | mm/day | 3.0 | 3.4 | 3.8 | 3.8 | 3.7 | 3.4 | 3.5 | 3.2 | 2.9 | 2.9 | 2.8 | 2.8 | 3.3 |

Reference evapotranspiration (ETo) values were calculated using the Penman-Monteith method.

## 2.3 EXISTING AND PLANNED WATER MANAGEMENT INFRASTRUCTURE

Similar to other catchments within the Tonle Sap basin, water resources in the Stung Pursat catchment are increasingly under pressure. This pressure is partly driven by a recent focus on rice exports and partly by an increase in knowledge gaps (i.e. awareness of the issues) in key development sectors (CDRI, 2011). To improve the situation, a series of irrigation (e.g., Damnak Ampil irrigation scheme) and hydropower and irrigation projects are currently under construction, with other projects in the planning stages. These water infrastructure projects often develop from either existing deteriorated infrastructure, a legacy of the Khmer Rouge era, or from previous studies conducted by the Interim Mekong Committee (IMC) (predecessor of the current Mekong River Commission (MRC) (H.E. Veng Sakhon (Secretary of State, MOWRAM) personal communication, March, 2013).

In total, 12 to 17 large and medium-sized existing and planned irrigation areas, including three in the Svay Donkeo river basin (neighboring basin), cover an area of 55,509 ha (JICA, 2013b). A summary of the different projects in the Stung Pursat catchment is presented in Table 2-2 followed by a description of the major projects. The location of all existing and planned water development structures in the Stung Pursat catchment, and a flow chart of these structures are shown in Figure 2-5 and Figure 2-6, respectively.

**Table 2-2 Summary of Water Resources Infrastructure Projects in the Stung Pursat Catchment (JICA, 2013b).**

| Water Resources Infrastructure | Storage Volume (MCM)[1] | Command Area (ha)[2] | Existing | Under Development | Planned |
|---|---|---|---|---|---|
| Dam # 1 | 1,014 | - | | | ✓ |
| Dam # 3 | 25.5 | - | | ✓ | |
| Dam # 5 | 24.5 | - | | ✓ | |
| Damnak Cheukrom Irrigation Scheme | n/a | 16,100 | | | ✓ |
| Damnak Ampil Irrigation Scheme-Extension | n/a | 15,000 | ✓ | | ✓ |
| Damnak Ampil - Sub-project (SAPI) | n/a | 2,519 | | | ✓ |
| Orokar Irrigation Scheme | n/a | 4,700 | ✓ | | |
| Loloksar Irrigation Scheme | n/a | 580 | ✓ | | |
| Wat Loung Irrigation Scheme (SAPI) | n/a | 2,410 | | | ✓ |
| Kbal Houng Irrigation Scheme (right bank) | n/a | 1,200 | ✓ | | |
| Kbal Houng Irrigation Scheme (left bank) | n/a | 2,000 | ✓ | | |
| Charek Irrigation Scheme | n/a | 11,000 | ✓ | | |
| **Total Command Area** | | **55,509** | | | |

Notes-[1]-MCM-million cubic meters

n/a – not applicable

[2-] irrigation command areas are for the wet season

Damnak Ampil Headworks command area is 24,629 ha and is the sum of Damnak Ampil Irrigation Scheme-Extension, Damnak Ampil – Sub Project, Orokar, and Wat Loung irrigation schemes.

Dam No.3 and No. 5 (see Figure 2-6), funded by Chinese institutions, have been under construction since 2010. Projected storage capacities are 25.5 million cubic meters (MCM) for Dam No.3 and 24.5 Dam for No.5 (MOWRAM, 2010). It is expected that these two projects will be completed in 2014, and will enable an additional 6,200 ha of paddy irrigation (Field Observation, MK16, November, 2013).

Dam No.1 is being developed by the Ministry of Industry Mines and Energy (MIME) with support from the Korean Government, and is currently in the pre-feasibility stages (MIME, 2013). This impoundment has a projected storage capacity in excess of 1,000 MCM, and it will store water for hydropower generation and for irrigation. Augmented flows from this impoundment have been studied by the Damnak Chheukrom irrigation project, and are expected to irrigate 16,100 ha of land located on the left bank of the Pursat River (MOWRAM, 2010).

The Damnak Ampil diversion weir, rehabilitated in 2006, is a structure with automated gates that diverts and conveys water from the Pursat River to the Stung Dauntry River. The Damnak Ampil Headworks encompasses several sub-projects (Damnak Ampil extension, Damnak Ampil, Wat Loung, and Orokar) that will provide irrigation for a total of 24,629 ha (MOWRAM, 2010). Current net storage capacity of the Stung Pursat at Damnak Ampil reservoir is estimated at 860 MCM. Recorded data for the canal or its diversion structure on the Pursat River are currently unavailable (JICA, 2012).

**Figure 2-5 Schematic of Water resources development in the Stung Pursat catchment (JICA, 2013).**

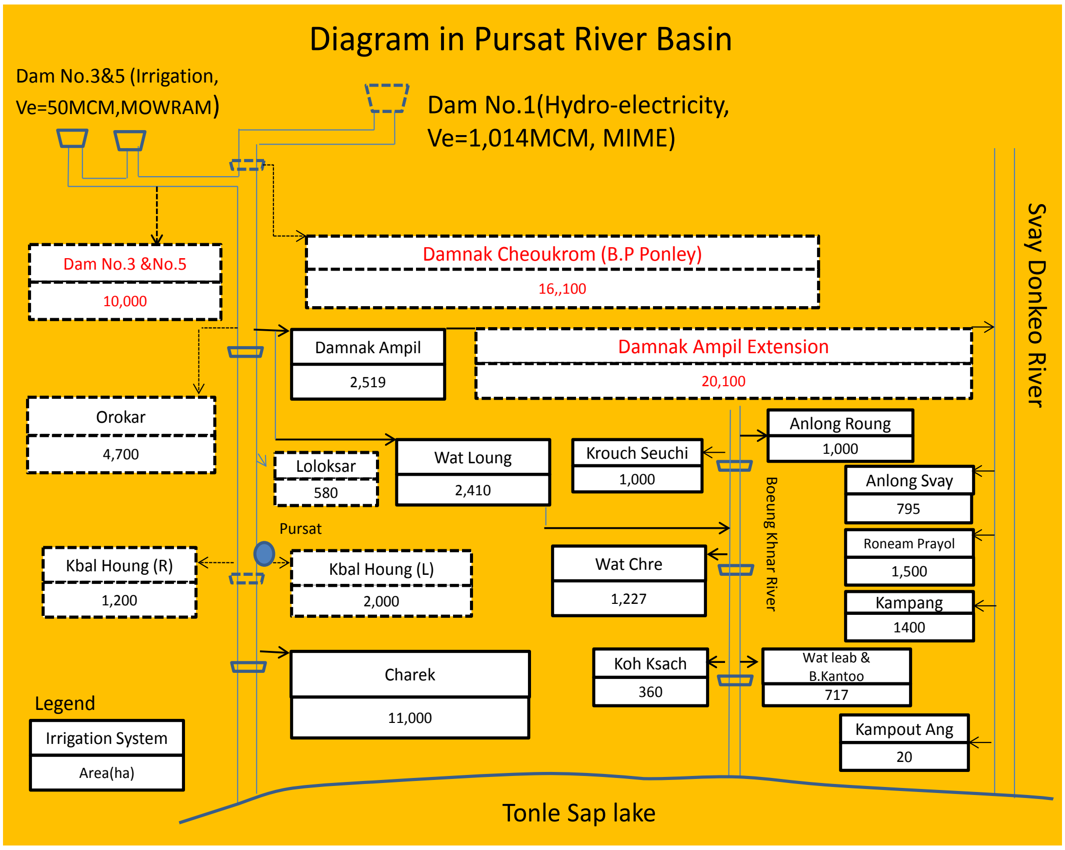
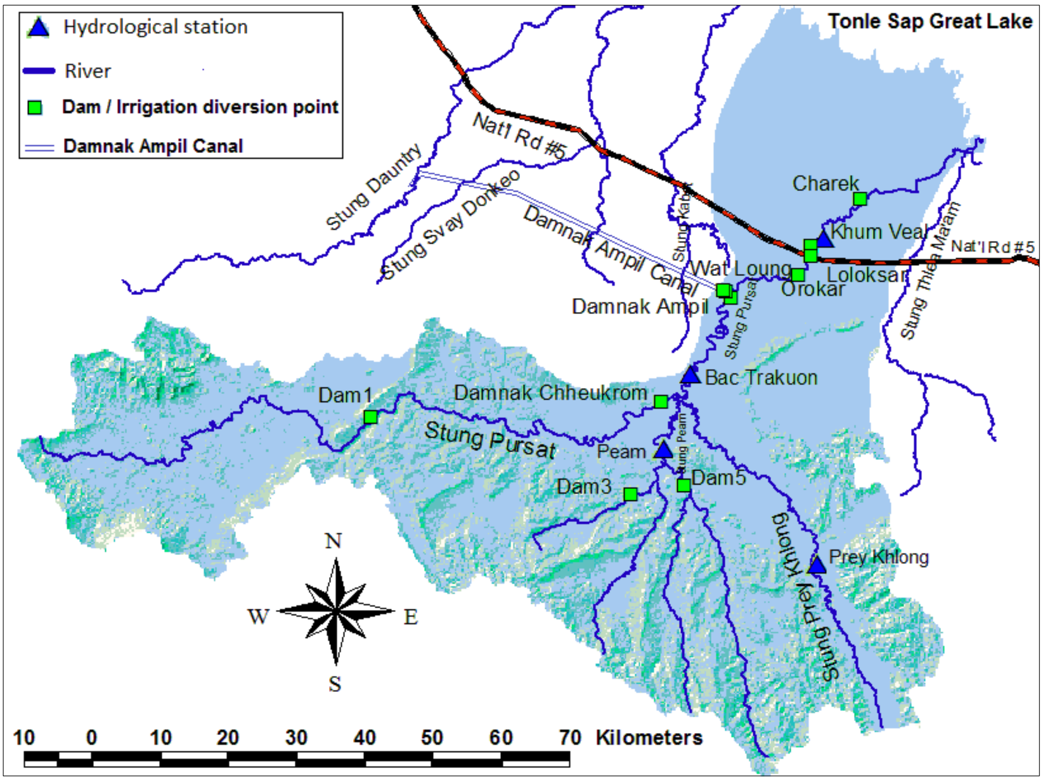


**Figure 2-6 Location of Water resources development in the Pursat river (JICA, 2013).**




# 3.0 HYDROMETEOROLOGICAL DATA

The Department of Hydrology and River Works (DHRW) and the Pursat Provincial Department of Water Resources and Meteorology (PDOWRAM) have collected daily time series of hydro-meteorological data since the mid-nineties. The locations of the hydrometric and climate stations are shown in Figure 2-1.

## 3.1 EXISTING HYDROLOGIC DATA

The Stung Pursat is the only tributary of the Tonle Sap Lake with more than one hydrometric station. Over the years, water level data have been collected at 13 stations, of which only six are currently operational. The station Bak Trakuon (ID 580103) is the station with the longest period of collecting data, spanning from 1995 to 2011. All other stations have fragmented data collection periods limited to a few years in the mid-nineties or the late-nineties onward. All hydrometric stations are currently concentrated at mid-to-low elevations in the catchment, and there are gaps in coverage at key locations of existing and planned water resources infrastructure (e.g., hydropower dams, diversion canals) (MK16, 2013b). Summaries of water level and discharge data for the Stung Pursat catchment are provided in Table 3-1 and Table 3-2, respectively. Representative hydrographs for the stations Bak Trakuon (ID 580103) and Khum Veal (ID 580104) are provided in Figure 3-1 and Figure 3-2, respectively.

**Table 3-1 Availability of daily water levels at stations within the Pursat river basin (JICA, 2011).**

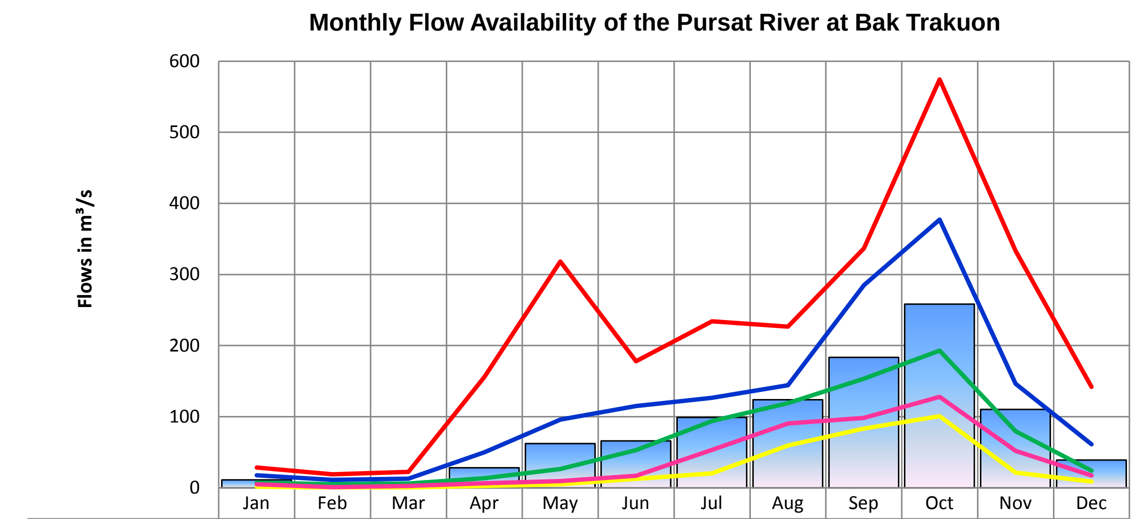
| River catchment | River Name | HYMOS ID CODE | Station Name | Area at Gauging Station, km² | X_COORD | Y_COORD | TYPE of Station run by project /organisation | Status till 2011 | Daily Data Availability | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 1990 | | | | | | 2000 | | | | | | | | | | | |
| | | | | | | | | | 4 | 5 | 6 | 7 | 8 | 9 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Pursat | Pursat | 580104 | Khum Veal | 4,596 | 363700.7 | 1346389.3 | DHRW | Non-Operational | | 120 | + | 306 | | + | + | + | + | + | + | + | + | | | | | |
| | | 580103 | Bak Trakuon | 4,245 | 364756.9 | 1365617.7 | DHRW | Operational | 255 | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| | | 580105 | Lolok Sar | | 367847.3 | 1347660.8 | DHRW | Operational | 90 | + | + | 306 | | | | + | + | + | + | + | + | + | + | 184 | | |
| | | 580106 | Phum Kos | | 378380.2 | 1351302.1 | DHRW | Non-Operational | 90 | + | + | 306 | | | | | | | | | | | | | | |
| | | 580110 | Kbal hong(up) | | 400493.0 | 1401662.8 | DHRW | Operational | | 120 | + | 306 | | | | + | + | + | + | + | + | + | + | + | + | |
| | | 580120 | Kbal hong(down) | | 394894.4 | 1396798.2 | DHRW | Non-Operational | | 242 | | | | + | + | + | + | + | + | + | | | | | | |
| | Stung Peam | 580201 | Peam | 1,059 | 359610.0 | 1344257.8 | DHRW | Operational | | | | | | | | + | + | + | + | + | + | + | + | + | + | |
| | Stung Santre / Prey Khlong | 580301 | Prey Klong(down) | 818 | 383622.0 | 1339545.0 | DHRW | Operational | 90 | + | + | 306 | | | | + | + | + | + | + | + | + | + | + | + | |
| | | 580302 | Prey Klong(up) | | 307961.4 | 1383516.3 | DHRW | Non-Operational | 243 | + | + | 306 | | | | + | | | | | | | | | | |
| | Stung Sanlong | 580310 | Sanlong(up) | | 371603.2 | 1410290.0 | DHRW | Non-Operational | | 212 | + | 306 | | | | | | | | | | | | | | |
| | | 580320 | Sanlong(down) | | 371852.5 | 1405434.4 | DHRW | Non-Operational | | 212 | + | 306 | | | | | | | | | | | | | | |
| | Stung Svay At | 580330 | Svay At | | 371833.1 | 1401163.8 | DHRW | Non-Operational | 90 | + | + | 306 | | | | | | | | | | | | | | |
| | Stung Bromauy | 580134 | Veal Veng | | 293934.0 | 1359853.0 | DHRW | Operational | | | | | | | | | | | | | 364 | | 146 | | | |

+ Data available
120 Number of gaps in a year

**Table 3-2 Availability of daily water discharges at stations within Pursat river basin (JICA, 2011).**

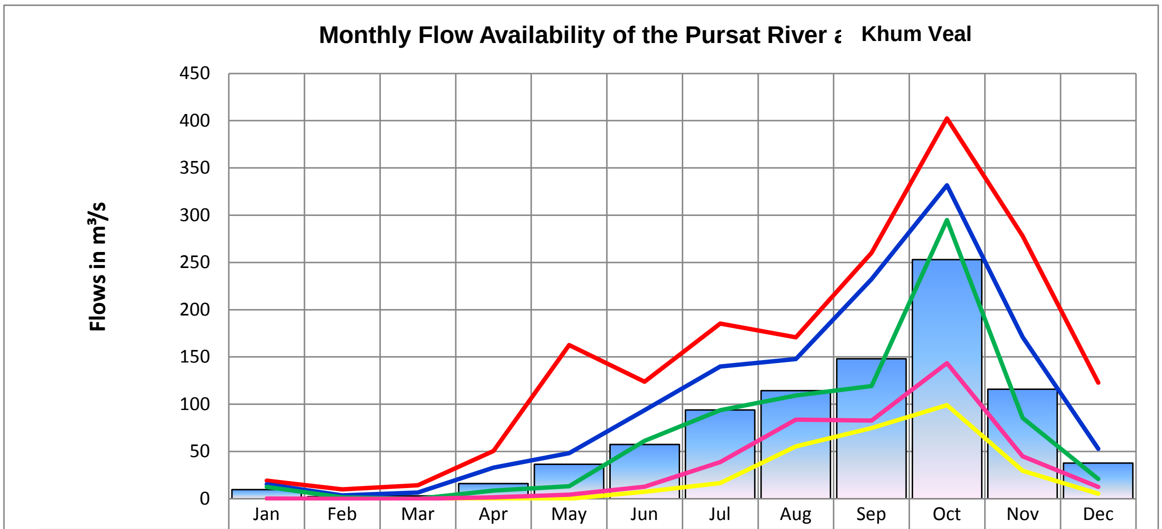
| No. | ID | Station Name | River sub-catchment | Computed daily timeseries | | Rating Curve used |
|---|---|---|---|---|---|---|
| | | | | Start Date | End Date | |
| 1 | 580104 | Khum Veal | Stung Pursat | 01-Jan-99 | 31-Dec-06 | New |
| 2 | 580103 | Bak Trakoun | Stung Pursat | 01-Oct-94 | 31-Dec-11 | New |
| 3 | 580201 | Peam | Stung Pursat (Peam) | 01-Jan-01 | 31-Dec-10 | New |
| 4 | 580301 | Prey Khlong | Stung Pursat (Santre) | 01-Jan-01 | 31-Dec-10 | New |

**Figure 3-1 Discharge hydrograph for the station Bak Trakuon (1995-2011) (JICA, 2013b).**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 11.1 | 6.3 | 7.8 | 28.2 | 62.2 | 66.1 | 99.1 | 123.8 | 183.5 | 258.3 | 110.1 | 39.1 |
| Maximum | 28.4 | 19.0 | 22.3 | 156.1 | 318.4 | 177.9 | 234.1 | 226.7 | 336.7 | 574.3 | 333.3 | 141.8 |
| Minuimum | 1.7 | 0.5 | 0.5 | 2.7 | 5.0 | 12.5 | 20.5 | 59.6 | 83.4 | 100.7 | 21.3 | 8.8 |
| 20% Exceedence | 17.8 | 11.1 | 12.8 | 50.0 | 95.9 | 115.2 | 126.7 | 144.4 | 285.1 | 377.1 | 146.4 | 61.1 |
| 50% Exceedence | 7.6 | 5.2 | 6.0 | 13.7 | 26.6 | 53.3 | 94.0 | 119.3 | 153.5 | 193.1 | 79.7 | 24.2 |
| 80% Exceedence | 5.2 | 1.1 | 2.6 | 6.3 | 9.4 | 17.1 | 53.5 | 90.5 | 98.2 | 128.0 | 52.2 | 17.2 |

**Figure 3-2 Discharge Hydrograph for the station Khum Veal (1995-2006) (JICA, 2013b).**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 9.8 | 2.4 | 3.2 | 16.0 | 36.6 | 57.5 | 93.9 | 114.6 | 148.0 | 253.0 | 115.9 | 37.9 |
| Maximum | 19.1 | 9.9 | 14.2 | 50.5 | 162.6 | 123.8 | 185.5 | 170.7 | 260.1 | 402.5 | 277.9 | 122.7 |
| Minuimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 7.4 | 16.7 | 55.5 | 74.9 | 99.1 | 29.5 | 5.4 |
| 20% Exceedence | 15.2 | 3.5 | 6.7 | 33.0 | 48.1 | 93.7 | 139.9 | 147.8 | 232.3 | 331.7 | 171.0 | 52.7 |
| 50% Exceedence | 12.5 | 1.5 | 0.0 | 8.7 | 13.3 | 61.4 | 93.6 | 109.3 | 119.2 | 294.8 | 85.4 | 20.9 |
| 80% Exceedence | 0.2 | 0.0 | 0.0 | 1.5 | 4.2 | 12.8 | 38.7 | 83.7 | 82.8 | 143.4 | 44.8 | 12.5 |

## 3.2 EXISTING METEOROLOGICAL DATA

There are 11 rainfall stations in the Pursat river catchment, resulting in a network density of approximately one station per 540 km²; however, the network does not cover the entire elevation range in the catchment, and the stations are concentrated at low and mid elevations (MK 16, 2013a). A description of climate stations in the Pursat catchment is presented in Table 3-3.

**Table 3-3 Rainfall stations with daily data availability within and around the Pursat river basin (JICA, 2013).**

| River Catchment | Station ID | Station Name | UTM Coordinates | | Period of Record |
|---|---|---|---|---|---|
| | | | Easting (m) | Northing (m) | |
| Stung Kambot/Beung Khnar | 120426 | Beung Khnar | 362,188.5 | 1,396,436.4 | 1994-1996, 2001-2008 |
| | 120004 | Phteah Rung | 361,016.4 | 1,369,770.9 | 2000-2008 |
| Stung Pursat | 120003 | Bak Tra | 375,989.1 | 1,373,551.5 | 2005-2010 |
| | 120304 | Dap Bat | 370,246.6 | 1,380,894.0 | 2000-2002, 2004-2010 |
| | 120002 | Kandieng | 390,515.1 | 1,394,023.5 | 2005-2008, 2010 |
| | 120312 | Kravanh | 365,457.0 | 1,364,266.0 | 1994-2010 |
| | 120313 | Peam | 360,322.6 | 1,356,910.4 | 2000-2010 |

**Table 3-3 (Cont'd.)**

| River Catchment | Station ID | Station Name | UTM Coordinates Easting (m) | Northing (m) | Period of Record |
|---|---|---|---|---|---|
| Stung Pursat (Cont'd.) | 120302 | Pursat | 381,845.0 | 1,386,941.0 | 1992-2011 |
| | 120005 | Roveing | 341,975.0 | 1,362,273.0 | 2007-2008, 2010 |
| | 120009 | Santre | 372,359.7 | 1,355,371.0 | 2010-2011 |
| | 120006 | Taing Luch | 352,425.1 | 1,361,891.5 | 2005-2010 |
| | 120301 | Tuolkruos | 320,034.5 | 1,368,732.7 | 2001-2002, 2010-2011 |
| | 120007 | Veal Veng | 293,501.2 | 1,361,041.1 | 2001-2002, 2004-2006, 2008-2010 |
| Stung Bamank/Thlea Ma' am | 120406 | Bamnak | 410,323.3 | 1,359,592.0 | 1993, 1999-2010 |
| | 120320 | Beung Kantout | 400,310.1 | 1,384,906.1 | 1994-1996, 1999-2008 |
| | 120001 | Koh Chum | 397,229.9 | 1,381,664.0 | 2007-2010 |

When conducting additional analyses, monthly rainfall distributions were calculated. The rainfall station Pursat (ID 120302) has the longest period of data collection (1981 to 2011), and was used as the representative station for the low elevation regions in the Stung Pursat catchment. The rainfall station Kravanh (ID 120312), with a period of record of 17 years (1994 to 2010), was used as the representative station for the mid-elevation regions in the catchment. Monthly rainfall distributions for the stations Pursat and Kravanh are shown in Figure 3-3 and Figure 3-4.

**Figure 3-3 Monthly rainfall distribution Pursat station (1981 to 2011) (Tes S, 2013).**

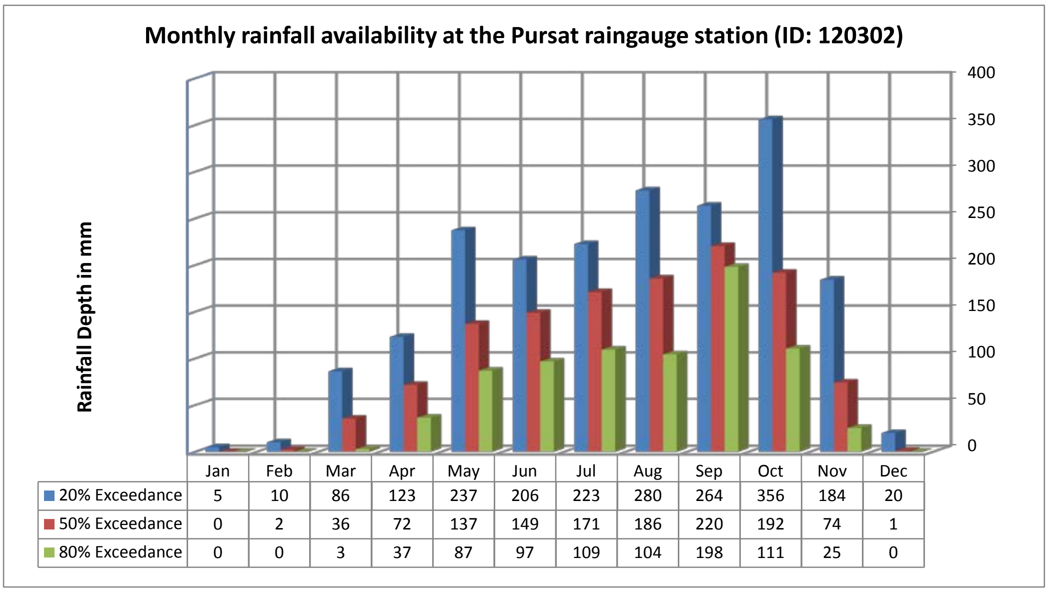
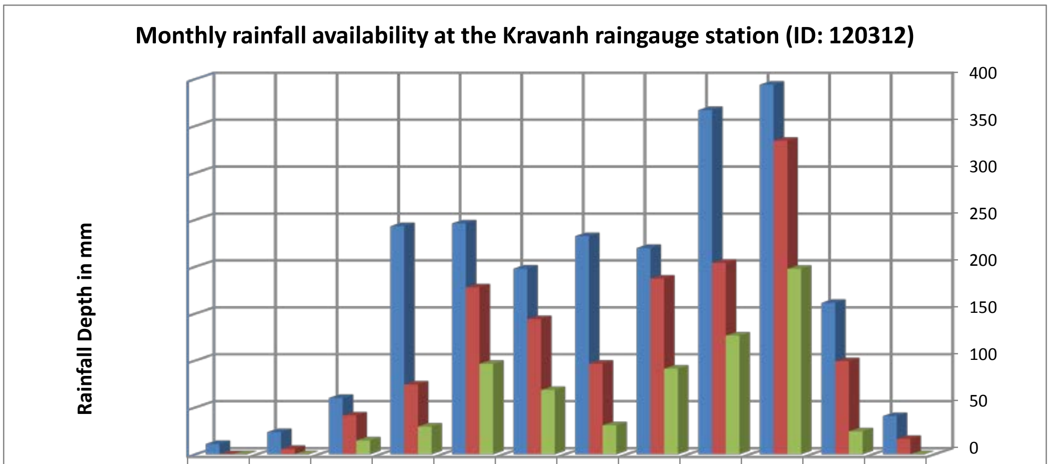


**Figure 3-4 Monthly rainfall distribution Kravanh station (1994 to 2010) (Tes S, 2013).**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20% Exceedance | 11 | 24 | 60 | 243 | 246 | 198 | 233 | 220 | 367 | 394 | 161 | 41 |
| 50% Exceedance | 0 | 6 | 41 | 74 | 178 | 144 | 97 | 187 | 204 | 334 | 99 | 16 |
| 80% Exceedance | 0 | 0 | 15 | 30 | 96 | 68 | 31 | 91 | 126 | 198 | 24 | 0 |

# 4.0 METHODS

## 4.1 GAP FILLING OF RAINFALL DATA FOR THE PURSAT RIVER CATCHMENT

Numerous gaps in the rainfall records make existing data in the Stung Pursat of limited value for further analysis (e.g., modeling and application of decision support tools) (JICA, 2013b). Data gaps in the rainfall records for stations in the Pursat catchment were filled by means of spatial interpolation techniques.

Several spatial interpolation techniques, including nearest neighbor (NN), Thiessen polygons, splines and local trend surfaces, global polynomial (GP), local polynomial (LP), trend surface analysis (TSA), radial basic function (RBF), inverse distance weighting (IDW), and various forms of Kriging have been used globally in similar studies. In this study, the inverse distance weighting (IDW) method was selected because of its applicability when the estimated parameters are not normally distributed.

In the IDW method, distances between the gauges with missing and available data are determined. Missing data are then calculated as an average of nearby gauges using a weight factor. The weight factor is inversely proportional to the squared distance between gauges (i.e., a heavier weight is placed on gauges that are closer to the gauge with missing records). Missing records are estimated using the formula:

$$Z_P = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i}$$

Where:

$Z_P$ = interpolated value at the grid node

$Z_i$ = rainfall value at location $(x_i, y_i)$

$W_i$ = weighted function, and

n = number of sample points

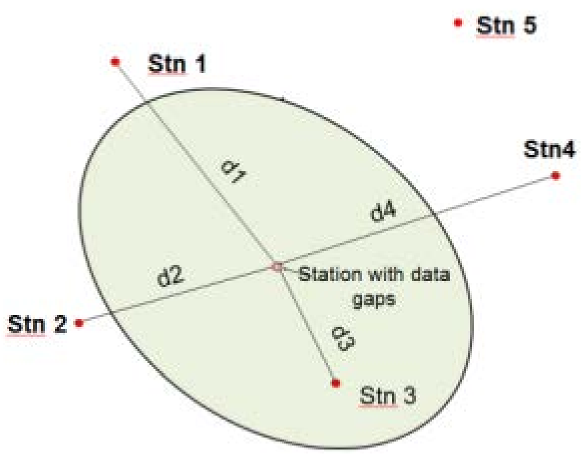
The weighted function is calculated using:

$$W_i = \frac{1}{d_i^2}$$

where
$d_i$ = distance between $Z_p$ and $Z_i$

The distance $d_i$ between $Z_p$ and $Z_i$ was determined by the difference of the coordinates between the two points. A maximum of four stations near the station with data gaps were used to estimate missing records (Figure 4-1).

**Figure 4-1 Schematic of Inverse Distance Weighing Method (IDW).**




Missing data were estimated for 15 stations distributed in the Stung Kambot, Stung Pursat, and Stung Bamnak catchments. A list of the stations is shown in Table 4-1.

**Table 4-1 Rainfall stations with data interpolated using the Inverse Distance Weighing Method (IDW) (Tes S, 2013).**

| No. | River Catchment | ID | Station Name | X_COORD | Y_COORD | Daily Data Availability | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1990 | | | | | | | | 2000 | | | | | | | | | | | |
| | | | | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 1 | Stung Kambot / Beung Khnar | 120426 | Beung Khnar | 362188.5 | 1396436.4 | F | F | + | + | + | F | F | F | + | + | + | + | + | + | + | + | + | F | F | F |
| 2 | | 120004 | Phteah Rung | 361016.4 | 1369770.9 | F | F | F | F | F | F | F | F | + | + | + | + | + | + | + | + | + | F | F | F |
| 3 | Stung Pursat | 120003 | Bak Tra | 375989.1 | 1373551.5 | F | F | F | F | F | F | F | F | F | F | F | F | F | + | + | + | + | + | + | F |
| 4 | | 120304 | Dap Bat | 370246.6 | 1380894.0 | F | F | F | F | F | F | F | F | + | + | + | F | + | + | + | + | + | + | + | F |
| 5 | | 120002 | Kandeing | 390515.1 | 1394023.5 | F | F | F | F | F | F | F | F | F | F | F | F | F | + | + | + | + | F | + | F |
| 6 | | 120312 | Kravanh | 365457.0 | 1364266.0 | F | F | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | F |
| 7 | | 120313 | Peam | 360322.6 | 1356910.4 | F | F | F | F | F | F | F | F | + | + | + | + | + | + | + | + | + | + | + | F |
| 8 | | 120302 | Pursat | 381845.0 | 1386941.0 | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| 9 | | 120005 | Roveing | 341975.0 | 1362273.0 | F | F | F | F | F | F | F | F | F | F | F | F | F | F | F | + | + | F | + | F |
| 10 | | 120009 | Santre | 372359.7 | 1355371.0 | F | F | F | F | F | F | F | F | F | F | F | F | F | F | F | F | F | F | + | + |
| 11 | | 120006 | TaingLuch | 352425.1 | 1361891.5 | F | F | F | F | F | F | F | F | F | F | F | F | F | + | + | + | + | + | + | F |
| 12 | | 120301 | Tuolkruos | 320034.5 | 1368732.7 | F | F | F | F | F | F | F | F | F | + | + | F | F | F | F | F | F | F | + | + |
| 13 | | 120007 | VealVeng | 293501.2 | 1361041.1 | F | F | F | F | F | F | F | F | F | + | + | F | + | + | + | F | + | + | + | F |
| 14 | Stung Bamank / Thlea Ma'am | 120406 | Bamnak | 410323.3 | 1359592.0 | F | + | F | F | F | F | F | + | + | + | + | + | + | + | + | + | + | + | + | F |
| 15 | | 120320 | Beung Kantout | 400310.1 | 1384906.1 | F | F | + | + | + | F | F | + | + | + | + | + | + | + | + | + | + | F | F | F |
| 16 | | 120001 | Koh Chum | 397229.9 | 1381664.0 | F | F | F | F | F | F | F | F | F | F | F | F | F | F | F | + | + | + | + | F |

+ Data available
F Data obtained from gap filling

## 4.2 RATING CURVE DEVELOPMENT

Stage-discharge rating curves (rating curves) were used to convert water level data (stage) recorded by the hydrometric monitoring stations into a discharge time-series or hydrograph. Rating curves were derived for the stations Stung Peam at Peam, Stung Santre at Prey Khlong, Stung Pursat at Bak Trakuon, and Stung Pursat at Kum Veal. The said four stations were considered without backwater effects and followed power function:

$$Q = b\,(H - H_0)^c$$

Where:

$Q$ is water discharge in $m^3/s$;

$H$ is gauge height in meters;

$H_0$ is the gauge height at zero flow (datum correction) in meters; and

$b$ *and* $c$ are coefficients

It is important to note that the station Bak Trakuon was relocated in 2010; thus, two rating curves were developed at this station to compute discharges before and after 2010. The developed rating equations for all stations are shown in Table 4-2.

**Table 4-2 Developed rating equations for four hydrometric stations in the Stung Pursat catchment (Tes S, 2013).**

| Station Name | Station ID | Rating Equation | $R^2$ | Number of Points used |
|---|---|---|---|---|
| Peam | 580201 | $Q = -0.84 + 6.7952H + 2.713H^2$ | 0.9848 | 44 discharges measured between 1999- 2001 |
| Prey Khlong | 580301 | $Q = 24.3175 \times (H-0.68)^{1.6134}$ | 0.9917 | 23 discharges measured in 1994 and 2001 |
| Bak Trakuon | 580103 | Before 2010: $Q = 27.5335 \times (H-0.05)^{1.9304}$ | 0.9933 | 108 discharges measured in 1997 to 1999, 2001, 2005 to 2006, and 2010 to 2012 |
| | | After 2010: $Q = -6.62 + 20.3279 H + 23.2066 H^2$ | 0.9946 | |
| Khum Veal | 580104 | $Q = -42.05 + 52.2099 H -8.2745 H^2 + 2.0294 H^3$ | 0.9977 | 36 discharges measured in 1998, 1999, and 2001 |

## 4.3 RIVER CATCHMENT MODELING

The Unified River Simulation Model (URBS v5.13) was selected to simulate rainfall-runoff processes at different points of interest (nodes) in the Stung Pursat catchment. This model was selected because it was used previously in the Mekong region, and it is a relatively robust model that can be developed with limited data (First Technical Focus Group Meeting, 2013).

URBS is a semi-distributed, non-linear network model that divides a river catchment into small sub-catchments or cells. The model generates runoff from rainfall at the center of each cell, and routes it from the cell center to the cell outlet. Runoff is then routed from each cell into the river channel until it reaches the main outlet of the catchment. The model can be run either as an event-based or as a continuous simulation (First Technical Focus Group Meeting, 2013).

Six main parameters are used by the model for simulations: three parameters to generate runoff from rainfall inputs (IF = infiltration, IL = Initial Loss, and PR = runoff proportion), and three non-linear channel routing parameters (Alpha, Beta, and m).

The minimum required inputs to the model are a rainfall definition file and a catchment definition file. The latter can be created based on a digital elevation model (DEM).

### 4.3.1 Model Setup and Calibration

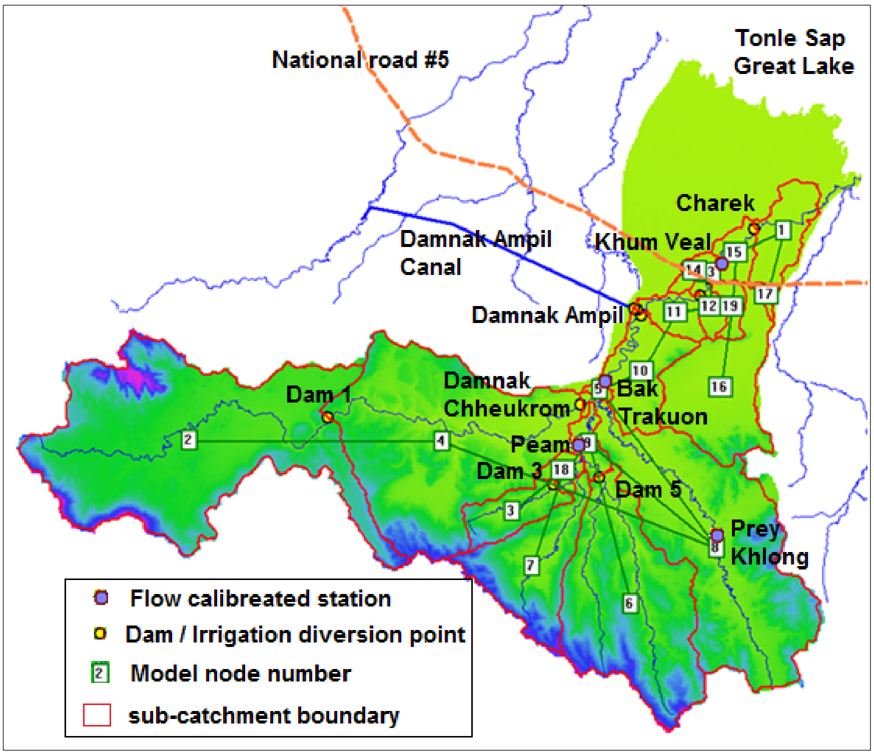
Digitized river networks and DEMs from the 2000 Shuttle Radar Topography Mission (SRTM)[2] were combined in a geographic information system (GIS) to generate a definition file of the Stung Pursat catchment for a JICA study (JICA, 2011 and JICA, 2013). The catchment was divided into 19 nodes or sub-catchments of which four were used for calibration purposes, three for flow

[2] The SRTM is a joined venture between the National Geospatial Intelligence Agency (NGA) and the National Aeronautics and Space Agency (NASA).

simulations at three dams (Dams No. 1, 3, and 5), five for simulation of water intakse at various irrigation points, and the remaining nodes for simulation of inflows to the Pursat catchment. The nodes used in the simulation is listed below and also shown in Figure 4-2.

| | | |
|---|---|---|
| Node 1 | : | Stung Pursat basin outlet |
| Node 2 | : | Dam 1 |
| Node 3 | : | Dam 3 |
| Node 4 | : | Damnak Cheukrom diversion point |
| Node 5 | : | Bak Trakuon hydrometric station |
| Node 6 | : | Dam 5 |
| Node 7 | : | River inflow below Dam 3 |
| Node 8 | : | Prey Khlong River |
| Node 9 | : | Node combining nodes 3, 7 and 6 |
| Node 10 | : | Damnak Ampil diversion point |
| Node 11 | : | Loloksar diversion point |
| Node 12 | : | Kbal Hong Right diversion point |
| Node 13 | : | Kbal Hong Left diversion point |
| Node 14 | : | Khum Veal Hydrometric station |
| Node 15 | : | Charek Irrigation diversion point |
| Node 16 | : | Subcatchment south of national road 5. Flows into node 15 |
| Node 17 | : | Subcatchment south of national road 5. Flows into node 1 |
| Node 18 | : | Node combining nodes 3 and 7 |
| Node 19 | : | Subcatchment south of national road 5. Flows into node 15 |

**Figure 4-2 URBS Model schematization for the Pursat river catchment (JICA, 2013b).**




There were slight differences between the irrigation scheme areas described in the JICA study and the areas determined in this study. The redefined areas by MK 16 used for model setup were based on an updated DEM. Details for each irrigation scheme are provided in Table 4-3.

**Table 4-3 Difference between areas defined in SAPI and in this study (Tes S, 2013).**

| Irrigation Scheme | Catchment Area | |
|---|---|---|
| | From SAPI Diagram, km$^2$ | New defined area by MK 16 km$^2$ |
| | 1 | 2 |
| Dam 1 | 1,263 | 1,221 |
| Damnak Chheukrom | 2,168 | 2,160 |
| Dam 3 | 94 | 107 |
| Dam 5 | 652 | 641 |
| Damnak Ampil | 4,484 | 4,303 |
| Lolok Sar | 4,596 | 4,366 |
| Kbal Hong Left + Right | 4,596 | 4,407 |
| Charek | 5,063 | 4,850 |

The URBS model was calibrated using rainfall data from 11 stations in the Stung Pursat catchment, two stations in the Stung Kambot, and three stations in the Stung Bamank. Rainfall Data from these stations for the period of record (1999-2006) were used to simulate daily discharges. Resulting discharges were calibrated against observed discharges recorded at the stations Peam, Prey Khong, Bak Trakuon, and Kum Veal.

The calibration process also involved fine tuning of the model runoff generation parameters (IF = infiltration, IL = Initial Loss, and PR = runoff proportion), and channel routing parameters (Alpha, Beta, and m). Once a satisfactory calibration was achieved daily discharge time series were generated for each of the 19 defined nodes for the period 1992 – 2011. Simulated results were used to compute monthly means and to verify water availability using 5-day mean discharges. The computed 5-day means were further used in water balance calculations.

## 4.4 WATER BALANCE COMPUTATION

Water balance computations were based on a modified version of the existing spreadsheet model program developed by JICA (2013). In the original model a reference period of 30 years (1982-2011) was used, while in this study the reference period was set at 20 years (1992-2011). In addition, discharges for the original 30-year reference period were simulated using a simple TANK[3] model, whereas in this study discharges for the 20-year reference period were simulated using the URBS model (JICA, 2013b and Tes S, 2013).

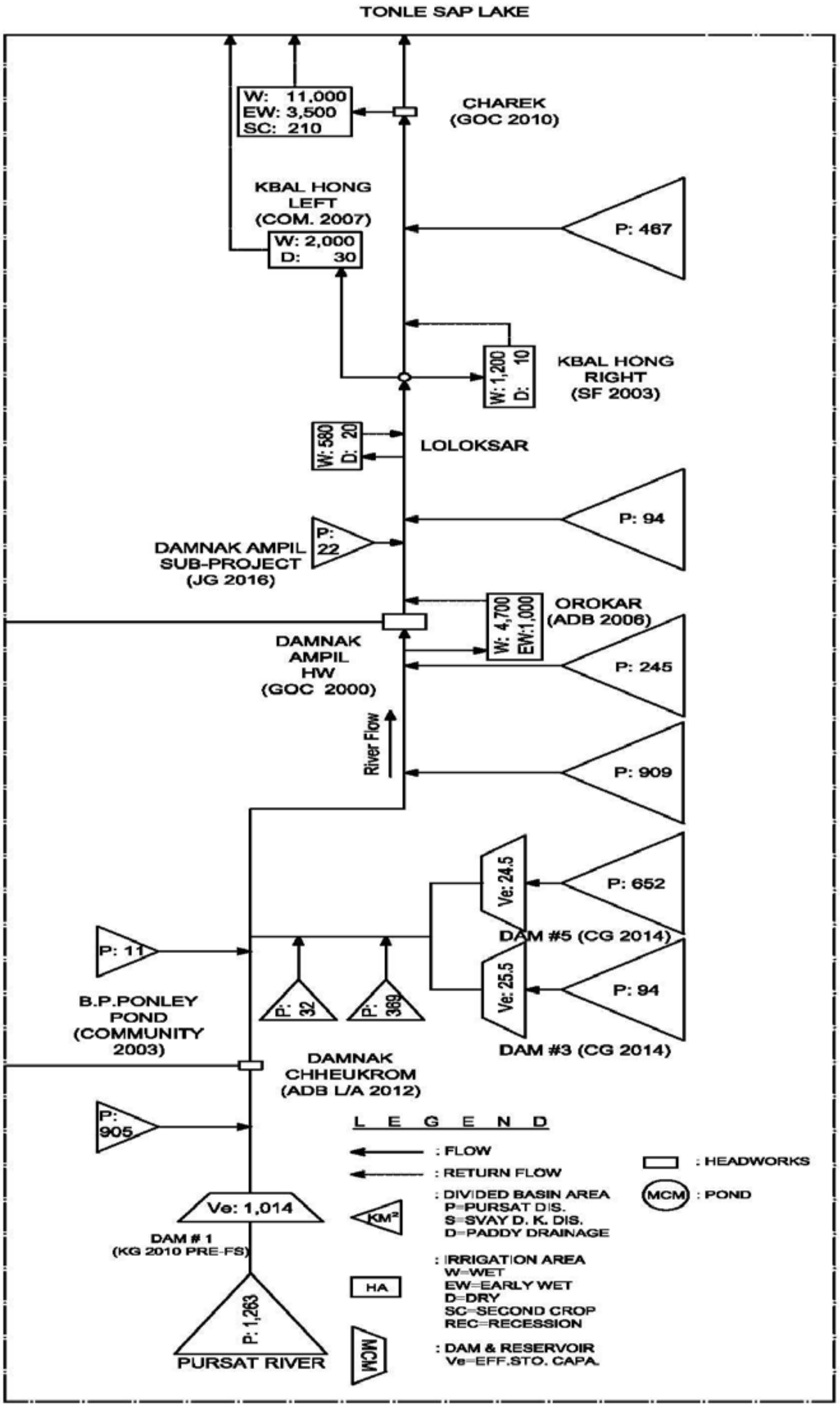
The water balance model was conducted setting 2020 as the target year, when construction of major water resource infrastructure is expected to be completed. All calculations were performed on a 5-day time step. Calculations in the model considered the following elements:

1. Basin schematic diagram;
2. River node diagram;
3. Dam data;
4. Generated runoffs (using the URBS model); and
5. Water demands (irrigation, domestic, industrial, hydropower, maintenance flows, return flows, and reservoir losses).

A schematic for the Stung Pursat catchment is shown in Figure 4-3. The schematic shows expected basin areas, irrigation systems and major structures along river systems for the target year 2020. River nodes in the schematic conceptualize the relations among river maintenance flows, inputs, and outputs (e.g., tributary inflows, return inflows, and intake sites).

[3] For more details refer to JICA (2013a) Brief Progress Report on Water Balance Examination Study for Pursat and Baribor River Basins

**Figure 4-3 Schematic Diagram of Pursat River Basin (JICA, 2013b).**




All calculations in the water balance model were conducted using the following assumptions:

- Flows for each sub-catchment of interest were downscaled from simulated flows at Khum Veal (using URBS) using a drainage area ratio (area of sub-catchment of interest/ drainage area of Khum Veal);

- For sub-catchments where the major land use was paddy agriculture, the flow Qi was derived using the expression:

  Qi = Rainfall x Paddy drainage area x 10%.

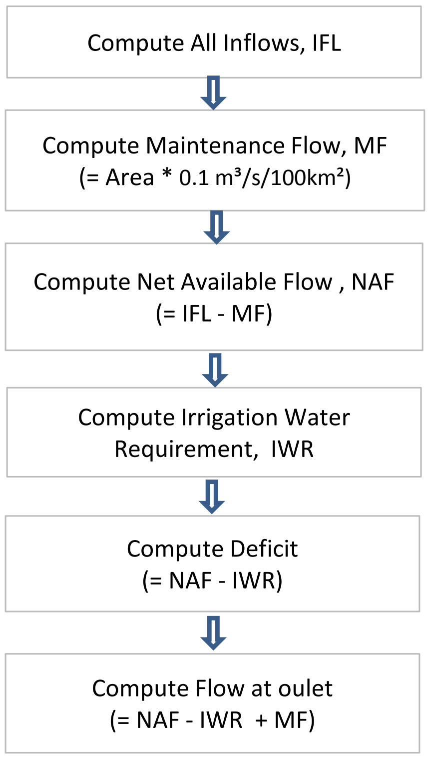
- Irrigation water requirements (IWR) for the 20-year reference period were defined from seven different crop patterns;

- A simple reservoir routing was conducted between Dam No. 3 and Dam No. 5. All information related to the dams were based on the feasibility study in the Stung Pursat Dam conducted by the Guangdong Foreign Construction Company in 2009; and

- Simulated monthly outflows for the hydropower Dam No.1 were further disaggregated into 5-day outflows.

Water balance calculations for each irrigation scheme followed the steps shown in Figure 4-4.

**Figure 4-4 Typical water balance computation procedure at each irrigation scheme (JICA, 2013b).**




A factor of 1/5 was adopted as the criterion to evaluate the safety level of irrigation water supply to various irrigation projects. For a given year, water balance calculations are considered acceptable if the continuous water deficit period is less or equal than a half month. Water deficits were only evaluated for periods of high priority water use. The safety level was calculated using the expression:

$$\text{Safety Level} = (x+1)/n$$

Where:

x = number of occurrence of 20-day successive deficit (irrigation failure)
n = total number of simulated years (i.e., 20 years)

Irrigation schemes were considered as optimum if the safety level was 1/5 (also expressed as 4/20), and acceptable if the safety level was 1/4 (also expressed as 5/20). In contrast, irrigation schemes falling outside of these safety levels were considered a failure.

The following sub-sections give a detailed description of the different water demand elements considered in the water balance model.

### 4.4.1 Irrigation Water Requirements

Irrigation water requirements of each crop for each diversion unit were estimated based on a cropping calendar and by the following equation:

$$IWR = (ETo \times Kc + PR + Lp - ER) / IE$$

Where:

IWR: Irrigation water requirement for diversion unit
ETo: Reference evapotranspiration
Kc: Crop coefficient
PR: Percolation rate (in case of paddy)
Lp: Land preparation requirement
ER: Effective rainfall
IE: Irrigation efficiency

### 4.4.2 Cropping Patterns

Water balance calculations in this study considered seven cropping patterns distributed among early-wet, wet, and dry seasons (Table 4-2). These cropping patterns are a combination of proposed patterns by the study conducted by JICA and by the Ministry of Water Resources and Meteorology (MOWRAM) (JICA, 2011 and JICA, 2013b). It is important to note that in contrast to JICA (2009), the patterns proposed by MOWRAM stress the importance of supplemental paddy irrigation during the wet season (JICA, 2013b).

Cropping patterns for the early-wet season are based on the assumption that the direct sowing method is the prevailing farming practice. This method was introduced in the Stung Pursat catchment to save costs associated with land preparation. It is estimated that this method is effective for parcels of land of approximately 1 ha in size. During the wet season the transplanting method is assumed as the dominant farming practice. This method produces a higher unit yield of rice than the direct sowing method. Lastly, during the dry season the direct sowing method is assumed. Irrigation areas for each cropping pattern, as well as a crop calendar for the Stung Pursat catchment are shown on Table 4-4 and Table 4-5, respectively.

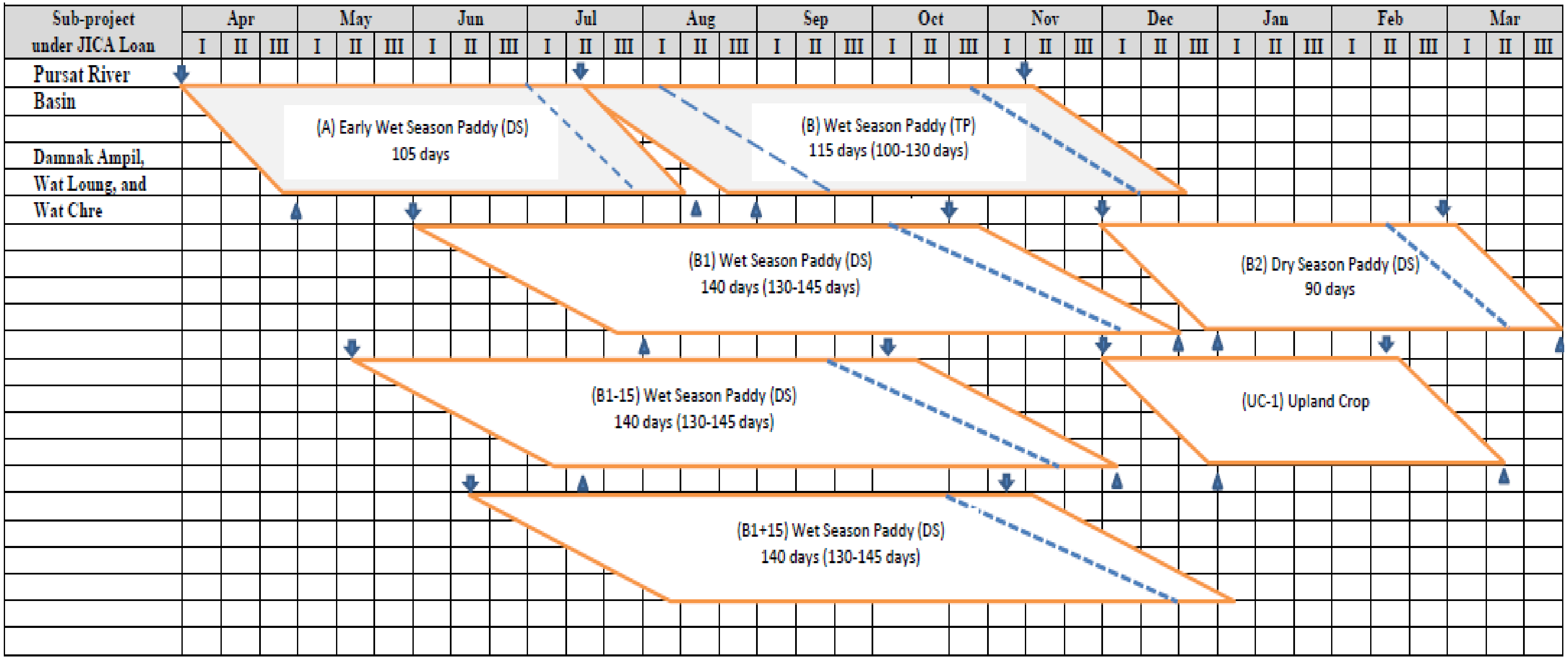
**Table 4-4 Assumed Cropping Patterns for Water Balance determination in the Stung Pursat Catchment (JICA, 2012).**

| Early Wet Season | Wet Season | Dry Season | Remarks |
|---|---|---|---|
| (A) Paddy (105 days, DS) | (B) Paddy (115 days, TP) | | Double crop of paddy, Proposed pattern for JICA's sub-project by SAPROF |
| | (B1) Paddy (140 days, DS) | | Single crop of paddy in Wet season, assuming that majority of the area applied this pattern |
| | (B1-15) Paddy (140 days, DS) | | Do. (15 days earlier than B1) |
| | (B1+15) Paddy (140 days, DS) | | Do. (15 days delay from B1) |
| | | (B2) Paddy (90 days, DS) | Limited from December to March |
| | | (UC-1) Upland crops | (mung bean) |

**Table 4-5 Irrigation areas for each cropping pattern in the Stung Pursat catchment (JICA, 2012).**

| Irrigation Area/ Cropping Pattern | | A (DS 105 days) | B (TP 115 days) | B1-15 (DS 140 days) | B1 (DS 140 days) | B1+15 (DS 140 days) | B2 (DS 90 days) | UC-1 | Total crop area per year | Cropping Intensity (CI) |
|---|---|---|---|---|---|---|---|---|---|---|
| Pursat | ha | | | | | | | | (Ha) | % |
| Damnak Chhoeukrom | 16100 | 6000 | 16100 | 0 | 0 | 0 | 0 | | 22,100.00 | 137% |
| Orokar | 4700 | 1000 | 0 | 0 | 4700 | 0 | | | 5,700.00 | 121% |
| Damnak Ampil (Ext.) | 15000 | 2462 | 0 | 0 | 15000 | 0 | 0 | | 17,462.00 | 116% |
| Damnak Ampil (SAPI) | 2519 | 189 | 2519 | | | | | | 2,708.00 | 108% |
| Wat Loung (SAPI) | 2410 | 180 | 2410 | 0 | 0 | 0 | | | 2,590.00 | 107% |
| Loloksar | 580 | 0 | 0 | 0 | 580 | 0 | 20 | | 600.00 | 103% |
| Kbal Hong (LB) | 2000 | | | | 2000 | | 30 | | 2,030.00 | 102% |
| Kbal Hong (RB) | 1200 | | | | 1200 | | 10 | | 1,210.00 | 101% |
| Charek | 11000 | 350 | | | | 11000 | | | 11,350.00 | 103% |
| **Total Area, Ha** | **55,509** | 10181 | 21029 | 0 | 23480 | 11000 | 60 | 0 | **65,750** | 118% |

**Table 4-6 Crop Calendar for the Stung Pursat river catchment (JICA, 2012 and Tes S, 2013).**

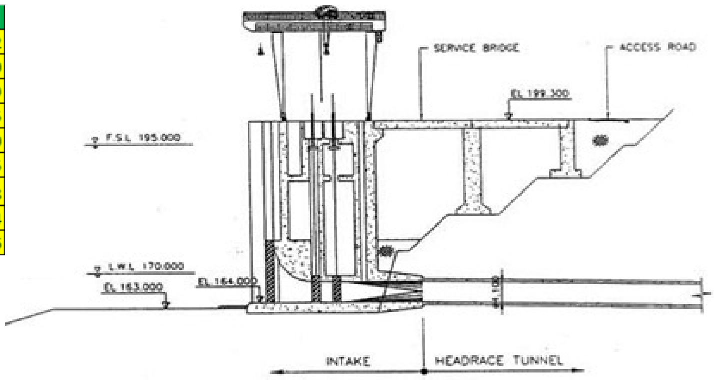


### 4.4.3 Hydropower dam simulation

Dam simulation at Dam No.1 was conducted by applying the RULE program, developed by the MRC. This program defines upper and a lower rule curves for dam operation and simulates water consumption for hydropower generation, dam outflows, and energy production. Characteristics of Dam No. 1 are shown in Figure 4-5.

**Figure 4-5 Characteristics of Dam No.1 (First Technical Focus Group Meeting of the MK 16, 2013 and MIME, 2013).**

| Hydropower dam #1 Characteristics | |
|---|---|
| RATED GROSS HEAD, M | 122 |
| INSTALLED CAPACITY, MW | 40 |
| OVERALL EFFICIENCY AT GROSS HEAD | 0.9 |
| FULL SUPPLY LEVEL, MAMSL | 195 |
| LOW SUPPLY LEVEL, MAMSL | 170 |
| TAILWATER LEVEL, MAMSL | 65 |
| DESIGN DISCHARGE, $M^3/S$ | 38.8 |
| LIVE STORAGE, MCM | 1014 |
| DEAD STORAGE, MCM | 306 |




### 4.4.4 Domestic and Industrial Water Use

Compared to other consumptive uses, domestic and industrial (D&I) water use is relatively small, but economically significant. The D&I data for the Stung Pursat catchment were estimated based on population size. According to the General Population Census of Cambodia (2008) the population in the Stung Pursat catchment was estimated at 203,522 inhabitants (Figure 4-6) (NIS, 2008).

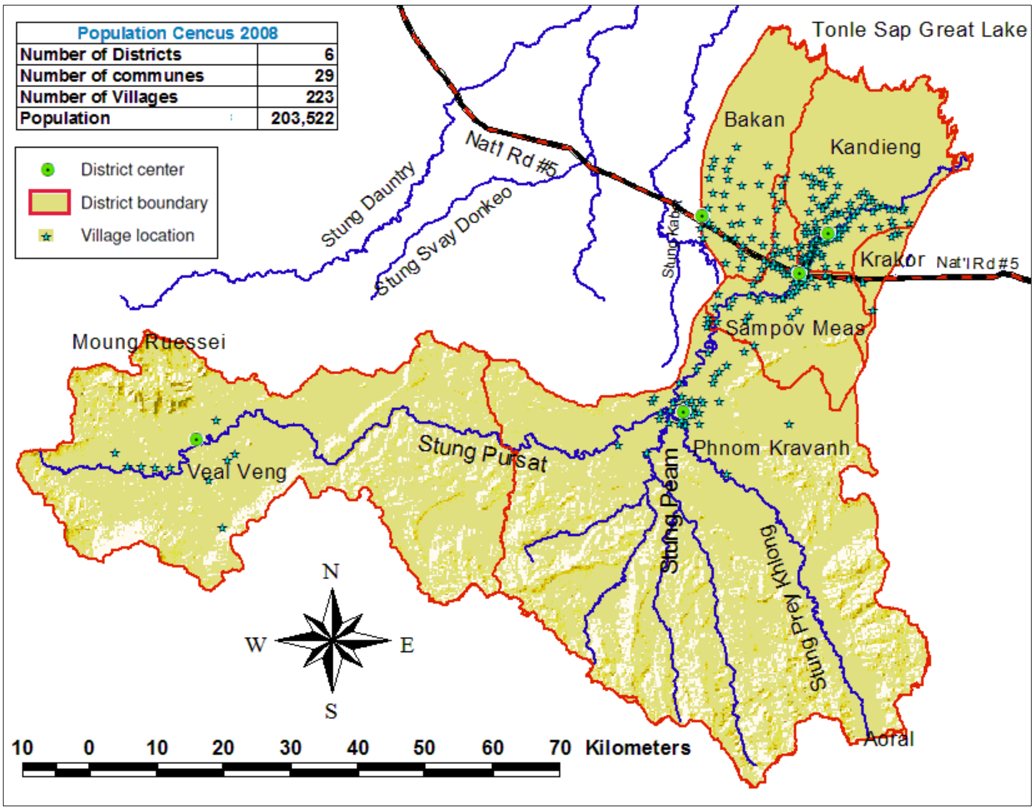
D&I water use per capita in Cambodia was determined to be 90 l/h/d (the 2006-2007 Water supply Performance and Consumption report of the Cambodian's Provincial Water Supply, referred to in JICA, 2012).

Based on the above, D&I water use in the Stung Pursat catchment was estimated as:

$$90 \times 10^{-3} \times 203{,}522 = 18{,}317 \text{ m}^3/\text{day; or}$$
$$0.212 \text{ m}^3/\text{s}.$$

The above D&I value was applied as an average value for the entire reference period (1992-2011) used in the water balance calculations.

**Figure 4-6 Population Census results in the Stung Pursat Catchment (2008) (NIS, 2008).**




## 4.4.5 Maintenance Flow, Return Flow, and Reservoir Losses

Maintenance or environmental flows refer to the quality, quantity, and timing of water flows required maintaining the components, functions, processes, and resilience of aquatic ecosystems that provide goods and services to people.

King et al. (2008) proposed maintenance flows to be defined as the minimum monthly flows that equaled or exceeded 95% probability of occurrence. These values are slightly higher than the annual minimum flows observed in the Stung Pursat catchment.

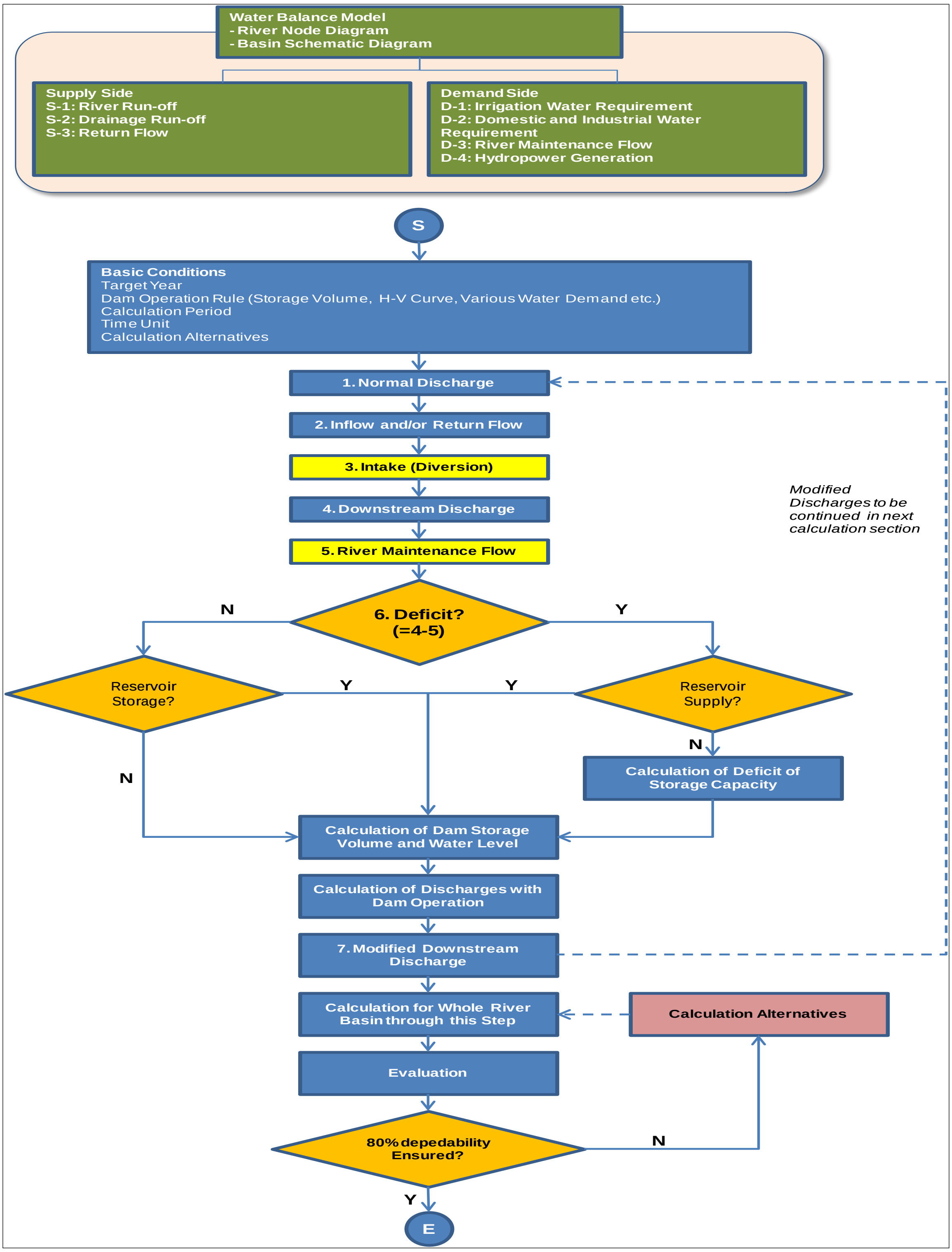
In the study by JICA (2011) and in the spreadsheet calculation program (JICA, 2013a), a river maintenance flow of 0.1 $m^3/s/100\ km^2$ was adopted. This value is greater than the natural minimum flows observed during the dry season, and if this value is adopted, it could lead to the occurrence of water shortages in the irrigation schemes located in the lower Stung Pursat catchment. For this reason, the estimated D&I value of 0.212 $m^3/s$ was adopted for water balance calculations. The return flow was estimated as half the value of irrigation loss (i.e., 17%).

Seepage losses from reservoirs were assumed as 0.05 % of storage volume per day. Further, evaporation losses from reservoir surface were estimated at 70% of observed evaporation. Estimated reservoir surface evaporation based on Pursat climate stations is 936 mm (annual average).

### 4.4.6 Water Balance Flowchart

Once all elements, assumptions, and water demands were carefully accounted for at all nodes in the Stung Pursat catchment, the water balance calculations were performed as described in the following flowchart (Figure 4-7).

**Figure 4-7 Water Balance Calculation Flowchart for the Stung Pursat Catchment.**



## 4.5 VERIFICATION OF WATER BALANCE RESULTS USING THE IQQM MODEL

The development of the integrated water quality and quantity model (IQQM) considered key components of the water balance in the Stung Pursat catchment including: inflows, return flows, impoundments, reservoir operation, consumptive and non-consumptive demands, and the general capability to simulate pollutants. IQQM was developed for the Stung Pursat catchment with the purpose of:

- Assessing water availability for different water use sectors/stakeholders to support development efforts in the Stung Pursat catchment; and
- Providing information to help develop appropriate Rules/Procedure in Climate Change Adaptation.

IQQM was also used to simulate a water balance for the Stung Pursat catchment and to verify results to the estimates generated by the simplified spreadsheet model developed by JICA (2013a).

IQQM operates on a continuous time basis and can be used to simulate river system behavior for periods ranging up to hundreds of years. It is designed to examine long-term behavior under various management regimes, which include environmental flow requirements. IQQM is based on a node-link concept. Each important feature of a river system is represented by one of thirteen node types. The movement and routing of water between nodes is carried out in the links. Normally the model is run on a daily time step, but for adequate representation of certain water quality and routing processes, the model can run down to an hourly step (Hameed and Podger, 2001).

### 4.5.1 Model Schematization

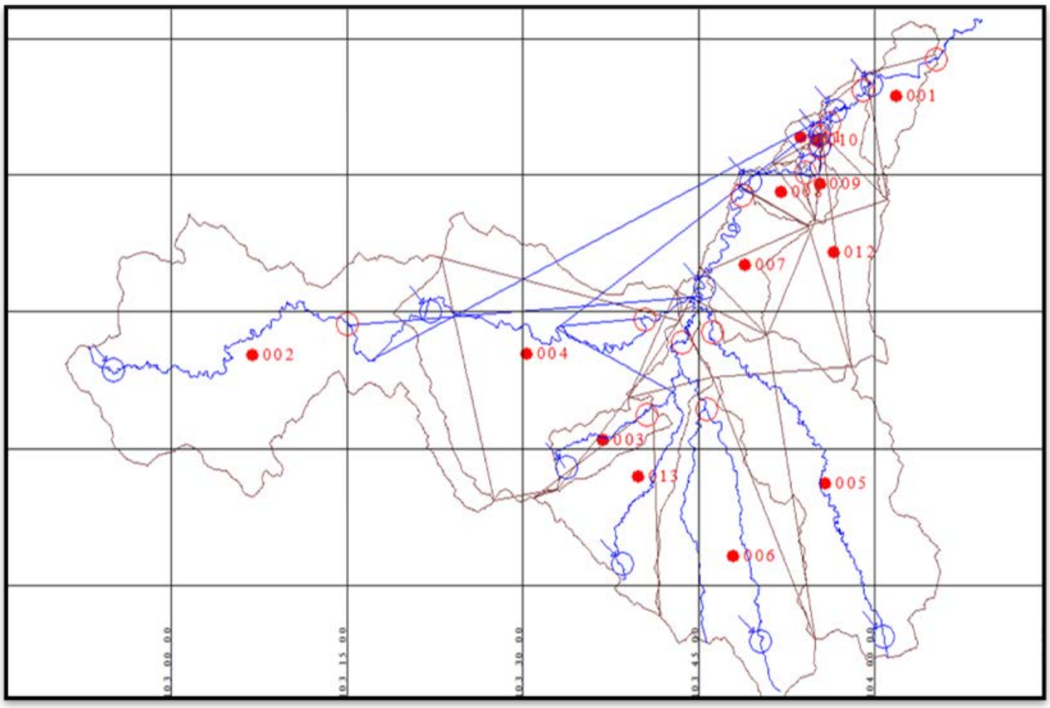
The Stung Pursat catchment was divided into 13 sub-basins, which were linked to each other by nodes (Figure 4-8). The following key processes that affect water balance in the catchment were:

- Consumptive and non-consumptive water demands;
- Water storage; and
- Movement of water through the catchment.

To generate useful results for planning purposes at the district level, different parameters were defined in the schematization. Sub-catchment size was set at 30 $km^2$; minimum storage volume was set to a value greater than 10 MCM; and individual irrigation schemes were set to 3,000 ha in the dry season, and greater than 10,000 ha in the wet season. It is important to note that the schematization was developed to agree with the sub-catchments defined for the URBS model developed for the Stung Pursat catchment.

The schematization of the Pursat catchment is a dynamic process and it will evolve as the model is further calibrated. For instance, depending on decisions of the line agencies on the required level of detail and the amount of data that they will provide, the schematization may be simplified in some cases, especially where storage information is not available.

**Figure 4-8 IQQM model schematization for the Stung Pursat catchment.**




### 4.5.2 Model Calibration and Validation

Due to limited data sets, calibration for the IQQM model was only conducted for flow data. Calibration and model validation was performed for the entire period of record (1999 to 2006 for Khum Veal and 1994 to 2011 for Bak Trakuon). This approach was used because of the dynamic nature of Stung Pursat catchment and the uncertainty in estimating demands (MK 16, 2013a). There is a steady increase in irrigation development over the calibration period, with substantial changes in some areas that occurred recently (JICA 2012). These considerations, coupled with relatively limited data sets, made it difficult to find a calibration period (representative of all the variability) and a separate period for validating modeled results in the Pursar catchment.

Model calibration was conducted in the three following stages:

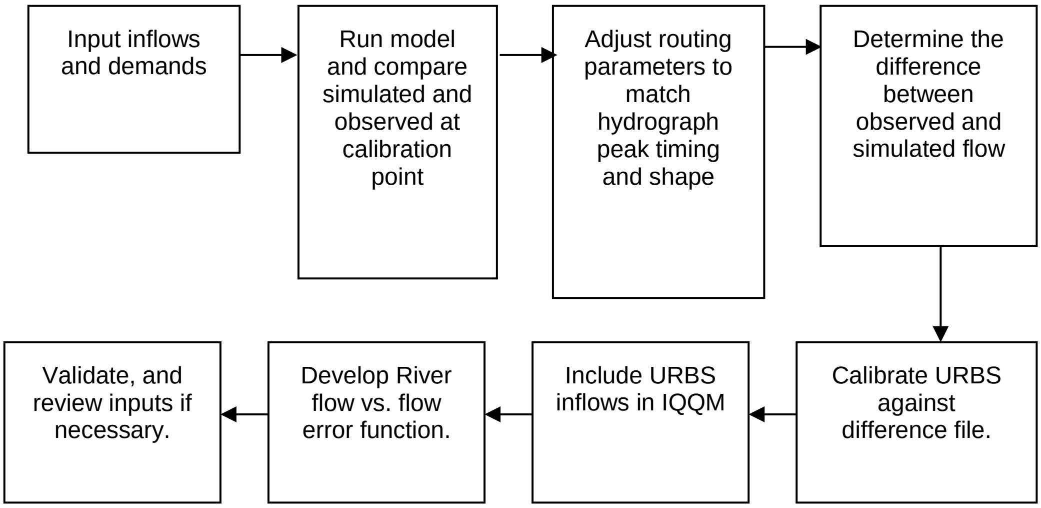
1. Routing: the first stage in the calibration is the adjustment of the routing parameters. Routing was done using lag and non-linear flow storage relationships. The lag parameter was adjusted first, followed by adjustments to the storage coefficient and exponent to match the timing of the hydrograph peaks and hydrograph shapes;

2. Residual Inflows: residual inflows were estimated by subtracting the simulated flow records from the observed flow records at the downstream gauge (Khum Veal). Observed data were used at the upstream gauge (Bak Trakuon); and

3. URBS Model Calibration: the URBS model was calibrated against the observed residual inflow determined in Stage 2. The calibrated inflows were then entered into IQQM. The calibration was conducted from 1999 to 2006. In many cases, the IQQM could not account for some of the physical characteristics (land use, land cover, soil properties); in this case only the URBS model was used (MK16, First Technical Focus Group Meeting, 2013).

The steps followed in the calibration procedure are shown in Figure 4-9. After all upstream flow and demands were entered in the model the results were compared with stream flow records from the Hymos data base.

**Figure 4-9 IQQM model calibration steps for the Stung Pursat catchment.**




## 4.6 SIMULATION OF FLOODS AND DROUGHTS USING THE ISIS MODEL HYDRODYNAMIC MODEL

The ISIS hydrodynamic model was used to simulate time series water level and flow data in the rivers and on the adjacent floodplains. Simulated results can help predict the extent, depth, and duration of flooding conditions. Simulated results can also help estimate impacts on low flow regimes during the dry season (First Technical Focus Group Meeting, 2013).

### 4.6.1 Data Requirements

The development of the ISIS model required the following data:

- Channel cross-sections;
- Floodplain data (including area/elevation relations) and controls (including spill levels and any structures);
- Boundary data, including hydrological data on inflows, direct rainfall and evaporation, crop water use and water level; and
- Calibration data, including satellite imagery, ground measurements of level and flow and local knowledge of flood patterns.

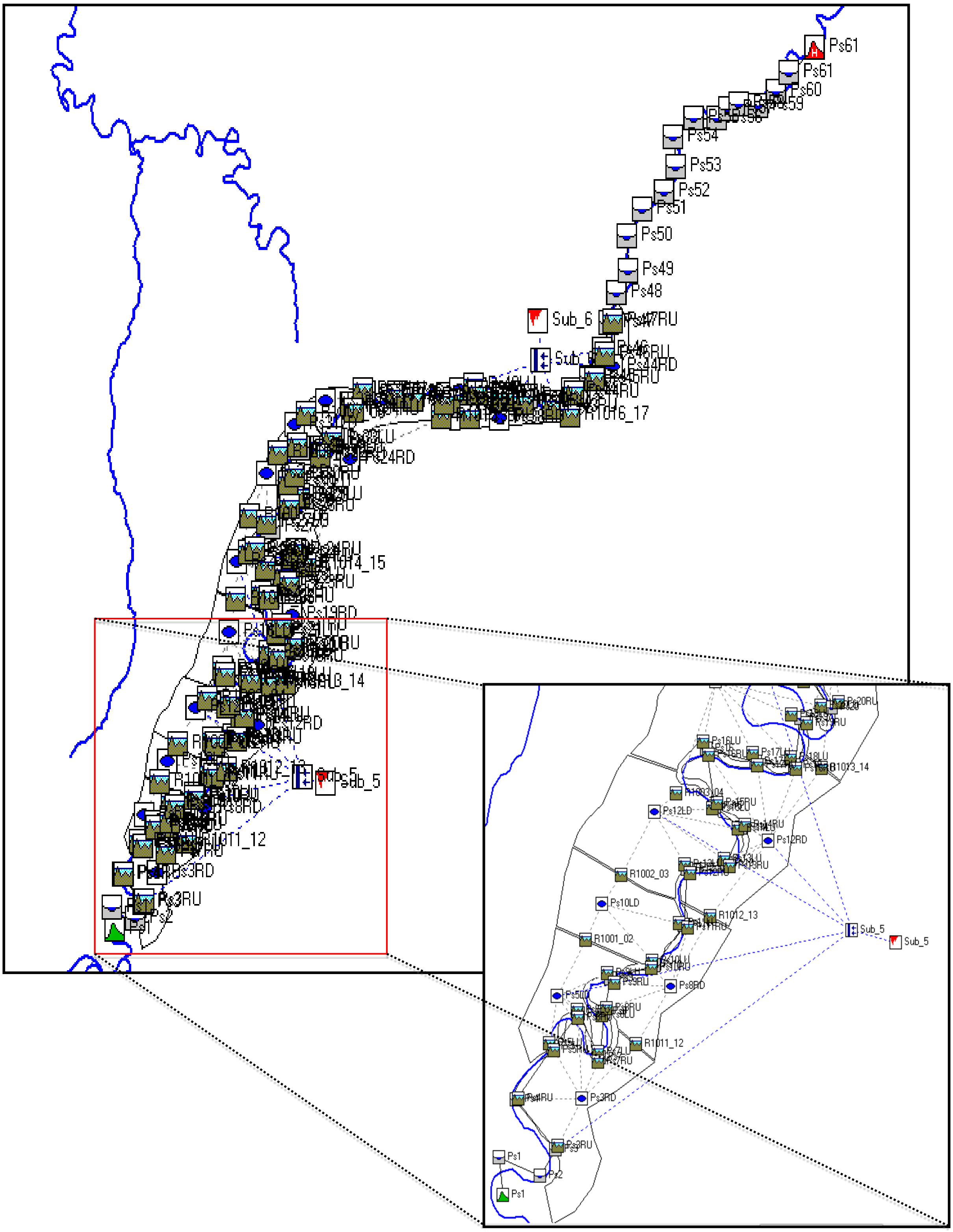
These data were collected from the following sources:

- Cross-section surveys conducted in the Stung Pursat River;
- Existing digital elevation model (DEM) developed for the Land and Resources Inventory Agriculture Development project (LRIAD) and an updated DEM generated by the MRC in 2013;
- Acoustic doppler velocity meter (ADCP) discharge measurements conducted in 2013 in the Stung Pursat River for the period pre-flood, flood and post-flood. These measurements help check the diversions onto the flood plain that are being simulated in the model; and
- Rainfall data collected at the Pursat climate station for the period (1992-2011).

### 4.6.2 Model Schematization

A total of 250 cross-sections (61 cross-sections and 190 units such as flood plain, spills, etc.) were used for the Stung Pursat. Flood plain sections, spill units, and breach sections were also included in the catchment schematization. Even though there is significant flow in the flood plain under flooding conditions, these flows are not considered natural because their extent is controlled by roads, village embankments, and openings. The schematic for the catchment is shown in Figure 4-10.

**Figure 4-10 ISIS model schematization of the Stung Pursat catchment (insert shows expanded section of the river).**



### 4.6.3 Model Calibration and Validation

Models were calibrated by visual comparison of simulated with observed data rather than by gauging the performance of the model by means of statistical goodness of fit tests. This procedure was used because there were inconsistencies in the observed data; variability of data quality for different model components and discrepancies in the variability of tide levels in the low reaches of the Stung Pursat (Tes S, 2013).

In contrast to the calibration approach used for the URBS and IQQM models, three years (1998, 2000, and 2001) were selected for calibration and verification of the ISIS model. This approach was used because of limited data availability, unusually high flood discharges that occurred in 2000, and sensitivity of the ISIS model to changes in infrastructure and channel geometry.

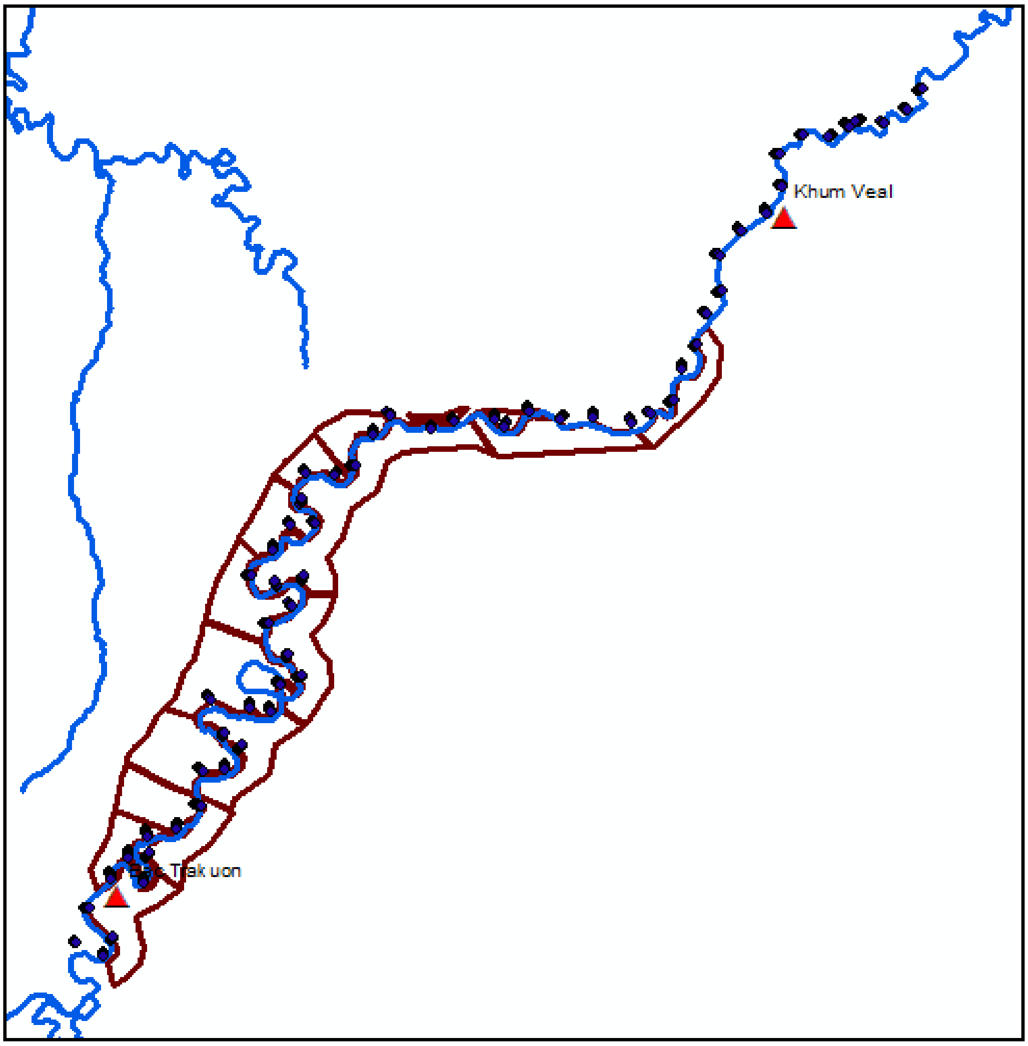
The peak flow event that occurred in 2000 was the largest on record at stations Perk Kdam and Kompong Luong (JICA, 2012). This event was assumed as a reasonable calibration point for high flood conditions. The second calibration point selected, the 2001 peak flow, was the second largest event on record. The third calibration point was the low flow event recorded at the station Kompong Luong. This event was the lowest event on record for this station. Calibration points along the Stung Pursat River are shown in Figure 4-11.

A model test-run was conducted for the year 2000 dry season. This helped identify a number of issues that needed to be changed in order to conform to the observed data. These issues were:

- There are a series of diversions along the main channel of Stung Pursat river for irrigation at the beginning of wet season. There was a need to better understand how these diversions were affecting water levels in the main channel;
- The point of zero flow (datum correction) was poorly defined at the hydrometric stations located at the upstream and downstream boundaries of the model extent;
- Lack of information on river cross-section geometry and adjacent floodplain elevations;
- Data interpolation methods (for river cross-section, flood plain, spill unit, DEM) were not accurate enough to include in model simulations.

After taking the above issues into consideration and making adjustments to the model, it was possible to generate acceptable results that were in close agreement with observed data for the wet and dry seasons.

**Figure 4-11 Model Calibration points along the Stung Pursat River (2000).**




# 5.0 RESULTS AND ANALYSIS

## 5.1 RIVER CATCHMENT MODELING

Model results show that calibrated flows are in agreement with observed flows. Volume ratios (calibrated volume:observed volume) for the stations Bak Trakuon and Khum Veal were close to 100%. Correlation coefficients (R) were 0.617 for Bak Trakuon and 0.6 for Khum Veal indicate moderately strong correlations between observed and calibrated flows at both stations .

Comparison hydrographs for observed and calibrated flows for the stations Bak Trakuon and Khum Veal are shown in Figure 5-1 and Figure 5-2, respectively.

Simulated flows for a period from 1992 to 2011 for the Pursat catchment are shown in Figure 5-3. Water availability is described in terms of monthly distributions of minimum, maximum, and mean flows. Monthly distributions of flows at the 80% and 95% probability of occurrence are also included.

**Figure 5-1 Comparison of Hydrographs between Calibrated and Observed flows at station Bak Trakuon (Volume ratio = 99.73; r = 0.617).**

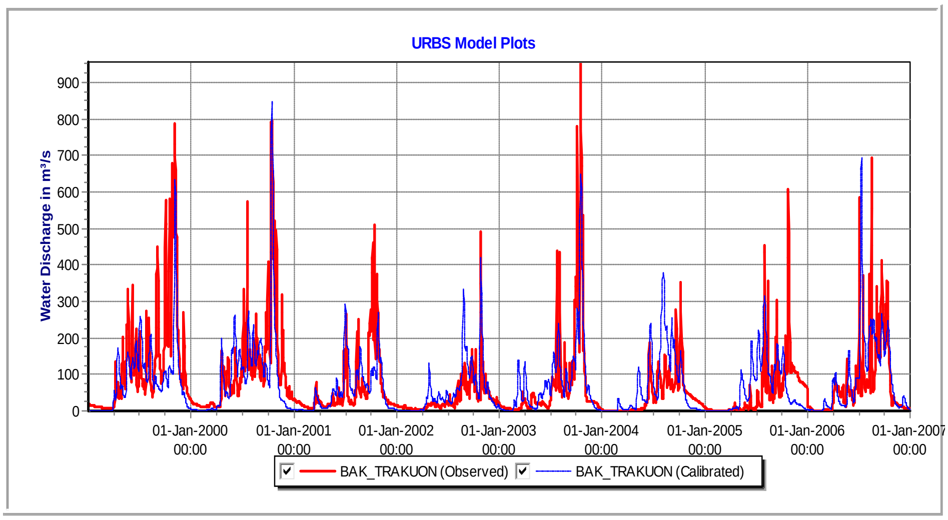



**Figure 5-2 Comparison of Hydrographs between Calibrated and Observed flows at station Khum Veal (Volume ratio = 98.37; r = 0.60).**

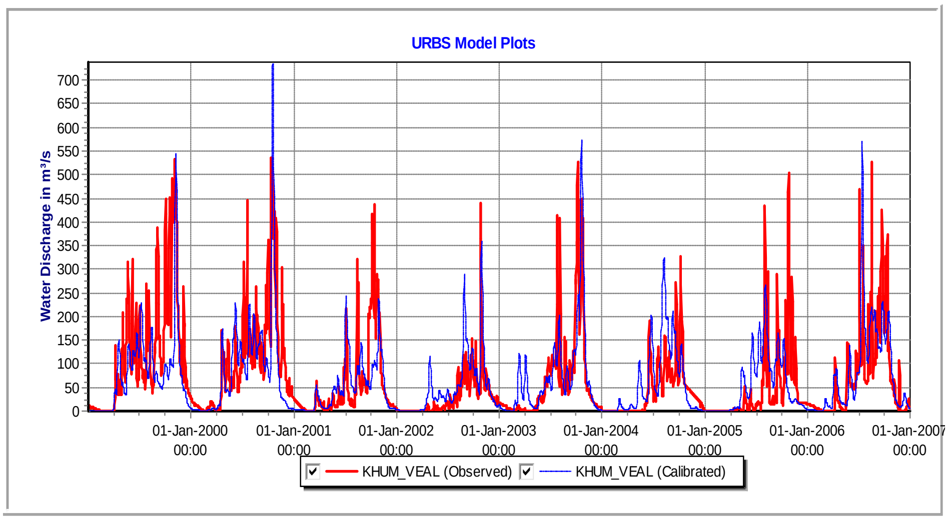
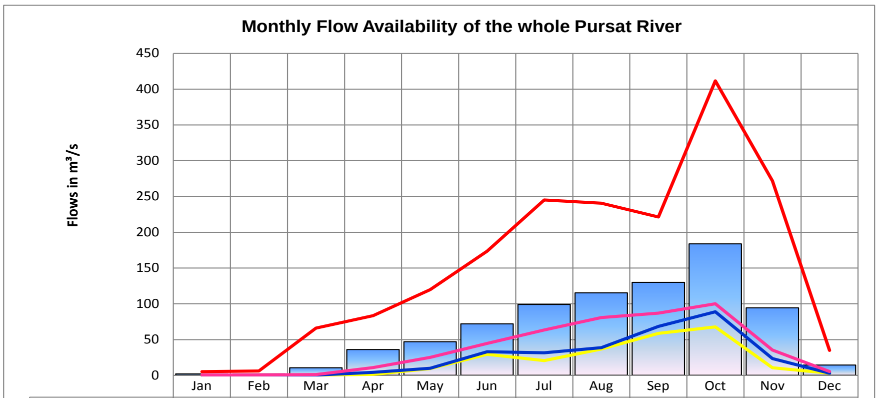


**Figure 5-3 Simulated flows in the Pursat catchment (1992-2011).**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 1.9 | 1.9 | 10.5 | 35.9 | 46.9 | 71.8 | 99.0 | 115.2 | 129.9 | 183.6 | 94.1 | 14.4 |
| Maximum | 5.1 | 6.2 | 66.0 | 83.5 | 119.8 | 173.6 | 245.0 | 240.6 | 221.4 | 411.7 | 271.8 | 34.9 |
| Minuimum | 0.0 | 0.0 | 0.4 | 1.3 | 9.5 | 29.4 | 20.8 | 36.8 | 58.7 | 67.7 | 10.7 | 3.1 |
| 95% Exceedence | 0.3 | 0.1 | 0.5 | 4.2 | 9.9 | 32.9 | 31.6 | 38.7 | 68.6 | 88.8 | 23.4 | 3.1 |
| 80% Exceedence | 0.6 | 0.6 | 1.1 | 11.0 | 25.2 | 44.6 | 63.5 | 80.7 | 87.0 | 100.1 | 35.5 | 5.5 |

## 5.2 WATER BALANCE COMPUTATION

The water balance computations were done by taking into account two scenarios:

1. Natural scenario: the 20-years reference simulated flows were treated as natural flows and they were used directly as input flows to the systems. All 3 dams were excluded; and
2. Dam scenario: Dam No. 1, No. 3, and No. 5 described in Section 2 were considered. The 20-years reference simulated flows were used directly as input flows to the dams and the computed outflows from the dams were used as input flows to the systems.

For the Natural scenario, water balance calculation checks were performed each year to define the deficit at each scheme outlet. Two options of computation were performed:

1. Exclude supplementary water supplies to the Beung Khnar and Svay Donkeo river basins; and
2. Include supplementary water supplies to the Beung Khnar and Svay Donkeo river basins.

Amounts of supplementary water supplies to the Beung Khnar and Svay Donkeo river basins were based on the JICA report (2013a).

The dam scenario includes supplementary water supplies to the Beung Khnar and Svay Donkeo river basins. Two steps of computation were performed:

1. Step 1: use outflow from the hydropower Dam No. 1 and only maintenance flows from Dams No. 3 and Dam No. 5. At each scheme outlet, the water balance checking was performed each year, i.e., by computing the deficit. In some years when water was not enough for the Damnak Ampil extension, then Step 2 was performed; and

2. Step 2: use outflow from the hydropower Dam No. 1 and from Dams No. 3 and No. 5 to overcome the deficit at Damnak Ampil extension, supply downstream reaches, and secure maintenance flows. Deficit years were reevaluated and water surplus at the Damnak Ampil extension was made available to the Svay Donkeo and Being Khnar catchments.

Water balance results for the Natural scenario show that all irrigation schemes are successful when supplementary flows to the Beung Khnar and Svay Donkeo catchment are excluded from the analysis. In contrast, when supplementary flows to the Beung Khnar and Svay Donkeo are included in the analysis, only the Damnak Cheukrom and Charek irrigation schemes are satisfied (Table 5-1).

Results for the Dam scenario show the water requirements for all irrigation schemes could be satisfied with the single water release from hydropower Dam No.1 (Table 5-2). With a combined release from the three dams, there would be no water shortages at any of the irrigation schemes, even if supplementary water releases to the Beung Khnar and Svay Donkeo river basins are considered.

**Table 5-1 Water balance analysis for the irrigation systems in Pursat river basin in Natural scenario.**

| Irrigation Scheme/Alternatives | Irrigated Command Area (Ha) | Using Catchment defined in SAPI | | Using Catchment defined in this CGIAR-DHRW Study | |
|---|---|---|---|---|---|
| | | Excluding supplementary supply to Beung Khnar and Svay Donkeo | Including supplementary supply to Beung Khnar and Svay Donkeo | Excluding supplementary supply to Beung Khnar and Svay Donkeo | Including supplementary supply to Beung Khnar and Svay Donkeo |
| Damnak Chheukrom scheme | 16,100.0 | 4/20 = 1/5 | 4/20 = 1/5 | 4/20 = 1/5 | 4/20 = 1/5 |
| Damnak Ampil headworks | 24,629.0 | 3/20 | 7/20 | 3/20 | 7/20 |
| Loloksar scheme | 580.0 | 2/20 | 6/20 | 2/20 | 7/20 |
| Kbal Hong (RB&LB) | 3,200.0 | 3/20 | 7/20 | 3/20 | 8/20 |
| Charek scheme | 11,000.0 | 5/20 = 1/4 | 5/20 = 1/4 | 5/20 = 1/4 | 5/20 = 1/4 |

| NOTE: | | |
|---|---|---|
| | 4/20 | successful |
| | 5/20 | acceptably successful |
| | 6/20 | Failed |

**Table 5-2 Water balance analysis for the irrigation systems in Pursat river basin in Dam scenario.**

| Irrigation Scheme/Alternatives | Irrigated Command Area (Ha) | Using Catchment defined in SAPI | | Using Catchment defined in this CGIAR-DHRW Study | |
|---|---|---|---|---|---|
| | | Dam #1 only | All 3 Dams | Dam #1 only | All 3 Dams |
| Damnak Chheukrom scheme | 16,100 | 1/20 | 1/20 | 1/20 | 1/20 |
| Damnak Ampil headworks | 24,629 | 3/20 | 1/20 | 3/20 | 1/20 |
| Loloksar scheme | 580 | 1/20 | 1/20 | 1/20 | 1/20 |
| Kbal Hong (RB&LB) | 3,200 | 4/20 | 1/20 | 3/20 | 1/20 |
| Charek scheme | 11,000 | 2/20 | 1/20 | 2/20 | 1/20 |

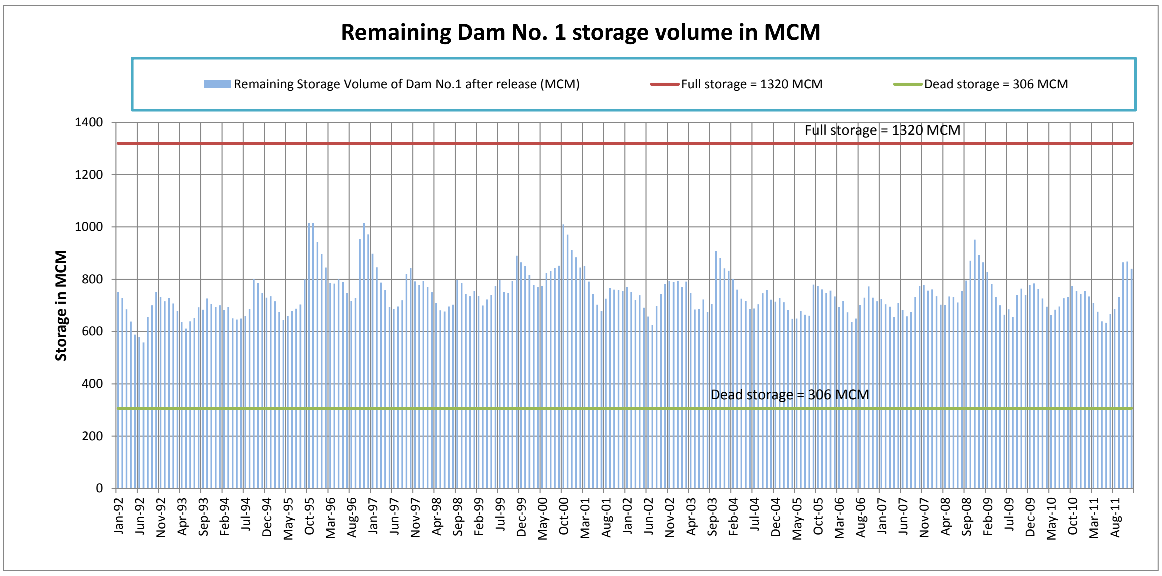
| Note | 1/20 | No deficit in any year |
|---|---|---|

The storage capacity of a reservoir is divided into distinct zones. Dead or inactive storage refers to the water that cannot be drained by gravity through the dam outlet works, spillway, or power plant intake and can only be pumped out. Active or live storage is the portion of the reservoir that can be drained by gravity and can be utilized for flood control, power production, and downstream releases.

Using MRC's RULE program storage capacities were estimated for Dam No.1. Full storage capacity was projected at 1,320 MCM and dead storage at 306 MCM. This translates into an effective storage capacity of 1,014 MCM. These values were used in the water balance simulations for the 20 year reference period (1992-2011). Results show that after taking into consideration all water releases from this dam the remaining storage capacity is on average well in excess of 300 MCM (Figure 5-4).

This water surplus could be used to augment water provided by Dam No. 3 and Dam No. 5 and minimize the possibility of water shortages in the Stung Pursat catchment. Using this scheme, surplus water releases from Dam No.1 will not only generate additional hydroelectric power, but will also improve water security of all irrigation schemes in the Stung Pursat catchment by reducing the safety factors to 1/20.

**Figure 5-4 Simulation of remaining storage volume at Dam No. 1 for the period 1992-2011 (Tes S, 2013).**



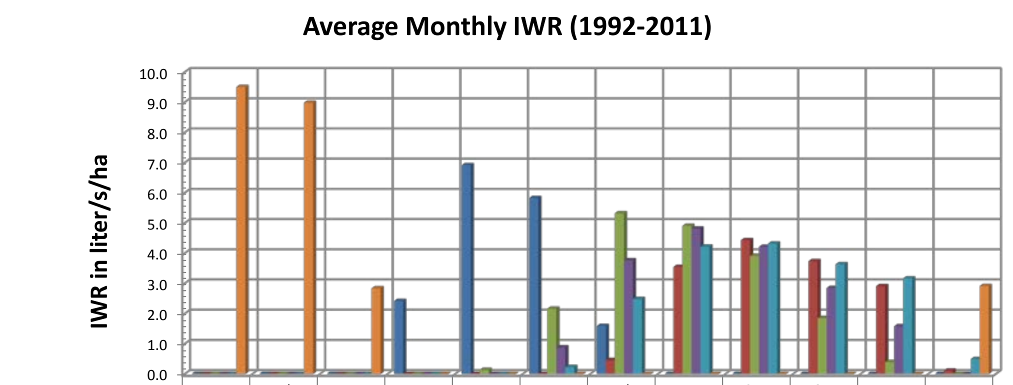

## 5.2.1 Irrigation Water Requirements

Unit diversion irrigation water requirements (IWR) of six cropping patterns for the 20 year reference period (1992 – 2011) were computed and are shown in Figure 5-5. IWR for the following six cropping patterns (JICA 2012) are shown in Figure 5-5:

- A is Basic crop calendar for early wet season paddy;
- B is Basic crop calendar for wet season paddy;

- B1 is Additional crop calendar for irrigation area other than JICA's sub-project;
- B1-15: 15 days ahead of Calendar B1;
- B1+15: 15 days delay of Calendar B1; and
- B2: Dry season paddy direct sowing.

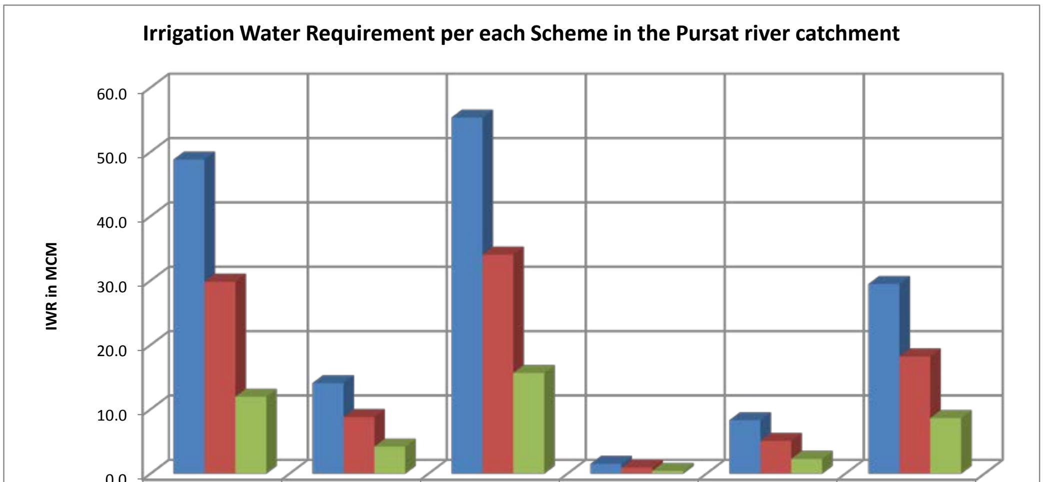
**Figure 5-5 Computed unit diversion irrigation water requirement of each crop (1992-2011).**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A (DS 105 days) | 0 | 0 | 0 | 2.42 | 6.92 | 5.83 | 1.59 | 0 | 0 | 0 | 0 | 0.00 |
| B (TP 115 days) | 0 | 0 | 0 | 0 | 0 | 0 | 0.46 | 3.55 | 4.43 | 3.74 | 2.91 | 0.11 |
| B1-15 (DS 140 days) | 0 | 0 | 0 | 0 | 0.14 | 2.16 | 5.32 | 4.91 | 3.91 | 1.85 | 0.40 | 0 |
| B1 (DS 140 days) | 0 | 0 | 0 | 0 | 0 | 0.88 | 3.77 | 4.82 | 4.21 | 2.85 | 1.58 | 0 |
| B1+15(DS 140 days) | 0 | 0 | 0 | 0 | 0 | 0.23 | 2.48 | 4.22 | 4.32 | 3.63 | 3.17 | 0.49 |
| B2 (DS 90 days) | 9.50 | 8.99 | 2.84 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.91 |

Irrigation water requirements for each irrigation scheme were also estimated for the reference period (1992-2011). Average IWR ranged from 34 MCM at Damnak Ampil to 0.9 MCM at Loloksar (Figure 5-6).

**Figure 5-6 Annual IWR per each scheme (1992-2011).**

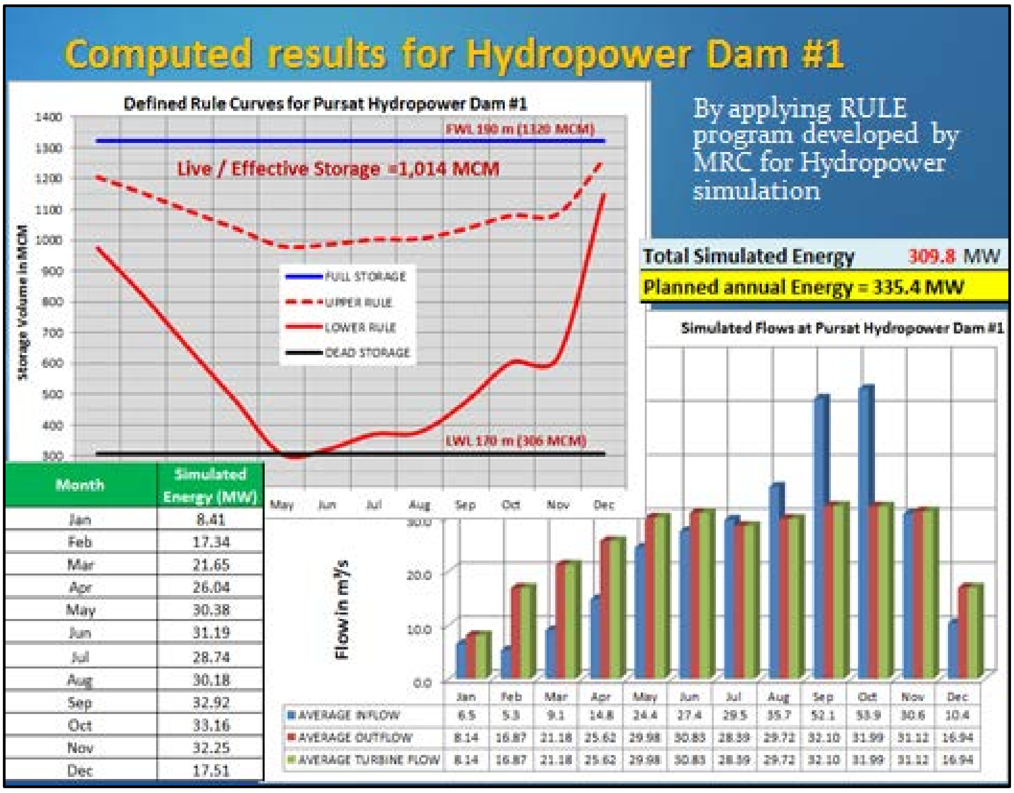



| | Damnak Chheukrom | Orokar | Damnak Ampil | Loloksar | Kbal Hong (LB & RB) | Charek |
|---|---|---|---|---|---|---|
| Maximum | 48.8 | 14.1 | 55.3 | 1.5 | 8.3 | 29.5 |
| Average | 29.8 | 8.8 | 34.0 | 0.9 | 5.1 | 18.2 |
| Minimum | 12.0 | 4.2 | 15.7 | 0.4 | 2.3 | 8.6 |

## 5.2.2 Hydropower Dam Simulation

Simulated results for Dam No. 1 are shown in Figure 5-7. The reservoir's full storage capacity was estimated at 1,320 MCM, dead storage capacity at 320 MCM, and effective storage capacity at 1,024 MCM. Using these storage values and rule curves, the total annual simulated energy production for this dam was estimated at 309.8 megawatts (MW). This estimate is in agreement with the projected energy output of 335.4 MW.

**Figure 5-7 Rule curves, flow and energy simulation for Dam No.1 (MIME, 2013 and) Tes S, 2013).**




## 5.3 EVALUATION OF THE IQQM MODEL FOR VERIFYING WATER BALANCE RESULTS

Due to inadequate data – on land use, land cover, soil type, rainfall, etc. – the URBS model was not able to produce good estimates for water flow (MK16, 2013a). As a result, the IQQM model, which relies on flow data from the URBS model, could not produce good estimates for water use for irrigation. One of the main constraints for modeling is that data is collected on a provincial basis and is subsequently disaggregated to URBS sub-basins. Higher resolution data would significantly improve the estimates of irrigation demand found through IQQM. Furthermore, there is no information on the efficiency of water use for irrigation in Cambodia (Tes S, 2013). Better estimates of irrigation efficiency for each URBS sub-basin will give a more realistic estimate of crop water demands. Moreover, the data on harvested area does not distinguish between irrigated and non-irrigated lands. This results in an exaggerated estimate of the water demand for irrigation (Tes S, 2013).

Finally, there is virtually no information on urban and industrial water demand (MK16, 2013a). An estimate for these values was derived from the provincial population and estimate of water usage per day. A better estimate of population in each URBS sub-basin and data on monthly urban and industrial demand patterns in each district would assist in estimating a more realistic urban and industrial demand.

## 5.4 EVALUATION OF THE ISIS HYDRODYNAMIC MODEL FOR FLOOD AND DROUGHT SIMULATION

Even with limited data, a hydrodynamic model was produced for the main channel of the Stung Pursat for calibration and validation, as described above. Furthermore, for the Khum Veal station, the results for water level and flow simulations were compared to the observed data, as shown in Figure 5-8 and Figure 5-9. As can be seen in these figures, there was greater agreement between simulated and observed values for the water level than flow data at the Khum Veal station.

**Figure 5-8 Simulated and observed water level in Khu Veal (Tes S, 2013).**

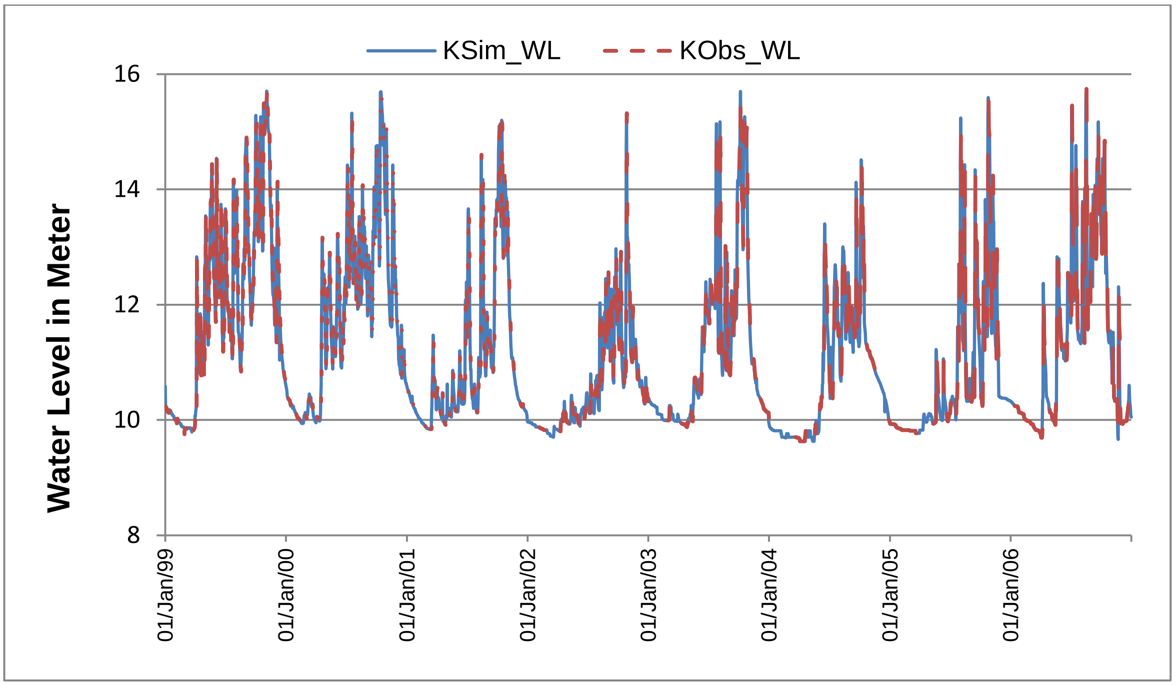
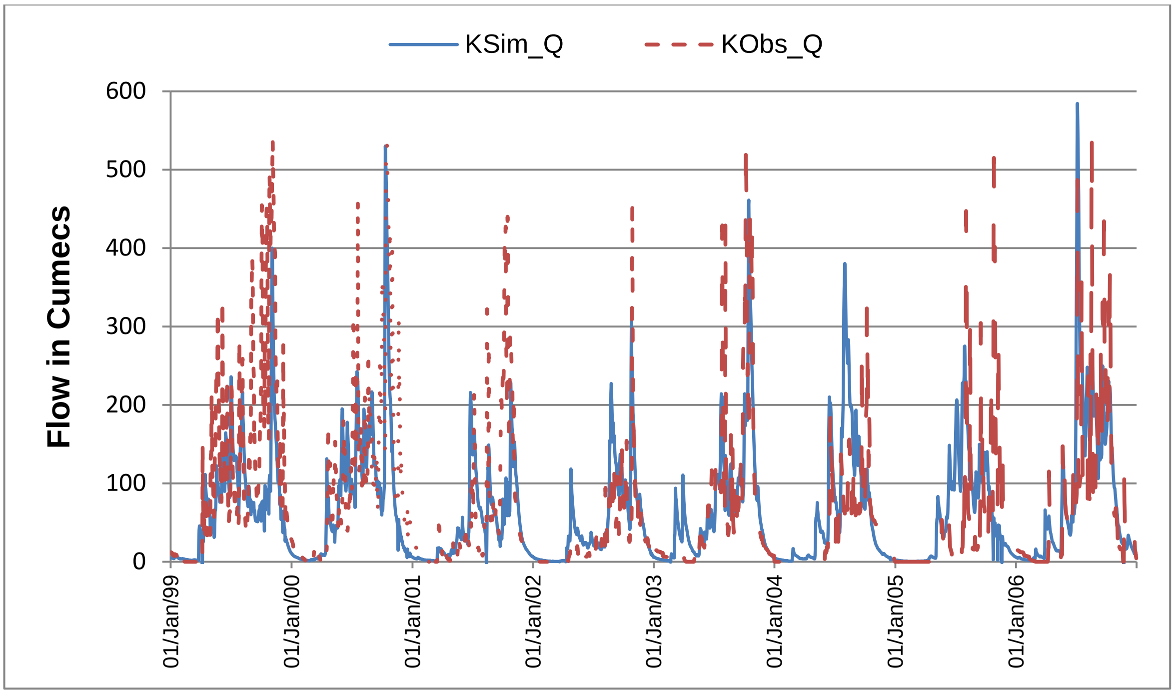


**Figure 5-9 Simulated and observed water flow at the Khum Veal station (Tes S, 2013).**




However, due to inadequate data, the ISIS model was not able to produce forecasts for floods and droughts in the Pursat catchment for the time-being. Important data gaps were revealed:

- Very little data is present for river cross-sections in the main channel. As a result, the representation of the Stung Pursat river in the models was greatly simplified with a consequent reduction in accuracy in the distribution of forecasted outflows;

- Whereas data on water levels is available for the time-period 1999 - 2006, data on discharge is unavailable in terms of real-time observations. Consequently, the result of calibrating the two parameters is poor; and

- There was limited climate data available, and as a result several inaccuracies were introduced in the model.

# 6.0 CONCLUSIONS

Considerable efforts were made by the MOWRAM to develop predictive tools to support a better understanding and management of water resources in the Stung Pursat catchment. However, challenges exist and the paucity of hydro-meteorological data remains one of the central issues that hindered the development of the applied modeling tools.

This study adopted a tripartite approach to describe water resources allocation in the Stung Pursat catchment.

Firstly, a theoretical watershed model (URBS) was developed and calibrated for the Stung Pursat. Model predictions were verified against existing observed data and field measurements and an effort was made to check for inconsistencies. Through model simulations, a synthetic continuous time series of flow data were generated for the period 1992-2011.

Secondly, a water balance simulation was conducted for the Stung Pursat by means of a simplified spreadsheet model. These simulations provided valuable insights about water resources allocations, projected irrigation schemes, and operation of water resources infrastructure (i.e. dams). Results from the water balance model were verified against results produced by the IQQM model.

Results from water balance simulations revealed that water supply under natural flow conditions (i.e. no dams considered) would support 55,509 ha of irrigation schemes in the Stung Pursat. In this scenario, flow would not support additional irrigation schemes for meeting growing demand in the lower part of Stung Pursat catchment in dry season, and in the neighboring catchments of the Svay Donkeo and Beung Khnar rivers (though inter-basin diversion). In contrast, simulations suggest that Dams No.1, 3, and 5 would theoretically store sufficient water to support all existing and planned irrigation schemes in Stung Pursat, Beung Khnar, and Svay Donkeo catchments. Access to the additional water resources would, however, require a strong communication and cooperation between different players, such as dam operators and upstream and downstream irrigation water users. This kind of multi-stakeholder dialog is also necessary to manage resources and mitigate impacts of natural disasters, like floods and droughts.

Lastly, the ISIS hydrodynamic model was developed to simulate time series water level and flow data in the rivers and on the adjacent floodplains. The simulations correlated better with the observed flow data than water level data. The analysis fell short of producing flood forecasts because of limited data availability, particularly for river cross-sections, discharge and climatic parameters in the catchment. Further studies are required to fill these data gaps, either by modeling or through other methods. This information would help to improve water management/allocation and disaster risk reduction practices and planning in the catchment.

# 7.0 RECOMMENDATIONS

Modeling tools can assist with water resource management in catchments. While this report demonstrated how three models produced varying quality (degree, accuracy, and precision) of information about water balance and flooding in the catchment, several recommendations can be made for improving modeling tools in the future:

- Improvements to the existing hydrometric monitoring network:
    - Improvements with respect to monitoring station datum. Efforts should be made to keep datum continuity during the operating life of each station. Permanent and redundant benchmarks should be installed at each station. These should be monitored periodically to make accurate gauge corrections; and
    - Installation of automated hydrometric monitoring stations. Continuous time series of water level data are the backbone of any water resources monitoring program. There is good cellular network coverage in the Stung Pursat. This is an advantage, and telemetry-enabled stations should be installed at key locations within the catchment.
- Expansion of the climate monitoring network in the catchment. Additional rainfall gauges are required, especially for the high elevation regions of the Stung Pursat;
- Improvements with respect to standards used for data collection. Clear standard operating procedures, in line with current international standards, should be prepared (e.g., discharge measurements using current meters, discharge measurements using ADCPs, suspended sediment collection, among others). This will facilitate training and mentoring of new hydrometric technicians, and ensure continuity in the methods used for data collection;
- Implementation of systematic and traceable quality assurance and control (QA/QC) procedures. Currently, water level data corrections, data grading, and rating curve development are not transparent enough;
- Continue with the sediment monitoring program. A good sampling effort started in 2013, but this is not enough to determine a sediment budget for the catchment; and
- Use of available technologies in DHRW (e.g. ADCP) to survey new and to ground-truth existing river cross-sections to fine-tune the developed hydrodynamic model.

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# 9.0 CLOSURE

We trust the above information meets your requirements. If you have any questions or comments, please contact the undersigned.

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