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# Semiarid Riparian Vegetation Water Demand and Its Influence to Compute the Sonora River Basin Water Availability

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## 1. Introduction

During the last decade, the riparian zones have received considerable attention in order to restore and manage them since they have an important role to plan water resources and land, among other functions in the ecosystem. The riparian zones are mainly located in the floodplain where the soil is characterised to be alluvial. However, arid zones channels and their floodplain are transitories and subject to frequent and rapid changes (Graf 1988a,b), thus there is not a clear distinction from where the channel finish and the floodplain starts. This condition could be disadvantageous to the vegetation settled in the floodplain which is subject to the floods' force, the wood debris and eroded sediments carried by. Conversely, this vegetation has the advantage to receive organic matter from the debris and minerals from the eroded soil resulting in a straightforward species capable to survive at adversely conditions (Bendix and Hupp, 2000). The adaptation of this vegetation generates species drought and flood resistant. In the first case, plants develop long roots in order to access groundwater and be wet. In the second case, plants can afford inundation since the modification of the hydraulic roughness reduces the flood velocity and spread seeds increasing the moisture and nutrients availability in the area (Bendix and Hupp, 2000).
However, the access of the riparian vegetation to groundwater produces high rates of transpiration and a high evaporative demand of the atmosphere. This is because water requirements are bigger in arid and semiarid regions, where rainfall is less and the vapour pressure deficit on the air is large. This implies great water consumption by this vegetation becoming as one of the components to be considered in the groundwater balance. Particularly, in semiarid sites where groundwater is the main water demand source, since water surface resources are highly compromised, temporal and spatially. Scott et al. (2003) observed that as groundwater is used to provide water among the different users, there is a depletion of the water levels that affects directly the riparian zones and, in consequence, modify ecological and hydrologically the watershed.
Scott et al. (2003) pointed out that in order to compute riparian water requirements it is common to use hydrological models that compute it as the residual discharge resulted after calibrated against known inputs, groundwater levels and discharges. This procedure could over or underestimate the groundwater balance in the basin, thus a better understanding of

this component is needed to improve water demand among the users. In order to guarantee a better management of the river basins, Mexico has made different water reforms through the last three decades. Some of these reforms deal with the increasing water over-exploitation and, particularly, there were established aquifers management councils supported by a national water law (Wester et al., 2005). In order to compute precise riparian water requirements, it is necessary to consider both internal (vegetation growth characteristics) and external conditions (atmosphere, plant and soil characteristics) of the vegetation (Ehlers and Goss, 2003). The external conditions can be achieved computing the evapotranspiration (ET), which depends of the solar radiation, vapour pressure, wind speed and direction, stage of the plant development, and soils features as soil moisture, among others. Conventional methods can be used to compute ET, but there are also remote sensing methods that have the advantage to consider its spatial and temporal variability.

Currently, there are not many studies focused on native riparian zones, researches have mainly carried out analysis for cropped income areas. This chapter presents the research performed to establish the water requirement of native vegetation (mesquites and elms) along the main channel and in the floodplain of the Sonora River corresponding to the Pesqueira, Topahue, Ures, La Mesa-Seri and Horcasitas aquifers. To address the water requirements, the ET was estimated using remote sensing techniques based on the energy balance. The study was considered for two hydrological cycles (1996-1997 Spring-summer and 2002-2003 autumn-winter), in particular, for the dry season since the Sonora River tributaries are dry and the flow in the main channel reaches its minimum level. The chapter concludes on the importance to consider a temporal and spatial analysis, to determine the water requirements of the riparian vegetation and its impact on the river basin water budget.

## 2. Theoretical ET approaches

Evapotranspiration (ET) is the total moisture lost to the atmosphere from the land surface when the vaporisation process starts as function of the input energy received and the vegetation present. Lakshmi and Susskind (2001) described ET as a “useful tool”, not only because it provides information that can be applied directly in the water budget, but also because ET has a high sensitivity which can be used to define some biophysical parameters. ET has been studied at different scales (Molden, 1997) providing a wide knowledge of how ET is affected or how it can affect the whole system (Menenti, 2000):

- Macro (e.g. impact of changes in available moisture on cloud formation, radiation budget and precipitation),
- Meso (e.g. depletion of soil moisture, and therefore, crop water requirements of irrigated lands and partitioning of precipitation) and
- Micro (e.g. crop water requirements)

In order to assess ET impacts on the water balance, and in consequence, on the land and water management, ET is defined for a specific crop and land condition. Thus, potential ET (ETp) considers *a reference surface as grass with a crop height of 0.12 m, a fixed surface resistance of 70 s.m$^{-1}$ and an albedo of 0.2*3, whereas crop ET (ETc) is *the rate of ET from disease-free, well fertilised crops, grown in large fields under optimum soil water conditions, and achieving full production under the given climatic conditions*. The actual ET (ETa) refers to *the ET from crops grown under management and environmental conditions that differ from the standard condition*s (Allen et al., 1998).

In general, the physics of the ET process is well understood, thus accurate ET values at local level are provided. However, as ET is highly sensitive to various land and atmospheric variables, particularly in their spatially distributed form, it makes regional ET estimations uncertain (Calder, 1998). This uncertainty increases when the ET contribution from riparian vegetation needs to be considered to determine the water budget (Goodrich et al., 2000).
Although some authors have studied the direct and indirect influence of the riparian ET into the water availability in a basin (Goodrich et al., 2000), this vegetation is still poorly understood being a non-easy task to explain its hydrogeomorphological influence since it interacts environmentally at different scales (Bendix and Hupp, 2000).
To compute actual riparian evapotranspiration (ETa) is complex since the vegetation communities are non-uniform linear varying in geometry, altitude and season. Also, the organisation and dynamics of the vegetation are strongly related to the channel river and its floodplain, thus the geomorphological process and forms define the pattern for the different aggregation communities maintained by the fluctuations of water discharge (figure 1). Goodrich et al. (2000) pointed out that this condition limits the application of traditional ET computations since the required fetch conditions are not achieved and in a strict term the definition of potential ET (Allen et al., 1998) did not apply due to differences in the canopy architecture, available energy, water availability and boundary layers differences between the atmosphere and leaf surfaces, among others. Additionally, only in few cases the crop coefficient has been defined for each riparian type (Goodrich et al., 2000).

Fig. 1. Riparian vegetation along the Sonora River

### 2.1 Traditional ET methods

The relationship between the different ET definitions (potential, crop and actual) is not always determined easily, but an accurate value is required for different uses and users. Favourably, at regional scales whatever the type of ET, these are not independent of each other. For example, during the crop growing period, water needs to be diverted on to the field to meet the ETc demands and to compensate losses by seepage and percolation in order to maintain a saturated root zone. Thus, the estimation of ETp is crucial to obtain ETc

rates and moreover to compute ETa values as the response to different reasons that generate non-standard conditions such as climate, pest, contamination, water shortage or waterlogging.
In the Sonora River Basin (SRB) and others semi-desert basins in Mexico, the Turc equation (1954) have been used to estimate the hydrological water balance and to infer the groundwater balance since very few aquifer data is available. Other condition to apply the Turc equation is that the average ETa is used for longer periods in order to reduce to zero the water retention in the basin. The Turc equation is defined as:

$$\begin{aligned} &if \quad \left(\frac{P}{L}\right)^2 > 0.1; \qquad \text{ETactual} = \frac{P}{\sqrt{0.9 + \left(\frac{P^2}{L^2}\right)}} \\ &or \quad \left(\frac{P}{L}\right)^2 < 0.1; \qquad \text{ETactual} = P \end{aligned} \tag{1}$$

$$L = 300 + 25 * Ta_{prom} + 0.05 * Ta_{prom}^3 \tag{2}$$

Where P is the precipitation and T is air temperature. Sometimes equation 2 is modified considering T at the power of 2 instead of 3 without any raison. The 300 constant value in L corresponds to the base runoff in the basin. Thus, L could increase above 300 as function of the T and ETa is related directly to rainfall. In 1964, the Truc equation was modified by changing the 0.9 coefficient by 1.0 (Turc-Pike, 1964). Despite to the simplicity of this method a high uncertainty is associated to it. Other methods based on meteorological data have been used such as Blaney-Criddle which is a temperature-based method that can be applied to different climates in a monthly base (Goodrich et al., 2000) or the Hargreaves-Samani equation that considers the air temperature and the extraterrestrial radiation (Allen et al., 1999). However, these types of methods are recommended only when data is not available. However, when data is available it is recommendable to used the Penman-Montheith equation (PM) (Allen et al., 1998) but a crop coefficient accurate is necessary to compute ETc. Gazal et al. (2006) applied the PM method to compute the transpiration of cotton/willow forest. The PM equation was inverted in order to asses the seasonal variation in stomatal resistance, results showed that the spatial and temporal heterogeneity of water availability modified the physiology of these riparian vegetation.

### 2.2 Advanced ET methods

Although riparian ETa values have been obtained with good accuracy using traditional methods and compared with available ET measurements for local areas, ETa values for large areas are still problematic. Also, it has been demonstrated by some authors such as Schultz and Engman (2000) that studies based only on conventional field data collection are often limited because they cover a specific area. In addition, the lack of available and reliable data is a big constraint in the application of different methods to compute accurate ET values. As riparian vegetation interacts environmentally at different scales, remote sensing techniques have been shown to be a reliable alternative to estimate ET, since some of the main constraints about suitable and available data can be overcome providing a precise spatial representation. One important advantage is that it provides detailed and independent ET estimations on a pixel-by-pixel basis among other data as mapping soil properties based on the reflectance variations, land use and land cover using the spectral signatures of vegetation, water requirements, monitoring water availability, and detecting some properties like water stress effects. This wide range of alternative data offers new possibilities for managing soil, water and land resources efficiently.

Remote sensing techniques have provided accurate estimations of ETa at several scales as a function of the spectral resolution of the satellite sensors. ETa can be estimated using data that describes the conditions in the soil-plant-atmosphere system. Thus, remote sensing provides specific information of some of the parameters involved in the ET estimation such as surface temperature, surface soil moisture, water vapour gradients, surface albedo, vegetative cover and incoming solar radiation.

According to Kite and Droogers (2000), methods and methodologies developed to estimate evapotranspiration (ET) using remote sensing data can be classified into four categories: i) satellite-derived feedback mechanisms, ii) biophysical processes based-model, iii) surface energy balance techniques, and iv) physically based analytical approaches. Qi et al. (1998) noticed that the canopy temperature is lower than the air temperature as water evaporates result of the heat extracted from the canopy leaves and from the air near to the canopy surface. This implies a temperature difference and the surface Energy Balance Techniques (SEB) can be applied because they are based on the spatial and temporal variability of the surface temperature (Ts) and air humidity as a reflection of the partitioning of net radiation available to the surface into soil, sensible and latent heat fluxes release to the atmosphere. Thus, the ET is obtained as the residual component of the energy balance equation:

$$\lambda E = Rn - G - H \tag{3}$$

where Rn is the net surface radiation ($Wm^{-2}$), G is the soil heat flux ( $Wm^{-2}$), H is the sensible heat flux ($Wm^{-2}$) and $\lambda E$ is the latent heat flux ($Wm^{-2}$). These methods estimate each parameter of the surface energy balance equation, which are characterised for a diurnal variation and are subject to significant changes from one day to another. To determine these critical variables, these methods first related the flux parameters of the energy balance in terms of variables such as the soil moisture profile, the surface, ground and near-surface air temperatures, and near-surface humidity. The algorithm employed was MEBES (Surface Energy Balance to Measure Evapotranspiration) that was based on the process theory of the original algorithm SEBAL (Surface Energy Balance Algorithm for Land) developed by Bastiaanssen et al. (1998a;b) applying some modifications to the data and condition of the region. The algorithm was chosen since it presents major advantages to compute ETa values among other SEB techniques (Ramos et al., 2008) using both remote sensing and meteorological-ground data for local and regional areas.

## 3. Sonora River watershed

The study area is the Sonora River Basin (SRB), located in the north-centre of the Sonora State in Mexico at the extreme latitude: 28°27' to 30°54' N and longitude: 110°06' to 111°03' W coordinates. The Sonora River Basin (SRB) is part of the Hydrological Region No. 9 and it has a total surface of 26,010 $Km^2$ almost 14.8% of the Sonora state. The SRB limits at the north with the USA and at the south with the Cortes Sea. The main river is the Sonora with 277 Km of longitude, starting at the north in the Cananea City with the union of several streams which down from the Magallanes, Los Ajos and Bacanuchi Mountain ranges. Then the river flows to the south crossing the Bacoachi, Chinipa, Arizpe, Banámichi, Baviácora, Ures and Hermosillo cities. In the last one the San Miguel de Horcasitas and el Zanjon afluents join the main river; both of them from the same basin. Finally, the Sonora River goes to the Coast but due to the sandy soil it disappears before reach the sea (INEGI, 2000). The SRB is divided into the Zanjóna and San Miguel de Horcasitas (8826 $Km^2$), Sonora (11680.6 $Km^2$) and the Coast watersheds (5503.4 $Km^2$) (figure 2).

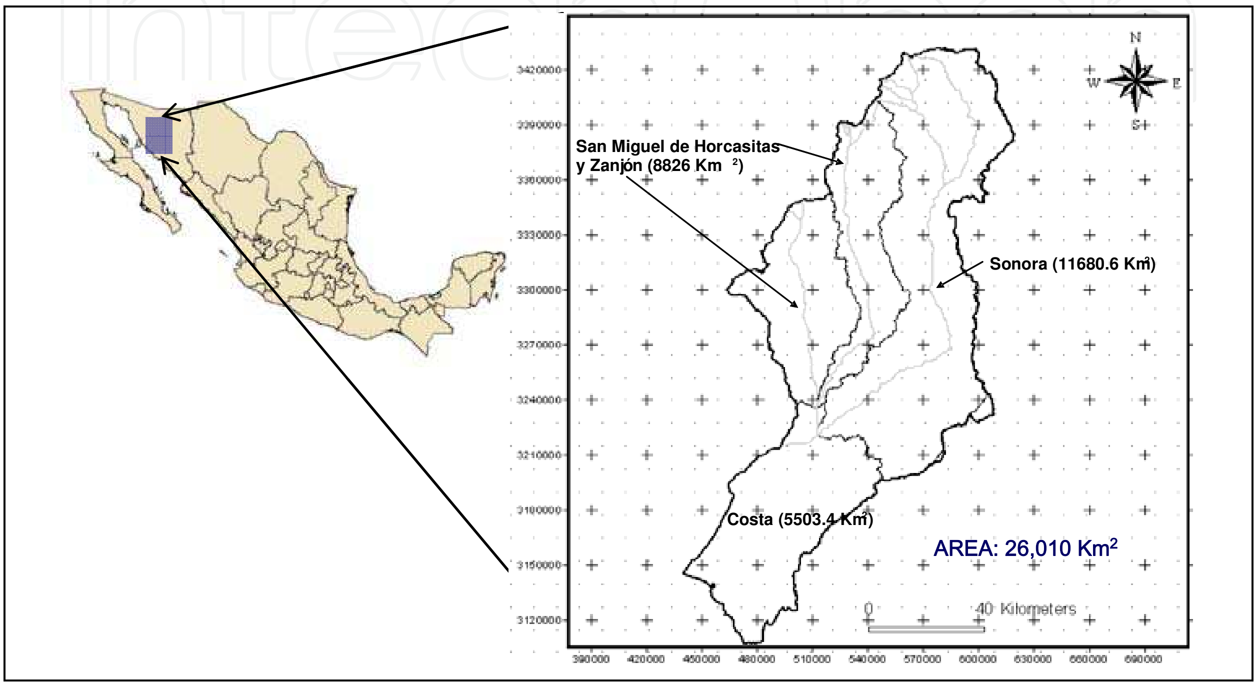


Fig. 2. The Sonora River Basin and its watersheds: Sonora, Zanjón, San Miguel de Horcasitas and the Coast.

The Sonora River has an erratic behaviour and, frequently, the runoff is concentrated into few days during the year. The river flow is controlled by a dam system that includes the Abelardo Rodriguez and Rodolfo Félix Valdés (El Molinito) dams with a total storage capacity of 525 $Hm^3$ (INEGI, 2000). Physiographically, the SRB is divided into two subprovinces (INEGI, 2000):

- Mountain ranges and North Valleys Subprovincie belonging to the Western Mother Mountain Range Province formed in the mountains by volcanic acid rocks with intrusive igneous outcrops and in the valleys by continental sediments. The mountain system is steep from 1000 to 2620 meters above sea level (masl). The weather is dry and semidry and varies as function of the altitude from warm and semi-warm to temperate and semi-cold.
- Sonorenses' Mountain range and plain subprovince belongs to the Sonorense' Desert covering 2/3 of the SRB. This subprovince is characterised ingy lower mountain ranges separate by plains being the mountains narrower than the plains; the plains have 80% of the total area. In the central basin intrusive and lavic igneous rocks predominated as well as metamorphic, ancient limestone and Tertiary conglomerates. In the plains alluvial fans are present with smooth slopes from the near mountains. The weather is very dry semi warm and warm.

There is a high climatological variation observed at the SRB as result of the accidental topography with more than 1000 masl in the mountains and less than 100 masl in the coastline. The climate variation produced two severe droughts (1982-1983 and 1997-1998) which have been related with El Niño event (IPCC, 2007). In fact, during 90s there were three events related to El Niño: 1991-1992, 1993-1994, 1997-1998, and in 2000s two events more in 2002-2003 and 2004-2005 (NOAA, 2008). The mean annual precipitation is 376 mm with a runoff coefficient of 2.8% being the main use the agriculture, followed by domestic, industrial, livestock and recreational. During the drought season it is necessary the groundwater extraction which is used in agriculture (93%), domestic and commercial (4.8%), industry (1.5%) and the rest 0.7% in livestock, recreational and others. The intensive use of groundwater in agriculture has generated an overexploitation of the aquifers present in the SRB. The aquifers are characterized according to the subprovinces in the SRB, thus for the Mountain ranges and North Valleys the non-consolidates material gave a lower infiltration capacity as result of the metamorphic, sedimentary (limestone and conglomerates) and acid extrusive (tuff and riolites) rocks which have a low breaking and porosity reducing the water circulation. Opposite to the Sonorenses' Mountain range and plain subprovince where non-consolidates materials present a high infiltration capacity since the presence of gravel and sand with different sizes and porosity favouring the intercommunication to the water circulation.

The climatic and topographic variation in the SRB provides a diversity of vegetation: pine woods in the north and mesquites (drought tolerant) in the rest of the basin, except irrigated areas aside the rivers and in the coast. The SRB vegetative coverage is quite similar to the state condition due to the extension of the basin, thus almost 50% of vegetal communities correspond to temperate climates under aridity conditions where drought-deciduous low woodlands of thorny and non-thorny trees and bushes are predominant. The thorny shrubs such as Gobernadora (*Larrea tridentata*), Mesquite (P*rosopis laevigata)*, Palo Verde (*Parkinsonia aculeate*) and Sangregado (*Jatropha cuneata*) are mainly allocated in hills around the San Miguel de Horcasitas and its affluents, as well as in Bacanuchi, Arizpe and Ures towns (figure 3).

Fig. 3. Mesquite scrubland along the Sonora River and floodplain

The 20% of the vegetation coverage are other type of mesquites as sarcocaulescent scrubland that is a subtype of the xerophyllous scrubland and elms (*Ulmus americana*) (León de la Cruz et al., 2008). These communities are in flat and deep soils, runoff areas, over yermosls, fluvisols or xerosols (figure 4).

Fig. 4. Mesquites as sarcocaulescent scrubland

Grassland represents 13% of the total vegetation and two types can be found in the area: native and introduced. The first one is represented by bluegrass plants and some herbaceous and shrubs used to livestock. The second one is related to the agriculture practise with only 3% of the total (figure 5a). Pine-oak forest and pines with herbaceous secondary vegetation represents 11% of the total vegetation and they can be found in subhumid temperate climates (mountain ranges) (figure 5b).

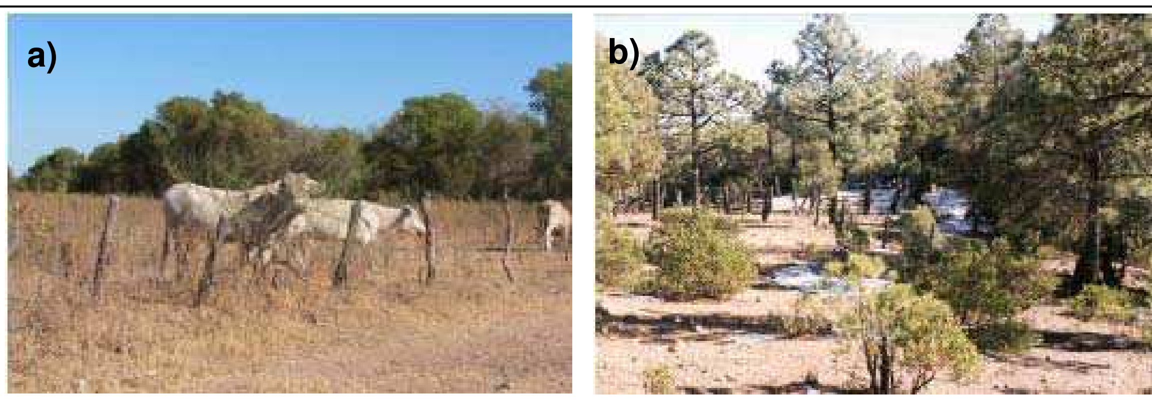


Fig. 5. (a) Grassland for livestock and (b) pine-oak forest at the SRB

Finally, introduced vegetation is 6.61% from which more or less 4% are agriculture lands where more than 95% of irrigation and the rest is rainfed. Crops are perennial as Lucerne, walnut and sugarcane and seasonal as ryegrass, barley, fodder oats, wheat, garlic and onion for autumn-winter period and fodder sorghum, beans, maize, and vegetables. The winter crops (i.e. wheat) showed a high vulnerability for prolonged drought seasons, thus farmers seemed to change into drought resistance crops or more economically productive crops, especially once the government stopped subsiding grains.

## 4. Methods

The methodology was divided into three steps: firstly an evaluation of the climate variation, after that a land cover classification was performed in order to identify those areas where the riparian vegetation is present. In this case drought-deciduous low woodlands of thorny and non-thorny trees and bushes were analised, in particular, thorny shrubs such as mesquite (P*rosopis laevigata*) and eml (*Ulmus americana*). Finally, MEBES was applied to estimated ETa and analysed to determine its influence to compute the water availability in the SRB.

### 4.1 Climatic data analysis

The climatological data available include traditional weather stations (CLICOM database) recording precipitation (P) and air temperature (T) (maximum and minimum), and Observatorios weather stations recording P, T, relative humidity, wind speed and isolation hours. Three Observatorios were analysed: Hermosillo within the SRB, and Nacozari and Empalme at the North and South, respectively, of the neighbour basin at the East.

The CLICOM dataset was updated to 2004 for the Sonora state and it has registered 273 stations. Two filters were applied in order to obtain complete and continuous data for a 20 year period. The results obtained were from 21 stations distributed throughout the entire basin. In order to analyze how the variables related to climate vary in time and space; essential for any study over large areas, data mining techniques were employed. Grouping techniques such as K-means (non-hierarchical) and Ward (hierarchical) methods were evaluated and the result was the basin division into three regions: north, central and south. This definition of homogeneous zones represents the climatic variation in the area accurately.

### 4.2 Remote sensing analysis

Two hydrological cycles were studied: spring-summer, 1996-1997, and autumn-winter, 2002-2003. Landsat images were acquired (table 1) as well as aerial photographs orthorectified.

The images were used for both classification of the riparian vegetation and estimation of the riparian ETa. For classification, it was considered the spectral response of vegetation to the Visible (VIS) and Infrared (IR) electromagnetic spectrum. A high reflectivity is presented in the near IR as consequence of the leaves structure and in the medium IR where the spectral response is affected by the water content in the surface and a low reflectivity observed in the VIS because the chlorophyll absorption. Also, it was observed the dynamics of the stream interact close with the riparian community characterized by the grow form, size, density, and aerial coverage of the plants (Fischenich and Copeland, 2001).

| Sensor | Date of acquisition | Path/row | Day of the Year (DOY) |
|---|---|---|---|
| TM | 1997/03/04 | 35/39<br>35/40 | 63 |
| | 1997/05/23 | 35/39<br>35/40 | 143 |
| | 1997/06/24 | 35/39<br>35/40 | 175 |
| ETM+ | 2003/03/29 | 35/39<br>35/40 | 88 |
| | 2003/04/30 | 35/39<br>35/40 | 120 |
| | 2003/01/31 | 35/39<br>35/40 | 31 |

Table 1. Date and path/row of the Landsat satellite images acquired to the USGS

The images were submitted to a pre-processing analysis to extract useful information from the images, and also to enhance them, to aid in the visual interpretation, and to correct or restore the images if these were subjected to geometric distortion, blurring or degradation. The pre-processing methods used include enhancement of the image, radiometric, atmospheric and geometric corrections, and the georeference of the scene for a chosen map scale and coordinate system.

In order to estimate the ETa, the first part involves the determination of the land surface physical parameters from spectral reflectance and radiance. This stage estimates surface albedo (αo), emissivity (εo), surface temperature (Ts), vegetation indices (NDVI and SAVI), fractional vegetation coverage (Pv) and leaf area index (LAI), and the roughness height (or height of the vegetation, zo). Here ground data are required, however, if the data are not available, it can be replaced using the vegetation indices and considering a standard crop height of 1.0 m. The second stage includes the introduction of meteorological data such as air temperature, humidity, and wind speed at a reference height. The reference height is the measurement height at the weather station (2 m). The last stage includes the estimation of the energy flux parameters and obtains ET as the residual form of the energy balance equation (Bastiaanssen and Bandara, 2001).

## 5. Results and discussion

### 5.1 Classification

To achieve the classification, vegetation indices were used since they represent a direct relation to the vegetation health linking the biomass and the leaf area index (LAI) in a spatial basis. In particular, the normalised difference vegetation index (NDVI) was used as well as the soil and wetness indices in the temporal analysis. Additionally, bands 5 and 7 of Landsat were applied to separate areas with high soil moisture, in order to differentiate between irrigated lands and riparian vegetation. The reason to use bands corresponding to the medium IR is to cover a major reflective spectrum allowing the observation of watered overages. Finally, LAI was also monitored, this parameter offers advantages since the geometrical, size and other conditions for the riparian vegetation is very characteristic.

A supervised classification was performed using the NDVI values for each image available, then other classification was done to a multitemporal image generated with the NDVI values. This classification allowed the identification of temporal homogenous areas. Finally, a multitemporal image was produced using a combination of the vegetation, soil and wetness indices, and the ratio between bands 5 and 7. The number of classes was established into 6, as the main interest was the aggregation of riparian vegetation thus mesquites, elms, palo verde, grass, water and bare soil were selected and the agriculture zones were removed from the images. The error matrix showed a confident level of 12% associated to a mix between palo verde and mesquite, and to a very small surfaces. Figure 6 illustrates the aggregation of elms, mesquites and some herbaceous vegetation in the Ures and Topahue aquifer.

The number of hectares obtained for elms was 68% bigger than the mesquites one within the 2000 ha in the Topahue and Ures region. The mesquite tree is a drought resistance obligate phreatophyte and indicator of the water table, and soil and nitrogen fixed, thus it controls the erosion and the soil fertility. The mesquite tree can be 10 m tall and its roots can go up to 50 m deep reaching the water table, also it has lateral roots that can be extended to 15 m. However, as riparian areas are characterised by the growth form, size, density, and aerial coverage of the plants aboveground, it made elms the predominant species since they are a taller facultative phreatophyte usually with 12 to 15 m in height, although they can reach 20 to 30 m or more (figure 7). As well as mesquites, the roots of elms have the ability to go deep

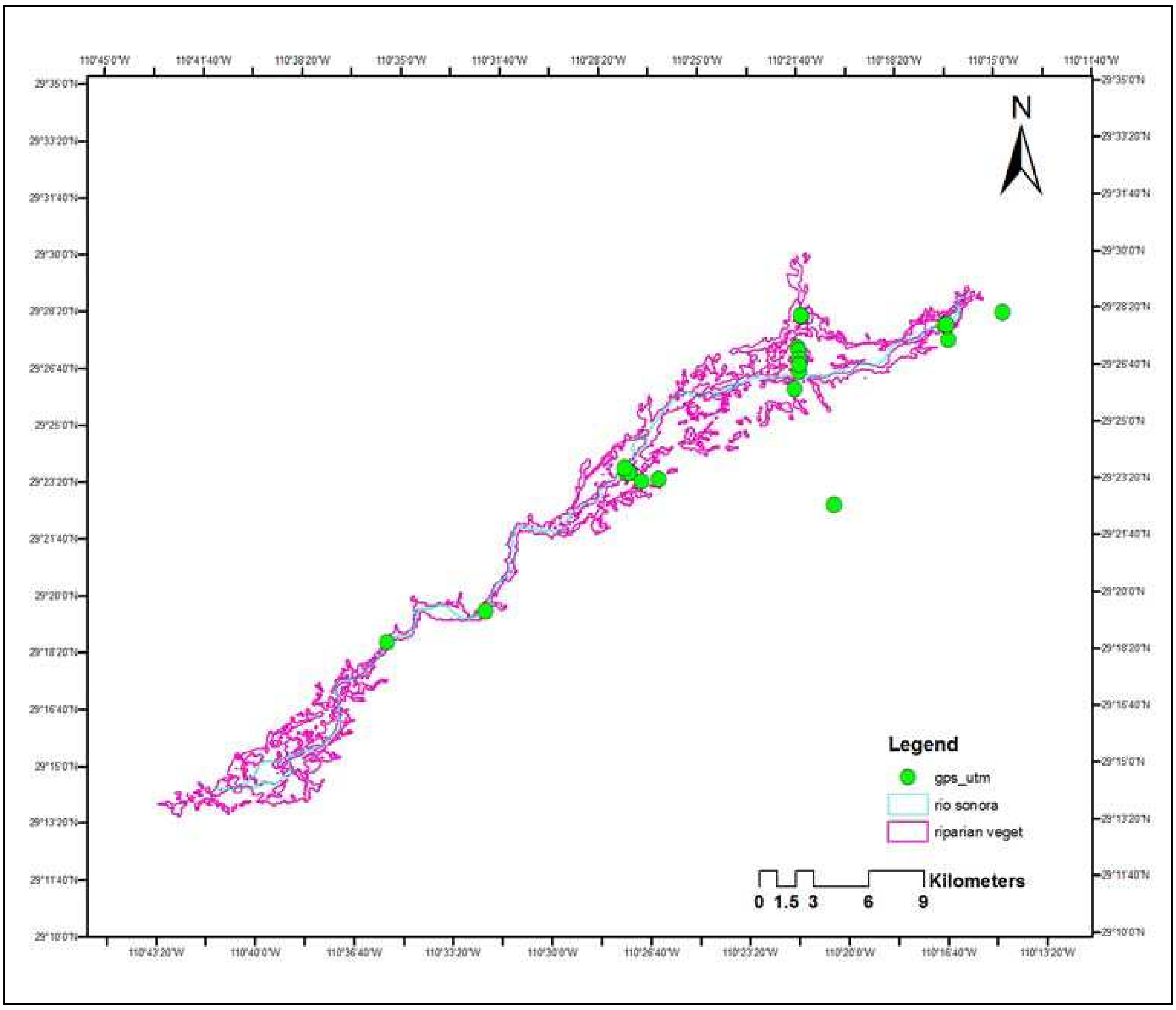


Fig. 6. Elms and mesquites distribution following the river channel and the floodplain and the gps points used in the supervised classification.

to get water, thus the elms can survive during the drought period. The elms posses lateral surface roots that go deep as they need to gather nutrients for the photosynthesis process, approximately from 5 to 20 cm. As elms growth well in moisture and drainage soils, the first precipitation or runoff is enough to obtain the water they need. Elms seeds can be disseminated by wind and water.

The grass area or other secondary herbaceous vegetation was also important for the number of hectares covered (1090 ha). It was observed in the floodplain as a groundcover of the riparian vegetation and their presence is related to the amount of flooding and the radiation allowed by the trees.

Elms LAI values for DOY143 were from 0.7 until 2.0 being the lowest ones during the drought season, whereas for mesquites were from 1.2 to 2.0, these values agreed with Kiniry (1998). LAI for grass or herbaceous vegetation growing around the riparian corridor was between 0.2 and 0.4, and in well irrigated orchards was between 3 and 4. Gazal et al. (2006) found that LAI is more sensitive in intermittent streams sites than in perennial ones due to the depth water table, thus plants modified their canopy structure in order to cope with water scarcity as it was observed in the study site.

Fig. 7. Elms predominance over mesquites and other thorny and non-thorny shrubs

### 5.2 ETa estimations

Average ETa values in DOY63 (after winter) showed for elms and mesquites 2.1 $mm \cdot d^{-1}$ and 1.5 $mm \cdot d^{-1}$ for groundcover grass of the riparian vegetation, respectively. It was observed a similar ETa rate for elms and mesquites and irrigated orchard. At this time the orchard is less irrigated since the fruit development is not impacted thus important water saving is made. For DOY143 and DOY120 during spring-summer where dry conditions are presented having more sunshine hours during the day, the average ETa values were from 5 to 8 $mm \cdot d^{-1}$ for riparian, and less than 1 $mm \cdot d^{-1}$ for their groundcover grass. Also, ETa values observed in mature orchard (more than 5 years old) and very well irrigated crops such as Lucerne were quite similar to riparian. The water evaporation was around 28 $mm \cdot d^{-1}$ in these DOYs (figure 8).

A 20 year climatological analysis at the centre of the SRB showed that temperature stars to rise from March until June where it reaches its maximum peak (28°C) as well as the wind speed with values of 5.2 ± 0.2 $km \cdot h^{-1}$, contrary to the precipitation that reach its minimum value in May (11 mm). The monsoon season starts late July and August increasing the relative humidity to 50 ± 5%. As the monsoon rains did not wet the saturated zone for DOY143, the climatic conditions imply a high vapour exchange between the surface and the atmosphere , thus the water necessities of the plants need to be covered to prevent wilting and the only source of water is from the aquifer. Due to the elms are located along the main channel their facultative conditions help them to obtain water at bit deep, thus drought conditions impact less although they are more exposed to radiation. This condition is not the same for mesquites where the main disadvantage is the size competence with elms receiving less energy and being protected from the strong winds. Mesquites as obligate phreatophytes needs to go deep to reach the water table establishing a high soil water dependence and, in consequence, reducing their hydraulic capacity to carried water from the roots to the stomata cavities as Gazal et al. (2006) noticed for cottonwood.

## 6. Conclusions

The riparian vegetation has a very important role in the ecosystems not only because they are a habitat to flora and fauna spices but also because they provide some hydrological control, particularly when flood and drought are present. The vegetation structure is highly related to the geomorphological process of the region being determinant in the valleys where the fluvial soils supply adequate conditions to the development of these plants. Also,

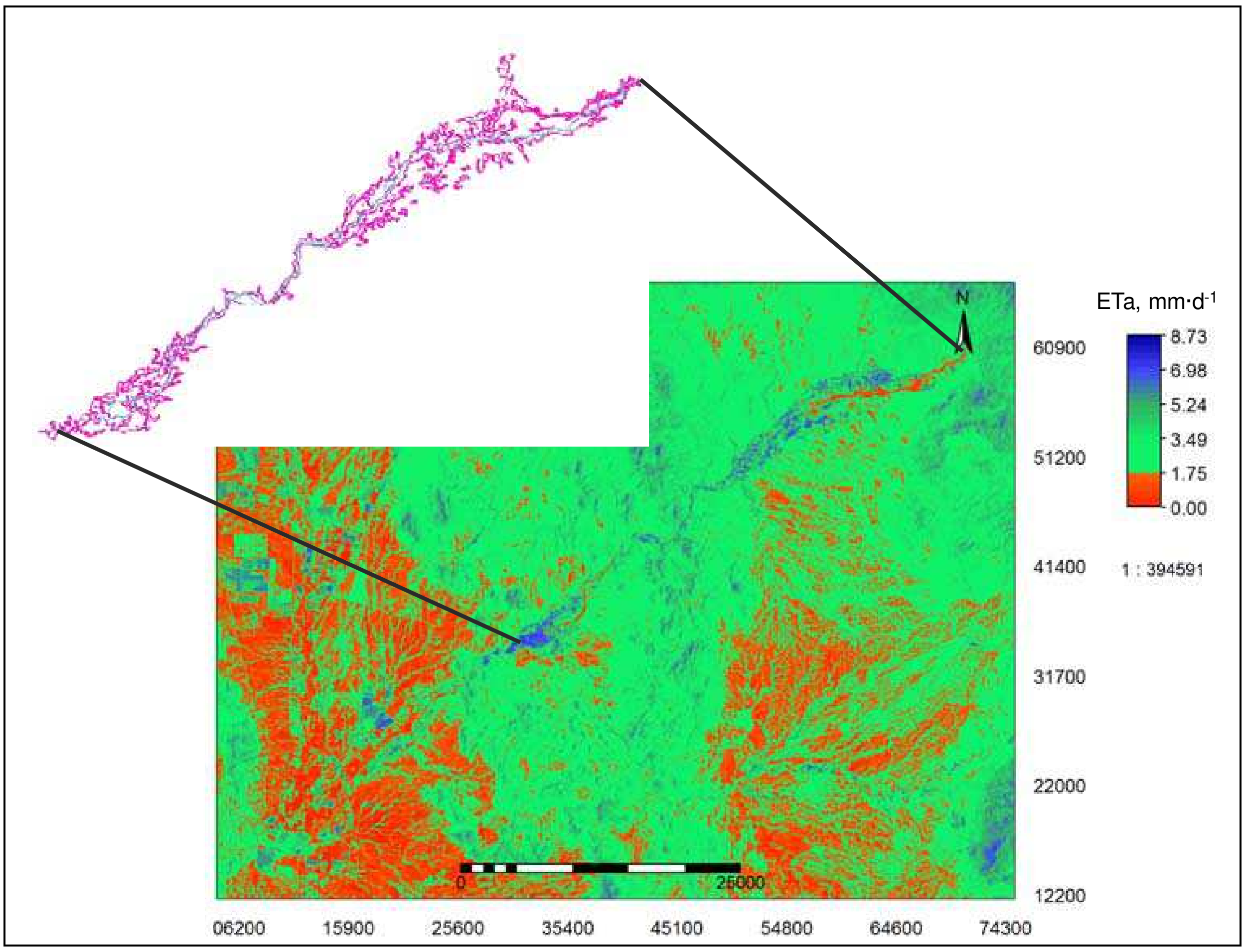


Fig. 8. ETa values for DOY143

the environmental and climatological conditions provide important characteristics since in arid and semi-arid zones the main river channel and the floodplain are undistinguished as result of the erosion and sediments deposition allowing the growth of obligate and facultative phreatophytes as well as herbaceous groundcover vegetation. This resulted in a hydrogeomorphological influence on the vegetation being severely affected but at the same time benefit by flooding and developing the capacity to survive under drought conditions.

In early stages the hydrological regime and the available energy are the main factors to control ET from riparian corridors, although these conditions change as the vegetation growth. Also, as the dry conditions is a limitation, the plant's capacity to extract water from the aquifer is determinant during their mature lives.

The similitude between the irrigated land and the riparian corridor implies a good water resource, in the first case irrigation is the explanation but in the second the only one possibility is the adaptation of plants to obtain water from the aquifers reaching their roots the water table after the depletion of the soil moisture in the saturated zones.

In the SRB, 95% of irrigation is provided by groundwater extraction with an average volume of 5 $m^3 \cdot s^{-1}$ for a total cropped area of 12,300 ha in 2003. In the Ures and Topahue region the cropped lands were almost 2000 ha in 2003 with a total volume of 3.5 $m^3 \cdot s^{-1}$, as ETa values were similar to very well irrigated lands, this would imply a volume of 6.6 $m^3 \cdot s^{-1}$ for riparian corridors considering elms, mesquites and grass. This raw estimation pointed out the amount required from the aquifer to cope with irrigation and riparian corridors without consider other uses. This amount needs to be carefully used since there is not still enough data to provide confident recharge values to these aquifers (Ures and Topahue), however, it is clear the high influence of the ETa to compute water requirements in arid zones. Further work is required in order to compute accurately each component of the water balance paying also attention to the precipitation and interception effect on the riparian corridor since its rapid recovering after the first precipitation during the monsoon months.

## 7. Acknowledgments

This project was founded by the Sonora State Water Commission (CEA) in 2005 and by the Instituto de Ingeniería, UNAM, in 2008.

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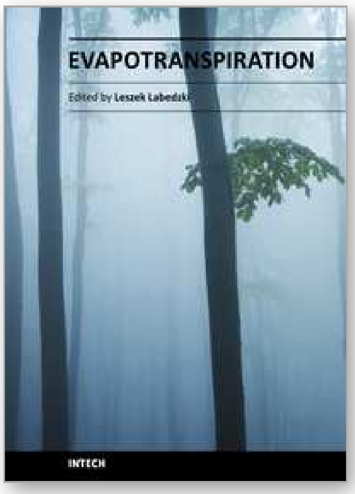


**Evapotranspiration**
Edited by Prof. Leszek Labedzki

ISBN 978-953-307-251-7
Hard cover, 446 pages
**Publisher** InTech
**Published online** 16, March, 2011
**Published in print edition** March, 2011

Evapotranspiration is a very complex phenomenon, comprising different aspects and processes (hydrological, meteorological, physiological, soil, plant and others). Farmers, agriculture advisers, extension services, hydrologists, agrometeorologists, water management specialists and many others are facing the problem of evapotranspiration. This book is dedicated to further understanding of the evapotranspiration problems, presenting a broad body of experience, by reporting different views of the authors and the results of their studies. It covers aspects from understandings and concepts of evapotranspiration, through methodology of calculating and measuring, to applications in different fields, in which evapotranspiration is an important factor. The book will be of benefit to scientists, engineers and managers involved in problems related to meteorology, climatology, hydrology, geography, agronomy and agricultural water management. We hope they will find useful material in this collection of papers.