RELATIONSHIP BETWEEN LAND USE CHANGE AND WATER BALANCE IN WETLANDS : A CASE STUDY OF BUNG BORAPED WILDLIFE NON-HUNTING AREA, NAKHONSAWAN PROVINCE, THAILAND

JUTARAT TRAIPO

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ABSTRACT

The objective of this research was to analyse the relationship between land use change and water balance in Bung Boraped, Nakhonsawan Province. The land use was classified into 7 type forest area, urban and built-up area, paddy field, field crop area, aquaculture area, water bodies, and idle land. The change of land use was analyed by using aerial photographs and land use maps from the Land Development Department, recorded in 1978, 1983, 1991 and 2000. Water balance was analysed using data on rainfall, evaporation rate, surface runoff, seepage, water utilization for irrigation, water consumption and sedimentation, during the period of 1978-2000. Multiple Regression Analysis, particularly the Stepwise method, was used for statistical analysis.

The results of this research indicated that water balance was negatively correlated with forest area and idle land but positively correlated with urban and built-up area, paddy field, field crop area, water bodies, and aquaculture area. Stepwise analysis showed that water balance was highly related with aquaculture area only. The results indicated that land use change surrounding Bung Boraped and water balance of Bung Boraped depended on seasons and severe floods in some years. The aquaculture area may continue to increase in the future, therefore monitoring the impacts of aqyacultural area expansion on ecology and hydrology of Bung Boraped is recommended.

KEY WORDS : LAND USE / WATER BALANCE / WETLAND / BUNG BORAPED

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ความสัมพันธ์ระหว่างการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินกับสมดุลน้ำในพื้นที่ชุ่มน้ำ กรณีศึกษาเขตห้ามล่าสัตว์ป่าบึงบอระเพ็ด จังหวัดนครสวรรค์ ประเทศไทย (RELATIONSHIP BETWEEN LAND USE CHANGE AND WATER BALANCE IN WETLANDS : A CASE STUDY OF BUNG BORAPED WILDLIFE NON-HUNTING AREA, NAKHONSAWAN PROVINCE, THAILAND)

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วท.ม. (การวางแผนสิ่งแวดล้อมเพื่อพัฒนาชุมชนและชนบท)

คณะกรรมการควบคุมวิทยานิพนธ์ : ศันสนีย์ ชูแวว, Ph.D., กัมปนาท ภักดีกุล, Ph.D., มนู ศรีขจร, Post. Grad. Diploma.

บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ระหว่างการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินและสมดุลน้ำในพื้นที่ชุ่มน้ำบึงบอระเพ็ด จังหวัดนครสวรรค์ วิเคราะห์การเปลี่ยนแปลงการใช้ประโยชน์ที่ดินด้วยการแปลภาพถ่ายทางอากาศและวิเคราะห์แผนที่การใช้ที่ดินของกรมพัฒนาที่ดินในปี 2521, 2526, 2534 และ 2543 โดยแบ่งการใช้ประโยชน์ที่ดินเป็น 7 ประเภท คือ พื้นที่ป่าไม้ พื้นที่เมืองและสิ่งก่อสร้าง พื้นที่นาข้าว พื้นที่พืชไร่ พื้นที่เพาะเลี้ยงสัตว์น้ำ แหล่งน้ำ และพื้นว่างเปล่า วิเคราะห์สมดุลน้ำโดยใช้ข้อมูลปริมาณน้ำฝน อัตราการระเหย ปริมาณน้ำท่าที่ไหลเข้าบึง ปริมาณน้ำที่สูญเสียจากการซึมผ่าน ปริมาณน้ำที่สูบไปใช้ในการชลประทานและอุปโภค และปริมาณตะกอน โดยใช้ข้อมูลช่วงปี 2521-2543 วิเคราะห์ความสัมพันธ์ระหว่างการใช้ประโยชน์ที่ดินกับสมดุลน้ำด้วยวิธีถดถอยพหุคูณ (Multiple Regression Analysis) แบบ Stepwise method

ผลการศึกษาพบว่าสมดุลน้ำมีความสัมพันธ์ในทิศทางตรงข้ามกับพื้นที่ป่าไม้ และพื้นที่ว่างเปล่า แต่มีความสัมพันธ์ในทิศทางเดียวกับพื้นที่เมืองและสิ่งก่อสร้าง พื้นที่นาข้าว พื้นที่พืชไร่ พื้นที่เพาะเลี้ยงสัตว์น้ำ และแหล่งน้ำ ส่วนผลการวิเคราะห์แบบ Stepwise method แสดงว่าสมดุลน้ำมีความสัมพันธ์สูงกับพื้นที่เพาะเลี้ยงน้ำอย่างมีนัยสำคัญเท่านั้น ผลการศึกษาแสดงว่าการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินโดยรอบบึงบอระเพ็ด และสมดุลน้ำของบึงบอระเพ็ดจะขึ้นกับฤดูกาล และเหตุการณ์น้ำท่วม ในอนาคตพื้นที่เพาะเลี้ยงสัตว์น้ำอาจจะเพิ่มขึ้นอย่างต่อเนื่อง ซึ่งควรมีการเฝ้าระวังผลกระทบที่อาจเกิดขึ้นต่อระบบนิเวศในพื้นที่ชุ่มน้ำบึงบอระเพ็ด

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CHAPTER 1
INTRODUCTION

1.1 Background and problem issues

Wetlands are of crucial significance for societies. Life style of Thai people, either in urban or rural area, has been dependent upon wetland for several generations. Each wetland has different role, productivity and unique properties (Choowaew, n.d.). Both values and services of wetland can be quantified. For example, in 1996 the output from wetland use in Thailand was worth at least 200,000 million baht or 8 percent of Gross Domestic Product (Coastal Resource Institute, 2001). The implicit value of wetland is enormous such as biological diversity, food and nursery ground for fish and birds, erosion control, water treatment, source of food herb and energy, trapping sediment and minerals, human settlement, research and education.

Wetlands in Thailand are of various types and sizes, scattering all over the country. The total area of wetlands is estimated at 36,616.16 sq km or about 7.5% of the country area (Office of Environment Policy and Planning, 1997). The existing area of wetland continuously declines because of many important causes. Increasing population associated with the rapid socio-economic development has led to intensive and unwise uses of wetland resources.

One major cause of wetland loss and degradation is the lack of appropriate wetland management. Additionally, people lack understanding of the nature of wetland ecosystem, and do not recognize the role, values and importance of wetlands.

Water balance and hydrological regime are important factors directly determining wetland status. Water balance can indicate the water quantity and pattern of hydroperiod affecting the hydrological characteristics of wetland. The hydrological conditions are very important for maintaining the structure and functions of wetland as well as wetland biodiversity (Mitsch and Gosselink, 2000). However, many natural wetlands are threatened by changing land use activities, drainage, excavation, development projects which affect their size, water quantity and quality

(Office of Environment Policy and Planning, 1999). The study of relationship between land use change and water balance of wetland will therefore enhance the understanding of how land use change may affect hydrology of wetland and will lead to better projection and guideline preparation for further impact protection.

This study describes the change of land use surrounding Bung Boraped, in Nakhonsawan, a wetland of international importance and the largest freshwater lake in the lower North of Thailand. Aerial photographs and land use map of Land Development Department are used for studying land use change. Water balance is analyzed using data on rainfall, evaporation rate, surface runoff, underground water, and water consumption. Bung Boraped is selected for this study because this wetland is now facing with the problem of decreasing water quantity from the average of 3 meters to 1.5-2.5 meters in depth (Bung Boraped Wildlife Conservation Promotion and Development Station, 2000). In addition, Bung Boraped has high sedimentation rate and is shallowing.

1.2 Conceptual framework

Land use change of Bung Boraped and surroundings between the period of 1978 to 2000 is studied. According to land-use classification (Wacharakitti, 1982), the land use can be grouped into 5 types. This study focuses on agricultural land uses, i.e. paddy field, field crops and aquaculture. Consequently, land use is classified into 7 classes : urban and built-up area, forest area, paddy field, field crops, aquaculture area, water bodies and idle land. The change of land use not only affects the physical characteristics of wetland i.e. size and volume, soil texture, floral community etc, but also influences hydrology of wetland change. Hydrological characteristic, namely water balance, is viewed as the factor indicating the change of water quantity in the wetland.

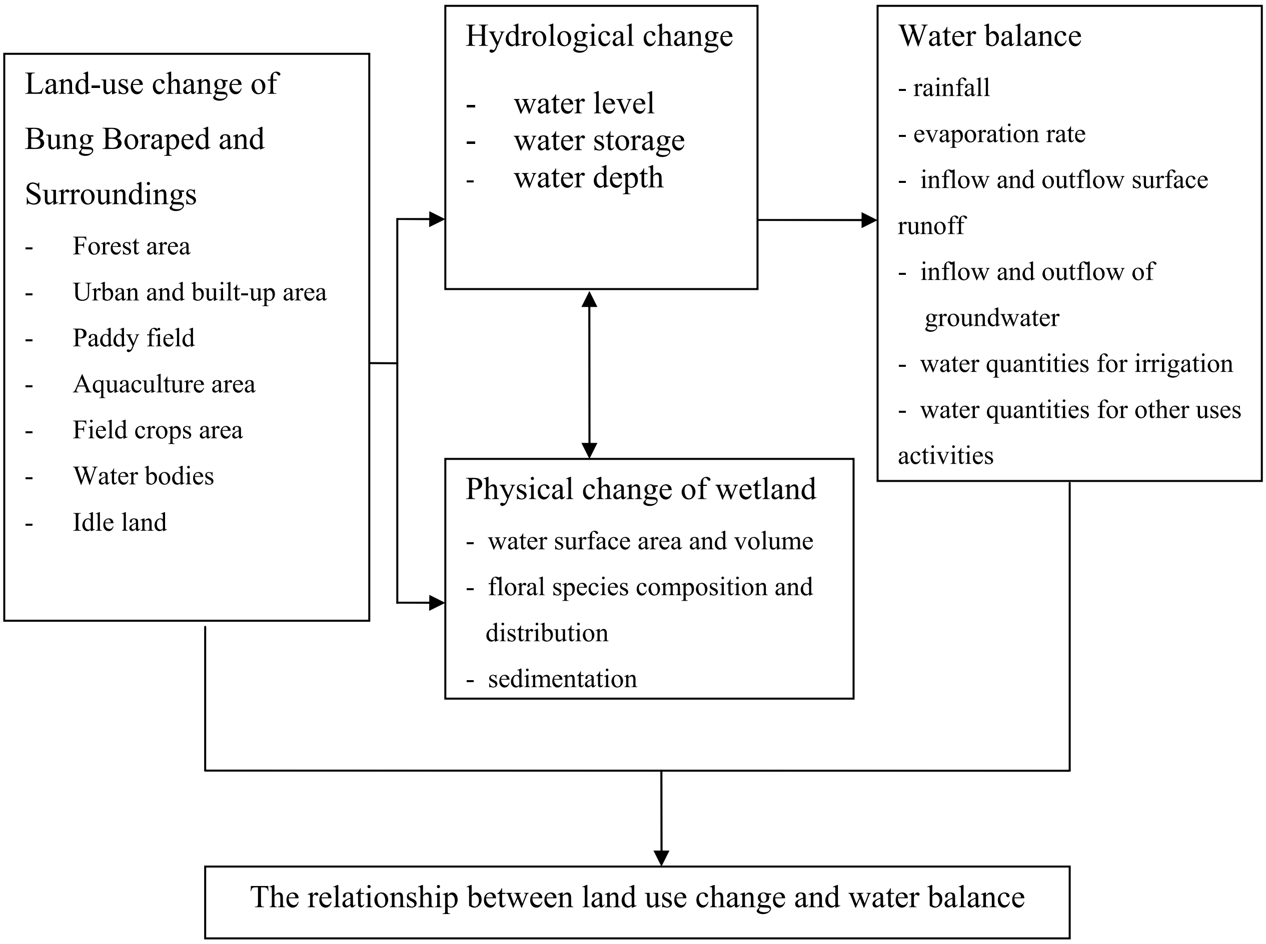

Figure 1-1 Conceptual framework

1.3 Research Objectives

1.3.1 To analyse the rate of land use change of Bung Boraped and surrounding area, between the period of 1978-2000.

1.3.2 To analyse the water balance of Bung Boraped between the period of 1978-2000.

1.3.3 To synthesize the relationship between land use change and water balance of Bung Boraped .

1.4 Research hypothesis

Water balance of Bung Boraped is related to land use change around Bung Boraped.

1.5 Scope of Research

1.5.1 The study area is 504.936 sq km (Figure 1-2) in Amphoe Muang, Amphoe Chumsaeng and Amphoe Tha-Tako in Nakhonsawan province, having the boundary as follows.

The North : Amphoe Muang-Amphoe Tha-tako road; from Ban Khlongplakod-nai, Amphoe Chumsaeng to Ban Tha-tako, Nakhonsawan province.

The South and The East : the highway No.3004 (Amphoe Muang-Amphoe Tha-Tako); from Nakhonsawan railway station, Amphoe Muang to Ban Tha-tako, Amphoe Tha-tako, Nakhonsawan province.

The West : Northern railway route; from Nakhonsawan railway station, Amphoe Muang to Khlongplakod-nai railway station, Amphoe Chumsaeng, Nakhonsawan province.

Water balance analysis is carried out for Bung Boraped catchment area (approximately 4,442 sq km) and Bung Boraped lake (exactly 212.397 sq km).

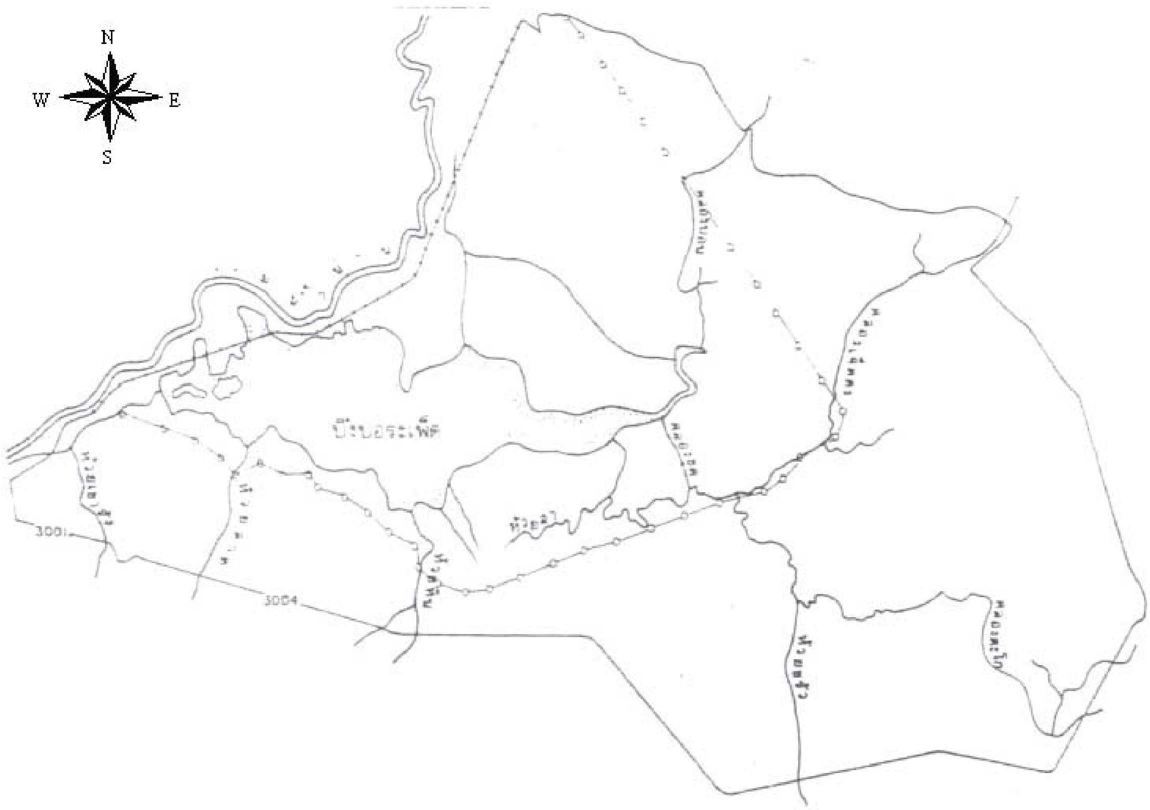

Figure 1-1 The Study area

Source : Faculty of Environment and Resources Studies, 1994

1.5.2 Land use is classified into forest area, urban and built-up area, paddy field, field crop area, aquaculture area, water bodies and idle land. Analysis is based on the interpretation of aerial photographs and land-use map of Land Development Department recorded in 1978, 1983,1991, 2000.

1.5.3 Analysis of water balance is based on rainfall data and evaporation rate recorded by Meteorological Department, during the period of 1978-2000 ; data of runoff, Royal Irrigation Department, during the period of 1978-2000 ; data of water utilization for irrigation, Office of Regional Irrigation Nakhonsawan province, during the period of 1978-2000; data of water consumption for other activities, during the period of 1978-2000.

1.5.4 Analysis of sedimentation in Bung Boraped between the period of 1978-2000 is based on the data derived from Royal Irrigation Department.

1.5.5 Analysis of the relationship between land use change and annual water balance is carried out by statistical process; namely correlation analysis. With the Multiple regression analysis, particularly the stepwise method, the equation for assessing the relationship is developed.

1.6 Research Expectations

1.6.1 The trend of land use change around Bung Boraped wetland, Nakhonsawan province.

1.6.2 The trend of water balance of Bung Boraped.

1.6.3 The relationship between land use change and water balance of Bung Boraped.

1.6.4 Information to support wetland management planning.

1.7 Definitions

1.7.1 Wetland : area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters (Ramsar Convention, 1971)

1.7.2 Land use : the realization of land value adopted for satisfying human needs i.e. agriculture use, commercial use, residential use etc. The land use can be classified into 7 groups :

1) Forestry land : natural forest e.g. dipterocarp forest, hill evergreen forest, tropical rain forest etc.

2) Urban and built-up land e.g. residential area, commercial area, industrial area, etc.

3) Paddy field.

4) Field crop area : shot-life and long-life cultivation e.g. vegetable crop, fruity crop, livestock farming, aquatic flora, mixed agriculture, etc.

5) Aquaculture area.

6) Water bodies: both natural and man-made water source i.e. streams, canals, swamps, reservoirs, ponds and lakes.

7) Idle land : uncovered area.

1.7.3 Water balance : change of water quantities maintained by wetland or the difference between water inflow and outflow of wetland, with the unit of cubic meters (Mitsch and Gosselink, 2000).

1.7.4 Water level : the altitude of water surface beyond specific line zero datum.

1.7.5 Hydrology : treats of the waters of the earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things (Taesombat, 1985).

CHAPTER 2
LITERATURE REVIEW

2.1 Water resource

2.1.1 The hydrological cycle

The interdependence and continuous movement of all forms of water provide the basis for the concept of the hydrology cycle. Water vapor in the atmosphere condenses and may give rise to precipitation. In the terrestrial portion of the cycle, not all of this precipitation will reach the ground surface because some will be intercepted by the vegetation cover and will, from there, be evaporated back into the atmosphere. The precipitation that reaches the ground surface may then follow one of three courses. First, it remains as surface storage in the form of pools, puddles and surface moisture. Second, it may flow over the surface into streams and lakes, from where it will move either by evaporation back into the atmosphere, or by seepage towards the groundwater, or by further surface flow into the oceans. Third, precipitation may infiltrate through the ground surface to join existing soil moisture. This may be removed either by evaporation from the soil and vegetation cover, or by throughflow towards stream channels, or by downward percolation to the underlying groundwater. The groundwater component will eventually be removed either by upward capillary movement to the soil surface or to the root zone of vegetation cover, when it will be returned by evaporation to the atmosphere or by groundwater seepage and flow into surface streams and into oceans (Ward and Robinson, 1989). The quantity of water in the hydrology cycle is changed by the factors, which control the processes. The relationship between rainfall on oneside and runoff and loss on the other, is " Water Balance" (Taesombat, 1985).

2.1.2 Factors Affecting Runoff

There are 3 factors determining how water flows and water quantity in wetland (Wisler and Brater, 1969 ; Chankaew, 1982).

1) Climatic factors :

◆ Type of precipitation : If precipitation falls in the summer in the form of rain, its influence is felt almost immediately provided only that its intensity and magnitude are great enough to affect runoff. On the other hand, if the precipitation is entirely in the form of snow with no thawing temperatures, runoff will be unaffected except by the snowfall that directly falls on the surface of stream.

◆ Rainfall intensity : When the intensity is great enough to exceed the infiltration capacity and produces surface runoff, the height of the stream rises rapidly.

◆ Duration of rainfall : Effect of duration of rainfall is the period of surface runoff and the infiltration capacity.

◆ Distribution of rainfall : Uniform of distribution of rainfall over the drainage basin respect both to area and to time of occurrence. If the topography, soil, and other conditions are uniform throughout the basin, the total volume of rainfall is the same. For drainage basin of many sizes, large flood-producing storms are very seldom uniform distributed.

◆ Direction of storm of movement : The direction in which the storm travels across one basin with respect to the direction of flow of the drainage system has influence upon the resulting peak flow and also upon the duration of surface runoff.

◆ Antecedent precipitation and soil moisture : The amount of soil moisture in the surface layers of the soil has an important effect on the infiltration capacity and also on groundwater accretion.

◆ Other climatic conditions : The temperature, wind velocity, relative humidity and average barometric pressure determine the climate of an area, evaporation, transpiration and also affect the runoff (Chankaew, 1982).

2) Physiographic factors :The physical and geological characteristics of drainage basin influence the flow characteristics, duration of surface runoff and quality of water in stream. Each physiographic factors also relate to other factors (Hammer and Viess, 1991).

◆ Area of basin : Area of basin affects the magnitude of floods, minimum flow, and average flow in different ways. The effects on flow characteristics can be considered separately. The base of the hydrograph of flood will broaden out as the area of basin increases. The larger the basin, the longer it takes for the total flood flow to pass a given station.

◆ Shape : The shape of a drainage basin mainly governs the rate at which water is supplied to the main stream.

◆ Elevation : The variation in elevation and the mean elevation of a drainage basin are important factors in relation to temperature and precipitation. The elevation has a profound effect upon water loss. It is an important factor determining the availability of water supply in a river (Chankaew, 1982).

◆ Slope : The slope of a drainage basin is important and has a complex relation with infiltration, surface runoff, soil moisture, and groundwater contribution to stream flow. It is a major factor controlling the time of overland flow and concentration of rainfall in stream channels and is of direct importance to flood magnitude (Hammer and Viess, 1991).

◆ Orientation : This factor affects the transpiration and evaporation losses because of its influence on the amount of heat received from the sun.

◆ The Drainage System : The drainage system is the pattern or arrangement of natural stream channels which through past ages has been developed by nature within the area. The drainage system affects the hydrograph. The basin is well drained if the length of overland flow is short, the surface runoff concentrates quickly, the flood peaks are high, and the minimum flow is corresponding low (Wisler and Brater, 1969).

◆ Soil conditions : In a drainage basin, the runoff characteristics are influenced by the predominant type of soil due to the varying infiltration capacities of different soils, which is the result of the size of soil grains, their aggregation, shape, and the arrangement of the soil particles. Soils containing colloidal material shrink and swell with changes in moisture content, thus affecting the infiltration capacity (Department of Soil Science, 1980).

◆ Geological characteristics : Geological characteristics are related with the topography, shape and area of basin, stream channels, slope, orientation of basin, and the hydrology of basin, as well as the soil conditions and water table in the basin (Chaithum, 1985).

◆ Vegetation : The vegetation cover affects the infiltration capacities of soils. Land use changes that modify the nature of vegetation can have significant impact on the timing and volume of flows (Chankaew, 1982).

3) Land use activities : Land use change can increase or decrease the volume of runoff and the maximal rate and timing of flow from a given area. The most influential factors affecting flow volume are the infiltration rate and storage. According to Wisler and Brater (1969), in an area of virgin forest, even during the heaviest downpours, no surface runoff would reach the streams, and no flood would result. In the other hand, if the forest is changed to cultivated and urban and developed land, the volume of the runoff will increase, the ground water recharge will decrease.

2.2 Definition and Classification of Wetlands

2.2.1 Definition of Wetland

Wetland is a general term used to define the wet habitats including swamps, marshes bogs, and similar areas. Wetlands have many distinguishing features, the most notable of which are the presence of standing water for some period during the growing season, unique soil conditions and unique vegetation, adapted to or tolerant to saturated soils. Wetlands have various characteristics that distinguish them from other ecosystems. Each wetland is different in shape, size, hydrological conditions, vegetation, soil condition and location (Mitsch and Gosselink, 2000).

Indeed over fifty separate definitions of wetlands are currently in use, with the broadest provided by The Ramsar Convention (1977 cited in Tiner, 1999). According to the Ramsar Convention, wetland is : area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including area of marine water the depth of which at low tide does not exceed six meters.

Generally, wetland definitions have been developed for various purposes. The earliest wetland definition, was presented by Shaw and Fredine (1956 cited in Tiner, 1999). The term " wetlands" refers to lowlands covered with shallow and sometimes temporary or intermittent waters. They are referred to by such names as marshes, swamps, bogs, wet meadows, potholes, sloughs, and river-overflow lands. Shallow lakes and ponds, usually with emergent vegetation as a conspicuous feature, are included in the definition, but the permanent waters of stream reservoirs, and deep lakes are not included. Neither are water areas that are so temporary as to have little or no effect on the development of moist-soil vegetation.

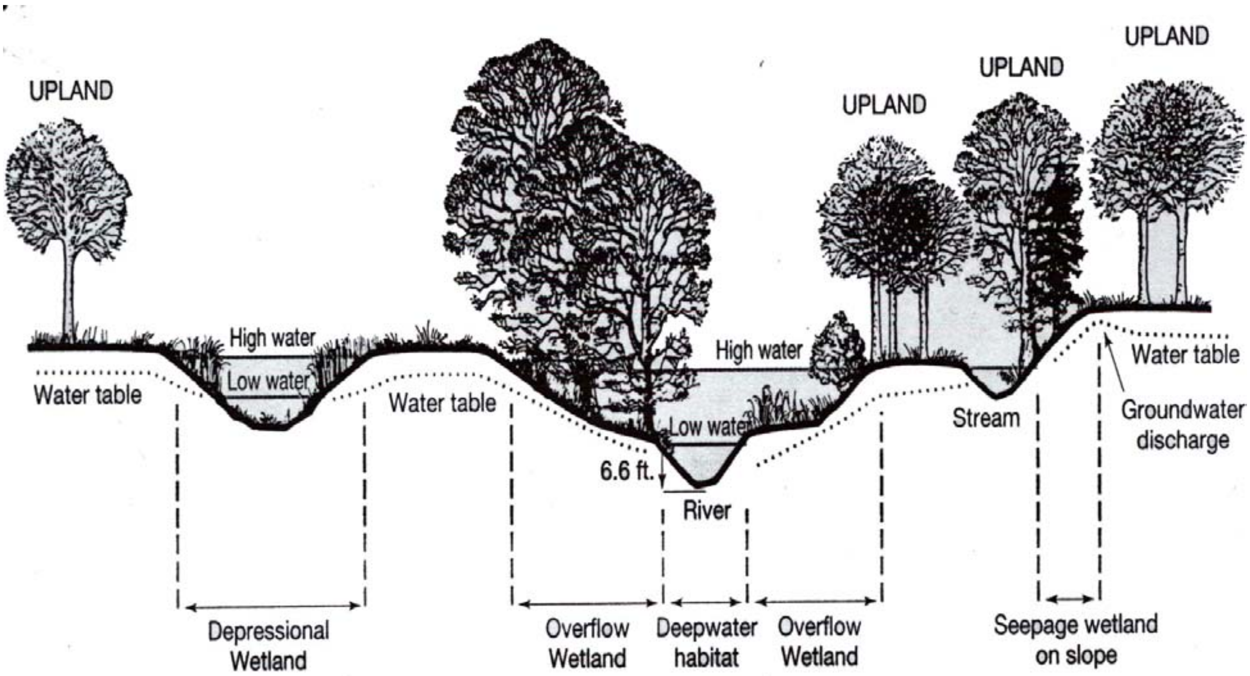

Figure 2-1 Schematic diagram showing wetlands, deepwater habitats, and uplands on the landscape.
Source : Tiner ,1999

In 1979 Cowardin et al and U.S. Fish and Wildlife Service (1979) presented definition of "wetland" as : wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetland must have one or more of the following three attributes :

1) at least periodically, that land supports predominantly hydrophytes ;
2) the substrate is predominantly undrained hydric soil; and
3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

According to the U.S., Clean Water Act (1977 cited in Tiner, 1999), the term "wetlands" means those areas that are inundated or saturated by surface or groundwater at frequency and duration sufficient to support and that under normal circumstances do support, a prevalence of vegetation typically adopted for life in saturated soil conditions.

Dugan (1996) describes that wetland groups together a wide range of inland, coastal and marine habitats which share a number of common features.

Sansanee Choowaew (1996) describes that characteristics of wetland are land transitional between terrestrial and aquatic ecosystems, having unique soil covered by shallow water for a duration sufficient to support vegetation and animals which can adapt for life in wetland conditions.

2.2.2 Classification of Wetlands

According to the definitions of wetlands, wetlands cover extensive areas including rivers, streams, creeks, lakes, marshes, swamps, bogs, fens, reservoirs, ponds, pools, lowland, flooded agricultural land, mudflats, coral reefs, seagrass beds, etc (Choowaew, n.d.).

There are various systems for wetland classification. Wetland and Deepwater Habitats of the United States are classified based on plants, hydric soils and frequency of flooding (Tiner, 1999). The Canadian Wetland classification system devides wetlands into 3 levels based on natural feature of the wetland . Forms are subdivisions of wetland classes base on surface morphology, water type and mineral soil. Types are subdivisions of wetland forms and subforms based on physiognomic characteristics of the vegetation communities (Mitsch and Gosselink, 2000).

The Ramsar Convention (1977 cited in Tiner, 1999) classifies wetland habitats according to their biological and physical characteristics into 30 categories of natural wetlands and 9 manmade wetlands. Dugan (1990) describes wetlands of 7 landscape units as follows.

1) Estuaries : Estuaries are bodies of water where a river mouth widens into a marine ecosystem, where the salinity is intermediate between salt and fresh water and where tidal action is an important bio-physical regulator. Estuaries and inshore marine waters are among the most naturally fertile ecosystems in the world, with micro and

macro flora maintaining a high production rate. Estuaries occur in all regions of the world, but their productivity varies with climate, hydrology and coastal geomorphology.

2) Open Coasts : Open coasts are those not subject to the influence of river water and lagoon ecosystems. Open coastal ecosystems can support a diversity of wetland habitats, including mudflats and mangroves.

3) Floodplains : The periodic flooding of land between a river channel and raised land on the edge of a valley is a common feature of rivers in many parts of the world. Many of the larger rivers spread out over floodplains far inland, many of them covering vast areas that include grassy marshes, flooded forest, oxbow lakes and other depressions.

4) Freshwater Marshes : Freshwater marshes are common wherever groundwater, surface springs, streams or runoff causes frequent flooding or permanent shallow water. Some of the larger marshes dominated by papyrus, cattail and reed, with standing water throughout most of the year are commonly termed "swamps".

5) Lakes : Lakes and ponds develop through several processes. Some are formed by folding, faulting, or movement of the earth 's crust. Some lakes in arid regions were formed by wind action. Stream action forms oxbow lakes and alluvial fan lakes, plunge pools, and basins.

6) Swamp Forests : Swamp forests develop in still water areas around lake margins, and in parts of floodplains, such as oxbows, where the water rests for longer periods. Their precise character varies according to geographical location and environment. Swamp forests are habitats for many rare animals and vegetation (Santisook, 1991).

7) Peatlands : Peatlands are area, under conditions of low temperature, high acidity, low nutrient supply, waterlogging and oxygen deficiency, where the process of decomposition is retarded and dead plant matter accumulates as peat.

In Thailand, Land Development Department (1994) classifies wetlands into 7 systems as follows.

1) Marine/ Coastal System, including rocky shores, cliffs, coral reefs, seagrass beds, mariculture, beaches, mudflats and islands.

2) Coastal Lagoon System, including coastal saline and brackish lagoon.

3) Inland Salt Lake System, including saline lake, fen, marsh or brackish inland.

4) Estuarine System, including estuaries, tidal marshes, mangrove.

5) Riverine System, including river channels, rapids, waterfalls, floodplains, rice paddy, and irrigated land.

6) Lacustrine System, including freshwater lakes, freshwater ponds, sewage treatment ponds, freshwater aquaculture ponds, reservoirs.

7) Palustrine System, including freshwater marshes, swamp forests, seasonal flooded grassland.

2.3 Wetland Values

Benefits and possible uses of wetland and wetland resources are enormous and varied. Wetlands support life of plant, animals and human-beings. Choowaew (1994) describes that interactions among and within 3 key i.e. physical, chemical, and biological, components allow wetlands to perform certain functions, provide products and attributes, that make wetlands important to society.

Wetland functions occur from processes among and within components, regardless of whether there are people present to benefit from those processes. Wetland functions are useful and important to people (Kent, 2001). Dugan (1990) and Choowaew (1994) describe functions of wetlands as follows.

1) Groundwater Recharge : Groundwater recharge occurs when water move from the wetland down into the underground aquifer. When water reaches the aquifer, it is filtered, cleaner, and can be drawn up for human uses. Recharge in one wetland may be linked to discharge in another. Recharge is also beneficial for flood storage because runoff is temporarily stored underground, rather than moving swiftly downstream and overflowing.

2) Groundwater Discharge : Groundwater discharge occurs when water that has been stored underground moves upward into a wetland and becomes surface water. Wetlands fed by groundwater discharge have more stable biological communities and have a direct influence on streamflow. Wetlands which are sites of

groundwater discharge at one time of the year, may act as sites of recharge to the groundwater at another, depending on the rise and fall of the local groundwater table.

3) Flood Control : By storing precipitation and releasing runoff evenly, wetlands can help prevent the destructive impacts of floods downstream.

4) Shoreline Stabilisation and Erosion Control : Wetland vegetation can stabilise shorelines by reducing the energy of waves, currents, or other erosive forces, by simultaneously holding the bottom sediment in place by their roots. This can prevent the erosion of valuable agricultural and residential land and property damage. At many sites, wetlands may help build up land.

5) Sediment and Toxicant Retention : Wetlands may serve as pools where sediment can settle. Wetland vegetation e.g. reeds and grasses, slow down a river's flow, and the opportunity for sediment settling is increased. Retaining sediment in wetlands improves water quality and reduces toxicants in ecosystem.

6) Nutrient retention : Wetlands remove nutrients by accumulating in the sub-soil, or storing in vegetation, and thus help improve water quality and prevent eutrophication.

7) Biomass Export : Nutrients produced and stored in wetlands may be carried away by surface flow, in streams, or by groundwater recharge. Those nutrients are beneficial to downstream areas and coastal waters.

8) Storm Protection and Windbreak : Many wetlands, in particular mangroves and other forested riverine and coastal wetlands, help dissipate the force and lessen the damage of storms and winds.

9) Micro-Climate Stabilisation : The overall hydrological, nutrient and material cycles and energy flows of wetlands may stabilise local climatic conditions, particularly rainfall and temperature.

10) Water Transport : Wetlands and waterways may serve as alternative means to the more expensive forms of road transport. In many places, wetlands provide cheap transport for the rural poor.

11) Recreation and Tourism : Wetland recreation and tourism include sport hunting, fishing, bird watching, nature photography, swimming and sailing.

12) Prevention of Sea Water Intrusion : Fresh water, which flows through wetlands and moves down into the underground, helps prevent intrusion of sea water into upland.

13) Nature Education and Research : Wetlands are perfect places for research and nature education. Schools nearby wetlands may use wetlands as natural laboratories for the schoolchildren.

In addition, wetlands provide a wide range of products, which are important to people and the country's economy.

1) Forest Resources : Direct harvest of the forest resources of many wetlands yields a number of important timber and non-timber products, ranging from fuelwood, timber and bark, resins and medicines.

2) Wildlife Resources : Wetlands are rich in wildlife, providing an important recreational resource and commercial products, ranging from meat and skins, to honey and eggs of birds, turtles, and ants.

3) Fisheries : Wetlands provide nutrient rich, sheltered habitats used by fish for spawning, as nursery areas, or as habitats for adults. Two-thirds of the fish we eat depend upon wetlands at some stage in their life cycle.

4) Forage Resources : Wetlands which contain grasslands and trees that are grazed by livestock are important to pastoral communities. Grasses may also be collected as fodder for sale or used for dry-season feed.

5) Agricultural Resources : Wetlands can be used for seasonal agriculture or can be cultivated in natural form with little modification or can be converted to intensive agriculture. Properly managed, natural wetland agriculture can yield substantial benefits to rural communities.

6) Water Supply : Wetlands are vital sources of water for direct human consumption, agriculture, livestock, and for industrial supply.

7) Energy Resources : Some wetlands contain potential energy for human use, normally in forms of plant matter and peat.

Besides, wetland have attributes i.e. biological diversity, uniqueness of habitats, and importance to culture and heritage. Wetlands have multiple functions and values, which are beneficial to people and society. In 1996, the benefits from wetland uses in Thailand is worth at least 200,000 million baht or 8 % of the gross domestic product (Coastal Resource Institute, 2001).

2.4 Wetland Hydrology

2.4.1 The Importance of Hydrology in Wetlands

The hydrology of a wetland creates the unique physicochemical conditions that make a wetland ecosystem different from both well-drained terrestrial system and deepwater aquatic system. Hydrological conditions including water depth, flow patterns, fluctuating water level , duration and frequency of flooding, characterize different types of wetlands (Hammer, 1999).

Wetland hydrologic conditions are extremely important for the maintenance of a wetland’s structure and functions. Hydrological conditions affect many abiotic factors, including soil anaerobiosis, nutrient availability and, in coastal wetland, salinity. These, in turn, determine the biota that develop in a wetland. Biotic components are also active in altering the wetland hydrology and other physicochemical features (Azous and Hurner, 2001). Climate influences the amount and timing of water availability, basin geomorphology, flow characteristics and fluctuating water level. The hydrology of wetland directly modifies and changes its physicochemical environment, particularly oxygen availability and related chemistry such as nutrient availability, pH, and toxicity. Hydrology also affects the transports of sediments, nutrients, and toxic materials into wetlands, thereby further influencing the physicochemical environment. Hydrology also causes water outflows from wetlands, removing biotic and abiotic materials such as dissolved organic carbon, excessive salinity, toxins, excess sediments and detritus. Modifications in the physicochemical environment, can influence the hydrology by changing the basin geometry or affecting the hydrologic inflow or outflow (Mitsch and Gosselink, 2000).

According to Azous and Hurner (2001), hydrology modifies or determines the structure and functioning of wetland by:

1) Controlling the composition of the plant community and thereby the animal community. Only a few of the many thousands of species of plants are able to grow in saturated or flooded soils. Consequently, site with short-term and /or shallow flooding will support many different types of plants and more species of animals. However, this

concept does not extend to productivity. Basic productivity may be as high or higher in the latter, even though they have much lower diversity; that is, the amount of biomass produced in a simple system can equal or exceed that produced in more complex system.

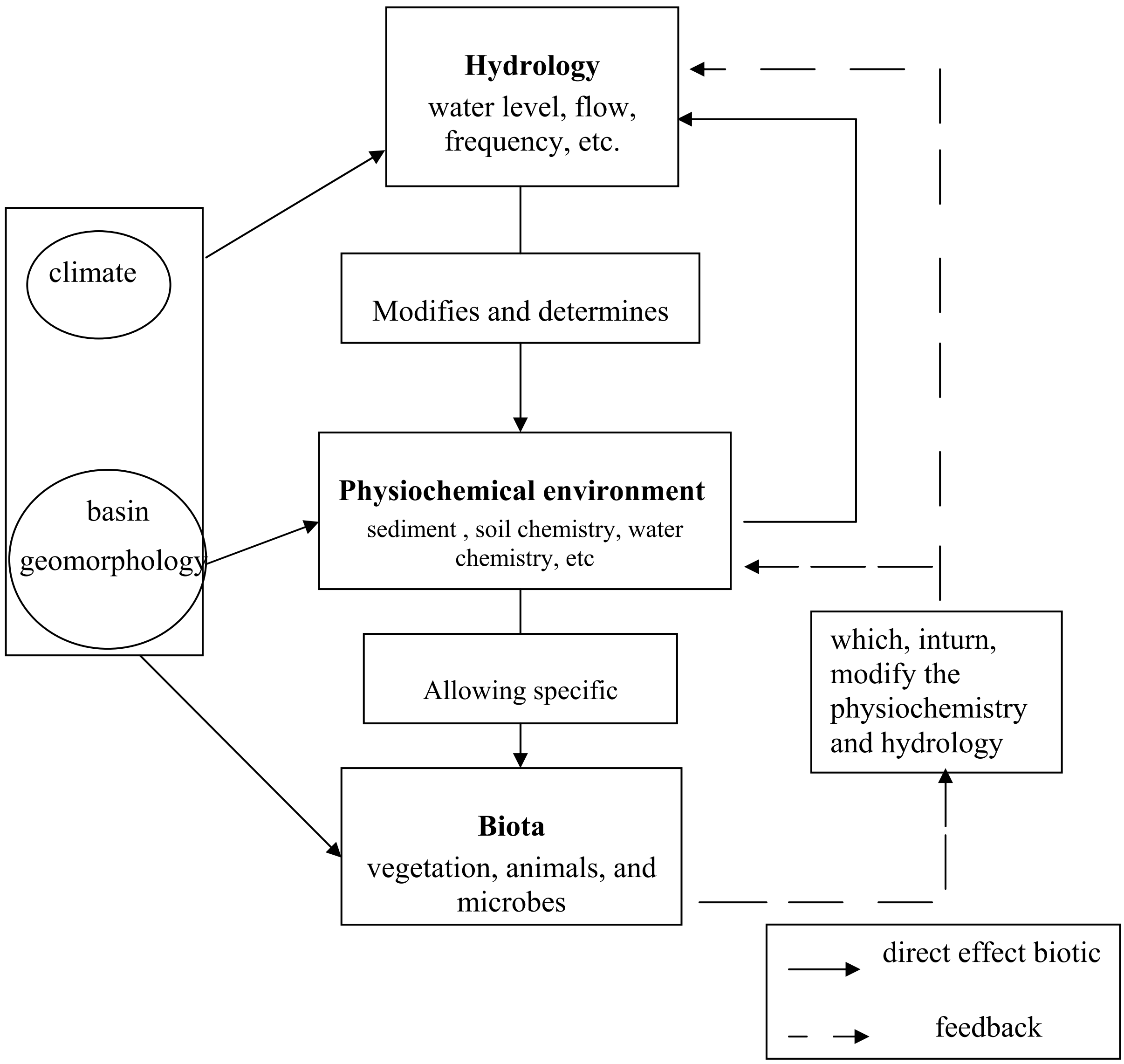

Figure 2-2 The effects of hydrology on wetland functions and biotic feedbacks that affect wetland hydrology.

Source : Mitsch and Gosselink, 2000

2) Directly influence productivity through controlling nutrient cycling and availability, import and export of nutrients, and fixed energy supplies in the form of organic particulars and decomposition rates. Under prolonged inundation, many important nutrients are immobilized under reducing conditions in the substrate and unavailable to plants as well as separated from the water column. Periodic drying and oxidation returns these substances to active portions of the cycles within the water column and near the surface of the substrate, resulting in an explosive growth response by plants and animals. Changes in oxygen availability and concentration caused by inundation also strongly influence decomposition rates. So low decomposition rate in anaerobic environments is the principal reason why many wetlands accumulate substantial quantities of partially decomposed organic material.

Wetland hydrology is often described in term of " hydroperiod", the pattern of fluctuating water levels resulting from the balance between water inflows and outflows, topography, subsurface soil, geology and groundwater condition. For a wetland that is not subtidal or permanently flooded, the amount of time that the wetland is under standing water is called the "flood duration" and the average number of time that the wetland is flooded in a given period is known as the "flood frequency" (Hammer, 1999).

According to Tiner (1999), factors indicating wetland hydrology include duration and frequency of wetness, depth of water saturation, and timing or seasons of wetness.

Factors influencing the hydrology of wetland are the balance between the inflow and outflow of water, which define the water budget in wetland. The landscape, soil condition, geology, and groundwater condition determine the capacity of wetland to store water (Mitsch and Gosselink, 2000).

Determining volumes of inputs and exports and the storage volume in the wetland is useful because changes in water depth or elevation can be calculated (Azous and Horner, 2000), as follows.

$$\Delta V = V + I - E \qquad \text{.....................} (1)$$

$$\Delta L = L + (\Delta V / A x D) \qquad \text{.....................} (2)$$

where V = volume of water storage in wetland (cubic meters)

I = volume of inputs (cubic meters)

E = volume of exports (cubic meters)

L = water level or elevation (meters)

A = wetland surface area (square meters)

D = depth (meters)

ΔV = change in volume of water storage in wetland (cubic meters)

ΔL = change in water level (meters)

The amount of water in wetland mainly comes from precipitation, which is determined by regional climate and topography, surface inflow and groundwater in wetland, soil conditions and geology. The quantity of outflows from wetland consist of surface runoff, groundwater and evapotranspiration. Outflow varies widely depending on vegetation type and site conditions. For some types of wetland, tides affect water balance. Water balance in wetland can be estimated (Mitsch and Gosselink, 2000) as follows.

$$\Delta V = P + S_i + G_i - ET - S_o - G_o + \Delta T \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ΔV = change in volume of water storage in wetland (cubic meters)

P = net precipitation (cubic meters)

S_i = surface inflows (cubic meters)

G_i = groundwater inflows (cubic meters)

ET = evapotranspiration (cubic meters)

S_o = surface outflows (cubic meters)

G_o = groundwater outflows (cubic meters)

ΔT = tidal inflow (+) or outflow (-)

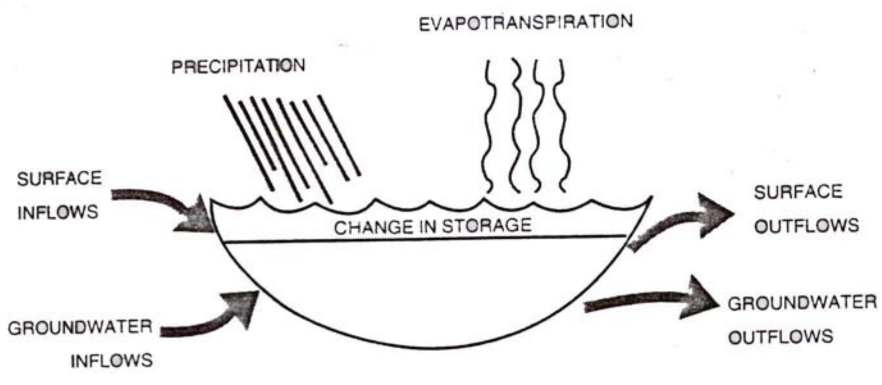

Figure 2-3 Wetland water budget components.

Source : Azous and Hurner, 2001

For some wetlands, turnover rate and renewal rate or residence time may be important characteristics. Turnover rate is simply the ratio of system volume to flow through (Azous and Hurner, 2001).

$$T = I / V \qquad \text{.......................(4)}$$

where T = Turn over rate

I = Quantity over a time period (cubic meters)

V = volume of storage (cubic meters)

and

$$R = 1 / T \qquad \text{.....................(5)}$$

where R = residence time

The water storage of wetland changes seasonally and in response to storm events.The water storage can be estimated as the mean depth of the wetland by area of wetland. Seasonal changes in wetland storage is attributable to local patterns of precipitation and evapotranspiration. In addition, basin topography i.e. height, slope length and slope gradient, affect the capacity of water storage, water balance and control of the subsurface in wetland. Slope gradient, influences the kinetic energy of runoff and slope length, influences the amount of water present at any point of the landscape. Wetlands are characterized by divergent slope (dome-like), disperse runoff across the slope, whereas runoff is collected on convergent (bowl-like) slopes. If wetlands are characterized by low slope gradients, they accumulate water, infiltration and groundwater recharge are maximize, water tables are high. On the other hand wetlands are characterized by steeper, infiltration rates and groundwater recharge are low. Other factors affecting storage volume of wetland include geology, basin conditions, soil conditions, type and structure of plants. Wetland plants are important to the amount of evapotranspiration, the formation of hydric soils, quality of water and movement of water.

This research, focuses on water balance because it influences hydrological conditions and determines the volume of water in wetland. In addition water balance defines pattern of fluctuating water levels. If volume of inputs is more than volume of outputs, water level increase. If volume of outputs is more than volume of inputs, water level decreases. Consequently, the study on water balance can indicate change in hydrology of wetland. This study determines water balance in Bung Boraped wetland using equation presented in Mitsch and Gosselink (2000). This study assumes that groundwater inflow equals to outflow and the quantity of water in wetland almost totally depends on surface inflow, precipitation, subsurface outflow and evaporation.

2.5 Threats to Wetlands and Their Resources

Increasing number of population and the development activities have led to changes in land uses and wetland resources. Theses changes have direct effects on wetland ecology. In Thailand, wetlands are changing due to development projects, ineffective planning and control of wetland uses and related land use change. Public wetlands have been converted into private wetlands for agriculture and housing, which created problems and threats. There problems have caused change in hydrology conditions, reduced amount of animals and plants, decreased wetland size and economic value (Office of Environment Policy and Planning, 1997).

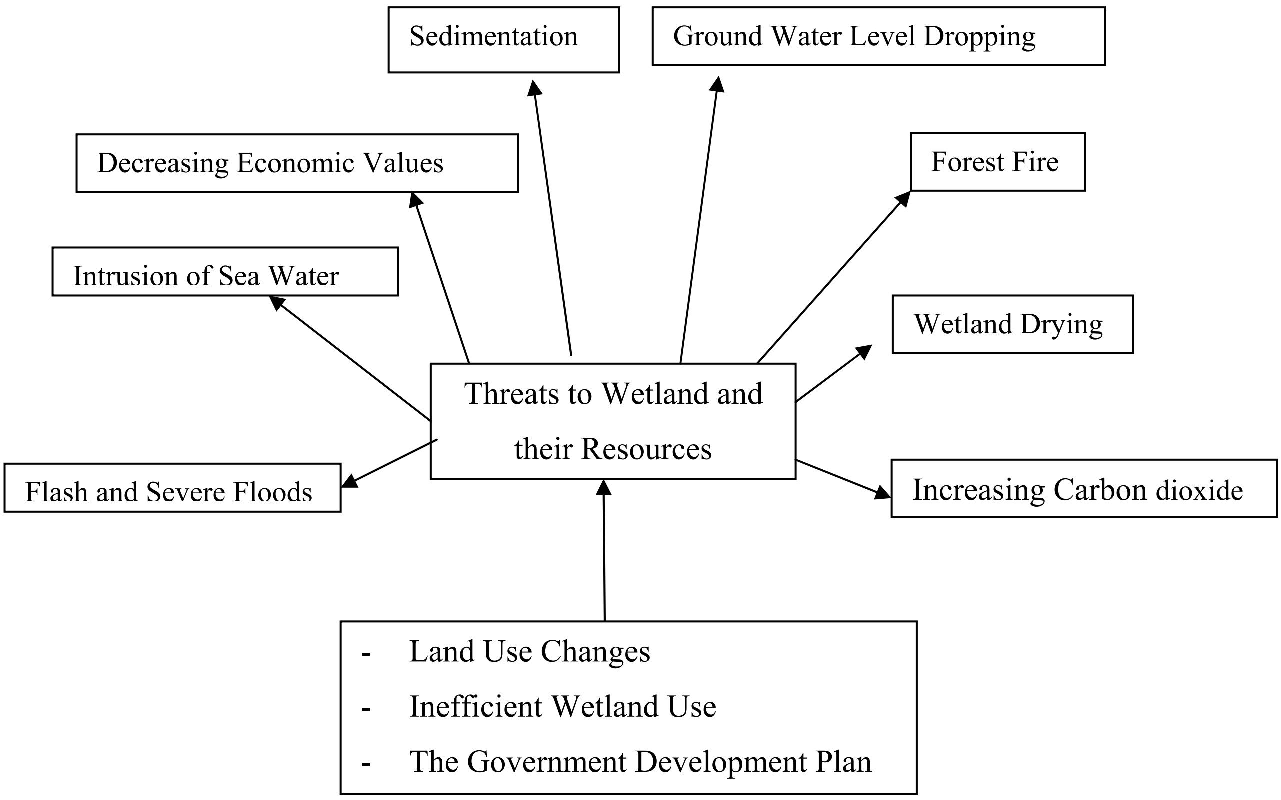

Figure 2-4 Threats to wetlands and their resources.

Source : Modified from Coastal Resource Institute, 2001

2.6 Land use

Land use means the realization of land value adopted for satisfying human needs e.g. agricultural use, commercial use, industrial use, residential use etc. Because of limited natural resources in term of size, location and characteristics, people should concern about the benefits as well as the impacts resulting from those land uses (Wacharakitti, 1982).

The pattern of using land can be classified by the consideration about current use of soil, geographical position, elevation, conditions of soil, and social and economic conditions. Wacharakitti (1982) classified land uses as follows.

1) Urban and built-up land consists of houses, shops, markets, trading places, industries, governmental offices.

2) Agricultural land consists of cropping such as vegetables, orchards, field crops, rice fields, grazing land, and shifting cultivation.

3) Forest lands include natural forest, forest plantation, bamboo forest.

4) Idle lands, barren land.

5) Water bodies, rivers, ponds, lakes and reservoirs.

Land Development Department (1998) classifies land uses into 5 types as follows.

1) Forest land of different types.

2) Agricultural land e.g. paddy field, shifting cultivation, vegetables, field crop, and mix agriculture.

3) Urban land e.g. commercial areas, industries, governmental offices, residential areas, golf courses, roads, airports.

4) Water bodies e.g. natural and artificial water bodies, canals, rivers, streams.

5) Others e.g. unclassified land, idle land.

Major land use in Thailand is agriculture. Due to increasing number of population, the forest land has been changed to agricultural land. Use of land which is not suitable for agriculture has caused land degradation and soil erosion.

In addition to the increasing population, there are many more factors affecting the change of land use pattern (Wacharakitti, 1982).

1) Increasing population, urbanization, and increasing demand for agricultural land and other activities.

2) Expansion of agricultural land without appropriate control.

3) Development activities such as construction of roads and dams have led to the change of land uses especially in rural area.

4) Government policy and international trades can cause the change of land use pattern.

In Nakhonsawan province, land uses can be classified as shown in Table 2-1

Table 2-1 Land utilization of Nakhonsawan Province.

Land utilization	Total land (rai)
Forest land	514,375
Residential area	71,636
Paddy field	2,703,999
Field crops	1,772,709
Vegetable and flower	44,940
Glazing land	172,968
Idle land	81,951
Lowland, mine	58,371
Unclassified	577,599
Total land	5,998,548

Source : Land Development Department, 1991

2.7 Bung Boraped Wildlife Non- Hunting Area

Faculty of Environment and Resource Studies, Mahidol University (1994) describes the physical characteristics and existing conditions of Bung Boraped as follows.

2.7.1 Physiography

Bung Boraped is the largest freshwater lake in the lower part of the northern region of Thailand situated in Nakhonsawan province. It locates on the left bank of the

Nan river within the premises of three districts, namely Muang Nakhonsawan, Tha Tako and Chumsaeng, covering an area of about 212.38 sq km (approximate 132,737 rai) (Office of Environmental Policy and Planning, 2002). Bung Boraped has been supervised by the Department of Fisheries and was developed in 1926 by the construction of weir at the western end and several water gates on the northern side of the lake where the inland fisheries station is located. When the lake was first developed, it covered an area of about 200 sq km but since then the size has been reduced to only 100 sq km with an average depth of 2 meters and a maximum depth of 5-8 meters.

Asian Institute of Technology (1981) surveyed the water level conditions, during the period from 1965 to 1978 and found that the retention water level was 23.8 m MSL and water surface area was around 102.8 sq km (64,282 rais) but in wet season the water surface area would increase. The catchment area of Bung Boraped was estimated at 4,200 sq km. In the vicinity of Bung Boraped, village areas expanded and affected both physical and biological status of Bung Boraped.

2.7.2 Wetland types of Bung Boraped

Bung Boraped and surrounding area consist of the following wetland types.

1) Lake locates in the central of the area, at elevation of 20 m.MSL. The lake occurred after construction of weir in the west of Boraped canal.

2) Marsh locates surrounding Bung Boraped, covered by shallow water and aquatic vegetation. This area receives the alluvial deposits for a long time and gradually change to alluvial plain.

3) Alluvial plain is the large plain located in the north and the east of Bung Boraped. The area was formed by the alluvial deposit from Nan River and Boraped canal.

4) Undulating hill at the south of Bung Boraped.

2.7.3 Geology

The geology and geomorphology consist of:

1) Recent flood plain or alluvial deposits, located around the lake,

2) Old alluvial fan locates next to the recent flood plain, found in pleistocence period from 1.8 to 0.01 million years,

3) Igneous rock including andesite and thyyolite, locates in hill area i.e. Phanomset hill.

2.7.4 Soils

The soils on the rim of Bung Boraped belong to the YangPong (Yp) series. These soils are continuously saturated with water and are rarely cultivated. Lotus is grown in this area where marshy vegetation generally predominates. The soils are composed of heavy clay with a dark humiferous surface horizon. Reduced, bluish to gray soil layers occur at shallow depths. Values of pH are strongly to slightly acid. Adjacent to the soil of Yang Pong series on the higher parts of the alluvial deposits are mostly soils of the Rat Buri (Rb) series and the Chum Saeng (Cs) series in the southeastern part of the lake.

Rat Buri soils are usually found at some distance from levees and abandoned river channels where the topography is flat to slightly undulating. These soils are subject to flooding during the wet season and are poorly drained and are used for growing rice giving moderate yield. They are usually composed of clay but in some areas a thin clay loam or silty clay loam layer occurs.

Chum Saeng soils are soils of the river basins with a slightly more leached profile. These soils are composed of clay and are mottled throughout (Asian Institute of Technology, 1981).

2.7.5 Climate

The climate of Nakhonsawan province is fundamentally a tropical savannah. This area is under the influence of the southwest monsoon and the northwest monsoon. Therefore, it rains almost through out the wet season and the weather is dry and cold in winter.Bung Boraped and surrounding area have 3 seasons.

The rainy season, the period from May to October.

The winter season, the period from October to February.

The summer season, the period from February to May.

Table 2-2 Climatic Data of Nakhonsawan province for the period 1992-2001.

Year	Mean Temperature(◦c)	Rainfall(mm.)	Relative Humidity(%)	Evaporation(mm.)
1992	28.3	983.9	67	2047.6
1993	28.5	890.5	67	1995.5
1994	28.4	992.5	69	1815.1
1995	28.4	1317.7	71	1963.7
1996	27.7	1168.2	74	1757.0
1997	28.3	1019.1	71	1891.9
1998	29.1	1114.8	73	1994.9
1999	27.6	1258.1	75	1649.0
2000	27.7	1257.1	75	1639.0
2001	28.3	1090.8	75	1686.0

Source : The Meteorological Department, 2002

2.7.6 Groundwater

The groundwater aquifer in this area is of Chao Praya groundwater (Ocp), which is recommended as good quality and flow rate ranks between 10-70 cubic meters / hour. It is in the space of sand-stone, consisting of sandy-clay drawn from both Ping and Nan river, and sorted paralleled with river width at most 30 km. It can be divided into 2 parts which are North Chao Phraya and, the lower of Bung Boraped, starting from Paknampo. The groundwater is supported by the slate rock. Chao Phraya groundwater mainly appears in Amphoe Chumsaeng, Nakhonsawan province (Land Development Department,1991).

2.7.7 The Hydrological Conditions

Topography of the catchment is relatively flat, so the weir was constructed in order to retain water within Bung Boraped. The surface inflow of the lake comes from rainfall and drainage from the upper catchment. Outflow drains into the Chao Phraya River. Detail of inflows and outflows are as follows.

1) Nan River flows through Amphoe Banpot Pisai, Amphoe Kao Leow and Bung Boraped, then drains into Chao Phaya River at Pak Nam Pho, Amphoe Muang Nakhonsawan province.

2) Klong Bon and Klong Lam Jed Ka flow from Amphoe Chum Saeng and drain into the north of Bung Boraped.

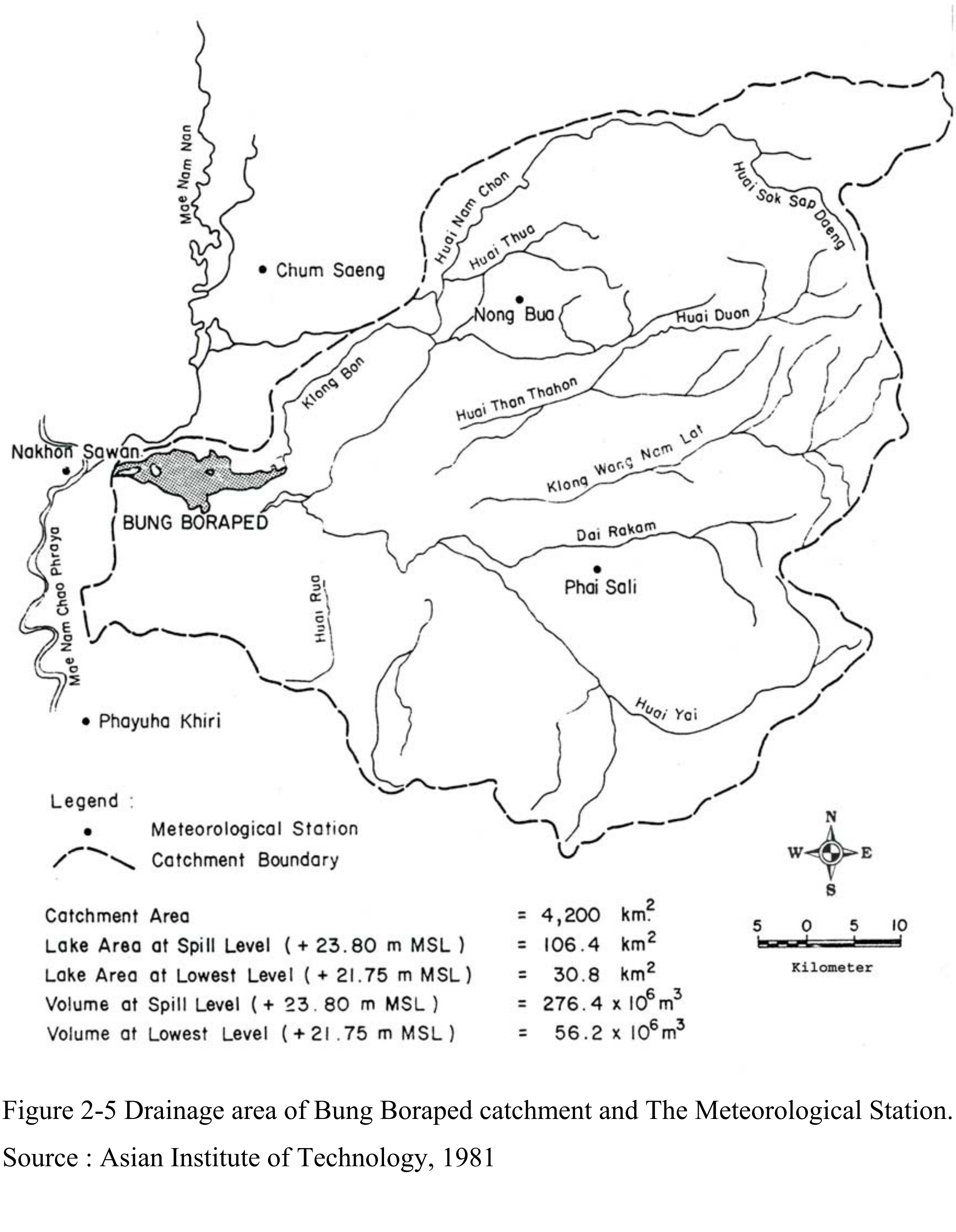

Figure 2-5 Drainage area of Bung Boraped catchment and The Meteorological Station.
Source : Asian Institute of Technology, 1981

3) Klong Tha Ta Ko, Huay Hin, Huay Sa, Huay Hrang flow from Amphoe Tha Ta Ko and flow into the south of Bung Boraped with big amount of inflow in rainy season.

Bung Boraped has 2 inflows: from Klong Bon, Klong Sa, Klong Jed Kong, Huay Hrang; from Klong Huay Hin. Outflow from Bung Boraped is via the dike at the Fisheries Station, and drains into the Chao Phraya River.

The water level in Bung Boraped depends on the water level of Chao Phraya River and the control of water gate at Klong Boraped by the Fisheries Station. In summer, the water level is controlled at 24 m (MSL) (Table 2-3), for the use of people around the area. The highest capacity of water storage of Bung Boraped is between November and January and the lowest storage is between May to June. This causes the change of water level in each season. The storage level is controlled for fish production and flooding prevention as follows .

- Minimum storage level : 23 m (MSL)
- Maximum retention level : 24 m (MSL)
- Maximum flood level : 24 m (MSL)

The useful storage is between the minimum storage level and the maximum retention level, 107.2 million cubic meters. The Department of Fisheries (1985) found that the water surface area and quantity of water in Bung Boraped varied according to the storage level (Table 2-4).

Topography of Bung Boraped is relatively flat which is not suitable for being a large storage reservoir. Water is used for irrigation by local people but the size of the irrigated area is small. The excess water is released to the Chao Phraya River (Faculty of Environment and Resource Studies, 1994).

Table 2-3 Maximum and minimum monthly water level in Bung Boraped (1999)

Months	Water Level (m MSL)	
	Maximum	Minimum
January	23.8	23.6
February	23.6	23.4
March	23.4	23.1
April	23.3	23.1
May	23.9	23.3
June	24.1	23.9
July	24.1	23.9
August	24.0	23.9
September	24.1	23.8
October	24.4	24.0
November	24.8	24.0
December	24.1	23.9
Mean	23.9	23.65

Source : The Fisheries Station (Panarat, 2000)

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Table 2-4 Surface area and the water storage level

Elevation m (MSL)	Surface Area (sq km)	Accumulative Volume (million cubic meters)
19.00	0.000	0.000
19.50	0.069	0.171
20.00	4.083	1.209
20.50	11.969	5.222
21.00	18.981	12.960
21.50	27.729	24.637
22.00	37.664	40.985
22.50	56.761	64.591
23.00	82.064	99.297
23.50	110.697	147.488
24.00	125.463	206.527
25.00	244.988	391.752
26.00	290.138	659.315
27.00	331.400	961.084
28.00	342.850	1289.209
29.00	378.338	1649.802

Source : Department of Fisheries, 1985

Department of Fisheries (1985) studied the water balance of Bung Boraped, based on the irrigation area of 19.2 sq km. Calculation was based on a period of 20 years and runoff data from 1965 to 1984. The water balance was estimated by the following equation

$$S_e = S_b + I + O_r - E - O_s - SP - DOMES - MIN$$

When S_e = storage in the lake at the end of the calculation period

S_b = storage in the lake at the beginning of the calculation period

I = lake inflow during the calculation period which consists of inflow from the uncontrolled sub-catchments, spill water from upstream reservoirs, excess water from paddy fields and return flow from irrigated areas.

SP = seepage loss through the lake floor which is assumed to be 10% of the lake inflow during the calculation period.

DOMES = the volume of water pumped out from the lake for domestic water supply.

MIN = the released water to meet with the downstream water requirement which takes the spill during the calculation period into account. If the requirement is not satisfied, the deficit must be supplied from the lake.

O_r = the volume of water released or pumped out from the lake during the calculation period for irrigation purpose.

E = evaporation loss from the lake water surface which is assumed to be at a rate of 70% of the Class-A Pan evaporation rate.

O_s = overspill during the calculation period which occurs when the storage at the end of the calculation period, S_e, exceeds the maximum retention level of the lake.

The water balance of Bung Boraped was calculated and presented in Table 2-5. As indicated in the Table, there would be much more water available than that required for irrigation in the proposed area, because almost agriculture area is far from the lake. Since there was no large community located around the lake, domestic water supply from Bung Boraped has not been considered in the study.

The study of Department of Fisheries (1985) did not considered the precipitation factor. The evaporation loss from the lake surface area was assumed to be at a rate of 70% of the Class-A Pan evaporation rate.

Table 2-5 The water balance in Bung Boraped

Unit : million cubic meters

Year	Total Inflow	Seepage Loss	Release for Irrigation	Evaporation	Return Flow	Excess (Δ S)
1965	524.13	52.41	20.41	33.66	6.95	427.78
1966	1461.54	146.15	27.25	-5.26	8.94	1284.15
1967	935.52	93.55	31.23	35.57	10.27	774.96
1968	242.71	24.27	31.62	56.11	10.42	134.20
1969	939.01	93.90	28.31	30.73	9.31	782.04
1970	528.87	52.88	19.99	33.14	6.51	422.69
1971	552.41	55.24	28.95	45.65	9.67	423.12
1972	478.45	47.84	31.35	66.50	10.34	332.19
1973	475.98	47.59	26.53	39.32	8.67	365.53
1974	393.35	39.33	29.34	72.38	9.60	252.30
1975	1000.45	100.04	26.16	28.37	8.61	845.87
1976	275.74	27.57	31.14	42.25	10.23	174.77
1977	92.69	9.26	39.52	85.83	13.16	11.46
1978	1544.19	154.41	26.76	47.65	8.69	1261.98
1979	115.06	11.50	39.48	42.50	13.06	47.94
1980	680.95	68.09	27.21	66.46	8.83	429.83
1981	679.65	67.96	23.78	46.98	7.72	540.92
1982	333.46	33.34	31.40	55.26	10.35	217.63
1983	599.87	59.98	28.12	80.67	9.19	426.92
1984	397.48	39.74	28.87	44.34	10.10	284.53
Mean	612.57	61.25	28.87	47.41	9.53	475.19

Source : Department of Fisheries, 1985

2.7.8 The land uses of Bung Boraped

The land uses of Bung Boraped and surrounding areas are related to the water levels in Bung Boraped, which is highest approximately at 24.10 m (MLS) between November and December. In the north of Bung Baraped, Tambon Kwae Yai and

Tambon Kriang Krai, most of land uses are agriculture (i.e. sugar cane, pepper and vegetables). The Nan River, lakes and ponds are used for fisheries. In Tambon Tubkrit, most areas are used for paddy fields. The east and the south of Bung Boraped are agricultural areas and field crop areas (Faculty of Environment and Resource studies, 1994).

According to the study of Faculty of Environment and Resource Studies (1994) major land uses are paddy field, mixed agriculture and idle land (Table 2-6).

Table 2-6 Land utilization surrounding Bung Boraped

Land Utilization	Area (sq km)
Mixed agriculture	31.06
Orange	0.81
Maize	4.56
Fiber crops	6.56
Sorghum	15
Paddy field	194
Forest land	1.4
Lowlands	37
Village land	15.8
Total land	306.9

Source : Faculty of Environment and Resource Studies, Mahidol University, 1994

2.7.9 Problems and changes

Bung Boraped is a dynamic ecosystem changing in shape, size and volume by the time and human activities (Faculty of Environment and Resource Studies, 1994). In the past, the Department of Fisheries developed Bung Boraped in 1959, 1972 and 1992, by excavation and weed eradication.

The critical problem of Bung Boraped is the decreasing water depth due to sedimentation, catchment erosion and wide spread of aquatic plants within the lake. Some land uses have caused increasing catchment erosion (Faculty of Environment and Resource Studies, 1994).

Department of Fisheries (1985) studied the sedimentation of lakes including Kwan Phayao, Nong Han and Bung Boraped, using the equation to analyse the relationship between streamflow and suspended sediment load. For Bung Boraped, however, no discharge nor sediment observation was made. Therefore, the equation of Kwan Phayao is applied for this study.

$$Q_s = 6.88\ Q^{1.056}$$

When Q = average monthly discharge in cubic meters / second

Q_s = suspended sediment load in ton / day

Total sediment load was estimated based on the above equation and for 20 years period from 1965 to 1984. For Bung Boraped, the average sediment inflow was 57,675.9 ton/ year, the minimum sediment inflow was 7,430.6 ton/ year and the maximum sediment inflow was 153,704.9 ton/ year (Table 2-7).

The sediment in the lake came from erosion, the growth of aquatic weeds e.g. water lettuce, water hyacinth. The sediment problem in Bung Boraped has caused the decreasing volume of the lake, encroachment of people in shallow area, and decreasing aquatic animals.

According to the Asian Institute of Technology (1981), there were 2,023 residential units encroached into Bung Boraped with a total area of 63,216 rais in 1981. Bung Boraped Wildlife Conservation Promotion and Development Station (2000) reported that there were 2,618 residential units in a total area of 95,544 rais in 1996.

These changes in Bung Boraped and activities around the lake may have the following effects.

1) The normal water level of Bung Boraped is 23 m (MSL) and the mean depth is 3 meters, but at present, the mean depth is 1.5-2.5 meters, the volume of water in the lake is decreasing accordingly.

2) The water surface area decreased from 132,737 rais in 1982 to about 80,000-100,000 rais in 1996 because of the shallowness of the lake and dispersion of aquatic vegetation. The encroachment into the lake for agriculture, aquaculture, and housing increased by a total area of 30,000 to 40,000 rais.

3) The quality of the water in the lake was not suitable for domestic use due to the release of waste water and aquatic plant decomposition.

4) Abundance of aquatic animals decreased due to illegal and inappropriate fishing techniques, the use of agricultural chemicals, and commercial aquaculture.

5) Disturbance to bird habitats and bird hunting has led to decreasing diversity and population of birds (Office of Environment Policy and Planning, 1997).

Table 2-7 Estimated sedimentation inflow of Bung Boraped from 1965 to 1984

Year	Suspended sediment load (ton / year)
1965	49,479.9
1966	141,326.9
1967	90,536.1
1968	21,048.4
1969	91,058.8
1970	48,521.8
1971	51,627.6
1972	44,764.7
1973	43,543.3
1974	35,513.8
1975	97,997.7
1976	23,925.4
1977	7,430.6
1978	153,704.9
1979	9,511.2
1980	64,902.5
1981	49,186.9
1982	30,434.8
1983	56,959.1
1984	36,053.4
Mean	57,375.9

Source : Department of Fisheries, 1985

This study focuses on analyzing the sediment flow into Bung Boraped during the 23 years period from 1978 to 2000, because this is a critical problem reducing the volume of the lake.

2.8 Relevant Research

2.8.1 The research concerning wetland hydrology.

Reinett and Taylor (2001) studied the effect of urban area development on the hydrological system of Puget Sound Wetland in Washington, USA. The characteristics of the hydrological systems in urban areas and in forest lands, water balance of urban area and forest land were studied. Factors contributing to water balance which were brought to consideration were the amount of rainfall, the rate of water evaporation, and the change of groundwater and water volume stored in wetlands. The study found that the ratio of stored water to the amount of rain water was higher in the forest areas than in the urban areas, but the rate of water evaporated by plants was greater in the urban areas than in the forest areas. Both kinds of land were different in the water level fluctuation, greater change in urban areas than in forest areas. Factors influencing hydrological conditions were forest areas, urban areas, wetland morphology, outlet construction, wetland-to-watershed area ratio. Hydrology parameters were water level fluctuation, water depth, and length of dry period. The study found that the water level fluctuation in wetland depended on forest area, urban area and outlet construction. The model was created to predict the fluctuation of water level in the future.

McBean et al. (1996) studied how urban areas could affect the amount and quality of water in the nearby wetland. The study area was around the River Oaks in Ontario, Canada, which was facing with urban development problems. The meteorological data, evaporation, volume of water, and the penetration of groundwater were analyzed. The study found that there was an increase in the area where the water could not flow down to underground aquifer. Therefore the volume of water remained on the land surface. Increasing urban area caused increasing water inflow to the wetland, due to changing of waterway and reducing evaporation rate. The results indicated that turning natural wetlands to urban areas could have effects on the hydrological system.

Durongdej et al. (1999) studied improvement of rice cultivation and water management in the flooded areas of the central plain of Thailand. DEM (Digital Development Model) was used to evaluate the capacity of wetlands in holding water. The relationship between the water depth and the volume of water in box was analysed using hydrograph data. The study found that DEM may provide incorrect data because the dam effected topography in some area, and the volume of surface runoff can not be estimated due to change by embankments, roads, dikes.

Beilfuss and Barzen (1992) studied the hydrological conditions of The Mekong Delta and the Plain of Reeds, in Vietnam. The hydrological system, water quality, flood duration, the change in the water level, monthly water balance in wetlands (rainfall, evapotranspiration, surface water, and water storage) and the change in water level from past to present, were analyzed. The geomorphology of the plain and water movement were archived from aerial photography. Hydrological effect upon the nutrients, sedimentation, and the export of organic matter, hydrological conditions and water quality were monitored. Sluices were installed to permit maximum surface runoff during flooding season and to prevent unnatural drainage during the dry season. A monitoring framework was developed to test the effectiveness implemented strategies and to respond to future change in Mekong Delta. The results showed the importance of hydrology system on wetlands and other factors which have effects on hydrology system such as the storage capacity and water balance.

Bradley and Brown (1997) conducted a research to study the relationship between hydrology system and ecosystem of wetland at Narborough Bog in Central England, which was the area where the water flowing route has been destroyed and the problem of water system management occurred. Moreover some parts of the area were close to urban area and there has been decrease in species diversity of plants. Underground water table was measured during 1993-1998 using a numerical model, USGS Groundwater Model MODFLOW. This study indicated the vulnerability of

Narborough Bog to changing water level and that the hydrological conditions depended on precipitation, evapotranspiration and river level. The model could predict water table response to varying hydrological inputs. The results showed the effects of changing surrounding area on the hydrological conditions and ecosystem.

Basso (2000) studied the change of water balance of Managua Lake in Central America. The study used inflow and outflow data between 1927-1987. Inflow data were calculated from the summation of the quantity of runoff from river, the direct precipitation into the lake, the surface and groundwater discharge into the lake. Outflow data were calculated from the summation of the surface outflow, groundwater outflow and evaporation from the lake. The flow corresponding to change in water level was estimated from the difference between inflow and outflow multiplied by the surface area of the lake, and divided by the time period. The study found that the water level decreased constantly, and the water balance changed. The results indicated that there were 2 main causes of the change in water balance: the change in hydrological system resulted from the change in shape of the lake, and the water evaporation from the change in surface area of the lake. These 2 causes could lead to the change in water level.

Kamp et al. (2002) studied the effects of the change in agriculture on prairie wetlands at the St.Denis National Wildlife Area (NWA), Canada. This change of land development could have effects on surface runoff and water balance of wetland. Data of water table recorded 30 years ago since 1986, was gathered from ten areas of wetlands linking with NWA. It was found that during 1968-1980, before the development of land, the forms of how water level changed were similar for both kinds of wetlands. But after 1987, the grassy wetlands were drier than other wetlands under non- development. The long term, water level data indicated that when the small wetlands were converted from cultivation to grassland, runoff into the wetlands decreased and the wetland dried out. The study indicated that the hydrology of wetland was highly sensitive to land use change.

2.8.2 The Research on Bung Boraped

Chinoresyothin (2000) estimated the values of direct benefits from Bung Borpet, Nakhonsawan, including the values or benefits from irrigation, fisheries and other activities. The values of irrigation and fisheries were estimated based on the products price while the values or benefits in other activities were estimated by the travel expenses. The research found that Bung Boraped provided direct benefits in 1999 at 67,926,646.3 Baht, including benefits from other activities, 36,898,640 Baht, from fisheries, 16,356,122 Baht and from irrigation, 14,671,884.3 Baht.

Kiatewongtong (1994) conducted a research on the effects of changing ecosystem on some species of bird nesting in Bung Boraped, Nakhonsawan. There was land development in Bung Boraped by digging some areas and draining water from the lake. This would affect the lives of birds around Bung Boraped. This research studied the effects on nesting, the characteristics of nesting and materials, the population and frequency in nesting. The study found that birds mostly nested in June and bird nesting was not found in November. For the effect of changing ecosystem, Black Bittern (*Dupetor flavicollis*) and Black-winged Stilt (*Himantopus himantopus*) are two species that received benefits from change; six species were adaptable to this change and eight species faced with negative effects.

Jynprasert (1994) studied the variety of water plants in Bung Boraped after fishery management in 1990. Species distribution and their relationship with environmental factors were analysed. The research found 32 species of water plants which were classified into 7 species of floating rooted plants, 3 species of floating leave plants, 5 species of submerged plants and 17 species of emergented plants.

Maneerat (2000) studied the role of local people in conserving birds around non-hunting area in Bung Boraped, Nakhonsawan. The research found that the local people participated moderately in bird conservation and also found that natural resources of Bung Boraped were greatly beneficial to the local people. In the past, people hunted a lot of birds for foods and commercial trade. But nowadays the catch of water birds has decreased because people corporated with each other more for conservation.

Dangsee (1996) conducted a research on the relationship between bird species and their habitats in Bung Boraped Non-Hunting area. Data on each type of habitats and distribution of species of birds were surveyed. It was found that there were 73 species of birds around the area. These birds most utilized the floating plants area, while they utilized a little water surface area. Distribution of some species of birds depended on habitat condition and water level in the lake.

The research conducted on Bung Boraped confirmed the values and importance of Bung Boraped to overall ecosystem, economic and social way of life, history and tradition. Changes to Bung Boraped either digging or draining water from the lake may affect the ecosystem, both in term of quantity and biodiversity.

CHAPTER 3
METHODOLOGY

3.1 Data and materials

Data and materials used for this study are as follows.

3.1.1 Maps

1) Aerial photographs,1:50,000, Royal Thai Survey Department (1991) for land use data.

2) Topography map,1: 50,000, Royal Thai Survey Department (1982), sheets 5040 I Amphoe Chumsaeng, 5040 II Amphoe Tha Tako, and 5040 III Nakhonsawan province.

3) Soil map,1: 100,000 Department of Land Development, (1991).

4) Land used map, 1: 50,000, Department of Land Development (1978, 1983, and 2000), Nakhonsawan province.

5) Hydrogeology map, 1:100,000, Department of Mineral Resources (1995).

3.1.2 Statistical data

1) Meteorological data, for the period of 1978 to 2000, consisting of monthly and annual rainfall, average monthly and annual temperature, monthly and annual evaporation, Department Meteorology, Nakhonsawan province station.

2) Monthly and annual streamflow data for the period of 1954 to 2000, from the streamflow gauging stations of the Royal Irrigation Department at Bung Boraped and surrounding area.

3) Groundwater data from the Department of Groundwater Resource.

4) Data on water level, water volume, water surface area from the Inland Fisheries Research and Development Center, Department of Fisheries.

5) Data on the water quantity pumped from Bung Boraped and connected canals for irrigation from Office of Regional Irrigation, Royal Irrigation Department.

6) Sedimentation data, for the period of 1951 to 2000, from the sediment gauging stations of the Royal Irrigation Department at Bung Boraped and surrounding area (11 stations).

7) Data on number of people and animals living around Bung Boraped for the period of 1978 to 2000 of the Provincial Administration Office and Provincial Livestock Office.

3.1.2 Equipments

1) Mirror stereoscope

2) Computer equipment

3) Program Arc View GIS Version 3.2a

4) HEC 4 Program

5) Microsoft Excel 2000

6) SPSS program for Window

3.2 Study process and data collection

3.2.1 The study on land use change

Land use data was obtained from the interpretation of 1991 aerial photographs, black and white photographs, 1:50,000, size 9x9 inch, and 60% overlapping area, using mirror stereoscope and topography map, and the analysis of land use maps from 1978, 1983, and 2000 obtained from secondary data of the Department of Land Development . The study process is as follows:

1) Visual interpretation

● Observation of difference in colors, shades, structures, shapes, textures, sizes, shadows, and patterns.

● Comparison of structures from aerial photographs and topographic maps to outline site and topography.

● Consideration of picture characteristic and outline mapping unit boundaries.

2) Classification of different types of land use using characteristics of features. Land uses were classified into 7 groups as follows:

● Forest areas (L_1)

- Urban and built-up areas (L_2)
- Paddy field (L_3)
- Field crop areas (L_4)
- Aquaculture areas (L_5)
- Water bodies (L_6)
- Idle land (L_7)

3) Verification of land use data by using the ground truthing method of each mapping unit in random sampling and comparison with the result of the interpretation.

4) Transformation of analog image to digital images by

- Using image scanning technique.
- Arc View GIS version 3.2a and Arc Info program, on-screen digitizing technique, were utilized to transform spatial data to digital data.

5) Producing a digitized map for the study area for each year data were available.

6) Using overlay technique to study land use change for three periods between 1978-1983, 1983-1991, and 1991-2000.

7) Measurement and calculation of the area of each land use type in terms of sq km and percentage of total area.

8) Analysis of the changes of each land use type for each period, and calculation of total area per land use type and of the change per one year.

3.2.2 The study on the water balance

1) Monthly rainfall data were collected from the Department of Meteorology, Nakhonsawan province, for the period of 1978 to 2000. Monthly volumetric of rainfall into surface area of within Bung Boraped area (unit: million cubic meters) were calculated by:

Volumetric rainfall into Bung Boraped = monthly rainfall (m.) x water surface area of Bung Boraped (sq m)

2) Monthly evaporation data were collected from the Department of Meteorology at Nakhonsawan province, for the period of 1978 to 2000. Monthly

evaporation within Bung Boraped area (unit: million cubic meters) were calculated assuming 70% of total monthly evaporation (Department of Fisheries, 1985) by:

Monthly evaporation of Bung Boraped area = 70% x monthly evaporation (m.) x water surface area of Bung Boraped (sq m)

3) Monthly streamflow data were collected from 16 streamflow gauging stations of the Royal Irrigation Department around Bung Boraped, for the period of data from 1978 to 2000. The detail of the streamflow gauging stations is shown in Table 3-1 and Figure 3-1. Monthly streamflow into Bung Boraped were calculated as follows (Taesombat, 1988):

● Analyse the relationship between mean annual streamflow and drainage area by Regression Analysis of Record data.

Table 3-1 The streamflow gauging stations surrounding Bung Boraped

Station	Code Station	Drainage area (sq km)	Period of data	Mean annual streamflow
1. Chao Praya River, Muang Nakhonsawan	C.2	110,569	1956-2000	22,077.8
2. Nam Wang Ma, Sal Chao Kai Tor	Ct.4	1,246	1975-1988	288.03
3. Nam Mae Wong, Ban Hindad	Ct.5	795	1968-1971	312.05
4. Nam Mae Wong, Ban Pangmaka	Ct.5A	979	1969-2000	351.6
5. Nam Mae Wong, Ban Hhao Chonkan	Ct.5B	930	1988-2000	412.1
6. Klong Po, Ban Hang Rai	Ct.7	457	1975-2000	124.9
7. Nam Mae Wong, Ban Kogmor	Ct.8	3,410	1975-1978	248.96
8. Huai Tub Sela, Ban Bang Bung Eyejiam	Ct.9	522	1977-2000	130.5
9. Nan River, Ban Bang Moon Nak	N.8	32,878	1951-2000	10,133.48
10. Nan River, Ban Taphan Hin	N.10	30,760	1954-1973	9,417.09
11. Nan River, Chum Saeng	N.14	33,197	1954-1970	8,738.86
12. Nan River, Chum Saeng	N.14A	33,182	1978-2000	11,263
13. Nan River, Ban Tub Krit	N.37	56,214	1967-1996	12,268.45
14. Klong Bud Sabong, Chon Dan	N.53	111	1971-2000	54.34
15. Ping River, Kanuwanaluk	P.16	45,677	1971-2000	6,487.2
16. Ping River, Bunpot Pisai	P.17	45,851	1954-2000	7,215.2

Source : The Royal Irrigation Department, 2000

● Select the streamflow gauging station, Nan River at Ban Tap Krit (N37) for calculation of monthly streamflow because it is the nearest station to Bung Boraped. Extend streamflow data to cover during the study period by HEC 4 (Monthly Streamflow Simulation).

● Bung Boraped basin was divided into 21 sub-basins, as shown in Table 3-2 and Figure 3-2.

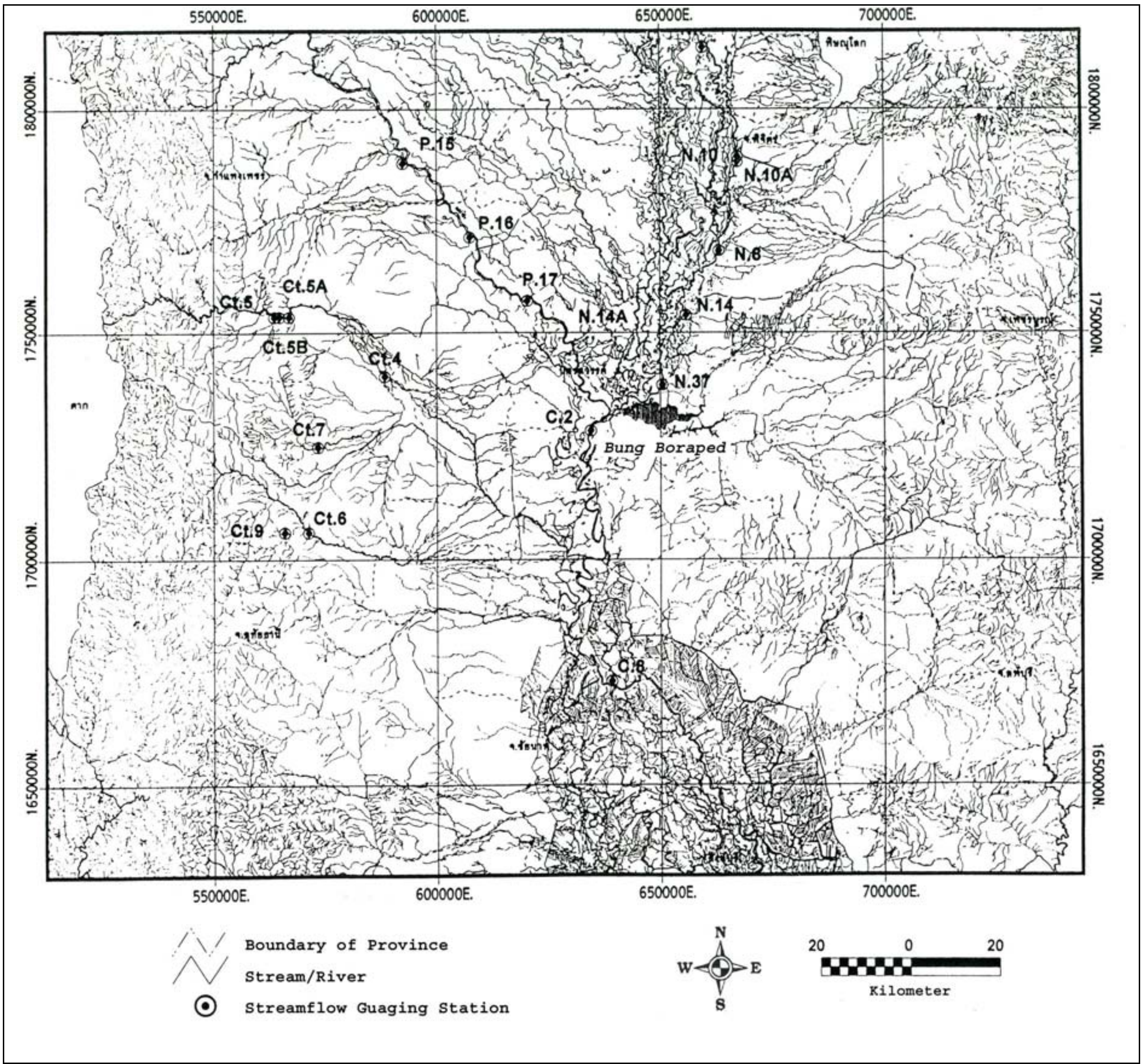

Figure 3-1 Location of the streamflow gauging stations

Source : The Royal Irrigation Department, 2002

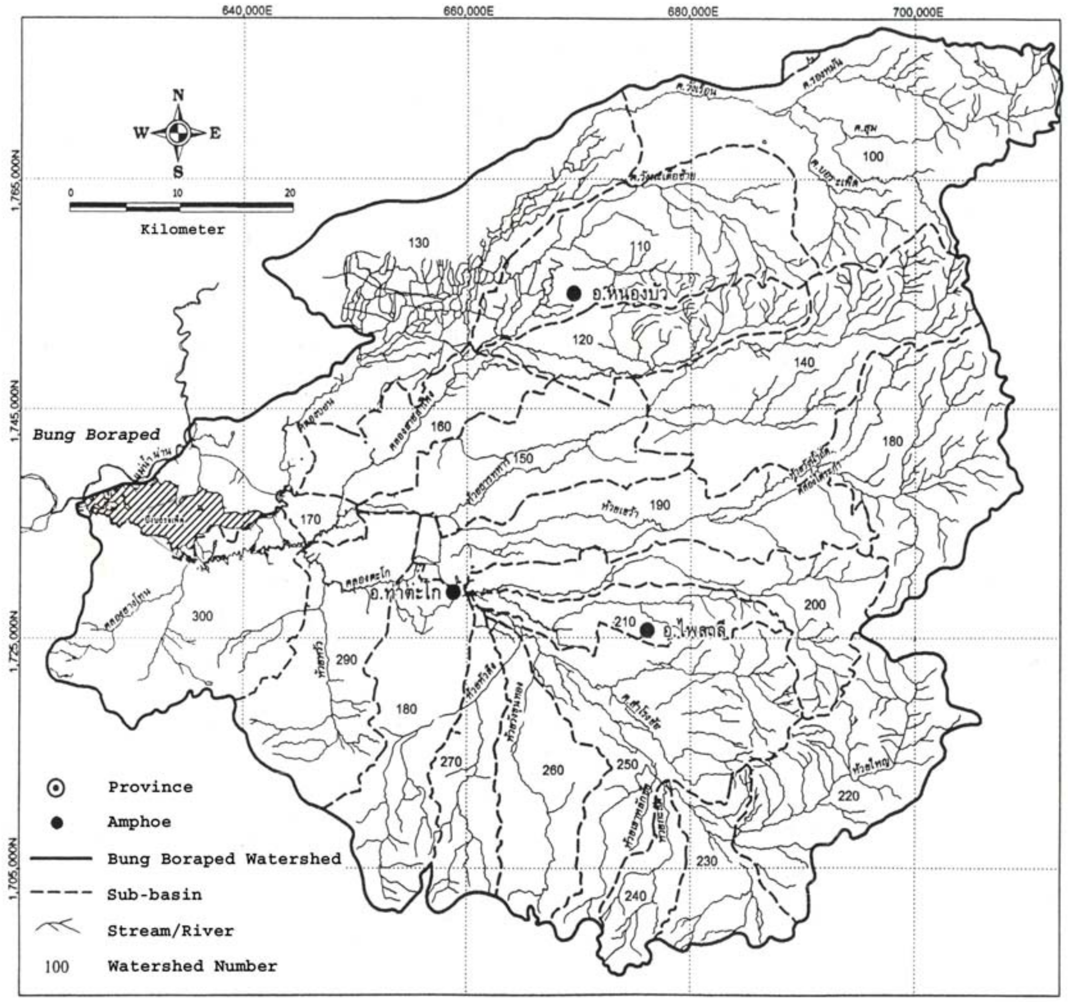

Figure 3-2 The boundary of sub-basins.

Source : The Royal Irrigation Department, 2002

- Calculate monthly streamflow of each sub-basin (Taesombat,1988) by

$$F = Q_1 / Q_2 = (A_1 / A_2)^n$$

When F = factor for adjusted monthly streamflow

Q_1= mean monthly streamflow of Ban Tap Krit station

Q_2 = mean monthly streamflow of each sub-basin within Bung Boraped basin

A_1 = drainage area of Ban Tap Krit station

A_2 = drainage area of sub-basin within Bung Boraped basin

n = regression coefficient

● Calculate monthly streamflow within Bung Boraped by summation of monthly streamflow of 21 sub-basins for the period of 1978 to 2000.

● Verification of monthly streamflow data of Bung Boraped by comparing with the estimated monthly streamflow analysed by The Royal Irrigation Department.

Table 3-2 Sub-basin and drainage area

Sub-basin	Code sub-basin	Drainage area (sq km)
1. Klong Wang Raun	100	375.00
2. Klong Bon	130	631.68
3. Klong Sai Lumpong	110	268.52
4. Klong Nam Sad	120	174.55
5. Huay Tan Tahan	140	310.29
6. Huay Tan Tahan Lang	150	200.68
7. Klong Sai Lumpong Lang	160	87.70
8. Klong Sai Lumpong Lang	170	33.28
9. Huay Tha Lob	180	257.80
10. Huay Tha Lob Lang	190	231.10
11. Klong Tuk Nam	200	173.45
12. Huay Pradoo Ngam	210	104.22
13. Klong Huay Yai	220	204.72
14. Klong Huay Yai Lang	230	102.19
15. Huay Yai	240	83.66
16. Klong Samrong Chai	250	294.37
17. Huay Wang Khuntong	260	161.39
18. Huay Lum Pong Mhon	270	111.75
19. Huay Hag Ling	280	174.85
20. Huay Rang	290	224.50
21. Huay Khao	300	292.81
Total area of basin		4,498.51

Source : The Royal Irrigation Department, 2002

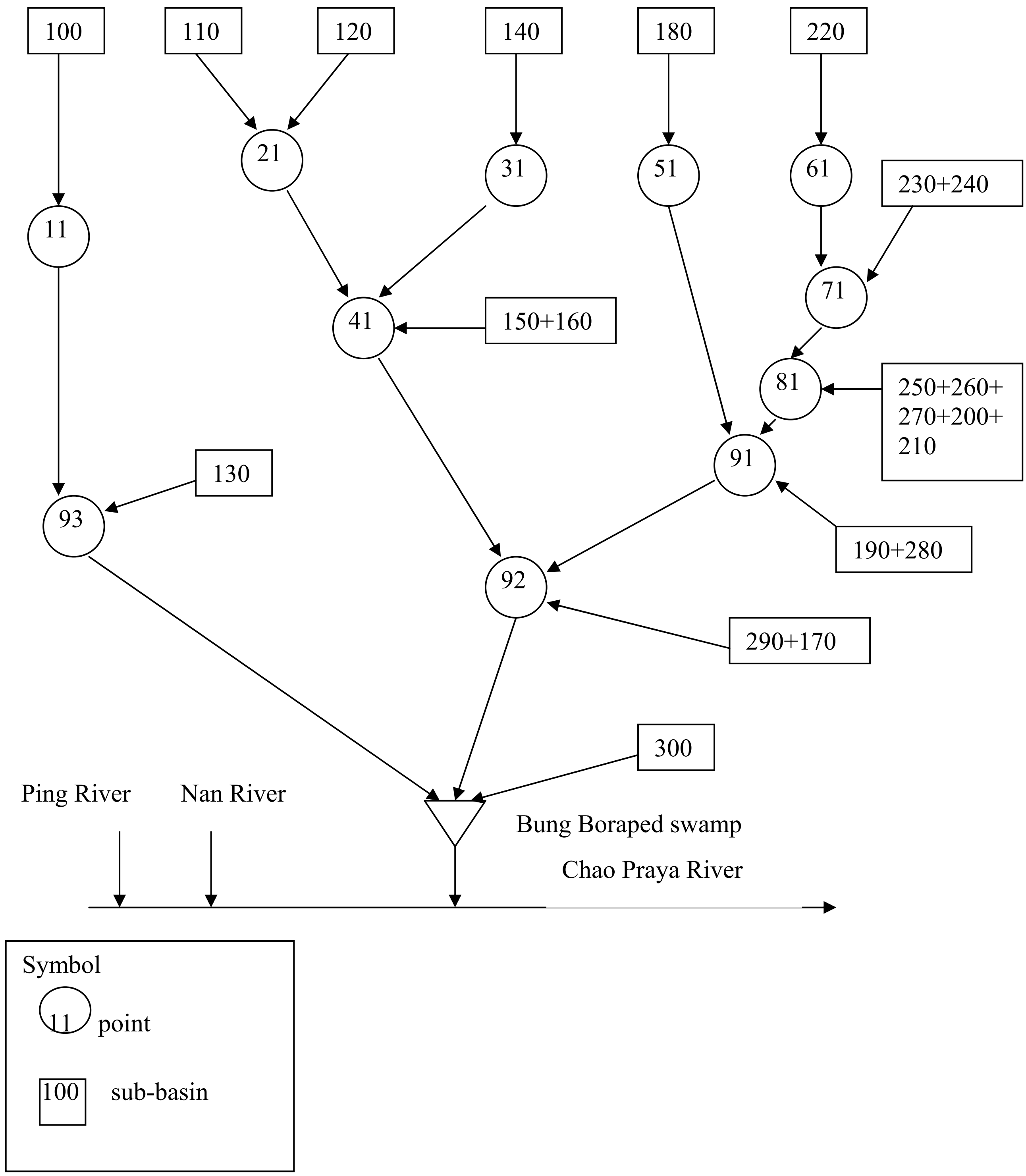

Figure 3-3 Chart of sub-basins within Bung Boraped basin

Source : The Royal Irrigation Department, 2002

4) Data on the volume of water pumped out from Bung Boraped and connected canals for irrigation during the period of 1978 to 2000 for irrigation (unit : million cubic meters) were collected from the Regional Irrigation Office, Nakhonsawan province.

5) Data on the volume of water pumped out from Bung Boraped for domestic use was derived from the calculation of water volume, which people and animals used per year (unit : million cubic meters). The following rates of water use were as follows: people- 150 liters/ person /day; cow and buffaloes- 50 liters /unit/day; pig- 20 liters/ unit/day; chicken 0.15 liters /unit/day (Maiklad, 1991).

6) Water balance (ΔV) of Bung Boraped was calculated by using the equation of Mitsch and Gosselink (2000).

$$\Delta V = P + S_i + G_i - ET - S_o - G_o$$

Where ΔV = change in volume of water storage in wetland

P = net precipitation (million cubic meters)

S_i = surface inflows (million cubic meters)

G_i = groundwater inflows (million cubic meters)

ET = evapotranspiration (million cubic meters)

S_o = surface outflows (million cubic meters)

G_o = groundwater outflows (million cubic meters)

This study assumed that groundwater inflow to the system is equaled to groundwater outflow, and seepage loss through the lake floor was 10% of the lake inflow during the study period 1978 to 2000. Most of Bung Boraped surface water area was open water, this study therefore did not consider transpiration rate. Thus the equation of Mitsch and Gosselink (2000) was modified as follows :

$$\Delta S = P + S_i - E - SP - IRR - DOMES$$

Where ΔS = volume of water storage in wetland (million cubic meters)

P = net precipitation (million cubic meters)

S_i = surface inflows (million cubic meters)

E = evaporation (million cubic meters)

SP = seepage loss through the lake floor (million cubic meters)

IRR = volume of water use for irrigation (million cubic meters)

DOMES = volume of water use for domestic (million cubic meters)

Monthly and annual water balance during the period of study (unit: million cubic meters) were calculated and change of water balance was analysed.

7) Sediment data were collected from 11 sediment stations of the Royal Irrigation Department around Bung Boraped. The period of data was from 1951 to 2000. The relationship between drainage area and annual suspended load (unit : ton per year) was estimated and compared with the estimated suspended load reported by the Department of Fisheries (1985),which was 57,375.9 ton/year. The volume of water storage in Bung Boraped was reduced by suspended load. Thus the equation of water balance of Bung Boraped was written as:

$$\Delta S = P + S_i - E - SP - IRR - DOMES - S_s$$

where S_s = volume of sediment (million cubic meters)

3.3 Data analysis

3.3.1 Analyse the relationship between land use and water balance by Pearson Product Correlation, SPSS program for Windows. Correlation coefficient (R) was analysed to indicate the level of relationship between each land use type and water balance.

3.3.2 Create a model of the relationship between land use and water balance by the Multiple Regression Analysis, Stepwise method.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Land use change

4.1.1 Land use

From the interpretation of the 1991 aerial photographs and the analysis of land use maps of 1978, 1983 and 2000, the land use of Bung Boraped and surrounding area during the study period was shown in Table 4-1 and Figure 4-1 to 4-4.

Table 4-1 Land use of Bung Boraped and surrounding area.

Land use type	Area							
	1978		1983		1991		2000	
	sq km	%	sq km	%	sq km	%	sq km	%
Forest area	7.47	1.47	3.89	0.77	3.57	0.7	3.47	0.68
Urban and built-up area	0.90	0.18	18.92	3.71	20.44	4.01	22.67	4.45
Field crop area	9.65	1.89	35.61	6.98	11.18	2.20	27.92	5.48
Paddy field	343.69	67.41	342.60	67.20	374.61	73.48	350.93	68.83
Aquaculture area	-	-	-	-	0.22	0.04	1.26	0.25
Water bodies	50.79	9.96	51.02	10.01	52.01	10.21	51.31	10.06
Idle land	97.32	19.09	57.78	11.33	47.79	9.37	52.26	10.25
Total land	509.82	100	509.82	100	509.82	100	509.82	100

Source: The result of study

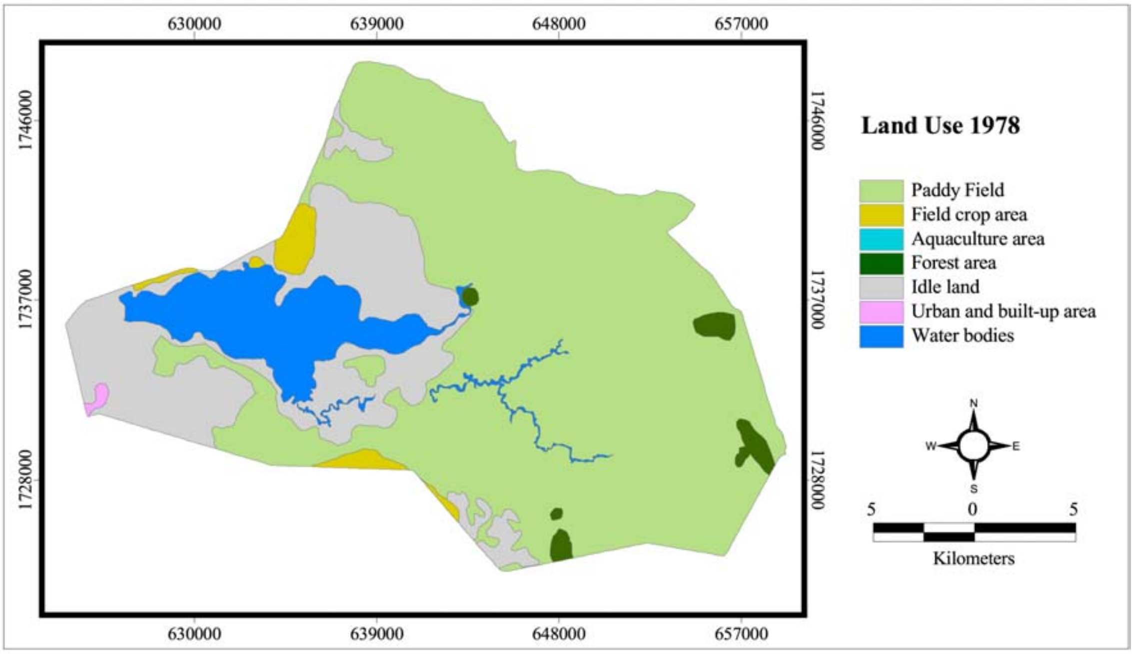

Figure 4-1 Land use of Bung Boraped and surrounding area in 1978

Source : Land use map, Department of Land Development, 1978

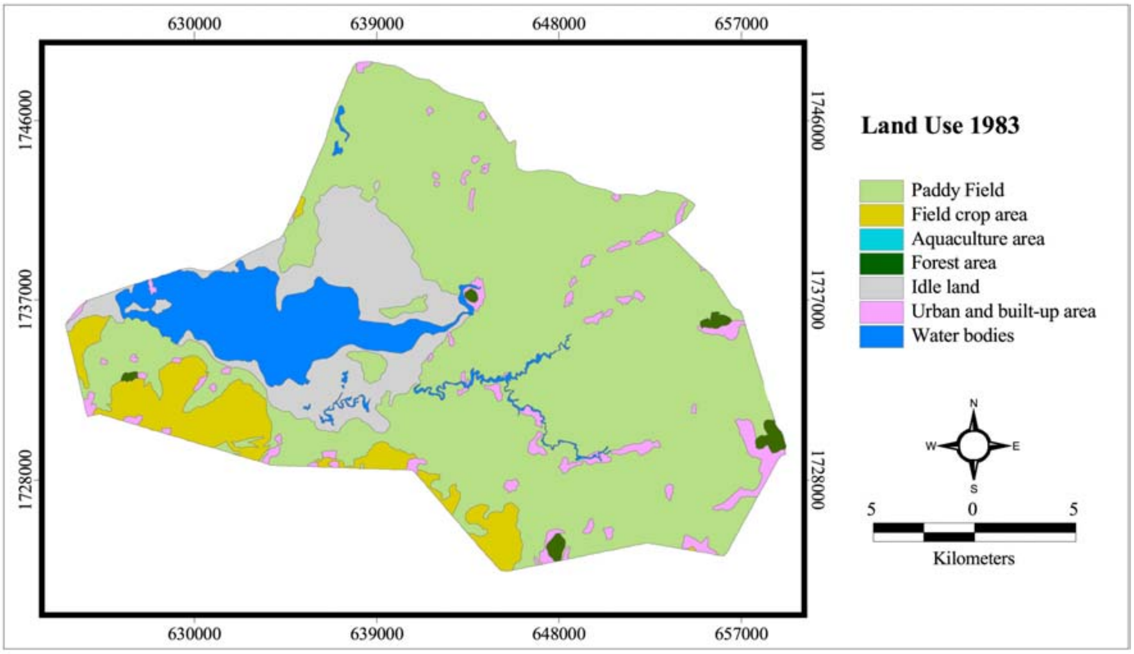

Figure 4-2 Land use of Bung Boraped and surrounding area in 1983

Source : Land use map, Department of Land Development, 1983

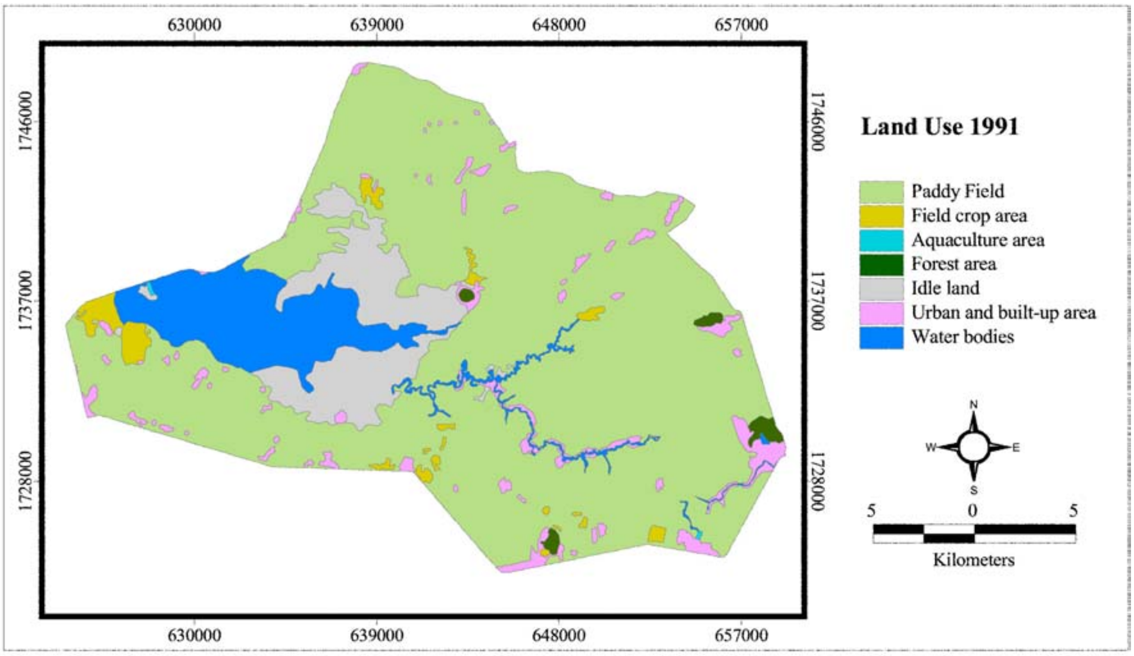

Figure 4-3 Land use of Bung Boraped and surrounding area in 1991

Source : Aerial photographs the Royal Thai Survey Department, 1991

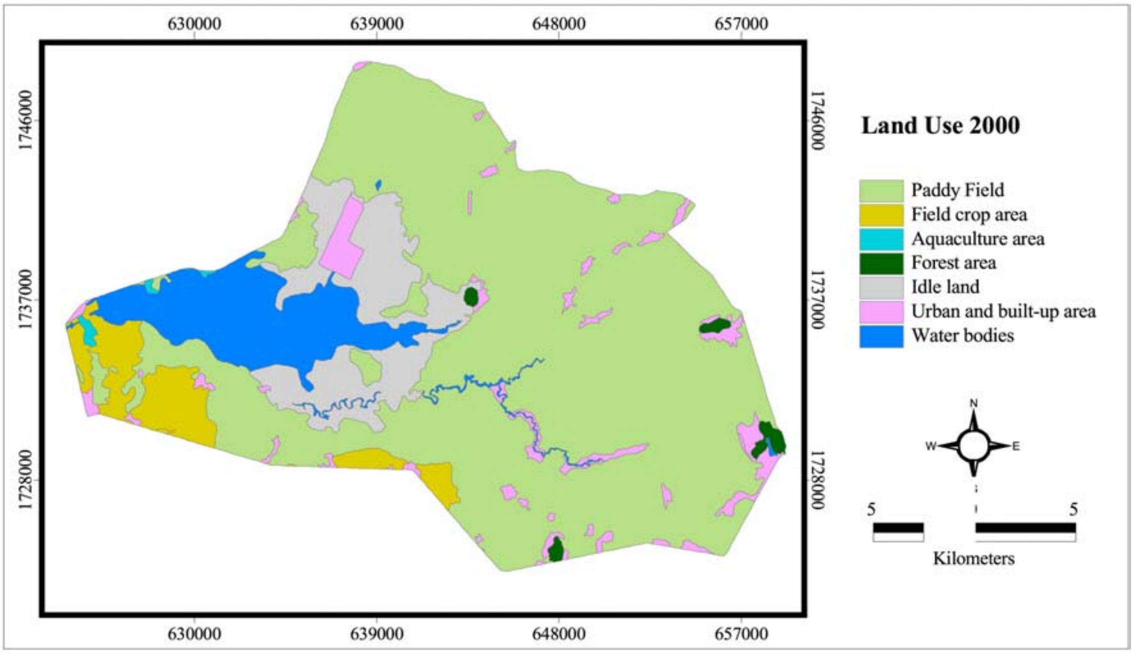

Figure 4-4 Land use of Bung Boraped and surrounding area in 2000

Source : Land use map, Department of Land Development, 2000

4.1.2 Land use change

The change in land use during the period of 1978 to 2000 was shown in Table 4-2.

Table 4-2 Land use change of Bung Boraped and surrounding area.

Land use type	Area of land use change					
	1978-1983		1983-1991		1991-2000	
	sq km	%	sq km	%	sq km	%
Forest area	-3.58	-0.70	-0.32	-0.06	-0.1	-0.02
Urban and built-up area	+18.02	+3.53	+1.52	+0.3	+2.23	+0.44
Field crop area	+25.96	+5.09	-24.43	-4.79	+16.74	+3.28
Paddy field	-1.09	-0.21	+32.01	+6.28	-23.68	-4.64
Aquaculture area	-	-	+0.22	+0.04	+1.04	+0.20
Water bodies	+0.23	+0.05	+1.29	+0.25	-1.0	-0.20
Idle land	-39.54	-7.76	-9.99	-1.96	+4.47	+0.88

Source: The result of study

Area of land use change at Bung Boraped and surrounding area can be described as follows.

1) For the period of 1978 to 1983, the forest area decreased by 3.58 sq km or 0.7% of the total land. During 1983-1991 and 1991- 2000, the forest area decreased only 0.32 sq km and 0.1 sq km, respectively.

2) The urban and build-up area during the period of 1978 to 1983 increased by 18.02 sq km or 3.53%. During 1983-1991 and 1991-2000, the expansion of urban and built-up area was much less.

3) Field crop area changed dramatically during 1978-1983 and 1991-2000

4) Paddy field area changed most during 1983-1991.

5) The idle land around Bung Boraped was covered by shallow water in rainy season and was changed to grassland in dry season. During 1978 -1983, the idle land decreased by 39.54 sq km or 7.76% of total land, increased by 4.47 sq km or 0.88% of total land during 1991-2000.

6) Water bodies slightly increased during 1978-1991, and slightly decreased during 1991-2000.

7) Aquaculture area was not found during 1978-1989 but continuously increased by 0.22 sq km during 1983-1991 and 1.04 sq km or 0.20% of the total land during 1991- 2000.

4.2 Water balance in Bung Boraped

4.2.1 Volumetric rainfall

Rainfall data during the period of 1978 to 2000 were collected from The Meteorological Department at Nakhonsawan province (Table 4-3 and Figure 4-5).

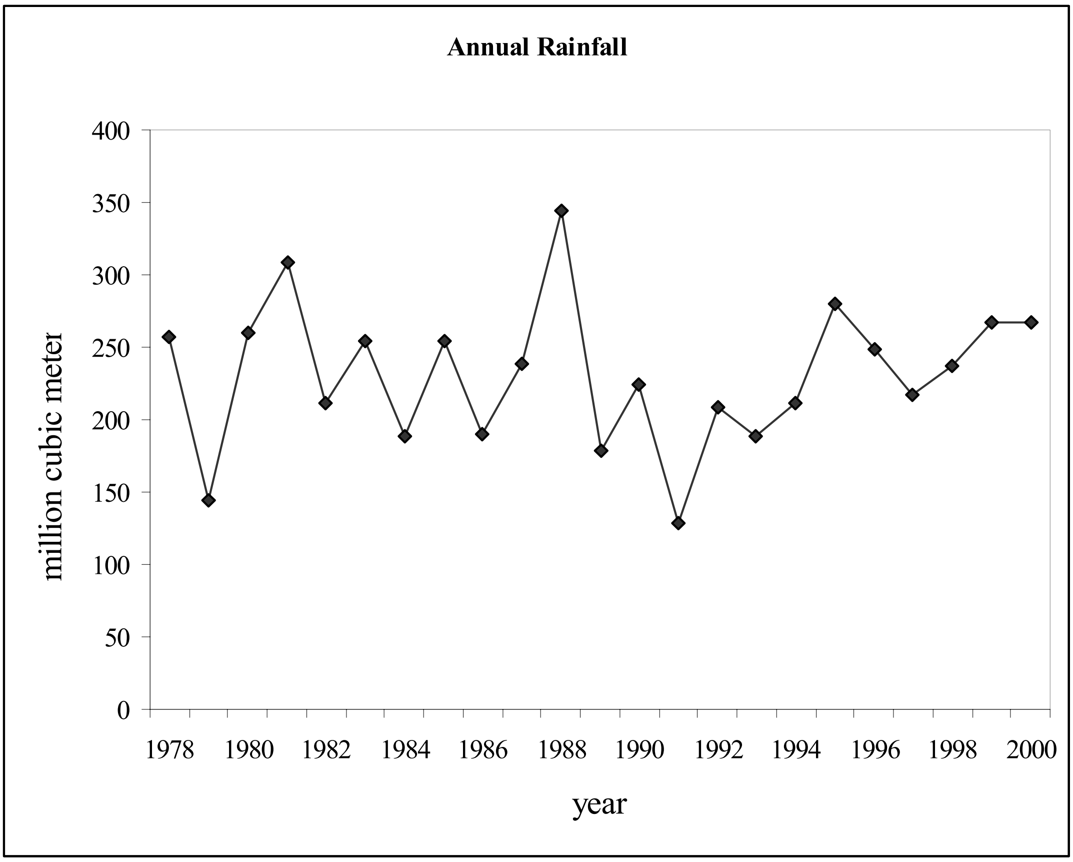

Figure 4-5 Annual rainfall of Bung Boraped swamp

Table 4-3 Monthly rainfall of Bung Boraped.

Year	Volumetric Rainfall (million cubic meters)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1978	0.11	11.79	2.25	4.61	18.27	34.54	53.93	30.29	70.6	29.72	0.59	0	256.68
1979	0.06	0.72	0	11.92	16.97	10.53	14.66	29.82	59.30	0.08	0	0	144.06
1980	0	4.69	2.97	4.82	32.77	27.48	38.53	26.17	64.67	47.0	10.53	0	259.66
1981	0	1.66	7.92	27.78	30.12	70.39	43.90	44.56	39.61	18.14	24.23	0	308.32
1982	0	0	0.49	19.35	18.90	12.3	20.75	54.33	52.76	20.58	10.11	2.4	211.97
1983	9.52	0	0	0	22.77	15.87	49.53	51.95	46.62	42.76	12.98	2.85	254.83
1984	0	4.67	0.93	10.22	22.51	20.11	49.45	25.42	40.57	12.49	1.81	0	188.18
1985	0.47	0.04	5.31	9.35	42.22	19.18	20.77	46.19	57.43	44.09	9.37	0	254.43
1986	0	0.47	0	17.16	36.94	10.94	19.52	58.35	26.93	18.71	1.13	0.45	190.58
1987	0	8.35	7.94	21.15	15.08	23.17	19.50	24.02	71.83	19.12	28.35	0	238.52
1988	0	0.83	13.76	35.17	39.85	39.59	47.85	39.55	70.49	56.60	0.02	0	343.72
1989	0.28	0	3.53	0.96	15.42	20.11	20.62	55.86	33.47	24.85	3.33	0	178.43
1990	0.08	6.24	9.56	1.4	51.89	16.74	10.98	33.07	42.14	45.0	6.86	0	223.97
1991	0	0	3.97	9.24	24.51	5.27	17.08	26.08	13.98	27.17	0	1.95	129.24
1992	0.19	0.08	0	3.91	32.84	28.86	30.86	28.59	44.03	36.43	0	3.19	208.98
1993	0	0	13.64	6.44	19.46	11.51	22.11	31.35	68.35	16.29	0	0	189.14
1994	0	0	37.19	5.2	49.83	39.57	8.9	33.33	21.18	15.53	0.06	0.02	210.8
1995	0.17	0	1.81	3.87	33.13	38.51	46.79	60.04	72.77	19.05	3.74	0	279.88
1996	0	3.93	3.19	27.87	32.26	27.97	13.40	27.25	51.44	32.94	27.87	0	248.12
1997	0	0	23.87	14.44	27.06	15.7	23.3	25.89	60.79	24.53	0.53	0.34	216.45
1998	0.21	0.04	2.76	2.63	42.2	32.31	55.82	36.87	35.41	18.97	8.30	1.25	236.78
1999	0.59	4.65	2.04	26.61	73.28	14.19	33.28	26.32	41.04	36.59	8.58	0.04	267.22
2000	0	1.83	8.16	38.49	35.56	57.30	24.89	18.92	37.30	44.54	0.02	0	267.00
Average	0.51	2.17	6.58	13.16	31.91	25.75	29.84	36.27	48.81	26.88	6.89	0.54	230.74

Source : Calculation rainfall data of the Department of Meteorology, Nakhonsawan province

During 1978-2000 Bung Boraped had the average of volumetric rainfall at 230.74 million cubic meters per year. Most of the rainfall occurred during May to October. Figure 4-5 showed that the distribution of rainfall was log-normal function characteristic.

4.2.2 Evaporation

The evaporation data (1978-2000) were collected from the Meteorological Department at Nakhonsawan province (Table 4-4 and Figure 4-6).

Table 4-4 Monthly evaporation in Bung Boraped

Year	Evaporation (million cubic meters)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1978	25.02	23.15	44.31	45.30	35.30	30.15	23.39	22.97	21.48	22.09	23.09	22.99	339.24
1979	24.22	31.16	41.61	40.54	36.43	25.13	35.21	19.12	25.19	25.19	25.59	24.03	353.96
1980	24.35	32.16	37.78	46.57	39.03	22.81	26.14	21.22	17.05	17.86	17.99	21.20	324.15
1981	21.07	25.54	34.39	35.98	29.81	26.30	25.04	22.02	19.02	18.54	18.54	19.46	295.60
1982	21.35	26.9	36.90	35.65	34.18	30.06	28.07	22.21	19.08	19.61	21.16	18.51	313.68
1983	19.85	28.23	39.33	42.70	36.75	31.15	27.40	24.86	19.43	16.93	17.31	19.18	323.12
1984	19.60	27.01	39.97	37.67	29.71	29.00	24.26	21.19	18.36	17.11	18.24	20.09	301.22
1985	22.29	29.91	38.48	36.78	26.49	22.85	21.26	23.34	18.48	18.41	17.80	19.77	295.87
1986	21.84	25.09	33.59	34.09	24.99	29.51	26.23	24.07	23.71	20.32	20.37	20.65	304.48
1987	22.91	26.05	29.53	35.34	33.09	27.89	27.51	23.48	18.47	18.42	15.05	18.26	295.99
1988	21.47	26.14	35.07	30.09	24.99	22.88	25.48	19.79	21.69	16.16	17.34	19.16	280.27
1989	22.66	24.31	32.50	39.64	30.21	25.84	23.18	23.92	20.53	17.95	18.88	19.48	299.09
1990	20.90	27.89	32.49	35.33	30.95	25.19	23.89	26.54	19.70	18.99	15.74	18.64	296.26
1991	20.41	23.73	38.97	37.04	33.88	25.07	27.25	19.92	17.07	18.23	18.96	19.67	300.20
1992	19.39	28.17	40.16	42.05	36.17	26.63	24.44	18.57	18.56	14.57	17.72	18.00	304.43
1993	21.37	23.58	30.78	32.98	32.78	28.89	29.75	21.51	17.79	18.76	19.09	19.40	256.69
1994	22.55	29.05	27.82	32.01	22.18	20.03	18.66	19.94	17.87	19.57	20.21	19.98	269.87
1995	22.14	27.49	38.09	38.69	27.88	26.32	21.47	19.46	19.34	16.18	16.41	18.50	291.96
1996	18.17	21.42	33.10	29.32	25.00	21.54	23.48	20.81	18.47	17.54	16.13	16.24	261.23
1997	19.12	22.51	30.70	27.88	30.93	29.47	23.10	22.63	19.63	17.93	17.00	20.38	281.28
1998	20.24	26.84	35.77	36.22	32.93	26.66	23.88	22.75	19.48	17.90	16.62	17.32	296.60
1999	18.96	21.50	31.56	23.89	20.71	20.68	23.99	19.42	18.99	15.21	15.17	15.10	245.17
2000	18.29	20.44	29.16	23.65	23.83	20.68	19.54	19.70	18.12	15.28	16.58	18.41	243.68
Average	21.22	26.01	35.26	35.63	30.36	25.86	24.90	21.99	19.37	18.17	18.30	19.32	296.26

Source : Calculation evaporation data of the Department of Meteorology,
Nakhonsawan province

During 1978-2000 Bung Boraped had the average evaporation at 296.26 million cubic meters per year. The mean of monthly evaporation varied from minimum in October to maximum in April. During the study period, most of the annual evaporation was higher than the annual volumetric rainfall.

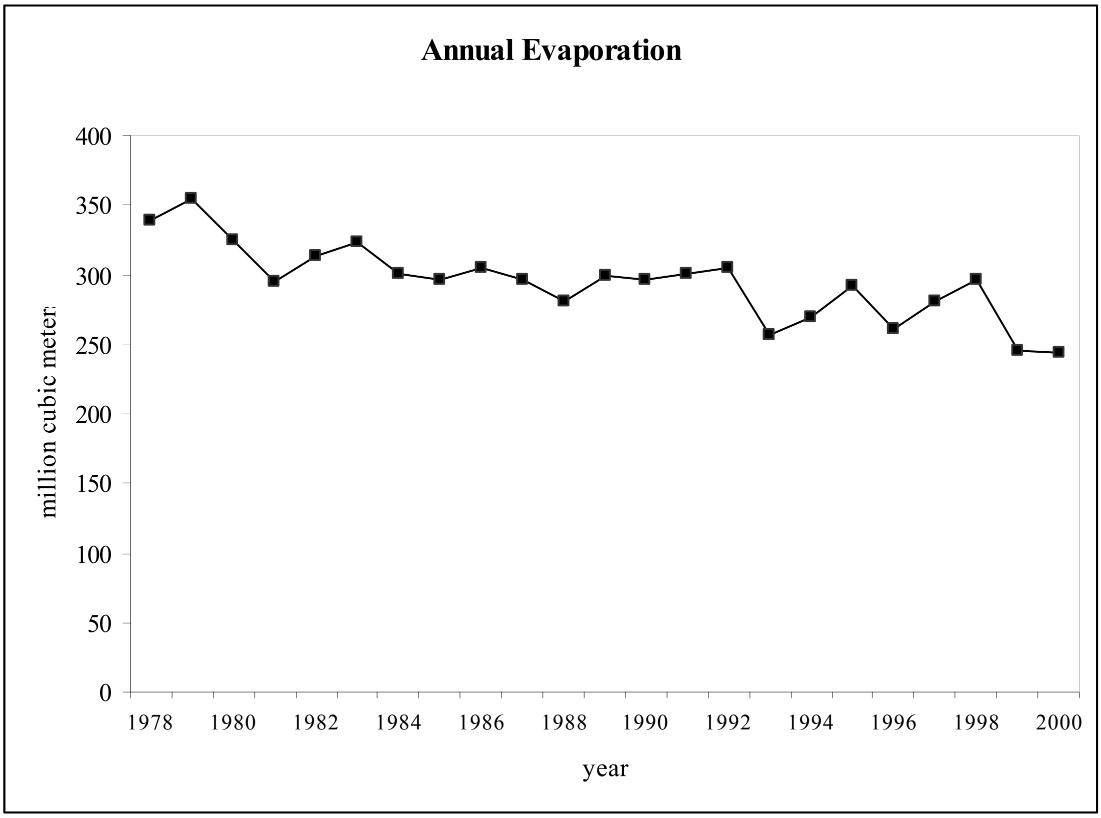

Figure 4-6 Annual evaporation of Bung Boraped .

4.2.3 Monthly streamflow

The monthly streamflow data were collected from 16 streamflow gauging stations of The Royal Irrigation Department at Bung Boraped and surrounding area. The streamflow record was analyzed and the relationship between drainage area and the mean annual streamflow was define by Regression Analysis of Record data.

$$Q = 0.4876\ A^{0.9222}\ (R^2 = 0.978)$$

When Q = mean annual streamflow (million cubic meters)

A = drainage area (sq km)

R = correlation coefficient

Monthly streamflow of sub-basin was calculated by adjusted monthly streamflow of Nan River at Ban Tub Krit (N.37) station. Monthly streamflow discharged to Bung Boraped was calculated from total monthly streamflow of sub-basin (Table 4-5, Table 4-6, and Figure 4-7).

Table 4-5 : Monthly streamflow data of Ban Tub Krit (N.37) was extended to completed by HEC-4

Year	Monthly streamflow of Ban Tub Krit (N.37) (million cubic meters)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	504.3	489.9	615.2	687.9	886.4	719.3	720	1044.3	2609	1863.7	1601.9	476.4
1978	94	146.6	332.6	390.1	347.1	390.4	1980.6	2663.9	2202.5	3237.6	1427.1	713.3
1979	351	361.4	731.6	812.7	833	1290.2	908.3	1189.4	1310.6	1167.2	823.5	555.1
1980	112.1	38.7	89.1	106.8	437.9	1069.7	1524.2	2279.3	3243	4126.4	1860.3	643.6
1981	214.7	344.1	520.3	642.3	914.5	1356.5	1469.7	3073.1	2503.8	1567.2	1783.5	999.1
1982	318	503	707	917	705	513	774	987	2607	2507	2019	686
1983	309	622	463	665	748	408	653	1007	2178	1981	1915	533
1984	75	196	452	563	534	1116	777	974	2266	2310	1641	608
1985	171	377	676	821	796	839	667	1099	2911	3112	2165	1062
1986	642	345	493	574	854	900	804	1413	2518	2667	1678	508
1987	181	483	508	653	1019	1772	1320	2522	2418	2821	1830	706
1988	320	273	459	479	559	1456	1494	2847	2581	2685	1415	487
1989	231	648	636	802	798	484	698	1021	2699	2784	1302	611
1990	722	876	816	984	1150	306	609	756	2266	1884	1282	585
1991	204	587	693	862	679	874	1090	2450	2794	2887	1268	596
1992	138	310	610	685	968	2323	2605	3886	2700	2205	1880	773
1993	446	475	593	703	670	689	1156	1543	1748	1639	2242	952
1994	377	425	728	849	642	750	1134	1557	1870	1127	2025	720
1995	234	338	402	573	893	949	1249	1791	3158	4576	2169	889
1996	572	687	635	1249	1485.3	1719.5	1071.2	1897.5	2874.4	3424	2534.3	1339.4
1997	907	719	738	886	1136	826	1320	1942	1815	1820	1528	631
1998	337	468	659	649	621	610	1364	1563	1579	1190	1552	616
1999	174	228	495	502	592	1139	2058	3125	2559	2739	2087	724
2000	375	627	722	871	620	2622	1457	2262	2556	2835	2321	893
Average	335.2	440.3	571.6	705.3	787.0	1046.7	1204.3	1870.5	2415.3	2464.8	1742.1	721.95

Source : The result of analyse from HEC-4

Table 4-6 Monthly streamflow into Bung Boraped

Year	Monthly streamflow into Bung Boraped (million cubic meters)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1978	11.14	17.37	39.41	46.23	41.13	46.26	234.70	268.27	260.99	383.66	169.11	84.53	1602.81
1979	41.59	42.83	86.69	96.30	98.71	152.89	107.63	140.94	155.31	138.31	97.58	65.78	1224.58
1980	13.28	4.59	10.56	12.66	51.89	126.76	180.62	270.09	384.3	488.98	220.45	76.27	1840.44
1981	25.44	40.78	61.66	76.11	108.37	160.75	174.16	364.16	296.70	185.71	211.34	118.39	1823.57
1982	37.68	59.61	83.78	108.66	83.54	60.79	91.72	116.96	308.93	297.08	239.25	81.29	1569.3
1983	36.62	73.71	54.87	78.80	88.64	48.35	77.38	119.33	258.09	234.75	226.93	65.53	1362.99
1984	8.89	23.23	53.56	66.72	64.35	132.25	92.07	115.42	268.52	273.74	194.46	72.04	1365.24
1985	20.26	44.67	80.11	97.29	94.33	99.42	79.04	130.23	344.95	368.77	256.55	125.85	1741.48
1986	76.08	40.88	58.42	68.02	101.2	106.65	95.27	167.44	298.38	316.04	198.84	60.2	1587.43
1987	21.45	57.24	60.2	77.38	120.75	209.98	156.42	298.86	286.53	334.29	216.86	83.66	1923.61
1988	37.92	32.35	54.39	56.76	66.24	172.54	177.04	337.37	305.85	318.17	167.68	57.71	1784.02
1989	27.37	76.79	75.37	95.04	94.56	57.35	82.71	120.99	319.83	329.90	154.29	72.4	1506.61
1990	85.56	103.8	96.70	116.60	136.28	36.26	72.17	89.59	268.52	223.25	151.92	69.32	1449.97
1991	24.17	69.56	82.12	102.15	80.46	103.57	129.17	290.33	331.09	342.11	150.26	70.63	1775.60
1992	16.35	36.74	72.29	81.17	114.71	275.28	308.69	460.49	319.95	261.29	222.78	91.60	2261.34
1993	52.85	56.29	63.87	83.31	79.40	81.65	136.99	182.85	207.14	194.22	265.68	112.81	1517.04
1994	44.67	50.36	86.27	100.61	76.08	88.88	133.19	184.50	221.6	133.55	239.96	85.32	1444.99
1995	27.73	40.05	47.64	67.9	105.82	112.46	148.00	212.23	374.22	542.26	257.03	105.35	2040.69
1996	67.78	81.41	75.25	148.0	176.0	203.76	126.94	224.85	340.62	405.74	300.31	158.72	2309.40
1997	107.4	85.20	87.45	104.99	134.62	97.88	156.42	230.13	215.08	215.67	181.07	74.77	1690.76
1998	39.93	55.46	78.09	76.91	73.59	72.29	161.63	185.22	187.11	141.01	183.91	72.19	1328.15
1999	20.62	27.02	58.66	59.49	70.15	134.97	243.87	370.31	303.24	324.57	247.31	85.79	1946.00
2000	44.44	74.30	85.56	103.21	73.47	310.71	172.65	268.05	302.89	335.95	275.04	105.82	2152.08
Average	38.67	51.92	67.52	83.67	92.79	125.73	145.15	223.85	285.21	295.17	209.94	86.82	1632.93

Source : The result of calculation

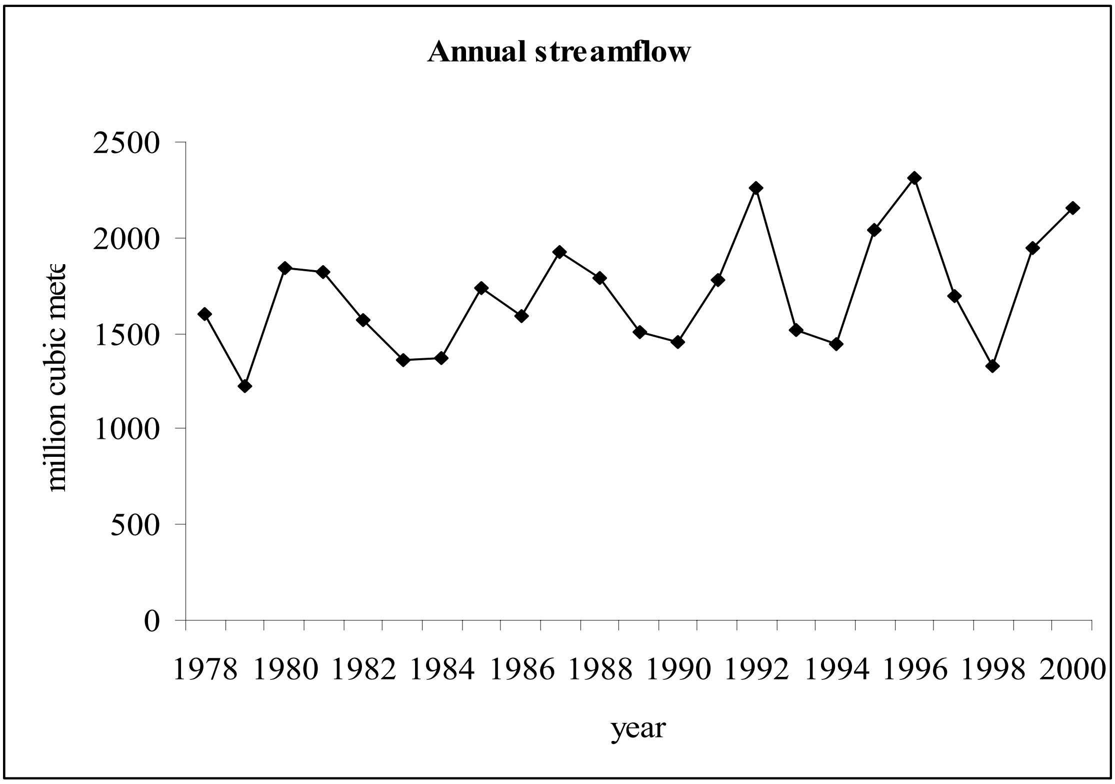

Figure 4-7 Annual streamflow into Bung Boraped.

4.2.4 Seepage loss

Seepage loss through the lake floor was assumed 10% of the total monthly streamflow (Table 4-7).

Table 4-7 Seepage loss through Bung Boraped

Year	Seepage loss through Bung Boraped (million cubic meters)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1978	1.11	1.74	3.94	4.62	4.11	4.63	23.47	26.83	26.1	38.37	16.91	8.45	160.28
1979	4.16	4.28	8.67	9.63	9.87	15.29	10.76	14.09	15.53	13.83	9.76	6.58	122.46
1980	1.33	0.46	1.06	1.27	5.19	12.68	18.06	27.01	38.43	48.9	22.05	7.63	184.04
1981	2.54	4.08	6.17	7.61	10.84	16.08	17.42	36.42	29.67	18.57	21.13	11.84	182.36
1982	3.77	5.96	8.38	10.87	8.35	6.08	9.17	11.7	30.9	29.71	23.93	8.13	156.93
1983	3.66	7.37	5.49	7.88	8.86	4.84	7.74	11.93	25.81	23.48	22.69	6.55	136.3
1984	0.89	2.32	5.36	6.67	6.44	13.23	9.21	11.54	26.85	27.37	19.45	7.20	136.52
1985	2.03	4.47	8.01	9.73	9.43	9.94	7.90	13.02	34.5	36.88	25.66	12.59	174.15
1986	7.61	4.09	5.84	6.80	10.12	10.67	9.53	16.74	29.84	31.60	19.88	6.02	158.74
1987	2.15	5.72	6.02	7.74	12.08	20.99	15.64	29.89	28.65	33.43	21.69	8.37	192.36
1988	3.79	3.24	5.44	5.68	6.62	17.25	17.70	33.74	30.59	31.87	16.77	5.77	178.40
1989	2.74	7.68	7.54	9.50	9.46	5.74	8.27	12.1	31.98	32.99	15.43	7.24	150.66
1990	8.56	10.38	9.67	11.66	13.63	3.63	7.22	8.96	26.85	22.33	15.19	6.93	144.1
1991	2.42	6.96	8.21	10.21	8.05	10.36	12.92	29.03	33.11	34.21	15.03	7.06	177.56
1992	1.64	3.67	7.23	8.12	11.47	27.53	30.87	46.05	31.1	26.13	22.28	9.16	226.13
1993	5.29	5.63	6.39	8.33	7.94	8.17	13.7	18.29	20.71	19.42	26.57	11.28	151.7
1994	4.47	5.04	8.63	10.06	7.61	8.89	13.32	18.45	22.16	13.36	23.1	8.53	144.5
1995	2.77	4.0	4.76	6.79	10.58	11.25	14.80	21.22	37.42	54.23	25.70	10.54	204.06
1996	6.78	8.14	7.53	14.8	17.6	20.38	12.69	22.49	34.06	40.57	30.03	15.87	230.94
1997	10.75	8.52	8.75	10.5	13.46	9.79	15.64	23.01	21.51	21.57	18.11	7.48	169.08
1998	3.99	5.55	7.81	7.69	7.36	7.23	16.16	18.52	18.71	14.10	18.39	7.22	132.82
1999	2.06	2.70	5.87	5.95	7.02	13.5	24.39	37.03	30.32	32.46	24.73	8.58	194.6
2000	4.44	7.43	8.56	10.32	7.35	31.07	17.27	26.81	30.29	33.6	27.50	10.58	215.21
Average	3.87	5.19	6.75	8.37	9.28	12.57	14.52	22.39	28.52	29.52	20.99	8.68	163.29

Source : The result of calculation

4.2.5 The volume of water pumped out from Bung Boraped and connected canals for irrigation

The data of the volume of water pumped out from Bung Boraped and connected canals for irrigation were collected from the Office of Regional Irrigation, Nakhonsawan province. For agricultural use, the water was pumped on average 8 hours per day, and 8 months per year. The characteristics of the pumps are shown in Table 4-8. The volume of water pumped out from Bung Boraped and connected canals for irrigation during the period of 1978 to 2000, is shown in Figure 4-8 and Table 4-9.

Table 4-8 Characteristics of the pumps in study area

Diameter of pump(inch)	Volume of water(m^3 / hour)	Irrigation area (rais)
6	230	300
8	500	500
10	750	900
12	1,200	1,250
39	6,200	7,500
52	10,800	12,000

Source : Office of Regional Irrigation, Nakhonsawan province, 2003

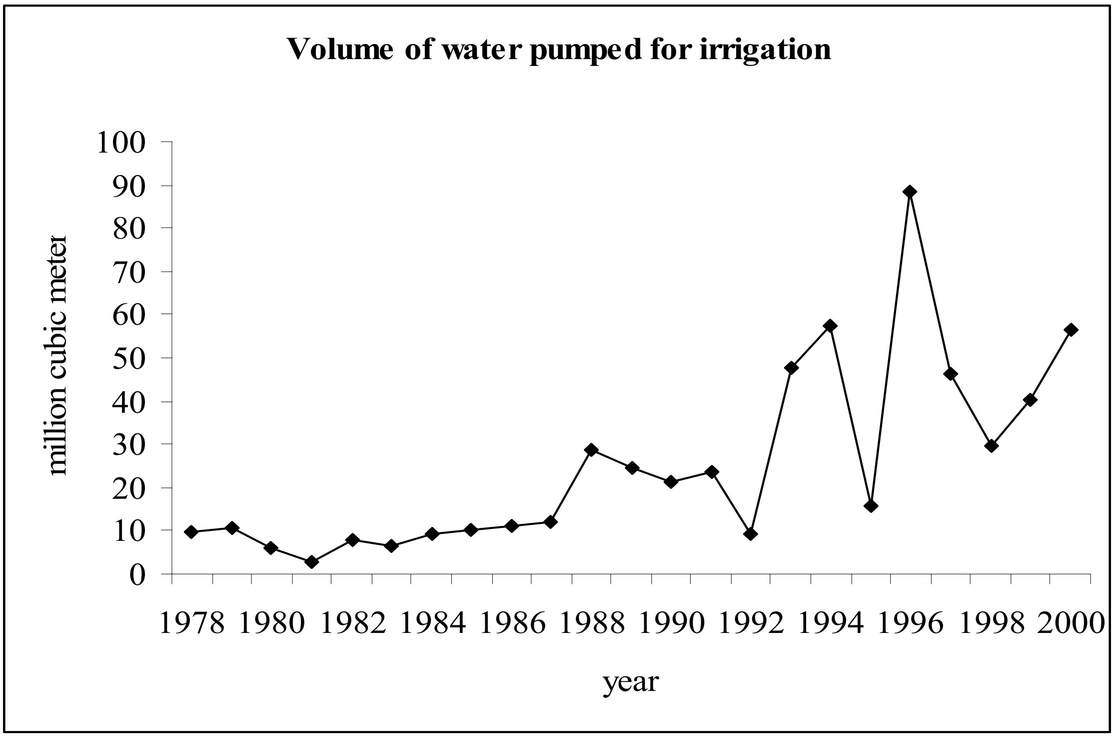

Figure 4-8 The volume of water pumped from Bung Boraped and canals for irrigation during 1978-2000.

Table 4-9 The volume of water pumped from Bung Boraped and canals for irrigation in dry and wet seasons during 1978-2000.

Year	Volume of water pumped from Bung Boraped and connected canal used for irrigation (million cubic meters)		
	Dry season	Wet season	Total
1978	7.488	2.304	9.792
1979	1.152	9.408	10.56
1980	1.152	5.088	6.24
1981	2.592	0	2.592
1982	1.152	6.768	7.92
1983	1.872	4.608	6.48
1984	2.304	6.912	9.216
1985	5.616	4.608	10.224
1986	1.152	9.792	10.944
1987	3.504	8.4	11.904
1988	6.144	22.6	28.744
1989	5.6	19.008	24.608
1990	5.952	15.36	21.312
1991	14.69	8.736	23.424
1992	1.92	7.392	9.312
1993	8.16	39.312	47.472
1994	18.336	39.12	57.456
1995	3.88	0	15.552
1996	34.464	53.904	88.368
1997	21.312	25.104	46.416
1998	18.432	11.05	29.482
1999	32.688	75.36	40.224
2000	33.696	22.608	56.304
Mean	10.142	17.28	24.98

Source : Calculation volume of water for irrigation data of the Office of Regional Irrigation, Nakhonsawan province

4.2.6 The volume of water pumped from Bung Boraped for domestic use

The surrounding area of Bung boraped is within 3 Amphoes as follows.

1) Amphoe Muang : including Tambon Kraing Krai, Tambon Kaw Yai, Tumbon Nakhonsawan Ook, Tambon Nong Pling, Tambon Pranon, having a total of 20 villages.

2) Amphoe Chumsang including Tambon Tab Krit, having a total of 9 villages.

3) Amphoe Tha Tako including Tambon Wang Mahakorn, Tambon Panomrok and Tambon Panomset, having a total of 15 villages.

Altogether the surrounding area of Bung Boraped has 6,455 families and 33,141 person. This study assumed that a person used 150 liter of water/ day. The volume of water used domestically by people in vicinity of Bung Boraped was estimated at 1.82 million cubic meters per year.

4.2.7 Sedimentation

The detail of Sediment Stations and annual suspended sediment are shown in Table 4-10. The relationship between the annual suspended sediment load and drainage area was defined by Regression Analysis of Record data.

$$Q_s = 860.74 A^{0.7461} \quad (R = 0.909)$$

When Q_s = annual suspended sediment load (ton / year)

A = drainage area (sq km)

R = correlation coefficient

The result revealed that annual suspended sediment of Bung Boraped basin is 457,536.573 ton / year. Because the characteristics of sediment bulk in Bung Boraped are mostly silt and clay, and the topography is low land, the bed sedimentation is approximately 10% of annual suspended sediment (Srikachorn, 1994). Thus bed sediment is 45,753.657 ton/ year, and total sediment is 503,290.23 ton/ year.

Table 4-10 Sediment stations and suspended sediment in surrounding study area

Sediment station	Code station	Drainage area (sq km)	Period of data	annual suspended sediment load (ton / year)
1. Ban Phai Lom, Muang Nakhonsawan	C.2	110,569	1960-2000	12,824,400.00
2. Ban Pang MaKha, Kamphaeng Phet	Ct.5A	979	1969-2000	93,576.57
3. Ban Mai Khlong Charoen,Latyao Nakhonsawan	Ct.7	457	1998-2000	54,048.00
4. Ban Bung Ai Chiam,Lan Sak Uthaithani	Ct.9	522	1977-1988	58,791.83
5. Muang, Phisanulok	N.5A	25,286	1978-1997	1,379,263.05
6. Ban Bang Mun Nak, Phichit	N.8	32,878	1997-2000	1,327,834.00
7.Ban Wang Bang, Nam Pat Uttaradit	N.33	2,463	1967-1987	804,588.95
8. Ban Huai Tum, Chon Daen Phetchabun	N.53	111	1999-2000	65,861.00
9. Ban Kaeng Luang, Si Satchanalai Sukhothai	Y.6	12,658	1953-2000	271,295.31
10.Ban Don Rabiang, Si Satchanalai Sukhothai	Y.14	12,131	1964-1987	1,616,783.63
11. Ban Huai Sak, Song Phrae	Y.20	5,410	1978-1993	484,949.50

Source : The Royal Irrigation Department, 2003

The Asian Institute of Technology (1982) studied the characteristics of sediment bulk in Bung Boraped, and found that the mean bulk density was 926.25 kg / m^3. This study calculated volume of sediment by :

$$D = M / V$$

When D = bulk density (kg / cubic meters)

M = mass bulk (kg)

V = volume of sediment (cubic meters)

Thus, the suspended sediment was 0.494 million cubic meters / year, the bed sediment was 0.049 million cubic meters/ year, and the total sediment in Bung Boraped was 0.543 million cubic meters/ year. Then useful life of Bung Boraped was estimated by

$$\text{Useful life of Bung Boraped(year)} = \frac{\text{Maximum retention level (cubic meter)}}{\text{Volume of sediment (cubic meters /year)}}$$

Bung Boraped had maximum retention level at 24 m (MSL), with the storage volume of 206.527 MCM, so useful life of Bung Boraped is approximately 380.34 years.

4.2.8 Water balance in Bung Boraped

Water balance of Bung Boraped during the period 1978 to 2000, was calculated, and shown in Figure 4-9 and Table 4-11.

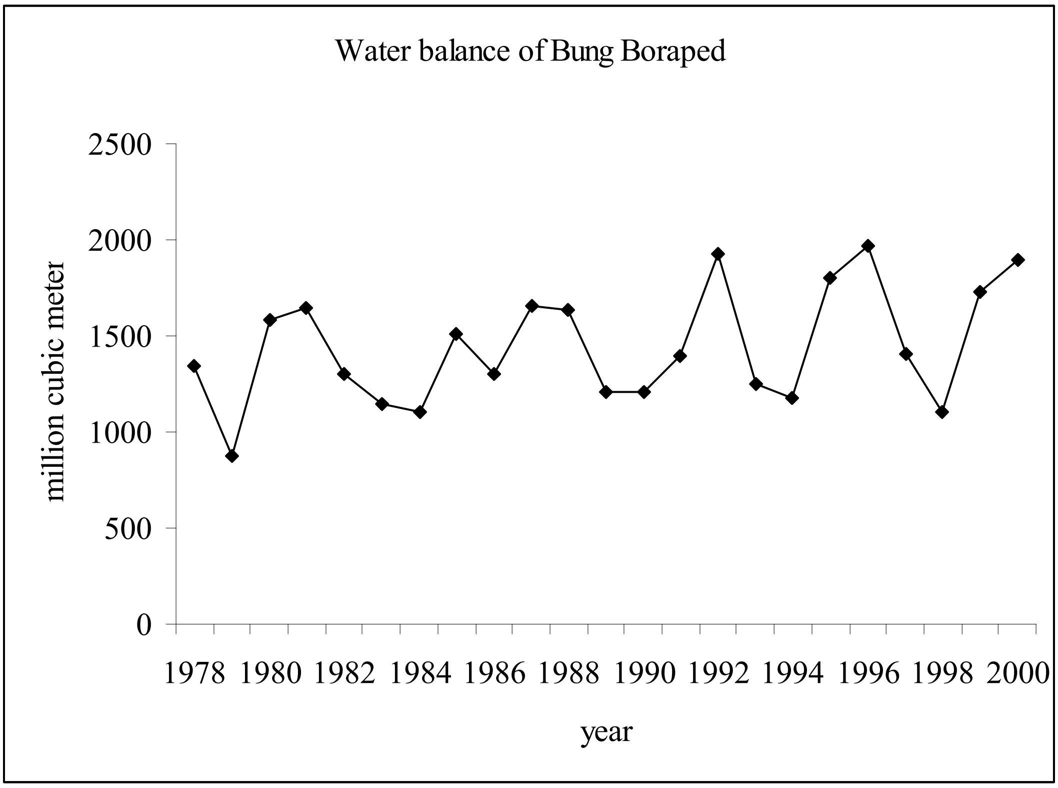

Figure 4-9 Water balance of Bung Boraped

Table 4-11 Water balance in Bung Boraped swamp

Unit: million cubic meters

Year	Rainfall (P)	Evaporation (E)	Stream Flow (S_i)	Seepage loss (SP)	Pumped for irrigation (IRR)	Pumped for domestic (DOMES)	Sediment (S_s)	Water balance (ΔS)
1978	256.68	339.24	1602.81	160.28	9.792	1.82	0.543	1347.82
1979	144.06	353.96	1224.58	122.46	10.56	1.82	0.592	879.25
1980	259.66	324.15	1840.44	184.04	6.24	1.82	0.641	1583.21
1981	308.32	295.60	1823.57	182.36	2.592	1.82	0.69	1648.83
1982	211.97	313.68	1569.3	156.93	7.92	1.82	0.739	1300.81
1983	254.83	323.12	1362.99	136.3	6.48	1.82	0.788	1149.31
1984	188.18	301.22	1365.24	136.52	9.216	1.82	0.837	1103.81
1985	254.43	295.87	1741.48	174.15	10.224	1.82	0.886	1512.96
1986	190.58	304.48	1587.43	158.74	10.944	1.82	0.935	1301.10
1987	238.52	295.99	1923.61	192.36	11.904	1.82	0.983	1659.07
1988	343.72	280.27	1784.02	178.40	28.744	1.82	1.033	1637.47
1989	178.43	299.09	1506.61	150.66	24.608	1.82	1.082	1207.78
1990	223.97	296.26	1449.97	144.1	21.312	1.82	1.131	1209.32
1991	129.24	300.20	1775.60	177.56	23.424	1.82	1.18	1400.66
1992	208.98	304.43	2261.34	226.13	9.312	1.82	1.229	1927.39
1993	189.14	256.69	1517.04	151.7	47.472	1.82	1.278	1247.22
1994	210.8	269.87	1444.99	144.5	57.456	1.82	1.327	1180.82
1995	279.88	291.96	2040.69	204.06	15.552	1.82	1.376	1805.80
1996	248.12	261.23	2309.40	230.94	88.368	1.82	1.425	1973.74
1997	216.45	281.28	1690.76	169.08	46.416	1.82	1.474	1407.14
1998	236.78	296.60	1328.15	132.82	29.482	1.82	1.523	1102.69
1999	267.22	245.17	1946.00	194.6	40.224	1.82	1.572	1729.83
2000	267.00	243.68	2152.08	215.21	56.304	1.82	1.621	1900.45
Average	230.74	296.26	1632.93	163.29	24.98	1.82		1444.19

Source : The result of calculation

During 1978-2000, Bung Boraped had the minimum water balance at 879.248 million cubic meters in 1979, the maximum at 1973.737 million cubic meters in 1996, and the average at 1444.19 million cubic meters. Figure 4.9 showed that the water balance was fluctuating and changing seasonally. Around Bung Boraped, the area was always flooded in wet season and the water level was high. During the study period Bung Boraped and surrounding area encountered to severe floods in 1978, 1980, 1988, 1995, 1996 and 2000 (The Royal Irrigation Department, 2002), which enormous streamflow and rainfall discharged into Bung Boraped and water balance were higher than other years. The calculated water balance indicated that Bung Boraped had a lot of excess water.

4.3 Statistical analysis

The relationship between land use and water balance of Bung Boraped was analysed using correlation, the correlation coefficient is shown in Table 4-12.

Table 4-12 Correlation coefficient between land use and water balance of Bung Boraped.

Correlation Coefficient	Forest Area (L_1)	Urban and built-up area (L_2)	Paddy field (L_3)	Field crop area (L_4)	Aquaculture area (L_5)	Water bodies (L_6)	Idle land (L_7)	Water balance (ΔS)
Forest area (L_1)	1.000	-0.997	-0.457	-0.554	-0.475	-0.657	0.992	-0.292
Urban and built-up area (L_2)	-0.997	1.000	0.567	0.567	0.541	0.634	-0.985	0.360
Paddy field(L_3)	-0.457	0.430	1.000	-0.479	0.082	0.978	-0.563	0.146
Field crop area(L_4)	-0.554	0.567	-0.479	1.000	0.279	-0.257	-0.450	0.300
Aquaculture area (L_5)	-0.457	0.541	0.082	0.279	1.000	0.203	-0.439	0.965
Water bodies(L_6)	-0.657	0.634	0.971	-0.257	0.203	1.000	-0.745	0.208
Idle land (L_7)	0.992	-0.985	-0.563	0.450	-0.439	-0.745	1.000	-0.277
Water balance (ΔS)	-0.292	-0.360	0.146	0.300	0.965	0.208	-0.277	1.000

The result indicated that water balance (ΔV) was negatively correlated with forest area (L_1) and idle land (L_7) but positively correlated with urban and built-up area(L_2), paddy field(L_3), field crop area (L_4), water bodies (L_6), and aquaculture area (L_5). The correlation coefficient between water balance (ΔS) and aquaculture area (L_5) was highest at 0.965, at a significance level of 0.05. This indicated that if water balance(ΔS) increased, aquaculture area (L_5) also increased. For other land uses, the correlation coefficient was less, the relationship between land uses and water balance was insignificant.

This study used the Stepwise Multiple Regression Analysis Program for Windows, to create the relationship model. The resulted is shown in Table 4-13.

Table 4-13 The result of the multiple regression analysis, Stepwise method

Variation	B	Beta	T	Significant T
Aquaculture area (L_5)	512.096	0.965	5.242	0.002
(Constant)	1260.083	-	20.171	0.35

Where R=0.965 R^2= 0.932 Adjust R^2 = 0.898 SE.= 101.90

The relationship between the aquaculture area and water balance, is

$$\Delta S = 1260.083+512.096 (L_5)$$

This model has the variance of water balance 89% and the standard error 101.9.

4.4 Discussion

Topography of Bung Boraped catchment is relatively flat, so the weir has been constructed in order to retain water within Bung Boraped. Bung Boraped has surface water inflow from the upper catchment, which is very large area (4,200 sq km). Numerous streams flow passing agricultural area and then, flow into Bung Boraped. Due to its connection with the Nan River, excess surface runoff from Nan River also flows into Bung Boraped. Outflow from Bung Boraped drains into the Chao Phraya river . Thus the water resource of Bung Boraped depends on rainfall, surface inflow and seasons.

In wet season, this area always suffers from flooding, Surface area of Bung Boraped is enlarged and surrounding Bung Boraped, which is idle land, is covered by shallow water and aquatic vegetation. However in dry season it changes to grassland. Thus land use always changes throughout the year.

This study analysed the land use data from different sources and did not consider seasonal factor, so the analysis of land use data and water balance may have some error and may affect the relationship between land uses and water balance. The study area was mainly covered by paddy field, which was planted three times a year and required a lot of water. This study did not classify types of paddy field (major or minor rice crop). Minor rice crop mainly used water from Bung Boraped and major rice crop was cultivated during the wet season. Paddy field was changed to field crop depending on season and market price, and in some area, lotus was planted. Thus paddy field in this area was always changed, and the trend of land use change as well as water consumption in Bung Boraped was hard to predict.

Bung Boraped is floodplain, it always encounters severe flood during August to November. During the study period Bung Boraped had severe flood in 1978, 1980, 1995, 1996 and 2000, the rainfall was high and numerous stream flowing into Bung Boraped and water balance was higher than other yeasr. The severe floods therefore influenced the relationship between land use change and water balance. Land use in some area changed after severe flood occurred. In 1992 Bung Boraped was developed to raise the retention water level by excavation and enormous water was released out of lake and affected water level and water balance.

The result of study indicated that the water balance of Bung Boraped was positively related with aquaculture area. Increase of water balance was related with increase of aquaculture area. The water level of Bung Boraped fluctuated and excess water released to surrounding area of Bung Boraped, where farmers used for aquaculture. Aquaculture area used a lot of water. It was found that the Inland Fisheries Research and Development Center used water in Bung Boraped for fish cultivation approximately 13 million cubic meters per year. Aquaculture area mainly located around and always drained water into Bung Boraped. This study however did not consider fish culture within Bung Boraped, which might affect water quality and water quantity of Bung Boraped.

The water balance was less related with forest area because within the study area, forest area covered only 1.47% of total area. During the study period, the forest area decreased only 4 sq km and it mainly changed to field crop area.

The water balance was less related to water bodies because water bodies slightly changed during the study period and Bung Boraped is the largest water body in this area. The change of water bodies was from the change of Bung Boraped shape, which might enlarge in wet season.

The increase of urban and built-up area was mainly from the decrease of paddy field and idle land. During 1983-1991 and 1991-2000, the increase of urban and built-up area was much less. Moreover some urban and built-up area located along Nan and Chao Phraya river and did not use water from Bung Boraped. Thus water balance in Bung Boraped was less related to increase of urban and built-up area .

This study indicated that the water balance of Bung Boraped and some land use area varied from season and flooding. Bung Boraped is dynamic ecosystem changing in shape, size and volume by the time and human activities. Seasons and sources of data might affect the result of this study. Moreover this study did not consider groundwater and transpiration of aquatic vegetation.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

5.1.1 Land use change

The study of land use change of Bung Boraped and surrounding area from the period of 1978 to 2000 covered a total area of 509.82 sq km. The study area was relatively flat and was frequently flooded in wet season. Major land use was paddy field, 343.69 sq km or 67.41% of total land in 1978. The change of paddy field was fluctuated. Paddy field area increased most during 1983-1991 by 32.01 sq km or 4 sq km per year. During 1991-2000, it decreased 23.68 sq km or 2.63 sq km per year. Paddy field was planted three times a year, and sometimes was changed to field crop depending on season and market price.

Field crop area increased a lot during 1978-1983 by 25.96 sq km or 5.2 sq km per year . However during 1983- 1991 it decreased by 24.43 sq km or 3.05 sq km per year. Like paddy field, the change of field crop area was fluctuated. Field crop area was mainly under maize, sorghum, water melon, soybean, cassava and sugarcane plantation.

Aquaculture area was not found during 1978-1983, but it was found 0.22 sq km in 1991 and it was increased by 1.04 sq km during 1991-2000. In the future the aquaculture area may continue increasing because it has been supported by the government. Aquaculture areas are mainly located in the north of Bung Boraped. The most common types of fish raised were Stripped snakehead fish (*Channa Striata*), Stripped cat fish (*Pangasius sutchi Fowler*), Cat fish (*Pangasius larnaudil Bocourt*), Thai carp (*Puntius gonionotus*), Cat fish (*Clarias batrachus*) and Sand goby (*Oxyeleotris marmoratus Bleeker*)

Forest area was 7.47 sq km or 1.47 % of total area in 1978. It decreased by 3.58 sq km or 0.72 sq km per year. During 1983-1991 and 1991-2000 it slightly decreased. Forest area was mixed deciduous forest type and located in the east of Bung Boraped . Most of forest area was changed to field crop area.

Urban and built-up area increased during 1978-1983 by 18.02 sq km or 3.6 sq km per year. During 1983-1991 and 1991-2000 urban and built-up area was slightly increased by 1.52 sq km and 2.23 sq km, respectively. Most of urban and building area was developed from paddy field and idle land.

Water bodies slightly changed during the study period. It covered approximately 10% of total area.

The idle land around Bung Boraped decreased by 39.54 sq km or 7.9 sq km per year during 1978-1983. During 1983-1991 and 1991-2000 the idle land was slightly changed approximately 4 to10 sq km. The idle land was floodplain, covered by shallow water and aquatic vegetation in wet season and was changed to paddy field and pasture in dry season.

5.1.2 Water balance in Bung Boraped

From the period 1978 to 2000, water balance of Bung Boraped was average at 1444.194 million cubic meters, the maximum at 1973.737 million cubic meters in 1996, the minimum at 879.248 million cubic meters in 1979. The change of water balance was fluctuating during the study period. Water balance in Bung Boraped depended on season and severe floods in some years. Surrounding area of Bung Boraped was covered by shallow water in wet season.

5.1.3 Sedimentation

The increased shallowness of water was a critical problem in Bung Boraped, which was the result of sedimentation, catchment erosion, decomposition of aquatic weeds within the lake, and encroachment of villagers into the lake. The suspended sediment was 0.494 million cubic meters/ year, the bed sediment was 0.049 million cubic meters/ year, and the total sediment in Bung Boraped was 0.543 million cubic meters/ year.

5.1.4 The relationship between land use and water balance

The statistical analysis indicated that water balance was highly related with aquaculture area only, at significance level 0.05. The study used Multiple Regressions, Stepwise method, for creating the model of the relationship between land use and water balance. The model of the relationship between aquaculture area and water balance was as follows.

$$\Delta V = 1260.083 + 512.096 (L_5)$$

The model indicated that the increase of water balance was related with the increase of aquaculture area. For other land uses, the relationship with water balance was insignificant.

5.2 Recommendations

5.2.1. Recommendations for monitoring

1) The result of the study indicated that water balance was highly related with aquaculture area. Increase of water balance and aquaculture area might affect ecology and hydrology in Bung Boraped. The aquaculture area may continue increase more in the future, therefore a protection planning and impacts mitigation should be prepared for this area.

2) Bung Boraped was encroached by the villagers in shallow area. Consequently, land use in this area was changed and it might affect ecology and hydrology in Bung Boraped. Thus, land use change in shallow area should be monitored.

3) The sediment problem in Bung Boraped came from erosion and the aquatic weeds. Sedimentation reduced both water storage capacity and fish production. Monitoring and management of the spread of aquatic plants and control of the growth of aquatic weeds within the lake are recommended.

4) The water quality of Bung Boraped needs to be monitored, especially pesticides and other agriculture chemicals as well as wastewater released from fish cultivation throughout the year.

5) Bung Boraped lacks of streamflow and sediment gauging stations, thus it is strongly recommended that the monitoring streamflow and sediment gauges should be installed at least along the major inflowing streams

5.2.2 Recommendations for further study

1) In this study the groundwater inflow and outflow was assumed to be equal and was not considered in the estimation of water balance, however, the groundwater affected the change of water volume of lake. Thus further study should take groundwater into consideration.

2) Hydrology of Bung Boraped was fluctuating throughout the year. Further study should consider the pattern of fluctuating water or hydroperiod throughout the year in order to forecast the future hydrological and provide protection planning.

3) In this study, land use was analyzed using land use maps in 1978, 1983 and 2000, and interpretation of aerial photographs in 1991. Further studies should take the seasons into consideration because water balance and the change of land use depended on season.

4) At present, the water of Bung Boraped was partly used by tourism sector, having a large number of tourists throughout the year. Further study should take water used in tourism section into consideration.

5) This study was based on data for 23 years, from the period 1978 to 2000, which may be regarded as a short period of time for study the change of land use and water balance. Further studies should extend the study period in order to provide clearer result about the relationship between the change of land use and water balance.

BIBLIOGRAPHY

Asian Institute of Technology. 1981. Rehabilitation and Development of Bung Boraped and Nong Han. Bangkok : Office of the National Economic and Social Development Board Kingdom of Thailand.

Azous, A.L., and Horner, R.R. 2001. (eds.). Wetland and Urbanization Implications for the future.New York : Lewis Publishers.

Basso, E. 2000. Alteration of the water balance of lake : Lake & Reservoirs Research and Management March 2000; 5 : 5-9.

Beilfuss, R.D., and Barzen, J.A. 1992. Hydrological Wetland Restoration in Mekhong Delta,Vietnam :Proceeding of workshop on wetlands management in the lower mekong basin 7-12 December 1992 . Vietnam:Ho Chi Minh City.

Bradley, C., and Brown, A.G. 1997 .Modelling of hydrological processes in a Floodplain wetland : Groundwater/ Surface water Ecotones:Biological and Hydrological Interaction and Management Option. United Kingdom : The Press Syndicate of the University of Cambridge.

Bung Boraped Wildlife Conservation Promotion and Development Station. 2000. Action Plan of Bung Boraped Wildlife Conservation Promotion and Development 2000. (Mimiographed). (Thai document)

Chaithum, V. 1985. Hydrology. Bangkok. (Thai document)

Chankaew, K. 1982. Principles of Watershed Management. Bangkok : Department of Conservative, Faculty of Forestry, Kasetsart University. (Thai document)

Chinoresyothin, P. 2000. The Valuation of Direct Uses Benefits of Bung Boraped Changwat Nakhon Sawan. [M.Sc. Thesis in Resource Management]. Bangkok: Faculty of Graduate Studies, Kasetsart University. (Thai document)

Choowaew, S. 1994. (Trans.). Wetland Conservation: A Review of Current Issues and Required Action. Bangkok : Department of Environmental Quality Promotion, Ministry of Science, Technology and Environment. (Thai document)

Choowaew, S. 1996. (ed.). Final Report: Main Report The Study for Planning and Management Sam Roi Yod National Park (Volume 1). Nakhon Pathom : Faculty of Environment and Resource Studies, Mahidol University. (Thai document)

Choowaew, S. (n.d.). Wetlands. Bangkok : Office of Environmental Policy and Planning, Ministry of Science, Technology and Environment. (Thai document)

Coastal Resource Institute. 2001. Wetland Agenda : The Necessity of Management of Wetland in Thailand. Songkhla : Prince of Songkhla University.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. La Roe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. Washington FWS/OBS-79/31 U.S. Fish and Wildlife Service, U.S. Department of Interior.

Dangsee, P. 1996. Relationship of Birds and Habitat Types at Bung Borapet Non-Hunting Area, Changwat Nakhon Sawan. [M.Sc. Thesis in Forest Biology]. Bangkok : Faculty of Graduate Studies, Kasetsart University. (Thai document)

Department of Fisheries. 1985. Large Swamp Inland Fisheries Project (LSIFP) Bung Boraped, Nong Han and Kwan Phayao. Bangkok : Ministry of Agriculture and Cooperatives, Kingdom of Thailand.

Department of Soil Science, Faculty of Agriculture. 1980. Introduction to Soil Science. Bangkok : Faculty of Agriculture, Kasetsart University. (Thai document)

Dugan, P.J. 1996. (ed.). Wetland Conservation: A Review of Current Issues and Required Action. Switzerland : IUCN.

Durongdej et al. 1999. Improvement of rice cultivation and water management in the flooded area of the central plain of Thailand : A zoning of rice varieties by using remote sensing imagery. Bangkok : Remote Sensing Division, The National Research Council of Thailand.

Faculty of Environment and Resource Studies. 1994. Final Report: Environmental Conservation Planning and Management at Bung Boraped., Nakhon Sawan province. Bangkok : Office of Environmental Policy and Planning, Ministry of Science, Technology and Environment. (Thai document)

Hammer, D.A. 1999. Creating Freshwater Wetlands. New York : Lewis Publishers.

Hammer, M.J. and Viess, W. JR. 1991. Water Supply and Pollution Control. New York : Happer & Raw, Publisher.

Hey, D.L. and Philippi, N.S. 1999. A case study for wetland restoration. New York : John Wiley & Sons, Inc.

Jantawat, S. 1979. Soil and Water Conservation (Volume1) : Soil Erosion. Bangkok : Department of Soil Science, Faculty Agriculture, Kasetsart University. (Thai document)

Jynprasert, T. 1994. Species Diversity and Biomass of Aquatic Plants in Bung Boraped after the 1992 Fishery Management. [M.Sc. Thesis in Environmental Science]. Bangkok : Faculty of Graduate Studies, Chulalongkorn University. (Thai document)

Kamp, G.V., Stolte, W.J., and Clark, R.G. 2002. Changes in Agricultural Practices Can Have Radical Impacts on Prairie Wetlands [Online]. Available: http://www.ImpactonPrairieWetlands.htm [16 July 2002].

Kent, D.M. 2001. (ed). Applied Wetland Science and Technology. New York: Lewis Publishers.

Kiatewongtong, N. 1994. Effect of Ecological Changes on Breeding Biology to Some Bird Species in Bung Borapet, Changwat Nakhon Sawan. Bangkok : [M.Sc. Thesis in Environmental Science]. Faculty of Graduate Studies, Kasetsart University. (Thai document)

Land Development Department. 1991. Map of Land Suitability for Economic Crop, Nakhonsawan Province. Bangkok : Ministry of Agriculture and Cooperatives. (Thai document)

Land Development Department. 1994. Classification of Wetlands in Thailand. (Mimiographed). (Thai document)

Maiklad, P. 1991. Handbook of small earth dam and weir. Nontaburi : Irrigation Engineer Alumni Association, The Royal' s Patronage. (Thai document)

Maneerat, J. 2000. Role of Local People in Conservation of Bird Bung Boraped Non-Hunting Area, Nakhonsawan Province. [M.Sc. Thesis in in Technology of Environmental Management). Bangkok : Faculty of Graduate Studies, Mahidol University. (Thai document)

McBean, E.A., Mulamoottil, G., Novak, Z., and Bowen, G. 1996. Urban Intensification and Environmental Sustainability : The Maintenance of Infiltration Gradients. In : Mulamoottil, G., Warner, B.G., and McBean, E.A. (eds.). Wetland Enviromental Gradients, Boundaries and Buffers. New York : Lewis Publishers.

Mitsch, W.J. and Gosselink, J.G. 2000. Wetlands. New York : John Wiley & Son. Inc.

Office of Environmental Policy and Planning. 1997. Proceeding of The Seminar on Wetland Status in Thailand. 13-14 January 1997 at Central Plaza Hotel, Bangkok, Thailand. (Thai document)

Office of Environmental Policy and Planning. 1999. Records of International and National Ramsar Site of Thailand. Bangkok : Ministry of Science Technology and Environment. (Thai document)

Office of Environmental Policy and Planning. 2002. Understanding to Ramsar Convention. Bangkok : Ministry of Science Technology and Environment. (Thai document)

Panomroungsak, U. and Chinpongsanon, N. 1998. Land Use Planning for Nan River Watershed. Bangkok : Land Use Planning Division, Land Development Department, Ministry of Agriculture and Cooperatives. (Thai document)

Reinelt, L.E. and Taylor, B.L. 2001. Effects of Watershed Development on Hydrology. In : Azous, A.L., and Horner, R.R. (eds). Wetland and Urbanization Implications for the Future. New York : Lewis Publishers.

Richardson, J.L. and Veprashas, M.J. 2001. (eds). Wetland Soils-Genesis, Hydrology, Landscape and Classification. New York : Lewis Publisher.

Santisook, T. 1991. Peat Swamp. Bangkok. (Thai document)

Srikhajon, M. 1994. Hydrology and Water Resource for Water Resource Development. Bangkok : Soil and Water Conservation Division, Land Development Department. Ministry of Agriculture and Cooperatives. (Thai document)

Taesombat, V. 1985. Principle of Hydrology. Bangkok : Department of Water Resource Engineering, Faculty of Engineering, Kasetsart University. (Thai document)

Taesombat, V. 1988. Applied Hydrology. Bangkok : Department of Water Resource Engineering, Faculty of Engineering, Kasetsart University. (Thai document)

The Hydrologic Engineering Center, U.S. Army Crop of Engineers. 1974. HEC-3. Reservoir System Analysis for Conservation : User Manual.

The Royal Irrigation Department. 2002. Final Report Draft : Main Report The Study For Development Bung Boraped Nakhonsawan Province (Volume 1). Bangkok: Ministry of Agriculture and Cooperatives. (Thai document)

Tiner, R.W. 1999. Wetland Indicators- A Guide to Wetland Identification,Delineation, Classification and Mapping. New York : Lewis Publishers.

Viessman, W. JR., Lewis G.L., and Knapp J.W. 1989. Introduction to Hydrology. New York : Happer & Row, Publisher .

Wacharakitti, S. 1982. Land Use Classification System. Bangkok : Department of Forest Management, Faculty of Forestry, Kasetsart University.

Ward, R.C. and Robinson, M. 1989. Principles of Hydrology. Singapore : McGraw-Hill Book Company.

Wisler, C.O. and Brater, E.F. 1969. Hydrology. New York : John Wiley & Sons. Inc.

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