13 Evapotranspiration in the Upper and Middle Nazas River Basins

Eduardo Chávez Ramírez, Guillermo González Cervantes, José Luis González Barrios and Alejandro López Dzul

13.1 Introduction

Evapotranspiration, a combination of two simultaneous physical processes which account for the loss of water in vegetation-covered soils, through water evaporation from the moist soil-vegetation surface and control of transpiration through specialized plant tissues (stomata), is a fundamental hydrological variable at regional and basin levels for decision-making aimed at improving the water planning and management demanded by farming activities so as to maximize its usefulness, especially in arid and semi-arid zones where water resources are scarce or uncertain (Pereira et al., 2006; Dinapashoh, 2006; Jacobs et al., 2008). Also, evapotranspiration is an important time and space descriptor for climate regime classification, especially when related to precipitation. This variable is also a major soil-water balance component (Arora, 2002; Mundo/Martínez, 2002).

The need to know evapotranspiration for various applications has encouraged the development of methods and instruments for measuring and estimating evapotranspiration at a relatively short timescale: millimetres per day (mm d\(^{-1}\)), and even shorter intervals (mm h\(^{-1}\)). Direct measurement of actual evapotranspiration is usually determined through weighing lysimeters and the gravimetric method. Other high-precision methods to determine actual evapotranspiration (ET) are energy balance and turbulent correlation (Eddy correlation). However, due to their high economic cost and the need for fairly large-sized plots, weighing lysimeters and turbulent correlation methods are only used with the purpose of generating new methods, and for testing and adjusting existing models (López et al., 1991; Jiyane/Zermeño, 2003; Sammis et al., 2004).

In 1975 the Food and Agriculture Organization (FAO) of the United Nations proposed that the term “reference evapotranspiration” (\(ET_0\)) be used to describe a reference crop’s (grass or alfalfa) water demand as a climate condition effect which, integrated with a series of crop and soil factors, is used to estimate ET (Doorenbos/Pruitt, 1975; Jensen et al., 1990; Smith, 1991), to the extent that nowadays there are numerous empirical and semi-empirical equations which may be used, although most of them require previous calibration in order to define their usefulness at a local level (López et al., 1991; Pérez J. P./Castellví, 2002; López et al., 2006). Among these semi-empirical mathematical models, the one developed by Penman-Monteith (Penman-Monteith FAO, 1956) is widely used to estimate \(ET_0\) and subsequently manage irrigation, due to the fact that it has been widely accepted by the world scientific community and has been proposed by the FAO as the standard method for calculating \(ET_0\) from climate information (Allen et al., 1998; Allen et al., 2005).

Direct ET and \(ET_0\) measurements have been made in very few sites in Mexico because, unfortunately, there are only about three lysimeters installed and working (Ojeda, 1999; Villaman et al., 2001). Meanwhile, direct field determination by means of turbulent correlation has recently been used more frequently in very detailed studies (Moguel et al., 2001; Jiyane/Zermeño, 2003). On the other hand, other work designed to improve irrigation water planning and use – based on ET as a variable to be measured in daily periods for soil-water balance modelling – have been reported by Mundo and Martínez (2002) for Irrigation District 05 (Delicias, Chihuahua) and by Ojeda (1999) for Irrigation District 075 (El Fuerte, Sinaloa). With these, it has become possible to achieve savings of up to 30 per cent of water per surface unit with field-validated parameters (Sifuentes et al., 1999).

Further important work has been reported by Catalán et al. (2007); however, unlike the other work mentioned, this proposes a computer program to calculate water demand in various irrigation districts of Mexico, based on ET obtained from historical climate data. In accordance with these, as of 2005 the Na-
tional Centre for Disciplinary Research on Water-Soil-Plant-Atmosphere Relationships (CENID RASPA, INIFAP) installed a climate monitoring system by telemetering land linking three autonomous weather stations in a network. Such stations are located at different sites in the Nazas River basin, with the purpose of monitoring the weather environment and having information available for various applications, among which has been the determination of ET as the main variable for describing climatology and irrigation water management: in the short term, for the pecan crop (6,375 ha) and, later on, for forage crops (in the case of alfalfa, 31,739 ha).

For describing the climatology of particular zones, the CENID RASPA network is evidently insufficient, both because of its size and because of the time it has been operating, since an observational analysis of over 30 years is required. Therefore, this can only be achieved with weather data recorded by conventional weather stations (e.g. the National Meteorological Service stations), although these are inconvenient because of the limited availability of observed weather variables, and it is in this sense that the interest of the CENID RASPA network lies. Based on the above, the object of this chapter is to estimate reference evapotranspiration (ET\(_0\)) in two sub-basins of the Nazas River from standard weather data, using the Penman-Monteith FAO, the Doorenbos-Pruitt, and the Hargreaves-Samani mathematical (1985) models, and to compare them with the data observed in the A-type tank.

13.2 The Nazas River Basin

The Nazas River basin is a hydrologic region with 36 main watersheds, located in north-central Mexico at a latitude of 23° to 27° N and a longitude of 106° to 102° W (figure 13.1). This watershed comprises 71,906 km\(^2\) in surface area, and 95 per cent of the water resources produced there are used for agricultural production (mainly for crop irrigation), a highly controversial issue as the water resource is nowadays being excessively exploited.

Researchers from CENID RASPA of INIFAP, in collaboration with the French Institute of Scientific Research for Development in Cooperation (ORSTOM), currently known as the IRD (Institut de Recherche du Développement), conducted studies which have allowed us to demarcate the Nazas basin into three main sub-regions, based on annual precipitation analysis using the regional vector method, and also based on major component analysis, with precipitation being the dependent variable and altitude, longitude, and vegetation density as independent variables (Decroix et al., 1997; Decroix et al., 2004). These sub-regions are as follows:

- **The Upper basin** starts in the Western Sierra Madre mountains in the state of Durango, and is classified as a sub-humid water-producing and -storing zone (this is where the Lázaro Cárdenas dam is located and obtains its water supply), with the highest vegetation indexes and over 500 mm average annual precipitation, generating 85 per cent of all run-off.

- **The Middle basin**, with a 300 to 500 mm mean annual precipitation generates only 15 per cent of all run-off and is considered as a semi-arid water storage, conveyance and resource management zone (this is where the Francisco Zarco dam is located) towards the lower Nazas River basin. Its limits may be defined as lying between the Francisco Zarco and the Lázaro Cárdenas dams.

- **The Lower basin** is located beyond the Francisco Zarco dam, downstream to the Mayrán Lake, with under 300 mm average annual precipitation. It is classified as an arid zone with water consumption for agricultural production from the upper and middle basins and water extraction from deep wells. Naturally, it is in this sub-basin that the water problem is at its greatest, with serious water management issues, excessive exploitation of aquifers, and accelerated diminishment of water quality.

Given the above, it is necessary to complete the characterization of the sub-regions with climate information. Therefore, the instrumentation of the basin is very convenient with respect to hydro-climatic applications (dry spells and their impact on the environment and on agricultural production) as well as to agro-climatic applications (water availability, demand, planning and management for agricultural activity, application of water saving technologies for irrigation, and crop selection, in the case of the lower basin).

13.3 Materials and Methods

Autonomous weather stations were the instruments used to monitor the climate for estimating ET\(_0\); these stations were distributed as follows (figure 13.2). Two weather stations were installed in the lower basin: a Davis station, in standard reference crop conditions,