Chapter 2

Literature Review

2.1 Irrigation systems in Chiang Mai – Lamphun valley

The Chiang Mai-Lamphun valley is considered as the earliest area in Thailand where water irrigation systems have been developed. The development of irrigation systems for agriculture and other consumption in this area dated back as early as 700 years (Surarerks, 1986). The main water supply was received from the Ping River and its branches such as Nam Mae Taeng, Nam Mae Ngad, Nam Mae Kuang, Nam Mae Cheam, Nam Mae Tha, and Nam Mae Li. The northern communities or "Lanna" were knowledgeable in managing irrigation water by building weir to divert water through a canal for using in their farms called "Muang Fai" system or the people's irrigation systems.

However, the people's irrigation systems constructed from bamboo and rock were replaced with concrete structure by the Royal Irrigation Department. Up to 2006, there are 734 irrigation projects in Chiang Mai and Lamphun provinces, they consist of 3 large-scale, 31 medium-scale, and 700 small-scale irrigation projects covering total irrigable areas of about 121,560 ha. (Royal Irrigation Department, 2006). Each of the large-scale project has its own head office to manage irrigation water delivery and maintain irrigation structures to achieve the designed irrigation efficiency.

The large-scale irrigation projects are multi-purpose schemes. Although the main purpose is to deliver water for irrigating farm land, the other objectives are to supply water for industrial, environmental, and domestic consumption particularly Mae Taeng and Mae Kuang Irrigation Projects. Both projects have to supply water to Chiang Mai city and the near by areas for local residents as well as tourists, this can bring about water scarcity in dry season in some years. In addition, the irrigated farm lands in Mae Taeng Irrigation Project were partly replaced by the rapidly expanding urban development that further reduce water productivity of agricultural land in Chiang Mai-Lamphun valley.

Another responsibility of the Royal Irrigation Department is to manage the electric power pump irrigation projects that were previously under the responsibility of Development and Extension Energy Department. These projects provide irrigation water to farm lands by pumping water from the perennial streams and distribute it along small concrete canals to farm lands near by.

Another source of water for irrigation is from groundwater which is controlled by Department of Groundwater Resource. The common type of ground water use is in the form of "Bor Tork" or shallow wells with the depth of about 15-30 meters, quantity and timing of irrigation water can be better controlled for longan cultivation (Hanviriyapant, 2002). Deep wells at the depth more than 50 meters were used for industry or large plantation where large quantity of water supply are needed. The total number of deep well in Chiang Mai and Lamphun are about 5,367. (Department of Groundwater Resources, 2008)

Although Thailand has water resource policy, more than ten laws and many water management organizations exist but conflict in managing water resource still remains at every level such as between government offices and water users, and among water users themselves. Kaosaard *et al*. (2001) summarized that the problems occur from five major causes namely, open access regime, non unity in management, lack of knowledge in watershed ecosystem, lack of participation from water users, and lack of demand management tool.

2.2 Approaches for studying water productivity

2.2.1 Water accounting approach

To understand how water is used in each component of the system, IWMI suggests a water accounting system to integrate water resource management (Molden, 1997). It provides a clear view of water resources in a river basin. It shows where water is flowing, how it is being used, and how much it remains available for the future. Water accounting follows a water balance approach to quantify the amount of water entering a system and leaving a system (Figure 1). The water input is the total amount of water within any system that comes from main three sources (rainfall, irrigation, and inflow from nearby systems). The sources of irrigation in each system may be different such as canal, and stream flow.

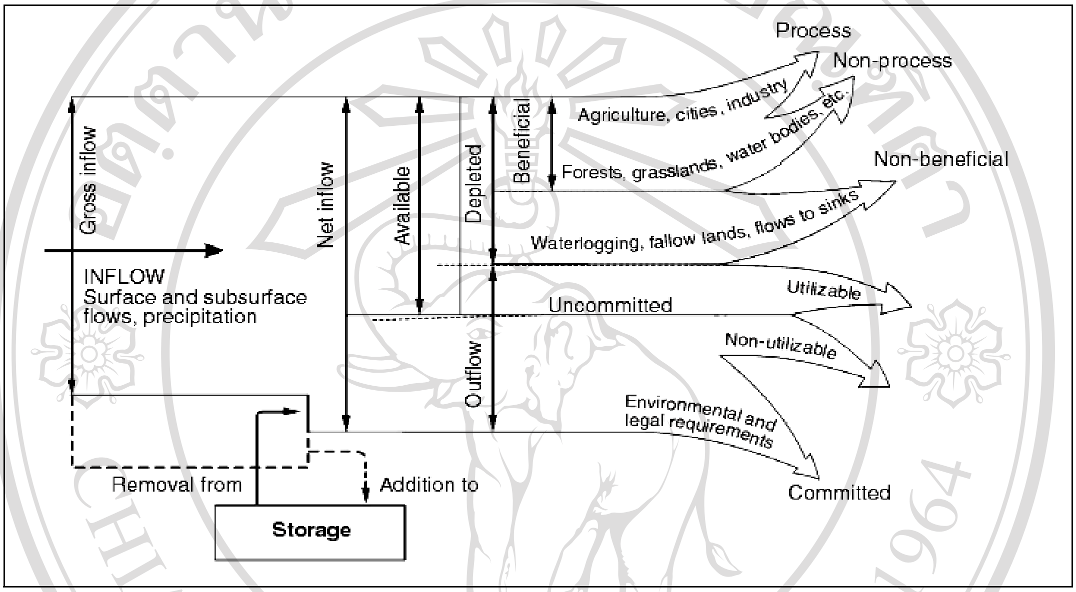

Figure 1 Water-accounting diagram applicable to basin analysis (Molden, 1997)

The water depletion is the water that is unavailable for further use in the present hydrological cycle. In cropping system process, water is depleted by the processes of plant growth and development (transpiration and evaporation). Water bodies such as farm ponds or reservoirs are depleted by evaporation. Cities and industries use water for consumption and production processes. The other causes of water depletion from a watershed are fallow land, and flows into the sea or other locations that are not readily or economically recoverable for reuse. The water outflow is the water that flows out of the system such as stream flow, and runoff (Kositsakulchai and Kwunyuen, 2002).

2.2.2 Water requirement estimation

The two main data that irrigation manager needs for planning is the quantity of water demand and water supply in growing season. The simple practice of irrigation management is water deliver to right site in suitable amount and time (Tarjuelo and de

Juan, 1999). The water supply can be measured at the head office and usually is recorded every day. The irrigation efficiency is normally known in each irrigation project from project design and development. The problem is water requirement in each plot at farm level measured by using lysimeter which is costly and time consumed to measure in every field. In practice, irrigation officer will survey present land use area and then estimate water requirement in each irrigation zone from standardized crops and climatic data.

The Food and Agriculture Organization of the United Nations (FAO) provides guidelines and methodologies on crop water requirements (Doorenbos and Pruitt, 1977; Allen *et al*., 1998). The international standard for calculating crop water requirement (ET_c) was derived from the multiplication of reference crop evapotranspiration (ET_o) by crop coefficient (K_c) according to Equation 1.

$$ET_c = ET_o * K_c \quad (1)$$

where ET_c is crop water requirement (mm d^{-1}), ET_o is reference crop evapotranspiration (mm d^{-1}), and K_c is crop coefficient.

A large number of empirical methods were developed to estimate the reference crop evapotranspiration from readily available climatic parameter for example Thornthwaite method, Blaney Criddle method, Hargreaves method, Priestley-Taylor method and Penman method (Jensen *et al*., 1989; van Lier *et al*., 1999). However, many researchers found that Penman method is the most suitable and acceptable method in Thailand (Tongaram (1981), Vudhivanich (1999))

Allen *et al*. (1998) described the FAO Penman-Monteith equation (Equation 2) to calculate reference crop evapotranspiration as ideal grass water requirement in perfect management that is a disease-free, well fertilized crop, under optimum soil water condition. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from climatic data.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

where ET_o is reference crop evapotranspiration (mm d^{-1}), R_n is net radiation at the crop surface (MJ $m^{-2}d^{-1}$), G is soil heat flux (MJ $m^{-2}d^{-1}$), T is average air temperature (^oC), U_2 is wind speed measure at 2 m height (m s^{-1}), (e_s-e_a) is vapor pressure deficit (kPa), Δ is slope of the vapor pressure curve (kPa $^oC^{-1}$), and γ is psychometric constant (kPa $^oC^{-1}$).

The crop coefficient (K_c) is the crop requirement factor that depends on crop type, variety and development stage. This data can be obtained from the experimental plot. It is basically the ratio of ET_c to ET_o. Since the effect of the various weather conditions are incorporated into ET_o estimate, Kc value can be used in different locations and climatic conditions. Follow the FAO approach, Kc is represented by straight lines connecting four general growth stages namely, initial, crop development, mid-season, and late season (Allen *et al*., 1998).

Another part of water requirement estimation is the study of water consumption in the city. In 2002, Chiang Mai Waterworks Authority supply about 21.15 million cubic meter of water , 7.89 and 3.89 million cubic meter of which is drawn from Mae Kuang Irrigation Project and Mae Taeng Irrigation Project respectively. Chantarasombat *et al*. (2003) found that average municipal water demand in Phitsanulok city was 0.3 cubic meter/people/day which was higher than standard rate of water use (0.2 cubic meter/people/day). For water supply in the country area, the Department of Health estimated as 0.05 cubic meter/people/day (Nimitrapiboon *et al*., 2002).

Although, water requirement at farm level and domestic uses can be estimated from the above methods, water allocation and operation of irrigation projects have to be considered in term of total water supply from the head work. Since irrigation efficiency is different among irrigation projects depending on distribution system, irrigation application and other factors, thus, the manager of the project usually supplies irrigation water more than actual needed to compensate water loss along the delivery system. However, in rainy season, if soils moisture is enough for crop growth, the head works don’t need to supply the irrigation water. The irrigation water requirement can be calculated from Equation 3 (Tingsanchali and Suiadee, 2002).

$$IWR = \frac{ET_C - R_{eff}}{I_{eff}} \quad (3)$$

where IWR is irrigation water requirement (mm), ET_c is crop water requirement (mm), R_{eff} is effective rainfall (mm), and I_{eff} is irrigation efficiency.

2.2.3 Water and crop yields

Many researchers have investigated relationships between crop yields and their limiting factors particularly water stress. One of the most extensive reports was given by Dorrenbos and Kassam (1979) who presented crop-water production functions in form of regression equations that were later improved by Allen *et al.* (1998).

Crop yields have high spatial variation due to variation in factors affecting them. Samranpong *et al.*, (2005) presented crop yields estimation by using the land evaluation methodology and fuzzy concept to yield continuous values of land suitability index. The physical suitability index was later converted into estimated crop yield and net return using field samplings to identify maximum crop yields attained in the farmers' fields. Economic land suitability was also determined from net return interpolated for land mapping units from physical suitability index, cost of production and gross return.

2.2.4 Water productivity indicator

Productivity is one of the agro-ecosystem properties (Ekasingh and Gypmantasiri, 1985). In broadest sense, productivity refers to the value obtained from a unit of resource uses assessed from output divided by input (Chambers, 1984). Water productivity is an efficiency term quantified as a ratio of product output (goods or services) over water input. The output could be biological goods or products such as crop (gain, fodder) or livestock (meet, egg, fish) and can be expressed in terms of yield, nutritional value or economic return. The output could also be an environment services or functions (Kassam and Smith, 2001).

Water productivity is often a key criterion because on so many irrigation systems for so much of the time water is the main factor limiting production. Water productivity is different from other irrigation efficiency because it is cross relation between crop yield and water consumed by crops that will enhance the benefit of water uses and water saving (Pereira *et al*., 2002). Water productivity can be quantified at different scales, and for a mixture of goods and services. IWMI suggested water productivity indicator and water accounting approach as new paradigm for water resource analysis to find out the problems and opportunity to improve the irrigation efficiency under water scarce situation (Perry, 1999). The issue about to get more crops per drop and crop-water productivity approach is essential for solving water use efficiency problems in many parts of the world (Molden *et al*., 2001, Kijne *et al*., 2003, Bouman, 2007).

2.3 Spatial tools for water resource management

2.3.1 Spatial database design and development

Geographic Information System (GIS) is a powerful tool to deal with area approach. It is a computer program for capturing, storing, querying, analyzing, and displaying geographic data (Burrough and McDonnell, 1998; Chang, 2002). The database management system is the fundamental of GIS software development because GIS data is very complex and large. Most GIS software development are also based on object-oriented analysis and design concept which can be effectively communicated among different applications through the Unified Modeling Language (UML).

The UML is a graphical language for visualizing, specifying, constructing, and documenting the artifacts of software intensive system (Booch *et al*., 2001). The UML help to write a system's blueprints, covering conceptual things, such as water-balance and irrigation scheduling model (Papajorgji and Shatar (2004)) and agro pastoral farm model (Herve *et al*. (2002)), as well as concrete things, such as class written in a specific programming language and database schemas (Ludwig *et al*. (2003)).

A geographic data model is a representation of the real world. The ArcGIS software (ESRI, 2003a) introduced a new object-oriented data model call the geodatabase data model. A geodatabase contains four representations of spatial data namely, vector data, raster data, triangulated irregular networks, and locators in the relational database (Zeiler, 1999). The geodatabase schema includes the definition, integrity rules, and behavior for an integrated collection of datasets used to present a collection of thematic layers. Each design includes properties for feature classes, topologies, network, raster catalogs, relationship, domain, and so forth (Arctur and Zeiler, 2004). The database developers can use object orientation software to design a logical database schema by defining the object models, relationship classes, and other properties in UML model. The ArcGIS has the schema wizard to generate the physical geodatabase schema from the Microsoft Repository databases or XMI files (ESRI, 2003c). The database developers have to fill up the GIS data from import the existing data or new input data follow database schema. Ekasingh *et al*. (2005) applied the UML model to construct the agricultural resource geodatabases such as soil, water, climate, land use, administration and watershed boundary to develop a decision support system in resource management planning for agriculture and services covering some provinces in northern Thailand.

2.3.2 Spatial water balance modeling

In most studies about planning and management of water resources, the important thing that researchers have to consider is to understand the situation of water by using water balance model (Boughton, 2005 and Portoghese *et al*., 2005). Panigrahi *et al*. (2001) presented water balance parameters for the rice fields by considering two major components, inflow and outflow. The inflow factors consisted of total water supplied from rainfall and supplemental irrigation while the outflow factors included actual crop evapotranspiration, seepage and percolation, and surface runoff, and considered the effective root zone of rice as a single layer.

However, water in the soil profile is always dynamic and controlled by climatic and management factors. Many researchers developed water balance models from series of equations that represent interrelationships among those factors and implemented through computer programming, some commonly used programs are CROPWAT (Smith, 1992), WatBal (Porter *et al*., 1998) and Budget (Raes, 2002).

The climatic water balance was also applied for predicting and mapping spatial variation of crop irrigation water requirement at the regional scale by employing GIS and geospatial techniques (Sousa and Pereira, 1999; Weatherhead and Knox, 2000; and Boken *et al*. 2004). The study of water balance during cold periods in specific agro-ecological region of India suggested that the surplus rainfall can be harvested and utilized for providing supplemental irrigation to winter crops or during the dry spell of rainy season crops (Kar and Verma, 2005).

Alemaw and Chaoka (2003) developed a GIS-based hydrological model using GIS and computational hydrology techniques. The model was based on water balance of surface and subsurface processes in geo-referenced grids of Southern Africa in order to assess the region's water resource availability. Behmanesh (2003) and Yarahmadi (2003) presented examples of using spatial water balance for managing irrigation projects. Both of them used GIS and spatial analysis to prepare spatial data such as rainfall, temperature and land use for estimating water balance in CROPWAT model. The results from CROPWAT are transferred back to GIS for assessing the volume of crop water requirement in project areas and the impact to the environment.

2.3.3 Spatial water productivity

Ines *et al*. (2002) employed crop growth simulation models, DSSAT v3.0 (Tsuji *et al*., 1999) coupled with GIS to analyze water productivity in Laoag River Basin in Ilocos Norte, Philipines. The result showed that the spatio-temporal analysis of water productivity could provide substantial information for water saving opportunities and, hence, strategies for improving the efficiency of irrigated agriculture.

Droogers and Kite (2001) estimated productivity of water at different scales using simulation modeling. At the field scale, the Soil-Water-Atmosphere-Plant model (SWAP) (Van Dam *et al*., 1997) was applied to quantify the local water balance. At the irrigation-scheme scale, the data were obtained from aggregation of field water fluxes to analyse water balance. Fluxes at the irrigation-scheme scale were integrated with hydrology of the Gediz Basin in western Turkey by using the Semi-Distributed Land-Use Runoff Process model (SLURP) (Kite, 1998). He concluded that water productivity indicator can be determined for different areas and effects of change in water supply at different spatial scales can be compared.

2.3.4 Spatial irrigation management

Water management includes planning, strategic and technical management. Irrigation scheduling models are always included in irrigation management to support individual farmers and irrigation project managers. The models deal with two question, “when” to irrigated and “how much” of water to apply at each irrigation event (George *et al*., 2000). A large number of tools and methodology are available to support irrigation scheduling management (Meeumpol, 1999; Bhaktikul, 2001; Rowshon *et al*., 2003; Wongtragoon, 2003).

Todorovic and Steduto (2003) developed the spatial modeling of GIS-based irrigation planning and management system to be used by irrigation consortia and local government institutions. The system provides tools for the exploration of spatially-referenced databases relevant for irrigation and the evaluation of irrigation scenario under different crop, soil, climatic, and management condition by make use of AVENUE programming language available in ArcView GIS Version 3.1 (ESRI, 1994). The system was also designed to link with two crop productivity modeling software, CROPSYST (Stockle and Roger, 1992) and EPIC (Williams *et al*., 1989).

Fortes *et al*. (2005) developed a package called GISAREG that integrated an irrigation scheduling simulation model (ISAREG) (Teixeira and Pereira, 1992) with ArcView GIS. The resulting information on alternative irrigation schedules in the Syr

Darya basin, Uzbekistan was spatially distributed and used for supporting irrigation scheduling and to help in the identification of practices that lead to water saving and for salinity control.

2.3.5 Spatial decision support systems

In the past few years, many attention have given by the agricultural management community to decision support systems (DSS) (da Silva *et al*., 2001; Pereira *et al*., 2002). Several researchers have interfaced the DSS to GIS for supporting land and water management (Hartkamp, 1999; Stockle, 2003).

The Agricultural and Environmental Geographic Information System for Windows (AEGIS/WIN) is a DSS that couples the DSSAT crop model with the GIS tools in ArcView (Engle *et al*., 1997). The user interface was programmed using Avenue script. This interface handles automatic data and command transfer between the simulation system and the mapping tool directly. Spatial data can be input into the model and the output from the model such as yield, biomass, and crop water use can be displayed as thematic maps that enhance presentation and interpretation of the analyses.

In Thailand, Ekasingh *et al*. (2000) developed a spatial decision support system (SDSS) for rice production, Phosop. Its user interface was developed to work in ArcView to support decision making of policy makers and resource planners. It can simulate rice yield by coupling with CERES-Rice model for different management practices, therefore, yield maps for different scenarios can be created.

Scheme irrigation management information system (SIMIS) is a DSS for management irrigation schemes (Mateos *et al*. 2002). SIMIS has been developed in Microsoft Access 97, MapObject 1.2 and Microsoft Visual Basic 6.0. The irrigation project managers can use SIMIS for assisting them in water management, water accounting, calculating irrigation requirements, scheduling water deliveries, controlling maintenance activities, developing irrigation layouts, keeping records of water consumption and monitoring project performance.

Although many software are available for researchers to estimate water requirement, most of them were developed with specific purpose and very few of them deal with spatial distribution of water productivity within irrigation service areas. Since water productivity assessment needs an integrated system which is able to describe and analyze dynamic nature of the key variables affecting water productivity, such a system is essential for supporting decision of water resource manager to plan for effective use of land and water. The proposed system will utilize the capability of GIS software and customize it by requesting appropriate programming objects from GIS system to manipulate and analyze spatial data for estimating water productivity. The graphic user interface in Thai is necessary to facilitate users for selecting target areas, data input, defining various scenarios for water productivity assessment. The design of such a system will be discussed in the next chapter.