A Review of hydrophyte evapotranspiration

M. E. CRUNDWELL (1)

ABSTRACT

A literature review of the relative rate of hydrophyte evapotranspiration (ETh) to open water evaporation (EW) is presented. This literature suggests that the ETh/EW ratio can exceed unity. Furthermore, the magnitude of the ETh/EW ratio is dependent upon the state of growth of the hydrophyte, species, climate and density. Mean annual ETh/EW ratios for various species of hydrophyte according to climate can be obtained from tabulation of the relevant literature.

KEY WORDS: Evaporation — Evapotranspiration — Hydrophytes — Wetland.

RÉSUMÉ

L'ÉVAPOTRANSPIRATION DES HYDROPHYTES : UNE ANALYSE BIBLIOGRAPHIQUE

Les résultats publiés concernant l'importance relative de l'évapotranspiration des hydrophytes (ETh) et de l'évaporation d'un plan d'eau libre (EW) sont présentés et résumés. Il apparaît que le rapport ETh/EW peut être supérieur à l'unité; ce rapport dépend en outre de la nature des hydrophytes, de leur développement, de la densité de la végétation et du climat.

Les divers résultats utilisés permettent de présenter des valeurs annuelles du rapport Eth/EW en fonction du climat.

MOTS CLÉS : Evaporation — Evapotranspiration — Hydrophytes — Marécages.

Hydrophytes can be defined as plants of wet habitats (WARMING, 1895). Helophytes are hydrophytes with at least 1 m of aerial growth. Many phreatophytes, plants whose roots are permanently in ground water, also can be termed "hydrophytes". In this review of hydrophyte evapotranspiration both helophytes and phreatophytes will be termed "hydrophytes" except in citations where the authors original wording will be used. A classification of the various species of hydrophytes reviewed below is presented in Table I.

The literature on hydrophyte evapotranspiration is small. Indeed, LINACRE's (pp. 343-344, 1976) comment that: "a thorough search of the (English) literature has demonstrated the paucity of knowledge on the physics of swamps (...) The process of evaporation from a reed field remains a matter of ignorance" is still appropriate. This "paucity of information" has been attributed to the difficulty in carrying out rigourous experiments in a hostile, inaccessible area, that is remote from power supplies or laboratories and is in nature rough, wet and unstable (INGRAM, 1983).

Within this literature, contrasting results of hydrophyte evapotranspiration have been reported by several authors (EISENHLOR, 1966; PRIBAN

(1) *Department of Geography, University College London, 26, Bedford Way, London, WCIH OAP, Great Britain.*

and ONDOK, 1980). BLANEY and YOUNG (1942), McDONALD and HUGHES (1968) and SMID (1975) all reported that hydrophyte evapotranspiration (ETh) could exceed open water evaporation (EW) under identical meteorological conditions. Conflicting results were obtained by MIGAHID (1952), SHJEFLO (1968) and LINACRE *et al.* (1970).

One of the aims of this review is to establish the magnitude of the ratio between hydrophyte evapotranspiration ETh and open water evaporation (EW) ie. the ETh/EW ratio. It is useful to know when studying the results of the various workers cited below that the ETh/EW ratio for wheat and barley is 0.13 to 0.7 depending upon stage of growth (DOORENBOS and PRUITT, 1975).

In order to facilitate the comprehension of the debate surrounding hydrophyte evapotranspiration, this review will be divided into three sections:

I) work that supports the hypothesis that hydrophyte evapotranspiration can exceed open water evaporation,

II) work that supports the hypothesis that hydrophyte evapotranspiration cannot exceed open water evaporation, and

III) a concluding section that evaluates both sets of results and attempts to explain the variation in their conclusions.

I. HYDROPHYTE EVAPOTRANSPIRATION CAN EXCEED OPEN WATER EVAPORATION

There have been various methodological approaches to calculate hydrophyte evapotranspiration. These approaches can be grouped into four broad headings: lysimeters, Bowen ratio/eddy flux, water balance and detached organ. Although some workers (GEL'BUKH, 1964) have used more than one methodological approach, it was decided to describe the work on hydrophyte evapotranspiration in these four main headings.

Lysimeters

Lysimeters have been defined (RODDA, DOWNING and LAW, 1976) as "a container that is installed so that its rim is level with the ground". The evapotranspiration losses from the container are usually calculated by differences in weight over a set time period. Also detailed in this section are tank experiments and soil monolith experiments. Tank experiments consist of growing hydrophytes in tanks and noting the water needed to top up the tank to a set level. Soil monoliths are undisturbed blocks of soil, where evapotranspiration is measured by either noting the fall/rise of ground water level or by some weighing technique. The similarity of the three methods is obvious.

OTIS (1914) was an early worker to study the water loss by hydrophytes compared to open water evaporation. He planted hydrophytes in large tanks which had been sunk into the margins of a lake to simulate natural conditions for evapotranspiration. He calculated the hydrophyte/open water (ETh/EW) ratio of evapotranspiration for six species: *Potamogeton nodosus* ETh/EW ratio 3.1; *Typha latifolia*, 2.5; *Acorus calamus*, 2.0; *Pontederia cordata*, 1.2; *Scirpus validis*, 1.9; *Nymphaea edorata*, 1.0. According to OTIS: "Water loss from the areas covered by normal densities of helophytes is several times greater than the evaporation loss from the same area of water." (OTIS, 1914 cited by BERNATOWICZ *et al.*, 1976, p. 276). OTIS concluded that the cause of this interspecies variation in the ETh/EW ratio were anatomical structure and differences in water management.

STEARNS and BRYAN (1925) also grew helophytes in a tank set into the margins of Mud Lake, Idaho. They found that water loss from a tank of *Scirpus acutus* exceeded the water loss from a neighbouring pan of water by as much as two times. They concluded that (p. 100): "The total losses by evaporation and transpiration from the marsh and tule *(Scirpus acutus)*-covered areas are considerably larger than the loss by evaporation from open water surfaces."

PRYTZ's (1932) pioneering work in Jutland showed that lysimeter readings of hydrophyte evapotranspiration exceeded adjacent sunken pan values of open water evaporation by as much as 25 %.

A most comprehensive, rigorous and diuturnous series of studies on tank hydrophyte evapotranspiration was initiated by BLANEY *et al.* (1933). Between 1933 and 1965, BLANEY, in conjunction with various other authors, published several papers on the subject of hydrophyte evapotranspiration (BLANEY *et al.*, 1933; BLANEY *et al.*, 1938; BLANEY *et al.*, 1942; YOUNG and BLANEY, 1942; MUCKEL and BLANEY, 1945; BLANEY and EWING, 1946; BLANEY and MUCKEL, 1955; BLANEY, 1959; BLANEY, 1961; BLANEY and HANSON, 1965). All these papers published differing "consumptive use" coefficients, for various hydrophytes and phreatophytes, depend ing upon species and climate. One experiment used to gain these "consumptive use" coefficients was carried out at San Louis Rey Valley in California (BLANEY and EWING, 1946). Tules *(Scirpus acutus)* were grown in 4 m² tanks, set up in in a swamp in the valley floors, for three years. The results were compared to an adjacent US Weather Bureau Class A pan. The hydrophyte/open water ratios ranged from 1.08 to 1.55 depending upon the time of year. The overall conclusions of BLANEY's work was that the ETh-EW ratio could range above and below unity, depending upon species, climate and time of year.

These conclusions are borne out by the following experiments. *Scirpus acutus* ratios ranged from 1.00 at Victorville and San Luis Rey, both in California (MUCKEL and BLANEY, 1945; BLANEY *et al.*, 1933), to 1.26 obtained at Parma, Colorado (YOUNG and BLANEY, 1942). *Spartinia* grown at Santa Ana in California had a ratio of only 0.6 while *Scirpus acutus* also grown in California had a ratio of 1.0.

TURNER and HALPENNY (1941) also worked in the south west of the USA, calculating that the ETh/EW ratio of *Tamarix* and *Baccharis* ranged from 0.4-2.1 and 0.3-1.2 respectively. These ratios were derived from circular pans compared to US Weather Bureau class A pan. The range in the ratio was attributed to the state of growth. GATEWOOD *et al.* (1950) also calculated the water lost by *Tamarix* and *Baccharis* in Arizona and found ratios to be 0.8-2.0 and 0.5-1.1 respectively.

TINBERGEN (1940), working in the head waters of the Roer, in the Belgium Ardennes, compared hydrophyte evapotranspiration values, obtained from soil monoliths to sunken pans of open water; the ratio for *Sphagnum* ranged from 0.8 to 1.6. KUZNETSOV (1949) carrying out lysimeter experiments in Russia, stated that: "Water loss from a surface overgrown by helophytes is 1.5-2.5 times higher than from an open water surface, sometimes even three times higher (depending on species and fheir density.)" (KUZNETSOV, 1949 cited by BERNATOWICZ *et al.* 1976).

KIENDL (1953) also used lysimeters while working on *Phragmites australis*, concluding that hydrophytes 'rob the water from water bodies'. KOVARIK (1958) showed that the ratio of water loss from *Typha latifolia* was between 2 and 2.5 depending upon the stage of growth. EGGLESMANN (1963 and 1964) worked upon the raised mires and swamps at the Konigsmoor in NW Germany. Using lysimeters with a surface area of 500 cm^2, EGGLESMANN calculated that the hydrophyte/open water ratio of *Sphagnum* and *Calluna* species ranged from 0.9 to 1.5, depending upon time of year. BADEN and EGGLESMANN (1966) concluded that, "Raised bogs displayed a higher rate of evapotranspiration than comparable catchments without mire development."

There has been a considerable amount of work by authors from the USSR on hydrophyte evapotranspiration from ponds, lakes, reservoirs and bogs. ROMANOV (1953) compared lysimeter and Bowen ratio measurements of hydrophyte evapotranspiration to values of open water evaporation derived from the Bowen ratio method. ROMANOV's hydrophyte/open water ratios were between 1.1 and 1.4. He then went on to develop an empirical equation to predict bog evapotranspiration set out below:

$E = Rz + C$ Where E is evaporation, R is the radiation balance of the bog, z and c are empirical coefficients.

KUZNETSOV (1954 and 1959) cited by KONSTANTINOV (1963) stated that partly submerged aquatic vegetation could exceed open water evaporation during the summer, by up to 10-20 %, but in winter open water evaporation was higher. BRASLAVSKII and VIKULINA (1963) cite other work by KUZNETSOV that took place at the Valdai reservoir. Hydrophytes grown in 0.3 m^2 tanks over two years gave ETh/EW ratios of between 1.28 and 2.02 depending upon species type. BRASLAVSKII and VIKULINA (1963 p. 113) stated that the reason for these ratios was, "because of the intensive transpiration of moisture by the vegetation."

GEL'BUKH (1964) calculated hydrophyte evapotranspiration rates from 0.3 m^2 "transpiration evaporimeters", comparing the results gained to a GGI-3000 pan, in northern Kazakhstan. He concluded that, "the evaporation from growths of aquatic vegetation can considerably exceed evaporation from an open water body". He then went on to postulate that this was because, first, the plants could utilize solar radiation better than a water surface; second, that plants were more susceptible to the effects of advection; and third that plants had a higher interchange of convectional heat from the air than open water. GEL'BUKH (1964) also linked hydrophyte evapotranspiration to the leaf area and thus the density of growth and then calculated the effect that hydrophytes would have on several Russian lakes. These results are detailed in the section on water balance methodologies.

BAVINA (1967) compared lysimeter readings (using a Russian B-1000 lysimeter) to BORISOV's (BORISOV 1965) estimate of potential evapotranspiration for the area where BAVINA was working, deriving an ETh/EW ratio of between 1.1 and 1.4, for *Sphagnum*. In a concluding/reviewing article BULAVKO (1971) cited lysimeter work that gave a hydrophyte/open water ratio of between 1.2 and 1.4. BULAVKO stated that, "The evaporation from a water-logged marsh is often 20-40 % more than from a free water surface."

PENFOLD and EARLE (1948) experimented on the water loss of water hyacinths in Louisiana, finding the hydrophyte/open water ratio to be 3.2 for 'tightly packed' (i.e. high density) 1 m^2 tanks of water hyacinths *(Eichhornia crassipes)*. TIMMER and WELDON (1967) and ROGERS and DAVIS (1972) both worked in Florida, deriving ETh/EW ratios for water hyacinth from tank experiments of 3.7 and 5.3 respectively. Van der WEERT and KAMERLING (1974) carried out tank experiments in Holland on water hyacinth evapotranspiration obtaining an ETh/EW ratio of only 1.44-1.48 substantially lower than the American work had indicated. Van der WEERT and KAMERLING (p. 212) stressed that "For water plants the "crop" characteristics determine to a large extent the transpiration rate. Evaporation of swamps therefore depends on the species growing in the swamp... The climatological conditions seem to be very dominating."

BRENZNY *et al.* (1973) also calculated the water loss from water hyacinth as well as from 5 other species of hydrophytes. Working in Rajasthan, India, they used 3600 cm^2 cement tanks to grow the hydrophytes, comparing the results to identical tanks with no hydrophytes. The ratios they obtained varied from 0.92 to 2.5 depending upon species type and time of year. For instance, *Typha augustifolia* ratio ranged from 1.64 in summer to 1.38 in winter. In the corresponding time period, water hyacinth's ratio ranged from 1.02 to 1.36.

BAY (1966, 1968) calculated the evapotranspiration of peat bogs in Minnesota. Comparing the results gained from 3 bottomless lysimeters, containing mainly *Sphagnum*, to US Weather Bureau Class A pan, and THORNTHWAITE and HAUDE's measure of evaporation, BAY derived a hydrophyte/open water ratio of 0.9 to 1.45 depending upon the time of year. NICHOLS and BROWN (1980) experimented upon cores transplanted from Minnesota peat bogs to an experimental station, and discovered that evapotranspiration from *Sphagnum* was twice that from a similar sized 'tub' of water. STURGES (1968) found that evapotranspiration from a lysimeter situated in a Wyoming sedge bog was 27 % greater than evaporation from a 1.8 m diameter pan.

SCHIEMDL *et al.* (1970) also experimented upon the evapotranspiration of *Sphagnum* using lysimeters of the POPOV and IVITSKII design, calculating the ETh/EW ratio to be 1.4. CLYMO (1973) calculated the evapotranspiration loss of various species of *Sphagnum* contained in small beakers in a laboratory, deriving hydrophyte/open water ratios of between 1.5 and 3, depending upon species type.

McDONALD and HUGHES (1968) found that *Typha latifolia* grown in 10 m^2 tanks in the fringes of Lake Mitty near Yuma, Arizona, had an ETh/EW ratio of 0.9 in winter and 1.56 in summer. PRIBAN and ONDOK (1978, 1980) experimented on a 1 m^2 tank of *Calmagrostisis canescens* in the Trebon fishpond in Czechoslovakia, deriving an ETh/EW ratio that lay between 1.1 to 1.5, depending upon the season. Gavenciack (1972) experimented upon *Phragmites australis* in southern Czechoslovakia and found that the maximum rate of evapotranspiration was as high as 27.8 mm per day. BERNATOWICZ *et al.* (1976) used small lysimeters (called phytometers) situated in Lake Mikolajskie, to calculate the water lost by *Phragmites australis*, *Scirpus lacustris*, *Typha angustifolia* and *Typha latifolia* over a three year period. The ratios they gained were 2.1, 3.0, 3.2, and 3.4 respectively.

NEWSON and GILMAN (1983), working in Great Britain, discovered that hydrophyte evapotranspiration from *Phragmites australis* and *Cladium marissus* communities in the Anglesey wetlands exceeded open water evaporation by about 1.2 to 2.0 times The hydrophyte evapotranspiration values were derived from 'measuring cylinders' and 'bucket tanks', whilst the open water evaporation was calculated using Penman's formulae.

WILLIAMS (1986), also working in Great Britain, calculated the loss of water from *Carex riparia*. Comparing the results gained from two adjacent floating US Class A pans, WILLIAMS derived ratios for high states of growth of 1.17 and 1.49 over the two year study period.

Detached organ

This methodology is based on the cutting and then periodic weighing of leaves from hydrophytes. In many cases only transpiration rates have been obtained and there were no direct comparisons to open water evaporation. These experiments are discussed in 'Pond Littoral Systems', edited by DYKYJOVA and KVET (1978). The experiments where the results were compared to open water evaporation are discussed below.

TUSCHL (1970) weighed water loss from single leaves of *Phragmites australis* from a lake in Austria and found that hydrophyte evapotranspiration exceeded open water evaporation. Czechoslovakian workers such as KROWLIKOWSKA, KVET and RYCHNOVSKA calculated transpiration losses for a variety of hydrophytes, coming to the conclusion that hydrophyte evapotranspiration was equal to, if not above open water evaporation (HENJY, 1969; KROWLIKOWSKA, 1971; KVET, 1973; RYCHNOVSKA, 1972; RYCHNOVSKA *et al.*, 1972; RYCHNOVSKA and SMID, 1973). NEUHAUSAL (1975) reporting on earlier work carried out in the fifties, concluded that hydrophyte transpiration rates, exceeded Piche atmometer values by up to 1.18, depending upon species type.

Water balance approach

This approach calculates the effect that hydrophytes have on the overall water budgets of lakes or swamps by either calculating the water loss from lakes with and without hydrophytes, or by applying evaporation empirical formulae with a hydrophyte 'crop coefficient' to the water budget of various lakes.

Blaney and Muckel (1955) used the "consumptive use" coefficients derived from their earlier work to calculate the effect of *Scirpus acutus* and *Typha latifolia* on the water balance of San Francisco bay. They calculated that *Scirpus acutus* and *Typha latifolia* would lose substantially more water than open water evaporation, from 1.16 to 1.4, depending upon location within the bay.

Gel'bukh (1964) used the results from his lysimeter and density studies to calculate the effects of hydrophytes on 11 Russian lakes. The ratios he derived ranged from 0.9 to 2.2. This range in ratios was mainly caused by the differences in densities of hydrophytes growing in the respective lakes, the size of the lake, and the annual average windspeed across the lake, for Gel'bukh calculated his open water evaporation values from a mass transfer methodology devised by Zaykov (1949).

Bernatowiecz *et al.* (1976) used their results described above to calculate the effect that emergent hydrophytes would have on the water balance of four Polish lakes. Using a formula developed by Novikova (1963), they found that in three out of the four cases presented, the presence of hydrophytes would mean more water loss than if there were no hydrophytes present.

Benton *et al.* (1978) calculated the effect of water hyacinth upon Texas reservoirs. Using Penfold and Earle's earlier work, Benton *et al.* calculated that on a variety of Texas reservoirs the "water loss by a mature plant is about three times as much as evapotranspiration from an equivalent area of open water".

Rutherford and Byers (1973) have been cited by Nicols and Brown (1980) as stating that evapotranspiration from a New England bog exceeds open water evaporation by 30 %.

Balek and Perry (1973) compared evapotranspiration from stands of *Brachystegia* woodland, in the Kafue basin in Zambia, calculated by a water balance approach to Penman's estimate of evaporation. They obtained average ETh/EW ratios for the three year study period of between 0.3 and 1.35 depending upon season.

Dolan *et al.* (1984) calculated the evapotranspiration of a freshwater wetland in Florida using a quasi water balance technique. Utilizing a groundwater measuring technique pioneered by Davis and DeWiest (1966), they calculated that the evapotranspiration from *Saggittaria lancifolia* could exceed open water evaporation by a factor of 2.5. The ETh/EW ratio they gained depended upon state of growth. They then linked the exact magnitude of the ETh/EW ratio to an indicator of state of growth: above ground biomass.

Bowen ratio/Eddy correlation

This methodology measures the vapour/temperature profile over hydrophytes and then compares the results gained to measures of open water evaporation.

The Bowen ratio methodology was extensively used by Russian mire workers such as Romanov (1953), Bavina (1967) and Belotserkovskaya *et al.* (1969). Rates of hydrophyte evapotranspiration rather than comparisons with open water evaporation were made so no ETh/EW ratio's were obtained.

Smid (1975) in Czechoslovakia, compared hydrophyte evapotranspiration to some form of open water evaporation. Working with mixed stands of *Phragmites australis* with an undergrowth of *Carex riparia*, at the Nesyt fishponds in South Moravia, Smid found that the hydrophyte evapotranspiration calculated from the Bowen ratio method was 0.8-1.8 times higher than from a moored pan of water situated in a nearby lake, depending upon species type and state of growth. Priban and Ondok (1980) also used a Bowen ratio method to calculate the evapotranspiration from a fishpond in Trebon. They concluded that using this approach, "The evaporation from the Treborn marsh must approach the potential evapotranspiration."

Conclusions

Table II is the tabulation of the work described above into climate, species and then stage of growth. Figure 1 is the means of each major species for each major climate. From table II and figure 1, few firm conclusions on hydrophyte evapotranspiration can be drawn, primarily due to the lack of detailed experiments. Many pieces of work cited above can not be tabulated because the authors did not describe their work fully. Gel'bukh (1964) is a good example of this, as he described the hydrophytes under investigation as "reeds". From table I this could be construed to mean *Phragmites*, but as no latin name was given the result can not be tabulated.

However, despite these problems, some tentative conclusions can be drawn. From table II it is clear that a dominating factor on the ETh/EW ratio is state of growth. It is important to note that in many of the pieces of work shown in table II, the ETh/EW ratio is below 1.0 for low states of growth and above 1.0 for high states of growth. This fact

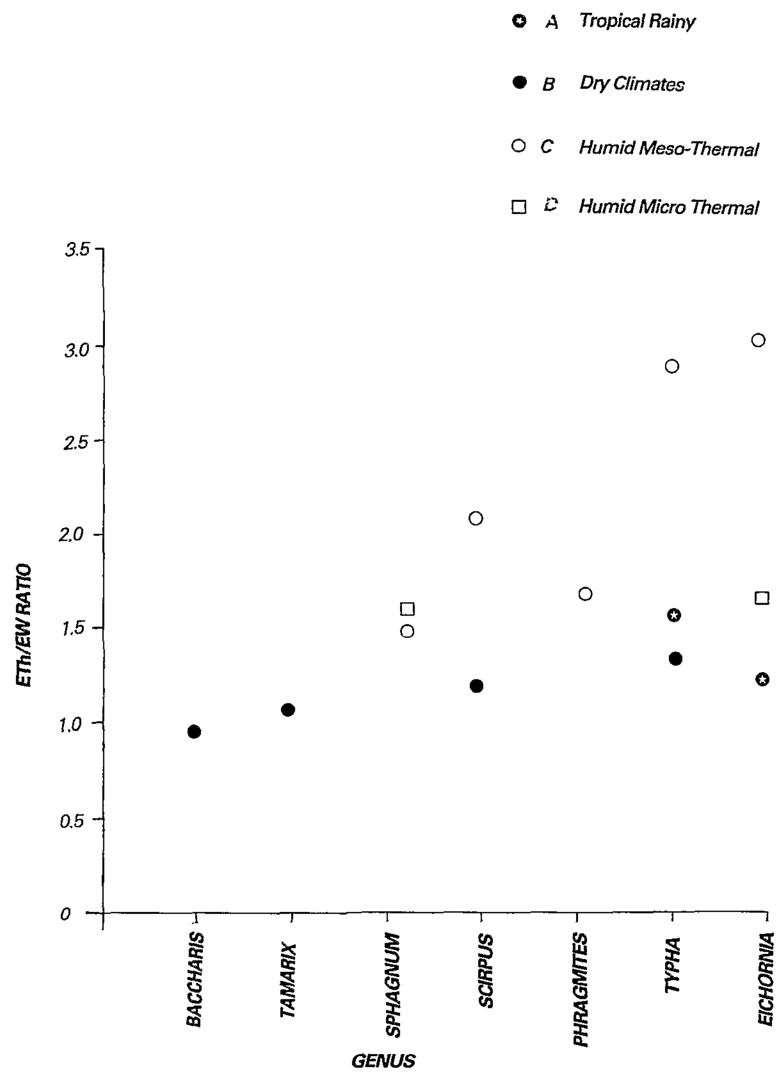

Fig. 1. — Mean ETh/EW ratios for selected hydrophytes in various climates
Rapports moyens de l'évapotranspiration d'un marais par rapport à l'évaporation d'une nappe d'eau libre pour divers types d'hydrophytes dans différents climats

will become more important when the results presented above are compared to those which state that the ETh/EW ratio is below 1.0. In fact differences in the ETh/EW ratio due to stage of growth can have a larger effect than that of climate. For instance, the difference in the ETh/EW ratio for stage of growth in *Typha* is 0.5 in climate types A and C while it is 1.1 in climate type B. The difference in climate for *Typha* has only the range of 1.2 to 2.1.

Many workers (Blaney *et al.* 1942, Van der Weert and Kamerling 1974) have stated that climate has an important effect on the ETh/EW ratio, yet from figure 1 it appears that this effect is not constant. A dry climate (B) would expect to have a higher ratio than a humid meso-thermal climate (C) yet figure 1 shows this not to be the case. The anomalies in the effect of climate shown in figure 1 could be due partly to the classification, as meso-thermal climates (C) groups a Mediterranean climate with a British climate. To overcome this problem, more classifications of climates could have been used, but there are not enough studies for each climate to obtain a meaningful average. It could also be due to the fact that while hydrophyte transpiration stays more or less the same from climate to climate, the open water evaporation decreases in the humid

TABLE I

Characteristics and habits of hydrophytes described in the review
Caractéristiques et comportement des hydrophytes décrits dans le texte

LATIN NAME	COMMON NAME	HABIT/HABITAT
Cyperus papyrus	Papyrus	Tall emergent macrophyte
Phragmites australis	Reeds	"
Scirpus lacustris	Bulrush	"
Scirpus validus	Soft-stem bulrush	"
Typha latifolia	Reedmacecat-tails	"
Typha angustifolia	Narrow leaf reedmace	"
Typha orientalis	Reedmacecat-tails	"
Equisetum	Horse-tail	Leafless emergent macrophyte
Scirpus acutus	Tules	"
Scirpus olneyi	"	"
Scirpus americanus	"	"
Calamagrotis canescens	Purple small-reed	Leafy emergent macrophyte
Carex riparia	Great pond sedge	"
Baccharis	Baccharis	Woody shrub
Tamarix gallica	Saltcedar	"
Cyperus rotundus	Purple nutsedge	Floating macrophyte
Eichhornia crassipes	Water hyacinth	"
Ipomaea aquatica	Swamp morning-glory	"
Lemna minor	Common duckweed	"
Nymphaea	Water lily	"
Pistia stratiotes	Water lettuce	"
Potamogeton nodosus	American pondweed	"
Trapa natans	Water chestnut	"
Sphagnum	Bog moss	Bog macrophyte
Thuja occidentalis	Eastern white cedar	Conifer

All nomenclature follows Tutin et al. 1964-1980

meso-thermal climate (C), the net effect being an increase in the ETh/EW ratio obtained.

OTIS (1914) and CLYMO (1970) are among many authors who identified species as having an important effect upon the ETh/EW ratio. Information gained from figure 1 tends to support this view as such genus as *Eichhornia* and *Typha* have a higher ratio than *Tamarix* or *Baccharis*.

Work by BAVINA (1967) and PRIBAN and ONDOK (1980) has shown the variance in results gained by different methodologies as shown in table III.

It has proved impossible to substantiate this with reference to other workers results as there are not enough studies in the same climate with the same species using different methodologies to obtain a meaningful average. Yet if the varying methodologies are scrutinized it is apparent that the choice of methodology affects the ETh/EW ratio.

KIESELLBACH (1916) lists the main sources of error in using tank/lysimeter experiments. Hydrophyte tank experiments add several other potential errors to those listed by Kiesellbach. Firstly, if the tanks are taken out of *situ* and thereby isolated, the resulting ETh/EW ratio will be artificially high due to the effects of advection. This is clearly shown by the results of BLANEY *et al.* (1933) who measured the water loss of a tank of *Scirpus* both inside and outside a swamp in California. The resulting ETh/EW ratios gained from either tank differed by a factor of four. BLANEY *et al.* (1933) stressed that "Consumptive use of water by tules or cat-tails grown in tanks in exposed locations is not closely indicative of the true use by these plants growing in their natural environment... use of water by swamp growth transplanted to exposed locations is inordinately high."

Indeed several authors (notably LINACRE, 1976) have stressed that advection would affect all tank experiments, whether grown *in situ* or not. NEWSON (pers. comm. 1986) stated that the biggest problem

TABLE II

Studies of individual species of hydrophyte which showed the ETh/EW ratio could be greater than unity
Étude des espèces d'hydrophytes dont le rapport ETh/EW montre une grandeur supérieure à l'unité

CLIMATE		SPECIES		REFERENCE of EW	STATE OF GROWTH		ANNUAL ETh /EW	AVERAGE ET /EW	WORKER
					High	Low			
A-Tropical rainy	1-Tropical rainforest								
	2-Tropical savanna	*Brachystegia*		Penman PEt	1.35	0.30	0.80	-	Balek and Perry 1973
		Cyperus	*rotundus*	$3.6m^2$ tanks	2.4	****	2.4	-	Brezny et.al 1973
		Eichhornia	*crassipes*	"	1.35	1.02	1.15	1.15	"
		Ipomaea	*aquatica*	"	1.24	1.01	1.10	-	"
		Pistia	*stratiotes*	"	1.08	0.90	1.00	-	"
		Trapa	*natans*	"	1.03	0.93	0.95	-	"
		Typha	*angustifolia*	"	1.65	1.27	1.40	1.40	"
B-Dry climates	1-Steppe	*Scirpus*	*acutus*	US Class A pan	2.0	0.7	1.35	1.35	Stearns and Bryan 1925
		Sphagnum		US Class A pan	****	****	1.27	1.27	Sturges 1968
	2-Desert	*Baccharis*		"	1.25	0.4	0.98	-	Turner and Halpenny 1941
		Baccharis		"	1.1	0.5	0.85	0.90	Gatewood et al. 1950
		Scirpus	*acutus*	"	****	****	1.26	1.26	Young and Blaney 1942
		Tamarix	*gallica*	"	2.0	0.35	1.02	-	Turner and Halpenny 1941
		Tamarix	*gallica*	"	2.1	0.5	1.30	1.15	Gatewood et al. 1950
		Typha	*latifolia*	"	1.6	0.5	1.20	-	McDonald and Hughes 1968
		Typha	*latifolia*	"	1.8	0.85	1.35	-	Blaney et al. 1938
		Typha	*latifolia*	"	1.62	0.77	1.18	-	Blaney et al. 1938
		Typha	*latifolia*	"	1.68	1.12	1.40	1.28	Blaney et al. 1942
C-Humid Meso-thermal	1-Mediterr-anean	*Scirpus*	*acutus*	US Class A pan	1.5	1.1	1.25	-	Muckel and Blaney 1945
		Scirpus	*acutus*	"	****	****	1.24	-	Blaney and Ewing 1946
		Scirpus	*acutus*	"	1.2	2.0	1.35	1.27	Blaney and Muckel 1955
	2-Humid sub-tropical	*Eichhornia*	*crassipes*	Small pot in Lab.	****	****	3.2	-	Penfold and Earle 1948
		Eichhornia	*crassipes*	****	****	****	3.7	-	Timmer and Weldon 1967
		Eichhornia	*crassipes*	****	****	****	5.3	4.06	Rodgers and Davis 1972
	3-Marine west coast	*Calamagrostis*	*canescens*	****	1.1	2.0	1.55	-	Priban and Ondok 1980 (tank)
		Calamagrostis	*canescens*	****	****	****	1.00	-	Priban and Ondok 1980 (B'wen)
		Eichhornia	*crassipes*	****	****	****	2.0	-	Otis 1914
		Eichhornia	*crassipes*	US Class A pan	1.69	1.28	1.48	1.75	V'D' Weert & Kamerling 1974
		Phragmites	*australis*	$3m^2$ floating pan	1.8	0.8	1.2	-	Smid 1975
		Phragmites	*australis*	$0.3m^2$ phytometer	****	****	2.1	-	Bernatowiecz et al. 1976
		Phragmites	*australis*	Penman PEt	2.0	1.2	1.6	1.65	Newson and Gilman 1983
		Potamogeton	*nodosus*	****	****	****	3.1	-	Otis 1914
		Scirpus	*olneyi*	US Class A pan	1.55	0.53	1.04	-	Blaney et al. 1933
		Scirpus	*lacustris*	$0.3m^2$ phytometer	****	****	3.0	-	Bernatowiecz et al. 1976
		Scirpus	*validis*	****	****	****	2.5	2.75	Otis 1914
		Sphagnum		Haude PEt	1.5	0.9	1.2	-	Egglesmann 1963
		Sphagnum		US Class A pan	1.45	0.9	1.14	-	Bay 1966
		Sphagnum		Thornthwaite PEt	1.4	0.6	1.1	-	Schmiedl 1970
		Sphagnum		Small beaker in lab	2.5	2.0	2.25	1.40	Clymo 1970
		Typha	*angustifolia*	$0.3m^2$ phytometer	****	****	3.2	-	Bernatowicz et al. 1976
		Typha	*latifolia*	****	****	****	2.0	-	Otis 1914
		Typha	*latifolia*	$0.3m^2$ phytometer	2.5	2.0	2.25	-	Kovarik 1958
		Typha	*latifolia*	"	****	****	3.4	2.7	Bernatowiecz et al. 1976
D-Humid micro-thermal		*Carex*		$0.3m^2$ phyometer	1.28	****	1.16	-	Kuznetsov 1952
		Carex		"	1.45	****	1.18	-	" 1953
		Equisetum		"	1.34	****	1.36	-	Kuznetsov 1953
		Equisetum		"	1.53	****	1.19	1.28	" 1952
		Sphagnum	*recurvum*	$0.15m^2$ 'tub'	****	****	2.0	-	Nicols and Brown 1980
		Sphagnum		$0.3m^2$ phytometer	1.4	1.1	1.25	-	Bavina 1967
		Typha		"	1.75	****	1.60	-	Kuznetsov 1953
		Typha		"	1.38	****	1.23	1.42	" 1952

N.B. i) Only tank experiments carried out in situ included
ii) Mean values obtained from at least one full year of results
iii) **** - Missing or data not available

TABLE III

A comparison of daily hydrophyte evapotranspiration for similar species with different methodologies (mm)
Comparaison de l'évapotranspiration journalière d'espèces similaires selon différentes méthodologies (mm)

		May	June	July	Aug.	Sept.	Oct.
Bavina (1967)	Heat balance method	4.0	3.9	3.5	2.6	1.6	0.3
	Tank measurements	4.1	4.7	4.1	3.2	1.9	0.8
Priban and	Heat balance method	3.6	3.5	3.2	2.4	1.7	1.2
Ondok (1980)	Tank measurements	4.7	4.6	5.1	3.3	2.6	1.5

in calculating hydrophyte evapotranspiration in the Anglesey wetland study was to overcome the effects of advection. Advection plays an important role in the process of hydrophyte evapotranspiration and affects tank methodologies in particular by the oasis and clothes line effects.

The oasis effect arises due to horizontal differences in the wetness of an area. Incoming dry warm air supplements the net radiation, providing more energy for evapotranspiration to occur. The oasis effect would, therefore, affect areas of hydrophytes along a narrow strip, such as a river bed or the edges of a larger swamp.

The clothes line effect increases evapotranspiration by increasing the ventilation of air through a canopy, increasing the turbulent exchange and thereby increasing evapotranspiration. The clothes line effect would affect all tall hydrophytes and all helophytes. A clear example of the combined effects of advection has been detailed by DAVENPORT and HUDSON (1967). Working on cotton fields in the US, they found that evapotranspiration decreased significantly as progression was made into the cotton fields. Advection will, therefore affect the results gained from workers using the tank methodology.

However, LINACRE (1976) states: "Advection affects all swamp evaporation except in the middle of a large swamp, where the air is remote from the influence of the surroundings." It is apparent that hydrophytes growing in natural conditions, in most, though not all, cases will be affected by advection and this therefore is an inherent part of their evaporative characteristics. GEL'BUKH (1964) certainly believed that advection was an inherent part of hydrophyte evapotranspiration. The conclusions that can be drawn from the above discussion on advection are that it is an important factor on *isolated* tank methodologies but as advection is an *inherent* part of most hydrophyte evapotranspiration as long as the tanks are sited *in situ* the results gained will be the actual values of hydrophyte evapotranspiration.

Secondly, if the pan of water is located within the swamp, there will be restricted airflow over the pan, reducing the evaporation and therefore raising the ETh/EW ratio. Yet if the pan of water is situated outside of the swamp, the pan is then subjected to the effects of advection described above.

Bowen ratio/heat transfer/eddy correlation techniques are also prone to inaccuracies. These are because the complex series of measurements are usually only taken for parts of the day, and there are great problems in data capture and analysis. Advection (which LINACRE (1976) stated affected all swamps except very large ones) could conceivably create air instability, which will certainly affect Bowen ratio measurements.

There are only a few water balance studies that primarily compute ETh/EW ratios; most use ETh/EW ratios gained from other methodologies, albeit their own work, and then apply those ETh/EW ratios to water balance studies. Thus the main errors in the water balance methodologies are the errors in other methodologies that have already been described.

Single leaf and detached organ methods suffer from two principle errors; firstly that the water lost from a cut leaf is un-natural. Secondly that not all the leaves on a plant will transpire at the same rate. It is not easy either to make leaf area estimates of large areas, so that applying ratios gained from single leaves is extremely hazardous.

KUZNETSOV (1949), GEL'BUKH (1964) and BERNATOWICZ *et al.* (1976) have all stressed that the density of the hydrophytes has an important effect upon the ETh/EW ratio. It is hard to quantify this from studying table I and figure 1. RANTZ (1968) published coefficients relating to BLANEY *et al.*'s consumptive use coefficients that were dependent upon the density of the hydrophyte under study. RANTZ suggested a simple linear decrease in the ETh/EW ratio with decreasing densities. However GEL'BUKH (1964) postulated that the effect of density was more complex than this, stating (p. 369), "The increased density increases the shading of the plants which, in turn, reduces the rate of transpiration and of total evaporation." Density, therefore, will be an important factor on hydrophyte evapotranspiration, yet the precise effect is unclear.

An indicator of the exact magnitude of the ETh/EW ratio was identified by DOLAN *et al.* (1984): above ground biomass. It is clear that this factor is influenced by state of growth, species type and density: three of the five factors that influence the ETh/EW ratio. Measurements of above ground biomass could thus potentially be important in calculating hydrophyte evapotranspiration. This is because if a relationship is experimentally derived which links above ground biomass to the exact magnitude of the ETh/EW ratio, this relationship could then be applied to values of above ground biomass gained from large areas of freely growing hydrophytes. Accurate measurements of evapotranspiration from this area of hydrophytes could be then be made by multiplying standard meteorological values of evapotranspiration by the ETh/EW ratio inferred from above ground biomass values. GEL'BUKH (1964) utilized this methodology by linking the magnitude of the ETh/EW ratio to the leaf area (which is highly correlated to above ground biomass) in his experiments in Kazakhstan.

Partial conclusions (I)

The following conclusions can be drawn :

1) There is very little long-term systematic work upon hydrophyte evapotranspiration. This entails that any conclusions can only be tentatively put forward.

2) The ETh/EW ratio can be greater than unity, and this ratio is affected by the following factors:

a. State of growth

b. Species

c. Climate

d. Methodological approach

e. Density

3) Hydrophyte evapotranspiration is affected by advection which in most cases is an inherent part of hydrophyte evapotranspiration.

4) The exact magnitude of the ETh/EW ratio for a particular species in a particular climate can be gained from measurements of the above ground biomass or the leaf area index.

II. OPEN WATER EVAPORATION EXCEEDS HYDROPHYTE EVAPOTRANSPIRATION

There is less work that suggests hydrophyte evapotranspiration cannot exceed open water evaporation. This work will, however be covered in the same manner as the earlier section.

Lysimeters

MIGAHID (1952 quoted by PENMAN, 1963) was an early worker to conclude that hydrophyte evapotranspiration, measured in a tank was lower than open water evaporation. In the Sud region of the Nile, papyrus was grown in 10 m^2 tanks set in the middle of a large swamp. Evapotranspiration from this tank was compared to evaporation measurements of a tank of water, situated in a nearby, open lagoon, taken the following year. The results for the two years in question gave a hydrophyte/open water ratio of 0.9. MIGAHID is also cited as saying, "Water lost by evaporation from a free water surface inside a swamp was about 20 % of the loss from a free water surface in the open." (MIGAHID cited by GIBB *et al.* 1956 *in* LINACRE 1976, p. 338).

Indeed, RIJKS (1969) cites other work by MIGHAD where plants left undisturbed for six years yielded a hydrophyte/open water ratio of 0.55.

GIBB *et al.* (1956), working near the Shambe in Sudan, compared tank values of hydrophyte evapotranspiration to values of open water evaporation obtained from Oliver's and Thornthwaite's evaporation formulae. The hydrophyte/open water evaporation ratio was found to be 0.6.

JOHANSSON (1974) working in Komosse, south Sweden, compared B-1000 lysimeter readings of *Sphagnum*, to estimates of open water evaporation derived from US Weather Bureau Class A pan, GGI-3000 pan and Penman's empirical formula. Johansson's ETh/EW ratio ranged from 0.64 to 0.85.

BREZNY *et al.* (1973) cite work by SEYBOLD (1930) which showed that a water surface covered by *Lemna minor* decreased the evapotranspiration loss.

One of the more recent pieces of work to be published on tank hydrophyte evapotranspiration being lower than open water evaporation was that of COOLEY and IDSO (1980) and ANDERSON and IDSO (1985). Responding to the work of BENTON *et al.* (1978) on the water loss of water hyacinths, COOLEY and IDSO published data on evapotranspiration from *Nymphaea* that had been collected in the month of May 1968. Two sunken evaporation pans were measured daily, one with *Nymphaea* cover of about 18 %, the other totally clear. The hydrophyte/open water ratio Cooley and Idso derived was 0.9.

ANDERSON and IDSO (1985) extended this work and calculated the water loss from four species of hydrophytes grown in a variety of pans. This was because they believed that the reason that some workers found the ETh/EW ratio to be above unity was due to differences in the evaporative surface areas of the tanks of hydrophytes and the tanks of open water. They wanted to show that there was a strong correlation between the ETh/EW ratio and the vegetation/open water surface area ratio. The ETh/EW ratios gained ranged from 0.85 to 1.5 depending upon species type and height of the vegetation.

Water balance

Novikova (1963) worked on the effects of the evapotranspiration losses of *Typha angustifolia* and *Phragmites australis* on the water balance of the Kengirdam reservoir in Kuzakh, finding the ratio of hydrophyte/open water to be 0.71-0.73. He then developed an empirical formula to calculate lake evaporation with the presence of hydrophytes shown below:

$$\mathrm{Eht} = \frac{\mathrm{T} + \mathrm{e}}{\mathrm{E}}$$

where Eht is total loss of water of lake as quotient (T + e) is water loss from the area overgrown by hydrophytes, and E is the evaporation from the open area of the lake.

Eisenhlor (1966) and Shjeflo (1968) calculated the water loss by evapotranspiration from vegetated and unvegetated prairie potholes in N. Dakota, USA, using a water balance approach and a mass-transfer approach devised by Harbeck (1962). They concluded that the hydrophyte/open water ratio for a mixture of 'white top' and 'hardstem bullrush' was between 0.7 and 0.86. Eisenhlor argued that hydrophytes would reduce evaporation in two ways:

1) by sheltering the water surface from the wind and

2) by shading the water surface, thereby reducing the incident solar radiation.

Eisenhlor (p. 452) concluded that; "The presence of hydrophytes reduces the evaporation from a free water surface significantly."

Bowen ratio/Eddy correlation methods

Rijks (1969) worked in a papyrus swamp in East Africa. Measuring hydrophyte evapotranspiration using the Bowen ratio method, he compared this to open water values of evaporation gained from Penman's 1948 empirical formulae. The hydrophyte/open water ratios gained by Rijks ranged from between 0.38 and 0.81.

Linacre *et al.* (1970) used an Eddy correlation method devised by Dyer *et al.* (1967) to compare calculations of evapotranspiration from *Typha orientalis* and *Typha dogingensis* to those of a lake some 16 km away, in the Barren Box Swamp in SW Australia. Taking readings for about 3 hours per day and for four days in February, Linacre *et al.* found the hydrophyte/open water ratio to be between 0.3 to 0.9, depending on prevailing weather conditions. This ratio was attributed to the lower albedo of clear water surface of the lake, the shelter given by the reeds in the swamp to the water surface and the internal resistance to water movement of the reeds themselves. Linacre (p. 385) concluded that, "It is likely that the growth of reeds in a lake or other water body will reduce rather than increase the water loss."

The evaporative characteristics of the saturated tundra around Hudson Bay, Canada were examined by Rouse *et al.* (1977). Comparing hydrophyte evapotranspiration calculated by the equilibrium technique, Rouse *et al.* found that the hydrophyte/open water ratio was 0.9-1.0.

Munro (1979) used a Bowen ratio method to calculate the evapotranspiration losses from a wooded swamp in southern Ontario, obtaining a hydrophyte/open water ratio of 0.76 to 1.04, over the five day study period.

Partial conclusions (II)

The results can be tabulated in the same manner as section I (table IV). Table IV shows that the ETh/EW ratio is never greater than unity. From the study of Migahid (1952) and Munro (1979) that stage of growth is an important factor in determining the exact magnitude of the ETh/EW ratio.

The following conclusions can be drawn:

1) Hydrophytes lose less water than a corresponding area of open water,

2) This ETh/EW ratio depends mainly upon the state of growth and

3) Although climate and species are probably important factors in determining the ETh/EW ratio, the results presented above do not justify this assumption.

III. THE EVALUATION OF HYDROPHYTE EVAPOTRANSPIRATION RESEARCH

The first major point in evaluating why there is a conflict in the conclusions drawn by the authors in I and II is that most of the work in I had ETh/EW ratios of below and above unity. Those in II generally did not.

To fully comprehend why this has occurred, section III will be split into two parts: firstly, to

TABLE IV

Studies of individual species of hydrophyte which showed the ETh/EW ratio was lower then unity

Étude des espèces d'hydrophytes dont le rapport ETh/EW montre une grandeur inférieure à l'unité

CLIMATE		SPECIES		REFERENCE OF EW	STATE OF GROWTH High	Low	ANNUAL ETh/EW	WORKER
A-Tropical rainy	1-Tropical rainforest							
	2-Tropical savanna							
B-Dry climates	1-Steppe							
	2-Desert	*Eichhornia*	*crassipes*	Various sized ponds	0.88	****	0.88	Anderson and Idso 1985
		Eichhornia	*crassipes*	"	1.44	****	1.44	"
		Nymphaea		3.46m² sunken pan	0.95	****	0.95	Cooley and Idso 1980
		Nymphaea		Various sized ponds	0.85	****	0.85	Anderson and Idso 1985
		Cyperus	*papyrus*	10m² pan	1.98	0.8	0.95	Migahid 1952
		Cyperus	*papyrus*	Penman PEt	****	0.6	0.6	Rijks 1969
		Typha	*orientalis*	Mas transfer	****	0.6	0.6	Linacre et al. 1970
C-Humid Meso-thermal climates	1-Mediterr-anean							
	2-Humid sub-tropical							
	3-Marine west coast	*Sphagnum*		GGI-3000	0.8	0.6	0.7	Johansson 1974
D-Humid micro-thermal	1-Humid Continental	*Thuja*	*occidentalis*	Equilibrium model	1.0	0.7	0.85	Munro 1979
		Typha		Mass Transfer	0.8	0.7	0.75	Eisenhlor 1966 & Shjeflo 1968
		Typha		****	****	****	0.5	Novikova 1963

N.B. i) Only tank experiments carried out in situ included
ii) **** indicates missing or data not available

assess whether hydrophyte evapotranspiration can theoretically exceed open water evaporation. Secondly, to explain why the two sets of workers came to different conclusions.

Can hydrophyte evapotranspiration theoretically exceed open water evaporation?

There are three main theories whereby it is possible that hydrophyte evapotranspiration can exceed open water evaporation: Increases in surface area, lower areodynamic resistances and finally high transpiration coefficients.

Increases in surface area

The basic premise is that as hydrophytes grow out of a water surface, an increase in the evaporative surface area results, due to the foilage of the hydrophytes.

Idso (1979) estimated that out of the ETh/EW ratio of 3.7 for water hyacinth derived from Timmer and Weldon (1967), 85 % was due to the differences in the total evaporative area of the hydrophyte compared to the open water. This factor is thus clearly important in determining not only whether hydrophyte evapotranspiration can exceed open water evaporation, but also the exact magnitude of the ETh/EW ratio. Thus the increase in surface area factor will depend upon species type, density and state of growth.

Low aerodynamic resistances

Monteith (1967) and Van Bavel (1968) published evaporation formulae with a term known as the 'aerodynamic resistance'. This factor was dependent upon the nature of the evaporative surface and was a surrogate value for the amount of turbulent exchange.

Van Bavel suggested that the evaporation rate is proportional to the sum of net radiation added to the daily range of ambient temperatures divided by the aerodynamic resistance of the evaporative surface. Because of the differences in the resistances of hydrophytes and open water it is theoretically possible for hydrophyte evapotranspiration to exceed open water evaporation. For example, using values obtained from Linacre's 1970 work it apears that at a temperature of 20°C and a wind speed of $2ms^{-1}$

the ratio of hydrophyte evapotranspiration to open water evaporation is 1.3. LINACRE (1970) studied the evapotranspiration of *Typha* and from table I it is clear that this ratio of 1.3 derived from VAN BAVEL's equation is very similar to the results of McDONALD and HUGHES (1968) who were working in a similar climate.

If the equation for predicting the aerodynamic resistance developed by THOM and OLIVER (1977) is studied it is seen that the exact magnitude of the aerodynamic resistance is dependent upon height as shown below:

$$Ra = \frac{4.72\ [Ln(Z/Zo)]^2}{1 + 0.54U}$$

Where Ra is aerodynamic resistance, U windspeed at height h, z is distance above surface's zero plane displacement and Zo is 0.1 the height of the vegetation.

Thus Ra is a function of species type as well as state of growth, for both of these factors will influence the height of the plant. Therefore, the aerodynamic resistance factor can mean that the ETh/EW ratio is above unity, though this will depend upon species type and state of growth. The similarity between this process and the clothes line effect discussed in I is abvious. This merely reinforces the belief that advection is an inherent part of hydrophyte evapotranspiration.

HIGH TRANSPIRATION COEFFICIENTS

LOFTFIELD (1921) was an early worker to comment that hydrophytes had very little control on their stomatal openings. LOFTFIELD (p. 299) stated: "Such plants as *Scirpus validus*, *Equisetum hiemale* and *Equisetum palustre*, showed the stomata continously wide open, and this seems to be their usual state." FIRBAS (1931) cited by INGRAM (1983, p. 83) concurred with LOFTFIELD's earlier results, stating, "Their [hydrophytes] stomata remain fairly wide open even on sunny days at noon, and showed maximum stomatal apertures in dull weather."

More recent confirmation of this lack of control of stomata has come in the work of PENMAN (1963), IDSO (1968) and VAN BAVEL (1968). All believed that hydrophytes behaved as passive wicks, responding to the atmospheric demand for water. As hydrophytes, by definition, live in areas where water supplies are not a limiting factor they must be able to transpire at a potential rate. Thus the transpiration coefficients as used in NOVIKOVA's work (detailed in II) can be high, thereby suggesting that hydrophytes can indeed lose more water than open water areas.

It is seen that through the three main processes described above it is theoretically possible for hydrophyte evapotranspiration to exceed open water evaporation. Therefore, why did the workers detailed in II come to varying conclusions to those detailed in I? The next section will detail why.

An evaluation of the varying conclusions

The variance in the conclusions drawn by the authors in I and II can be explained by three main factors: poor experimental design resulting in incorrect conclusions, the drawing of sweeping conclusions from a limited amount of work. finally, the current 'accepted' geographical thinking.

POOR EXPERIMENTAL DESIGN

The best example of poor experimental design is that of MIGAHID (1952). Widely quoted as the first to prove that hydrophyte evapotranspiration was lower than open water evaporation, the experiment was published in 1952 and was not widely known until it was cited by PENMAN in 1963. The fatal flaw in the experimental design was that MIGAHID compared tank values of hydrophyte evapotranspiration gained in 1947 to open water values gained in 1948. When the results are examined, the 'real' ratio is 1.14 as shown in table V. The value of 0.98 was only gained by claiming that 1947 was a abnormal year and that the value of hydrophyte evapotranspiration should be lowered accordingly. PENMAN then went on to quote other work by MIGAHID that compared tanks of hydrophytes to open water tanks. The ratio then was 6.0. This second result of MIGAHID, published on the same page as the other experiment seems to have received scant attention shown by those who cite the experiment.

Another example of poor experimental design is that of the USGS work of the potholes of the Dakota prairies (EISENHLOR, 1966 and SHJEFLO, 1968). The error in this work was the division of the evapotranspiration term into its two components: evaporation and transpiration. Each component was calculated separately, and then added together to produce a value of evapotranspiration for each of the potholes studied. This experimental design leads to errors for no account of the transpiration of water drawn from the roots is made in the calculations. This would lead to an under-estimation of the transpiration term, and a consequent under-estimation of the total hydrophyte evapotranspiration.

The errors in this work are clearly shown when the seepage losses of the potholes are studied (SHJEFLO, 1968). A straight comparison of clear pothole to

TABLE V

Evaporation from swamp vegetation and open water: Sudan
Évaporation d'un marais et d'un plan d'eau libre au Soudan

Month	Papyrus Year	Evaporation (mm/day)	Month	Open water Year	Evaporation (mm/day)
May	1947	6.6	May	1948	5.8
June	"	6.7	June	"	7.5
July	"	5.3	July	"	5.4
Aug.	"	4.4	Aug.	"	6.3
Sep.	"	7.8	Sep.	"	4.0
Oct.	"	7.1	Oct.	"	5.2
Nov.	"	7.1	Nov.	"	5.2
Dec.	"	8.3	Dec.	"	4.7
Jan.	1948	6.1	Jan.	1949	6.3
Feb.	"	6.2	Feb.	"	5.1
Mar.	"	6.3	Mar.	"	6.1
Apr.	"	6.2	Apr.	"	6.5
	Mean (12)	6.5			5.7
Omit Sept.-Dec.		6.0			6.1

After Migahid 1952,from Penman 1963 p63

vegetated pothole gives a result of 0.89 for the ETh/EW ratio. Yet vegetated potholes *always* had a higher average seepage rate than clear ones, on average 33 % higher. This means that if seepage is taken into account the true ETh/EW ratio is about 1.14, much closer to the results gained for other hydrophytes in the same climate (see table II).

Thus it is seen that two of the results that proved hydrophyte evapotranspiration was below that of open water were obtained from poor experimental design. Yet there are several others who came to the same conclusions as MIGAHID and EISENHLOR/SHJEFLO. Some of these are explained by the next section.

The above discussion is not meant to imply that the experiments detailed in I all have good methodologies. Rather it is the author's intention to show that since it is clear that hydrophyte evapotranspiration *can* exceed open water evaporation *theoretically*, the variance in the conclusions between I and II must be due to something such as the factors mentioned above.

EXPERIMENTS WITH LIMITED APPLICABILITY

These are the experiments detailed in II which drew conclusions far beyond the scope that their work actually allowed. LINACRE *et al.* is a prime example of this. Although they used a correct experimental procedure their experiments were for only 4 days *at the end of the growing season.* As stated in I, one of the key factors in determining the ETh/EW ratio was state of growth. MCDONALD and HUGHES (1968) working on the same species and in a similar climate found the average ratio of ETh/EW in the low season of growth to be 0.5. This is very similar to the average of 0.6 derived by LINACRE *et al.* It is thus dubious to claim (LINACRE *et al.* 1970, p. 385) that, "it is likely that growth of reeds in a lake or other water body will reduce rather than increase water loss", due to the fact that LINACRE *et al.* only measured "low state of growth evapotranspiration."

Exactly the same criticisms can be levelled at the work of RIJKS (1969) who calculated the water loss of an "old stand of papyrus with a fair proportion of brown and dried out heads". COOLEY and IDSO (1980) also only calculated the water loss for one month and 'fiddled' the results from a true ratio of 0.98 obtained from the actual result to a result of 0.85 by subtracting from the original ETh/EW ratio a factor of reflectivity.

MUNRO (1979) had a flawless experimental design, but the results that he gained from a wooded swamp containing mainly *Cederus* could not apply to all other hydrophytes. To draw this latter conclusion as COOLEY and IDSO did in 1980 is obviously incorrect.

Finally, a last possible cause in the difference between the two sets of workers could be the date at which the work was published. This is elaborated upon below.

CURRENT GEOGRAPHICAL THINKING

If all the work listed in I and II are tabulated then grouped into year of publication and result, the theory that hydrophyte evapotranspiration was lower than open water evaporation started in the late 1940's to early 1960's- the time that PENMAN was presenting his views upon potential evapotranspiration. This idea of a theoretical maximum evapotranspirational loss calculated from meteorological variables seemed to mean that it was not possible for hydrophytes to exceed it. Yet not only has this idea been shown to be untrue, but the whole concept of potential evapotranspiration is under attack, from the theories of causal evapotranspiration developed by PRIESTLY and TAYLOR (1972) and from the idea of complementary relationship areal evapotranspiration proposed by MORTON (1983).

IV. CONCLUSIONS

From the preceding sections, the following conclusions can be drawn:

1) Hydrophyte evapotranspiration can on occasion exceed open water evaporation. This is due to the increases of surface area, the differences in the aerodynamic resistances of water bodies and hydrophytes, and the large transpirational coefficients that hydrophytes have.

2) The conflict reported by several authors was due to poor experimental design, the drawing of conclusions from inadequate data sets and the reluctance of some authors to accept a value of hydrophyte evapotranspiration above that of Penman's potential evapotranspiration.

3) The exact magnitude of the ETh/EW ratio depends upon the state of growth, species type, climate and density.

4) Above ground biomass and leaf area index can be useful indicators of the ETh/EW ratio.

It is important to compare these conclusions with those of the published review articles on hydrophyte evapotranspiration. This is dealt with below.

Review papers on hydrophyte evapotranspiration

There have been three review papers published on hydrophyte evapotranspiration (LINACRE, 1976; IDSO, 1981; INGRAM, 1983). LINACRE, described by INGRAM (1983) as carrying out a 'careful' review, posed (p. 332) the fundamental question: "The main concern has been to determine the evaporation rates of swamps for comparison with the rate of evaporation from a lake in a similar environment", but avoided answering it by concluding (p. 344): "Compared with regional climate and local advection, the presence of swamp vegetation and its type have relatively minor influences on evaporation rates, at least while the vegetation is growing."

This is in contrast to LINACRE *et al.* work of 1970 cited in II. Yet, despite this apparent neutrality on the exact magnitude of ETh/EW ratio expressed in the literature review, LINACRE (1976) was at pains to find fault in the work that gave a hydrophyte/open water ratio greater than 1. LINACRE correctly noted that most of the tank experiments were grown in the fringes of swamps or lakes, and that this would lead to misleading results due to the clothes line and/or oasis effects. These effects and the errors that could arise have been dealt with in I and need no further comment here. LINACRE (1976) made few conclusions but it appears that he did recognize climate as an important factor controlling hydrophyte evapotranspiration.

The next review paper to be published was that of Idso in 1981. It was considerably shorter in lenght than that of LINACRE (1976), and started by *quoting* (IDSO, 1981, *p.* 47): "*The presence of* vegetation does indeed increase the evaporative water loss [on an open water surface]".

IDSO then used results gained by MUNRO (1979) and COOLEY and IDSO (1980), detailed in II, to introduce new coefficients for stomatal resistances into LINACRE's 1970 equations so that the hydrophyte/open water ratio was less than 1. IDSO concluded that for an extensive body of water the ETh/EW ratio will be about unity, though for smaller bodies the ETh/EW ratio will be greater than unity. He also recognized the effect of state of growth on the ETh/EW ratio.

The last review to be published was that of INGRAM (1983). It covered mainly bog and fen evapotranspiration. It is the most extensive of the three reviews. He concluded (p. 98) that: "Actual evapotranspiration from bogs is approximately equal to potential evapotranspiration, while on the limited evidence that from fens is greater."

As far as swamps were concerned, INGRAM (p. 98-99) concluded that: "The evidence presented so far tends to make one cautious of accepting LINACRE's 1976 conclusion that tall helophytes reduce lake evaporation (...) In their evaporative behaviour, reed swamps and allied systems therefore differ profoundly from the majority of true mires (...) and one is justified in regarding the tall helophyte swamps as special cases." INGRAM (p. 99) then tentatively put forward the conclusion from the study of the literature presented in the preceeding review that, "(Hydrophyte/open water ratio for tall helophytes) falls between 1 and 1.4...in summer advection may cause a temporary rise above 2.5".

From the sections above, the conclusions drawn in III. 2 are backed up to some extent by the three reviews. Where there was a major diagreement, as in LINACRE's 1976 critic of tank experiments, a justification of the results was presented.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. G. E. HOLLIS for all his help. Dr. A. C. STEVENSON deserves special mention for the prompt and helpful suggestions that he gave during the preperation of this manuscript. The work has been carried out as part of NERC studentship award GT4/84/AAPS/32.

Manuscrit accepté par le Comité de Rédaction le 12 février 1987

REFERENCES

ANDERSON (M.) and IDSO (S. B.), 1985. — Evaporative rates of floating and emergent aquatic vegetation. 17th Conf. Agr. & For. Met. Scotsdale, Arizona, USA May 1985 : 49-52.

BADEN (W.) and EGGLESMANN (R.), 1966. — Diskussionsbeitrag. *Dtsch. Gewasserkdl. Mitt.*, 10 : 22-24.

BALEK (J.) and PERRY (J. E.), 1973. — Hydrology of seasonally inundated African headwater swamps. *J. Hydrology*, 19 : 227-249.

BAVINA (L. G.), 1967. — Refinement of parameters for calculating evaporation from bogs on the basis of observations at bog stations. *Trudy GGI*, 145 : 69-96.

BAY (R. R.), 1966. — Evaluation of a evapotranspirometer for peat bogs. *Water Resources Research*, 2 : 437-442.

BAY (R. R.), 1968. — Evapotranspiration from two peatland water sheds. In 14th Gen. Assem. Int. Un. Geod. Geophys. Bern. Sept.-Oct. 1967 : 300-307.

BELOTSERKOVSKAYA (G. A.), LARGIN (I. F.) and ROMANOV (V. V.), 1969. — Investigation of surface and internal evaporation on highmoor bogs. *Trudy GGI*, 177 : 16-38.

BENTON (A. R.), JAMES (W. P.) and ROUSE (J. W.), 1978. — Evapotranspiration from water hyacinth. *Water Resources Research Bull.*, 14 : 919-930.

BERNATOWIECZ (S.), LESZCYNSKI (S.) and TYCZNSKA (S.), 1976. — The influence of transpiration by emergent plants on the water balance of lakes. *Aquatic Bot.*, 2 : 275-288.

BLANEY (H. F.), 1957. — Evaporation study at Silver Lake in the Mojave Desert, California. *Trans. Am. Geophys. Un.*, 38 : 209-215.

BLANEY (H. F.), 1959. — Monthly coefficients for consumptive use of water formula and use of water by phreatophytes. Met. Meeting Tel Aviv May 6-9th 1959 : 690-699.

BLANEY (H. F.), 1961. — Consumptive use and water waste by phreatophytes. *Am. Soc. Civil Eng. Proc.*, 87 : 37-46.

BLANEY (H. F.) and CRIDDLE (W. D.), 1950. — Determining water requirements in irrigated areas from climatological and irrigation data. *Soil Cons. Serv.* TP-96.

BLANEY (H. F.), EWING (P. A.), ISRAELSEN (O. W.), ROHWER (C.) and SCOBEY (F. C.), 1938. — Water utilization, Upper Rio Grande Basin. National Resources Committee, Pt 3, Feb. 1938 : 19-87.

BLANEY (H. F.) and EWING (P. A.), 1946. — Irrigation practices and consumptive use of water in Salinas Valley, California. *Calif. St. Div. of Water Resources Bull.*, 52 : 61-66.

BLANEY (H. F.) and HANSON (E. G.), 1965. — Consumptive use and water requirements in New Mexico. *Tech. Rep. N. Mex. Eng.*, 32 : 43 p.

BLANEY (H. F.) and MORIN (K. V.), 1942. — Evaporation and consumptive use of water empirical formulas. *Trans. Am. Geophys. Un.*, 23 : 76-83.

BLANEY (H. F.), MORIN (K. V.) and CRIDDLE (W. D.), 1942. — Consumptive use and water requirements, Report of the participating agencies, Pecos river joint investigation. National Resources Planning Board, June 1942 : 170-230.

BLANEY (H. F.) and MUCKEL (D. C.), 1955. — Evaporation and evapotranspiration investigations in the San Fransisco Bay area. *Trans. Am. Geophys. Un.*, 36 : 813-820.

BLANEY (H. F.), TAYLOR (C. A.) and YOUNG (A. A.), 1933. — Water losses under natural conditions in wet areas of Southern California. *St. Dept. of Pub. Wrks. Div. of Water Res. Bull.*, 44 : 126 p.

BORISOV (A. A.), 1965. — Climates of the USSR. Oliver and Boyd, Edinburgh 255 p.

BRASLAVSKII (A. P.) and VIKULINA (Z. A.), 1963. — Evaporation norms from water reservoirs. Israel program for scientific Translations (A. I. Chebotarev, Ed.) Jerusalem 1963 : 100-135.

BREZNY (O.), MEHTA (I.) and SHARMA (R. K.), 1973. — Studies on evapotranspiration of some aquatic weeds. *Weed Science*, 21 : 197-204.

BULAKVO (A. G.), 1971. — The hydrology of marshes and marsh-ridden lands. *Nature Res.*, 7 : 12-14.

CHRISTIANSEN (J. E.) and LOW (J. B.), 1970. — Water requirements of waterfowl marshlands in Northern Dakota. *19th Utah div. Fish and Game, Wildlife management Int. Bur. of Sport Fisheries and Wildlife.*

COOLEY (K. R.) and IDSO (S. B.), 1980. — Effects of Lily pads on evaporation. *Water Resources Research*, 16 : 605-606.

CLYMO (R. S.), 1973. — The growth of Sphagnum : some effects of environment. *J. Ecology*, 61 : 849-869.

DAVENPORT (D.C.), HUDSON (J. P.), 1967. — Changes in evaporation rates along a 17 km transect in the Sudan Gezira. *Agricultural Meteorology*, 4 : 339-352.

DAVIS (S. N.) and DEWIEST (R. J. M.), 1966. — Hydrogeology. Wiley, New York.

DOLAN (T. J.), HERMANN (A. J.), BAYLEY (S. E.) and ZOLTEK (J.), 1984. — Evapotranspiration of a Florida, USA., wetland. *J. Hydrology*, 74 : 355-371.

DOORENBOS (J.) and PRUITT (W. O.), 1975. — Crop water requirements FAO Irrigation & Drainage paper 24, Rome, 144 p.

DYER (A. J.), HICKS (B. B.) and KING (K. M.), 1967. — The Fluxatron. A revised approach to the measurement of eddy fluxes in the lower atmosphere. *Quart. J. Roy Met. Soc.*, 93 : 501-508.

DYKYJOVA (D.) and KVET (J.), 1978. — Pond Littoral Ecosystems. Springer-Verlag, Berlin, 464 p.

EGGLESMANN (R.), 1963. — Die potentielle und aktuelle Evaporation eines Seeklimahochmoors. *IASH Publ.*, 63 : 88-97.

EGGLESMANN (R.), 1964. — Die Verdunstung der Hochmoore und deren hydrographischer Einfluss. *Dtsch. Gewasserkdl Mitt.*, 8 : 138-147.

EISENHLOR (W. S.), 1966. — Water loss from a natural pond through transpiration of hydrophytes. *Water Resources Research*, 2 : 443-453.

FIRBAS (F.), 1931. — Untersuchungen über den Wasserhaushalt der Hochmoorpflanzen. *Pringsheims Jahsb. Wiss. Bot.*, 74 : 459-696.

GATEWOOD (J. S.), ROBINSON (T. W.), COLBY (B. R.) and HALPENNY (L. C.), 1950. — Use of water by bottomland vegetation in Lower Safford Valley Arizona. *USGS Water supply paper*, 1103, 245 p.

GEL'BUKH (T. M.), 1964. — Evaporation from reed fields in water bodies. *Trudy GGI*, 92 : 152-174.

GESSNER (F.), 1959. — Hydrobotanik Bd. II, VEB Deutscher Verlag, Berlin, 701 p.

GIBB (A.), 1956. — Water resources survey of Uganda : Applied to irrigation and swamp reclamation. *Supplementary report on swamp hydrology* : 9-12.

GILMAN (K.) and NEWSON (M. D.), 1983. — The Anglesey Wetland Study. Publ. *Inst. Hydr.* Wallingford, 113 p.

HALL (P. R.), RUTHERFORD (R. J.) and BYERS (G. L.), 1972. — The influence of a New England wetland on water quantity and quality. *Uni. New Hants. Water Res. Centre Res. Dept Report*, 4, 51 p.

HARBECK (G. E.), 1962. — A practical field technique for measuring resevior evaporation utlizing mass transfer theory. USGS Prof. Paper, 272-E, 105 p.

HENJY (S.), 1969. — Coleanthus subtilis. *Bohemoslov*, 4 : 345-399.

IDSO (S. B.), 1968. — Comments on a paper by R. Lee. *Water Resources Research*, 4 : 665-666.

IDSO (S. B.), 1979. — Discussion on paper by Benton *et al.* *Water Resources Research Bull.*, 15 : 1466-1467.

IDSO (S. B.), 1981. — Relative rates of evaporative water losses from open and vegetation covered water bodies. *Water Resources Research Bull.*, 17 : 46-48.

INGRAM (H. A. P.), 1983. — Hydrology. In Mires : Swamp, Bog, Fen and Moor Ecosystems of the world. A. Gore (Ed.) Vol. 4, Elsevier, Amsterdam : 67-155.

JOHANSSON (I.), 1974. — Hydrologiska undersokningar inom myrkomplexet Komosse. *Rap. K. Tec. Hogsk. Sekt. Lantmat. Inst.* Kulturtek, 3 : 1-161.

KIENDL (J.), 1953. — Zum Wasserhalt des Phragmitetum Communis und Glycerietum aquatiacae. *Berichte der deutschen Bot. Ges.*, 66 : 246-263.

KONSTANTINOV (A. R.), 1963. — Regime of evaporation from the surface of ponds and reservoirs. *Trans. Ukrainian Sci. Hyd. Inst.*, 39 : 78-89.

KROWLIKOWSKA (J.), 1971. — Transpiration of reed. *Pol. Arch. Hydrobiol.*, 18 : 347-358.

KUZNETSOV (V. I.), 1949, cited by BERNATOWIECZ (S.), LESZCYNSKI (S.) and TYCZNSKA (S.), 1976. — The influence of transpiration by emergent plants on the water balance of lakes. *Aquatic Bot.*, 2 : 275-288.

KUZNETSOV (V. I.), 1952. — Cited *in* 'Evaporation norms from water reservoirs, by A. P. Braslavskii and Z. A. Vikulina. Israel program for scientific translations, Jerusalem, 1963 : 100-135.

KUZNETSOV (V. I.), 1953. — Cited *in* 'Evaporation norms from water reservoirs'. By A. P. Braslsvskii and Z. A. Vikulina. Israel program for scientific translations, Jerusalem 1963 : 100-135.

KUZNETSOV (V. I.), 1954. — Effect of water vegetation on evaporation. *Trudy GGI*, 46 : 45-89.

KUZNETSOV (V. I.), 1959. — On evaporation from overgrown reservoirs. *Trans. 3rd All-Union Hydr. Conv.*, Girdrometeoizdat, Leningrad, USSR, 3.

KVET (J.), 1973. — Transpiration of S. Moravian phragmites communis. *In* Littoral of the Nesyt Fishpond. (Ed. Kvet) Studie CSAV 15/1973 Publ. Academia Phraha.

KVET (J.), 1975. — Transpiration in seven plant species colonizing a fishpond shore. *Biol. Plant*, 17 : 434-442.

LEICK (E.), 1929. — Zur frage der Wasserbilanz von Hochmooren. *Mitt. Naturwiss. ver. Neu-Vorpommern*, 52-56 : 146-174.

LINACRE (E. T.), HICKS (B. B.), SAINTY (G. R.) and GRAUZE (G.), 1970. — The evaporation from a swamp. *Agricultural Meteorology*, 7 : 375-386.

LINACRE (E. T.), 1976. — Swamps. *In* Vegetation and the Atmosphere, J. L. Monteith (Ed.) Academic Press, London : 329-347.

LOFTFIELD (J. V. G.), 1921. — The behaviour of stomata. *Carnegie Inst. Wash. Publ.* 314.

McDONALD (C. C.) and HUGHES (G. H.), 1968. — Studies of consumptive use of water by phreatophytes and hydrophytes near Yuma, Arizona. *USGS Prof. Paper*, 486-F, 24 p.

MIGAHID (1952). — Cited *in* PENMAN (H. L.), 1963. — Vegetation and Hydrology. *Commonwealth Bur. Soil Sci. Tech. Comm.*, 53, 124 p.

MORTON (F. I.), 1983. — Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. *J. Hydrology*, 66 : 1-76.

MUCKEL (D.) and BLANEY (H. F.), 1945. — Utilization of the waters of the lower San Luis Rey Valley, San Diego county California. *Calif. Div. of Irrig., Soil Cons serv.*

MUNRO (D. S.), 1979. — Daytime energy exchanges and evaporation from a wooded swamp. *Water Resources Research*, 15 : 1259-1265.

NEUHAUSL (R.), 1975. — Hochmoore am Teich Velke Darka. Academia, Prague 267 p.

NICOLS (D. S.) and BROWN (J. M.), 1980. — Evaporation from a sphagnum moss surface. *J. Hydrology*, 48 : 289-302.

NOVIKOVA (Y. V.), 1963. — Transpiration of hydrophytes and their part in the total evaporative discharge of water from the Kengirdam reservoir. *Tr. Inst. Bot. Akad. Nauk. Kaz. SSR*, 16 : 118-135.

PENFOLD (W. T.) and EARLE (T. T.), 1948. — The biology of the water hyacinth. *Ecological Monographs*, 18 : 447-472.

PENMAN (H. L.), 1963. — Vegetation and Hydrology. *Commonwealth. Bur. Soil Sci. Tech. Comm.*, 53, 124 p.

PRIBAN (K.) and ONDOK (J. P.), 1978. — Microclimate and evapotranspiration in two wetland grassland communities. *Folia Geobotanica et Phytotaxonomica.*, 13 : 113-128.

PRIBAN (K.) and ONDOK (J. P.), 1980. — The daily and seasonal course of evapotranspiration from a central european sedge-grass marsh. *J. Ecology*, 68 : 547-559.

PRIESTLEY (C. H. B.), TAYLOR (R. J.), 1972. — On the assessment of surface heat flux and evaporation using large scale parameters. *Monthly Weather Review*, 100 : 81-92.

PRYTZ (K.), 1932. — Der Kreislauf des Wassers auf unberuhrtem Hochmoor. *Ingeniorvidensk. Skr. Ser. A.*, 33 : 1-126.

RANTZ (S. E.), 1968. — A suggested method for estimating evapotranspiration by native phreatophytes. USGS Prof. Paper 600-D.

RIJKS (D. A.), 1969. — Evaporation from a Papyrus swamp. *Quat. J. Roy. Met. Soc.*, 95 : 643-649.

ROBINSON (T. W.), 1952. — Phreatophytes and their relation to water in western United States. *Trans. Am. Geophysical Un.*, 33 : 57-66.

RODDA (J. C.), DOWNING (R. A.) and LAW (F. M.), 1976. — Systematic Hydrology. Newnes-Butterworths, London 376 p.

ROGERS (H. H.) and DAVIS (D. E.), 1972. — Nutrient removal by water hyacinth. *Weed Science*, 20 : 423-428.

ROMANOV (V. V.), 1953. — Study of evaporation from Sphagnum bogs. *Trudy GGI*, 39.

ROMANOV (V. V.), 1966. — Evaporation from bogs in the European territory of the USSR. N. Kaner (Translator) Heimann (Editor). Israel Programme for scientific translations, Jerusalem, 183 p.

ROMANOV (V. V.), 1968. — Hydrophysics of bogs. N. Kaner (Translator) Heimann (Editor). Israel Programme for scientific translations, Jerusalem, 299 p.

ROUSE (W. R.), MILLS (P. F.) and STEWART (R. B.), 1977. —, Evaporation in high latitudes. *Water Resources Research*, 13 : 909-914.

RUTHERFORD (R. J.) and BYERS (G. L.), 1973. — Conserving wetland water by suppressing evaporation. *Canadian Agricultural Engineering*, 15 : 9-11.

RYCHNOVSKA (M.), 1972. — Transpiration of meadow communities. *In* Ecosystem Study on Grassland Biome in Czechoslavakia. Czechoslovak IBP/PP-PT Report 2 : 37-43.

RYCHNOVSKA (M.), KVET (J.), GLOSER (J.) and JAKRLOVA (J.), 1972. — Plant water relations in three zones of grasslands. *Acta. Sci. Nat. Brno.*, 6 : 1-38.

RYCHNOVSKA (M.) and SMID (P.), 1973. — Preliminary evaluation in two Phragmites stands. *In* Ecosystem study on Wetland Biome in Czechoslovakia. Czec. IBP/PP-PT Report 3 : 111-119.

SCHIEMDL (H.), SCHUCH (M.) and WANKE (R.), 1970. — Wasserhaushalt und Klima einer kultivierten und unberuhrten Hochmoorflache am Alpenrand. *Schrifteur. Kurat. Kult. Hamburg.*, 20 : 1-171.

SHJEFLO (J. B.), 1968. — Evapotranspiration and the water budget of prairie potholes in N. Dakota. *USGS Water Supply paper 585-B*, 49 p.

SMID (P.), 1975. — Evaporation from a reed swamp. *J. Ecology*, 63 : 299-309.

STEARNS (H. T.) and BRYAN (L. L.), 1925. — Geology and water resources of the Mud lake Basin, Idaho. *USGS Water supply paper 560-D*, 160 p.

STURGES (D. A.), 1968. — Evaporation at a Wyoming mountain bog. *J. Soil water Conservation*, 23 : 23-25.

THATCHER (K. M.), 1921. — The effect of peat on the transpiration and growth of several plants. *J. Ecology*, 8 : 39-59.

THOM (A. S.) and OLIVER (H. R.), 1977. — On Penman's equation for estimating regional evapotranspiration. *Quart. J. Royal Met. Soc.*, 103 : 345-347.

TIMMER (C. E.) and WELDON (L. W.), 1967. — Evapotranspiration and pollution of water by water hyacinth. *Hyacinth Control J.*, 6 : 34-37.

TINBERGEN (L.), 1940. — Observations sur l'évaporation de la végétation d'une tourbière dans les Hautes-Fagnes de Belgique. *Mem. Soc. R. Sci. Liège*, 4 : 21-76.

TURNER (S. F.) and HALPENNY (L. C.), 1941. — Ground water inventory in the upper Gila river valley, New Mexico and Arizona. *Trans. Am. Geophys. Un.*, 22 : 738-744.

TUSCHL (P.), 1970. — Die Transpiration von Phragmites communis Trin. im geschlossenen Bestand des Neusiedler Sees. *Wiss. Arb. Burgenld.*, 44 : 126-186.

VAN BAVEL (C. H. M.), 1968. — Further to the hydrologic importance of transpiration control by stomata. *Water Resources Research*, 4 : 1387-1388.

VAN DER WEERT (R.) and KAMERLING (G. E.), 1974. — Evapotranspiration of water hyacinth. *J. Hydrology*, 22 : 201-212.

WARMING (J. E. B.), 1895. — Plantesamfund, grundtraek af den okologiske plantegeografi. Philipsen, Copenhagen, Denmark.

WILLIAMS (W. A.), 1986. — Evaporation from a weeded water surface. Unpublished Ph. D. Thesis, Dept. of Civil Eng. Univ. Newcastle Upon Tyne, England, 317 p.

YOUNG (A. A.) and BLANEY (H. F.), 1942. — Use of water by native vegetation. *St. Cal. Pub. Wrks. Div. Water Res. Bull.* 50, 154 p.

ZAYKOV, 1949. — Cited in GEL'BUKH (T. M.), 1964. — Evaporation from reed fields in water bodies. *Trudy GGI*, 92 : 152-174.