1. INTRODUCTION

1.1 Background

The world's thirst for water is likely to stay as one of the most pressing resource issues of the 21st century. Considering the population growth, increasing urbanization, industrial development and intensive agricultural production, global demand for water has continued to increase by roughly 2.4 % annually since 1970. Global water withdrawal is even expected to increase by 35 % by the year 2020, with growth in demand rising fastest in developing countries (Rosegrant et al. 1997). This high water demand, however, is characterized by the problem of water availability. In many Asian countries, for instance, per capita availability of water resources declined by 40-60 % between 1955 and 1990, and is expected to decline further by 15-54 % over the next 35 years (Gleick 1993). There are various reasons for this decline, which could be location-specific. These include decreasing resources (e.g., falling groundwater tables, silting of reservoirs), decreasing quality (e.g., chemical pollution, salinization), and increased competition among agricultural, urban and industrial uses.

Water for agriculture claims the largest share of water consumption worldwide, but particularly in the Asian region where it accounts for 86 % of total annual water withdrawal there (compared with 49 % in North and Central America, and 38 % in Europe). This is not surprising considering the significance of the sector in the economy. However, bearing in mind the present state of water consumption and availability, it is deemed necessary to look at possible ways to improve the efficiency of water use in the sector, particularly in rice production, which is very important for most developing countries but where water-use efficiency is unfortunately very low. To illustrate this, about two to three Olympic-sized swimming pools full of water are required to produce just one ton of rice (IRRI 2001).

Rice being its major staple food, Asia produces and consumes about 92 % of the world's rice (IRRI 1997). Of the total world rice supply, more than 75 % comes from 79 million hectares (ha) of irrigated land in Asia. It should be noted that 90 % of the total diverted fresh water in Asia is used for irrigated agriculture, of which more than 50 % goes to rice irrigation (Tabbal et al. 2002). To keep up with the population growth and income-induced demand for food in most low-income Asian countries

(Hossain 1997), it is estimated that rice production has to increase by 56 % over the next 30 years (IRRI 1997). In 2025, in South and Southeast Asia approximately 17 million ha irrigated rice areas will suffer "physical water scarcity" and 22 million ha "economic water scarcity" in the dry season (Tuong and Bouman 2002). Against this background, measures to increase water-use efficiency are deemed critical for achieving food security. In addition, Klemm (1999) noted that a reduction of 10 % in water used for irrigating rice would free up to 180,000 million m^3, which is equivalent to about 25 % of all fresh water used globally for non-agricultural purposes. Thus, improvement in water-use efficiency in the agriculture sector could also lessen the impacts of water scarcity-related problems on other sectors.

1.2 Problem statement

Irrigation efficiency is the most commonly used term to describe how well water is being used within a system (Molden and Sakthivadivel 1999). However, many scientists caution on possible misconceptions on irrigation efficiency within the basin context. Bagley (1965) noted that failure to recognize the boundary characteristics when describing irrigation efficiencies can lead to erroneous conclusions. He pointed out, for example, that water lost due to low efficiencies of one system, such as in a farmer's field, may not be lost to a larger system, such as an irrigation system. In the same way, water lost from an irrigation system may not necessarily be considered as an inefficiency loss if this water is re-used within the water basin.

This argument has been corroborated by a number of studies. Bos (1979) identified several flow paths of water entering and leaving an irrigation project, clearly identifying water that returns to the basin and is available for downstream use. Bos and Wolters (1989) reiterated that the portion of water diverted to an irrigation project that is not consumed, is not necessarily lost from a river basin, because much of it is being re-used downstream. Van Vuren (1993) listed several constraints on the use of irrigation efficiency and identified situations when lower efficiencies are tolerable. Palacios Velez (1994) also argued that water that is lost is not always necessarily wasted. Inasmuch as water losses from one field may be re-used in downstream fields, any gains from reducing losses in a particular field may negatively affect the water balance of those other fields (Seckler 1996, Keller et al. 1996). However, whether local water savings affect the water productivity at higher scale levels depends on whether local water "losses" are being re-used elsewhere, and on the possibilities to effectively use water savings at one point in the system at another point in the system (Solomon and Davidoff 1999).

Whether or not the water saved at the field level will increase efficiency at the irrigation system level depends on where the water that was delivered to the field is drained. For example, water that eventually drains into oceans or deep saline aquifers is considered permanently lost from the irrigation system so that reduction in this type of drained water can lead to real water saving or increase in water-use efficiency. On the other hand, water that flows out of a field into creeks, groundwater, or downstream areas can possibly be re-used, i.e. by blocking creeks and diverting the water into new irrigation canals, by directly pumping from creeks and drains, or by pumping from the (shallow) groundwater. In this way, one farmer's water loss may be another farmer's water gain (Seckler 1996).

The possibility for re-use of irrigation water has led some people to advocate that water savings at the field scale are only false savings that do not really contribute to increased water-use efficiency. In view of this possibility, water-use efficiency at the system level is deemed higher than at the individual field level. It is noted, however, that recapture and re-use of water that is "lost" upstream mostly involve additional investments and operation costs, such as pumping or the building of dams downstream (Guerra et al. 1998). Moreover, the potentials for water re-use depend on a number of factors, such as topography (e.g. can a creek be converted to a dam), sub-surface hydrology (e.g., does percolated water re-charge a shallow groundwater reservoir that can subsequently be pumped), quality issues (e.g., water may be too polluted with agrochemicals or salts) and costs of pumping. Eventually, a complete cost-benefit analysis for water savings at different scales is asked for. Here, the focus is on the benefit side of the re-use of water downstream from where losses occur. Therefore, the crucial issue for this thesis is finding "real" water saving, that is, the reduction of water flows to sinks from which it cannot be recovered any more, i.e., the sea and atmosphere. In this regard, the components of water inflows and outflows, which describe water balance in the system, will have to be analyzed to determine current levels of efficiency and to develop strategies to improve efficiency.