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Optimization of Surface Water Allocation in the Upper Ayeyarwady River Basin

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Abstract

This study investigates the optimization of surface water allocation for hydropower irrigation and navigation sectors in the Upper Ayeyarwady River Basin. AQUARIUS (a modelling system for river basin development planning model) software is used. In this study, Kinda, Sedawgyi, Yeywa, Thaphanzeik, Zawgyi, Shweli, Dapein and Chibwenge hydropower plant are considered as demand sites for hydropower sector. Moreover, Kinda, Sedawgyi and Thaphanzeik irrigated areas are considered as demand sites for agricultural sector. The Ayeyarwady river and these above eight reservoirs are considered as supply sources. The required data for this study are collected from the department of meteorological, the electric power, agricultural and irrigation and inland water transport. Monthly discharges are collected from five stations. CROPWAT 8.0 model is used to calculate crop water requirement (ET_c) and net irrigation water requirement (IWR). For computation of crop evapotranspiration (ET_c), cropping pattern and crop data are required as input data into CROPWAT 8.0 and irrigation water requirement are calculated. Parameter relating water uses for reservoir, hydropower and irrigation water requirement in water system components are calculated. And then, the calculated irrigation water requirement, hydropower data, the reservoir data and economic data are inputted in AQUARIUS model. A flow network is created in the network worksheet screen (NWS) using AQUARIUS model. Flow network is used to determine water allocation for hydropower, irrigation and navigation in the Upper Ayeyarwady river basin. These reservoirs are supplied water to their respective hydropowers and irrigated areas. Based on the year 2014 water supply and demand condition, six future scenarios are simulated. According to model results, the overall allocated flows are about 90340 MCM and the values of State income are $11.42 million per year in the scenario 6.

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As the main purpose of water allocation is balancing supply and demand and, promoting the efficient use of water, this scenario 6 should be selected for irrigation, navigation and hydropower sectors and for maximum State income of the Upper Ayeyarwady River Basin.

Keywords: AQUARIUS model; irrigation water requirement; water allocation; flow network; future scenario; State income.

1. Introduction

Water shortage is one of the real challenges facing many countries in the world. As water scarcity has increased globally, water allocation plans and agreements have increasing significance in resolving international, regional and local conflicts over access to water [5]. In Myanmar, the process of population growth, urbanization and industrialization are occurring at an ever increasing phase at every year. According to report from Asian Development Bank, total water available water resources in Myanmar are around 89% for agriculture, 10% for municipalities and 1% for industries, respectively. Approximately 91% of the total water withdraw comes from surface water [8]. River basins are cradles of many of the ancient civilizations on the earth where humanity is endowed with numerous social and economic services that flowing water provides. The seasonal flow patterns of rivers decide agricultural practices, replenish nutrients in the soil, and support fisheries that feed societies, provide transportation which is the cheapest and the only mode of haulage in several places, supply power and basic water needs for daily life and form the overall cultures and religions in a region. Over the years, a number of computer-based tools that employ simulation and optimization techniques for water allocation have been developed. Among them, AQUARIUS is a state-of-the-art computer model devoted to the temporal and spatial allocation of water among competing uses in a river basin [1]. The water allocation evaluates the hydrologic and economic linkages from water used by hydropower irrigation and navigation for the Upper Ayeyarwady River Basin. The Ayeyarwady River flows through the heartlands of Myanmar. It is Myanmar's largest river (about 2170 km long) and it is the most important commercial waterway. It originates at the confluence of the Mali Hka and Mai Hka rivers in Kachin State. Flow network are used to determine water allocation for hydropower, irrigation and navigation in the Upper Ayeyarwady Basin.

2. Study area and problem statements

2.1. Study area

The principal river of Myanmar is Ayeyarwady River. The Ayeyarwady River runs through the country from north to south and empties into the Andaman Sea. The Ayeyarwady River has its source from the confluence of the Mali Kha and Mai Kha Rivers, both of which originate from the Eastern Himalayas and the Tibetan Plateau. The Ayeyarwady Basin area is 414,100 km^2, over 90% lies within Myanmar with some small parts in China and India. Over half of the basin area is forested. About 36.1 million live in the Ayeyarwady Basin. Cultural diversity is high within the basin comprising predominantly Kachin in the upper basin, Burman in middle and lower as well as Karen, Arakan, Shan and Chinese [7]. The Ayeyarwady River empties through a nine-armed delta (Bassein, Thetketaug, Ywe, Pyamalaw, Pyinzalu, Ayeyarwady, Bogale, Thande), the Ayeyarwady Delta, one of the world's major rice growing areas contributing 60% of Myanmar's rice production. Ayeyarwady River basin is covered about 57% of the country area. The Ayeyarwady River can be divided into two parts upper and lower basin. The portion just lying above confluence with Chindwin River is known as the upper Ayeyarwady River basin. Upper Ayeyarwady river is 1310 length (km) and catchment area is 1933000 km^2. It lies between 20° 22' and 28° 31' north latitude and 94° 56' to 98° 45' east longitude. The study area is covered by Kachin State, Mandalay Division, south eastern part of Sagaing Division and western part of Shan State. The basin has eight hydro powers such as Kinda, Sedawgyi, Yeywa, Thaphanzeik, Zawgyi., Shweli, Dapein and Chibwenge and three irrigated area such as Kinda, Sedawgyi and Thaphanzeik. The location map of study area is shown in Figure 1.

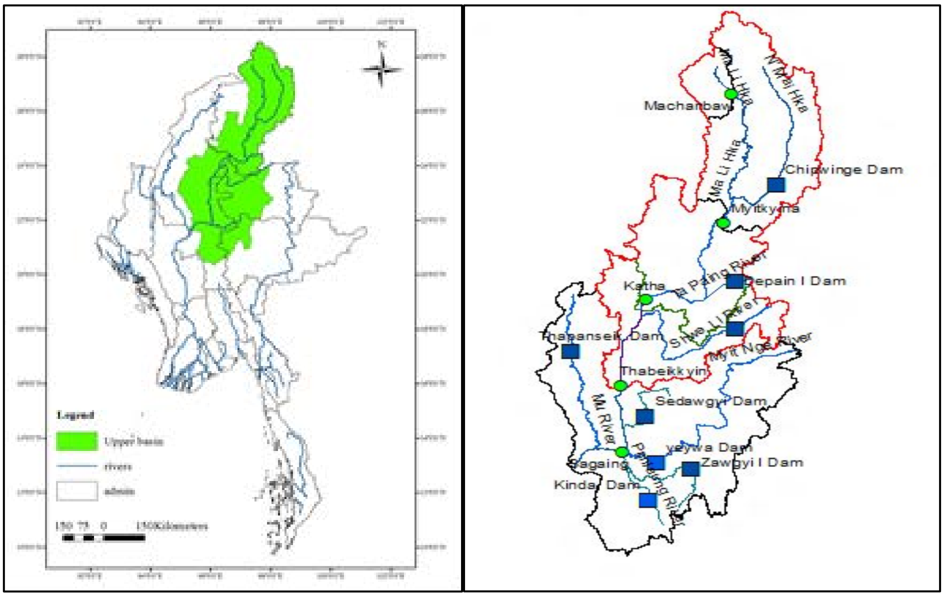

Figure 1: Location Map of Study Area

Chibwenge dam is located in near Chibwe Township, Kachin State. The design capacity of the hydropower station is 99MW of Pelton turbine. It is situated at north latitude 98.130188 and east longitude 25.882923. Shweli dam is situated in Namkham, near Man Tat village (Palaung) Shan (N) State and Dapein dam is located in Dawphoneyan Township, Kachin State. The design capacity of the hydropower station are 100MWx6 units and 240MWof Francis turbine. Zawgyi dam is located in Yatsauk, Shan (S) State. The design capacity of the hydropower station is 6MWx2 units of Francis turbine. Yeywa dam is located in Mandalay Kyauksei Township. The design capacity of the hydropower station is 197.5MWx3 units of Francis turbine. It is situated at north latitude 21°41′20″and east longitude 96°25′17″. Thaphanzeik Dam is an earth dam type and it is constructed to supply water to the irrigable area and hydropower. Thaphanzeik Dam is situated near Thaphanzeik Village in Kyunhla Township, Shwe Bo District, Sagaing Division. The design capacity of the hydropower station is 10MWx3units of Kaplan turbine. The main dam lies at north latitude 95° 22' 0" and east longitude 23° 19' 0". In this study 14 years meteorological data (2001-2014) are collected from 10 stations (Ye U, Shwe Bo, Sagaing, Butalin, Tabayim, Taze, Kanbalu, Wetlet, Khin U and Ayardaw). These are minimum and maximum temperature, wind speed, relative humidity, sunshine and rainfall. Sedawgyi dam is located in Madayar, Mandalay Division. It is situated at north latitude 22°24′2.70″and east longitude 96°18′1.298″.The design capacity of the hydropower station is 12.5 MW x 2 Units of Kaplan turbines. In Sedawgyi irrigated area, 20-

years (1995-2014) recorded local meteorological data for Mandalay Station are used to calculate reference evapotranspiration (ET_0). The Kinda Dam is located in Myitthar Township, Kyaukse District of Mandalay Region. It is situated at north latitude 21° 09' 52" and east longitude 96° 19' 56". The meteorological data of 15 years record are collected for the period of 2000-2014 in the Kinda irrigated area. The minimum and maximum temperature, wind speed, sunshine, relative humidity and rainfall are collected from Kyaukse, Meiktila and Tadaoo stations. In this study, fixed percentage method is used to calculate effective rainfall. Since FAO suggest that for most rainfall values below 100 mm/month, Fixed Percentage method is selected and 80% is given as requested value.

2.2. Problem Statements

The river flow is also necessary to maintain and safeguard proper functioning of the river including several subsistence uses such as subsistence irrigation, hydropower developments, navigation, using of riparian people and livestock etc. Allocating water efficiently to all water uses is a critical issue. To assess the water allocation on the local or sub-basin scale, a case area can be used. Moreover, water allocation is often focused on maximization of benefit or minimization of shortage of water. A number of studies carried out on hydro-economic modeling for water allocation considering different allocation criteria such as improvement of basin water use efficiency and alternative water pricing etc. In several modeling studies the instream water use benefits are mainly considered as hydropower generation and lake and reservoir recreation. However, it is apparent in many developing countries that the poor's livelihood carries significantly more economic value than recreation. Dams also result in adverse impacts to the flow regime of a river with grave implications to the health of floodplains and the ecosystem services they provide to local livelihoods. Major threats to the ecological and hydrological integrity of the Ayeyarwady River Basin include: hydropower developments; logging and deforestation; mineral prospecting; unsustainable fishing practices and overfishing; land use change; habitat destruction; and climate change. The navigation route needs to be maintained, particularly from Hyacinth growth and keeping depth required for navigation in order to intensify transport of passengers and goods. Inland water transportation, which is expected to be low cost and a means of mass-transit transportation, is impeded by large difference of water level between rainy and dry season in Myanmar. Inland water transportation in dry season is sometimes very difficult as a lot of shallow places (only 1m draft) appeared in Ayeyarwady River. Shallow water depth of navigable waterways due to water shortage during the hot season in some parts of Inland Water Transport at Mandalay Station is shown in Figure 2.

Figure 2: Some Part of Inland Water Transport at Mandalay Station

In most dams, problems have risen that during the rainy season, the water level is too high in the reservoir and the spill gates have to be opened shown in Figure 3. This leads to large flow going downstream of the dam into the irrigation network and causes flooding of irrigated fields. A lot of water is wasted in such a way and it is not used for agriculture. So, this leads to a low overall efficiency of water usage of dam.

Figure 3: Flooding of Paddy Fields during the Rainy Season and Overflowing from Spill Gates in Sedawgyi Dam

3. Data and methodology

AQUARIUS was developed by Diaz and Brown (1997) to describe an analysis framework rather than a single dedicated model for water allocation. The computational model developed here employs Aquarius to represent the hydropower and irrigation in Upper Ayeyarwady River Basin as a network of demand and supply nodes for surface water. Using a monthly time step to optimize derived in a single year, quantitative data describe the physical characteristics of these demand and supply nodes, including the spatial relationships among upstream uses, return flows, and downstream outcomes. The software AQUARIUS requires incoming water inputs as monthly data.

In order to apply Aquarius model to the upper Ayeyarwady basin, the major steps involved are data preparation, a flow network, physical data and economic data. The incoming water inputs data requires as monthly data. Model data for these reservoirs include the initial and final storage volumes, minimum and maximum storage capacities. Specific area storage and elevation-storage curves describe the monthly fluctuation in the volume of water stored. Aquarius facilitates the interpretation and analysis of all that information through readily accessible graphical output display formats. Year 2014 is used as reference year which is the basic definition of the water supply as it currently exists including specification of supply and demand data for the first year of study on a monthly basis. The study period may start from January, 2014 and end at December, 2023. The upper ayeyarwaddy River basin is represented by the flow network, in which the water flows from left to right.

In this study, the flow characteristics of the upper Ayeyarwady River basin are analysed based on 10 years (2005 – 2014) mean monthly flow at five stations, Sagaing, Thebeikkyin, Katha, Myitkyina and Machanbaw Basin which was obtained from meteorological department. The natural flows in the system are regulated by eight reservoirs: Kinda, Sedawgyi, Yeywa, Thaphanzeik, Zawgyi, Shweli, Dapein, and Chibwenge and three irrigated area such as Kinda, Sedawgyi and Thaphanzeik. Hydropower is generated using releases from these eight reservoirs. The powerplants and irrigated areas operate directly connected to the reservoir. Additional nodes and links can be added to a network, but links can only be placed between existing nodes.

3.1. Water Allocation Plan

The flow chart of scenarios for optimal water allocation plan for study area is shown in Figure 4.

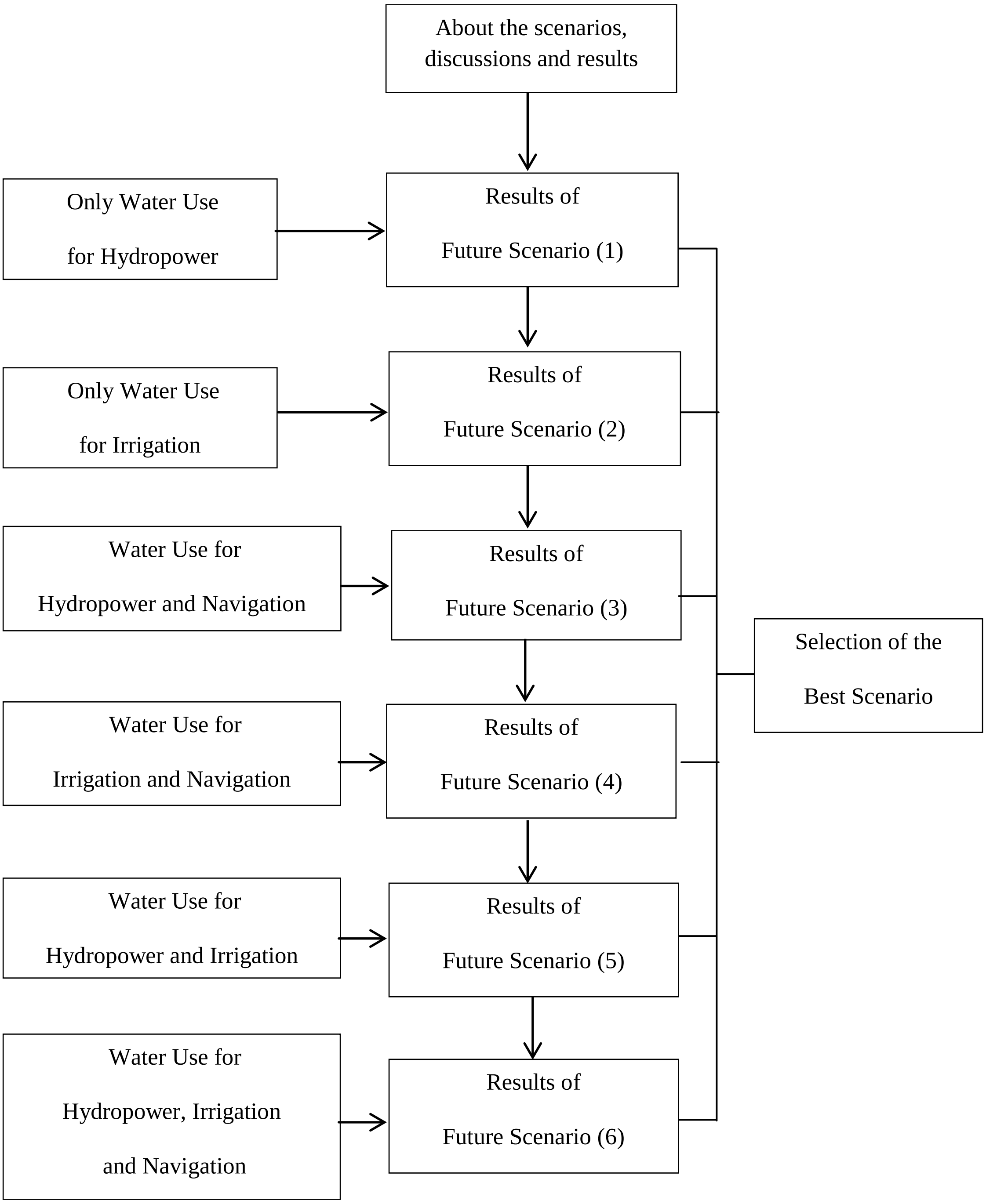

Figure 4: Flow Chart of Scenarios to Water Allocation Plans

3.2. Water Use for Hydropower

Reservoirs play an important role during the process of allocating water in the basin. The foremost water use in the basin is power generation. For each reservoir AQUARIUS requires the corresponding physical characteristics (i.e., minimum and maximum volume, elevation vs storage and area vs storage functions), the operational characteristics (i.e., volumes at the initial and final) as well as the operational constraints. Elevation versus storage function is used by $E=c_1S^{d1}$ (as a power function). Surface area versus storage function is used by $A=c_2S^{d2}$ (as a power function). Initial and final storage, minimum and maximum storage are imposed as operational constraint for each reservoirs. Physical characteristics related to power plant such as installed capacity, design discharge, effective head and power production are collected from the electric power station. The generated electrical energy, P (kW) is approximated by P(kW)=9.8ηQH. The energy rate function (erf), which calculates the amount of energy (in kilowatt hours) generated by the plant per unit volume of water released through its turbines (in cubic meters) during a unit period of time (one hour), which is expressed in and erf (kWh m)=1/367ηH. Plants operate directly connected to their reservoirs. In hydropower sector, eight hydropowers around upper Ayeyarwady river Basin, such as Kinda, Sedawgyi, Yeywa, Thaphanzeik, Zawgyi, Shweli, Dapein and Chibwenge power plant, are considered as demand sites and for these above eight reservoirs and five discharges stations of upper Ayeyarwady river as supply sources.

The required data, such as installed capacity, design discharge, effective head and power production are collected from the electric power station. The storage volume of principal reservoirs to the surface water elevation and area are firstly calculated by a power function. The energy rate function is estimated by the linear functions and State income of power plant is estimated by an exponential function. The upper Ayeyarwady river basin for hydropower plant is represented by the flow network in Figure 5.

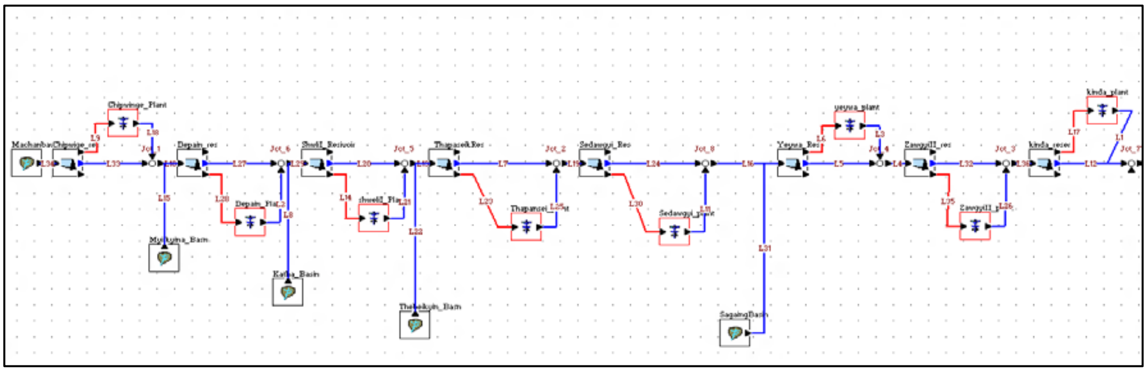

Figure 5: Schematic Map of Aquarius Model for hydropower plant of upper Ayeyarwady River basin

3.3. Water Use for Irrigation

In this study, CROPWAT 8.0 model is used to calculate crop water requirement and net irrigation requirement to input irrigation demand node. CROPWAT is a decision support system for planning and management of irrigation. All calculation procedures used in CROPWAT are based on two FAO publications of the Irrigation and Drainage series No. 33 and 56. In order to run properly, CROPWAT 8.0 model needs some input data, namely, climatic and rainfall data, crop characteristics. After all data have been correctly inputted, the monthly results, such as reference evapotranspiration (ET_0), effective rainfall, actual crop evapotranspiration (ET_c) and net irrigation water requirement are ouputted. Then, the different irrigated areas around upper Ayeyarwady basin are constructed by AQUARIUS model. Three irrigated area were considered such as Kinda, Sedawgyi and Thaphanzeik. The summary of total net Irrigation water requirement for Thaphanzeik, Kinda and Sedawgyi irrigated are shown in Table 1.

Table 1: Net Irrigation Water Requirements for Thaphanzeik, Kinda and Sedawgyi Irrigated Areas (MCM/month)

Township	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Butalin	6.60	3.00	3.80	5.70	4.30	3.90	8.60	3.90	0.00	0.30	5.30	8.10
Ayardaw	1.50	1.00	0.20	0.00	0.00	0.80	1.80	0.70	0.00	0.00	0.60	1.40
Kanbalu	0.00	2.70	13.70	33.50	7.60	7.50	18.80	0.70	0.00	0.50	0.50	0.00
khin-u	5.10	3.30	17.40	46.30	40.90	17.80	36.70	2.00	0.00	0.60	8.20	6.60
Sagaing	4.30	1.20	0.00	0.00	0.00	1.60	5.50	3.50	0.50	0.00	0.70	3.30
Taze	23.60	4.80	23.10	38.80	23.80	19.60	28.10	1.10	0.00	1.00	18.70	26.10
Tabayin	42.90	3.30	5.00	35.90	26.60	21.40	52.90	9.70	0.00	0.50	21.60	36.70
Ye-U	18.10	12.50	40.00	72.10	25.70	23.50	46.60	5.20	0.00	0.00	15.00	19.30
Shwebo	13.80	3.80	57.40	139.20	76.90	55.60	69.10	7.50	0.60	0.10	19.50	32.70
wetlet	41.90	17.00	47.20	117.60	49.40	34.90	67.10	3.70	0.20	13.90	69.90	88.40
Kyaukse	4.81	3.26	3.17	4.23	0.00	4.04	5.69	3.89	0.15	0.02	2.21	0.57
Wundwin	2.77	2.28	6.31	9.54	4.90	4.51	3.76	6.01	0.52	2.72	11.60	7.91
Myitthar	14.84	7.87	29.68	29.57	0.00	15.24	31.18	14.08	0.53	0.00	5.52	2.29
Tadaoo	1.59	1.22	0.00	0.00	0.00	2.17	2.24	1.39	0.00	0.00	0.27	0.81
Mandalay	0.00	0.00	0.02	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Amarapura	0.14	0.22	2.46	6.24	2.21	1.40	0.26	0.02	0.00	0.36	1.61	0.85
Patheingyi	1.40	1.16	5.55	13.39	5.11	3.34	0.54	0.04	0.00	0.80	3.81	2.60
Mattaya	9.45	8.76	13.43	25.32	8.67	4.27	2.14	0.17	0.00	0.87	4.92	6.24

The flows from Machanbaw, Myitkyina and Katha and Thebeikkyin subbasin are regulated by AQUARIUS model in the middle part and flow to the Thaphanzeik Reservoir and the Sedawgyi reservoir. The flow from the above four subbasins and Sagaing subbasin supply to Kinda reservoir. These reservoirs are conveyed water into different irrigated areas. State income for irrigation water use from irrigation department is estimated. The AQUARIUS model for irrigated area shown in Figure 6 consists of three reservoirs node in which supply and demand nodes were connected by red links.

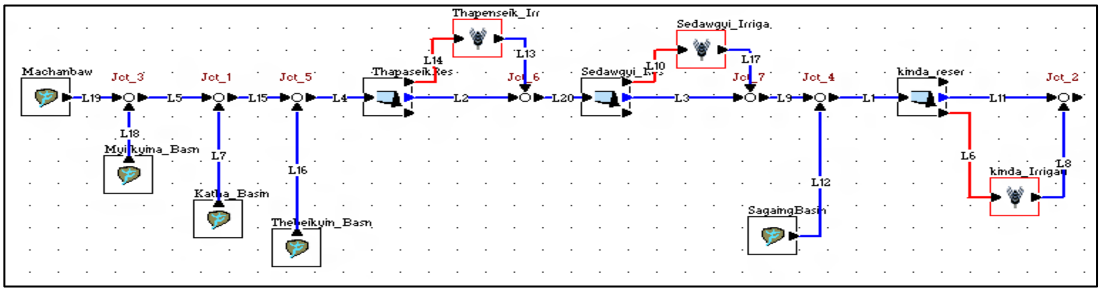

Figure 6: Schematic Map of Aquarius Model for Irrigated Area of upper Ayeyarwady River Basin

3.4. Water Use for Navigation

Navigation is the main direct water use and an important mode of transportation. The main function of Inland Water Transport (IWT) is to carry out the transportation of passenger and commodity at low cost along the navigable waterways of upper Ayeyarwady River in Myanmar. Wet season is favourable for navigation whereas income becomes the lowest in the dry season. Average discharge flow is considered to develop the total benefit function for navigational water use. In this study, the flow characteristics of the upper Ayeyarwady river basin are analyzed based on 10 years (2005 – 2014) mean monthly flow at Mandalay station. The required parameters are estimated by the linear function. A very low flow is found in the driest month as most likely in February. Estimating the total benefit from instream use required data from the inland water transport. According to the early dry season (December and January) follows the low income whereas income falls to the lowest in the February. The late dry season month, March normally follows an income pattern similar to that of the February. Income in intermediate flow season (April and May) increased than the dry season. The wet season months (August and September) rise income and (June and July) reach a peak income. The State income is considered as the economic benefit from navigation water use. State income for navigation water use from inland water transport estimated at Mandalay station. Opportunity costs of time and labour of the concerned group are regarded negligible in the context of poor socio-economic condition of the study area and considered as zero. Capital cost has not been accounted for in this study. Low flow season, except severe low flow, for the fishermen and high flow season for the inland water transport are economically beneficial. The upper Ayeyarwady river basin for irrigated areas, hydropower plant and navigation is represented by the flow network in Figure 7.

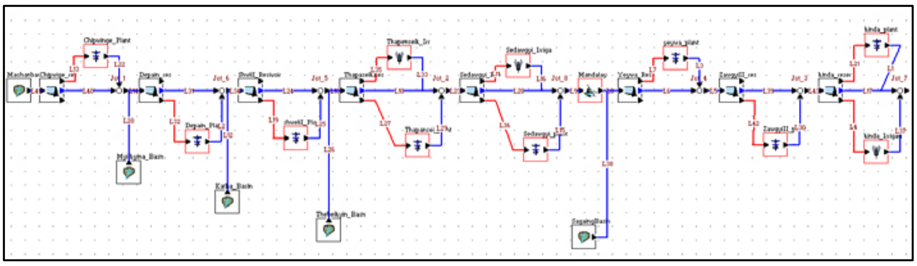

Figure 7: Schematic Map of Aquarius Model for Irrigated areas, Hydropower Plant & Navigation of Upper Ayeyarwady River Basin

4. Results and discussions

4.1. Results of Future Scenario 1(Only Water Use for Hydropower)

The scenario represents the current system condition with water supplies for eight reservoirs. It is based on Year 2014 condition for which the current data are established. These reservoirs regulate the natural flows by Aquarius and inflows from the river basin enter to the reservoir. Releases water from the reservoir supply to the power plant by Aquarius. The average total inflows are about 254912 MCM for eight reservoirs. The scenario was based on the required data of eight hydropower plant in the year 2014.

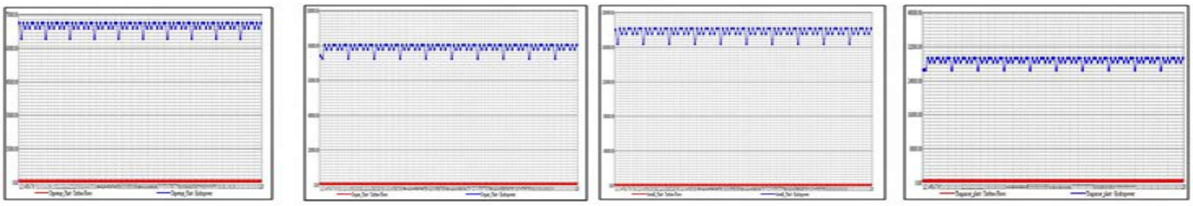

Figure 8: Turbine Flows and Hydropower Generation for Chipwinge, Dapein Shweli and Thaphzeik Plant

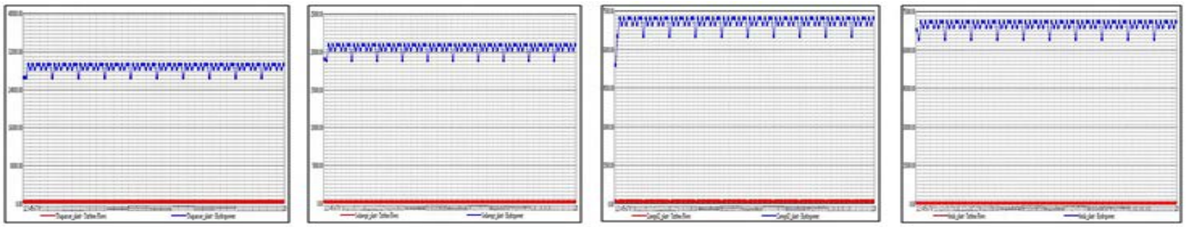

Figure 9: Turbine Flows and Hydropower Generation for Sedawgyi, Yeywa, Zawgyi and Kinda Plant

Figure 8 and 9 represented the results from powerplant flows and hydropower generation for the Chipwinge, Dapein, Shweli, Thaphzek, Sedawgyi, Yeywa, Zawgyi and Kinda hydropower. According to model results, the average turbine flows are about 2209, 730, 699, 631, 294, 497, 237,103 MCM for Yeywa, Shweli, Dapein, Chipwinge, Kinda, Thaphzek, Sedawgyi and Zawgyi hydropower. The percentages in power production are about 31%, 27%, 12%, 10.7%, 10.6%, 4%, 3% and 1% for eight hydropowers. The State income of powerplant function is estimated by an exponential function. The average value of State income of powerplant are about $1.1, 0.46, 0.36, 0.34, 0.27, 0.15, 0.13 and 0.05 million per year in Yeywa, Shweli, Dapein, Chipnge, Kinda, Thaphzek, Sedawgyi and Zawgyi hydropower. The average values of State income of powerplant are illustrated by the graphs in Figure 10 and 11.

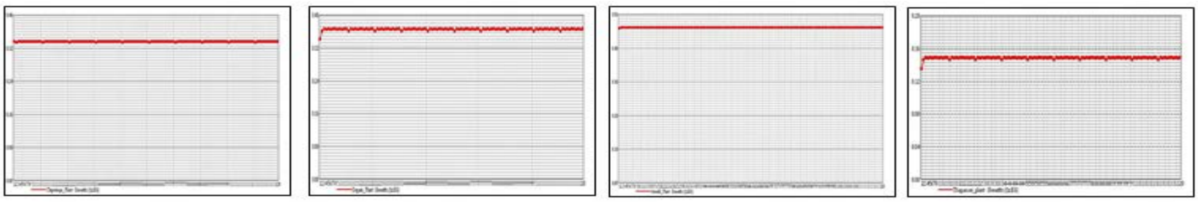

Figure 10: State Income for Chipwinge, Dapein, Shweli and Thaphzeik Plant

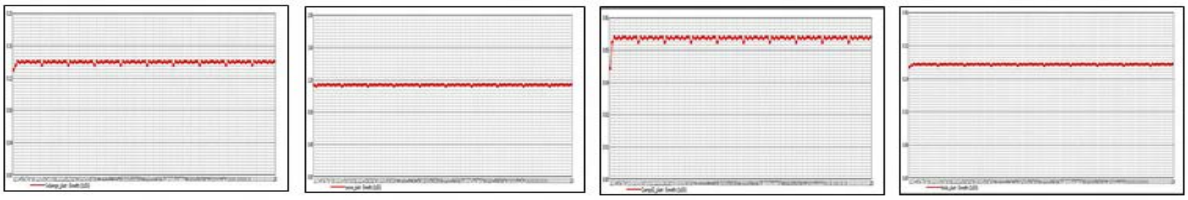

Figure 11: State Income for Sedawgyi, Yeywa, Zawgyi and Kinda Plant

4.2. Results of Future Scenario2 (Only Water Use for Irrigation)

This scenario represents water use for irrigation for Kinda, Sedawgyi and Thaphanzeik Reservoir. The irrigable areas are 85603 acres, 107463 acres and 742058 acres and supplied to different irrigated areas. Figure 12 show allocated flows, return flows and State income for Kinda, Sedawgyi and Thaphanzeik irrigated areas. The model results revealed that the average allocated and return flows are about 18580, 21574 and 37164 MCM and 9290, 10787and 18582MCM for Sedawgyi, Kinda and Thaphanzeik different irrigated areas. According to model results, the values of State income for irrigation water use are about $0.057, 0.055 and 0.053 million per year.

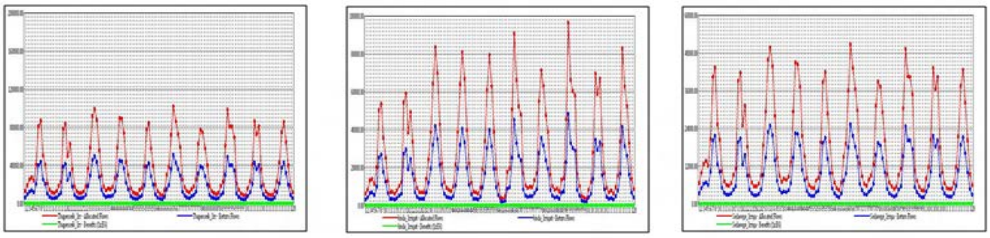

Figure 12: Allocated Flows, Return Flows and State Income for Kinda, Sedawgyi and Thaphanzeik

4.3. Results of Future Scenario3 (Water Use for Hydropower and Navigation)

The scenario was considered the combination of hydropower and navigation sector. The graphs in Figure 13 and 14 are illustrated the outcomes from turbine flows, hydropower generation and state income for Chipwinge, Dapein, Shweli, Thaphzeik, Sedawgyi and Yeywa plant. According to model results, the average turbine flows are about 5399 MCM and the values of total State income of powerplants are about $2.9 million per year for hydropower sector.

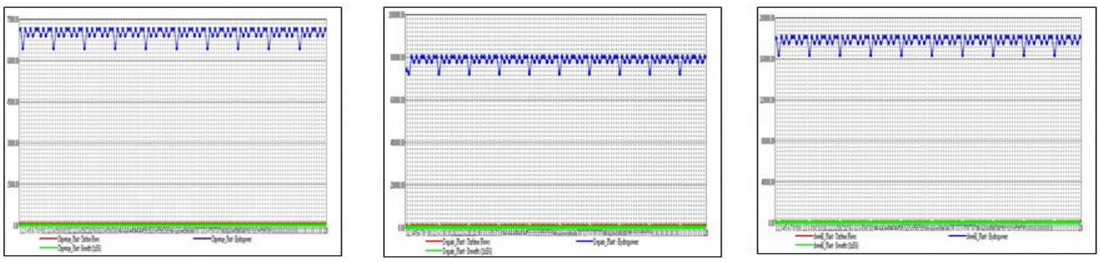

Figure 13: Turbine flows, Hydropower generation and State Income for Chipwinge, Dapein and Shweli Plant

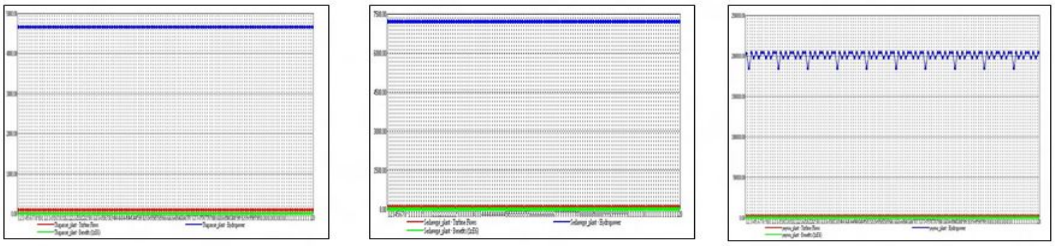

Figure 14: Turbine flows, Hydropower generation and State Income for Thaphzeik, Sedawgyi and Yeywa Plant

The model results revealed that the average allocated flow is about 9286MCM for navigation sector. The values of total State income are about $8.39 million per year for navigation sector. Figure 15 represented the results turbine flows, hydropower generation and State income for Zawgyi, Kinda and allocated flows and State income at Mandalay Station from navigation water use.

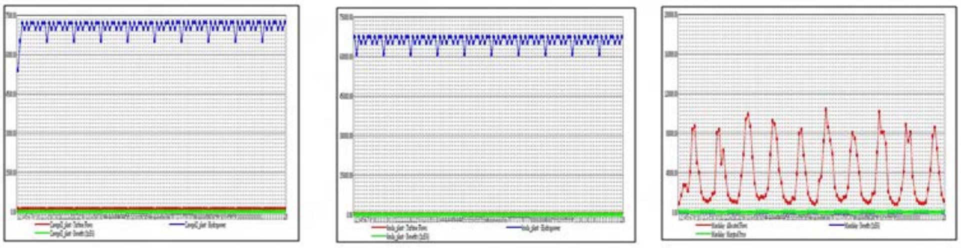

Figure 15: Turbine flows, Hydropower generation and State Income for Zawgyi, Kinda and Allocated Flows and State Income for Mandalay Station

4.4. Results of Future Scenario 4 (Water Use for Irrigation and Navigation)

The scenario was considered the combination of irrigation and navigation sector. And Kinda, Sedawgyi and Thaphanzeik irrigated areas were considered as demand sites for irrigation sector. The results from allocated flows, return flows and State Income for Kinda, Sedawgyi and Thaphanzeik irrigated areas and allocated flows and State income for Mandalay Station are represented in Figure 16.The model results revealed that the average allocated flow is about 9290 MCM and State income are about $8.42 million per year for navigation sector. According to model results, the average allocated flows and return flows are about 77317MCM and 38658 MCM and the State incomes are about $0.168 million per year for irrigation sector.

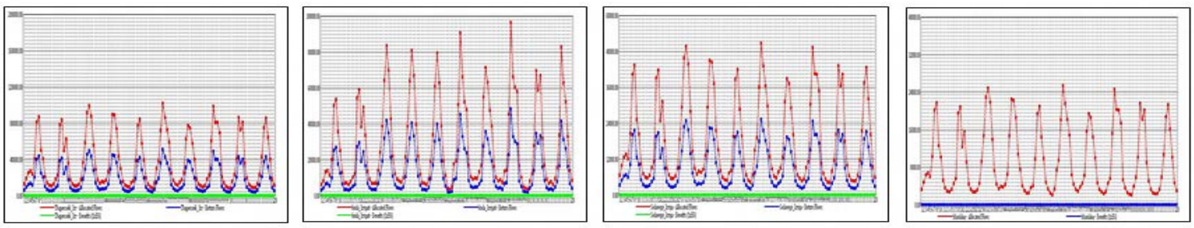

Figure 16: Allocated Flows, Return Flows and State Income for Kinda, Sedawgyi and Thaphanzeik and Allocated Flows and State Income for Mandalay Station

4.5. Results Of Future Scenario 5 (Water Use for Hydropower and Irrigation)

The scenario 5 is considered from demand side of hydropower and irrigation sector. The results from the turbine flows, hydropower generation and State income for Chipwinge, Dapein Shweli, Thaphzeik, Sedawgyi, Yeywa, Zawgyi and Kinda plants are represented in Figure 17 and 18. The overall average turbine flows and hydropower generation are required about 4972.4 MCM and 617595GWh and the State income is $2.78 million per year.

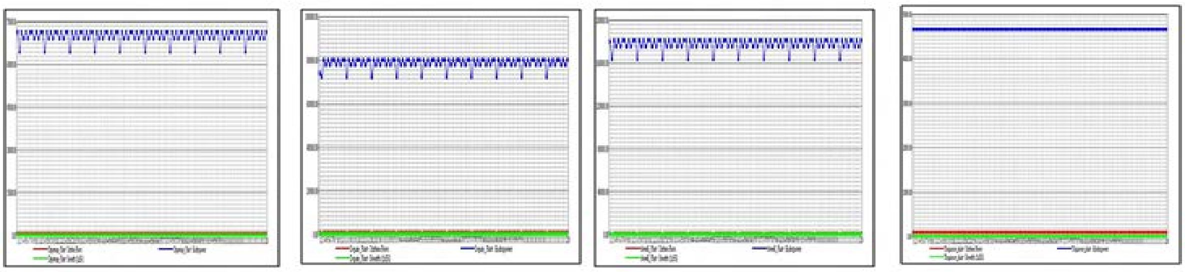

Figure 17: Turbine Flows, Hydropower Generation and State Income for Chipwinge, Dapein Shweli and Thaphzeik Plant

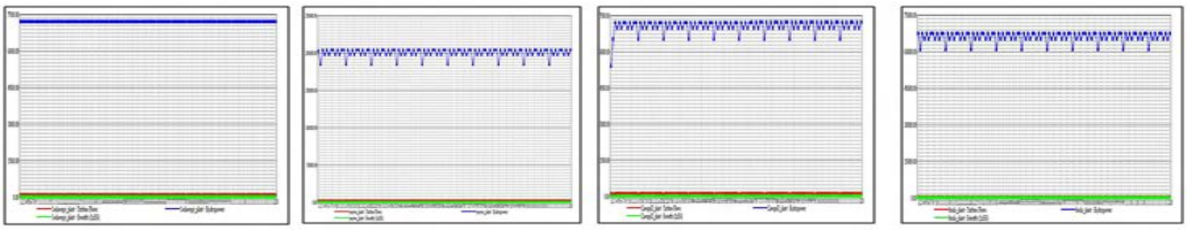

Figure 18: Turbine Flows, Hydropower Generation and State Income for Sedawgyi, Yeywa, Zawgyi and Kinda Plant

According to model results, the overall average allocated and returns flows are about 76084MCM and 38042 MCM and the value of State income for irrigation water use is about $0.1658 million per year. The results from allocated flows, return flows and State Income for Kinda, Sedawgyi and Thaphanzeik irrigated areas are represented in Figure 19.

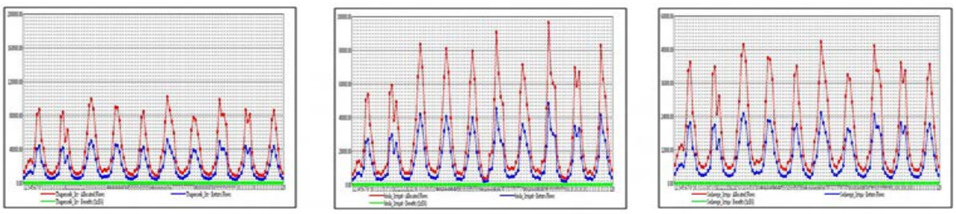

Figure 19: Allocated Flows, Return Flows and State Income for Kinda, Sedawgyi and Thaphanzeik

4.6. Results of Future Scenario 6 (Water Use for Hydropower, Irrigation and Navigation)

The scenario 6 considers the combination of hydropower, irrigation. Figure 20 and 21 are illustrated the results from turbine flows, hydropower generation and State income for Chipwinge, Dapein, Shweli, Thaphzeik, Sedawgyi, Yeywa, Zawgyi and Kinda plant. At the last scenario 6, the overall average turbine flows and hydropower generations are required about 4970 MCM and 617857 GWh and the State income is $2.8 million per year.

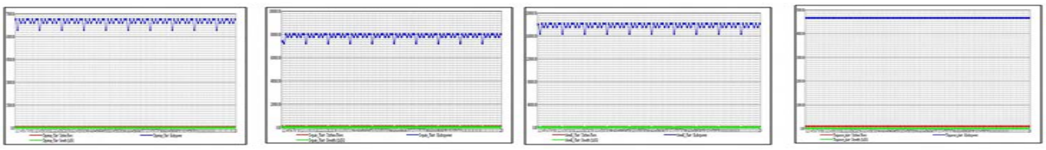

Figure 20: Turbine Flows, Hydropower Generation and State Income for Chipwinge, Dapein Shweli and Thaphzeik Plant

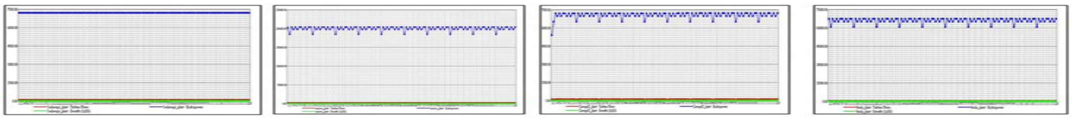

Figure 21: Turbine Flows, Hydropower Generation and State Income for Sedawgyi, Yeywa, Zawgyi and Kinda Plant

In this scenario, the allocated flow and State income is about 9286 MCM and $8.392 million per year for navigation sector. The allocated, return flows and State income are about 76084 and 38042 MCM and $0.165 million per year in irrigation sector. The results from allocated, return flows and State Income for Kinda, Sedawgyi and Thaphanzeik irrigated areas and allocated flows and State income for Mandalay Station are represented in Figure 22.

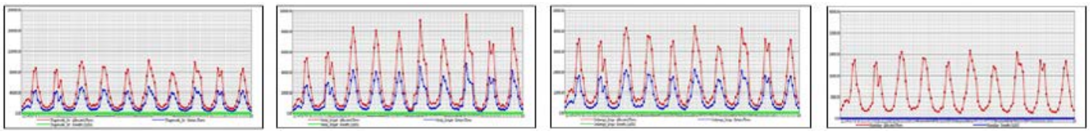

Figure 22: Allocated Flows, Return Flows and State Income for Kinda, Sedawgyi and Thaphanzeik and Allocated Flows and State Income for Mandalay Station

5. Conclusion

The purpose of the study is to simulate optimal water allocation plans for irrigation, navigation and hydropower sectors in the upper Ayeyarwady river basin. Based on the year 2014 supply and demand data, reference scenario is simulated and is created future scenarios and is selected the best allocation plan. The model results revealed that the water demand is the highest during the month April because of less rain and summer paddy cultivation at almost irrigated areas in that month. According to the analysis of scenario 1, the average turbine flows are about 5399.3 MCM and the State income $2.9 million per year. The maximum hydropower generation of powerplant is Yeywa hydropower (31%) and the minimum hydropower generation is Zawgyi hydropower

(1%). Under irrigation sector, three reservoirs are considered in different irrigated area. Thaphanzeik reservoir is the biggest capacity and Sedawgyi reservoir is the smallest capacity. According to the analysis of scenario 2, the overall allocated annual volume is about 77318 MCM and the State income for irrigation water use is about $0.165million per year in different irrigated areas and return annual flow from the result generated by AQUARIUS model are 38659 MCM. Under the scenario 3, the overall allocated flow is about 14685 MCM in water use for hydropower and navigation sector. Moreover, the value of State income of powerplants in this scenario is about $11.29 million per year .For the scenario 4, the model results showed that the overall allocated annual volume increased to 1233MCM than the scenario 2 because of no use for navigation sector. According to the analysis of scenario 5, the average turbine flow increased 427 MCM than the scenario 3. According to the analysis of scenario 6, the overall allocated flows are about 90340 MCM and the values of State income are about $11.42 million per year. Based on six scenarios, the scenario 6 should be selected because this scenario gives the maximum State income. This study showed that water use for irrigation sector is more than the water use for hydropower sector and achieved State income from each sector. Therefore, AQUARIUS is a very useful river basin planning tool to optimize the allocation of surface water use for agriculture, hydropower and navigation while considering the environmental flow in the river.

6. Recommendations

The followings are recommended for further study:

1. The detailed design of water supply network should be analysed in upper Ayeyarwady river basin.

2. Cost and benefit analysis should be advanced in this model to select the best water allocation plan and to get the water price for water pricing policy.

3. Flood mitigation study of Ayeyarwady river and ground water should be integrated with this model to develop the water resources management plan.

4. Scenarios analysis results from this study should be used in discussion among water planners, decision makers, stakeholders and local authorities for green and sustainable environment.

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